Appendix F: Supplemental Information for Analyses in the Infectious Diseases Chapter

This appendix describes methods, data sources, and assumptions for the infectious disease analyses presented in Chapter 7 of the main report. The first section of this appendix provides information on the detailed analysis of Lyme disease. The second section provides information supporting the discussion of emerging literature related to West Nile Virus.

Detailed Analysis of Lyme Disease in Children

This section includes details of the analysis on climate change effects on Lyme disease incidence in children, organized into the following subsections: a summary of studies used in the analysis, analysis steps, detailed results, and limitations of the approach.

SUMMARY OF STUDIES USED IN THIS ANALYSIS

YANG ET AL. (IN REVIEW)[1]

Yang et al. studied the associations between temperature, precipitation, land cover, tick presence, bacteria presence, and Lyme disease incidence in 21 eastern U.S. states and the District of Columbia, where Lyme is currently prevalent[*], and then assigned estimates of the costs of changes in disease incidence. The author team projected the probability of *Ixodes scapularis*, the most common Lyme disease vector within the region, based on the tick species presence, the presence of *Borrelia burgdorferi,* the bacteria responsible for causing Lyme disease, and environmental factors. The authors determined a Lyme disease incidence rate at the county level for children (aged 0-20) and adults from data on confirmed and probable cases provided by the U.S. CDC, which served as the baseline. They then related these historical associations to projections from six different climate models (CanESM2, CCSM4, GISS E2 R, HadGEM2 ES, MIROC5, and GFDL CM3) using variables for precipitation and temperature, to assess future changes to potential tick habitat. Results suggest that warming is likely to increase overall Lyme disease incidence in the eastern U.S. For details on the model coefficients (and standard errors) used for projections purposes, see Yang et al.

ANALYSIS STEPS

Chapter 7 of this report describes how Lyme disease incidence could vary among children as the climate continues to change. The analysis relies on data from Yang et al. and presents the results in an impacts-by-degree format. In addition to converting between CONUS degrees of warming to

[*] The states included in the analysis are Connecticut, Delaware, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia, and Wisconsin; as well as the District of Columbia.

global degrees of warming, the other adjustment made to the projections from Yang et al. is refining the definition of children to match the definition used in this report (aged 0-17). To do that, the case rates per 100,000 children aged 0-20 are applied to children aged 0-17 instead. Available case data show that children aged 5-9 have the highest case rate across all age groups; therefore, it is possible this approach leads to an under-estimation of cases among children in the 0-17 age range, although it is also possible that this approach over-estimates cases.[2] The analysis considers all areas of the eastern U.S. included in the underlying study and is performed at the county level. Results also are interpreted at the census tract-level, with identical incidence rates assumed for all tracts within a county, for the social vulnerability analysis.

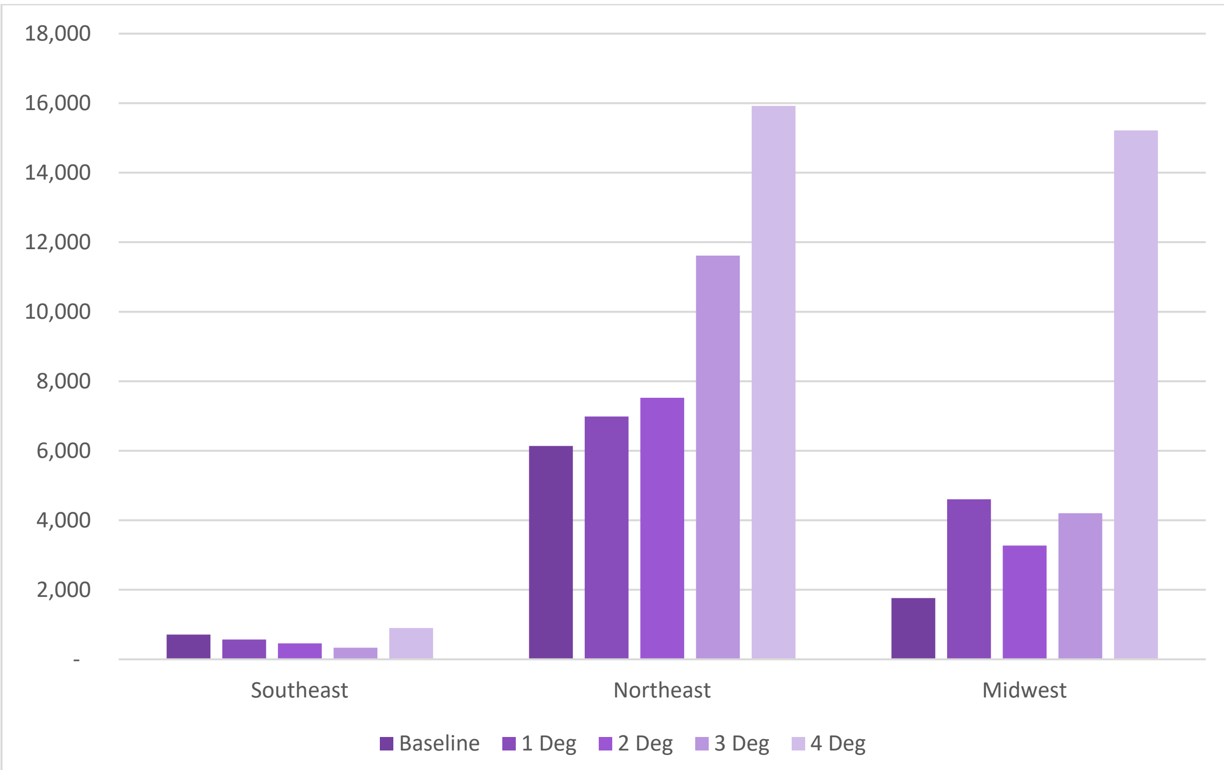
Table 1: Analytic Steps in Climate Change Impacts on Lyme Disease in Children Analysis

Step		Data	Methods, Assumptions, and Notes
Baseline Risks	1. Identify baseline incidence of health impacts under baseline Lyme disease exposure and population	Yang et al. and U.S. Census data	Modeled using baseline incidence per 100,000 children aged 0-20 from Yang et al., and baseline population of children aged 0-17 from the U.S. Census.
Future Climate Stressor	2. Forecast future temperature and precipitation patterns associated with the tick vector	**Future climate:** LOCA (downscaled) future climate data at the census tract level **Environmental function:** Yang et al.	This analysis relies on the analysis completed in Yang et al. that model Lyme disease incidence and changes in temperature and precipitation patterns and associated those with tick habitat suitability. See the paper for details.
Future Effects on Children	3. Estimate the incidence of health impacts among children associated with each degree-C increase in global mean temperatures	Yang et al. created a model related estimated habitat suitability for the ticks, *B. burgdorferi presence,* and Lyme disease incidence. See paper for details. See Chapter 2 of the main report and Appendix A for details on population methods and data sources used throughout the analysis.	This assessment relies on the analysis completed in Yang et al. See that paper for details. Given the unique spatial patterns in the underlying data, results are presented by National Climate Assessment (NCA) region.

EFFECTS ON CHILDREN RESULTS

Figure 1 presents the annual baseline new cases of Lyme disease each year among children aged 0-17 in all counties in the eastern U.S. by National Climate Assessment (NCA) region, and projected annual new cases for 1 to 4°C of global warming, using population growth consistent with EPA's ICLUS population tool. For comparison, baseline annual new cases of Lyme disease appear in the far-left bar column for each region.

Figure 1: Projected Annual Total New Cases of Lyme Disease Among Children Aged 0-17 in the Eastern U.S. by NCA Region (with Population Growth)



Notes: All estimates presented are not baseline corrected. See Table 1 of this appendix for details on methods and data sources. Because the analysis only considers a sub-set of states; the results presented for the Southeast do not reflect all counties or states in that NCA region.

Table 2 depicts analogous results for the complete study area (and baseline corrected), with the total number of new Lyme disease cases under population growth and assuming a consistent U.S. population size using 2010 levels. See Chapter 2 and Appendix A for details of population projections.

Table 2: Projected New Cases of Lyme Disease Each Year in the Eastern U.S.

Degree of Global Warming (°C)	With Population Growth	Constant 2010 Population
1°C	3,500 *(-7,500 to 21,200)*	2,800 *(-7,500 to 19,000)*
2°C	2,600 *(-7,500 to 20,200)*	1,700 *(-7,700 to 19,000)*
3°C	7,500 *(-8,400 to 42,300)*	6,100 *(-8,400 to 38,200)*
4°C	23,400 *(7,800 to 47,000)*	17,200 *(5,500 to 35,700)*

Notes: All estimates presented are incremental relative to baseline risks and convey impacts among children aged 0-17 per year. The baseline is 8,600 cases in all 21 states and the District of Columbia in the underlying sample. Negative numbers imply decreases in new cases relative to the baseline. The table displays the average and range across climate models. Results are not available at 5°C.

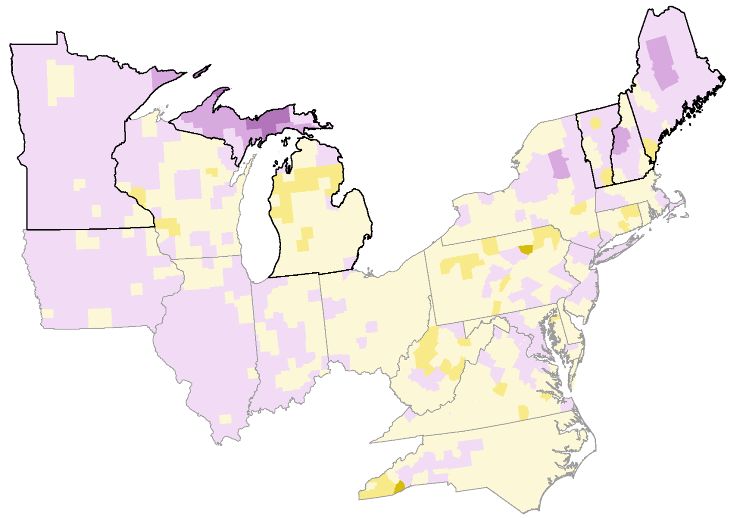
Figure 2 shows the projected change in new annual Lyme cases per 100,000 children aged 0-17 at 2°C and 4°C of global warming at the county level. The five states with largest impacts per 100,000 children are outlined in black and listed below each map.

Tables 3 and 4 convey the number of new Lyme cases per 100,000 children annually for each state at 2°C and 4°C of global warming to provide perspective on the range of impacts across states, although there can be considerable heterogeneity within the area of interest (see Figure 2).

Figure 3 shows the change in total new Lyme cases among children aged 0-17 at 2°C and 4°C of global warming at the county level. Impacts are generally highest in areas with large populations of children. The five states with the largest total impacts are outlined in black and listed below each map. The relevant quantities presented in each map are provided in parentheses after the state name in the lists of top 5 states.

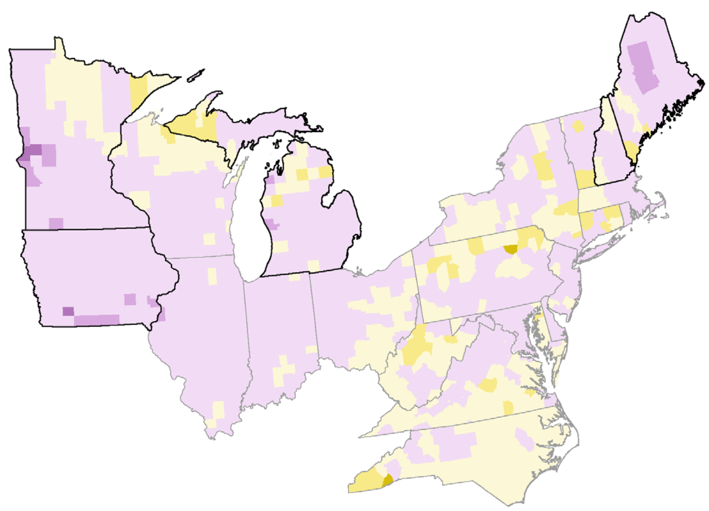
Figure 2: Projected Changes in New Cases of Lyme Disease Per 100,000 Children Each Year (Aged 0-17) (with Population Growth)

2°C of Global Warming



Top five states: ME (104), NH (102), VT (79), MN (54), MI (22)

4°C of Global Warming



Top five states: IA (267), MN (184), MI (123), ME (115), NH (89)

Additional Lyme Cases per 100,000 Children

-3,000 - -1,000 | -1,000 - -100 | -100 - 0 | 0 - 1,000 | 1,000 - 3,000 | 3,000 - 6,300

Note: These maps describe the projected change in new Lyme disease cases per 100,000 children per year at 2°C and 4°C of global warming relative to the baseline (1986-2005). Purple shading denotes increases in cases relative to baseline while yellow shading denotes decreases in cases relative to baseline. The five states with the largest increases on average are outlined in black.

Table 3: Projected New Lyme Cases Per 100,000 Children Per Year by State with 2°C Global Warming (with Population Growth)

State	Incidence Per 100,000 Children	State	Incidence Per 100,000 Children
Maine	103.7	Indiana	2.2
New Hampshire	101.5	Massachusetts	1.3
Vermont	78.9	Virginia	-0.01
Minnesota	53.8	Maryland	-2.1
Michigan	22.4	Delaware	-2.7
Washington, DC	20.6	Pennsylvania	-3.0
New York	19.7	Ohio	-5.2
Iowa	12.8	North Carolina	-10.4
New Jersey	10.4	West Virginia	-19.3
Wisconsin	4.4	Rhode Island	-29.5
Illinois	2.4	Connecticut	-46.9

Notes: This table describes the projected change in new Lyme disease cases per 100,000 children per year at 2°C of global warming using the methods described in Table 1 averaged to the state level. States are listed from largest to smallest impacts. Negative numbers signal reductions in new annual cases relative to baseline levels.

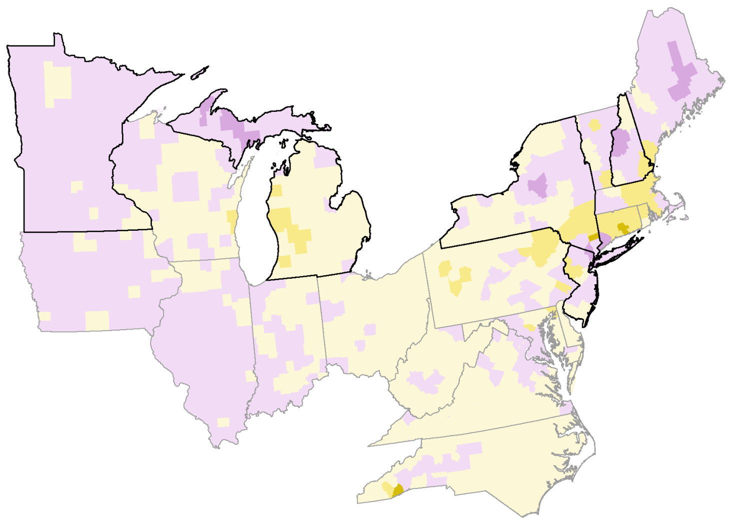
Table 4: Projected New Lyme Cases Per 100,000 Children Per Year by State with 4°C Global Warming (with Population Growth)

State	Incidence Per 100,000 Children	State	Incidence Per 100,000 Children
Iowa	267.1	New Jersey	27.5
Minnesota	184.5	Ohio	25.0
Michigan	123.3	Rhode Island	22.7
Maine	114.7	Virginia	19.5
New Hampshire	89.3	Maryland	18.8
New York	80.6	Washington, DC	13.6
Indiana	78.0	Delaware	7.5
Pennsylvania	69.4	West Virginia	6.5
Massachusetts	60.0	Vermont	3.0
Wisconsin	58.4	Connecticut	-7.0
Illinois	40.5	North Carolina	-9.9

Notes: This table describes the projected change in new Lyme disease cases per 100,000 children per year at 4°C of global warming using the methods described in Table 1 averaged to the state level. States are listed from largest to smallest impacts. Negative numbers signal reductions in new annual cases relative to baseline levels.

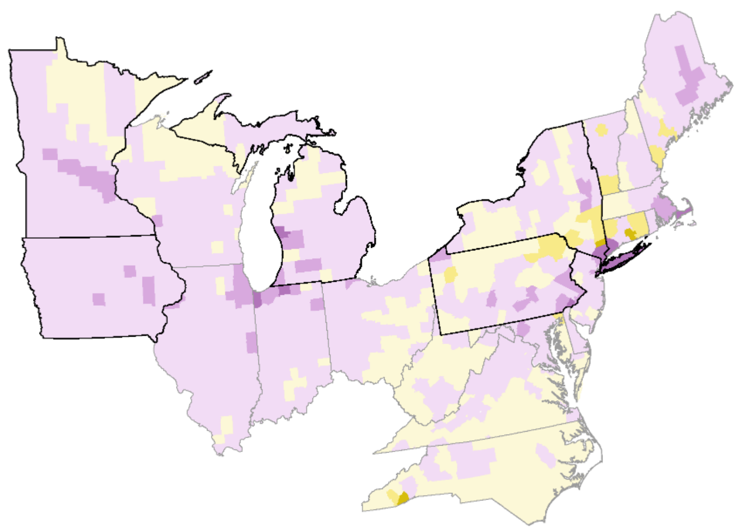
Figure 3: Estimated Changes in Total New Cases of Lyme Disease in Children (Aged 0-17) Per Year (with Population Growth)

2°C of Global Warming



Top five states: NY (1,098), MN (766), MI (569), NJ (293), NH (286)

4°C of Global Warming



Top five states: NY (4,975), MI (3,232), MN (2,753), IA (2,593), PA (1,982)

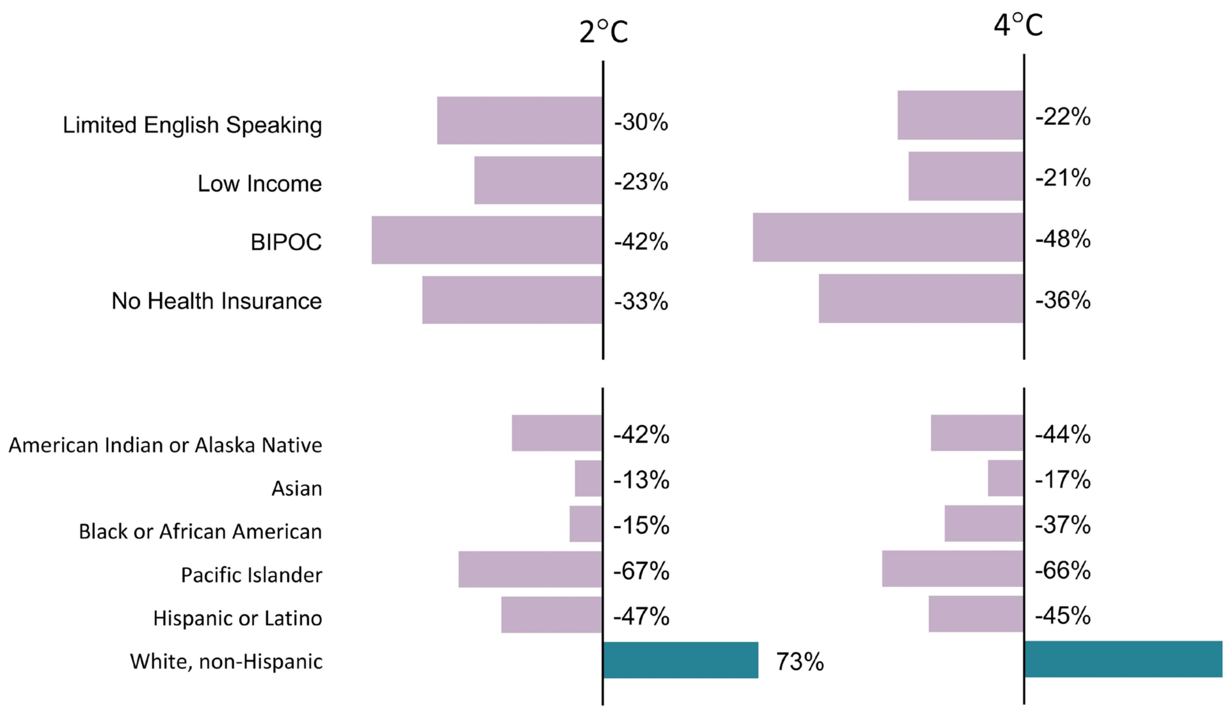
New Cases of Lyme Disease

-260 - -100 | -100 - -10 | -10 - 0 | 0 - 100 | 100 - 250 | 250 - 1,730

Note: These maps describe the projected change in total new Lyme disease cases per year at 2°C and 4°C of global warming relative to the baseline (1986-2005). Purple shading denotes increases in cases relative to baseline while yellow shading denotes decreases in cases relative to baseline. The five states with the largest increases on average are outlined in black.

Figure 6 describes the results of the social vulnerability analysis at 2°C and 4°C of global warming across geographies included in the analysis (see Chapter 2 and Appendix A for methods, data sources, and assumptions for the social vulnerability analysis). The estimated risks for each socially vulnerable group are presented relative to each group's "reference" population, defined as all individuals other than those in the group analyzed. Positive numbers indicate the group is disproportionately affected by the referenced impact. Negative numbers indicate the group is less likely to live in the areas with the highest projected impacts.

Figure 6: Social Vulnerability Analysis Results for New Lyme Disease Cases Among Children



LIMITATIONS

Below are several limitations of the analysis:

1. ***Assumes case rates in children aged 0-20 also applies to children aged 0-17:*** Yang et al. include all children aged 0-20 in one group. Because this report considers a narrower definition of children (aged 0-17), the incidence rates per 100,000 among 0-20-year-old children are also applied to 0-17-year-old children. Because children aged 5-9 have the highest baseline case rate across all age groups, this approach likely leads to an under-estimation of cases among children aged 0-17.
2. ***Lyme disease cases are underreported and under diagnosed:*** Like many infectious diseases, cases of Lyme disease are underreported to the Centers for Disease Control & Prevention's National Notifiable Disease Surveillance System. Additionally, Lyme disease symptoms mirror

those of other diseases, and misdiagnoses may occur. This also may occur in areas in which Lyme disease is not prevalent or is not currently endemic. Therefore, the Yang et al. analysis (and, thus, this analysis) likely underestimate Lyme disease prevalence.[3]

3. *Only considers habitat and climate conditions, overlooking tick or host movement.* Changes in tick and host (e.g., humans, small mammals, birds, reptiles) behavior, play a role in exposure to Lyme disease. Climate change may impact the range of host species that do/do not allow for the replication of the *B. burgdorferi* bacteria. The spread of Lyme disease shifts as a result of outdoor activities.[4]
4. *Only accounts for ticks in 22 states and Washington, DC, in the eastern U.S.* A different species of tick (western blacklegged tick, *I. pacificus*) is responsible for the majority of Lyme disease cases throughout the western U.S. However, this species of tick does not transmit Lyme disease as readily as its eastern counterpart, and Lyme disease cases in the West are much less common.[5] Further, there are many areas of the country that are adjacent to locations where tick and bacteria are established, in which Lyme disease is not prevalent.[6] Therefore, inclusion of these states would skew the analysis.
5. *Does not account for genotypic differences in tick populations*. Subpopulations of ticks across the country have different genotypes, with some subpopulations being more resilient to overly hot, dry, or wet conditions.[7] It is possible that if this analysis included for those types of genetic variations, it would provide a more accurate depiction of tick survival and transmission of Lyme disease in endemic areas.

DATA SOURCES

Table 5: Summary of Data Sources Used in the Lyme Disease in Children Analysis

Data Type	Description	Data Documentation and Availability
Historical climate modeling	Yang et al. relied on Livneh et al. for baseline climate data (precipitation, temperature) for 1986-2005. Livneh et al. data are provided at a spatial resolution of 1/16° (~6 km).	Livneh, B., Bohn, T.J., Pierce, D.W., Munoz-Arriola, F., Nijssen, B., Vose, R., Cayan, D.R. and Brekke, L., 2015. A spatially comprehensive, hydrometeorological data set for Mexico, the US, and Southern Canada 1950–2013. *Scientific Data*, *2*(1), pp.1-12.
Habitat suitability modeling	Habitat suitability for Yang et al. was determined based in part on forest cover and land use, via the United States Geologic Survey's (USGS) National Land Cover Database (NLCD), which is informed by EROS and provides information on U.S. land cover and	USGS. 2016. National Land Cover Database. Last updated: September 11, 2018. Retrieved from: https://www.usgs.gov/centers/eros/science/national-land-cover-database

Data Type	Description	Data Documentation and Availability
	land cover change for the years 2001-2019.	
	USGS EROS Elevation Derivatives for National Application Seamless Three-Dimensional Hydrologic Database (EDNA) provides three-dimensional elevation data based on hydrologic drainage.	USGS (2018) USGS EROS Archive - Digital Elevation - Elevation Derivatives for National Applications (EDNA) Seamless Three-Dimensional Hydrologic Database. Last updated: July 13, 2018. Retrieved from: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-elevation-derivatives-national?qt-science_center_objects=0#qt-science_center_objects
Tick and bacteria (*Borrelia burgdorferi*) distribution	Tick and bacteria presence were incorporated based on a dataset indicator of being "established" in a particular county, in which at least 6 ticks, or ticks at a minimum of two life stages, were observed within the same 12-month period.	U.S. Centers for Disease Control and Prevention. "Established and reported records of Borrelia burgdorferi sensu stricto or Borrelia mayonii through Dec. 31, 2021." Last updated: October 21, 2022. Retrieved from: https://www.cdc.gov/ticks/surveillance/TickSurveillanceData.html
Baseline health effect incidence rates	Lyme disease incidence at the county level for the years 2008-2019.	U.S. Centers for Disease Control and Prevention. "National Notifiable Diseases Surveillance System, Lyme Disease Surveillance Data 2008–2019." Fort Collins, CO. CDC Division of Vector-Borne Diseases.
Future climate modeling (temperature and precipitation)	*See Appendix A for data sources*	
Future population of children	*See Appendix A for data sources*	
Demographics for social vulnerability analysis	*See Appendix A for data sources*	

West Nile Virus in Children

Chapter 7 highlights research about the possible effects of West Nile Virus on children. This analysis estimates an additional 59 and 133 cases of West Nile neuroinvasive disease (WNND) among children per year at 2°C and 4°C of global warming, respectively, based on Lindsey et al. (2009) and Belova et al. (2017).[8,9] Belova et al. estimated the future number of WNND cases among individuals of all ages associated with climate change in two future eras: 2050 and 2090. The authors project an additional 1,270 cases of WNND in 2050 above a baseline of 971 annual cases, rising to 3,280 additional cases in 2090. These estimates translate to 1,490 and 3,330 additional cases of WNND at 2°C and 4°C of global warming, respectively, using the impact by degree approach described in Chapter 2 and Appendix A. Lindsey et al. found that child patients accounted for about 4% of all WNND cases reported from 1999 to 2007. As a result, this analysis estimates the number of children's cases of WNND attributable to climate change to be 4% of the total cases of WNND projected in Belova et al., presented above and in Chapter 7.

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