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Hazard Identification and Risk Assessment (HIRA)

Climate Change and Vector-borne Diseases

Report

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Public Health Ontario

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Introduction

Ontario is already experiencing the consequences of climate change, namely the range expansion of the blacklegged tick (*Ixodes scapularis*) and the emergence of anaplasmosis, babesiosis, Lyme disease, and Powassan virus infection.[1–4] Our understanding of the public health risks posed by emerging vector-borne diseases (non-Diseases of Public Health Significance [DoPHS]) in Ontario is limited, especially in the context of climate change. Using a 10-year view for the prioritization of vector-borne disease policies and programming in Ontario, we completed a Hazard Identification and Risk Assessment (HIRA) to assess the probability and impact of five diseases (alpha-gal syndrome [AGS], eastern equine encephalitis virus [EEEV] infection, malaria, *Orthobunyavirus* [OBV] infections, and Rocky Mountain spotted fever [RMSF]) that were selected based on a prioritization exercise. In addition, we identified priorities for public health planning, aimed at mitigating the impact of disease emergence.

Purpose

A HIRA is a strategic and evidence-based assessment of public health risks that helps public health practitioners in the planning and prioritization of response activities. In addition, a HIRA can include considerations for strengthening public health capacities and reducing exposures and population vulnerability to hazards. Ensuing preparedness actions aim to increase readiness to manage a potential threat and support a more effective public health response. This type of risk-informed approach to response planning has the potential to reduce the effects of vector-borne diseases, including preventing excess mortality and morbidity. We applied rapid risk assessment methodologies to emerging vector-borne disease risks and, to support public health planning in the context of climate change, we used a novel and comprehensive approach to assessing the risks of vector-borne diseases in Ontario.

Risk Question

For each prioritized vector-borne disease, what is the likelihood and impact of local transmission in Ontario in the next ten years?

Key Findings

- In the next 10 years, the risks associated with locally acquired eastern equine encephalitis virus (EEEV) infections were deemed **high**. EEEV is one of the deadliest mosquito-borne pathogens in North America, with survivors often experiencing long-term neurological complications. EEEV infections will affect Ontario's public health capacity and represents a high priority for public health planning.

- In the next 10 years, the risks associated with locally acquired alpha-gal syndrome (AGS), malaria, *Orthobunyavirus* (OBV) infections, and Rocky Mountain spotted fever (RMSF) were deemed **moderate**; these four diseases could affect Ontario's public health capacity and are a medium priority for public health planning.
- Few climate-modelling studies included Ontario in their projections. However, increased temperatures will increase the abundance and distribution of mosquitoes and ticks, leading to increased pathogen transmission and risk of vector-borne disease.
- This Hazard Identification and Risk Assessment (HIRA) identified several priorities for public health planning, including updating vector-borne disease guidance, adopting additional human case surveillance tools, enhancing vector surveillance programs, supporting climate change and vector-borne disease modelling, and developing knowledge products to increase awareness.

Background

The threats vector-borne diseases pose to public health are ever changing and a challenge to assess. The incidence and emergence of vector-borne diseases are difficult to predict due to the complex ecological interactions of humans, reservoirs, vectors, pathogens, and the environment. Climate change (e.g., increased temperatures and extreme weather events), along with land use changes and increased travel and trade, are altering the distribution of vectors and the pathogens they transmit.

In 2023, local transmission of *Plasmodium vivax* and *Plasmodium falciparum* in the United States (US) highlighted the ever-present threat of malaria wherever competent mosquito vectors are present.[5–7] The vectors responsible for malaria emergence in the US are present in Ontario, such as *Anopheles quadrimaculatus*, where historically malaria was endemic.[8] In 2022 and 2023, there was local transmission of dengue virus in southern Florida, likely transmitted by *Aedes aegypti* and/or *Aedes albopictus*.[9] In 2016, the first established population of *Aedes albopictus* in Canada was detected in Windsor, Ontario, along with the first detection of transient populations of *Aedes aegypti*, emphasizing the threat that exotic mosquitoes and associated pathogens pose to Ontario.[10] In addition, ticks are expanding their range, as is the case with the American dog tick (*Dermacentor variabilis*), blacklegged tick (*Ixodes scapularis*), and the lone star tick (*Amblyomma americanum*), ticks associated with RMSF (*Rickettsia rickettsii*), Lyme disease (*Borrelia burgdorferi*), and AGS (acquired red meat allergy), respectively.[11,12] Collectively, these examples highlight the potential for climate change, among other factors, to influence vector-borne disease emergence in Ontario.

The intent of a HIRA is to plan for potential risks; however, public health may prioritize actions across all phases of the emergency management cycle to prevent and/or mitigate concurrent emergency risks, and adapt plans based on a risk-informed approach. We are applying this risk-informed approach to the emergence of vector-borne diseases through a climate change lens. In addition, we identify potential public health actions based on the evidence in this HIRA.

Methods

Appendix A provides a full description of the prioritization exercise for vector-borne diseases and Appendix B provides the methodology for the literature review. While we consider impacts to the healthcare system (e.g., disease severity) in our risk assessments, we concentrate results on the public health impacts of emerging vector-borne diseases.

After considering the likelihood and impact of disease emergence, we prioritized the following five vector-borne diseases (with specific causative agents, if applicable) for this HIRA:

- AGS (an acquired allergy)
- EEEV infection (EEEV)
- Malaria (*Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium ovale*, *Plasmodium malariae*, *Plasmodium knowlesi*)
- OBV infections (specifically infections caused by Cache Valley virus [CVV], Jamestown Canyon virus [JCV], La Crosse virus [LACV], snowshoe hare virus [SSHV])
- RMSF (*Rickettsia rickettsii*)

Risk Estimation

We estimated risk using evidence gathered from the literature review and epidemiological data. Here we define levels for probability or likelihood of incident, impact of incident, risk, and uncertainty. The risk matrix defines risk as the intersection between impact and probability. We conducted assessments as a group, with consensus reached with a majority following discussion.

Probability of Incident

Very likely: Multiple incidents have occurred in Ontario in last 10 years; multiple incidents have occurred in neighbouring jurisdictions in last 10 years; multiple incidents are very likely to occur in Ontario in next 10 years

Likely: One or two incidents have occurred in Ontario in last 10 years; multiple incidents have occurred in neighbouring jurisdictions in last 10 years; a few incidents are likely to occur in Ontario in next 10 years

Unlikely: One or two incidents have occurred in Ontario more than 10 years ago; one or two incidents have occurred in neighbouring jurisdictions in last 10 years; an incident is unlikely to occur in Ontario in the next 10 years

Very unlikely: Zero or one incident occurred in Ontario in the past 10 years; an incident has not occurred in a neighbouring jurisdiction in the last 10 years; an incident is very unlikely to occur in Ontario in the next 10 years

Impact of Incident

Major: Incidents will result in substantial or prolonged morbidity, and some mortality (including vulnerable populations) and/or incidents will overwhelm healthcare and public health systems

Significant: Incidents will result in some morbidity, and some mortality (including vulnerable populations) and/or incidents will strain healthcare and public health systems

Moderate: Incidents could result in morbidity or mortality, and the healthcare and public health systems will cope with incidents

Minor: Incidents are unlikely to result in adverse consequences or fatalities to the community (noting that even one case would constitute some morbidity) and the healthcare and public health systems will cope with incidents

Risk Matrix

The risk matrix presents risk at the intersection between likelihood and impact. The definitions for the degrees of impact, likelihood, and level of risk are outlined.

Table 1: Risk Matrix Table

Impact/ Likelihood	Minor Impact	Moderate Impact	Significant Impact	Major Impact
Very Likely	Low	Moderate	High	High
Likely	Low	Moderate	Moderate	High
Unlikely	Low	Low	Moderate	Moderate
Very Unlikely	Low	Low	Low	Moderate

Risk Levels

High: An incident is a threat to Ontario's public health capacity and is a high priority for incident-specific planning.

Moderate: An incident could affect Ontario's public health capacity and is a medium priority for incident-specific planning.

Low: The incident will not affect Ontario's public health capacity and is a lower priority for incident-specific planning.

Uncertainty Levels

We assigned a level of uncertainty to the risk estimate for each disease. We used three levels of uncertainty. The factors to consider at each level align with World Health Organization's (WHO's) methodology in their Strategic Toolkit for Assessing Risk (STAR).[14] To assign an uncertainty level, not all factors need to be met for that level.

High: Minimal, poor-quality evidence; conflicting views among experts; no experience with similar incidents

Moderate: Adequate-quality evidence; consistent results published in the grey literature; agreements by two (or more) experts – assumptions made by analogous incidents

Low: Good-quality evidence; multiple reliable resources; expert opinion concurs; experience with previous similar incidents

Supporting Evidence

Exposure Summary:

- **Ontario Epidemiology:** The Exposure Summary section in the Results provides an overview of the latest trends for emerging vector-borne diseases in Ontario. We based the Ontario epidemiology primarily on information entered in integrated Public Health Information System (iPHIS) (EEEV infection; Appendix C). For malaria and RMSF, we used Public Health Ontario (PHO) Laboratory data and for OBV infections we used Public Health Agency of Canada (PHAC) data (Appendix C).
- **Global Epidemiology:** To assess global epidemiological trends (and risk of importation into Ontario), we used multiple data sources, including WHO, PHAC, PHO Laboratory, Centers for Disease Control and Prevention (CDC), and peer-reviewed literature. Data sources varied by disease, please refer each data table for data sources.

Context Summary:

- **Ontario Context:** The Context section of the Results summarizes Ontario's existing controls for the vector-borne diseases included in the HIRA and any studies examining potential impacts of climate change on vector-borne disease emergence. This report includes Ontario surveillance data (iPHIS, PHOs Laboratory) as well as data from peer-reviewed publications. Case and contact management were out of scope for the evidence summary but may be addressed in the section on key considerations for public health planning.
- **Global Context:** Since our prioritized vector-borne diseases are not widely distributed throughout the world, the risk of importation is context dependent, e.g., RMSF only found in the Americas. Therefore, subject matter experts provided additional international context by choosing countries with high volumes of travellers to Ontario and countries with relatively high burdens of malaria. For simplicity, and given the regional distribution of EEEV infection, OBV infections, and RMSF, we restricted assessments of importation risk to North America jurisdictions. In addition, we restricted assessment of AGS to North America. For the purposes of this HIRA, North America includes Canada, Mexico, and US.

- The only prioritized vector-borne disease with a global distribution and available data was malaria; therefore, countries with the highest risk of malaria importation to Ontario are China, Guatemala, India, Iran, Jamaica, Mexico, Nigeria, Pakistan, Philippines, and the US. We used travel and immigration data to generate a list of 10 countries considered to have a risk for malaria importation into Ontario. The travel and immigration data included: 1) the top 10 countries of birth reported by recent immigrants to Canada from 2016 to 2021; 2) the top 10 countries of birth for permanent residents admitted to Canada in 2021; 3) the top 10 countries of study VISA permit holders by country of citizenship to Canada in 2022; 4) the top 10 countries by citizenship for temporary foreign workers in the agricultural sector in Ontario in 2022; 5) the top 10 countries with inbound tourists (into Ontario) as reported by Ontario tourism statistics; and 6) the top 10 countries visited by Canadians as tourists, reported by Ontario tourism statistics.[15–20]

Results

Summary of HIRA Findings

We found that the risk of local transmission over the next 10 years was **high** for EEEV infection. Diseases rated high will potentially affect Ontario's public health capacity and are high priority for incident-specific planning (Figure 1). We found that the risk of local transmission over the next 10 years was **moderate** for AGS, malaria, OBV infections, and RMSF. Diseases rated moderate could affect Ontario's public health capacity and are medium priority for incident-specific planning. We considered the probability of transmission and impact level when assigning risk for each disease. We provide a 10-year view of disease risk in Ontario; however, the evidence and context may change, shifting risk level designations. PRISMA flowcharts are available upon request.

Figure 1: Risk Matrix of Local Transmission of Each Vector-borne Disease Within the Next 10 Years

Impact/ Likelihood	Minor Impact	Moderate Impact	Significant Impact	Major Impact
Very Likely		*Orthobunyavirus* infections	Eastern equine encephalitis virus infections	
Likely		Alpha-gal syndrome Rocky Mountain spotted fever		
Unlikely			Malaria	
Very Unlikely				

Green = low risk, yellow = moderate risk, red = high risk

The impacts of prioritized vector-borne diseases on public health services are similar, given the anticipated small number of cases; however, impact also considers the severity of disease. While incidents of emerging vector-borne disease will require medical attention and/or hospitalization, we do not anticipate disruptions to acute care services. Disruption of essential services in Ontario is unlikely during an incident or incidents of the described vector-borne diseases. Incidents will potentially require additional work by public health, specifically local risk assessments, case follow-up and management, vector surveillance, vector management, and risk communication.

There are several key considerations for public health planning that are common among the diseases, considerations to be made at the provincial and/or public health unit (PHU) level:

- Consider strategies to support reporting of EEEV and OBV infections to public health under appropriate DoPHS (provincial, PHU)
- Consider making emerging vector-borne diseases DoPHS (provincial)
- Development of knowledge products aimed at increasing physician and public awareness and providing guidance for PHUs (provincial, PHU)
- Development of necessary risk assessments and risk communications (provincial, PHU)
- Implementation of provincial coordination for key response activities, particularly when multiple jurisdictions are impacted by local transmission incidents (provincial)
- Support climate change and vector-borne disease modelling and research for Ontario (provincial, PHU)

Summary of Supporting Evidence

Exposure (Epidemiology): We provide an epidemiological overview of the latest trends for Ontario included jurisdictions. Where available, epidemiological data shows an increase in Ontarians exposed to EEEV, OBVs, and *Rickettsia rickettsii*. Epidemiological data for AGS does not exist for the province, while data on exposure to *Plasmodium* (malaria) is limited to those who have travelled to malaria-endemic regions. In regions similar to Ontario (rest of Canada and US), there is evidence of a modest increase in exposures to alpha-gal, EEEV, OBVs, and *Rickettsia rickettsii*, while there has been a modest increase in exposure to *Plasmodium* for travellers to malarial regions.

Context (Climate Change): We provide a contextual overview of the prioritized vector-borne diseases, focusing on climate change, for Ontario and included jurisdictions. Few studies included Ontario as part of climate change projections with respect to vector-borne diseases. The lack of predictive studies on climate change and future vector-borne disease incidence is not unexpected, as modelling vector-borne diseases is difficult due to the complexity and interactions of pathogen/vector/host ecologies, and the environment. This lack of predictive ability is due in part to the unpredictable nature of non-climatic factors in models.[21] Examples of non-climatic drivers include urbanization and land use changes, travel, surveillance, socioeconomics, insecticide resistance, and population composition (e.g., vulnerable populations). Modelling climate change and vector-borne diseases in Ontario is a key area for future research.

The Climate Atlas of Canada estimates that under the “less climate change” scenario for London, Ontario, the number of days above 30°C will increase to 36 by 2050 compared to historical average of <17 days (1950–2005); for the “more climate change” scenario, the number of days above 30°C will increase to 45 days by 2050.[22]

In general, increased temperatures associated with climate change, increase the risk of mosquito- and tick-borne diseases.[23] Increased temperatures allow for:

- Faster vector development, leading to more abundant vectors
- Shorter extrinsic incubation period, leading to faster pathogen replication and dissemination in vector
- Increased rates of blood feeding, leading to increased pathogen transmission
- Changes in reservoir and vector abundance and distribution, leading to increased pathogen transmission

Alpha-gal Syndrome

Description: Alpha-gal syndrome (AGS) is a tick-borne, IgE-mediated allergy to a sugar molecule of mammalian origin (galactose-α-1,3-galactose [alpha-gal]), causing mild to anaphylactic reactions.

Incident Description: An AGS patient, or cluster of AGS patients, with no history of travel outside of Ontario

Probability: Likely

Impact: Moderate

Uncertainty: High

Overall Risk: Moderate

Probability Rationale: The incidence of AGS in the US has risen since 2014; however, there is no surveillance data elsewhere in North America for comparison (Table 2).[24,25] Climate change will aid the northerly expansion and abundance of lone star ticks, thus increasing the probability of AGS in Ontario in the future.[26–28] Incidents of locally acquired AGS are likely to occur in Ontario in the next 10 years; however, importation of disease from the US is very likely–especially travellers from states with a high incidence of AGS.

Table 2: Reported Cases of Alpha-Gal Syndrome in North America

Year	Ontario	Rest of Canada	Mexico	US
2014	NA	NA	NA	4,295*
2015	NA	NA	NA	4,722*
2016	NA	NA	NA	5,077*

Year	Ontario	Rest of Canada	Mexico	US
2017	NA	NA	NA	13,371
2018	NA	NA	NA	13,821
2019	NA	NA	NA	17,372
2020**	NA	NA	NA	16,936
2021**	NA	NA	NA	18,885
2022**	NA	NA	NA	9,633
2023	NA	NA	NA	NA

NA, not available. Data for US extracted from Binder et al. (2021)[24] and Thompson et al. (2023).[25] AGS data for selected jurisdictions, except US, were not available.
*Data from Binder et al. (2021) does not include additional panel of tests targeting beef IgE, pork IgE, and lamb/mutton IgE (see Thompson et al. 2023).[24,25]
**Data provided during the pandemic may not reflect actual epidemiological situation in some jurisdictions, so readers should interpret epidemiology with caution.

In the absence of human surveillance data, measuring AGS risk focused on the range expansion of the lone star tick. In the US, lone star ticks are the primary source of alpha-gal in patients with AGS, and disease incidence is highest where lone star ticks are more abundant (e.g., >2.35 cases per 100,000 population in Arkansas, Kentucky, Missouri, Oklahoma, and Virginia).[24,25,29–31] There is no evidence of established populations of lone star ticks in Ontario, however, adventive lone star ticks are routinely detected in the province, usually associated with travel to the US.[11] From 1999 through 2016, the number of lone star ticks submitted for identification to PHO's laboratory increased; e.g., from an annual median of 24 (interquartile range [IQR]: 20.5–46.0; 1999–2004) to 70.5 (IQR: 63.5–85.0; 2011–2016), then to 78.0 (IQR: 58.0–89.0; 2017–2019), and a decrease to 15.5 (IQR: 14.3–19.0; 2020–2023) during the pandemic when overall tick submissions decreased.[11,32]

Impact Rationale: We consider the impact of an AGS incident or incidents on the public health system as moderate over the next 10 years. System capacities for managing AGS emergence are limited in Ontario and the province does not have experience with similar non-infectious conditions associated with arthropods. Surveillance for lone star ticks could be adapted from existing tick surveillance programs, expanding tick dragging to the summer months (when adult lone star ticks are most active) instead of the current spring and fall collections targeting adult blacklegged ticks. Preventative measures that can reduce the impact of AGS include personal protection against tick bites (e.g., use of N, N-diethyl-meta-toluamide [DEET] or icaridin, performing tick checks), quick administration of epinephrine, immunotherapy, and red meat avoidance.[30,33,34]

In cases of non-anaphylactic AGS, patients may experience hives, itching, swelling, and gastrointestinal symptoms.[26,35] Patients with delayed anaphylaxis, which is about 50% of all patients with AGS, usually require acute care; death due to AGS is rare.[26,33]

Factors associated with developing AGS include male gender, >50 years old, A or O blood types, childhood allergies, family history of food allergies, rural residence, tick-bite exposure, and working in wooded areas.[26,29–31,36,37] In a case-control study conducted in North Carolina, US, patients with AGS were more likely to report finding a tick on themselves (odds ratio [OR]: 11.2, 95% CI: 4.97–25.15) and spend >17 hours a week in wooded areas (OR: 5.6, 95% CI: 2.56–12.19), compared to control patients without evidence of AGS.[31]

Uncertainty Rationale: Our probability and impact assessments are associated with a high level of uncertainty, due to a lack of data sources for surveillance, availability of peer-reviewed literature, and experience with similar disease conditions in Ontario. AGS awareness among health-care providers is likely low, with limited options for laboratory testing and diagnostics, representing vulnerabilities for Ontario.[38] In addition, Ontario-specific climate change projections for lone star ticks and AGS are lacking in the literature.

Current Surveillance Tools (Data Source):

- **Human:** None
- **Animal:** Not applicable
- **Vector:** Active (PHUs, PHAC) and passive (PHO Laboratory, eTick) tick surveillance

Key Considerations for Public Health Planning:

- **Human Case Surveillance:** Consider surveillance tools and data from syndromic surveillance, retrospective case finding (e.g., biobanks),[29] reference laboratories,[39] or private laboratory testing[40]; consider strategies to support reporting of AGS to public health.
- **Vector Surveillance:** Continue passive tick surveillance, assessing for established populations of the lone star tick;[11] consider mid-summer enhanced active surveillance (tick dragging) in areas at higher risk of lone star tick establishment.

Exposure Summary:

- **Ontario and Canada:** No AGS surveillance data was available for Ontario or for the rest of Canada (Table 2).
- **US:** AGS incidence per 100,000 population in the US rose from 0.4 in 2011 to 2.4 in 2018 (Table 2).[24] In a more recent study (2017–2022), the proportion of people with a positive AGS test increased from 14.9% (13,371/35,869) in 2017 to 21.0% (18,885/66,106) in 2021, with a decrease to 10.4% (9,633/36,177) in 2022.[25]

Context Summary:

- **Ontario and Canada:** We did not include any studies that modelled climate change and projected future AGS trends in Ontario or Canada. Studies modeling the range expansion of lone star ticks, in partial response to climate change, indicate portions of southern Ontario are likely to see established populations emerge; however, the timing of establishment is unknown.[41,42] PHUs of southern Ontario at higher risk of lone star establishment are those with the highest average annual temperatures and those nearest to the US border; e.g., Chatham-Kent, Niagara Regional Area, and Windsor-Essex County.

- **US:** We did not include any studies that modelled climate change and projected future AGS trends for the US. Established populations of the lone star tick are expanding northward in the US, specifically to southern portions of Michigan, New York, Ohio, and Pennsylvania.[43,44] In addition, areas along the Great Lakes will become more suitable for lone star ticks, due in part to climate change (increased temperature), adaptive evolution (cold hardiness), and changes in host distribution (wild turkey, white-tailed deer).[28,41,42,45–50]

Eastern Equine Encephalitis Virus Infection

Description: Eastern equine encephalitis virus (EEEV) infection is a mosquito-borne disease transmitted primarily among birds, with zoonotic spillover causing encephalitis in horses and humans.

Incident Description: An EEEV infection, or cluster of EEEV infections, with no history of travel outside of Ontario

Probability: Very likely

Impact: Significant

Uncertainty: Moderate

Overall Risk: High

Probability Rationale: There is no clear trend for human EEEV infections in Ontario or the US; however, most human infections have occurred since 2018 (Table 3).[51] While Ontario-specific studies on projecting EEEV risks under climate change represent a gap in the literature, increased temperatures are likely to increase mosquito populations and virus transmission. Incidents of locally acquired EEEV infections are very likely to occur in Ontario in the next 10 years. We expect a low number of imported cases.

Table 3: Reported Human Cases (Equine Cases) of Eastern Equine Encephalitis Virus Infection in North America

Year	Ontario*	Rest of Canada	Mexico	US
2014	0 (24)	0 (3)	NA	8 (136)
2015	0 (5)	0 (4)	NA	6 (70)
2016	1 (0)	0 (2)	NA	7 (118)
2017	0 (2)	0 (0)	NA	5 (86)
2018	0 (13)	0 (0)	NA	6 (107)
2019	0 (7)	0 (0)	NA	38 (184)
2020**	0 (8)	0 (0)	NA	13 (142)
2021**	1 (6)	0 (0)	NA	5 (111)
2022**	1 (0)	NA	NA	1 (NA)
2023**	0 (18)	NA	NA	7 (NA)

NA, not available. Human case data extracted from iPHIS for Ontario (see Appendix C), rest of Canada (PHAC), and US (CDC).[51,52] Data for equine cases for Ontario extracted from Ontario Ministry of Agriculture, Food and Agribusiness (OMAFA), Canada (PHAC), and US (USDA).[52–54] While EEEV infection occurs in Mexico along the Gulf of Mexico, systematic epidemiological data was not available.

*Reported as encephalitis or meningitis in Ontario.

**Data provided during the pandemic may not reflect actual epidemiological situation in some jurisdictions, so readers should interpret epidemiology with caution.

In the Eastern US, EEEV activity is highest along the Atlantic Coast, Gulf of Mexico, and Great Lakes; states bordering Ontario, such as Michigan and New York, have a history of EEEV infection outbreaks in humans.[55–59] Typically in the Northeast US and Ontario, human EEEV infections occur from July through October.[56] Predictive modelling of EEEV is complex, but in general, cases in equines and increased rainfall forecast cases in humans in the US.[60–63] In Québec, proximity to wetlands is predictive of EEEV infections in equines, while close proximity to agricultural land is protective.[64] During outbreaks, abundance of the primary enzootic vector (responsible for bird-to-bird transmission) of EEEV (*Culiseta melanura*) is high, along with bridge vectors (responsible for bird-to-human transmission) such as *Aedes canadensis*, *Aedes sollicitans*, and *Coquillettidia perturbans*.[55,63,65–67] Reservoir birds include the wood thrush, common grackle, northern cardinal, and American robin, with enzootic and epidemic foci located near hardwood wetlands.[68–71]

Impact Rationale: We consider the impact of an EEEV infection incident or incidents on the public health system as significant over the next 10 years. System capacities in Ontario for EEEV emergence include a comprehensive mosquito identification and pathogen surveillance program for EEEV. Ontario has previous experience in developing mosquito-borne disease programs; however, Ontario's West Nile virus (WNV) program focuses on suburban and urban areas, rather than rural areas where EEEV activity is greatest. The primary prevention methods for EEEV infections are similar to WNV illness, such as personal protection (e.g., use of DEET or icaridin, covering up, getting rid of standing water on property) and communicating risk to the public. Several EEEV vaccines for humans are in development.[72] Managing populations of *Culiseta melanura* is problematic, as the immature stages reside in the underwater crypts of wetlands, which are impervious to insecticides and habitat modification. Non-specific vector surveillance and the difficulty with mosquito control are challenges for EEEV management. Ludwig et al. (2019), while reporting on the increased risks of mosquito-borne diseases in Canada under conditions of climate change, called for expanded surveillance targeting mosquito vectors in rural areas and further research on EEEV.[73] Using equine cases as a surveillance tool to forecast human infection is challenging, as equine cases depend not only on spillover transmission (bridge vectors feeding on infectious birds then on humans or other mammals) but also on the vaccination practices of horse owners.

EEEV infection presents as a febrile illness characterized by chills, muscle pain, and joint pain, which can progress to viral encephalitis, an infection of the brain which may cause headache, confusion, seizures, or coma and may lead to death. Approximately 96% of those exposed to EEEV remain asymptomatic; however, of the 4% that develop symptoms, 33% die and survivors often experience long-term sequelae.[74] In a study of eight patients with EEEV infections in Michigan, during a 2019 outbreak, six patients died and two recovered with sequelae (one with severe neurological disability).[75] During the same year in Connecticut, there were three deaths among four patients; the surviving patient experienced neurological sequelae.[76] In August 2024, Ottawa Public Health reported a fatal case of EEEV infection.[77]

Risk factors for the development of severe disease include male sex, age (individuals <10 years and >60 years), and residence in rural or suburban settings in close proximity to vector and reservoir habitats such as wetlands.[78] In rare instances, transmission during organ transplants can occur.[79]

Uncertainty Rationale: EEEV outbreaks are difficult to predict and difficult to manage, contributing to a moderate level of uncertainty in our probability and impact assessments. In addition, there is uncertainty in estimates of disease in Ontario, since those with mild infections likely do not seek medical attention or laboratory testing (only mechanism of surveillance in Ontario). Ontario-specific climate change projections for EEEV are lacking in the literature.

Current Surveillance Tools (Data Source):

- **Human:** Can be reported (if applicable) under the DoPHS Encephalitis (Primary Viral) or Meningitis, Acute (Viral) (integrated Public Health Information System [iPHIS]); laboratory results such as serology and molecular testing (Public Health Ontario [PHO] Laboratory)
- **Animal:** Equine surveillance (Ontario Ministry of Agriculture, Food and Agribusiness [OMAFA])
- **Vector:** Mosquito surveillance (PHUs, PHO)

Key Considerations for Public Health Planning:

- **Human Case Surveillance:** Consider strategies to support reporting of EEEV infections to public health; consider routine review of iPHIS for EEEV infections reported as encephalitis or meningitis; consider routine review of PHO Laboratory data for potential EEEV infections.
- **Vector and Animal Surveillance:** Explore additional non-human animals as sentinels for EEEV activity (e.g., white-tailed deer);[56] explore altering mosquito trapping locations and protocols (e.g., more testing of bridge vectors). For example, most trapping is in urban and suburban areas, targeting *Culex* mosquitoes and WNV. Targeted mosquito trapping near wetlands would provide a better assessment of EEEV risk.[65]
- **Knowledge Translation:** Consider updating Ontario's West Nile Virus Preparedness and Prevention Plan or Infectious Disease Protocols to include specific or enhanced guidance on EEEV.[80]

Exposure Summary:

- **Ontario and Canada:** From 2014 through 2023, EEEV activity has been an annual occurrence in Ontario, with human and/or equine cases (Table 3). The first human EEEV infection case for Ontario and Canada was detected in 2016; since 2016, a further three cases have been identified in Ontario (latest in late summer 2024), but none in the remainder of Canada. The earliest records of EEEV transmission in Ontario was for 1938, when equine cases were reported in Brant County and Niagara Regional Area.[81] Equine cases occurred most years throughout southern Ontario, with peaks in equine cases every four or five years. There were no human EEEV infections reported for the rest of Canada, with equine cases reported from Québec and Nova Scotia from 2014 through 2016.
- **US:** The number of EEEV infection cases in the US ranges from one case in 2022 to 38 in 2019, with a median of 6.5 cases per year (IQR: 5–9.25) (Table 3).[51] The most recent outbreak occurred in the Northeast US in 2019, with 36 cases in Connecticut, Massachusetts, Michigan, New York, and Rhode Island.[59,67]

Context Summary:

- **Ontario and Canada:** Climate change (increased temperatures, changing precipitation patterns) will increase the distribution of reservoirs, vectors, and EEEV, thereby, increasing mosquito abundance, duration of the transmission season, and the risk of EEEV infections in humans.[63,73,82,83] We note there were no climate change-based projections or predictive models for EEEV, specifically for Ontario or the Great Lakes Region.[58] In eastern Ontario, by 2050 and 2070, agriculture and urbanization will intensify with a decrease in forested land; climate change will alter vector and host species richness and diversity, placing more of the population near swamps and potentially increasing the risk of EEEV infections.[84] Under current and projected climate change, researchers consider EEEV a high priority vector-borne disease in Canada.[13]
- **US:** We did not include any climate change-based projections or predictive EEEV models for the US.[58] However, increased precipitation and temperatures in northern reaches of *Culiseta melanura* distribution are expected to increase vector populations, leading to increased virus amplification in birds and human infections.[63,85]

Malaria

Description: Malaria is a mosquito-borne infection with long-standing prevalence worldwide causing potentially fatal illness.

Incident Description: A *Plasmodium* sp. infection, or cluster of *Plasmodium* sp. infections, with no history of travel outside of Ontario

Probability: Unlikely

Impact: Significant

Uncertainty: Moderate

Overall Risk: Moderate

Probability Rationale: Currently, there is no local transmission of malaria in Ontario, or elsewhere in Canada, and the number of annual imported infections has remained stable over the last decade (Table 4). The highest number of malaria infections imported into Ontario is from travellers returning from Nigeria and India, along with other countries with high incidence rates and higher volume of travellers to Ontario; imported infections represent a potential reservoir capable of seeding local transmission.[8] Climate change is likely to increase the risk of local transmission in Ontario in the coming decades. Incidents of locally acquired malaria are unlikely to occur in Ontario in the next 10 years; however, the increased importation of cases from malarious regions is very likely.

Table 4: Malaria Cases (Presumed/Confirmed Imported and Locally Acquired Cases): Canada, Top-10 Countries with Highest Risk of Disease Importation, and Worldwide

Country	2014	2015	2016	2017	2018	2019	2020***	2021***	2022***	2023***
Ontario*, **	158	160	172	178	166	193	78	110	156	279
Canada*, **	449	552	611	603	368	424	185	197	424	NA
China	3,080	3,279	3,151	2,672	2,511	2,487	1,051	NA	820	NA
Guatemala	4,931	5,540	5,001	4,124	3,021	2,072	1,058	1,274	1,856	3,053
India	1.1m	1.2m	1.1m	0.84m	0.43m	0.34m	0.19m	0.16m	0.18m	0.23m
Iran	1,243	799	705	939	625	1,190	1,051	999	5,677	10,004
Jamaica	0	0	0	0	0	0	0	0	0	0
Mexico	666	551	596	765	803	641	369	275	244	342
Nigeria	17.3m	16.7m	24.0m	20.2m	20.5m	23.4m	21.6	23.6m	25.0m	26.4m
Pakistan	3.7m	3.8m	2.1m	2.2m	1.1m	0.41m	0.37m	0.40m	1.8m	2.7m

Country	2014	2015	2016	2017	2018	2019	2020***	2021***	2022***	2023***
Philippines	6,099	11,445	6,690	6,791	4,641	5,778	6,120	4,297	3,245	6,248
US**	NA	NA	1,955	2,056	1,748	1,936	603	1,503	1,932	NA
Top-10 Total	22.0m	21.7m	27.2m	23.3m	22.0m	24.1m	22.1m	24.2m	27.0m	29.4m
Estimated Worldwide Total	227m	226m	229m	237m	234m	236m	247m	249m	252m	263m

NA, not available; m, million. Data for Ontario extracted from Public Health Ontario Laboratory Information Management System (PHO LIMS) (see Appendix C, Technical Notes), for Canada from PHAC, for US from CDC, and remaining international jurisdictions from WHO.[86–88]

*Malaria is a reportable disease in every province of Canada, except Ontario since 2018.

**Imported cases only.

***Data provided during the pandemic may not reflect actual epidemiological situation in some jurisdictions, so readers should interpret epidemiology with caution.

Malaria was commonplace in southern Ontario in the 18th and 19th centuries, transmitted by *Anopheles* populations that are still present today (e.g., *Anopheles quadrimaculatus*, *Anopheles punctipennis*, *Anopheles walkeri*).[89,90] Multiple factors contributed to the eventual decline of malaria in Ontario including improved standards of living (air conditioning, window screens), increased urbanization, increased insecticide use (dichlorodiphenyltrichloroethane [DDT]), antimalarial use, and habitat modification such as the drainage of swamps. While no longer endemic in the US and Canada, local transmission in Ontario remains possible under the following conditions: 1) individuals with parasitemia (imported malaria), 2) *Anopheles* mosquitoes (local or imported), and 3) warm weather. Vivax malaria represents a unique challenge for preventing local transmission in Ontario.[91] First, individuals with vivax malaria can remain asymptomatic with low parasitemia, which can lead to missed diagnoses and cryptic reservoirs of *Plasmodium vivax*.[92] Second, a characteristic of vivax malaria is a dormant and undetectable stage (hypnozoite) that persists in the liver, thus, hypnozoites can cause intermittent relapses of parasitemia up to a year after initial infection. Third, infectious sexual stages (gametocytes) of *Plasmodium vivax* mature rapidly and may circulate in blood prior to symptom onset and case identification.[93–96] Since *Plasmodium vivax* can infect a greater variety of *Anopheles* mosquitoes and tolerates lower temperatures than *Plasmodium falciparum*, *Plasmodium vivax* will be a more likely culprit of locally acquired malaria in Ontario.[96] Hereditary red blood cell or hemoglobin variants known to provide protection against *Plasmodium vivax* infection (e.g. Duffy-negative blood group) may be less frequent in Ontario communities. *Plasmodium vivax* has a relatively high burden in South Asia (e.g., India, Pakistan), South America (e.g., Brazil, Venezuela), and the Horn of Africa (e.g., Ethiopia); India and Pakistan are countries with high volumes of travel to Ontario (Table 4). Currently, Ontario has a suitable climate and vectors needed for local transmission, requiring only infectious, imported cases.

Beyond climate change, other factors such as political instability, insecticide resistance, antimalarial resistance, armed conflict, deforestation, and natural disasters can contribute to increased risk of malaria in endemic and non-endemic regions.[97–100] In Panama (2015–2022), the incidence of malaria increased by a factor of 10 among Indigenous populations, due in part to an influx of cases from migrant workers with limited access to health services.[101] In Venezuela, malaria resurgence has been due to political unrest and an economic downturn, which has led to a shortage of antimalarials, ecological degradation, failure of the health-care system, and failure of malaria prevention programs.[102,103] Deforestation in Malaysia has increased the prevalence of the zoonotic *Plasmodium knowlesi* as mosquito vectors now have more access to humans.[104] In Uganda, insecticide resistance emerged in *Anopheles funestus*, leading to a resurgence of malaria, represented by an 8-fold increase in incidence rates.[105] Increased transmission in endemic regions increases the risk of imported malaria and local transmission in Ontario.

Impact Rationale: We consider the impact of a malaria incident or incidents on the public health system as moderate over the next 10 years. System capacities are limited in Ontario for malaria emergence, focusing on vector surveillance (vector identification only) and mosquito control administered at the local level. Review of laboratory results has the potential to identify clusters of cases and potential local transmission; however, review of results is currently not a routine practice. In non-endemic regions such as Canada, personal protection is a key to preventing malaria, including the use of insect repellents and minimizing standing water in the peridomestic environment. Voluntary pre-exposure prophylaxis is available at a cost to travellers from Ontario visiting malaria-endemic regions, minimizing risks of imported malaria, although real-world usage is inconsistent. In endemic regions, integrated vector management, personal protection, and disease treatment remain the primary modes of mitigation. A vulnerability for the province is that malaria is not a DoPHS, thus a key surveillance tool for Ontario is missing. Ontario is the only province in which malaria is not a DoPHS. Currently, detection of local transmission in Ontario would have to rely on physician-initiated epidemiological investigations or through laboratory surveillance.[106] Ontario does not have a similar contemporary experience dealing with emergence of a mosquito-borne parasitic disease, but enhanced vector surveillance using targeted trapping locations and vector control could be performed alongside Ontario's WNV surveillance program.

Total deaths from malaria worldwide decreased from 864,000 in 2000 to 586,000 in 2015, since then the decreases in deaths have stalled with 576,000 deaths in 2019 and 608,000 deaths in 2022.[99] Deaths from malaria are primarily from *Plasmodium falciparum* infections and 76% of deaths are among children less than 10 years old. Malaria deaths among imported malaria cases to Canada do occur, along with severe disease requiring intensive care.[107–109] A complication of *Plasmodium falciparum* infection requiring intensive care is cerebral malaria, which presents as impaired consciousness, seizures, and coma.[110] Survivors of cerebral malaria often have long-term sequelae such as loss of muscle control, muscle paralysis, muscle weakness, altered behaviour, and cognitive impairments. An assessment of malaria practices in France demonstrated a significant impact on the healthcare system from children with imported falciparum malaria presenting with hyperparasitemia (an indicator of severe malaria requiring intensive care) and with neurological disorders, hemodynamic disorders, kidney failure, and jaundice.[111] Severe disease in *Plasmodium vivax* is uncommon (0.01% mortality); however, respiratory and renal complications, along with anemia, occur in children.[112] *Plasmodium vivax* also causes maternal anemia, prematurity, fetal loss, and low birth weight.

In endemic regions, portions of the population vulnerable to malaria include those living in rural areas with limited access to personal protection options and healthcare. For travellers returning to Ontario, imported malaria is more common among those that have visited friends and relatives in malarious areas.[109,113] In the case of potential local transmission in Ontario, populations at risk for severe malaria include young children (<10 years), older adults, pregnant women, and unborn children.

Uncertainty Rationale: Compared to other diseases included in this HIRA, the literature on malaria is more fulsome. However, the lack of local surveillance in Ontario adds uncertainty to our probability and impact assessments, leading to a moderate level of uncertainty. In addition, Ontario-specific climate change projections for malaria are lacking in the literature.

Current Surveillance Tools (Data Source):

- **Human:** Microscopy and molecular testing (PHO Laboratory); or research activity[8]
- **Animal:** Not applicable
- **Vector:** Mosquito surveillance (PHUs, PHO)

Key Considerations for Public Health Planning:

- **Human Case Surveillance:** Consider strategies to support reporting of malaria to public health; consider routine review of microscopy and molecular testing results for infections (PHO Laboratory).
- **Vector Surveillance:** Consider enhanced vector surveillance and testing of *Anopheles* where clusters of cases (no travel outside Ontario) occur.

Exposure Summary:

- **Ontario and Canada:** Local transmission of malaria no longer exists in Ontario since the early 20th century. A single case of locally-acquired *Plasmodium vivax* malaria was reported from the Greater Toronto Area in 1996.[106] The patient did not travel to an at-risk country in nine years, making relapse of vivax malaria unlikely. Airport malaria was also unlikely as the patient lived beyond the flight range (airport to patient home) of *Anopheles* mosquitoes. There has been a 7.4-fold increase, due in part to climate change, in airport malaria in Europe (2010–2020), compared to 2001 through 2009.[114] The number of imported malaria infections reported in Ontario has remained stable at approximately 152 per year (IQR: 122–177) from 2014 through 2021 (Table 4). However, there was a notable increase to 279 infections in 2023, likely reflecting an increase in travel following the pandemic and reduced global activities addressing malaria control and prevention. Approximately 36% (1,215/3,389; 2014–2021) of imported malaria infections in Canada are from Ontario. For Canada, there was a median 424 imported cases reported per year (2014–2021) (IQR: 240–590).

- **US:** Recently, Dye-Braumuller and Kanyangarara (2021) sounded the alarm on the US's vulnerability to future outbreaks of malaria.[115] Within two years of this warning, this vulnerability was realized as there were several outbreaks of locally transmitted malaria; i.e., *Plasmodium vivax* in Arkansas, Florida, and Texas and *Plasmodium falciparum* in Maryland.[7,116,117] The vulnerability of the US to malaria outbreaks will increase with climate change and increased international travel, exacerbated by the presence of competent vectors and inadequate outbreak preparedness (vector surveillance and management).[115]

- **Global:** In 2023, the world burden of malaria was 263 million cases, which was higher than pre-pandemic numbers and 11 million higher than 2022 (Table 4).[99] Most source countries of interest show decreasing case counts. A notable exception is Nigeria, with 17.2 million reported cases in 2014 increasing to 26.4 million cases in 2023. In 2021, Nigeria accounted for 27% of all cases worldwide and 31% of all deaths. In addition, case counts increased dramatically in Iran, with 1,243 in 2014 and 10,004 in 2023. Case counts in other jurisdictions remain stable, such as China, Guatemala, Mexico, and the Philippines; however, case counts in these countries are much lower than Nigeria. Nigeria is among the primary sources of imported falciparum malaria in Ontario. Overall, the total number of malaria cases in the top 10 jurisdictions examined increased slightly, 22 million in 2014 to 29.4 million in 2023; in similarly, total world case estimates increased from 227 million in 2014 to 263 million in 2023. While volumes of travellers returning from Central and South America are relatively low, there have been increases in imported malaria (*Plasmodium vivax*) along the US-Mexico border from immigrants, asylum seekers, and migrant workers.[118,119]

Context Summary:

- **Ontario and Canada:** Berrang-Ford et al. (2009) stated, "Climate change will increase the occurrence of temperature conditions suitable for malaria transmission in Canada, which, combined with trends in international travel, immigration, drug resistance, and inexperience in both clinical and laboratory diagnosis, may increase malaria incidence in Canada and permit sporadic autochthonous cases."[90] Modelling studies of climate suitability predict an increased risk of malaria re-emerging in much of its historical distribution in North America over the next 50 years, including southern Ontario.[120,121]

- **Global:** Climate change can increase the risk of malaria transmission (e.g., higher temperatures, humidity, rainfall) in malarious regions and cause emergence or re-emergence in currently, non-malarious regions; all contributing to increased risk of imported cases and local transmission in Ontario. Higher temperatures result in shorter extrinsic incubation periods (faster development of parasite in mosquito), increasing the risk of transmission.[122] In risk areas such as New Delhi, India, the peak in malaria cases (96.2% of all cases caused by *Plasmodium vivax*) typically occurs a month following the peak in rainfall; during the peak in cases, the mean temperature was 25–30°C with a relative humidity of 60–80% (similar to summer conditions in Ontario).[123] In addition, *Anopheles* vectors (e.g., *Anopheles stephensi*) in India have been adapting to increased temperatures, reducing the extrinsic incubation period for *Plasmodium* and making transmission faster; similarly, increased temperatures will increase the risk of malaria in Sub-Saharan Africa wherever the invasive *Anopheles stephensi* is found.[124–126]

- Besides the increased temperatures associated with climate change, extreme weather events also contribute to the changing risks of malaria. For example, Pakistan experienced monsoons and flooding in 2022 and 2023, leading to increased standing water and a 5-fold increase in cases of malaria.[99] Climate change can also decrease the risk in certain contexts (drought conditions), where transmission is decreased in previously endemic regions. In Ethiopia, increased malaria incidence is associated with increased temperature and rainfall, with higher malaria rates associated with high-density settlements in one region and low-density settlements in another.[127] The impacts of climate change on malaria are difficult to predict in the long-term, are scale-dependent, and do not always relate to an increased risk of disease.[128,129] From 1898 through 2016 in Africa, increasing temperatures coincided with the southerly range expansion of *Anopheles* mosquitoes (4.7 km/year), along with expansion of suitable habitat at higher elevations (6.5 m/year).[130] Increasing temperatures are projected to expand malaria distribution toward temperate regions and lengthen transmission season by approximately seven weeks in the highlands of Africa, eastern Mediterranean, and Americas.[121]

- **US:** The vulnerability to malaria outbreaks in the US will increase with climate change and increased international travel, along with the presence of competent vectors and inadequate outbreak preparedness (vector surveillance and management).[115] The US, by 2070, will see a northern shift of malaria transmission due to warming temperatures.[121]

Orthobunyavirus Infections

Description: *Orthobunyavirus* (OBV) infections, in the context of this HIRA, are mosquito-borne infections found in temperate North America, reaching into northern Canada and, unlike EEEV and WNV, OBVs have mammalian reservoirs. OBVs found outside of North America, such as Bunyamwera virus, Guaroa virus, and Oropouche virus, are excluded from this HIRA.

Incident Description: An OBV infection, or cluster of OBV infections, with no history of travel outside of Ontario

Probability: Very likely

Impact: Moderate

Uncertainty: Moderate

Overall Risk: Moderate

Probability Rationale: Since 2014, Ontario averages two OBV infections per year, 36 per year for Canada; in addition, seropositivity levels are relatively high in similar Canadian jurisdictions and Michigan in the US (Table 5). OBV infections are likely underreported, since about half of all encephalitis cases in Canada lack a causative agent.[131] While Ontario-specific studies on projecting OBV infection risks under climate change represent a gap in the literature, increased temperatures are likely to increase mosquito populations and virus transmission. OBV incidents are very likely to occur in Ontario over the next 10 years. We expect a small number of imported cases.

Table 5: Reported Cases of OBV Infections in North America

Year	Ontario (JCV, SSHV, unclassified)**	Rest of Canada (JCV, SSHV, unclassified)*,**	Mexico	US (JCV, LACV)
2014	NA	NA	NA	91
2015	4	36	NA	66
2016	2	22	NA	51
2017	1	121	NA	139
2018	10	62	NA	127
2019	0	18	NA	100
2020***	0	13	NA	102
2021***	1	0	NA	72
2022***	0	18	NA	34
2023***	1	NA	NA	58

NA, not available. Data for Ontario and Canada extracted from PHAC and for US from CDC.[52,132] OBV infection data for Mexico were not available.

*OBV infection is a reportable disease in Alberta (JCV, SSHV) and Québec (neuroinvasive arboviruses).

**Testing not OBV-specific, rather includes other members of the California serogroup viruses (CSGVs) such as California encephalitis virus, JCV, LACV, SSHV, and trivitattus virus.

***Data provided during the pandemic may not reflect actual epidemiological situation in some jurisdictions, so readers should interpret epidemiology with caution.

The mosquito vectors responsible for CVV, JCV, LACV, and SSHV transmission are present in Ontario and abundant. In New York (2001–2022), researchers reported JCV from 12 mosquito species, but more commonly in *Aedes canadensis* and *Anopheles punctipennis*; infection rates in mosquitoes increased during the study.[133] *Aedes albopictus*, a newly invasive mosquito in Ontario, is capable of transmitting CVV and LACV.[10,134–136] In the US, additional vectors of CVV include *Aedes japonicus*, *Aedes vexans*, *Anopheles punctipennis*, *Anopheles quadrimaculatus*, and *Coquillettidia perturbans*.[137–139] The primary vectors of LACV are *Aedes albopictus*, *Aedes canadensis*, *Aedes japonicus*, and *Aedes triseriatus*.[140–142] SSHV vectors include several *Aedes* species, *Culiseta inornata*, and *Culiseta impatiens*. Unlike the WNV and EEEV transmission cycle involving birds, OBVs occur within a cycle involving mammals. The non-human animal hosts of CVV (white-tailed deer, other ungulates and ruminants), JCV (white-tailed deer), LACV (chipmunks, squirrels), and SSHV (snowshoe hares, chipmunks, squirrels) are all present in Ontario.[143]

Impact Rationale: We consider the impact of an OBV infection incident or incidents on the public health system as moderate over the next 10 years. System capacities for OBV infection emergence include a comprehensive WNV/EEEV vector identification and pathogen surveillance program, which can be adapted for OBVs. Ontario has previous experience in developing mosquito-borne disease programs; however, the WNV program focuses on suburban and urban areas, instead of rural areas where OBV activity is likely greatest. Monitoring of laboratory results is a potential tool to identify infections or clusters of infections (currently rely on PHAC reporting). Since vaccines are not available for OBVs and there are no specific treatments, personal protection is a key to preventing OBV infections, including the use of insect repellents and minimizing peridomestic standing water. Researchers have developed several community-based programs for LACV awareness, *Aedes* biology education, and *Aedes* population management in East Tennessee, which could provide basis for programs in Ontario.[144,145] Vector surveillance targeting OBVs is lacking in Ontario, which could be a useful tool in identifying at-risk populations in Ontario.

The primary outcome of concern with OBV infections is neuroinvasive disease, which requires intensive care and rehabilitation following recovery. In a study of 152 children (≤18 years) in the US with LACV infection, 43% had severe disease; seizures and altered mental status at presentation were predictive of severe disease and long-term neurological sequelae.[146] OBV infections also occur following transfusion of blood and organ transplants, adding an additional threat to public health.[147] Contributing to uncertainty in our impact assessment is the likely underreporting of cases, as 50% of hospitalized cases of encephalitis in Canada lack an etiological agent (some of which are suspected arboviruses; cases also occur during periods of highest mosquito-borne transmission, June–Sept).[131,148]

In the US (2003–2019), the median age of patients among 1,281 LACV reported infections was 8 years, 88% were <18 years, 75% had encephalitis, and 17% had meningitis; the fatality rate was 1%.[149] Researchers reported similar patient characteristics in a study of 355 cases of LACV infection in North Carolina (2000–2020), median age of 9 years, 79% of patients ≤18 years, 82% had encephalitis, and 46% had meningitis; the fatality rate was 1.4%.[150] OBV (except LACV) infections are considered emerging diseases in Canada and likely contribute to a higher burden of morbidity than previously thought.[151] Unlike infections with LACV/SSHV, CVV/JCV infections are typically found in adults; however this relationship is based on relatively few cases (e.g., n=7 for CVV).[137,141] In the Appalachian region of the US (2003–2021), high-risk foci of LACV disease are associated with low socioeconomic status.[152] In Québec, seropositivity to California serogroup viruses (CSGVs such as JCV and SSHV) in humans was associated with living in areas with higher densities of white-tailed deer, being male, and having more than 10 mosquito bites per week.[153]

Uncertainty Rationale: Given the lack of reportability and specific vector surveillance in Ontario, our assessment of probability and impact of OBV infections are associated with a moderate level of uncertainty. In addition, there is uncertainty in estimates of disease in Ontario, since those with mild infections likely do not seek medical attention or laboratory testing (only mechanism of surveillance in Ontario). Finally, there is a lack of Ontario-specific climate change projections for OBV infections.

Current Surveillance Tools (Data Source):

- **Human:** Can be reported (if applicable) under the DoPHS Encephalitis (Primary Viral) or Meningitis, Acute (Viral) (iPHIS); laboratory testing results such as serology and molecular tests (PHO Laboratory)
- **Animal:** Research activity[154]
- **Vector:** Research activity

Key considerations for Public Health Planning:

- **Human Case Surveillance:** Consider strategies to support reporting of OBV infections to public health under appropriate DoPHS; consider routine review of PHO Laboratory data for infections.
- **Vector and Animal Surveillance:** Explore additional non-human animals as sentinels for OBV activity (e.g., sheep, white-tailed deer); trap mosquitoes in rural areas, as currently, most trapping is in urban and suburban areas, targeting *Culex* mosquitoes and WNV.
- **Knowledge Translation:** Consider updating Ontario's West Nile Virus Preparedness and Prevention Plan and Infectious Disease Protocols to include specific or enhanced guidance on OBV infections.[80]

Exposure Summary:

- **Ontario and Canada:** PHAC reported 19 OBV infections (average two cases per year) in Ontario (2015–2023) (Table 5). For the rest of Canada, from 2015 through 2022, there were 290 cases (average 36 cases per year). No cases of LACV infection have been reported in Canada.[155] Seroprevalence of California serogroup viruses (CSGVs) in humans is often high; e.g., in New Brunswick (2014–2016) seroprevalence against CSGVs was estimated at 31.6% (n=452 sera); seroprevalence for JCV was 26.6% (plaque reduction neutralization test [PRNT], n=143) and for SSHV was 2.1% (PRNT, n=143).[156] Seroprevalence for specific OBVs are also high depending on population studied, JCV (9–24%) and SSHV (1–42%) in Cree communities of James Bay, Canada, and JCV (21–48%) in Nova Scotia.[157,158]
- **US:** In the jurisdictions examined, there was no evidence of increasing case counts for OBV infections (Table 5). From 2017 through 2019, in Wisconsin, there was an outbreak of 60 cases of JCV infection, higher than the 28 cases reported in the previous 10 years. In the US, 1,281 LACV infections occurred from 2003 through 2019, with the highest incidence reported from West Virginia, North Carolina, Tennessee, and Ohio (0.16–0.61 per 100,000 population).[149,159] Seroprevalence for JCV was high in Michigan, at 52% (15–30% for US).[160] As of Oct 10, 2024, there were two cases of JCV infection in Michigan (Wayne and Livingston Counties) across the border from Windsor, ON; in addition 14 pools of mosquitoes were positive for JCV and were widely distributed in the state.[161]

Context Summary:

- **Ontario and Canada:** We did not include any studies that modelled climate change and projected future OBV infection trends in Ontario. Climate change is expected to increase JCV and SSHV distribution further north in Canada, along with longer transmission seasons, shifts in host and vector species, and increased abundance of mosquitoes.[162] Ludwig et al. (2019), while reporting on the increased risks of mosquito-borne diseases in Canada under conditions of climate change, called for expanded surveillance (new target mosquito vectors and pathogens) and research.[73] In northern Canada, CSGV seroprevalence is highest in caribou (63%), followed by polar bears (28%), red foxes (12%), and artic foxes (4%).[163] Exposure to CSGVs in northern Canada are associated with climate change, specifically there was increased seroprevalence in caribou and polar bears following a warmer summer. Recently, a rare case of SSHV infection with meningoencephalitis was reported in northern Manitoba, underscoring the risk for those living in rural northern climates.[164] Climate change (increased temperatures, erratic winter weather) will increase the distribution of competent vectors for LACV, such as *Aedes albopictus*.[165] Under current and projected climate change, CVV and LACV infections are prioritized vector-borne diseases in Canada.[13] Researchers are calling for more surveillance of OBVs (i.e., mosquito infection prevalence, human/animal seroprevalence) in Canada, which will allow for better risk assessments and disease modelling.[166,167] Using ecological niche modelling, Muller et al. (2024) noted that much of southern Ontario has a suitable climate for CVV transmission.[168]

- **US:** We did not include any climate change studies or predictive modelling for OBV infections in the US.

Rocky Mountain Spotted Fever

Description: Rocky Mountain spotted fever (RMSF) is a tick-borne disease found throughout much of North America, with the highest burden of disease in the southern US (i.e., Alabama, Arkansas, Missouri, North Carolina, and Tennessee).

Incident Description: A *Rickettsia rickettsii* infection, or cluster of *Rickettsia rickettsii* infections, with no history of travel outside of Ontario.

Probability: Likely

Impact: Moderate

Uncertainty: Moderate

Overall Risk: Moderate

Probability Rationale: Cases of RMSF are exceedingly rare in Ontario and the rest of Canada. The incidence of spotted fever rickettsioses has been increasing in the US since the early 2000s.[169–172] Similar trends of increasing seropositivity for spotted fever group rickettsioses (which includes RMSF) are evident for Ontario, especially prior to the pandemic (Table 6). American dog ticks (*Dermacentor variabilis*), a vector of RMSF, are expanding their range in Ontario, especially in warmer, low elevation areas with poorly drained soils.[12] Climate change will increase tick abundance and northern range expansion for American dog ticks and brown dog ticks.[173] On June 26, 2025, PHO was notified by the Ontario Veterinary College (University of Guelph) of a cluster of confirmed RMSF cases among dogs all exposed at Long Point, Ontario (Grand Erie Public Health). Upon initial investigation, *Rickettsia rickettsii* was detected in American dog ticks collected from locales where the dogs were active. The source of *Rickettsia rickettsii* at this location and whether it becomes established and spreads further is currently under investigation. In August 2025, PHO became aware of two confirmed human cases of RMSF, both likely to have acquired the infection from the Long Point area. Incidents of RMSF are likely in Ontario over the next 10 years and we expect a small number of imported cases.

Table 6: Reported Cases of Rocky Mountain Spotted Fever, or Cases Positive for Spotted Fever Rickettsiae Serology, in North America

Year	Ontario* Cases Positive for Spotted Fever Rickettsiosis	Rest of Canada	Mexico	US Cases Positive for Spotted Fever Rickettsiosis*
2014	44	NA	NA	3,749
2015	62	NA	NA	4,198
2016	66	NA	NA	4,269
2017	198	NA	NA	6,248
2018	306	NA	NA	5,544
2019	215	NA	NA	5,207
2020**	100	NA	NA	1,175
2021**	34	NA	NA	1,258
2022**	46	NA	NA	1,292
2023**	43	NA	NA	NA

NA, not available. Data on spotted fever rickettsiae for Ontario extracted from PHO LIMS (see Appendix C), and for US from CDC.[174] RMSF data for the rest of Canada and Mexico were not available.

*Not RMSF-specific, includes other members of the spotted fever group rickettsioses. In Ontario, results include all patients with a seropositive result (titers: IgG and/or IgM ≥1:64); serology interpreted as "serology is suggestive of recent infection" or "serologic evidence of prior or recent infection. Resubmit if clinically indicated." On Jan 1, 2020, the CDC changed the cutoff IgG titer to ≥1:128 from ≥1:64 and eliminated IgM serology.

**Data provided during the pandemic may not reflect actual epidemiological situation in some jurisdictions, so readers should interpret epidemiology with caution.

The American dog tick (*Dermacentor variabilis*), Rocky Mountain wood tick (*Dermacentor andersoni*), and brown dog tick (*Rhipicephalus sanguineus*) are the primary vectors of *Rickettsia rickettsii*. While found throughout North America, RMSF incidence is greater in the southern US (i.e., Alabama, Arkansas, Missouri, North Carolina, and Tennessee), southwestern US (e.g., Arizona, California), and northwestern Mexico (e.g., Baja California, Sonora).[107, 108, 110, 175–178] Recently, RMSF has been reported from Illinois and Connecticut, highlighting disease risks for more northern US states and southern Ontario.[179] Assays for *Rickettsia rickettsii* in American dog ticks, in the Northern US and Ontario, typically detect few or no positive ticks.[180–182] *Rickettsia rickettsii* detections in Ontario ticks have been from American dog ticks and rabbit ticks (*Haemaphysalis leporispalustris*), all prior to 1973.[183–185] Recent detection of *Rickettsia rickettsii* in American dog ticks at Long Point, Ontario in 2025 are the first in the province in over 50 years. While the brown dog tick can be found in Ontario, the numbers of these ticks are low (less than 20 submitted per year through passive surveillance) and usually associated with dog kennels or dogs that have travelled to warmer climates.[186,187] The brown dog tick can complete its entire life cycle indoors, allowing for survival in cooler climates. In comparison, the American dog tick is the second most common tick submitted to PHO for identification in Ontario at 36% (5,177/14,369), after the blacklegged tick (*Ixodes scapularis*) at 55% (7,84214,369).[123,124]

Impact Rationale: We consider the impact of a RMSF incident or incidents on the public health system as moderate over the next 10 years. System capabilities in Ontario for RMSF emergence include a comprehensive tick and pathogen surveillance system, which could be adapted for identifying RMSF vectors. Prevention options include environmental tick control, tick repellents for dogs, managing stray dog populations, personal protection against tick bites (e.g., use of DEET or icaridin, performing tick checks), timely diagnosis, and prompt treatment.[188,189] Given RMSF is not a DoPHS in Ontario, alternative human case detection would rely on case reports or routine review of laboratory test data. Our understanding of vector transmission dynamics is poor outside of the well-characterized epidemiology of RMSF in the southwestern US and northwestern Mexico. Although RMSF surveillance would focus on American dog ticks instead of blacklegged ticks, Ontario has experience in developing tick-borne disease programs (i.e., anaplasmosis, babesiosis, Lyme disease, Powassan virus infection).

RMSF is an acute febrile illness with non-specific symptoms, characterised by diffuse maculopapular rash, headache, muscle pain, abdominal pain, nausea, vomiting, respiratory distress, and neurological symptoms.[190,191] If left untreated, RMSF can lead to meningoencephalitis or death, and those that survive suffer from long-term sequelae.[192,193] In cases of meningoencephalitis, most patients require intensive care. Children are particularly susceptible to RMSF and severe disease. Depending on study location, the case fatality rate for RMSF ranges from 7% to 49%. In a study of 80 hospitalized patients in Arizona, 21% died, 38% survived with ongoing symptoms and loss of function, and 23% had neurological sequelae.[190] Patients at risk of long-term sequelae had a longer hospital stay, higher level of disability at discharge, and delayed antibiotic treatment. Delayed antibiotic treatment is a contributing factor in death from RMSF.[194] In a study of 78 patients in California (1980–2019), 57% required hospitalization and 7% died; incidence increased over the study period.[195] In a study of 510 cases (49% ≤18 years old) in Sonora, Mexico (2015–2018), 49% of patients died; increasing age and molecular testing positivity were associated with increased probability of death.[196] In an epidemic in Mexicali, Mexico (2009–2019), 18% of 4,290 cases died.[197] In Sonora, Mexico, a study of 104 hospitalized children reported that 20% died, in which death was associated with acute kidney injury, delay in treatment, and hemorrhage.[198]

Typically, in the US, RMSF or spotted fever rickettsioses are more common among white non-Hispanics.[169,195] In Mexico, positive spotted fever group rickettsial serology was higher in those with lower socioeconomic status, high burden of brown dog ticks on dogs and in environment, owning a dog, and having stray dogs around the household.[199–202] Since *Rickettsia rickettsii* can be aerosolized, veterinarian staff and groomers are at risk of infection.[203] In a modelling study of RMSF epidemiology in the Midwestern US (i.e., Arkansas, Kansas, Missouri, Oklahoma), factors contributing to increased prevalence of RMSF included higher average relative humidity and higher average land surface temperature (>35°C) (at county-level).[199] The highest incidence rates of spotted fever rickettsiosis occur in those aged 55–79 years (>19/1,000,000).[174]

Uncertainty Rationale: We based the probability and impact assessments on evidence with a moderate level of uncertainty. There is uncertainty in estimates of locally acquired disease in Ontario, since those with mild infections likely do not seek medical attention or laboratory testing (only mechanism of surveillance in Ontario but limited due to limited patient information on test requisitions). In addition, Ontario-specific climate change projections for RMSF are lacking in the literature.

Current Surveillance Tools (Data Source):

- **Human:** Serology and molecular testing (PHO Laboratory); research activity[204]
- **Non-human Animal:** Voluntary notification from veterinarians of cases among dogs
- **Vector:** Research activity[184]

Key Considerations for Public Health Planning:

- **Human Case Surveillance:** Consider strategies to support reporting of RMSF to public health; consider routine review of PHO Laboratory data for potential RMSF infections.
- **Vector and Animal Surveillance:** Consider altering active tick surveillance program to include testing of American dog ticks for *Rickettsia rickettsii*, with targeted tick dragging; consider strategies to support reporting of RMSF among animals; consider using non-human animals (e.g., seroprevalence in dogs) for surveillance.[205]

Exposure Summary:

- **Ontario and Canada:** Seropositivity to rickettsiae (spotted fever group and typhus group) in Ontario residents increased from 13% (317/2,438) in 2013 to 35% (648/1,851) in 2018, there was a 30% annual increase in the odds of a seropositive result (odds ratio = 1.3, 95% confidence interval: 1.23–1.39).[204] Using updated data prior to the pandemic, the number of patients seropositive for spotted fever group rickettsiae in Ontario increased from 44 in 2014 to 214 in 2019 (average = 150/year) (Table 6). Post pandemic, the number of seropositive patients decreased to an average of 56/year. A putative laboratory diagnosed case of RMSF occurred in Ontario (2013–2018).[204] Previously, a non-travel case of RMSF in the province was reported in 1979 from the Ottawa area, while in 2024, a possible case was detected with potential exposure in Ottawa a week prior to illness onset.[206,207]

- No RMSF surveillance data was available for Canada, except for provinces where the diseases is reportable. In British Columbia (2010–2019), the mean number of rickettsial disease (including RMSF) cases per year was 2.5 (IQR: 1–6.5); in Alberta (2018–2022) the median number of rickettsial infections (including RMSF) was 1 (IQR: 0.5–3); and in Saskatchewan (2012–2016), the median number of rickettsial infections was 1 (IQR: 1–5). Taken together with vector surveillance studies, surveillance of human disease shows that RMSF is rare in Canada.[208–210]

- **US:** The incidence of spotted fever rickettsiosis has been increasing in the US since the early 2000s.[169–172] In the US, the incidence rate per 1,000,000 population of spotted fever rickettsiosis increased from 11.9 in 2014 to 19.3 in 2017.[174] The highest incidence rate of spotted fever rickettsiosis was in Arkansas (56/1,000,000) and Alabama (25/1,000,000). The same increasing incidence is evident in states bordering Ontario, such as Michigan;[211] in contradistinction, reported cases are cyclical in New York,[212] and "extremely rare" in Minnesota.[213]

Context Summary:

- **Ontario and Canada:** Climate change modelling predicts that more of Ontario will become suitable for American dog ticks in the coming decades, at least further north to the edge of the Boreal forest.[214] As temperature increases, the brown dog tick feeds preferentially on human hosts compared to dogs, potentially putting more people at risk of infection.[215] Under current and projected climate change, RMSF is a prioritized vector-borne disease for Canada.[13] However, no studies were included that modelled climate change and projected future RMSF trends in Ontario.

- **US:** In the central Midwestern US, incidence of RMSF increases in areas as relative humidity and poverty increases (2005–2014), with decreases in incidence as temperatures exceed 35°C.[199]

Public Health Planning and Considerations

Provincial

The HIRA has identified several considerations at the provincial level for public health planning for vector-borne diseases:

Surveillance Mechanisms

- Consider strategies to support reporting of EEEV and OBV infections to public health under appropriate DoPHS. For example, ensuring EEEV infections are reported as Encephalitis (Primary Viral) or Meningitis, Acute (Viral) (if applicable).
- Consider designating prioritized vector-borne diseases as DoPHS, where appropriate.
- Consider PHO Laboratory surveillance to identify exposures, such as the routine review of test result data for EEEV, malaria, OBV infections, and RMSF.
- Consider routine monitoring of iPHIS data for EEEV and OBV infections within overarching DoPHS for Encephalitis (Primary Viral) or Meningitis, Acute (Viral).
- Consider enhancing tick and mosquito surveillance programs, including targeted vector surveillance and the testing of vectors for additional pathogens (e.g., OBVs in rural mosquito populations).
- Consider mechanisms to monitor disease emergence in the province, such as seroprevalence studies or private laboratory data sharing for AGS.
- Explore additional non-human animals as sentinels for disease activity (e.g., hunter-killed white-tailed deer for monitoring EEEV or OBVs, dogs for *Rickettsia rickettsii*).

Knowledge Translation

- Support the development of knowledge products aimed at increasing awareness of emerging vector-borne diseases.
- Consider updating Ontario's West Nile Virus Preparedness and Prevention Plan and Infectious Disease Protocols to include specific guidance on EEEV and OBV infections.[80,147]

Support and Response

- Support public health partners and PHUs in development of risk assessments and communications.
- Consider provincial coordination of response activities.
- Consider developing a response plan for vector-borne disease outbreaks, outbreaks that warrant provincial coordination of response activities.[216] This consideration would include taking a One Health approach to assessing climate change impacts on emerging vector-borne diseases, which includes climate modelling, animal health surveillance, and public health policy making.[217]

Public Health Units

The HIRA has identified several considerations for PHUs for public health planning for vector-borne diseases:

Surveillance Mechanisms

- Support reporting of EEEV and OBV infections to public health under appropriate DoPHS. For example, ensuring EEEV infections are reported as Encephalitis (Primary Viral) or Meningitis, Acute (Viral) (if applicable).
- Enhancing tick and mosquito surveillance programs, including targeted vector surveillance.

Knowledge Translation

- Development of knowledge products aimed at increasing awareness of emerging vector-borne diseases.

Response

- Development of risk assessments and risk communications (e.g., healthcare professionals, veterinary health professionals, public).
- Consider developing a response plan for vector-borne disease outbreaks or vector-borne disease emergence.
- Development of health promotion activities to encourage personal protective measures against vector-borne diseases.

Limitations

Our HIRA addressed the risks to the general population of Ontario and therefore does not address specific populations that might have unique vulnerabilities, experience disproportionate health inequities, or experience exacerbation of health inequities because of elevated vector-borne disease risk in Ontario. For example, there is likely a disproportionate impact from vector-borne disease outbreaks to certain communities or regions of the province (e.g., rural areas, northern communities, Indigenous communities); consideration could be given to planning and resource allocation in this context. There is an opportunity for PHO to collaborate with Indigenous communities to assess the shared risks of emerging vector-borne diseases throughout Ontario. In addition, while the use of risk matrices can be helpful when considering several risks/hazards and wanting a systematic, relatively comparable approach across assessments, matrices may not be equally suitable across risks/hazards.

While the impacts of climate change on vector-borne disease distribution and transmission are well established, attributing cause and effect is difficult. This difficulty is due to numerous contributing factors such as changes in reservoir abundance, land use changes, political stability, access to healthcare services, and vector control measures used.[218–221]

Knowledge Gaps and Future Research

Few climate-modelling studies concentrated on Ontario, making projections of vector-borne disease risk in the province difficult. There are opportunities for scenario-based modelling of climate change and vector-borne diseases in Ontario (including non-climatic factors), as the province has one of the most comprehensive collections of mosquito and tick surveillance data, along with environmental data.[142] Although most of the impacts of climate change occur beyond the 10-year window we used for the HIRA, a longer assessment window may be associated with greater levels of uncertainty.

While the Ontario context is unique, risk assessments from other public health agencies can be insightful; however, there were few publicly-available HIRAs of emerging vector-borne diseases in North America.[222–224] PHO's Hazard Identification and Risk Assessment (HIRA): Climate Change and Vector-borne Diseases addresses a gap in assessing the risks of emerging vector-borne diseases in Ontario and, more broadly, Canada.

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Appendix A: Prioritization of Vector-borne Diseases

The objective of this HIRA is to assess the public health risks posed by emerging vector-borne diseases in the context of climate change. The first step in developing this HIRA is the prioritization of vector-borne diseases. The specific objectives of the HIRA are to:

- Prioritize emerging vector-borne diseases for Ontario
- Describe a risk assessment question or incident for each vector-borne disease
- Estimate likelihood of an incident occurring, including imported cases
- Estimate the impact of the incident (includes healthcare [disease severity] and public health impacts)
- Estimate the risk level for each vector-borne disease using the risk matrix
- Provide options for public health planning to mitigate risks of emerging vector-borne diseases

Candidate Vector-borne Diseases to Include in the HIRA

To prioritize vector-borne diseases for inclusion in our HIRA, we followed the World Health Organization's (WHO's) methodology in their Strategic Toolkit for Assessing Risk (STAR) and using a modified version of the prioritization tool of Otten et al. (2020).[13, 14]

For our initial assessment list of candidate vector-borne diseases to include in the HIRA, we considered:

- Diseases not designated Diseases of Public Health Significance (DoPHS) in Ontario
- Pathogens present in Ontario or surrounding jurisdictions
- Vectors present in Ontario or surrounding jurisdictions
- Diseases highlighted by subject matter experts (SMEs)

Flea-borne:

- Cat scratch disease (*Bartonella henselae*)
- Flea-borne spotted fever (*Rickettsia felis*)
- Murine typhus (*Rickettsia typhi*)

Louse-borne:

- Trench fever (Bartonella quintana)
- Epidemic typhus (*Rickettsia prowazekii*)
- Louse-borne relapsing fever (*Borrelia recurrentis*)

Mite-borne:

- Rickettsialpox (*Rickettsia akari*)

Mosquito-borne:

- Chikungunya (*Alphavirus chikungunya*)
- Dengue (*Orthoflavivirus denguei*)
- Eastern equine encephalitis virus (EEEV) infection (*Alphavirus eastern*)
- Highlands J virus infection (*Alphavirus highlandsj*)
- Malaria (including *Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium ovale*, *Plasmodium malariae*, *Plasmodium knowlesi*)
- *Orthobunyavirus* (OBV) infections (specifically Cache Valley virus [CVV] or *Orthobunyavirus cacheense*, Jamestown Canyon virus [JCV] or *Orthobunyavirus jamestownense*, La Crosse virus [LACV] or *Orthobunyavirus lacrosseense*, snowshoe hare virus [SSHV] or *Orthobunyavirus khatangaense*)
- Rift Valley fever virus infection (*Phlebovirus riftense*)
- Sindbis fever virus infection (*Alphavirus sindbis*)
- St. Louis encephalitis virus infection (*Orthoflavivirus louisense*)
- Usutu virus infection (*Orthoflavivirus usutuense*)
- Western equine encephalitis virus infection (*Alphavirus western*)
- Zika virus infection (*Orthoflavivirus zikaense*)

Tick-borne:

- Bourbon virus infection (*Thogotovirus bourbonense*)
- Hard tick relapsing fever (*Borrelia miyamotoi*)
- Borreliosis (*Borrelia mayonii*)

- Heartland virus infection (*Bandavirus heartlandense*)
- Ehrlichioses (*Ehrlichia chaffeensis*, *Ehrlichia muris eauclairensis*, *Ehrlichia ewingii*)
- Rocky Mountain spotted fever (RMSF) (*Rickettsia rickettsii*)
- Soft tick relapsing fever (*Borrelia hermsi, Borrelia turicatae*)
- Tick-borne encephalitis virus (*Orthoflavivirus encephalitidis*)

Others (Source):

- Alpha-gal syndrome (AGS) (lone star ticks)
- Myiasis (flies)
- Scabies (*Sarcoptes scabiei*)
- Pediculosis (*Pediculus humanus*)

When prioritizing vector-borne diseases for inclusion in our HIRA, we considered factors associated with the probability and impact of disease emergence.

Probability of Disease Emergence

- Likelihood of detecting a locally acquired human case within the next 10 years
- Likelihood of detecting a locally acquired non-human case (if applicable) within the next 10 years
- Pathogen (or vector) recently documented in neighbouring jurisdictions (i.e., Canada: Manitoba, Québec; US: Ohio, Michigan, Minnesota, New York, Pennsylvania)
- Pathogen documented in Ontario (if applicable)
- Vector documented in Ontario

Impact of Disease Emergence

- Impact increases as disease severity (hospitalization, mortality) increases
- Impact increases as the surveillance capacity for detecting cases decreases (i.e., pathogen detection in vector and human, if applicable)
- Impact increases as the likelihood of a provincial coordinated response increases (public health interventions to mitigate transmission, e.g., risk communications, active case finding, public health unit [PHU] capacity building, vector management, and vector surveillance)

- Impact increases as the availability of treatment and/or prophylaxis decreases (e.g., vaccinations, antibiotics, antimalarials)
- Impact increases with increases in health-care system disruption (i.e., disease severity and impact on emergency room and intensive care capacity)
- Impact increases with increases in public health system disruption (e.g., case-contact management, case interviews, disease and vector surveillance)

After considering the likelihood and impact of disease emergence, four SMEs prioritized the following five vector-borne diseases for this HIRA through consensus: AGS (chosen by 3 out of 4 SMEs), EEEV infection (4/4), malaria (3/4), OBV infections (4/4), and RMSF (4/4). Other diseases considered were chikungunya (1/4) and ehrlichiosis (1/4). Our top five results correlated with the published literature; e.g., Otten et al. (2020) had four of our five diseases in their top-12 diseases (AGS was not considered in their exercise).[13]

Appendix B: Literature Review

PHO Library Services designed and executed database search strategies to retrieve peer-reviewed evidence on vector-borne disease surveillance and the impact of climate change on disease emergence (AGS, EEEV infection, malaria, OBV infections, RMSF). Database searches were run in MEDLINE and limited to articles published in English from Jan 1, 2014, to the dates noted for each disease: AGS (June 17, 2024), EEEV infection (July 11, 2024), malaria (Aug 2, 2024; limited to Jan 1, 2019, and onwards), OBV infections (Sept 6, 2024), and RMSF (May 30, 2024). Supplemental searches were run in Embase, Environment Complete, and Scopus and limited to articles published in English from Jan 1, 2014, to the dates noted for each disease: AGS (June 17, 2024), EEEV infection (July 11, 2024), malaria (Aug 12, 2024; limited to Jan 1, 2019 and onwards), OBV infections (Sept 6, 2024), and RMSF (May 28–30, 2024). Two independent reviewers conducted preliminary screening first by title and abstract, then screened the search results by full-text review. Reviewers determined whether articles marked for full text review would be included. Consensus was used in cases of uncertainty to make a final decision. We supplemented searches with resources and articles provided by SMEs.

We searched grey literature at the end of May 2024. We searched for epidemiological reports from:

1. Canadian public health agencies (provincial/federal) (e.g., PHAC)
2. International public health agencies (e.g., CDC, European Centre for Disease Prevention and Control [ECDC], WHO).

Studies (primary literature or reviews) were included if they reported on seroprevalence or case counts or incidence rates, importation risk, disease severity, vulnerable populations, epidemiology, and impact on healthcare and public health services (see inclusion criteria below). Included studies also focused on vector ecology, reservoir ecology, and ecological impacts of climate change on vectors. We excluded studies if they focused on data collected prior to 2014, pathogen/vector/host genetics, treatment options, and treatment efficacy. News, commentaries, correspondence, editorials, letters to the editor, conference abstracts, posters, essays, thesis, message boards, and social media were excluded. The same inclusion and exclusion criteria apply for grey literature (see below for an example).

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowcharts for each disease are available upon request, outlining search results, SME-contributed literature, grey literature, and final number of resources used in writing the HIRA.

Inclusion Criteria (e.g., RMSF)

- Population-wide prevalence studies in low (Canada) and high burden jurisdictions (US, Mexico)
- Studies describing the projected distribution of disease and vectors under conditions of climate change

- Time period (2014–2024)
- Studies describing the importation of cases to Ontario
- Studies examining the clinical presentation and severity of disease (e.g., signs and symptoms, morbidity, mortality, hospitalization), including groups vulnerable to severe disease (e.g., elderly, children, those with immune compromise)
- Studies describing public health interventions to prevent or mitigate RMSF, including impacts of RMSF on healthcare or public health system functioning
- Studies describing vector and reservoir ecology (e.g., climate change modelling, distribution, habitat)

Exclusion Criteria (e.g., RMSF)

- News, commentaries, correspondence, editorials, letters to the editor, conference abstracts, posters, essays, thesis, blogs, message boards, social media
- Time period (pre-2014), and papers with data pre-2014
- Studies focusing on pathogen/vector/host genetics
- Studies using non-human animal models
- Studies concentrating on treatment and treatment options or complications related to RMSF
- Studies performed outside of North America

Evidence Gathering

Using the literature, we collected evidence for each "type of information" for each vector-borne disease (see below). Since none of our selected vector-borne diseases are DoPHS, there was no Ontario Ministry of Health (MOH) integrated Public Health Information System (iPHIS) data to use for exposure assessments. An exception is EEEV infections reported as encephalitis or meningitis cases in iPHIS. Where reportable disease data was not available for exposure assessments, we used Public Health Ontario Laboratory Information Management System (PHO LIMS) data along with published primary literature or government reports.[204]

The following types of information was gathered from the following sources to populate summaries:

- **Background:** Are the vectors in Ontario or neighbouring jurisdictions? Are the pathogens/diseases in Ontario or neighbouring jurisdictions? What are the climate requirements for transmission? What is the impact of climate change on disease distribution?
    - **Source:** Peer-reviewed literature; expert opinion

- **Exposure assessment:** Cases and trends in Ontario? Detections of pathogen in reservoir or other hosts, including vector? Cases and trends in top countries with risk of importation to Ontario?
    - **Source:** Peer-reviewed literature; surveillance data; grey literature; expert opinion
- **Context assessment:** Are there surveillance tools and vector management programs in Ontario? Is there disease awareness?
    - **Source:** Grey literature; expert opinion
- **Impacts on individual:** Are there vulnerable populations (those with immune compromise, children)? What are the clinical manifestations? What is the disease severity (self-limited, hospitalization, morbidity)? Is there prophylaxis or treatments available?
    - **Source:** Peer-reviewed literature; expert opinion
- **Impacts on community:** Geography of populations affected (urban versus rural)? Does disease exacerbate health inequities (gender, marginalization)? Impacts on healthcare and public health systems?
    - **Source:** Peer-reviewed literature; expert opinion
- **Proposed public health actions or planning considerations:** Do we have any surveillance tools (vector, human, non-human)? What are laboratory limitations? What are potential response actions?
    - **Source:** Expert opinion

Appendix C: Technical Notes

iPHIS Data

Data

We based our EEEV infection data for this report on information entered in the MOH iPHIS database as of March 6, 2024. From January 1, 2012 through December 31, 2023, we identified three cases of possible EEEV infection (Table 3).

EEEV infection is not reportable (i.e., a DoPHS) in Ontario, however, PHUs report severe cases with encephalitis and/or meningitis under those conditions. As a result, counts are likely an underestimate.

All three cases reported exposure locations within Ontario prior to illness onset (i.e., none of the cases reported travel outside of Ontario).

Methods

Includes cases with episode dates from January 1, 2014 through December 31, 2023, inclusive.

Cases for which the Disposition Status was reported as ENTERED IN ERROR, DOES NOT MEET DEFINITION, DUPLICATE-DO NOT USE, or any variation on these values, were excluded from analyses.

Cases for which the Diagnosing Health Unit was reported as 'MOHLTC' (to signify a case that is not a resident of Ontario) were excluded.

Multiple iPHIS fields (e.g., risk factor and exposure fields) were reviewed in order to classify the location of exposure of a case. Locations were classified by PHU in Ontario, outside of province but within Canada, and outside of Canada. Only unique exposure locations (e.g., PHU, country) were included for a case. For example, if a case reported multiple exposure locations within one PHU, that exposure was captured only once. For cases reporting both known and unknown exposure locations, only the known exposure location was included. For example, if a case reported an exposure within Ontario and 'UNKNOWN', only the Ontario exposure was included.

Data Caveats

The data includes confirmed and probable cases of EEEV infection. We classified cases as per the current provincial case definitions (Encephalitis, Primary Viral; Meningitis, Viral).

iPHIS is a dynamic disease reporting system that allows ongoing updates to previously entered data. As a result, data extracted from iPHIS represent a snapshot at the time of extraction and may differ from previous or subsequent reports.

These data only represent cases and case details (e.g. exposure location) reported to public health and recorded in iPHIS. As a result, all case counts are subject to varying degrees of underreporting due to a variety of factors, such as disease awareness and medical care seeking behaviours that may depend on severity of illness, clinical practices, and changes in laboratory testing and reporting behaviours.

The potential for duplicates exists unless they were resolved at the local level prior to data extraction.

Cases are reported based on the Episode Date, which is an estimate of the onset date of disease for a case. In order to determine this date, the following hierarchy exists in iPHIS: Onset Date > Specimen Collection Date > Lab Test Date > Reported Date.

Multiple exposure locations can be reported for a case. For example, a single case could report multiple locations within Ontario as well as outside of Ontario or Canada. Disease acquisition cannot be attributed to exposure locations reported in iPHIS. Instead, exposures represent events reported prior to the onset of illness (i.e. exposures do not demonstrate a causal link).

PHO Laboratory Data

Data

We extracted data from the PHO LIMS on May 17, 2024 for samples logged from January 1, 2014 through December 31, 2023.

We extracted data on malaria microscopy, malaria polymerase chain reaction (PCR), and spotted fever group (SFG) *Rickettsia* serology from PHO LIMS using the analyses MALARIA_MIC, MALARIA_PCR, RMSF_IFA (2014-2020), and RICK_IGG_OVRL (2020-2023). Data for malaria is reported in Table 4 and data for RMSF is reported in Table 6.

Methods

We checked data for proficiency samples and if present, these samples were removed.

We assigned patient IDs using a combination of name, birthdate, and/or health card number.

If a patient had multiple samples tested in the same calendar year, we only counted the patient once per year. Similarly, a patient with multiple positive samples was counted as positive once per calendar year.

For malaria, positive samples were restricted to those where malarial parasite(s) were found by microscopy or reported positive by PCR.

For SFG *Rickettsia*, positive samples were restricted to those indicative of prior or recent infection:

- Serologic evidence of prior or recent infection. Resubmit if clinically indicated.
- Serology is suggestive of recent infection

- May indicate infection. Resubmit if clinically indicated.
- May indicate recent infection. Advise follow up specimen
- Serological evidence of SFG infection/exposure

The following interpretations were not considered as positive samples for SFG *Rickettsia*:

- No serologic evidence of infection
- No serological evidence of SFG or murine typhus group (MTG) infection
- Serological evidence of MTG infection/exposure
- Serological evidence of SFG and/or MTG infection/exposure
- Antibody status inconclusive/resubmit if clinically indicated
- Specimen showed non-specific staining. Advise follow-up specimen.
- Unable to determine antibody status

Data Caveats

As of January 2020, PHO's laboratory no longer provides IgM testing using indirect immunofluorescence (IFA) for detection of SFG *Rickettsia* antibodies and only performs IgG IFA testing. Interpretations do not differentiate between recent and past infection.

For testing prior to January 2020, as cross-reactivity is possible between SF and MT groups of *Rickettsia*, a seropositive test for SFG rickettsiae could indicate prior exposure to other *Rickettsia* species (e.g., *Rickettsia typhi*).

In counting patients once per calendar year, testing from the same episode of illness or exposure may be duplicated in the event that a patient was tested near the end of one year and tested again early in the next year.

Data includes patients from outside of Ontario.

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