Risk Assessment

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Section 3 – Risk Assessment

Stafford Act 44 CFR §201.4(c)(2)(i)-(iii) [1]

3.1 Summary

The following section identifies, profiles, and assesses the vulnerability of the State of Maine to identified natural hazards in compliance with *44 CFR §201.4(c)(2)*. The risk assessment is designed with an intent to capture all best-available data and knowledge of probable natural hazards in the State of Maine; identify assets, community lifelines, and socially vulnerable and disadvantaged communities that are potentially vulnerable to these hazards; and report how current/projected changes in climate, development, and demographics may change vulnerability. Maine's climate, geography, demography, and infrastructure all influence the State's risk to impacts from natural hazards. The risk assessment provides a summary of identified hazards and vulnerabilities for the State of Maine, followed by comprehensive hazard profiles and vulnerability assessments for each identified hazard. Justifications are provided for all hazards not profiled in this Plan.

This Risk Assessment employs a spectrum of subject matter experts, data resources, historical events, potential loss estimates, model projections, probability of occurrence, and GIS and statistical analyses to analyze natural hazards that are most likely to impact Maine. The Risk Assessment is the foundation for determining an appropriate mitigation strategy for the State of Maine. Stakeholders who contributed Risk Assessment information and editing assistance are represented in Section 2 – Planning Process. Footnote citations link to sources for all technical information.

Twelve natural hazard groups are profiled in this Risk Assessment. Of these, 9 are considered Tier 1 hazards and 3 are considered Tier 2 hazards. Tier 1 hazards hold a higher priority for assessment because they are historically proven to pose risks to Maine communities. Tier 1 hazards include flooding, severe summer weather, tropical cyclone, severe fall/winter weather, wildfire, drought, erosion, mass wasting, and earthquake. Based on assessments by subject matter experts, all hazards except earthquakes are considered to be responsive to climate change, making it more challenging to determine their future nature.

Tier 2 hazards currently pose a moderate risk to communities, but these may become more prominent with the effects of climate change. Tier 2 hazards include forest pests, harmful algal blooms, and air quality (criteria air pollutants and acid rain). These hazards were included based on assessments by subject matter experts and on climate projections for Maine.

Table 3.1 shows general information for each hazard profiled in this Risk Assessment.

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[1] Stafford Act 44 CFR §201.4: https://www.law.cornell.edu/cfr/text/44/201.4

Natural Hazard Summary Table

Table 3.1: Hazard profile and vulnerability summary.

Hazard	Locations (approximate area of state)	Planning Extent/ intensity	Number of occurrences	Future probability	Potential exposure, millions (2022 USD)		Analysis type
					State assets (# assets*)	Local assets (# assets*)	
Flood							
Inland and coastal flooding	Low lying areas across the state (2,184 sq mi, 6.2%)	100-500 year floods, 20% damage to exposed structures	55 since 1846	Increasing due to projected increase in precipitation	$17.93 (117)	$10,511 (22,192)	GIS asset-hazard overlay
Sea level rise	Low lying coastal areas (76 sq mi, 0.21%)	1.6 feet of sea level rise projected for 2050, 100% relocation for exposed structures	Incremental	sea level rise is increasing coastal flooding occurrence	$9.95 (24)	$1,944 (3,454)	GIS asset-hazard overlay
Severe Summer Weather							
Wind	Statewide	Damaging 70 mph gusts, 2% damage to exposed structures	~Annual	Potential increase	$16.4 (2,238)	$6,600 (758,999)	GIS asset-hazard overlay
Hail	Statewide	Damaging hail >1 inch, 0.2% damage to exposed structures	670 since 1950	Potential increase	$1.64 (2,238)	$658.8 (758,999)	GIS asset-hazard overlay
Tornado	Statewide	EF2, 0.2% damage to exposed structures	17 since 1950	Potential increase	$1.64 (2,238)	$658.8 (758,999)	GIS asset-hazard overlay
Tropical Cyclone							
Storm surge	Coastal areas (115.7 sq mi, 0.33%)	Category 2 Storm Surge, 75% damage to exposed structures	1-3 since 1842	Increase	$82.79 (71)	$8,678 (16,768)	GIS asset-hazard overlay
Hurricane winds	Statewide	Category 2 winds: 100 mph, 130 mph wind gusts, 5% damage to exposed structures	1-3 since 1842	Increase	$41 (2,238)	$16,470 (758,999)	GIS asset-hazard overlay
Severe Fall/Winter Weather							
Extratropical cyclone	Statewide, storm surge limited to coast (115.7 sq mi, 0.33%)	Similar to Category 1 Hurricane event, 75% damage to exposed structures		Potential increase	$59.6 (28)	$3,712 (6,725)	Historic event
Winter storm	Statewide	NWS Hazardous weather criteria	>200 since 1996	May increase or decrease depending on location	$0.83	$0.43	Historic, average of top three events
Heavy snow	Statewide	6-8 inches in 24 hours	>400 since 1996	May increase or decrease depending on location	$0.83	$6.83	Historic event
Ice storm	Statewide	> 1/4 inch ice accumulation	12 since 1996	Potential increase with warmer winters	$14.95	$196.90	Historic, average of top three events

Wildfire							
Wildfire	Multi-county wildfire (1/4 of state)	Similar to Wildfire of 1947, 100% damage to exposed structures	2 in the last 250 years	May increase with drought and reduced suppression capabilities	$301 (433)	$62,143 (151,121)	Historic, GIS asset-hazard overlay
Drought							
Drought	Statewide	Similar to 2002 drought, 25% crop losses	6 statewide droughts in last 85 years	May become more extreme	$0	$166.74 (25% crop loss), 300 dry wells	Agricultural Census loss model
Erosion							
Beach erosion	Entire beach coastline (2% of total)	Coastwide storm impacting all exposed assets, 100% damage to exposed structures	Unprecedented	Expected to increase with sea level rise	$4.36 (3 state parks)	$753.1 (2,040)	GIS asset-hazard overlay
Bluff erosion	Entire bluff coastline (53% of total)	Coastwide storm impacting all exposed assets, 100% damage to exposed structures	Unprecedented	Expected to increase with sea level rise	$27.7 (Structures and state highway)	$311.4 (803)	GIS asset-hazard overlay
Mass Wasting							
Landslide	Statewide - state and local roads	All reported landslide sites, 100% damage to exposed structures	Unprecedented	May increase or decrease depending on location	$42.4 (21.2 mi state highway)	$69.2 (34.62 mi local roads)	GIS asset-hazard overlay
Earthquake							
Earthquake	Multi-county event (1/4 of state)	Large earthquake, 100% damage to exposed structures	Unprecedented	No change in probability	$720 (686)	$59,923 (132,533)	GIS asset-hazard overlay
Tier 2 Hazards							
Forest pests	*There is insufficient data to calculate the recurrence interval and impacts/losses to state and jurisdictional assets caused by forest pests. Negative impacts are expected for forest industries, inland/coastal tourism, and health impacts related to browntail moth.*						
Harmful algal blooms (HABs)	*There is insufficient data to calculate the recurrence interval and impacts/losses to state and jurisdictional assets caused by HABs. Negative impacts are expected for freshwater and marine tourism, human and animal health risks, shellfishing industry, and public water suppliers.*						
Air quality	*There is insufficient data to calculate the recurrence interval and impacts/losses to state and jurisdictional assets caused by air quality. Negative impacts are expected for most of Maine, particularly urban centers, if a poor air quality event were to occur.*						

* Number of assets provided for GIS analyses only.

3.2 Identification and Description of Natural Hazard Types

The SHMP Planning Team prepared Table 3.2 as an overview of all natural hazards that may impact Maine. Please visit MEMA's Maine Risk Map site [2] to access the geospatial hazard and asset data used to conduct this analysis. To simplify the Risk Assessment, multiple hazards were grouped based on their similar characteristics and seasonal co-occurrence. For example, the flood hazard profile group consists of multiple hazard types (including inland, coastal, and flash flood) with each involving inundation but occur under different conditions and/or unique flood drivers and mechanisms. Different hazard types tend to occur in the summer season are included under the Severe Summer Weather group, while colder season hazards are included in the Severe Fall/Winter Weather group. It is important to note, although these hazards could potentially occur at any time, they have been grouped under the season in which they are most likely to occur. Despite their summer occurrence, tropical cyclones are a unique hazard to warrant a separate hazard group from Severe Summer Weather.

Hazard profile groups are further organized under Tier 1 and Tier 2 classifications. Tier 1 hazards hold a higher priority for assessment because of the historical proof to pose risks to Maine communities. Except for earthquakes, all Tier 1 hazards are responsive to climate change. Tier 2 hazards currently pose a moderate risk to communities, but these may become more prominent with the effects of climate change. The Risk Assessment includes 9 Tier 1 hazards and 3 Tier 2 hazards. A further 5 hazards are identified but not profiled for this Risk Assessment for reasons explained below.

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[2] MEMA Maine Risk Map: https://maine.maps.arcgis.com/apps/mapviewer/index.html?webmap=eb8ec0935ce544dbaa80aec18c8db785

Table 3.2: Maine Natural Hazard Identification Summary

Hazard Profile Group	Type of hazard and base mechanisms	Subject matter expert agencies and supporting resources
TIER 1 NATURAL HAZARDS		
Flood	Inland flood	NOAA, FMP, FEMA, County EMA, MGS, USGS, UMS
	Coastal flood	NOAA, FMP, FEMA, County EMA, MGS, USGS, UMS
	Flash flood	NOAA, USGS, UMS, FEMA
	Urban/surface water floods	NOAA, USGS, FEMA
	Tsunami	NOAA, USGS
	Dam failure	MEMA Dam Safety
Severe summer weather	Severe storms	NOAA
	High winds	NOAA
	Extreme heat	NOAA, UMS
Tropical cyclone	Tropical storm	NOAA: NHC
	Hurricane	NOAA: NHC
Severe fall/winter weather	Heavy snow	NOAA
	High winds	NOAA
	Blizzard	NOAA
	Sleet	NOAA
	Hail	
	Ice storm/freezing rain	NOAA
	Extreme cold	NOAA, UMS
Drought	Meteorological drought	NOAA, Northeast DEWS, USDA, USGS, UMS, MGS, DACF
	Hydrologic drought	
	Agricultural drought	
	Socioeconomic drought	
Mass wasting	Creep	MGS, USGS, UMS
	Rockfall	
	Landslides	
Erosion	Beach erosion	MGS
	Bluff erosion	MGS
Fire	Wildfire	MFS
	Urban fire	
	Air quality	MEMA, DEP
Earthquake	Tectonic earthquake	MGS, USGS
	Explosive earthquake	
	Collapse earthquake	
	Volcanic earthquake	
	Cryoseism/frost quake	MGS, USGS
TIER 2 NATRUAL HAZARDS		
Blight/infestation	Invasive species/Forest pests	MFS
Harmful Algal Blooms	Freshwater and Marine	DMR, DEP
Air quality	Winter and summer	MEMA, DEP
HAZARDS NOT PROFILED IN THIS PLAN		
Subsidence		USGS
Volcanic activity		USGS
Avalanche		USGS
Geomagnetic Storm		NWS
Pandemic		CDC

List compiled by Maine Emergency Management Agency – 2022

3.3 Hazard Classification

Each Hazard Profile Group consists of one or more basic hazard mechanisms, which can occur as a part of several other groups. Table 3.3 demonstrates hazard interrelationships and how each Hazard Profile Group shares these different hazard mechanisms as primary, contributing, or consequential to the hazards. For example, heavy rain and strong winds are primary mechanisms for severe summer weather, severe fall/winter weather, and tropical cyclones. Also, there are several mechanisms that may contribute to a Hazard Profile Group but are not a primary cause for the hazard. For example, mass wasting and erosion may be a consequence of heavy rain and multiple flooding and earthquake mechanisms. Finally, there are other mechanisms that may “cascade” from or become a consequence of a hazard profile group, though they are not a primary characteristic of the hazard. For example, tropical cyclones are likely to cause multiple types of flooding classified under the Flood Hazard Profile Group, while large mass wasting and earthquake events can trigger tsunamis classified under the Flood Hazard Profile Group.

Table 3.3: Profiled Meteorological and Geological Hazards Sharing Mutual Potential Hazards

Hazard Group / Hazard Mechanism	Flood	Severe Summer Weather	Tropical Cyclone	Severe fall/Winter Weather	Drought	Mass Wasting	Erosion	Fire	Earthquake	Blight/ Infestation	Not a natural hazard	Not profiled
Heavy rain	🟨	🟦	🟦	🟦		🟨	🟨					
Inland flood	🟦	🟧	🟧	🟧		🟨						
Riverine and lacustrine flood	🟦	🟧	🟧	🟧		🟨						
Ice jam	🟦			🟧								
Snowmelt	🟦			🟧		🟨						
Coastal flood	🟦	🟧	🟧	🟧		🟨	🟨					
High astronomical tide	🟦					🟨	🟨					
Storm surge	🟦		🟧	🟧		🟨	🟨					
Sea level rise	🟦					🟨	🟨					
Waves	🟦	🟧	🟧	🟧		🟨	🟨					
Flash flood	🟦	🟧	🟧	🟧		🟧	🟨					
Urban/surface water floods	🟦	🟧	🟧	🟧			🟨					
Tsunami	🟦					🟧	🟨		🟧			
Dam failure	🟦	🟨	🟨	🟨		🟧	🟨		🟧			
Thunderstorms	🟨	🟦										
Lightning		🟦										
Tornado		🟦	🟦									
Hail		🟦										
Strong straight-line winds		🟦	🟦	🟦								
Extreme heat		🟦			🟨							
Tropical storm	🟨		🟦			🟨	🟨					
Hurricane	🟨		🟦			🟨	🟨					
Heavy snow				🟦								
Ice storm/freezing rain				🟦								
Sleet				🟦								
Extreme cold				🟦								
Cryoseism/frost quake				🟦								
Meteorological drought		🟧		🟧	🟦			🟨				
Dry or warm snow drought				🟧	🟦			🟨				
Hydrologic drought		🟧		🟧	🟦			🟨				
Agricultural drought		🟧		🟧	🟦			🟨				
Socioeconomic drought		🟧		🟧	🟦			🟨				
Creep		🟧				🟦	🟨					
Rockfall		🟧				🟦	🟨		🟧			
Landslides	🟧	🟧				🟦	🟨	🟧	🟧			
Beach erosion	🟧					🟧	🟦					
Bluff erosion	🟧					🟧	🟦					
Wildfire					🟧			🟦				
Urban Fire								🟦	🟧		⬛	
Tectonic earthquake						🟨	🟨		🟦			
Explosive earthquake						🟨	🟨		🟦		⬛	
Collapse earthquake						🟨	🟨		🟦		⬛	
Volcanic earthquake						🟨	🟨		🟦			
Forest pests		🟧		🟧	🟧					🟦		
Air quality		🟧		🟧	🟧			🟧				
Subsidence									🟧			⬛
Harmful Algal blooms	🟧	🟧			🟧							⬛
Avalanche				🟧					🟧			⬛
Volcanic activity						🟨	🟨	🟨	🟨			⬛

	Flood	Severe Summer Weather	Tropical Cyclone	Severe fall/Winter Weather	Drought	Mass Wasting	Erosion	Fire	Earthquake	Blight/ Infestation
🟦 Primary mechanisms of hazard	13	7	5	11	5	3	2	2	4	1
🟨 Mechanisms that may contribute to hazard	4	0	0	0	1	15	19	5	0	0
🟧 Mechanisms that may be consequence of hazard	3	16	7	13	2	5	0	2	5	0

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3.4 Process for Identifying Vulnerabilities in State Assets and Jurisdictions [S6.a.1.]

Each hazard profile and vulnerability assessment considers the most vulnerable assets in the State of Maine. However, identification of vulnerable sites is no guarantee that future natural hazard events will damage these assets. As the Mitigation Act of 2000 requires every jurisdiction to have a hazard mitigation plan in order to be eligible for grant funding, and due to the large number of small Maine municipalities, it was decided to define a "jurisdiction" in Maine as a county except in cases where it is possible to provide municipal or individual asset scale details. Although county government in Maine is very small with few authorities, the preparation of county plans was determined to be the best way to create a regional approach to creating these plans. All sixteen Maine counties are eligible to apply for FEMA Plan Update Grants to develop multi-jurisdictional Hazard mitigation Plans with participation from their communities. FEMA mitigation grants are offered through the BRIC and FMA non-disaster programs, or when available, the HMGP post-disaster program [3]. As of this writing, most County Hazard Mitigation Plans are in their fourth version.

In 2022-2023, the State of Maine conducted a risk assessment, updating both the methodology and data from the previous risk assessment conducted in 2018. The intent of this process was to provide emergency management planners with a broad perspective on the hazards and threats that pose a risk to the State of Maine. The selection of hazards and threats presented in the tool was derived from existing literature within the emergency management community, to include the 2018 State Hazard Mitigation Plan. The methodology used in the risk assessment process is based on the Code of Federal Regulations, Emergency Management Accreditation Program Standards, and best practices in the field of risk assessment to include the assessment conducted in 2017 by the Rhode Island Emergency Management Agency. Execution of this methodology was primarily virtual, leveraging the emergency managers in each of the state's (16) counties.

3.4.1 Geospatial Analysis of Assets and Known Hazard Locations

MEMA's Natural Hazards Planner developed a geospatial workflow to identify the occurrence of geolocated assets within areas known or projected to be exposed to the natural hazards identified within this Plan. Assets include State owned or leased properties and insured contents, state road infrastructure, state and municipal conserved lands, municipal road infrastructure, and a general assessment of building footprint locations (including state, local, and privately owned assets of residential, commercial, and industrial class) across the state. The overlay analysis does not take into account any pre-existing mitigation efforts at each site.

The hazard layers used in this assessment consist of public data that can be accessed through MEMA's Hazard Mitigation Plan Risk Assessment Map [4]. MEMA encourages Maine communities to use this tool to assess their own patterns of risk and inform their own Local Hazard Mitigation Plans in the future. Please refer to our list of stakeholders in Section 2 – Planning Process, where we acknowledge the agencies and organizations that provided the data for this assessment.

Locations for categorized assets were determined through use of the Maine E911 database. State assets were geolocated based on address data and verified using satellite imagery. Building footprints were provided by Microsoft's Bing Maps database [5]. For Maine DOT assets, the primary focus was on stream crossings for inland and coastal flood risks and road mileage for severe fall/winter storms.

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[3] MEMA Mitigation Grants webpage: https://www.maine.gov/mema/grants/mitigation-grants

[4] MEMA Hazard Mitigation Plan Risk Assessment Map: https://maine.maps.arcgis.com/home/item.html?id=eb8ec0935ce544dbaa80aec18c8db785

[5] Microsoft building footprints database: https://www.microsoft.com/en-us/maps/building-footprints

Aggregate damage estimates for State assets are based on building replacement cost values provided for insurance purposes by Maine Bureau of General Services. Aggregate damage estimates for the generic buildings identified from footprint data are based on the average value per square foot for commercial, residential, and industrial structures. Unfortunately, the building footprint data provided by Microsoft does not include zoning/classification fields. To account for this, the relative proportion of zoning class was used to produce a weighted average price per square foot for all building footprints in Maine (Table 3.4). The average square footage value is used to estimate cumulative damages in dollar value for all building footprints that intersect the hazard layers used in this Plan.

The "select layer by location (Data Management)" tool was used in ArcMap to identify assets that are overlain by hazard layers. These assets were tagged based on this condition and counted toward the vulnerability assessment for each hazard profile described below. This data was aggregated by municipality and by county in order to provide a general sense of vulnerability at a more interpretable scale for the entire state.

Table 3.4: Building class types and relative proportion used to estimate average value (2022 USD)

Building Class	% of US buildings	Average value per square foot
Residential	94.5%	$210
Commercial	5.2%	$301
Industrial	0.3%	$145
Average	**100%**	**$215**

Vulnerable asset value data is also rendered in kernel density maps providing the general location of potentially vulnerable assets. Kernel density maps, or heat maps, provide an estimate of the total number of assets located within a unit of area, and are useful for interpreting relative spatial differences in development and associated vulnerabilities.

3.4.2 Disadvantaged communities Assessment

Disadvantaged community assessments were performed based on availability of information for disadvantaged and/or socially vulnerable communities and their potential exposure in locations known for prominent natural hazard occurrence (for example, flood plain maps published by the National Flood Insurance Program). The objective of the assessment is to identify potentially disadvantaged communities who are disproportionately impacted by natural hazards both historically and under future projections. The equity assessment then ties to pre-existing mitigation capabilities directly assisting disadvantaged communities, to inform mitigation strategies to ensure fair and just mitigation assistance determined by level of need.

The Social Vulnerability Index (SVI [6]) is used for our assessment, a standard used by Federal Agencies to plan assistance for disadvantaged communities. SVI is available at Census track resolution to identify intersections between hazard occurrence layers and communities, with specific focus on those disadvantaged communities identified with a SVI score of 0.6 or greater [7]. Though Census Track SVI is broadly considered to be the best available resource for a statewide equity assessment, it must be acknowledged the census track resolution is, in many rural locations, not fine enough to provide a consistent assessment of disadvantaged and potentially vulnerable communities. SVI analyses, therefore provides less accuracy in rural locations that compose the majority of Maine by area.

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[6] Social Vulnerability Index: https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

[7] FEMA equity definitions: https://www.fema.gov/sites/default/files/documents/fema_equity-webinar-final_8-17-21.pdf

3.4.3 Process Used to Analyze Information from County Risk Assessments

In the preparation of this Plan, all county Local Hazard Mitigation Plans were evaluated to determine the nature of hazards and how they differed throughout the state, as well as the extent to which specific hazards contribute to the overall statewide hazard risk. Flooding, Severe Fall/Winter Weather, Severe Summer Weather, and Wildfires are considered the highest priority hazards for nearly all areas of Maine. The estimate of potential dollar losses contained in this Plan was also obtained from each of the county plans. In general, the jurisdictions with the highest potential damages are the ones with the most risk. Vulnerability assessments for jurisdictions incorporate Local Hazard Mitigation plan data as well as many other resources cited throughout the plan.

The following paragraphs represent a composite summary of the findings from the various county plans as well as the knowledge gained in the preparation of this Plan.

3.4.4 Tracking Development Trends in Hazard Prone Areas

Several resources are available for tracking general development trends in Maine. However, capabilities are limited for tracking development trends specifically in known hazardous areas in Maine. Local governments are responsible for documenting construction and septic installation permits and they may provide this information to the State. For purposes of this plan update, MEMA utilizes satellite imagery data to identify specific overlaps of development within hazard prone areas, such as Special Flood Hazard Areas. Other beneficial resources include septic permit records, development trend assessments from Local Hazard Mitigation Plans, and data from the US Census and American Community Survey.

3.5 Flooding – General Definition and Types of Events [S3.a., S3.b.]

Flooding is an overflow and inundation of water onto normally dry land as a result of: 1) the overflow of inland or tidal waters, or 2) the unusual and rapid accumulation or runoff of surface waters from any source [8] The following are types of flooding events experienced in Maine:

3.5.1 Inland Flood

Inland flooding occurs when moderate precipitation accumulates over several days, intense precipitation falls over a short period, there is abundant runoff from spring snowmelt, a river overflows because of an ice or debris jam or dam or levee failure, or a combination of these factors. The following flood mechanisms occur during inland flooding:

Riverine Flood: A river flood occurs when water levels rise over the top of the riverbanks due to excessive rainfall from low pressure systems, landfilling tropical systems, persistent nearly stationary thunderstorms over extended periods of time, or a combination of snowmelt and rainfall along with ice jams [9]. Periodic overbank flow of rivers and streams is a typical result of spring runoff in Maine. See "Location of River Basin" section for flooding details.

Lacustrine Flood: Lacustrine or lake flooding occurs when the outlet for the lake cannot discharge the flood waters fast enough to maintain the normal pool elevation of the lake. During a base flood event, normal increases in water surface elevations on most Maine lakes and ponds range from 1 to 5 feet. However, in Maine there are some examples where the base flood event will reverse the flow of the outlet stream. In such instances, river and base flood elevations can rise more than 15 feet above normal pool. Maine's mandatory shore land zoning and floodplain management elevation requirements do much to mitigate lake and pond development by imposing significant setbacks from the water's edge. This type of flooding can impact private camps built near the water's edge. Though less common than riverine floods, there is documented damage from lacustrine flooding in Aroostook County in 2018 [10].

Ice Jam: Ice jams occur when warm temperatures and heavy rain cause snow to melt rapidly. Snow melt combined with heavy rains can cause frozen rivers to swell, which breaks the ice layer on top of the river. The ice layer often breaks into large chunks, which float downstream and often pile up in sharp river bends, shallow river channels, mouths of tributaries, points where river slope decreases, and near narrow passages around other obstructions such as bridges and dams. The channel blockage acts like a temporary dam causing the water to rise rapidly behind the jam causing a rapid onset of upstream flooding. If the ice jam suddenly breaks, a torrent of water is rapidly released downriver causing flash flooding below the jam location [11]. Damages from ice jam flooding usually exceed those of clear water flooding because of higher than predicted flood elevations, rapid increase in water levels upstream and downstream, and physical damage caused by ice chunks. Moving ice masses can shear off trees and destroy buildings and bridges above the level of the flood waters.

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[8] NWS Flood definitions: https://www.weather.gov/mrx/flood_and_flash

[9] NOAA definition of flood types: https://www.nssl.noaa.gov/education/svrwx101/floods/types/

[10] Rains threaten major flooding along Fish River chain of lakes: https://thecounty.me/2018/05/02/news/rain-threatens-major-flooding-in-fort-kent-along-fish-river-chain-of-lakes/

[11] NESEC Ice Jam Definition: http://nesec.org/ice-jams/

3.5.2 Coastal Flood

A coastal flood, or the temporary inundation of low-lying land areas along the coast, is caused by higher-than-average astronomical tide and is worsened by heavy rainfall, storm surge driven by onshore winds (i.e., wind blowing landward from the ocean), damaging waves, and sea level rise. Coastal flooding comes with two significant components: an increase in still-water levels and storm surge. The typical high winds associated with coastal storms exacerbate flooding by “pushing” more water toward land and increasing base water levels, or still-water levels. Strong storms such as tropical cyclones or nor’easters can cause large damaging waves and storm surges along areas of the coast of Maine. Fetch, or the distance the wind can blow over open water, is a significant factor in the size of storm waves. The shape of the ocean floor just offshore is another variable. The following flood mechanisms contribute to coastal flooding:

High Tide: High astronomical tides are produced in the ocean waters by the "heaping" action resulting from the horizontal flow of water toward two regions of the earth representing positions of maximum attraction of combined lunar and solar gravitational forces [12]. Low tides are created by a compensating maximum withdrawal of water from regions around the earth midway between these two humps. The alternation of high and low tides is caused by the daily (or diurnal) rotation of the earth with respect to these two tidal humps and two tidal depressions. High astronomical tides are the highest levels that can be predicted to occur under average meteorological conditions.

Storm Surge: Storm surge is an abnormal rise in water level in coastal areas, over and above the regular astronomical tide, caused by forces generated from a severe storm's wind and low atmospheric pressure. Storm surge is extremely dangerous because it is capable of flooding large coastal areas. Extreme flooding can occur in coastal areas particularly when storm surge coincides with normal high tide, resulting in storm tides (see below). Along the coast, storm surge is often the greatest threat to life and property.

Storm Tide: Storm tide is a combination of predicted astronomical tide and storm surge. It is the overall water level achieved during a storm event and is usually measured at a tide gauge. For example, if a predicted astronomical tide is 10 feet, and 4 feet of storm surge comes in on top of that high tide, the storm tide level would be 14 feet.

Waves: Wind-driven waves, or surface waves, are created by the friction between wind and surface water. Generally, the larger the fetch (or the distance across open water that wind can blow), the larger the wave height. As wind blows across the surface of the ocean or a lake, the continual disturbance creates waves. As the wind blows for extended periods of time and over large distances, the wave heights increase [13].

Sea Level Rise: Global sea level rise is an increase in the world’s ocean’s surface height due to two dominant factors: volumetric increase and thermal expansion. Melting glaciers and land-based ice sheets, such as the Greenland ice sheet, which are linked to changes in atmospheric temperature, can contribute significant amounts of freshwater input to the Earth's oceans, increasing the volume of the oceans. Additionally, a steady increase in global atmospheric temperature creates an expansion of sea water molecules, thereby increasing ocean volume through thermal expansion. The Intergovernmental Panel on Climate Change Report estimates that the global sea level rise was approximately 1.7-1.8 millimeters per year (mm/yr) over the past century, based on tide station measurements around the world. Since 1993, satellites have measured average global sea levels and shown that the rate has increased to about 3.3 mm/yr (ref: U. Colorado). Climate models show that sea levels will continue

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[12] NOAA tidal forces: https://tidesandcurrents.noaa.gov/restles2.html

[13] NOAA ocean waves definition: https://oceanservice.noaa.gov/facts/wavesinocean.html

to rise, with the 2017 US National Climate Assessment concluding that it is *very likely to rise between 1 and 4 feet by the end of the century*. Relative sea level rise, or local sea level rise, refers to how the height of the ocean changes relative to the land at a particular location. In Maine, there are four long-term tide gauges monitoring local sea levels [14], [15]. Long-term sea level trends in Maine indicate about half of the observed sea level rise has occurred since 1990, and rates are generally at or slightly above global long-term and short-term averages. The Maine Climate Council recommends managing for 1.5 feet of relative sea level rise by 2050 and 4 feet by 2100 [16]. The Maine Geological Survey maintains a monthly Sea Level Rise Ticker and Dashboard for keeping track of local sea level trends [17]). over the past century, based on tide station measurements around the world, with projected increased trends in sea level in the 20th Century based on global climate models.

3.5.3 Flash Flood

A flash flood is caused by heavy or excessive rainfall in a short period of time, generally less than 6 hours. Flash floods are usually characterized by raging torrents after heavy rains that rip through riverbeds, urban streets, or mountain canyons sweeping everything before them. They can occur within minutes or a few hours of excessive rainfall. They can also occur even if no rain has fallen, for instance after a levee or dam has failed, or after a sudden release of water by a debris or ice jam. Flash floods are very dangerous and destructive not only because of the force of the water, but also the hurtling debris that is often swept up in the flow [18].

3.5.4 Urban/surface water flood

Surface water floods occur when an urban drainage system is overwhelmed, and water flows out into streets and nearby structures. Flooding from surface runoff can happen within minutes or more gradually, while the level of water is often shallow (rarely more than 1 meter deep). It creates no immediate threat to lives but may cause significant economic damage [19]. The combined sanitary and storm water systems that some urban areas installed years ago cause flooding of sanitary sewerage when riparian or coastal floods occur. Runoff is increased due to many impervious surfaces such as roof tops, sidewalks, and paved streets.

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[14] Portland ME tide gauge: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8418150

[15] Eastport ME tide gauge: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8410140

[16] Maine Won’t Wait: https://www.maine.gov/future/sites/maine.gov.future/files/inline-files/MaineWontWait_December2020.pdf

[17] Maine Geological Survey Sea Level Rise Dashboard: https://www.maine.gov/dacf/mgs/hazards/slr_ticker/slr_dashboard.html

[18] NWS flash flood: https://www.weather.gov/mrx/flood_and_flash

[19] Three Common Types of Flood: https://www.zurich.com/en/knowledge/topics/flood-and-water-damage/three-common-types-of-flood

3.5.5 Tsunami

A tsunami is a series of extremely long waves caused by a large and sudden displacement of the ocean, usually the result of an earthquake below or near the ocean floor. This force creates waves that radiate outward in all directions away from their source, sometimes crossing entire ocean basins. Unlike wind-driven waves, which only travel through the topmost layer of the ocean, tsunamis move through the entire water column, from the ocean floor to the ocean surface. Over 80% of tsunamis are caused by earthquakes on converging tectonic plate boundaries. Other causes include landslides, volcanic activity, certain types of weather, and—possibly—near-earth objects (e.g., asteroids, comets) colliding with or exploding above the ocean [20]. Once a tsunami forms, its speed depends on the depth of the ocean. In the deep ocean, a tsunami can move as fast as a jet plane, over 500 mph, and its wavelength, the distance from crest to crest, may be hundreds of miles [21]. All areas with elevation less than 100 feet and within two miles of the coast could be impacted by a tsunami [22]. However, based on information obtained from the Maine Geological Survey, the chances of a catastrophic event impacting the Maine coastline are minimal [23]. Tsunami modeling from the University of Rhode Island [24] indicates the possibility of 5 to 6 meter waves along the coast of Maine if submarine landslides occur along the U.S. Continental Shelf. Maine is relatively protected from distant tsunami sources in the Azores and Caribbean, but local submarine landslides could produce waves reaching the coast of Maine.

3.5.6 Dam Failure/Breach [HHPD2]

Any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function of impounding water is considered a dam failure. Lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure, which may result in an uncontrolled release of the reservoir and can have a severe effect on persons and properties downstream. Dam breaches can cause rapid and expansive downstream flooding, loss of life, damage to property, and the forced evacuation of people. A dam breach has a low probability of occurring, but with a potentially high impact [25].

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[20] NOAA tsunami definition: https://www.noaa.gov/education/resource-collections/ocean-coasts/tsunamis

[21] KOMAR, P.D., 1996. Tidal-Inlet Processes and Morphology Related to the Transport of Sediments. J. Coastal Research, Special Issue No. 23, 23-45.

[22] Cal OES Tsunami Fact Sheet: https://www.conservation.ca.gov/cgs/Documents/Tsunami/How-to-Survive-a-Tsunami.pdf

[23] Maine Geological Survey Tsunami Page : https://www.maine.gov/DACF/mgs/hazards/tsunamis/index.shtml

[24] Grilli, S., Grilli, A. R., Tehranirad, B., & Kirby, J. T. (2017). Modeling Tsunami Sources and Their Propagation in the Atlantic Ocean for Coastal Tsunami Hazard Assessments and Inundation Mapping along the US East Coast. In *Coastal Structures and Solutions to Coastal Disasters 2015: Tsunamis* (pp. 1-12). Reston, VA: American Society of Civil Engineers. https://personal.egr.uri.edu/grilli/COPRI15_sgrilli.pdf

[25] FEMA Dam Safety Awareness: https://www.fema.gov/sites/default/files/2020-08/fact-sheet_dam-awareness.pdf

3.6 Flooding – Location of Hazard [S3.a.1]

All of Maine has locations that are susceptible to flooding from flood types listed above. Notable locations of potential flooding by flood type are listed below (Figure 3.1).

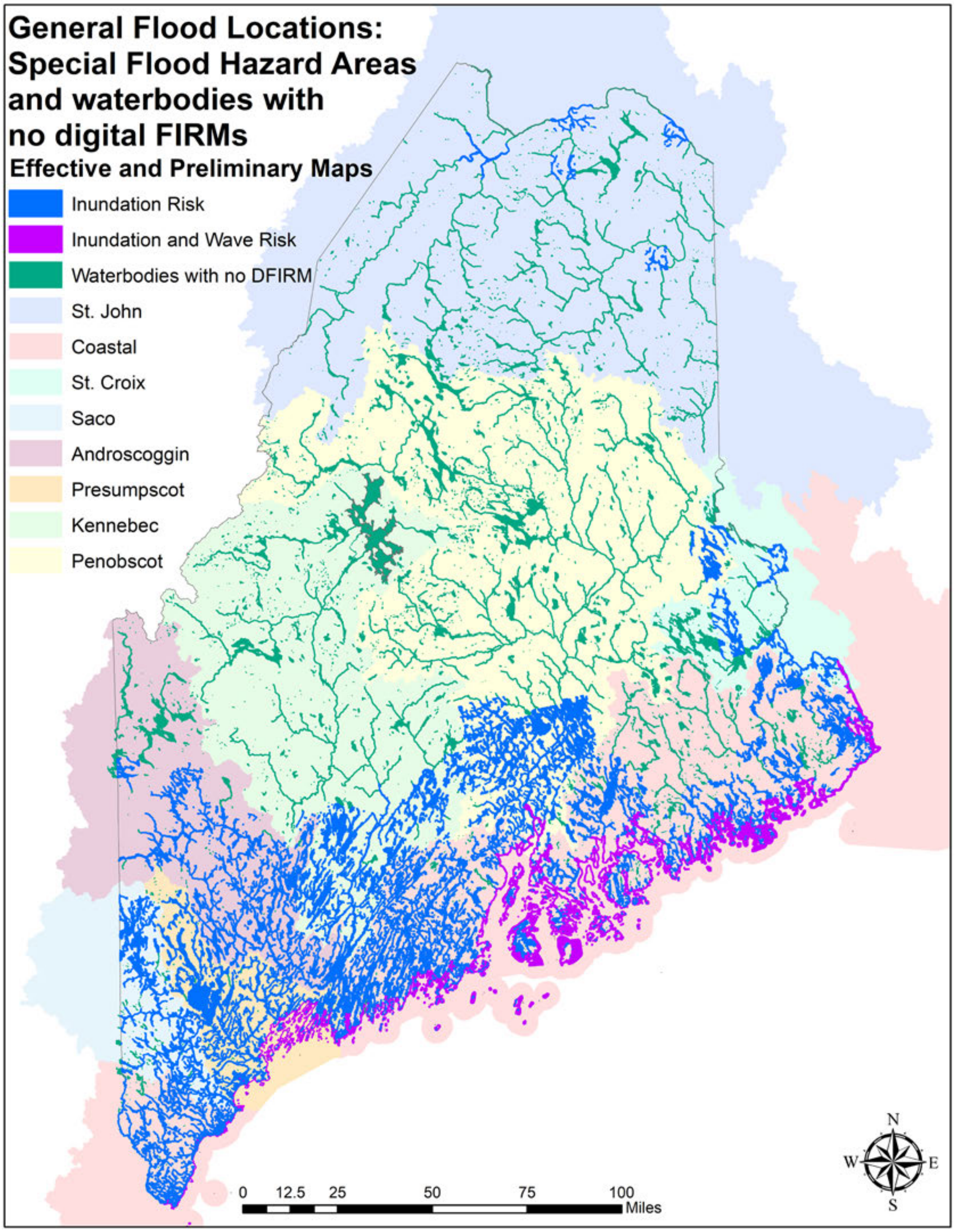

Figure 3.1. State-level overview of available resources for identifying flood locations in each major river basin. Visit [FEMA's National Flood Hazard Layer Viewer]() to review flood occurrence in specific locations.

Due to the nature of Maine's geographic features, many of its rivers flow steeply from the mountains eastward toward the sea. Rivers in mountainous regions tend to rise very quickly after heavy rainfall because of the gradient of riverbeds and drainage areas. Generous precipitation (about 42.6 inches a year) contributes to the flood potential. The low-pressure system over the seaboard and the tendency of some storms to follow one another in rapid succession provide heavy, combined moisture. The nature of Maine's geography, geology and hydrology is such that flooding is usually fast rising but of short duration (Figure 3.2).

With five major rivers, more than 5,000 streams and brooks, 6,000 ponds and lakes, and 3,500 miles of coastline, water abundance is one of the state's most valuable natural resources as well as its primary hazard. Maine's geography and climate are critical factors which affect the flows of these water bodies.

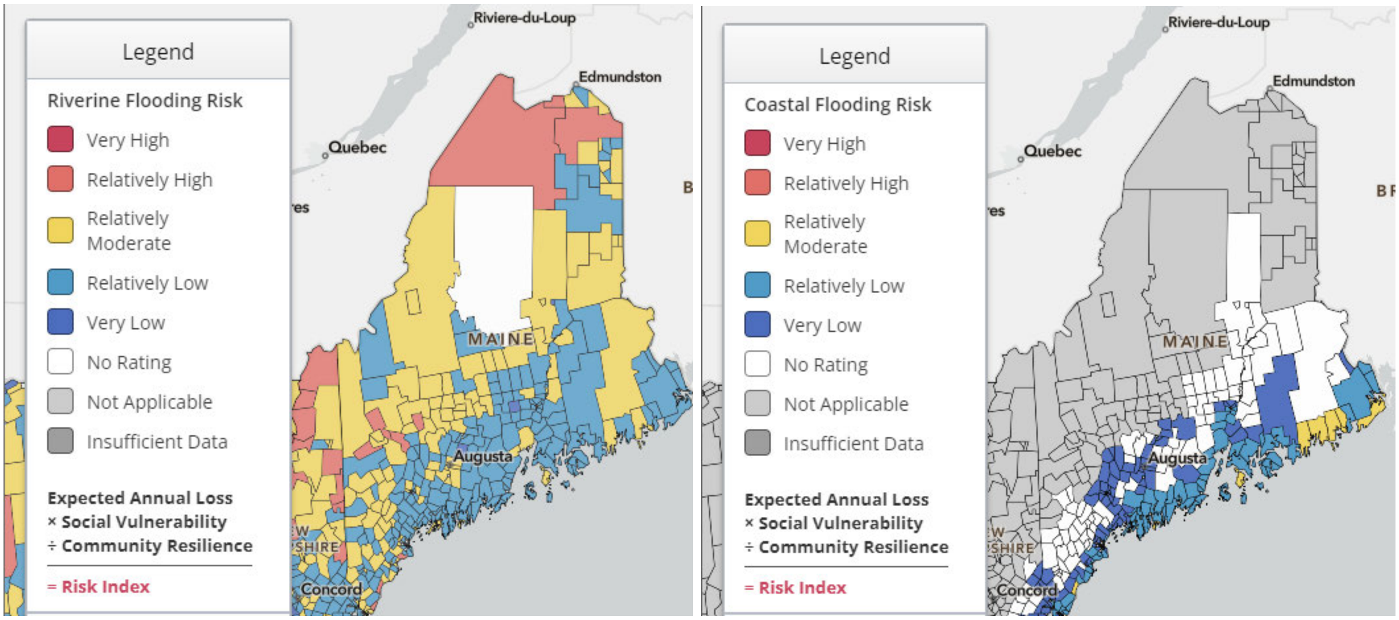

Figure 3.2: National Risk Index map of riverine (left) and coastal (right) flooding risk by census track in Maine. Though these maps indicate risk, rather than simply the occurrence of floods, the general location of historic flooding is captured by the "relatively moderate/high" census tracts. https://hazards.fema.gov/nri/map#

3.6.1 Location of Riverine/Riparian Flooding

Some of Maine's rivers have overflowed many times, but recent flooding has caused increased damage because of the extensive development and denser population of the floodplains. For example, the floods of 1896 and 1936 were more severe but much less destructive than the flood of 1987[26]. By the late 20th century, a much larger population was living and working in the floodplain areas and more people, businesses and infrastructure were affected. Maine's susceptibility to flooding is further exacerbated by the wide-ranging weather variables as discussed in the climate section. Due to seasonal (and regional) factors such as heavy rains, rapidly melting snow pack and/or ice jams, major flooding most frequently occurs between December and May. The most flood prone months are April, January, and March respectively. Floods can also be caused by hurricanes or any other hazardous event involving heavy and/or sustained rainfall. Flooding often occurs along the state's major river basins, outlined below. The most vulnerable of Maine's rivers are the Kennebec and Androscoggin. Refer to MEMA's Risk Assessment Map[27] to view specific locations susceptible to flood.

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[26] Flood of April 1987 in Maine; US Geological Survey Water-Supply Paper 2424: https://pubs.usgs.gov/wsp/2424/report.pdf

[27] MEMA Risk Assessment Map: https://maine.maps.arcgis.com/apps/mapviewer/index.html?webmap=eb8ec0935ce544dbaa80aec18c8db785

Androscoggin River Basin

The Androscoggin River Basin runs 169 miles from its Umbagog Lake source in Errol, New Hampshire to its mouth at Merrymeeting Bay near the borders of Cumberland, Lincoln, and Sagadahoc Counties. The Androscoggin River Basin drains from the western boundaries of Maine and New Hampshire. While it drains less area than the Kennebec River Basin, the river has a more rapid fall (1,245 feet from its source) with an average slope of almost eight feet per mile. The river's steep slope has historically attracted mill-based industries and towns such as Livermore Falls, Lewiston, Auburn, Lisbon Falls and Topsham along its course. Before offshore outsourcing, the mills manufactured products as diverse as paper, textiles, and shoes. Floods have historically been severe in some of the downtown locations where development was extensive, particularly in Oxford County which has been the most vulnerable to floods in the last 36 years. After major ice jam flooding in December 2003, the Town of Canton located in Oxford County applied for, and won a $3 million FEMA Pre-Disaster Mitigation acquisition/demolition project. Due to the proximity of the river to Oxford County, York County, and the state of New Hampshire, mutual aid agreements have been established to emphasize cooperation across emergency plans.

Kennebec River Basin

The Kennebec River Basin occupies approximately 5,900 square miles of southwestern Maine. The river basin originates at Moosehead Lake and flows south approximately 145 miles to Merrymeeting Bay. The Kennebec River joins the Androscoggin River in Merrymeeting Bay before exiting to the ocean at Fort Popham. The upper two-thirds of the basin are hilly and mountainous and the lower third of the basin has gentle topography representative of a coastal drainage area. Major communities in this basin include Bingham, Anson, Madison, Norridgewock, Skowhegan, Waterville, Winslow, Augusta, Hallowell, and Gardiner. Storage dams, such as Wyman Dam in Somerset County, control the upper part of the Kennebec River Basin, and the basin below the dams is largely uncontrolled affecting communities built extensively in floodplains. Notably, the lower third of the river basin is also relatively susceptible to tidal influence as far north as Augusta.

Presumpscot River Basin

Sebago Lake is the source of the Presumpscot River which drains into Casco Bay in Portland, 26 miles downstream. The basin includes some area to the north of Sebago Lake, and the terrain across the basin is generally hilly. While the Presumpscot River Basin covers a small geographic area, it is home to some of the highest population density in the State of Maine.

Penobscot River Basin

The Penobscot River Basin runs 105 miles from its source at the confluence of its east and west Branches in Medway to its mouth in Penobscot Bay. With a land area of 8,570 square miles, the Penobscot River Basin drains almost as large an area as the Kennebec and Androscoggin Rivers combined. It drains a large portion of the north-central part of the state from the Canadian border to Penobscot Bay. It includes most of Maine's pristine bogs and ponds and includes Baxter State Park near its center. A system of upstream dams, the relatively gradual fall of the river averaging only three feet per mile, and the presence of extensive wetlands in the eastern part of the basin have in the past prevented massive floods. The Piscataquis River in the upper part of the basin, however, passes through a series of small communities with many downtown areas vulnerable to spring flooding. The Kenduskeag River flows through Bangor and joins the Penobscot in the downtown area. It has occasionally caused considerable flooding damage to Bangor's downtown.

Saco River Basin

With a land area of 1,700 square miles, the Saco River Basin has approximately a quarter of the drainage area of the Kennebec River but no upstream storage dams. The Saco Basin is generally described as embracing all of York County, as well as most of Cumberland County, and the southern portion of Oxford County. The Saco River runs 75 miles from Crawford Notch in New Hampshire to Biddeford. Several small rivers with small exclusive basins comprise this area. It includes small rivers like the Kennebunk, Mousam, Presumpscot, Royal, Ogunquit and the Maine portion of the Piscataqua and Salmon Rivers. Many of the smaller rivers such as the Mousam have experienced significant flooding in recent years.

St. Croix River Basin

At 1,650 square miles, the St. Croix River Basin has as much drainage area as the Saco River Basin, but it is controlled by upstream storage dams. The Saco, St. Croix, and St. John rivers do not have the extensive floodplain development of the Kennebec and Androscoggin Rivers. The St. Croix River runs 71 miles from the Chiputneticook Lakes to Passamaquoddy Bay and serves as the international border between Maine and Canada. The basin includes the area known as “Down East”. Most of the basin is subject to tidal influence, but it is also comprised of many smaller rivers such as the Dennys, Pleasant, Machias, Narraguagus and Union Rivers. This area has historically been sparsely populated but has experienced increasing pressures for development. Most flood damages in this basin are due to infrastructure rather than residential and commercial structures.

St. John River Basin

The St. John River Basin includes portions of Aroostook, Somerset, Piscataquis, and Penobscot Counties. The river basin drains 1,650 square miles from a vast area in both Canada and northern Maine. The St. John River runs 420 miles and has a considerable drop in elevation in the upper section followed by generally flat topography with rolling hills. The state’s only National Scenic Waterway the Allagash, which forms the headwaters of the St. John basin, is world renowned for its wilderness canoeing. The St. John forms Maine’s northernmost border. Because of the wide channel and steep banks, the main stem of the St. John River has relatively moderate flooding. Some tributaries of the St. John, such as the Aroostook River, are prone to flooding. There is, however, very little development at risk in the St. John Basin. Maine’s two most significant levees, Fort Kent and Fort Fairfield, are in this basin. The Fort Kent levee was built in the late 1980’s, and has since seen numerous updates. The Fort Fairfield levee was built in 2001. In 2008, a flood on the Saint John River came within three inches of the top of the levee but did not overtop it. Despite the height of the water, the levee withstood the flood.

3.6.2 Location and Hazard Characteristics of Dams [HHPD1.a; HHPD2.a]

The result of a dam failure is a flood. The location of each dam is, therefore, a location of potential flooding from a dam breach or failure. Figure 3.3 identifies the extent of dams spread throughout the state. The Maine Dam Safety Program[28] continues to maintain records indicating the level of hazard associated with each unique structure, summarized in Table 3.5, and updated paper copies of dam failure inundation maps for every high hazard dam in the state reported in Emergency Action Plans. Though these maps are not sharable in paper form there is interest in providing digital map resources with future onboarding of new technical staff.

The terms “high”, “significant” and “low” refer to the downstream hazard potential of the dams as defined within *Title 37B MSRA*, Chapter 24. *Title 37B MSRA* assigns administration of the Maine Dam Safety Program (DSP) to the Maine Department of Defense, Veterans and Emergency Management.

High Hazard Potential Dam: A dam assigned the high hazard potential classification where failure or mis-operation will probably cause loss of human life; [2001, c. 460, §3]

Significant Hazard Potential Dam: A dam assigned the significant hazard potential classification where failure or mis-operation results in no probable loss of human life but can cause major economic loss, environmental damage or disruption of lifeline facilities or affect other concerns. Significant hazard potential dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure. [2001, c. 460, §3]

Low Hazard Potential Dam: A dam assigned the low hazard potential classification where failure or mis-operation results in no probable loss of human life and low economic and environmental losses. Losses are principally limited to the owner's property; and [2001, c. 460, §3]

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[28] Maine Dam Safety Program: https://www.maine.gov/mema/hazards/dam-safety

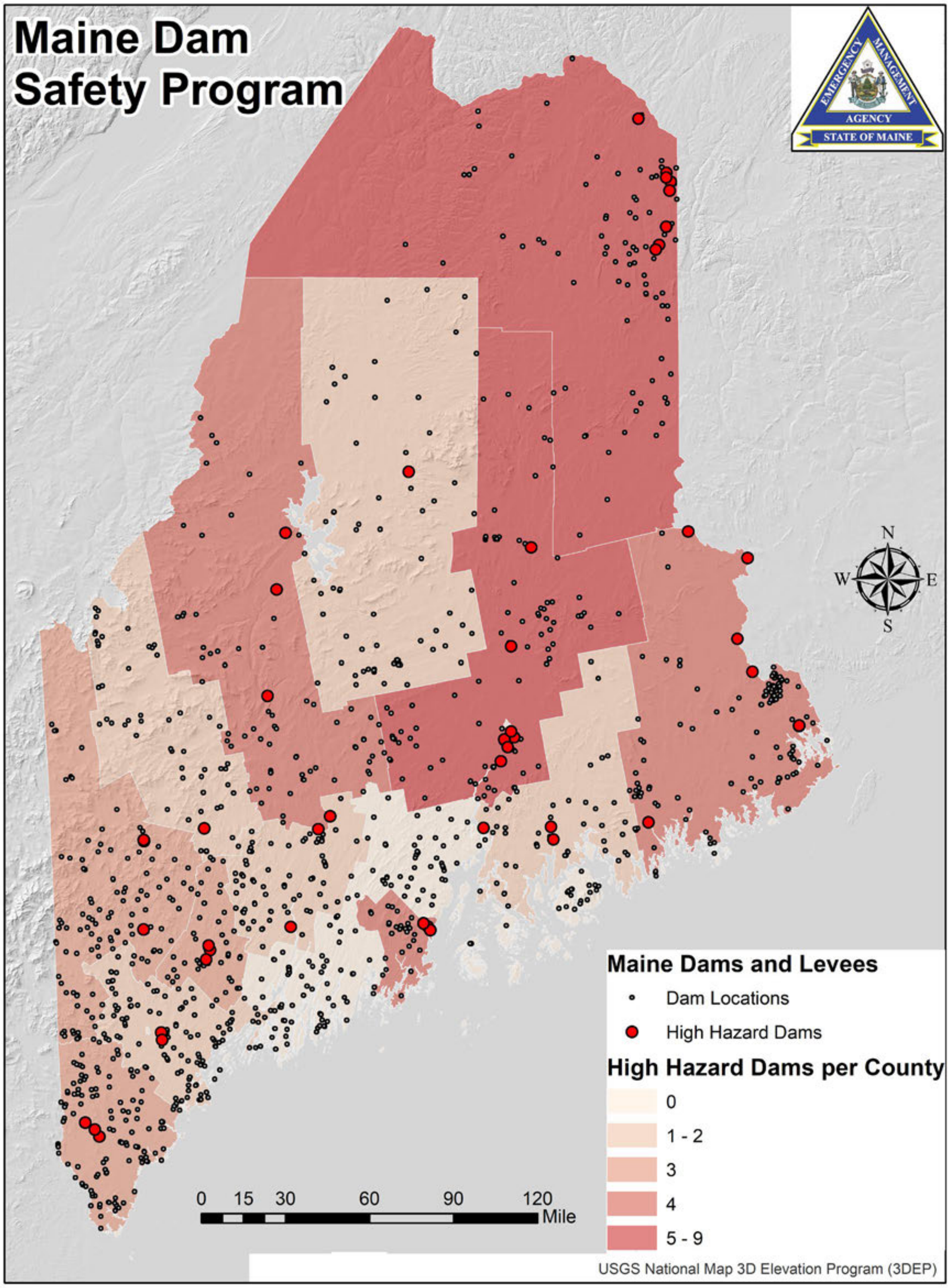

Figure 3.3 – An overview of dam locations in the State of Maine. Coordinates were last updated in 2022.

The Maine Office of Dam Safety maintains records of 1,145 dams, of which 743 meet definitions of dams that require regulation, apportioned as follows:

- (529) Five hundred and twenty-nine dams are regulated by the Maine Dam Safety Program.
- (155) One hundred and fifty-five jurisdictional dams are regulated by the Federal Energy Regulatory Commission.
- (59) Fifty-nine dams on the Maine–New Hampshire border are regulated by the New Hampshire Department for Environmental Services Dam Bureau (43) and the Federal Energy Regulatory Commission (16) (these are excluded in the state regulated numbers).
- (2) Two dams located on the Canadian border, Woodland and Grand Falls, are regulated by the Maine Dam Safety Program and the International Joint Commission (IJC) on dams (these are included in the state regulated numbers).

The hazard classifications for regulated dams in Maine are shown in Table 3.5. Refer to Appendix HHPD2 for a list of high hazard dam names and location/identification data.

Table 3.5: State and FERC Regulated Dams in the State of Maine (March 24, 2023)

Hazard	State Regulated Dams	FERC Regulated Dams	Totals Dams
High	39	34	73
Significant	67	17	84
Low	423	104	527
Total	529	155	684

Maine Dam Safety Program 2023

Maine law requires the High and Significant dams be inspected every six years respectively and the High and Significant dams have Emergency Action Plans (EAPs) to mitigate the effects of a failure. The FERC regulates 32 High Hazard and 9 Significant hazard dams in Maine and has up to 5 engineers to do the inspections. The state regulates 32 High Hazard and 72 Significant hazard dams and employs one engineer.

In its most basic form, the Emergency Action Plan requires a Notification Flowchart and Inundation Map. The Flowchart is a communications tool, a call down list, based on the Incident Command System for use by first responders and emergency personnel in notifying and evacuating downstream populations. The complexity of the inundation map is largely determined by the population downstream and available resources for producing such documents. Dams producing electricity tend to have the most engineered inundation maps because their owners have a vested interest in their continued operation. Current EAP compliance includes 100% of High Hazard and 100% of Significant hazard dams. According to the Association of Dam Safety Officials (ASDSO) website, Maine has one of the highest compliance rates in the nation.

3.6.3 Location of Coastal Flooding/Storm Surge

There are 152 jurisdictions in ten Counties in Maine that are vulnerable to flooding from storm surge (Figure 3.4). Storm surge locations are determined using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model produced by the National Weather Service [29]. Numerous storm factors determine the overall extent of storm surge, therefore a composite approach is used, compiling thousands of modeled storm tracks to generate the Maximum Envelopes of Water (MEOWs) and Maximum of MEOWs (MOMs). The National Hurricane Center regards these as the best approach for determining storm surge location and vulnerability. This approach assumes landfalling hurricanes along the coastline during mean high tide, and outputs both storm tides and storm surge amounts. It is important to note that the SLOSH modeling does not account for the potential impacts from waves, extreme tides, freshwater flow, precipitation, or potential future scenarios of sea level rise. Storm surge maps are then used by communities to expand the local analysis of storm surge impact and designate evacuation zones that are susceptible to inundation. Refer to the Maine Hurricane Evacuation Dashboard for more information on designated evacuation zones [30] and Maine Geological Survey's SLOSH Maps viewer for location-specific information on storm surge [31]. SLOSH model products are continually updated and governed by the Interagency Coordinating Committee on Hurricanes (ICCOH).

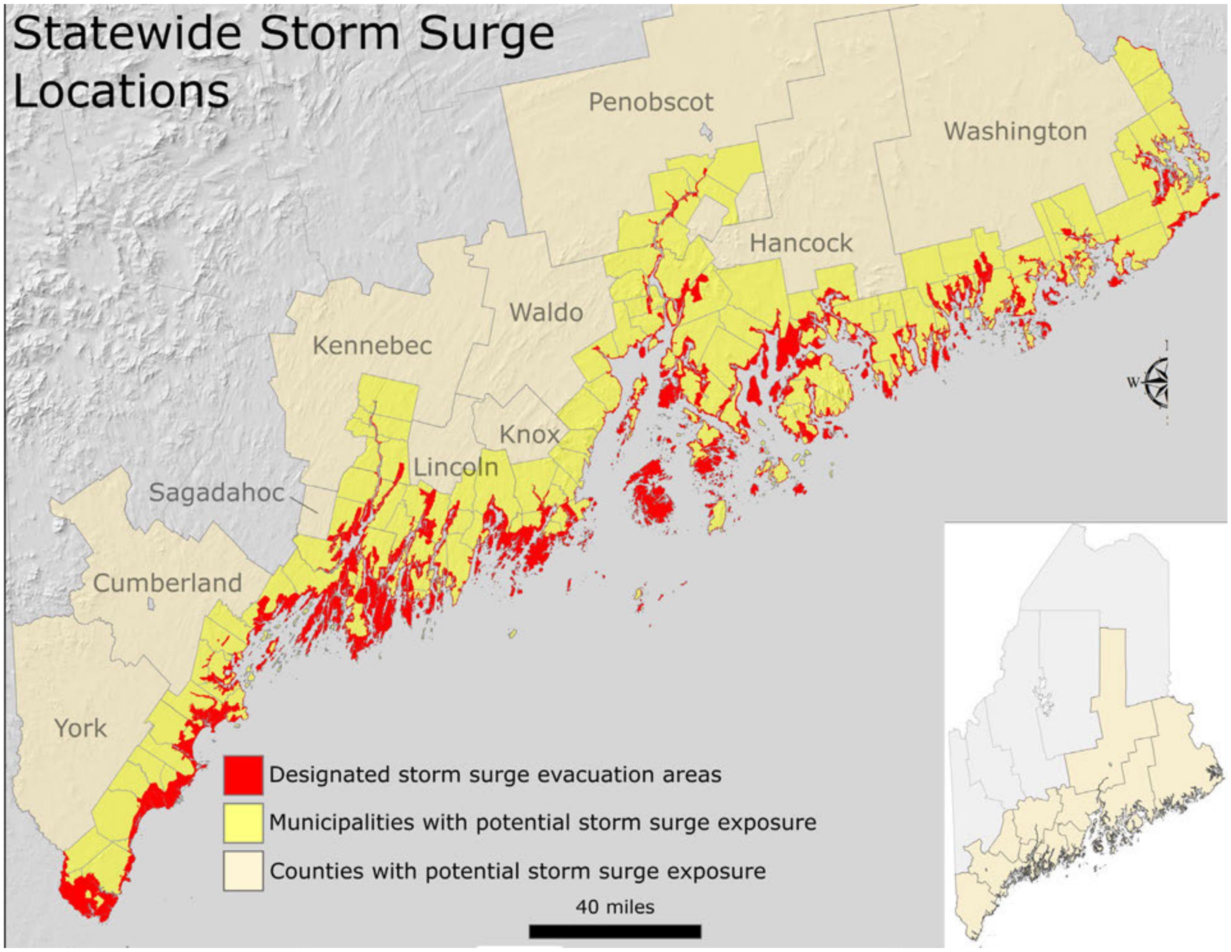

Figure 3.4: Statewide storm surge locations, evacuation areas determined based on storm surge models results.

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[29] NOAA SLOSH models: https://www.nhc.noaa.gov/surge/slosh.php
[30] Maine Hurricane Evacuation Dashboard: https://storymaps.arcgis.com/stories/4fb502bf0ea6467693ff4191a1859e92
[31] Maine Geological Survey SLOSH Maps viewer: https://www.maine.gov/dacf/mgs/hazards/slosh/index.shtml

3.6.4 Location of Tsunami flooding

The State of California Governor’s Office of Emergency Services states, in locations where tsunami maps and signs are unavailable, evacuation sites should be located 100 feet above sea level or greater or two miles inland, away from the coast. Maine has no official tsunami flood/evacuation map. Based on this general guidance, Figure 3.5 identifies the maximum area that may be impacted by a tsunami event. Tsunamis in Maine are a very unlikely occurrence, and if they do occur, they are anticipated to be much smaller events relative to these guidelines, which are more relevant to tectonically active coastal regions in the western United States [32].

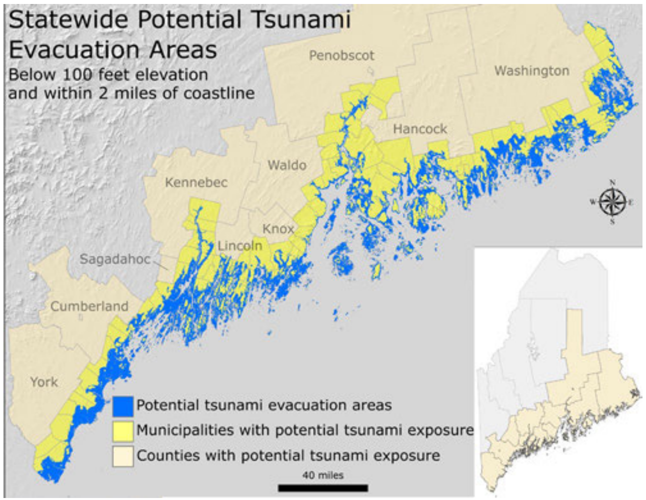

Figure 3.5: Potential tsunami flooding locations.

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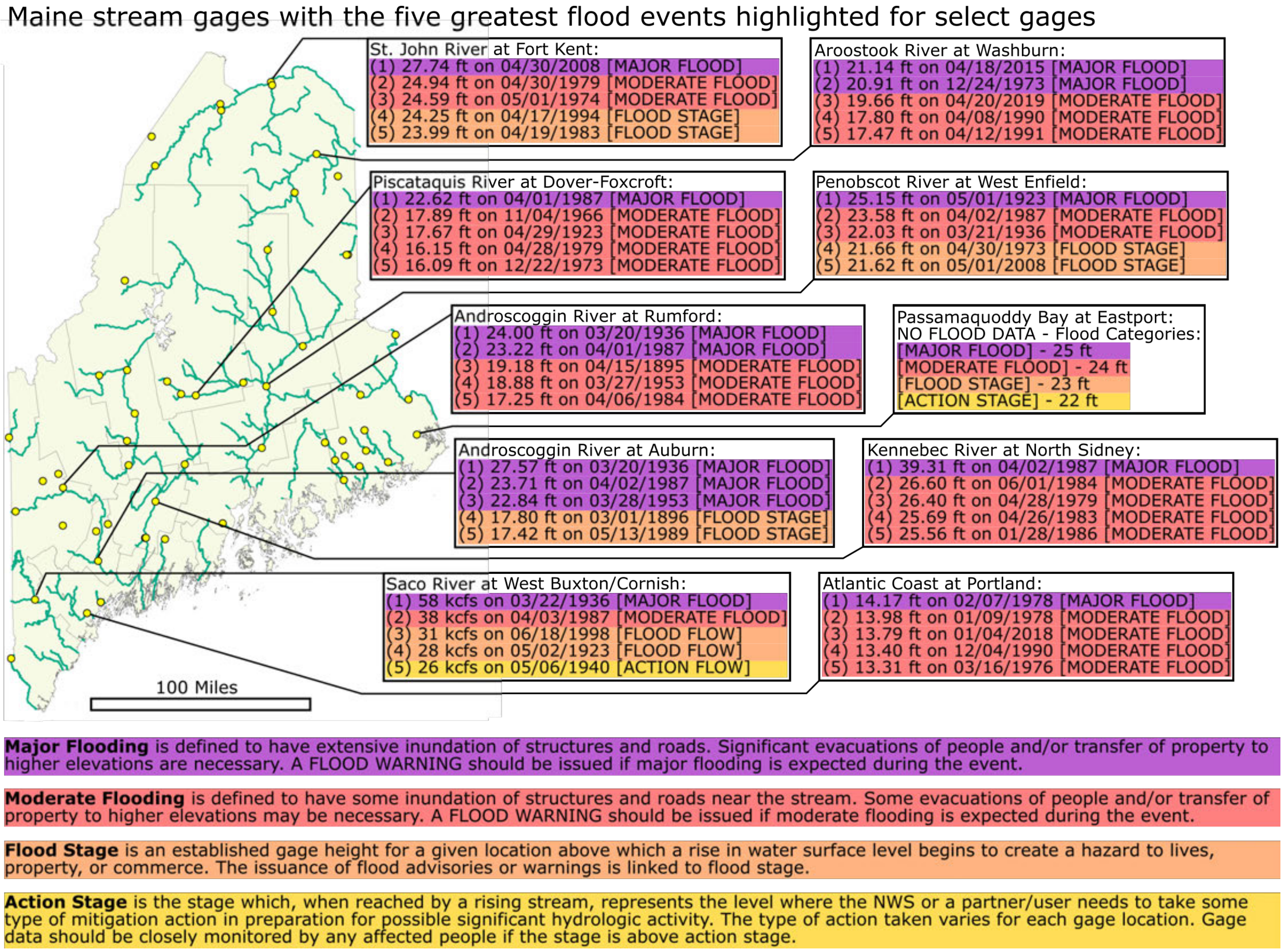
[32] USGS, “Could it Happen Here?”: https://www.usgs.gov/centers/pcmsc/could-it-happen-here

3.7 Flooding – Intensity and Previous Occurrences [S3.a.2.]

Maine uses 'probability of occurrence' to measure the magnitude of a flood event and place it into historical context. Flooding from a 10-year rainfall event is less severe than flooding from a 100-year rainfall event, which is less severe than flooding from a 500-year rainfall event. Through coordination with the United States Geological Survey and National Weather Service, Maine uses stream gauges to measure river levels, which can also be used to estimate the magnitude and recurrence interval of a flood; and inundation depths at specific locations for determining the localized extent of flooding (Figure 3.6).

There are multiple areas in Maine that are not monitored by flood forecasting stream gauges. In these cases, the extent or intensity of flooding is most easily described by noting the speed at which floodwaters rise and the amount of time in which the area remains flooded.


Maine stream gages with the five greatest flood events highlighted for select gages

St. John River at Fort Kent:
(1) 27.74 ft on 04/30/2008 [MAJOR FLOOD]
(2) 24.94 ft on 04/30/1979 [MODERATE FLOOD]
(3) 24.59 ft on 05/01/1974 [MODERATE FLOOD]
(4) 24.25 ft on 04/17/1994 [FLOOD STAGE]
(5) 23.99 ft on 04/19/1983 [FLOOD STAGE]

Aroostook River at Washburn:
(1) 21.14 ft on 04/18/2015 [MAJOR FLOOD]
(2) 20.91 ft on 12/24/1973 [MAJOR FLOOD]
(3) 19.66 ft on 04/20/2019 [MODERATE FLOOD]
(4) 17.80 ft on 04/08/1990 [MODERATE FLOOD]
(5) 17.47 ft on 04/12/1991 [MODERATE FLOOD]

Piscataquis River at Dover-Foxcroft:
(1) 22.62 ft on 04/01/1987 [MAJOR FLOOD]
(2) 17.89 ft on 11/04/1966 [MODERATE FLOOD]
(3) 17.67 ft on 04/29/1923 [MODERATE FLOOD]
(4) 16.15 ft on 04/28/1979 [MODERATE FLOOD]
(5) 16.09 ft on 12/22/1973 [MODERATE FLOOD]

Penobscot River at West Enfield:
(1) 25.15 ft on 05/01/1923 [MAJOR FLOOD]
(2) 23.58 ft on 04/02/1987 [MODERATE FLOOD]
(3) 22.03 ft on 03/21/1936 [MODERATE FLOOD]
(4) 21.66 ft on 04/30/1973 [FLOOD STAGE]
(5) 21.62 ft on 05/01/2008 [FLOOD STAGE]

Androscoggin River at Rumford:
(1) 24.00 ft on 03/20/1936 [MAJOR FLOOD]
(2) 23.22 ft on 04/01/1987 [MAJOR FLOOD]
(3) 19.18 ft on 04/15/1895 [MODERATE FLOOD]
(4) 18.88 ft on 03/27/1953 [MODERATE FLOOD]
(5) 17.25 ft on 04/06/1984 [MODERATE FLOOD]

Passamaquoddy Bay at Eastport:
NO FLOOD DATA - Flood Categories:
[MAJOR FLOOD] - 25 ft
[MODERATE FLOOD] - 24 ft
[FLOOD STAGE] - 23 ft
[ACTION STAGE] - 22 ft

Androscoggin River at Auburn:
(1) 27.57 ft on 03/20/1936 [MAJOR FLOOD]
(2) 23.71 ft on 04/02/1987 [MAJOR FLOOD]
(3) 22.84 ft on 03/28/1953 [MAJOR FLOOD]
(4) 17.80 ft on 03/01/1896 [FLOOD STAGE]
(5) 17.42 ft on 05/13/1989 [FLOOD STAGE]

Kennebec River at North Sidney:
(1) 39.31 ft on 04/02/1987 [MAJOR FLOOD]
(2) 26.60 ft on 06/01/1984 [MODERATE FLOOD]
(3) 26.40 ft on 04/28/1979 [MODERATE FLOOD]
(4) 25.69 ft on 04/26/1983 [MODERATE FLOOD]
(5) 25.56 ft on 01/28/1986 [MODERATE FLOOD]

Saco River at West Buxton/Cornish:
(1) 58 kcfs on 03/22/1936 [MAJOR FLOOD]
(2) 38 kcfs on 04/03/1987 [MODERATE FLOOD]
(3) 31 kcfs on 06/18/1998 [FLOOD FLOW]
(4) 28 kcfs on 05/02/1923 [FLOOD FLOW]
(5) 26 kcfs on 05/06/1940 [ACTION FLOW]

Atlantic Coast at Portland:
(1) 14.17 ft on 02/07/1978 [MAJOR FLOOD]
(2) 13.98 ft on 01/09/1978 [MODERATE FLOOD]
(3) 13.79 ft on 01/04/2018 [MODERATE FLOOD]
(4) 13.40 ft on 12/04/1990 [MODERATE FLOOD]
(5) 13.31 ft on 03/16/1976 [MODERATE FLOOD]

Major Flooding is defined to have extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations are necessary. A FLOOD WARNING should be issued if major flooding is expected during the event.

Moderate Flooding is defined to have some inundation of structures and roads near the stream. Some evacuations of people and/or transfer of property to higher elevations may be necessary. A FLOOD WARNING should be issued if moderate flooding is expected during the event.

Flood Stage is an established gage height for a given location above which a rise in water surface level begins to create a hazard to lives, property, or commerce. The issuance of flood advisories or warnings is linked to flood stage.

Action Stage is the stage which, when reached by a rising stream, represents the level where the NWS or a partner/user needs to take some type of mitigation action in preparation for possible significant hydrologic activity. The type of action taken varies for each gage location. Gage data should be closely monitored by any affected people if the stage is above action stage.

Figure 3.6: USGS stream gages (yellow points) with select peak flow events listed for key locations. Flood extent scales differ between locations based on local hydrologic conditions, terrain, and affected infrastructure. See the National Weather Service River Forecasts website for more detailed information [33].

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[33] NWS River Forecasts: https://water.weather.gov/ahps/forecasts.php

3.7.1 Previous Occurrences

Table 3.6 Summarizes a 48-year record of major seasonal flooding occurrence in Maine’s 16 counties. Major flood occurrences are defined as Presidential Declarations, Emergency Declarations, or Small Business Administration claims. Though the 70’s, 90’s, and the first decade of the twenty-first century were flood prone decades, note that the years of 1987, 1993, 2005, and 2007 were the years where at least 75 percent of all Maine counties were affected. Though 2017 is also highlighted, the damages associated with this event include wind damage as well as flooding. More details on storms of record are provided below.

Table 3.6. Major floods by county

Major Floods	AN	AK	CD	FN	HK	KC	KX	LN	OD	PT	PS	SC	ST	WO	WN	YK	Total Counties	Estimated Damages (2022 USD)	
Mar 1846	X					X				X							3	$UNK	-
Mar 1896	X																1	$UNK	-
Apr 1923						X				X							2	$34,639,883	-
Mar 1936	X		X	X					X	X			X			X	7	5 deaths, $532,681,655	-
Aug 1946			X														1	$3,037,651	-
Apr 1950				X		X											2	3 bridges	-
Apr 1951		X															1	$UNK	-
Mar 1953	X		X			X			X								4	$UNK	-
May 1961															X		1	$9,905,3845	-
Jan 1970				X					X		X		X				4	$22,899,820	FEMA-284-DR-ME
Feb 1972			X													X	2	$UNK	-
Apr 1973		X		X					X	X				X	X		6	$6,059,525	Request denied
May1973		X															1	$UNK	SBA
Jul 1973		X		X					X	X				X			5	$UNK	SBA
Dec 1973		X				X		X		X		X	X	X			7	$20,011,554	-
May 1974		X															1	$18,022,576	-
May 1975			X				X									X	3	$1,651,511	SBA
Feb 1976										X					X		2	$13,533,297	SBA
Apr 1976		X															1	$1,041,023	-
Aug 1976		X															1	Crop damage $UNK	SBA
Mar 1977	X		X						X							X	4	$UNK	SBA
Feb 1978			X					X							X	X	4	$93,998,775	FEMA-550-DR-ME
Apr 1979		X				X				X	X						4	$2,645,550	SBA
Jun 1984	X		X			X				X		X	X				6	$UNK	-
Jan 1986	X		X	X		X		X	X			X	X			X	9	Roads, bridges, dams	-
Apr 1987	X		X	X	X	X	X	X	X	X	X	X	X	X		X	14	$260,713,908	FEMA-788-DR-ME
May1989	X			X					X								3	$3,334,599	FEMA-830-DR-ME
Apr 1991		X															1	$31,313,233	FEMA-901-DR-ME
Mar 1992	X		X	X		X	X		X	X			X	X		X	10	$7,309,887	FEMA-940-DR-ME
Apr 1993	X	X	X	X	X	X		X	X	X	X		X	X		X	13	$7,125,540	FEMA-988-DR-ME
Apr 1994		X															1	$11,391,192	FEMA-1029-DR-ME
Oct 1995				X			X		X								3	$UNK	-
Jan 1996	X			X					X	X	X		X	X			7	$4,117,268	FEMA-1106-DR-ME
Apr 1996	X		X				X		X							X	5	$5,042,116	FEMA-1114-DR-ME
Oct 1996			X						X							X	3	$16,985,947	FEMA-1143-DR-ME
Jun 1998	X			X		X			X				X			X	6	$4,577,855	FEMA-1232-DR-ME
Oct 1998			X													X	2	$3,629,557	FEMA-1263-DR-ME
Mar 2000	X	X		X		X			X		X		X		X		8	$4,960,618	FEMA-1326-DR-ME

Mar 2001				X		X			X	X					X	X	6	$2,947,609	FEMA-1371-DR-ME
Dec 2003				X		X			X		X	X	X	X			7	$3,882,012	FEMA-1508-DR-ME
Mar 2005	X	X		X	X	X	X	X	X		X		X	X	X		12	$10,569,049	FEMA-1591-DR-ME
May2006																X	1	$4,113,486	FEMA-1644-DR-ME
Mar 2007					X		X	X						X			4	$1,773,572	FEMA-1691-DR-ME
Apr 2007 [34]	X		X	X	X	X	X	X	X			X	X	X	X	X	13	$39,926,610	FEMA-1693-DR-ME
Jul 2007 [35]									X								1	$2,378,416	FEMA-1716-DR-ME
Apr 2008 [36]		X					X	X		X	X		X	X			7	$6,878,004	FEMA-1755-DR-ME
Jul 2008	X		X													X	3	$3,660,153	FEMA-1788-DR-ME
Dec 2008	X		X				X	X				X		X		X	7	$13,756,009	FEMA-1815-DR-ME
Jun 2009				X	X		X	X	X		X		X	X	X		9	$3,451,281	FEMA-1852-DR-ME
Feb-Mar 2010 [37]			X				X	X				X				X	5	$7,192,141	FEMA-1891-DR-ME
Mar-Apr 2010 [38]					X											X	2	$1,710,001	FEMA-1920-DR-ME
Dec 2010 [39]		X									X				X		3	$2,173,793	FEMA-1953-DR-ME
Oct 2017 [40]			X	X	X	X	X	X	X	X	X	X	X	X		X	13	$9,563,906	FEMA-4354-DR-ME
May 2018 [41]																X	1	$6,047,943	FEMA-4367-DR-ME
Oct 2021							X							X		X	3	$2,623,207	FEMA-4647-DR-ME
TOTALS	19	16	20	20	8	18	14	13	24	16	12	9	17	16	10	23	255	$1,332,425,578	31 Declarations
Major Floods	AN	AK	CD	FN	HK	KC	KX	LN	OD	PT	PS	SC	ST	WO	WN	YK	Total Counties		

KEY: County Codes			
AN = Androscoggin	HK = Hancock	OD = Oxford	ST = Somerset
AK = Aroostook	KC = Kennebec	PT = Penobscot	WO = Waldo
CD = Cumberland	KX = Knox	PS = Piscataquis	WN = Washington
FN = Franklin	LN = Lincoln	SC = Sagadahoc	YK = York

SBA: Activation of Small Business Association Low Interest Loan Recovery Programs
DR: Presidential Disaster Declaration

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[34] FEMA-1693-DR-ME: https://www.fema.gov/disaster/1693
[35] FEMA-1716-DR-ME: https://www.fema.gov/disaster/1716
[36] FEMA-1788-DR-ME: https://www.fema.gov/disaster/1788
[37] FEMA-1891-DR-ME: https://www.fema.gov/disaster/1891
[38] FEMA-1920-DR-ME: https://www.fema.gov/disaster/1920
[39] FEMA-1953-DR-ME: https://www.fema.gov/disaster/1953
[40] FEMA-4354-DR-ME: https://www.fema.gov/disaster/4354 (primarily wind damage)
[41] FEMA-4367-DR-ME: https://www.fema.gov/disaster/4367

Flood of Record: The Great Flood of 1936

The flooding on March 19, 1936, was significant throughout southwestern and central Maine [42]. The Kennebec, Androscoggin, and Saco River basins experienced the worst of the flood damage in Maine. According to the gaging station on the Androscoggin River at Auburn, the peak discharge was 135,000cfs, the largest discharge recorded at that site. Similarly, the peak discharge of the Mattawamkeag River near Mattawamkeag was the highest on record.

The meteorologic and soil conditions from the early winter season to just before March 19 were instrumental factors in the large discharges of the flood. In the early winter, the ground had frozen and was almost impermeable. Through January and February, many river basins of the State accumulated significant quantities of snow that created deep snowpack. The first warning sign came when warmer weather around March 9 began an early spring thaw. During the following 10 days, the Northeast experienced 2 major storms that only exacerbated the snowmelt and ice melt.

The first of the major storms, the March 11-12 storm coincided with the breakup of thick ice that had formed on streams during the winter months. Streamflow records indicate the runoff from this first storm was about equal to the rainfall: thus, snowmelt didn't contribute much to discharge after the first storm. While snowmelt was insignificant in the March 11-12 storm event, streamflow records report they had a much larger role in discharge during the second storm. Snowmelt, as well as the severe rainfall of the second storm, combined to release sizeable flows into already swollen river systems. Peak discharges after the second storm were far greater than those of the first storm.

While snowmelt and rainfall combined to dramatically elevate the water levels, large ice jams also played a major role in the heightening flood levels and damage. "Elevated river stages in Augusta and Hallowell, caused by ice jams, were 3.6 feet higher than the previous high-water records from March 2, 1896" (Maloney and Bartlett, 1991, p. 313). Another notable ice jam formed in a reach several miles long on the Androscoggin River just upstream from the pond of the powerplant above Lewiston. "According to powerplant records, this ice jam broke on March 20 and released a large volume of water that caused a rise of 1.75 feet in the pond in less than one-half hour" (p. 313). Those are just a couple of examples of the massive influence the ice jams had on increased flood levels.

When the ice jams released, the resulting ice flows compounded damage on several rivers by crashing through buildings and bridges downstream. Overall, the flood and ice floes destroyed or damaged 81 highway bridges. That is just one metric that highlights the immense damage the flood caused. In the aftermath of the flooding, five lives were lost, and property damage reached about $25 million. The one saving grace in this flood event was the timely warnings delivered to the public. Because the telephone, telegraph, and radio services kept the public advised about the severity of the floods well in advance of the flood crests, the loss of life was considerably lower than it could have been.

Flood of Record: The "April Fools Flood of 1987"

Records of past floods indicate that the April 1987 flood was one of the most significant in Maine's history. At selected sites, it was the worst since the area was settled more than 200 years ago. Flood damage in the Penobscot and Kennebec River basins in 1987 was the greatest for any flood (including March 1936) for which data is available.

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[42] Maloney, T. J., & Bartlett, W. P. (1991). National Water Summary 1988–89 — Floods and Droughts: MAINE. U.S. Geological Survey Water-Supply Paper. https://doi.org/10.3133/wsp2375

Hydrometeorology conditions before the April 1987 flood gave no clear indication of the severity of the flooding that was to come. From December 1986 through March 1987, precipitation was below normal. In early March, the snowpack was below normal in northern Maine, normal in southern interior sections and above normal in coastal areas."[43] However, as spring approached, climatic conditions began to change and set the stage for trouble. March temperatures had finally gone above freezing, and then above normal, rapidly melting off the snowpack. Runoff was then above normal in upland areas of western Maine. From March 20 through April 2, multiple areas of low pressure moved slowly northeast toward Maine, bringing two storms that unleashed heavy rains. The resulting floods had only one missing factor – ice. Had there been ice jams, the damage would have been far worse. "In contrast to the 1936 flood, during which backwater from ice jams was common, peak stages for the 1987 flood reflect primarily free-flowing conditions.[44]

Still, the damages were far reaching, affecting 14 of the 16 counties and a wide range of enterprises. Many businesses had waterways instead of streets. Even in the first estimations, the Small Business Administration thought that 400 businesses had sustained losses totaling approximately $36,000,000. The Agricultural Stabilization and Conservation Service reported $300,000 worth of equipment and $100,000 in livestock losses. Pollutants in flood waters contaminated clam beds at the mouth of rivers, putting clam diggers out of business. That alone necessitated Disaster Unemployment Assistance funding of over $300,000.[45]

According to MEMA accounting records, the "April Fool's Flood" of 1987 was a $100,000,000 event. Were it to happen today, nearly 20 years later, the costs would be much higher, primarily because real estate and infrastructure values have continued to rise.

Flood of Record: The 2007 "Patriot's Day Storm"

According to the Gulf of Maine Ocean Observing System website, the Patriot's Day Storm of 2007 (Figure 3.7) will be long remembered for its meteorological significance and devastating power. Violent waves destroyed homes, businesses, coastal roads and beaches, while forceful winds tore down power lines, leaving many residents in the dark for days. Portland had a peak wind of 59 mph and winds in Cape Elizabeth exceeded 80 mph measured on April 16th. An abnormally high spring tide plus a storm surge of 3 feet (2.72 feet at the Portland tide gauge) produced a high tide of 13.28 feet (the 7th highest tide measured since the early 1900's).

Figure 3.7: Damage from the Patriot's Day Storm, 2007 Photo by John Cannon National Weather

As the storm deepened it stalled over the area for a full day before it slowly moved to the northeast. Very heavy rain fell on the coast with 5 to 8" over a 3-day period leading to river flooding. In addition to the rain, strong winds caused significant storm surge and very large battering coastal waves. During this time there were four high tide cycles in which the water was near or above flood stage. Waves just off the coast were recorded at 25+ feet. This combination caused the tremendous amounts of damage seen during the storm. The flood resulted in peak streamflows with recurrence intervals greater than 100 years throughout most of York County, and recurrence intervals up to 50 years in Cumberland County [46, 47].

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[43] "Flood of April 1987 in Maine," US Geological Survey Water Supply Paper 2424, p.37: https://pubs.usgs.gov/wsp/2424/report.pdf
[44] Ibid, p.27
[45] Interagency Hazard Mitigation Report, FEMA-788-DR-Maine, April 1987, p.2.: https://www.fema.gov/disaster/788
[46] Lombard, P.J., 2009, Flood of April 2007 in southern Maine: U.S. Geological Survey Scientific Investigations Report 2009–5102, 34 p., available only online at http://pubs.usgs.gov/sir/2009/5102.
[47] Lombard, P.J., 2009, Floods of May 2006 and April 2007 in Southern Maine: U.S. Geological Survey Fact Sheet 2009-3049, 2 p., available online at https://pubs.usgs.gov/fs/2009/3049.

Notable Flood: The 1976 "Groundhog Day Storm"

On February 2, 1976, downtown Bangor, Maine, was flooded with 12 feet (3.7 m) of water [48]. The water surface elevation reached 17.46 feet (5.32 m) above the national geodetic vertical datum of 1929 (NGVD), approximately 10.5 feet (3.2 m) above the predicted astronomical tide at Bangor. Analysis of meteorological and hydrologic data indicates that the major cause of the flooding at Bangor was the combination of storm surge and high astronomical tide (storm tide). Anomalously high storm tide inundated the Penobscot River from Penobscot Bay and prevented the Kenduskeag from discharging into the Penobscot. Fresh water from Kenduskeag then overflowed directly into downtown Bangor. The storm surge generated on the open coast from Brunswick to Eastport and in the Penobscot Bay was funneled and amplified by hurricane-level south-southeasterly winds that "piled up" water into the Penobscot River to Bangor. The storm surge was generated by a fast-moving extratropical cyclone that had originated in the Gulf of Mexico three days before the event. The resulting flood was the third highest in Bangor since 1846 and is the first documented tidal flood at Bangor. Previously recorded floods at Bangor had been attributed to streamflow or backwater from debris or ice jams.

Damages were estimated to be $2.6 million by the Maine Office of Civil Emergency Preparedness. No deaths were reported. Because the unusually high water in Bangor occurred suddenly, was of short duration, and involved a large volume of water, it was considered to be a "flash flood." The flood peak occurred late morning on February 2, 1976. Flood waters rose very quickly; it was estimated that it took less than 15 minutes for the water to reach maximum depth. Office workers could see the rising waters, but many could not get to their cars. Several people were caught by the flood as they tried to move their cars and had to be rescued. The flood submerged approximately 200 motor vehicles and many downtown businesses were inundated. Much of the damage was in flooded basements and in the cellar vaults of several downtown banks. There was a power loss in the area and electrical damage sparked at least two fires. Coastal areas from Brunswick to Eastport experienced substantial beach erosion and damage to coastal infrastructure. The storm surge reached a maximum height at Portland of 3.6 feet, Rockland 3.7 feet, and Bar Harbor 5.5 feet. Floodwaters began to recede an hour later. The following day, the rivers were well within their normal channels, but floodmarks remained visible and were used by the U.S. Geological Survey to document the extent of flooding.

Notable Flood: the 2021 "Halloween Storm"

On October 30-31, 2021 a rapidly developing area of low pressure tracked across western and southern Maine, delivering between 2-6.5 inches of rain within a matter of hours to various localities and driving extensive flash flooding and runoff. The annual probability of occurrence of this rainfall rate is 1 in 50, or 2%. Locations in Knox, Waldo, and York County experienced considerable damage to public infrastructure, as well as private homes and businesses, and the loss of electrical power to nearly 50,000 customers. Storm damage included culvert collapse and road washouts, flooding of a healthcare facility, and the most dramatic incident, the collapse of the Pepperell Mills Riverwalk along the Saco River in Biddeford. Damage estimates from flooding totaled $2.4 million.

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[48] Morrill, R.A. et al. (1979), Maine coastal storm and flood of February 2, 1976, Geological Survey Professional Paper 1087: https://pubs.usgs.gov/pp/1087/report.pdf

History of Dam Failure/Breach

Known dam failures/breaches include the following:

- In 1952, Lovell Dam breached during a flood, washing away two mills. It was subsequently repaired.
- In the storm of October 20, 1996, Willet Brook Dam, owned by the town of Bridgton in Cumberland County, failed, and affected the public water supply for the town (population 4,307).
- In Alfred, York County, the Littlefield River Dam, owned by the Town of Alfred, was washed out.
- In 1997, the Owens Marsh Dam in Concord Township, owned by the Department of Inland Fisheries and Wildlife, had been built upon by beavers, and breached after three days of heavy rains causing over a million dollars in road damages.
- In 1997, the Apple Valley Dam in Monmouth breached, causing about $350,000 in damages.
- In 2000, Mt. Zircon Dam showed signs of extensive toe seepage; water level lowered as safety measure, but dam not repaired.
- In 2004, the Meadow Cove Dam in Boothbay breached, causing about $30,000 in damages.
- In 2005, during the April flooding events, the Sherman Lake Dam in Newcastle washed out.
- In 2008, Appalachee Pond showed signs of movement, subsequently repaired to include new spillway.
- In the spring runoff of March 30, 2010, Colcord Pond in Porter gave way, washing out two county roads. It has since been repaired.
- In 2011, the Southport Water Supply Dam showed signs of embankment leakage. It has since been repaired.

3.8 Flooding - Probability of Future Occurrence [S4.]

Floods are described in terms of their extent (including the horizontal area affected and the vertical depth of floodwaters) and the related probability of occurrence. Flood studies use historical records to determine the probability of occurrence for different flood recurrence intervals. The probability of occurrence is expressed in percentages as the chance of a flood of a specific recurrence interval in any given year. The most widely adopted design and regulatory standard for floods in the United States is the 1-percent annual chance flood and this is the standard formally adopted by FEMA. The 1-percent annual flood, also known as the base flood, or regulatory flood, has a 1 percent chance of happening in any particular year. It is also often referred to as the "100-year flood." Recurrence intervals can vary widely based on location.

The flood records presented in Table 3.6 can also be used to identify historic probability of occurrence for events reaching certain impact levels. For example, in the time interval between 2022 and the Great Flood of 1936, there have been 7 flood events impacting a majority of Maine counties, with an estimated annual exceedance probability (the chance an event that will impact more than 8 counties) of 8.1%. Within this same time interval, there have been 12 events with damages exceeding $5 million and 4 events exceeding $20 million, with estimated annual exceedance probabilities (the chance of events that meet or exceed these damage thresholds) of 13.9% and 4.7%, respectively. It is important to note that severe floods can occur at any time and these calculations provide only an averaged sense of flood event distribution over a multidecadal timespan.

Smaller floods occur more frequently than larger floods. Thus a "10-year" flood has a greater likelihood of occurring than a "100-year" flood. Table 3.7 shows a range of flood recurrence intervals and their probabilities of occurrence.

Table 3.7: Flood Recurrence Intervals and Probabilities [49]

Flood Recurrence Intervals	Percent Chance of Occurrence Annually	Percent Chance of Occurring in Flood Recurrence Interval	Percent Chance of Occurring in a 30-year Mortgage
10-year	10.0%	65%	95.8%
25-year	4.0%	64%	70.6%
50-year	2.0%	64%	45.5%
100-year	1.0%	63.4%	26.0%
500-year	0.2%	63.2%	5.8%

3.8.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Coastal Flood: Records of regional and global climate trends and model projections of future conditions indicate sea levels are rising, annual average atmospheric temperatures are increasing, and the rate of change for both is accelerating [50, 51, 52]. Sea level rise increases the baseline height of sea water, thereby potentially exacerbating other typical drivers of coastal flooding including storm surge, astronomical tides, waves, and runoff. For example, a flood event caused by high storm surge and astronomical tide is expected to impact a larger area and reach a cumulatively greater flood height in the future versus an equivalent historic event because of the base increase in flood height caused by a relatively higher sea level. Sea level rise may therefore impact coastal flooding by increasing the frequency of flood events of any magnitude, and increasing the maximum intensity of rare, record flood events (Figure 3.8) [53]. Currently for Maine, the average sea level has risen by 7 to 8 inches since the early 1900s. Sea level is projected to rise by another 1.5 feet by 2050 and 4 feet by 2100 [54].

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[49] NOAA Flood Return Period Calculator: https://www.weather.gov/epz/wxcalc_floodperiod

[50] Maine's Climate Future: 2020 Update: https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?article=1005&context=climate_facpub

[51] Maine Won't Wait 2020: https://www.maine.gov/future/sites/maine.gov.future/files/inline-files/MaineWontWait_December2020.pdf

[52] IPCC Sixth Assessment Report: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

[53] NOAA Sea Level Rise Technical Report and Companion Application Guide: https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html

[54] Maine Climate Science Dashboard: https://climatecouncil.maine.gov/maine-climate-science-dashboard

Along the Maine Coast, the 10-year and 100-year storm elevations are only about one foot apart. Thus, a sea level rise of one (1) foot means a storm that had a 1 percent chance of occurring in any one year (the 100-year storm) will now have a 10 percent chance of occurring in any one year (the 10-year storm). As a result, more homes, businesses, public infrastructure such as roads, and entire communities will be subject to more devastating coastal storms, as well as coastal erosion and landslides, on a more frequent basis. In addition, nuisance flooding of low-lying areas that now occurs about 5 to 10 times a year will see a 10 to 15-fold increase with just one foot of sea level rise. There is also concern in the scientific community that global warming may be increasing the intensity of coastal storms [55].

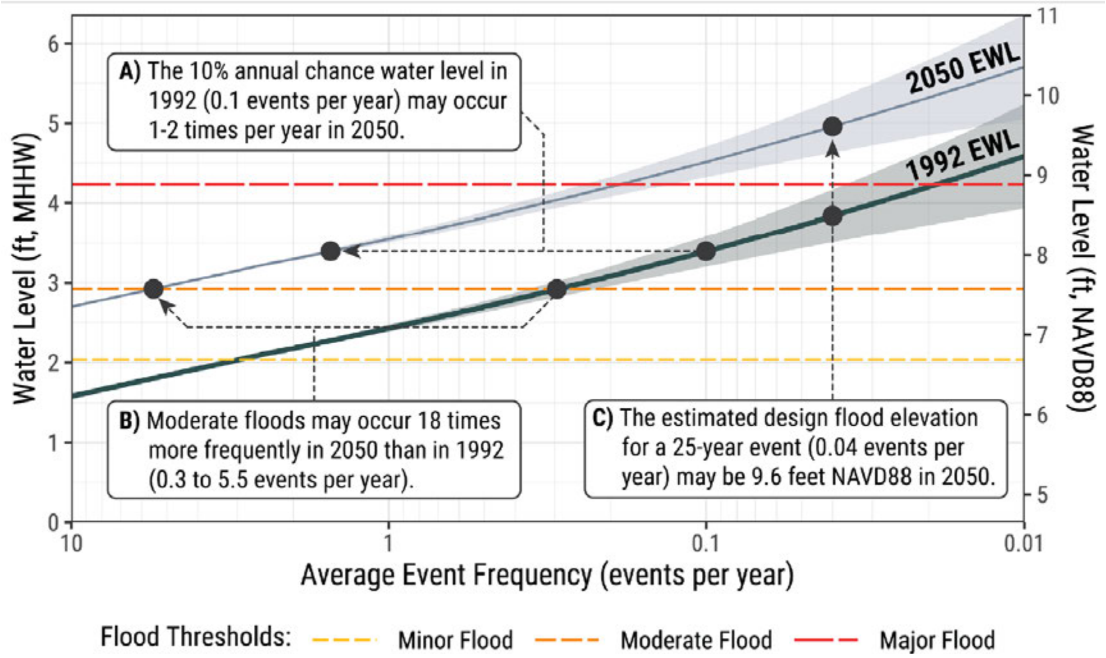

Figure 3.8: Change in frequency and magnitude of extreme coastal water level events in Portland, Maine, as sea level rises based on the supplementary extreme water level tables from the 2022 Technical Report. The lower curve represents extreme water levels (EWL) with average event frequencies ranging from 10 events per year to 0.01 events per year (the "100-year event") calibrated to the year 1992. Frequent events have lower magnitude water levels and vice versa. The upper curve represents the extreme water levels for the year 2050 using data from the Intermediate SLR scenario (approximately 1 foot). The Intermediate SLR scenario was selected because it is the upper bound for the observation-based extrapolation at this location. Local statistically derived flood thresholds are overlaid for context. Three annotations show **A)** the 10% annual chance event in 1992 shifts to an event that may occur at least once a year in 2050, **B)** the Moderate flood threshold may be exceeded 18 times more frequently in 2050 than in 1992 (which is more frequent than a Minor flood in 1992), and **C)** the design flood elevation for a 25-year event may increase from 8.5 to 9.6 feet NAVD88 between 1992 and 2050. This figure is from the NOAA 2022 Sea Level Rise Technical Report Companion Application Guide.

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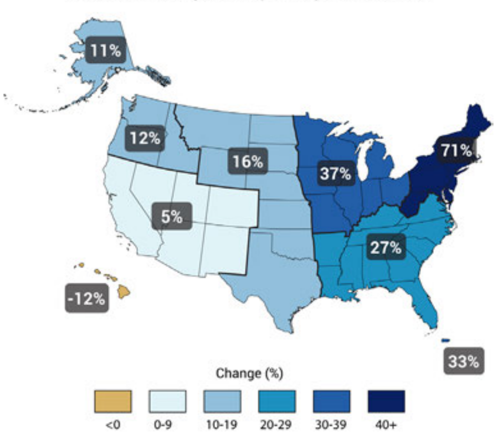
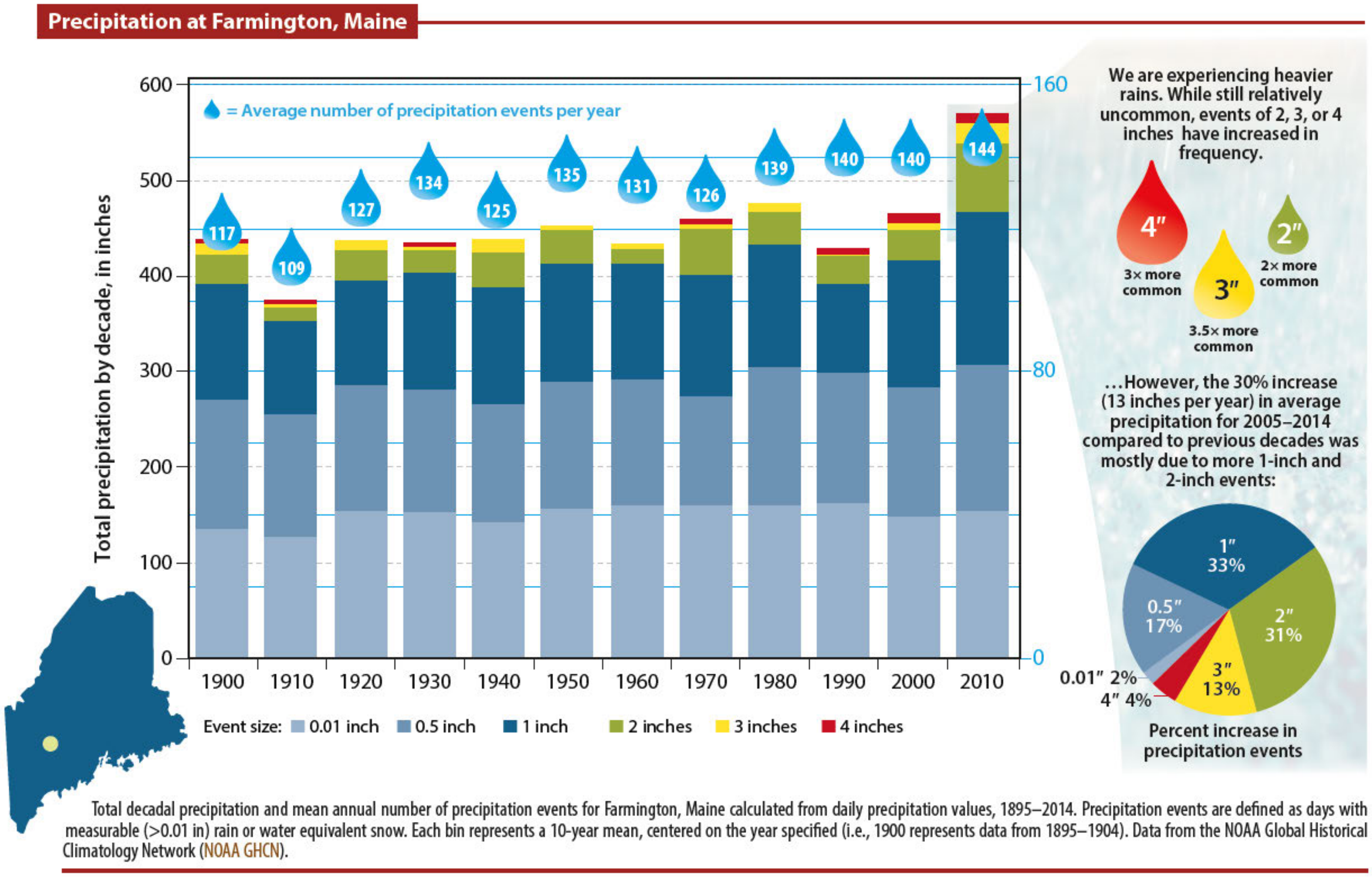
[55] Hurricanes and Climate Change: https://www.c2es.org/content/hurricanes-and-climate-change/


Observed Change in Very Heavy Precipitation

Inland Flood: Increasing atmospheric temperature contributes to a greater capacity for air to hold moisture and therefore a potentially greater occurrence of rainfall in the affected area relative to correct conditions. Annual precipitation trends show a general increase in the region and model projections indicate that this trend is expected to continue through 2100 (Figure 3.9) [56, 57]. Precipitation is expected to occur more frequently as rainfall and less frequently as snowfall when compared to historic trends, with potential impacts on the timing and extent of specific inland flood mechanisms such as snowmelt flooding and ice jams. Further, current trend analyses suggest that increasing precipitation coincides with an increase in the intensity of events. For example, decadal trends from Farmington, Maine indicate a two- to three-times greater occurrence of 2, 3, and 4-inch rainfall events during the recent decade 2004-2020, relative to all preceding decades (Figure3.10).


Precipitation at Farmington, Maine

We are experiencing heavier rains. While still relatively uncommon, events of 2, 3, or 4 inches have increased in frequency.

…However, the 30% increase (13 inches per year) in average precipitation for 2005–2014 compared to previous decades was mostly due to more 1-inch and 2-inch events:

Percent increase in precipitation events

Total decadal precipitation and mean annual number of precipitation events for Farmington, Maine calculated from daily precipitation values, 1895–2014. Precipitation events are defined as days with measurable (>0.01 in) rain or water equivalent snow. Each bin represents a 10-year mean, centered on the year specified (i.e., 1900 represents data from 1895–1904). Data from the NOAA Global Historical Climatology Network (NOAA GHCN).

Figure 3.10: Decadal mean precipitation categorized by rain depth for individual events indicates a substantial rise in total precipitation and occurrence of large individual rainfall events. Original figure from Maine's Climate Future: 2020 Update.

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[56] Nazari, Behzad, Dong-Jun Seo, and Ranjan Muttiah. "Assessing the impact of variations in hydrologic, hydraulic and hydrometeorological controls on inundation in urban areas." *Journal of Water Management Modeling* (2016), https://www.chijournal.org/C408.

[57] Walsh, J., D. Wuebbles and K Hayhoe. 2014. "Our Changing Climate." Chap 2 in *Climate Change Impacts in the United States: The Third National Climate Assessment.*, no. October: 19–67.

Maine peak flow analyses from 2020 shows some evidence of increasing annual peak flows and no evidence for decreasing annual peak flows. Peak flow trends vary substantially depending on the period analyzed and the stream gauge, making it difficult to attribute trends to known causes that are expected to continue into the future (Lombard and Hodgkins, 2020 [58]). Annual peak stream flows and other frequently occurring floods have increased at most stream gages during the last century for watersheds in Maine with minimal human influence (Hodgkins and Dudley, 2005 [59]; Collins, 2009 [60]; Hodgkins, 2010 [61]; Armstrong et al., 2011 [62]) Trends in peak flows that occur infrequently, such as the 100-yr peak flow, are more difficult to assess because analyses depend on very high peak flows that occur a few times per century or less. Changes in the frequency and magnitude of peak stream flows do not always track those in heavy precipitation in Maine — the 99th percentile precipitation only results in the 99th percentile streamflow 36% of the time in the United States (Ivancic and Shaw, 2015 [63]). In the Northeast, much of the increase in precipitation has occurred in seasons outside of the primary flood season (Small et al., 2006 [64]; Frei et al., 2015 [65]). Furthermore, decreases in winter snowpack modeled to occur with increasing air temperatures can offset increased flows caused by increased precipitation (Hodgkins and Dudley, 2013 [66]). Statistical hydrologic models such as Maine's peak flow equations (Lombard and Hodgkins, 2020) assume stationarity.

3.8.2 Probability of Dam Failure/Breach [HHPD2.a.]

As previously described, Maine Dam Safety Law [67] requires regular inspections, maintenance and current EAPs. Maine's approach to dam management recognizes that dam failure probability studies are prohibitively expensive, and that establishing a definitive risk of failure for specific dams is virtually impossible. Rather than insisting on the preparation of expensive dam failure studies, Maine has chosen to require EAPs be prepared for the possibility of dam failure.

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[58] Lombard, P.J., and Hodgkins, G.A., 2020, Estimating flood magnitude and frequency on gaged and ungaged streams in Maine: U.S. Geological Survey Scientific Investigations Report 2020–5092, 56 p., https://doi.org/10.3133/ sir20205092

[59] Hodgkins, G.A., Dudley, R.W. (2005). Changes in the magnitude of annual and monthly streamflows in New England, 1902–2002: U. S. Geological Survey Scientific Investigations Report 2005–5135, 37 p. [Also available at http://pubs.usgs.gov/sir/2005/5135/.]

[60] Collins, M.J. (2009). Evidence for changing flood risk in New England since the late 20th century: Journal of the American Water Resources Association, v. 45, no. 2, p. 279–290

[61] Hodgkins, G.A. (2010). Historical changes in annual peak flows in Maine and implications for flood-frequency analyses: U.S. Geological Survey Scientific Investigations Report 2010–5094, 38 p. [Also available at http://pubs.usgs.gov/ sir/2010/5094/.]

[62] Armstrong, W.H., Collins, M.J. and Snyder, N.P. (2011). Increased Frequency of Low-Magnitude Floods in New England 1. JAWRA Journal of the American Water Resources Association, 48(2), pp.306-320

[63] Ivancic, T.J. and Shaw, S.B. (2015). Examining why trends in very heavy precipitation should not be mistaken for trends in very high river discharge. Climatic Change, 133(4), pp.681-693

[64] Small, D., Islam, S., & Vogel, R.M. (2006). Trends in precipitation and streamflow in the eastern US: paradox or perception? *Geophys. Res. Lett.*, 33, 3, L03403

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[66] Hodgkins, G.A., and Dudley, R.W. (2013). Modeled future peak streamflows in four coastal Maine rivers: U.S. Geological Survey Scientific Investigations Report 2013–5080, 18 p., http://pubs.usgs.gov/sir/2013/5080/

[67] Maine Dam Safety Program Website: https://www.maine.gov/mema/hazards/dam-safety

Flooding – Vulnerability Assessment

3.9 Flooding – Impacts

All structures in the floodplain and/or the storm surge inundation zone are vulnerable to damages from flooding; particularly assets that are situated below the base flood elevation (BFE). Utilities such as furnaces, generators, oil tanks, and electricity meters, often situated near or below ground level, are especially susceptible to water damage from flood events. As noted in Table 3.6, all counties have experienced at least eight floods substantial enough to warrant Disaster Declarations with nearly $300M in cumulative damages from flooding alone. Severe flooding can cause loss of life, property damage, disruption of communications, transportation, electric service and community services, crop and livestock damage, health issues from contaminated water supplies, molds and mildew within structural components, and loss and interruption of business. Public safety is also affected when firefighting efforts are compromised if fire fighters and equipment are responding to a flood emergency.

Roads, bridges, and ditches are the most vulnerable assets exposed to flooding. Flood damage to roads, bridges, and ditches continue to be a common occurrence throughout the state and a primary impact of flood disaster events. Most washouts are quickly repaired, but often are not mitigated. As a result, replacement culverts, ditching, and fill are just as susceptible to future flood damages as they were before the storm event. As noted in this Risk Assessment, impacts are greatest for road networks experiencing frequent and heavy traffic. In many cases the most heavily impacted infrastructure is aging, undersized for flood flows, or made of degrading, damaged, or inappropriate materials. Many high traffic roadways have historically been impacted by damage to small cross culverts inundated by extreme flows, requiring commuters and residents to take long detours or to shelter in place if they become completely isolated.

To provide mitigation leadership, the Maine Emergency Management Agency has partnered with the Local Road Center of the Maine Department of Transportation to provide workshops for local officials on the use of geo-synthetics to stabilize and protect transportation infrastructure from flooding. Workshops on the use of geo-synthetics have been included as part of the Local Road Center’s continuing series of workshops for local transportation officials. Mitigation leadership is also provided on a continuing basis through the Department of Economic and Community Development’s Code Enforcement Officer Certification and Training Program.

Transmission lines, though more vulnerable to damaging winds, ice, and flying debris, may also be impacted by flooding, especially along the many river crossings in the state. In some cases, substantial flooding and high velocity flows may damage the energy infrastructure and cause widespread power outages to portions of the state. Some power plants may also experience dangerous flooding, especially hydropower plants where flows exceed maximum discharge capacity. This again would potentially lead to power outages or a need to rebalance supply to meet demand.

3.10 Flooding – Vulnerability of State Assets [S5.]

The Maine Department of Administration and Financial Services Bureau of General Services provided location data on all state-owned and operated facilities and insured values of buildings and contents. With this information, Maine Emergency Management Agency used GIS to map and identify those state facilities which are located in areas of the state subject to flooding. Unfortunately, nearly half of the counties in the state do not have digital FIRM data, limiting this analysis and reducing our capability determine what state facilities are located in flood zones in those areas. Of these counties without digital FIRM resources, Hazus [68] was used to generate potential flooding areas based on a hypothetical 500-year flooding event.

Critical Infrastructure and Key Resources (CIKR) have been identified throughout the State of Maine in accordance with the sectors determined by DHS [69]. An all-hazards risk assessment of Maine's CIKR in each sector has been done. Natural hazards identified in this plan continue to pose the greatest risk to Maine's CIKR particularly those located near flood prone areas. Identification and risk assessment of Maine's CIKR have been done in accordance with the National Infrastructure Protection Plan (NIPP).

3.10.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

The following section is split into state building/structure assets and state road infrastructure due to the importance of road infrastructure and its unique vulnerability to flood damage.

State building/structure assets and summary of impacts

It was determined no state facilities that would be used during an emergency or disaster for response or recovery are located in the flood zone. However, MEMA identified 117 assets located within special flood hazard areas or Hazus-identified flood areas. The top 10 assets rated by valuation are listed in Table 3.8.

Table 3.8: 10 highest valued State assets located in potential flood areas. Note that one location may hold multiple assets.

Address	County	Occupancy type	Property Type	Year Built	Last Inspected	Total Valuation	Agency
78 Exchange St, Bangor	Penobscot	OFFICE	Class 4 building.	2009	7/1/2017	$65,000,000	MMB, MAINE MUNICIPAL BOND BANK
78 Exchange St, Bangor	Penobscot	OFFICE				$4,500,000	JUD, ADMIN. OFFICE OF THE COURTS
Ponce Landing	Cumberland	PIER	Wood framed.	2001	2/6/2006	$4,160,000	DOT, SOUTHERN REGION
Ferry Rd, Islesboro	Waldo	PIER	Wood framed.	2009	7/1/2011	$3,016,000	DOT, MAINTENANCE & OPERATIONS
20 McKay Rd, Lincolnville	Waldo	PIER	Wood framed.	2009	7/1/2011	$3,016,000	DOT, MAINTENANCE & OPERATIONS
79 Sands Rd, Vinalhaven	Knox	PIER	Wood framed.	1999	7/1/2011	$3,016,000	DOT, MAINTENANCE & OPERATIONS
288 ME-3, South China	Kennebec	STORAGE	Wood framed.	1968	7/1/2014	$642,720	DOT, MID COAST REGION
Swan Island Lndg, Richmond	Sagadahoc	PIER	Wood framed.	2017	11/1/2005	$442,000	IFW, BUREAU OF RESOURCE MANAGEMENT
Pepperrell Rd, Kittery	York	OFFICE	Wood framed.	1865	6/4/2014	$416,000	ACF, PARKS
78 Exchange St, Bangor	Penobscot	OFFICE				$404,000	ADF, OFFICE OF INFO TECH, COMPUTERS SERVERS ETC.

There is no guarantee that these assets will be damaged in a natural hazard event. Vulnerable state assets in Bangor may experience major impacts to the functioning of the Maine Municipal Bond Bank, judicial courts for one of the most populous counties in the State, and information technology capabilities for the State of Maine. However, Maine’s Floodplain Management Program indicates that these assets have benefitted from flood mitigation efforts and are NFIP compliant. MaineDOT’s ability to respond to local flooding may be impacted by flooding in one of their storage units. Several of the ferry piers on this list have also been identified as susceptible to frequent coastal flooding due in part to sea level rise since their original construction. Flooded ferry terminals are unable to operate, potentially stranding many island communities and preventing evacuation to the mainland.

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[68] Hazus: https://www.fema.gov/flood-maps/products-tools/hazus
[69] DHS Critical Infrastructure Sectors: http://www.dhs.gov/critical-infrastructure-sectors

Since the 2020-Tiered State Framework, The Maine Floodplain Management Program has done flood hazard determinations on the following properties:

16 Deep Cove Rd, Eastport: Not located in SFHA.
70 Fish Hatchery Rd, Casco: Currently in SFHA, will be outside SFHA when the preliminary maps in Cumberland County go effective.
50 State Park Rd, Dover-Foxcroft: Inconclusive based on aerial photos/no DIFRM.
Warren Island, Islesboro: No buildings appear to be located in the SFHA based on aerial photos.
93 Cottage St, Bar Harbor: Not located in SFHA.
62 Fish Hatchery Rd, New Gloucester: Not located in SFHA.
78 Exchange St, Bangor: This building is in the SFHA, and it complies with Floodplain Management regulations

It is not expected that the state-owned and operated buildings will suffer 100% losses from a flooding event in Maine. Flood damage estimates reported here therefore account for only 20% of the valuation for assets and their contents located in flood areas. During a flood event, state employees would attempt to relocate the building contents to prevent content loss, but the rate of flooding may be too rapid for this to be successful.

The total valuation for all state assets is $3.3 Billion (2022 USD), with $89.7 million in assets identified within flood areas. Assuming 20% of each asset is damaged, total losses for the state would equal $17.9 million. These estimates are further disseminated by county in Table 3.9, and general locations are provided in Figure 3.11.

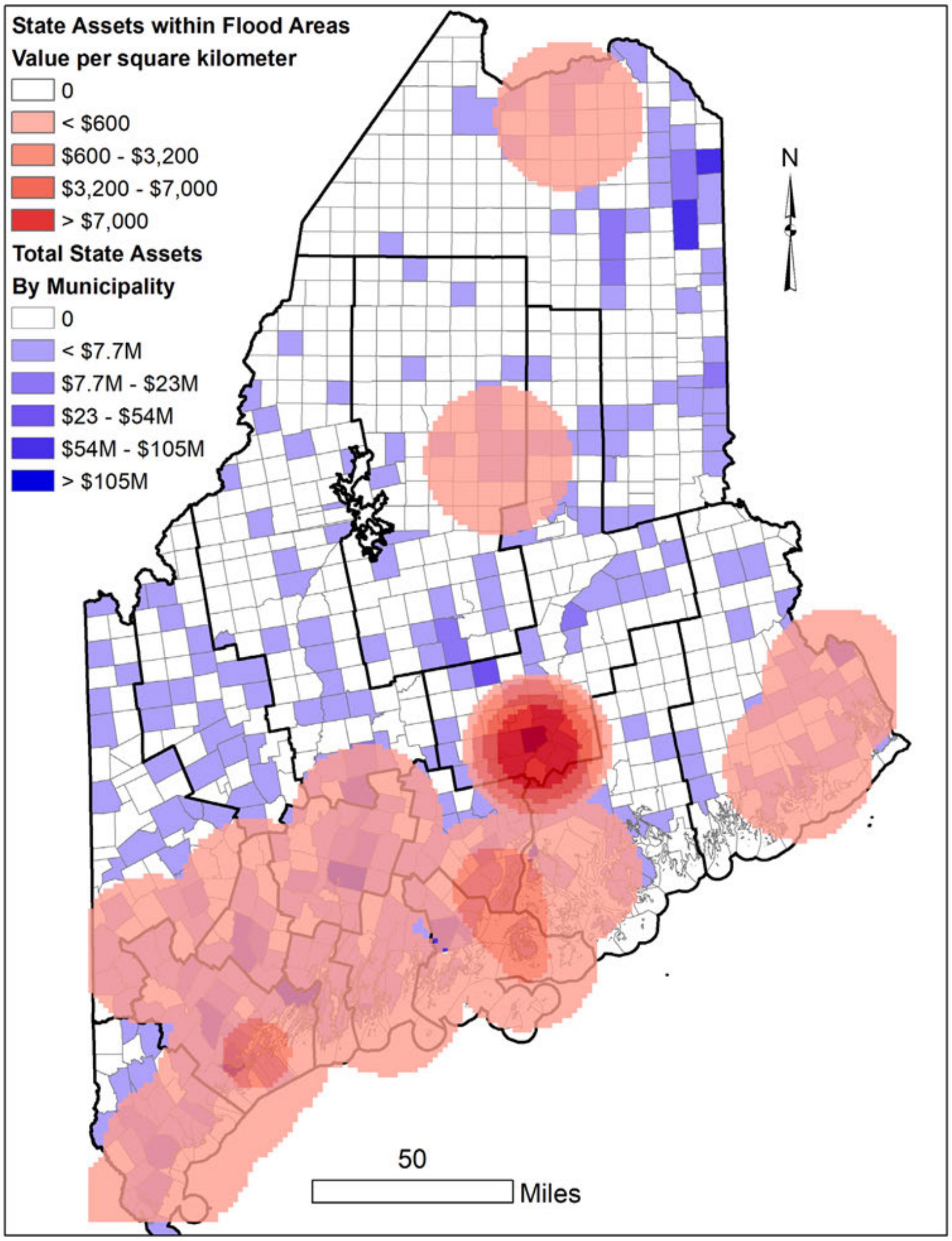

Figure 3.11.a: State Assts within SFHAs and potential losses.

Flooding caused by sea level rise is assumed permanent and therefore would account for 100% of damage to assets. For a scenario where sea level rises by 1.6 feet, as projected by NOAA for the year 2050, total losses for the state would equal $9.9 Million. A rise in sea level of 3.9 feet, projected by NOAA for the year 2100, would lead to $10.6 million in total losses to state assets. These models do not incorporate storm surge damages; refer to the section Tropical Cyclone – Vulnerability Assessment for asset damage estimates related to coastal storm surge.

Table 3.9: Potential dollar losses to state assets by flooding

Region	**Totals**		**Assets in SFHA***			**Assets inundated by 1.6 ft sea level rise**			**Assets inundated by 3.9 ft sea level rise**			**Assets inundated by 10.9 ft sea level rise**		
	State Assets Count	Total Value (2022 USD)	State Assets Count	20% Losses (2022 USD)	% of total value	State Assets Count	100% Losses (2022 USD)	% of total value	State Assets Count	100% Losses (2022 USD)	% of total value	State Assets Count	100% Losses (2022 USD)	% of total value
State of Maine	3,769	$3,357,697,809	117	$17,931,645	0.5%	24	$9,950,520	0.3%	29	$10,605,408	0.3%	120	$120,097,015	3.6%
Androscoggin	103	$131,857,212	5	$11,469	0.0%									
Aroostook	421	$287,502,123	5	$119,464	0.0%									
Cumberland	604	$628,202,559	11	$942,346	0.2%	3	$5,833,360	0.9%	5	$6,217,328	1.0%	44	$32,091,576	5.1%
Franklin[a]	145	$21,036,865	6	$143,270	0.7%									
Hancock	153	$202,125,602	1	$1,200	0.0%							4	$646,520	0.3%
Kennebec	518	$990,500,148	11	$265,411	0.0%									
Knox	108	$163,413,511	4	$729,384	0.4%							7	$6,936,440	4.2%
Lincoln	80	$44,121,502	1	$1,560	0.0%				1	$7,800	0.0%	2	$85,800	0.2%
Oxford	109	$38,868,587	-	-	-									
Penobscot	355	$383,400,261	5	$13,997,360	3.7%							8	$70,430,801	18.4%
Piscataquis[b]	228	$32,190,309	30	$92,878	0.3%									
Sagadahoc	87	$28,347,445	15	$226,280	0.8%	1	$21,840	0.1%	1	$21,840	0.1%	16	$1,175,914	4.1%
Somerset	191	$130,572,689	-	-	-									
Waldo	179	$46,703,979	14	$1,376,390	2.9%	9	$3,339,710	7.2%	11	$3,602,830	7.7%	14	$6,881,950	14.7%
Washington	225	$122,944,012	3	$22,624	0.0%	2	$36,720	0.0%	2	$36,720	0.0%	6	$602,700	0.5%
York	263	$105,911,005	12	$145,278	0.1%	9	$718,890	0.7%	9	$718,890	0.7%	19	$1,245,313	1.2%

*SFHA: Special Flood Hazard Areas designated in FEMA Flood Insurance Rate Maps.

[a,b] estimates produced using Hazus-delineated 500-year flood areas

3.10.2 Community lifeline Risks

The facilities enabling continuous operation of community lifelines are not all necessarily managed by state authorities, but they are necessary for continued operation of state functions and services. Therefore, the description of community lifeline risks for this and other hazard profiles includes an assessment of resources that may or may not be managed by the State government. Not all hazards will impact each community lifeline in equal ways, therefore MEMA has chosen to focus only on specific lifelines that are directly impacted by each hazard. Flooding is anticipated to impact each lifeline to a potentially substantial degree.

State road assets

Though any type of road infrastructure could be vulnerable to flooding and associated erosion hazards, culverts and other small road stream crossings tend to be the most susceptible and are therefore the primary focus of this section. Maine DOT reports 38,251 small/cross culverts, 1,901 large culverts, and 10 bridges categorized as culverts. Culverts require regular maintenance and replacement when their design life is exceeded. Streambanks along the edges of culverts also require regular maintenance as they are particularly susceptible to slumping/erosion due to typically steep slopes, unstable ground, and heavy traffic. Table 3.10 lists the number of Maine DOT culvert assets by size class and the proportion of these culverts with a rating of "poor" or lower, assuming poorly performing culverts may indicate potential locations of structural failure under stresses of flooding and erosion. Using Maine DOT culvert asset data in a financial impact model developed by the New England Environmental Finance Center [70], the cost to fully replace these culverts including materials and construction labor exceeds $50 million.

Table 3.10: Maine DOT culvert assets and modeled replacement costs.

Culvert class	Total number of culverts	% with "Poor" culvert rating (≤3[a])	Cost to replace[b] "Poor" culverts (2022 USD)
Cross culverts	38,251	10.3%	$40,787,678
Large culverts	1,901	8.8%	$10,062,811
Bridge culverts	10	10%	$24,629
Total	40,162	10.2%	$50,875,118
[a] Culvert rating 3: Poor. Excessive amounts of spalling, heavy scaling, and wide cracks [b] Replacement assumes installation of a new culvert of equal size and materials			

Culvert replacements are scheduled regularly each year. Refer to Maine DOT's Work Plan Map for more details [71]. Larger construction projects can be found at Maine DOT's Current Projects website [72].

Culverts categorized undersized or otherwise unfit for flow conditions at their site require improvement to mitigate against future flooding. The most common approach to improve performance is to upsize the culvert and allow for more natural flow conditions to occur in and around the stream crossing point. Improved flow conditions also enhance freshwater ecosystems by reducing barriers for migratory organisms such as brook trout and endangered Atlantic salmon. Roy et al. (2020) [73] studied the dual benefits to flood and environmental mitigation provided by the improved design and spatially optimized selection of state-managed culverts distributed across watershed scales in Maine. Measuring the flood safety performance of culverts based on their capacity to function under different flow recurrence levels and maintenance needs, the study identified that $62 million invested in upsizing culverts would essentially halve current flood risk levels on state roads (dollar values converted to 2022 USD).

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[70] NEEFC (2011), A Financial Impact Assessment of LD 1725: Stream Crossings Presentation: digitalcommons.usm.maine.edu/economicsfinance/4/

[71] Maine DOT Work Plan Map: https://www.maine.gov/mdot/mapviewer/?show=Work%20Plan%2023-24%2cWork%20Plan%202022%2cHighway%20Corridor%20Priority&hide=Wetlands

[72] Maine DOT Current Projects: https://www.maine.gov/mdot/projects/

[73] Roy, S. G., Daigneault, A., Zydlewski, J., Truhlar, A., Smith, S., Jain, S., & Hart, D. (2020). Coordinated river infrastructure decisions improve net social-ecological benefits. *Environmental Research Letters*, *15*(10), 104054, https://doi.org/10.1088/1748-9326/abad58.

Coastal causeways and sea level rise

Several coastal communities rely on causeways to connect to the mainland. Coastal causeways were often constructed on top of sand bars or other low-lying coastal landforms that are now more frequently submerged by king tides and storm surge due to sea level rise, putting island communities at risk of being separated from services on the mainland. Maine DOT, in collaboration with local communities, is studying options to rehabilitate or replace causeway structures that carry state or state aid roads, including the Machias Dike Bridge Project [74] and the Deer Isle Causeway [75].

Conserved Lands

Conserved lands may also be potentially exposed to flooding if they are located in flood zones (Table 3.11a). Flooding may be a common occurrence for conserved lands located along riparian corridors or coastal preserves that were established to protect natural areas from development. Impacts can include flood damage to structures and erosion.

Table 3.11a: area of conserved lands located in special flood hazard areas (SFHAs), delineated from effective and preliminary Flood Insurance Rate Maps.

Interest type	Lands in SFHAs acres (thousands)	Portion of all conserved lands
State	28	2.1%
Municipal	5	11.9%
Private	39	1.5%
Federal	20	6.6%
Total	92	2.1%

Hazardous Material Regulated Sites

Maine Department of Environmental Protection has conducted a geospatial vulnerability assessment of their regulated sites, including but not limited to fuel storage tanks, wastewater locations, remediation sites, and closed municipal landfills [76]. From this assessment and under a sea level rise scenario of 1.6 feet, a total of 34 fuel tanks, 3 waste discharge sites, 11 remediation sites, and 2 municipal landfills will be flooded. Further impacts are expected for higher sea level rise and large inland flooding events.

Water: Regulated Public Water Utility Sites

Maine's Department of Health and Human Services Drinking Water Program monitors conditions at 2,085 public wells across the state. Water utilities serve just under half the population of Maine with the rest using privately owned wells to access water. Any event that impacts water utilities would limit potable water access to hundreds to thousands of people. MEMA conducted a hazard-asset overlay analysis of well locations to identify potential vulnerabilities from riverine, coastal, storm surge, and sea level rise flooding (Table 3.11b). The Drinking Water Program proposes to target these public water systems for flood mitigation funding and assistance in the future. The overlay analysis does not account for any pre-existing mitigation efforts at each site. For more information on storm surge flooding, review the section Tropical Cyclone – Hazard Profile.

Table 3.11b: Potential flood exposure of wells monitored by Maine Drinking Water Program.

Flood type or data source	Total (% of wells)
Riverine/Coastal: FIRM*	85 (4.1%)
Category 1 storm surge	3 (0.1%)
Category 2 storm surge	7 (0.3%)
Category 3 storm surge	21 (1%)
Category 4 storm surge	37 (1.8%)
1.6 feet sea level rise	1 (~0%)
3.9 feet sea level rise	8 (0.4%)
6.1 feet sea level rise	10 (0.5%)
10.9 feet sea level rise	20 (1%)

Digital Flood Insurance Rate Maps are not available in all parts of the state.

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[74] Machias Dike Bridge Project: https://www.maine.gov/mdot/projects/machiasbridge/

[75] Deer Isle Causeway: https://storymaps.arcgis.com/stories/b51eb909a1fb4c489be56e88561469d2

[76] Maine DEP Vulnerable Sites and Infrastructure: https://www.arcgis.com/home/item.html?id=783cab9dc7754893ac6bd16c74dce011

Shelter

Shelter sites are managed at the local government level. Site selection is determined by local emergency managers who have historic knowledge of hazardous sites in their town and draw upon the knowledge of road commissioners, public works directors, town planners, and code enforcement officers when available to inform these decisions. Shelter sites would only be opened in the event of an emergency and the activation of sites would be dependent on the type, extent, and location of the hazard. For example, sites prone to flooding or access issues would be excluded from selection. Currently there are no shelter sites located in FEMA special flood hazard areas. Schools are commonly selected as shelter sites. Of the 784 public schools in Maine, none are located in FEMA special flood hazard areas.

Energy

Power plants, transmission lines, and other energy-related infrastructure may be vulnerable to flooding. MEMA performed a hazard-asset overlay analysis for power plant locations and transmission lines for the entire state (Table 3.11c). Hydropower plants are excluded from riverine flooding analysis because they are intentionally positioned in rivers. A single solar power plant is located within the 100-year floodplain.

Table 3.11c: Potential flood exposure of energy infrastructure, number of power plants and transmission line miles exposed.

Flood type or data source	Power plants (%)	Transmission line miles (%)
Riverine/Coastal: FIRM*	1 (0.9%)	118 (4.3%)
Category 1 storm surge	1 (0.9%)	4.6 (0.2%)
Category 2 storm surge	2 (1.9%)	9.14 (0.3%)
Category 3 storm surge	2 (1.9%)	14.9 (0.5%)
Category 4 storm surge	4 (3.8%)	20.9 (0.8%)
1.6 feet sea level rise	0 (0%)	0.7 (~0%)
3.9 feet sea level rise	1 (0.9%)	2.7 (0.1%)
6.1 feet sea level rise	1 (0.9%)	5 (0.2%)
10.9 feet sea level rise	3 (2.8%)	11.4 (0.4%)

Digital Flood Insurance Rate Maps are not available in all parts of the state.

A total of 2,751 miles of transmission lines cross rivers and higher order streams a total of 357 times in the State of Maine, and though they are designed specifically to mitigate against surface-level hazards such as flooding, certain types of flooding events may impact service. Other hazards related to wind, wildfire, and debris damage are therefore more likely to cause failure in energy services.

Safety and Security

The primary challenge of disaster response by fire service and law enforcement is access to impacted sites caused by road flooding and debris damage. However, there are critical facilities that are also directly impacted by flooding which would hinder the ability to respond to a flooding event. Of the 568 fire stations in Maine, 14 (2.5%) are located within a FIRM-designated floodplain. Of the 153 law enforcement offices in Maine, only one is located in the floodplain, located in the Town of Camden, Knox County.

Medical and Healthcare

The primary vulnerability of Maine's medical lifeline is accessibility and energy issues caused by road flooding and transmission line failure rather than flooding of the facility itself. Refer to the state road data described above. Of the 71 medical facilities and 107 assisted living centers in Maine, none are in the floodplain as designated in effective and preliminary FIRMs.

Food

The primary vulnerability of the food community lifeline is threatened access to a food source caused by road flooding and power outages rather than flooding of the facilities themselves. Please refer to the road and energy sections above for more information. A breakdown in the food community lifeline would require emergency intervention to avoid issues of malnutrition and starvation.

Communications

No communication towers, nor the agencies responsible for sending emergency alerts, warnings, and message are located in the floodplain. One concern may be loss of power to communication towers, though many of these facilities have backup diesel generators to provide emergency power until the grid is restored.

Historic and Cultural Resources

The Maine Historic Preservation Commission (MHPC) has developed a Historic Properties Toolkit [77], including a map of properties listed in the National Register of Historic Places, Landmarks, or museums/archives overlain with flood, fire, sea level rise, and storm surge layers.

Using the limited spatial scope of digital FIRMs for Maine, 105 of the 1,266 historic places in Maine (8.3%) are located in special flood hazard areas. Many of these historic places are coastal. Of these, 60 (4.7%) would be affected by 1.6 feet of sea level rise, and 68 (5.4% would be affected by a 3.9-foot rise. It is important to note that, though many of these sites are coastal, there are historic places in central Maine communities located on tidal rivers, such as the cities of Augusta and Bangor, that will also see the detrimental impacts of sea level rise. If these sites were impacted, Maine would potentially lose an irreplaceable part of its history.

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[77] Weathering Maine: https://www.maine.gov/mhpc/programs/protection-and-community-resources/climate-change

3.11 Flooding – Vulnerability of Jurisdictions and Disadvantaged communities [S6.]

3.11.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

In all Maine counties, the greatest amount of damage from flooding events occurs to the state and local roadway system. This is followed in severity and probability with damage to homes and businesses located along the shores of rivers, lakes and the coastal waters.

Flood mitigation needs in Maine currently exceed available resources. As noted in previous SHMP updates, and again in this update, the completion of FEMA-approved hazard mitigation plans for 16 counties and the jurisdictions within them, and the University of Maine System has resulted in the identification of 2,276 hazard mitigation projects amounting to $223 million. At least 90 – 95 percent of these projects are flood mitigation projects.

Disadvantaged Communities

The objective of the disadvantaged community's assessment is to identify potential disadvantages felt by communities who are disproportionately impacted by natural hazards both historically and under future projections. Flooding is a prominent hazard in Maine with a wide distribution of locations that may be impacted, though these locations are predictably located in low lying areas adjacent to bodies of water. However, waterfront properties are generally considered to be more valuable, unless they are frequently damaged by floods, lack flood insurance, or are not regulated by a local floodplain ordinance.

In Maine, the average overall SVI score is 0.42, greater than averages from areas prone to coastal and inland flooding (Figure 3.12), indicating that potentially disadvantaged communities compose a smaller portion of the overall population exposed to flooding. SVI for coastal flood areas is the lowest, and therefore considered to be less vulnerable than the state average, with an average value of 0.33, while inland flood areas average SVI is 0.39. This trend initially suggests that communities with less overall social vulnerability reside in areas with greater overall flooding vulnerability. However, 17 of the 19 (89.5%) census tracts with SVI ≥ 0.8 (indicating a potentially disadvantaged community) intersect with flood zones, and it is likely that more would be identified if digital Flood Insurance Rate Maps were available in all parts of the state. Further, many households in these tracts, particularly in the urban centers of Portland, Lewiston, and Bangor, speak limited English, ranging from 6.7-17% limited English, posing communication challenges for hazardous weather updates, flood preparedness/safety instructions, and if need be, evacuation instructions (Census data accessed using FEMA's RAPT tool [78]).

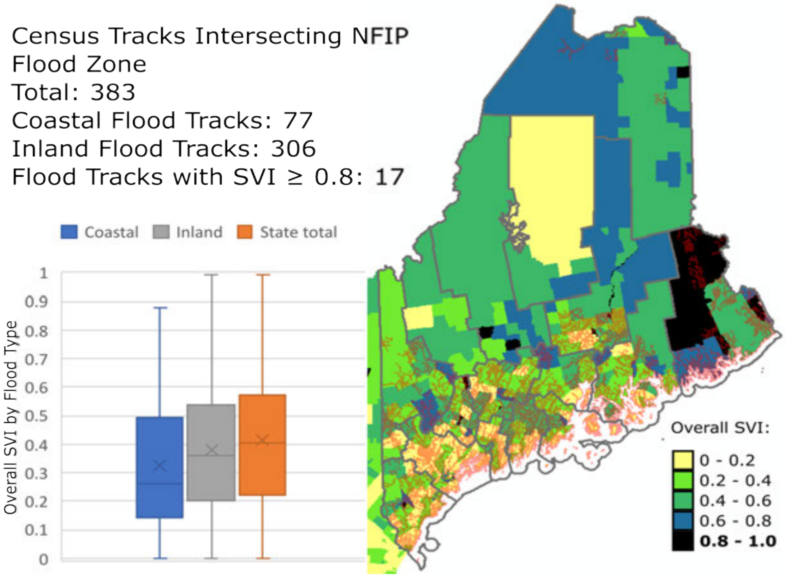

Figure 3.12: Potential impact of flooding on census tracts with elevated SVI. Higher SVI scores indicate greater vulnerability. For coastal and inland flood zones, average SVI distributions trend lower than the state average (box and whisker plots, lower left). NFIP flood zones are also not available in digital format for the majority of the state by area, preventing a full statewide equity assessment.

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[78] FEMA RAPT tool: https://fema.maps.arcgis.com/apps/webappviewer/index.html?id=90c0c996a5e242a79345cdbc5f758fc6

Of these communities at risk of flooding, the following have the greatest measured vulnerability: Northern/Central Washington County, Town of Machias, Eastern Washington County and Passamaquoddy Nation at Sipayik, Penobscot Nation at Indian Island, City of Bangor, City of Gardiner, City of Lewiston, Town of Livermore, City of Portland/Bayside neighborhood, and City of Sanford. These communities are located in urban and rural settings. In summary, the impacts to these communities are similar to the general impacts described above, but they are amplified due to the already high vulnerability of community members caused by disabilities, lack of transportation, older adults, and people with limited English proficiency. The ability to get services to these areas or to evacuate from these areas will be limited by the physical impacts of flooding, but also during the recovery phase where socially vulnerable community members are not always appropriately represented in assistance programs. The impacts to these communities will therefore be long term, making recovery difficult, unless more equitable assistance can be provided.

These results suggest disadvantaged communities are likely exposed to flood risks but are poorly represented within the larger census tracts. The resolution of SVI data likely misses truly disadvantaged communities that remain in flood prone areas, such as urban centers, working shorelines, and rural communities with less capacity to enact and enforce flood plain ordinances and building codes. Further, many community members may be unable to afford the cost of living in these areas but commute to work where flood hazards may disrupt their livelihoods or limit their access to critical services. This analysis is therefore not a comprehensive assessment of flood hazard vulnerability because it may be more responsive to the coarse resolution of available data, lack of a statewide digital floodplain dataset, and the conflicting distribution of property values and public services that likely vary below the resolution of census tracts.

National Flood Insurance Program (NFIP)

The National Flood Insurance Program (NFIP), managed by FEMA, enables homeowners, business owners and renters in participating communities to purchase federally backed flood insurance. This insurance offers an insurance alternative to disaster assistance to meet the escalating costs of repairing flood damage to buildings and their contents. Participating communities agree to adopt and enforce floodplain management ordinances to reduce future flood damage. There are now more than 20,600 participating communities across the United States and its territories.

Federal flood insurance is available for residents and business owners in both high-risk and moderate-to-low risk areas. The insurance is required for buildings in high-risk areas that have loans from federally regulated or insured lenders. This requirement extends to disaster assistance loans from the Small Business Administration.

Flood Insurance Rate Maps (FIRMs)

Communities maintain a repository of Flood Insurance Rate Maps (FIRMs) for residents to use to determine whether a property location is in an area with a 1 percent or greater chance of flooding annually [79]. These maps are usually available at the planning and zoning department where building permits are obtained, or they can be accessed online [80]. FEMA also provides some communities with digital FIRMs [81].

Digital FIRMs are still not available for many communities in Maine (Figure 3.1), making it more challenging to identify whether properties are located within special flood hazard areas. In the past, FEMA's National Flood Insurance Program (NFIP) remapping efforts have been limited by technology and funding. In recognition, in 2003, Congress committed to a five-year Flood Map Modernization Program (FMMP), also known as Map Modernization. The goal of Map Modernization was to upgrade flood hazard data and mapping to create a more

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[79] Benefits.gov NFIP: https://www.benefits.gov/benefit/435
[80] FEMA Map Service Center: http://msc.fema.gov
[81] FEMA National Flood Hazard Viewer: hazards-fema.maps.arcgis.com/apps/webappviewer/index.html?id=8b0adb51996444d4879338b5529aa9cd

accurate digital product to improve floodplain management across the country. This was undertaken with priority given to areas of greater population, need and ability to leverage resources. Digitizing is one more step towards FEMA's goal to acquire more accurate mapping. Digitizing does not address all of the flaws in existing maps; however, it will make it easier to change the maps in the future and reduce the costs of printing maps in the long run.

Repetitive Loss Properties

FEMA maintains a file of repetitive and severe repetitive loss properties (properties that have experienced more than one flood loss). The following is a summary of the repetitive loss properties by county and municipality. Some properties have benefitted from mitigation actions. If a structure has been mitigated, then it should suffer no, or fewer, damages. It also lowers the insurance premium cost for the property owner.

A number of repetitive loss properties in Maine are not insured. FEMA's statistics on repetitive loss properties include only properties having flood insurance. There are other properties suffering repetitive flood losses but are not insured and often unreported. Therefore, statistics on these properties are not tabulated unless damaged during a declared individual disaster (Table 3.12, 3.13).

Table 3.12: Repetitive loss properties by community (10/7/2022). Repetitive Losses involve 4 or more claims.

Municipality	Repetitive Loss Properties	Residential	Non-residential	Total losses	Total Building payments	Total Contents payments	Properties mitigated (by county)
TOTAL - STATE	284	205	79	787	$13,616,256.90	$3,589,849.91	23
Androscoggin County	3	3	0	6	$34,937.87	$2,020.45	0
GREENE	1	1	0	2	$6,752.51	$0.00	
MECHANIC FALLS	1	1	0	2	$17,481.69	$2,020.45	
WALES	1	1	0	2	$10,703.67	$0.00	
Aroostook County	30	21	9	92	$1,352,813.02	$381,862.31	5
EAGLE LAKE	2	2	0	4	$26,250.17	$10,332.47	
EASTON	1	1	0	2	$7,402.03	$0.00	
FORT FAIRFIELD	16	10	6	56	$849,250.46	$138,686.50	
FORT KENT	7	4	3	22	$387,920.89	$213,404.40	
ISLAND FALLS	1	1	0	2	$13,796.15	$0.00	
OAKFIELD	1	1	0	2	$8,883.26	$0.00	
SHERMAN	1	1	0	2	$7,310.06	$0.00	
WALLAGRASS	1	1	0	2	$52,000.00	$19,438.94	
Cumberland County	15	13	2	37	$226,774.35	$50,827.91	0
CAPE ELIZABETH	1	1	0	3	$6,319.28	$1,264.23	
CASCO	3	3	0	8	$38,886.06	$17,011.00	
FALMOUTH	1	1	0	2	$7,805.31	$700.60	
GORHAM	1	1	0	2	$7,373.09	$1,656.34	
GRAY	1	1	0	3	$19,459.76	$0.00	
HARRISON	1	1	0	2	$19,526.03	$0.00	
NAPLES	1	1	0	2	$3,281.42	$0.00	
PORTLAND	1	1	0	2	$3,838.49	$0.00	
SCARBOROUGH	2	2	0	5	$36,150.86	$1,152.80	
SOUTH PORTLAND	1	1	0	3	$25,475.29	$0.00	
WESTBROOK	1	0	1	3	$50,000.00	$29,042.94	
YARMOUTH	1	0	1	2	$8,658.76	$0.00	
Franklin County	6	5	1	15	$280,306.26	$39,892.41	1
CARRABASSETT VALLEY	2	2	0	6	$99,066.28	$20,615.81	

Municipality	Repetitive Loss Properties	Residential	Non-residential	Total losses	Total Building payments	Total Contents payments	Properties mitigated (by county)
FARMINGTON	1	0	1	3	$21,472.09	$15,600.00	
KINGFIELD	2	2	0	4	$157,551.85	$1,530.48	
TEMPLE	1	1	0	2	$2,216.04	$2,146.12	
Kennebec County	32	8	24	98	$1,330,137.99	$789,005.73	3
AUGUSTA	9	1	8	34	$945,251.59	$534,175.70	
GARDINER	7	1	6	21	$81,046.31	$171,701.55	
HALLOWELL	8	0	8	26	$123,898.87	$46,997.03	
WAYNE	3	3	0	7	$48,208.53	$5,607.05	
WINSLOW	5	3	2	10	$131,732.69	$30,524.40	
Knox County	1	1	0	2	$10,099.89	$0.00	0
OWLS HEAD	1	1	0	2	$10,099.89	$0.00	
Lincoln County	6	3	3	18	$539,086.36	$61,723.18	1
BOOTHBAY	2	1	1	4	$10,277.30	$0.00	
BOOTHBAY HARBOR	1	0	1	8	$445,050.70	$48,593.18	
BRISTOL	1	1	0	2	$22,620.06	$0.00	
SOUTH BRISTOL	1	0	1	2	$46,947.40	$0.00	
SOUTHPORT	1	1	0	2	$14,190.90	$13,130.00	
Oxford County	17	14	3	43	$543,700.87	$124,814.96	1
BETHEL	1	1	0	2	$9,728.65	$1,022.00	
CANTON	7	6	1	16	$138,976.25	$52,989.10	
FRYEBURG	5	5	0	16	$227,359.87	$47,061.27	
MEXICO	1	0	1	2	$116,331.36	$0.00	
NORWAY	1	1	0	2	$7,720.88	$2,698.81	
RUMFORD	2	1	1	5	$43,583.86	$21,043.78	
Penobscot County	18	18	0	47	$327,788.38	$79,345.04	1
BRADLEY	3	3	0	11	$108,995.38	$7,484.39	
CHESTER	1	1	0	2	$25,447.85	$13,517.01	
DREW PLANTATION	1	1	0	2	$23,640.85	$705.96	
GLENBURN	1	1	0	2	$6,017.58	$0.00	
GRINDSTONE	4	4	0	10	$59,256.44	$25,079.82	
MEDWAY	2	2	0	5	$19,312.79	$11,501.89	
MILFORD	4	4	0	11	$65,927.72	$20,129.22	
OLD TOWN	2	2	0	4	$19,189.77	$926.75	
Piscataquis County	9	6	3	23	$834,436.98	$705,289.52	3
BROWNVILLE	1	1	0	2	$12,661.99	$2,603.59	
DOVER-FOXCROFT	2	1	1	6	$19,322.41	$3,595.20	
GUILFORD	4	2	2	10	$738,957.24	$683,284.63	
MILO	2	2	0	5	$63,495.34	$15,806.10	
Sagadahoc County	3	1	2	9	$355,254.18	$51,791.17	0
BATH	1	0	1	4	$290,957.13	$51,791.17	
BOWDOINHAM	1	0	1	2	$46,308.51	$0.00	
PHIPPSBURG	1	1	0	3	$17,988.54	$0.00	

Municipality	Repetitive Loss Properties	Residential	Non-residential	Total losses	Total Building payments	Total Contents payments	Properties mitigated (by county)
Somerset County	5	5	0	11	$76,299.31	$22,957.20	1
ANSON	1	1	0	3	$12,213.10	$5,787.70	
FAIRFIELD	1	1	0	2	$14,019.74	$5,417.50	
HARTLAND	1	1	0	2	$14,960.51	$1,752.00	
NORRIDGEWOCK	1	1	0	2	$24,398.95	$10,000.00	
SKOWHEGAN	1	1	0	2	$10,707.01	$0.00	
Waldo County	3	1	2	12	$273,294.77	$222,616.61	0
BELFAST	1	0	1	6	$151,369.10	$221,128.53	
LINCOLNVILLE	1	0	1	3	$105,063.98	$0.00	
UNITY	1	1	0	3	$16,861.69	$1,488.08	
York County	131	102	29	363	$7,364,382.76	$1,046,597.42	6
ACTON	2	2	0	8	$107,311.42	$0.00	
ARUNDEL	1	1	0	2	$37,092.19	$8,726.10	
BERWICK	2	1	1	4	$243,380.09	$0.00	
BIDDEFORD	5	5	0	10	$67,481.59	$14,850.58	
BUXTON	1	1	0	2	$5,517.14	$0.00	
DAYTON	1	1	0	2	$5,349.64	$0.00	
KENNEBUNK	22	19	3	66	$1,010,495.26	$148,878.25	
KENNEBUNKPORT	9	6	3	31	$778,445.20	$246,664.26	
KITTERY	2	1	1	5	$15,339.86	$0.00	
NORTH BERWICK	1	1	0	3	$92,114.92	$0.00	
OGUNQUIT	9	2	7	25	$1,120,991.88	$126,831.77	
OLD ORCHARD BEACH	9	8	1	22	$205,091.28	$23,000.34	
SACO	18	17	1	53	$1,114,408.26	$228,780.10	
SANFORD	3	2	1	8	$285,136.05	$482.45	
SOUTH BERWICK	4	4	0	13	$264,319.43	$28,480.36	
WELLS	14	14	0	37	$470,447.58	$36,859.57	
YORK	28	17	11	72	$1,541,460.97	$183,043.64	
UNKNOWN	5	4	1	11	$66,943.91	$11,106.00	1

Maine Dept. of Agriculture, Conservation and Forestry Floodplain Management Program 2022.

Table 3.13: Severe Repetitive Loss Properties by community (10/7/2022). Severe Repetitive Losses involve 4 or more claims.

Municipality	Severe Repetitive Loss Properties	Residential	Non-residential	Total losses	Total Building payments	Total Contents payments
TOTAL - STATE	35	20	15	174	$3,015,005.49	$1,063,819.05
Aroostook County	6	3	3	36	370110.58	295287.13
EAGLE LAKE	1	1	0	2	$4,185.80	$0.00
FORT FAIRFIELD	3	2	1	23	$317,075.24	$83,352.94
FORT KENT	2	0	2	11	$48,849.54	$211,934.19
Franklin County	1	0	1	3	21472.09	15600
FARMINGTON	1	0	1	3	$21,472.09	$15,600.00
Kennebec County	4	0	3	27	283298.61	174947.85
AUGUSTA	1	0	1	13	$155,410.13	$116,085.59
GARDINER	1	0	1	5	$40,793.86	$46,796.31
HALLOWELL	2	0	1	9	$87,094.62	$12,065.95
Lincoln County	1	0	1	8	445050.7	48593.18
BOOTHBAY HARBOR	1	0	1	8	$445,050.70	$48,593.18
Oxford County	1	1	0	5	61962.7	5000
FRYEBURG	1	1	0	5	$61,962.70	$5,000.00
Penobscot County	2	2	0	10	89965.95	10828.39
BRADLEY	1	1	0	7	$83,048.61	$7,484.39
MEDWAY	1	1	0	3	$6,917.34	$3,344.00
Waldo County	1	0	1	6	151369.1	221128.53
BELFAST	1	0	1	6	$151,369.10	$221,128.53
York County	19	14	5	79	1591775.76	292433.97
KENNEBUNK	3	3	0	14	$136,429.24	$26,051.43
KENNEBUNKPORT	2	0	2	15	$455,578.35	$122,348.32
OLD ORCHARD BEACH	1	1	0	2	$17,456.70	$647.70
SACO	1	1	0	4	$111,964.47	$0.00
SOUTH BERWICK	2	2	0	9	$224,771.70	$27,287.36
WELLS	3	3	0	10	$132,341.69	$4,462.10
YORK	7	4	3	25	$513,233.61	$111,637.06

Maine Dept. of Agriculture, Conservation and Forestry Floodplain Management Program 2022.

Community Rating System (CRS)

The Community Rating System (CRS) is a voluntary incentive program recognizing and encouraging community floodplain management practices that exceed the minimum requirements of NFIP. Over 1,500 communities participate nationwide [82]. Currently 16 Maine communities participate in CRS (Table 3.14).

In CRS communities, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from the community's efforts that address the three goals of the program:

1. Reduce and avoid flood damage to insurable property.
2. Strengthen and support the insurance aspects of the National Flood Insurance Program.
3. Foster comprehensive floodplain management.

Table 3.14: Communities participating in CRS as of October 2022.

Community	County	CRS Class	% Savings Flood insurance policies in the SFHA
Auburn	Androscoggin	9	5%
Lewiston	Androscoggin	8	10%
Cape Elizabeth	Cumberland	8	10%
Portland	Cumberland	8	10%
Farmington	Franklin	8	10%
Southwest Harbor	Hancock	9	15%
Old Town	Penobscot	7	15%
Dover-Foxcroft	Piscataquis	9	5%
Arrowsic	Sagadahoc	8	10%
Skowhegan	Somerset	8	10%
Alfred	York	8	10%
Ogunquit	York	8	10%
Old Orchard Beach	York	7	15%
Saco	York	8	10%
South Berwick	York	7	15%
York	York	7	15%

Maine Dept. of Agriculture, Conservation and Forestry Floodplain Management Program 2022.

Flood Insurance Trends [S8.a.3]

The number of NFIP policy holders has in general decreased since the last SHMP update (Table 3.14b). All counties except Knox County saw a noticeable drop in NFIP policy holders, and many counties witnessed a drop in policies from a high of 2009 to a low in 2023. The Maine Floodplain Management Program (FMP) has noted that this drop may be due to a larger number of Maine homeowners who choose not to continue investing in flood insurance after they pay off their mortgage. Another likely reason is that more homeowners wish to continue investing in flood insurance, but they may find a more affordable private insurance option. Whatever the case, FMP identifies that Mainers may be underinsured when it comes to flooding. Refer to Section 6 – Mitigation Strategy for a list of mitigation actions to address this issue.

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[82] FEMA Community Rating System: https://www.fema.gov/floodplain-management/community-rating-system

Table 3.14b: NFIP policy trends in Maine from 2009-2023

County	1/29/09	7/26/18	3/1/23	% Change since 2009
Androscoggin	302	202	139	-53.97
Aroostook	295	158	106	-64.07
Cumberland	1343	1421	1148	-14.52
Franklin	190	137	60	-68.42
Hancock	344	339	235	-31.69
Kennebec	493	382	215	-56.39
Knox	228	341	264	15.79
Lincoln	343	400	280	-18.37
Oxford	434	287	184	-57.60
Penobscot	468	391	256	-45.30
Piscataquis	104	65	42	-59.62
Sagadahoc	159	169	125	-21.38
Somerset	287	189	104	-63.76
Waldo	167	151	104	-37.72
Washington	94	113	73	-22.34
York	3505	3583	2795	-20.26
State Total	**8756**	**8328**	**6130**	**-29.99**

Green = highest value from 2009-2023
Red = lowest value from 2009-2023

3.11.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Hazard-Asset Footprint Overlay Analysis

It is not expected buildings will suffer 100% losses from a flooding event in Maine. Flood damage estimates reported here therefore account for only 20% of the valuation for assets and their contents located in flood areas. Given prior warning of a flood event, residents may attempt to relocate the building contents to prevent content loss, but the rate of flooding may be too rapid for this to be successful.

The total estimated valuation for all building assets is $329 billion (2022 USD), with $10.5 billion in assets identified within flood areas. Assuming 20% of each asset is damaged statewide, total losses would equal $2.1 billion. These estimates are further disseminated by county in Table 3.15.

Conversely, flooding caused by sea level rise is assumed permanent and therefore would account for 100% of damage to assets. For a scenario where sea level rises by 1.6 feet, as projected by NOAA for the year 2050, total losses to all buildings are estimated to equal $1.9 billion. A rise in sea level of 3.9 feet, projected by NOAA for the year 2100, may lead to $4.1 billion in total losses to buildings. These models do not incorporate storm surge damages; refer to the section Tropical Cyclone – Vulnerability Assessment for asset damage estimates related to coastal storm surge.

Table 3.15: Potential dollar losses to all building assets by flooding in millions (2022 USD).

Region	Totals		Assets in SFHA*			Assets inundated by 1.6 ft sea level rise			Assets inundated by 3.9 ft sea level rise			Assets inundated by 10.9 ft sea level rise		
	Assets Count	Total Value	Assets Count	20% Losses	% of total value	Assets Count	100% Losses	% of total value	Assets Count	100% Losses	% of total value	Assets Count	100% Losses	% of total value
State of Maine[a,b]	758,999	$329,411	22,192	$2,102	1.38%	3,454	$1,945	0.26%	7,445	$4,095	0.54%	21,034	$10,440	1.38%
Androscoggin	40,678	$20,282	584	$95	2.35%	0	$0	0.00%	0	$0	0.00%	0	$0	0.00%
Aroostook[b]	47,211	$21,437	314	$19	0.44%	0	$0	0.00%	0	$0	0.00%	0	$0	0.00%
Cumberland	120,034	$60,316	2,608	$289	2.40%	481	$466	0.77%	1,183	$1,082	1.79%	4248	$2,810	4.66%
Franklin[a]	21,643	$8,534	1,269	$98	5.77%	0	$0	0.00%	0	$0	0.00%	0	$0	0.00%
Hancock	47,129	$17,737	1,524	$143	4.03%	389	$263	1.48%	688	$388	2.19%	2517	$1,125	6.34%
Kennebec	65,768	$29,533	2,000	$216	3.66%	4	$10	0.03%	9	$20	0.07%	43	$65	0.22%
Knox	28,812	$11,720	1,197	$106	4.50%	372	$178	1.53%	664	$313	2.67%	1913	$796	6.80%
Lincoln	27,821	$10,680	957	$82	3.86%	305	$169	1.58%	500	$248	2.33%	1482	$670	6.28%
Oxfordb	40,062	$16,050	2,196	$221	6.88%	0	$0	0.00%	0	$0	0.00%	0	$0	0.00%
Penobscot[b]	79,169	$35,301	827	$92	1.31%	24	$98	0.28%	54	$123	0.35%	187	$264	0.75%
Piscataquis[a]	16,376	$5,782	1,010	$95	8.22%	0	$0	0.00%	0	$0	0.00%	0	$0	0.00%
Sagadahoc	20,394	$8,210	487	$53	3.23%	173	$120	1.46%	305	$261	3.18%	967	$518	6.31%
Somerset[b]	38,723	$15,823	148	$9	0.29%	0	$0	0.00%	0	$0	0.00%	0	$0	0.00%
Waldo	26,926	$10,879	447	$40	1.82%	42	$45	0.41%	83	$61	0.56%	281	$191	1.76%
Washington[b]	24,214	$8,175	577	$43	2.65%	212	$90	1.10%	428	$175	2.14%	1521	$524	6.41%
York	107,149	$45,785	6,047	$2,102	5.45%	1,452	$505	1.10%	3531	$1,423	3.11%	7875	$3,477	7.59%

*SFHA: Special Flood Hazard Areas designated in FEMA Flood Insurance Rate Maps (FIRMs).

[a] incomplete digital FIRM record. Estimates produced using Hazus-delineated 500-year flood areas.

[b] incomplete digital FIRM record.

3.12 Impact of a Dam Failure/Breach [HHPD2.b]

3.12.1 *Cascading impacts [HHPD2.b.1]*

Dams may fail because of the occurrence of other natural hazards causing an unprecedented load on the dam structure. For example, a poorly designed or mis-operated dam may overtop during a flood, posing a safety risk for downstream communities. Overtopping may occur in a structurally sound dam, but overtopping may also lead to a dam breach with catastrophic implications for downstream communities. The flood itself could occur due to heavy rain and/or rapidly melting snowpack during severe summer, winter or tropical storms [83]. Overfilling of a dam often leads to greater upstream flood hazard risks. Ground accelerations from earthquakes may directly damage the dam structure or cause nearby mass wasting that makes a dam likely to fail and challenging to operate [84]. Mass wasting at the dam site may cause structural failure, while upstream mass wasting may displace enough water to quickly overwhelm operations. Mass wasting itself can form natural dams that may rapidly fill, breach, and pose significant and imminent flood risks [85]. Upstream erosion in reservoir dams may hinder dam operations [86]. Wildfires and other hazards that reduce cohesion on steep vegetated slopes may increase the vulnerability of erosion and failure in heavy rainfall events, particularly for earthen dams [87]. Earthen dams are also susceptible to internal erosion that may contribute to dam failure even during "blue sky" conditions. Finally, the deep and rapid floodwaters expected with a dam failure would trigger many instances of erosion and mass wasting downstream contributing much more to the flood risk itself.

3.12.2 *Economic, environmental, social impacts of dam failure [HHPD2.b.2, HHPD2.b.3]*

Dam breaches are extremely rare in Maine based on the Maine Dam Safety Program incident database. There are very few dams in Maine capable of causing significant downstream infrastructure damage due to operation or mis-operation. These dams tend to be some of the larger dams in the state, and therefore managed by professional operators with controls to prevent mis-operation. These controls are reviewed by the State Dam Safety Program or Federal Energy Regulatory Commission (FERC) depending on jurisdiction.

The economic, environmental, and social impacts of potential dam failures are mitigated through enforcement of floodplain ordinances for a vast majority of municipalities and the entirety of the Unorganized Territory in Maine. Floodplain ordinances implement land use restrictions in floodplains determined by Flood Insurance Rate Maps (FIRMs) produced for the National Flood Insurance Program. Though the location and extent of inundation by a dam failure may vary significantly from the floodplains identified with FIRMs, they provide a useful general assessment of flood risk for a majority of dam-related flood hazards. Much like other flood-related hazards, Maine's road infrastructure may be the most vulnerable to dam failure. Numerous road-stream crossings in Maine are undersized for flood conditions, causing inundation and washout risks for anyone attempting to cross them. Please refer to Flooding – Hazard Profile and Flooding – Vulnerability Assessment for more detail.

Maine dams were constructed incrementally over a period of 300 years. Businesses harnessed the abundant fast flowing rivers and rocky rapids for the development of energy and transportation. Many dams throughout the country are now aged, and in Maine the majority of these structures are nearly 100 years old and beyond the normal design life of civil engineering works. Many are low head dams constructed by using local materials of stone, timber, and earth. Some old dams have now been removed or lie in ruins. Unfortunately, some of the old

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[83] FEMA Dam Failure document: https://www.fema.gov/sites/default/files/2020-08/fema_dam-safety_aware-community_fact-sheet_2016.pdf

[84] Wieland, M. (2006). Earthquake safety of existing dams: https://episodesplatform.eu/eprints/207/1/paper4010.pdf

[85] Marui, H., & Nadim, F. (2009). Landslides and multi-hazards. *Landslides–disaster risk reduction*, 435-450: https://link.springer.com/chapter/10.1007/978-3-540-69970-5_23

[86] Wang, G., Wu, B., & Wang, Z. Y. (2005). Sedimentation problems and management strategies of sanmenxia reservoir, yellow river, china. *Water resources research*, *41*(9): https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2004WR003919

[87] Moody, J. A., Shakesby, R. A., Robichaud, P. R., Cannon, S. H., & Martin, D. A. (2013). Current research issues related to post-wildfire runoff and erosion processes. *Earth-Science Reviews*, *122*, 10-37: https://www.sciencedirect.com/science/article/pii/S0012825213000536

(or unmonitored) sites have been built upon by beavers, impounding enough water to cause minor road washouts when they breach after heavy rains.

Table 3.15b provides information on specific rivers and streams where high hazard dams are located, the total number of dams, names of downstream towns and cities, state and federal road crossings, and the number of transmission line crossings below the dams. Main's Dam Safety Program does not calculate populations at risk, but the information provided here may give an estimate of communities and infrastructure that may pursue dam failure mitigation resources. The communities, road crossings, and transmission line crossings downstream of high hazard potential dams would potentially be impacted by a major dam breach or failure. There are no known state owned or operated assets (other than assets noted below) within dam breach inundation zones.

Table 3.15b: High hazard dams and downstream communities and infrastructure

Watershed	Number of HH Dams	Downstream municipalities	State/Fed Road Crossings	Transmission line crossings (count)
Mousam	3	Sanford, Shapleigh, Kennebunk	I-95, Rt. 1, Rt. 9	4
Saint Croix	2	Baileyville, Baring, Calais	3 International border crossing points	3
Narraguagus	1	Cherryfield	Rt. 1	2
Penobscot	9	Millinocket, Medway, Lincoln, Howland, Orono, Old Town, Bradley, Bangor, Brewer	I-395, Rt. 15B, Rt. 2, Rt. 155, Rt. 116 (twice), I-95, Rt. 11	8
Sebasticook	1	Dexter, Corinna, Rt. 23, Rt. 7, Rt. 43	None	3
Zircon Brook	1	Rumford	None	0
Saco	2	Fryeburg, Brownfield, Baldwin, Cornish, Hollis, Biddeford, Saco	Rt. 113 (twice), Rt. 160, Rt. 5 (twice), Rt. 11, Rt. 25, Rt. 35, Rt. 202, I-95, Rt. 1	6
Megunticook	3	Camden	Rt. 105 (twice)	1
Tannery	1	Gorham	Rt. 202	0
Lower West Bay Stream	1	Sullivan	Rt. 1	0
Narramissic	2	Orland	Rt. 1, Rt. 166	0
Wilson Pond	1	Monmouth	Rt. 11	0
Presumpscot	3	Portland, Falmouth, Westbrook, Gorham, Windham	I-295, I-95, Rt. 1, Rt. 100, Falmouth Spur, Presumpscot Falls Bridge, Rt. 302, Babb's Covered Bridge, Rt. 35	2
Prestile stream	2	Easton, Westfield, Mars Hill	None	3
Libby Brook	2	Fort Fairfield	None	1
Limestone, Durepo, Noyes Streams	3	Limestone	Rt. 1A, Rt. 229	0
Hanson, Mantle, Violette Brooks	3	Presque Isle, Mapleton, Cyr Plantation, Presque Isle Airport	Rt. 1, Rt. 163	1
Dunham, Davee Brooks	2	Dover-Foxcroft	Rt. 6	0
Howard Pond	1	Hanover	Rt. 2	0
Cobbosseecontee	2	Gardiner	Rt. 201	0
Sebec	1	Sebec, Milo	Rt. 6	0

Watershed	Number of HH Dams	Downstream municipalities	State/Fed Road Crossings	Transmission line crossings (count)
Androscoggin	1	Lewiston, Auburn, Durham, Lisbon Falls, Topsham, Brunswick	Rt. 202, I-95, Rt. 125, I-295, Rt. 201, Rt. 196	8
Mooselookmeguntic	1	Rangeley	Rt. 4, Rt. 16	0
Magalloway, Abbott	2	Lincoln Plt.	Rt. 16	0
Bobbin Mill Brook	1	Auburn	Rt. 4	0
Scopan Stream	1	Masardis, Ashland	Rt. 11	1
Rapid	2	Richardson Twp. Twp. C	None	0
Kennebec	6	Moscow, Pleasant Ridge, Bingham, Solon, Madison, Norrigewock, Skowhegan, Fairfield, Waterville, Winslow, Halifax State Historic Site, Bailey Farm Windmill, Vassalboro, Sidney, Augusta, Hallowell, Gardiner, Farmingdale	Rt. 197, Rt. 27, R. 202, Rt. 3, Rt. 137, Rt. 201, Rt. 100, I-95, Rt. 23, Rt. 201, Rt. 201A (4x)	8
Dead	1	Dead River Twp., Flagstaff Lake, The Forks	None	0
Millinocket Stream	1	Millinocket	Rt. 157	3
Union	3	Ellsworth	Rt. 1A, Rt. 1	1
Messalonskee Stream	1	Oakland, Waterville	Rt. 137 (twice), I-95, Rt. 11	2
Moose	1	Jackman, Moose River, Rockwood	Rt. 201, Rt 6	0
Mill Stream	1	Madison, Skowhegan	Rt. 150	1

3.12.3 Methodology and Assumptions [HHPD2.b.4]

It can be difficult to determine the impacts of dam failure due to the need for specialized technical modeling software and incorporation of multiple data sources. Maine law, consistent with federal law, classifies the hazard potential of dams as High, Significant or Low. Generally speaking, failure of high hazard dams could cause loss of life; Significant hazard dams could cause significant property damage and low hazard dams would generally cause damage only to the owner's property. Therefore, it's possible a small (low head) dam located above a large community could be rated high hazard while a structurally larger dam sited in an unpopulated area could have a low hazard potential. Three analyses are combined to interpret dam hazard and are central to an Emergency Action Plan (EAP) [88]:

- Measuring the flow expected from a modeled uncontrolled release of the reservoir
- Determining the flood inundation area from the model release
- Identifying the potential consequences of flooding in the inundation area

Every high hazard dam in Maine has an EAP on file with Maine's Dam Safety Program available for review on request. These documents include either paper and digital failure inundation maps. Very few maps are in a georeferenced format that can easily be combined with other geographic-based data important for calculating Population at Risk. Further, EAPs for FERC-regulated dams are under restricted release. Currently the Maine Dam Safety Program does not have the capacity to convert existing map images into a georeferenced format. One future opportunity for modeling and presenting dam failure risk for non-FERC regulated dams is available through the Decision Support System for Water Infrastructural Security (DSS-WISE) Lite tool [89]. However, this tool still requires substantial knowledge of the dam site, local communities, and technical/GIS knowledge to run accurate simulations.

3.12.4 *Dam Safety Limitations [HHPD2.c]*

Though Maine's Dam Safety Program has achieved full dam regulation compliance, the program lacks the capacity to expand on current progress. For example, greater capacity is needed to develop digital resources for EAPs. More staff will be needed to monitor dam-related issues extending beyond the base requirements for dam safety inspections and EAP publication. Currently the Dam Safety Program is working collaboratively with other divisions of the Maine Emergency Management Agency, as well as other regulatory state agencies to share resources and improve GIS capabilities for updating the dam database and supporting dam safety compliance. Recently there has been a reclassification of the Program's Dam Safety Engineer position to encourage greater interest from professional engineers, and there is an Assistant Dam Safety Engineer position advertised by local university engineering programs. When these baseline requirements are addressed, the Dam Safety Program can begin to establish a HHPD funding prioritization strategy that is suited for the State of Maine.

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[88] Maine EAP guidelines: https://www.maine.gov/mema/hazards/dam-safety/emergency-action-plan

[89] DSS-WISE: https://dsswiseweb.ncche.olemiss.edu/

Severe Summer Weather – Hazard Profile

TIER 1 HAZARD

3.13 Severe Summer Weather – General Definition and Types of Events [S3.a., S3.b.]

For the purposes of this plan, severe summer weather events are defined as those characterized by violent weather phenomenon producing winds, heavy rains, excessive heat, lightning, and hail that can cause injuries, and destruction of property, crops, and livestock. Note: While considered "summer weather," drought and hurricanes are not included in this profile as they are profiled separately within this section of the plan.

3.13.1 Severe Weather

Thunderstorm

A thunderstorm is formed from a combination of moisture, rapidly rising warm air, and a force capable of lifting air such as a warm or cold front, or a sea breeze. All thunderstorms have lightning and can occur singly, in clusters or in lines. Lightning is an electrical discharge that results from the buildup of separated positive and negative charges within a thunderstorm. When the buildup becomes strong enough, an electric current forms between the separated charges, commonly known as a 'bolt' of lightning. This flash of light usually occurs within the clouds or between the clouds and the ground. A bolt of lightning reaches a temperature approaching 50,000 degrees Fahrenheit in a split second. The rapid heating and cooling causes thunder [90].

Tornado

Tornadoes are violently rotating columns of air touching the ground, usually generated by especially severe thunderstorms. Tornadoes are nature's most violent storms, develop extremely rapidly, and may dissipate just a quickly. Most tornadoes are on the ground for less than 15 minutes. Spawned by powerful thunderstorms, tornadoes can cause fatalities and devastate a neighborhood in seconds. Winds of a tornado may reach 300 miles per hour. Damage paths can be in excess of one mile wide and 50 miles long. Strong downburst (straight-line) winds may also occur due to the same thunderstorm, but these are independent of tornado winds. Hail is very commonly found very close to the tornadoes, as the strongest thunderstorms that spawn tornadoes are formed under the atmospheric conditions that are also highly likely to make hail [91]. For all their destructive fury, tornadoes are relatively small when compared to some other extreme weather events. Hurricanes, for example, can span hundreds of miles, whereas the biggest tornado ever recorded measured 4.2 kilometers (2.6 miles) wide. They are also very short lived, lasting from a few seconds to a few hours as opposed to days or weeks at a time [92].

Strong straight-line winds

Damaging winds are often called "straight-line" winds to differentiate the damage they cause from tornado damage. Strong thunderstorm winds can come from a number of different processes. Most thunderstorm winds that cause damage at the ground are a result of outflow generated by a thunderstorm downdraft. Damaging winds are classified as those exceeding 50-60 mph [93].

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[90] NWS Thunderstorm definition: https://www.weather.gov/phi/ThunderstormDefinition
[91] NWS Tornado definition: https://www.weather.gov/phi/TornadoDefinition
[92] Tornadoes and Climate Change: https://education.nationalgeographic.org/resource/tornadoes-and-climate-change
[93] NWS wind definition: https://www.nssl.noaa.gov/education/svrwx101/wind/

Microburst

A microburst is a localized column of sinking air (downdraft) within a thunderstorm and is usually less than or equal to 2.5 miles in diameter. Microbursts can cause extensive damage at the surface, and in some instances, can be life-threatening. There are two primary types of microbursts: 1) wet microbursts and 2) dry microbursts. Wet microbursts are accompanied by significant precipitation. Updrafts within thunderstorms may be strong enough to suspend large amounts of water droplets and hailstones as a "core" in the upper portions of the thunderstorm. Evaporation from lofted water droplets and hail cools the air (evaporational cooling), causing it to sink and eventually weakening the updraft. As a result, the core plummets to the ground causing very strong straight-line winds to spread out in all directions. The location in which the microburst first hits the ground experiences the highest winds and greatest damage [94].

Hail

Hail is a form of precipitation occurring when updrafts in thunderstorms carry raindrops upward into extremely cold areas of the atmosphere where they freeze into ice. Hailstones then grow by colliding with liquid water drops that freeze onto the hailstone's surface. The hail falls when the thunderstorm's updraft can no longer support the weight of the hailstone, which can occur if the stone becomes large enough or the updraft weakens [95]. Hailstones larger than 1 inch in diameter are capable of causing property damage. But from an agricultural perspective, hailstones below 1 inch diameter can wipe out a crop of apples, peaches, strawberries, and other fruit in a matter of seconds. Hail is a common cause of crop loss in apples and protective netting is used in regions where hailstorms are more prominent.

3.13.2 Extreme Heat

Extreme heat is defined as summertime temperatures that are much hotter and/or humid than local and seasonal average conditions. Maine's Center for Disease Control classifies an extreme heat event as one with temperatures above 90 degrees lasting for three or more days. Heat is the leading cause of weather-related deaths in the United States. Heat-related illnesses, like heat exhaustion or heat stroke, happen when the body is not able to properly cool itself. While the body normally cools itself by sweating, during extreme heat, this might not be enough. In these cases, a person's body temperature rises faster than it can cool itself down. This can cause damage to the brain and other vital organs [96].

3.14 Severe Summer Weather – Location of Hazard [S3.a.1]

3.14.1 Storm-related events

The entire state is vulnerable to one or more severe summer storms each year, usually in the form of thunderstorms, strong winds, and heavy rain. Fortunately, the effects are often more common in the less populated areas of the western, mountainous regions, and less noticeable along the more populated Atlantic coast where the cooling effects of the ocean tend to suppress thunderstorm conditions. Weather events such as hail, tornadoes, and microbursts may also occur anywhere in the state but are less common with more localized impacts (Figure 3.13).

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[94] NWS Microburst definition: https://www.weather.gov/bmx/outreach_microbursts
[95] NWS Hail definition: https://www.nssl.noaa.gov/education/svrwx101/hail/
[96] CDC Extreme Heat website: https://www.cdc.gov/disasters/extremeheat/heat_guide.html

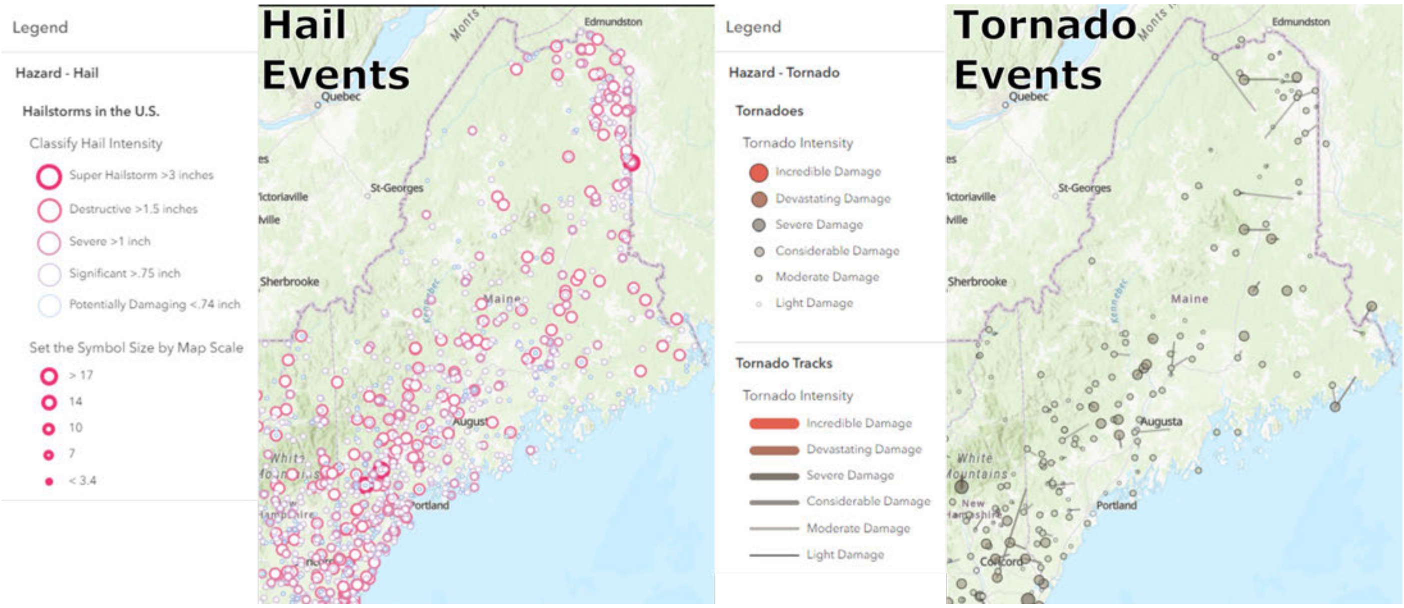

Figure 3.13: NOAA historic reports of hail (left) and tornado (right) events in Maine.
Hail: https://maine.maps.arcgis.com/home/item.html?id=5972242f44714758b97c415a62a49ad5
Tornado: https://maine.maps.arcgis.com/home/item.html?id=0db253f3e83a4c5f9f5ab9577f2dcb49

3.14.2 Extreme Heat

Extreme heat can occur throughout the entire state, with southern counties generally experiencing a greater number of days with high heat index. Locations susceptible to extreme heat are expected to increase with the rise in average global temperatures [97] (Figure 3.14). Of these locations, urban centers are susceptible to heat-related impacts due to the urban heat island effect [98] (Figure 3.15a). However, rural populations are found to be even more vulnerable to extreme heat, suffering heat-related illnesses at five to ten times the rates of people in urban areas (www.aamc.org/news/rural-americans-find-little-escape-climate-change). Maine CDC has conducted some preliminary assessments of the heat island effect in a few urban centers. Some refined work in Biddeford indicates a relatively large and impactful urban heat island effect in the city, though not to the degree seen in large urban centers outside of Maine. This work is benchmarked using studies from New York City. However, the impacts may be greater for Maine residents acclimated to a lower average summer temperature. Heat-related health risks are more common in York, Cumberland, and Androscoggin counties relative to other northern regions. Occurrences are rare in Aroostook County (Figure 3.15b).

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[97] Killer heat un the United States: the future of dangerously hot days

[98] Li Y, Odame EA, Silver K, Zheng S (2017) Comparing Urban and Rural Vulnerability to Heat-Related Mortality: A Systematic Review and Meta-analysis. J Glob Epidemiol Environ Health 2017: 9-15. doi:https://doi.org/10.29199/2637-7144/GEEH-101016

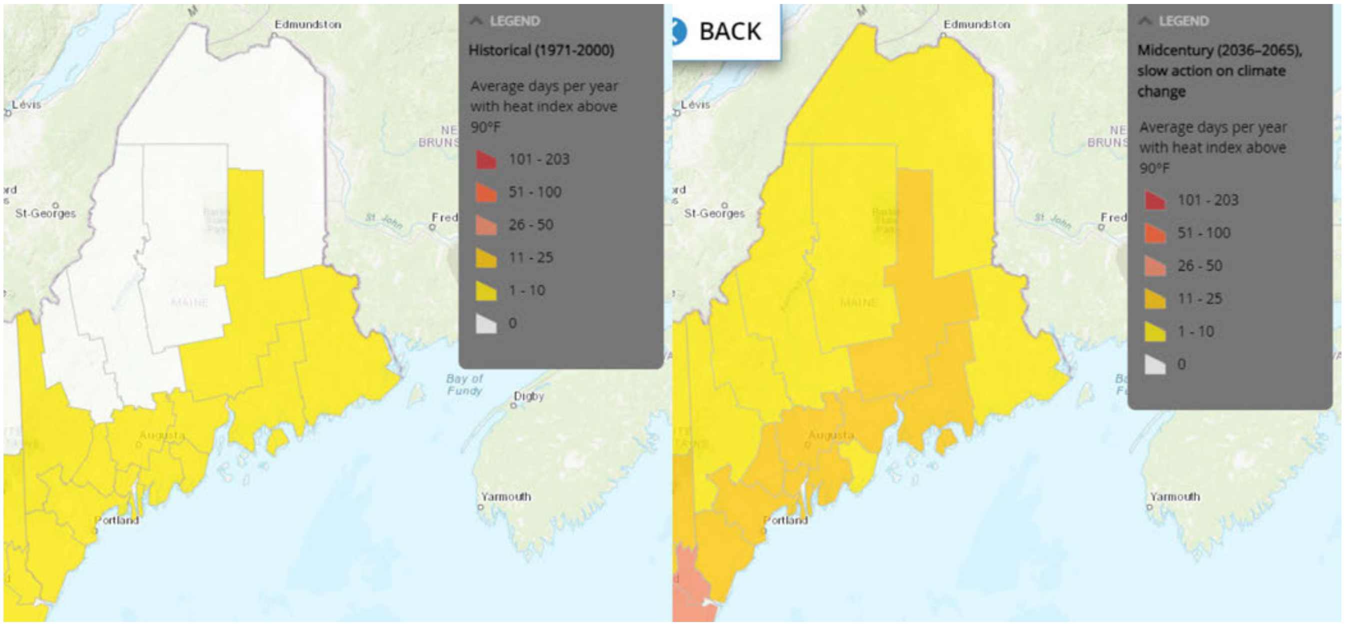


Figure 3.14: Historic (left) and midcentury model-projected (right) average number of days with heat index above 90° F. https://ucsusa.maps.arcgis.com/apps/MapSeries/index.html?appid=e4e9082a1ec343c794d27f3e12dd006d

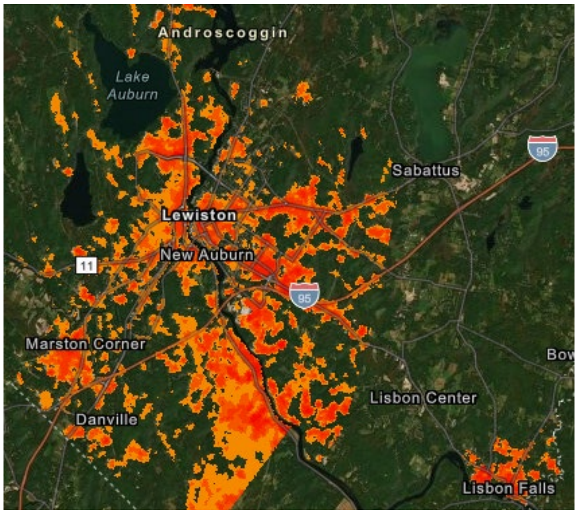
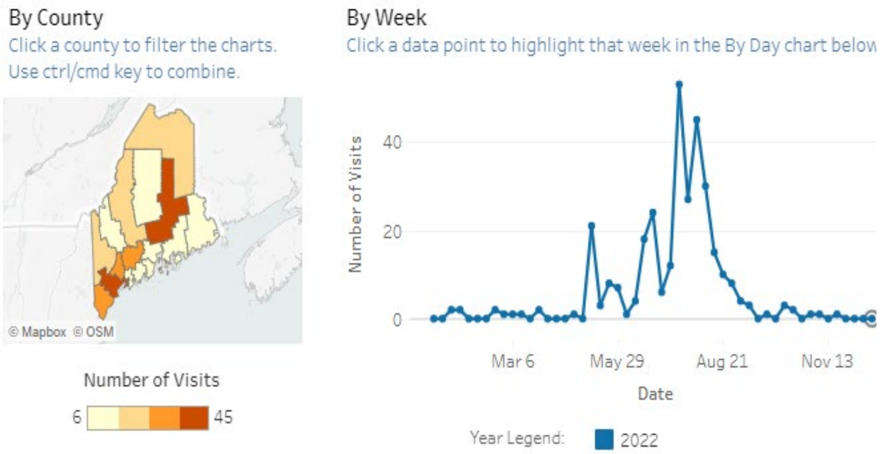


Figure 3.15a: example of urban heat island effect in Lewiston-Auburn Area. Red shaded area indicates elevated temperatures, deeper red color indicates greater heat intensity.


By County

Click a county to filter the charts.
Use ctrl/cmd key to combine.

By Week

Click a data point to highlight that week in the By Day chart below

Figure 3.15b: Heat-related illness trends in Maine by county and date.

3.15 Severe Summer Weather – Intensity and Previous Occurrences [S3.a.2.]

The methods outlined below are used to classify the strength or magnitude of possible severe summer weather events.

3.15.1 Thunderstorm

The National Weather Service defines severe thunderstorms as damaging wind gusts greater than 58 mph and/or hail stones greater than 1". Considerable thunderstorm damage is defined as 70 mph winds and 1.75" hail. Destructive thunderstorm damage is defined as 80 mph winds and 2.75" hail.

3.15.2 Lightning

The extent of a lightning event can be measured by the amount of energy discharged. However, *all* lightning strikes present an immediate threat to life safety and potential wildfires, so the extent of a lightning event will not be discussed further in this plan.

3.15.3 Tornado

Maine uses the Enhanced Fujita Tornado Scale to classify the extent of a tornado (Table 3.16).

Table 3.16: The Enhanced Fujita Tornado Scale (abbreviated)

Scale	3 Second Gust	Typical Effects
EF0	65-85 mph	Gale tornado (weak); light damage to chimneys; breaks twigs and branches off trees; pushes over shallow-rooted trees; damages signboards; some windows broken.
EF1	86-110 mph	Moderate tornado (weak); Moderate damage: peels surface off roofs; mobile homes pushed off foundations or overturned; outbuildings demolished; moving autos pushed off roads; trees snapped or broken.
EF2	111-135 mph	Significant tornado (strong); considerable damage: roofs torn off frame houses; mobile homes demolished; frame houses with weak foundations lifted and moved; boxcars pushed over; large trees snapped or uprooted; light-object missiles generated.
EF3	136-165 mph	Severe tornado (strong); severe damage: roofs and some walls torn off well-constructed houses; trains overturned; most trees in forests uprooted; heavy cars lifted off the ground and thrown; weak pavement blown off roads.
EF4	166-200 mph	Devastating tornado (violent); devastating damage: well-constructed homes leveled; structures with weak foundations blown off some distance; cars thrown and disintegrated; large missiles generated; trees in forest uprooted and carried some distance away.
EF5	Over 200 mph	Incredible tornado (violent); Strong-framed, well-built houses leveled; steel-reinforced concrete structures damaged, tall buildings collapse or have severe deformations; some vehicles can be thrown great distances.

Source: The Enhanced Fujita Scale (EF Scale), National Weather Service. (https://www.weather.gov/oun/efscale)

Maine tornados have been documented on the NOAA website; see Table 3.17. Because there have been no F3 or greater tornados reported, only the worst occurrences, F2s, are captured below. When the history of occurrences in Maine is considered, there have been a total of 19 F2 tornados over a 71-year period, averaging 0.27 F2 tornados per year. A total of 139 tornados of any magnitude have occurred in Maine since reporting began in 1950, averaging 1.96 tornados per year in Maine.

Table 3.17: F2 & EF1 Tornados in Maine (1950 –2021) [99]					
Tornado Scale	Reported Occurrences	Deaths	Injuries	Damages	Damages per Event
F0 or EF0	35	0	1	$131,000	$3,723
F1 or EF1	73	0	13	$30,411,000	$416,589
F2 or EF2	19	1	4	$1,450,250	$76,329
Undefined	12	0	2	$315,250	$26,271

3.15.4 Hail

The extent of damage from a hailstorm event is generally measured based on the average range of hail sizes. One example of this is the TORRO Hailstorm Intensity Scale or H Scale [100].

There have been 1,163 reports of hailstorms in Maine with average ail size equal to or greater than ¾ inch since the first reported event in 1957 (Table 3.18). One-third of these hailstorms have occurred in June, while roughly one-quarter have each occurred in July and August. A minority of hailstorms have occurred outside of the summer season. Of these reports, approximately 23% of all hailstorms generated hail greater than an inch in diameter. There have been three reports of hail reaching four inches in diameter, roughly equal to grapefruit size.

Table 3.18: Hailstorms in Maine (1950 –2021) [101]			
Hailstone Size	Reported Occurrences	Injuries	Damages
< 1 inch	477	0	$160,000
1 – 2 inches	651	2	$1,701,000
> 2 inches	35	0	$500

3.15.5 Extreme Heat

The severity of an extreme heat event can be a result of one exceptionally warm day or from the cumulative effect of a series of consecutive warm days. Maine CDC uses these thresholds and terminology to categorize an extreme heat event:

Danger (NWS Excessive Heat Warning): Heat index values of 105 or greater lasting two hours or more.

Extreme Caution (NWS Heat Advisory): Heat index values of 94 to 104 for two or more hours.

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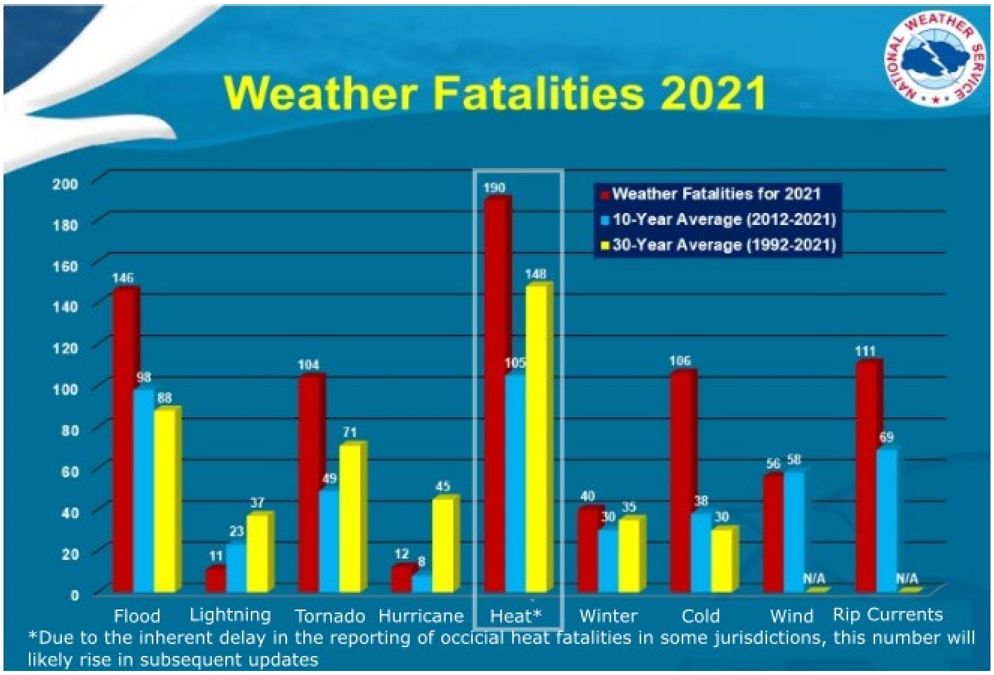
[99] NOAA Storm Events Database: https://www.ncdc.noaa.gov/stormevents/

[100] H Scale: https://www.torro.org.uk/research/hail/hscale

[101] NOAA Storm Events Database: https://www.ncdc.noaa.gov/stormevents/

NOTE: The highest temperature ever recorded in Maine is 105° F on July 10th, 1911, in Bridgton.

From 2018 to 2021 there have been 9 heat wave episodes reported in NOAA's Storm Events Database with elevated heat indices impacting 6 of 16 counties. Nationally, extreme heat has been the greatest weather-related cause of death in the US for the past 30 years, killing over 700 people per year [102] (Figure 3.16).


Weather Fatalities 2021

*Due to the inherent delay in the reporting of occicial heat fatalities in some jurisdictions, this number will likely rise in subsequent updates

Figure 3.16: fatalities reported by weather related hazards. https://www.weather.gov/hazstat/

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[102] NOAA Weather Related Fatality and Injury Statistics: https://www.weather.gov/hazstat/

3.16 Severe Summer Weather – Probability of Future Occurrence [S4.]

3.16.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Summer Storm

Based on past experiences, and the frequency of National Weather Service Warnings, there is a high probability the state can expect thunder and lightning every year, especially in the summer months. According to NOAA, there were 211 lightning events and 2,713 thunderstorm wind events recorded in Maine between 1950 and 2021. Based on historical records, Maine can expect several lightning events and thunderstorms each year.

Climate change projections indicate a growing prevalence of warm, moist air conducive to thunderstorm activity in Maine. The occurrence of thunderstorms in Maine is therefore expected to increase through the next five years and indeed through future Plan updates.

EF2-5 Tornado

While the state has not done probability studies, historically, the probability of an EF2 strength tornado or greater is low. The National Weather Service recorded 79 tornados, with a magnitude of (E)F1 or greater in Maine between 1954 and 2014. Based on that history of previous occurrences, Maine can expect an average of approximately 1.33 tornados a year.

As noted by the National Geographic Resource Library [103], predicting whether climate change will have an effect on the frequency and power of tornadoes is a challenge. The brief, highly localized damage caused by tornadoes is challenging to capture in broadscale climate projection models. Scientists therefore instead focus on how climate change might affect the individual weather “ingredients” that support the development of supercell thunderstorms (the type that produce tornadoes), including the co-occurrence of warm, moist air; an unstable atmosphere; and sufficient wind shear.

As global temperatures rise, the hotter atmosphere is able to hold more moisture. This increases atmospheric instability, a vital supercell ingredient. On the other hand, as the planet warms, wind shear (another vital ingredient) is likely to decrease. These two forces work against each other, and it is difficult to anticipate which might have a greater impact on tornado formation.

Some studies predict that climate change could provide the opportunity for more severe thunderstorms to form. However, this does not necessarily mean that more tornadoes will occur, especially in light of the fact that only about 20 percent of supercell thunderstorms produce tornadoes. To complicate things further, no one fully understands how tornadoes are formed.

Hail

Research is inconclusive on whether hailstorms will become more common in Maine, and it is not known whether use of protective netting will need to become standard practice for fruit production.

Extreme Heat

As noted above, occurrences of high heat index days and heat-related illnesses are expected to increase, and more communities will be impacted by heat as annual average temperatures continue to rise.

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[103] Tornadoes and Climate Change: https://education.nationalgeographic.org/resource/tornadoes-and-climate-change

3.17 Severe Summer Weather – Impacts

Maine generally experiences comfortable summer weather, which encourages residents from in state and away to recreate out of doors, and often times away from permanent structures. Those recreating on trails, in boats, or in campgrounds are vulnerable to immediate physical damage from a severe summer weather event. Economic stakeholders of Maine's tourism industry are susceptible to economic damage in the event of hazardous summer weather.

Flooding is a viable consequence of severe summer weather with location-specific impacts, refer to the flooding vulnerability assessment for reference.

Strong straight-line winds are one of the most damaging consequences of severe summer weather, often from trees falling onto buildings, roads, railways, and power lines. Refer to the tropical cyclone vulnerability assessment for further reference. Though rare in Maine, tornadoes have significant damage potential within a focused path. Hail has a potential to cause damage to homes, crops, forests, and infrastructure but historically the impact of hail has been relatively limited in Maine. Most severe summer weather events tend to be highly localized, causing substantial damage in a relatively small area.

Power outages are the primary impact of damaging winds. Maine experienced the greatest number of power outages than any other state on average from 2015 to 2019 [104]. Power outages can be widespread and may extend beyond the scale of the damaging summer storm itself, especially in rural areas without redundancies in the local energy grid. The impacts of power outages are many, and may include loss of perishable food supplies, temporary loss of business and services, and temporary loss of medical equipment and air conditioning requiring power, which may potentially lead to loss of life. State offices are unable to function without power and so all non-critical state functions would halt until power is restored. Luckily, most critical state functions, such as MEMA's Emergency Operations Center, are supported by backup generator power. Installation of generators in critical facilities is a common mitigation strategy in Maine.

According to the U.S. Center for Disease Control, older adults, the very young, people with mental illness, and chronic diseases are the most vulnerable to feeling the impacts of an extreme heat event (https://www.cdc.gov/disasters/extremeheat/heat_guide.html). If extreme heat coincides with a loss of power, the impacts of heat-related diseases, and stress on the critical medical services deployed to address these incidents, increases substantially.

Wind damage can have major impacts on working forests and natural areas protected by the state. Damage to standing timber will impact Maine lumber, pulp, and other wood products industries which compose a major part of the State's economy. Wind and flood damages to protected areas may lead to long-term or permanent impacts to Maine's unique ecosystems. Debris blown onto roads and power lines requires lengthy cleanup efforts and detours for commuters.

In the summer, southwest to southerly winds tend to become prevalent across the state. Because of the frequent formation of sea breezes, southerly winds prevail along the Mid-Coast and "Down East" portions during the

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[104] Power outage statistics: https://www.mroelectric.com/blog/most-least-power-outages

summer months. When severe summer storms arrive in the state, high winds can cause fallen trees and branches onto power lines, causing power and communication outages. Heavy rains that often accompany thunderstorms can result in flash flooding or erosion. Hail can cause crop damage for farmers and backyard gardeners. Lightning strikes can start fires. Any of these weather events can cause personal injury or property damage.

Because of Maine's sparse population, there have been no significant amounts of property damage or personal injury. Reports of tornado damage are usually limited to individual properties that have been struck. If a tornado were to strike a mobile home park, there would inevitably be substantial damage. The tornados experienced in recent history in Maine have been generated by severe summer storms with the southwestern and central sections of the state most often affected.

Due to severity of summer storms Maine residents often experience brief power outages, posing an increased risk to elderly and disabled populations.

3.18 Severe Summer Weather – Vulnerability of State Assets [S5.]

Summer storm damages such as thunderstorms and F0-F2 tornadoes to state owned or operated buildings or infrastructure are no more likely than damages to other buildings or infrastructure. General damage can be caused by flooding or wildfires, but these are covered in their own sections. Costs typically come from the overtime use of Maine Department of Transportation and National Guard personnel and equipment to clear state-maintained roads of debris. Although utilities can be damaged during summer storms, the utilities are owned and operated by private utility companies.

Structure asset data provided by the Maine Department of Administration and Financial Services Bureau of General Services forms the basis for this assessment. All locations within Maine are potentially susceptible to severe summer weather, therefore a GIS analysis is not provided for this section, nor are there selected state assets that are particularly vulnerable to these hazards.

3.18.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

State facilities that would be used during an emergency or disaster for response or recovery are not at an elevated risk from severe summer weather, though all state assets may be at minor risk of damages and temporary power outages.

Wind, hail, and tornado damages are anticipated to be localized and would likely impact wood framed structures to a greater degree through direct wind, precipitation, or falling debris damage. No probability spatial overlays for these hazards exist for Maine. The occurrence of wind damage is expected to be local, from isolated thunderstorms that may be scattered throughout a larger impacted area. Therefore, damage estimates for strong winds (damaging 70 mph gust [105]) account for 2% of the total valuation for wood structure assets [106]. Total losses for the state, assuming a statewide disaster, may equal $16.4 million. Conversely, the impacts of hailstorms and tornadoes are expected to be highly localized, assumed here to only damage 0.2% of all assets with a total amount equal to $1.6 million. There is no guarantee that these assets will be damaged in a natural hazard event.

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[105] NOAA wind threat definitions: www.weather.gov/mlb/wind_threat

[106] Pita, G., Pinelli, J. P., Gurley, K., & Mitrani-Reiser, J. (2015). State of the art of hurricane vulnerability estimation methods: a review. *Natural Hazards Review*, *16*(2), 04014022.

3.18.2 Community lifeline Risks

Severe summer weather is anticipated to primarily impact transportation, energy, medical, and communication lifelines to the greatest degree.

Transportation

Summer storms can require a significant amount of debris cleanup before roads are reopened to the public. This means that access to other critical facilities may be hindered until debris cleanup is complete. Debris cleanup resource needs are difficult to estimate due to huge variations of the amount of debris involved in any given event, whether debris is tangled in utility lines, and where it's being hauled to. A ballpark estimate for brush removal is around $20,000 per shoulder mile for roads managed by MaineDOT. Non-tropical severe summer weather events are not typically substantial enough to warrant a disaster declaration, but in the past these impacts have cost towns and State Government hundreds of thousands of dollars in damages, labor costs, and indirect impacts to commerce, shipping, and service coverage. Damages from tornadoes would be more focused and likely far more destructive than thunderstorm winds. Damage by hail alone would be less significant but would have the greatest impact on structures designed with less resilient building materials such as wood and vinyl siding, both of which are common materials used in Maine.

Energy

Primary impacts of severe summer storms on the energy sector are strong winds damaging transmission lines. The impacts of power outages are similar to that of flooding. After large summer storms, it often takes several days to clear debris and restore power. Power outages are a very common occurrence across the entire state, but rural areas tend to have far more prolonged outages.

Severe summer storm events such as hail and tornadoes may have direct impacts on energy production. Table 3.19 presents observational records of hail and tornado occurrence discussed above by tracking the occurrence of these events within 10 miles of power plant locations. Power plants do not have any higher level of exposure to these hazards than other types of infrastructure based on the distribution of power plant sites in Maine, combined with the reported locations of hailstorms and tornadoes. Location-specific vulnerability data are not currently available for transmission line exposure because there is generally equal risk of wind damage across the state from severe summer weather.

Table 3.19: Occurrence of hailstorms and tornadoes within 10 miles of current power plant locations, 1950-present.

Type of Power Plant (total count)	Hailstorms	Tornadoes
All types (106)	603	62
Solar (8)	121	20
Wind (18)	94	13

Maine solar energy farms have grown sevenfold in the last few years. Many solar panel manufacturers affirm that installed panels can resist damage from the magnitude of hailstorms and windstorms commonly experienced in Maine. However, under extreme conditions, damage to Maine's solar infrastructure would have substantial long-term impacts on Maine's grid resilience and goals for green energy production.

Medical

Extreme heat can result in substantial medical impacts, as noted in Maine CDC's Extreme Heat Plan [107]. In addition to the concerns identified in the hazard profile, an additional concern is that not all assisted living centers have installed air conditioning. More specifically, many coastal nursing homes have relied on typically more moderate temperatures but now require air conditioning due to rising atmospheric temperatures. All 90 nursing

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[107] Maine CDC Extreme Heat Plan: https://www.maine.gov/dhhs/mecdc/public-health-systems/phep/documents/mainecdcallhazheat.doc

homes in Maine could be at risk of power outages, though not all at once would be at risk of power outages by localized severe summer weather events. It is unknown how many of these have backup generators.

Communication

Thunderstorm winds are the likeliest hazard to stress Maine's ability to effectively distribute emergency communications to the public. Wind can cause cyclical loading on towers and guy wires. After a certain point, this cyclical loading will cause permanent damage that can lead to failure. Any tower should be checked on a regular basis for this type of wear before it leads to a major problem [108]. Impacts to cell service are expected to be localized based on the location and extent of the wind event. Though cell towers usually have backup generators, the tower would still be nonfunctional if there was direct damage to the structure itself. State employees and public citizens alike depend heavily on cell service for communication and a large outage event would cause major issues. The threat of thunderstorm winds is uniform across the state.

3.19 Severe Summer Weather – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

Similar to state assets, the greatest impacts of severe summer weather, such as hail and tornadoes, are expected to occur in localized areas. Damaging winds and flooding may impact a broader area, please refer to the tropical cyclone and flooding sections for more information.

3.19.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

All jurisdictions are potentially vulnerable to damages from severe summer weather. Other than wind and lightning damage, there is no conclusive indication that any one jurisdiction is more likely to experience an event than others (Figure 3.17). However, regions that are more densely populated, such as Cumberland and York counties, or jurisdictions with relatively less community resilience, may host a greater total impacted population if an event were to occur. Jurisdictions with a greater proportion of elderly or disabled community members may also be at greater risk from hazards such as summer heatwaves.

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[108] Common causes for tower failure: https://www.tower-engineers.com/unnamed

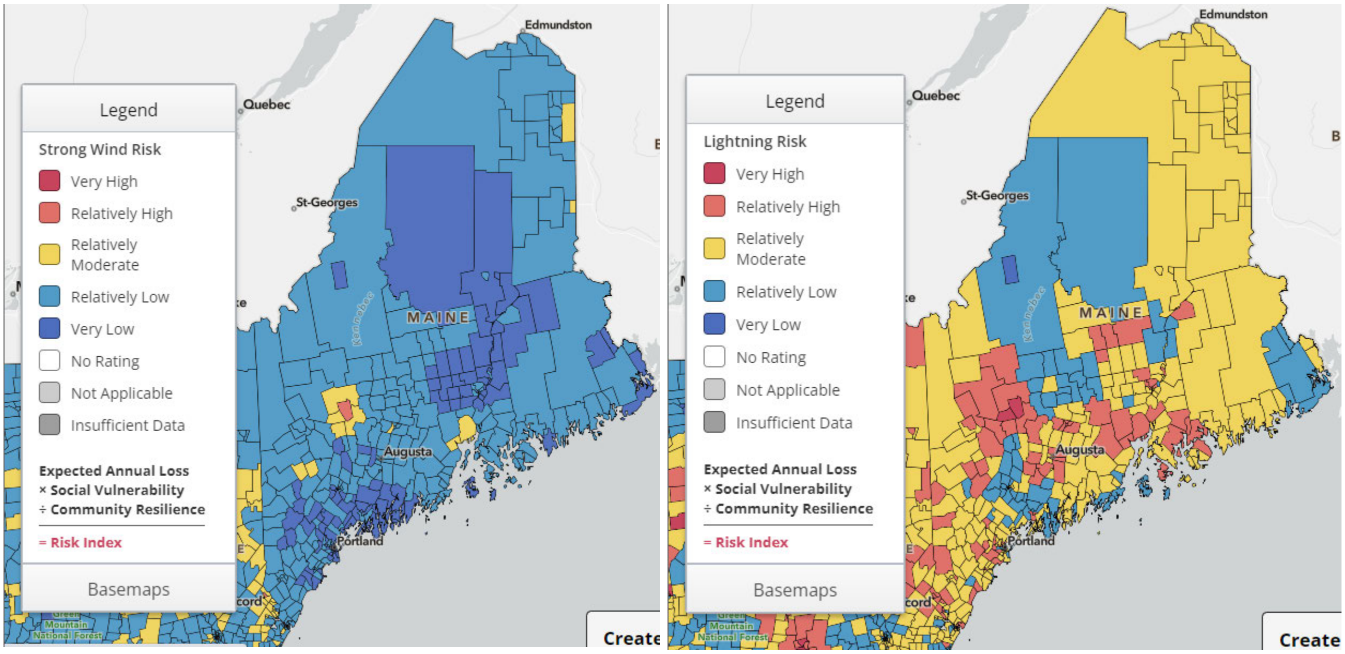

Figure 3.17: National Risk Index maps of strong wind (left) and lightning (right) risk. https://hazards.fema.gov/nri/map#

Disadvantaged Communities

The objective of the disadvantaged communities' assessment is to identify potential disadvantages felt by communities who are disproportionately impacted by natural hazards both historically and under future projections. Severe summer weather contains a large number of hazards that may occur individually or together in a larger storm. Based on analysis of FEMA's National Risk Index, severe summer weather events are not expected to occur any more frequently in disadvantaged communities than elsewhere, though the vulnerability of these communities is expected to be much greater due to a relative deficit of infrastructure, services, social networks, and the financial means of mitigating against natural disasters.

Heat waves and high heat index days are anticipated to increase within the next decade, with amplified impacts expected for disadvantaged communities experiencing socioeconomic, health, and environmental deficits. Strategies for equitable heat adaptation will be crucial to offset the growing risk of heat-related illness and death in hardest hit communities. Extreme heat mortality disproportionately affects Native American and Black communities, as well as those living in the urban core or very rural neighborhoods, according to the Centers for Disease Control and Prevention (CDC) [109]. For Maine, these urban centers include Portland, Lewiston/Auburn, and Bangor, All of which also host high SVI values and therefore are inherently vulnerable.

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[109] https://www.noaa.gov/news-release/biden-administration-launches-heatgov-with-tools-for-communities-facing-extreme-heat

3.19.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Damage Assessments from Disaster Declarations

The windstorm of October 2017 caused substantial damage across 13 of 16 counties (185 municipalities), much of which came in the form of downed trees on roads and power lines. Though it is a fall storm, debris damages from summer events would be similar. MEMA's Public Assistance Program reports that debris removal costs for the entire impacted region amounted to $8.3 million (2022 USD). Given that the total amount of state and municipal roads in the impacted areas is approximately 23,000 miles (39% state/state aid, 61% townway), the cost of debris cleanup per mile for an equivalent event is $361 per mile. Please note that the total number of impacted roadways is unknown, therefore this cost per mile is spread over the entirety of the impacted counties and is considered a substantial underestimate.

Hazard-Asset Footprint Overlay Analysis

Much like state assets, it is not expected buildings will suffer 100% in losses from severe summer weather. Wind damage estimates reported here therefore account for only 2% of the valuation for assets.

The total estimated value of all identified buildings in Maine is $329 billion. The proportion of more vulnerable wood framed structures is unknown but assumed to make up the majority of construction in Maine. Assuming widespread strong winds (damaging 70 mph gust [110]) damaging 2% of all identified buildings in the state, the total amount may equal $6.6 billion. The impacts of hailstorms and tornadoes are expected to be highly localized, assumed here to only damage 0.2% of all assets with a total amount equal to $658.8 million.

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[110] NOAA wind threat definitions: www.weather.gov/mlb/wind_threat

Tropical Cyclone – Hazard Profile

TIER 1 HAZARD

3.20 Tropical Cyclone – General Definition and Types of Events [S3.a., S3.b.]

Tropical cyclones are warm-core non-frontal synoptic-scale cyclones, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export at the low temperatures of the upper troposphere. In this way they differ from extratropical cyclones, which derive their energy from horizontal temperature contrasts in the atmosphere (baroclinic effects). Tropical cyclones rotate counterclockwise in the northern hemisphere. Hurricanes and tropical storms are classifications of tropical cyclones [111].

Tropical cyclones are a cause of several natural hazards. The primary hazards associated with tropical cyclones, as identified by the National Hurricane Center, are listed below and further defined in the Flooding and Severe Summer Weather Events Hazard Profiles above.

3.20.1 Inland Flood

Inland flooding is the inundation of normally dry land due to heavy precipitation during tropical cyclones. It is common for fast moving tropical systems to provide between 6 to 12 inches of precipitation in a very short amount of time, while slower moving systems (including tropical storms that have been downgraded to “lows”) may result in even more precipitation. Such large amounts of precipitation overwhelms streams, rivers, and stormwater infrastructure, commonly resulting in inland flooding of low-lying areas.

3.20.2 Coastal Flood: Storm Surge and Waves

One of the largest risks with tropical cyclones is storm surge. Storm surge is the abnormal rise in seawater level during a storm, measured as the height of the water above the normal predicted astronomical tide. Storm surge is generally caused by a storm’s winds pushing water onshore. The amount of storm surge at any given location depends on the shape of the coastline (straight, open coast vs. peninsulas), the orientation of the coastline in relation to a storm track; the intensity, size, and speed of the storm; and the local bathymetry [112]. Land areas within enclosed bays or at the heads of rivers can be especially susceptible to storm surges though they may be several miles from the open coastline. Along the open coast, an additional factor is coastal waves that form during tropical systems. As storm winds blow across the surface of the ocean, the continual disturbance creates waves. When storm winds blow for extended periods of time and over large distances, wave heights increase. Tropical systems that stay well out to sea can produce large swells with long periods (time between wave crests), but these typically don’t cause much damage. However, as systems approach the coastline, these waves can batter the coastline, resulting in erosion, overtopping, flooding, and damage to infrastructure.

3.20.3 Strong Straight-Line Winds

Strong straight-line winds are common in tropical cyclones. The degree of damage from the winds depends on the strength of the storm and its angle of approach. These winds, named for their damage path, are distinct from tornadoes because their destruction lies in a straight line, pushing debris in the same direction that the storm is moving [113]. The classification of a tropical cyclone is based on wind speed.

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[111] NHC Tropical cyclone definition: https://www.nhc.noaa.gov/aboutgloss.shtml

[112] NOAA Bathymetry: https://oceanservice.noaa.gov/facts/bathymetry.html

[113] Straight-line winds: https://www.aspwindows.com/damaging-types-of-wind-prep/

3.20.4 Tornado

Hurricanes and tropical storms can produce tornadoes. These tornadoes most often occur in thunderstorms embedded in rain bands well away from the center of the hurricane; however, they can also occur near the eyewall. Most tornadoes associated with tropical systems occur in the right front quadrant of the storm. This area typically has the best wind shear and instability. Tornadoes will scatter damage debris in various directions. Usually, tornadoes produced by tropical cyclones are relatively weak and short-lived, but they still pose a significant threat [114].

3.21 Tropical Cyclone – Location of Hazard [S3.a.1.]

Tropical cyclones that can threaten Maine originate in the Atlantic basin which includes the Atlantic Ocean, Caribbean Sea, and the Gulf of Mexico. Hurricanes typically weaken before reaching Maine, but it is possible for strong systems to reach the state. NOAA's Historical Hurricane Tracks tool indicates that 65 tropical systems cyclones have passed through Maine's borders since 1851. According to this same tool, only five of these systems have been hurricanes and actually made direct landfall along the Maine coastline. However, it is important to note that systems do not need to make "landfall" in Maine to have significant impacts due to coastal and inland flooding. Hurricane forecasts will have uncertainty due to variables of the hazard which include storm track and approach, storm speed, wind speed, storm size, and precipitation [115].

All of Maine is susceptible to high winds and inland flooding associated with hurricanes. Between York and Washington Counties, there are 152 local jurisdictions within ten counties that are vulnerable to inundation from storm surge. Refer to Figure 3.18 below for more information.

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[114] NWS tropical tornadoes: https://www.weather.gov/cae/tropicaltornadoes.html

[115] MGS Potential Hurricane Inundation Mapping – Frequently Asked Questions: https://www.maine.gov/dacf/mgs/hazards/slosh/faq.htm

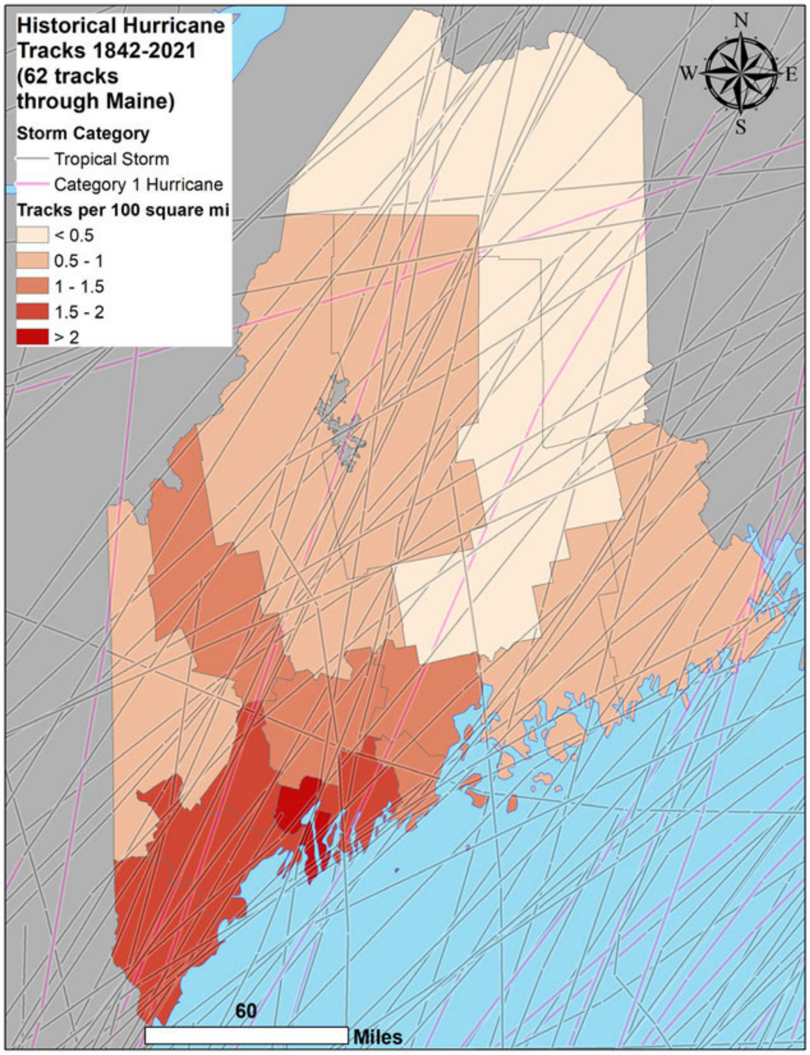

Figure 3.18: Historic storm tracks and occurrence by county [116].

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[116] NOAA Historical Hurricane Tracks viewer: https://coast.noaa.gov/hurricanes/

3.22 Tropical Cyclone – Intensity and Previous Occurrences [S3.a., S3.b.]

The Saffir-Simpson scale is used to determine the intensity/magnitude of tropical cyclones (Table 3.20). The scale rating is based on sustained wind speeds, but as indicated above, there are many additional hazards that coincide with strong winds that may not be fully represented by these storm categories. For example, a large Category 1 hurricane may produce a greater amount of rainfall and cause flooding and other damages over a more expansive area compared to a relatively more compact but higher wind speed Category 2 hurricane. Hurricanes with sustained winds greater than 110 mph (Category 3, 4, and 5) are considered major hurricanes.

TABLE 3.20: Saffir-Simpson Hurricane Scale with excerpt of Beaufort Wind Scale for tropical depression category

Category	Sustained Wind speed	Effects
Tropical Depression	0 to 38 mph	Tropical disturbances originate in tropical waters
	Beaufort Scale 5 19-24 mph	Moderate waves (6-10 ft), small trees begin to sway
	Beaufort Scale 6 25-31 mph	Large waves (9-13 ft), large branches in motion
	Beaufort Scale 7 32-38 mph	High wind, moderate gale, Large 13-19 ft waves, sea "heaps up," large trees in motion
Tropical Storm	Winds: 39-73 mph	Sustained winds capable of causing structural damage
Strong Tropical Storm: winds ≥ 58 mph, threshold for damaging winds		
Category 1	Winds: 74–95 mph	Very dangerous winds will produce some damage
Category 2	Winds: 96–110 mph	Extremely dangerous winds will cause extensive damage
Category 3	Winds: 111–129 mph	Devastating damage will occur
Category 4	Winds: 130–156 mph	Catastrophic damage will occur
Category 5	Winds: 157+ mph	Catastrophic damage will occur

3.22.1 Previous Occurrences

Table 3.21 summarizes the occurrences and estimated damages of tropical cyclones dating back to 1938. Damages from these events were caused by a combination of coastal storm surge, inland flooding, damaging winds, and other hazards defined above. Many of these storms did not make landfall in Maine but did pass through or near the state.

Table 3.21: History of Hurricanes

Month of Occurrence	Category	Year	County (ies)	Estimated Damage (2022 $USD)	Declaration
Sep 21	Tropical Storm	1938	Androscoggin, Cumberland, York	$2,836,685	
Sep 14	Tropical Storm	1944	Cumberland		
Aug 31 "Carol"	Category 1	1954	Cumberland, Knox, Lincoln, Sagadahoc, Waldo, York	$55,069,888 3 Deaths Power outages Downed trees	SBA
Sep 11	Category 1	1954	STATEWIDE	$77,097,844	DR-24-ME

Table 3.21: History of Hurricanes

Month of Occurrence	Category	Year	County (ies)	Estimated Damage (2022 $USD)	Declaration
“Edna”			(flooding)	8 Deaths Power outages	
Sep 12 “Donna”	Tropical Storm	1960	Cumberland	$2,502,331 Power outages	
Oct 6 “Daisy”	Category 1	1962	Cumberland (flooding)	2 Deaths Power outages	
Oct 29 “Ginny”	Category 2	1963	STATEWIDE		
Aug 9-19 “Belle”	Post-Tropical Storm	1976	Aroostook (flooding)	$20,646,411 Agricultural loss (potato crop)	SBA
Sep 6 “David”	Tropical Storm	1979	Coastal	Minor Damage	
Sep “Diana”	Tropical Storm (did not make landfall)	1984	Coastal Counties Threatened		
Sep 17 “Gloria”	Tropical Storm	1985	Androscoggin, Cumberland, Franklin, Kennebec, Somerset, York	3 Injuries Downed trees Power failures (up to 14 days, 250,000 people affected)	
Sep 10 “Bob”	Tropical Storm	1991	Androscoggin, Cumberland, Franklin, Kennebec, Sagadahoc, York	$11,980,449 3 Deaths >150,000 Power outages	DR-915-ME
Sep 16-19 “Floyd”	Tropical Storm	1999	Androscoggin, Cumberland, Kennebec, Oxford, Somerset	$2,135,525	DR-1308-ME
Aug 27-29 Tropical Storm “Irene”	Tropical Storm	2011	Franklin, Lincoln, Oxford, York	$3,478,354 Extensive flooding Power Outages Debris cleanup from high winds	DR-4032-ME
October “Sandy”	Tropical Storm (did not make landfall)	2012	N/A	Though NY and NJ had billions in damages, the storm did not cause any significant damages in Maine	N/A
July “Arthur”	Tropical Storm (did not make landfall)	2014	Washington, Hancock		N/A
September “Dorian”	Tropical Depression (did not make landfall)	2019	Washington, Hancock	Debris cleanup	N/A
September “Isaias”	Tropical Storm	2020	Sagadahoc, Cumberland, York, Waldo, Knox, Lincoln, Franklin, Oxford, Androscoggin	Limited to moderate impacts, 125,000 power outages, debris cleanup	N/A

Table 3.21: History of Hurricanes

Month of Occurrence	Category	Year	County (ies)	Estimated Damage (2022 $USD)	Declaration
Note: There have been no Presidential Declarations for Tropical Cyclones in Maine since 2011. SBA: Activation of Small Business Association Low Interest Loan Recovery Programs DR: Presidential Disaster Declaration					

Storm of Record: Hurricanes Edna & Carol in 1954

The worst hurricane damage in Maine occurred in 1954 when Hurricanes Edna and Carol swept into the state within a two-week period. Hurricane Edna made landfall near Mount Desert Island, while Carol made landfall in Connecticut and moved north toward western Maine. Maine suffered a total of 11 deaths and damages of $17 million (more than $130M in 2022 USD) as a result of these two storms. Storm force winds took down trees, debris, and powerlines. Precipitation induced inland flooding washed cars into ditches. Edna became the costliest hurricane in the history of Maine, where the hurricane caused flooding that washed out roads and rail lines. There were 21 deaths in New England, eight of whom in Maine due to drownings. Later, high winds severely damaged crops in Atlantic Canada. Though the impacts of Carol were marginally less in Maine compared to Edna, overall, the storm caused 72 fatalities and damage totaled $462 million (more than $5 billion in 2022 USD), making it the costliest hurricane in the history of the United States, at the time.

Storm of note: Hurricane Gloria, September 1985

Hurricane Gloria was a powerful hurricane that caused significant damage along the east coast of the United States and in Atlantic Canada during the 1985 Atlantic hurricane season. It was the first significant tropical cyclone to strike the northeastern United States since Hurricane Agnes in 1972 and the first major storm to affect New York City and Long Island directly since Hurricane Donna in 1960. Gloria was a powerful Cape Verde hurricane originating from a tropical wave on September 16 in the eastern Atlantic Ocean. Though it did not make landfall in Maine, Gloria made two subsequent landfalls on Long Island and across the coastline of western Connecticut, before becoming extratropical on September 28 over New England. The remnants moved through Atlantic Canada and went on to impact Western Europe, eventually dissipating on October 4.

In Maine, about 600,000 people lost power due to the storm; this was the most since the passage of hurricanes Carol and Edna in 1954. Wind gusts in Maine reached 86 mph (138 km/h), and the storm knocked down about 100 power poles in addition to the downed lines. Downed trees blocked roads and damaged houses and cars. The winds damaged roofs, including the 127-year-old spire of a church in Groveville. Damage to the apple crop was estimated at $3 million. High waves along the coast damaged lobster traps and dozens of boats, many of which were driven ashore [117].

Storm of note: Hurricane Bob, August 1991

Hurricane Bob was the second named storm and first hurricane of the 1991 Atlantic Hurricane Season. Bob developed from an area of low pressure near The Bahamas on August 16. The depression steadily intensified and became Tropical Storm Bob late on August 16. Bob curved north-northwestward as a tropical storm, but recurved to the north-northeast after becoming a hurricane on August 17 (Figure 1). The storm would brush the Outer Banks on August 18 and August 19, and subsequently intensified into a major Category 3 hurricane. After peaking in intensity with Maximum Sustained Winds of 115 mph, Bob weakened slightly as it approached the coast of New England [118].

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[117] NOAA Storm Data September 1985: https://www.ncei.noaa.gov/pub/orders/IPS/IPS-42DDDF86-7D23-451F-B310-5B7A19B28650.pdf

[118] NWS Hurricane Bob: https://www.weather.gov/mhx/HurricaneBob1991EventReview

After passing over the Gulf of Maine, Bob made landfall near Rockland on the evening of August 19 as a tropical storm. A wind gust of 92 miles per hour was observed in Wiscasset. Portland received over eight inches of rainfall in just a 36-hour period. Mainers who lived within a quarter mile of the coast were urged to evacuate. Sadly, three Mainers were killed by the impacts of Bob. Over 150,000 people were left without power. The storm caused millions in damages, most of which occurred in the Portland area [119].

3.23 Tropical Cyclone – Probability of Future Occurrence [S4.]

Hurricane season in the Atlantic runs from June 1 to November 30, and hurricane threats increase late in the summer as ocean temperatures have warmed, with a peak of September 10th (Figure 3.19). Hurricane return periods in Maine range from 29 years in eastern Maine to 50 years in the midcoast/Penobscot Bay area (Figure 3.20). In other words, during the past 100 years, a Category 1 hurricane has passed within 58 miles of these locations approximately 2-3 times. Probabilistically, there is a 2-3.5% chance per year of a hurricane reaching Maine. For a major hurricane of Category 3 or greater, the occurrence period ranges from 180 years in southern and eastern Maine to 290 years in midcoast Maine, with annual probability of occurrence ranging from 0.3-0.6%.

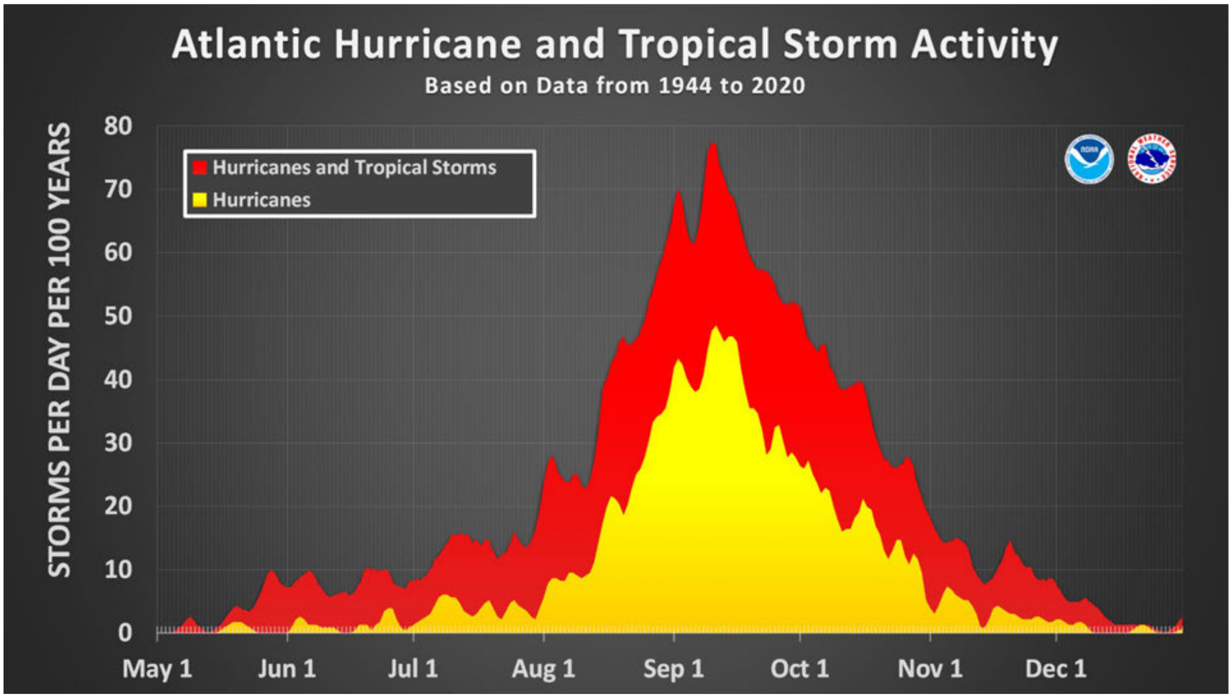

Figure 3.19: Atlantic Hurricane season tropical cyclone occurrence by classification.

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[119] WGME: 30 Years later: remembering Hurricane Bob and its impact on Maine: https://wgme.com/news/local/30-years-later-remembering-hurricane-bob-and-its-impact-on-maine

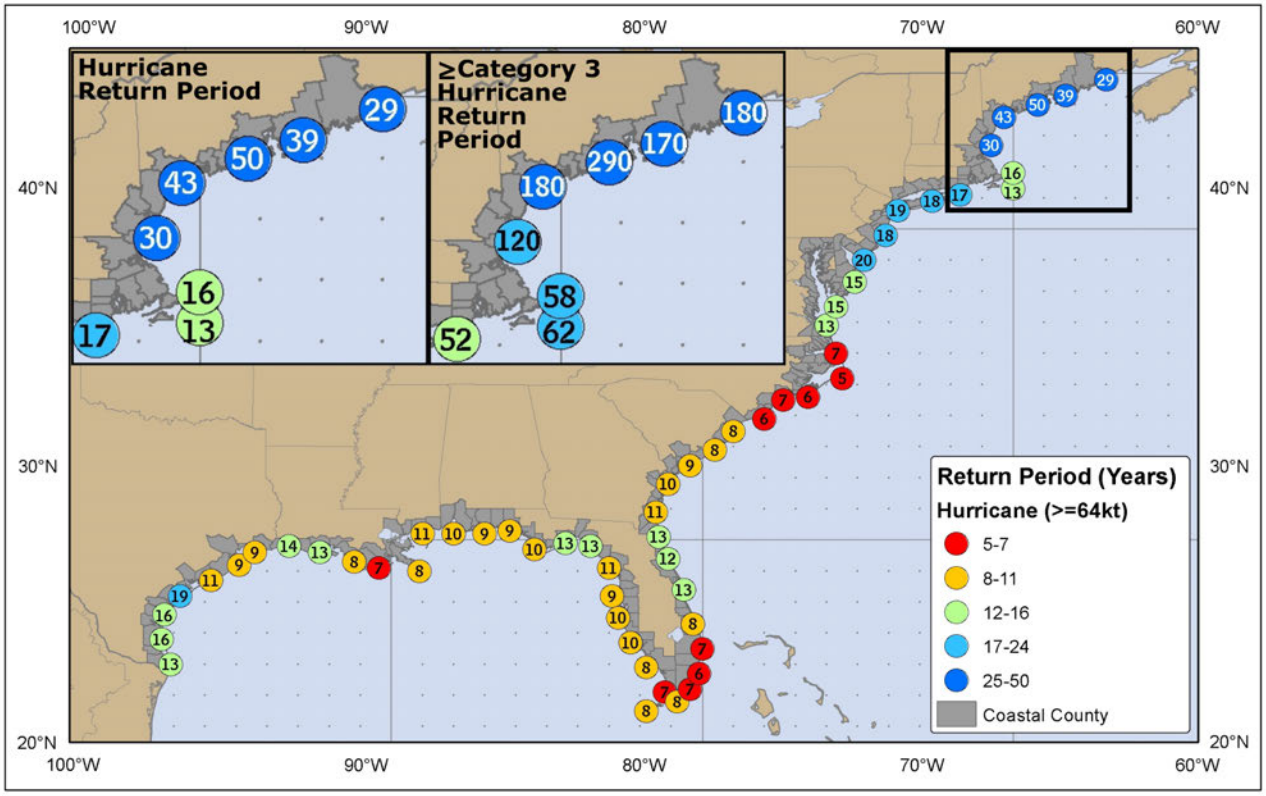

Figure 3.20: Estimated return period in years for hurricanes passing within 50 nautical miles of various locations on the U.S. Coast [120]. Black rectangle denotes map insets for Maine coast on upper left.

3.23.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Recent NOAA projections of hurricane activity originating in the Atlantic Basin support the notion of an increased intensity of approximately four percent, and higher rainfall rates of between 10 and 15 percent. The following section uses language from NOAA's Geophysical Fluid Dynamics Laboratory overview of current research results relating global warming to hurricane activity [121]. Historically, hurricanes tend to weaken before hitting the Maine coastline, but rising sea levels combined with a projected increase in intensity could result in an increase of the number of hurricanes actually reaching the coast. However, even with increasing threats, occurrence of a Category 2 or stronger storm on a year-to-year basis is still a low percentage event in Maine. Different factors of climate change are expected to influence tropical cyclone activity now and in the future:

- Sea level rise should cause higher coastal inundation levels for tropical cyclones that do occur
- Tropical cyclone rainfall rates are projected to increase in the future (*medium to high confidence*) due to anthropogenic warming and accompanying increase in atmospheric moisture content. Modeling studies on average project an increase on the order of 10-15% for rainfall rates averaged within about 100 km of the storm for a 2-degree Celsius global warming scenario.
- Tropical cyclone intensities globally are projected to increase (*medium to high confidence*) on average (by 1 to 10% according to model projections for a 2-degree Celsius global warming). This change would imply an even larger percentage increase in the destructive potential per storm, assuming no reduction in storm size. Storm size responses to anthropogenic warming are uncertain.

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[120] NOAA hurricane return periods: http://www.nhc.noaa.gov/climo/#returns

[121] Global Warming and Hurricanes: An Overview of Current Research Results: https://www.gfdl.noaa.gov/global-warming-and-hurricanes/

- The global *proportion* of tropical cyclones that reach very intense (Category 4 and 5) levels is projected to increase (*medium to high confidence*) due to anthropogenic warming over the 21st century. There is less confidence in future projections of the global *number* of Category 4 and 5 storms, since most modeling studies project a decrease (or little change) in the global frequency of all tropical cyclones combined.
- One study finds an increase in the fraction of tropical cyclone intensity estimates of at least Category 3 intensity both globally and in the Atlantic basin, over the past four decades.
- A study of rapid intensification of Atlantic hurricanes finds an observed increase in the probability of rapid intensification (1982-2009) which is highly unusual compared to one climate model's simulation of internal multidecadal climate variability. Rapid intensification suggests that tropical cyclones may strengthen to hurricane winds more quickly after formation.

There is no strong evidence of century-scale increasing trends in U.S. landfalling hurricanes or major hurricanes, Similarly for Atlantic **basin-wide** hurricanes (after adjusting for observing capabilities), there is not strong evidence for an increase since the late 1800s in hurricanes, major hurricanes, or the proportion of hurricanes that reach major hurricane intensity.

3.24 Tropical Cyclone – Impacts

All of Maine is vulnerable to tropical cyclone induced hazards, depending on the location of the storm track. Many structures in Maine are traditionally not designed to handle sustained storm force winds. The impact of a tropical cyclone will also vary significantly depending on whether it strikes a rural or urban population. Potential impacts of each hurricane associated hazard are as follows:

3.24.1 Inland Flooding

Inland flooding can also cause loss of life, rainfall accounted for 27 percent of tropical cyclone related deaths between 1963 and 2012, according to the National Hurricane Center. Inland flooding can also damage to roads, property, and lifeline utilities. Residents located in the base floodplain, delineated to some degree by FEMA Flood Insurance Rate Maps [122], are vulnerable to rainfall induced inland flooding.

3.24.2 Storm Surge

According to the National Hurricane Center, storm surge is potentially the deadliest hazard associated with hurricanes, accounting for 49 percent of tropical cyclone related deaths in the United States between 1963 and 2012. Storm surge can also cause extensive damage to property and lifeline utilities.

In general, coastal communities are vulnerable to storm surge, though the potential extent of storm surge is greater in the lower lying southern counties, which are also the most densely populated. Other locations, such as the City of Bangor on the tidal portions of the Penobscot River, are also historically vulnerable to storm surge. Maine Geological Survey collaborated with the U.S. Army Corps of Engineers to update Hurricane Storm Surge Inundation Maps for every coastal community using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model in 2020 [123]. The SLOSH model outputs storm tide elevations, which are a combination of predicted normal tides (for mean tide and mean high tide) and storm surge associated with Category 1 to 4 landfalling storms. The resulting maps show potential areas of inundation, and depth of inundation, associated with these events. However, the model and maps do not take into account the potential impacts from waves, extreme tides, freshwater flow, precipitation, or potential future scenarios of sea level rise.

3.24.3 Tornadoes

Tornadoes can also threaten life safety and cause damage to property and lifeline utilities. Refer to the Severe Summer Weather Hazard Profile.

3.24.4 Strong Straight-Line Wind

Storm force winds can cause extensive damage to structures and trees, and wind-blown debris can become deadly projectiles during hurricanes and tropical storms.

Mobile homes (trailers) and substandard structures are highly vulnerable to storm force winds, as are glass structures that can be shattered from flying debris. Powerlines are vulnerable to damage from wind induced flying debris and fallen trees. Roads can become inaccessible from the debris. The same can be said for tornadoes.

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[122] FEMA Flood Map Service Center: https://msc.fema.gov/portal/home

[123] Maine Geological Survey hosted SLOSH maps: http://www.maine.gov/dacf/mgs/hazards/slosh/index.shtml

3.25 Tropical Cyclone – Vulnerability of State Assets [S5.]

Hurricane damages to state owned or operated buildings or infrastructure are no more likely than damages to other buildings or infrastructure. Costs typically come from the overtime use of Maine Department of Transportation and National Guard personnel and equipment to remove state-maintained roads of debris. Although utilities can be damaged during winter storms, the utilities are owned and operated by private utility companies.

The Maine Department of Administration and Financial Services Bureau of General Services provided location data on all state-owned and operated facilities and insured values of buildings and contents. With this information, Maine Emergency Management Agency used GIS to map and identify those state facilities which are located in areas of the state that may be subject to storm surge associated with strong coastal storms, including tropical or extratropical cyclones. These areas were identified using NOAA's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model and more specifically based on the Storm Surge Maximum of the Maximum Envelope of High Water (SLOSH MOM) model results that represent a worst-case snapshot for a particular storm category under "perfect" storm conditions [124]. These inundation areas were also used by MEMA and county EMAs to designate evacuation zones that would be activated under different storm categories.

3.25.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

MEMA identified 28 to 139 state assets located within storm surge inundation areas from category 1 to 4, respectively. The top 10 assets within a category 2 storm surge area, rated by valuation, are listed in Table 3.22.

Table 3.22: 10 highest valued State assets located in potential Category 2 storm surge inundation areas.

Address	County	Occupancy	Property Type	Year Built	Last Inspected	Total valuation	Agency
78 Exchange St, Bangor, Maine, 04401	Penobscot	OFFICE	Class 4 building	2009	7/1/2017	$65,000,000	MMB, MAINE MUNICIPAL BOND BANK
78 Exchange St, Bangor, Maine, 04401	Penobscot	OFFICE		0		$4,500,000	JUD, ADMIN. OFFICE OF THE COURTS
Ferry Rd, Islesboro, Maine, 04848	Waldo	PIER	Wood framed	2009	7/1/2011	$3,016,000	DOT, MAINTENANCE & OPERATIONS
20 McKay Rd, Lincolnville, Maine, 04849	Waldo	PIER	Wood framed	2009	7/1/2011	$3,016,000	DOT, MAINTENANCE & OPERATIONS
460 Commercial St, Portland, Maine, 04101	Cumberland	OFFICE	Wood framed	2012	2/8/2022	$2,250,000	MPA, MAINE PORT AUTHORITY
Bangor, Maine	Penobscot	RADIO EQUIP/TOWER	Steel/ Masonry	1900	6/4/2015	$416,000	ADF, OFFICE OF INFO TECH, RADIO
460 Commercial St, Portland, Maine, 04101	Cumberland	MISC.	Unknown	2010	2/8/2022	$80,000	MPA, MAINE PORT AUTHORITY
460 Commercial St, Portland, Maine, 04101	Cumberland	MECHANICAL AREA	Unknown	2012	2/8/2022	$77,000	MPA, MAINE PORT AUTHORITY
460 Commercial St, Portland, Maine, 04101	Cumberland	MECHANICAL AREA	Unknown	2012	2/8/2022	$55,068	MPA, MAINE PORT AUTHORITY
468 Commercial St, Portland, Maine, 04101	Cumberland	OFFICE	Steel structure	2014	2/8/2022	$33,592	MPA, MAINE PORT AUTHORITY

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[124] NOAA SLOSH MOMs: https://www.nhc.noaa.gov/surge/momOverview.php

There is no guarantee that these assets will be damaged in a natural hazard event. Under a Category 2 scenario, state assets managed by the Maine Municipal Bond Bank and Office of the Courts may experience severe impacts. Maine's communities may hit financial challenges if they need to access low-cost capital funds for normal projects or for rebuilding after a disaster event. If court offices are damaged or inaccessible, the Judicial Branch may face challenges administering court proceedings. It is unknown whether vital records are held on these premises. This property has previously benefitted from flood mitigation, but these efforts are based on designation of special flood hazard areas prone to flooding for a 100-year riverine flood event. Therefore, the asset is untested for storm surge flooding and may be vulnerable.

Maine Port Authority assets are also within category 2 storm surge inundation zones. Flooding or damage to these assets may impact the ability to fulfill state port and intermodal responsibilities to the detriment of Maine's economy. MaineDOT ferry terminals would also potentially be impacted by a Category 2 storm, threatening ferry services and accessibility for many island communities until recovery is completed.

Though it is not expected the state-owned and operated buildings will suffer 100% losses from a storm surge event in Maine, damages are expected to be greater than from a normal flood due to destructive waves. Storm surge damage estimates reported here therefore account for 75% of the valuation for assets and their contents located in potential storm surge areas. During an event, state employees would attempt to relocate the building contents to prevent content loss, but the rate of flooding may be too rapid for this to be successful.

The total valuation for all state assets is $3.3 Billion (2022 USD), with $110.4 million in assets identified within Category 2 storm surge inundation zones. Assuming 75% of assets are damaged, total losses for the state would equal $82.8 million. These estimates are further disseminated by county in Table 3.23, and general locations are provided in Figure 3.22.

Wind damages are anticipated to be more widespread and would primarily impact wood framed structures. No spatial overlays for wind hazard exist for Maine. Given Maine's densely forested landscape the likeliest cause of building damage from high winds is falling tree debris, causing substantial but highly localized roof and structural damage primarily to wood framed buildings. The occurrence of wind damage is expected to be driven by local wind gusts that would be scattered throughout the impacted area, therefore damage estimates for Category 2 winds (100 mph sustained, 130 mph gust [125]) account for 5% of the total valuation for wood structure assets [126]. Total losses for the state, assuming a statewide disaster, would equal $41 million.

3.25.2 Community lifeline Risks

Tropical cyclones are anticipated to have similar community lifelines impacts to flooding and severe summer weather. Please refer to those sections for more details. Here we provide more information on location specific impacts to transportation, energy, and critical services/facilities in Maine's coastal region. This assessment of community lifeline impacts are based on modeled impacts of a large category 2 hurricane, which is an unprecedented event for Maine.

Transportation

Culverts are typically the first type of infrastructure to be impacted by flooding. Under category 2 storm surge conditions, 308 cross culverts (<1% of cross culverts) would potentially be impacted by high storm surge and 73 large culverts (3.8% of large culverts) would be impacted. Though the number of impacted culverts are small

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[125] Engineering Guidance regarding Wind-Caused Damage Descriptors: https://www.nhc.noaa.gov/pdf/SSHWS-Masters-et-al.pdf

[126] Pita, G., Pinelli, J. P., Gurley, K., & Mitrani-Reiser, J. (2015). State of the art of hurricane vulnerability estimation methods: a review. *Natural Hazards Review*, *16*(2), 04014022.

relative to the total across the state, these are critical stream crossing points for coastal communities who will experience issues with access to many other services.

Food, Water, Shelter

Refer to Flood – Vulnerability Assessment section above for details on storm surge impacts to food, water, and shelter access. There is a tendency to focus on coastal storm surge for tropical cyclones, though inland flooding can also be a significant factor of risk. The spatial extent of tropical cyclone hazards can be very large, requiring greater coordination between municipalities and County EMAs to appropriately coordinate activation of shelter sites well out of the expected range of flooding and wind hazards.

Schools are commonly selected as shelter sites. Of the 784 public schools in Maine, none are located in category 1 or 2 storm surge inundation areas, three are located in category 3 areas, and nine are located in category 4 areas.

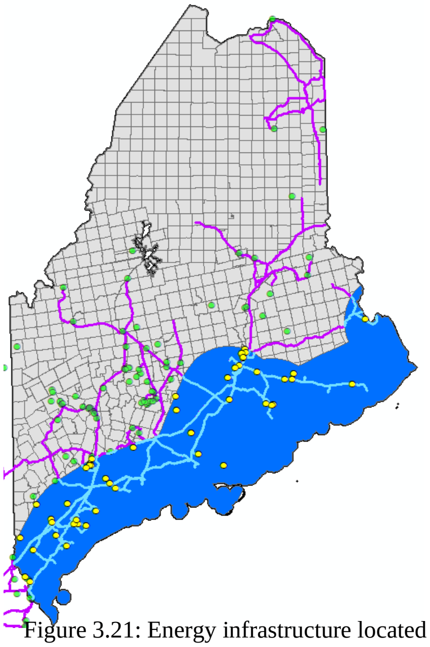

Figure 3.21: Energy infrastructure located within 25 miles of the coast (blue = within 25 miles of coast, cyan = transmission lines, yellow = power plants)

Energy

Unlike severe summer weather, wind damages from tropical cyclones are anticipated to be greatest along coastal Maine. Assuming the greatest wind impacts would occur within 25 miles of the coastline (Figure 3.21), a total of 1,906 miles of transmission lines may be exposed to hurricane strength winds. This exposure constitutes 49.8%, nearly half, of all transmission lines in Maine with a statewide length of 3,829 miles. Fifty power plants are located within the 25-mile coastline buffer. These include 22 hydropower projects, eight biomass plants, four natural gas plants, three petroleum plants, seven solar projects, and six wind turbine projects. Refer to Flooding – Vulnerability Assessment for a determination of transmission line and power plant exposure to storm surge hazards.

Safety and Security

Access issues for emergency response are the greatest issue for safety and security. Direct impacts caused by storm surge are limited. Under an unprecedented category 2 hurricane scenario, nine (1.5% of all stations) coastal fire stations would be directly flooded by storm surge. No law enforcement offices are directly threatened by category 2 storm surge.

Communications

Referring once again to cellular and radio tower GIS data, just under half of all cell towers in Maine are located within 25 miles of the coast. These towers may be more susceptible to hurricane-level wind damage as this part of the state would see the greatest winds during landfall.

Historic and Cultural Resources

Using historic locations data overlain with storm surge inundation layers, 24 historic sites of 1,266 total in Maine (1.9%) would be impacted by category 1 storm surge, 39 (3.1%) by category 2, 64 (5.1%) by category 3, and 97 (7.7%) by category 4. The vast majority of these impacted sites are coastal, but still others are located on tidal rivers in central and Downeast Maine.

Table 3.23: Potential dollar losses to state assets by storm surge, Category 2 winds

Region	**Totals**		**Assets in Category 1 Inundation Zone**		**Assets in Category 2 Inundation Zone**		**Assets in Category 3 Inundation Zone**		**Assets in Category 4 Inundation Zone**		**Assets in Category 2 winds (wood framed structures)**	
	State Assets Count	Total Value (2022 USD)	Count	75% Losses (2022 USD)	Count	75% Losses (2022 USD)	Count	75% Losses (2022 USD)	Count	75% Losses (2022 USD)	Count	5% Losses (2022 USD)
State of Maine	3,769	$3,357,697,809	28	$59,646,429	71	$82,786,374	116	$96,519,563	139	$132,210,032	2,238	$41,001,017
Androscoggin	103	$131,857,212		$0		$0		$0		$0	54	$504,988
Aroostook	421	$287,502,123		$0		$0		$0		$0	227	$3,967,327
Cumberland	604	$628,202,559	8	$1,827,869	32	$18,917,037	46	$20,744,038	52	$26,471,227	365	$6,843,459
Franklin	145	$21,036,865		$0		$0		$0		$0	110	$927,144
Hancock	153	$202,125,602	3	$2,459,340	6	$5,482,789	16	$11,059,804	24	$25,996,144	97	$3,595,225
Kennebec	518	$990,500,148		$0		$0		$0		$0	156	$8,089,614
Knox	108	$163,413,511		$0		$0	9	$5,209,170	9	$5,209,170	62	$1,999,911
Lincoln	80	$44,121,502		$0	3	$135,330	2	$129,480	3	$14,189,640	56	$1,974,240
Oxford	109	$38,868,587		$0		$0		$0		$0	72	$1,455,142
Penobscot	355	$383,400,261	7	$52,802,101	9	$52,825,441	17	$53,285,250	17	$53,285,250	174	$2,453,306
Piscataquis	228	$32,190,309		$0		$0		$0		$0	201	$1,369,336
Sagadahoc	87	$28,347,445		$0	1	$33,384	1	$33,384	1	$33,384	69	$565,473
Somerset	191	$130,572,689		$0		$0		$0		$0	125	$2,172,931
Waldo	179	$46,703,979	3	$2,459,340	6	$4,918,680	6	$4,918,680	6	$4,918,680	148	$1,019,048
Washington	225	$122,944,012	2	$27,540	3	$41,580	5	$227,025	7	$510,525	156	$2,281,986
York	263	$105,911,005	5	$70,240	11	$432,133	14	$912,733	20	$1,596,013	166	$1,781,887

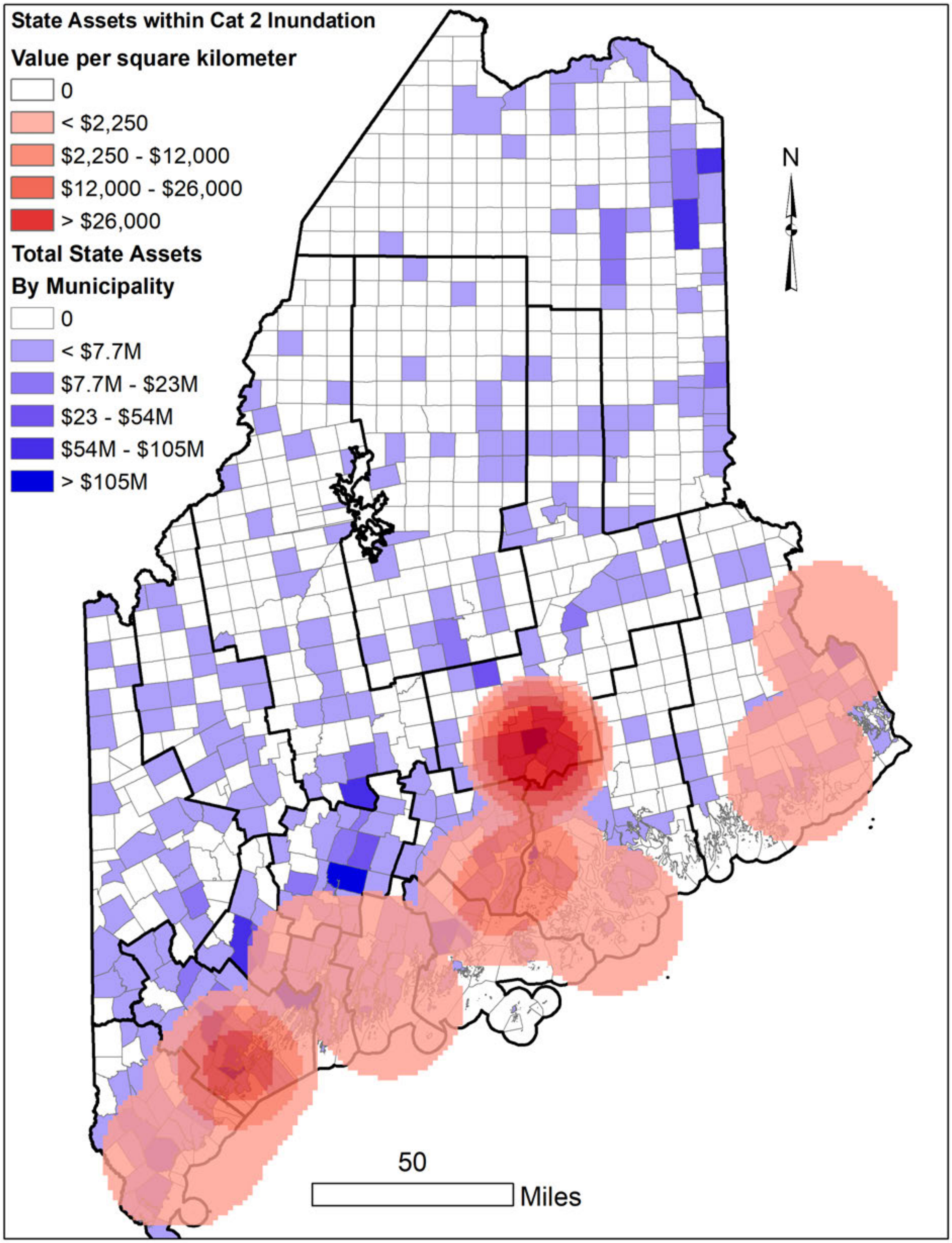

Figure 3.22: State Assets within Category 2 hurricane storm surge inundation areas and potential losses.

3.26 Tropical Cyclone – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.26.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

In 1954 Carol and Edna occurred within a two-week period, a highly unusual pairing caused deaths and extensive damage. Hurricane Donna in 1960 also caused damage in Maine. The experiences of Hurricane Gloria in September 1985 and Hurricane Bob in 1991 temporarily raised awareness of the state's vulnerability. Since these events, coastal populations have significantly increased, and valuations of many coastal communities have increased more than a hundred-fold. Consequentially, it is expected that damage today from equivalent storms would be many times greater. Awareness did become heightened in September of 2011, as Hurricane Irene tracked into New England resulting in record breaking damages and multi-state declarations. When it reached Maine as a tropical storm, Irene resulted in declaration DR-4032 because of the extensive flooding to roads from the heavy rains and the debris cleanup and power outages from the high winds. The four counties of Franklin, Lincoln, Oxford, and York were part of the declaration. In 2012, Hurricane Sandy devastated much of the northeast coast but spared Maine. Had Irene or Sandy affected more of the coastal counties, fishing, commercial and pleasure boating losses would have been significant if boats, gear, piers, and wharfs had been severely damaged.

To date, the State of Maine does not have any specific policies directing public facilities away from potential hurricane storm surge inundation areas. Maine’s Uniform Building and Energy Code (MUBEC) requires cities and towns with a population greater than 4,000 to adopt the International Building Code’s wind resistant standard.

Disadvantaged Communities

The objective of the disadvantaged communities’ assessment is to identify potential disadvantages felt by communities who are disproportionately impacted by natural hazards both historically and under future projections. Tropical cyclones are an infrequent hazard in Maine, but this assessment suggests an increasing occurrence. Two major impacts of tropical cyclones are storm surge and winds. For impacts of inland flooding, refer to the Flooding – Vulnerability Assessment section. Locations susceptible to storm surge are coastal, low-lying areas. These areas are identified within Maine’s Hurricane Evacuation Zones [127]. Wind damage can occur anywhere in the state; however, it is possible to review historical hurricane tracks to identify locations that may experience a greater general recurrence of larger tropical cyclones. Further, the Office of the State Fire Marshal enforces the Maine Uniform Building and Energy Code (MUBEC [128]), requiring communities with population greater than 4,000 to adopt recent International Building Codes and Standards. Unfortunately, rural communities are not held to this standard and may enforce their own, potentially less stringent building codes that may leave structures less resilient to high winds.

Use of SVI census tracts (Figure 3.23) indicate a wide distribution of overall SVI values located in hurricane evacuation zones, with approximately one third of all disadvantaged communities located in evacuation zones. Looking more closely there are two clusters of disadvantaged communities that may be relatively more vulnerable to tropical cyclones. The City of Portland is the most populated city in Maine and contains several vulnerable communities in urban areas susceptible to storm surge. Namely, the Bayside neighborhood is severely disadvantaged and would experience the greatest magnitude of flooding in the city. The impacts would be long term and would be tied to the ability of the region to receive recovery assistance, similar to the flooding impacts indicated above.

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[127] Maine Hurricane Dashboard: https://storymaps.arcgis.com/stories/4fb502bf0ea6467693ff4191a1859e92
[128] MUBEC: https://www.maine.gov/dps/fmo/building-codes

Washington County includes many communities vulnerable to storm surge, but also this area has a greater overall occurrence of hurricanes than other counties in Maine. Overall, SVI values Portland are wide ranging, but looking closely at the inset map indicates two census tracts denoting disadvantaged communities that are primarily located in hurricane evacuation zones. Further, many households in these tracts speak limited English, ranging from 6.7-17% limited English, posing communication challenges for hazardous weather updates and evacuation instructions (Census data accessed using FEMA's RAPT tool [129]). In Washington County, overall, SVI is much greater than the state average, with the majority of the county by area defined as disadvantaged.

These results suggest a disproportionate exposure of disadvantaged communities to storm surge in urban settings and higher occurrence of damaging winds in areas with potentially less stringent building codes in rural settings. Suggested mitigation actions would be to ensure that communities adopt MUBEC or other building codes to encourage reduction in potential damages from flooding and winds. Further, it will be crucial for community members to understand evacuation plans if a hurricane were to impact the City of Portland, or any other populated locations in Maine.

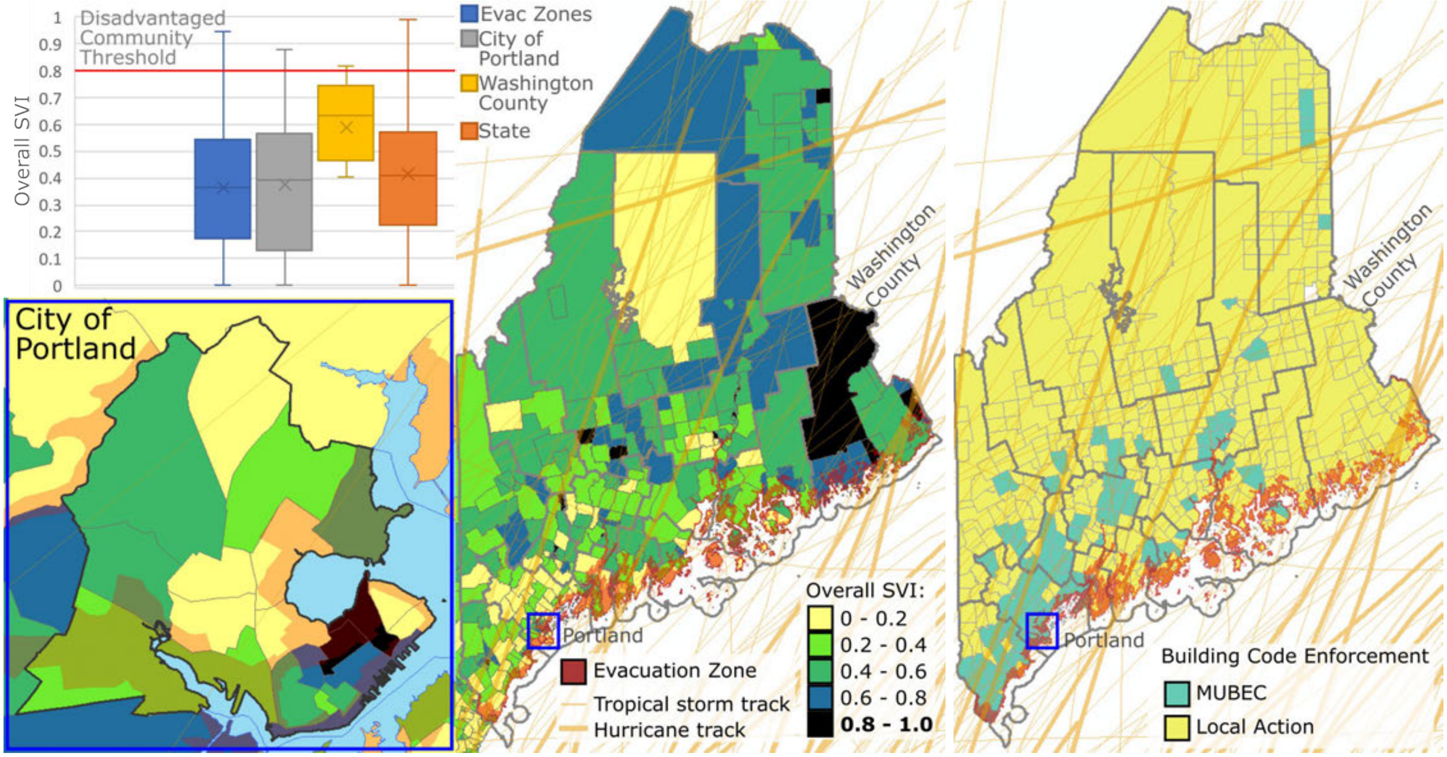

Figure 3.23: Overall SVI values for locations that may be more susceptible to tropical cyclone impacts. These include all hurricane evacuation zones, locations with a historic prevalence of storm tracks, and locations with local, rather than state, building code enforcement. Disadvantaged communities such as in in the City of Portland and Washington County may be more vulnerable to tropical cyclone impacts due to potentially greater exposure to storm surge, damaging winds, and uncertainty around building code standards.

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[129] FEMA RAPT tool: https://fema.maps.arcgis.com/apps/webappviewer/index.html?id=90c0c996a5e242a79345cdbc5f758fc6

3.26.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Hazard-Asset Footprint Overlay Analysis

It is not expected buildings will suffer 100% losses from a hurricane event in Maine. Damage estimates for storm surge flooding and high winds are expected to account only for only 75% and 5%, respectively, of the valuation for assets and their contents located in impacted areas.

The total valuation for all identified structure assets in Maine is $329 Billion (2022 USD). There are $46 billion in assets identified within hurricane evacuation zones, though not all of these assets are directly vulnerable to storm surge flooding. Assuming 75% of assets are damaged within a Category 2 storm surge, total losses equal $8.7 billion. Assuming statewide 5% losses due to Category 2 hurricane winds, total losses would be $16.5 billion. These estimates are further disseminated by county in Table 3.24.

For more information on potential dollar losses due to inland flooding and sea level rise, refer to the section Flooding – Vulnerability Assessment. For more specific information on debris damages caused by high winds, refer to the section Severe Summer Weather – Vulnerability Assessment.

Table 3.24: Potential dollar losses (millions 2022 USD) to all building assets by tropical cyclone hazards

Region	Totals		Assets in Evacuation Zone			Category 1 storm surge		Category 2 storm surge		Category 3 Storm Surge		Category 4 Storm Surge		Category 2 winds* (100 mph sustained)	
	Assets Count	Total Value	Assets Count	Full value	% of total value	Assets Count	75% Losses	Assets Count	75% Losses	Assets Count	75% Losses	Assets Count	75% Losses	Assets Count	5% Losses
State of Maine	758,999	$329,411	104,361	$45,967	14.0%	6,725	$3,712	16,768	$8,678	26,546	$13,434	36,947	$18,499	758,999	$16,471
Androscoggin	40,678	$20,282												40,678	$1,014
Aroostook	47,211	$21,437												47,211	$1,072
Cumberland	120,034	$60,316	20,828	$11,621	19.3%	1,203	$1,056	3,780	$2,597	6,281	$3,928	9,386	$5,751	120,034	$3,016
Franklin	21,643	$8,534												21,643	$427
Hancock	47,129	$17,737	18,081	$7,072	39.9%	794	$438	2,090	$965	3,641	$1,669	5,404	$2,351	47,129	$887
Kennebec	65,768	$29,533	313	$227	0.8%	2	$1	19	$14	39	$20	93	75.617	65,768	$1,477
Knox	28,812	$11,720	8,592	$3,111	26.5%	372	$194	1,075	$478	1,887	$810	2,664	$1,095	28,812	$586
Lincoln	27,821	$10,680	9,694	$3,916	36.7%	380	$212	1,097	$536	1,889	$864	2,949	$1,331	27,821	$534
Oxford	40,062	$16,050												40,062	$803
Penobscot	79,169	$35,301	2,366	$1,626	4.6%	143	$168	715	$535	1,141	$889	1,232	$1,022	79,169	$1,765
Piscataquis	16,376	$5,782												16,376	$289
Sagadahoc	20,394	$8,210	6,748	$2,735	33.3%	219	$156	599	$365	998	$548	1,430	$737	20,394	$411
Somerset	38,723	$15,823												38,723	$791
Waldo	26,926	$10,879	2,074	$1,012	9.3%	105	$92	366	$228	698	$395	1,029	$573	26,926	$544
Washington	24,214	$8,175	6,111	$2,128	26.0%	190	$89	673	$252	1,317	$441	2,064	$711	24,214	$409
York	107,149	$45,785	29,554	$12,518	27.3%	3,263	$1,272	6,212	$2,609	8,423	$3,719	10,366	$4,619	107,149	$2,289

*Wind damage assumed across entire region of study.

Severe Fall/Winter Weather – Hazard Profile

TIER 1 HAZARD

3.27 Severe Fall/Winter Weather - General Definition and Types of Events [S3.a., S3.b.]

Severe fall/winter weather conditions are distinguished by low temperatures, strong winds, ice, and often large quantities of snow that typically occur in the seasons of fall, winter, and occasionally early spring.

3.27.1 Heavy Snow

Heavy snow is generally defined as a snowfall of 6 to 8 inches or more within 24 hours which disrupts or slows transportation systems and public safety departments' response capability [130] (Figure 3.24).

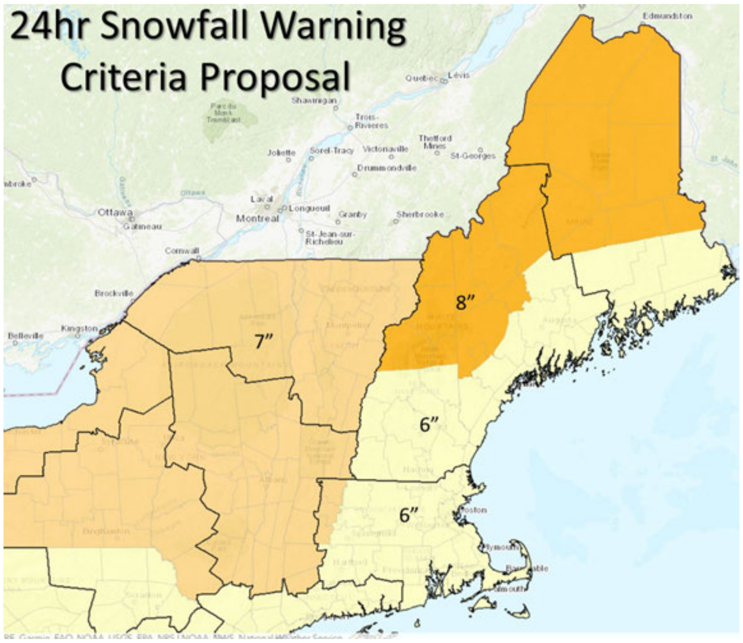

Figure 3.24: Regional heavy snowfall warning criteria

3.27.2 High Winds

High winds are common during the winter months, especially at higher elevations. In addition to potential damaging winds, high winds in winter often coincide with cold temperatures to cause wind chill [131]. High winds and blowing snow can lead to the development of dangerous snow drifts and white out conditions that pose roadway hazards.

3.27.3 Snow Squall

A snow squall is an intense, but limited duration, period of moderate to heavy snowfall, accompanied by strong, gusty surface winds and possibly lightning (generally moderate to heavy snow showers). Snow accumulation may be significant [132].

3.27.4 Sleet Storm

Sleet is defined as pellets of ice composed of frozen or mostly frozen raindrops or refrozen partially melted snowflakes. These pellets of ice usually bounce after hitting the ground or other hard surfaces. Heavy sleet is a relatively rare event defined as an accumulation of ice pellets covering the ground to a depth of one-half inch or more [133]. Sleet can be extremely slick and hazardous to drive on compared to snow, but it doesn't drift or cause low visibility.

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[130] NWS Heavy snow definition: https://forecast.weather.gov/glossary.php?word=heavy%20snow

[131] NWS Wind Chill Definition: https://www.weather.gov/ama/windchill

[132] NWS Snow squall definition: https://forecast.weather.gov/glossary.php?word=SQUALL

[133] NWS Sleet Definition: https://w1.weather.gov/glossary/index.php?word=SLEET

3.27.5 Freezing Rain and Ice Storms

Freezing rain is liquid water precipitation freezing upon impact with the sub-freezing surface. Any amount of freezing rain can be dangerous for travel conditions on untreated roads. An ice storm is used to describe occasions when damaging accumulations of ice are expected during freezing rain situations. Mean radial ice coating at least one-fourth inch in thickness is heavy enough to begin to damage tree branches, overhead wires, and similar objects. A mean radial ice coating of one half an inch is heavy enough to produce destructive widespread power outages [134].

3.27.6 Extreme Cold

Extreme cold is defined as temperatures much colder than local and seasonal average conditions. Health effects of extreme cold temperatures are often exacerbated by wind chill [135]. In Maine, these temperature definitions vary from –35F in the North to –25F across the Southwest.

3.27.7 Freezing Fog

Tiny, supercooled liquid water droplets in fog can freeze instantly on exposed surfaces when surface temperatures are at or below freezing. Some surfaces that these droplets may freeze on include tree branches, stairs and rails, sidewalks, roads, and vehicles. Extreme caution should be taken if travel is necessary. Freezing fog in Maine is a rare occurrence that is normally confined to valleys or along the coastline in the heart of winter.

3.27.8 Blizzard

Blizzards are a combination of heavy snow and high winds. Sustained winds or frequent gusts of 35 miles per hour (mph) or more with heavy falling or blowing snow limiting visibility to ¼ mile or less that persists for three or more hours. The combination of conditions along with subfreezing temperatures brings potentially life-threatening traveling conditions.

3.27.9 Extratropical Cyclones (Nor’easters and Southeasters)

A cyclone of any intensity for which the primary energy source is baroclinic, that is, results from the temperature contrast between warm and cold air masses [136]. Extratropical cyclones may bring high winds, expansive coastal flooding, and any combination of heavy winter precipitation and/or rainfall. These storms can occur any time of the year, but they are most frequent between September and April. In contrast with tropical cyclones, extratropical cyclones produce rapid changes in temperature and dew point along broad lines, called weather fronts, about the center of the cyclone. The warm conveyor belts associated with these cyclones produce approximately half of the wintertime precipitation in middle and high latitudes [137]. In fall, extratropical cyclones bring heavy rain and damaging winds. In winter, extratropical cyclones produce hazardous winter weather ranging from heavy snowstorms to blizzards [138].

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[134] NOAA Freezing Rain Definition: https://www.nssl.noaa.gov/education/svrwx101/winter/types/

[135] CDC Extreme Cold Guide: https://www.cdc.gov/disasters/winter/pdf/extreme-cold-guide.pdf

[136] NHC Extratropical Cyclone Definition: https://www.nhc.noaa.gov/aboutgloss.shtml

[137] Cotton, W. R., Bryan, G., & van den Heever, S. C. (2011). The mesoscale structure of extratropical cyclones and middle and high clouds. In *International Geophysics* (Vol. 99, pp. 527-672). Academic Press. https://doi.org/10.1016/S0074-6142(10)09916-X

[138] Extratropical Storms in Winter: https://atmos.illinois.edu/research/areas/extratropical-cyclones-and-winter-storms

3.28 Severe Fall/Winter Weather – Location of Hazard [S3.a.1]

The entire State is subject to severe storms *every* winter. Western and northern areas historically receive more snowfall (Figure 3.25) while coastal areas are more likely to have freezing rain, sleet, tide surges and flood damage (Table 3.25, Figure 3.26). Although average snowfall amounts are lower on the coast, coastal areas are more prone to blizzard conditions and very heavy snowfall of 2 feet or more during Nor'easter storms.

Average seasonal snowfall amounts generally increase north and northwestward from the coastal region. Total seasonal snowfall ranges between 50 and 80 inches in the Coastal Division, between 60 to 90 inches in the Southern Interior Division, and 90 to 110-plus inches in the Northern Division. The largest average seasonal snowfall totals on record are the 118 inches per winter season from Jackman and the 116 inches per winter season from Caribou. Higher snowfall totals may be found locally, particularly at higher elevations in the northwest mountains.

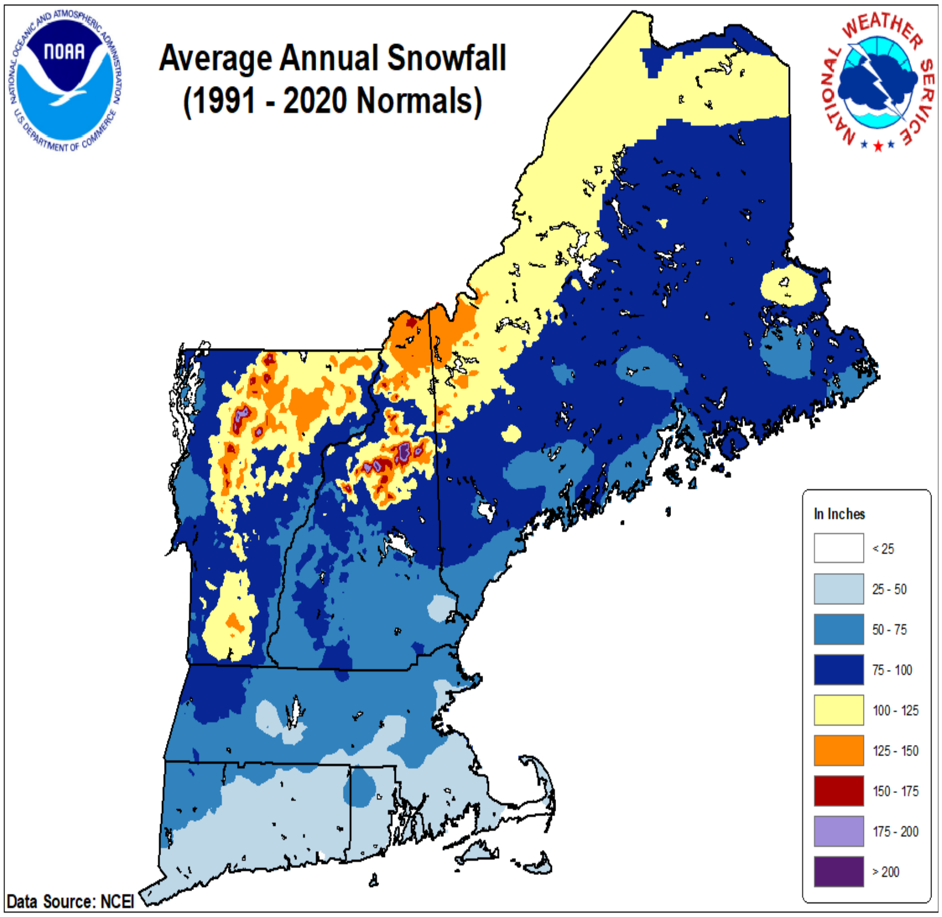

Figure 3.25: regional snowfall normals for New England.

Table 3.25: Severe Fall/Winter Weather Event Occurrence by County, 1996-2021 [139]

County	Blizzard	Extreme Cold	Heavy Snow	Ice Storm	Winter Storm	Sleet	Winter Flood*	Total
Androscoggin	4	22	118	4	53	0	6	207
Aroostook	24	125	220	3	271	6	9	658
Cumberland	10	41	237	6	95	0	33	422
Franklin	0	49	248	3	109	0	13	422
Hancock	28	37	82	7	144	1	15	314
Kennebec	6	24	103	4	55	0	24	216
Knox	6	21	101	4	37	0	7	176
Lincoln	6	20	100	4	40	0	9	179
Oxford	0	47	255	4	112	0	23	441
Penobscot	20	76	170	7	253	6	23	555
Piscataquis	14	113	168	3	227	8	22	555
Sagadahoc	5	20	107	4	39	0	9	184
Somerset	6	99	293	3	166	1	22	590
Waldo	10	46	201	8	80	0	14	359
Washington	41	47	142	9	208	3	13	463
York	10	39	224	6	87	0	25	392
Total	190	826	2,769	79	1,976	25	267	6,133

*Record of floods occurring in December, January, or February

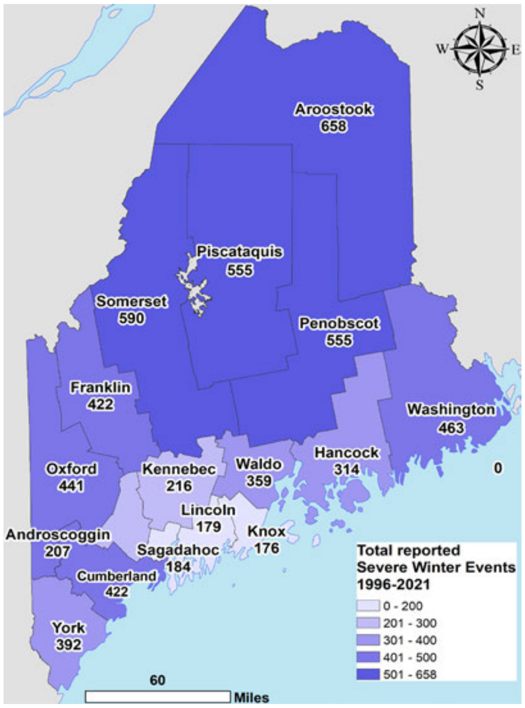

Figure 3.26: Total reported severe fall/winter

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[139] NOAA Storm Events Database: https://www.ncdc.noaa.gov/stormevents/

3.29 Severe Fall/Winter Weather – Intensity and Previous Occurrences [S3.a.2.]

The extent of severe fall/winter weather related hazards is dependent on factors such as temperature, snow fall, ice cover, sustained wind speed, wind gust speed, duration of event, and time between events. The extent of one winter weather event can be exacerbated if it occurs shortly after a previous weather event.

During the winter months Maine often has heavy snowfall, snow combined with high winds, freezing rain, or ice storms. Extratropical cyclones can impact the state in winter, spring, and fall. They rarely develop during the summer. These storms often bring an ensemble of wind, precipitation, and flooding hazards. Precipitation amounts may exceed several inches of water equivalent (20-30 inches of snow or more), while wind speeds can be equal to or greater than those for hurricanes that reach Maine. As an example, the Groundhog Day Nor'easter in 1976 produced 100-knot (115 mph) winds at Southwest Harbor, exceeding the wind speed threshold for a category 3 hurricane. A loss of electrical power and communication services can occur when utility lines yield under the weight of ice and snow. These conditions can impede the response time of ambulance, fire, police, and other emergency services, especially to remote or isolated residents.

The intensity of severe winter storms can be measured based on the magnitude and duration of wind and precipitation, and the combination of different precipitation types. However, there is no widely used standard scale to classify the intensity of snowstorms because the degree of associated damage cannot be determined solely by the amount of snowfall. Wind, temperature, ice accumulation, snow density, and other factors must be incorporated. One approach attempts to isolate the impacts of snowfall: The Northeast Snowfall Impact Scale (NESIS) developed by the National Weather Service [140] characterizes and ranks high-impact Northeast snowstorms. These storms have large areas impacting heavily populated areas with 10-inch snowfall accumulations and greater. NESIS has five categories: Extreme, Crippling, Major, Significant, and Notable (Table 3.26). The index differs from other meteorological indices in that it uses population information in addition to meteorological measurements. Thus, NESIS values incorporate a storm's societal impacts in addition to total snowfall and area. This scale was developed because of the impact Northeast snowstorms can have on the rest of the country in terms of transportation and economic impact.

Table 3.26: NESIS impact categories

Category	NESIS Value*	Description	Number of occurrences in Maine
1	1-2.499	Notable	18
2	2.5-3.99	Significant	19
3	4-5.99	Major	23
4	6-9.99	Crippling	8
5	10.0+	Extreme	1

*NESIS value calculated based on total snowfall area and total population impacted in the snowfall area.

The NOAA NESIS website [141] indicates that, from 1996 to 2021 Maine received greater than 10 inches of snow during 1 out of 2 total Extreme Events, 8 out of 10 total Crippling Events, 18 out of 23 Major Events, and many Significant and Notable Events.

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[140] Kocin and Uccellini, 2004: https://www.ncdc.noaa.gov/monitoring-content/snow-and-ice/rsi/docs/kocin-and-uccellini-2004.pdf
[141] Northeast Snowfall Impact Scale: https://www.ncdc.noaa.gov/snow-and-ice/rsi/nesis

3.29.1 Previous Occurrences

The snowfall season usually runs from late October (in the north) or November (mid to lower portion of the state) through to April and sometimes into May. Occasionally an early season storm can bring snow in the first weeks of October even along the coast. January is usually the snowiest month throughout the state with many stations averaging over 20 inches of snow. December typically averages out to be the second snowiest month.

Table 3.27 is a summary of some of the most severe winter storms during the past 41 years.

Table 3.27: Severe Winter Storm and extreme cold record.

Month of Occurrence	Year	County/region	Damage (2022 USD [142])	Declaration
December	1929	***Statewide***	Ice storm extended from western New York into Maine; widespread power outages from tree and overhead line damage. Part of historical summary to the DR-1198 FEMA Interagency Report [143].	N/A
Feb. 19 Snowstorm	1972	Hancock, Knox, Washington		State Aid
March 7 Ice Storm	1972	Cumberland, Lincoln, Sagadahoc, York	$2,960,484 Severe storms, flooding	***Presidential*** **DR-326-ME**
Jan 10 Rain/Snow/Ice	1978	***Statewide***		
March 15 Ice jams & heavy rains	1978	Franklin, Kennebec, Somerset		State Aid
Mar 13-14 Blizzard	1993	***Statewide***	Maine blizzards, severe winds and snowfall, coastal storm	***Presidential*** **EM-3099-ME**
Jan 5-25 “Great Ice Storm of 98”	**1998**	***Statewide*** As in 1929, this storm extended from western New York into all of Maine.	$87,542,231 Power outages [Loss of heat, refrigeration, sanitation services] Forestry damage	***Presidential*** **DR-1198-ME**
Mar 5-31	2001	Androscoggin, Aroostook, Cumberland, Franklin, Hancock, Lincoln, Oxford, Penobscot, Piscataquis, Sagadahoc, Somerset, Washington, York	$7,539,599 Maine severe winter storm.	***Presidential*** **EM-3164-ME**
Dec 17 2002 - Jan 1, 2003	2003	Androscoggin, Aroostook, Cumberland, Franklin, Hancock, Kennebec, Lincoln, Oxford, Penobscot, Piscataquis, Washington	$3,496,704 Maine Extreme winter weather; severe cold deep and frost; the “frozen pipes” disaster	***Presidential*** **DR-1468-ME**
Feb 2-4	2003	Aroostook	$2.61 million Maine snowstorms Winter storms and extreme cold	***Presidential*** **EM-3174-ME**
Dec 6-7	2003	Aroostook, Cumberland, Franklin, Hancock, Kennebec, Oxford, Penobscot, Piscataquis, Somerset	$2.77 million Maine snow, winter storms, and extreme cold	***Presidential*** **EM-3190-ME**

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[142] CPI Inflation Calculator, U.S. Bureau of Labor Statistics: https://www.bls.gov/data/inflation_calculator.htm

[143] Cold Regions Research Engineering Laboratories (CRREL).

Table 3.27: Severe Winter Storm and extreme cold record.

Month of Occurrence	**Year**	**County/region**	**Damage (2022 USD [142])**	**Declaration**
Dec 14-15	2003	Aroostook, Franklin, Hancock, Penobscot, Piscataquis, Somerset, Washington	Maine snow, winter storms, and extreme cold	***Presidential*** **EM-3194-ME**
Jan 22-23	2005	Cumberland, York	$15.54 million Maine snow, winter storms and extreme cold	***Presidential*** **EM-3205-ME**
Feb 10-11	2005	Androscoggin, Aroostook, Cumberland, Franklin, Hancock, Knox, Oxford, Penobscot, Piscataquis, Somerset, York	$15.54 million Maine snow, winter storms, and extreme cold	***Presidential*** **EM-3206-ME**
March 9	2005	Androscoggin, Aroostook, Cumberland, Franklin, Hancock, Oxford, Penobscot, Piscataquis, Somerset, York	$15.54 million Maine snow, winter storms, and extreme cold	***Presidential*** **EM-3209-ME**
March 11-12	2005	Androscoggin, Cumberland, Oxford	$15.54 million Maine snow, winter storms, and extreme cold	***Presidential*** **EM-3210-ME**
Dec 25-27 "Christmas Storm"	2005	Aroostook	Maine snow, winter storms, and extreme cold	***Presidential*** **EM-3265-ME**
Dec 11	2008	Cumberland, Knox, Lincoln, Sagadahoc, Waldo, York	Maine severe winter storm, winter storms and, and extreme cold	***Presidential*** **EM-3298-ME**
Feb 8-9	2013	Androscoggin, Cumberland, Knox, Sagadahoc, Washington, York	$3,975,117 Severe winter storm (blizzard)	***Presidential*** **DR-4108-ME**
Dec 21-26 "Christmas Ice Storm"	2013	Androscoggin, Kennebec, Knox, Lincoln, Penobscot, Waldo, Washington	Severe ice storm caused extended power outages. Accompanied by the "Polar Vortex" it kept subfreezing conditions in place, also resulting in frozen pipes and water damage to homes; at least two deaths from CO poisoning.	***Disaster Declaration denied***
Nov 1-2 Nor'easter [144]	2014	Kennebec, Lincoln, Knox, Penobscot, Waldo	Nor'easter with 50 mph gusts cause 100k power outages. Heavy, wet snow, accompanied by winds caused severe power outages for several days.	***None requested***
Jan 26-28	2015	Androscoggin, Cumberland, Sagadahoc, York	$3,355,200 Blizzard that closed state and town offices. Highways were treacherous due to winds and drifting snow. Portland received 19.1 inches of snow.	***Presidential*** ***DR-4208-ME***
13 Feb	2017	Statewide	Blizzard closed state and town offices. Public was warned to avoid any unnecessary travel which made snow removal efforts timely.	***N/A***
14 Mar	2017	Statewide	Blizzard conditions along the coast and heavy snow fell throughout the state. School and meeting cancellations. State offices closed at 2PM.	***N/A***

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[144] 2014 storm: https://www.usatoday.com/story/weather/2014/11/03/snow-storm-maine/18405771/

Table 3.27: Severe Winter Storm and extreme cold record.

Month of Occurrence	Year	County/region	Damage (2022 USD [142])	Declaration
30 October	2017	Statewide	$9,507,448 - A bomb cyclone with south/southeast winds with up to 70 mph gusts caused 500k power outages [145, 146] A bomb cyclone with south/southeast winds with up to 70 mph gusts caused 500k power outages [147, 148]	***DR-4354-ME***
1 Jan	2018	Aroostook, Piscataquis, Penobscot, Somerset	Wind chill temperatures ranging from 30 to 40 below zero.	***N/A***
4 Jan	2018	Statewide	Blizzard: high winds statewide, 10 to 15 inches of snow in western Maine, coastal flooding and erosion	***N/A***
6 Jan	2018	Aroostook, Piscataquis, Penobscot, Somerset	Wind chill temperatures ranging from 30 to 40 below zero.	***N/A***
13 Mar	2018	York, Knox, Lincoln, Sagadahoc, Cumberland, Penobscot, Hancock, Washington	Blizzard: 12 to 24 inches of snow across York County and western Maine, some reports of 30 inches in eastern Maine, several hours of blizzard conditions on the coast.	***N/A***
22 Jan	2019	Aroostook, Piscataquis, Penobscot, Somerset	Wind chill temperatures ranging from 35 to 40 below zero.	***N/A***
17 October	2019	Statewide	Bomb cyclone with gusts up to ~60 mph caused 219k power outages [149]	***N/A***
1 Nov	2019	Aroostook, Piscataquis	Wind storm with gusts up to ~53 mph caused 230k power outages [150]	***N/A***
10 Apr	2020	Aroostook, Piscataquis, Penobscot, Hancock, Washington	Damaging winds, heavy snow, coastal flooding	***N/A***
2 Mar	2021	Aroostook, Piscataquis, Penobscot, Somerset	Wind chill temperatures ranging from 35 to 40 below zero.	***N/A***

Storm of Record: The "Great Ice Storm of '98"

The residents of Northern New England will never forget the Ice Storm of 1998. In Maine, more than six hundred thousand customers were without power. Extending from Western New York to Maine, below-freezing temperatures combined with record rainfall contributed to the formation of a blanket of solid ice. In some places, more than three inches of ice coated the rural and urban landscape.

The storm began January 5th and continued through January 25, 1998. Advisories for freezing precipitation from The National Weather Service (NWS) in Gray, Maine, began during Sunday, January 4, 1998. On Monday morning, freezing drizzle and rain began in several areas and continued through Tuesday. On January 6th, the NWS advised Maine Emergency Management Agency (MEMA) to expect a major ice storm. From January 7th through January 9th, heavier freezing rain developed over Central and Southern Maine. To the north of the front, cold air remained entrenched near the ground as warm, moist air moved northward from the Mid-Atlantic states over the wedge of colder air. The combination of peak low-pressure areas, abundant moisture in the atmosphere, and cold temperatures near the ground caused significant rainfall and severe icing to occur in Central and Southern

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[145] 2017 storm: https://www.newscentermaine.com/article/news/local/historic-october-wind-storm-hit-maine-one-year-ago/97-609203380
[146] DR-4354-ME: https://www.fema.gov/disaster/4354#funding-obligations
[147] 2017 storm: https://www.newscentermaine.com/article/news/local/historic-october-wind-storm-hit-maine-one-year-ago/97-609203380
[148] DR-4354-ME: https://www.fema.gov/disaster/4354#funding-obligations
[149] 2019 storm: www.mainepublic.org/environment-and-outdoors/2019-10-17/strong-october-noreaster-knocks-out-power-to-more-than-200k-in-maine
[150] November 2019 storm: https://www.pressherald.com/2019/11/01/heavy-winds-knock-out-power-to-thousands-in-maine/

Maine, with increased amounts of sleet in the central areas. In Northern Maine more than two feet of snow fell during this same period of time creating severe conditions and safety concerns.

Mixed precipitation developed on January 13th as the low-pressure system moved eastward. Gusts were reported up to 50 mph and brought much colder air into the state. Temperatures dropped into the single digits in Central Maine, and below zero temperatures in both the mountains and the northern part of the state. Wind chills were in the minus 20 to minus 40-degree range. The evening of January 15th brought a low-pressure system to the mid-Atlantic coast that deposited four to eight inches of snow in extreme Southwestern Maine, three to six inches across the central part of the state, and five to ten inches in the western mountains. On January 23rd, snow developed from south to north during the day, changing to sleet and then to freezing rain in Southern and Central Maine. The mixture of precipitation continued into the afternoon of January 25th, with significant icing along the southwestern coast of Maine.

On January 13th, President Clinton declared 15 of Maine's 16 counties as a federal disaster area eligible for infrastructure support assistance. The Disaster Declaration was amended to cover Individual Assistance on January 15th, and Aroostook, the final county, was added to the declaration. Hazard Mitigation funds to reduce future disaster risks were made available on January 13th.

At its peak, more than half of Maine's population was without power, caused by ice that coated lines and branches an inch thick. Many state and secondary roads were closed because of downed trees on power lines. State government offices were closed, and innumerable businesses were forced to close and remain closed because of blocked roadways and power outages. As a result, 130 emergency shelters were opened throughout the state. Heat, electricity, refrigeration, running water, and sanitary facilities were all interrupted by the power outage. Maine Public Television and Radio remained unavailable to most viewers for more than a week. Other commercial radio and television stations in South-Central Maine lost communication towers and/or electrical power and were unable to broadcast. Even the Emergency Alert System failed.

Across the Northeast states, 17 deaths were attributed to the storm. The fast response of voluntary organizations, local and state governments prevented many more casualties. Utility crews partnered with the Maine Department of Transportation (DOT) and the Maine Army National Guard (MENG) to restore power to the region. All worked through frigid temperatures and snow to clear debris and keep roads open so utility crews could reconnect downed lines.

Central Maine Power (CMP) estimated their cost to restore power to the more than 600,000 residents at 60 million dollars. Clean-up and repair costs of local and state government agencies increased the estimate to more than 87 million dollars.

Long-term impacts of the widespread devastation continue to be identified. More than 17,000,000 acres of urban and rural forest in the four-state area sustained some degree of damage, creating an immediate safety hazard and potentially threatening the long-term regional economy.

The Salvation Army and The American Red Cross (ARC) estimated their recovery costs at $600,000 on March 4, 1998, and the Maine State Bureau of Insurance (MSBI) issued a report indicating $28,353,000 in claims had been paid. The Maine Forest Service (MFS) reported as much as $28,000,000 in forest damage, along with devastating losses to blueberry farmers, maple syrup producers, and beekeepers. An agribusiness survey taken by the Farm Bureau in each county summarized a total damage estimate of $24,970,890.

3.30 Severe Fall/Winter Weather – Probability of Future Occurrence [S4.]

Records dating as far back as 1972 indicate that every year, between November and April, there is a high probability that severe fall/winter weather will occur. On average, the length of annual maximum snow cover ranges from about 50 days along the coast to over four months in the northern and particularly the northwestern part of the state.

3.30.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Maine winters have warmed about 4°F and the snow season length has decreased 1–2 weeks on average over the past century (Figure 3.27), with most of the latter associated with warmer temperatures in late fall/early winter. These trends are expected to continue over the next several decades. It is uncertain whether ice storms will become more or less common in a warmer climate, but there is a tendency toward more extreme weather events in relation to warmer temperatures driving an intensified hydrologic cycle. Warmer winter temperatures may lead to a greater occurrence of ice and heavy snow hazards. However, variability can and will continue to deliver impactful snowstorms and cold-air outbreaks. For a recent example, consider the record breaking "snow year" of 2014-2015 that blanked the northeast; this winter also produced the coldest February in Maine since 1934 due to an unusually persistent atmospheric ridge-trough pattern over North America that repeatedly brought Arctic flow into the region.

Local observations indicate that extratropical cyclones, specifically southeasters, are becoming more prevalent in late fall/early winter (October to January) which are causing high winds, lots of precipitation, waves, and as a result, high levels of erosion among south and east facing beaches, marshes, and bluffs. These events are also causing very large power outages from wind damage and downed trees. Simonson et al. (2020) [151] examined the historical incidence of mid-fall extratropical cyclones in New England in a climate context and found since 1979 there is not a statistically significant trend in storm frequency or intensity. However, the study does find a statistically significant trend toward increasing precipitation accompanying storms with maximum winds exceeding 58 mph. This increased rainfall associated with high-wind producing storms could potentially increase damage risk.

Figure 3.27: This map shows changes in the timing of annual high winter-spring flow carried by rivers and streams from 1940 to 2018. This analysis focuses on parts of the country where streamflow is strongly influenced by snowmelt. Trends are based on the winter-spring center of volume, which is the date when half of the total January 1–July 31 streamflow (in the West) or half of the total January 1–May 31 streamflow (in the East) has passed by each streamflow gauge, reflecting the timing of spring snowmelt.

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[151] Simonson, J. M., Birkel, S. D., Maasch, K. A., Mayewski, P. A., Lyon, B., & Carleton, A. M. (2020). Historical incidence of mid-autumn wind storms in New England. *Meteorological Applications*, *27*(5), e1952. https://rmets.onlinelibrary.wiley.com/doi/10.1002/met.1952

Winter snowpack makes an irreplaceable contribution to spring surface and groundwater supplies. Years with a low snowpack can lead to water shortages and drought by late summer. Melting of the snowpack in April and May is often gradual enough to prevent serious flooding, although there have been times when a quick melt has led to disastrous conditions. Historic streamflow records indicate that the timing of annual high spring flows caused by snowmelt is occurring earlier than in previous decades by 5-10 days or more (Figure 3.27) [152]. Trends in lake ice out also indicate earlier transitions into spring weather and associated hydrologic conditions (Figure 3.28) [153], posing a potential hazard also for community members wishing to recreate or fish on late season ice [154].

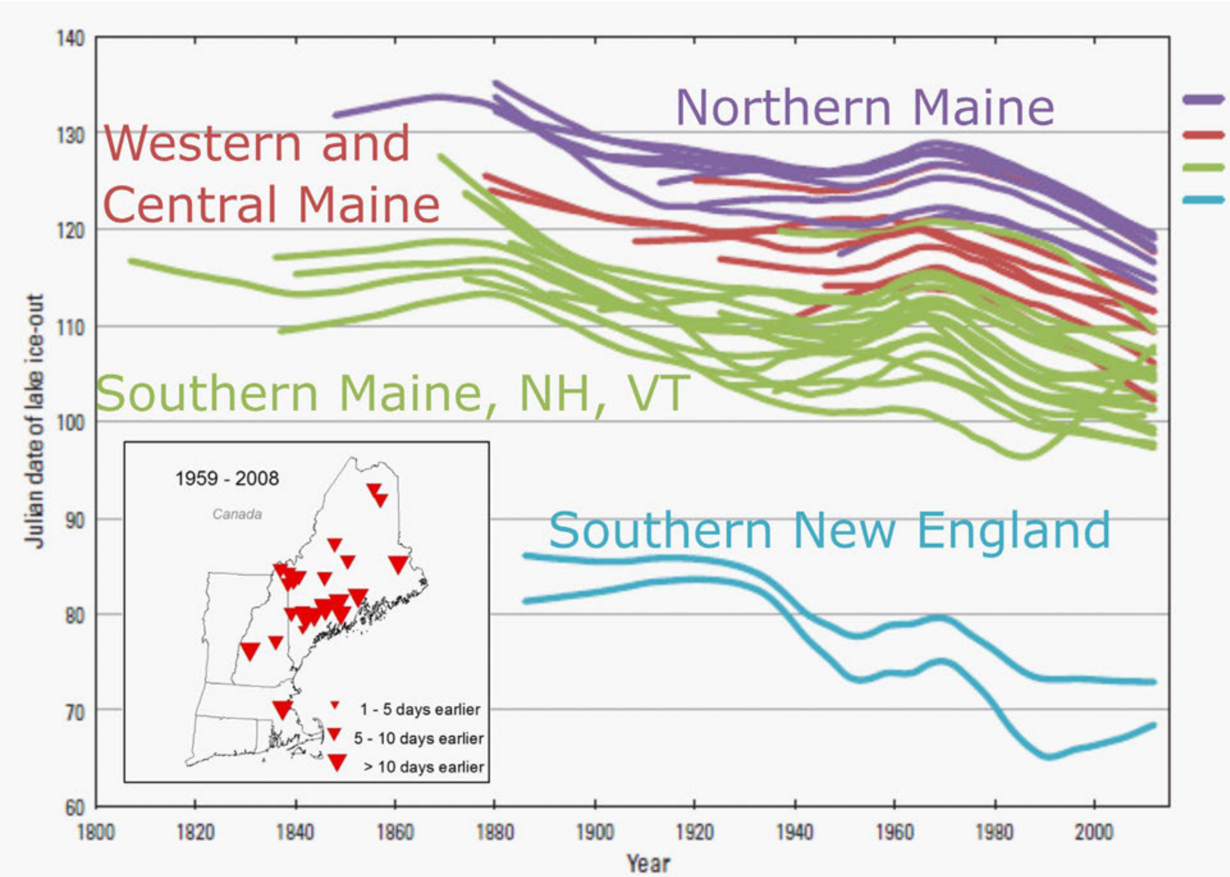

Figure 3.28: Ice-out dates over time for eight selected lakes in New England. Data smoothed by locally weighted regression.

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[152] https://www.epa.gov/climate-indicators/climate-change-indicators-streamflow#ref4

[153] Hodgkins, G. A. (2013). The importance of record length in estimating the magnitude of climatic changes: an example using 175 years of lake ice-out dates in New England. *Climatic change*, *119*(3), 705-718. https://link.springer.com/article/10.1007/s10584-013-0766-8

[154] Learning to ice fish on Maine's changing lakes: spectrumlocalnews.com/me/maine/news/2022/02/28/learning-to-ice-fish-on-maine-s-changing-lakes

Severe Fall/Winter Weather – Vulnerability Assessment

3.31 Severe Fall/Winter Weather – Impacts

A severe fall/winter weather event can down power lines and cause widespread outages, shut down roads, and close businesses. Even in the absence of a major snowfall event, the accumulation of multiple snowfall events can come at high costs to local governments. Roof collapses can occur on residential and commercial properties when snow loads become extreme.

All of Maine is vulnerable to severe fall/winter weather events every year and on a larger scale/extent than severe summer storms. In general, the Southern Interior and Northern Climate Divisions receive more snowfall while the Coastal Climate Division experiences more ice storms. Severe fall/winter weather of all types can still happen anywhere in Maine. In the event of an extended power outage residents without an alternate heating source are vulnerable to cold temperatures, and remote populations could be without power for a upwards to several weeks.

3.32 Severe Fall/Winter Weather – Vulnerability of State Assets [S5.]

Winter storm damages to state-owned or operated buildings or infrastructure are no more likely than damages to other buildings or infrastructure. Costs typically come from the overtime use of Maine Department of Transportation and National Guard personnel and equipment to remove state-maintained roads of ice, snow, and debris. Although utilities can be damaged during winter storms, the utilities are owned and operated by private utility companies.

Primary impacts to state assets are power outages leading to a halt in state services that do not have backup generators, potential cold weather damages, frozen/broken pipes, and resultant flooding, roof/structure damage from heavy snow, and debris damages to Maine's transportation network and structures. Essential state workers are at greater risk of being injured as they serve critical roles that may involve travel and maintenance during severe winter weather.

3.32.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

Damages from an extratropical cyclone on state assets would be similar in scale to damages modeled for tropical cyclones in this Plan. Refer to Tropical Cyclones – Vulnerability Assessment for damage estimates. There is no guarantee that these assets will be damaged in a natural hazard event.

Damage Assessments from Disaster Declarations

As noted in the section Severe Summer Weather – Vulnerability Assessment, the windstorm of October 2017 caused substantial damage across 13 of 16 counties (185 municipalities) primarily in the form of vegetative debris cleanup on state and town roads, with cleanup costs equal to $361 per mile ($8.3 million 2022 USD for the total impacted area). This cost per mile estimate is spread across the entirety of impacted counties rather than the roads that were directly impacted and is therefore considered an underestimate.

3.32.2 Community lifeline Risks

Severe fall/winter weather impacts are anticipated to have a similar influence on community lifelines as tropical cyclones with the added threat of heavy snowfall and freezing temperatures. A primary impact of heavy snowfall is the transportation lifeline and freezing temperatures can impact shelter needs.

Transportation

Snow and ice control are crucial in Maine winters. The cost of snow and ice clearing is around $10,000-12,000 per centerline mile, for the season, for a state highway. This includes all material, labor, and equipment costs. Higher level-of-service corridors will be on the higher side of that range, lower will be on the lower side. State aid corridors should be somewhat less. Municipal road winter maintenance may be more or less than this rate depending on their contracts.

Shelter

Several programs exist to protect vulnerable communities from exposure to cold winter temperatures. Two examples are warming centers and home heat assistance programs. Refer to the disadvantaged communities section below for details on LIHEAP. A Warming Center is a facility that has been opened for short term operations due to a specific emergency or event. They are normally opened when temperatures or a combination of precipitation, wind chill, wind and temperatures have or may become dangerous. Their paramount purpose is the prevention of death and injury related to exposure to the elements. Warming centers can help stranded motorists, or residents that have lost critical services. Some warming centers may provide limited food, showers, charging stations and places to rest [155].

3.33 Severe Fall/Winter Weather – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.33.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

All jurisdictions are vulnerable to different forms of severe fall/winter weather. Figure 3.26 indicates varying degrees of risk and annual expected losses jurisdictions may have for typical fall/winter hazards including ice storms, winter weather, cold waves, and strong winds. For these maps, the calculation of risk is a function of expected annual losses determined from past events, social vulnerability metrics, and community resilience metrics. Under these assumptions, southern/coastal Maine holds the greatest risk for ice storms, while northern Maine holds the greatest risk of cold waves. Parts of central Maine hold the greatest risk for winter weather, while the risk of strong wind is fairly evenly distributed across the state.

Disadvantaged Communities

The objective of the disadvantaged communities' assessment is to identify potential disadvantages felt by community members who are disproportionately impacted by natural hazards both historically and under future projections. Exposure of disadvantaged communities for large storm events, such as nor'easters, would follow similar trends shared in the Tropical Cyclone – Vulnerability Assessment.

Exposure to cold temperatures leads to higher energy burdens on low-income residents who must spend more of their own budgets on electricity and heating fuels than higher income residents. In fact, the average home energy burden for low-income households is 19%, far exceeding most definitions of energy poverty [156]. In 2020, the Maine Low Income Home Energy Assistance Program (LIHEAP) allocated $40.34 million for utility payment and home weatherization programs across the state, with 158,381 households eligible for the program [157]. Further, 82.5% of LIHEAP recipients also have at least one vulnerable member (elderly over 60, disabled, or child under 6).

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[155] MEMA Mass Care: https://www.maine.gov/mema/response-recovery/mass-care

[156] Maine Low-Income Home Energy Burden: https://www.maine.gov/meopa/sites/maine.gov.meopa/files/inline-files/Maine%20Low%20Income%20Energy%20Burden%20Study%20June%202019.pdf

[157] LIHEAP funding: https://neuac.org/wp-content/uploads/2021/02/Maine-State-Sheet-2022.pdf

3.33.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Severe fall/winter weather events have the potential to cause significant damage, cripple critical infrastructure, and impact community lifelines. Table 3.28 indicates total damages by winter weather category as reported by NOAA's Storm Events Database. Only storm categories with reported damages are listed, and not all events led to Presidential Disaster Declarations, as noted above.

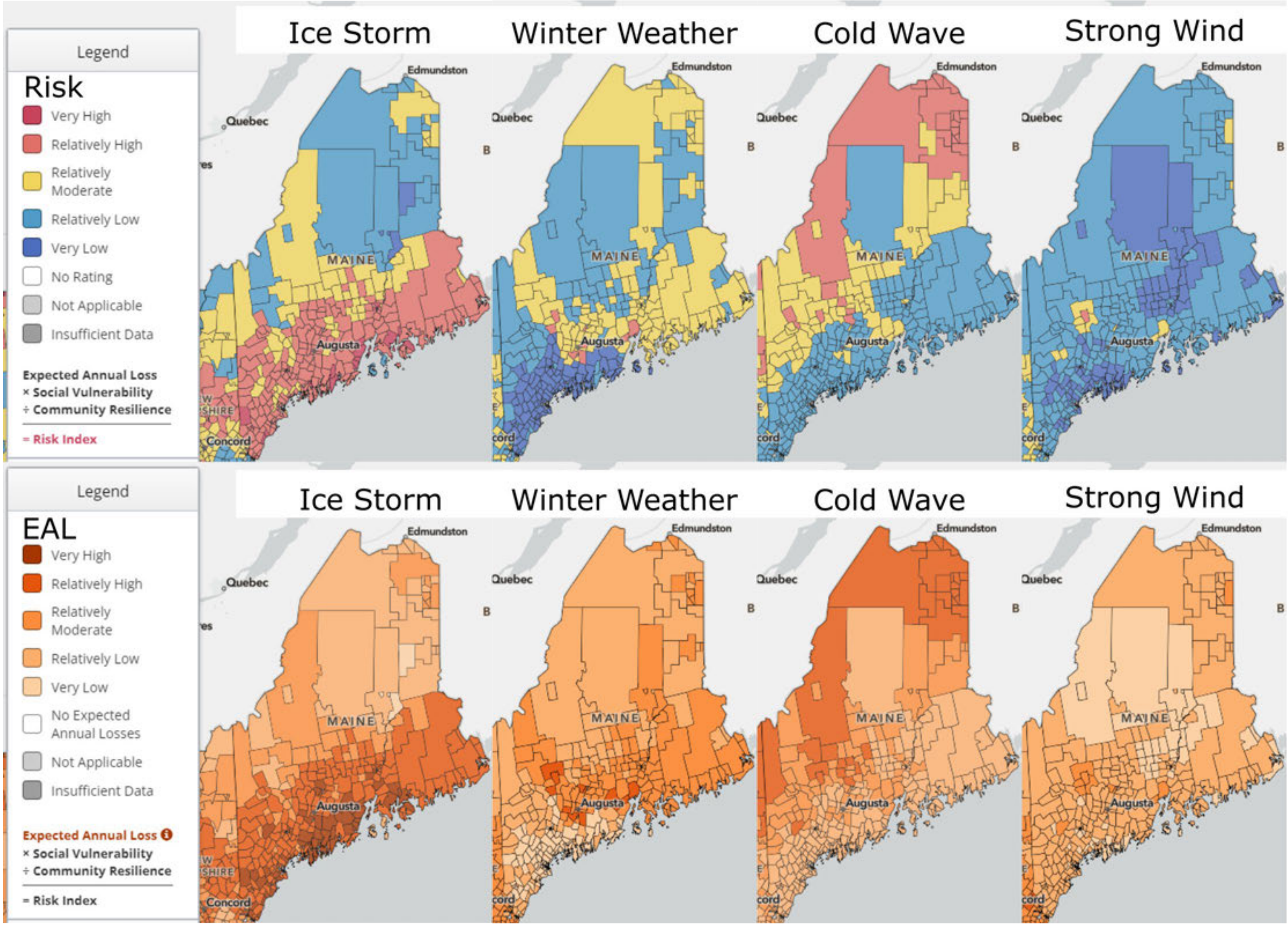

Figure 3.29: National Risk Index map calculations of risk (top row) and expected annual loss (EAL, bottom row) for ice storm, winter weather, cold wave, and strong wind. https://hazards.fema.gov/nri/map#

Table 3.28: winter storm events and collective damages.

Weather Event Category	Event Year(s) Reported	Total Sum of Damages (2022 $USD)	
		Storm Events Database	PA/IA programs
Winter Storm	2013, 2015	$864,928	$9,714,543
Heavy Snow	1996, 1998	$13,669,279	$4,126,123
Ice Storm	1998, 2008, 2013	$590,691,322	$107,492,368

Lack of resources continues to be the greatest issue for severe winter storms. For larger storms, snow removal resources are often maxed out leaving some of the more rural areas more vulnerable to isolation and loss of power.

Wildfire – Hazard Profile

3.34 Wildfire – General Definition and Types of Events [S3.a., S3.b.]

A wildfire or wildland fire is an unplanned fire burning in an area of combustible vegetation that occurs in forests, shrublands, grasslands, or prairies. Areas damaged by wildfires are particularly susceptible to flash floods and debris flows during rainstorms. Rainfall that is normally absorbed by soil and vegetation can run off almost instantly, causing creeks and drainage areas to flood much earlier and with higher magnitude than normal. Heavy rainfall on recently burned areas can also mobilize sediments and cause a much more destructive debris flow.

3.34.1 Wildland Fire

Any non-structure fire, other than prescribed fire, occurring in the wildland or wildland urban interface [1]. Wildfire is a natural phenomenon initially finding its origin in lightning. However, humans have become the greatest cause of fires in Maine. Today, about 95 percent of all forest fires are caused by human activity while lightning causes about ten percent. Though wildland fires originate in wildland areas, they can potentially spread into urban areas and become an even greater threat to lives and property [2].

3.35 Wildfire – Location of Hazard [S3.a.1]

Maine has 17.52 million acres of forest land that provide more than 500 different wood products and lumber. Maine continues to be the most heavily forested state in the nation at 89% [3]. The state's forest land base has remained essentially stable for the last several decades and is close to the estimated acreage of forest land present at the time of European settlement.

Well-distributed rainfall normally reduces wildfire risks, but seasonal variations, rapidly draining soils, and unusually dry periods can induce major blazes. In addition, insect damage (such as the hemlock woolly adelgid and spruce budworm) diseases, severe weather, and residential and commercial developments in wooded areas greatly increase the potential for catastrophic fires. Over time, a considerable fuel supply can accumulate from the ignitable slash of some logging operations and/or from dead trees left standing on the forest floor after insect infestations.

The Department of Agriculture, Conservation, and Forestry; Maine Forest Services; Forest Protection Division, tracks all reported fire occurrences in the state on an annual basis. These are coded by cause such as: campfire, children, debris burning – which can include backyard burning as well as the agricultural practice of "burning over" blueberry fields, incendiary (includes arson) lightning, machinery, miscellaneous, railroad, and smoking. Maine Forest Service uses a national system called InFORM that uses ArcGis, Survey 123 to capture wildfire incidents [4].

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[1] US Forest Service wildfire definition: https://www.fs.fed.us/nwacfire/home/terminology.html

[2] Urban fire definition: https://www.eugene-or.gov/1175/Urban-Fire

[3] Maine Forest Health Highlights 2020: https://www.maine.gov/DACF/mfs/forest_health/documents/2020MaineForestHealthHighlightsForUSFS.pdf

[4] InFORM: https://in-form-nifc.hub.arcgis.com/

The Maine Forest Service's (MFS) Forest Protection Division provides wildfire protection services for all of Maine's forest lands. In the Unorganized Territory of Maine, which accounts for 44 percent of the state's total land area, MFS is the only fire suppression entity and is often requested to respond to structure and vehicle fires as well as wildland fires. Their goals are to keep the number of forest fire starts to less than 1,000 and annual acreage loss to less than 3,500. MFS has met those goals in recent years because of:

- Quick and effective initial attack on all fires
- Effective air detection and aerial suppression
- Modern forest firefighting equipment
- Strong emphasis on fire prevention, including state control of statewide burning permits
- Aggressive training and preparation
- Improved access to remote areas of the state
- Northeast Forest Fire Compact membership, providing resources during periods of high fire danger
- Proactive public information campaigns
- Law enforcement
- Extensive automated weather stations providing accurate daily information used to assist in planning fire operations

3.36 Wildfire – Intensity and Previous Occurrences [S3.a.2.]

With 17.52 million acres of forested land covering 90 percent of the State of Maine, the entire state remains at risk for wildfires. With an increase in drought and other extreme conditions driven by climate change and seen across the state, wildland fires could originate anywhere, potentially placing a large burden on the state's limited resources. Maine Forest Service uses several different scales to measure the intensity of wildfire events as noted in Table 3.29.

Table 3.29: Wildfire intensity scales

Wildfire intensity scale	Definition/use
Energy Release Component (ERC) [5]	Available energy in BTU per unit area within the flaming front at the head of a fire, incorporating all live and dead fuels available.
Initial Spread Index [6]	Integrates conditions of fuel moisture and surface windspeed to estimate the potential for wildfire spread.
Keetch-Byram Drought Index (KBDI) [7]	A drought index designed specifically for wildfire potential assessment, representing the net effect of evapotranspiration ad precipitation in producing cumulative moisture deficiency in deep duff and upper soil layers.
Probability of Ignition [8]	Probability of wildfire ignition estimated from temperature, shading from forest canopy/cloud cover, and 1-hour fuel moisture content.

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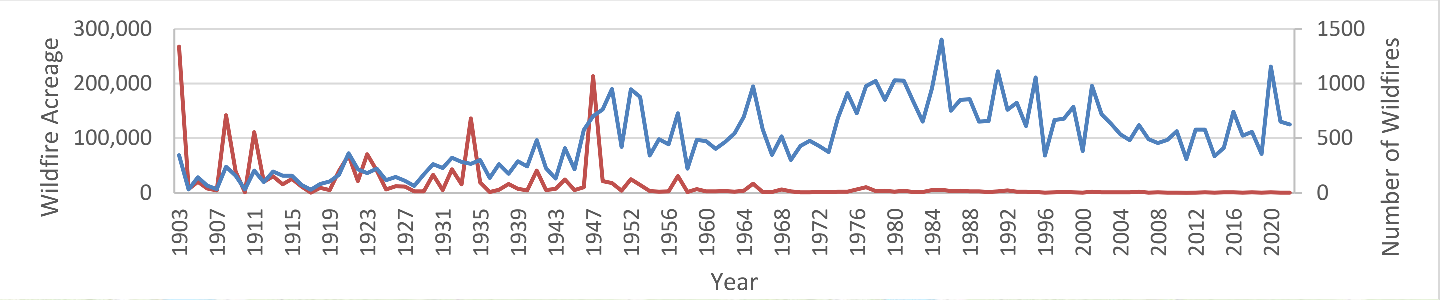
[5] Energy Release Component: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5339121.pdf
[6] Fire Weather Index System: https://www.nwcg.gov/publications/pms437/cffdrs/fire-weather-index-system
[7] KBDI: https://www.wfas.net/index.php/keetch-byram-index-moisture--drought-49
[8] Probability of Ignition: https://www.nwcg.gov/publications/pms437/fuel-moisture/probability-of-ignition

3.36.1 Previous Occurrences

Fire occurrences in 2016 increased with a record total of 747 events, increasing about 32 percent from a five-year average of 504 fires. Acreage burned also increased by 30 percent from the previous five-year average of 599 acres to a total of 907 acres. Traditional leading causes prevailed with debris burning and equipment use topping the list, with drought conditions exacerbating fire occurrence and intensity.



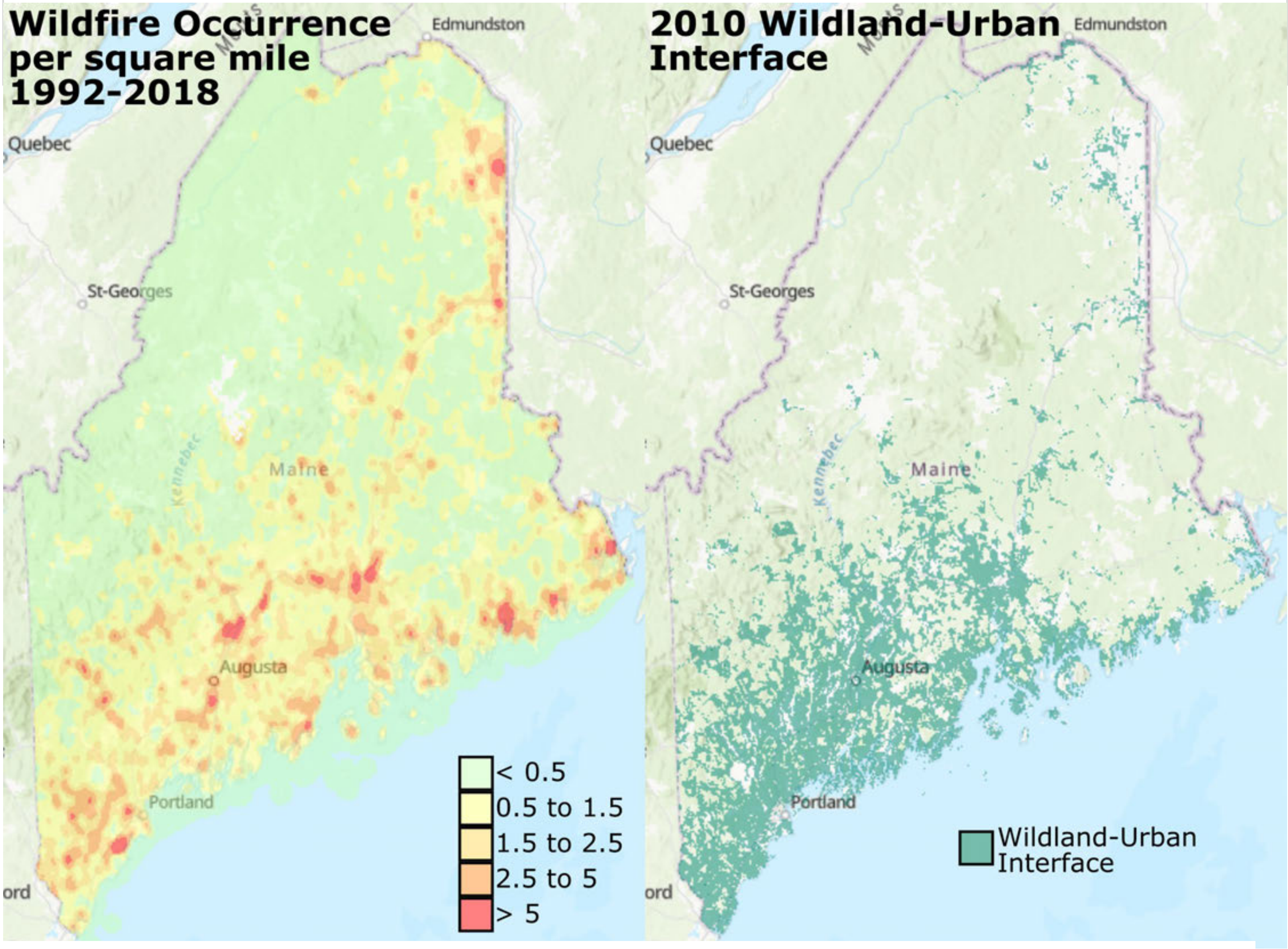


Figure 3.30: (top) wildfire occurrence over time in Maine by acreage (red) and total count (blue).

Figure 3.31 (bottom): distribution of wildfires in Maine from 1992 – 2018. (left) Wildfire occurrence in Maine, (right) Wildland Urban Interface delineated by US Forest Service based on 2010 US Census data.

The Maine Forest Service; Forest Service Division has identified a total of 1.85 million acres burned across 57,871 wildfires since 1903 (Figure 3.30). While historically major wildfires have correlated more with a higher number of acres burned, wildfire trends now reflect a higher number of smaller, more destructive fires due to an increase of people living in the wildland-urban interface. On average, the Maine Forest Service responds to 500 acres and fires annually. Figure 3.31 depicts the distribution of wildfires in Maine from 1992 to 2018. Moderate to severe drought conditions, as seen during the droughts of 2002, 2016, and 2020, inevitably help to exacerbate the likelihood of an event occurring.

Fire of Record: The "Great Fire of 1947"

The worst fires in Maine's history occurred in the fall of 1947. This event was actually a series of wildfires that flared all over Eastern and Southern Maine. Several fires that burned concurrently leveled nine towns in Southern Maine before the blazes were controlled. A similar situation occurred in Bar Harbor during the same period. Until 1947, Maine's record for a low incidence of fires was one of the best of the eastern states. Though that year had begun with excessive rainfall and cold temperatures, rapid onset of drought led to severe wildfire danger through the summer and into fall. Eventually, it would be apparent that the state was experiencing its severest drought in 30 years. A post-war boom in housing led to greater than normal amounts of slash and mill waste that contributed to a large amount of fuel near newly developed areas.

On Friday, October 3rd, a fire got out of hand when a crew was clearing brush for the new turnpike. With the help of local firefighters, they thought that it had been extinguished, but on Sunday, it flared up, burning underground along the roots of trees. By then, other fire reports were coming into the Office of the Forest Service in Augusta. As sunny, dry weather continued, more fires burst to life:

- **October 7** - fires were burning in the Topsham and Bowdoin areas, the Wells-Sanford Road in York County, and in Portland.
- **October 16** - there were 20 fires burning – double the number of 24 hours earlier.
- **October 17** - there were 50 fires burning; Gov. Hildreth closed the Maine woods to hunting, and a season of revenue.
- **October 18** - the Topsham-Bowdoin blaze was two weeks old, still out of control, and had consumed 1,000 acres of slash and timber.
- **October 23 –** "Red Thursday" the day of the big wind that spread the fire through Newfield, Shapleigh, Alfred, and Lyman.
- **October 24 –** rumors were rampant; Central Maine Power, the state's largest utility, had to issue a statement to stop further erosion of its stock value.
- **October 29 –** there were 40 fires still burning; there was a second attempt to "make rain" by combined efforts of "Project Cirrus."

In just a week, nine communities had been practically wiped out, four more had suffered severe damage, and scores of others had lost buildings. Property damage was estimated at $30,000,000. Fifteen had died. Many thousands of acres of trees had burned, and 3,000,000 feet of cut lumber had been destroyed.

Other notable wildfires

- October 1825, the Great Miramichi Fire burned 3.84 million acres in New Brunswick and spread into parts of eastern Maine, ranking within the top three largest wildfires recorded in North America.
- In July 1977, a forest fire, started by lightning in Baxter Park, burned nearly 4,000 acres and seriously threatened the entire park and surrounding developed areas.

- May 1992, a wildfire burned 1,200 acres near the towns of Allagash and St. Francis, requiring evacuation of 400 people and construction of a fire line in an effort to protect the communities [9]. Wildfire suppression costs totaled $1,106,114 (2022 USD) [10] and required federal support through the FMAG program [11].
- 1997, the Moxie fire burned 2,000 acres [12]

3.37 Wildfire – Probability of Future Occurrence [S4.]

Based on historical records of fires, the Department of Agriculture, Conservation and Forestry, Maine Forest Service Forest Protection Division anticipates there will be an average of 550 low acreage fires (from all causes) each year (a low acreage fire is less than 1,000 acres). Ironically, even though Maine has seen record drought conditions since the publication of the 2018 Plan, anticipated wildfires are still down from the 600-700 predicted five years ago. While the probability of a major wildfire, based on the last 115 years of wildfire data, is once a decade, it is currently unclear as to how changing climate conditions may either contribute to or inhibit future wildfire events. Most wildfires, however, are likely to occur between the months of April and October.

One aspect of risk analysis for wildfires in Maine which deserves attention is that of a “complex” of wildfires at the same time. Recent lightning events have resulted in this type of scenario, with multiple fires being reported simultaneously. While these fires are generally not large, challenges for managing multiple incidents exist. Recently, a single lightning storm caused over a dozen fires across the Unorganized Territory of Maine, resulting in fires ranging in size from one to twelve acres.

MFS has launched a community assessment program aimed at focusing its fire prevention efforts on geographical areas of the state with relatively high occurrences of wildfires. The assessment involves working with local officials and the public to identify vulnerable homes in the urban/wildland interface. MFS then prepares a community wildfire protection plan that contains guidelines that homeowners can use to protect their homes. The emphasis is on maintaining a 30-foot defensible space around homes.

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[9] Allagash Fire: https://www.upi.com/Archives/1992/05/19/Forest-fire-threatens-two-northern-Maine-towns/9446706248000/

[10] Wildland-Urban Interface Communities at Risk, Community Wildfire Protection Program, Tacoma Lakes Improvement Society: https://static1.squarespace.com/static/6171b2817275ae7fb6410428/t/618aa37e6e426d31e3543736/1636475776566/Wildfire-Protection-Plan.pdf

[11] FEMA Fire Management Assistance Grants: https://www.fema.gov/assistance/public/fire-management-assistance

[12] Maine Forest Products Council: https://maineforest.org/maines-forests-dont-have-major-wildfires-every-year-in-fact-the-average-wildfire-in-maine-is-less-than-one-acre/

3.37.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

The landscape of wildfire control in Maine is rapidly changing on several fronts. These changes are presenting very significant challenges to the Forest Protection Division of the Maine Forest Service, as well as to Maine's rural municipal fire service. Changes in the ownership and timber management practices of Maine's commercial timber land base are presenting new challenges for the state's wildfire control program. Additionally, climate change, reductions in the forest ranger force and a reduced number of available firefighters are all concerning when considering the wildfire hazards for Maine. The following outlines several of these present and continually growing challenges to assess the hazards presented by wildfire to the State of Maine.

Climate Change

Maine's wildfire season usually begins in late March/early April with the Spring snow melt. This start time varies across the state, with the southern and Downeast coastal areas usually being the first to have reported wildfires. As temperatures increase, the wildfire threat spreads northward. The wildfire season generally only stops when snowfall begins. It is not uncommon for wildfires to occur in the months of November and December. The wildfire season in Maine is generally split, with a large number of wildfires occurring in April and May due to dry, cured grass brush. With a green-up period that occurs in late May and early June, wildfires generally subside a bit. The summer fire season, resulting from long-term drying of heavier forest fuels, coupled with lightning and unextinguished campfires, can produce some intense fire incidents.

Recent changes in Maine's weather patterns have resulted in "extremes" to become more of the norm. Long term drought, as cataloged by the US Drought Monitor, shows that Maine is not immune to longer periods of time without sustained precipitation. Additionally, we have increasingly experienced longer periods of time with uncharacteristically low relative humidity. In fact, in 2022 Maine experienced a continuous 5-day period with relative humidity of less than 20 percent. National Weather Service records show that this had not happened since 1948. Conversely, As our climate changes, federal agencies like the National Oceanic and Atmospheric Administration and the Environmental Protection Agency believe storms are becoming more frequent and more volatile.

The Maine Forest Service operates a network of remote automated weather stations, strategically located across Maine, to collect hourly weather data to understand current wildfire danger. We work cooperatively with the National Weather Service and our state and federal partners to share this information so that we can make sound decisions and inform the public of the wildfire danger.

Land Management Changes

In Maine, several industrial landowners and the Maine Bureau of Parks and Lands are now employing "Outcome Based Forestry", utilizing enhanced land management techniques for timber harvesting which give them the chance to develop more broad-based harvesting prescriptions. Outcome Based Forestry operations are timber harvesting techniques that are conducted in a manner that are touted as ecologically sustainable, economically viable and socially responsible. These science-based techniques allow participating parcels to have fewer compartmentalized sections of forest, resulting in fewer abrupt changes in forest stand types. As such, many contiguous harvest stands are larger in size and less fragmented in composition. Land managers who utilize Outcome Based Forestry state that an economic advantage of the program is that they now must establish and maintain fewer roads and larger road systems. They also state that because of these enhanced practices they can effectively, "put older road systems to bed," and not have to contend with them for 20-30 years post-harvest.

These byproducts, resulting from Outcome Based Forestry practices, will have a profound impact on present and future wildfire control efforts in our state. With forested areas having fewer stand type changes, fewer mandated clear-cut (surrounding) buffer zones and with forest stands which are often more intensely managed for spruce and fir timber products, the likelihood of larger and certainly more intense wildfires has and will continue to increase. Additionally, if road systems are not established, or existing systems are not maintained or are even made dormant, access for forest rangers and wildfire suppression resources become significantly limited. This is both good and bad – the good being less wildfire risk from reduced public access to remote forested areas – the bad is that it may become more difficult to quickly access areas for successful initial attack on wildfire incidents. And, as we certainly all know, lightning can happen anywhere, and its risks are nearly impossible to mitigate. Many land management companies and forest landowners are also deferring existing logging road maintenance simply to keep costs down and profitability up. Roads once passable with most passenger cars are now highly deteriorated and, in many cases, are grown in. Bridges and culverts are often temporarily pulled and/or permanently removed, limiting access to foot traffic and helicopter. In essence, Maine is now what one renowned national fire historian characterized as, "rewilding." This descriptor makes reference to what Maine was like in the 1950s relative to forest road access and to its reverting toward a more contiguous and wildfire susceptible forest.

Declines in Rural Fire Service

Maine's volunteer fire service is experiencing the widely publicized problem of a downward trend in firefighters willing to serve their communities, as seen in all areas of the United States. In recent years, Maine has not been immune to repeated cases in which existing volunteer fire departments are unable to respond with full crews to fires and other emergencies, requiring a much greater reliance on mutual aid, and resulting in the shuttering of several volunteer fire departments altogether. In recent years, there have been no fewer than 10 departments across Maine which have closed due to lack of members. Also, the Maine Legislature has allowed several organized municipalities to "deorganize" to become part of Maine's Unorganized Territories. In these townships, the State of Maine has replaced municipal government functions, including the full responsibility for wildfire control. As a result, since 2006 there has been a noteworthy shift in the responsibility for wildfire control to the Maine Forest Service in the amount of an additional 355,000 acres of forestland, including the associated protection of 2,775 structures situated on those acres with no additional personnel for this purpose either allocated or appropriated.

A recent survey of the Maine Forest Service's three Forest Protection Division regions paints a concerning picture of the growing threat of increased difficulty in ensuring quick and effective initial attack of wildfires. In our Central Region, comprised of 7.42 million acres, the Maine Forest Service is solely responsible for protecting 3.87 million acres (52.2%) of this total area from wildfires. This area of the region is referred to as Maine's unorganized territories and is home to over 10,000 structures. Remaining areas of the region consist of organized towns with no fire department of their own – 886,220 acres (11.7%) – and they rely heavily on the Maine Forest Service for wildfire protection. Still more concerning are those towns in the region whose fire departments have been classified as, "Limited Resource Fire Departments." This designation is applied to any town fire department which has documented and chronic low firefighter enrollment, and which the department is likely unable to successfully conduct initial attack operations on a 1-acre wildfire in their town without the help of mutual aid. This area totals 606,722 acres, or 8.2% or the Central Region's total acreage. In short, the Central Region's 16 field forest rangers are the de facto wildfire control officers responsible for the protection of 72 percent, or 5,349,813 of the region's 7.4 million acres7. There are towns and cities within the region which have no less than daytime staffing of their fire departments. Many of these provide 24 hour/7 day per week staffing, and this area accounts for 466,697 acres, or 6.3% percent of the Central Region's land area.

3.38 Wildfire - Impacts

Though wildfires are a common occurrence in Maine, the state has a low risk for large, damaging wildfires due to a temperate climate; strong preparedness and response capabilities at local, county, and state levels; and a growing interest in wildfire mitigation actions. However, several demographic factors make Maine's rural areas less resistant to the threat of fires. First, the shrinking tax base is putting a strain on local funding for volunteer fire departments. Second, as in all of New England, Maine's housing stock is also aging. When old farm homes and wood frame buildings are located in remote areas, it can be very challenging for volunteer firefighters to respond before the structures are destroyed, especially since 90% of all firefighters in Maine are volunteers. In many areas of the state, fulltime fire departments are scarce. These departments often contract their services with adjoining towns which stretches them even further. They are not available for out-of-area fire response.

The Division utilizes fixed and rotary wing aircraft [helicopters] in its wildfire prevention, detection, and suppression missions. Currently, the inventory includes three Bell UH-1H "Huey" helicopters, three Bell 407s, and 1 Jet Ranger acquired from the Department of Defense through a loan agreement brokered by the U.S. Forest Service. These aircraft are the backbone of the state's suppression fleet.

Though rare in Maine's history, the impacts of large, statewide wildfires have been tremendous. Wildfires can destroy entire communities, causing major loss of life and property, severe injuries and mental health challenges, dramatic economic downturns, challenging local and state resources to manage the situation, and pose long-term recovery issues with lack of housing and resources for the recently unhoused. The environmental impacts of the Great Fire of 1947 are still visible on Mount Desert Island. The logistical challenges of wildfire impacts are discussed in the community lifelines considerations below.

3.39 Wildfire – Vulnerability of State Assets [S5.]

3.39.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

State Wildfire Suppression Costs

As a rural state, the biggest issues Maine continues to face in terms of mitigating wildfire revolves around limited resources. With a significant portion of the population living in wooded areas and limited capabilities to both monitor conditions and suppress fire hazards, a higher risk does exist. In recent years, Maine has also experienced exceedingly dry conditions posing the extra challenge of educating the public on prevention of fires and basic fire suppression techniques. Recent years have shown an increase in total fire suppression costs above the average listed in Table 3.30. For example, 2016 suppression costs reached $1.3 million, and damages reached $3.6 million.

State Building/Structure Assets

Wildfire damage to state structure assets is extremely unlikely given the successful history of fire suppression programs in the State of Maine. The US Forest service designates Maine wildfire hazard potential [13] as "Low" to "Very Low." However, the potential exposure of assets to wildfire is substantial under the assumption that wildfires are more likely to occur within the Wildland Urban Interface, as delineated by the US Forest Service [14].

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[13] US Forest Service Wildfire Hazard Potential 2022 Map - https://usfs.maps.arcgis.com/apps/mapviewer/index.html?layers=55226e8547f84aae8965210a9801c357

[14] Radeloff, V.C., Helmers, D.P., Kramer, H.A., Mockrin, M.H., Alexandre, P.M., Bar-Massada, A., Butsic, V., Hawbaker, T.J., Martinuzzi, S., Syphard, A.D. and Stewart, S.I. (2018). Rapid growth of the US wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences, 115*(13), 3314-3319. http://silvis.forest.wisc.edu/wp-content/uploads/2018/10/Radeloff_2018_PNAS_SI.pdf

MEMA identified 1,733 state structure assets located in the Wildland Urban Interface. The top 10 structure assets rated by building and contents replacement cost are listed in Table 3.31.

Table 3.30: Average annual wildfire suppression costs by cause (values in 2022 USD).

Cause	Average Annual Suppression Cost
CAMPFIRE	$128,972
CHILDREN	$18,946
DEBRIS	$195,771
ARSON	$64,789
LIGHTNING	$101,136
EQUIPMENT USE	$139,038
MISCELLANEOUS	$80,689
RAILROAD	$32,177
SMOKING	$42,570
FIREWORKS	$4,311
POWERLINE	$48,174
PRESCRIBED FIRE	$16,272
STRUCTURE	$63,660
Totals	**$841,276**

Table 3.31: Wildfire potential exposure - State assets in Wildland Urban Interface

Address	County	Occupancy	Property Type	Year Built	Last Inspected	Total	Agency
250 Arsenal St, Augusta	Kennebec	MEDICAL FACILITY	Class 4 building*	2004	7/1/2016	$52,875,000	DHS, RIVERVIEW PSYCHIATRIC CENTER
54 Pleasant St, Castine	Hancock	DORMITORY	Steel/masonry[a]	1970	7/1/2017	$42,744,000	MMA, MAINE MARITIME ACADEMY
23 Blue Star Ave, Augusta	Kennebec	OFFICE	Class 4 building	2017	8/3/2017	$31,861,558	DVS, MILITARY BUREAU
807 Cushing Rd, Warren	Knox	OFFICE	Steel/masonry	2002	7/1/2015	$28,479,770	COR, MAINE STATE PRISON
112 College Dr, Wells	York	CLASSROOM	Steel/masonry	1997	5/11/2022	$26,248,033	TC, YORK COUNTY COMMUNITY COLLEGE
26 Edison Dr, Augusta	Kennebec	OFFICE	Steel/masonry	2020	8/14/2020	$22,250,000	MSH, MAINE STATE HOUSING AUTHORITY
45 Commerce Dr, Augusta	Kennebec	OFFICE				$21,613,000	ADF, OFFICE OF INFO TECH, COMPUTERS SERVERS
11 Market St, Belfast	Waldo	OFFICE	Class 4 building	2019	2/13/2019	$20,000,000	MMB, MAINE MUNICIPAL BOND BANK
66 Industrial Dr, Augusta	Kennebec	STORAGE	Class 4 building	2014	12/31/2014	$19,879,038	DOT, MID COAST REGION
185 Western Ave, Augusta	Kennebec	MILITARY	Steel/masonry	1954	7/1/2016	$19,293,248	DVS, MILITARY BUREAU

*A class 4 building with a fire resistive rating of at least one hour but less than two hours.

[a] Steel or masonry framed building. Masonry siding. Steel or masonry roof decking may be covered with any type of covering.

There is no guarantee that these assets will be damaged in a natural hazard event. The state assets identified in the WUI are all constructed with fire resistive materials, meaning that the exterior walls, floors, and roof consist of masonry, metal, or other non-combustive materials. However, under a severe wildfire, any building can be at risk of damage or destruction. The Riverview Psychiatric Center is a 92-bed inpatient psychiatric hospital treating patients with severe and persistent mental illness. Besides posing a risk to all patients and staff, evacuations of a psychiatric hospital under threat of a wildfire would be an immense challenge as there are few alternative options for inpatient care. Similar issues exist to evacuate state prisons. State-owned university buildings would face major logistical and financial challenges if wildfire damage were to occur. Finally, impacts to MaineHousing and the Maine Municipal Bond Bank would pose much larger challenges as communities would rely on these resources to acquire housing for survivors and rebuild communities.

Though state assets are distributed across Maine, most are in the Capital District in the City of Augusta. This area has a low to moderate wildfire risk and many of these assets are found in urban areas where wildfire risk is not calculated (Figure 3.32).

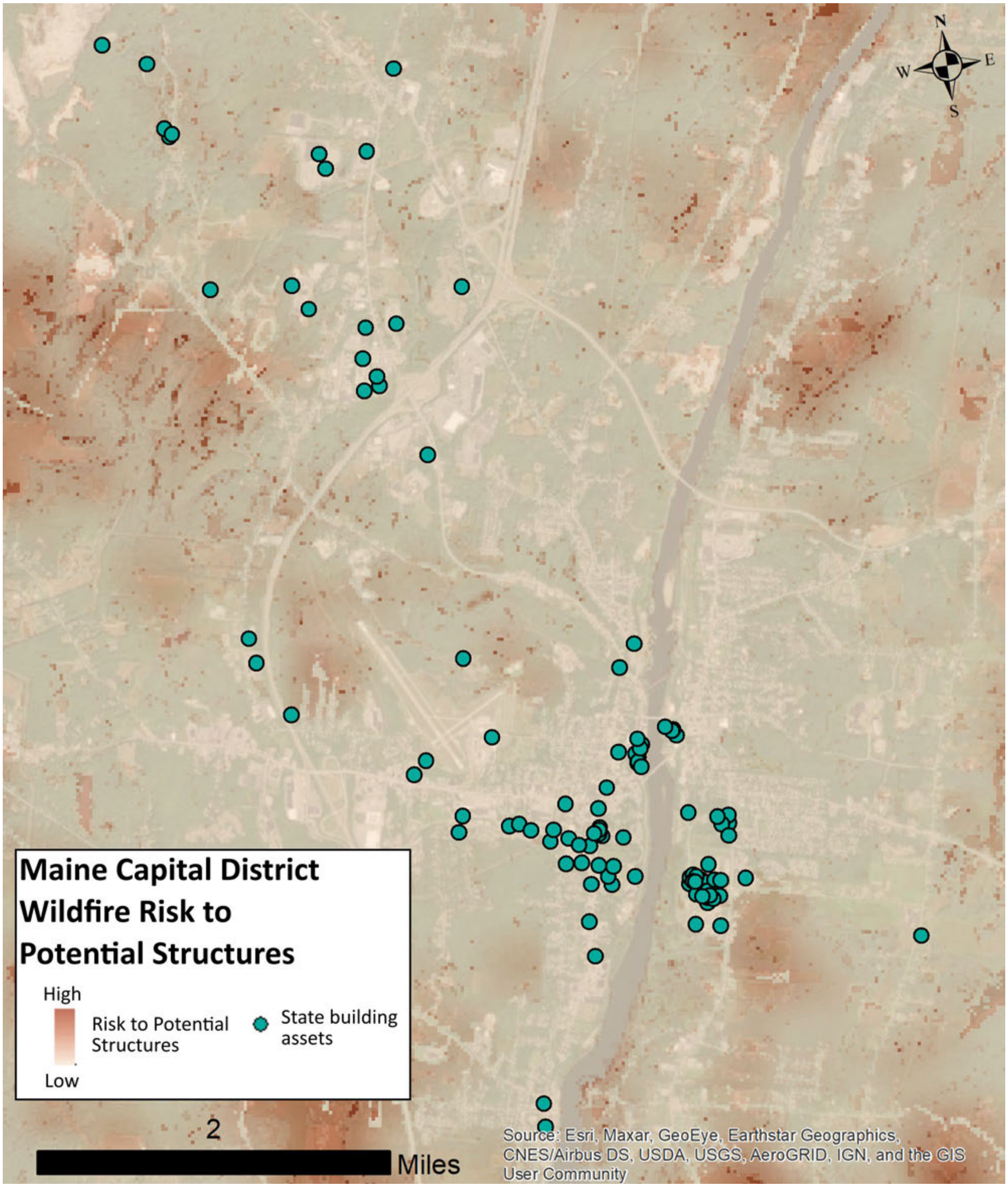


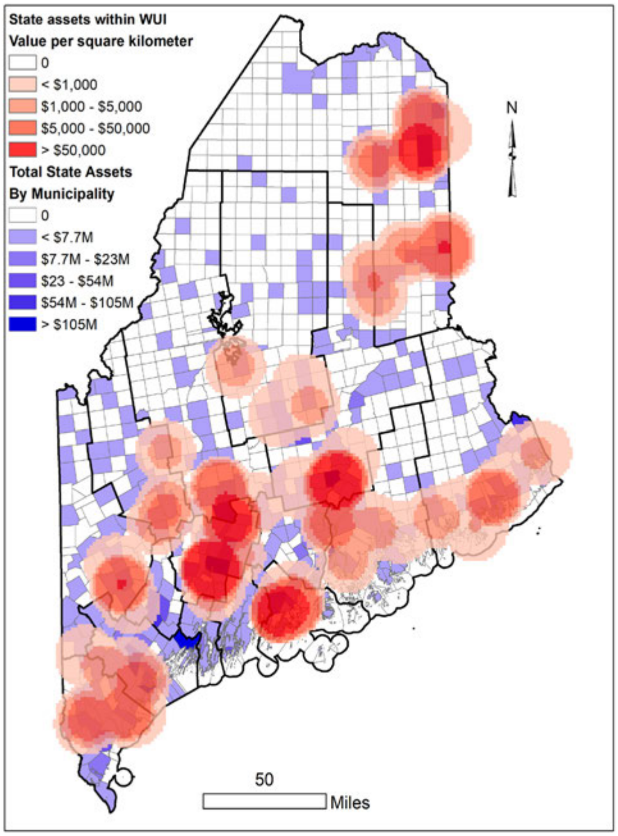
Figure 3.32: Wildfire risk to potential structures in the Capital District, Augusta, Maine.

Approximately 36% of all state structure assets are located in the Wildland Urban Interface (Table 3.32). Four counties, Hancock, Knox, Sagadahoc, and York County have more than 75% of state assets located in the Wildland Urban Interface. General locations are provided in Figure 3.33. Wildfire risk is low (Figure 3.34).

Table 3.32: Potential state asset exposure to wildfire - structures located in 2010 Wildland Urban Interface (Building and contents replacement values in millions 2022 USD)

Region	Totals		Potential exposure in WUI		
	Assets Count	Value	Assets Count	Value	% of total value
State of Maine	*3,769*	*$3,357.70*	*1,733*	*$1,206.71*	*35.9%*
Androscoggin	103	$131.86	41	$13.89	10.5%
Aroostook	421	$287.50	171	$76.58	26.6%
Cumberland	604	$628.20	246	$76.98	12.3%
Franklin	145	$21.04	63	$9.38	44.6%
Hancock	153	$202.13	110	$168.04	83.1%
Kennebec	518	$990.50	281	$399.99	40.4%
Knox	108	$163.41	80	$131.08	80.2%
Lincoln	80	$44.12	56	$11.89	27.0%
Oxford	109	$38.87	58	$15.70	40.4%
Penobscot	355	$383.40	105	$33.44	8.7%
Piscataquis	228	$32.19	38	$23.76	73.8%
Sagadahoc	87	$28.35	43	$22.09	77.9%
Somerset	191	$130.57	89	$63.95	49.0%
Waldo	179	$46.70	58	$32.64	69.9%
Washington	225	$122.94	92	$38.20	31.1%
York	263	$105.91	202	$89.07	84.1%

Figure 3.33: State assets potentially exposed to wildfire within the Wildland Urban Interface (WUI).



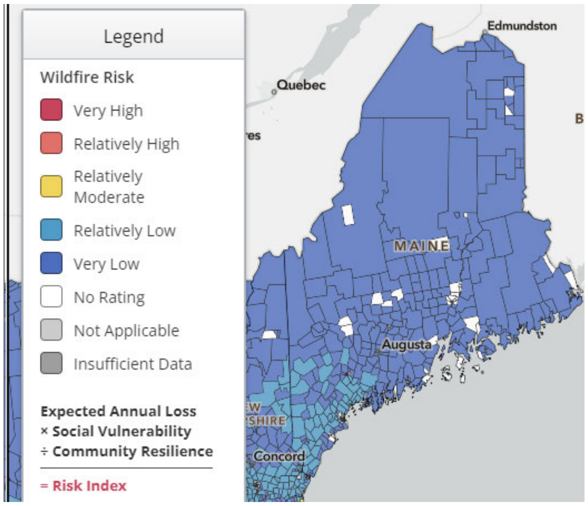


Figure 3.34: National Risk Index maps of wildfire risk in Maine census tracts. https://hazards.fema.gov/nri/map#

Conserved Lands

Conserved lands may also be potentially exposed to wildfire based on their intersection with the Wildland Urban Interface (Table 3.33). Conserved lands, held by state, municipal, private, or federal agencies/organizations, may be more susceptible to wildfire because they tend to be forested with relatively more challenging wildfire suppression access versus structures. Conserved lands in southern, central, and coastal portions of Maine are more likely to be located in the Wildland Urban Interface.

Table 3.33: Conserved lands in Maine and portion of area within Wildland Urban Interface.

Interest type	Total acres (thousands)	WUI Intersect acres	Portion of area
State	1,349	29	2.2%
Municipal	42	28	66.8%
Private	2,670	144	5.4%
Federal	304	5	1.7%
Total	4,366	206	4.7%

3.39.2 Community lifeline Risks

Wildfire is anticipated to impact each lifeline to a potentially substantial degree. However, it is difficult to identify location-specific issues for each lifeline because wildfires can occur in any forested part of the state. Please refer to other sections of the Wildfire – Hazard Profile and Vulnerability Assessment for greater detail. Here we provide a count of certain facilities located within the WUI. As noted before, using the WUI to assume wildfire risk is an imperfect approach as it can only provide a relative comparison of wildfire occurrence in developed areas on the interface of forested areas.

Food, Water, Shelter

The vast majority of Maine shelters are in the WUI and are therefore at greater risk of wildfires. Municipal emergency managers would need to coordinate with the County EMA to activate shelters that are outside of the impacted area, and traffic would need to be diverted away from the burn path. Of the 270 identified shelter sites, 218 (81%) are located in the WUI.

Schools are commonly selected as shelter sites. Of the 784 public schools in Maine, 585 or nearly 75% are in the WUI, signifying the importance of mutual aid and multi-jurisdictional shelter coordination efforts. Outside of use as shelter sites, wildfire damages to schools would be a significant disruption to local education and childhood development.

Energy

A total of 35 power plants are located in the wildland urban interface in Maine, with 1,388 miles of transmission lines, or just over 50%, also located in the WUI. Damage to transmission lines could be very extensive depending on the size of the fire, leading to very long-term power outages and associated health, food, and service issues mentioned under other hazard profiles.

Medical

Most assisted living centers in Maine (83%) and 41% of hospitals are located in the WUI, including the Riverview Psychiatric Center and many other facilities that would be logistically challenging to evacuate and relocate patients to sites outside of the burn path.

Safety and Security

Local/regional fire stations are evenly distributed across the populated parts of the state, virtually all have mutual aid agreements with neighboring communities, and each is a crucial asset for fire suppression.

Communications

The majority (59%) of Maine cellphone towers are located in the WUI. As noted in other sections, damage to communications towers would drastically reduce the capacity for communication, increase load on remaining towers, and make communication in rural areas nearly impossible.

Hazardous Material

Maine's wildfire suppression and HAZMAT [15] capabilities would be a crucial component of preparedness and response to a wildfire event.

Historic and Cultural Resources

Using historic locations data overlain with the WUI layer, 841 historic sites of 1,266 total in Maine (66.4%) are located in the WUI, where the risk of wildfire occurrence is statistically higher due to the interface between human activity and forests.

Timber stands and state-protected lands are at a high risk of wildfire damage due to the abundance of fuels. Historic major wildfires have led to an estimated millions to hundreds of millions of dollars in lost timber stands for the lumber industry, a major economic driver for Maine. There are still some visible burn locations in Acadia National Park from the Great Fire of 1947, signifying the long-term impacts wildfires have on local ecology.

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[15] MEMA HAZMAT: https://www.maine.gov/mema/hazards/human-caused-hazards/hazardous-materials

3.40 Wildfire – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.40.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

All jurisdictions are potentially vulnerable to damages from wildfire caused either by human activity or through natural conditions such as lightning strikes in fuel-rich and/or abnormally dry or drought-stricken areas. Geographic and slope factors and available fuel types also contribute to vulnerability. However, the WUI areas surrounding urban centers tend to experience a greater frequency of wildfires and can be considered to have greater vulnerability. These areas include jurisdictions surrounding the Cities of Bangor, Lewiston/Auburn, Portland, in addition to many communities in York and Cumberland Counties that are experiencing elevated development trends (refer to the Development Trends section of this plan). FEMA's National Risk Index indicates very low wildfire risk in most of Maine and relatively low risk in parts of southern and western Maine. Consequently, expected annual losses are very low to relatively low across the state.

Communities that have established plans that are implemented to mitigate against wildfire risks are considered to have lower vulnerability and fewer potential impacts. Ten communities have created Community Wildfire Protection Plans [16] in Maine: these include Thompson Lake in Oxford, Taylor Pond in Auburn, Brightwater-Windburg in Phippsburg, Raymond Neck, Southwest Harbor, Harford's Point near Greenville, Portage lake, Stoneham, Stow, and Albany/Mason Townships. Many other communities have also become involved in the state Firewise program [17]. These communities are Indian Point in Georgetown (2009), Cushing Island in Portland (2011), Sprucewold in Boothbay Harbor (2011), Pequawket Lake Preservation Association in Limington (2012), Little Diamond Island in Portland (2012), Great Diamond Island in Portland (2013), Bustins Island (2014), Wynburg-Brightwater-Wynburg East in Phippsburg (2017), and Harfords Point near Greenville (2021). Many Firewise and CWPP communities are located in remote areas where wildfire suppression resources are very limited, such as coastal islands and small communities surrounded by forest, suggesting the importance of wildfire mitigation.

Disadvantaged Communities

The objective of the disadvantaged communities' assessment is to identify potential disadvantages felt by communities who are disproportionately impacted by natural hazards both historically and under future projections. Wildfires are a frequent but typically low impact hazard in Maine thanks in large part to capable wildfire suppression efforts across jurisdictions.

Overlaying Maine's wildfire occurrence map onto the Overall SVI map (Figure 3.35) indicates a few coincident trends between disadvantaged communities and the frequency of wildfires, though wildfire trends are fairly well scattered across populated areas in the state. In some of these areas, the risk to potential structures is elevated relative to other populated parts of the state (calculated in part with data from the large wildfire simulation system FSim and presented by the Northeast-Midwest Wildfire Risk Explorer [18, 19]). This is particularly true for the eastern, southern, and northern portions of the state. One further disadvantage is the declining trend in rural fire service, which may have substantial consequences for rural disadvantaged communities.

Rural disadvantaged communities, such as those in Washington, Somerset, and Aroostook Counties, face major impacts from wildfire due to long evacuation routes and longer response times from wildfire suppression resources. At the same time, urban disadvantaged communities such as those in Kennebec, Androscoggin, and Cumberland counties, face the issue of evacuating and organizing shelters for much larger populations and

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[16] CWPPs: https://www.usfa.fema.gov/downloads/pdf/publications/creating_a_cwpp.pdf
[17] Maine Firewise: https://www.maine.gov/dacf/mfs/forest_protection/firewise/index.html
[18] Northeast Region Cohesive Wildland Fire Management Strategy: https://www.northeasternwildfire.net/
[19] Northeast WRAP: https://northeastwrap.uat.timmonsdev.com/

recovering from higher anticipated losses in more heavily developed areas. Dry, forested areas with greater relief and abundant fuels have both a greater probability of wildfire occurrence and a much greater challenge for wildfire suppression efforts, And are therefore expected to see greater total impacts. These areas would benefit from wildfire mitigation efforts and reduce their reliance on wildfire suppression resources.

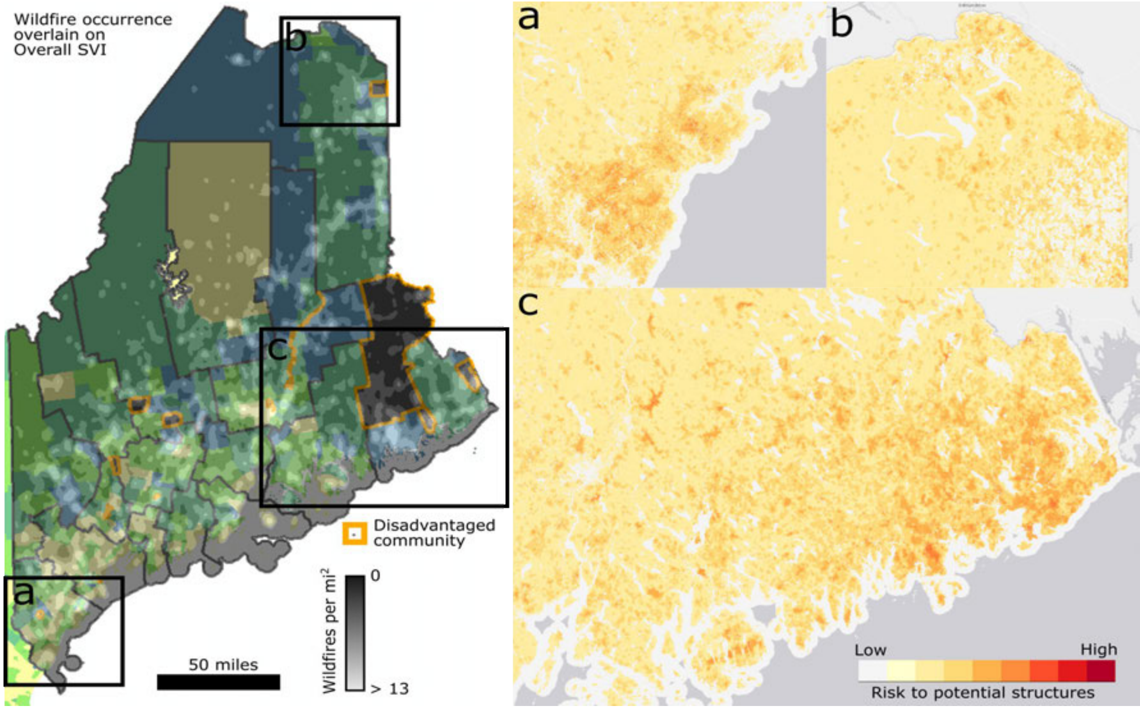

Figure 3.35: overlay map of wildfire occurrence and Overall SVI indicates some coincident trends between wildfires and disadvantaged communities. Southern, northern, and eastern portions of the state exhibit higher

The Justice40 initiative, which was created by the White House to confront and address decades of underinvestment in disadvantaged communities impacted by climate change, pollution, and environmental hazards, identifies these communities through use of the Climate and Economic Justice Screening Tool (CEJST)[20]. In addition to having a higher relative wildfire risk, many communities in Downeast Maine are identified as disadvantaged by CEJST. Many of these communities are rural as noted in Figure 3.36, and there is no substantial overlap for jurisdictions that have high wildfire risk, disadvantaged status, and a relatively large population. Some of the wildfire risk factors are somewhat unique in the Downeast region. For example, many parts of Mount Desert Island have a high wildfire suppression difficulty index which may lead wildfires to burn out of control if they were to occur. In this area, as in the western mountains of Maine, steep topography, difficult terrain, and fuel type are the primary causes of suppression difficulty. Steep terrain areas of Maine are sparsely populated but often include disadvantaged communities. However, wildfire risk is lower in the western mountain region than in the Downeast region.

Maine Forest Service notes that, though the Northeast-Midwest Wildfire Risk Explorer is a useful regional-level tool for assessing relative risk, it does not incorporate specific wildfire data reported by wildfire suppression efforts but is instead based on model data. An important future action will be to incorporate both types of data into a single viewer, combined with important vulnerability metrics such as SVI and Justice40, to verify risk and better prioritize disadvantaged communities.

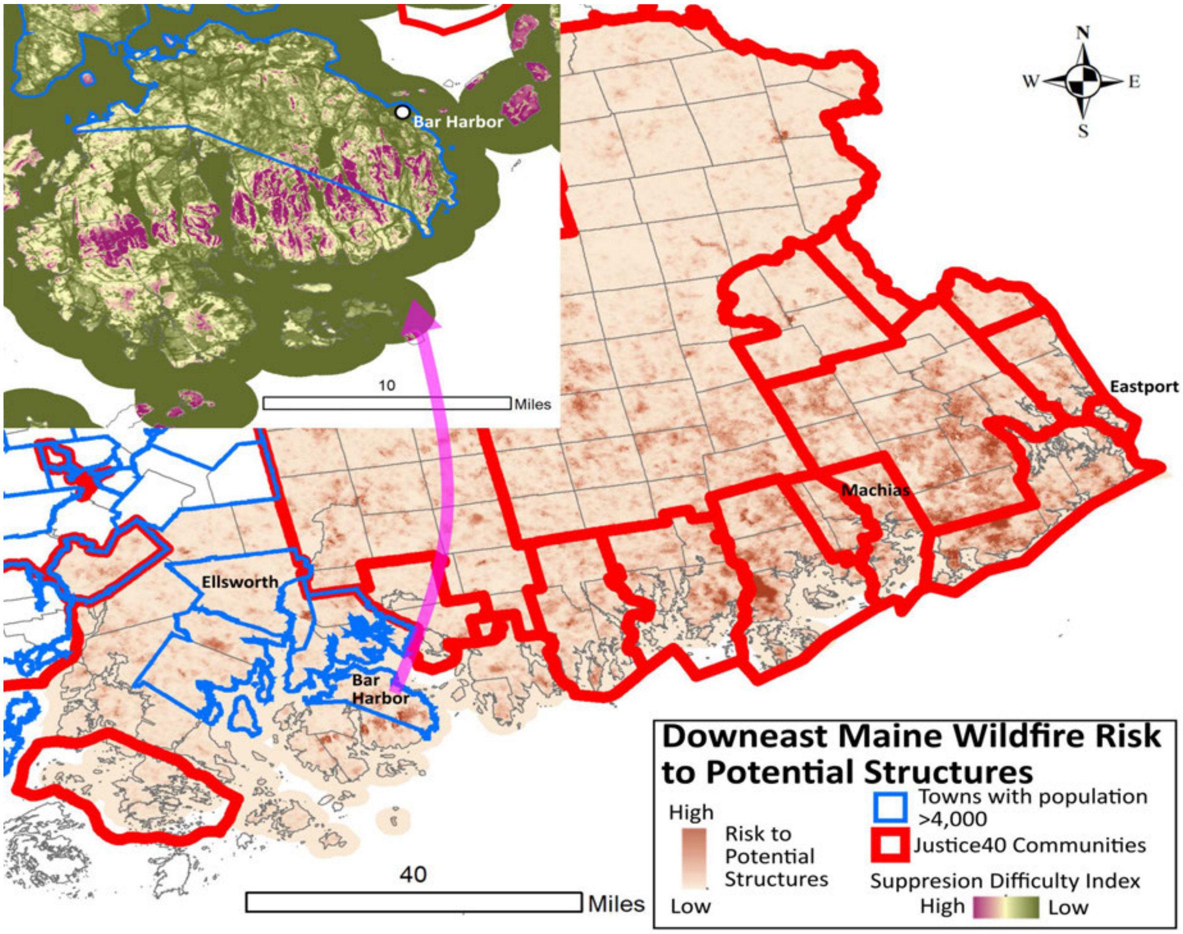

Figure 3.36: overlay of wildfire risk, town population, and disadvantaged communities in Downeast Maine.

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[20] CEJST: https://screeningtool.geoplatform.gov/

3.40.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Hazard-Asset Footprint Overlay Analysis

Though wildfire risk is low in Maine, most populated portions of the state are located in the wildland urban interface and therefore may be potentially exposed to human caused wildfires. In some counties, as much as 92% of all structure assets are located in the wildland urban interface (Table 3.34). This does not mean that all of these structures are vulnerable to wildfire, though it does mean they are located in areas that statistically see a greater number of wildfire occurrences.

Table 3.34: Potential wildfire exposure for all structure assets in wildland urban interface (millions 2022 USD)

	Totals		**Assets in WUI**		
Region	Assets Count	Total Value	Assets Count	Replacement Cost	% of total value
State of Maine	758,999	$329,411	604,483	$248,573	75.46%
Androscoggin	40,678	$20,282	34,724	$15,690	77.36%
Aroostook	47,211	$21,437	25,391	$10,562	49.27%
Cumberland	120,034	$60,316	93,745	$41,919	69.50%
Franklin	21,643	$8,534	16,718	$6,634	77.74%
Hancock	47,129	$17,737	42,429	$15,919	89.75%
Kennebec	65,768	$29,533	56,404	$23,648	80.07%
Knox	28,812	$11,720	26,991	$10,691	91.22%
Lincoln	27,821	$10,680	25,460	$9,733	91.13%
Oxford	40,062	$16,050	30,361	$12,166	75.80%
Penobscot	79,169	$35,301	57,976	$24,011	68.02%
Piscataquis	16,376	$5,782	10,931	$4,032	69.73%
Sagadahoc	20,394	$8,210	19,436	$7,530	91.72%
Somerset	38,723	$15,823	28,242	$11,189	70.71%
Waldo	26,926	$10,879	21,309	$8,606	79.11%
Washington	24,214	$8,175	16,222	$5,529	67.64%
York	107,149	$45,785	98,144	$40,713	88.92%

Drought – Hazard Profile

TIER 1 HAZARD

3.41 Drought – General Definition and Types of Events [S3.a., S3.b.]

Drought is a period of unusually persistent dry weather resulting in prolonged shortages in water supply with many associated impacts. Drought is defined by its spatial extent, intensity, magnitude and duration, the components of the hydrological cycle that it affects and the systems that it impacts. These multiple factors that define drought make it difficult to predict, quantify or put into historical context.

Drought is a normal recurring feature in *all* climatic regions. While all droughts originate with a deficiency of precipitation, drought is a unique hazard due to the usually slow progression of the phenomenon [21]. Drought impacts respond to precipitation anomalies on varied timescales (see “Impacts” on following pages). This makes it difficult to determine a clear beginning or end to any drought event, particularly ones that are prolonged. The duration of drought can vary from several weeks to several years.

There are four different ways in which drought can be defined.

3.41.1 Meteorological Drought

Meteorological Drought is based on the degree of dryness or precipitation deficit and the length of the dry period [22]. Due to climatic differences, what might be considered a drought in one location of the country may not be a drought in another location.

Snow drought is a form of meteorological drought occasionally occurring in Maine and other regions accumulating the snowpack in winter. Snow drought is a period of abnormally low snowpack for the time of year occurring under two separate conditions. First, a "dry" snow drought is caused when a lack of winter precipitation leads to a reduced snowpack. Second, a "warm" snow drought is caused when there are unseasonably warm temperatures combined with winter precipitation that occurs as rainfall that does not contribute, and may even reduce, the total snowpack [23]. A reduced snowpack will eventually contribute less snowmelt in spring, potentially contributing to early season drought.

3.41.2 Hydrologic Drought

Hydrological Drought is based on the impact of precipitation deficits on the water supply such as stream flow, reservoir and lake levels, and ground water table decline. Hydrologic drought indicators lag significantly behind meteorological drought indicators.

Agricultural Drought

Agricultural Drought refers to soil moisture deficits, and subsequent impact to plants and agriculture, resulting from precipitation deficits and/or above-normal temperatures and wind that cause evaporative losses [24]. Agricultural drought can increase the need for crop irrigation.

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[21] US Drought Monitor: http://drought.unl.edu/Education/DroughtBasics.aspx

[22] NWS drought types: https://www.weather.gov/safety/drought-types

[23] American Geophysical Union Definition of Snow Drought: https://eos.org/opinions/defining-snow-drought-and-why-it-matters

[24] https://www.drought.gov/topics/agriculture

3.41.3 Socioeconomic Drought

Socioeconomic Drought considers the impact of drought conditions (meteorological, agricultural, or hydrological drought) on supply and demand of some economic goods such as fruits, vegetables, grains and meat. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related deficit in water supply.

3.42 Drought – Location of Hazard [S3.a.1]

Drought classification is relative to longer term (weekly, monthly, seasonal) and often broadscale precipitation trends, surface and groundwater levels, soil moisture content, and other dryness indicators, the entire State of Maine is evenly susceptible to drought.

3.43 Drought – Intensity and Previous Occurrences [S3.a.2.]

The extent of drought can vary significantly from localized events in a specific watershed to a statewide occurrence; from short term (one summer) to long term duration (several years); or from an abnormally dry spell to a drought of exceptional intensity.

Maine uses the U.S. Drought Monitor's (USDM) classification method (Table 3.35) to measure the extent of drought events as they occur.

Table 3.35: U.S. Drought Monitor Drought Classification.

Category & Description	Historically observed impacts	Palmer Drought Severity Index	CPC Soil Moisture Model*	USGS Weekly Streamflow*	Standard Precip. Index (SPI)	Objective Drought Indicator Blends*
D0 Abnormally Dry	-Crop growth is stunted; planting is delayed -Fire danger is elevated; spring fire season starts early -Lawns brown early; gardens begin to wilt -Surface water levels decline	-1 to -1.9	21 to 30	21 to 30	-.5 to -.7	21 to 30
D1 Moderate Drought	-Irrigation use increases; hay and grain yields are lower than normal -Honey production declines -Wildfires and ground fires increase -Trees/landscaping stressed; fish stressed -Voluntary water conservation is requested; reservoir and lake levels below normal capacity	-2 to -2.9	11 to 20	11 to 20	-.8 to -1.2	11 to 20
D2 Severe Drought	-Specialty crops (yield/fruit size) impacted -Producers begin feeding cattle; hay prices are high -Warnings are issued on outdoor burns; air quality is poor -Golf courses conserve water -Trees are brittle and susceptible to insects -Fish kills occur; wildlife move to farms for food -Poor water quality; declining groundwater; dry irrigation ponds; outdoor water restrictions implemented	-3 to -3.9	6 to 10	6 to 10	-1.3 to -1.5	6 to 10
D3 Extreme Drought	-Widespread crop loss; Christmas tree farms are stressed; dairy farmers are struggling financially -Well drillers, bulk water haulers see business rise -Water recreation and hunting are modified; wildlife disease outbreak is observed -Extremely reduced/ceased surface flow; warm river temperatures; wells run dry; people digging more/deeper wells	-4 to -4.9	3 to 5	3 to 5	-1.6 to -1.9	3 to 5
D4 Exceptional Drought	- Unprecedented drought - Exceptional and widespread crop/pasture losses - Shortages of water creating emergencies	-5 or less	0 to 2	0 to 2	-2 or less	0 to 2

* Percentile values

3.43.1 Previous Occurrences

Maine’s 1999-2002 drought period was the most damaging to date (Figure 3.37, Table 3.36). There were an estimated 17,000 private wells that ran dry in the nine months prior to April 2002, and farmers lost more than 32 million dollars in crop yield between 2001 and 2002 [25].

Maine’s Drought Task Force convened in August 2016 for the first time in 14 years and continued to meet monthly through December. The 2016 drought was a result of three years of below average precipitation which led to low groundwater levels statewide, but particularly in the southern portion of Maine. As of this writing, the final impacts of the drought are undetermined, but it is reasonable to assume that the significant investments water utilities have made after the 2001 drought mitigated the impacts of the 2016 drought. Hundreds of millions of dollars have been spent replacing antiquated water mains. That has resulted in reduced loss of water through leakage. Additionally, many of those projects upgraded interconnections which have improved the ability of water utilities to purchase water from neighboring systems when the need has arisen.

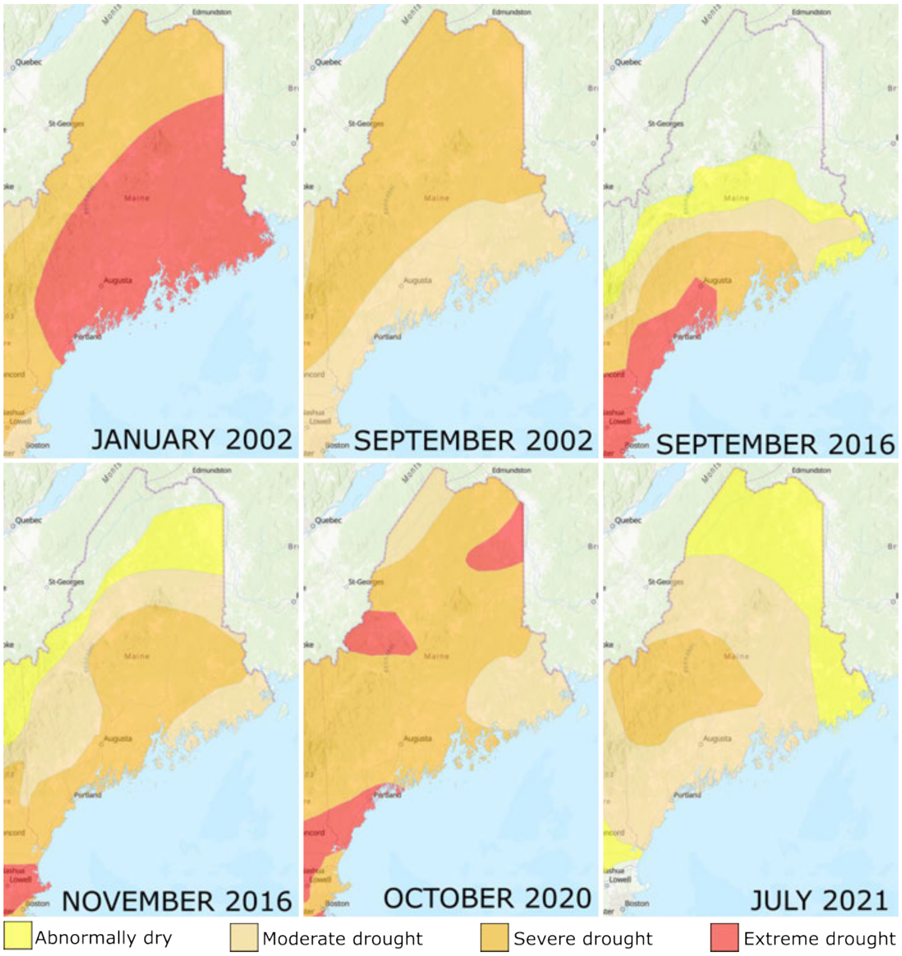

Figure 3.37: Peak drought conditions in Maine over the past 20 years based on analysis of U.S. Drought Monitor map records.

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[25] Lombard, P. J. (2004). Drought conditions in Maine, 1999-2002: a historical perspective. *US Geological Survey*, 03-4310. https://pubs.usgs.gov/wri/wrir034310/pdf/wrir03-4310.pdf

Table 3.36: Chronology of Major Droughts in Maine

Date	**Affected Areas**	**Average Recurrence Range**	**Remarks**
1938-1943	Western Areas	15 to > 30	Severe in Androscoggin and Kennebec River Basins
1947-1950	Statewide	25	Severe in central coastal region
1955-1957	Nearly entire state	20	Severe in northern and eastern parts of state
1963-1969	Statewide	70	Longest endured drought, stream flows in southern portions of Maine reached 100-year lows
1984-1988 [26]	Statewide	20	Severe in northern Maine
1999-2002[120]	Statewide	60	2001 was driest year on record (to date), August 2002 was driest month on record
2015-2016	Statewide	40 to 50	Most severe in York and parts of Cumberland Counties
2020-2022 [27]	Statewide	25	2020 flash drought Moderate to extreme drought across entire state, 2020 had the highest wildfire occurrence in 35 years. Severe drought re-emerged in 2021, 2022 triggering USDA Secretarial Disaster Designations in 2021

A 2020 drought impacted the entirety of New England and set records in Northern Maine [28]. Northeastern and central parts of the state went from normal conditions on June 9 to moderate drought (D1) on June 23, and then to severe drought (D2) by July 7 (this fast onset generally meets the criterion of a flash drought). Mean streamflows in July were below the 10th percentile, with three of eight sites recording a 30-year low in mean streamflow in July. D2 persisted for 12 weeks. Parts of northeastern Maine then saw conditions deteriorate to extreme drought (D3) by September. Extreme drought includes widespread crop loss, modified recreation and hunting, extremely reduced flow to no flow in streams, and increased well drilling and bulk water hauling. Indeed, in mid-September – a month in which some places saw no rain for 30 days – the U.S. Department of Agriculture declared crop disaster areas in Aroostook and adjacent counties. By fall 2020, substantial rainfall reduced the scope of drought in Maine, but this was soon followed by a warm winter and snow drought (Figure 3.38) [29]. In 2021, a dry spring and early summer saw moderate to severe drought conditions persisting across central and western portions of Maine until July when beneficial rainfall brought relief. Conditions improved for all but westernmost portions of the state. In 2022, a dry summer led to renewed drought in southern, coastal, and central Maine. As of this writing, counties along the southwest coast remain afflicted by severe (D2) drought.

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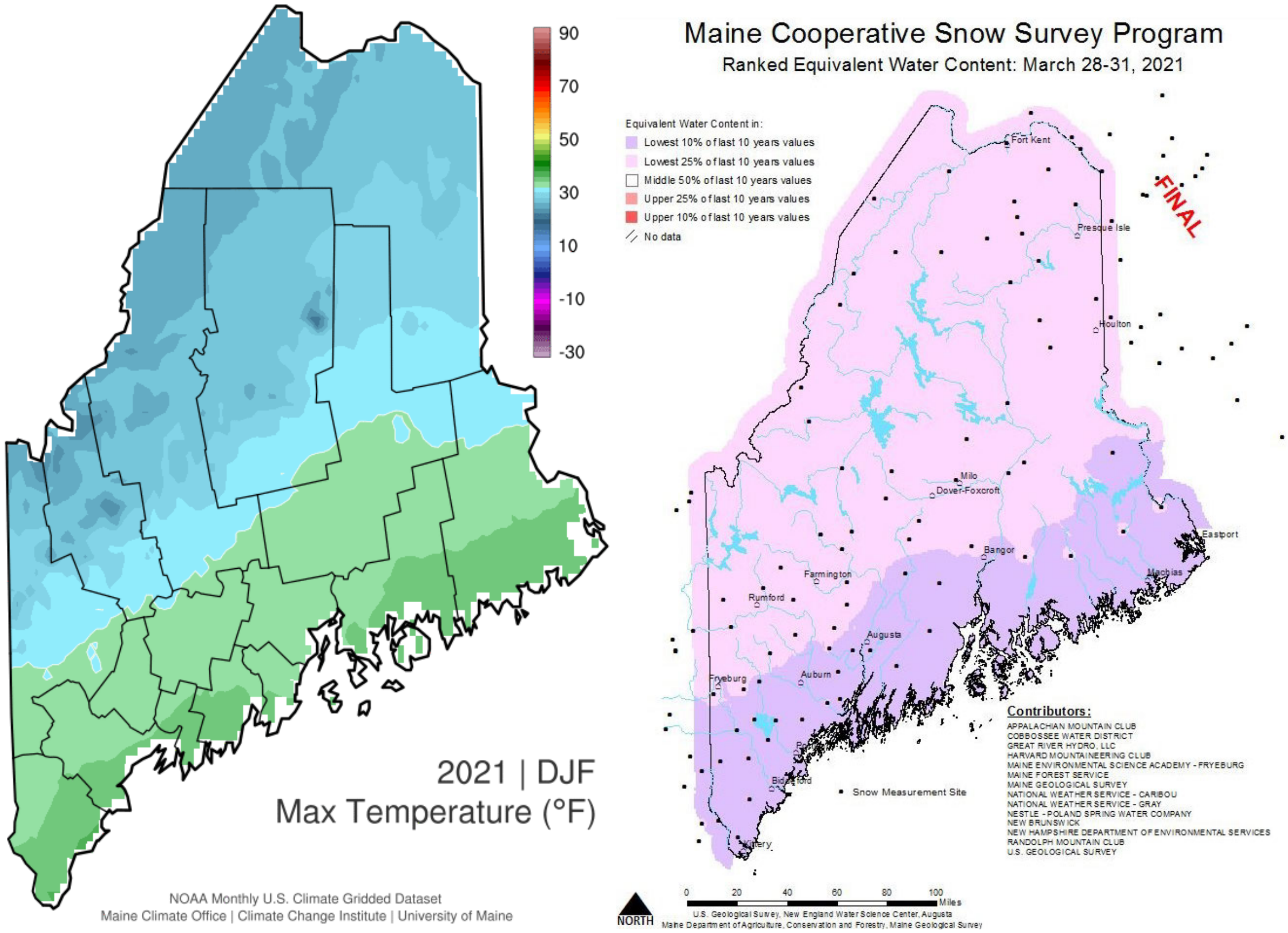
[26] Water Supply Paper 2375; National Water Summary 1988-89 – Hydrologic Events and Floods and Droughts. https://doi.org/10.3133/wsp2375

[27] Lombard, P. J., Barclay, J. R., & McCarthy, D. A. E. (2020). *2020 drought in New England* (No. 2020-1148). US Geological Survey. https://pubs.usgs.gov/of/2020/1148/ofr20201148.pdf

[28] Lombard, P.J., Barclay, J.R., and McCarthy, D.E. (2020), 2020 drought in New England (ver. 1.1, February 2021): U.S. Geological Survey Open-File Report 2020–1148, 12 p., https://doi.org/10.3133/ofr20201148.

[29] Maine Cooperative Snow Survey, March 31, 2021 Water Content Comparison map: https://www.maine.gov/dacf/mgs/hazards/snow_survey/



2021 | DJF
Max Temperature (°F)

NOAA Monthly U.S. Climate Gridded Dataset
Maine Climate Office | Climate Change Institute | University of Maine

Maine Cooperative Snow Survey Program
Ranked Equivalent Water Content: March 28-31, 2021

U.S. Geological Survey, New England Water Science Center, Augusta
Maine Department of Agriculture, Conservation and Forestry, Maine Geological Survey

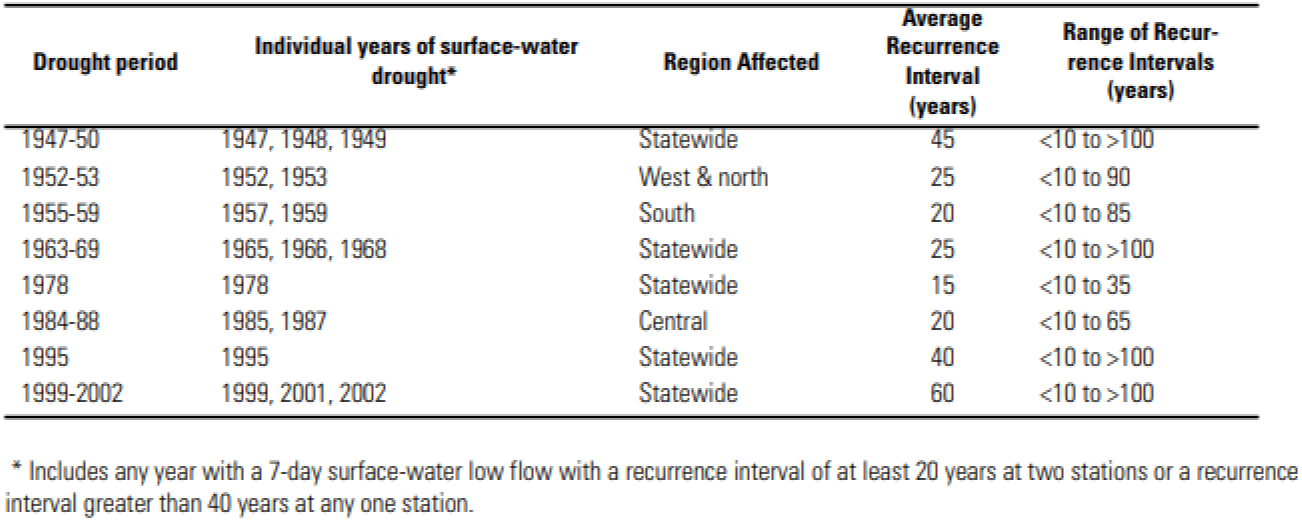
Figure 3.38: Mean maximum winter 2021 temperatures (left) denote substantial southern and coastal areas above melting temperature (green). Warm winter conditions led to warm snow drought (right): lower to much lower equivalent water content in snowpack remaining in late March across the entire state.

3.44 Drought – Probability of Future Occurrence [S4.]

Similar to floods, which are primarily driven by precipitation, meteorologists and hydrologists define the extent of drought by the probability of occurrence. Drought is defined by its spatial extent, intensity, magnitude and duration, the components of the hydrological cycle that it affects and the systems that it impacts. These multiple factors that define drought make it difficult to predict, quantify or put into historical context.

Extreme droughts are relatively uncommon and are expected to happen on average once every 20 to 50 years in our region, while moderate droughts are common and may occur every 5 to 10 years (Svoboda and others, 2002 [30]). Drought occurrence is difficult to determine in Maine due to the varied nature of drought conditions and their tendency to occur at different magnitudes and over multiple consecutive years. During the 1999-2002 drought, USGS reported recurrence of 7-day surface water low flow intervals for historic droughts in Maine for individual year occurrences (Table 3.37).

Table 3.37: Approximate recurrence intervals for historical droughts in Maine, 1947-2002 (Recurrence interval, the average interval of time within which streamflow will be less than a particular value; <, less than; >, greater than)



Drought period	Individual years of surface-water drought*	Region Affected	Average Recurrence Interval (years)	Range of Recurrence Intervals (years)
1947-50	1947, 1948, 1949	Statewide	45	<10 to >100
1952-53	1952, 1953	West & north	25	<10 to 90
1955-59	1957, 1959	South	20	<10 to 85
1963-69	1965, 1966, 1968	Statewide	25	<10 to >100
1978	1978	Statewide	15	<10 to 35
1984-88	1985, 1987	Central	20	<10 to 65
1995	1995	Statewide	40	<10 to >100
1999-2002	1999, 2001, 2002	Statewide	60	<10 to >100

* Includes any year with a 7-day surface-water low flow with a recurrence interval of at least 20 years at two stations or a recurrence interval greater than 40 years at any one station.

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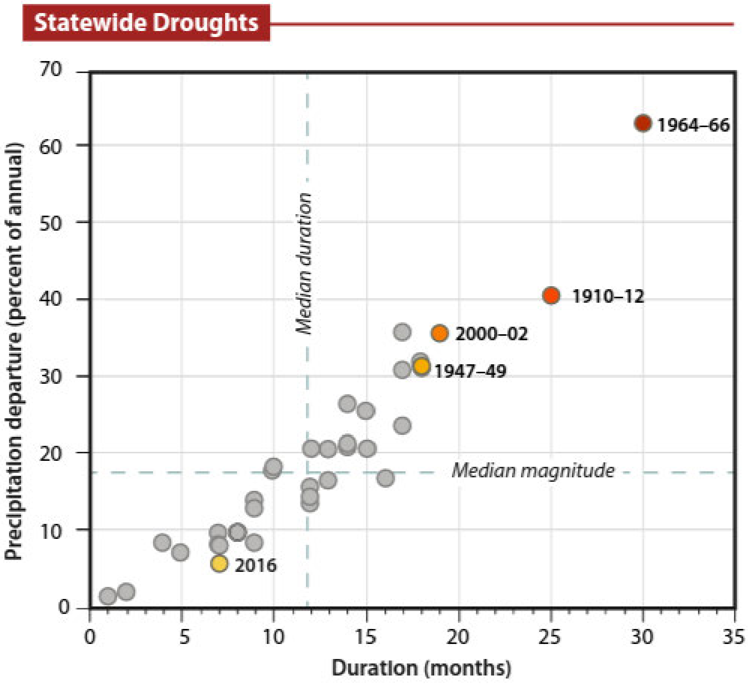
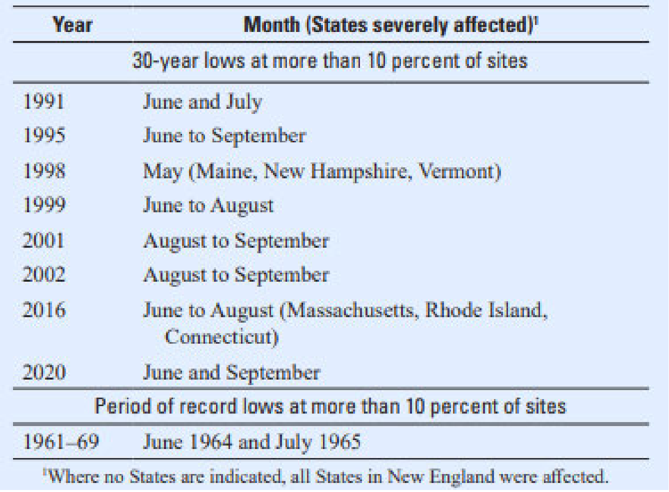
[30] Svoboda, M., LeComte, D., Hayes, M., Heim, R., Gleason, K., Angel, J., Rippey, B., Tinker, R., Palecki, M., Stooksbury, D., Miskus, D., and Stephens, S., 2002, The drought monitor: Bulletin of the American Meteorological Society, v. 83 no. 8, p. 1181–1190, accessed December 22, 2020, at https://doi.org/10.1175/1520-0477-83.8.1181.

An alternative approach was used for the 2020 drought report by focusing on occurrence of 30-year low flows at more than 10 percent of streamgages. The analysis also indicates the typical time of year for these low flow occurrences is through late spring to late summer (Table 3.39).



Statewide droughts based on the six-month Standardized Precipitation Index (SPI6), computed from monthly precipitation values averaged across Maine using climate division data, 1900–2018 (NOAA CAAG 2019). An index value of zero indicates average conditions, while negative values indicate drier than average conditions. Drought severity is measured by both drought duration (here, the number of months with SPI6 below 0) and associated cumulative precipitation deficit (the sum of monthly departures of precipitation from average over the course of the drought, displayed here as a percentage of annual average statewide precipitation).



Year	Month (States severely affected)[1]
30-year lows at more than 10 percent of sites	
1991	June and July
1995	June to September
1998	May (Maine, New Hampshire, Vermont)
1999	June to August
2001	August to September
2002	August to September
2016	June to August (Massachusetts, Rhode Island, Connecticut)
2020	June and September
Period of record lows at more than 10 percent of sites	
1961–69	June 1964 and July 1965

[1] Where no States are indicated, all States in New England were affected.

Table 3.39: Left: monthly duration of historic droughts versus their magnitude in terms of annual precipitation departure. Source: University of Maine (https://climatechange.umaine.edu/wp-content/uploads/sites/439/2020/02/Maines-Climate-Future-2020-Update-3.pdf). Right: Droughts in New England for individual annual occurrence and months impacted in the last 30 years. Source: USGS (https://pubs.usgs.gov/of/2020/1148/ofr20201148.pdf).

For prediction purposes, this plan will compare the Standard Precipitation Index (SPI) value associated with each drought intensity classification level used in the USDM to estimate the recurrence interval for each drought level (Table 3.38). The World Meteorological Association endorsed the SPI as the standard for determining the existence of meteorological drought.

Table 3.38: Recurrence Intervals for U.S. Drought Monitor Classifications

Intensity	SPI Trigger	SPI Recurrence Range[1]	USDM Recurrence Interval[2]
D0 (Abnormally Dry)	-0.5	3.25	3 – 5
D1 (Moderate Drought)	-0.8	4.75	5 – 10
D2 (Severe Drought)	-1.3	10.5	10 - 20
D3 (Extreme Drought)	-1.6	18.25	40 - 50
D4 (Exceptional Drought)	-2.0	44	50 - 100

NOTE: [1] The USDM uses a variety of indicators and indices to determine drought intensity in addition to the SPI. See table in Extent. The above recurrence intervals use the 30-day SPI timescale. [2] The authors of the USDM use objective and subjective input to develop their finished product. They design the USDM to have the recurrence intervals stated in USDM column (Rippey, Brad. Northeast Drought Outlook Forum. Boston, MA, 11 October 2016).

3.44.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Much like events of any type it is difficult to determine probability of occurrence for future drought events because "the global hydrological cycle is exhibiting significant variability, especially in the geographic distribution and intensity of precipitation, the availability of water resources, [and] prolongation of periods of drought" [31]. There is considerable uncertainty whether drought will become more frequent in the future, presenting challenges for mitigation strategies, however, there is an anticipation for greater occurrence of extreme events of all kinds in Maine, suggesting that droughts may become a more prominent event in a future climate. Increasing atmospheric temperatures may be able to hold greater moisture and provide greater total rainfall, but warmer temperatures will also encourage increased drying between rainfall events.

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[31] Williams Jr, R. S., Williams Jr, R. S., & Ferrigno, J. (2012). Changes in the Earth's Cryosphere and global environmental change. *State of the Earth's cryosphere at the beginning of the 21st century: Glaciers, global snow cover, floating ice, and permafrost and periglacial environments.* *http://pubs.usgs.gov/pp/p1386a/pdf/pp1386a-1-web.pdf*

Drought – Vulnerability Assessment

3.45 Drought – Impacts

A drought impact is defined by the World Meteorological Organization (WMO) as an observable loss or change at a specific time because of drought. [32] It is uncommon for drought to significantly impact Maine because of typical precipitation levels, the state's ground water hydrology, and a relatively low statewide demand for water compared to available resources. Still, all Maine communities can be vulnerable to impacts of drought. Droughts can impact stakeholders, who include homeowners (on private and public water supply), hydroelectric generators, the agricultural community, commercial businesses, foresters, and natural ecosystems.

All Maine residents are vulnerable to drought if it impacts water supply and food production. However, households on private wells are more vulnerable to water shortages because they are dependent on local ground water levels, which may already be in short supply, and are thus more susceptible to water scarcities. Private well owners do not benefit from the redundant measures that are set to protect public water supply. There are limited resources available to private homeowners with dry wells. With 42 percent of the state on private water supply, or 561,000 residents, Maine has the highest proportion of residents not served by a public water supplier. [33] Recent estimates indicate that closer to half of Maine's population may depend on private wells. Because many of these private wells are dug or shallow, any prolonged drought period can have significant impacts and reduce access to potable water.

The agricultural community is also vulnerable to drought, as drought is historically the most significant risk factor to the sector. Maine agriculture is the basis of over 1.2 billion dollars of food and fiber products annually. It employs 22,000 workers statewide and there are an estimated 8,000 family farms in Maine. [34]

Forest health is also vulnerable to drought events, as drought conditions can lead to high threat of forest fires. Forest and brush fire hazards are also common in early spring prior to leaf-out. Forest litter from the previous year may be especially dry if insufficient spring rains follow an early melting of the snowpack. Both of these situations occurred in 1947 as detailed in the Wildfire section. Residents in rural parts of Maine are the most susceptible to forest fires due to possible urban wildfire interface. The vulnerability of rural residents to drought events is compounded because rural residents make up most of the population on private wells.

Ineligibility for Hazard Mitigation Assistance – Since droughts do not receive presidential declarations, common drought mitigation activities, which include measures to increase efficiency and/or drilling wells deeper into the water table, are not eligible for funding through FEMA's Individual Assistance Program.

Residents on Private Wells – With nearly half of the state's population relying on private wells for water supply, the state has limited capacity for managing individual water supply.

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[32] http://www.droughtmanagement.info/literature/GWP_Handbook_of_Drought_Indicators_and_Indices_2016.pdf
[33] https://pubs.usgs.gov/circ/1405/pdf/circ1405.pdf
[34] https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MAINE

3.46 Drought – Vulnerability of State Assets [S5.]

Damages to state-owned or operated buildings or infrastructure are not likely from drought events. Costs typically come from the overtime use of Maine Department of Agriculture, Conservation and Forestry personnel to assist farmers and private well owners. The State of Maine does not own or operate any public water utilities but the Public Utilities Commission does regulate water supplier rates, and Maine's Drinking Water Program regulates water quality and facilitates needs for bulk water hauling in the event of water quantity issues.

3.46.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

Historically, the largest impacts of drought in Maine have been on agriculture, public water suppliers, and private wells. Drought has also had an indirect impact on resources needed for wildfire suppression (see Wildfire – Vulnerability Assessment). There have not been any documented damages to state owned buildings, infrastructure, or critical facilities at the time of this Plan update. There is no guarantee that these assets will be damaged in a natural hazard event.

3.46.2 Community lifeline Risks

In addition to the risks already described, the greatest impacts of drought relate to food and water. By definition, drought is a prolonged period of water shortage. State agencies have little authority over municipal water suppliers when it comes to taking emergency drought measures, but the state Drinking Water Program will help facilitate temporary solutions such as bulk water hauling to avoid a complete loss of local potable water. Local food production is a primary concern with drought as noted below. Currently the state is exploring funding programs that would support installation of irrigation infrastructure.

Drought has had major impacts on crop production in the past, posing potential issues for food supply at least on a local level. From an economic perspective, drought can put farms out of business if they are unable to produce. The pulp industry, a historically major contributor to Maine's economy, has been the largest industrial user of surface and groundwater in the State. Lack of abundant water could even influence pulp and paper production.

3.47 Drought – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.47.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

Jurisdictions that rely on small public water suppliers are expected to be at greater risk of running out of water and relying on expensive bulk water hauling arrangements to accommodate potable water needs. Private well owners may be impacted if they have shallow wells, or wells that are more susceptible to contamination from sea water intrusion or other natural (e.g., arsenic [35]) or human-caused (e.g., nitrates [36]) groundwater contaminants. A total of 394 wells ran dry during the drought years of 2020, 2021, and 2022. Jurisdictions may also see direct impacts if agriculture is a large contributor to the local economy and workforce.

Disadvantaged Communities

Like all other hazards profiled in the Plan, disadvantaged communities are expected to be hit hardest by drought given a lack of resources to mitigate, prepare, or recover against natural disasters. Some of the most significant impacts in Maine are felt by rural farming communities whose livelihoods depend on a consistent supply of water that is threatened by drought. Systems to mitigate against the impacts of drought, such as drilling additional wells and installing irrigation systems, are expensive and often not within the typical budget of

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[35] Maine CDC arsenic webpage: https://www.maine.gov/dhhs/mecdc/public-health-systems/health-and-environmental-testing/arsenic.htm
[36] Maine CDC nitrates webpage: https://www.maine.gov/dhhs/mecdc/environmental-health/dwp/sitemap/nitrateNitrite.shtml

smaller farming operations. The quality and yield of agricultural commodities will suffer under drought conditions without proper irrigation [37], with longer term economic impacts for rural disadvantaged communities as a whole. Many other impacts can be felt by urban communities who depend on public water suppliers who may also face challenges meeting demand without using expensive alternatives.

Drought also heightens the potential occurrence of wildfires, with further amplified impacts for disadvantaged communities as described in the section Wildfire – Vulnerability Assessment.

3.47.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Though there may be several contributing factors to losses during a drought, some primary impacts include agricultural costs, bulk water hauling costs for dry public water suppliers, and costs associated with improving or redrilling private wells.

Agricultural losses could be significant under different drought scenarios (Table 3.39 [38]). Drought may lead to crop failures or greater use of irrigation that can increase operating costs for farmers, which may lead to increased prices for consumers.

Table 3.39: Impacts to agricultural commodities under different drought levels. Colors denote relative high (green) and low (red) values.

Location	Commodity Totals	Commodity totals under drought scenarios		
		Moderate drought: 25% losses	Severe drought: 50% losses	Extreme drought: 75% losses
State	$666,962,000	$500,221,500	$333,481,000	$166,740,500
Androscoggin	$40,536,000	$30,402,000	$20,268,000	$10,134,000
Aroostook	$201,974,000	$151,480,500	$100,987,000	$50,493,500
Cumberland	$25,644,000	$19,233,000	$12,822,000	$6,411,000
Franklin	$12,853,000	$9,639,750	$6,426,500	$3,213,250
Hancock	$18,372,000	$13,779,000	$9,186,000	$4,593,000
Kennebec	$49,007,000	$36,755,250	$24,503,500	$12,251,750
Knox	$9,116,000	$6,837,000	$4,558,000	$2,279,000
Lincoln	$12,882,000	$9,661,500	$6,441,000	$3,220,500
Oxford	$12,882,000	$9,661,500	$6,441,000	$3,220,500
Penobscot	$50,915,000	$38,186,250	$25,457,500	$12,728,750
Piscataquis	$9,108,000	$6,831,000	$4,554,000	$2,277,000
Sagadahoc	$7,749,000	$5,811,750	$3,874,500	$1,937,250
Somerset	$83,931,000	$62,948,250	$41,965,500	$20,982,750
Waldo	$22,954,000	$17,215,500	$11,477,000	$5,738,500
Washington	$69,253,000	$51,939,750	$34,626,500	$17,313,250
York	$28,551,000	$21,413,250	$14,275,500	$7,137,750

2017 USDA Agricultural Census

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[37] Maine Drought Task Force 4 August 2022 Report: https://www.maine.gov/mema/sites/maine.gov.mema/files/inline-files/Drought%20Task%20Force%20Report%2008-04-2022.pdf

[38] USDA 2017 Agricultural Census: https://www.nass.usda.gov/Quick_Stats/CDQT/chapter/2/table/1/state/ME/county/031/year/2017

A total of 394 wells were reported to have run dry for the years 2020-2022, with some counties impacted more than others (Table 3.40). Southern counties are generally more populated and typically experience a greater total number of wells running dry under drought conditions versus other locations in the state, assuming uniform levels of drought.

Table 3.40: total number of wells reported to have run dry by county and state.

County	2020	2021	2022	TOTAL
Androscoggin	6	0	4	10
Aroostook	96	1	0	97
Cumberland	17	4	18	39
Franklin	21	2	4	27
Hancock	5	0	4	9
Kennebec	10	1	10	21
Knox	5	1	7	13
Lincoln	4	2	12	18
Oxford	13	4	2	19
Penobscot	9	2	3	14
Piscataquis	2	1	0	3
Sagadahoc	6	0	6	12
Somerset	20	1	3	24
Waldo	9	0	5	14
Washington	9	0	3	12
York	45	2	15	62
TOTAL	277	21	96	394

MEMA Dry Well Survey (maine-dry-well-survey-maine.hub.arcgis.com/)

The cost of drilling a new well can be highly variable depending on materials and labor cost. Installing a complete well water system costs $25-65 per foot, with the national average costing $3,750-15,300 per well [39]. Costs for building municipal water storage facilities can exceed $1 million [40]. Assuming the 394 wells would need to be redrilled from the 2020-2022 drought, the total average cost may equal $1.5 to $6 million dollars.

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[39] State of California Central Valley Flood Protection Board Well Drilling Costs Report: http://cvfpb.ca.gov/wp-content/uploads/2020/11/8b.-EIS-Attachment-Well-Drilling-Costs.pdf

[40] https://www.mainepublic.org/environment-and-outdoors/2022-07-28/stonington-is-trucking-in-drinking-water-because-of-drought-and-summer-crowds

Erosion – Hazard Profile

TIER 1 HAZARD

3.48 Erosion – General Definition and Types of Events [S3.a., S3.b.]

Erosion is the process of the gradual wearing away of land masses. The focus of erosion as a hazard in Maine is widespread soil erosion, including the detachment, transport, and deposition of sediment. There are generally four recognized agents of sediment erosion: water, wind, ice/glaciers, and mass wasting/gravity. The focus of this hazard profile is on erosion caused by water movement, with a primary focus on coastal processes. Hazards associated with mass wasting are discussed in a separate profile. Rates of erosion can be rapid, such as within the timeframe of a single coastal storm event, or more prolonged, such as the gradual erosion of coastal land features through sea level rise. Beach and bluff coastal land features exhibit the greatest rates of erosion in Maine and are therefore the primary focus of this hazard profile.

3.48.1 Coastal Beach and Dune Erosion

Coastal beaches are narrow, gently sloping strips of land that lie along ocean shores. Beaches may consist of any combination of grain sizes though sand, gravel, and cobble beaches are more well recognized types in Maine. The sediments may consist of several different rock types and/or shell fragments. Sandy beaches are typically associated with passive margins, a wide continental shelf, and a geologic framework conducive to abundant sediment supply [41]. These regions may host coastal dunes (Figure 3.40) that consist of a series of ridges of sediment that form landward of a beach. Dunes differ from most other coastal landforms in that they are formed by winds in addition to wave overtopping [42]. Dunes provide natural protection to inland areas from wind, waves, and coastal flooding. Dunes are typically naturally stabilized by vegetation, including American beachgrass, which helps to decrease erosion. Gravel (cobbles, boulders, and pebbles) beaches and dunes are typically found in high-energy coastal environments and are a common occurrence in Maine, especially in mid-coast and downeast areas of the State.

Maine's coastal beaches and dunes are constantly changing. Erosion or accretion can reshape the beach and dunes over time, so remapping is needed for resource protection and coastal development. Beaches and dunes comprise about 2% of Maine's overall shoreline. Beach and dune erosion occurs in widely scattered locations, primarily on the state's larger beaches and sand dune systems located in York, Cumberland, and Sagadahoc Counties, though beaches and dunes are located throughout the State's coastal municipalities. The Maine Geological Survey has mapped the extent of dunes that comprise the State's coastal sand dune systems [43] and also keeps track of dune and beach shoreline changes at Maine's larger beach systems through its Maine Beach Mapping Program

Figure 3.40: dune grassland.

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[41] National Park Service, Coastal sediments: https://www.nps.gov/articles/coastal-sediments-material-size.htm
[42] Coastal dunes: https://www.nature.com/scitable/knowledge/library/coastal-dunes-aeolian-transport-88264671/
[43] Maine Geological Survey Coastal Sand Dune Geology: https://www.maine.gov/dacf/mgs/pubs/digital/dunes.htm

3.48.2 Coastal Bluff Erosion

Bluffs are defined as a steep shoreline slope formed in sediment (loose material such as clay, sand, and gravel) that has three feet or more of vertical elevation just above the high tide line (The slope, shape, and amount of vegetation covering a coastal bluff and the adjacent shoreline are directly related to the susceptibility of the bluff face to ongoing erosion. As might be expected, less vegetated bluffs are more likely to be eroding than completely vegetated bluffs. Another important factor related to stability is the material that makes up the bluff. Clay, gravel, and sand react differently to erosion and, when combined with variations of vegetation and slope, affect the rate of erosion. Cliffs or slopes in bedrock (ledge) surfaces are not bluffs and are not subject to significant erosion in a century or more. Beaches and dunes do not form bluffs, except along the seaward dune edge as a result of erosion [44]. Bluffs in Maine have been classified as stable, unstable, or highly unstable (Figure 3.41).

About 48% of the Maine coastline is comprised of unconsolidated, erodible coastal bluffs that are three feet or greater in relief. The Maine Geological Survey estimates that about one-third of these bluffs are currently eroding. Bluff stability maps are available through MGS. Note that these maps provide information on bluff stability based on the time of the survey; conditions may have changed since mapping was completed. The stability of coastal bluffs above the high tide line are classified by MGS as follows:

Highly Unstable

Near vertical or very steep bluffs with little vegetation and common exposure of bare sediment. Fallen trees and displaced blocks of sediment are common on the bluff face and at the base of the bluff.

Unstable

Steep to gently sloping bluffs, mostly covered by shrubs with a few bare spots. Bent and tilting trees may be present.

Stable

Gently sloping bluffs with continuous cover of grass, shrubs or mature trees. A relatively wide zone of ledge or sediment occurs at the base of the bluff.

No Bluff

Broad, gently sloping vegetated land or bare ledge with less than three feet of sediment cover.

Maine Geological Survey Coastal Bluffs Maps also describe the shoreline at or below the high tide line. The shoreline can consist of ledge, salt marsh, a beach or tidal flat, or it may be armored (protected by man-made interventions such as riprap, seawalls or other engineered structures).

Finer grained sediments are typically more responsive to the flow of water than larger grained gravels and therefore may exhibit more rapid erosion rates under the same magnitude of waves, currents, and other influential coastal processes [45]. Marine clays are common in Maine, but they typically occur in tidal flats along bays and inlets that are more protected from wave activity. Clays also exhibit particle interaction forces that make them more cohesive and therefore less responsive to detachment and transport mechanisms. However, the presence of glaciomarine clay layers tends to destabilize coastal bluffs under certain conditions that can lead to mass wasting. Refer to the mass wasting hazard profile for more details.

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[44] Maine Geological Survey, definition of bluffs: https://www.maine.gov/dacf/mgs/pubs/digital/bluffs.htm

[45] Nguyen, V. B., Nguyen, Q. B., Zhang, Y. W., Lim, C. Y. H., & Khoo, B. C. (2016). Effect of particle size on erosion characteristics. *Wear*, *348*, 126-137: doi.org/10.1016/j.wear.2015.12.003

▤ **Stable bluff** with a vegetated bluff face and an armored shoreline. The bluff face is fully vegetated and supports a mature stand of trees with vertical trunks. The presence of a wooden bulkhead suggests that erosion has occurred in the past.

▧ **Stable bluff** with a vegetated bluff face and a salt marsh shoreline. A low bluff face is covered by shrubs landward of a salt marsh terrace. In this location the mature marsh protects the base of the bluff from rapid erosion and slows bluff recession or retreat.

▧ **Highly unstable bluff** with an unvegetated bluff face and a salt marsh shoreline. Sediments on the bluff face are exposed and fallen tree trunks lie at the base of the bluff. A salt marsh has recently formed on the tidal flat, partly on the top of an old landslide deposit.

▨ **Highly unstable bluff** with an unvegetated bluff face and a beach/gravel flat shoreline. The bluff face is too unstable to support vegetation. This bluff, a glacial esker, is eroded by waves to create a mixed sand and gravel beach in front the bluff.

Figure 3.41: Examples of stable (top) and highly unstable (bottom) bluffs.

3.49 Erosion – Location of Hazard [S3.a.1]

3.49.1 Coastal Beach Erosion

Beaches, which are part of Maine's "soft coast," only account for about 2 percent of the state's tidal shoreline, with the larger beaches concentrated in York and Cumberland Counties. Beaches are dynamic systems subject to erosion and accretion changes associated with seasonality. However, because of rising sea levels, erosion is expected to continue to dominate over accretion in most beach locations. Chronic long-term erosion along many beaches is on the order of a foot or more per year and is classified by MGS Maine Beach Mapping Program and summarized every 2 years in the State of Maine's Beaches Report.

3.49.2 Coastal Bluff Erosion

Maine is famous for its rockbound coast, buttressed by rugged, unchanging cliffs of stone. Rocky points such as Portland Head, photographed a century ago, show little change after a hundred years of storms. This is because Maine's bedrock is very strong and consolidated, so that it resists erosion from waves and weather. About 50% of Maine's coastline is comprised of consolidated bluffs. However, about 48% of Maine's coastline is comprised of unconsolidated bluff, and 17.5% of the Maine coastline consists of unstable to highly unstable bluff consisting of loose or unconsolidated materials that are subject to erosion. Although a slow, steady rise in sea level is the underlying reason for erosion along the coast, the most noticeable erosion occurs quickly during individual storms or landslide events.

Roughly half the coast of Maine consists of coastal bluffs. Bluff erosion is part of a natural cycle with consequences for the land below and above the bluff. Fine-grained silt and clay eroded from bluffs may be deposited on mud flats or salt marshes which help reduce wave energy at the base of a bluff and slow the overall rate of bluff erosion. Coarse-grained sediments, such as sand and gravel, eroded from bluffs become part of a beach at the base of the bluff and help stabilize the shoreline position.

Bluff erosion can result in a landward shift of the top edge of the bluff. This shoreline change is a natural process that, by itself, is not a coastal hazard (Figure 3.42). It becomes a hazard when it threatens something of value, such as a building near the edge of the bluff.

Coastal bluffs erode episodically[46]. Some bluffs may not change much over many years, even though there are steep banks along the shore. Bluffs may not lose much ground in any one year but may slump a large amount of sediment every few years. Through this process, bluffs may become stable for a period of time before erosion of the toe continues and causes instability. Coastal bluffs that are classified as being either highly unstable or unstable are retreating at an average rate of about one (1) foot per year.

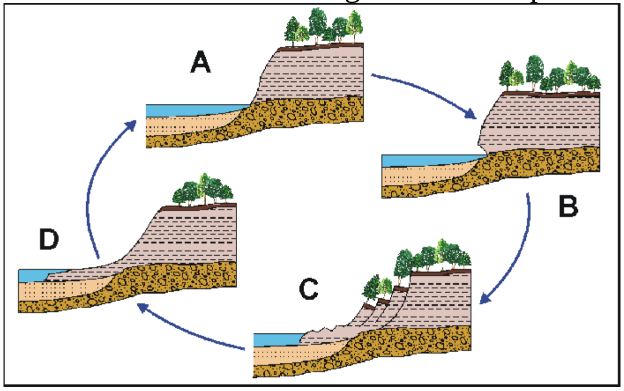

Figure 3.42: Side view of the coastal bluff erosion process. Maine Geological Survey.

Unlike dunes, which may reappear in our lifetimes due to sediment deposition by waves and wind, bluff erosion is irreversible, and bluffs will not "reform" in a similar sense. Refer to the section Mass Wasting – Hazard Profile for more information on related bluff erosion mechanisms.

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[46] MGS Coastal Property Owner Guide https://digitalmaine.com/cgi/viewcontent.cgi?article=1605&context=mgs_publications

3.50 Erosion – Intensity and Previous Occurrences [S3.a.2.]

Coastal Beach Erosion

Many Maine beaches are eroding 1 foot per year, while others are eroding up to 3 feet per year [47]. Along Maine's larger beach and dune systems (mostly in York, Cumberland, and Sagadahoc Counties), the Maine Geological Survey conducts monitoring of beach and dune erosion through the Maine Beach Mapping Program (MBMAP) [48]. MBMAP monitors annual shoreline change, along 36 beaches in 16 coastal municipalities and provides updated data in early fall of each year (Figure 3.43). In addition, MGS, the University of Maine, and Maine Sea Grant established the State of Maine Beach Profiling Program (SMBPP) in 1999. This program uses trained volunteers to monitor beach profiles on a monthly basis at select locations along the southern Maine coastline. As of 2022, 12 beaches in 10 communities are monitored as part of the program. Collected data is available for observation and download through MGS Collect (https://www.maine.gov/dacf/mgs/collect/). Every 2 years, MGS summarizes both MBMAP and SMBPP observations in a State of Maine's Beaches Report. The most recent report, from 2022, is located at: https://digitalmaine.com/mgs_publications/618/, and past reports are available from MGS.

Figure 3.43: 2021 beach dune monitoring map. www.maine.gov/dacf/mgs/hazards/beach_mapping/index.shtml

Coastal Bluff Erosion

Bluff stability along about 75% of Maine's shoreline is classified by the Coastal Bluff Map series. About one-third of unconsolidated bluffs along the Maine shoreline are eroding.

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[47] Maine Coastal Erosion and Hazards: https://www.maine.gov/dacf/mgs/explore/marine/virtual/erosion/virtual_coastal_erosion.pdf
[48] MBMAP: https://www.maine.gov/dacf/mgs/hazards/beach_mapping/index.shtml

3.50.2 Previous Occurrences

According to the Maine Geological Survey, during the past century, 30-40 buildings have been destroyed by beach erosion in Maine:

- At Camp Ellis, Saco; 33 lots are now in the ocean (Figure 3.40).
- At least 10 buildings, including a hotel, were lost at Popham Beach in Phippsburg in 1976 (Figure 3.44). A number of others were undermined and threatened by erosion and have since been moved landward and elevated.
- A hotel at Higgins Beach in Scarborough was destroyed by erosion.

Some of the worst erosion, on the order of 2-3 feet/year, is occurring at Camp Ellis Beach in Saco. Over 30 lots have been lost to the sea since 1908. The erosion in the area is caused by a lack of natural sediment to adjacent beaches due to the presence of the northern jetty of the Saco River (placed in 1869), wave focusing on Camp Ellis Beach due to offshore bathymetry, and reflected wave energy that directs wave energy from the jetty onto

Figure 3.40: (Left) Aerial photograph of the Saco River jetties and Camp Ellis. Incoming waves during northeast storms reflect off the northern jetty and focus wave energy along Camp Ellis Beach. Tax map overlay from 1908 indicates the number of parcels that have been lost by erosion. Erosion rates immediately adjacent to the jetty are 2-4 feet per year. A deep trough adjacent to the jetty has formed. Map created by Maine Geological Survey.

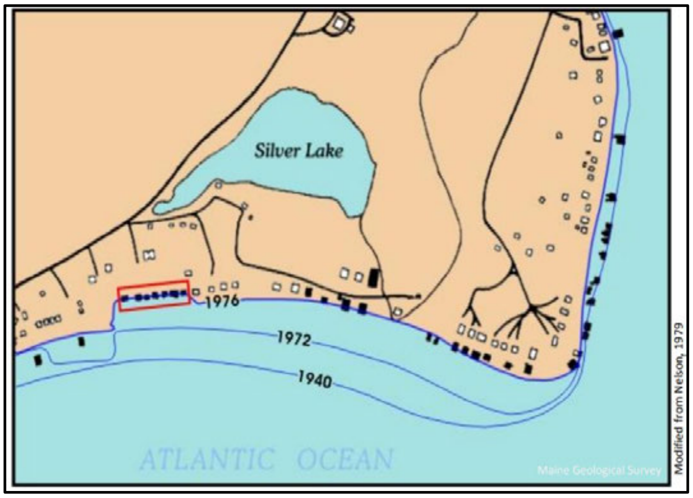

Figure 3.44: Historic shorelines along Popham Beach in Phippsburg. The blue lines show the location of the shoreline in 1940, 1973, and 1976. The small rectangles represent houses along the coast. The black rectangles represent houses that have been destroyed due to the coastal erosion. The red box outlines a row of

In the last 20 years, five houses in Saco were completely destroyed by erosion. Many others were damaged. Erosion of coastal beaches and bluffs occurs on a continuous basis along many parts of the Maine coast, resulting in an average annual loss of a foot or more on some beaches, and about a foot on highly unstable/unstable bluffs.

3.51 Erosion – Probability of Occurrence [S4.]

Maine's experience with erosion, coupled with the continual rise in the level of the sea, indicate that there is a high probability that erosion will continue to occur on an annual basis in various locations along the Maine coast. Rising sea levels are exacerbating coastal erosion by elevating water levels, which allows waves to erode higher areas of dunes and bluffs. In Maine, there is only a 1-foot difference between the water level associated with a 1% event and a 10% event. Thus, with just 1 foot of sea level rise, the storm that has a 10% chance of occurring in any given year will have the impact of a storm that has a 1% chance of occurring

3.51.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Shoreline erosion is driven in part by the elevation of the high tides. As sea level rises, the height of the high tide rises, and the height of the coastal flood plain rises. A higher floodplain will alter the frequency and inland extent of property damage from floods. Waves and currents can erode soil, bluffs, and beaches when they wash ashore at higher and higher levels. Salt water will reach farther inland and damage roots of trees, shrubs, and grasses. Underground salt water will flow farther inland and "intrude" on freshwater aquifers, perhaps turning some coastal wells salty. As the ocean rises, all coastal environments - salt marshes, mud flats, exposed ledge, and beaches - will attempt to migrate inland. If the transgression of marine environments over terrestrial ones is prevented, then some loss of coastal wetlands can be expected. Over decades, coastal infrastructure - docks, pipelines, roads, utilities, among others - will need to be rebuilt at higher levels or farther inland to provide an equal amount of protection or service.

Beaches undergo changes during storms and in response to sea-level rise. During storms, waves attack the berm and dunes, causing overtopping of the dunes and overwash. At the same time, the berm and dunes are eroded, and sediment is transported offshore and deposited in sandbars. This causes waves to break farther offshore, decreasing the wave energy that reaches the beach. As sea level rises, the same process occurs: waves can attack the upper part of the beach profile, pushing sand over the dune in a process called overwash. At the same time, sand is pulled offshore. The barrier beach migrates landward, rolling landward over itself. The initial beach migrates landward over its own marsh into its second position. This is why you can find peat deposits, tree stumps, and oyster shells in the surf zone. Think of the beach as a tread on a tank rolling over itself in a landward direction [49].

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[49] Maine Geological Survey Coastal Erosion FAQ: https://www.maine.gov/dacf/mgs/hazards/erosion/faq.htm

3.52 Erosion – Impacts

The erosion of portions of Maine's coastline, notably along beaches, dunes, and bluffs, is driven largely by coastal storm events such as extratropical (nor'easters and southeasters) and tropical cyclones. The health of beaches and dunes is related to their available supply of sediment. Those beaches and dunes with a healthy sediment supply, often from a nearby river, can have an excess of sediment and accrete, or build seaward. Beaches and dunes with a limited sediment supply, such as small pocket beaches surrounded by headlands, depend on seasonal shifts in sand to maintain their overall shapes. Beaches and dunes undergo distinct seasonal changes – for example, during the winter months, dunes are eroded, and beaches are typically concave in shape, with sand from the beach and dune stored in offshore bars. During summer months, the sand typically returns to the beach and dune, and the beach becomes higher and more convex in shape, while dunes usually recover from the previous winter erosion.

In natural areas, beaches and dunes respond to coastal storms and sea level rise by migrating landward over time, rolling over the back-barrier similar to a tank tread. In highly developed areas, such as those with structures and/or seawalls, this process is impeded, and the beach or dune has limited room to migrate. Coastal bluffs, unlike coastal sand dunes, erode one-way in our lifetimes, and don't reform. Eroding bluffs can "heal" themselves through the bluff erosion cycle, in which a section of eroding bluff calves off through a small landslide process, which decreases the unstable slope and then stabilizes the toe of the bluff for a period of time. Beach, dune, and bluff erosion is a natural process that, by itself, is not a hazard. It becomes a hazard when erosion threatens man-made structures such as dwellings that are in a fixed location on the coastline.

The unconsolidated sections of Maine's coastline – beaches, dunes, and bluffs – are vulnerable to coastal erosion. However, as stated before, erosion by itself isn't necessarily a hazard, but becomes a hazard when it threatens man-made infrastructure. Highly developed areas of the southern Maine sandy coastline are particularly vulnerable to erosion impacts. Locations such as Camp Ellis, Wells Beach, and Popham Beach experience significant erosion rates in a year, threatening coastal properties and diminishing state-protected areas.

3.53 Erosion – Vulnerability of State Assets [S5.]

3.53.1 Potential Dollar Losses to State Owned Buildings, Infrastructure, Critical Facilities

State building/structure assets

It was determined that no state facilities that would be used during an emergency or disaster for response or recovery are located in erosion hazard zones. MEMA identified 4 structure assets located within 60 feet of unstable to highly unstable bluffs with a total building replacement cost of $3.3 million. These assets rated by valuation are listed in Table 3.41. No state assets were identified to be within beach dune erosion hazard areas.

Table 3.41: Identified state assets within 60 feet of unstable to highly unstable coastal bluffs. Note that one location may hold multiple assets.

Address	**County**	**Occupancy Type**	**Property Type**	**Year Built**	**Last Inspected**	**Total Valuation**	**Agency**
45 Granville Rd, Bass Harbor, Maine, 04653	Hancock	PIER	Steel framed and sided.	-	2/6/2006	$3,016,000	DOT, MAINTENANCE & OPERATIONS
45 Granville Rd, Bass Harbor, Maine, 04653	Hancock	OFFICE	Wood framed. Wood siding.	1997	7/1/2005	$244,400	DOT, MAINTENANCE & OPERATIONS
45 Granville Rd, Bass Harbor, Maine, 04653	Hancock	OFFICE	-	-	-	$18,720	ADF, OFFICE OF INFO TECH, COMPUTERS SERVERS ETC.
2255 US-1, Sullivan, Maine, 04664	Hancock	REST ROOM	Wood framed. Wood siding.	2002	6/3/2015	$15,600	DOT, EASTERN REGION

There is no guarantee that these assets will be damaged in a natural hazard event. The state operated ferry at Bass Harbor is in close proximity to an unstable to highly unstable bluff, making it potentially vulnerable to erosion impacts that could directly damage the infrastructure. A temporary or long-term closure of the Bass Harbor terminal would impact ferry services to Swans Island and the ability for its 324 residents to reach the mainland, or the many seasonal tourists to visit the island.

State Road Assets

A total of 55.75 miles of state and municipal roads were identified within 60 feet of unstable to highly unstable coastal bluffs (Table 3.42). The state roads host an average of 4,910 vehicles per day. Assuming that road replacement costs equal $1.5 to $2 million per mile, the value of potentially exposed state roads range from $18.5 to $24.2 million.

Table 3.42: Public roads intersected by unstable to highly unstable bluff locations, indicating potential exposure to future erosion events.

Jurisdiction	Road miles	AADT* average	Reconstruction cost (millions)
Total	55.75	1,697	$83.6-$112
State	12.1	4,910	$18.5-$24.2
Local	43.6	273	$65.4-$87.2

*AADT: annual average daily traffic per segment

Conserved Lands

Many of Maine’s most visited state parks contain beach and bluff erosion hazards (Table 3.43). A total of 31 parks are potentially exposed to coastal erosion hazards, and in many cases these hazards involve beach and bluff erosion processes. These parks are distributed across all coastal counties.

Table 3.43: Maine State Parks exposed to beach and bluff erosion hazards. Parks in bold are high visitation sites.

State Park	Beach Erosion	Bluff Erosion	Municipality	County	Building replacement cost*
Andrews Beach	🟨		Long Island	Cumberland	
Barrett Park		🟧	Boothbay Harbor	Lincoln	
Birch Point State Park	🟨		Owls Head	Knox	
Camden Hills State Park		🟧	Camden	Knox	
Clark Cove		🟧	Harpswell	Cumberland	
Crescent Beach State Park	🟨	🟧	Cape Elizabeth	Cumberland	
Duck Trap	🟨	🟧	Lincolnville	Waldo	
Eastern Head	🟨		Trescott	Washington	
Ferry Beach State Park	🟨	🟧	Saco	York	
Fort Point State Park and Fort Pownal		🟧	Stockton Springs	Waldo	
Fort Popham	🟨		Phippsburg	Maine	
Fort Webber (Fort Island)		🟧	Boothbay	Lincoln	
Gleason Point	🟨		Perry	Washington	
Holbrook Island Sanctuary State Park	🟨	🟧	Castine	Hancock	
Jewell Island	🟨	🟧	Jewell Island	Cumberland	
Lamoine State Park	🟨	🟧	Lamoine	Hancock	$2,105,941
Laudholm Farms	🟨	🟧	Wells	York	
Little Chebeague Island	🟨	🟧	Little Chebeague	Cumberland	
Mackworth Island State Park		🟧	Falmouth	Cumberland	
Marblehead Boat Launch		🟧	Biddeford	York	
Moose Point State Park		🟧	Searsport	Waldo	
Owls Head Light State Park		🟧	Owls Head	Knox	
Penobscot River Boating Access		🟧	Verona Island	Hancock	
Piscataqua River Boat Access		🟧	Eliot	York	
Popham Beach State Park	🟨	🟧	Phippsburg	Sagadahoc	$2,130,973
Quoddy Head State Park	🟨		Lubec	Washington	
Reid State Park	🟨		Georgetown	Sagadahoc	
Roque Bluffs State Park	🟨		Roque Bluffs	Washington	
Scarborough Beach State Park	🟨	🟧	Scarborough	Cumberland	$124,706
Warren Island State Park	🟨	🟧	Islesboro	Waldo	
Wolfes Neck Woods State Park		🟧	Freeport	Cumberland	
Total Park Building Replacement Cost:					$4,361,620

*Building replacement costs are assumed to be an incomplete assessment for this analysis of State Parks.

Building replacement costs are available for 3 of the 31 parks, with a total valuation of $4.36 million. Please note that this is likely an underestimate of total structural state assets located within these and all other parks.

3.53.2 Community Lifeline Risks

As already noted, erosion can impact transportation needs, which may hinder the ability of emergency responders to access the impacted area and impact access to critical medical, food, and shelter services.

3.54 Erosion – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.54.1 Identifying Jurisdictions with Greatest Vulnerability [S6.a.1.]

All jurisdictions may be exposed to hazardous erosion processes. Coastal processes are the most well studied, though there are still many uncertainties related to potential future erosion events in coastal communities. Best available data provide a foundation for a vulnerability analysis that can, at a bare minimum, provide a summation of georeferenced assets that may potentially become exposed to bluff and beach erosion risks in the future.

Disadvantaged Communities

The objective of the disadvantaged communities' assessment is to identify potential disadvantages felt by communities who are disproportionately impacted by natural hazards both historically and under future projections. Erosion is a hazard of growing concern in coastal Maine with sporadic events occurring further inland as well (see Mass Wasting- Hazard Profile). Locations at risk of erosion are predictably located in areas of potentially unstable sediments adjacent to flowing water and/or wave activity. However, much like flood risks, such properties are often highly valued due to their viewsheds and proximity to water.

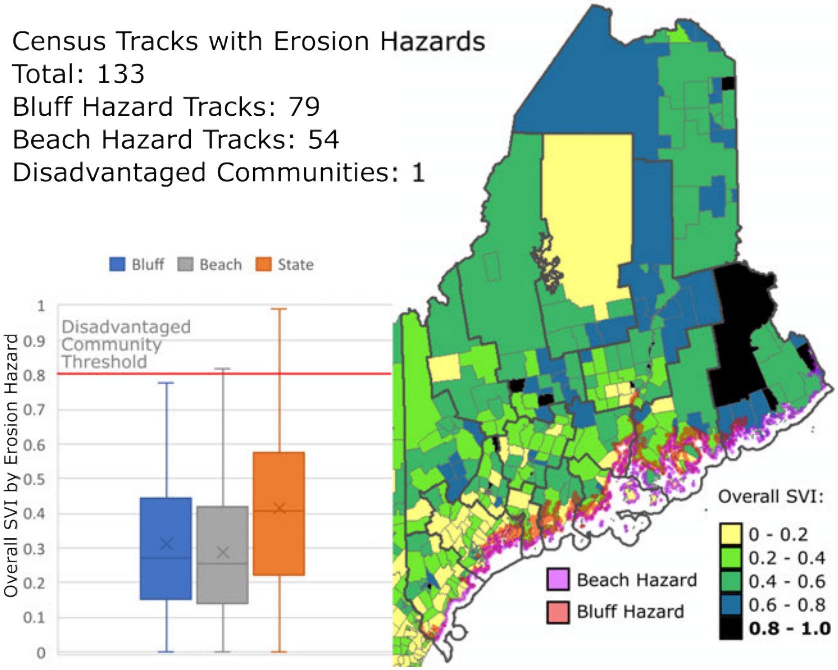

Figure 3.45

Use of SVI census tracts indicate a single disadvantaged community (5% of all disadvantaged communities in Maine) is potentially exposed to identified beach erosion hazards while none are exposed to identified bluff erosion hazards. Overall, SVI values for communities within these hazard areas are on average substantially less than the state SVI average. One limitation of this analysis is the coarse resolution of census tracts in Maine relative to the finer scale socioeconomic, ethnic, and cultural diversity that exists in Maine but is diluted by the averaging calculations made for census track SVI.

Further, many other disadvantaged community members may be unable to afford the cost of living along the coast but work in coastal areas prone to erosion hazards that could disrupt their livelihoods. Maine's large tourism industry is heavily concentrated on a fragile coast experiencing accelerated changes from sea level rise. Any reduction or loss in coastal tourism would be devastating for the economy and identity of local working communities.

Finally, sea level rise directly impacts working shorelines that support the seafood industry. Many working piers have been identified in this Risk Assessment as vulnerable to sea level rise and erosion, each of which is crucial for the fishing industry. Coincident with sea level rise, rising ocean temperatures are threatening the long-term sustainability of Maine's lobster industry, which supplies 90% of the national supply [50]. Shellfish harvesters and aquaculture businesses need to access clean mudflats. Changes in sea level will alter accessibility to these sites in the future, while increased coastal development will ultimately reduce the number of clean places to harvest.

3.54.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

MEMA performed a geospatial analysis to identify structures and parcels adjacent to beach and bluff erosion hazard locations (Table 3.43). Structure values were determined using the approach described in the Geospatial Analysis of Assets section above. Total structure values near bluff erosion hazards are estimated to be $311.4 million, the majority of which reside in Cumberland County, though Hancock County contains most exposed land parcels. Please note that the bluff hazards database does not include the full coastline of Washington County, and therefore potential exposure to bluff erosion may be greater than what is shown here. Total structure values near beach erosion hazards are estimated to be $753.1 million, the majority of which reside in York County.

Table 3.44: Parcels and structures exposed to unstable to highly unstable bluffs and sand dune erosion hazard areas. Structure values given in millions $USD 2022.

Region	Bluff			Beach		
	Parcels	Structures	Structure Value	Parcels	Structures	Structure Value
State	8,447	803	$311.4	4,774	2,040	$753.1
Cumberland	1,769	292	$102.9	499	155	$54.5
Hancock	2,561	176	$74.7	492	59	$21.5
Knox	892	91	$34.2	142	15	$2.8
Lincoln	1,206	81	$27.8	21	6	$2.6
Penobscot	127	4	$2.0	-	-	$0.0
Sagadahoc	403	42	$15.0	154	77	$25.7
Waldo	443	20	$10.5	115	14	$8.5
Washington*	416	23	$5.1	287	25	$6.6
York	630	74	$39.2	3,064	1,689	$630.9

* Bluff map does not cover entirety of Washington County.

Issues and Challenges

The following is a partial list of some of the erosion mitigation challenges in Maine.

Limited funding for Beach Profiling Program. The beach profiling program has been a cost-effective way to gather detailed information on changes in beach profiles every month and is dependent upon grant funding in conjunction with support fees from participating communities. The program continues to provide assistance to communities facing challenges related to coastal erosion and climate change as outlined in the Scientific Assessment of Climate Change and its Effects in Maine report by the Maine Climate Council [51].

Limited commitment to coastal geology hazard monitoring. Maine funds only one full-time, General Fund position in the Maine Geological Survey to deal with the complexity of issues surrounding the geology of Maine's coast. MGS relies heavily on grant funds for most of its data collection and mapping.

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[50] Maine's key industries: https://www.maine.gov/decd/business-development/move/key-industries

[51] Scientific Assessment of Climate Change and its Effects in Maine: https://online.fliphtml5.com/gkqg/jqys/#p=102

Limited insurance for geological risks. It may be extremely difficult or prohibitively expensive for individuals to purchase erosion insurance for their properties. As such, many of the erosion hazards represent uninsurable risks.

Increasing mitigation need. As sea level continues to rise, erosion will continue along the waterfront. Mitigation, including relocation of infrastructure and environmentally sound coastal restoration and coastal engineering practices will be increasingly important in the coastal zone.

3.55 Mass Wasting – General Definition and Types of Events [S3.a., S3.b.]

Mass wasting is the downslope movement of earth materials under the force of gravity. There are many types of mass wasting, and the definition of their characteristics vary worldwide. The following sections describe the most common types of mass wasting in Maine and are generally aligned with the definitions set by the U.S. Geological Survey. [52]

Mass wasting is a hazard that has been occurring for thousands of years in the State of Maine, but new technology such as lidar topographic data has allowed greater understanding of its extent and characteristics [53]. Instability associated specifically with sediment known as the Presumpscot Formation has raised major concern within the highly populated coastal communities. The Presumpscot Formation is a glaciomarine mud that was deposited in areas of southern Maine that were covered by the ocean at the end of the last Ice Age [54]. The mud can be very soft and can liquefy and flow when disturbed (earthquakes, man-made vibrations) or exposed in a slope by excavation, stream cut bank or coastal bluff erosion).

3.55.1 Creep

Creep is the gradual downslope movement of soil or other unconsolidated earth materials due to freeze-thaw action (Figure 3.46). Creep does not pose a direct risk to human life, but it can impact infrastructure over time by tilting fences and utility poles that were not properly driven below the frost line. In some cases, creep *may* indicate an unstable slope prone to other types of mass wasting, but this is not always a reliable indicator. Creep may be identified on a slope by curved tree trunks, tilted fences and utility poles, cracks in pavement, or soil ripples.

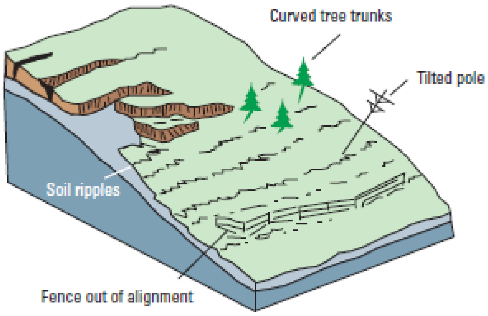

Figure 3.46: Illustration of features resulting from creep (Highland and Bobrowsky, 2008).

3.55.2 Rockfall

A rockfall is the sudden and rapid downslope movement of rocks (Figure 3.47). The rocks may bounce and break into smaller pieces as they move and tend to continue until they reach an obstruction or flatter topography. Rockfalls may occur in areas with steep slopes and exposed bedrock (natural or manmade). Freeze-thaw action tends to slowly loosen rock blocks from slopes along pre-existing fractures until they fall, but earthquakes may also trigger rockfalls.

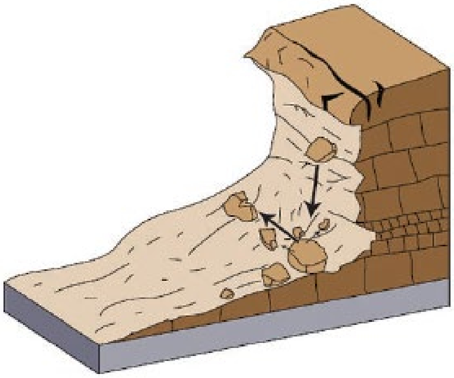

Figure 3.47: Illustration of a rockfall (from Highland and Bobrowsky, 2008).

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[52] Highland, L.M., and Bobrowsky, P., 2008, The landslide handbook—A guide to understanding landslides: Reston, Virginia, U.S. Geological Survey Circular 1325, 129 p. https://pubs.usgs.gov/circ/1325/pdf/Sections/Section1.pdf

[53] Maine Geological Survey Inland Landslides Map: https://www.maine.gov/dacf/mgs/hazards/landslides/inland/index.shtml
[54] Presumpscot Formation: https://digitalmaine.com/cgi/viewcontent.cgi?article=1334&context=mgs_publications

3.55.3 Landslides

A landslide is the downslope movement of earth materials (due to gravity) along a rupture surface (shear plane). The following factors or a combination of these factors may trigger a landslide:

- **Undermining Slope.** Removing the base or toe of a slope through natural or human processes, resulting in unstable areas upslope.
- **Adding weight to slope.** Overloading a slope due to human alteration (buildings, roads) or natural processes (growth of large trees, addition of water weight from snowmelt or rainfall).
- **Wet conditions.** High water content in the pore spaces of unconsolidated earth materials decreases friction between particles and reduces slope strength. Wet conditions also add water weight to a slope. Snowmelt and heavy rain are the most common causes of wet conditions, but other sources include septic leach fields and other manmade drainage outlets.
- **Earthquakes.** Shaking causes a slope to lose strength. Man-made vibrations (drilling, blasting, etc.) can also trigger landslides.

There are many different types of landslides, and sometimes an individual landslide can have the characteristics of multiple types. When assessing a landslide, it is best to categorize it as the type it most resembles since a perfect match is unlikely. Landslides may start with slow movement (inches to feet per day) that ends in very rapid movement (feet per second), or they may happen very rapidly without warning. The most common types of landslides in Maine are described in detail below.

3.55.4 Rotational landslide/slump

A rotational landslide (sometimes called a slump) is the down and outward movement of earth materials along a curved plane (Figure 3.48). This type of landslide may be triggered by undermining the base of a slope, adding weight to a slope, wet conditions, an earthquake, or a combination of these factors.

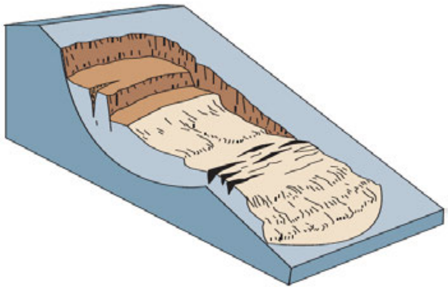

Figure 3.48: Illustration of a slump (from Highland and Bobrowsky, 2008).

3.55.5 Translational landslide

A translational landslide is the downslope movement of earth materials along a plane with little to no rotational movement (Figure 3.49). This type of landslide may be triggered by undermining the base of a slope, adding weight to a slope, wet conditions, an earthquake, or a combination of these factors.

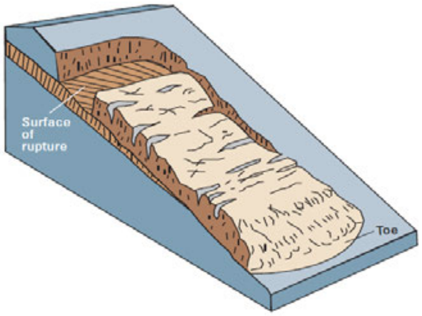

Figure 3.49: Illustration of a translational landslide (from Highland and Bobrowsky, 2008).

3.55.6 Flow

A flow is the downslope movement of water-saturated earth materials (Figure 3.50). There is little structure to a flow, with materials often moving as a slurry. This type of landslide requires wet conditions but may also be triggered by undermining the base of a slope, adding weight to a slope, an earthquake, or a combination of these factors. Flows are often confused with gullies and vice versa. In a gully, sediments are picked up and carried downslope by flowing water, not by gravity alone. Gullies often originate in areas of concentrated surface runoff, such as a culvert or drain outlet. It is important to recognize the difference, as flows tend to be one event, while gullies can remain active, resulting in long-term erosion problems.

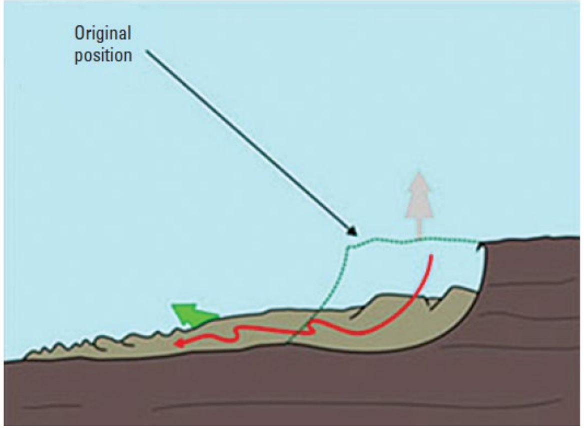

Figure 3.50: Illustration of flow (from Highland and Bobrowsky, 2008).

3.55.7 Spread

Spread landslides occur when a stronger earth material layer breaks apart and moves along and/or sinks into a weaker/softer underlying layer (Figure 3.51). This type of landslide requires unstable earth materials at depth and may be triggered by undermining the base of a slope, adding weight to a slope, wet conditions, an earthquake, or a combination of these factors.

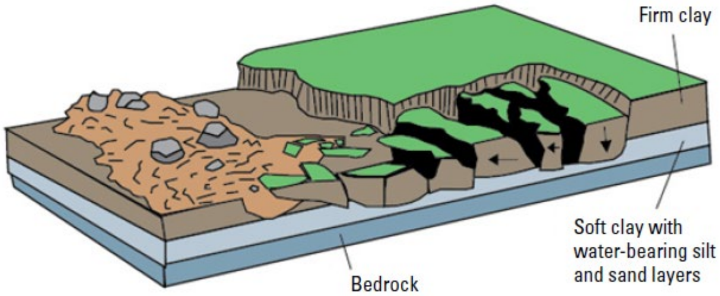

Figure 3.51: Illustration of a spread (from Highland and Bobrowsky, 2008). In Maine, “clay” layers would most likely be Presumpscot Formation.

3.56 Mass Wasting – Location of Hazard [S3.a.1]

Mass wasting may occur statewide (Figure 3.52), but specific types are more common in different areas of the state as described below.

3.56.1 Creep

Common statewide on slopes consisting of unconsolidated earth materials.

3.56.2 Rockfalls

Most common in areas with exposed bedrock on steep slopes, such as in the mountainous western and central regions of the state (Oxford, Franklin, Somerset, and Aroostook Counties). May also occur anywhere there are steep man-made exposures of bedrock, such as road cuts.

3.56.3 Rotational Landslides/Slumps

May occur statewide on slopes of unconsolidated earth materials, but most common in river cut bank and coastal bluff areas shortly after periods of high water, especially where the Presumpscot Formation is present. In river corridors, erosion tends to occur during high flows at the outside of a channel bend. The base of the riverbank is eroded/undermined leading to slumping or sliding as flood waters recede and expose the now unstable bank.

In coastal bluff areas consisting of unconsolidated earth materials, wave action may undermine the base of a bluff, particularly during strong storms (see Erosion – Hazard Profile). This process may lead to slumping and sliding, especially when combined with other triggers such as wet conditions.

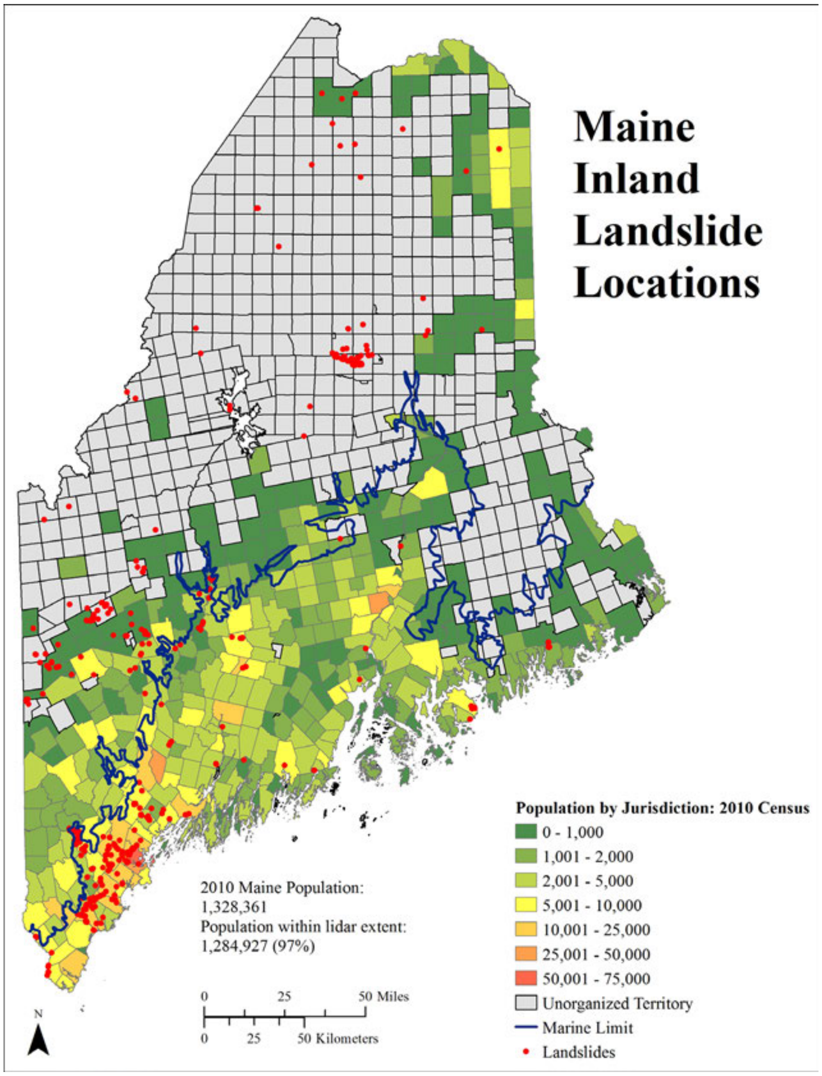

Figure 3.52: Map of landslide locations mapped from lidar as of September 2022. The highest density of landslides coincides with the most populated area of the state. The Presumpscot Formation may be present in areas south of the dark blue line (known as the "marine limit") and is likely related to the high number of landslides in southern Maine. Map: Maine Geological Survey.

3.56.4 Translational Landslides

Most common in mountainous areas with thin soils on steep slopes. Most likely to occur during or after prolonged wet periods when water adds weight to the slope and/or reduces the strength of the earth materials.

3.56.5 Flows

May occur on slopes of unconsolidated earth materials statewide but require water-saturated earth materials, making flows more likely after prolonged wet conditions. Flows may also result from disturbance and liquefaction of the Presumpscot Formation.

3.56.6 Spread Landslides

May occur in areas of southern Maine where the Presumpscot Formation glaciomarine deposit is present, usually at lower elevations in valleys. Lidar topographic data recently revealed many prehistoric spread landslides associated with the Presumpscot Formation.

3.57 Mass Wasting – Intensity and Previous Occurrence [S3.a.2.]

An accepted standardized scale to classify mass wasting event magnitudes does not currently exist, but landslides can be assessed in terms of the land area disturbed by the events. An analysis of existing lidar hillshade imagery was conducted to assess the sizes of Maine landslides that could be recognized and measured in a GIS program (Figures 3.53). There are 405 landslides recorded in this inventory, but this analysis probably does not include every landslide in Maine due to the lack of ability to field check all suspected landslide localities, and natural or human processes that may have altered a landslide beyond recognition, but it is a large enough sample size to portray the magnitude of these events in Maine. The average disturbed area for the 365 inland landslides for which extents could be mapped in GIS is about 19 acres, although there are situations that could increase or decrease this value. When a landslide occurs along a river channel or coastal area, the lower margin of the landslide (known as the “toe”) can be washed downstream or eroded over time making it difficult to determine the full landslide extent. This is a common scenario in Maine, although this underestimation may be offset by very small slumps and slides that are difficult to map in GIS (<0.1 acre). If a landslide occurs along a river channel, the affected area may be increased substantially if the landslide toe blocks the river causing flooding upstream and potential flash flooding downstream once the river breaches the landslide toe.

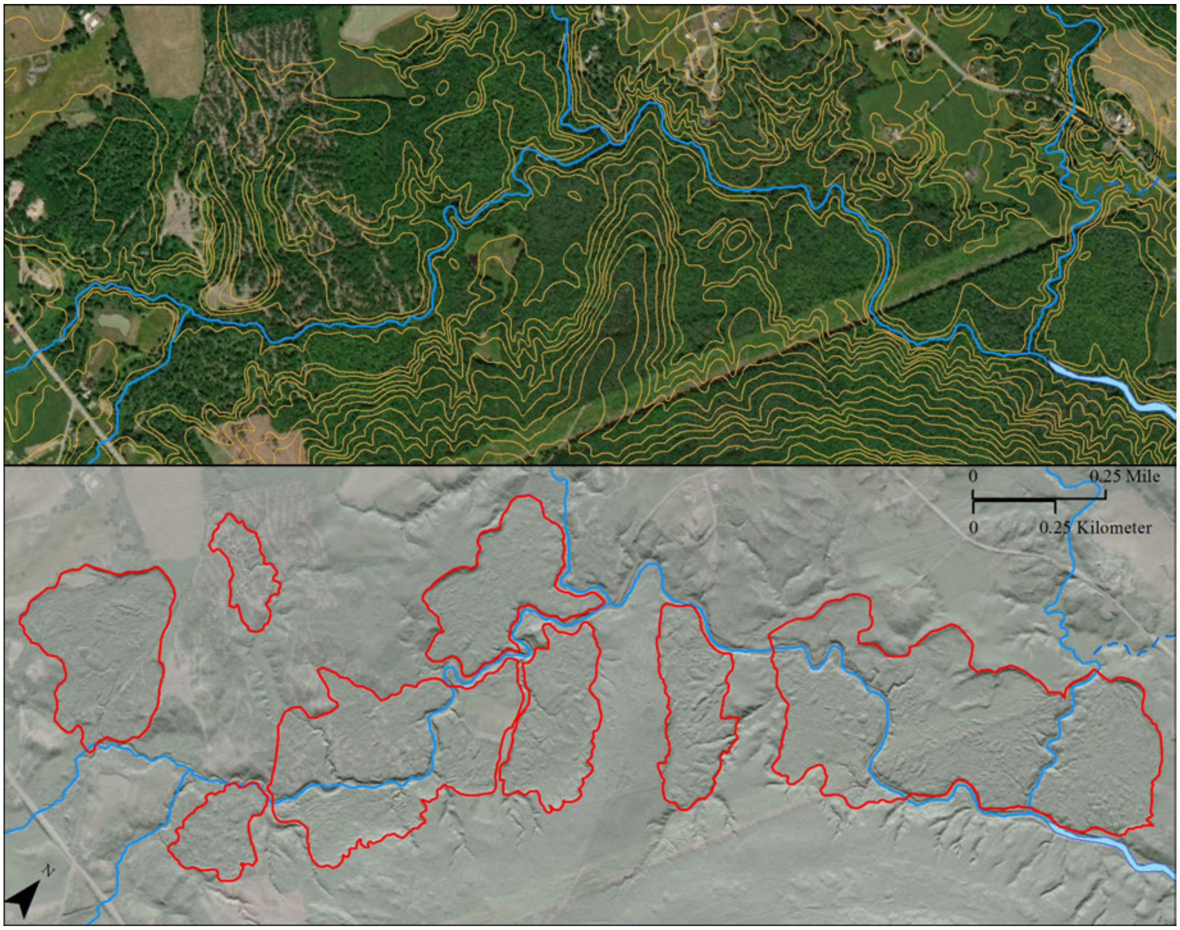

Figure 3.53: Lidar hillshade imagery revealed many landslides in this river valley (bottom image, outlined in red) that were not recognizable with traditional topographic maps and aerial imagery (top image).

3.57.1 Previous Occurrence

A complete list of mass wasting events in Maine does not exist in part because these events tend to affect individual properties and not entire communities. The following list is a sub-sample of known events for the modern, historic, and pre-historic eras.

Modern Landslides (1950-present)

Figure 3.54: 2021 Rockport landslide. Photo courtesy of Knox County EMA.

- **2021, Rockport, Maine:** a small spread landslide occurred along Glen Cove, displacing several cubic yards of soil on a private property (Figure 3.54).
- **2020, Westbrook, Maine**: A spread landslide occurred along the Presumpscot River directly opposite of the 1868 landslide (see description below).
- **2016, Brunswick, Maine:** A rotational landslide occurred in the Bugnanuc coastal bluff area with a history of similar events.
- **2010, Sandy River, Chesterville, Maine:** A rotational landslide along the river forced the town to relocate a road.
- **2007, Brunswick and Gilead, Maine:** The “Patriot’s Day Storm” triggered a coastal bluff landslide in Brunswick and gullying/possible flows along the Wild River in Gilead. A house was condemned due to the Brunswick landslide. A similar event was noted along the Wild River in 1998.
- **2006, Greenbush, Maine:** A rotational landslide along the Penobscot River threated U.S. Route 2.
- **2006, Mount Desert Island, Maine:** Earthquakes trigger roadcut and mountainside rockfalls in Acadia National Park, blocking roads and hiking trails.
- **2005, Wells, Maine:** A rotational landslide along the Merriland River resulted in removal of at least one nearby home. In March 2019, another small rotational landslide occurred in this area.
- **1996, Rockland, Maine:** A coastal bluff rotational landslide destroyed two homes that had been evacuated. A similar event occurred in the same harbor in 1973.
- **1990, Grafton, Maine:** A translational landslide occurred on Mount Hittie.
- **1983, Gorham, Maine:** A spread landslide along the Stroudwater River destroyed a home that was under construction.
- **1966, Waterville, Maine:** A rotational landslide occurred along the Kennebec River, threatening a local park known as Couture Field.

Historic Landslides (1600s-1950)

- **1927: Grafton, Maine:** A landslide occurred on the northeast flank of Old Speck Mountain due to heavy rainfall..
- **1917, Jackman, Maine:** A landslide on Mount Sally was noted in historical records.
- **1868, Westbrook, Maine:** The largest landslide witnessed in recorded Maine history occurred on the Presumpscot River. This flow landslide affected about 40 acres and blocked the river, flooding the paper mill upstream until workers dug out a path for the river by hand.
- **1849, Westbrook, Maine: A** spread landslide occurred along the Stroudwater River.
- **1826, Gilead, Maine:** A landslide on Peaked Hill was noted in historical records.
- **1670, Kennebunk, Maine:** A landslide along the Kennebunk River was noted in historical records.

Prehistoric Landslides

Lidar topographic data recently revealed over 200 landslides of unknown age that are concentrated in the most populated area of the state. Working in cooperation with MEMA, the Maine Geological Survey determined the ages of 28 prehistoric landslides in southern Maine through radiocarbon dating of vegetation buried by, caught up in, or deposited on top of the landslides (Figures 3.55-3.57). Prior to this study, only one prehistoric landslide (about 13,500 years old) had been studied when a large construction project in Portland revealed trees that were buried by the event. The oldest landslide in the current study is about 12,000 years old and occurred just south of Sebago Lake. Clusters of landslides occurred about 600, 3, 300, and 4,000 years ago. This clustering of activity suggests a more regional trigger, such as earthquakes or wet conditions. Other landslides occurring somewhat randomly over time may have more complex causes, such as the convergence of multiple factors like river cut bank erosion and wet conditions at that location. The youngest landslide in the study was determined to be the 1849 Stroudwater River landslide – the exact location was previously unknown. This research indicates that the previously unknown landslides are not as ancient as the Bramhall landslide – some are quite young, indicating that large landslides may be possible into the future.

Figure 3.55: A soil core revealing soils buried by a landslide in Lyman, Maine. The darkest layer in the middle of the core was the topsoil and the grey layer on the right was the bottom of the landslide (in this case, consisting of Presumpscot Formation). Plant fragments from the buried soil layer were sent for radiocarbon analysis to estimate the landslide age. Photo: Maine Geological Survey.

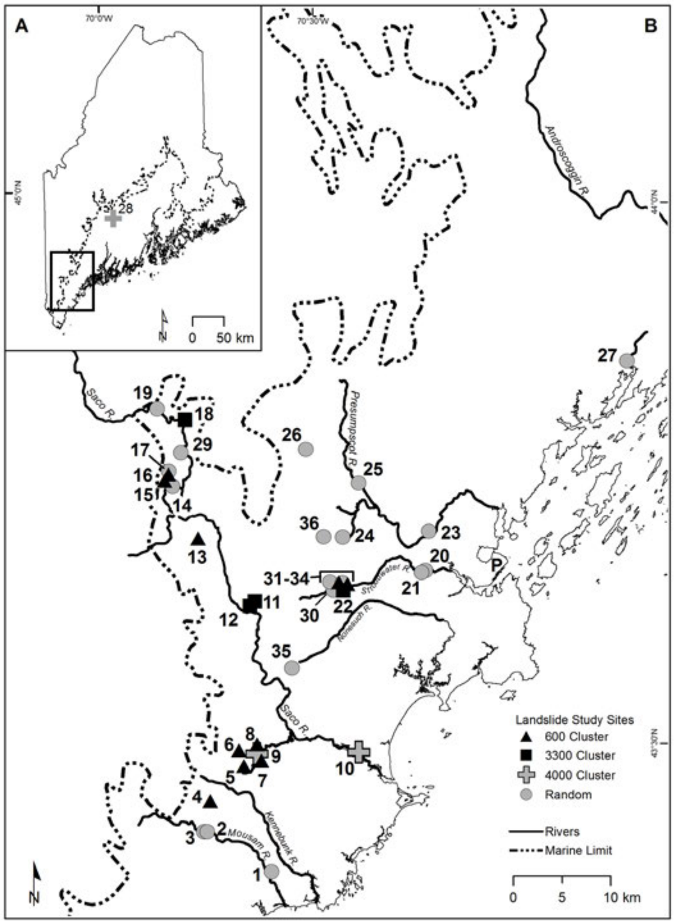

Figure 3.56: Locations of 36 prehistoric landslide sites with estimated ages (more than 36 were studied but some did not yield samples for radiocarbon dating). Site symbols are grouped by observed timing clusters, which may indicate a regional trigger such as a large earthquake or very wet conditions.

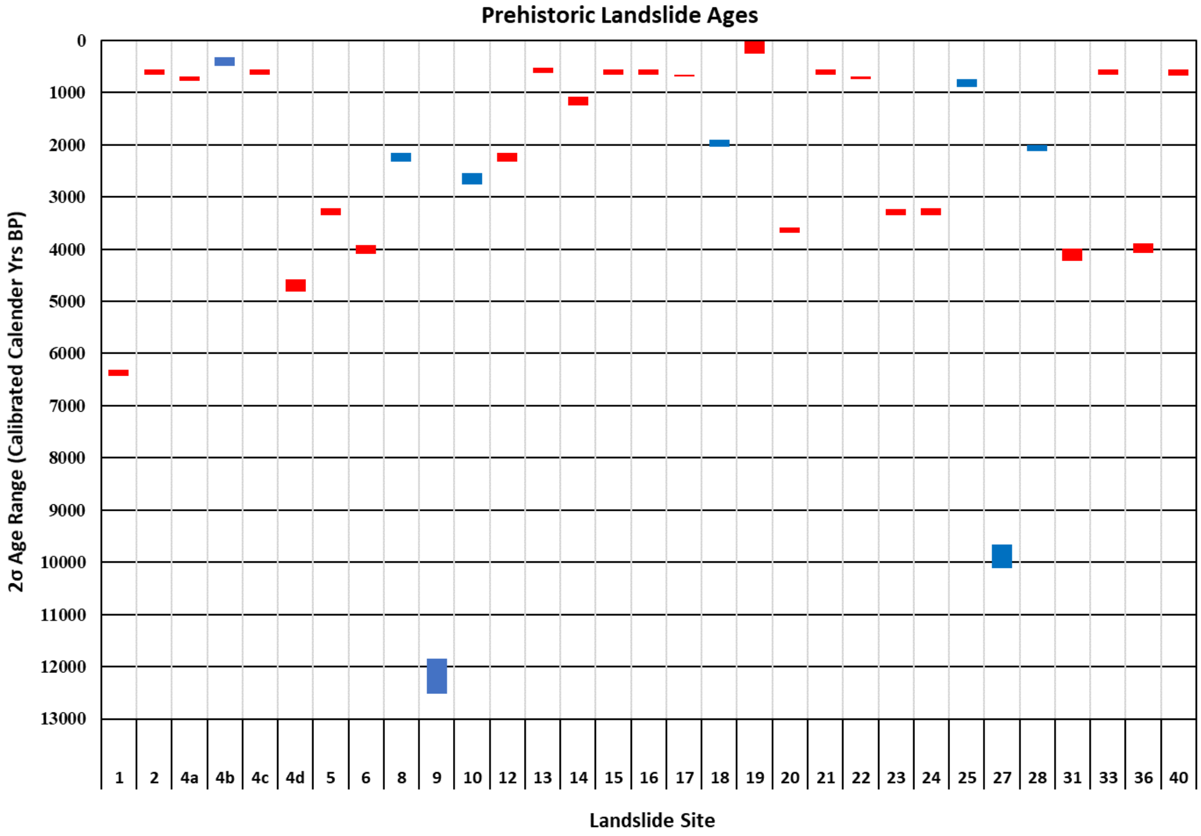

Figure 3.57: Graph of estimated landslide ages (2σ ranges are reported to account for error in radiocarbon analysis and conversion to calendar years before present). Blue ranges are from samples deposited on top of the landslide after it occurred, which provide a minimum age estimate. Red ranges are from samples that were buried by or caught up in the landslide, which provide a maximum age estimate. Ages shown are the best estimate from each site, which may have been selected from multiple samples at a site. Site 4 is a very large landslide complex (about 1 square mile) that was active at different times (shown as 4a-d).

3.58 Mass Wasting – Probability of Future Occurrence [S4.]

There are no specific statistical studies of mass wasting probability in Maine due to the small sample size of events with a known age and/or location. Geologic research can increase the sample size of dated prehistoric landslides, but the locations of landslides included in this sample is heavily dependent on permission to access features on private property. Many historic landslides have been documented, but their exact locations are often unknown or have been altered beyond recognition. Modern landslides are increasingly difficult to document, as landowners become hesitant to report any issues that may affect their property values, especially in coastal areas. Landslide susceptibility maps exist for portions of southern Maine, but new lidar topographic data and advances in GIS could greatly improve these maps. Despite the limitations described above, history indicates that mass wasting is more likely in areas of Maine with:

- Steep slopes (natural or manmade) that have been undermined or overloaded.
- River cut banks and coastal bluffs that have been undermined and/or overloaded, especially where the Presumpscot Formation is present.

As population increases in southern Maine, these communities should be encouraged to avoid development in river corridors and coastal bluff areas, especially where the Presumpscot Formation is present. Mountain recreation towns should consider the potential for mass wasting when developing these areas as well.

3.58.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Many historic and modern landslides have occurred in spring during prolonged wet periods fed in part by seasonal snowmelt [55]. Current climate projection models indicate trends that may indirectly impact the occurrence and seasonal timing of mass wasting in Maine, but such events continue to be very difficult and often impossible to predict. Climate projections suggest warming winter temperatures may reduce total snowpack available during spring snowmelt and this may reduce the potential for spring mass wasting events in the future. However, models also project an overall increase in precipitation in the northeast, particularly for large rainfall events exceeding 2 inches of rain (see section Flooding – Hazard Profile). These events may become more prevalent in summer and fall months under scenarios of prolonged heavy rainfall [56]. Severe summer and fall storms may increase the likelihood of mass wasting outside of the normal spring season, especially in steeper terrain. Further, greater fluctuations in freeze-thaw cycles through milder winters increase rockfall hazards through frequent expansion of ice forming within near surface rock fractures, causing them to weaken and fail. Further, the impacts of climate change, and their timing, will vary across the state of Maine, where there is a noticeable difference in how annual average snowpack is changing in northern versus southern locations.

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[55] Landslides in the Presumpscot Formation: NEGSA Field Trip Guide

[56] Gauthier, D., & Hutchinson, D. J. (2012). Evaluation of potential meteorological triggers of large landslides in sensitive glaciomarine clay, eastern Canada. *Natural Hazards and Earth System Sciences*, *12*(11), 3359-3375. https://nhess.copernicus.org/articles/12/3359/2012/nhess-12-3359-2012.pdf

Mass Wasting – Vulnerability Assessment

3.59 Mass Wasting – Impacts

The impact of a mass wasting event varies substantially based on its size and location within the state. A rockfall in a rural mountainous area may go completely unnoticed, while a landslide in more populated southern Maine may take lives, destroy homes and infrastructure.

The entire state is vulnerable to some type of mass wasting, but events are much more likely to occur due to the following conditions:

- Steep slopes with thick deposits of unconsolidated earth materials, especially in areas where the Presumpscot Formation is present.
- River cut banks and coastal bluff areas that have been undermined by high flow/tides or storm events, especially where the Presumpscot Formation is present.
- Prolonged wet periods that add water weight and reduce slope strength, usually in spring when snowmelt is followed by persistent rain. Persistent rain is also frequently associated with high river flow or storm surges, which can undermine river cut banks and coastal bluffs.
- Earthquakes, which can occur throughout the state but are usually low magnitude (2 or less). The earthquake magnitude threshold trigger for mass wasting in Maine is unknown, but a 2006 swarm of earthquakes in the Mount Desert Island area (magnitude 2.3-4.2) was enough to cause several rockfalls.

The impacts of mass wasting in Maine have mostly been major damage to structures built along the top of steep slopes rather than damage and burial of structures at the base of a slope. Typically, rivers and other shorelines compose the base of these unstable slopes, and in some cases the mass wasting event can form a natural dam that may cause flooding of assets upstream. There are no known state assets that are vulnerable to these issues other than road infrastructure. The impacts of road infrastructure damage are noted below.

3.60 Mass Wasting – Vulnerability of State Assets [S5.]

Mass wasting is not expected to pose a substantial risk to state owned buildings. A geospatial analysis indicated no substantial state building assets are located adjacent to historically active inland landslide locations. However, the potential still exists given the historic difficulty in predicting locations and extents for mass wasting events. State roadways are likely to have the greatest potential exposure to mass wasting, either from erosion or debris coverage of roads.

3.60.1 Potential Dollar Losses to State Owned Buildings, Infrastructure, Critical Facilities

State Road Assets

MEMA conducted a geospatial analysis to identify public road sections located adjacent to known landside locations. This analysis was held under the assumption that these locations may be prone to future mass wasting events with the potential to damage roads. All public road sections within 20 meters of landslide disturbance sites were selected and are indicated in Figure 3.58 and detailed in Table 3.45. These road segments consist of 55.8 miles in total length and host an average 4,107 vehicles per day based on annual average daily traffic calculations provided by Maine DOT. Municipalities are responsible for the majority of maintenance for these road segments (but minimum road traffic) with 34.62 total miles. Of all exposed road segments, the most actively used is State Route 25 which connects Portland to towns in western Cumberland County and northern York County, with a maximum daily traffic estimate of 16,833. There is no guarantee that these assets will be damaged in a natural hazard event.

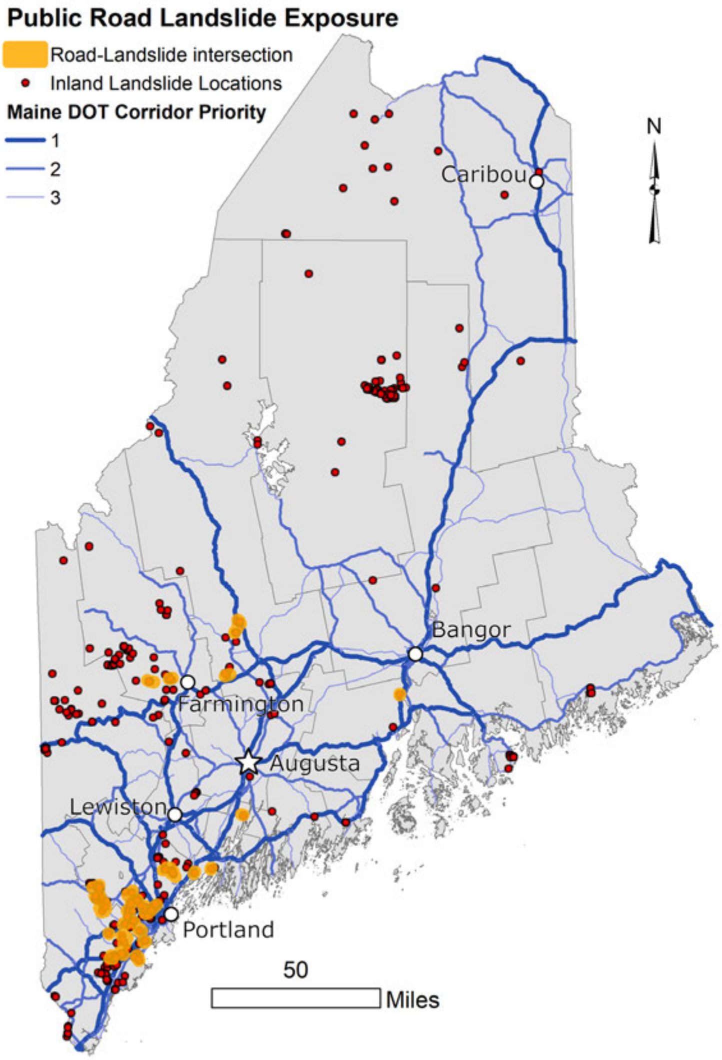

Figure 3.58: Exposure of public roads to historic landslide sites.

Table 3.45: Public roads intersected by historic landslide locations indicating potential exposure to future mass wasting events.

Jurisdiction	Road miles	AADT* average	Reconstruction cost (millions)
Total	55.8	4,107	$83.7 - $111.6
State	21.18	7,109	$31.8 - $42.4
Local	34.62	624	$51.9 - $69.2

*AADT: annual average daily traffic per segment

Maine DOT estimates that the cost of paved road reconstruction is $1.5 to $2 million per mile. Under these cost assumptions, the total cost of reconstructing all road-landslide exposure sites would cost approximately $83.7 to $111.6 million at a minimum. This would not include costs associated with debris removal or fill to reconstruct the land surface after a mass wasting event.

3.61 Mass Wasting – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.61.1 Identifying Jurisdictions with Greatest Vulnerability [S6.a.1.]

No critical facilities were located near historic landslide locations. However, as indicated above, there are several miles of local roads that may be exposed to future landslides based on their proximity to historic landslide sites. Further, community members with properties adjacent to steep terrain, cliff faces, or coastal/riverine bluffs may be susceptible to mass wasting events.

Disadvantaged Communities

Based on the analysis shown in Figure 3.55 and overlaying the Overall SVI census track dataset, there is one disadvantaged community in Somerset County hosting a public road-landslide intersection, suggesting that this community may face a higher likelihood of exposure to mass wasting. However, all rural communities are likely at greater risk given the potential impacts of mass wasting on public road infrastructure and transportation systems. Rural communities typically need to travel further to access critical services and depend heavily on safe and dependable roads. Road closures caused by mass wasting would lead to establishment of long-term detours until debris is removed and the road is repaired. In some cases, these detours can add a significant travel time to commuters, leading to potential economic and job security issues.

3.61.2 Community Lifeline Risks

Similar to erosion, mass wasting can impact transportation needs, which may hinder the ability of emergency responders to access the impacted area and impact access to critical medical, food, and shelter services.

3.61.3 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Potential dollar losses to jurisdictions based on road exposure may exceed $51 million dollars in total. However, a single mass wasting event will generally be localized to within a mile of road length or less. In this case losses may be closer to $1.5 to $2 million. Refer to the section Erosion – Vulnerability of Jurisdictions for guidance on bluff mass wasting.

Earthquake – Hazard Profile

3.62 Earthquake – General Definition and Types of Events [S3.a., S3.b.]

A sudden motion or trembling caused by a release of strain accumulated within or along the edge of earth’s tectonic plates. This complex motion is caused by a sudden shifting or breaking of subsurface rock to relieve built up stress. The energy released at the center produces a variety of seismic waves that travel out in all directions through the surrounding rock. Some of these waves make their way to the surface and travel out across the countryside.

3.62.1 Tectonic Earthquake

The result of the earth's crust breaking due to geological forces on rocks and adjoining plates that cause physical and chemical changes.

3.62.2 Explosive Earthquake

The result of the detonation of a nuclear and/or chemical device.

3.62.3 Collapse Earthquake

A small earthquake(s) in underground caverns and mines caused by seismic waves produced from the explosion of rock on the surface

3.62.4 Volcanic Earthquake

A result of tectonic forces which occur in conjunction with volcanic activity.

3.62.5 Cryoseism/Snow Quakes

While not a storm, this is an occasional winter phenomenon, usually occurring in January or February, when a very localized section of earth suddenly freezes. Since it most often happens during the coldest hours of the day – between midnight and dawn – the sudden shaking, and/or noise, can be very startling.

3.63 Earthquake – Location of Hazard [S3.a.1]

Earthquakes have been reported from all 16 counties in Maine, thereby indicating some level of statewide exposure, with a somewhat higher activity in the eastern, central, and southern parts of the state. As indicated on Figure 3.59, the three areas of most seismic activity in Maine are in northwestern Aroostook and a region spanning form central to southern Maine [57, 58].

Seismic activity in Maine is typical of the Appalachian region of Northeastern North America where there is a slow but steady rate of earthquake occurrence. The earthquakes are presumably caused by modern stress being released occasionally along zones of weakness in the earth's crust, but a more specific cause for the earthquake activity is not known. Recorded earthquake locations and detailed seismic motion studies do not show any clear correlation with either local or regional geologic features.

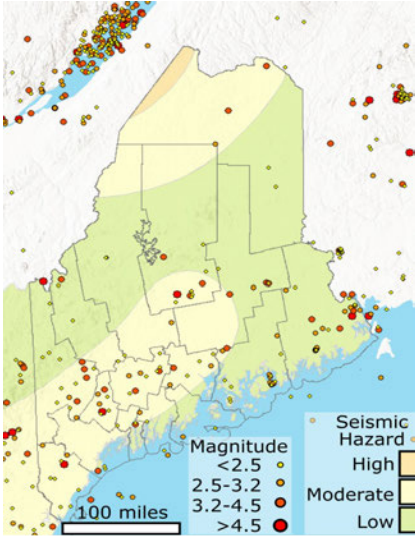

Figure 3.59: 2014 USGS Seismic Hazard Map and earthquake occurrence for Maine and region (1800-2022).

3.64 Earthquake – Intensity and Previous Occurrences [S3.a.2.]

Geologists use the Richter Scale to measure the strength, or magnitude, of an earthquake at its epicenter. However, geologists use the term 'intensity' to measure the extent of an earthquake at a given location and use the Mercalli Intensity Scale to measure intensity (Table 3.46).

Table 3.46: Richter Scale and Mercalli Intensity Scale [59]

Magnitude	Mercalli Intensity	Average Effects
1	I	Microearthquakes not felt.
2	I	Minor earthquakes felt slightly by some people.
3	II to III	Minor earthquake often felt by people but rarely causes damage.
4	IV to V	Light earthquake with noticeable shaking of indoor objects but little damage.
5	VI to VII	Moderate earthquake felt by everyone and can damage poorly constructed buildings.
6	VII to IX	Strong earthquake that can cause damage to well-constructed buildings.
7	VIII or greater	Damages most buildings, some of which partially or completely collapse.
8	VIII or greater	Major damage to buildings. Structures likely to be destroyed.
9	VIII or greater	Permanent changes in ground topography. Severe damage or collapse to all buildings.

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[57] USGS Long Term National Seismic Hazard Map: https://www.usgs.gov/programs/earthquake-hazards/hazards
[58] USGS Earthquake Database search: https://earthquake.usgs.gov/earthquakes/search/
[59] Source: https://earthquake.usgs.gov/learn/topics/mag_vs_int.php

3.64.1 Previous Occurrences

Volcanic earthquakes play an enormous part in Maine's geological history, although there has not been an active volcano in Maine for approximately 420 million years. Currently, a tectonic earthquake is considered the most likely of earthquake events while still considered as a low likelihood event. Explosive earthquakes and collapse earthquakes could occur as the result of a human-induced event but are not likely to occur as a natural hazard in the State of Maine.

No significant amount of motion has been shown for any fault since the last Ice Age about 20,000 years ago, and geologic evidence demonstrates that many faults have been inactive since the formation of the Appalachians, over 300,000,000 years ago. None of the ancient faults in Maine have been identified as active.

As of this update, the largest earthquake recorded in Maine since 1747 was near Eastport in 1904 with an estimated intensity of VII. The largest accurate measurement was in 1973 just on the Quebec side of the border from Oxford County, with a magnitude 4.8.

Earthquakes have been reported from all counties in Maine, thereby indicating some level of statewide exposure, with a somewhat higher activity in the eastern, central, and southern parts of the state (Table 3.47).

Table 3.47: Earthquakes with magnitude 3 or greater in Maine and surrounding area.

Date	**Place (County)**	**Intensity**	**Magnitude**	**Comments**
1755	Cape Ann, Massachusetts	VIII	6.0	Toppled chimneys in Boston.
1857	Lewiston (Androscoggin)	VI	5.0 – 5.9	
1869	Passamaquoddy Bay (Washington)	VI	5.0 – 5.9	
1904	Eastport (Washington)	VII	*5.0 – 5.9*	Maine's largest earthquake.
1905	Sabattus (Androscoggin)	VI	5.0 – 5.9	
1912	Eastport (Washington)	VI	5.0 – 5.9	
1918	Bridgton/Norway (Cumberland/Oxford)	VI	5.0 – 5.9	
1925	La Malbaie, Quebec	IX	6.4-6.6?	90 miles from Quebec City. Damaged some types of stone and brick walls over 100 miles away.
1928	Milo (Piscataquis)	VI	5.0 – 5.9	
1935	Temiscaming, Quebec	VII	6.2	
1940	Ossipee, NH (2 events)	VII	5.5 & 5.5	Some chimneys in Augusta cracked.
1949	Houghton (Piscataquis)	VI	5.0 – 5.9	
1957	Portland (Cumberland)	VI	5.0 – 5.9	
1973	Bowmantown Twp. (Oxford)	VI	5.0 – 5.0	
1979	Bath	V	4.0	
1982	Miramichi, N.B.	VII	5.7	Felt across Maine.
1983	Dixfield	V	3.9	
1984	Machias	IV	3.8	
1988	Albion	IV	4.0	
1988	Chicoutimi, Quebec	VIII	6.0	Felt in New York City. Largest in Eastern North America since 1935.
1994	Springfield		3.9	
1997	Wilton		3.0	
1997	Quebec City	VII	5.1	Felt across Maine.
1999	Waterville		3.7	
1999	Newport-Etna area		3.0	
2000	Turner-Livermore area		3.4	
2000	Rumford		3.4	
2000	Waterville		3.2	
2001	Howland		3.3	
2002	Near Plattsburgh, N.Y.		5.3	
2005	Pembroke		3.5	
2005	Northeast of Quebec City		5.4	
2006	Portage		3.8	
2006	East of Cadillac Mountain, Mount Desert Island		3.4	
2006	East of Cadillac Mountain, Mount Desert Island		4.2	
2006	East of Cadillac Mountain, Mount Desert Island		3.1	
2010	Orrington-Bucksport area		3.0	
2010	Canada, about 35 miles north-northeast of Ottowa			Felt in southwestern Maine.
2012	Canada, near La Malbaie, Quebec		4.4	Felt in northernmost Maine.
2012	East Waterboro		4.5	
2016	Lubec		3.6	
2016	Vanceboro		3.3	
2017	Passamaquoddy bay, Eastport		3.3	
2020	Robbinston		3.0	
2022	Centerville		3.0	

The earthquake in Virginia in 2011 that damaged structures in DC, including the National Monument certainly heightened awareness of east coast earthquake possibilities. Source: Maine Geological Survey, USGS

To date, the worst earthquake in Maine history occurred in 1904 in Eastport (Washington County).

The Maine Geological Survey (MGS) provides advisory and interpretive information on earthquakes for planning and regulatory agencies. After an earthquake event, the MGS collects information from people in the area and through an earthquake questionnaire made available to the general public and to county emergency management agencies.

The New England Seismic Network, operated by USGS, maintains a network of seismic stations across New England that monitors, analyzes, and reports earthquake activity in Maine.

3.65 Earthquake – Probability of Future Occurrence

Based on 124 years' worth of data, the probability of a major earthquake (intensity VI or higher) occurring in Maine is about once every 11.5 years. However, the table above also shows that major earthquakes do not occur on a regular basis. They may come in clusters, as they did in the early 1900s, or "swarms" as they did in 2011, then skip several decades before occurring again. To date, there is no accurate way to predict when another major earthquake will occur in Maine.

Based on past earthquake data collected over a limited time span (1975-1982) from New England and assuming that Maine is a representative part, John Ebel, of Weston Observatory, has estimated the return times for earthquakes (Table 3.48).

Table 3.48: Return Times for Earthquakes of Different Magnitudes in Maine

Magnitude	4.6	5.0	5.5	6.0	6.5	7.0
Return Time (Years) (+/-) (20-30%)	24	52	138	363	955	2,512

NOTE: Sources for the above paragraphs: Henry Berry, Physical Geologist

3.65.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Seismic hazard is not anticipated to change in Maine within the next update cycle of this Plan.

Earthquake – Vulnerability Assessment

3.66 Earthquake – Impacts

Most Maine earthquakes are of small magnitude (less than 2.0 on the Richter scale) and are therefore too small to feel. No Maine earthquake has caused significant damage to date. The persistent activity, however, indicates that some crustal deformation is occurring and that a larger earthquake cannot be ruled out.

Most Maine buildings are not constructed to withstand the lateral motion of a significant earthquake (magnitude six or higher). Brick and masonry structures that have not been reinforced are especially prone to earthquake damage. Interestingly, the masonry structures that are more resilient against wildfire damage are more vulnerable to earthquakes.

Coastal and lakefront structures built on water-saturated, unconsolidated material such as artificial fill may be vulnerable to liquefaction in a severe earthquake (liquefaction is a loss of cohesion between particles due to lubrication by water during vibration causing a sudden loss of strength). Most death and injury during earthquakes result from people being struck or trapped by falling debris.

Other possible concerns in an earthquake emergency would be the disruption of infrastructure facilities, such as road access, gas and oil pipelines, sewer systems, electricity and water supplies, and the disruption of emergency services such as police, firefighting, ambulance, and hospital services.

With increased development, the likelihood of marked destruction escalates. Metropolitan areas encounter far more structural damage because of the density and design of urban buildings, especially multi-story structures.

The majority of infrastructure across the State of Maine is aging and unable to sustain the impact of a significant earthquake event. Should an event occur, there is a likelihood that significant damage would be incurred at a high cost to the affected area. Both public and private aging infrastructure remain vulnerable to damages associated with an earthquake event, however the cost of bringing an older facility up to code is usually excessive and unfeasible.

3.67 Earthquake – Vulnerability of State Assets [S5.]

3.67.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

USGS earthquake hazard assessments identify regions in Maine where there are low, moderate, and high potential for a seismic event. Building replacement costs for state assets potentially exposed to earthquakes located in moderate to high hazard areas equal $2.88 billion (2,742 total assets). The top 10 state assets, ordered by building replacement cost, are listed in Table 3.49. Many of these are located in the Capital District, where some of the most valuable state assets are located. The state asset with the greatest earthquake risk is the Maine State House, where the state legislature conducts business. Any potential damages to the State House would directly impact the ability of the state to conduct legislation. Maine Municipal Bond Bank and State Redevelopment Authorities would also be impacted by a damaging earthquake with many extended economic and development challenges for local communities. There is no guarantee that these assets will be damaged in a natural hazard event.

These assets are not expected to sustain 100% damages from a magnitude 5 or 6 earthquake, so total damages from a single seismic event are expected to be much less than the total valuation. Because the degree of damage is difficult to predict for an event that has never occurred in Maine, total building replacement values are reported as a measure of potential exposure for structures in moderate to high earthquake hazard areas (Table 3.50). Damage curves are not factored into this assessment. The total scope of state assets potentially exposed to seismic hazards, based on the USGS hazard map, are shown in Figure 3.57.

Table 3.49: Top 10 state assets located in moderate to high earthquake hazard area, ranked by building replacement cost.

Address	County	Occupancy	Property Type	Year Built	Last Inspected	Total	Agency
210 State St, Augusta	Kennebec	OFFICE	Class 4 building	1832	1/10/2003	$86,630,000	ADF, BUREAU OF GENERAL SERVICES ADMIN
1 Court St, Augusta	Kennebec	OFFICE	Class 4 building	2014	7/1/2017	$85,000,000	MMB, MAINE MUNICIPAL BOND BANK
78 Exchange St, Bangor	Penobscot	OFFICE	Class 4 building	2009	7/1/2017	$65,000,000	MMB, MAINE MUNICIPAL BOND BANK
2 Pegasus St, Brunswick	Cumberland	SHOP	Steel/masonry	2005	7/1/2014	$56,553,900	MRRA, MIDCOAST REGIONAL REDEVELOPMENT AUTHORITY
112 Orion St, Brunswick	Cumberland	SHOP	Steel/masonry	1982	2/15/2012	$55,628,960	MRRA, MIDCOAST REGIONAL REDEVELOPMENT AUTHORITY
250 Arsenal St, Augusta	Kennebec	MEDICAL FACILITY	Class 4 building	2004	7/1/2016	$52,875,000	DHS, RIVERVIEW PSYCHIATRIC CENTER
675 Westbrook St, South Portland	Cumberland	PRISON	Steel/masonry	2002	11/27/2018	$48,940,000	COR, LONGCREEK YOUTH DEVELOPMENT CENTER
74 Orion St, Brunswick	Cumberland	OFFICE	Steel/masonry	1956	9/27/2017	$46,310,000	MRRA, MIDCOAST REGIONAL REDEVELOPMENT AUTHORITY
54 Pleasant St, Castine	Hancock	DORMITORY	Steel/masonry	1970	7/1/2017	$42,744,000	MMA, MAINE MARITIME ACADEMY
111 Sewall St, Augusta	Kennebec	OFFICE	Steel/masonry	1955	6/30/2001	$41,395,380	ADF, BUREAU OF GENERAL SERVICES ADMIN

Table 3.50: Potential exposure of state assets to a seismic event. Building Replacement cost (Value) in millions USD 2022.

Region	Assets in moderate to high hazard area		
	Assets Count	Value	% of total value
State of Maine	2,742	$2,880.5	85.8%
Androscoggin	103	$131.9	100.0%
Aroostook	61	$9.8	3.4%
Cumberland	604	$628.2	100.0%
Franklin	92	$15.4	73.2%
Hancock	78	$180.3	89.2%
Kennebec	518	$990.5	100.0%
Knox	97	$155.5	95.2%
Lincoln	80	$44.1	100.0%
Oxford	94	$37.1	95.5%
Penobscot	288	$363.6	94.8%
Piscataquis	56	$18.4	57.3%
Sagadahoc	87	$28.3	100.0%
Somerset	142	$124.6	95.4%
Waldo	179	$46.7	100.0%
Washington	-	-	-
York	263	$105.9	100.0%

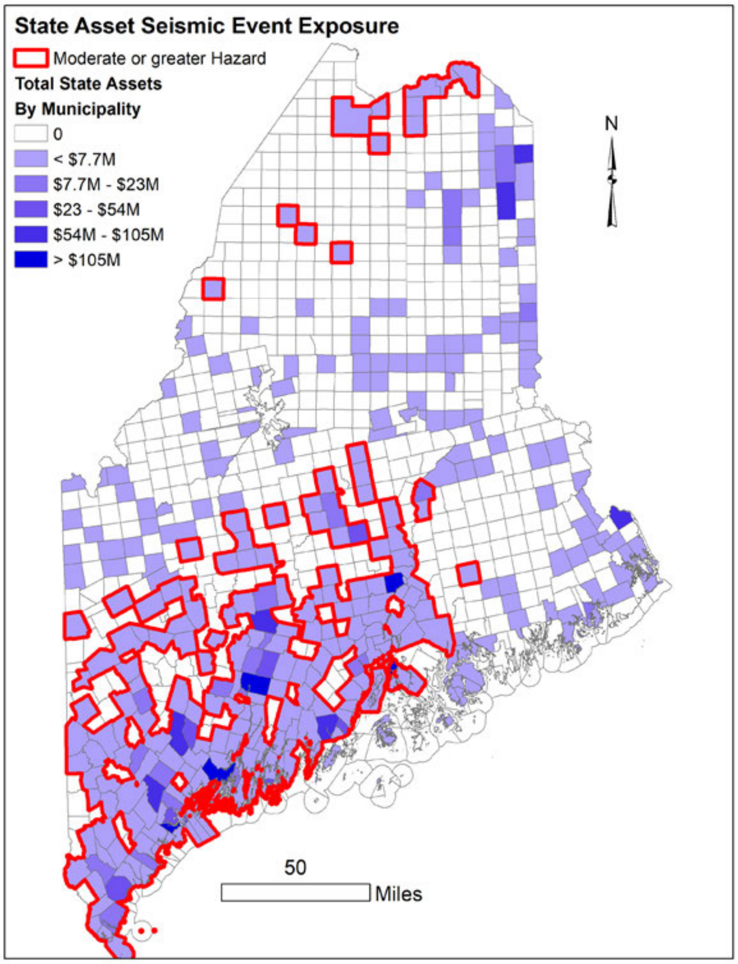

Figure 3.60: State assets exposed to moderate to high earthquake hazard.

3.67.2 Community Lifeline Risks

A major earthquake in Maine would likely impact all community lifelines but it is impossible to narrow down a specific location where the hazard may occur. The cities of Portland, Lewiston, and Bangor would likely have the greatest level of vulnerability due to the total population and infrastructure exposed to the hazard. As noted above, the Capital District in Augusta could be severely impacted by a damaging earthquake, limiting the ability to govern the state.

3.68 Earthquake – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

It is infeasible to accurately predict where future earthquakes will occur in Maine, though larger events are anticipated to impact broader areas that are more likely to occur in moderate to high hazard areas denoted by USGS. However, it is possible that an earthquake may occur anywhere in or directly adjacent to Maine, putting a greater importance on local building codes that potentially mitigate against seismic damages. The Maine Uniform Building and Energy Code (MUBEC) incorporates Seismic Codes into regulations for building construction in Maine communities with populations exceeding 4,000. Smaller communities have local authority to enact their own building codes and standards.

3.68.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

Disadvantaged Communities

The objective of the disadvantaged communities' assessment is to identify potential disadvantages felt by communities who are disproportionately impacted by natural hazards both historically and under future projections. Of the 19 disadvantaged communities in Maine, 7 are located in rural areas that are not regulated by MUBEC [60] and may not locally incorporate Seismic Codes (Figure 3.61). Another important consideration is that building codes are not retroactive; structures in MUBEC-regulated jurisdictions that predate the adopted building codes may not necessarily be brought up to the new standard. Figure 3.61 identifies the jurisdictions where MUBEC applies, and the disadvantaged communities located within and outside of these jurisdictions. Although Washington County is considered to have a low earthquake hazard exposure, the City of Eastport has witnessed multiple moderate-sized seismic events in the past, suggesting that exposure for disadvantaged communities in that area may be greater than these data suggest.

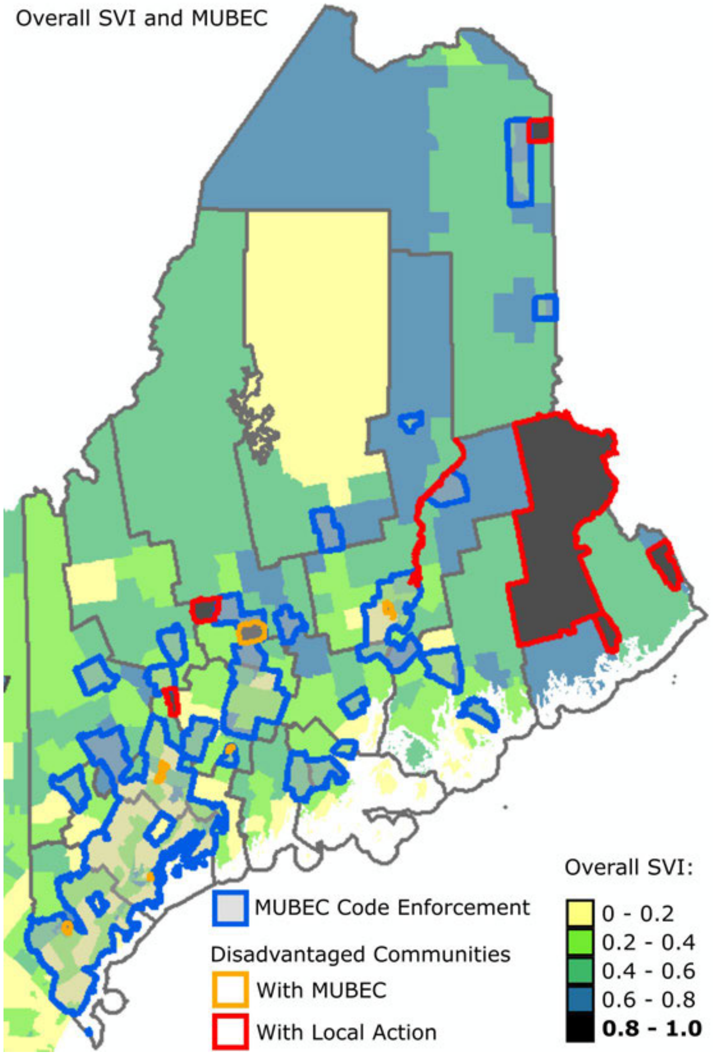

Figure 3.61: Map of Overall SVI, highlighting jurisdictions with and without MUBEC Code Enforcement

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[60] Office of the State Fire Marshal, MUBEC: https://www.maine.gov/dps/fmo/building-codes

3.68.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Hazard-Asset Footprint Overlay Analysis

It is not expected that all buildings will suffer 100% losses from a magnitude 5 to 6 earthquake in Maine. Because the degree of damage is difficult to predict for an event that has never occurred in Maine, total building replacement values are reported as a measure of potential exposure for structures in moderate to high earthquake hazard areas. Damage curves are not factored into this assessment.

The total valuation for all identified structure assets in Maine is $329 Billion (2022 USD). There are $240 billion in assets identified within moderate to high earthquake hazard areas, though not all of these assets are necessarily vulnerable to damage from seismicity. Exposure estimates are further disseminated by county in Table 3.51.

Table 3.51: Potential earthquake exposure for all structure assets in moderate to high hazard areas (millions 2022 USD)

Region	**Assets in WUI**		
	Count	Value	% of total value
State of Maine	530,131	$239,692	72.76%
Androscoggin	40,678	$20,282	100.00%
Aroostook	9,185	$3,646	17.01%
Cumberland	104,437	$54,242	89.93%
Franklin	10,842	$4,724	55.36%
Hancock	3,100	$1,323	7.46%
Kennebec	65,768	$29,533	100.00%
Knox	3,342	$1,208	10.31%
Lincoln	9,212	$3,313	31.02%
Oxford	34,258	$13,864	86.38%
Penobscot	62,543	$29,334	83.10%
Piscataquis	12,460	$4,584	79.27%
Sagadahoc	11,237	$4,670	56.88%
Somerset	32,914	$13,947	88.15%
Waldo	23,082	$9,262	85.14%
Washington	-	-	-
York	107,073	$45,759	99.94%

Forest Pests – Hazard Profile

TIER 2 HAZARD

3.1 Forest Pests – General Definition and Types of Events [S3.a., S3.b.]

A Forest Pest/Damage Agent is an insect, disease, weed or other abiotic or biotic factor that can cause damage or death to a host tree. Some forest pests, such as the browntail moth[1], can cause damage to forests as well as pose direct health risks to humans. Damage Agents are categorized as: Insects, Diseases, Weeds, and Other Damage Agents. Within insects and diseases, the categories are broken out into the area of the tree damaged, or the type of damage inflicted on the tree; i.e., wood boring, gall makers, and foliage diseases. Weeds are divided by the habit of the weed species; e.g., tree, shrub, and vine. Other damage agents are divided into three sections by cause of the damage to the host tree: Abiotic Damage, Human Damage, and Animal Damage[2].

The Maine Forest Service maintains a Forest Pest Index including 87 different insects and diseases, each of which may target different tree species[3]. Not all of these forest pests are currently found in Maine, though based on growth trends many of these are expected to eventually enter the state. As a result, it can be challenging to generalize the impacts, location, intensity, and occurrence of each forest pest under a single Hazard Profile. The Maine Forest Service categorizes the impacts of forest pests as contributing to either chronic or acute stress. Several native and invasive species contribute to these types of forest stress.

3.1.1 Chronic Stress

Chronic stress is recurring and lasts for long periods of time. Longstanding stressors like white pine blister rust, balsam woolly adelgid, beech bark disease and others throughout the state as well as newer arrivals beech leaf disease and hemlock woolly adelgid in central and coastal counties are examples of stressors that lead to chronic impacts and frequently compound with other long-term hazards such as drought or other chronic forest pests.

3.1.2 Acute Stress

Acute stress imposes an immediate impact on a forest. Fast-acting agents such as emerald ash borer and native and introduced outbreak-prone defoliators such as spruce budworm, spongy moth and winter moth, damage forests and cause tree decline/mortality in a shorter time frame.

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[1] Browntail moth: https://www.maine.gov/dacf/mfs/forest_health/invasive_threats/browntail_moth_info.htm
[2] Forest Pests of North America: https://www.forestpests.org/faq.cfm
[3] Maine Forest Pest Index: https://www.maine.gov/dacf/mfs/forest_health/forest_pest_index.html

3.2 Forest Pests – Location of Hazard [S3.a.1]

Forest pests are found in all parts of Maine. It is difficult to specify locations in general terms due to the abundance of forest pests and their variable distribution across the state. For this reason, we include examples of forest pests with known locations where spread has occurred.

3.2.1 Browntail Moth

Surveys from 2021 and 2022 indicate that browntail moth occurrence is most prevalent in central and midcoast Maine (Figure 3.63). Along the coast the greatest occurrence lies between Portland to the west and Penobscot Bay/Frenchman Bay in the east. Inland, the greatest occurrence lies between eastern Oxford County, through the Augusta area, encompassing the Bangor area to the east, and as far north as Lincoln. The web survey counts indicate that Androscoggin, Kennebec, Cumberland, Lincoln, Knox, and Waldo are the most impacted counties. Maine Forest Service provides a Browntail Moth dashboard providing updated occurrence information[4].

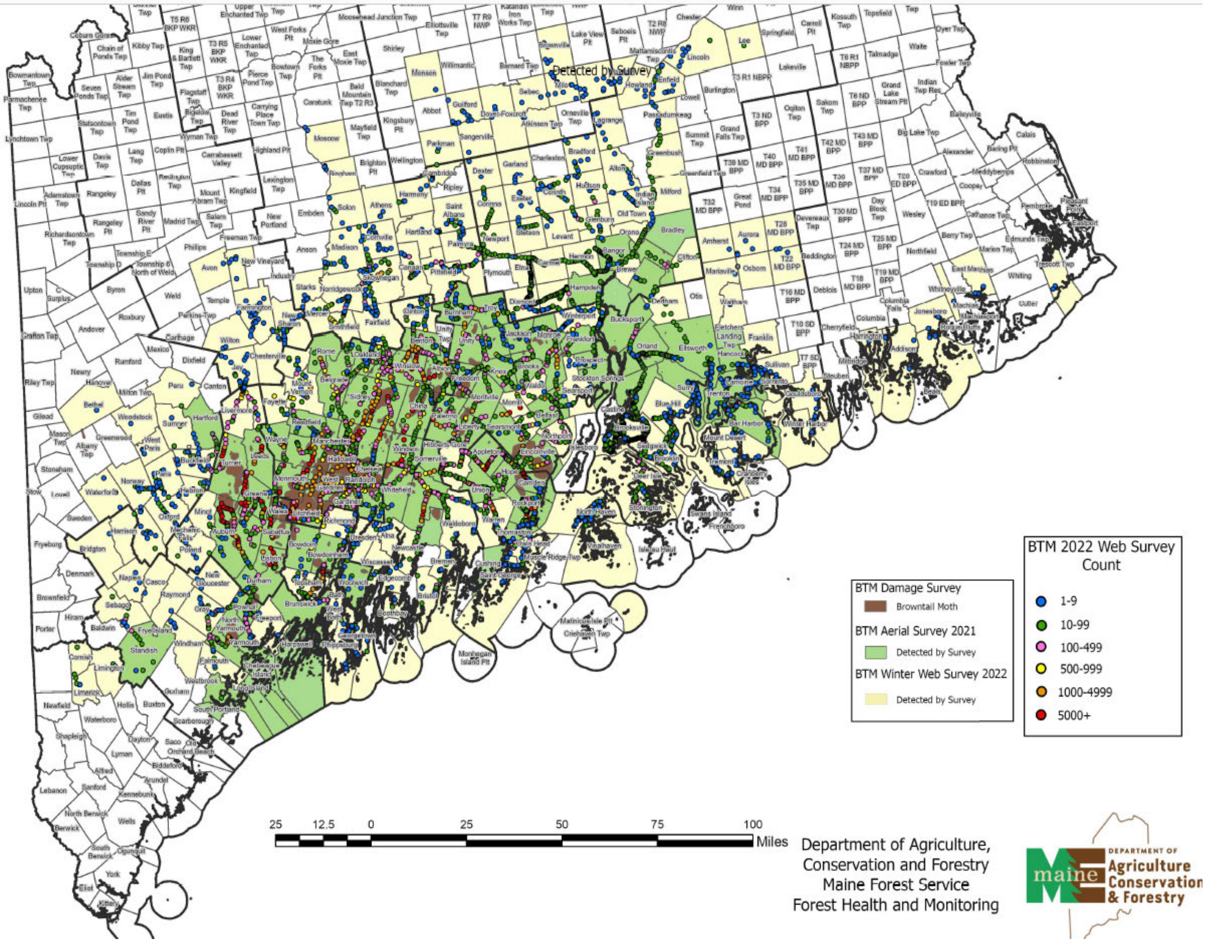

Figure 3.63: Browntail moth survey map data.

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[4] Browntail Moth Dashboard: https://www.maine.gov/dacf/mfs/forest_health/forest_pest_index.html

3.2.2 Beech Leaf Disease

First reported in Ohio in 2012, beech leaf disease has been leading to decline and mortality of beech trees from Ohio to Southern New England. The first case in Maine was identified in Waldo County in May 2021, and is now found as far west as York County, as far east as Acadia National Park, Hancock County, and as far north as the Penobscot Experimental Forest (Figure 3.64). The disease may be established elsewhere, and efforts continue to determine disease distribution through survey and reports from the public.

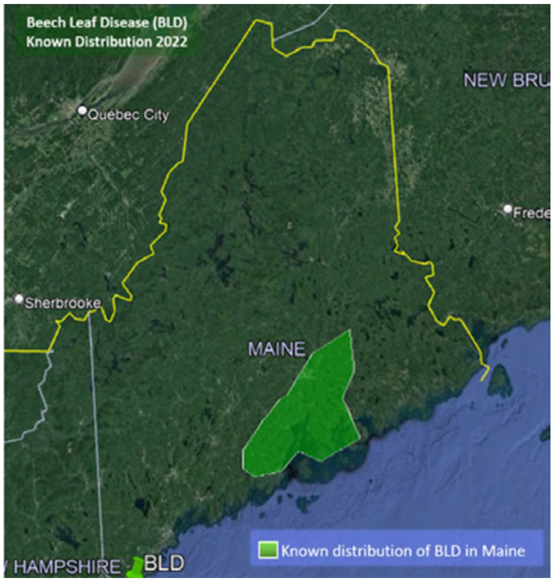

Figure 3.64: Beech Leaf Disease known distribution (2022).

3.2.3 Hemlock Wooly Adelgid

Hemlock Woolly Adelgid (Uh-**dell**-jid) is an introduced, aphid-like insect from Asia that attacks eastern hemlock. As of 2011, eighteen states from Maine to Georgia have HWA[5]. Many infested areas display extensive tree decline and mortality. All species of hemlock are affected, but not pine, spruce, fir or other conifers. The most obvious sign is the covering of wool-like wax filaments produced as the insect matures. The woolly masses generally range from about 1/16-inch to 1/8-inch in diameter. They are most visible from late fall to early summer on the undersides of the outermost branch tips of hemlock trees.

In March 2020, the woolly adelgid quarantine area[6] in Maine was expanded to include 3 entire counties and 29 additional towns (Figure 3.65). The quarantine area for hemlock woolly adelgid in Maine includes parts or all of Androscoggin, Cumberland, Hancock, Kennebec, Knox, Lincoln, Sagadahoc, Waldo, and York Counties.

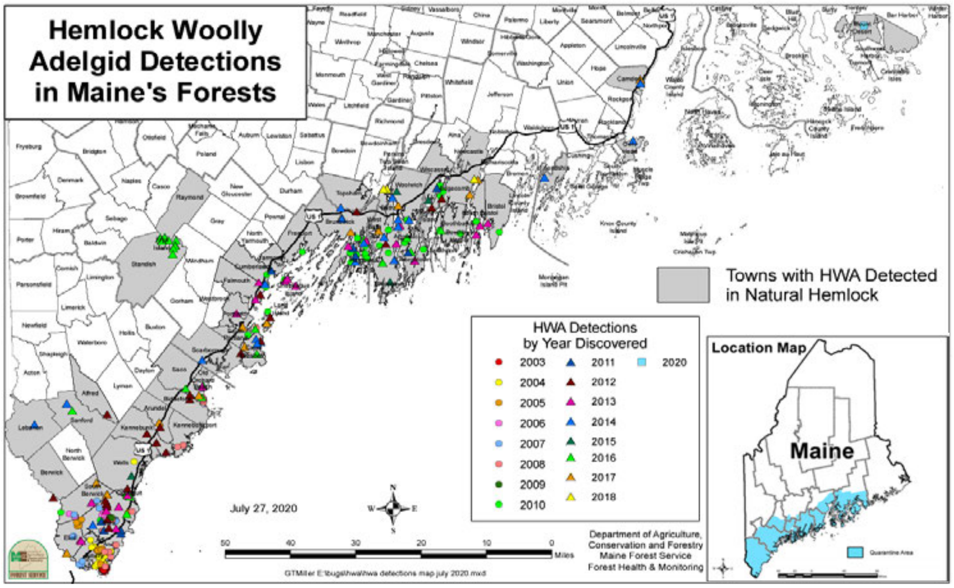

Figure 3.65: Hemlock Wooly Adelgid detection, 2003-2020. Blue in reference map indicates quarantine areas.

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[5] Maine Forest Service, Hemlock Wooly Adelgid: https://www.maine.gov/dacf/mfs/forest_health/insects/hemlock_woolly_adelgid_overview.htm

[6] Maine Forest Service quarantine site: https://www.maine.gov/dacf/mfs/forest_health/quarantine_information.html

3.2.4 Emerald Ash Borer

The emerald ash borer (EAB), *Agrilus planipennis*, is one of the most serious invasive species threatening our ash resources and forests (Figure 3.66). All species of (*Fraxinus*) ash trees, but not (*Sorbus*) mountain ash, that grow in Maine are susceptible to injury and death by the emerald ash borer.

EAB was first found in Aroostook County (Madawaska, Frenchville, and Grand Isle), and York County (Acton, Berwick, and Lebanon), ME in 2018. It was detected in Cumberland County (Portland) in September 2019.

The quarantine area includes all of York County, all of Cumberland County, parts of Oxford, Kennebec, Sagadahoc, and Somerset Counties, and northern corner of Aroostook County. The quarantine boundaries were drawn to include a buffer on those towns where EAB had been detected. EAB was found in northern Aroostook County in May 2018, western York County in September 2018, and Cumberland County in September 2019.

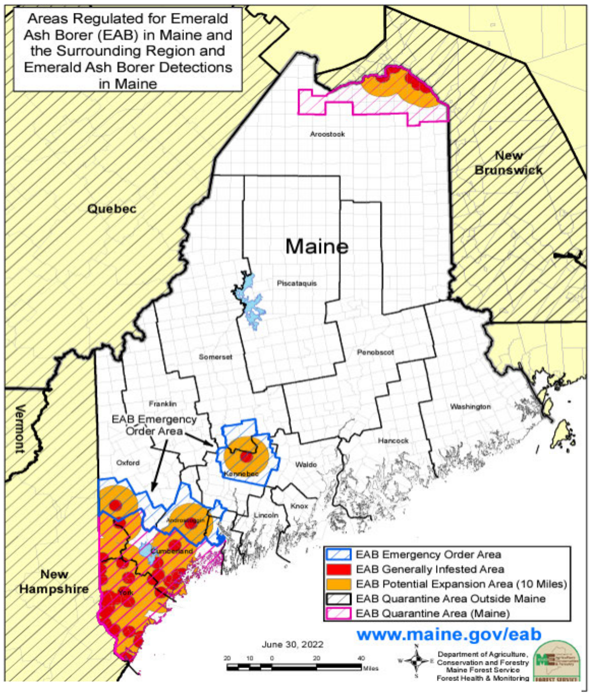

Figure 3.66: Emerald ash borer outbreak locations and quarantine orders (2022).

3.3 Forest Pests – Intensity and Previous Occurrences [S3.a.2]

The intensity of forest pest hazards is typically measured by the total area of tree damage. There is no standard scale for measuring the intensity of the hazard, but it is possible to compare the area of damage each year and identify trends. For example, the 2021 Maine Forest Health Highlights Report identified 262 thousand acres of tree/forest damage in Maine based on aerial surveys, exceeding the previous year's damage by 77 thousand acres (185 thousand in 2020)[7]. This is identified by the Maine Forest Service as a substantial increase. In addition to aerial survey results, a further 163 thousand acres of damage were identified through ground surveys, bringing the total damaged forest area to 425 thousand acres statewide, much of which takes the form of defoliation. Previous years exhibited smaller damage areas, including 14 thousand acres in 2019 and 145 thousand acres in 2018[8].

3.3.1 Previous Occurrences

Spruce Budworm Outbreak of the 1970s-80s

At its peak, the last SBW outbreak, which lasted from 1967 to 1993, covered about 136 million acres across eastern Canada and Maine[9]. The outbreak was severe and produced dead and dying stands of trees that could be seen on the horizons in some areas. This outbreak defoliated fir and spruce trees across most of the northern half of Maine, killed between 20 and 25 million cords of spruce and fir, and resulted in hundreds of millions of dollars in lost revenue to the state's forest-based economy. Efforts to protect the forest during this period launched a wave of aerial insecticide spraying across millions of acres, with the area sprayed exceeding a million acres per year at peak times during the outbreak. These protection efforts cost state and federal governments, as well as

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[7] Maine Forest Health Conditions 2021: https://www.maine.gov/dacf/mfs/forest_health/documents/2021-maine-forest-health-highlights112321.pdf

[8] Maine Forest Health Conditions Highlights 2019: www.maine.gov/dacf/mfs/forest_health/documents/2019MaineForestHealthHighlightsForUSFS.pdf

[9] Maine Spruce Budworm Task Force: https://www.sprucebudwormmaine.org/historical-perspectivespast-infestations/1970s-80s-outbreak/

private landowners, many additional millions of dollars, and photos of budworm damaged fir trees in Maine resulted in conflicts over how the costs would be shared.

In addition to these immediate impacts, the SBW outbreak drastically changed forest structure and composition across northern Maine and had ripple effects on forest management, politics, public policy, and the forest-based economy over the next 40 years. For example, salvage logging to capture dead and dying trees caused landowners to increase the use of clearcut harvesting during the 1970s. These clearcuts had a large visual impact on the forest landscape, which caused substantial public controversy. This controversy led to the passage of the 1989 Forest Practices Act (FPA), which defined and heavily regulated clearcut harvesting. Efforts by landowners to reduce the use of clearcutting after implementation of the FPA were very successful. Clearcutting as a proportion of forest harvesting fell from 45% in 1989 to less than 8% by 1996 and has hovered between 2% and 6% every year since that time.

3.4 Forest Pests – Probability of Future Occurrence [S4.]

An almost invisible war takes place each year between Maine's forest and insects and diseases. Occasionally, insects or disease get the upper hand and either forests or people are affected to the point where action must take place. Native pests, while at times expensive to deal with like the Spruce budworm, don't eliminate the host species like balsam fir which the budworm feeds on heavily. Exotic pests are a different story, for example, Chestnut Blight and Dutch Elm Disease eliminating the host species of American Chestnut and American Elm as significant components of the forest [10].

Spruce Budworm

As noted by State Entomologist Allison Kanoti [11], the Maine Forest Service (MFS) and its cooperators are closely watching spruce budworm in Maine to monitor and prepare for another epidemic of this native defoliator. Over the last several years, Spruce budworm populations in Maine have left the "stable" phase and appear to be building. Pheromone and light trap catches have been above zero for a number of years, defoliation in Quebec has increased year after year, defoliation has been mapped in New Brunswick. This is an insect whose epidemics cover vast regions and flights of moths from heavily infested areas can migrate to new areas. Another outbreak in Maine, soon, is undeniable. When, where, how severe, and what the specific impacts and reactions will be, remain to be seen.

3.4.2 Projected Changes in Hazard location, Intensity, Frequency, and Duration

Introduction/spread of invasive forest pests

Increasing world trade is intensifying the opportunity for invasive pests to become established in North America. We have several invasive insects right now either active in Maine's forests or just "next door." The Hemlock Woolly Adelgid is causing damage to our coastal hemlocks while the very lethal Emerald Ash Borer has footholds in both far northern and far southern Maine; the Asian Longhorned Beetle is being fought in Worcester, Massachusetts and Oak Wilt is being addressed in several places in New York. The MFS is actively engaged in reducing the threats from pests using a number of different strategies. For those not having reached Maine, like the Asian longhorned beetle, efforts continue to slow its spread by restricting the flow of contaminated wood. For others like the Hemlock Woolly Adelgid, damage is mitigated through efforts such as the release of biological

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[10] Message from the State Forester: https://www.maine.gov/dacf/mfs/forester/index.htm

[11] Maine Forest Service Spruce Budworm Report, 2019: www.sprucebudwormmaine.org/wp-content/uploads/2019/06/MFS_2018_SpruceBudwormMaineReport.pdf

agents. Fortunately, the federal government is very active and lends significant assistance to states like Maine. In all cases, the involvement of the public is absolutely essential[12].

Climate Change

As noted by Quirion et al. (2021)[13], both native and non-native insects and diseases are expected to exhibit increased impacts in response to climate change. Introduced and native insects and diseases can act solely or collectively with other forest stressors to damage or kill large numbers of trees in short periods of time, reducing a forest's capacity to sequester C as well as increasing emissions of stored C through decomposition of wood in dead or injured trees[14], [15], [16]. Historically, native and introduced forest insects and diseases have impacted an average of 20.4 million hectares, or approximately 15% of the US's total forest cover, annually[17]. An estimated 41% of the live forest biomass in the contiguous US could be impacted by the fifteen most damaging non-native insects and diseases already established in the US[18].

In general, climate projections favor many, but not all, forest insects and diseases, with a mixed effect on forest stressors. For example, the current expansion of browntail moth appears to have been aided by warm late-summer temperatures during the early instar caterpillar stage of the insect. Conversely, spruce budworm is also a young caterpillar in late-summer, and warm temperatures at that time make it less likely to survive overwinter.

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[12] Message from the State Forester: https://www.maine.gov/dacf/mfs/forester/index.htm

[13] Quirion, B. R., Domke, G. M., Walters, B. F., Lovett, G. M., Fargione, J. E., Greenwood, L., ... & Fei, S. (2021). Insect and disease disturbances correlate with reduced carbon sequestration in forests of the contiguous United States. *Frontiers in Forests and Global Change*, *4*. https://doi.org/10.3389/ffgc.2021.716582

[14] Ellison, A. M., Bank, M. S., Clinton, B. D., Colburn, E. A., Elliott, K., Ford, C. R., et al. (2005). Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Front. Ecol. Environ* 3, 479–486. doi: 10.2307/3868635

[15] Hicke, J. A., Allen, C. D., Desai, A. R., Dietze, M. C., Hall, R. J., Hogg, E. H. T., et al. (2012). Effects of biotic disturbances on forest carbon cycling in the United States and Canada. *Glob. Chang. Biol.* 18, 7–34. doi: 10.1111/j.1365-2486.2011.02543.x

[16] Lovett, G. M., Weiss, M., Liebhold, A. M., Holmes, T. P., Leung, B., Lambert, K. F., et al. (2016). Nonnative forest insects and pathogens in the United States: impacts and policy options. *Ecol. Appl.* 26, 1437–1455. doi: 10.1890/15-1176

[17] Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., et al. (2001). Climate change and forest disturbances. *Bioscience* 51, 723–734.

[18] Fei, S., Morin, R. S., Oswalt, C. M., and Liebhold, A. M. (2019). Biomass losses resulting from insect and disease invasions in US forests. *Proc. Natl. Acad. Sci. U. S. A.* 116, 17371–17376. doi: 10.1073/pnas.1820601116

3.5 Forest Pests – Impacts

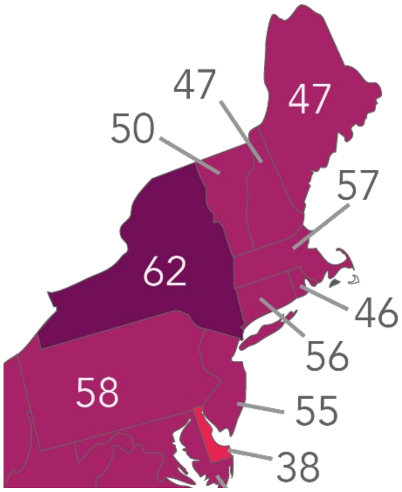

Figure 3.67: Imported forest pests occur in every state in the US. Map credit: Cary Institute/Leslie Tumblety https://www.caryinstitute.org/science/tree-smart-trade/tree-smart-trade-resources

Maine now hosts several invasive insects with several more advancing toward the state (Figure 3.67). The Hemlock Woolly Adelgid is causing damage to our coastal hemlocks while the very lethal Emerald Ash Borer has footholds in both far northern and far southern Maine; the Asian Longhorned Beetle is being fought in Worcester, Massachusetts and Oak Wilt is being addressed in several places in New York. The MFS is actively engaged in reducing the threats from pests using a number of different strategies. For those not having reached Maine, like the Asian longhorned beetle, efforts continue to slow its spread by restricting the flow of contaminated wood. For others like the Hemlock Woolly Adelgid, damage is mitigated through efforts such as the release of biological agents. Fortunately, the federal government is very active and lends significant assistance to states like Maine. In all cases, the involvement of the public is absolutely essential.

The impacts of forest pests include but are not limited to ecosystem damage, negative impacts to forest resource and tourism economies, impacts to state protected lands such as state parks in forested areas, health risks, increased wildfire vulnerability due to greater available fuels, increased vulnerability to erosion and mass wasting due to loss of root structures holding soil in place, and loss of a cultural identity in a heavily forested state.

3.6 Forest Pests – Vulnerability of State Assets [S5.]

State forests, parks, and other conserved lands are likely the most directly vulnerable of all state assets to forest pests. Impacts may include direct declines in forest health and indirect impacts to visitation and the tourism economy (especially for pests such as browntail moth). Table 3.52 and Figure 3.68 indicate the current expanse of three four pests (emerald ash borer, hemlock woody adelgid, browntail moth, beech leaf disease) overlain on conserved lands for local, private, state, and federal jurisdiction. Browntail moth expanse is provided based on greater relative occurrence, as its impacts are felt to varying degree across most of the state.

Table 3.52: Total number of conserved lands by interest type located in counties with some reported exposure to forest pests*. Percentages denote proportion of statewide conserved lands per interest type.

Region/exposure area	State	Municipal	Federal	Private/Other
State	3,176	2,101	1,804	4,850
Browntail Moth	2,060 (64.9%)	1,657 (78.9%)	755 (41.9%)	3,279 (67.6%)
Hemlock Wooly Adelgid	1,497 (47.1%)	1,496 (71.2%	1,016 (56.3%)	3,212 (66.2%)
Emerald Ash Borer	1,304 (41.1%)	1,419 (67.5%)	841 (46.6%)	2,286 (47.1%)
Beech Leaf Disease	815 (25.7%)	551 (26.2%)	438 (24.3%)	1,646 (33.9%)

*Not all portions of each county are currently exposed to these forest pests. Total browntail moth exposure is greater than reported in these "higher impact" counties.

Conserved lands contribute to Maine's economy. In 2021, Maine's State Parks and Historic Sites drew a record of 3.3 million visitors, surpassing the prior visitor record of 3 million in 2020. These visitors and their activities contribute an estimated $100 million to the state's economy[19]. Further, a new National Park Service report shows that visitors to national parks in Maine spent $490 million in 2021. The total of 4.1 million visits supported 7,070 jobs and had a cumulative economic output of $770 million[20]. Damage/impacts by forest pests would likely reduce visitation and bring down economic output on local to regional levels.

The forest products industry also contributes an estimated $276 million in state and local taxes[21]. Any impact to productivity and/or forest land value caused by large-scale forest pest activity (such as spruce budworm outbreaks) may impact tax contributions to state and local government. There is no guarantee that these assets will be damaged in a natural hazard event.

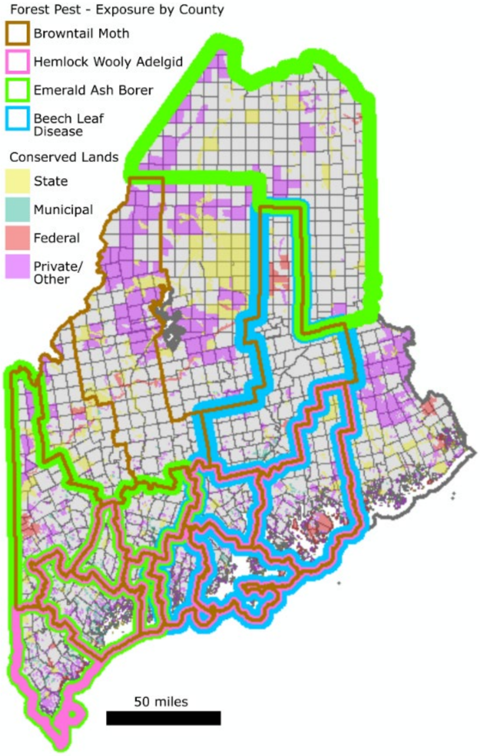

Figure 3.68: Forest pest exposure by county, with conserved lands.

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[19] Maintain Maine State parks report: https://www.maine.gov/jobsplan/program/maintain-maine-state-parks

[20] National Park visitation: https://www.nps.gov/subjects/socialscience/vse.htm

[21] Maine Forest Products Council 2019 Forest Products Economic Impact: Revised November 2021: https://maineforest.org/wp-content/uploads/2022/08/2019-FP-Impact-Final-to-MFPC-Revised-Nov-2021.pdf

3.6.1 Potential Dollar Losses to State Owned Buildings, Infrastructure, Critical Facilities

As noted above, forest pests may impact the economic benefits of conserved lands as well as the tax value of forest land across the entire state. Direct impacts to state owned buildings and infrastructure are more challenging to determine at this time but are likely to be secondary to the direct impacts to forests.

3.6.2 Community Lifeline Risks

Maine Forest Service will continue to monitor the impacts of forest pests and work collaboratively with MEMA to determine risks to community lifelines.

3.7 Forest Pests – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.7.1 Identifying Jurisdictions with Greatest Vulnerability [S6.a.1.]

Jurisdictions that rely on forest resources will be directly impacted by the spread of forest pests in Maine. An assessment by the Cary Institute[22] identifies that local governments and homeowners will likely bear the brunt of economic impacts (Figure 3.69).

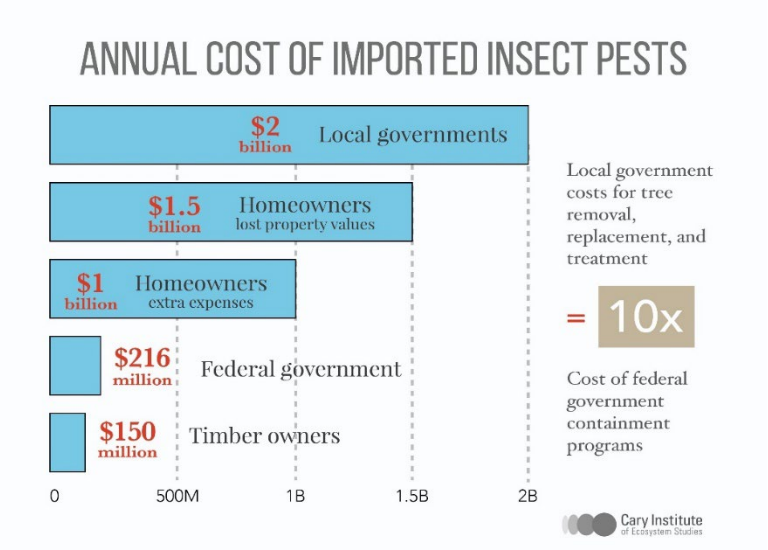

Figure 3.69: Annual average cost of forest pests for different entities. https://www.caryinstitute.org/science/tree-smart-trade/tree-smart-trade-resources

Disadvantaged Communities

Economically disadvantaged rural communities will likely see the greatest impacts, economic or otherwise, of forest pests. Exposure in these jurisdictions is anticipated to be greater due to proximity in the Wildland Urban Interface, traditional reliance on a forest resource-based economy, and their capacity to mitigate against this and related issues is overall far less than wealthier jurisdictions.

3.7.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

Maine's forest products sector includes (but is not limited to) businesses, organizations, and individuals involved with logging and forestry, paper and related product manufacturing, sawmills and wood-product manufacturing, wood furniture manufacturing, the generation of biomass electricity, and the Maine Forest Service. The estimated overall annual (2019) economic contribution of Maine's forest products sector, including multiplier effects, was an estimated $8.1 billion in output, over 31,000 jobs, and $1.7 billion in labor income. The total employment impact of 31,822 jobs in 2019 is equivalent to about 4 percent of the jobs in Maine. Put another way, roughly 1 out of 25 jobs in Maine is associated with the forest products sector. Maine's forest products sector had a total, including multiplier effects, value-added impact of an estimated $2.8 billion. This is equivalent to 4.14 percent of the state's gross domestic product in 2019[23].

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[22] Cary Institute, Tree-SMART Trade Resources: https://www.caryinstitute.org/science/tree-smart-trade/tree-smart-trade-resources

[23] Maine Forest Products Council 2019 Forest Products Economic Impact: Revised November 2021: https://maineforest.org/wp-content/uploads/2022/08/2019-FP-Impact-Final-to-MFPC-Revised-Nov-2021.pdf

Harmful Algal Blooms – Hazard Profile

3.8 Harmful Algal Blooms – General Definition and Types of Events [S3.a., S3.b.]

Harmful Algal Blooms (HABs) occur when algae – simple plants that live in the sea and freshwater – grow rapidly and produce toxic or harmful effects on people and aquatic organisms[24]. Human illnesses caused by HABs, though rare, can be debilitating or even fatal. Other algae are nontoxic but may cause hypoxia in the water as they decay[25], clog the gills of fish and invertebrates, smother aquatic vegetation, or contaminate drinking water.

HABs generally occur in summer months though there are some algal species that may also spread in winter. More comprehensive HAB-related preparedness and health risk mitigation considerations are detailed in other planning efforts provided by the Maine Department of Marine Resources[26] and Maine Department of Environmental Protection[27].

Every U.S. coastal and Great Lakes state experiences HABs. These blooms are a national concern because they affect not only the health of people and marine ecosystems, but also the "health" of our economy — including communities along the coast and in lake regions dependent on the income of jobs generated through fishing and tourism. In Maine, HABs typically occur between April and October, but some species have also recently come out of seasonal dormancy and bloomed in winter months[28].

3.8.1 *Marine HABs*

The Maine Department of Marine Resources (DMR) Public Health Bureau tests coastal shellfish areas for biotoxins bi-weekly beginning in March, changing to weekly testing from May to October, or later when necessary. Precautionary regional closures along the coast are implemented annually starting in May when the likelihood of biotoxin blooms increases with the temperature. With climate change and increasing nutrient pollution potentially causing HABs to occur more often and in locations not previously affected[29], it's important for us to learn as much as we can about how and why they form and where they are, so that we can reduce their harmful effects.

Biotoxin closures of shellfish areas occur because conditions in the water make shellfish unsafe for human consumption. Maine DMR Public Health Bureau monitors several biotoxins produced by different types of marine algae known as phytoplankton. The types of phytoplankton include: *Alexandrium* ("Red Tide"), which produces the toxins that causes Paralytic Shellfish Poisoning; *Pseudo-nitzschia*, which produces the toxin that causes Amnesic Shellfish Poisoning; and *Dinophysis* and *Prorocentrum lima*, which produce the toxins that cause Diarrhetic Shellfish Poisoning. It's normal for biotoxin-producing algae to be present in marine water. They are usually at very low concentrations and pose no problems. Toxic shellfish can be found in clear, clean, and remote waters off the coast of Maine. Toxic shellfish do not look or taste any different from non-toxic shellfish and toxins cannot be cooked out. Visit Maine DMR's shellfish closures inventory[30] to find out whether it is safe to harvest

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[24] NOAA, "What is a harmful algal bloom?": https://www.noaa.gov/what-is-harmful-algal-bloom

[25] NOAA, "Hypoxia": https://oceanservice.noaa.gov/hazards/hypoxia/

[26] Maine DMR Bureau of Public health Programs: https://www.maine.gov/dmr/fisheries/shellfish/bureau-of-public-health-programs

[27] Maine DEP Cyanobacteria webpage: https://www.maine.gov/dep/water/lakes/cyanobacteria.html

[28] Maine DMR, "Biotoxins in Maine": https://www.maine.gov/dmr/fisheries/shellfish/bureau-of-public-health-programs/biotoxins-in-maine

[29] EPA, "Climate change and harmful algal blooms": https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms

[30] Maine DMR Growing Area Closures: https://www.maine.gov/dmr/fisheries/shellfish/closures

in a specific area. Bacterial closure information which is caused by pollution instead of biotoxins is also located on the same webpage.

Additionally, DMR monitors visible marine algal blooms, considered “nuisance blooms”, through aerial surveillance and water sampling with accompanying light microscopy identification. Though the nuisance bloom algal species do not pose a human health risk they may cause marine organism die-off. Notable temporal and spatial nuisance bloom events are communicated to the public but do not lead to bivalve shellfish closures.

3.8.2 *Freshwater HABs*

Most freshwater HABs are caused by a type of bacteria called cyanobacteria. Under certain conditions, the cyanobacteria can quickly multiply, and many species of the bacteria can produce toxins that can cause rashes, nausea, diarrhea, and in severe cases death. Maine DEP has created several Water Programs that help to mitigate risks associated with freshwater HABs[31], therefore we provide only a brief summary of this hazard. Maine DEP’s monitoring program primarily tracks blooms that reduce the transparency of the water to less than 2 meters. Blooms not only turn the water murky, but they can also cause bad odors (musty or fishy smell), green or blue-green scums or streaks near-shore, and foam[32]. Since 2008, DEP has been measuring concentrations of microcystins (toxins produced by some freshwater cyanobacteria) in lakes that regularly support algal blooms and in lakes considered free of blooms. By sampling a variety of great ponds with surface areas of 150 acres or more, biologists are confident that we are establishing a dataset that will characterize all Maine lakes and provide insight on how toxin concentrations compare to EPA’s guidelines. In addition, these data will form the basis for how the State of Maine’s Department of Health and Human Services, Center for Disease Control will create an advisory specific to our lakes.

3.9 Harmful Algal Blooms – Location of Hazard [S3.a.1.]

HABs include multiple different algal species that exist in either freshwater or marine environments. Marine HABs of all observed types and extents may occur across the entire coast of Maine. Refer to Maine DMR’s Shellfish Closure and Aquaculture Leases interactive map for real-time information on closures[33]. Numerous coastal municipalities enforce shellfish ordinances, in part to assist with managing shellfish closure orders[34].

Freshwater HABs tend to occur in lakes beneath the Marine Transgression, an area that was depressed below sea level due to substantial ice overburden during the Last Glacial Maximum of the Laurentide Ice Sheet and subsequent melting[35]. Clays deposited by the marine transgression provide greater availability of nutrients required for growth of HABs. However, there are a number of exceptions to this trend, especially in northern Maine. Visit DEP’s Algal Bloom Risk map for more information on impacted locations and bloom frequency for lakes[36]. There are currently 6 lakes at very high risk (annual bloom likely) and 27 lakes at high risk (will likely bloom again) of HABs, based on current information.

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[31] Maine DEP Water Programs: https://www.maine.gov/dep/water/programs/index.html

[32] Maine DEP, “Cyanobacteria”: https://www.maine.gov/dep/water/lakes/cyanobacteria.html

[33] DMR Shellfish Closures Map: https://www.maine.gov/dmr/fisheries/shellfish/shellfish-closures-and-aquaculture-leases-map

[34] General Shellfish Ordinance Information: https://www.maine.gov/dmr/fisheries/shellfish/municipal-shellfish-management-program/general-shellfish-ordinance-information

[35] Joseph T. Kelley, Daniel F. Belknap, R.Craig Shipp, Sedimentary framework of the southern Maine inner continental shelf: Influence of glaciation and sea-level change, Marine Geology, Volume 90, Issues 1–2, 1989, Pages 139-147, doi.org/10.1016/0025-3227(89)90124-2.

[36] Dep Algal Bloom Risk Map: https://www.maine.gov/dep/water/lakes/bloomriskmap.html

3.10 Harmful Algal Blooms – Intensity and Previous Occurrences [S3.a.2.]

As noted by Record et al. (2022)[37], Maine has a rapidly growing shellfish aquaculture industry with careful toxin monitoring. Paralytic shellfish toxins are sampled in shellfish tissue weekly at multiple sites by DMR during the bloom season and are processed by Bigelow Analytical Services. The toxin testing dataset dates back to 2014 and follows a chemical analytical technique that uses high-performance liquid chromatography approved for regulatory purposes (Rourke et al., 2008), generating information on 12 congeners of saxitoxin that contribute to a total toxicity value for each sample (µg SAX eq 100 g-1 shellfish). The toxin level used to initiate shellfish growing area closures is ≥80 µg SAX eq 100 g-1 shellfish. The Interstate Shellfish Sanitation Conference provides the National Shellfish Sanitation Program Guide for the Control of Molluscan Shellfish and threshold values for managing outbreaks and mitigating against health issues[38].

As noted by DEP[39], most Freshwater HABs in Maine are "nuisance blooms" that reduce water transparency. DEP defines nuisance blooms as the condition when water clarity is 2 meters (6.6 feet) or less, while HABs are the condition when water clarity is less than 1-meter (3.3 feet)[40]. Tests conducted by DEP indicate that most Maine lakes do not produce algal blooms and are safe to drink (after disinfection) and recreate in. In contrast, lakes that regularly produce algal blooms are most likely to produce toxins, the highest concentrations of which are found in the scums that accumulate along the shoreline; these scums may be 100-1000 times the levels of concern issued by EPA. Swimming areas and deep waters occasionally produce toxin concentrations that exceed EPA guidelines, but in the range of 1-10 times EPA's guidelines. Results also indicate that toxins are produced later in the bloom period, when cell numbers are most dense, and cells are beginning to die. Toxins are not readily absorbed through the skin, and it is not clear if health problems can arise from inhaling water droplets with toxins. Though small amounts can cause mild reactions in sensitive individuals, significant human illness has been only rarely reported. However, severe reactions and death of pets or livestock drinking contaminated water have been reported from many locations outside of Maine. The Environmental Protection Agency (EPA) provides health and safety threshold values for the toxins generated by various species of algae[41]. Refer to DMR and DEP informational sites for further information.

3.10.1 Previous Occurrences

Prior to 1972, paralytic shellfish poisoning (PSP) toxicity was historically restricted to the far eastern sections of Maine near the Canadian border, with the first documented PSP in Maine in 1958. In 1972, a massive, visible red tide of *Alexandrium fundyense* stretched from southern Maine through New Hampshire and into Massachusetts, causing toxicity in southern areas for the first time. Virtually every year since the 1972 bloom event, western Maine has experienced PSP-related algal blooms, and on a less-frequent basis, New Hampshire and Massachusetts have as well. This pattern has been viewed as a direct result of *Alexandrium* cysts being retained in western Gulf of Maine waters once introduced there by the 1972 bloom[42].

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[37] Record NR, Evanilla J, Kanwit K, Burnell C, Cartisano C, Lewis BJ, MacLeod J, Tupper B, Miller DW, Tracy AT, White C, Moretti M, Hamilton B, Barner C and Archer SD (2022) Benefits and Challenges of a Stakeholder-Driven Shellfish Toxicity Forecast in Coastal Maine. Front. Mar. Sci. 9:923738. doi: 10.3389/fmars.2022.923738

[38] FDA National Shellfish Sanitation Program: https://www.fda.gov/media/143238/download

[39] Maine DEP, "Cyanobacteria": https://www.maine.gov/dep/water/lakes/cyanobacteria.html

[40] DEP algal bloom webpage: https://www.maine.gov/dep/water/lakes/algalbloom.html

[41] EPA Cyanobacteria Monitoring recommendations in recreational waters: https://www.epa.gov/sites/default/files/2019-09/documents/recommend-cyano-rec-water-2019-update.pdf

[42] Woods Hole Oceanographic Institute Harmful Algal Bloom/Red Tide information: https://www.whoi.edu/sbl/liteSite.do?litesiteid=3230&preview=true

3.11 Harmful Algal Blooms – Probability of Future Occurrence [S4.]

According to NOAA's National Centers for Coastal Ocean Science[43], the magnitude and severity of *Alexandrium* blooms, and the subsequent need for shellfish harvesting closures to protect human health, vary considerably from year to year and between decades. Shellfish toxicity was severe and widespread from 1978 to 1988 and again from 2003 to 2009 but has been lower since then. The causes of the decadal variations are the subject of ongoing research. Currently the Gulf of Maine is in a low to moderate red tide cycle.

For freshwater HABs, there are six lakes expected to have annual blooms and 27 more lakes that will likely bloom again on an annual or longer period. A further 55 lakes could occasionally blooms, and 11 lakes that have bloomed in the past but are unlikely to again, given other data. During the summer of 2022, a few lakes produced more algae than in previous years, but did not reach bloom status; this could change in future years (more lakes, more blooms).

3.11.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Research conducted in Florida[44] indicates that increased temperatures of nearshore ocean water caused by climate change could lead to increased growth of harmful microorganisms. These include algae that form noxious or toxic blooms, including red tides, bacteria, and other pathogens. This situation could have negative consequences regarding human health and also ocean-related economies. Though the Gulf of Maine differs substantially from the coast of Florida, another early study from Canada[45] suggests that marine HABs will generally become more prevalent and intense in the future in cold water marine environments as well.

Freshwater HABs are also expected to become more prevalent and grow in intensity due to two factors: average annual increases in atmospheric temperatures due to climate change, and increased nutrient loads caused by further development in lake watersheds[46]. These blooms may limit freshwater recreational use, pose health risks, and increase stress on drinking water systems that draw from surface waters, which includes many public drinking water suppliers in Maine.

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[43] NCCOS: coastalscience.noaa.gov/news/low-to-moderate-red-tide-bloom-predicted-for-gulf-of-maine-in-2022/

[44] Havens, K. (2015). Climate change and the occurrence of harmful microorganisms in Florida's ocean and coastal waters. https://edis.ifas.ufl.edu/publication/SG136

[45] Mudie, P. J., Rochon, A., & Levac, E. (2002). Palynological records of red tide-producing species in Canada: past trends and implications for the future. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *180*(1-3), 159-186.: https://www.sealevel.ca/petra/papers/redtides.pdf

[46] "Worsening algal blooms are making Maine's lakes and ponds more toxic": https://wgme.com/news/local/worsening-algae-blooms-are-making-maines-lakes-and-ponds-more-toxic

3.12 Harmful Algal Blooms – Impacts

Health-related impacts of HABs, particularly marine HABs, would be expansive in Maine if not for the careful testing and regulatory efforts of DMR Bureau of Public Health. As a result, the impacts of a large HAB event in Maine would be primarily economic, due to the temporary closure of shellfish harvest and sale.

Freshwater HABs are also closely monitored through testing efforts by DEP, and the greatest expected impacts of persistent HABs is economic implications for tourism in Maine's lake districts.

3.13 Harmful Algal Blooms – Vulnerability of State Assets [S5.]

HABs have potentially detrimental effects to state-owned freshwater and marine beaches and other facilities offering water recreation. These facilities may include state parks and conservation lands. HAB-related beach closures are an unusual occurrence in Maine, however there are occasional beach closures caused by bacterial outbreaks. Refer to the Maine Health Beaches Dashboard for real-time coastal beach water quality information[47].

3.13.1 Potential Dollar Losses to State Owned Buildings, Infrastructure, Critical Facilities

HABs are not expected to have a direct impact on sate-owned infrastructure. However, future occurrences could have potential impacts to revenue drawn from Maine State Parks. According to a 2021 report made by Maine's Department of Agriculture, Conservation and Forestry, State Park visitors and their associated activities contribute an estimated $100 million to our state's economy[48]. A portion of this may be at risk with the increasing prevalence of HABs in Maine. There is no guarantee that these assets will be damaged in a natural hazard event.

3.13.2 Community Lifeline Risks

The Departments of Environmental Protection and Marine Resources will continue to monitor the impacts of HABs and work collaboratively with MEMA to determine risks to community lifelines.

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[47] Maine Healthy Beaches Dashboard: https://www.maine.gov/dep/water/beaches/beach-status.html

[48] The Case for Maine State Parks: http://legislature.maine.gov/doc/5156

3.14 Harmful Algal Blooms – Vulnerability of Jurisdictions and Disadvantaged communities [S6.]

3.14.1 Identifying Jurisdictions with Greatest Vulnerability [S6.a.1.]

All coastal jurisdictions are at risk of HABs; jurisdictions where shellfishing is a large portion of their local economy, such as in the midcoast and Penobscot/Frenchman Bay region, will hold greater economic risk. Many of these communities have authorized shellfishing ordinances in part to plan for these risks[49]. Maine DMR is effective at mitigating against public health risks through rigorous testing and closure planning based on the thresholds noted above.

Disadvantaged Communities

Disadvantaged communities traditionally reliant on a shellfish/fishing-based economy will bear the economic brunt of marine HABs, while inland communities reliant on a tourism-based economy will see impacts from growing freshwater HAB occurrence. To complicate issues, these communities are often feeling the parallel stress of increased development in areas that were previously serving a resource-based economy. The Island Institute recently documented 20 miles of coastal working waterfront out of Maine's 5,300-mile coastline, and development trends indicate working waterfronts will further decrease in the next 30 years[50]. Such a trend would reduce the total number of locations available for clean harvesting of shellfish to more easily avoid local HAB occurrence. Freshwater HABs respond to the availability of nutrients; increased development in a watershed will invariably increase the total runoff of nutrients into the water column, increasing the likelihood of blooms and also, potential impacts on tourism.

3.14.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

As determined by Dr. Kevin Athearn in 2008[51], the molluscan shellfish industry is one of Maine's most valuable marine sectors. In 2006, the industry generated $82.3M (in 2022 USD) in total economic impact for the state including labor income. In 2001, this value was $105.8M (2022 USD). Occasional closures of shellfish growing/harvesting areas and aquaculture leases are a frequent occurrence, though longer-term, complete closures across the Maine coast would cause major local to regional economic issues, supply shortages in shellfish markets, and health impacts in the very unlikely event of an unidentified outbreak.

Dr. Adam Daigneault of the University of Maine is in the process of conducting a study of the economic impacts of Maine's lakes and ponds[52]. According to preliminary results, Maine's lakes and ponds produce more than $10 billion per year in net economic value, including nearly $3 billion per year in recreation and other lake-use expenditures. Damages to these freshwater resources by future HAB occurrence may substantially impact these values, including potential losses to shorefront property owners and the municipalities that depend on tax revenue from these prime properties.

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[49] Jurisdiction shellfish ordinances: https://www.maine.gov/dmr/fisheries/shellfish/municipal-shellfish-management-program/general-shellfish-ordinance-information/general-town-shellfish-information

[50] Island Institute: The Last 20 Miles https://www.islandinstitute.org/wp-content/uploads/2020/09/TheLast20Miles_web.pdf

[51] Athearn, K. 2008. Economic Impact of Maine's Shellfish Industry. 439 http://maineclammers.org/wp-content/uploads/2013/07/eco_impact_shellfish_es_jan08.pdf.

[52] Genoter, M. and Daigneault, A. (2022), Valuing the Economic Benefits of Maine's Great Ponds in the 21st Century

Air Quality – Hazard Profile

3.15 Air Quality – General Definition and Types of Events [S3.a., S3.b.]

Temperatures are rising, snow and rainfall patterns are shifting, and more extreme climate events, like heavy rainstorms and record high temperatures, are becoming more common. The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants (also known as "criteria air pollutants"). These pollutants are found all over the U.S. They can harm your health, the environment, and cause property damage. The State of Maine is known as the exhaust pipe of the east coast due to its location, wind patterns and transportation systems, and air pollution traveling from the south through New England and the south and west from Canada through the State of Maine. As the State's population and tourism increases, the State is posturing for mitigation in the future of air pollution effects.

3.15.1 Criteria Air Pollutants

Ozone is an odorless, colorless gas made up of three oxygen molecules (O3) and is a natural part of the environment. It occurs both in the Earth's upper atmosphere, or stratosphere, and at ground level in the lower atmosphere, or troposphere. Tropospheric, or ground level ozone, is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC). This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight and increase temperature as the result of climate change. Ozone is a respiratory crisis to any human and flora or fauna because ground level ozone sheds lung tissue and provides other detrimental effects including stunted plant growth, delayed human gestation, cardiac diseases, and respiratory illnesses. The USEPA National Ambient Air Quality Standards determine ozone reports using the Air Quality Index (AQI) (Table 3.65)[53].

Particle pollution, also called particulate matter (PM), is made up of particles (tiny pieces) of solids or liquids that are in the air. Particulate matter (2.5 microns) are primarily gaseous aerosols that clog lung tissue. Particulate matter (10 microns) is primarily smoke, soot, dust, pollen, etc., which is typically expelled from the lungs. Due to the increase of drought, there has been an increase of wildfires, promoting an increase in particulate matter. The State of Maine is also a popular destination and route for tourism and commodity goods throughout the State and into Canada. These activities promote an increase in particulate matter in the form of greenhouse gas emissions and fire (campfires, wildfires, and woodstoves). The USEPA National Ambient Air Quality Standards determine particulate pollution reports using the Air Quality Index (AQI) (Table 3.53).

Also due to climate change, an increase in the production of pollen occurs, providing similar detrimental effects including an increase in respiratory illnesses. Since warmer weather signals plants to bloom, pollen seasons are starting earlier and lasting longer. Additionally, greenhouse gas emissions (GHGs) increase the atmospheric levels of carbon dioxide, a gas that stimulates plants to increase the production and release of pollen. GHGs are not featured in this SHMP update. Pollen production with the State has increased due to having over 17.5 million acres of forested areas. [54]

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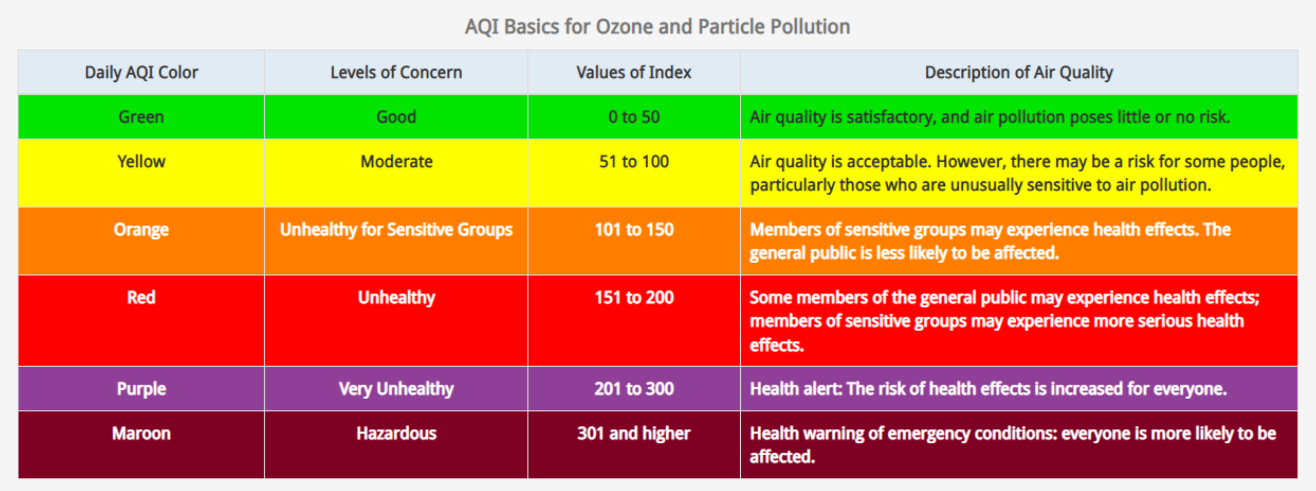
[53] https://www.airnow.gov/aqi/aqi-basics/

[54] https://www.hsph.harvard.edu/news/hsph-in-the-news/allergies-are-getting-worse-with-climate change/#:~:text=Since%20warmer%20weather%20signals%20plants,production%20and%20release%20of%20pollen.

Table 3.53



AQI Basics for Ozone and Particle Pollution

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Nitrogen Dioxide (NO2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NO_x). Other nitrogen oxides include nitrous acid and nitric acid. NO_2 is used as the indicator for the larger group of nitrogen oxides. NO_2 primarily gets into the air from the burning of fuel. NO_2 forms from emissions from cars, trucks, buses, power plants, and off-road equipment. Breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma, and potentially increase susceptibility to respiratory infections. People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO_2. NO_2 along with other NO_x, reacts with other chemicals in the air to form both particulate matter and ozone. Both of these are also harmful when inhaled due to effects on the respiratory system. NO_2 and other NO_x interact with water, oxygen, and other chemicals in the atmosphere to form acid rain. Acid rain harms sensitive ecosystems such as lakes and forests. NO_x in the atmosphere contributes to nutrient pollution in coastal waters.[55]

Sulfur dioxide (SOx) EPA's national ambient air quality standards for SO_2 are designed to protect against exposure to the entire group of sulfur oxides (SO_x). SO_2 is the component of greatest concern and is used as the indicator for the larger group of gaseous sulfur oxides (SO_x). Other gaseous SOx (such as SO_3) are found in the atmosphere at concentrations much lower than SO_2. Control measures that reduce SO_2 can generally be expected to reduce people's exposures to all gaseous SO_x. This may have the important co-benefit of reducing the formation of particulate sulfur pollutants, such as fine sulfate particles. Emissions that lead to high concentrations of SO_2 generally also lead to the formation of other SO_x. The largest sources of SO_2 emissions are from fossil fuel combustion at power plants and other industrial facilities. Short-term exposures to SO_2 can harm the human respiratory system and make breathing difficult. People with asthma, particularly children, are sensitive to the effects of SO_2. SO_2 emissions that lead to high concentrations of SO_2 in the air generally also lead to the formation of other sulfur oxides (SO_x). SO_x can react with other compounds in the atmosphere to form small particles. These particles contribute to particulate matter (PM) pollution. Small particles may penetrate deeply into the lungs and in sufficient quantity can contribute to health problems. At high concentrations, gaseous SOx can harm trees and

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[55] https://www.epa.gov/no2-pollution/basic-information-about-no2#What%20is%20NO2

plants by damaging foliage and decreasing growth. SO_2 and other sulfur oxides can contribute to acid rain which can harm sensitive ecosystems.[56]

3.15.2 Acid Rain

Acid Rain or acid deposition is a broad term including any form of precipitation with acidic components, such as sulfuric or nitric acid that fall to the ground from the atmosphere in wet or dry forms. This can include rain, snow, fog, hail or even dust that is acidic. Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NOX) are emitted into the atmosphere and transported by wind and air currents. The SO_2 and NOX react with water, oxygen, and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground. Wet deposition is what we most commonly think of as acid rain. The sulfuric and nitric acids formed in the atmosphere fall to the ground mixed with rain, snow, fog, or hail. Dry deposition are acidic particles and gases can also deposit from the atmosphere in the absence of moisture as dry deposition. Acidic particles and gases may deposit onto surfaces (water bodies, vegetation, buildings) quickly, or may react during atmospheric transport to form larger particles that can be harmful to human health. When the accumulated acids are washed off a surface by the next rain, this acidic water flows over and through the ground, which can harm plants and wildlife, such as insects and fish. The amount of acidity in the atmosphere that deposits to earth through dry deposition depends on the amount of rainfall an area receives. Measuring Acid Rain is based on the pH scale, refer to Figure 3.69:

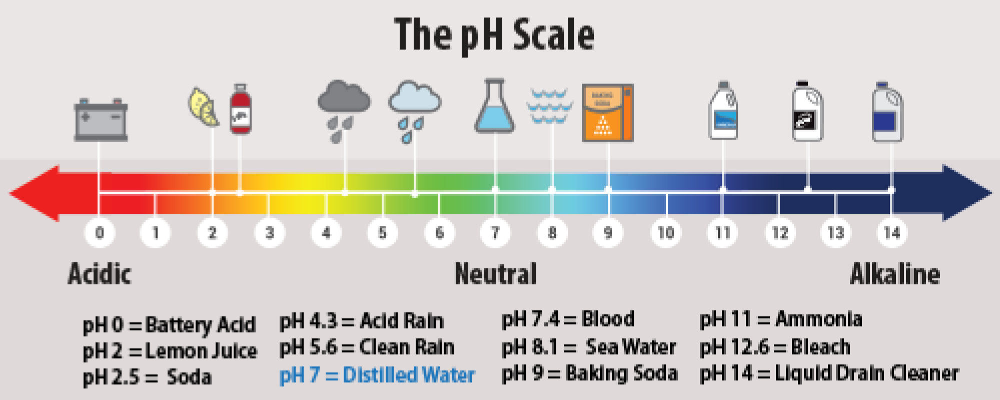

Figure 3.69

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[56] https://www.epa.gov/so2-pollution/sulfur-dioxide-basics#what%20is%20so2

3.16 Air Quality – Location of Hazard, Intensity and Previous Occurrences [S3.a.1, S3.a.2.]

The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to set health-based limits, called National Ambient Air Quality Standards (NAAQS), for six dangerous outdoor air pollutants: particulate matter, ozone, nitrogen oxides, sulfur dioxide, carbon monoxide and lead. "State of the Air" looks at two of the most widespread and dangerous pollutants from this group, fine particulate matter, and ozone.

Ozone and short-term particle pollution. The data on air quality throughout the United States were obtained from the U.S. Environmental Protection Agency's Air Quality System (AQS). The American Lung Association contracted with Dr. Allen S. Lefohn, A.S.L. & Associates, Montana, to characterize the hourly averaged ozone concentration information and the 24-hour averaged PM2 .5 concentration information for the three-year period for 2019-2021 for each monitoring site[57].

Exposure to unhealthy levels of ozone air pollution makes breathing difficult for more Americans all across the country than any other single pollutant. More than 30% of the nation's population, including 23.6 million children, 15 .4 million people ages 65 or older, and millions in other groups at high risk of health harm, are exposed to high levels of ozone on enough days to earn the air they breathe a failing grade.[58]

Unhealthy for Sensitive Groups (USG) days are typically rare in Maine. Air quality is largely a transmission issue in Maine; what is brought in from the west exceeds what is generated in the state itself. But what is brought in rarely causes exceedance of thresholds. The biggest sources of air quality issues in Maine are wildfire smoke and ozone.

Maine does not emit a substantial amount of ozone, most of the amounts that locally meet USG thresholds are transported from the west and activated in the presence of strong sunlight. It is a photochemical pollutant. Ozone monitors are activated from April through the end of September as the occurrence of ozone is largely contingent on seasonal temperatures for Maine. Ozone peaks in early spring are of greatest concern.

Central and eastern region wildfires in 2021 caused some instances of USG, or orange-level, air quality levels. Fires in the Canadian prairies caused higher levels of pollution to drift into Maine, with several days of running average at USG levels. Otherwise, Maine has not experienced a USG level of air quality for several years.
"In the 70's total suspended particulates, but in 80's they parsed out PM10, now PM 2.5 reason being is the super fine stuff is what goes in and doesn't come out. More of a health burden. PM 2.5 continuous monitors were added late '99".

The State of Maine's Environmental Protection Agency monitors all criteria air quality pollutants (Figure 3.70):

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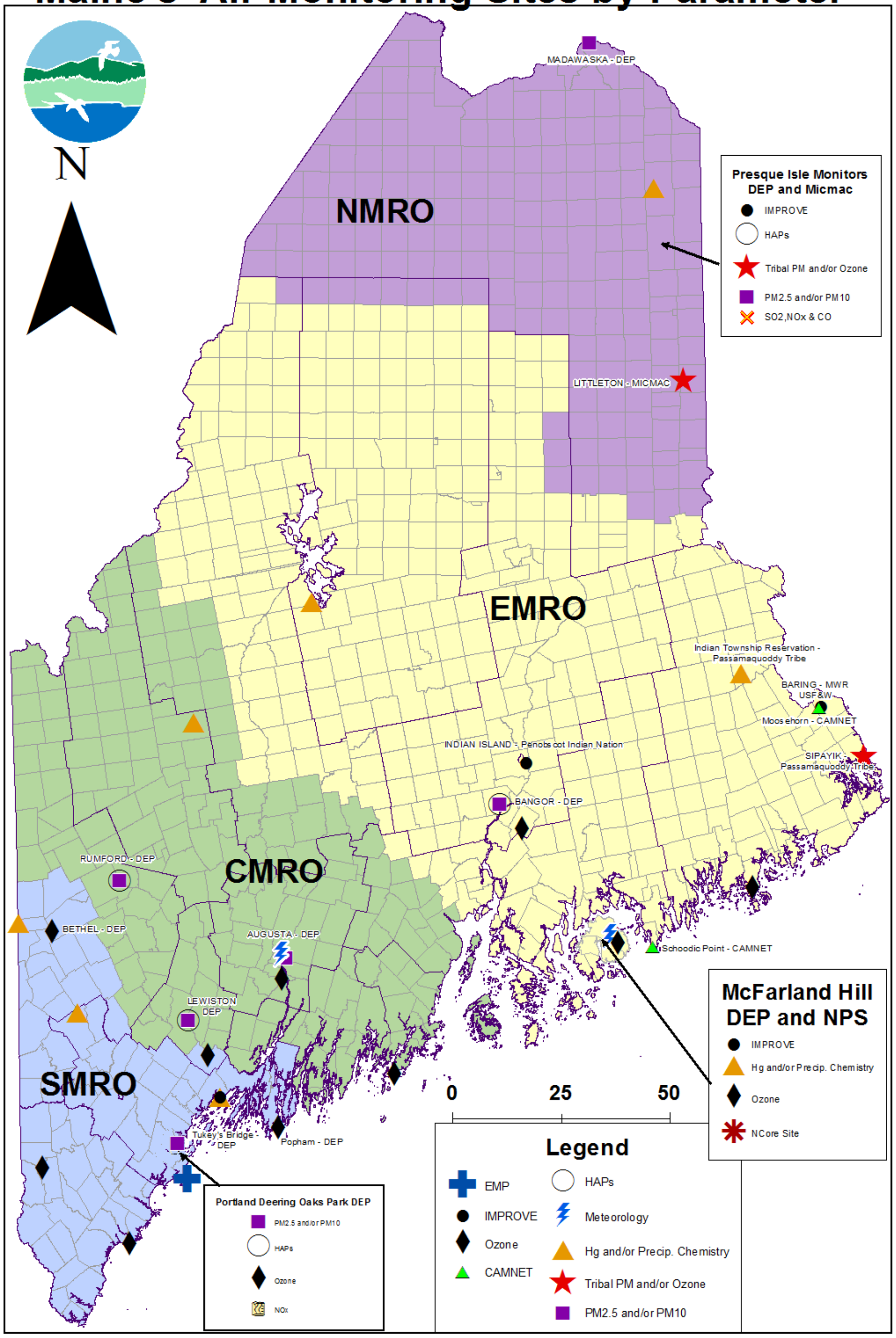
[57] https://www.lung.org/getmedia/338b0c3c-6bf8-480f-9e6e-b93868c6c476/SOTA-2023.pdf
[58] https://www.lung.org/getmedia/338b0c3c-6bf8-480f-9e6e-b93868c6c476/SOTA-2023.pdf

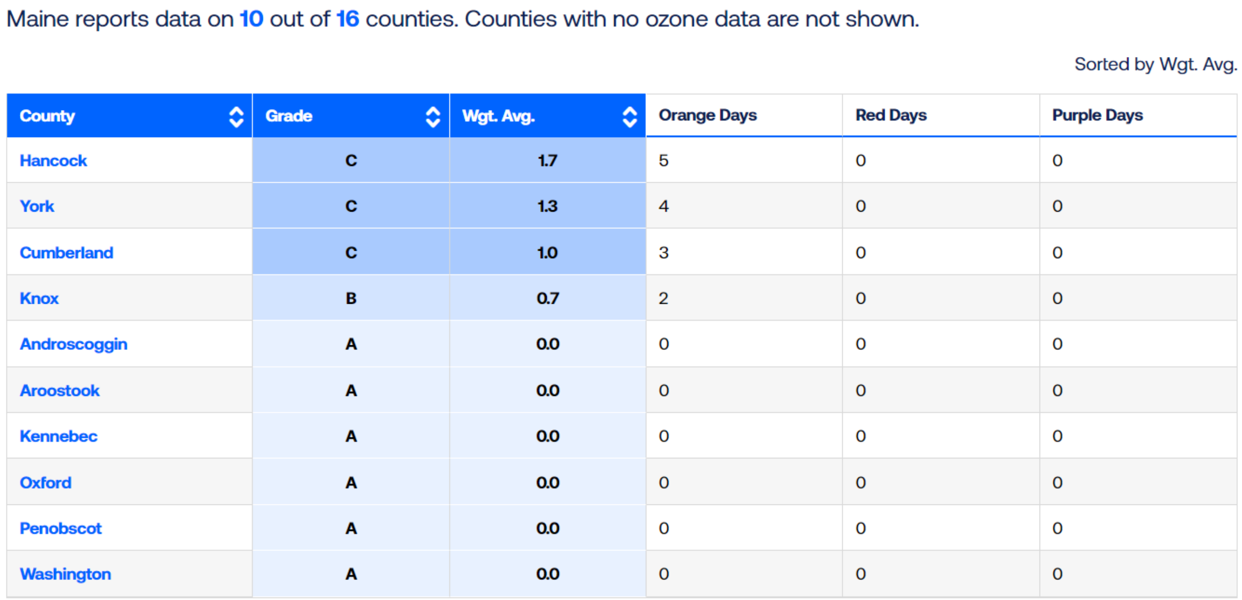
Figure 3.70

Maine's Air Monitoring Sites by Parameter



Data Source MEGIS and MEDEP; updated 5/25/2022

Per the American Lung Association's State of the Air report, the below counties statistics on ozone and particulate pollution for 2023 are below (Tables 3.54 and 3.55) [59]:

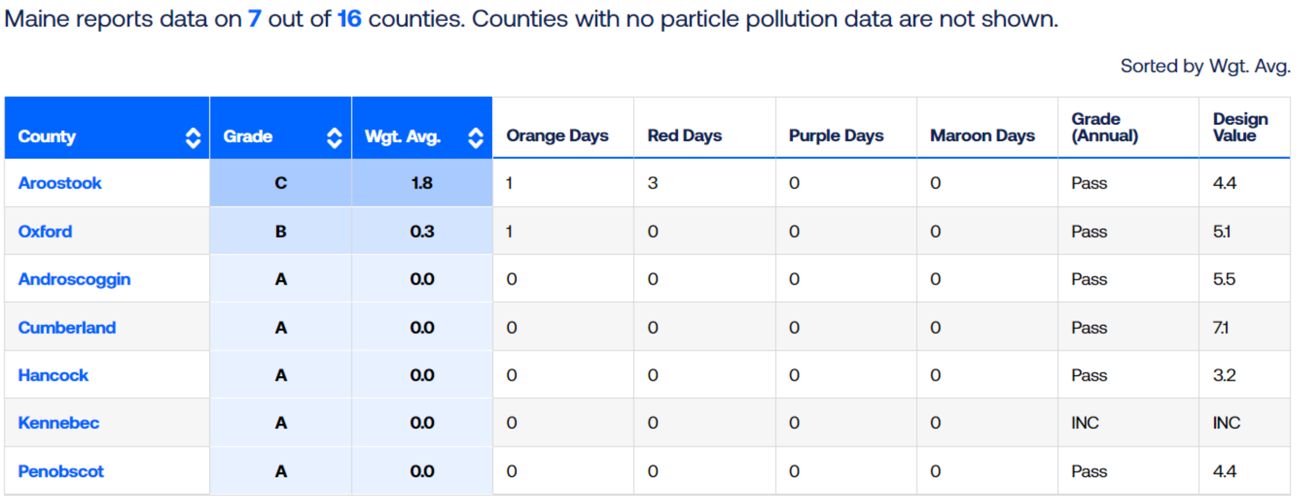


Maine reports data on **10** out of **16** counties. Counties with no ozone data are not shown.

Sorted by Wgt. Avg.

County	Grade	Wgt. Avg.	Orange Days	Red Days	Purple Days
Hancock	C	1.7	5	0	0
York	C	1.3	4	0	0
Cumberland	C	1.0	3	0	0
Knox	B	0.7	2	0	0
Androscoggin	A	0.0	0	0	0
Aroostook	A	0.0	0	0	0
Kennebec	A	0.0	0	0	0
Oxford	A	0.0	0	0	0
Penobscot	A	0.0	0	0	0
Washington	A	0.0	0	0	0

(Table 3.54)



Maine reports data on **7** out of **16** counties. Counties with no particle pollution data are not shown.

Sorted by Wgt. Avg.

County	Grade	Wgt. Avg.	Orange Days	Red Days	Purple Days	Maroon Days	Grade (Annual)	Design Value
Aroostook	C	1.8	1	3	0	0	Pass	4.4
Oxford	B	0.3	1	0	0	0	Pass	5.1
Androscoggin	A	0.0	0	0	0	0	Pass	5.5
Cumberland	A	0.0	0	0	0	0	Pass	7.1
Hancock	A	0.0	0	0	0	0	Pass	3.2
Kennebec	A	0.0	0	0	0	0	INC	INC
Penobscot	A	0.0	0	0	0	0	Pass	4.4

(Table 3.55)

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[59] https://www.lung.org/research/sota/city-rankings/states/maine

Environmental Effects of Ozone: Elevated exposures to ozone can affect sensitive vegetation and ecosystems, including forests, parks, wildlife refuges, and wilderness areas. In particular, ozone can harm sensitive vegetation during the growing season.[60] Ozone can affect sensitive vegetation and ecosystems, including forests, parks, wildlife refuges and wilderness areas. In particular, ozone can harm sensitive vegetation during the growing season. When sufficient ozone enters the leaves of a sensitive plant, it can:

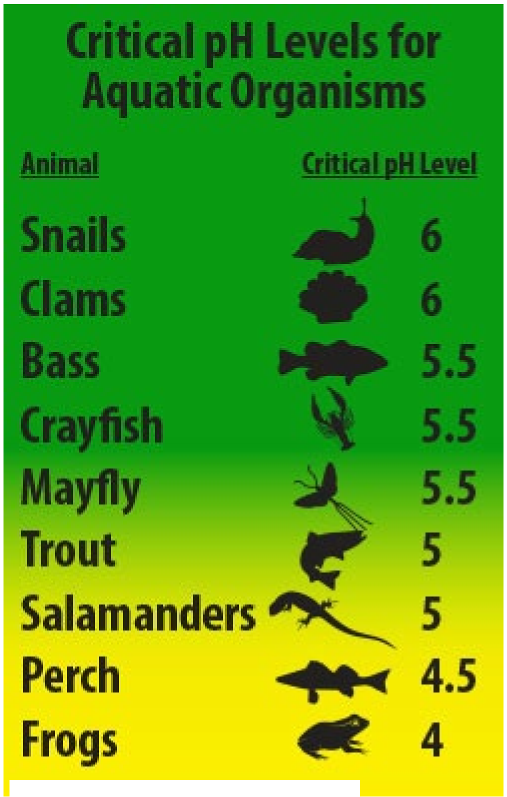
- Reduce photosynthesis, which is the process that plants use to convert sunlight to energy to live and grow.
- Slow the plant's growth.
- Increase sensitive plants' risk of:
    - Damage from insects
    - Effects of other pollutants
    - Harm from severe weather.

Also, some plants can show visible marks on their leaves when ozone is present under certain conditions.
Disease,

The effects of ozone on individual plants can then have negative impacts on ecosystems, including:

- changes to the specific assortment of plants present in a forest
- changes to habitat quality
- changes to water and nutrient cycles.[61]

Figure 3.71 illustrates the pH level at which key organisms may be lost as their environment becomes more acidic. Not all fish, shellfish, or the insects that they eat can tolerate the same amount of acid. [62]



Critical pH Levels for Aquatic Organisms

Animal	Critical pH Level
Snails	6
Clams	6
Bass	5.5
Crayfish	5.5
Mayfly	5.5
Trout	5
Salamanders	5
Perch	4.5
Frogs	4

Figure 3.71

3.16.1 Summer and Winter Air Quality

Per research through the U.S. EPA and the American Lung Association, increase in temperatures and vehicle emissions promote the production of ozone. “Ozone production accelerates at high temperatures, and emissions of the natural components of ozone increase. High temperatures are also accompanied by weak winds, causing the atmosphere to stagnate. So, the air just cooks and ozone levels can build up.” - Loretta J. Mickley[63] However, at extremely high temperatures, beginning in the mid-90s Fahrenheit, ozone levels at many sites stop rising with temperature. The phenomenon, previously observed only in California, is known as ozone suppression.[64] Typically, particle pollution is seen more in the winter months, however, due to the State of Maine’s heavy

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[60] https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics#effects
[61] https://www.epa.gov/ground-level-ozone-pollution/ecosystem-effects-ozone-pollution
[62] https://www.epa.gov/acidrain/effects-acid-rain

[63] https://news.harvard.edu/gazette/story/2016/04/the-complex-relationship-between-heat-and-ozone/
[64] https://news.harvard.edu/gazette/story/2016/04/the-complex-relationship-between-heat-and-ozone/

tourism, campfires are a contributing factor to summer air pollution. Due to the increase of drought, the increase in wildfires during the summer months also adds to the State of Maine's particle pollutions.

During the winter, winter peaks are caused by long cold nights, skies clear, nocturnal inversions where poor air quality is trapped close to surface. Within the State of Maine, woodstoves and fireplaces contribute to higher levels of particle pollution throughout the cold Maine winter. Ozone is not an issue during the winter due to the temperatures being below the mid-90s.

Figure 3.72[65]

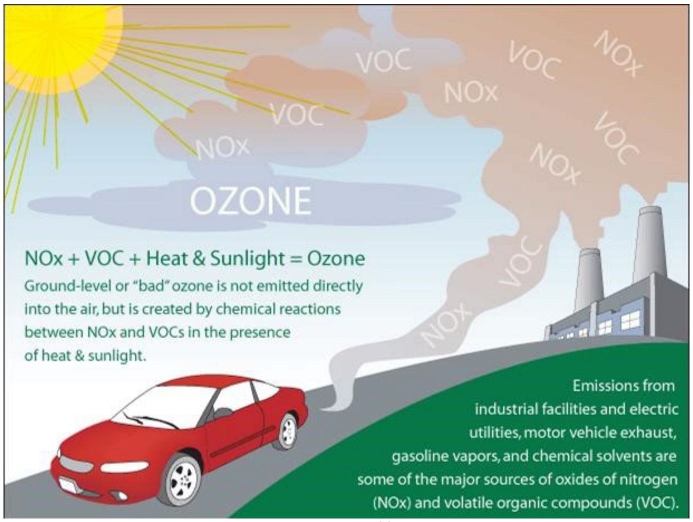

Figure 3.73[66]

3.17 Air Quality – Probability of Future Occurrence [S4.]

Due to the rise in temperature, tourism, population increase, and vehicle emissions, the probability of the State of Maine increasing air pollution is imminent. Data provided by federal and state agencies regarding increase temperature, drought, wildfire, and wind, as well as population data provides a basis of evidence.

3.17.1 Projected Changes in Hazard Location, Intensity, Frequency, and Duration

Ambient ozone levels are influenced by a complex interaction of factors that can vary from year to year. Some fluctuation is to be expected and does not necessarily represent lasting change. However, at least some of the significant improvements in ozone levels in this year's report can be attributed to the fact that the Clean Air Act has been working. Controls placed on emissions have increasingly resulted in the replacement of more polluting engines, fuels, and processes nationwide. The transition of the economy away from the coal, the dirtiest fossil fuel, has unquestionably had an impact, especially in parts of the eastern United States. It is also possible that pandemic-related changes in activity patterns in 2020 and 2021, such as increased telework, have made a difference, but that is still being studied and characterized[67]

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[65] https://www.cdc.gov/air/particulate_matter.html
[66] https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics#wwh
[67] https://www.lung.org/getmedia/338b0c3c-6bf8-480f-9e6e-b93868c6c476/SOTA-2023.pdf

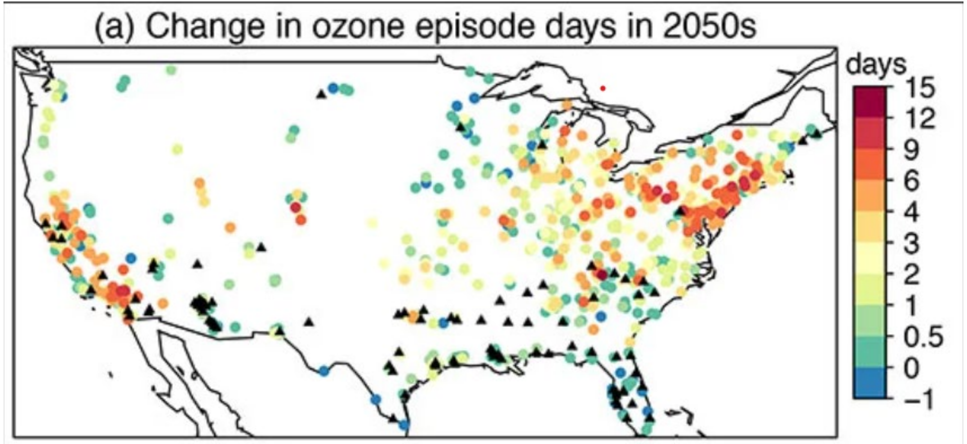
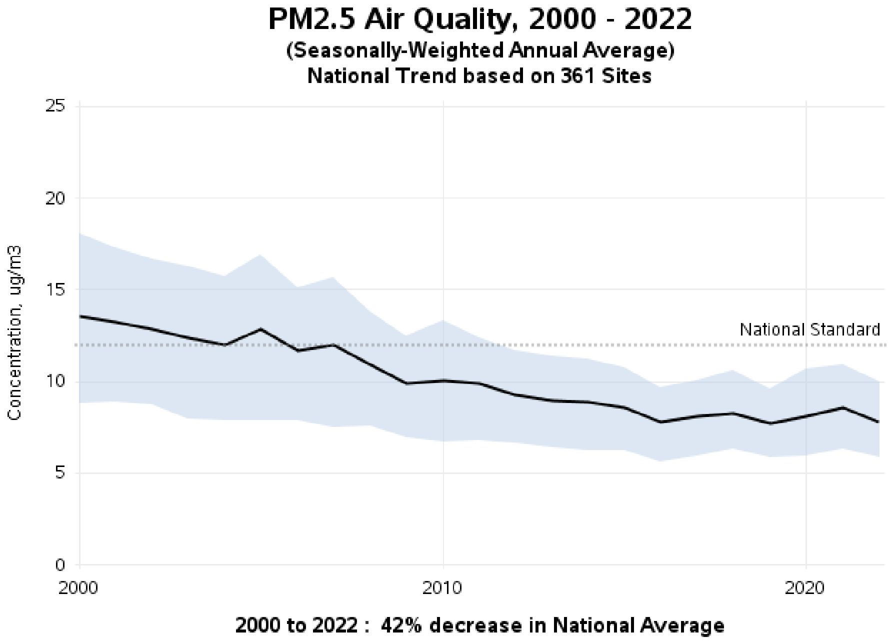


Figure 3.74: California, the Southwest, and the Northeast would be the most affected, each possibly experiencing up to nine additional days of dangerous ozone levels, with much of the rest of the country experiencing an average increase of 2.3 days.[68]

Using a nationwide network of monitoring sites, EPA has developed ambient air quality trends for particle pollution, also called Particulate Matter (PM). $PM_{2.5}$ describes fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller. Under the Clean Air Act, EPA sets and reviews national air quality standards for PM. Air quality monitors measure concentrations of PM throughout the country. EPA, state, tribal and local agencies use that data to ensure that PM in the air is at levels that protect public health and the environment. Nationally, average $PM_{2.5}$ concentrations have decreased over the years. For information on PM standards, sources, health effects, and programs to reduce PM.



[69]

Figure 3.75

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[68] https://news.harvard.edu/gazette/story/2016/04/the-complex-relationship-between-heat-and-ozone/

[69] https://www.epa.gov/air-trends/particulate-matter-pm25-trends

The Acid Rain Program (ARP) has delivered significant reductions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions from fossil fuel-fired power plants, extensive environmental and human health benefits, and far lower-than-expected costs. Together with more recent power sector regulations, including the Cross-State Air Pollution Rule (CSAPR), and a rapidly changing energy sector, the ARP has helped deliver annual SO_2 reductions of over 93% and annual NO_X emissions reductions of over 87%. The Power Plant Emissions Trends page has maps and data highlighting these emissions reductions, and the Progress Reports provide an annual overview of program features and results, from compliance to air quality impacts.

Figures 3.74-3.77 below illustrate acid rain trends: [70]

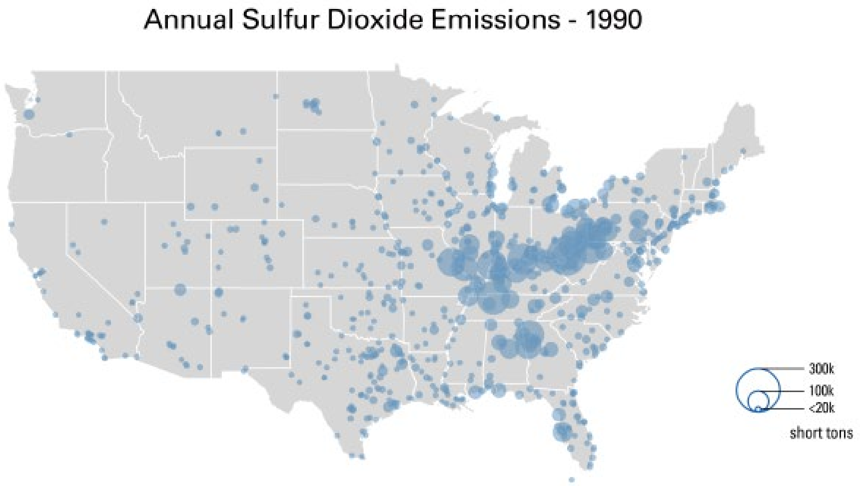

Figure 3.76

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[70] https://www.epa.gov/acidrain/acid-rain-program-results

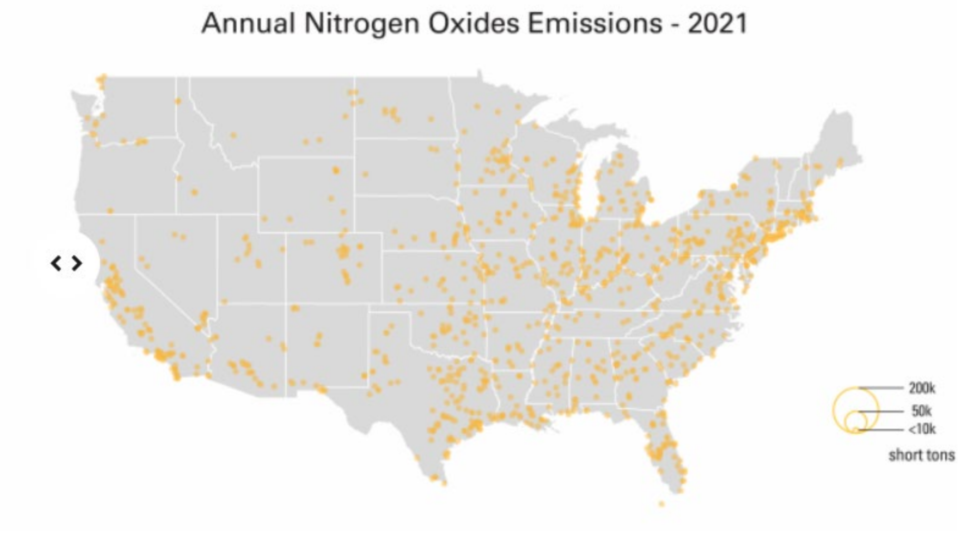

Figure 3.77

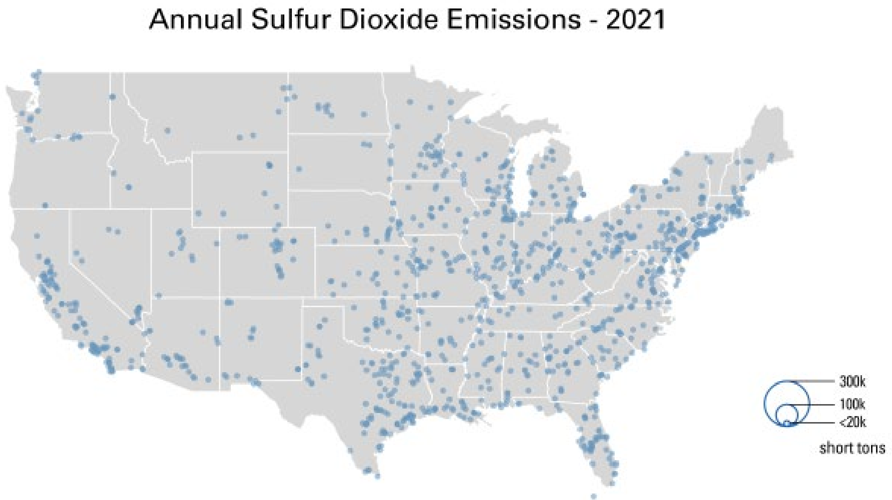

Figure 3.78

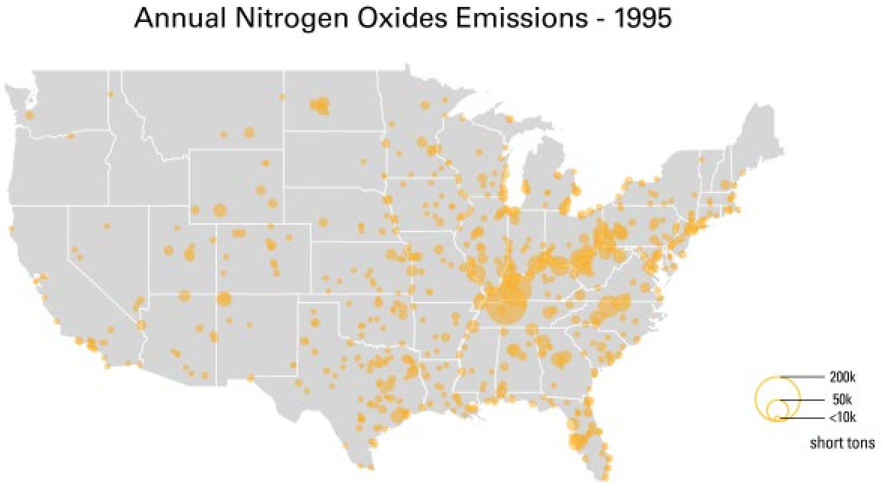

Figure 3.79

3.18 Air Quality – Impacts

Years of scientific research have clearly established that particle pollution and ozone are a threat to human health at every stage of life, increasing the risk of premature birth, causing or worsening lung and heart disease, and shortening lives. Some groups of people are more at risk of illness and death than others, because they are more likely to be exposed, or are more vulnerable to health harm, or often both.

Air pollution impact to the environment, which includes flora and fauna, shows decrease of plant growth and animal health issues. Increased vehicle transportation along the State of Maine's corridors, provides premature death of flora.[71]

Effects of Wildlife

Toxic pollutants in the air, or deposited on soils or surface waters, can impact wildlife in a number of ways. Like humans, animals can experience health problems if they are exposed to sufficient concentrations of air toxins over time. Studies show that air toxins are contributing to birth defects, reproductive failure, and disease in animals. Persistent toxic air pollutants (those that break down slowly in the environment) are of particular concern in aquatic ecosystems. These pollutants accumulate in sediments and may biomagnify in tissues of animals at the top of the food chain to concentrations many times higher than in the water or air.[72]

Crop and Forest Damage

Air pollution can damage crops and trees in a variety of ways. Ground-level ozone can lead to reductions in agricultural crop and commercial forest yields, reduced growth and survivability of tree seedlings, and increased plant susceptibility to disease, pests and other environmental stresses (such as harsh weather). As described above, crop and forest damage can also result from acid rain and from increased UV radiation caused by ozone depletion.[73]

Figures 3.78 and 3.79 illustrate human and environmental effects from air pollution.[74],[75]

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[71] https://www.ontario.ca/page/effects-air-pollution-agricultural-crops
[72] https://www.mass.gov/doc/health-environmental-effects-of-air-pollution/download
[73] https://www.mass.gov/doc/health-environmental-effects-of-air-pollution/download
[74] https://www.pca.state.mn.us/air-water-land-climate/air-quality-and-health
[75] https://www.encyclopedie-environnement.org/en/life/impact-air-pollutants-on-vegetation/

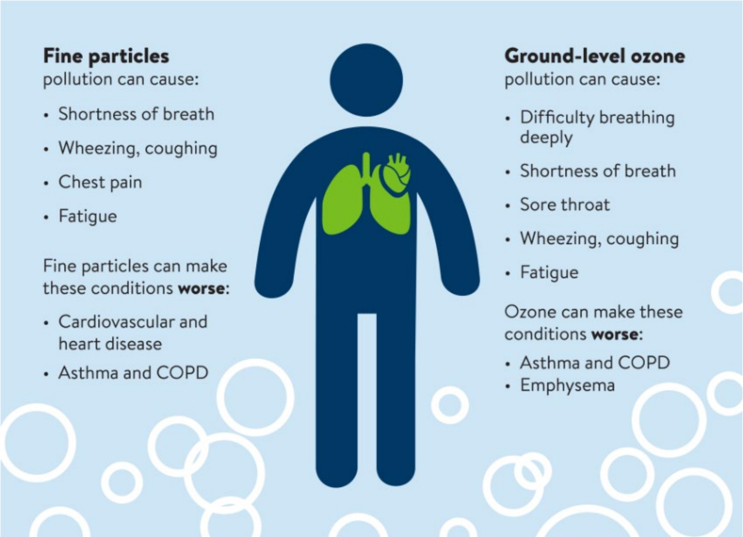

Figure 3.80

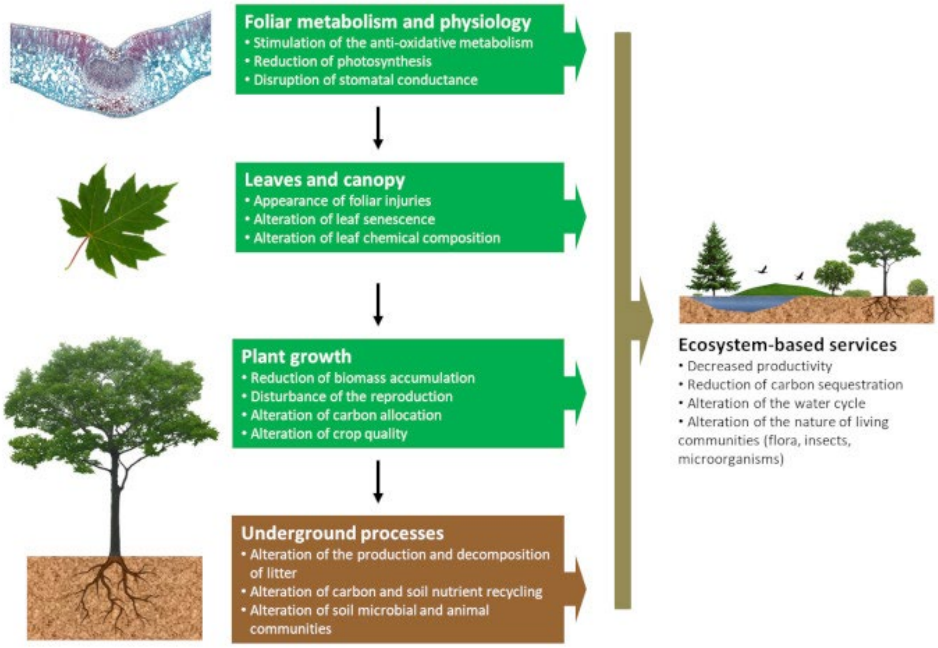

Figure 3.81

3.19 Air Quality – Vulnerability of State Assets [S5.]

3.19.1 Potential Dollar Losses to State owned buildings, infrastructure, critical facilities

No losses to buildings, infrastructure, and critical facilities are expected from poor air quality except for acid rain, however, the State of Maine state parks and forests are directly affected by drought which in turn causes wildfires that produces particulate matter that effects the air quality. Also increase in ozone production will affect the State of Maine's parks and forests by decreasing plant production and health of wildlife. An increase in public health and stress on state asset healthcare facilities is imminent.

Effects of Acid rain on materials

Not all acidic deposition is ***wet***. Sometimes dust particles can become acidic as well, and this is called ***dry deposition***. When acid rain and dry acidic particles fall to earth, the nitric and sulfuric acid that make the particles acidic can land on statues, buildings, and other manmade structures, and damage their surfaces. The acidic particles corrode metal and cause paint and stone to deteriorate more quickly. They also dirty the surfaces of buildings and other structures such as monuments. There is no guarantee that these assets will be damaged in a natural hazard event.

The consequences of this damage can be costly:

- damaged materials that need to be repaired or replaced,
- increased maintenance costs, and
- loss of detail on stone and metal statues, monuments, and tombstones.[76]

Figure 3.80 illustrates the acid rain pathway for material and environmental effects concerning state assets.

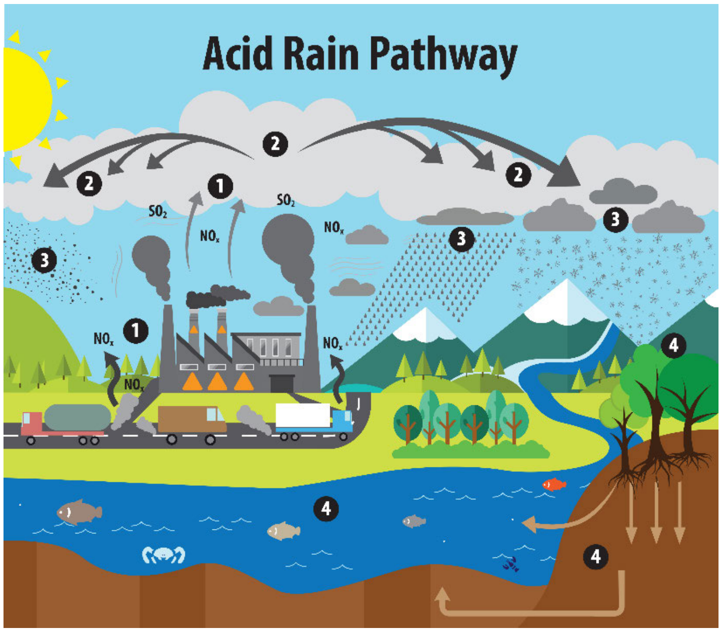

Figure 3.82

3.19.2 Community Lifeline Risks

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[76] https://www.epa.gov/acidrain/effects-acid-rain#health

The Department of Environmental Protection will continue to monitor the impacts of poor air quality and work collaboratively with MEMA to determine risks to community lifelines.

3.20 Air Quality – Vulnerability of Jurisdictions and Disadvantaged communities[S6.]

3.20.1 Identifying Jurisdictions with greatest vulnerability [S6.a.1.]

Within the United States, nearly 264 million people live in the 922 counties for which there is monitored data for at least one pollutant in this year's report. The proportion of the population in those counties varies by pollutant. The majority of U.S. counties actually do not have monitors, which means that many communities, especially rural ones, do not have official monitored information on their air quality.[77]

Research has shown that the people in these high-risk groups are at the greatest risk from ozone and particle pollution:[78]

- **People of color**—Some 64 million people of color live in counties that received at least one failing grade for ozone and/or particle pollution. Over 13 million people of color live in counties that received failing grades on all three measures, including over 9 million Hispanics.
- **People experiencing poverty**—More than 14 .6 million people with incomes meeting the federal poverty definition live in counties that received an F for at least one pollutant. Nearly 2 .6 million people in poverty live in counties failing all three measures.
- **Children and older adults**—More than 27 million children under age 18 and some 18 million adults ages 65 and over live in counties that received an F for at least one pollutant. Almost 4 .3 million children and 2 .6 million seniors live in counties failing all three measures.
- **People with underlying health conditions including:** [79]
    - **Asthma**—1 .7 million children and nearly 8 .7 million adults with asthma live in counties that received an F for at least one pollutant. More than 217,000 children and 1 .2 million adults with asthma live in counties failing all three measures.
    - **Chronic Obstructive Pulmonary Disease (COPD)**—Over 5 million people with COPD live in counties that received an F for at least one pollutant. Almost 630,000 people with COPD live in counties failing all three measures.
    - **Lung Cancer**—More than 55,000 people diagnosed with lung cancer in 2019 live in counties that received an F for at least one pollutant. And nearly 6,900 people diagnosed with lung cancer live in counties failing all three measures
    - **Cardiovascular Disease**—More than 6 .6 million people with cardiovascular disease live in counties that received an F for at least one pollutant. Some 864,000 people live in counties failing all three measures.
    - **Pregnancy**—Adverse impacts from air pollution have been shown both for those who are pregnant as well as for the developing fetus. More than 1.3 million pregnancies were recorded in 2021 in

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[77] https://www.lung.org/getmedia/338b0c3c-6bf8-480f-9e6e-b93868c6c476/SOTA-2023.pdf
[78] https://www.lung.org/getmedia/338b0c3c-6bf8-480f-9e6e-b93868c6c476/SOTA-2023.pdf
[79] https://www.lung.org/getmedia/338b0c3c-6bf8-480f-9e6e-b93868c6c476/SOTA-2023.pdf

counties that received at least one F for particle pollution. Of those, nearly 198,000 are in counties that received failing grades for all three measures

The health burden of air pollution is not evenly shared. Some people are more at risk of illness and death from air pollution than others. Several key factors affect an individual's level of risk:[80]

- **Exposure**—Where someone lives, where they go to school and where they work make a big difference in how much air pollution they breathe. In general, the higher the exposure, the greater the risk of harm.
- **Susceptibility**—Pregnant people and their fetuses, children, older adults and people living with chronic conditions, especially heart and lung disease, may be physically more susceptible to the health impacts of air pollution than other adults.
- **Access to healthcare**—Whether or not a person has health coverage, a healthcare provider, and access to linguistically and culturally appropriate health information may influence their overall health status and how they are impacted by environmental stressors like air pollution.
- **Psychosocial stress**—There is increasing evidence that non-physical stressors such as poverty, racial/ethnic discrimination and fear of deportation can amplify the harmful effects of air pollution.

These risk factors are not mutually exclusive and often interact in ways that lead to significant health inequities among subgroups of the population. Taken all together, these high-risk categories account for a large proportion of the U.S. population. Table 3.56 represents the 16 counties within the State of Maine and their vulnerability to air pollution. [81]

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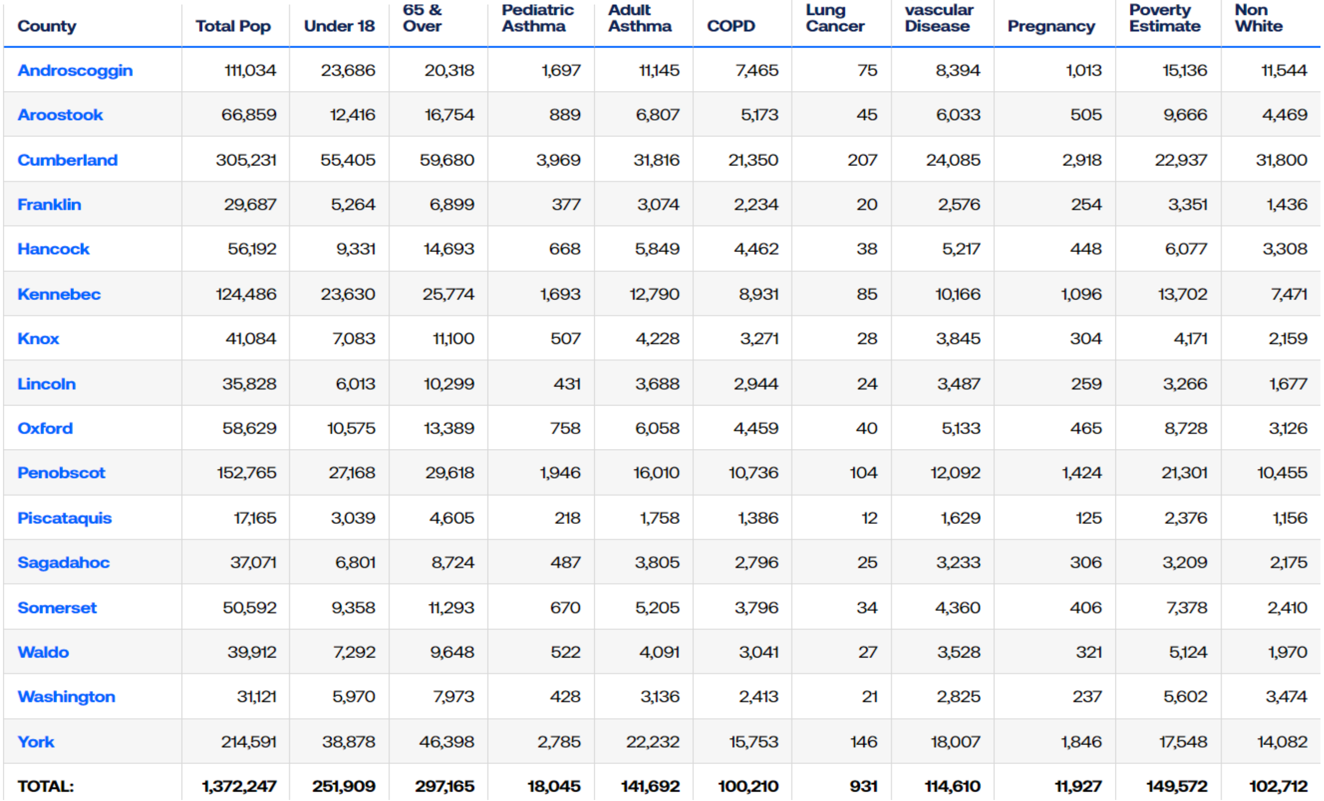
[80] https://www.lung.org/getmedia/338b0c3c-6bf8-480f-9e6e-b93868c6c476/SOTA-2023.pdf

[81] https://www.lung.org/research/sota/city-rankings/states/maine

Table 3.56: State of Maine air pollution vulnerability



County	Total Pop	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	Cardio-vascular Disease	Pregnancy	Poverty Estimate	Non White
Androscoggin	111,034	23,686	20,318	1,697	11,145	7,465	75	8,394	1,013	15,136	11,544
Aroostook	66,859	12,416	16,754	889	6,807	5,173	45	6,033	505	9,666	4,469
Cumberland	305,231	55,405	59,680	3,969	31,816	21,350	207	24,085	2,918	22,937	31,800
Franklin	29,687	5,264	6,899	377	3,074	2,234	20	2,576	254	3,351	1,436
Hancock	56,192	9,331	14,693	668	5,849	4,462	38	5,217	448	6,077	3,308
Kennebec	124,486	23,630	25,774	1,693	12,790	8,931	85	10,166	1,096	13,702	7,471
Knox	41,084	7,083	11,100	507	4,228	3,271	28	3,845	304	4,171	2,159
Lincoln	35,828	6,013	10,299	431	3,688	2,944	24	3,487	259	3,266	1,677
Oxford	58,629	10,575	13,389	758	6,058	4,459	40	5,133	465	8,728	3,126
Penobscot	152,765	27,168	29,618	1,946	16,010	10,736	104	12,092	1,424	21,301	10,455
Piscataquis	17,165	3,039	4,605	218	1,758	1,386	12	1,629	125	2,376	1,156
Sagadahoc	37,071	6,801	8,724	487	3,805	2,796	25	3,233	306	3,209	2,175
Somerset	50,592	9,358	11,293	670	5,205	3,796	34	4,360	406	7,378	2,410
Waldo	39,912	7,292	9,648	522	4,091	3,041	27	3,528	321	5,124	1,970
Washington	31,121	5,970	7,973	428	3,136	2,413	21	2,825	237	5,602	3,474
York	214,591	38,878	46,398	2,785	22,232	15,753	146	18,007	1,846	17,548	14,082
TOTAL:	**1,372,247**	**251,909**	**297,165**	**18,045**	**141,692**	**100,210**	**931**	**114,610**	**11,927**	**149,572**	**102,712**

3.20.2 Potential Dollar Losses to Jurisdictions and Property Owners [S6.a.2.]

According to the Global Burden of Disease 2019 study, air pollution from fine particulate matter caused 6.4 million premature deaths and 93 billion days lived with illness in 2019. Over the past decade, the toll of ambient air pollution has continued to rise. Air pollution's significant health, social, and economic effects compel the World Bank to support client countries in addressing air pollution as a core development challenge. This publication estimates that the global cost of health damages associated with exposure to air pollution is $8.1 trillion, equivalent to 6.1 percent of global GDP. People in low and middle-income countries are most affected by mortality and morbidity from air pollution. Air pollution negatively impacts the U.S. economy, costing the U.S. roughly 5 percent of its yearly gross domestic product (GDP) in damages ($790 billion in 2014). The highest costs come from early deaths, attributable to exposure to fine particulate matter (PM2.5).[82] Research dollar loss in public health/air quality, death 7.5mil/pp, hospitalization 2.3m/pp, and treat/release - 61K/pp, self-treat – 14k/pp.[83]

The US Acid Rain Program (Title IV of the 1990 Clean Air Act Amendments) has achieved substantial reductions in emissions of sulfur dioxide (SO2) and nitrogen oxides (NOx) from power plants in the United States. We compare new estimates of the benefits and costs of Title IV to those made in 1990. Important changes in our understanding of and ability to quantify the benefits of Title IV have occurred. Benefits to human health now take a much higher profile because the contribution of SO2 and NOx emissions to the formation of fine particulate (PM2.5) is substantial, and evidence of the harmful human health effects of PM2.5 has emerged in the last 15 years. New estimates of the health benefits of PM2.5 reductions are the largest category of quantified health and environmental benefits and total over $100 billion USD annually for 2010 when the program is expected to be fully implemented. Although important uncertainties exist in any specific estimate of the benefits, even if the estimates were calculated using more limiting assumptions and interpretations of the literature, they would still substantially exceed the costs. Estimates of annualized costs for 2010 are about $3 billion USD, which is less than half of what was estimated in 1990. Research since 1990 also suggests that environmental problems associated with acid deposition and nitrogen deposition are more challenging to resolve than originally thought and will require larger reductions in emissions to reverse. The greater than expected benefits to human health, the greater vulnerability of natural resources and ecosystems, and the lower-than-expected costs all point to the conclusion that further reductions in SO2 and NOx emissions from power plants beyond those currently required by Title IV are warranted.[84]

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[82] https://earth.stanford.edu/news/how-much-does-air-pollution-cost-us
[83] https://openknowledge.worldbank.org/entities/publication/c96ee144-4a4b-5164-ad79-74c051179eee
[84] https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=OAP&dirEntryID=139587

Hazards Not Profiled

Hazards not profiled because of little or no hazardous impact on Maine include avalanches, subsidence, volcanic activity, and natural electromagnetic pulses.

3.20.3 Pandemic

Widespread health crises caused by naturally occurring pathogens or viruses are defined by FEMA as a natural hazard. Maine CDC provides comprehensive plans for COVID-19[85], influenza and flu-like pandemics[86], and other diseases for the State of Maine, therefore MEMA chooses to rely on guidance from this program for pandemic-related hazards rather than build a new plan.

3.20.4 Avalanches

Avalanches occur when large storms bring substantial amounts of snow or rainfall to steep sloped areas, destabilizing the snowpack. Indicators of a potential avalanche risk include cracking or caving in of snowpack along slopes or other avalanches in the adjacent area. Avalanches do occur in Maine, but they are isolated to a small number of undeveloped, steep terrain areas, such as Baxter State Park and the western mountains[87].

3.20.5 *Subsidence*

Subsidence is the gradual settling or sudden sinking of an area of land[88]. There are a number of natural processes that may contribute to subsidence, including earthquakes, soil compaction, glacial isostatic adjustment, erosion, and sinkhole formation. Maine has experienced regional, gradual subsidence due to glacial isostatic adjustments due to changes in ice overburden during and after the Last Glacial Maximum[89]. Eastern Maine has also exhibited some tectonic subsidence that, combined with sea level rise, potentially contributed to coastal erosion[90]. There have also been some isolated cases of subsidence by sinkholes forming across Maine and these cases are typically caused by erosion and weathering of soil and bedrock by surface and groundwater. For example, a 50-foot-deep sinkhole formed in Rockland in 2010 caused by the gradual erosion and dissolution of limestone bedrock underneath the surface[91]. Though instances of subsidence are typically too isolated or too gradual to warrant substantial action to mitigate the risk to Maine communities, planning partners will continue to monitor conditions to anticipate future planning needs. Along the coast, subsidence can be a contributing factor to long-term sea level rise.

3.20.6 Volcanic activity

Volcanic Activity occurs via vents that act as a conduit between the Earth's surface and inner layers, and erupt gas, molten rock, and volcanic ash when gas pressure and buoyancy drive molten rock upward and through zones of weakness in the Earth's crust. According to the National Risk Index, volcanic activity is a non-applicable risk in Maine[92]. Though Maine is home to multiple extinct volcanoes that formed hundreds of millions of years ago,

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[85] Maine CDC COVID-19 Plan: https://www.maine.gov/dhhs/mecdc/infectious-disease/epi/airborne/coronavirus/index.shtml

[86] Maine CDC Influenza Plans: https://www.maine.gov/dhhs/mecdc/infectious-disease/epi/influenza/maineflu/pandemic-plans.shtml

[87] WAGM, "Avalanches…they do happen in Maine": https://www.wagmtv.com/2021/02/23/avalanchesthey-do-happen-in-maine/

[88] NOAA "What is subsidence?": https://oceanservice.noaa.gov/facts/subsidence.html

[89] Borns, H.W. et al. (2004), "The deglaciation of Maine, USA", *Earth Science Faculty Scholarship*, 276. https://www.polartrec.com/files/journals/docs/the-deglaciation-of-maine-usa.pdf

[90] Lee, F.T. (1985), Geomechanical aspects of subsidence in Eastern Maine, USGS Open-File Report 85-519: https://pubs.usgs.gov/of/1985/0519/report.pdf

[91] Bangor Daily News, "50-foot deep sinkhole opens on Rockland road": https://www.bangordailynews.com/2010/02/16/news/50footdeep-sinkhole-opens-on-rockland-road/

[92] FEMA, "Volcanic activity": https://hazards.fema.gov/nri/volcanic-activity

the geologic forces required to form eruptions today no longer exist and do not occur in the northeast region[93]. Extremely large volcanic eruptions, though unlikely, may pose significant global impacts through the alteration of atmospheric temperatures by release of volcanic gasses and risks to human health and infrastructure through broad distribution of volcanic ash.

3.20.7 Geomagnetic Storm/Natural Electromagnetic Pulse (EMP)

A geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is a very efficient exchange of energy from the solar wind into the space environment surrounding Earth. The largest storms that result from these conditions are associated with solar coronal mass ejections (CMEs) where a billion tons or so of plasma from the sun, with its embedded magnetic field, arrives at Earth. CMEs typically take several days to arrive at Earth, but have been observed, for some of the most intense storms, to arrive in as short as 18 hours[94].

During storms, the currents in the ionosphere, as well as the energetic particles that precipitate into the ionosphere add energy in the form of heat that can increase the density and distribution of density in the upper atmosphere, causing extra drag on satellites in low-earth orbit. The local heating also creates strong horizontal variations in the in the ionospheric density that can modify the path of radio signals and create errors in the positioning information provided by GPS. While the storms create beautiful aurora, at worst they also can disrupt navigation systems such as the Global Navigation Satellite System and create harmful or damaging geomagnetic induced currents in the power grid and pipelines. NOAA provides the Geomagnetic Storm Scale, or G-Scale, used to describe space weather that can disrupt systems on Earth[95].

Larger and far more impactful geomagnetic storms are possible and have occurred in recorded history. As stated by the EMP commission[96]:

Natural EMP from a geomagnetic super-storm, like the 1859 Carrington Event or 1921 Railroad Storm, or nuclear EMP attack from terrorists or rogue states, as apparently practiced by North Korea during the nuclear crisis of 2013, are both existential threats that could kill up to 9 of 10 Americans through starvation, disease, and societal collapse. A natural EMP catastrophe or nuclear EMP attack could blackout the national electric grid for months or years and collapse all the other critical infrastructures--communications, transportation, banking and finance, food and water--necessary to sustain modern society and the lives of 310 million Americans.

The EMP Commission recognizes high-altitude nuclear EMP attacks as the worst potential EMP threat. Given that nuclear attacks are an adversarial rather than natural hazard, we choose not to profile this hazard but will instead follow guidance from adversarial planning mechanisms addressing this largely unexplored issue.

The U.S. Geological Survey started a conversation with Maine Geological Survey about where a geomagnetic observatory might be established in Maine. The State will soon receive criteria that will help with site selection, but there are already some options to redevelop unoccupied structures across the state that fit criteria. As of the writing of this plan, Maine Geological Survey, USGS, and MEMA have begun discussions.

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[93] USGS: https://www.usgs.gov/faqs/will-extinct-volcanoes-east-coast-us-erupt-again

[94] NOAA definition of Geomagnetic Storm: https://www.swpc.noaa.gov/phenomena/geomagnetic-storms

[95] NOAA Space Weather Scales: https://www.swpc.noaa.gov/noaa-scales-explanation

[96] The EMP Threat: The State of Preparedness Against the Threat of an Electromagnetic Pulse (EMP) Event: https://republicans-oversight.house.gov/wp-content/uploads/2015/05/Pry-Statement-5-13-EMP.pdf

Additional Findings from Local Hazard Mitigation Plans

Stafford Act 44 CFR §201.4(c)(2)(i)-(iii)[97]

3.21 Summary of Potential Losses Identified in County Risk Assessments

This section incorporates the findings of county Multi-Jurisdictional Hazard Mitigation Plans to provide an statewide overview of the total loss estimates for Maine (Table 3.57). Though many of the resources created for county LHMPs is incorporated into this plan in the "Vulnerability of Jurisdictions…" sections, this provides a summary of findings provided by local planners. Unlike the individual asset-based loss estimates provided in the vulnerability assessments above, these loss estimates are based on a combination of historic damage amounts reported for disaster declarations and Hazus models, both of which are general estimates of potential damages. These estimates were taken from the submitted local county hazard mitigation plans. This review will describe the distribution of losses across the state, with specific reference to quantifying losses to local critical facilities.

Table 3.57: potential losses identified in county hazard mitigation plans based primarily on Public Assistance dollars

County	Tier 1 Hazards (in 2022 $USD)									Tier 2 Hazards		
	Wildfire	Flooding	Severe Summer Weather	Severe Fall/Winter Weather	Tropical cyclone	Drought	Earthquake	Erosion	Mass Wasting	Forest Pests	Harmful Algal Blooms	Air Quality
Androscoggin	-	$1.19	$0.45	$3.90	$0.93	-	$126.48*	-	-	-	-	-
Aroostook	$827.91	$12.15	$120.90	$120.90	$8.15*	$93.80	$564.34*	-	-	-	-	-
Cumberland	$184.18	$11.98	$76.01	$11.90	$1,051.95*	$12.82	$2,060.98*	-	$1.22	-	-	-
Franklin	$21.20	$7.35	-	$2.37	$39.50*	-	$103.12*	-	-	-	-	-
Hancock	$37.18	$11.64	$4.57	$3.65	$197.94*	-	$40.22*	-	-	-	-	-
Kennebec	$68.20	$24.46	-	$8.77	$9.22*	-	$55.63*	-	-	-	-	-
Knox	$3.77	$8.70	-	$2.66	$1,963.45*	-	$28.83*	-	$1.57	-	-	-
Lincoln	$19.57	$2.27	-	$1.95	$8.66	$6.80	$30.78*	-	-	-	-	-
Oxford	$40.48	$12.37	$4.66	$3.47	$28.09*	-	$363.71*	-	-	-	-	-
Penobscot	$7,050.65	$3.40	$1.69	$8.39	$573.10*	-	$69.18*	-	-	-	-	-
Piscataquis	$10.95	$3.43	$1.85	$0.97	$1.23	$247.53	$24.07*	-	-	-	-	-
Sagadahoc	$9.07	$7.08*	-	$1.95	$7.74*	-	$31.49*	$0.65	-	-	-	-
Somerset	$64.94	$1,117.44*	-	$3.52	$375.67*	-	$44.51*	-	-	-	-	-
Waldo	-	$2.45	$3.48	$1.03	$3.48	-	$6.20*	-	-	-	-	-
Washington	$22.45	$7.04	-	$3.45	$2.76	-	$820.00*	-	-	-	-	-
York	-	$305.94	-	$1.16	$171.85*	-	$432.61*	-	-	-	-	-
Total	$8,360.55	$1,538.88	$213.62	$180.04	$4,443.72	$360.95	$4,802.17	$0.65	$2.79	$0.00	$0.00	$0.00

*Loss estimates produced by NESEC using Hazus. Otherwise, loss estimates were projected from reported damages from past natural disaster events including the Flood of 1987, Fire of 1947, 2007 Patriots Day Storm, Ice Storm of 1998, Windstorm of 2017, Salmon River Flood of 2008, Westbrook Landslide of 2020.

Source: County Local Hazard mitigation Plans 2016-2022, NESEC Hazus model reports.

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[97] Stafford Act 44 CFR §201.4: https://www.law.cornell.edu/cfr/text/44/201.4

The majority of County Plans utilize a culmination of base population and inflated costs associated with historical events to estimate potential losses in a worst case-scenario across their top three to four hazards. For this reason, estimated potential losses across severe summer weather, drought, earthquake, erosion, and landslide hazards may not be discussed within the County Hazard Mitigation Plans. Many plans also combine severe summer weather with hurricanes without distinguishing potential losses, leading to potential inaccuracies. The York County Hazard Mitigation Plan did not specify potential losses in terms of monetary losses per hazard, so total potential losses may not be accurately represented.

The Northeast States Emergency Consortium (NESEC) produced loss estimates for flood, tropical cyclone, and earthquake hazards using Hazus; where county estimates are unavailable these Hazus values were used instead. Tier 2 hazards (forest pests, harmful algal blooms, air quality) are newly introduced and therefore are not included in county plans predating this 2023 update.

3.21.1 Local hazard vulnerability descriptions

Counties interpret flooding, severe fall/winter weather, Severe Summer Weather, and Wildfires as high priority hazards for nearly all areas in Maine. The following paragraphs represent a composite summary of the findings from the various county plans as well as the knowledge gained in the preparation of this Plan.

Wildfires

All Maine counties are susceptible to wildfires. The primary damage is to homes located in the wildland-urban interface and loss of valuable timberland. A larger percentage of homes in rural counties are located within the wildland-urban interface, however, wildfires are still a major threat to the higher population-density southern counties. The northern counties have vast tracts of undeveloped forestland that could be damaged by wildfires.

Severe Summer Weather

Severe summer storms, in the form of thunderstorms, microbursts, tornadoes, and severe storms can occur in any county in Maine. Damages typically involve the washout of roads, downed utility lines and trees crashing onto homes.

Flooding

In all Maine counties, the greatest amount of damage from flooding events occurs to the state and local roadway system. This is followed in severity and probability with damage to homes and businesses located along the shores of rivers, lakes and the coastal waters.

Severe fall/winter weather

In all Maine counties, severe fall/winter weather can damage overhead utility lines, cause flooding (ice jams and spring melt off), and dump debris and large amounts of snow in the roads. Although the entire state can experience ice storms, it is the southern coastal counties that experience ice storms most often. Conversely, the more northern and western counties experience greater snowstorms.

Hurricanes

Hurricanes tend to downgrade to a Category 1 by the time they reach Maine. These events typically follow either a coastal, diagonal, or northern route. Maine hurricane events have caused widespread inland flooding, coastal storm surge and wind damage. Damages usually range from washed out roads, flooded homes and businesses, downed utility lines, and trees crashing onto homes. All Maine counties can experience the effects of a hurricane.

Erosion/Landslides

Although profiled in only a few county plans, it has become clear through this planning effort, and recent mitigation projects, that coastal erosion and landslides along the coast and in some interior locations are a growing problem. Erosion is affecting Maine's beaches and about half of the state's coastal shoreline. The problem is most severe in coastal York and Cumberland counties in Southern Maine. At approximately $100,000 per 100 feet of mitigation, the challenge for Maine is finding the funding to address the issue.

Drought

Drought has occurred in all counties in Maine. The primary damage is low water wells in all counties, and damages to crop production in the agricultural counties.

Earthquake

Earthquakes have not caused any structural damages in Maine in the past and statistically, are not likely to cause such damage in the future.

3.21.2 Effects of Changes in Development on Loss Estimates

Most of the losses cited above will not change as a result of the development that has taken place since preparation of the county plans. In general, each county has about the same number of roads, bridges, critical facilities, and utility distribution lines in 2023 as it had when the county plans were prepared between 2010 and 2012. These findings from local plans conflict somewhat with changes in development that have been identified in the making of this plan. Please refer to the section below indicating changes in development found by state assessments and provided to county planners for future use.

3.22 Further Resources for Local and Regional Hazard Mitigation Planning Efforts

Climate Mapping for Resilience and Adaptation: https://livingatlas.arcgis.com/assessment-tool/search

Social Vulnerability Index: https://www.atsdr.cdc.gov/placeandhealth/svi/interactive_map.html

Social Vulnerability Index Dashboard:
https://neo.maine.gov/DOE/neo/Nutrition/Reports/NutritionPublicReports.aspx?reportPath=ED534byDistrict

National Risk Index: https://hazards.fema.gov/nri/map

Resilience Analysis and Planning Tool:
https://fema.maps.arcgis.com/apps/webappviewer/index.html?id=90c0c996a5e242a79345cdbc5f758fc6

Changes in Development in Hazard-Prone Areas

Stafford Act 44 CFR §201.4(d)[98]

3.23 Changes in Population

Recent updates for local hazard mitigation plans in Maine use 2020 Census data in the preparation of their risk assessments (Table 3.58). The latest Census data show that Maine grew by 6.9% between 2000 and 2020. However, the growth was not evenly distributed throughout the state. Together, York and Cumberland County (the state's largest county on the basis of population) grew by a total of 62,687 people, or 72% of the state's total growth during the last 20 years. Growth pressures along the coastal areas of these and other counties continued to push seaside housing and lot prices higher, including areas that may be subject to coastal erosion, coastal landslides and hurricane storm surges.

Increasing development around lakes likely has not resulted in an increase in hazard potential because shore land zoning setbacks and floodplain management ordinance elevation requirements do a great deal to mitigate risk in those areas.

Table 3.58: Change in County Population 2000 – 2020 [99]

County	2000 Population	2010 Population	2020 Population	Change 2000-2020	
				#	%
Androscoggin	103,793	107,702	111,139	7,346	7.1%
Aroostook	73,938	71,870	67,105	-6,833	-9.2%
Cumberland	265,612	281,674	303,069	37,457	14.1%
Franklin	29,467	30,768	29,456	-11	0.0%
Hancock	51,791	54,418	55,478	3,687	7.1%
Kennebec	117,114	122,151	123,642	6,528	5.6%
Knox	39,618	39,736	40,607	989	2.5%
Lincoln	33,616	34,457	35,237	1,621	4.8%
Oxford	54,755	57,833	57,777	3,022	5.5%
Penobscot	144,919	153,923	152,199	7,280	5.0%
Piscataquis	17,235	17,535	16,800	-435	-2.5%
Sagadahoc	35,214	35,293	36,669	1,455	4.1%
Somerset	50,888	52,228	50,477	-411	-0.8%
Waldo	36,280	38,786	39,607	3,327	9.2%
Washington	33,941	32,856	31,095	-2,846	-8.4%
York	186,742	197,131	211,972	25,230	13.5%
Maine - Total	1,274,923	1,328,361	1362,359	87,436	6.9%

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[98] Stafford Act 44 CFR §201.4: https://www.law.cornell.edu/cfr/text/44/201.4

[99] Decennial Census: 2000, 2010, 2020: https://www.census.gov/data.html

3.24 Changes in Development [S7.]

3.24.1 Building Permits Survey

The US Census Bureau conducts an annual Building Permit Survey [100] covering total units and valuation for each state. In Maine, building permits have increased steadily from 2014 to 2021 (Figure 3.83), with the greatest increase in permits and valuation from 2020 to 2021. This indicates a recent increase in development in Maine, though it does not indicate whether development is occurring in locations with a greater likelihood of exposure to natural hazards. Local building codes, ordinances, and zoning are established to reduce the overall likelihood of exposure.

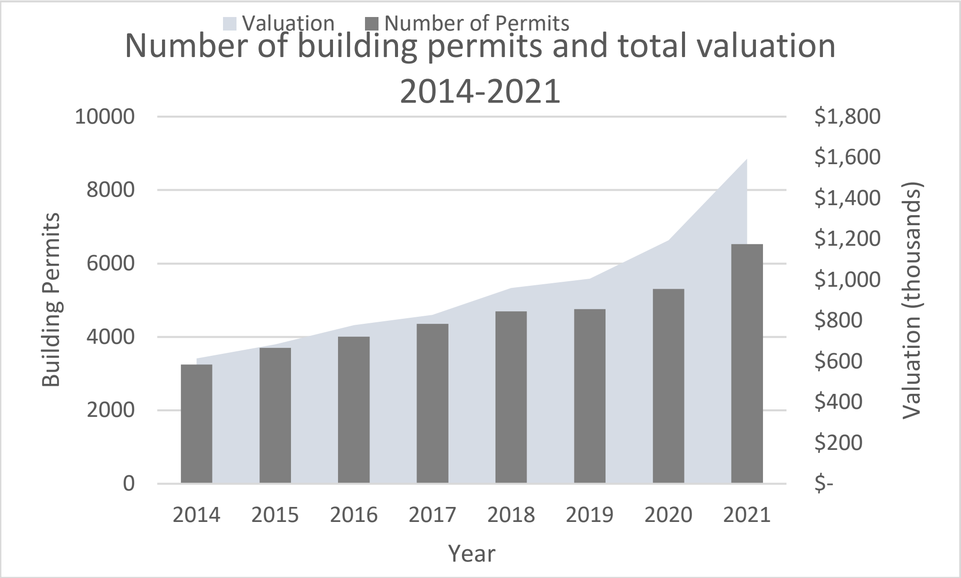

Figure 3.83: Building permits and valuation in Maine 2014 to 2021.

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[100] State Annual Building Permit Survey: https://www.census.gov/construction/bps/stateannual.html

3.24.2 Remote Sensing Data

Maine lacks a comprehensive repository of local building permit data; therefore, alternative approaches are required to monitor development in potentially hazard-prone areas. Sentinel-2 10-meter Land Use/Land Cover Timeseries data offer spatial information on changes in land use/land cover through remote sensing techniques. MEMA identified areas of new development by taking the difference in developed area between 2017 and 2021 (using the Clip tool in ArcMap version 10.8.1). There is some assumed error in these calculations due to the spatial resolution of the data, necessary simplification of polygon boundaries during analysis, and to the process of classifying built/developed areas from the return data using supervised deep learning classification algorithms. However, Sentinel-2 is currently the most accurate global remote sensing resource for purposes of tracking land use change[101].

The individual areas of new development are too small to observe on a statewide map, so results are summarized in Table 3.59 and Figure 3.84. Based on this assessment, the total area of new development has increased by 14.5%. The total area of built/developed land covers 2.4% of the entire land area of Maine.

Table 3.59: Trends in development in hazard prone areas determined by use of categorized Sentinel-2 10-meter imagery[102].

Total built/developed area 2021	546,455
Net change in developed area since 2017	79,497
Total % Change	14.5%
Portion of total increase in development by hazard area:	
No Identified Hazard Location	6.7%
% Change in FEMA 100-year flood zone	5.0%
% Change in Wildland Urban Interface	89.0%
% Change in Category 1 Storm Surge	1.0%
% Change in Category 2 Storm Surge	2.4%
% Change in Category 3 Storm Surge	3.9%
% Change in Category 4 Storm Surge	5.6%

Of this change in developed land, 5% occurred within the 100-year flood zone while 1% of development occurred in the area that may be exposed to Category 1 storm surge. The Wildland Urban Interface (WUI) is the area between unoccupied land and human development, where wildfires are more likely to occur, as delineated by the US Forest Service[103]. The majority (89%) of development has occurred in the WUI. This high value makes sense given that the WUI is delineated to encompass developing areas. However, please note that wildfires that have occurred in Maine within the last several decades are relatively small and within the scope of control of local fire districts and the Maine Forest Service.

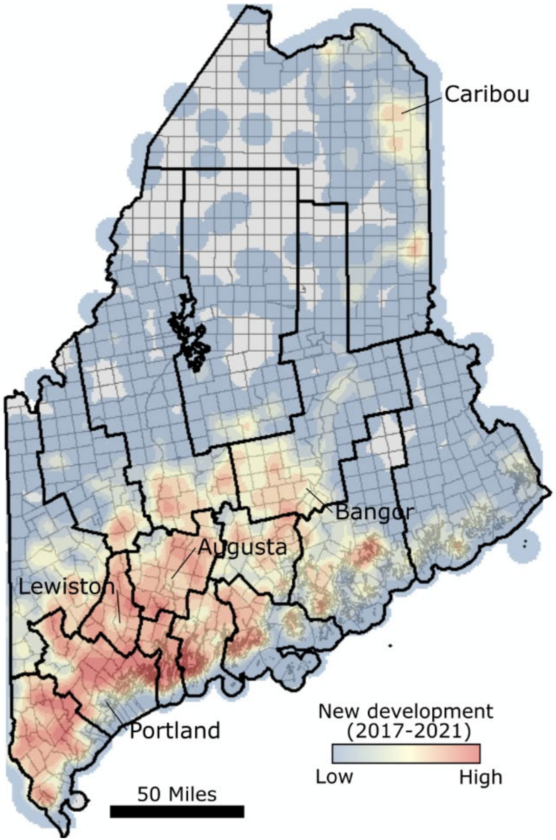

Figure 3.84: New development heatmap of Maine based on Sentinel-2 data, 2017-2021.

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[101] Xi, Y., Thinh, N. X., & Li, C. (2019). Preliminary comparative assessment of various spectral indices for built-up land derived from Landsat-8 OLI and Sentinel-2A MSI imageries. *European Journal of Remote Sensing*, *52*(1), 240-252.https://www.tandfonline.com/doi/full/10.1080/22797254.2019.1584737

[102] Sentinel-2 10 meter Land Use/Land Cover Timeseries Imagery download site: https://www.arcgis.com/apps/instant/media/index.html?appid=fc92d38533d440078f17678ebc20e8e2

[103] Radeloff, V.C., Helmers, D.P., Kramer, H.A., Mockrin, M.H., Alexandre, P.M., Bar-Massada, A., Butsic, V., Hawbaker, T.J., Martinuzzi, S., Syphard, A.D. and Stewart, S.I. (2018). Rapid growth of the US wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences*, *115*(13), 3314-3319. http://silvis.forest.wisc.edu/wp-content/uploads/2018/10/Radeloff_2018_PNAS_SI.pdf

3.24.3 Septic permitting data

MEMA's Natural Hazards Planner reviewed septic permitting data[104] for years 2015-2019 including municipalities across the state. More recent data are currently unavailable, and not all municipalities provide data. Septic permits are a good proxy for determining new residential development in a community, but only in rural or suburban locations where public sewer utilities are unavailable. For example, septic permitting is rare in the City of Portland because the sewer district manages most of the jurisdiction. However, many of Portland's suburbs utilize private septic systems.

Septic permits were counted for 96 municipalities, located across several regions in Maine. Of these municipalities the average number of permits was 120 for the 2015-2019 time period. Of these regions, the greatest number of septic permits were registered in the Portland Suburbs, followed by York County. The Town of Gorham had the greatest number of permits with 1,222, followed by Windham with 984, Wells with 474, and York with 448. The Towns of Wells and York are coastal and therefore may experience greater overall vulnerability due to exposure to coastal hazards.

Other regions that saw higher than average permit totals include Midcoast Maine, the Capital Region, Bangor Suburbs, Lewiston Suburbs, and the Ellsworth-Bar Harbor Region. Of these locations, the Town of Sidney (213), Town of Hermon (208), City of Ellsworth (198), City of Augusta (184), Town of Bar Harbor (181), and Town of Poland (172) saw the greatest totals.

Still other regions that were studied were all below the state average. These regions include the Machias-Downeast Region, Caribou-Presque Isle Region, Dover-Foxcroft Region, and Franklin and Somerset Counties. Though some of these areas are forecast to increase in population in the next 5-10 years, these areas have traditionally seen population declines in recent decades and these septic permitting data support that trend.

3.24.4 Changes in Ordinance, Codes, and Policy Guidance [S7.a.3.]

As noted in Section 4 – State Capabilities, there are many state and federal regulations that prevent state assets from ever being constructed in hazard prone areas. Currently all physical development of state infrastructure is intended to improve resilience of our state-run transportation infrastructure, such as the upsizing and increased elevation of roads and coastal assets. MaineDOT guidelines for road stream crossings increase the standards of road infrastructure to mitigate against flood and erosion risks. Improvements in the Piscataqua Bridge were recently completed, reducing overall risk of damage to this important gateway to Maine. Finally, there has been a significant growth in solar farms in Maine, some of which are located on state lands, which may be vulnerable to the hazards profiled in this plan.

According to other state agencies, there have been no other major changes in development that have impacted vulnerability of state assets. As a result, the primary changes in development that impact the vulnerability of state assets is the passing of laws and regulations that incorporate new sea level rise and related hazard trends[105]. The Maine Legislature recently passed laws requiring state regulatory agencies to incorporate sea level rise trends into all current and future coastal development. The state will adhere to these new regulations and enforce them for all further private and municipal development where applicable.

Municipalities are responsible for enacting and updating local floodplain ordinances. The State of Maine offers guidance for this process through State Model Ordinance, though towns are not required to use the model

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[104] Maine Septic System Permit Search: https://apps.web.maine.gov/cgi-bin/online/mecdc/septicplans/index.pl

[105] An Act to Help Municipalities Prepare for Sea Level Rise: https://legislature.maine.gov/legis/bills/getPDF.asp?paper=HP0407&item=3&snum=129

ordinance. Recent modifications to guidance have occurred from 2015 to 2019[106] and guidance/templates are offered through the website of the Maine Floodplain Management Program[107].

The most recent update to the State Model Ordinance was applied to cases in Zone A floodplains. The ordinance now allows the applicant to build so that the lowest floor of the building is two feet higher than the highest adjacent grade to the building. This means no below grade crawl spaces or basements should be allowed. In Zone A, flood insurance is rated on the elevation differential between the highest adjacent grade to the building and the lowest floor. The lower the floor is below the highest adjacent grade; the more expensive flood insurance becomes. Amendments located at Article III.H.; Article V.B.2.; and Article VI.F., G., and H.

The Southern Maine Planning and Development Commission (SMPDC) and partners (FB Environmental) have published Municipal Guidance for Coastal Resilience: Model Coastal Ordinance Language for Maine Municipalities to support municipal staff and planning boards with integrating resilience measures into land use regulations[108]. The document provides a menu of land use provisions and resilience measures that municipalities can incorporate into existing ordinances or combine for a standalone coastal resilience ordinance. Suggested measures are intended to integrate with floodplain management ordinances, shoreland zoning, subdivision and site plan review, and other zoning and land use regulations. Importantly. the model ordinance language facilitates land use planning that accounts for climate change impacts, minimizes risk from those impacts, and is designed for flexibility and adaptability to changing environmental conditions.

The Office of the State Fire Marshal is in the process of updating the Maine Uniform Building and Energy Code (MUBEC), which applies to all towns in the State of Maine and is enforced in communities with population exceeding 4,000 as determined by the last decennial census. The update will bring MUBEC into conformance with 2021 International Codes, including updates to building design, construction, inspection, and maintenance standards, as well as general health, safety, and egress standards[109]. Currently MUBEC consists of 2015 International Residential Code, Building Code, Existing Building Code, Energy Conservation Code, and Mechanical Code, in addition to 2016 Standards from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

3.25 Future Development and Redevelopment Projections [S7.a.]

3.25.1 Risk Implications from Development [S7.a.3.; S7.a.4]

Current trends in development and population increase suggest continued growth in areas already host to new development. These include the Portland suburbs, Midcoast Region, York County, and various locations in Central Maine. These general trends do not specifically indicate a forecasted increase in development in hazard prone areas except potentially for coastal communities with generally greater exposure to wind and storm surge inundation impacts from tropical and extratropical cyclones.

Dallas Plantation, a small community in Franklin County, has experienced a sudden increase in development caused in part by the recent reopening and redevelopment of the Saddleback Ski Resort. Development in this area is taking the form of subdivisions of ski condos in steep sloped areas accessed by dead end roads. These areas will need to be monitored closely to assess a potential increase in risk from erosion, mass wasting, wildfire, severe summer and winter weather, flooding, and many other natural hazards.

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[106] 2015-2019 Changes to State Model Floodplain Management Ordinance: https://www.maine.gov/dacf/flood/docs/ordinances/2015thru2019OrdinanceChanges.pdf

[107] https://www.maine.gov/dacf/flood/whichord.shtml

[108] SMPDC Model Coastal Ordinance: https://smpdc.org/index.asp?SEC=EB353312-031E-4651-8CE5-4B482BABB42A&DE=610B6C36-DB91-4ED7-BD39-96F98BC9EE91

[109] 2021 International Building Code Overview of Changes: https://codes.iccsafe.org/content/IBC2021P2

In 2020, the City of Westbrook experienced a large landslide along the banks of the Presumpscot River. Though damages were not substantial, the city has chosen to move forward with a Presumpscot River Corridor Vulnerability Assessment to determine further mass wasting risks along the banks of the river. The timing for this vulnerability assessment is important because Westbrook is currently one of the fastest growing communities in Maine.

An overall increase in population may equate to a general increase in vulnerability due to a greater total population at risk of natural hazards within a more densely populated area and incomplete coverage of implementation of the latest International Code Council's family of codes. Local emergency services, often already stretched thin, may need greater support in order to continue to function properly. State assets such as parks, protected lands, historic sites, and other public facilities may see greater visitation that, if left unchecked, may lead to degradation of state resources, make them more vulnerable if exposed to natural hazards. For example, as noted in the Erosion Hazard Profile, some of the most visited state parks are fragile coastal beaches that are susceptible to dune erosion and devegetation that can accelerate beach recession if a greater number of visitors end up disturbing the sites.

Contrary to the findings in this State Hazard Mitigation Plan, virtually all Local Hazard Mitigation Plans from Maine jurisdictions note that changes in development have recently been minimal, with no change in natural hazard risks.

Maine's population is aging, which increases overall community vulnerability in the event of a natural hazard. Challenges that increase risk for aging populations include a greater prevalence of chronic conditions, multi-morbidity, cognitive impairment, and medication concerns.

There are positive implications for future policy developments focused on resilience planning and mitigation. Maine has recently incorporated sea level rise projections into regulations associated with coastal development and environmental protection. Further inland, work has begun to improve FIRMs in communities that are in dire need of more accurate and digital floodplain resources. FEMA has also enacted their Risk Rating 2.0 platform, which more accurately prices flood insurance policies based on risk. FEMA's HMA programs are now accepting a greater array or wildfire mitigation projects and there is interest in exploring more opportunities for drought mitigation efforts.

A combination of three years of drought and steady population increase has led some water utilities to consider merging to offer greater overall supply to their municipalities. Gray and Yarmouth water districts intend to apply for a BRIC grant to combine their districts as they will not be able to keep up with growing supply needs on their own. Wiscasset water district may also merge with four other adjacent towns due to increased service population and recent saltwater intrusion into their aquifer.

3.25.2 Maine Population and Demographics Outlook 2018-2028 [S7.a.1.]

Recent development trends in Maine have been strongly influenced by the COVID-19 pandemic, causing growth to increase by more than expected for many parts of the state. The State Economist completed a revised population outlook report[110] to account for this recent shift, replacing a report completed in 2018 to forecast population trends out to 2028. Overall the State Economist projects a population increase of 2.1% from 2018 to 2028. However, Maine's prime working age population is projected to decrease by 7.8% as the state continues to age. The

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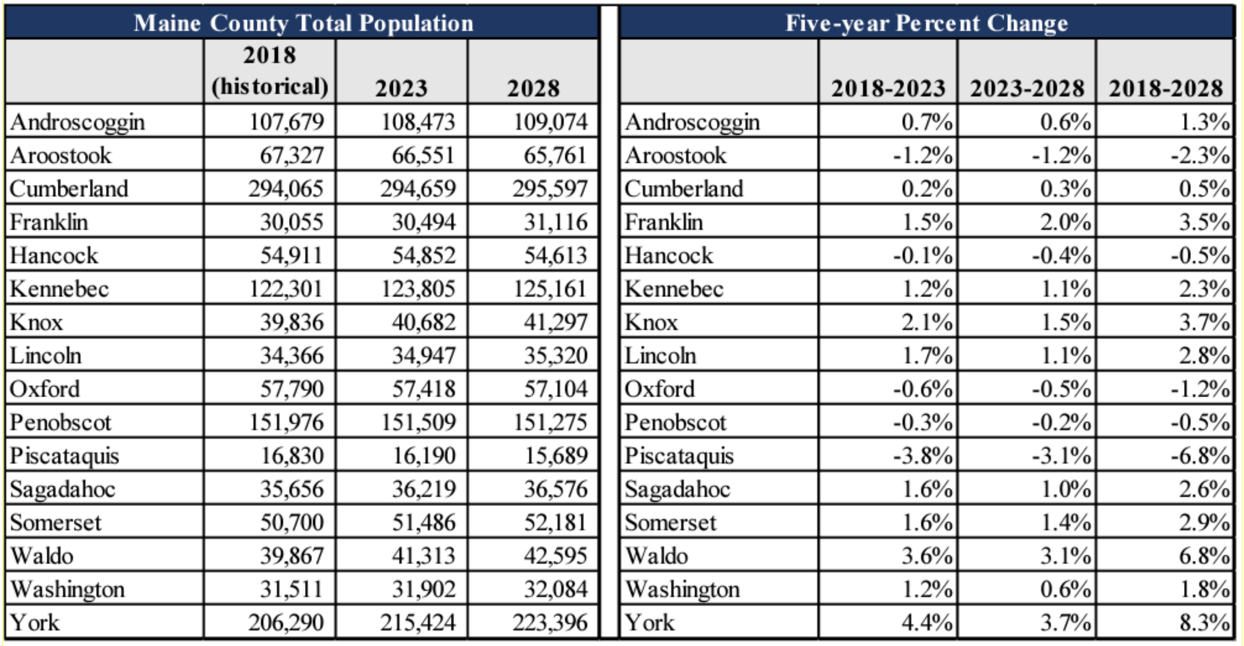
[110] Maine Population Outlook 2018-2028: https://www.maine.gov/dafs/economist/sites/maine.gov.dafs.economist/files/inline-files/Maine%20Population%20Outlook%20to%202028.pdf

population aged 65 or over is the only population expected to have a net increase from 2018 to 2028. The Baby Boom generation is by far the largest population in the State at 27.4%.

Eleven of sixteen counties are expected to gain population from 2018-2028. York County is projected to see the greatest growth rate of 8.3%. Piscataquis has the largest negative projected growth rate of -6.8%.



Maine County Total Population

	2018 (historical)	2023	2028
Androscoggin	107,679	108,473	109,074
Aroostook	67,327	66,551	65,761
Cumberland	294,065	294,659	295,597
Franklin	30,055	30,494	31,116
Hancock	54,911	54,852	54,613
Kennebec	122,301	123,805	125,161
Knox	39,836	40,682	41,297
Lincoln	34,366	34,947	35,320
Oxford	57,790	57,418	57,104
Penobscot	151,976	151,509	151,275
Piscataquis	16,830	16,190	15,689
Sagadahoc	35,656	36,219	36,576
Somerset	50,700	51,486	52,181
Waldo	39,867	41,313	42,595
Washington	31,511	31,902	32,084
York	206,290	215,424	223,396

Five-year Percent Change

	2018-2023	2023-2028	2018-2028
Androscoggin	0.7%	0.6%	1.3%
Aroostook	-1.2%	-1.2%	-2.3%
Cumberland	0.2%	0.3%	0.5%
Franklin	1.5%	2.0%	3.5%
Hancock	-0.1%	-0.4%	-0.5%
Kennebec	1.2%	1.1%	2.3%
Knox	2.1%	1.5%	3.7%
Lincoln	1.7%	1.1%	2.8%
Oxford	-0.6%	-0.5%	-1.2%
Penobscot	-0.3%	-0.2%	-0.5%
Piscataquis	-3.8%	-3.1%	-6.8%
Sagadahoc	1.6%	1.0%	2.6%
Somerset	1.6%	1.4%	2.9%
Waldo	3.6%	3.1%	6.8%
Washington	1.2%	0.6%	1.8%
York	4.4%	3.7%	8.3%

Two-thirds of the cities and towns in Maine are projected to see population growth between 2018 and 2028. The growth rates in these 305 towns range from 0.1% to 25.6%. Sixteen towns are projected to see no change from 2018 to 2028. The remaining 201 cities and towns are projected to see declines ranging from -0.1% to -45.2%.

Most of the cities and towns projected to see growth are in counties that are also expected to see population growth. For example, all constituent towns in York and Lincoln counties are expected to grow from 2018 to 2028. Conversely, none of the towns in Piscataquis County are expected to see increases, a reflection of underlying demographics of the county, which has the oldest median age in the state.

Maine's five largest cities are projected to remain so in 2028. However, only Auburn is expected to see growth over the 10-year period. Even though Portland has seen recent growth and Cumberland County is projected to see growth from 2018 to 2028, Portland's share of Cumberland County has been shrinking, leading to the projected decline. However, city/town projections should be viewed with caution and used in conjunction with local knowledge, as the methodology used here is not as refined as that for the counties and the state.

Demographics and Migration Trends [S7.a.2.]

Maine's population can only grow through in-migration due to a predominantly older population. From 2016-2019 Maine has seen net domestic migration accelerate, with 6,613 new Mainers from other states in 2019. Strong in-migration in the past four years has contributed to improved population projections and will have a positive impact on Maine's economy in the future.

Maine's demographics are similar to those of Vermont and New Hampshire, but quite different from the nation. The chart below compares the demographics of Maine to its Northern New England neighbors (Vermont and New Hampshire), its Southern New England neighbors (Massachusetts, Connecticut, and Rhode Island) and the

United States. Maine compares closely to the rest of Northern New England in its age structure and levels of diversity. There are more pronounced differences when comparing to Southern New England and the United States, which are home to younger and more diverse populations.

Maine's Diversity index was 18.5% in the 2020 Decennial Census, and increase from 10.8% in the 2010 census[111]. The diversity index measures the probability that two people chosen at random will be from different race and ethnicity groups. The three most diverse counties in Maine are Androscoggin (25%), Cumberland (24.8%), and Washington (20.9%). Androscoggin and Cumberland counties are home to the state's two largest cities, both of which have become a new home to immigrants and refugees. Conversely, Washington County is home to large blueberry farms that hire many migrant workers to perform harvesting operations. In 2010, Washington County had the greatest diversity index (16.4%).

The pandemic has resulted in significant short-term changes to migration as well as birth and death rates. For example, the way labor markets interact with geographic boundaries has changed over the past year. The rapid and widespread implementation of remote work made it possible for many workers, particularly those in middle- and high-wage jobs, to work from anywhere. If this trend toward remote work continues in the long-term, it could usher in an era of counter-urbanization, which Maine could benefit from. Maine's lower population density may have been attractive to urban dwellers throughout the height of the pandemic, as it posed less risk than crowded city centers. While migration patterns generally change gradually over time, the COVID-19 pandemic could lead to a sudden, drastic change in migration patterns, however, it remains to be seen what the long-term effects are.

Challenges with tracking development [S7.a.4.]

This plan identifies specific examples of rapid development in some communities in Maine. Unfortunately, there is limited authority at state or county levels to establish a definitive process for monitoring development, requiring us to use several different techniques. For example, most permitting processes are regulated at the municipal level. Municipalities may elect to share this information with the state. As a result, there is no one best way to track development at a scale that is useful for determining whether it is causing a change in natural hazard risks or if it is in an area prone to natural hazards.

County EMAs often take on the responsibility of updating Local Hazard Mitigation Plans on the behalf of their jurisdictions. It is equally challenging for counties to discern these development trends, and often towns indicate that they do not know of any development occurring. It is likely too challenging for local governments to review building permits, septic permits, and other permits indicating new development and determine whether they are posing a risk to the community. As a result, many Local Hazard Mitigation Plans report that development is minimal, that populations are generally decreasing in Maine, and that there is no change in risk. Given that this conflicts with findings in this State Hazard Mitigation Plan, MEMA has begun to provide much greater technical assistance to counties in order to better capture these development trends and verify any perceived changes in risk. Local Regional Planning Organizations may also support these efforts.

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[111] Maine Census Facts: https://www.census.gov/library/stories/state-by-state/maine-population-change-between-census-decade.html