Developing a Risk Assessment Framework for Evaluating and Mitigating Occupational Exposure of Migrant Farmworkers to Enteric Pathogens in Canada's Seasonal Agricultural Worker Program

by

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Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Seasonal migrant farmworkers are a group of workers that annually participate in the Seasonal Agricultural Worker Program (SAWP), a federally managed labour migration program set up to respond to the labour shortage in the Canadian agricultural sector. Workers spend up to eight months living and working on farms across Canada and participate in primary agricultural work opportunities that include the care of animals and the harvesting of crops. Migrant farmworkers undergo a detailed process ensuring suitability for participation in the program, which includes health screenings and medical clearances confirming workers are fit to work and are generally healthy without any signs of illness or disease. Despite the requirement for health screening prior to arrival, data describing their health after their work period has ended are scant. This work aims to evaluate the enteric disease health risks that migrant farmworkers face in the SAWP occupational setting. The agricultural setting inherently presents sources of enteric pathogens and the SAWP occupational setting increases the possibility of exposure given occupational hazards (i.e., handling or use of managed manure, the care and sanitation of animals) and elevated risk from cross-contamination and secondary transmission from one person to another given the on-farm congregate housing.

Risk-based methodologies at the interface of environmental engineering and occupational and public health were used to investigate the health risks attributable to enteric pathogens that migrant farmworkers face in the SAWP occupational setting. A risk assessment involving risk identification, risk analysis, and risk evaluation and drawing on Quantitative Microbial Risk Assessment (QMRA), Hazard Analysis and Critical Control Points (HACCP) and Failure Mode and Effects Analysis (FMEA) were utilized to identify hazards and opportunities for their mitigation. The risk assessment resulted in the identification of key hazards and hazardous situations, the development of a transmission network identification of key exposure pathways, and the development of two risk matrices for the evaluation of health risks in the SAWP occupational setting. Key factors contributing to migrant farmworker health risk in the SAWP occupational setting included (1) agriculture environmental factors leading to exposure to sources of enteric pathogens in the agricultural setting, (2) infrastructure factors contributing to hazardous situations related to the migrant farmworker living and working conditions, (3) occupational factors such as the provision of health and safety training, and (4) SAWP management factors including access to health care.

The development of the risk-based framework, including the hazard identification and preliminary health risks evaluation, highlights evidence of workers experiencing relatively heightened health risk attributable to enteric pathogens as a result of the occupational setting. More broadly it also emphasizes enabled pathogen pathways and the spread of infectious disease in this occupational setting recently exemplified with multiple major outbreaks of COVID-19 among workers across distinct geographic locations. Risk tools as a part of the overall framework, including the conceptual model, transmission network, and risk matrices provide an approach to identifying, evaluating, and mitigating significant health risks posed by enteric pathogens to migrant farmworkers. Further research requiring collection and centralized reporting of migrant farmworker health data can contribute to overall framework development, helping to inform policy for the health protection of both workers and the general public.

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Dedication

To all the workers who have suffered or have lost their lives on foreign lands, in the noble cause to support their families and their livelihoods.

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AGIs	Acute Gastrointestinal Illnesses
CCID	Close Contact Infectious Disease
CCPs	Critical Control Points
CSA Group	Canadian Standards Association
ESDC	Employment and Social Development Canada
FMEA	Failure Mode and Effects Analysis
GAPs	Good Agricultural Practices
HACCP	Hazard Analysis and Critical Control Points
ISO	International Organization for Standardization
LMIA	Labour Market Impact Assessment
NOC	National Occupational Classification
NSAGI	National Studies on Acute Gastrointestinal Illnesses
OHCOW	Occupational Health Clinics for Ontario Workers
OHS	Occupational Health and Safety
PHAC	Public Health Agency of Canada
PPE	Personal Protective Equipment
QMRA	Quantitative Microbial Risk Assessment
SAWP	Seasonal Agricultural Worker Program
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization

Chapter 1
Introduction

Over the last century, infectious disease as a major cause of death has decreased by 97% from 1900 to 2010 due to advances in hygiene and sanitation practices and water treatment (Jones, Podolsky, & Greene, 2012; Kim, 2014). Nonetheless, infectious disease continues to impact human health and challenge public health management, especially in the absence of sufficient control strategies. It is notable that the current COVID-19 global pandemic has drawn attention to the health risks attributable to the spread of infectious disease (Abrams & Szefler, 2020) and the associated impacts on public health systems including "all public, private, and voluntary entities that contribute to the delivery of essential public health services within a jurisdiction" (Centers for Disease Control and Prevention, 2020). It has not only highlighted the risk associated with the transmission of respiratory infectious disease, but also underscores several parallel pathways that are relevant for other pathogens of public health concern. In particular, limited opportunities for maintaining sufficient hygiene and sanitation practices may increase exposure to pathogenic microorganisms and associated health risks of respiratory and enteric diseases. In Canada and the United States, infectious diseases attributable to enteric pathogens annually result in millions of illnesses and thousands of associated deaths; thus, they remain an important public health concern (Centers for Disease Control and Prevention, 2018b; Thomas, Murray, Nesbitt, & Pollari, 2017). Enteric infectious diseases leading to gastrointestinal illnesses are caused by pathogenic microorganisms such as bacteria, viruses and protozoa. Enteric pathogens are capable of causing gastrointestinal illnesses and may be acquired directly from food, water, or environmental sources, including exposure to animals; they also may spread through secondary transmission from one person to another (Aw, 2018; Lee & Middleton, 2003; Musher & Musher, 2004; Pachepsky, Shelton, McLain, Patel, & Mandrell, 2011)

Individuals in which an enteric disease leading to a gastrointestinal illness presents the greatest potential consequence include older populations, young children, and those who are immunocompromised (Anderson, Jaykus, Beaulieu, & Dennis, 2011), as well as those with frequent and direct exposures as a result of their occupation (Adam-Poupart et al., 2021). Groups that may face increased occupational exposure to biological contamination include food handlers, healthcare workers and farmworkers (Adam-Poupart et al., 2021) who may be exposed to sources of biological hazards from livestock and animal-based soil amendments (i.e., manure) among other sources in the agricultural setting (Bach, McAllister, Veira, Gannon, & Holley, 2002; Gannon et al., 2004). In addition to increased exposures, those living in congregate housing such as long-term care facilities, group homes and migrant worker on-farm housing, are also faced with increased secondary transmission from one person to another via contaminated hands and surfaces (Alberta Health Services, 2019; Centers for Disease Control and Prevention, 2018a). Infection from these potential exposures is facilitated through a fecal–oral route in which enteric pathogens are transmitted to a susceptible host's mouth by contaminated hands, food, or water (Aw, 2018). Spread of the disease continues when an infected animal or person further sheds enteric pathogens, which can then be transmitted to another individual through contaminated hands, food or water via the fecal–oral route.

The agricultural setting has to a certain extent been observed to present greater chances of exposure to pathogens leading to enteric infections, particularly when there are animals on site. The burden of zoonotic disease has been shown to be much higher for people in the agricultural setting with exposure to domestic and farm animals (Klumb, Scheftel, & Smith, 2020). Given the typical agricultural setting, enteric pathogens may inherently be present in animal sources, raw animal products (e.g., raw milk or eggs), surface water sources, or managed manure on site. Exposure to these potential hazards can lead to an enteric infection and may be heightened for individuals with occupational roles in the agricultural setting given their job duties. Occupational roles with duties such as contact with and care of animals (Adam-Poupart et al., 2021), the handling or use of managed manure (Manyi-Loh et al., 2016) and exposure to potentially contaminated irrigation water sources (Bach et al., 2002; Sampson et al., 2017; Solomon, Yaron, & Matthews, 2002) are all factors that can contribute to heightened worker exposure to enteric pathogens.

Some populations may experience both increased exposures and transmission as a result of their occupational setting and associated living arrangements—migrant farmworkers that enter Canada under the Seasonal Agricultural Worker Program (SAWP) are one such group. Seasonal migrant farmworkers, mainly citizens from Mexico and the Organization of the Caribbean States, participate in this long-standing, federally managed labour migration program set up to respond to labour shortages in the agricultural sector. Workers participate in agricultural work, as general farm labourers and harvesters, on an annual basis and stay for a period of up to eight months. The occupational setting for workers is usually the farm, which also includes on-farm congregate housing where workers reside for the duration of their work period (Canadian Council for Refugees, 2018; Hennebry, 2009; McLaughlin, Hennebry, & Haines, 2014; The North-South Institute, 2006). This occupational setting presents hazards and hazardous situations leading to exposure to enteric pathogens within the farm setting given migrant farmworker job requirements and duties. The setting also supports secondary transmission from one person to another within congregate living quarters presenting concerns related to maintaining adequate hygiene and sanitation practices. In addition to potential hazards attributable to enteric pathogens and many fecal–oral transmission routes within this occupational setting, there is also evidence of substantial occurrence of gastrointestinal illnesses, which comprise one of the highest diagnoses of disease among migrant farmworkers (Frisvold, Mines, & Perloff, 1988; Hennebry & McLaughlin, 2012b; Hennebry & Preibisch, 2008; McLaughlin et al., 2012; Orkin, Lay, McLaughlin, Schwandt, & Cole, 2014; Preibisch & Hennebry, 2011). Previous studies have also shown that migrant farmworkers are especially vulnerable to the spread of infectious diseases due to limited access to health care, language barriers and typical living arrangements (Anthony, Williams, & Avery, 2008; Oren et al., 2016).

The SAWP occupational setting, as discussed and supported in this thesis, likely results in migrant farmworkers experiencing relatively heightened exposures to enteric pathogens, thereby increasing associated health risks; however, this has not been described. To date, neither the hazards and hazardous situations leading to migrant farmworker exposure to enteric pathogens nor the fecal–oral transmission routes leading to their potential enteric infection have been integrated for the purposes of health risk evaluation. Application of risk assessment principles including key elements of risk identification, risk analysis and risk evaluation (Rovins et al., 2015) can be utilized as a prospective method for integrating and evaluating the health risks facing migrant farmworkers.

1.1 Research Objectives

The overall goal of this work was to evaluate whether the unique occupational setting of seasonal migrant farmworkers in Canada heightens the human health risk attributable to enteric pathogens. The following research objectives were developed to address this goal:

1. identify relevant hazards and hazardous situations contributing to migrant farmworker health risks;
2. characterize relevant exposure pathways that may lead to migrant farmworker exposure to enteric pathogens;
3. develop a framework for evaluating the migrant farmworker health risks attributable to enteric pathogens;
4. conduct a preliminary evaluation of migrant farmworker health risks attributable to enteric pathogens; and
5. identify potential control points for mitigating the human health risks associated with enteric disease that are faced by migrant farmworkers participating in Canada's SAWP.

1.2 Research Approach

Risk assessment principles at the interface of environmental engineering and occupational and public health were used to investigate the human health risks attributable to enteric pathogens faced by migrant farmworkers in the SAWP occupational setting. Although some health risks faced by migrant farmworkers have been recognized, hazards and hazardous situations leading to exposure to common enteric pathogens have not been formally described for the purpose of human health risk assessment. To address this knowledge gap, a risk assessment approach involving risk identification, risk analysis, and risk evaluation was utilized to identify (1) hazards and hazardous situations leading to exposure to enteric pathogens relevant to the SAWP occupational setting and (2) opportunities for their mitigation. Enteric pathogens such as bacteria, protozoa and viruses were identified as key biological hazards (Canadian Centre for Occupational Health & Safety, 2021a) because of their widespread presence in multiple sources in the agricultural environment (Bach et al., 2002; Beuchat, 2006; Klumb et al., 2020; Solomon, Potenski, & Matthews, 2002). The exposure pathways of enteric pathogens that contribute to human health risk were mapped using a systems theory approach and risk matrices were developed to relatively evaluate migrant farmworker health risk attributed to enteric pathogens in the SAWP occupational setting. This research drew on Quantitative Microbial Risk Assessment (QMRA), Hazard Analysis and Critical Control Points (HACCP) approaches and Failure Mode and Effects Analysis (FMEA) to evaluate risk and identify possible control points along exposure pathways to support mitigation. This approach provides a unique application of risk assessment methodology as an effective tool for understanding and assessing the migrant farmworker human health risks associated with enteric disease in the Canadian SAWP occupational setting.

1.3 Thesis Structure

This thesis integrates knowledge from several diverse disciplines to evaluate whether the unique occupational setting of seasonal migrant farmworkers heightens health risks attributable to enteric pathogens. Chapter 2 summarizes relevant literature on enteric disease, as well as sources of pathogens and fecal–oral transmission routes in the agricultural setting. Additionally, an overview is provided of the management of enteric disease in Canada and the potential application of risk management tools and methods to characterize enteric disease and inform decision-making. Seasonal migrant farmworkers were identified as a population at risk and a review of their occupational setting including review of the occupational hazards and controls was conducted. Chapter 3 describes the design of the research methodology by outlining the adaptation and application of risk assessment principles to carry out a health risk assessment in the migrant farmworker context. The identified hazards and exposure pathways that contribute to migrant farmworker health risks associated with enteric disease, as well as the framework developed to evaluate migrant farmworker health risks attributable to enteric pathogens in the Canadian SAWP occupational setting, are detailed and discussed in Chapter 4. Finally, Chapter 5 summarizes the main conclusions reached and recommendations for further development in addressing the risk faced by migrant farmworkers.

Chapter 2
Background and Literature Review

This chapter provides an overview of infectious enteric diseases resulting in acute gastrointestinal illnesses and the sources and transmission routes of pathogenic microorganisms in the agricultural setting (section 2.1). Additionally, it provides background on the management of enteric disease in Canada and the potential application of risk management tools and methods to characterize enteric disease and inform decision-making (section 2.2). Migrant farmworkers are identified as a population at heightened health risk to enteric diseases and a preliminary review of existing research on migrant farmworker populations is provided. The review includes a description of the migrant farmworker occupational setting, an overview of the Seasonal Agricultural Worker Program (section 2.3) and a review of occupational health hazards and controls within the agricultural migrant farmworker occupational setting (section 2.4).

2.1 Overview of Infectious Enteric Disease

Exposure to pathogenic microorganisms may lead to gastrointestinal infections in humans, which can result in enteric illnesses. Pathogenic microorganisms attack the gastrointestinal system, leading to inflammation of the gastrointestinal tract involving both the stomach and small intestine (Al Jassas et al., 2018). Common reported symptoms of these infections include diarrhea, abdominal pain, fever, cramping, nausea/vomiting, bloody diarrhea, headaches, dehydration and fatigue (Lee & Middleton, 2003). Most enteric infections affecting the gastrointestinal system are acute (i.e., characterized by rapid onset of disease) and self-limiting (i.e., resolved without treatment) in nature (Alberta Health Services, 2019; Musher & Musher, 2004; Public Health Agency of Canada, 2021b). The general association between health risks and poor access to water, sanitation, and hygiene (WASH) is well recognized. It has recently been suggested, however, that household- and community-level factors beyond WASH access—which include intra-household pathogen transmission, exposure to animal feces, and contextual factors that reflect setting-specific transmission routes (e.g., flies, food contamination, and stored drinking water that can result in clustering or increased incidence of disease)—may be important risk factors for enteric infections (Chard et al., 2020).

Enteric pathogens originate in fecal matter from infected animals and humans and may persist in environmental reservoirs such as surface water or soil (Chard et al., 2020). Pathogens that cause gastrointestinal illness can include bacteria, protozoa, and viruses. These pathogens are transmitted by fecally contaminated hands, food and water (Aw, 2018). Foodborne illness is caused by consumption of contaminated food and beverages. Analogously, waterborne illnesses are caused by consumption of or contact with contaminated water. Enteric illnesses not related to food or water may result from animal-to-person transmission, secondary transmission from one person to another via contaminated hands and surfaces, and hand contact with fecally contaminated environmental sources such as surface water and soil (Foodnet Canada Annual Report, 2017; Manitoba Public Health Branch, 2008; Musher and Musher, 2004). This highlights contaminated hands as a main factor in the transmission of enteric infectious disease and further underscores the importance of good hand hygiene as a tactic in breaking the chain of transmission and, in particular, reducing the incidence of gastrointestinal infection (Bloomfield, Aiello, Cookson, O'Boyle, & Larson, 2007).

2.1.1 Sources of Enteric Pathogens in the Agricultural Setting

Enteric pathogens in the agricultural setting can originate in fecal matter from wild animals (e.g., birds), domestic livestock animals (e.g., cattle, poultry) and other domestic animals on the farm (e.g., cats, dogs) as well as waste from infected humans. They can also exist in environmental reservoirs such as managed manure, water and soil, potentially causing illness upon entry to the body. These sources are inherently present in the agricultural setting, and specifically the farm setting, given hazards such as contact with and care of domestic animals (Adam-Poupart et al., 2021; Klumb et al., 2020; Whitfield et al., 2017), handling or use of managed manure (Guan & Holley, 2003; Manyi-Loh et al., 2016) and exposure to potentially contaminated irrigation water sources (Bach et al., 2002; Sampson et al., 2017; Solomon, Yaron, et al., 2002). In addition to domestic animals, wild animals (e.g., birds) can also be a source of enteric pathogens in the agricultural setting (Beuchat, 2006). Wild animals can contaminate soil or produce grown on site through droppings which workers can become exposed to while carrying out their occupational duties on the field. Additional pathogen sources in the agricultural setting include raw animal products, agricultural run-off, contaminated surface water and human waste (Olaimat & Holley, 2012). Pathogen shedding by domestic and wild animals can contaminate the work environment (Steinmuller, Demma, Bender, Eidson, & Angulo, 2006); as a result, the associated increase in exposure potential can increase human health risk.

Pathogens associated with acute gastrointestinal illnesses (AGIs) include bacteria such as *Shigella* spp., *Campylobacter* spp., *Salmonella* spp., enteropathogenic *Escherichia coli* (e.g., *E. coli* O157:H7); protozoa including *Giardia duodenalis* and *Cryptosporidium* spp.; and viruses including adenovirus, enterovirus, norovirus and rotavirus (Lee & Middleton, 2003; Musher & Musher, 2004; Pachepsky et al., 2011). Epidemiological evidence of reported outbreaks has pointed to agricultural areas with high cattle densities being linked to *E. coli* O157:H7, noting beef cattle on site to likely be the primary source of this organism (Bach et al., 2002). *E. coli* O157:H7 was also found in a survey of bird fecal samples (mainly gulls), highlighting wilds birds as potential vectors for dissemination of *E. coli* O157:H7 in the environment (Wallace, Cheasty, & Jones, 1997). Additionally, cryptosporidiosis (i.e., illness caused by *Cryptosporidium* spp.) among farmworkers has been linked to workers exposed to cattle, sheep, goats and horses in the occupational setting (Mahdi & Ali, 2002). Analyses from other reported outbreak data have implicated poultry such as chickens and turkeys as likely sources of *Campylobacter* spp. in the agricultural setting (Adam-Poupart et al., 2021; Public Health Agency of Canada, 2017).

2.1.2 Transmission Routes of Enteric Pathogens in the Agricultural Setting

To cause illness, enteric microorganisms need to enter the body. Enteric infections typically occur through the fecal–oral route wherein pathogens in fecal waste from contaminated sources are ingested through the mouth, leading to the proliferation of pathogens in a host. The modes of transmission through the fecal–oral route can generally be described through five main factors (Wagner & Lanoix, 1958) now known as the “Five Fs”; fluids, food, field, fingers and flies, which are common means of transmission for all potential exposures. This can be through direct ingestion of food or water contaminated by microorganisms or through accidental ingestion by contact with animals, their waste or their environment, or contact with environmental reservoirs of pathogens such as surface water and soil (Chard et al., 2020). Another possible transmission mode can be from one person to another through hands contaminated with the waste of an infected person (Centers for Disease Control and Prevention, 2018b). Although the modes of transmission in the fecal–oral route are mainly attributed to one of the five factors identified, the degree and likelihood of exposure in the agricultural setting are elevated given environmental factors increasing the potential of exposure.

Waterborne illnesses can occur as a result of pathogens making their way into water sources. In the agricultural setting this occurrence may be more probable as a result of surface water contamination by on-farm animal waste runoff or upstream sources. This also presents the possibility of contaminating groundwater sources that may be used for drinking water supplies such as private wells (Gannon et al., 2004; Keegan et al., 2009). This may be problematic given that most rural agricultural areas in Ontario, Canada primarily rely on private wells for drinking water (Goss, Barry, & Rudolph, 1998). Foodborne illnesses within the agricultural setting can occur as a result of workers consuming contaminated fruits and vegetables grown on site or through preparing and eating food with contaminated hands. The pre-harvest contamination of crops with enteric pathogens can occur as a result of contaminated irrigation water, the application of soil-amendments such as manure or reconstituted pesticides, or from wild animal droppings (Iwu & Oko, 2019; Machado-Moreira, Richards, Brennan, Abram, & Burgess, 2019; Pachepsky et al., 2011; Rajwar, Srivastava, & Sahgal, 2016). The potential of consuming contaminated fruits and vegetables is a possibility for all agricultural workers and potentially the general public as well; however, the potential of this occurrence is more probable for farmworkers whose primary role includes harvesting produce versus other roles of farmworkers (e.g., managers, farm machinery operators) in the agricultural setting.

Transmission from animal to person is another transmission route contributing to a potential enteric infection. The possibility of exposure to animal sources of enteric pathogens in the agricultural setting is likely elevated, especially when there is contact with domestic livestock animals (e.g., cattle, poultry) on site (Klumb et al., 2020; Whitfield et al., 2017). Transmission can occur as a result of touching, washing and feeding animals or from accidental ingestion from splashes of contaminated animal fluid (Mobo, Rabinowitz, Conti, & Taiwo, 2010). Transmission can also occur by coming in contact with contaminated surfaces or objects in the animal's habitat such as bedding or food, additionally contaminants can also make their way onto clothing or shoes before being accidentally ingested (Steinmuller et al., 2006). These transmission routes are also potentially more probable for farmworkers who carry out the primary duties related to animal contact, care and sanitation. In one report, an outbreak of *Campylobacter* spp. infections among farmworkers was a result of exposure to an occupational hazard (i.e., working with 6-week-old turkey poults) where occupational controls were missing (Ellis et al., 1995). Workers were given masks, but their use was not enforced, and gloves were also not used. Additionally, workers did not have access to handwashing stations with running water and soap and a dedicated break time was not scheduled, so workers ate while working.

Some transmission routes can, however, be unique to the occupational agricultural setting. For example, workers that live and work on the same site may uniquely experience increased events of cross-contamination. Pathogens in this setting can be propagated through contaminated hands, and further spread in an environment to food, water, surfaces, objects and other people in the absence of adequate hygiene practices such as handwashing or the use of personal protective equipment, where needed (Barnes, Davaasuren, Baasandagva, & Gray, 2017; Centers for Disease Control and Prevention, 2018b; Julien-Javaux, Gérard, Campagnoli, & Zuber, 2019).

2.2 The Management of Enteric Illness in Canada

Foodborne or waterborne pathogens resulting in AGIs present an important public health concern, with an estimated 20.5 million annual cases (including under-reporting and under-diagnosis) in Canada (Murphy et al., 2016). Estimating the true number of AGIs caused by foodborne and waterborne pathogens is a challenge, given the self-limiting nature of the illness where only a small proportion of cases are reported and accurately diagnosed (Keegan et al., 2009; Public Health Agency of Canada, 2012). In Canada, the burden of enteric disease is informed through the National Studies on Acute Gastrointestinal Illnesses (NSAGI) initiative, which estimates the incidence of AGI in a community from exposure to foods, animals and water that may serve as sources for enteric pathogens (Thomas et al., 2017). Most enteric illnesses are sporadic, endemic in nature and not always outbreak-related. Irrespective of outbreaks, endemic cases of enteric illnesses present significant health concerns to communities in Canada and can become difficult to control due to the challenges with reporting.

One of the roles of the Public Health Agency of Canada (PHAC) is to prevent and control the spread of infectious disease. With support and collaboration at all three levels of government including provincial ministries of health and local public health units, this objective is met through duties and functions that include reporting, investigation, management, assessment and surveillance of disease (Public Health Agency of Canada, 2021a; Public Health Ontario, 2020). Reporting of enteric illness outbreaks is a key function that is carried out by public health units across the country to meet the overall goal of preventing and controlling the spread of infectious disease. Public Health units are responsible for following all reporting protocols including promptly reporting all identified disease outbreaks to the appropriate regional channels (Manitoba Public Health Branch, 2008; Public Health Ontario, 2020). Specifically, data related to food-borne illnesses are collected and submitted by all provinces and territories to the Public Health Agency of Canada, which analyzes the data and reports on the national incidence of laboratory confirmed pathogens through the National Enteric Surveillance program, specifically capturing cases of enteric infections (Public Health Agency of Canada, 2018). The data submitted and analyzed are stripped of any patient information or other confidential information and are only grouped by province and pathogen (Public Health Agency of Canada, 2018). This type of surveillance data supports detection of outbreaks at a national level and guides public health intervention. However, it does not capture the details needed to identify populations at heightened risk as a result of their health status, occupation or living conditions at the local level and the associated specific control measures required.

2.2.1 Risk Assessment to Characterize the Spread of Disease and Inform Decision-Making

Risk assessment is an approach that can be used to characterize the risk faced by affected populations. Risk can be defined as the combined answer to the following three questions; (1) what can go wrong? (2) what is the likelihood of that happening? and (3) what are the consequences? (Kaplan & Garrick, 1981; Rausand & Haugen, 2020). Characterization of the risk to affected populations through risk assessment can be quantitively or qualitatively evaluated for a relative risk score; which is defined as the combined likelihood of occurrence and severity of the consequence from exposure to a hazard (Canadian Centre for Occupational Health & Safety, 2021b). The risk can be assessed by identifying the specific contributing hazards and the likelihood of exposure for populations at heightened risk.

The generalized risk management framework provided by the International Organization for Standardization (ISO) highlights one representation of key elements for risk management (Figure 2-1). Different risk management tools and methods can be used to identify, analyze, and evaluate risk in wide range of applications including healthcare and disaster management. The risk assessment process occurs within the overall risk management framework, which also includes the control, review and communication of the risks (International Organization for Standardization, 2009). Establishing the context as part of the overall risk management framework is the first step before conducting the risk assessment. This step requires identifying the relevant background and scope such as available data, the population at risk and the setting for application of the risk assessment.

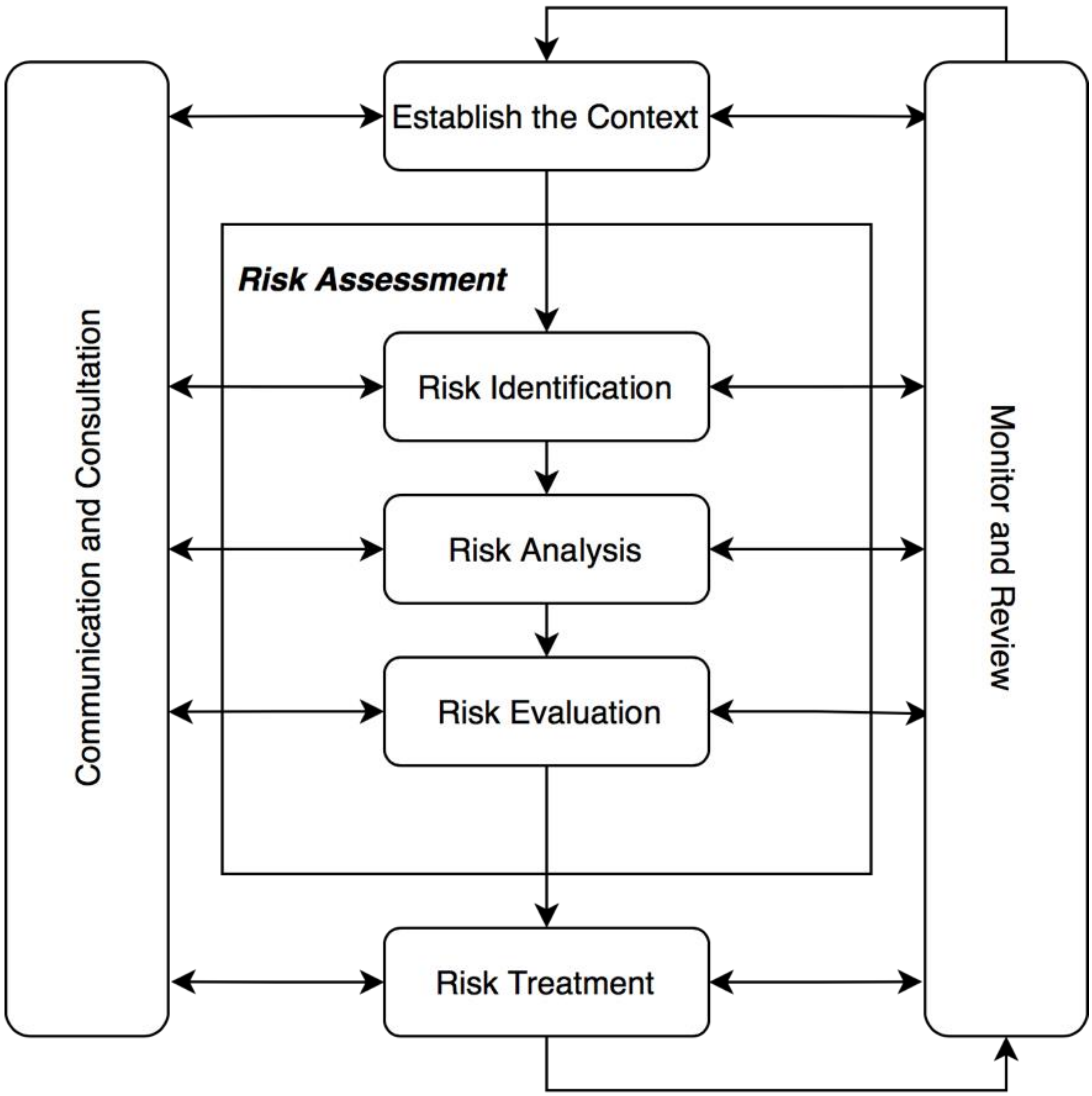


Figure 2-1: Generalized Risk Management Framework Highlighting Key Elements for Risk Management

After the context is established, the risk assessment is initiated through risk identification, which consists of identification of hazards and exposure pathways through a hazard assessment and an exposure assessment. The hazard assessment identifies the nature, location, severity and likelihood of a hazard for the established context (Rovins et al., 2015). The second element of the risk identification process is the exposure assessment identifying the population, systems or assets that are at risk within the identified context. The final step in the risk identification process is conducting a vulnerability assessment to determine the capacity of populations, systems, or assets at risk to handle a given hazard. For example, the vulnerability of a building increases with the intensity of an earthquake or decreases with improved seismic design standards (Rovins et al., 2015).

The second key step of a risk assessment is risk analysis. In this step, the objective is to understand the impact of the risk by categorizing or quantifying hazards (Praxiom Research Group Limited, 2015). There are two main types of risk analysis methods: qualitative or quantitative risk analysis. The foundational basis of both assessments is to provide a measure of risk by understanding the likelihood of occurrence and severity of consequence (Rovins et al., 2015). Qualitative risk analysis describes risk using defined descriptive terms usually representing a range of risk impact (e.g., High, Medium, Low). It is carried out after a systematic examination of hazards and is usually based on expert judgement and or personal experience (HASpod, 2019). Quantitative risk analysis calculates risk numerically, often with a level of uncertainty described. Such analysis can provide a direct measurement of the impacts of an identified hazard (HASpod, 2019). Analysis approaches can be deterministic, based on a single scenario with static inputs and fixed outputs, or probabilistic if the risk outcome is expressed as a distribution based on possible instances of the hazard (Rovins et al., 2015). Risk assessments can be generic, site-specific or dynamic, different types of assessments (i.e., generic and dynamic) can also be combined depending on the scope of work. Generic assessments are a starting point for site-specific assessments, where risk is assessed for a specific item, location, environment, or individual exposed to the hazards. A dynamic assessment is one that is constantly changing given the circumstances and the development of new information (HASpod, 2019).

Risk evaluation is the third step and requires evaluation of the risk as a result of exposure to the hazard. In the risk evaluation process, decisions on acceptability are made based on a comparison of the outcomes to a predetermined risk criterion (Rovins et al., 2015). The risk criterion will generally be dependent on the contextual situation. Risk mitigation strategies as part of the overall risk management framework and outside of the risk assessment will then follow with utilization of one of the following four strategies: risk avoidance, acceptance, transfer and limitation (Herrera, 2013; Riverlogic, 2018). Depending on the costs and benefits of certain mitigation strategies, their implementation will depend on the net cost of taking the risk or net benefit of implanting a control (International Organization for Standardization, 2009).

Having completed the risk assessment, action can be implemented through risk treatment which involves controlling the risk by implementing strategies that either reduce the likelihood of occurrence or the severity of the consequence or a combination of both for overall risk reduction. Once risk controls are defined as part of the risk treatment, monitoring and review is required to update assumptions and verify that expected results are being achieved to ensure risk controls are effective. The need for effective communication and consultation is an aspect that is required throughout the entire process of carrying out the steps of the risk management framework. This involves (1) developing a communication plan, (2) ensuring stakeholder interests are understood and considered in the assessment and (3) securing endorsements and support for the risk treatment plan (International Organization for Standardization, 2009).

2.2.2 Risk Assessment Methods and Tools

There are multiple risk assessment tools that can be used to characterize the health risks attributable to enteric pathogens from water, food and other environmental sources. The following sections explore risk assessment tools with examples from water safety, food safety and reliability engineering. The scope and objective of the work helps determine which risk management tool is most appropriate for the application (U.S. Department of Health and Human Services, Food and Drug Administration, Center for Drug Evaluation and Research (CDER), & Center for Biologics Evaluation and Research (CBER), 2006). The integration of multiple methods and tools is also possible for development of an overall risk framework. Quantitative Microbial Risk Assessment (QMRA) is a tool that is used to support water safety by identifying interventions or enhancements to meet health-based targets (Smeets, 2019; World Health Organization, 2016). Hazard Analysis and Critical Control Points (HACCP) is an approach that employs preventative methods in the evaluation and control of food safety hazards from harvest to consumption (US Food & Drug Adminstration and National Advisory Committee on Microbiological Criteria for Food, 1997). Failure Mode and Effects Analysis (FMEA) is another tool that establishes and prioritizes failure modes and effects to address reliability issues for example in mechanical, automated and technical systems before utilizing risk reduction methods (American Society for Quality, 2021; Bazu & Bajenescu, 2011).

2.2.2.1 Quantitative Microbial Risk Assessment to Support Water Safety

QMRA is an approach that often involves modelling to evaluate the risk from an exposure to a pathogenic microorganism from environmental sources (Brouwer, Masters, & Eisenberg, 2018; Haas, Rose, & Gerba, 2014). There are four key steps as part of the QMRA approach: hazard identification, exposure assessment, health effects assessment using dose-response models, and characterization of the risk. In the hazard identification step, the scope and purpose of the risk assessment is defined, including determination of the pathogen of concern and the specific context for application of the risk assessment (Brouwer et al., 2018; World Health Organization, 2016). Following the hazard assessment, an exposure assessment is carried out to evaluate the dose of pathogens to which an individual may be exposed. The exposure assessment aims to fulfil three distinct steps; identification of the exposure pathway from pathogen source to potential exposure, quantification of each component of the exposure pathway based on pathogen occurrence data, and evaluation of the magnitude and frequency of exposure to reference pathogens via the identified exposure pathways and hazardous situations (World Health Organization, 2016). Health effects data for each reference pathogen including dose-response relationships are compiled from the literature to determine the probability of infection for a given pathogen dose. Finally, the exposure and health effects information are combined to characterize the risk, often by determining a distribution of outcomes and probability of harm (Brouwer et al., 2018; World Health Organization, 2016).

QMRA is often used to ensure microbial safety of water. The tool allows for a risk-based approach to water quality management at both the regulatory and site-specific levels, covering all elements from source to exposure. QMRAs can support (1) determining whether microbial health-based targets within the specific system are achieved, (2) identifying and establishing critical limits for monitoring and (3) evaluating and choosing potential interventions for overall system planning and development (World Health Organization, 2016). QMRA can be used for the purpose of deriving operational performance targets including targets to achieve after repair work or an outage. QMRA can also provide guidance on evaluating the health risks associated with different water source types. Howard et al. (2006) provided a comparison of health risks from an enteric pathogen for different water supplies used in Kampala, Uganda. Compared water supplies included lake water treated by conventional treatment and transported via piped networks to homes, water collected from standpipes and water collected from local springs. Results showed the highest estimated occurrence of disease was connected to water collected in containers from the springs and the standpipes, highlighting the need for effective household water treatment and safe storage for the protection of public health.

2.2.2.2 Hazard Analysis and Critical Control Points for the Evaluation and Control of Food Safety Hazards

HACCP is a systematic approach that utilizes preventative methods in the evaluation and control of food safety hazards from harvest to consumption. The approach attempts to avoid hazards by introducing control strategies throughout the process rather than attempting to inspect and manage effects of the hazard at the end of the process (Buchanan & Whiting, 1998). To ensure food safety, seven principles are used to develop HACCP plans aimed at meeting this goal. HACCP principles include:

"(1) conducting a hazard analysis, (2) determining the critical control points (CCPs), (3) establishing critical limits, (4) monitoring procedures, (5) establishing corrective actions, (6) establishing verification procedures, and (7) record-keeping and documentation procedures" (US Food & Drug Adminstration and National Advisory Committee on Microbiological Criteria for Food, 1997).

Principle one aims to develop a list of-hazards that can cause harm including injury or illness. This is done by carrying out a hazard identification to identify hazards at every step of the process. This is followed by the hazard evaluation stage, which evaluates each hazard based on likelihood of occurrence and severity of the potential harm. An example of hazard analysis can be applied to the crop production of lettuce plants. The hazard identification helps to determine enteric pathogens such as *Salmonella* spp. and enteropathogenic *Escherichia coli* as possible hazards based on outbreak data of foodborne illness from lettuce, and the associated control measure can be adequate washing prior to consumption to eliminate the hazard (Food and Drug Administration, 2008). Principle two of the HACCP plan includes determining Critical Control Points (CCPs). Control points can be introduced at hazard locations for elimination, prevention, or reduction of possible contamination. An example of a critical control can include a specific process aimed at destroying or inactivating a pathogen such as disinfection processes. Principle three is closely related and is associated with establishing critical limits of maximum and/or minimum values of temperature, time, or other parameters that must be controlled at a specific CCP. Principles four and five highlight the need to monitor hazards and the effectiveness of the CCP, followed by establishing corrective actions if deviation from the process occurs or if CCPs are no longer effective. Principle six ensures the verification of the HACCP plan to ensure that the plan is valid; such verification is usually carried out by a third party. Finally, principle seven ensures that details of the HACCP Plan including the hazards, CCPs, and all monitoring, corrective actions and verification records are generated and maintained (US Food & Drug Adminstration and National Advisory Committee on Microbiological Criteria for Food, 1997).

2.2.2.3 Failure Mode and Effects Analysis to Detect System-Based Threats to Safety

FMEA is an approach for reviewing as many components, assemblies, processes, and systems as possible to identify all possible modes of failure and determine the consequences of those failures. The approach breaks down complex processes or systems into smaller tasks, subsystems, or inputs, identifies all possible modes of failure and assesses the relative risk of different failures for every task, subsystem, or input. Once all the failure modes for every step are determined, the failures are scored and prioritized according to the level of consequence, the frequency of occurrence and how easily failures can be detected given the current controls in place. The product of these factors for each failure mode helps determine the overall effect of the failure on the process or system, highlighting the highest-priority failures that need to be dealt with first for failure reduction or elimination (Bazu & Bajenescu, 2011). The prioritization of failure modes aids in identifying specific actions, such as adding control measures where they do not currently exist or decreasing the frequency of the failure occurring. Current knowledge and results from FMEAs are usually documented and updated as processes and systems evolve for continuous improvement. In addition to using FMEA to assess existing processes and systems, the approach can also be used at the initiation stage to prevent failure and used through the lifecycle of processes or systems to control and manage failures (American Society for Quality, 2021).

FMEA as a risk tool is usually used in the assessment of industrial manufacturing to examine the failure modes of specific components. Very few studies have looked at applying the FMEA methodology in the assessment of health risks, especially those that are related to infectious disease. One study by Yanagisawa et al. (2018), however, modified and adapted the FMEA methodology to examine the current control for dengue disease detection and assessment. The approach looked at the spread of communicable disease through secondary transmission from one person to another in the case of large assemblies with international visitors. The FMEA approach was used to identify existing failures and effects and evaluate existing controls associated with the following three processes: the process of detecting disease including failing to identify cases among visitors upon entry, the process of assessing disease including physicians failing to accurately diagnose cases at hospitals, and the patient communication process which can include failures in communicating symptoms. Results showed gaps in three specific areas where new controls can be added, and existing controls can be strengthened. It was recommended that increased and specific infectious tropical disease training be offered to physicians to help them better recognize disease. It was also recommended to provide training and resources to places offering accommodations and that multi-language services be strengthened for improved communication in the health sector.

2.3 Migrant Farmworkers and Enteric Disease Exposure in the Seasonal Agricultural Worker Program Occupational Setting

Enteric diseases may pose elevated health risks to certain populations as a result of their health status, occupation or living conditions. These populations include the very young, the elderly, those who are immunocompromised as well as those with frequent and direct exposure to sources of enteric pathogens. As mentioned in section 1, some workers face increased occupational exposure to biological contaminants (Adam-Poupart et al., 2021) as a result of their jobs (e.g., food handlers, healthcare workers and farmworkers). In addition to increased exposures, populations living in congregate living arrangements (e.g., long-term care facilities, group homes, bunk houses) may also experience potentially elevated health risks because congregate settings influence the extent of spread through secondary transmission from one person to another via contaminated hands and surfaces (Centers for Disease Control and Prevention, 2018a; Health and Social Services - Government of Northwest Territories., 2007; Jones & Shortt, 2010). Farmworkers are a population that may experience exposure to pathogenic microorganisms capable of causing enteric infections as a result of their occupational duties; the effects of those exposures may be further magnified for seasonal migrant farmworkers in the SAWP as a result of their living conditions. The occupational setting for migrant farmworkers typically includes onsite congregate living quarters due to the requirement for employers to provide accommodations for the duration of their stay (Canadian Council for Refugees, 2018; Hennebry, 2009; McLaughlin et al., 2014; The North-South Institute, 2006).

Only preliminary research has looked at the spread of infectious disease in the migrant farmworker context. No study has done empirical work or synthesized relevant research to comprehensively identify enabling factors of infectious disease or describe the routes of transmission in the Canadian SAWP setting. However, some relevant work in the United States, which is similar to the Canadian agricultural context, has indicated that risks associated with enteric infectious disease could be higher, and generally pointed to many health risks experienced by migrant farmworkers during their tenure in the occupational setting (Anthony et al., 2008; Arbab & Weidner, 1986; Arcury & Quandt, 2007; Oren et al., 2016). While, most studies related to the health of migrant farmworkers are based in the US, there is a growing amount of literature that describes the experience of migrant farmworkers in Canada and suggests that workers experience similar health risks to those in the United States (Hennebry & Preibisch, 2008; McLaughlin, 2009; Preibisch & Hennebry, 2011; Pysklywec, McLaughlin, Tew, & Haines, 2011; Sargeant & Tucker, 2009). Additionally, there is also epidemiological evidence which points to migrant farmworkers' health risks associated with enteric disease (Frisvold et al., 1988; Hennebry & McLaughlin, 2012b; Hennebry & Preibisch, 2008; McLaughlin et al., 2012; Orkin et al., 2014; Preibisch & Hennebry, 2011).

2.3.1 The Migrant Farmworker Occupational Setting

The migrant farmworker occupational setting is often geographically isolated in rural areas where workers are employed at farms, greenhouses or nurseries and temporarily live at the same site in congregate housing. Migrant farmworkers are assigned occupational roles in rural agricultural areas across Canada but are concentrated in the provinces of Ontario and Quebec (Figure 2-2). From 2015 to 2020, the number of workers has been consistent year after year with slight fluctuation in some provinces. Given the structure of the SAWP and the naming system which allows employers to request workers by name, most workers will work on the same farm year after year. In Ontario, workers are mainly concentrated in a few key geographic areas (Figure 2-3) with some spread throughout the rest of southwestern Ontario. Key areas include Haldimand County and Norfolk County, the latter of which has been dubbed Ontario's garden and leads in the growing of pumpkins, strawberries, asparagus, cabbage, peppers and other vegetables (Norfolk Tourism, 2020). Another key area is the Niagara region which leads in the production of Ontario's tender fruit including peaches, cherries, pears, plums, prunes and grapes (Niagara Economic Development, 2020). Windsor-Essex County is another key area known as a major grower of field tomatoes with some of the largest (i.e., square footage) greenhouses (Essex County Federation of Agriculture, 2015).

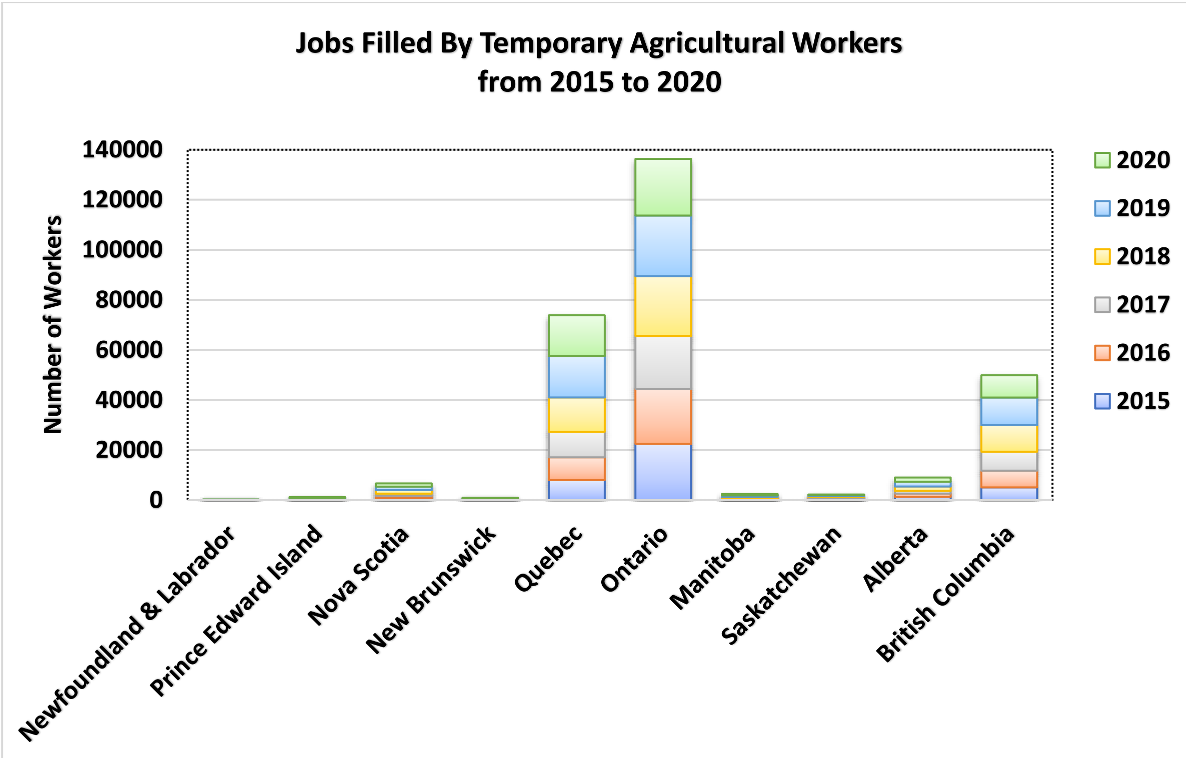


Figure 2-2: Jobs Filled by Temporary Agricultural Workers in Canada from 2015 to 2020

Data From: Government of Canada (2021a)

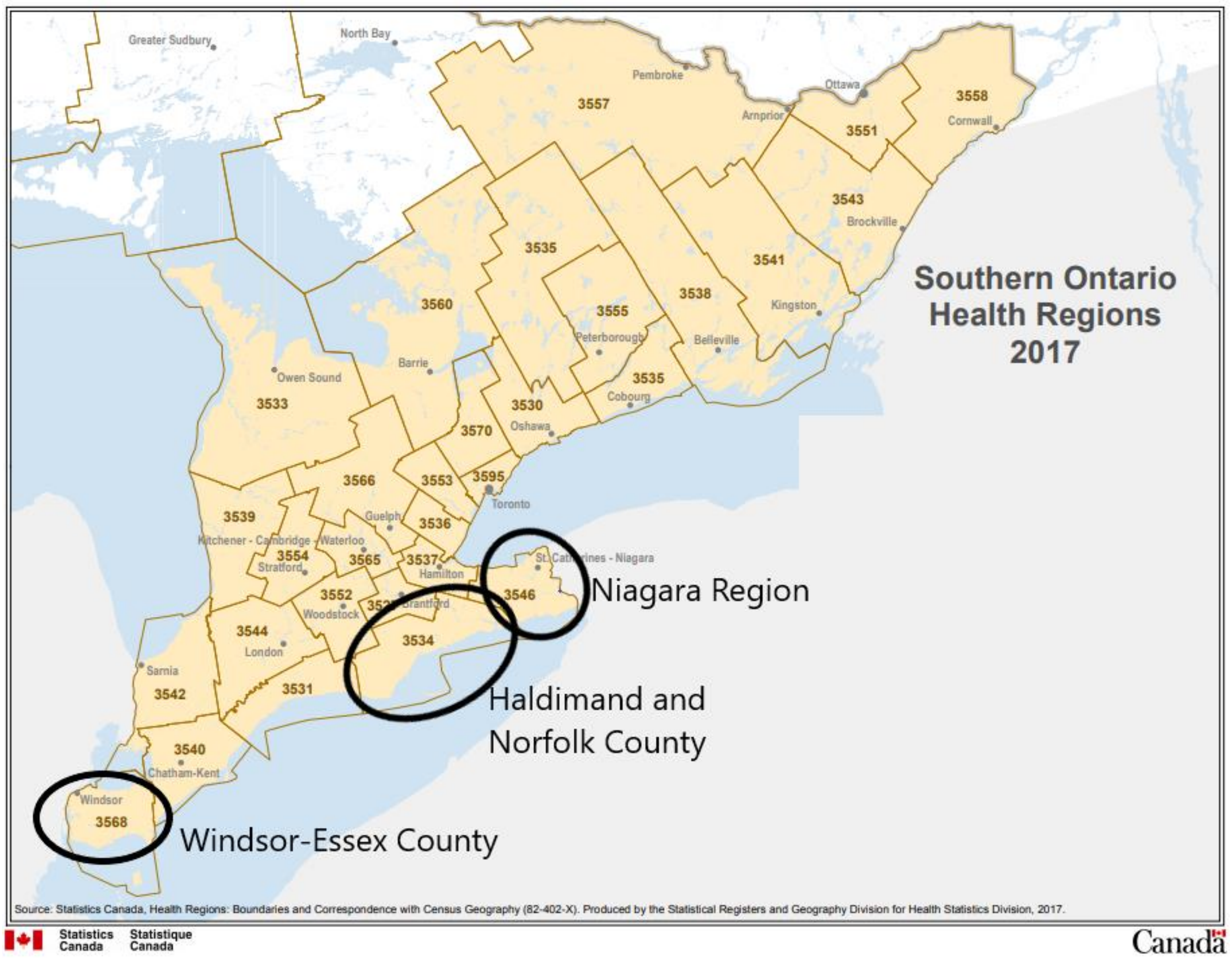


Figure 2-3: Map of Health Regions in Southwestern Ontario Indicating Geographic Locations with a High Number of Migrant Farmworkers Recruited Under the SAWP

Source: Reproduced from the Statistical Registers and Geography Division for the Health Statistics Division, 2017. Statistics Canada, Health Regions: Boundaries and Correspondence with Census Geography, (82-402-X).

The occupational setting for migrant farmworkers can include orchards, fields, barns, food processing facilities, greenhouses or nurseries where workers are required to complete occupational duties related to primary agricultural activities. Primary agricultural activities are defined as "work duties that must be performed within the boundaries of the farm, greenhouse, or nursery" and involve activities such as the "planting, care, harvesting or preparation of crops, trees, sods or other plants and the boarding, care, breeding, and sanitation of animals or other handling of animals for the purposes of obtaining raw animal products for market" (Employment and Social Development Canada, 2020b).

Under the employment contract for the SAWP, employers are responsible for providing workers with transportation and adequate accommodation for the duration of their stay. Employer-provided accommodations to fulfil this requirement have previously included trailers, portables and new and modified farm buildings. Housing is typically congregate and is often located on the farm, which in many cases is also the employer's property (Hennebry & Mclaughlin, 2016). As part of the Labour Market Impact Assessment (LMIA), which is part of the approval process for employers to hire temporary foreign labour, housing inspections are required for submission to ESDC for application approval. Initial inspections are typically carried out by local public health units or municipal housing inspectors, and guidelines vary across municipalities though most include a review of general construction, washroom and sewage facilities, occupancy densities, water supply, garbage control and safety (Employment and Social Development Canada, 2020b; Haldimand Norfolk Health Unit, 2010; The Town of Niagra on the Lake, 2016). Existing literature has identified concerns related to the housing provided, including proximity to sources of pathogenic microorganisms (i.e., storage of managed manure), overcrowded facilities (Preibisch & Hennebry, 2011), deteriorating dwellings lacking indoor plumbing (Preibisch & Otero, 2014), insufficient handwashing and toilet facilities (Salami, Meharali, & Salami, 2015), inadequate food refrigeration and storage (Preibisch & Otero, 2014), inadequate food preparation areas and deficient cleaning facilities and supplies (Hennebry & McLaughlin, 2012b), reliance on temporary water and wastewater infrastructure including the use cisterns and septic tanks (S. Ciesielski, Handzel, & Sobsey, 1991) and overall infrequent inspections (Yousefi, 2009).

2.3.2 Overview of the Seasonal Agricultural Worker Program (SAWP)

Annually, approximately 50,000 seasonal migrant farmworkers, mainly citizens from Mexico and the Organization of the Caribbean States, enter Canada to participate in the long-standing Seasonal Agricultural Worker Program. The SAWP is a federally managed labour migration program and a specialized component of the Temporary Foreign Worker Program set up to respond to a labour shortage in the agricultural sector (Canadian Council for Refugees, 2018). The SAWP is the primary program established to recruit seasonal migrant farmworkers and began with a partnership with the Commonwealth Caribbean in 1966 that later expanded to include partnership with Mexico in 1974. Workers recruited as part of the program are recruited under the National Occupational Classification categories C&D. Category C defines roles as intermediate positions requiring job-specific training and category D defines roles as labour jobs with on-the-job training (Government of Canada, 2021a). For the last 50 years, this program has facilitated the organized entry of skilled farmworkers into Canada for up to eight months annually (Hennebry, 2009; The North-South Institute, 2006).

Migrant farmworkers' annual participation in the SAWP makes them an experienced, reliable and consistent workforce (Hennebry & McLaughlin, 2016). Access to this workforce on a consistent basis has enabled agricultural businesses to access very competitive markets that would not have been accessible with a domestic workforce under the Employment Standards Act, but is possible with a migrant farmworker labour force that is excluded from many parts of the Act (Preibisch, 2010). The growth of the SAWP has transformed the Canadian agricultural industry, shifting Canada into a net exporter from a net importer of key crops and accounting for about 6.7% of Canada's total GDP (Agriculture and Agri-Food Canada, 2017; The North-South Institute, 2006). In 2017, 27.4% of employees in crop production were foreign workers (Migrant Workers Alliance for Change, 2020). The majority of workers participating in the SAWP are males and are at least 30 years old, with an average age of 37.97 years (Hennebry & Preibisch, 2008). Older workers are likely to be selected for participation in the program as they are less likely to remain in Canada permanently. The average number of years that workers participate in the program is approximately 10 years for Jamaican workers and about seven years for Mexican workers (Hennebry & Preibisch, 2008). Participation of migrant farmworkers in this program ensures a reliable and skilled work force, especially in aiding to meet key dates for planting, and harvesting of crops (The North-South Institute, 2006).

2.3.3 SAWP Requirements

The SAWP is jointly organized by Canada and participating countries[1] according to bilateral agreements that outline the objective and identify the roles of each party to bring workers in as part of the SAWP (The North-South Institute, 2006). The agreements stipulate that sending countries have to recruit workers, ensure they have all the required documentation, appoint a representative from the country of origin to aid workers in Canada and maintain a list of qualified workers (Employment and Social Development Canada, 2020b). Workers selected for participation in the program additionally must meet a certain set of requirements prior to participation. They must be at least 18 years of age, have experience in farming, be a citizen of the sending country and meet all immigration laws of both Canada and the sending country (Employment and Social Development Canada, 2020b). Canadian employers must first obtain approval to recruit migrant farmworkers by submitting an LMIA document, where employers are required to justify the impact of hiring foreign labour on the Canadian labour market. If the application highlights that the region or industry is healthy enough to sustain foreign labour and efforts have been made to hire Canadian workers, then the request is accepted and a positive LMIA is issued. Once the need has been established and the request accepted, the sending countries select and recruit participants in the program. An additional requirement as part of the LMIA application is for employers to provide housing and to ensure that housing is inspected within 8 months of when workers are expected to arrive. Documentation for a valid work permit for the duration of the work period includes submitting a valid medical clearance, which ensures workers are fit to work and are generally healthy without any signs of illness or disease, for approval by a Canadian immigration office a couple of months before arrival of workers into Canada. Given the current COVID-19 pandemic, workers coming into Canada need to also present a negative COVID-19 test within 72 hours of a scheduled flight to Canada (Government of Canada, 2021b, 2021d). After completion of the administrative part of the program, workers are then sent to specific farms to start their work term. Upon arrival, participants, or the representative of the sending country, and the employers sign an employment agreement. The agreement identifies rights and obligations and is the final requirement of the program. Items in this contract include elements such as minimum hours of work, housing, health coverage, access to worker compensation, transportation, wages, meals and repatriation of workers (i.e., a clause in the contract available to employers). Once these agreements are signed, workers begin their work term at the assigned occupational location. Generally, federal program requirements as a result of the COVID-19 pandemic have mainly been related to implementing quarantine measures (Government of Canada, 2021d).

[1] Anguilla, Antigua and Barbuda, Barbados, Dominica, Grenada, Jamaica, Montserrat, St. Kitts-Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, and Mexico

2.4 Occupational Health Hazards and the Associated Controls in the SAWP Occupational Setting

The agricultural occupational setting presents workers with an array of biological, chemical, physical and psychosocial hazards that can negatively impact worker health (Sargeant & Tucker, 2009). Migrant farmworkers are primarily hired as general farm labourers and seasonal harvesters (Hennebry, 2008), and can face many of these hazards as part of their occupational duties. The term hazard is defined as the potential to cause harm, and occupational hazards are defined as items, tasks, or situations with the potential to harm a worker in the workplace (Canadian Centre for Occupational Health & Safety, 2021b). Workers can become exposed to hazards, which can then lead to a potential harm (e.g., enteric infection). Occupational hazards are generally split into two main categories: safety hazards associated with accidents leading to physical injuries and health hazards associated with exposures leading to illness and the development of disease. Certain hazards pose varying levels of risk, depending on the impact and frequency of exposure to the hazards. Removing hazards in the workplace is one way of protecting workers in the agricultural occupational setting; however, workplaces often have to manage the risks associated with the hazards through controls such as the provision of personal protective equipment or training (Ontario Ministry of Labour Training and Skills Development, 2016).

Hazards in the workplace generally need to be identified before they are assessed and eliminated, or if necessary controlled or managed. Hazard identification is an important part of the process that includes understanding how workers are exposed to the hazards and determining if the hazard can cause harm. In the occupational migrant farmworkers setting, hazards can be identified by determining workers' job responsibilities and tasks and how they are completed. Hazards generally can be controlled at the source, along the pathway leading to worker exposure or just before worker exposure to the hazard. Risks posed by the hazards can be controlled using one of four main methods, depending on the hazard: (1) elimination of the hazard by removing it completely, (2) engineering controls such as designing or modifying processes to reduce worker exposure, (3) administrative controls such as job schedules, work-rest cycles, training and hygiene practices that reduce the amount of time a worker is exposed to a hazard, and finally (4) personal protective equipment such as gloves or masks (Ontario Ministry of Labour Training and Skills Development, 2016).

2.4.1 Occupational Health Hazards in the SAWP Setting

Occupational health hazards include exposure to disease-causing microorganisms or chemicals because of workplace conditions. The resulting illnesses can vary in severity from acute illnesses such as a headache or a skin rash to a chronic disease such as recurring gastroenteritis or cancer (Ontario Ministry of Labour Training and Skills Development, 2016). Many occupational hazards and the illnesses they cause are recognizable, while others are not. Regardless, a critical consideration for risk management, and mitigation specifically, is how workers are exposed to the hazards. The agricultural occupational setting, given the scale of operations in comparison to the smallholding or hobby farms setting, inherently presents more opportunities for worker exposure to health hazards such as enteric pathogen sources associated with animal waste, manure-based field applications, contaminated irrigation water, and crop management. The following sections summarize health hazards and hazardous situations leading to exposure to enteric pathogens in the SAWP occupational agricultural setting.

2.4.1.1 Animal Sources

The care, breeding, sanitation and handling of animals and the management of raw animal products (e.g., raw milk, or eggs) can present workers with the possibility of exposure to biological, physical and chemical hazards. Zoonotic pathogens are biological hazards that originate in animal sources. Exposure to animal sources of enteric pathogens is likely elevated for migrant farmworkers in the SAWP because of proximity to animals in this occupational setting. As outlined in the SAWP (Employment and Social Development Canada, 2020b), migrant farmworkers may be assigned tasks that include contact, care and sanitation of animals as part of their job duties. Workers are therefore exposed to unique occupational hazards as compared to that of other farmworkers who do not deal with animals (e.g., managers, farm machinery operators) or as compared to the general public. Zoonotic pathogens may be bacterial, viral or parasitic and can spread from animals to humans through direct contact or through contaminated food, water or the environment, ultimately causing illness in humans (World Health Organization, 2020). Direct exposure to zoonotic pathogens includes exposure via accidental ingestion from hands touching contaminated surfaces, objects and animal waste (Mobo et al., 2010). Evidence of exposure from animals to workers in the occupational setting includes documented occupational cases of *Campylobacter* spp. infections among poultry workers (Wilson, 2004).

2.4.1.2 Field Applications

A potential hazard that can lead to exposure to enteric pathogens in the agricultural setting is the preparation, handling and use of animal manure for soil amendment (Beuchat, 2006; Stine, Song, Choi, & Gerba, 2005). Given the soil characteristics and conditions and depending on the time of application and source of manure utilized, fields can become reservoirs for enteric pathogens. Internal conditions such as the soil type, moisture content and pH, as well as the sources of manure, can impact the persistence of enteric pathogens in the soil (Iwu & Oko, 2019). Additionally, the application process, including aeration of the manure, the physicochemical properties of the soil and external conditions such as rainfall and temperature, can also play a role in the persistence of enteric pathogens within manure-amended agricultural soils (Beuchat, 2006; Iwu & Oko, 2019). Workers can be exposed to pathogens during the handling or application of manure via occupational exposures (Sobsey, Khatib, Hill, Alocilja, & Pillai, 2011). Manure management best practices can, however, reduce the potential of exposure to enteric pathogens in manure or manure amended soil. Best practices include taking into consideration things such as the number of turnings, the timing required for manure to compost, as well as active monitoring of the manure pile temperature and finally consideration of application practices as controls for pathogen inactivation (Manyi-Loh et al., 2016; Spiehs & Goyal, 2007).

An additional hazard tied to field applications in the agricultural setting includes the use of reconstituted pesticides. Ng et al. (2005) suggested that reconstituted pesticides can potentially become a source of microbial contaminants with a potential exposure to enteric pathogens. The authors looked at ten commercially available pesticides used mainly in the cultivation of vegetables. The pesticides showed no presence of microorganisms as purchased; however, after being reconstituted with water, pesticide samples showed microbial growth and survival. Pesticides were reconstituted with sterile, bore, dam and river water, to assess the extent of microbial growth. Pesticides reconstituted with untreated water sources supported the growth and survival of *Salmonella* spp. and *E. coli* as a result of the water sources, although not all pathogenic species, in nine of the ten pesticides studied. Untreated water used to reconstitute pesticides was also found to include human norovirus (Verhaelen, Bouwknegt, Rutjes, & de Roda Husman, 2013).

2.4.1.3 Irrigation Water Sources and Methods

Irrigation water sources and the methods of irrigation used on site also present a health hazard to workers with a potential exposure to enteric pathogens in the agricultural setting. Water used for irrigation can be from many sources, either treated or untreated. Untreated water sources include surface water, rainwater and groundwater, while treated water sources are usually municipally supplied or treated on site for the purposes of irrigation (Uyttendaele et al., 2015). Understanding of pathogen occurrence in source water types is essential for understanding the microbial risk of a selected water source. Pathogen occurrence in surface and groundwater sources can be impacted by many factors including physical, chemical, and can be influenced by a range of human activities and animal sources. Impacts from these factors on the microbial quality of source water can be reduced by barriers against contaminants and protection of water sources (WHO, 2013).

In the agricultural setting surface water sources used for irrigation can often become contaminated, with enteric waterborne pathogens being present in higher amounts as compared to treated water sources (Uyttendaele et al., 2015). Surface water sources in the agricultural setting are likely to be contaminated from things such as livestock or wildlife feces, storm runoff or runoff from manure storage and potentially from faulty septic systems (Jones & Shortt, 2010). Rainwater sources used for irrigation are generally of relatively good microbial quality relative to surface water, but their quality also varies considerably (Uyttendaele et al., 2015). Depending on the collection system, its location, and how it is transported and applied, rainwater can be contaminated with enteric pathogens from animal droppings in the collection system or from mixing with other stormwater runoff, which can also be contaminated. Groundwater sources used for irrigation are also typically of good microbial quality in comparison to surface water, however, they too can be variable; shallow sources are more typically vulnerable to contamination (Tufenkji & Emelko, 2011), though even very deep sources may be contaminated as well and may require treatment prior to consumption (Emelko et al., 2019). Generally, groundwater from deeper aquifers is less variable in microbial load than rainwater (Uyttendaele et al., 2015). The relative risk of contamination, therefore, varies depending on the water source used. In the agricultural setting, the fate and transport of pathogenic microorganisms with regard to the irrigation water source is an important consideration. Pachepsky et al. (2011) reviewed contamination of irrigation water by pathogens and summarized the factors that affect microbial quality (Figure 2-4). Their review identifies inputs such as directly deposited animal waste and mechanisms such as runoff by which microbial quality of irrigation water is impacted in the agricultural setting.

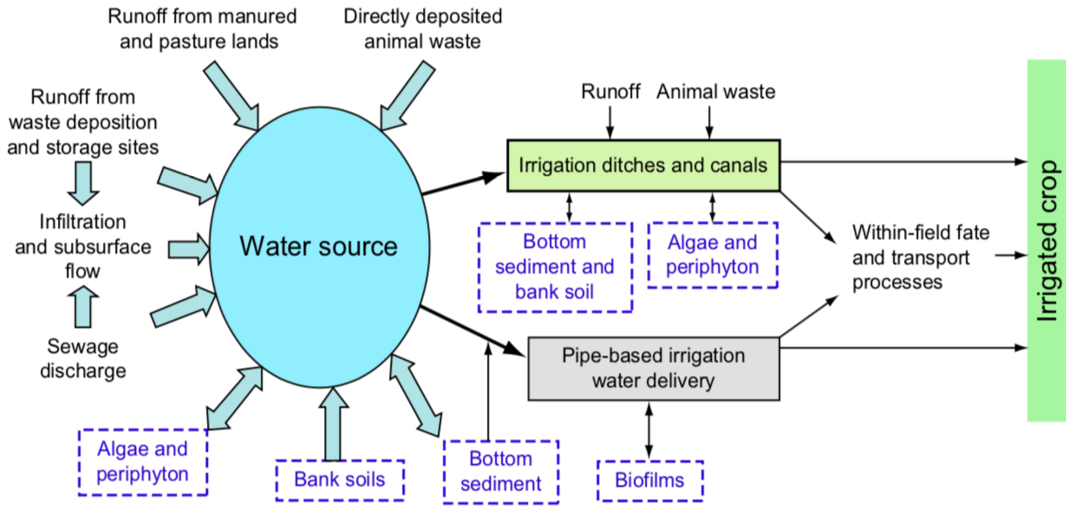


Figure 2-4: Factors Impacting Microbial Quality of Irrigation Water in the Agricultural Setting

Source: Reprinted from Advances in Agronomy, 113, Yakov Pachepsky, Daniel R Shelton, Jean E T Mclain, Jitendra Patel, Robert E Mandrell, Irrigation Waters as a Source of Pathogenic Microorganisms in Produce: A Review, 73-137, Copyright (2011), with permission from Elsevier.

Irrigation water used in Canada includes surface and groundwater sources. In a survey of agricultural water usage, 68% of irrigation water used was from off-farm water sources including private irrigators and provincial or municipal sources, 27% was from on-farm surface water and 3% was from on-farm groundwater sources (Statistics Canada, 2019). Surface water in Canada include lakes, rivers, creeks, ponds and springs that come to the surface, while groundwater sources include the use of wells (Jones & Shortt, 2010). Additional data from Statistics Canada showed that in 2010, 3260 farms obtained at least some of their water for irrigation from on-farm lakes and rivers, while another 1555 farms drew at least some of their water from on-farm wells (Statistics Canada, 2010). Globally, reclaimed wastewater is also becoming an increasingly used source of irrigation water. In Western Canada, specifically, 55 farms were identified to have used at least some treated wastewater (unknown type) for irrigation to supplement on-farm water sources (Statistics Canada, 2010). The use of wastewater for irrigation was examined as a potential health hazard facilitating exposure of farmworkers in Ghana to enteric pathogens. Although the specific details of the study may be irrelevant to the Canadian context given that untreated wastewater is not used for irrigation, it highlights the occupational hazard facing workers, nonetheless. The results showed that farmworkers experience a higher probability of being infected by *Cryptosporidium* due to frequent exposure to wastewater as compared to the risk to consumers of wastewater irrigated produce (Sampson et al., 2017).

The movement and transfer of pathogens in irrigation water are also influenced by the irrigation method used, where the impact and degree of exposure is dependent on the irrigation method. In Canada, there are three main categories of irrigation methods: sprinkler, micro-irrigation and surface irrigation. Sprinkler methods, also known as overhead methods, spray the top of crops at high-velocity and high-volume rates and is the most common method used by farms in Canada (Statistics Canada, 2010). Micro irrigation systems can include drip and subsurface mechanisms where crops are watered close to the surface. Drip methods allow for minimum contact between the above-ground portion of the crop and the irrigation water, and subsurface methods irrigate below the soil surface where water is guided towards the plant root system directly (Stine et al., 2005). Surface irrigation methods including flood and furrow techniques, flow water down trenches over the soil (Machado-Moreira et al., 2019). In one study, the presence of *E. coli* O157:H7 on lettuce was compared between plants irrigated using spray and surface methods (Solomon, Potenski, et al., 2002). *E. coli* detection was much higher (29 of 32 plants compared to 6 of 32 plants when spray methods were used. Notably, nine of 11 plants remained positive with *E. coli* O157:H7 for a minimum of 20 days after spray irrigation (Solomon, Potenski, et al., 2002).

Workers can be exposed to irrigation water potentially contaminated with enteric pathogens during use or through contact with crops contaminated with the irrigation water via spraying or splashing (Kudva, Blanch, & Hovde, 1998; Rajwar et al., 2016). The extent of a potential exposure depends on the type of irrigation method used. In a study looking at the primary production of berries, the potential for microbial contamination was shown to increase if there is contact between the crop and the untreated irrigation water (Nestlé Research Center, 2016). It was recommended that spray or overhead irrigation methods be reduced and alternative methods such as drip methods be used instead. The microbiological risk associated with water source and irrigation method is illustrated below (Figure 2-5), where the microbiological risk is highest with flood and overhead methods and is reduced with furrow and drip methods. Given the impact of irrigation water sources and methods on microbial contamination, the consideration of irrigation water source and method as hazards is necessary in this occupational setting.

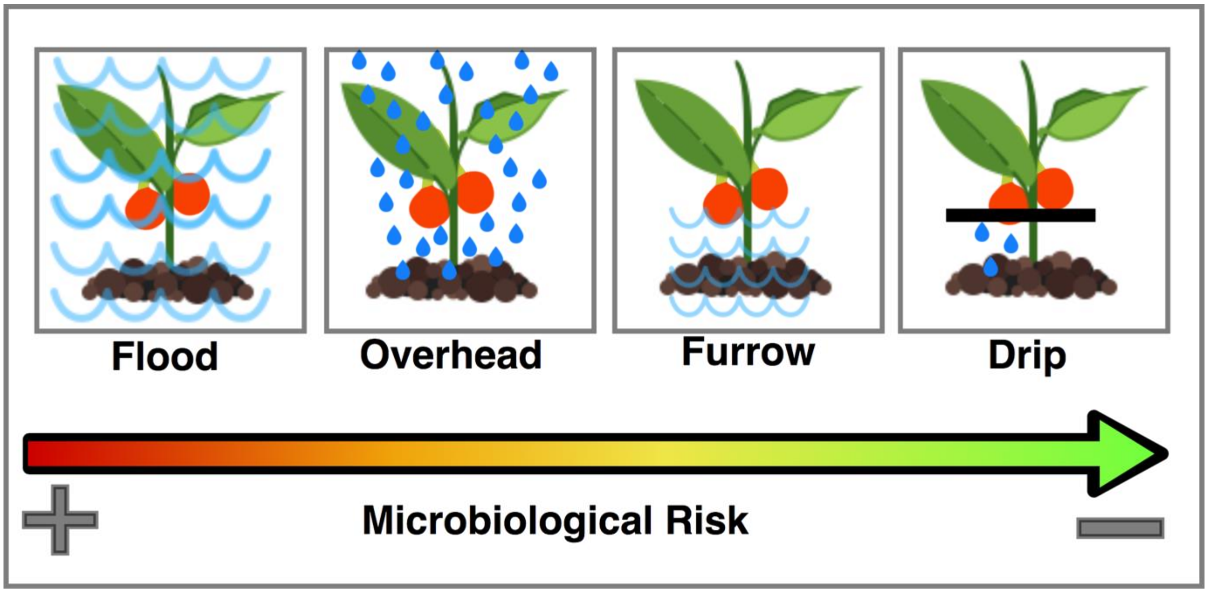


Figure 2-5: A Relative Comparison of Microbiological Risk Varying by Irrigation Method, Moving from the Highest Relative Risk (Flood) to the Lowest Relative Risk (Drip)

Source: Reproduced and Adapted from Nestlé Research Center (2016)

2.4.1.4 The Management of Crops

The duties related to the management of farm commodities such as the planting, cultivating and harvesting of crops and other plants such as trees and sod can also contribute to hazards facing workers in the agricultural occupational setting. Hazards can be as a result of the crop type or crop growth location. The adherence of pathogens within a plant can be crop-specific (Beuchat, 2006; Olaimat & Holley, 2012; Pachepsky et al., 2011), which can result in varying levels of worker exposure to the hazard when handling crops. Plant phytotomy, which describes the anatomy of the plant, plays a role in how and where pathogens adhere to the crop. Parts of the crop exposed to wetting are key areas of bacterial growth and biofilm development (Olaimat & Holley, 2012). The adherence of pathogens to crops was mainly found within damaged and scarred tissues where microbial growth was promoted (Aruscavage, Miller, Lewis Ivey, Lee, & LeJeune, 2008). Pathogens may also reach the plant surface by way of soil amendments including use of manure or through use of untreated irrigation water. This can happen when heavy rain or spray irrigation cause some splashing and spraying to occur, moving pathogens from the soil to the crop or from the irrigation water to the crop (Kudva et al., 1998; Rajwar et al., 2016). The literature also shows evidence of potentially strong pathogen-produce combinations associated with major foodborne outbreaks (Anderson et al., 2011). The presence of *Salmonella* spp. is strongly associated with tomatoes and cantaloupes, while the presence of *E. coli* O157:H7 is mainly linked to leafy green vegetables (Denis, Zhang, Leroux, Trudel, & Bietlot, 2016; Olaimat & Holley, 2012). In one study *E. coli* prevalence was highest in parsley (13.4%) and organic leaf lettuce (11.6%) in a microbial survey of 1183 fresh fruits and vegetables grown in Ontario (Arthur, Jones, Fabri, & Odumeru, 2007).

Crop growth location, including raised crops, crops with limited to no ground contact and crops with direct ground contact was considered by the World Health Organization (2016) as a potential factor of microbial crop contamination. Crops with direct ground contact were deemed to have an increased potential for microbial contamination. This is an important consideration, as workers handling crops with direct ground contact may also face an increased possibility of an exposure to enteric pathogens. As such, the tasks associated with crops can present a workplace hazard that contributes to the possibility of a microbial exposure given parameters such as crop type and pathogen adherence as well as crop growth location.

2.4.1.5 Congregate Living Settings

Most migrant farmworkers in Canada are usually housed in on-farm congregate housing, effectively at or near their workplaces; as such, it is also relevant to discuss their living conditions as occupational hazards. Further, since migrant farmworkers in Canada under the SAWP are required to live in housing provided by employers (which is typically on farm sites), most provincial workers' compensation insurance systems (e.g., Workplace Safety and Insurance Board in Ontario) consider worker housing to be an extension of their workplace, and therefore workers' compensation covers injuries and illness in relation to housing (McLaughlin et al., 2012; WSIB, 2009). Congregate housing as an extension of the workplace presents the potential for occupational hazards related to issues of proximity to sources of pathogenic microorganisms (Arcury, Lu, Chen, & Quandt, 2014). It can also affect the potential for secondary transmission if a worker develops an enteric infection, the impacts of which may be magnified with crowding in the living site (World Health Organization, 2021).

Proximity to animal living sites and storage of reconstituted pesticides and manure is a hazard presenting workers with a potential exposure to enteric pathogens. Additional issues discussed in the literature focus on the interior of buildings used to house migrant farmworkers with concerns about housing reported in surveys of workers in different locations across Canada. In Ontario, approximately 50% of 600 workers noted that their housing was overcrowded and poorly ventilated (Preibisch & Hennebry, 2011), while 37% of workers in British Columbia noted that their housing contributed to deteriorating health (Preibisch & Otero, 2014).

The relationship between household crowding and close contact infectious disease (CCID) was examined by Baker et al. (2013) in a systematic review of internationally published studies. It showed that 55% (189/345) of the studies found a positive association between crowding and the risk of contracting CCID. Details of the type of infectious disease among the studies that found a positive association were consistent across enteric diseases (59%), dermatitis/ocular infections (59%) and respiratory diseases (51%). They concluded that household crowding was a main factor in the transmission of CCIDs. Notably, the wide spread of respiratory illness in the migrant farmworker occupational setting was evident with outbreaks of COVID-19 cases, with at least 2,230 positive cases and four deaths as of May 2021 (Mojtehedzadeh, 2021). Additional evidence of crowding increasing exposure to enteric pathogens was reported in a study of the prevalence of *Cryptosporidium* infection among adults (25%), children (17%) and infants (20%) in Andhra Pradesh, India. *Cryptosporidium* prevalence was mainly attributed to high density living in close contact with domestic animals in rural agricultural areas (Sahimin, Douadi, Yvonne Lim, Behnke, & Mohd Zain, 2018). Crowding in migrant farmworker living arrangements has also been tied to overloading the design capacity of on-site sanitary disposal systems (Migrant Clinicians Network, 2017). The use of septic tanks in housing for migrant farmworkers is very common given that most locations are remote. In a study looking at worker living sites in North Carolina it was shown that most of these septic systems had also exceeded their expected lifespan, leading to tank overflow or seepage (S. Ciesielski et al., 1991).

2.4.2 Occupational Controls in the SAWP Occupational Setting

Risk resulting from exposure to occupational health hazards can be controlled along the pathway leading to worker exposure, or directly at the source. Occupational control methods can generally be categorized into four main areas (Figure 2-6). The first is elimination of the hazard completely, or the use of engineering controls to control the hazard, these can include three types: isolation, substitution and ventilation. The third category is the use of administrative controls which includes things such as job schedules, work-rest cycles, timing of maintenance procedures, training and work and hygiene practices. Finally, the last category is the provision and use of personal protective equipment (PPE) such as gloves, masks and safety clothing.

Selection of a control strategy is usually dependent on the hazard or hazardous situation. Often, risk assessments are used to evaluate and prioritize the hazards and the health risk is determined before a control is selected and implemented. The most effective control on the hierarchy is elimination of the hazard, which includes removing the sources of the hazard in the workplace completely (Canadian Centre for Occupational Health & Safety, 2021c). The implementation of control strategies when elimination is not possible, however, can include a combination of controls and can also include the use of temporary, as opposed to permanent controls, depending on the situation. In the following sections, evidence of control strategies or lack thereof in the migrant farmworker occupational setting are explored (Canadian Centre for Occupational Health & Safety, 2021c).

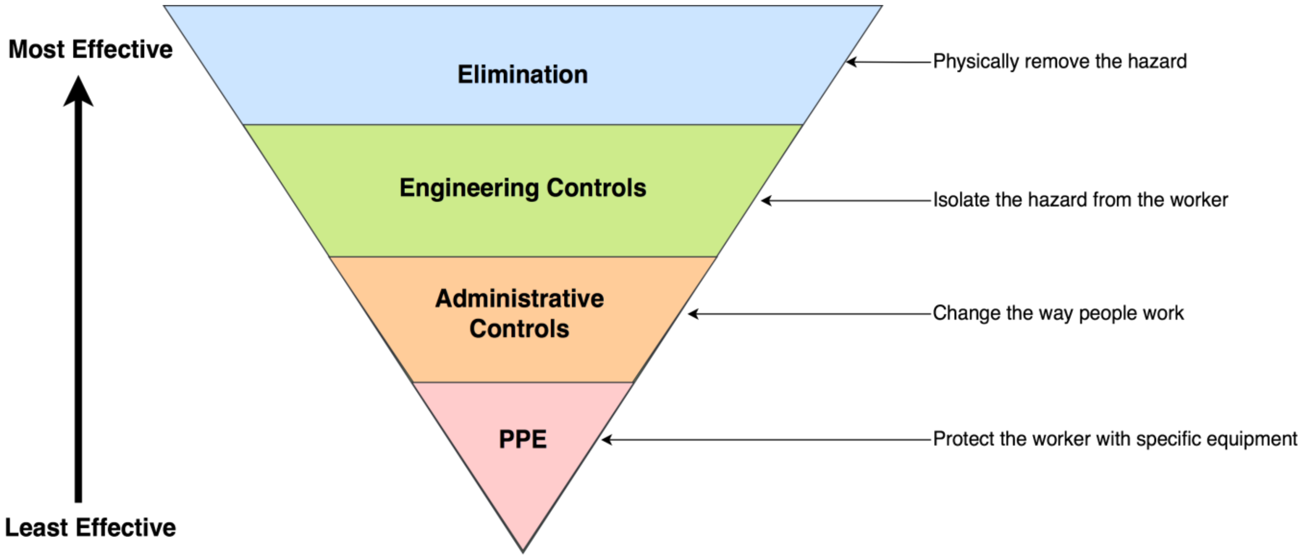


Figure 2-6: Hierarchy of Occupational Controls Describing the Level of Controls for Worker Protection from Most Effective to Least Effective

Source: Reproduced from Department of National Defence Canada (2020) and Adapted from National Institute for Occupational Safety and Health (2015)

2.4.2.1 Engineering Controls

The next most effective level of control on the hierarchy includes the use of engineering controls, which can be further divided into three types: isolation, substitution, and ventilation. Engineering controls target changes to the design or process of a system for overall reduction of a potential hazard. Those using isolation methods aim to isolate the worker from the hazard by geographically removing the hazards or fencing it off (Canadian Centre for Occupational Health & Safety, 2021c). In the migrant farmworker context, this can be used to geographically isolate managed manure or reconstituted pesticides, items that may contain biological hazards such as enteric pathogens, from worker living sites and worksites. Substitution as an engineering control involves the use of a less hazardous material, a change in the process or a change in the job activity (Canadian Centre for Occupational Health & Safety, 2021c). In the migrant farmworker context this can include the substitution of irrigation water source or method. To ensure a substitution is in fact controlling the hazard, monitoring before and after a substitution is recommended before implementation (Ontario Ministry of Labour Training and Skills Development, 2016). Ventilation as an engineering control is a method that ensures air quality in the workplace and is generally relevant to controlling hazards causing respiratory illnesses (Canadian Centre for Occupational Health & Safety, 2021c).

2.4.2.2 Administrative Controls

The following level on the hierarchy of occupational controls is the use of administrative controls, which are approaches used to change the way people work. This includes changes to procedures, processes, the timing of work and work practices related to training and hygiene (Canadian Centre for Occupational Health & Safety, 2021c). The application of employment standards can potentially act as an administrative control by stipulating criteria around hours of work and overtime to control the number of hours a worker is potentially exposed to a hazard (Ontario Ministry of Labour Training and Skills Development, 2016). Migrant farmworker entitlements under the Employment Standards Act have been characterized as limited, with workers excluded from aspects related to minimum wage, hours of work, rest periods and vacation (McLaughlin et al., 2014; Vosko, Tucker, & Casey, 2019). Some of these aspects are addressed under the SAWP contract guidelines. The guidelines stipulate requirements such as eight-hour workdays and one rest day for every six consecutive days. The agreements, however, are open to employers' modifications and requests given the urgency of work at hand (Employment and Social Development Canada, 2020a; McLaughlin et al., 2014). These open-ended agreements have translated into migrant farmworkers averaging 63-65 hours of work per week beyond the standard 40-hour work week. In a survey completed by Hennebry and McLaughlin, (2016) of 600 migrant farmworkers in Ontario, workers reported working up to 74 hours a week and more than half of those workers expressed often working without any breaks throughout the day (Hennebry & Preibisch, 2008). Migrant farmworkers are also excluded from the labour relations act; this prevents workers from accessing the right to collectively bargain or belong to a union (McLaughlin et al., 2014).

Additional elements of occupational administrative controls are related to safe work practices including the delivery of job specific training and standard workplace training such as Workplace Hazardous Materials Information System training. Adequate training of employees helps minimize the risk from exposure by ensuring that workers are aware of the hazards they face in the workplace and provides them with the tools necessary to protect themselves and their co-workers (Canadian Centre for Occupational Health & Safety, 2021c). Surveys of migrant farmworkers in Canada, however, have shown that most workers have not received formal training for the occupational hazards they experience in their workplace. Survey results showed that only a small percentage of workers reported receiving adequate training relevant to the workplace hazards, often in an informal manner (McLaughlin et al., 2014). In another survey, most workers reported receiving very limited workplace health and safety training and, in some cases, migrant farmworkers received no training at all. Nearly 60% of workers in

Ontario reported not receiving any training (Hennebry & McLaughlin, 2016) and 74% of workers in British Columbia reported not receiving health and safety training (Preibisch & Otero, 2014).

Workers additionally face barriers to accessing training in the country of origin. It was found that sending countries do not provide formal occupational health and safety training (McLaughlin et al., 2014), and employers in Canada are not mandated to do so under the program requirements. The expectation of sending countries was that workers will receive training on site from their employers or will depend on their previous experience. This highlights a gap in the responsibility to administer formal health and safety training (McLaughlin et al., 2014). In addition to the lack of training as an administrative control, the limited training that was offered often lacked relevance to both the working and living conditions faced by migrant farmworkers. Workers often also struggled with comprehension of the training material given language and literacy barriers (Hennebry & McLaughlin, 2016). Workers in a study by Hennebry and Preibisch (2008) reported that due to language barriers, training was mainly conducted through hand signals and was often communicated by other workers on site.

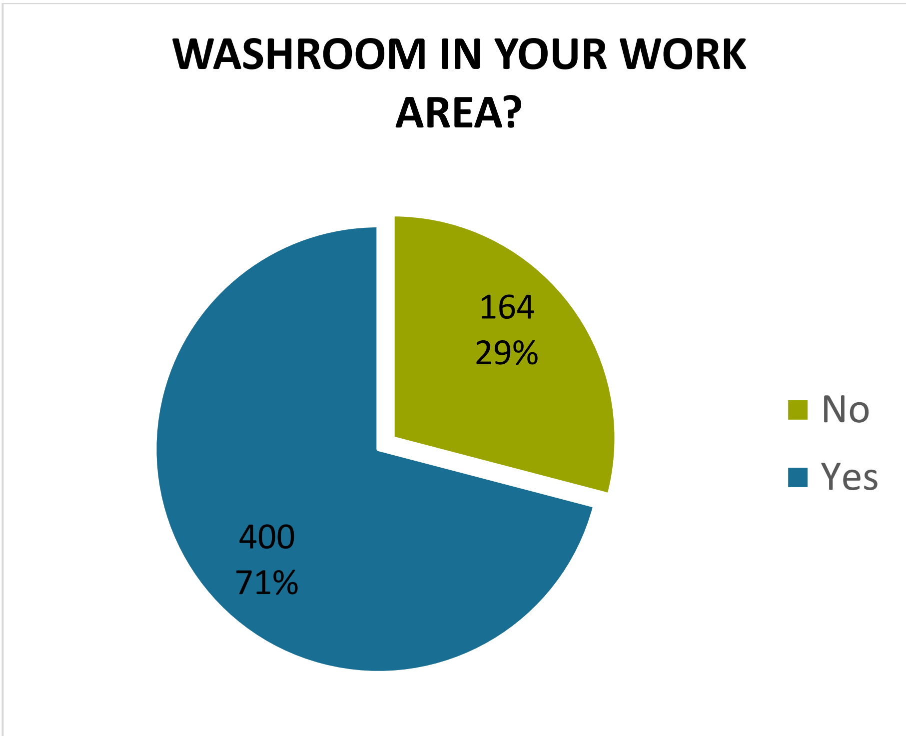
Additional examples of safe work practices as part of the administrative controls include establishing and maintaining work sanitation and hygiene practices that reduce the potential for exposure. Establishing sanitation and hygiene best practices prevents the accumulation, ingestion or inhalation of hazards such as pathogens that workers may be exposed to and reduces the risk from secondary transmission from one person to another via contaminated hands. Examples of hygiene best practices in the workplace can include correctly applying handwashing procedures for an adequate amount of time, avoiding contact of face (e.g., lips, eyes, nose) with contaminated hands and assigning separate meal and break areas (Canadian Centre for Occupational Health & Safety, 2021c). In the migrant farmworker occupational setting, many challenges related to sanitation and hygiene facilities were documented by Hennebry and McLaughlin (2016), highlighting challenges related to lack of bathroom facilities in the workplace, scarce handwashing facilities, insufficient laundry equipment and inadequate separation between sleeping, kitchen and bathroom areas and insufficient food storage, heating and refrigeration. Not having access to a refrigerator was shown to triple the probability from 13.4 % to 43.3% of getting a gastrointestinal disorder from the consumption of unprotected food among migrant farmworkers in a study of workers in Tulare County, California (Frisvold et al., 1988).

In a study of boarding schools with communal eating, sleeping, sanitation and hygiene arrangements, the transmission of communicable disease was shown to be raised, highlighting concerns for the protection from hazards leading to potential biological exposures (Adams, Bartram, Chartier, & Sims, 2009). The Foreign Agricultural Resource Management Services (F.A.R.M.S.), an organization that coordinates requests for migrant farmworkers, stipulates in their guidelines that "no toilet room or combined toilet room and washroom opens directly into any room used for the preparation, storage or serving of food" (F.A.R.M.S. Ontario, 2010, 2020). Yet, in a study completed by Preibisch and Otero (2014), survey results amongst Mexican migrant farmworkers in Canada show that 12% of housing reviewed did not have a door or separation barrier between the kitchen and bathroom (toilet) areas and 28% did not have a separation barrier between stove tops and sleeping areas. Migrant farmworker perception of the living conditions included the following comment:

"Our kitchen is very close to the bathroom. We are 32 workers in total with four people living in a bedroom. All of us have to share 2 bathrooms and six showers…" Mexican worker in Leamington ON, July 2008 – (Hennebry & Preibisch, 2008)

Documented sanitation and hygiene infrastructure issues in the literature also extend to the worksite. Studies have shown that workers do not always have access to toilets while working in the field. In a survey completed by Hennebry and Preibisch (2008), it was shown that 61% of workers would go to the bathroom while working in the field in nearby ditches or off to the side due to a lack of portable facilities, posing a public health concern and heightening the risk of foodborne and waterborne enteric disease. Details of the survey are shown in Figure 2-7 below. One worker noted:

"There are no portable washrooms… if I have to go … I go on the field or I wait until I go home." - *Mexican Worker in Bradford ON, June 2008* – (Hennebry & Preibisch, 2008)



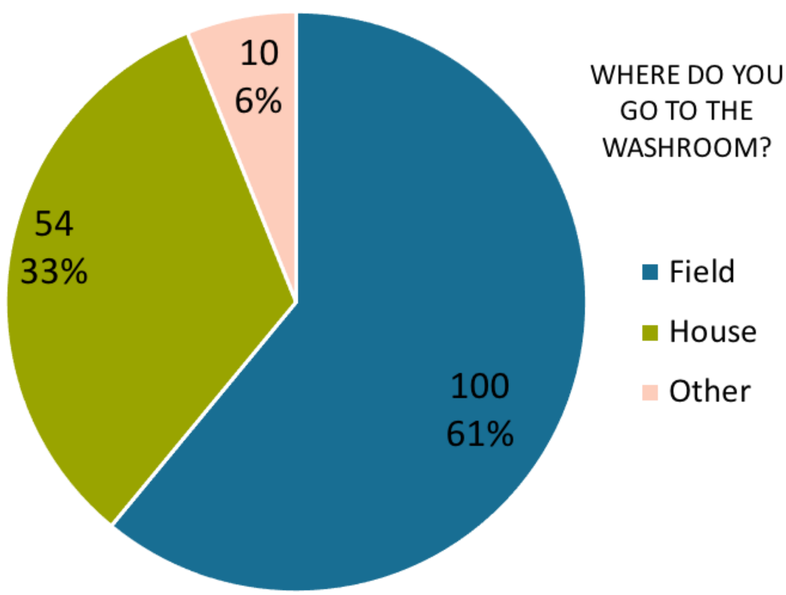


Figure 2-7: Survey Results Indicating Whether or not Migrant Farmworkers Have Access to a Washroom, Worker Responses of Alternatives if no Washroom in the Work Area

Source: Reproduced and Adapted with permission from Hennebry and Preibisch (2008)

Closely tied to the access to bathroom facilities is access to handwashing facilities—31% of workers in the study by Hennebry and Preibisch (2008) expressed not having access to handwashing facilities in the field. Hennebry and Preibisch (2008) discuss the health risks associated with lack of handwashing facilities, noting concerns related to food safety of harvested produce and worker illness from contaminated hands during meal breaks on the worksite. Under the SAWP employment contract agreement, workers are allotted two 10-minute breaks and one 30-minute lunch break for every five hours of work (Employment and Social Development Canada, 2020a) to carry out any hygiene activities. Contamination of hand-harvested carrots in a study by Monaghan and Hutchison (2016) was attributable to inadequate handwashing hygiene. Workers handling fresh produce should have access to handwashing stations with running water and soap to reduce the potential exposure from contaminated crops via hand to mouth contact or from secondary transmission from one person to another through contact via contaminated hands or surfaces (Bloomfield et al., 2007).

2.4.2.3 Personal Protective Equipment

PPE is the final element of control on the hierarchy of controls for protection from hazards in the workplace. Equipment such as gloves, masks and safety shoes are worn by individuals to reduce the risk from exposure to hazards (Canadian Centre for Occupational Health & Safety, 2021c). Hazards in the agricultural setting can be related to contact with animals, hazardous waste such as manure-based soil amendments or reconstituted pesticides, and contaminated crops or sources of irrigation water. Lack of controls such as protective equipment including gloves, masks and eyewear in the agricultural workplace can lead to a potential health risk from exposure to microbial contaminants. Antwi-Agyei et al. (2016) reported that soil-to-mouth contact was a critical pathway contributing to illness of farmworkers in Accra, Ghana. On average workers experienced 10 hand-to-mouth events per day, 86% of workers in the study encountered hand-to-soil contact and 53% experienced soil-to-mouth. Exposure to soil was found to be the most important pathway of pathogen exposure in the absence of PPE.

The provision and use of PPE among seasonal migrant farmworkers in Canada has been variable and insufficient (McLaughlin et al., 2014). Several reports have also noted multiple instances of workers on the field, without adequate or any PPE (Basok, 2002; McLaughlin et al., 2014). Other reports indicated that around 75% of workers were given gloves, while only 5% were also given a mask or other PPE (McLaughlin et al., 2014). While not all tasks require the use of full PPE (e.g., PPE suits, mask, gloves, boots, face shields, etc.) this form of incomplete and often inappropriate supply and use of PPE does present a concern directly tied to the protection of workers. McLaughlin et al. (2014) have also argued that these potential protections are inconsistent and under-regulated. In addition to concerns tied to the provision of adequate PPE, migrant farmworkers are also challenged with precarious working conditions (i.e., lack of stability and unpredictability in the workplace). These precarious conditions can constitute barriers to implementation of occupational controls in the workplace. Evidence in the literature indicates that workers are inherently disempowered from refusing unsafe work or asking for PPE given the fragile state of their temporary status and the employer–employee power dynamic including things such as the repatriation clause or the naming system (McLaughlin et al., 2014).

2.4.2.4 Workplace Health Model – Access to Health Care and Compensation to Manage Realized Health Risks

Another workplace-based intervention for the protection of worker health is the overall workplace health model. The model includes the implementation of health protection, health promotion, and disease prevention programs (Centers for Disease Control and Prevention, 2016). Although employers are primarily responsible for providing safe workplaces through the elimination or management of hazards, they are also responsible for promoting health and ensuring a healthy workplace. Supportive environments where access to health and compensation are ensured are primary examples of health promotion programs. Access to healthcare and compensation in the event of an exposure leading to an illness can be a method for workers to manage the effects of an exposure if it cannot be addressed through the hierarchy of occupational controls.

Quality healthcare includes a few baseline services such as primary care, and emergency care for the protection of health and the achievement of health goals. Access to these primary services can, however, be influenced by a community' social determinants of health, which can include the level of literacy, access to transportation, and healthy workplaces (Bhatt & Bathija, 2018). Access to workplace compensation can protect workers from the financial hardships associated with work-related injury and occupational diseases. To access compensation benefits, workers are required to file a claim (Government of Canada, 2015).

For migrant farmworkers access to healthcare is often limited given literacy, transportation, and third-party intervention barriers such as employers or volunteers acting on their behalf (McLaughlin et al., 2014; Preibisch & Hennebry, 2011; Vosko et al., 2019). Access to the Ontario Health Insurance Plan (OHIP) was also highlighted as a concern; 19% of workers expressed not being aware of the plan or not picking up the card from an employer (Hennebry & Preibisch, 2008). Additionally, it was reported that 92% of workers did not know how to fill out hospital forms or fully communicate their health issues due to literacy and language concerns. This is a concern given that workers may not be able to have their health issues fully addressed. Evidence suggests that almost 30% of workers will often choose to engage in consultations with health professionals in their country of origin because of the barriers associated with accessing health care in Canada (Hanley, Gravel, Lippel, & Koo, 2014). Being able to communicate health issues to health workers was a common worry among migrant farmworkers, nearly half of the workers interviewed (45%) expressed having problems with effectively communicating their concerns (Hennebry & Preibisch, 2008). Among the workers who did not express issues, reasons were usually because they had help from a co-worker or volunteer who provided translation services. Given the employer–employee dynamic, workers may choose not to involve employers when seeking health care service given the privacy and confidentiality issues that may result from relying on an employer to provide transportation to the hospital or offer translation services (Hennebry & Preibisch, 2008).

As for compensation claims, the majority of the workers interviewed (93%) reported not knowing how to file a Workplace Safety and Insurance Board (WSIB) claim. Several workers (28%) also chose not to file a claim in fear of employer retaliation or because they simply did not consider their injury or illness serious enough (Hennebry & McLaughlin, 2012b). Many workers (41%) also did not qualify for WSIB, often because they conducted assigned tasks that fell outside of their work contract such as construction labour, or work on a neighboring farm (McLaughlin, 2009). Additionally, employers may not be aware of the incident so that no claim is put forward regardless of coverage, and sometimes workers are repatriated before any form of claim or compensation can occur (Basok, 2002; Hennebry & Preibisch, 2008; McLaughlin, 2007, 2009). As per the SAWP contract, employers have the ability to lay off workers without notice for “non-compliance, refusal to work, or any other sufficient reason” (McLaughlin et al., 2012). Workers who are fired are often also immediately repatriated. Analyzed medical repatriation data found that 787 workers out of 170,315 migrant farmworkers arriving in Ontario between 2001-2011 (4.62 repatriations per 1000 workers) were repatriated mainly for medical or surgical reasons (Orkin et al., 2014).

Chapter 3
Methodology

This chapter describes the research methodology used by outlining how risk assessment approaches were applied and adapted to build a risk-informed framework to meet the objectives of this work (section 1.1). No specific method existed for integrating various literature sources required to assess the health risks faced by migrant farmworkers in the SAWP occupational setting. Hence, a novel methodology rooted in risk theory and application of risk assessment tools was designed. The designed methodology was used to integrate concepts drawn from Quantitative Microbial Risk Assessment (QMRA), Failure Mode and Effects Analysis (FMEA), and Hazard Analysis and Critical Control Points (HACCP) to support framework development. The applied risk assessment included carrying out hazard and exposure assessments as part of the risk identification process (section 3.2). These were followed by risk analysis and risk evaluation in the SAWP occupational setting (section 3.3 and section 3.4). To meet the first objective of identifying all relevant hazards contributing to migrant farmworker health risks, a literature review and synthesis of the literature was conducted to identify and establish categories of hazards and hazardous situations contributing to exposure to enteric pathogens as part of the hazard assessment. The second objective of characterizing relevant exposure pathways leading to exposure to enteric pathogens was also met through synthesis of the literature. Identification of control points for mitigation of health risks as part of objective five followed this step and control points were built into the transmission network but were not strictly part of the exposure assessment. The third objective for evaluating health risks attributable to enteric pathogens was met by constructing risk matrices based on an FMEA analysis and synthesis of the literature to evaluate the migrant farmworker health risks attributable to enteric pathogens. In the absence of quantitative data, the fourth and fifth objectives of conducting a preliminary evaluation of health risks, and identifying control points for mitigation, were met through identification of key literature as evidence. The fourth objective was met through identification of epidemiological evidence of enteric disease in the migrant farmworker context, and the fifth objective was met through identification of commonly agreed-upon hygiene and sanitation control strategies for the protection of health.

3.1 Risk Assessment Process

Application of a risk assessment process provides a structured, science-based method for meeting the objectives of this work. It utilizes a systematic approach for evaluating the potential risk through the key activities of risk identification, risk analysis and risk evaluation (International Organization for Standardization, 2009). Here, these approaches were adapted to develop a risk assessment methodology to identify and evaluate health risks attributable to enteric pathogens and to explore mitigation strategies as part of the overall risk management framework for health risks associated with enteric disease facing migrant farmworkers participating in Canada's SAWP. These approaches are rooted in risk theory and apply risk assessment tools such as the modification and use of an FMEA analysis and development of risk matrices from engineering risk analysis. The designed methodology in Figure 3-1 below can be further developed with more information and can also potentially be applied or modified to fit other applications. It is worth noting that the application of the risk assessment highlights hazards and exposure pathways that have the greatest health impact and those that are most relevant to the migrant farmworker population in the agricultural occupational setting. It is not an exhaustive list of all the possible hazards and exposure pathways facing migrant farmworkers. Missed pathways of concern can however be accounted for given the structure provided with this methodology, allowing for further development and inclusion of missed pathways of concern.

QMRA is a risk assessment tool that can be utilized to evaluate the risk from exposure to a pathogenic microorganism. This approach was considered to evaluate the health risks associated with enteric disease facing migrant farmworkers. The steps required to fully carry out a QMRA include a hazard identification, exposure assessment, health effects assessment using dose-response models and characterization of the risk. Based on the information gathered to assess applicability of the approach in the migrant farmworker context, it was possible to carry out a hazard identification along with a partial exposure assessment looking at exposure pathways. Dose-response models are available in the literature for common enteric reference pathogens. However, it was determined that quantitative data describing the exposures encountered by migrant farmworkers was limited and that characterization of the risk facing them was not possible. Hence, the assessment carried out was inspired by QMRA; however, given limited available data, it focused on application of the preliminary aspects of the risk assessment by identifying the hazards and exposure pathways and creating a foundation for future development. Design of the methodology through adaptation of general risk assessment tools, how they were applied for this work and the resulting outcomes are illustrated in Figure 3-1 below.

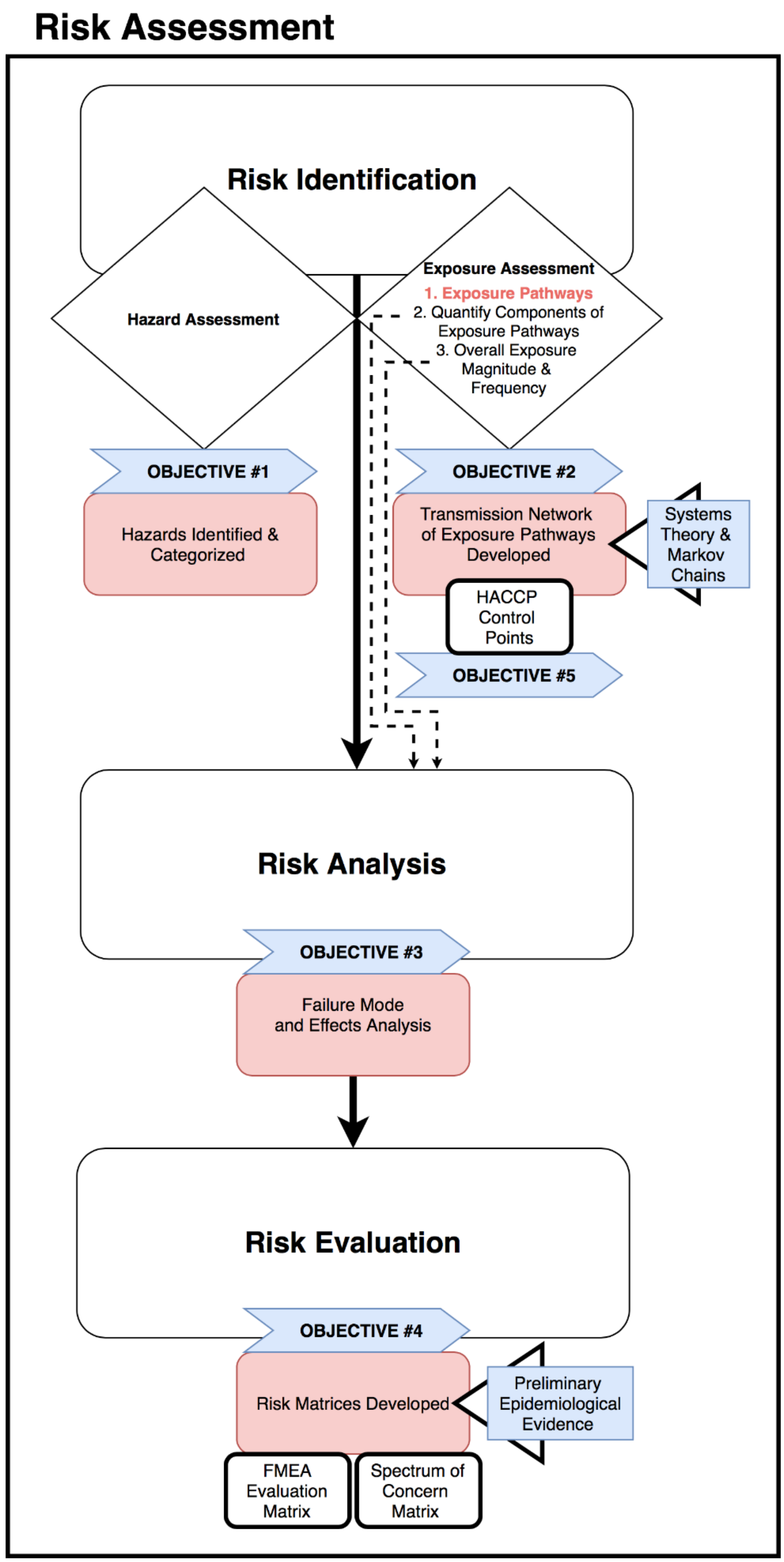


Figure 3-1: Framework Design Integrating Risk Assessment Tools to Evaluate the Health Risks Faced by Migrant Farmworkers in the SAWP Occupational Setting

Hazards and hazardous situations contributing to the exposure of seasonal migrant farmworkers to enteric pathogens were identified and categorized systematically as part of the hazard assessment (section 4.1). The second element of the risk identification process was an exposure assessment, within which emphasis was put on the first aspect of identifying exposure pathways. The second and third aspects of the exposure assessment are highlighted in Figure 3-1 with dotted lines feeding into risk analysis, indicating where they can be used when data are available. The exposure assessment was used to map out the movement of pathogens in this setting using systems theory and an illustrative example of how to utilize a simple Markov chain is provided to show the potential for future development (section 4.2). Adaptation of a HACCP approach was also used to introduce control points along mapped pathogen pathways within the pathogen transmission network (section 4.2.2) with prescribed mitigation strategies to avoid, transfer or limit the risk. In the risk analysis step, scenarios leading to a potential exposure to enteric pathogens were developed to carry out a Failure Mode and Effects Analysis (FMEA). The FMEA was used to prioritize and score failures based on the severity of contamination, the intensity of a potential exposure and the frequency of exposure (section 4.3). The outcomes from the FMEA provided a useful way of thinking about risk. In the absence of data, risk matrices are commonly used to relatively score risk on a scale. In this context the outcomes of the FMEA were used to summarize the results through development of an FMEA evaluation risk matrix (section 4.4.1). The risk evaluation was further extended to inform a simple evaluation of other hazards and hazardous situations identified through development of a spectrum of concern risk matrix as a starting point for a risk assessor (section 4.4.2). Evaluation was also supported through preliminary evaluation based on epidemiological evidence (section 4.5.3).

3.2 Risk Identification – Hazard and Exposure Assessment

A hazard assessment as part of the risk identification step was conducted to identify and categorize hazards and hazardous situations contributing to exposure to enteric pathogens in the migrant farmworker occupational setting. Following the hazard assessment, an exposure assessment mapping the transport of enteric pathogens from sources to a potential migrant farmworker infection was also carried out as part of the risk identification step in the overall assessment.

3.2.1 Hazard Assessment

The hazard assessment involved the identification, categorization, and evaluation of hazards through synthesis of diverse information and data describing the migrant farmworker setting. The primary goal of carrying out the hazard assessment was to identify and categorize health hazards and hazardous situations leading to exposure to enteric pathogens facing migrant farmworkers specifically within their occupational setting. This step was also necessary for providing the foundation to assess the risk for purposes of risk mitigation and control.

Risk identification techniques used in the hazard assessment are established methods for analyzing information and identifying data gaps and opportunities in established scientific methodologies and approaches such as QMRA, HACCP, FMEA, Fault Tree Analysis (FTA) and Preliminary Hazard Analysis (PHA) (U.S. Department of Health and Human Services, Food and Drug Administration, Center for Drug Evaluation and Research (CDER), & Center for Biologics Evaluation and Research (CBER), 2006). Techniques include brainstorming, surveys, interviews, documentation review, scholarly review, data analysis, root cause analysis and assumption analysis. The risk identification process is key to effective decision-making, helping to set priorities (Dinu, 2015).

Risk identification techniques offer flexibility in bringing together a wide array of information from a diverse literature base. It is the initial step in synthesizing information about a specific problem. The process allows for inductive reasoning in which observations and facts are gathered to make broad generalizations and coming up with a theory. This approach was fitting in examining the health hazards and hazardous situations leading to exposure of migrant farmworkers to enteric pathogens, helping bring together different pieces of information given the lack of specific data describing migrant farmworker health in Canada.

Application of the risk identification approach was used as part of the hazard assessment to gather information about hazards facing seasonal migrant farmworkers. Insights regarding the hazards faced by migrant farmworkers and the associated implications of those hazards were drawn from a diverse scholarly research base looking at the occupational health of seasonal migrant farmworkers. Hazards were deduced from a wide range of information including: (1) review of policies and SAWP parameters affecting workers, (2) program guidelines describing occupation types and activities (Employment and Social Development Canada, 2020b), (3) the physical environment in which migrant farmworkers live and work during their stay (Preibisch & Otero, 2014), (4) agricultural tasks performed by workers, (5) equipment used by workers, (6) materials and products used and handled by workers, and (7) training provided to workers. Data sources considered included: (1) survey data describing specific health hazards as identified by migrant farmworkers (Hennebry, 2010), (2) studies examining migrant farmworkers' medical records (Orkin et al., 2014), (3) scholarly research pertaining to barriers to accessing healthcare and hygiene facilities, (4) repatriation data pointing to specific enteric health concerns facing this population, (5) data collected by the Occupational Health Clinics for Ontario Workers (OHCOW) during migrant farmworker health clinics, (6) review of studies discussing worker compensation claims, and (7) results of housing and workplace inspection data. Not all data sources were available in raw form; most data were analyzed and discussed in summarized form in studies. Data pertaining to repatriation of workers from 2001-2011 were available in raw form, upon request under the *Freedom of Information and Privacy Act* from a court case under the Human Rights Tribunal of Ontario; HRTO file TR-0680-09 (Peart v. Ontario). The data were made publicly available and shared in Appendix 1 of a study by Orkin et al. (2014). The study used the data to analyze and discuss medical reasons workers were repatriated during that period. Raw data of workplace inspection forms and worker compensation claims were unavailable; however, analysis and discussion of the data was summarized in studies by Hennebry & McLaughlin (2012b).

As part of this overall review, key themes emerged as main contributors to health risks. Gathered information regarding relevant hazards contributing to exposure of migrant farmworkers to enteric pathogens was grouped into four factor categories: (1) agriculture environmental factors including exposure to environmental pathogens in the agricultural setting, (2) infrastructure factors including hazardous situations related to the migrant farmworker living and working conditions, (3) occupational factors such as the provision of health and safety training or availability of personal protective equipment, and (4) SAWP management factors including access to health care. The hazard assessment provided the structure needed to bring together a diverse evidence base for synthesis of health hazards and hazardous situations leading to exposure to enteric pathogens in the migrant farmworker occupational setting of the SAWP.

Some assumptions of the risk identification step for hazard assessment include assuming that all identified hazards are relevant and can contribute to a possible worker exposure. Additionally, there is an assumption that all hazards and hazardous situations identified can be analyzed or measured quantitatively or qualitatively. Limitations of the risk identification process for hazard assessment include insufficient data, incomplete data (such as the lack of raw data) and the possibility of not reviewing or omitting a potential hazard or hazardous situation during the investigation process.

3.2.2 Exposure Assessment – Pathogen Pathways and Controls

Exposure assessment is one of the primary components of risk assessment that is initiated in the risk identification step and detailed in the risk analysis step given sufficient data. It describes how humans come into contact with hazards and can address the intensity and duration of human contact. Given understanding of the hazards and hazardous situations identified in the hazard assessment, the first objective of the exposure assessment was carried out to map out the transport and potential control points for enteric pathogens from source to ingestion by migrant farmworkers within the agricultural environment using a systems theory approach. The transmission network can be further developed using concepts from Markov chains. Preliminary structure through development of a four-state pathogen transition matrix and an illustrative example of how this can be done is detailed in section 4.2. It is important to note that exposure to just one pathogen can lead to a possible infection.

Systems theory is a methodology used in interdisciplinary studies to explore how components relate to one another within a larger, more complex system (Sheridan, 2010). The systems theory approach structures systems in terms of components, interconnections and boundaries (Mele, Pels, & Polese, 2010). There are multiple tools or techniques that can be used within a systems theory approach, they are generally mathematical in nature and can include linear programming, game theory and Markov chains (Bode & Holstein, 2015).

Markov chains are mathematical models used to describe a stochastic system that relies on the outcome of a previous event to determine the probability of a future event at discrete time intervals. Fundamentally, Markov chains are based on conditional probability where the probability of an event at time step *n*+1 is based on the preceding status at time step *n*. This can be denoted mathematically by the following:

$$\boldsymbol{P_{ij}} = \mathbf{Pr}\{\boldsymbol{X_{n+1}} = \boldsymbol{j} \mid \boldsymbol{X_n} = \boldsymbol{i}\} \quad \mathbf{(1)}$$

Equation (1) represents the probability of moving from state i to state j in one time step, which is also known as the transition probability. This probability can be denoted for an entire system through use of a transition probability matrix and a transition diagram. In the transition matrix, the probability of all possible states in the system must sum to 1 (all rows in matrix must sum to 1). In the diagram, the probabilities are assigned to pathways that move from nodes (i.e., X, Y, Z) denoting the change of states from one node to another, where the rows correspond to the current state i and the columns correspond to new state j. An example of a simple transition matrix is provided in equation (2) and a Markov transition diagram can be seen below in Figure 3-2.

$$P = \begin{bmatrix} 0.5 & 0 & 0.5 \\ 1 & 0 & 0 \\ 0.5 & 0.5 & 0 \end{bmatrix}$$

Equation 2: Simple Markov Transition Matrix

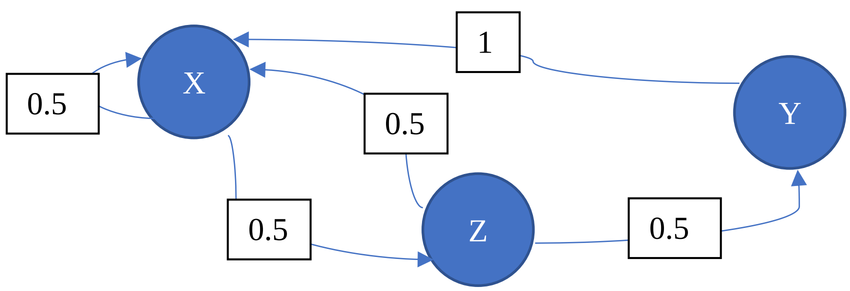


Figure 3-2: Simple Markov Transition Diagram

Markov chain models are a potential method that can be used to model the spread and transmission of infectious disease. Infectious disease dynamics can be described as stochastic systems (Yaesoubi & Cohen, 2011) in which the outcome of each event is based on the outcome of the event prior to it. In the spread and transmission of infectious disease, this can be characterized by events that lead to potential exposure and infection. The application of Markov chains in the study of epidemiology is not new; however, it has not been explored in the transmission of enteric pathogens among migrant farmworker populations in Canada's SAWP.

Concepts from Markov chains were used to build a transmission network to describe the movement of enteric pathogens from source to potential worker exposure within the SAWP occupational setting. Specific exposure pathways leading to the exposure and potential infection of migrant farmworkers were identified within the network. The transmission network was initiated with a systems identification process as part of the systems theory approach by identifying what information to include and what information to exclude. Establishing the context is inherently subjective and is directly tied to the components the risk assessors deem important (Hatfield & Hipel, 2002). After the context was established, pathogen pathways were mapped using a systems theory approach to develop a transmission network. Preliminary structure using concepts from Markov chains assuming a simplified first order process (only dependent on the state before it) were also detailed with an illustrative example for future development of the network.

The developed transmission network specifically described the potential of exposure from disease-causing microorganisms such as bacteria, protozoa, and viruses that cause enteric illnesses among migrant farmworkers in the SAWP occupational setting. In the context of infectious disease, the spread of pathogenic microorganisms can be characterized by four discrete states: pathogen at source (0), pathogen along active pathway (1), pathogen removed (sink/decay) (2) and pathogen at host (exposure) (3). Pathogens at the source can move to any of the other three states. Pathogens along active pathways can also move to any of the other three states; however, for simplicity in this system, pathogens were assumed to only move forward within the transmission network and so pathogens along an active pathway (active) will not go back to pathogens at source. Pathogens removed (sink/decay) cannot be moved to any other state, as they are removed from the entire system. Pathogens at host (exposure) can also be moved to any of the other states in this scenario and can go back to pathogens at source since exposed workers who are infected can become a source of enteric pathogens in the system. The pathogens at source, pathogens along active pathways and pathogens at host can be described as transient states because they can enter or exit the system or change states many times (Zipkin et al., 2010). These defined states can be used to build a four-state transition probability matrix shown below in equation (3).

$$P = \begin{bmatrix} p_{00} & p_{01} & p_{02} & p_{03} \\ p_{10} & p_{11} & p_{12} & p_{13} \\ 0 & 0 & 1 & 0 \\ p_{30} & p_{31} & p_{32} & p_{33} \end{bmatrix}$$

Equation 3: Transition Matrix for Pathogen States

The rows indexed from 0 – 3 represent the state of the pathogen (0 – source, 1 – active, 2 – sink/decay, 3 – exposure) at time *n* and the columns represent the state of the pathogen at time n+1. For example, p_{01} represents the probability of the pathogen moving from a source to another specific location where the pathogen is still active in the system. The probabilities p_{02}, p_{12} and p_{32} represent the removal or the decay of the pathogen in the system. The values in row 2 represent the transition from a removed or decayed pathogen state, this state cannot change, so the probability of a removed or decayed pathogen in becoming a source, activated, or leading to an exposure is 0. The probability p_{30} represents the transition from an exposure state to a source state; this can be described by a worker who becomes infected after an exposure and can then become a source in the system.

Enteric pathogens of interest can be waterborne or foodborne and can make their way into the body via fecal–oral routes involving contact with animal wastes, contaminated food and water, feces of an infected human or objects that have become contaminated (Centers for Disease Control and Prevention, 2018b). The transmission network looked at identifying how these pathogens enter, move through, and exit the system within the SAWP occupational agricultural farm setting. The status of pathogens in the network were assigned to nodes, and the possible probabilities are assigned to pathways moving between the nodes. Nodes identified in the transmission network included contributing sources of microbial contamination (i.e., source nodes), specific locations where pathogens can be found as they are moved within the system (i.e., active nodes), mechanisms removing them from the system (i.e., sink/decay nodes) and a state where workers are exposed (i.e., exposure node) and are then potentially infected.

For example, a source node may be waste from domestic animals within the occupational setting; pathogens in this state can transition at a given probability to an active node such as managed manure or can be removed by a sink/decay node such as infiltration or surface runoff. Pathogens continue to transition within the system moving between active and sink/decay states until ultimately transitioning to an exposure state where there is a potential for exposed workers to become infected.

Some simplifying assumptions were made to allow for application of the method; it was assumed that all transition states were first order (only dependent on the state prior to it) and that pathogens can only be in one state at a time. The movement of pathogens from one state to another was assumed to be unidirectional with the exception of an infected worker back-feeding into the system and becoming a potential source. Additionally, nodes and corresponding pathways identified in the transmission network were assumed to be the most relevant, noting that the network does not depict an exhaustive list of all possible nodes and pathways. Finally, it was assumed that all transitions are within the system identified for the SAWP occupational setting and that no outside factors, such as a potential contamination outside of the farm system, have an impact. Limitations to this approach include not being able to quantitively characterize p_{ij} values in the matrix to describe the probability of a pathogen transitioning between states. This is a limitation because we do not have data describing this probability.

To ensure completeness of the connections between all nodes and pathways described in the network, each node was checked against every other node in the system to consider mechanisms for direct node-to-node transfer. A list of all the identified nodes was used to build a square matrix in which the rows indicate where the pathogen is and the columns indicate where the pathogen may go next. Through a preliminary assessment, a direct pathway between two nodes is identified as a connection. It is assumed that no direct connection exists if the pathogen must pass through several intermediary nodes to reach a new node. Details of the transmission network verification matrix can be found in Appendix A.

During development of this transmission network, possible control points were identified along active pathogen pathways using HACCP methodology to facilitate control of exposure to pathogenic enteric microorganisms in the migrant farmworker setting. HACCP is a systematic approach that utilizes preventative methods in the evaluation and control of food safety hazards from harvest to consumption. The approach attempts to avoid hazards by introducing control strategies throughout the process rather than attempting to inspect and manage effects of the hazard at the end of the process (Buchanan & Whiting, 1998). HACCP principle 2 (section 2.2.2.2) was used to introduce control points as a form of risk mitigation in the SAWP occupational setting.

The integration of HACCP as part of the exposure assessment offers a means for relating drivers of exposure scenarios to public health goals. This capability may be an important factor in assessing mitigation strategies. However, the limitations associated with applying HACCP methods in this study include not being able to apply all seven principles looking at monitoring, correcting, and verifying introduced strategies for continuous improvement as per HACCP principles four, five and six (section 2.2.2.2).

3.3 Risk Analysis – Application of Failure Mode and Effects Analysis

Risk analysis integrates understanding of the identified hazards and the exposure pathways leading to the spread of infectious enteric diseases and is the second step in the risk assessment process required to evaluate the health risks associated with enteric disease faced by migrant farmworkers. Risk analysis was carried out for the estimation of exposure to enteric pathogens, based on the hazard and exposure assessments (section 3.2), through the application of an FMEA. The general FMEA process was modified to meet the objective of this work. In this context, where there is a combination of low-risk and high-risk factors contributing to a potential enteric exposure and an absence of data, the application of the FMEA provided the ability to deal with multidimensional factors contributing to the overall risk. Specifically, section 4.3 exemplifies application of an FMEA by identifying exposure scenarios, analogous to failure scenarios in the general FMEA process, for the combination of irrigation water sources and irrigation water methods leading to a potential exposure to enteric pathogens in the SAWP occupational setting. The following section details the general FMEA methodology before discussing how it was adapted and applied to meet the objective of this work.

FMEA is a systematic method for evaluating all parts of a process or system to understand how each component might fail, aiding to identify the most vulnerable aspects of the process or system. FMEA first requires defining and listing all potential parts of a process or system and understanding how they relate to each other (Bazu & Bajenescu, 2011). Every part of the process is then examined for failure modes and the effects of those failures. After the failure modes and effects are identified, a rating is assigned to each of the failure modes according to the severity (S) of the effect. For each failure mode and effect, a list of all possible causes is identified and rated according to the likelihood of their occurrence (O). Finally, a list of all current controls that can be taken if a failure occurs is determined and rated according to how likely the control will be able to detect the failure or prevent it from occurring (D). To determine the overall vulnerability of each failure mode, the three rating factors severity (S), occurrence (O) and detection (D) are multiplied to calculate the Risk Priority Number (RPN) in equation (4). Failure modes are then prioritized based on the values of the RPN.

$$Risk\ Priority\ Number\ (RPN) = \text{Severity (S)} \times \text{Occurrence (O)} \times \text{Detection (D)} \qquad \textbf{(4)}$$

Risk indices from the FMEA can be used to evaluate risk in a number of different ways; some approaches include determining an FMEA RPN threshold for failure modes requiring action or only dealing with the top RPN values before moving onto the next one. Representation of RPN values through a risk matrix can also be used to evaluate risk visually. This approach can be summarized in an FMEA table examining failure modes, failure effects, potential causes and current controls with all associated severity (S), occurrence (O) and detection (D) ratings. Guiding questions for each factor for a generalized FMEA process (Lean Six Sigma, 2021) detailed in Table 3-1 below.

Table 3-1: Generalized FMEA Questions

Potential Failure Mode	Potential Failure Effects	SEVERITY SCORE	Potential Causes	OCCURRENCE SCORE	Current Controls	DETECTION SCORE	RPN
In what ways could the step, change or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?		

Given the variability of different hazards and hazardous situations identified within each of the four categories from section 3.2.1, it is difficult to assess and compare the impacts of each hazard and hazardous situation. For certain hazards and hazardous situations identified, it may be possible to modify and apply the use of FMEA for analysis. In the context of potential enteric exposure, FMEA can be used to carry out a semi-quantitative exposure assessment given a hazard and pathway. Factors include looking at the degree of contamination, the frequency of a specific activity leading to a potential exposure, and the potential intensity of exposure if contamination is present. An example of how this approach can be applied is looking at a failure scenario that exposes workers to hazards with many pathogens, such as the handling or application of manure with no PPE. This failure scenario is an exposure scenario of higher severity than that of a scenario exposing workers to pesticides reconstituted with treated water, for example, which is a less severe source of contamination. The outcomes of scenarios can also vary depending on how frequently workers are exposed to potential hazards. This engineering risk analysis method can be applied in the area of occupational health and safety to assess failure modes pertaining to workplace exposures leading to illnesses and injury where applicable.

However, to the best of the author's knowledge, the FMEA framework has not been applied to occupational illnesses facing migrant farmworkers from exposure to enteric pathogens.

Modification and application of the FMEA method was used to carry out an FMEA looking specially at the potential of migrant farmworker exposure to enteric pathogens from the combination of irrigation water sources and irrigation water methods in the SAWP occupational setting. There was adequate information about irrigation water sources and methods in the literature to be able to apply an FMEA for this specific hazard. However, the FMEA could not be conducted for all of the hazards and hazardous situations identified due to lacking data and lots of variability between potential sites. In the analysis, the focus was on identifying different sources and methods of irrigation water that may be used and that may contribute to a potential worker exposure to enteric pathogens. The effects of the failure scenarios (exposure scenarios) defined, were examined for severity (S) of the contamination (enteric pathogen) in the type of irrigation water source scenario, intensity (I) of a potential exposure and frequency (F) of activity leading to exposure. These were then prioritized based on the values of the RPN calculated as:

$$Risk\ Priority\ Number\ (RPN) = \text{Severity of Contamination (S)} \times \text{Intensity of Exposure (I)} \times \text{Frequency of Activity (F)} \qquad \textbf{(5)}$$

Novel criteria for each of the components of severity, intensity and frequency were developed and ranged from 1 to 5 (Table 4-2, Table 4-3 and Table 4-4). The modified approach can also be summarized in an FMEA table examining failure scenarios (exposure scenarios), failure severity, potential intensity of exposure and frequency of activity. Modified guiding questions for each factor in the specific application of FMEA are detailed below in Table 3-2. Discussion of how risk was evaluated in review of irrigation water sources and methods based on the result of the FMEA is discussed further in section 3.4.

Table 3-2: Modified FMEA Questions for Specific Scope

Potential Failure Mode	Potential Severity of Contamination	SEVERITY SCORE	Potential Intensity of Exposures	INTENSITY SCORE	Frequency of Activity	FREQUENCY SCORE	RPN
What kind of irrigation failure scenarios can contribute to worker exposure to enteric pathogens?	What is the severity of the contamination (enteric pathogens) in the water source for irrigation		How could a potential exposure to enteric pathogens occur and what is the intensity of a potential exposure from the irrigation method?		What is the frequency of worker engagement in the potential exposure scenario from irrigation water sources and methods?		

Assumptions used in carrying out the FMEA for potential exposure from irrigation water sources and methods include assuming that the factors used (severity, intensity, frequency) are sufficient relative comparators to assess exposure. It is also assumed that the ratings for each of the components provided cover most possible exposure scenarios. Another simplifying assumption needed to apply the method was assuming each scenario contributes to a potential exposure or at least exacerbates an existing one. It is also assumed that each scenario identified is independent of another scenario happening at the same time. Some assumptions are also made about the intensity of pathogen exposures in scenarios where the intensity is unknown or variable. There are also limitations to the approach; the analysis is based on the synthesis of available information from the literature and therefore may not be complete if certain sources were not explored, missed, or do not exist.

3.4 Risk Evaluation – Risk Matrix Development

Risk evaluation involved determining whether the assessed risk in the migrant farmworker context is acceptable, tolerable, or unacceptable. After that determination, risk mitigation strategies as part of the overall risk management framework can follow by utilization of one of the following controls: risk avoidance, transfer, limitation and acceptance (Herrera, 2013; Riverlogic, 2018). This is the final step in the risk assessment process required to inform decisions on the risk faced by migrant farmworkers as a result of the assessment outcomes. The evaluation of risk was based on the hazard and exposure assessments (section 3.2) to generate a spectrum of concern risk matrix for the range of exposures tied to each of the identified hazards and hazardous situations. An evaluation matrix was also generated to evaluate the results of the FMEA carried out for the combination of irrigation water sources and methods.

The risk matrix is a widely accepted tool for assessing risks and setting priorities in the management of risk. It provides a means for simple and rapid evaluation of relative risk, facilitating reproducibility and formalizing what would otherwise be a subjective risk assessment process in the migrant farmworker context. The first matrix developed for evaluation addressed the results of the FMEA carried out for the combination of irrigation water sources and methods. It summarizes all of the possible results of RPN using the severity of contamination (S), intensity of exposure (I) and frequency of activity (F) factors. The RPN values calculated were split into five ranges of risk categories based on the lowest and highest values. This resulted in a range of RPN values of (1-4), (5-12), (13-24), (25-63) and (64-125) colour-coded and corresponding to very low, low, medium, high, and very high risk, respectively. RPN results of the exposure scenarios from irrigation water sources and methods exposing workers to enteric pathogens fall within the overall matrix developed. The second matrix that was developed addresses all of the hazards and hazardous situations identified as part of the hazard and exposure assessments (section 3.2) to generate a spectrum of concern risk matrix for the range of exposures tied to each of the identified hazards and hazardous situations, also ranging from very low, low, medium, high and very high. To further support the evaluation of the occupational health risk that migrant farmworkers face from enteric pathogens, a preliminary evaluation of epidemiological evidence was conducted. Further development of validation of the risk framework was not possible because of the lack of quantitative data available to complete the assessment.

Nonetheless, the risk matrices help to visually and qualitatively identify areas of concern for overall risk reduction. In the FMEA evaluation matrix, the RPN provides an overall value for prioritization but can also be used to highlight the high and very high intensity but low frequency scenarios as well as the lower intensity but higher frequency scenarios to aid in determining the type of mitigation action (avoidance, transfer, limitation) or acceptance if no action is required for overall risk reduction. In the spectrum of concern matrix, areas of concern are also highlighted visually for each hazard and hazardous situation. The rationale for the range of concern determined was based on evidence from the literature and potential ways workers can be exposed. This is inherently a subjective process; hence a range was established as a guidance for evaluation. In this evaluation it is assumed that the range determined provides a starting point in assessing the concern for each hazard; however, depending on the scenario under review the determined range may not be applicable.

Chapter 4
Results and Discussion

A risk assessment framework was developed to evaluate migrant farmworker health risks attributable to enteric pathogens. The tools within the overall framework (Figure 4-1) include conceptualization of the contributing hazards and exposure pathways (section 4.2.1) for problem formulation, a transmission network (section 4.2.2) characterizing the relevant exposure pathways potentially leading to migrant farmworker exposure to enteric pathogens, application of an FMEA looking at the exposure to enteric pathogens from the combination of irrigation water sources and irrigation water methods (section 4.3), and risk matrices (section 4.4) relatively evaluating the potential health risks. The combination of all developed tools as part of the framework offers a starting point for synthesizing knowledge about the health risks of enteric disease facing migrant farmworkers to inform research and policy.

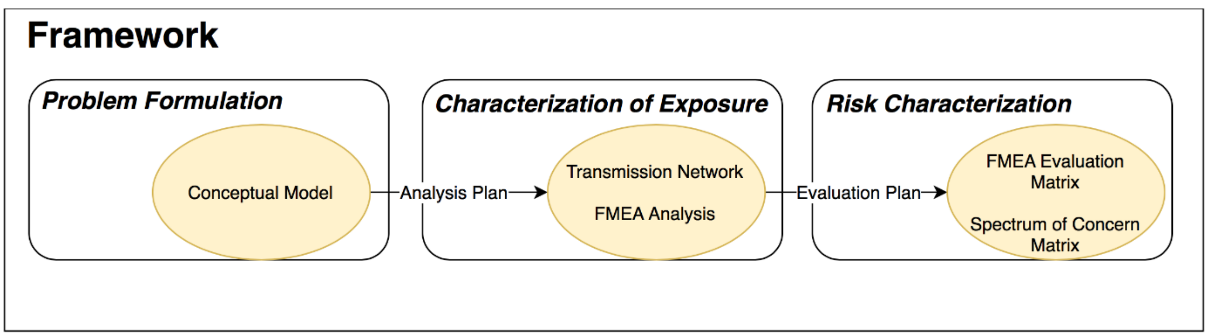


Figure 4-1: Key Components and Tools of the Overall Risk Framework for the Evaluation of Migrant Farmworker Health Risks

Hazards and hazardous situations contributing to migrant farmworker exposure to enteric pathogens were identified and categorized as part of the hazard assessment (section 4.1, thesis objective 1). Exposure pathways describing how workers come in contact with enteric pathogens were evaluated through development of a conceptual model and a detailed transmission network highlighting primary sources, enabled enteric pathogen pathways and possible control points (section 4.2, thesis objectives 2 and 5). Application of an FMEA (section 4.3) and evaluation of the identified hazards and exposure pathways through development of risk matrices (section 4.4, objective 3). Preliminary evaluation of migrant farmworker health risks associated with enteric disease using epidemiological evidence is discussed in section 4.5.3, thesis objective 4.

4.1 Identifying Health Hazards Contributing to Migrant Farmworker Health Risks

The Occupational Health and Safety (OHS) strategy provides the framework needed for a safe and healthy workplace. Some of the goals of the strategy include assisting the most vulnerable workers, promoting the culture of health and safety, and addressing hazards that result in workplace injury and illness. To achieve these goals, the OHS strategy utilizes approaches such as legislation and regulations, development, monitoring and enforcement of published standards, awareness programs, education and training (Ontario Ministry of Labour Training and Skills Development, 2019). One relevant standard for the reduction of workplace injury and illness is provided by the Canadian Standards Association group (CSA); CSA Z1002, "Occupational Health and Safety – Hazard Identification and Elimination and Risk Assessment and Control", which defines harm as physical injury or damage to health and a hazard as a potential source of harm to a worker. The standard describes the requirements for the identification of OHS hazards and their elimination where practical (Canadian Centre for Occupational Health & Safety, 2021d). One of the goals of the OHS strategy is to assist the most vulnerable workers; recognizing that not all workers experience the same level of risk (regardless of whether they are in the same occupation and doing the same job) is key to reducing the risk of a workplace injury and illness. Using concepts from this standard can help identify hazards faced by all workers in a specific occupational setting and additional factors that are not related to job duties and responsibilities that can make some workers more vulnerable than others to a workplace injury and illness.

In the migrant farmworker occupational setting, external factors specifically impacting seasonal migrant farmworkers and contributing to their vulnerability to workplace injury and illness, include (1) regulatory frameworks such as policies around the recruitment of temporary migrant farmworkers, (2) social dynamics such as worker literacy, gender and status, and (3) organizational factors such as the size of a workplace or the safety protocols and procedures in place. The confluence of these factors can magnify the risk of occupational injury and illness. In the agricultural setting, workers experience an array of biological, chemical, physical, and psychosocial occupational hazards that can negatively impact worker health (Sargeant & Tucker, 2009). Migrant farmworkers in the agricultural occupational setting are a group of workers with overlapping vulnerabilities meaning they are simultaneously a member of two or more at risk groups, such as being temporary and migrant. As such, workers can be more vulnerable to occupational hazards given worker legal status, temporary working condition, and social and economic status (National Institute for Occupational Safety Health & American Society for Safety Engineers, 2015).

Hazards and hazardous situations related to enteric pathogens and contributing to health risks were categorized into four main categories of factors affecting migrant farmworker health details summarized in (Table 4-1): (1) agriculture environmental factors including exposure to environmental pathogens in the agricultural setting, (2) infrastructure factors including hazardous situations related to the migrant farmworker living and working conditions, (3) occupational factors such as the provision of health and safety training or availability of personal protective equipment, and (4) SAWP management factors including access to health care. Figure 4-2 summarizes potential hazards and hazardous situations within each of the categories. The findings in Chapter 4 apply the information from various literature sources summarized in Chapter 2 to the migrant farmworker occupational setting through a novel risk-based approach. Section 4.1 provides a review of the overarching categories, and specifically focuses on synthesizing the literature to identify the hazards or hazardous situations with each of the categories contributing to a potential enteric exposure, the exposure pathway to workers and if applicable discussion of mitigation that can eliminate or reduce the impact of an exposure. Information about the hazards and hazardous situations, the potential exposure pathways and possible mitigations strategies were then integrated into risk tools for analysis and evaluation. The analysis includes an FMEA and development of a transmission network to characterize the exposure and the evaluation includes risk matrices to evaluate and characterize the risk.

Table 4-1: Factors Contributing to Migrant Farmworker Health Risk in the SAWP Occupational Setting

Contributing Factors			
Agriculture Environmental Factors	Infrastructure Factors	Occupational Factors	SAWP Management Factors

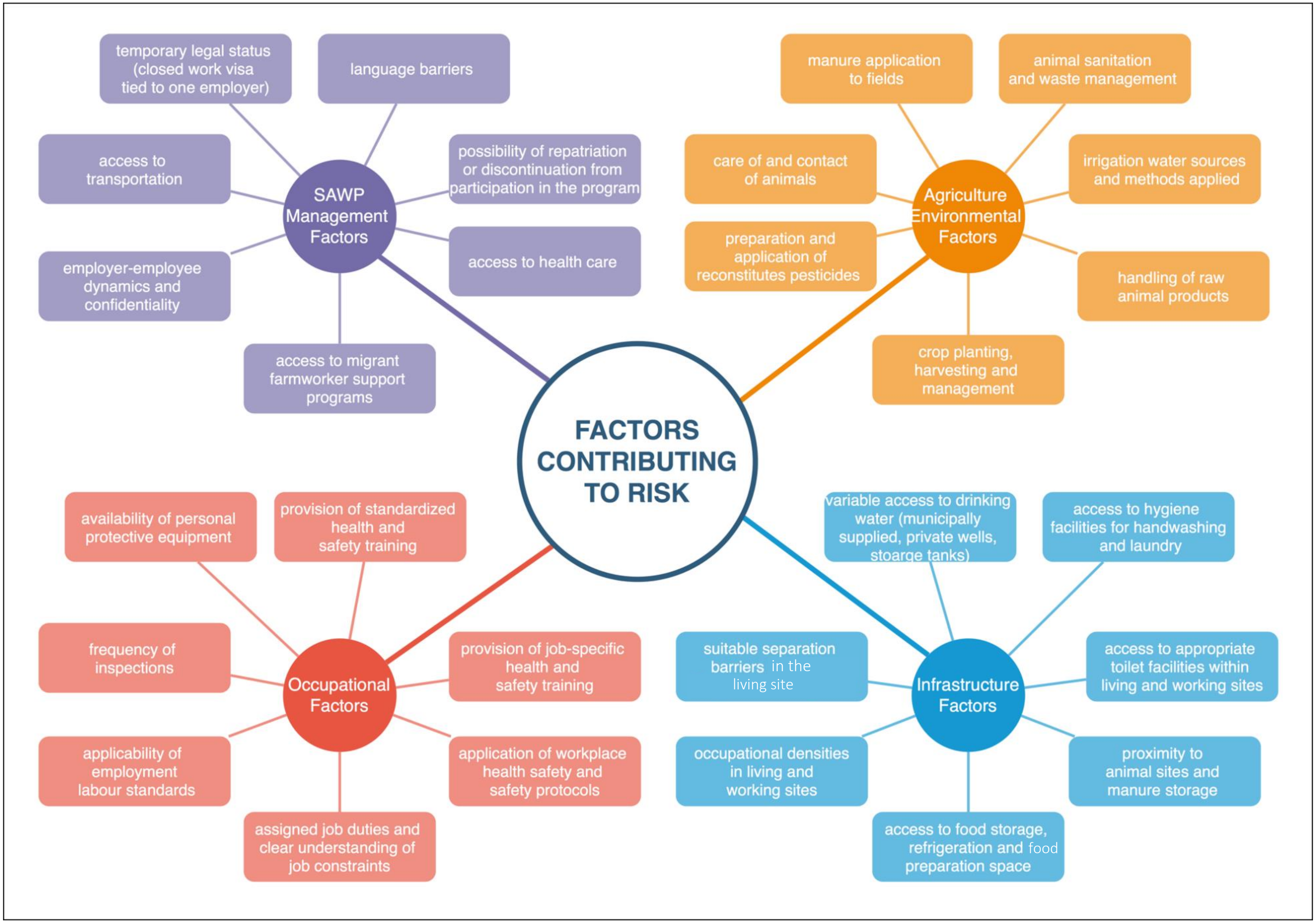


Figure 4-2: Hazards and Hazardous Situations within the Four Main Factors Contributing to Migrant Farmworker Health Risks

Figure 4-3 provides a previously published overview of routes of microbial contamination of food (Julien-Javaux et al., 2019). It identifies seven routes of microbial contamination in the production of berries that were related to primary production stages, including planting, and harvesting within the farm environment. Additionally, recommendations for Good Agricultural Practices (GAPs) were also highlighted for potential risk mitigation. The factors they identified are aligned with the hazards identified as part of this work, especially the agriculture environmental factors category and some in the infrastructure factors and occupational factors categories. However, the focus of this work upon occupational health of migrant farmworkers rather than food safety uniquely provides both a comprehensive overview of the sources leading to potential exposures as well as other factors contributing to an exposure and potentially intensifying the consequences of exposure to enteric pathogens. This work integrates hazards and hazardous situations contributing to exposure to enteric pathogens, capturing unique vulnerabilities specifically facing migrant farmworkers.

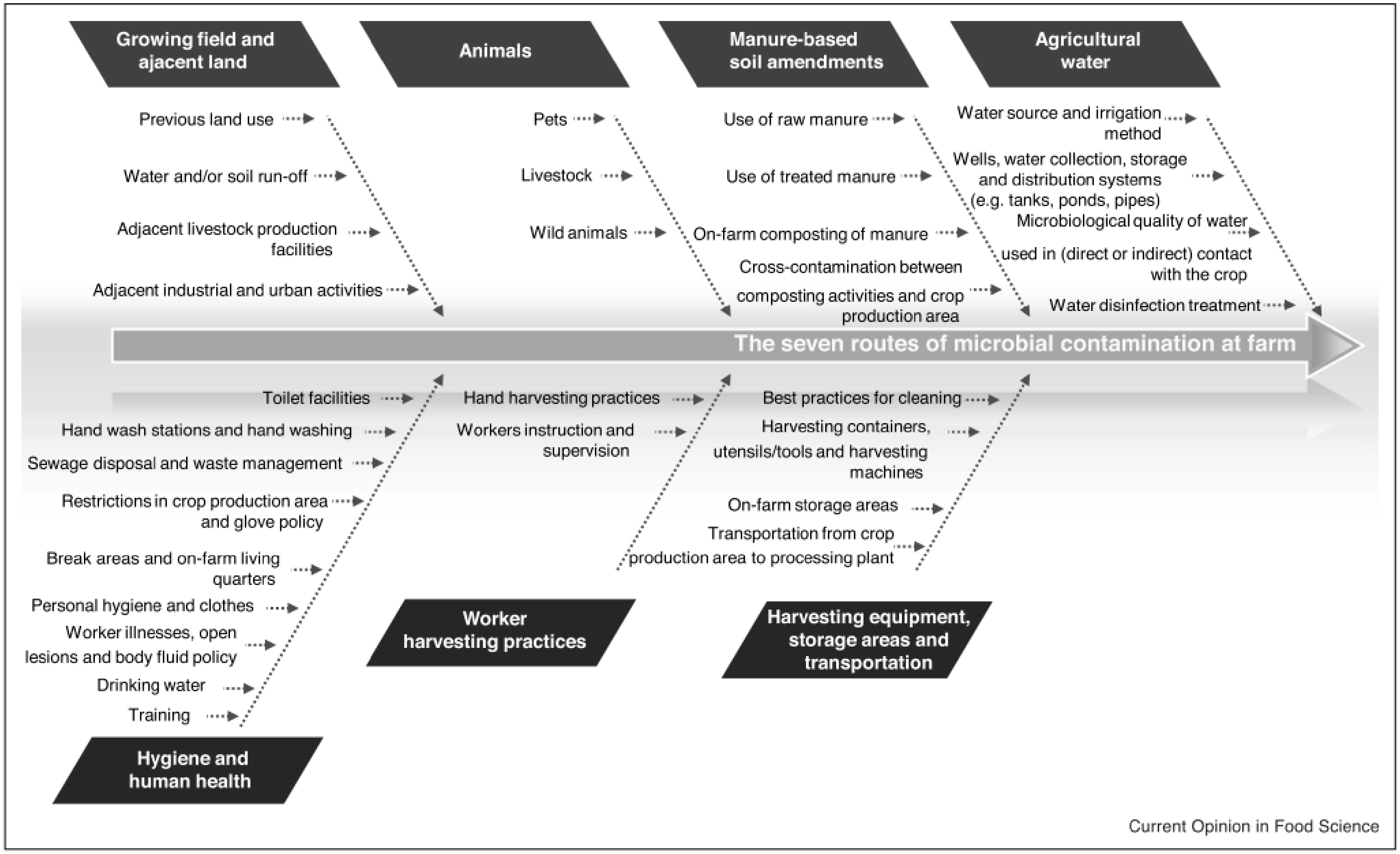


Figure 4-3: Seven Routes of Microbial Contamination in the Primary Production of Berries and Potential Good Agricultural Practices for Risk Reduction

Source: Reprinted from Current Opinion in Food Science, 27, Francoise Julien-Javaux, Cedric Gérard, Matteo Campagnoli, Sophie Zuber, Strategies for the safety management of fresh produce from farm to fork, 145-152., Copyright (2019), with permission from Elsevier.

4.1.1 Agriculture Environmental Factors

The first category of health hazards facing migrant farmworkers and contributing to their risk of enteric disease covers exposure to sources of enteric pathogens inherent to the agricultural setting. Seasonal migrant farmworkers carry out specific agricultural duties as part of their occupational role and are inevitability exposed to sources of microbial contamination in this setting (Iwu & Oko, 2019). Workers recruited under the SAWP are recruited based on National Occupational Classification categories and are employed as part of classifications C and D as low skill jobs and occupations requiring lower levels of training (Hennebry, 2008). Farmworkers are employed on crop, livestock, fruit and vegetable farms, primarily carrying out manual labour activities related to planting, fertilizing, cultivating, spraying, irrigating, and harvesting crops, or feeding and tending to livestock and poultry (Statistics Canada, 2018). Sources of enteric pathogens leading to a possible microbial exposure and contamination include domestic livestock, other domestic farm animals and the presence of wild animals on site in addition to the use and handling of animal manure. Other relevant hazards within this category include the preparation and application of reconstituted pesticides, irrigation water sources and methods used and the type of crops grown on site (Beuchat, 2006; Manyi-Loh et al., 2016; Vojkovská et al., 2017). The following discussion focuses on establishing connections of how these factors can become hazards impacting migrant farmworkers and contributing to a potential enteric exposure, by identifying the hazard or hazardous situation, the exposure pathway and if applicable any potential mitigation.

Workers recruited under the SAWP may be required to perform tasks related to the care, breeding, and sanitation of animals and the management of animal waste. In addition to the handling of raw animal products such as milk and eggs. These duties present a potential hazard for workers engaged in carrying out these tasks (Cancino-Padilla, Fellenberg, Franco, Ibáñez, & Vargas-Bello-Pérez, 2017; Sobsey et al., 2011). Exposure pathways to sources of enteric pathogens from these hazards can occur if workers accidentally consume or transmit animal waste via contaminated hands or raw animal products. The presence of wild animals (e.g., birds) can also be a source of enteric pathogens on site (Wallace et al., 1997) and may also present a similar health risk if workers are exposed to wild animal waste. Workers can become exposed to pathogens via contaminated soil or contaminated produce grown on site.

Tasks related to the handling or application of managed animal manure to amend fields, or the preparation and application of reconstituted pesticides, also present a possible source of microbial contamination (Olaimat & Holley, 2012). Workers can be exposed to this hazard through soil ingestion, crop consumption or hands propagating contamination directly to the mouth or to other tools or surfaces. As such, considerations to protect the workers on the field from exposures to enteric pathogens through use of PPE or through the provision and use of washing stations in both working and living areas should be considered as possible mitigation strategies to reduce a potential exposure.

The use of untreated irrigation water represents one of the most important exposure pathways to enteric pathogens during the primary production and pre-harvest stages, given the number of possible routes and the frequency and duration of exposures (Dickin, Schuster-Wallace, Qadir, & Pizzacalla, 2016). Contact between untreated irrigation water possibly containing pathogens (Stine et al., 2005) and crops or workers can act as a pathway for enteric pathogens to spread and potentially cause illness. This potential exposure is further exacerbated depending on the irrigation method used on site. The use of sprinkler and spray methods on site can increase the extent of pathogen movement (Solomon, Potenski, et al., 2002), presenting more possibilities for a worker to come in contact with the water and pathogens while in the field. Therefore, alternative irrigation methods such as subsurface or drip irrigation, depending on water quality, should be considered. Additional considerations include providing workers with adequate PPE or removing workers from the field during and after sprinkler or spray irrigation.

Crop type, growth location and plant phytotomy can influence the potential exposure facing migrant farmworkers (Anderson et al., 2011; Pachepsky et al., 2011). Crop types with a large surface area that can trap and hold moisture, such as lettuce, are prone to higher pathogen contamination (Jones & Shortt, 2010) and crop types that are usually eaten raw or unpeeled or that are minimally processed can also impact microbial contamination (Stine et al., 2005). Crops growing close to or at ground level (e.g., lettuce and cabbage) present a higher potential of contamination as certain pathogens can be transported from the soil to the edible parts via the plant root system (Solomon, Yaron, et al., 2002). Therefore, type of crop and associated attributes, such as location and phytotomy, can influence pathogen entry and adherence to the plant, affecting potential migrant farmworker exposure to the hazard of handling the crop, through direct consumption of produce in the field or accidental consumption via contaminated hands. Migrant farmworkers on farms growing crops prone to microbial contamination may experience more instances of encountering a potential microbial exposure. It is worth noting that potential worker exposure can be further propagated in the "farm-to-fork" chain posing a food safety concern if workers manage crops with contaminated hands. As a result, workers should therefore be provided with clear training, PPE and best practices for each crop type so that they are aware of the potential health risk associated with an enteric infection that can arise from direct consumption of possibly contaminated produce or through accidental ingestion via contaminated hands.

The linkage and interaction that occurs within and between the hazards is important to consider. There is evidence of pathogen-produce associations revealed in major foodborne outbreak data (Anderson et al., 2011). The presence of a pathogen-produce relationship indicates an enabled transmission route specific to the crop types and highlights the importance of surveillance. Soil type and characteristics including soil moisture, pH and temperature are all factors in the persistence of enteric pathogens in soil (Beuchat, 2006; Erickson et al., 2010; Guo, Chen, Brackett, & Beuchat, 2002; Lang & Smith, 2007; Leifert, Ball, Volakakis, & Cooper, 2008; Tate, 1978). *Salmonella* spp. have been shown to survive for longer periods of time in clay soil types versus sandy soil types, while *E. coli* O157:H7 has been shown to survive in clay and loamy soil types versus hardly existing in sandy soil types (Fongaro et al., 2017; Tate, 1978). Therefore, another linkage that can be made is between the presence of enteric pathogens and the type of soil on site; workers on farms with specific soil types may face an exposure influenced by the soil type. These connections are valuable to consider when assessing the potential exposure faced by migrant farmworkers. The health impact from the effect of certain enteric pathogens varies (Troeger, Khalil, & Reiner, 2019), as such the prevalence of specific pathogens driven by crop type or soil type in the migrant farmworker context is an important consideration when assessing mitigation strategies.

The combination of irrigation water and irrigation method can also be a significant consideration in determining the potential exposure faced by migrant farmworkers. Irrigation water used on site can be from two main sources—surface water or groundwater and can either be in the untreated or in the treated form (Jones & Shortt, 2010). Irrigation methods that are used on site can also vary, methods can include spray or surface irrigation, drip irrigation and subsurface irrigation methods (Nikolaou, Neocleous, Christou, Kitta, & Katsoulas, 2020; Statistics Canada, 2010). The interplay of these two hazards can converge to either increase the exposure or reduce it. For example, farms that use treated water for irrigation present minimal potential for microbial exposure from that source as compared to farms that use untreated water for irrigation, regardless of the irrigation method utilized. However, workers on farms that use untreated water sources will experience variable exposure depending on the irrigation method utilized. In this case, untreated water sources with spray or surface irrigation methods will lead to higher exposure, versus untreated water sources with drip or subsurface irrigation methods. This interplay between hazards is a significant consideration when assessing the potential exposure that migrant farmworkers face in this agricultural setting; an FMEA was carried for this relationship and discussed in section 4.3.

4.1.2 Infrastructure Factors

As workers become exposed to potential sources of microbial contaminants within worksites, their unique working and living arrangements further facilitate hazardous situations. Notably, the occupational setting for migrant farmworkers also includes the living site because workers are usually housed in on-farm congregate housing (Hennebry & McLaughlin, 2016). Housing as an extension of the workplace can present potential hazardous situations that face migrant farmworkers (McLaughlin et al., 2012; WSIB, 2009). In this category hazardous situations include exterior and interior issues such as location and proximity to sources of pathogenic microorganisms (i.e., manure or reconstituted pesticide storage) and crowding within the living and working sites (Preibisch & Hennebry, 2011). They also include sanitation and hygiene issues such as insufficient separation barriers and handwashing, laundry and toilet facilities in the living and working sites (Salami et al., 2015), and issues related to temporary amenities including inadequate food refrigeration (Bischoff et al., 2012; Preibisch & Otero, 2014) and reliance on wastewater and water infrastructure such as septic tanks (S. Ciesielski et al., 1991) and private wells with limited accessibility to year-round, municipally supplied treated drinking water. The following discussion focuses on establishing connections of how these factors can become hazardous situations that can contribute to a potential enteric exposure by identifying the hazardous situation, the exposure pathway and if applicable any potential mitigation.

Migrant farmworker housing in the past has included trailers, portables and new and modified farm buildings. Modified farm buildings have included retrofitted barns or warehouses previously used to store manure, fertilizer, reconstituted pesticides and equipment and tools (Hennebry & McLaughlin, 2016). Building sites with proximity to sources of pathogenic microorganisms, such as animal shelters or storage of manure and reconstituted pesticides, pose a microbial health hazard to migrant farmworkers by supporting a pathway of exposure and enabling cross-contamination from the worksite into the living site via contaminated hands, shoes or clothing. Crowding in these spaces also exacerbates the spread of close contact infectious diseases (CCIDs) such as enteric diseases (Baker et al., 2013; World Health Organization, 2021) by facilitating secondary transmission from one person to another via contaminated hands and surfaces. Crowding in migrant farmworker living arrangements has also been tied to overloading the design capacity of on-site sanitary disposal systems leading to overflow or seepage of tanks (S. Ciesielski et al., 1991). Overflow or seepage of septic tanks can potentially lead to groundwater contamination with enteric pathogen through infiltration (Borchardt, Bertz, Spencer, & Battigelli, 2003). If groundwater is then used on site as a potential drinking water source through use of a private well, then exposure can be through direct consumption of drinking water. These findings are particularly important in identifying policy and guidelines aimed at housing and occupational densities in the migrant farmworker settings to reduce the potential of secondary transmission from one person to another and cross-contamination from the field or worksites to break areas and living sites.

Sanitation and hygiene concerns in the migrant farmworker context as discussed in section 2.4.2.2 include limited access to sanitation and hygiene facilities and insufficient separation barriers in the living areas (Salami et al., 2015). The lack of sanitation and hygiene facilities can increase the potential for secondary transmission from one person to another in this setting if workers' contaminated hands are not washed or sanitized allowing for further pathogen propagation. The lack of suitable barriers for hygiene segregation can present a risk of air-borne dissemination of microorganisms when flushing waste down toilets and associated contamination of surfaces that may spread microorganisms within the living areas (Barker & Jones, 2005). Poor sanitation and inadequate means for proper hygienic segregation in these typically close living quarters (Preibisch & Hennebry, 2011) contribute to heightened risk of developing and spreading enteric diseases originating from pathogens in food, water, or environmental. Another consideration in this setting is the sharing of limited sanitation and hygiene facilities among workers during working hours, where often not all workers have enough time to wash during breaks or before going back to work, given the allotted break times discussed in section 2.4.2.2. Inadequate sanitation facilities such as toilets are a major factor in several infectious diseases, including enteric disease (World Health Organization, 2019b). Workers lacking adequate sanitation facilities can face exposure situations from contaminated hands or surfaces or through secondary transmission from one person to another. Therefore it is important to update and enforce existing guidelines outlining a specific number of bathrooms (i.e., toilets), handwashing and laundry facilities, to replace latrines or aging portable bathrooms with flush toilets where possible and to implement hygienic segregation as an effective control measure (Adams et al., 2009; S. D. Ciesielski, Seed, Ortiz, & Metts, 1992).

Workers' temporary stays in the SAWP occupational setting contribute to likely hazardous living situations that are further exacerbated by insufficient and inconsistent housing regulations and oversight. The lack of specific housing guidelines pertaining to addressing issues tied to the spread of infectious disease (Migrant Worker Health Expert Working Group (MWH -EWG), 2020) means that many workers may experience inadequate food refrigeration, heating and storage, and inadequate food preparation facilities (Hennebry & McLaughlin, 2016; McLaughlin, 2009; Preibisch & Otero, 2014). In one documented case, a migrant farmworker in Ontario suffered severe foodborne illness after eating contaminated chicken that had been left out and stored in a cupboard due to insufficient fridge space (Hennebry & McLaughlin, 2012b). Although the consumption of raw meat or spoiled food affects everyone and is not specific to this occupational setting, poor infrastructure and limited access to amenities exacerbate the health risk it poses. Workers' precarious employment and migration status situation prevents them from voicing concerns around housing issues and refusing unsafe work (B. T. Basok, 2007; Hennebry & McLaughlin, 2016; Migrant Workers Alliance for Change, 2020; Sargeant & Tucker, 2009) to protect their health and safety, and better practicing hygiene and food safety. Exposure to pathogenic microorganisms can be through direct consumption of contaminated food if not properly stored and protected. Improved access to amenities such as adequate food storage and food preparation area, and sufficient working refrigerators for all workers can be a potential mitigation strategy. Another infrastructure concern is the type of drinking water infrastructure available in migrant farmworker housing. Work locations for migrant farmworkers are typically on farms in rural Ontario which primarily rely on private wells for drinking water (Goss et al., 1998). While there is lots of variability and complexities related to the quality of drinking water from private wells, generally these systems may have less stringent requirements for monitoring and compliance, making it difficult to detect microbial contamination proactively (National Collaborating Centre for Environmental Health, 2014). Exposure to enteric pathogens can occur via direct consumption of contaminated drinking water.

Housing guidelines and requirements regarding responsibilities for carrying out inspections are inconsistent and vary across jurisdictions. This presents challenges for compliance and enforcement purposes making it difficult to establish a baseline standard for adequate housing. There are also challenges associated with the timing of when initial inspections are carried out. Currently, initial inspections can be done within eight months of the LMIA application, often before worker arrival. Follow-up inspections are rarely conducted given the complaint-based enforcement regime that primarily relies on complaints to perform additional and unannounced inspections (Vosko et al., 2019). This is problematic, as issues that arise in the eight months that follow the inspection will not be captured and addressed. For well water testing specifically, the failure of this pre-occupancy inspection can result in inaccurate water quality results. Given the lack of regulation and oversight tied to migrant farmworker housing, workers may be subject to an intermittent water supply during their temporary stay, which can contribute to microbial contamination as a result of re-growth in the distribution system during periods when not in use (Bivins et al., 2017). Inevitably, sufficient access to adequate amounts of potable drinking water is essential to the protection of public health. Contaminated water, insufficient access, and inadequate management and oversight can expose workers to preventable health risks (WHO, 2019a) contributing to the spread of enteric disease in the migrant farmworker context. Improved surveillance and frequent testing of water quality is a proactive approach to help reduce the potential exposure to waterborne pathogens.

4.1.3 Occupational Factors

A lack of sufficient occupational controls can lead to hazardous situations contributing to migrant farmworker exposure to enteric pathogens. These include sufficient access to PPE, the provision of standardized and specific training, the application of health and safety protocols, the applicability of specific employment labour standards, assigned job duties and clear understanding of job constraints and the requirement to ensure effectiveness of the controls through monitoring and inspections. The following discussion below focuses on describing how the lack of occupational controls contributes or exacerbates situations leading to potential enteric exposures by identifying the hazard or hazardous situation and the exposure pathways.

Incomplete and inappropriate supply or use of PPE facilitates exposure of migrant farmworkers to microbial contamination in the worksite. Given the requirements of their role, workers rely heavily on physical labour mainly carried out through hand contact (Employment and Social Development Canada, 2020b) and hence may experience increased exposure to workplace pathogens in the absence of PPE. The lack of controls such as protective equipment including gloves, masks and eyewear in this environment can increase the potential of pathogen ingestion given that soil-to mouth contact is a critical pathway leading to an enteric illness (Antwi-Agyei et al., 2016). Exposure can also occur through transfer via contaminated hands propagating contamination directly to the mouth or to other tools or surfaces in the living space. A clear policy on the provision and use of PPE is an occupational control that may contribute to reducing the occupational microbial exposures faced by workers (Julien-Javaux et al., 2019).

Inconsistent and limited training related to the health and safety procedures in the workplace can put migrant farmworkers at risk from exposure to hazards, as they may not be aware of the occupational microbial hazards they face. In addition to limited training, often the training that was offered lacked relevance to both the working and living conditions faced by migrant farmworkers (McLaughlin et al., 2014). In some cases training was not always accessible; language and literacy barriers often caused problems of comprehension (Hennebry & McLaughlin, 2016). Given that workers are often unaware of the microbial hazards they may experience on site, exposure can be direct via consumption or accidental via contaminated hands depending on the situation. In the migrant farmworker context, specifically, the inclusion of water sanitation and hygiene (WASH) training was identified as a gap in training. Additional factors beyond WASH such as the intra-household pathogen exposure pathways and contextual factors that reflect setting specific transmission routes (Chard et al., 2020) are relevant in this setting and can influence the effectiveness of WASH strategies. The inclusion of WASH training, however, in this setting as a preliminary tactic is generally a well-recognized strategy that can act as a mitigation strategy against the spread of infectious enteric diseases, and one that is currently missing in the migrant farmworker occupational setting. The World Health Organization has identified WASH training as necessary for the protection of public health and as an intervention in the control and prevention of the spread of infectious disease (World Health Organization, 2015). Specific training modules in this domain relevant to the employer include understanding what constitutes clean water and ensuring its supply and creating sanitation barriers between living and working areas, while elements relevant to workers may include hand hygiene, hygiene promotion in shared living spaces and the management of waste (World Health Organization, 2015). Implementation of occupational administrative controls related to consistent standardized and specific training can make it easier to establish and follow health and safety protocols, aiding to reduce the potential exposures migrant farmworkers face.

The application of workplace health and safety protocols in the agricultural occupational setting varies widely across different organizations and employers. Since the inclusion of agricultural workers in the Occupational Health and Safety Act, the culture around health and safety in this sector has slowly tried to evolve, but largely still varies and is inconsistent (Hennebry & McLaughlin, 2012b). This is further amplified as migrant farmworkers have limitations around access to the use of joint health and safety committees, which are key to ensuring safe workplaces by identifying hazards and making recommendations to improve conditions (McLaughlin et al., 2014). Additionally, migrant farmworkers in this occupational setting also face variable assigned duties that are sometimes outside the constraints of their contract role (McLaughlin, 2009). This may involve performing work on a neighbouring farm or through the transfer and loaning of workers from one farm operation to another. The transfer and loaning of workers is usually done in an effort to meet tight harvesting windows for crops like asparagus on small farms that may not necessarily have the capabilities to bring in seasonal migrant farmworkers (Zamecnik, 2020). Generally, the transfer of workers is acceptable if employers have written approval from ESDC and the foreign government representative, and worker consent. However, the transfer of workers presents a risk to worker health as workers are moving in and out of different environments, often mid-season and without adequate training or awareness of the new hazards, increasing the potential for microbial cross-contamination from one working environment to another and increasing the possibility of a worker occupational illness.

The lack of occupational administrative controls related to employment standards mandating minimum wage, maximum hours of work, overtime and rest periods can also potentially contribute to a heightening degree of exposure. In the long workdays, workers are exposed to occupational sources of microbial contaminants for longer periods of time, increasing the possibility of exposure even if persistent vigilance concerning sanitation and hygiene best practices while working is maintained. Inclusion of administrative controls under the Act and ensuring their application through compliance, such as providing adequate break times for hygiene management and a cap on the number of working hours, can be used as a mitigation strategy to control the risk from exposure to enteric pathogens.

The lack of a comprehensive data collection mechanism and a centralized reporting system is a missing occupational administrative control that can potentially heighten the degree of exposure to a hazard. There is limited data being collected or that is publicly available in regard to migrant farmworker health, housing, safety and occupational workplace claims and enforcement (Migrant Worker Health Expert Working Group, 2020). In the absence of such data and the establishment of routine and unannounced inspections, it becomes very difficult to assess adherence to public health measures, housing standards and workplace health and safety protocols. Additionally, of importance are the gaps associated with the current inspections processes; currently housing inspections do not include a summary of items for review pertaining to the health risks associated with enteric disease in this occupational setting. As such, the frequency of inspections is not as impactful if hazards pertaining to enteric disease are not addressed. This can have a multitude of impacts on migrant farmworkers in this setting. An inadequate number and timing of unannounced inspections can lead to underreporting of living and working issues as they relate to health and safety. Lack of an accessible and confidential reporting mechanism in the workers' preferred language, in addition to unclear and complicated procedures for reporting can prevent workers from full and objective participation in advocating for their rights and health (Migrant Worker Health Expert Working Group, 2020). Undetected deteriorating conditions in this setting can in turn contribute to the risk of a workplace illness, where missing or unmaintained elements such as washing facilities or hygiene separation barriers can contribute to the spread of infectious disease. This lack of adequate data collection, inspection and oversight can further amplify issues related to migrant farmworker living and working conditions. While migrant farmworker occupational factors leading to exposure to enteric pathogens are often similar to those affecting all agriculture workers, it is important to highlight that there are unique barriers that face migrant farmworkers. Access to PPE and training alone do not ensure safe workplaces; for OHS controls to be truly effective workers need to feel empowered to question, review, revise or refuse unsafe work when their health and safety is in question.

4.1.4 Seasonal Agricultural Worker Program Management Factors

Program and procedural hazards under the SAWP potentially hinder the effectiveness of mitigation strategies required to control exposures to pathogenic microorganisms. This can include limited access to health care as a result of language, cultural, transportation and third-party intervention barriers (Preibisch & Otero, 2014) and circumstances tied to their precarious legal status putting them in a position where they may feel obligated to tolerate workplace injuries and illnesses in fear of losing employment and continued inclusion in the program—or repatriation. The following discussion below examines how the impact from these factors can contribute to hazards that exacerbate a potential exposure situation.

Workers' inability to independently access medical care can be one of the major contributors to health risks (Preibisch & Otero, 2014) by elevating the likelihood and consequence of infection in congregate settings when issues are unresolved medically. Workers heavily rely on their employers to mediate their interaction within the health care system. Employers choose health facilities and provide transportation to them, and also often play the role of a translator in that setting (Migrant Worker Health Expert Working Group, 2020). Employers, however, often do not have the skills or training necessary to be health advocates for workers (McLaughlin, 2009), aside from also being a partial party given the employee–employer relationship. Workers are also hesitant to report medical concerns given the power dynamic that exists with their employer (Migrant Worker Health Expert Working Group, 2020); this may further exacerbates the impact of preventable medical conditions and communicable disease. For example, this concern was evident in emergency room (ER) data collected from Norfolk Hospital (2006–2010): workers predominantly rely on ER services in the absence of family doctors, yet only 4% of migrant farmworkers on average per year accessed ER services while 42% of non-migrants accessed the service during the same time period (Hennebry & McLaughlin, 2012b). Additionally, language and communication barriers also limit workers from communicating concerns when seeking help (Migrant Worker Health Expert Working Group, 2020). Language and communication barriers also apply to worker comprehension of instructions or safety training, increasing the risk of work-related injury and illness (Preibisch & Otero, 2014). The combination and effect of these barriers plays a significant role in hindering control strategies that help mitigate disease severity when enteric illnesses arise.

Under the SAWP guidelines, workers receive closed work permits tied to one employer, preventing them from seeking other employment during their stay in Canada (Hennebry & McLaughlin, 2012a). This legal arrangement puts migrant farmworkers in a predicament where they may feel obligated to tolerate workplace harassment, unsafe or unprotected work, and injuries and illnesses due to fear of losing employment or legal status (Hennebry & McLaughlin, 2016). Under these guidelines, employers also have access to the option of worker repatriations (Employment and Social Development Canada, 2020a). Migrant farmworkers facing health conditions inhibiting them from performing ongoing work can be repatriated back to their home country, never accessing workplace insurance that employers pay into and that workers are eligible for. The use of medical repatriation, and the health access and equity concerns from this practice, were documented in a study completed by Orkin et al. (2014) examining medical repatriation data collected by the Foreign Agricultural Resource Management Services (F.A.R.M.S.). The data showed that in Ontario between 2001-2011, 787 workers out of 170,315 were repatriated for medical reasons. The data were further analyzed to determine the dominant reasons and rates of repatriation and it was concluded that the second highest reason for repatriation was gastrointestinal illnesses (26.5%), only closely behind musculoskeletal disorders (27.7%) such as hand and lower limb injuries (Hennebry & McLaughlin, 2012b). These findings are indicative of how these precarious situations can contribute to the risk of infectious enteric diseases, possibly increasing the potential for secondary transmission, and exacerbating the consequences of a worker infection in the absence of healthcare services.

Employers acting as intermediaries for sick and injured workers is a violation of patient confidentiality, a confidentiality that is provided and ensured for all other workers in the province (Migrant Worker Health Expert Working Group, 2020). This specific migrant farmworker vulnerability coupled with workers' inability to seek out community support given their typical rural locations can be damaging to workers' physical and mental health. In these situations, workers are left to navigate complex systems of accessing care and compensation (Hennebry, 2010; Migrant Worker Health Expert Working Group, 2020). Given the complexities tied to accessing care, workers often wait to have health concerns checked out (Preibisch & Otero, 2014). Alternatively, almost 30% of workers have noted engaging in transnational health consultations with health professionals in the country of origin as a way of filling this unmet gap (Hanley et al., 2014). Workers have also noted reliance on migrant support groups. The presence of volunteer groups and grassroot organizations were reported to be one of the only forms of support to workers for empowerment and facilitation of access to things such as compensation, resources and healthcare during their tenure (Canadian Council for Refugees, 2018). Workers unable to promptly manage health concerns through health care services and in some cases dealing with them in alternative ways (e.g., calling doctors in the country of origin or reaching out to friends, volunteers, or family), ultimately prolongs the process of managing or controlling potential infectious enteric disease spread. These vulnerabilities can amplify the impact of an infectious enteric disease within this unique occupational setting, where enteric illnesses among this population can go unnoticed and continue to spread, contributing to magnified health risks. This is especially relevant as current mechanisms of data collection for acute enteric disease outbreaks do not identify migrant farmworkers as a population at a potentially heightened health risk.

4.2 Exposure Pathways of Enteric Pathogens and Potential Control Points

Exposure pathways describing how workers come in contact with enteric pathogens leading to a potential infection within the limits of the SAWP occupational setting were evaluated through development of a conceptual model (section 4.2.1) and a detailed transmission network (section 4.2.2). The conceptual model is the outcome of the systems identification process. The model highlights primary sources of enteric pathogens and key pathogen pathways leading to exposure of migrant farmworkers as the limits of the assessment, the model also highlights locations of possible hygiene and sanitation control points. The model was further detailed to identify the many possible pathways from source to potential worker exposure with the development of a transmission network. Further development of the transmission network is also discussed. Potential control points were introduced to demonstrate how possible mitigation strategies may be developed.

4.2.1 Conceptual Model of Hazards, Exposure Pathways and Potential Controls

The developed conceptual model describes the potential for a migrant farmworker exposure from source to potential infection highlighting the limits of the assessment through a few key components: specifically, (1) the sources from which a contamination can occur, (2) the hazards and hazardous situations contributing to migrant farmworker exposure to enteric pathogens, categorized under work and living sites, (3) the drivers leading to contamination which have been distinguished as direct and accidental, (4) the pathways leading to a potential worker infection, and (5) the location of possible control points.

The sources of fecal contaminants include enteric pathogens originating in animal and human hosts on site or in untreated water used on site. Original contamination pathways identified as sparsely dotted brown lines in Figure 4-4 are enabled as migrant farmworkers come in contact with these contaminants in their worksites and living sites. These contaminants can then be transferred to items in the work and living sites, and pass from one location to the other. In the worksite, enteric pathogens can originate in manure and untreated irrigation water and can be transferred to items such as work equipment and crops in the field. Through cross-contamination pathways, pathogens can be brought into the living sites from the worksites, and can be transferred to bathroom, kitchen and common area surfaces via contaminated hands potentially. Within these two sites there are intermediate spaces and items like portable toilets, worker personal items, PPE, clothing and work boots to which enteric pathogens can be transferred and then moved from the work site to the living site or vice versa. The overlap between the living and working sites in the migrant farmworker setting enables exposure to enteric pathogens by facilitating cross-contamination pathways represented by the solid brown lines as migrant farmworkers move between the two sites. The dashed pink lines represent enabled pathways leading to ingestion of enteric pathogens from both site locations through direct means via consumption of food, crops and drinking water, or through accidental ingestion via contaminated hands and surfaces. Once pathogens have been ingested, dose-response pathways characterize the potential of infection given the amount of pathogen contamination to which a worker was exposed. There is a cyclical element in the model in which an infected worker can become a source in the cycle through shedding, represented by the dotted brown lines. The final details represented here are the OHS control points and their location, showing sanitation and hygiene controls as risk mitigation strategies along the enabled pathways. Sanitation controls are geared towards the environmental hazards by preventing the introduction of fecal contamination into the worksites and living sites (i.e., separation barriers), while the hygiene controls are geared towards preventing ingestion of pathogens that may be encountered in the worksites and living sites by the migrant farmworkers (i.e., handwashing facilities).

The conceptual model is a visual representation of actual and predicted relationships between migrant farmworkers and the hazards to which they may be exposed, as supported by literature, leading to a potential enteric infection. Of importance are the cross-contamination pathways highlighted within the migrant farmworker setting. The overall risk to workers from a potential exposure may be understated if cross-contamination is ignored. This conceptual model underscores the rationale for the sources, the hazards and the main exposure pathways within the migrant farmworker setting. It also emphasizes the need for targeted hygiene and sanitation control points as mitigation strategies. Access to additional data such as migrant farmworker health records and workplace inspection records can be used to quantify pathogen pathways and test the effectiveness of specific control measures within the model.

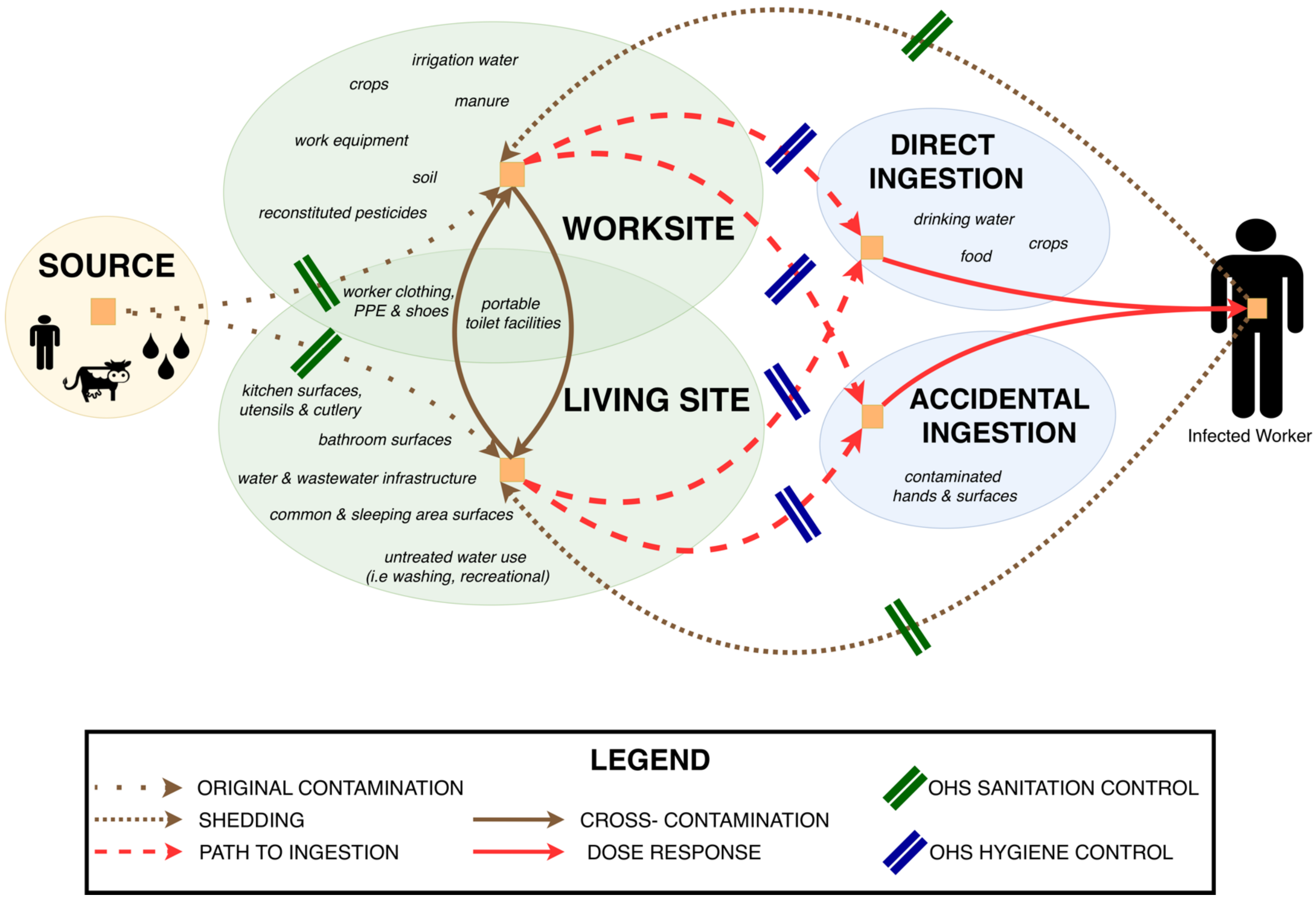


Figure 4-4: Conceptual Model Describing Main Exposure Pathways and Control Points of Enteric Pathogens Leading to Exposure of Migrant Farmworkers in the SAWP Occupational Setting

4.2.2 Transmission Network Identifying Enabled Pathogen Pathways

Three main sources contributing to the spread of infectious enteric disease in the migrant farmworker context were highlighted by developing a transmission network that includes components (i.e., nodes), interactions (i.e., pathways) and boundaries (i.e., infection or decay). The movement of enteric pathogens from source to potential worker exposure within the system can be modelled with Markov chains, with four possible states (source, active, sink/decay, and exposure). Sources of enteric pathogens introduced into the system include animal or human waste on site and waterborne enteric pathogens. The first two sources involve inputs into the system created on site, while waterborne pathogens could have originated on or off-site and can flow in and out of the system. Other sources originating off-site, such as a worker infection off-site or contaminated food obtained off-site, are considered out of scope.

Three modular source transmission networks describing the movement of pathogens from animal feces, human waste and untreated water sources were developed. Potential interactions between these transmission network modules are shown below with dotted orange lines in Figure 4-5. Details of individual modules are shown later in Figure 4-7, Figure 4-8 and Figure 4-9. Pathogens in the network were assigned to nodes with four possible states. The four states identified were pathogens at source, pathogens along active pathways, pathogens removed and pathogens at the host. The nodes to which these states were assigned were defined source nodes, active nodes, sink/decay nodes and exposure nodes. In all three source modules, the primary sources are connected to source type nodes, which flow into active nodes that allow for an enabled pathway for the pathogen to move within the system, potentially leading to an exposure or being eliminated in the system by sink/decay nodes. Active nodes within the transmission network are identified as green nodes with pathogen pathways moving forward allowing for the transfer of pathogens, and sinks are shown in red where the pathogen is removed from the system. An exposure is identified as an orange node, which can then lead to a possible infection (i.e., infected worker). The movement of the pathogens within the transmission network is organized through phases: Phase one shows the pathogen sources and the primary pathways of enteric pathogens within the transmission network. Phase two shows the secondary pathways of pathogen transfer in the worksite and living site and potential removal of enteric pathogens. Phase three also shows the potential for pathogen removal as well as the potential for exposure to enteric pathogens via direct and accidental ingestion.

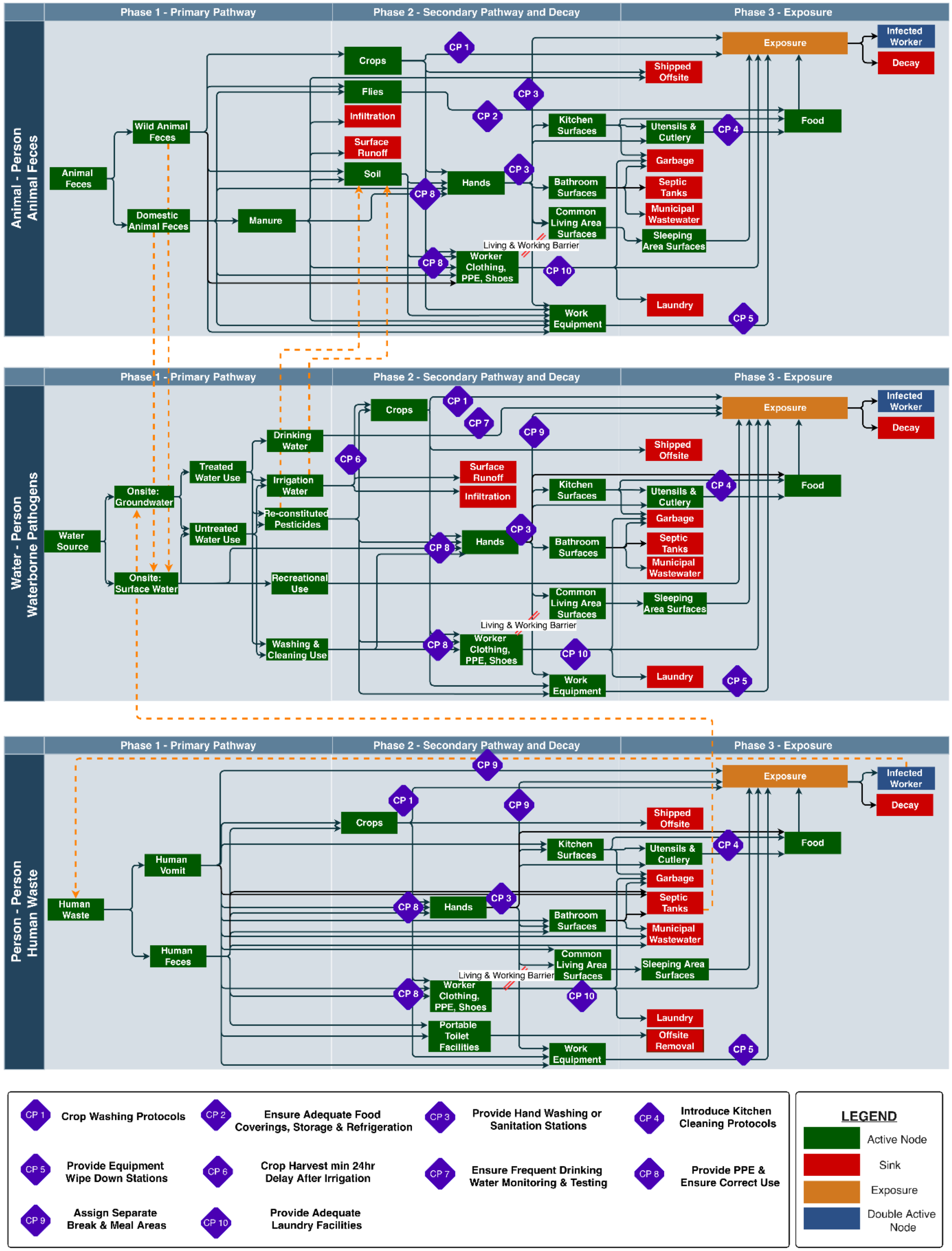


Figure 4-5: Transmission Network Describing the Transfer of Enteric Pathogens from Source to Potential Migrant Farmworker Infection in the SAWP Occupational Setting

Each active node in the transmission network specifically leads into another node, pathogens at nodes are either moved forward along pathways to active nodes or are removed from the system by sink/decay nodes. To assess interconnections within the transmission network each node was checked against every other node in the system for conceptual completeness in assessing nodes and possible connections and pathways, with details summarized in Appendix A. Within the transmission network a proposed barrier is identified between the living and working area, and throughout control points using a HACCP approach were added as purple diamonds. Control points were identified at potential locations where mitigation strategies can be used to impede or disable the pathway allowing pathogens to move forward. Control point locations based on HACCP principles can also serve as locations for verification of current strategies, implementation of corrective actions, or modification of strategies for continuous improvement.

Using the overall network in Figure 4-5, transition probability matrices for each interaction based on the four-state transition probability matrix defined in equation (3) can be generated. Each interaction in the system can be described using a Markov chain. For example, one possible interaction in the network is initiated with animal feces and specifically wild animal feces as a source, followed by crops as a possible active node, and an exposure node where there is a potential for exposed workers to become infected or for the pathogen to be removed. In this interaction the pathogen transitions through all four possible states are defined. This interaction can be summarized by the Markov transition matrix in equation (6) and the Markov transition diagram in Figure 4-6.

$$P = \begin{bmatrix} 0 & p_{01} & 0 & 0 \\ 0 & p_{11} & p_{12} & p_{13} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & p_{32} & 0 \end{bmatrix}$$

Equation 6: Markov Transition Matrix for a Potential Initial Pathway

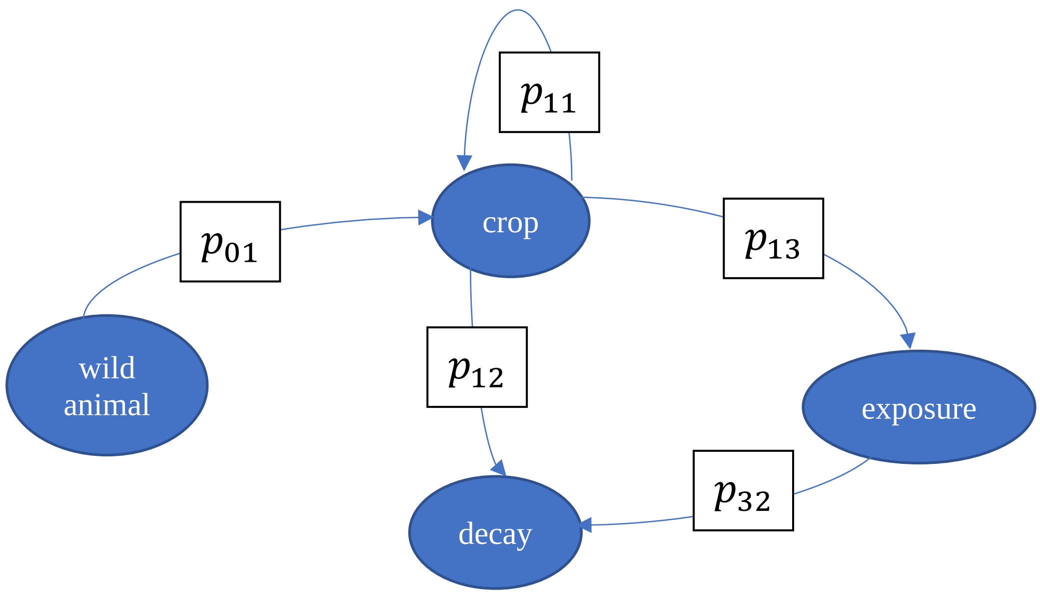


Figure 4-6: Markov Transition Diagram for a Potential Pathway

The sum of interactions using the transmission network as a starting point can be modelled and further analyzed to explore the movement of pathogens based on actual or assumed data. This illustrative example of one pathway in the network highlights how Markov chains can be used to determine the highest probability routes contributing to an exposure. This information can also inform where controls can add the most value in reducing the probability of exposure. An attributed effectiveness for a control, assumed or based on actual data, can be added into the network to reduce the probability of exposure. In this example, CP1 is introduced along an active pathway in the network (Figure 4-5) between the crop node and the exposure node, if we assume an effectiveness for CP1 introduced at that location, then the probability of p_{13} in the matrix is reduced based on the addition of the control. Exposure pathways highlighted in the transmission network represent pathways that are most relevant to the migrant farmworker population in the agricultural occupational setting; pathways describing the potential for pathogen decay at every node are not represented in the network. It is apparent within all three-source modules that there are common nodes past the primary source inputs. The overall transmission network is built on one-way transfer through nodes, with the exception of an infected worker potentially back feeding into the system by infecting another worker, either directly or indirectly, this is highlighted in Figure 4-5 as a double active blue node. For simplicity the back feed of infected worker back into the network is only shown in the Human Waste module (Figure 4-8).

In the overall system there are key interactions that occur between the three transmission network modules. Themes of hygiene and consumption emerge as a concern enabling pathogen pathways in the overall transmission network. The hygiene element of concern is facilitated through the hand contact node potentially leading to direct or indirect exposures. Here the hand node allows for the enablement of many potential pathways to move forward. The consumption element is tied to multiple nodes, such as crops, food and drinking water leading to a potential direct exposure. These specific themes are consistent across all three modules. Details of each of the three transmission network modules are discussed further below.

All three source modules are interconnected, connections between the three source modules are highlighted in the network as orange dotted lines. Here a primary source leading to a sink in one module can be reintroduced as an active node into another module. For example, human feces making their way into a septic tank can potentially infiltrate into groundwater sources. This is illustrated as a sink in the human waste module, as it is removed from that source module, with no likely pathway leading to an exposure in that form. However, enteric pathogens from that source, can be transferred into the waterborne pathogen module, and captured within the groundwater source type node, leading to a potential exposure in the waterborne form. Another example highlighted in the overall transmission network, is the potential for enteric pathogens from the animal feces module to also make their way into the waterborne pathogen module through runoff within the agricultural setting. This interconnectivity highlights the importance of analyzing all different sources as a system versus analyzing them individually in an effort to avoid understating the risk of an enteric infection through missed exposure pathways and connections (Canan, 2018). The following sections below detail the development of the three individual source modules.

4.2.2.1 The Transfer of Enteric Pathogens from Animal Sources to a Potential Migrant Farmworker Infection

The presence of animals on site presents a potential source of enteric pathogens through the secretion of animal waste (Aw, 2018). The microbial flora of bacteria and protozoa that exists in animals can continue to exist in the animal host without causing an enteric illness, however, upon exposure to humans, theses pathogens can cause illness in human hosts (Sobsey et al., 2011). Animal feces can be of two types: from domestic livestock and other domestic animals onsite, or from wild animals making their way into the agricultural farm setting. The distinction between the two source types is essential from a control and management perspective. Waste from domestic animals is easier to manage with appropriate control strategies (i.e., PPE), while wild animal waste might be harder to manage, and control given the spread and unpredictability. This is a necessary distinction prior to the introduction of control strategies in the transmission network.

Enteric pathogens in animal feces from domestic livestock and wild animal sources may contaminate crops, directly through fecal droppings or indirectly through runoff from contaminated irrigation water (Jay-Russell, 2013). Enteric pathogens from animal sources can also exist in the soil surrounding the crop, or in managed manure used for field amendments; or it can be transmitted by vectors (i.e., flies). A secondary pathway for pathogen transfer can be through direct ingestion of food or through accidental ingestion via contaminated hands from contamination on surfaces and objects (e.g., clothes, PPE and shoes) ultimately leading to a potential exposure. Contamination from both livestock domestic and wild animals in the field can be transferred into the living space through contaminated hands, and on worker clothing, PPE, and shoes. Another potential pathway of contamination, not highlighted in the network, can be through the movement of other domestic animals (i.e. cats, dogs) between the field and the living areas as well as the presence of wild animals (i.e., rodents) in the living area. For example, rodents in the living sites can be a potential source of enteric pathogens, where enteric disease such as salmonellosis can be transmitted through consumption of food contaminated with rodent feces (Centers for Disease Control and Prevention, 2017).

The addition of control points is also identified within the transmission network; in the Animal–Person transmission network module, there were ten instances where control points were recommended. Details of the exposure pathways from animal feces as a source leading to a potential worker exposure and infection, and control points highlighting locations where mitigation strategies can be used are shown in Figure 4-7 below.

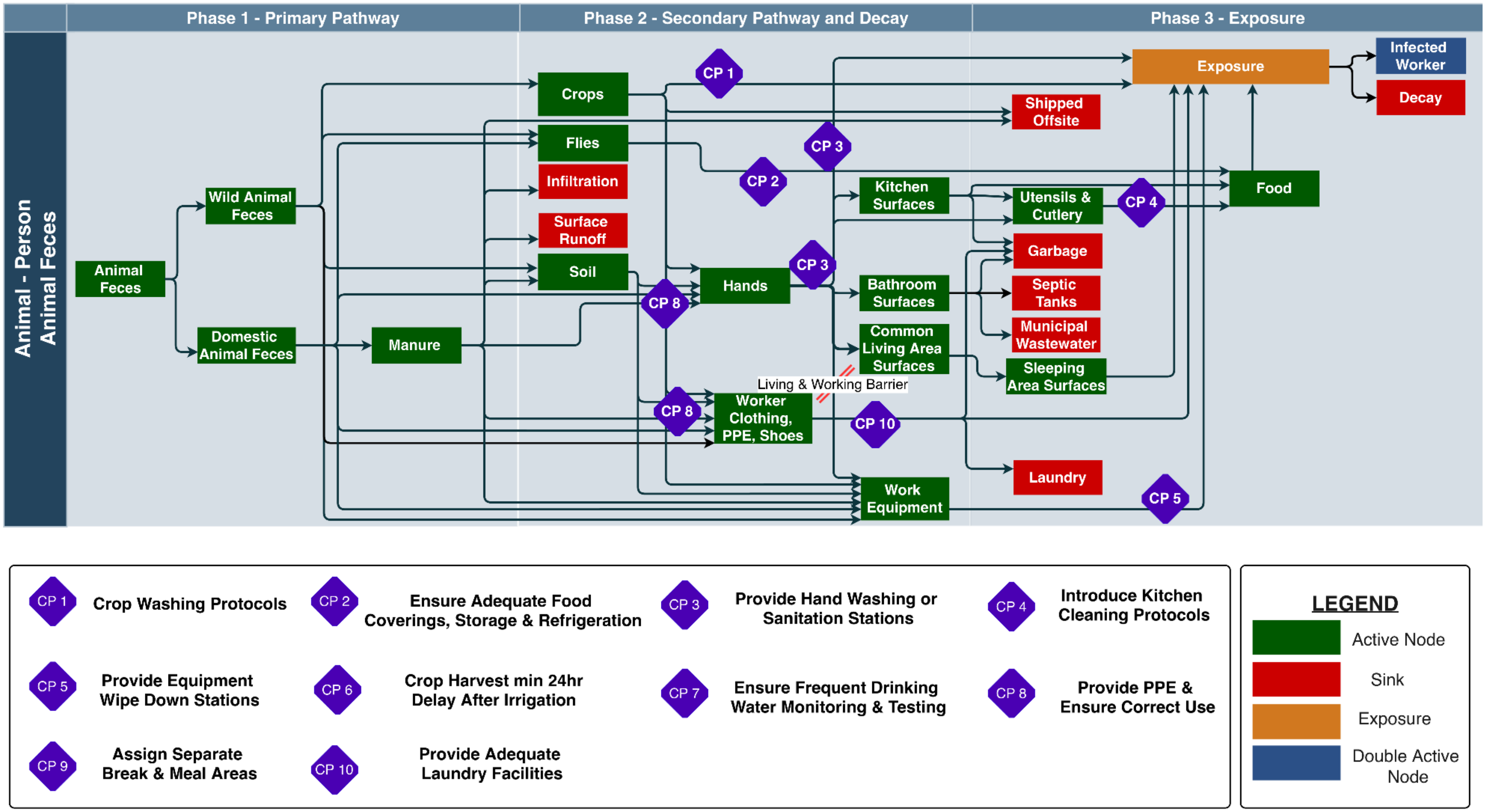


Figure 4-7: Animal—Person Transmission Network Describing the Transfer of Enteric Pathogens from Animal Sources to a Potential Migrant Farmworker Infection in the SAWP Occupational Setting

Control points within the transmission network modules were classified into three main categories of control, the primary being through hygiene controls and sanitation controls encompassing infrastructure and resource changes. In the Animal–Person transmission network the first control point CP1 focuses on mitigating the risk associated with a potential exposure through direct ingestion of crops that may have been contaminated by wild animal feces. This risk is specifically focused on contamination from wild animals, because domestic animal waste such as manure is typically managed, and domestic livestock are usually separated from where crops are grown, relatively reducing the risk associated with domestic animal droppings (Beuchat, 2006). The recommendation put forward highlights a hygiene control by necessitating a crop washing protocol to protect against a potential exposure through crop consumption. Control point CP3 focuses on introducing hygiene controls within this setting. It recommends limiting the risk associated with accidental ingestion via contaminated hands from animals' feces in the soil or in managed manure by recommending the introduction of sufficient handwashing and sanitation stations. Control points CP2, CP4, and CP5 are sanitation control points focused on introducing protocols to limit the risk from direct ingestion and cross-contamination in shared spaces. CP2 identifies the need for adequate and sufficient food coverings, storage, and refrigeration, limiting the risk through direct ingestion of contaminated food. CP4 and CP5 include the introduction of cleaning procedures within the shared kitchen space and of shared equipment. Finally, control points CP8, CP9 and CP10, are also sanitation controls focused on infrastructure and resources, CP9 recommends infrastructure changes that separate the working and eating areas, and CP8 and CP10 focus on providing the resources necessary to limit exposure of migrant farmworkers from on the field sources in this occupational setting through PPE and adequate laundry facilities.

Additional control strategies not shared as formal control points within the module include strategies that focus on controlling contamination directly at the source (i.e., animal feces) and strategies that prevent or mitigate cross-contamination from occurring. Control strategies at the source include controlling the movement of domestic animals on site, especially if there is crop production occurring on site. Movement of domestic animals can be controlled by using tactics such as dedicated grazing areas that are far from water sources, or fences around crop production areas. While, movement of wild animals cannot be controlled, tactics such as the use of bird repellants or fences around crop production areas can be used. Another control strategy focuses on reducing cross-contamination, by ensuring the use of dedicated tools for animals and for crops. Cross-contamination can also be controlled by ensuring workers are washing hands and changing PPE if necessary as they move between animal sites and crop production sites, or by limiting the use of farm vehicles between manure sites and crop production areas. Finally, to reduce further cross-contamination corrective actions need to be taken when evidence of animal intrusion in the fields is found, this may include disposing of the produce and isolating the area (Nestlé Research Center, 2016).

4.2.2.2 The Transfer of Enteric Pathogens in Waste from an Infected Human to another Potential Migrant Farmworker Infection

Waste from an infected worker in this setting can lead to the transmission of enteric disease between migrant farmworkers, making an infected worker a potential source in this setting. Human waste of an infected worker can be of two primary source types: human vomit and human feces. Other human waste from showering or bathing is captured through waste management methods such as septic tanks or municipal wastewater and is not considered as a source type in this module. The distinction between the two is necessary to highlight the significance of multiple exposure pathways of possible enteric pathogens in human feces, as compared to that of possible enteric pathogens in human vomit. It is worth noting that the impact of human vomit is mainly tied to sources of pathogenic viruses such as norovirus (Aw, 2018; Health Protection Surveillance Centre, 2016).

Human vomit as a source can become a concern, if vomit is carrying pathogenic microorganisms, such as bacteria, protozoa, and viruses that cause enteric illnesses. Exposure to possible enteric pathogens in human vomit in this setting can be via exposure through aerosolization or by accidental ingestion through contaminated hands. Human feces, however, can make their way into multiple active nodes given the migrant farmworker setting. Management of human feces in this setting based on documented reports is usually through the use of septic tanks and/or portable toilet waste tanks (Hennebry & Preibisch, 2008). These waste management methods as compared to a municipal sewer system pose the potential risk of re-introduction of possible enteric pathogens into the agricultural farm system through contamination of the surrounding environment via leakage or seepage into the groundwater (Borchardt et al., 2003). Human waste can also make its way onto bathroom surfaces through aerosolization or contaminated hands and can be further propagated through accidental ingestion via contaminated hands (Barker & Jones, 2005; Johnson, Mead, Lynch, & Hirst, 2013). The addition of control points was also identified within the transmission network; in the Person–Person transmission network module, there were ten instances where control points were recommended. The details of the transmission network showing the pathogen pathways and potential control points are shown in Figure 4-8 below.

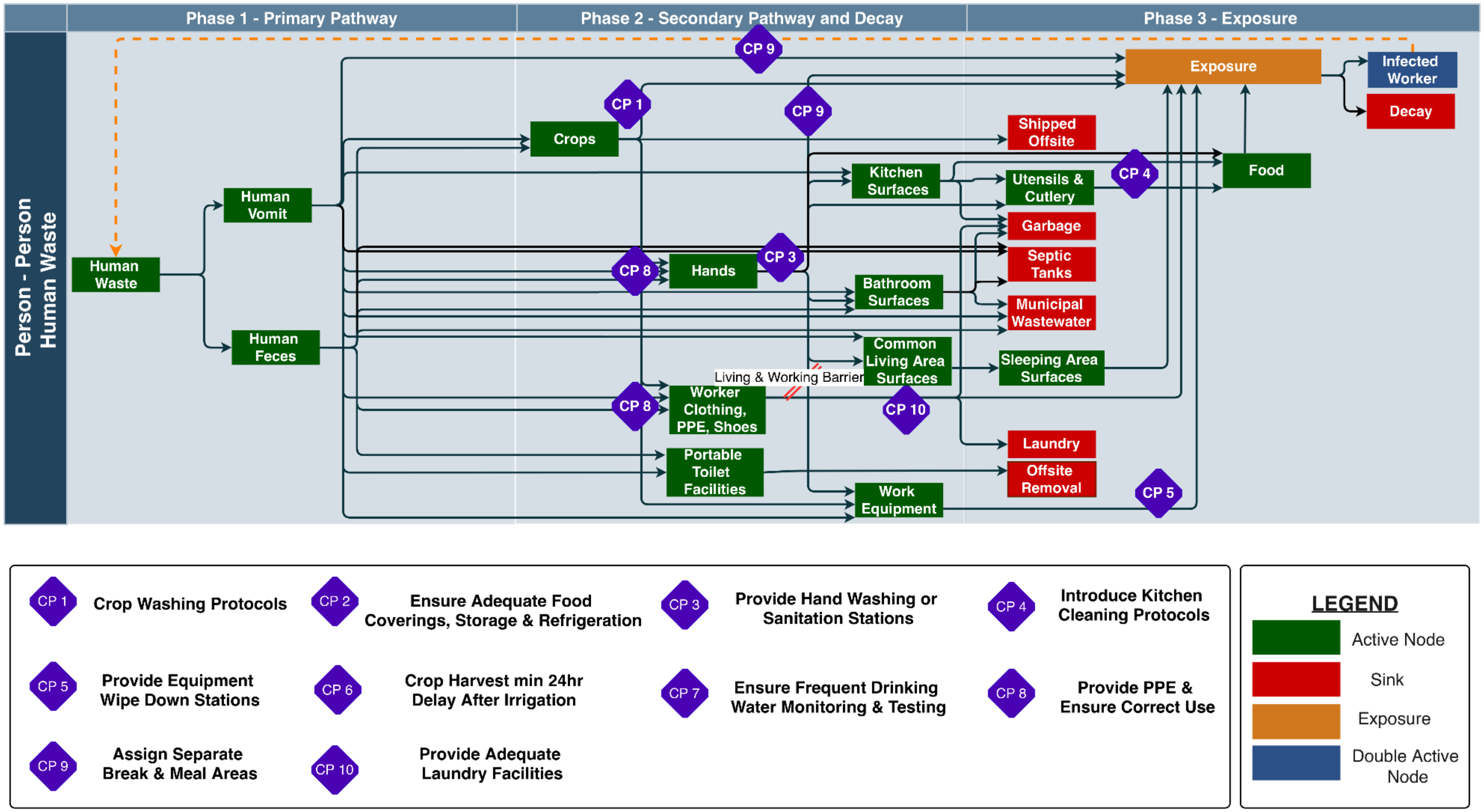


Figure 4-8: Person—Person Transmission Network Describing the Transfer of Enteric Pathogens in Waste from an Infected Human to another Potential Migrant Farmworker Infection in the SAWP Occupational Setting

In the Person–Person transmission network similarly all recommended control points were categorized into hygiene control, sanitation control including infrastructure and resources changes, and regulatory controls. Control points CP1 and CP3 are hygiene control points, where CP1 in the Person–Person transmission network module is identified to control an exposure from direct ingestion of crops contaminated by hands as opposed to contaminated by wild animal feces. CP3 highlights contamination of hands leading to a potential accidental ingestion from both human waste types. The recommendations prescribed to both control point locations is crop washing protocols prior to consumption and hand washing stations to limit the spread. Similar to the Animal–Person transmission network module, control points CP4, CP5, are sanitation control points focused on protocols to limit the risk from cross-contamination in shared spaces, by introducing cleaning procedures for shared spaces and shared items. Control points CP9 and CP10 are also sanitation controls that focus on ensuring that infrastructure such as separate working and eating areas, as well as laundry facilities are in place to limit cross-contamination and exposure in this setting from waste of an infected human.

Additional control strategies for further consideration (not in transmission network) include ensuring well maintained, non-leaking septic systems; this can be achieved through adequate selection, construction and maintenance of septic tanks (Adams et al., 2009). This strategy can be used as a mitigation to prevent the potential of contamination to a groundwater source (Borchardt et al., 2003). Other strategies include ensuring adequate hygiene infrastructure in the field but also ensuring migrant farmworkers are well informed and well trained to deal with the hazards they experience in this occupational setting. Ensuing workers have access to a close-proximity toilet facility in the field and not just when workers are on break, will reduce the chances of contamination in the field. Toilets should be accessible, but also sufficient to accommodate the number of workers in the field. Facilities should be in good working order including having a sink with clean running water and soap, a closing door, and waste tanks are inspected regularly to confirm no leakage. The second aspect of control from secondary transmission from one person to another via contaminated hands and surfaces is ensuring workers on site are well informed of the hazards through training and are given the resources (e.g., sufficient handwashing facilities) to carry out hygiene best practices. Strategies include ensuring workers understand the potential consequences of illness and are given tools and training on how to react to an illness in the field such as vomiting in or near the crop production areas.

4.2.2.3 The Transfer of Enteric Pathogens from Water Sources to a Potential Migrant Farmworker Infection

Enteric pathogens originating from animal and human hosts can exist in untreated water sources as waterborne pathogens. Water sources can be ground and surface water sources and are a transient source into the network, not bounded within the agricultural farm setting system. The distinction between the two sources is further detailed as treated and untreated water sources. This distinction is necessary, due to the array of possible uses and the potential amount of enteric pathogens depending on the source and whether it is treated or not (Murphy et al., 2016). Enteric pathogens in waste from animal hosts can make their way into water sources through runoff. Factors influencing the risk from runoff include the location and proximity of animal rearing sites to water sources and is further exacerbated by the lack of buffer zones (City of Abbots Ford, 2014). While enteric pathogens from human hosts can make their way into water sources from recreational use in above ground water sources and/or through seepage from septic tanks into underground water sources (World Health Organization, 2016).

Enteric pathogens in water sources can make their way onto primary active nodes through different uses of water in both the treated and untreated form within the agricultural farm setting (Hamilton et al., 2006). Groundwater can carry the potential of pathogenic microorganisms but often at a lower level than untreated surface water sources (Jones & Shortt, 2010). A groundwater source carrying the potential for enteric pathogens in the network may be propagated forward through primary active nodes of use including drinking water, irrigation water, water for reconstituting pesticides, and water for washing or cleaning purposes. It is worth noting that treated, municipally supplied drinking water was not considered as a source of pathogenic microorganisms under the drinking water active node within the transmission network. The potential of contamination from treated, municipally distributed water is low relative to other water sources such as untreated groundwater or surface water sources (section 2.4.1.3).

Secondary transmission routes for this specific source type can then be through direct ingestion of drinking water and/or contaminated crops or through accidental ingestion via contaminated hands. Untreated surface water sources such as lakes or rivers often have a higher concentration of enteric pathogens as compared to groundwater sources (Uyttendaele et al., 2015). In this system, untreated water from surface sources carrying the potential for enteric pathogens can move through primary active nodes of uses such as irrigation water, water for reconstituting pesticides, recreational uses of water, and water for washing and cleaning purposes. Similarly, secondary transmission routes from these sources can also be through direct ingestion or through accidental ingestion via contaminated hands in the absence of handwashing facilities in the work and living sites. Eleven instances of control points were recommended for mitigation in this transmission network module. Details of the transmission network showing the movement of waterborne pathogen pathways based on source type and use with the recommended locations for control points can be seen in Figure 4-9 below.

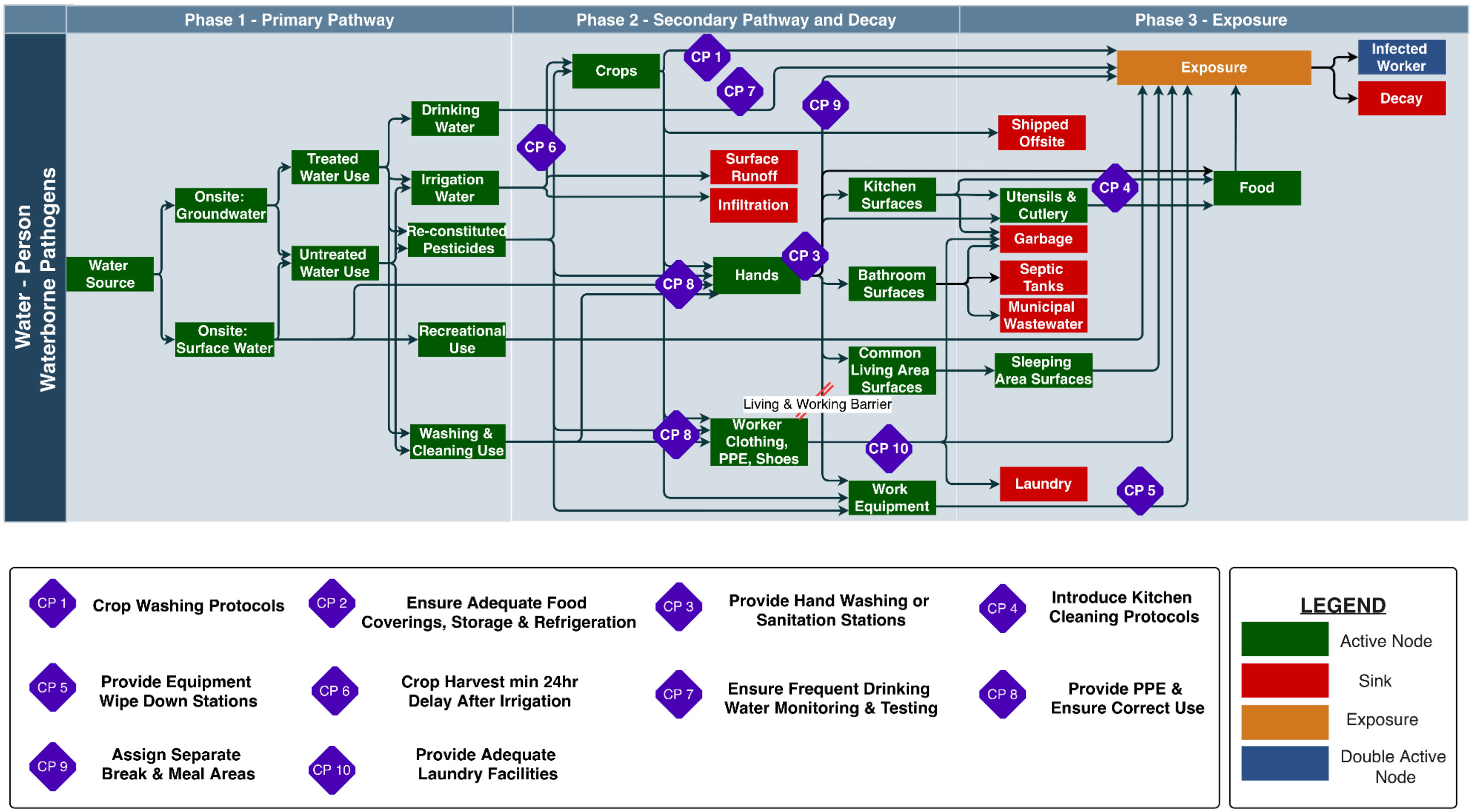


Figure 4-9: Water—Person Transmission Network Describing the Transfer of Enteric Pathogens from Water Sources to a Potential Migrant Farmworker Infection in the SAWP Occupational Setting

In the Water–Person transmission network the first control point, CP7, is a regulatory control point tied to frequent monitoring and testing of drinking water systems that are not municipally supplied. Verification of water source quality through a consistent regime of testing and frequent monitoring before, during and after migrant farmworker occupancy is recommended, given evidence highlighted by Ciesielski et al. (1991). The evidence suggests that testing only prior to migrant farmworker occupancy may not be a true representation of expected water quality during use as a result of bacterial die-off, dispersion in the groundwater, or dilution. Control CP6 is also a regulatory control that recommends a 24hr delay between irrigation and crop harvesting to reduce the risk from a possible contamination (Weller et al., 2015). Similar to the previous two transmission network modules, control point CP1 highlights potential exposure through direct ingestion of contaminated crops, but from an irrigation water source as opposed to via contaminated hands or directly from a wild animal source. The recommendation here, again, is to ensure crop washing protocols to reduce contamination through consumption. Control point CP3 is the same as the other two transmission network modules, focusing on a hygiene control by recommending handwashing or hand sanitation stations for contaminated hands. Control points CP4, and CP5 are sanitation control points, recommending strategies to deal with the spread of cross-contamination in shared spaces and shared items through cleaning protocols. Finally, control points CP9, and CP10 are also sanitation controls that recommend infrastructure changes such as adequate laundry facilities and hygiene segregation barriers to limit exposure from contaminated water sources (Carollo, 2010).

One long-term control point not highlighted in the transmission network is the addition of a buffer zone around surface water sources. Buffer zones can be used to limit potential contaminants from making their way into surface water sources (World Health Organization, 2016). Buffer zones can be physical barriers such embankments, or natural vegetative barriers to redirect or reduce runoff from animal production or waste operations (Iwu & Oko, 2019). Another consideration here is the careful selection of new fields for crops further away from sources of possible contamination, and at higher elevation grounds to avoid contamination from runoff upstream. This strategy can be introduced into the network along a pathway from domestic animal feces to surface water sources.

4.3 Analysis of Migrant Farmworker Health Risks

The modified FMEA conducted to examine the risk of a potential exposure to enteric pathogens from the combination of irrigation water sources and methods resulted in 16 possible exposure scenarios with five levels of possible frequencies leading to an exposure. Ways that exposure can occur (failure modes) were identified for each of the water source and irrigation method combinations that can contribute to workers' exposure to enteric pathogens. Using the guiding questions defined as part of the modified FMEA methodology (Table 3-2), scores were determined under each possible exposure scenario for all three factors. The effects of the exposure scenarios defined were examined for severity (S) of the contamination (enteric pathogen) in the type of irrigation water source. Different irrigation methods were then examined to assess how exposure to irrigation water sources can occur. An intensity score (I) measuring the intensity of a potential exposure was assigned to the exposure scenario. Finally, the frequency (F) of worker engagement in the potential exposure scenario was examined and can be rated accordingly. The exposure scenarios were prioritized based on the values of the RPN as per equation (5) using the scores from the factors of severity (S), intensity (I), and frequency (F).

The criteria used to score each of the factors of severity, intensity and frequency ranged from 1 to 5 with metrics defining each of the possible scores. The developed criteria focused on defining the severity of the contamination in a specific exposure scenario by assigning a rating to the number of potential pathogens that may be present in an irrigation water source. The intensity of a potential exposure to workers was examined based on the irrigation method; a rating was assigned to the degree of exposure to irrigation water given the irrigation method. The frequency was defined through a range of possible time periods of exposure. The criteria for each of the factors are summarized below in Table 4-2, Table 4-3 and Table 4-4. Summarized results of the scenarios with corresponding factor scores and RPN values are below in Table 4-5.

Table 4-2: Severity of Contamination Criterion

Severity	Severity of contamination in exposure scenario	Ranking
Very High	Severity of contamination in exposure scenario may be very high with an abundant number of pathogens	5
High	Severity of contamination in exposure scenario may be high with many pathogens	4
Medium	Severity of contamination in exposure scenario may be medium with a moderate number of pathogens	3
Low	Severity of contamination in exposure scenario may be low with a limited number of pathogens	2
Very Low	Severity of contamination in exposure scenario may be very low with a minimal number of pathogens expected	1

Table 4-3: Intensity of Potential Exposure Criterion

Intensity	Intensity of potential exposure to workers	Ranking
Very High	Intensity of exposure is very high; workers directly exposed to hazard or hazardous situation	5
High	Intensity of exposure is high; workers may be directly exposed to hazard or hazardous situation	4
Medium	Intensity of exposure is medium; workers indirectly exposed to hazard or hazardous situation	3
Low	Intensity of exposure is low; workers may be indirectly exposed to hazard or hazardous situation	2
Very Low	Intensity of exposure is very low and is not expected to expose workers to hazard or hazardous situation	1

Table 4-4: Frequency of Activity Criterion

Frequency	Frequency of activity leading to a potential worker exposure	Ranking
Frequently	Activity is frequently done; may be multiple times a day	5
Often	Activity is often done; may be multiple times a week	4
Occasionally	Activity is occasionally done; may be multiple times a month	3
Rarely	Activity is rarely done; may be only seasonally	2
Very Rarely	Activity is very rarely done, may be done annually or not applicable	1

Table 4-5: FMEA to Characterize the Potential Migrant Farmworker Exposure to Enteric Pathogens from Irrigation Water Sources and Methods

Potential Failure Mode	Potential Severity of Contamination	SEVERITY (1-5)	Potential Intensity of Exposures	EXPOSURE (1-5)	Frequency of Activity	FREQUENCY (1-5)	RPN	RANKING
What kind of irrigation failure scenarios can contribute to worker exposure to enteric pathogens?	What is the severity of the contamination (enteric pathogens) in the water source for irrigation		How could a potential exposure to enteric pathogens occur and what is the intensity of a potential exposure from the irrigation method?		What is the frequency of worker engagement in the potential exposure scenario from irrigation water sources and methods?			
Workers on farms with a municipally supplied treated irrigation water source	Severity of contamination in exposure scenario may be very low with a minimal number of pathogens expected	1	Workers on farms with subsurface irrigation methods	1	Never	1	1	Very Low
					Rarely	2	2	Very Low
					Occasionally	3	3	Very Low
					Often	4	4	Very Low
					Frequently	5	5	Low
			Workers on farms with drip irrigation methods	2	Never	1	2	Very Low
					Rarely	2	4	Very Low
					Occasionally	3	6	Low
					Often	4	8	Low
					Frequently	5	10	Low
			Workers on farms with spray/sprinkler irrigation methods	3	Never	1	3	Very Low
					Rarely	2	6	Low
					Occasionally	3	9	Low
					Often	4	12	Low
					Frequently	5	15	Medium
			Workers on farms with surface (furrow/flood) irrigation methods	4	Never	1	4	Very Low
					Rarely	2	8	Low
					Occasionally	3	12	Low
					Often	4	16	Medium
					Frequently	5	20	Medium
Workers on farms with an onsite treated irrigation water source (treated private wells)	Severity of contamination in exposure scenario may be medium with a moderate number of pathogens	3	Workers on farms with subsurface irrigation methods	1	Never	1	3	Very Low
					Rarely	2	6	Low
					Occasionally	3	9	Low
					Often	4	12	Low
					Frequently	5	15	Medium
			Workers on farms with drip irrigation methods	2	Never	1	6	Low
					Rarely	2	12	Low
					Occasionally	3	18	Medium
					Often	4	24	Medium
					Frequently	5	30	High
			Workers on farms with spray/sprinkler irrigation methods	3	Never	1	9	Low
					Rarely	2	18	Medium
					Occasionally	3	27	High
					Often	4	36	High
					Frequently	5	45	High
			Workers on farms with surface (furrow/flood) irrigation methods	4	Never	1	12	Low
					Rarely	2	24	Medium
					Occasionally	3	36	High
					Often	4	48	High
					Frequently	5	60	High

Potential Failure Mode	Potential Severity of Contamination	SEVERITY (1-5)	Potential Intensity of Exposures	EXPOSURE (1-5)	Frequency of Activity	FREQUENCY (1-5)	RPN	RANKING
What kind of irrigation failure scenarios can contribute to worker exposure to enteric pathogens?	What is the severity of the contamination (enteric pathogens) in the water source for irrigation		How could a potential exposure to enteric pathogens occur and what is the intensity of a potential exposure from the irrigation method?		What is the frequency of worker engagement in the potential exposure scenario from irrigation water sources and methods?			
Workers on farms with an untreated groundwater irrigation source	Severity of contamination in exposure scenario may be high with many pathogens	4	Workers on farms with subsurface irrigation methods	1	Never	1	4	Very Low
					Rarely	2	8	Low
					Occasionally	3	12	Low
					Often	4	16	Medium
					Frequently	5	20	Medium
			Workers on farms with drip irrigation methods	2	Never	1	8	Low
					Rarely	2	16	Medium
					Occasionally	3	24	Medium
					Often	4	32	High
					Frequently	5	40	High
			Workers on farms with spray/sprinkler irrigation methods	3	Never	1	12	Low
					Rarely	2	24	Medium
					Occasionally	3	36	High
					Often	4	48	High
					Frequently	5	60	High
			Workers on farms with surface (furrow/flood) irrigation methods	4	Never	1	16	Medium
					Rarely	2	32	High
					Occasionally	3	48	High
					Often	4	64	Very High
					Frequently	5	80	Very High
Workers on farms with an untreated surface water irrigation source	Severity of contamination in exposure scenario may be very high with an abundant number of pathogens	5	Workers on farms with subsurface irrigation methods	1	Never	1	5	Low
					Rarely	2	10	Low
					Occasionally	3	15	Medium
					Often	4	20	Medium
					Frequently	5	25	High
			Workers on farms with drip irrigation methods	2	Never	1	10	Low
					Rarely	2	20	Medium
					Occasionally	3	30	High
					Often	4	40	High
					Frequently	5	50	High
			Workers on farms with spray/sprinkler irrigation methods	3	Never	1	15	Medium
					Rarely	2	30	High
					Occasionally	3	45	High
					Often	4	60	High
					Frequently	5	75	Very High
			Workers on farms with surface (furrow/flood) irrigation methods	4	Never	1	20	Medium
					Rarely	2	40	High
					Occasionally	3	60	High
					Often	4	80	Very High
					Frequently	5	100	Very High

The 16 possible exposure scenarios included the combination of four possible irrigation water sources (municipally supplied irrigation water, treated groundwater, untreated groundwater and untreated surface water) and four possible irrigation methods. The irrigation methods examined included subsurface irrigation methods, drip irrigation methods, spray or sprinkler irrigation and surface irrigation methods.

The range for severity of contamination in the water sources was highest for untreated surface water and lowest for municipally treated water. The number of pathogens in surface water is often more than in treated water sources particularly municipal water sources utilizing a multi-barrier approach for treatment to actively remove or deactivate pathogens. This situation is not expected to expose workers to pathogens (WHO et al., 2004). Onsite irrigation water sources that are treated may contain a few pathogens if treatment on site is not comprehensive. Therefore, severity of contamination from this water source is medium since it is treated. Untreated groundwater sources are scored as high since water is not treated; however, groundwater sources are usually of good microbial quality in comparison to untreated surface water sources (Uyttendaele et al., 2015). Surface water sources used for irrigation in the agricultural setting can often become contaminated with animal waste runoff and can contain a high number of pathogens (Uyttendaele et al., 2015). Therefore, severity of contamination in surface water sources; very high with the potential for an abundant number of pathogens.

The range for intensity of potential exposure for the irrigation methods was highest for surface irrigation methods that flow water over the soil, usually covering the crops, presenting workers with many chances for a potential exposure during crop handling. The range was lowest for subsurface irrigation methods that water crops below the soil surface, minimizing the chance for workers to come in contact with it. Drip irrigation methods water crops close to the soil surface (Stine et al., 2005) workers may be indirectly exposed to it, but the chance of exposure is low. Spray or sprinkler irrigation methods spray the top of crops presenting a higher chance for workers to come in contact if they are working in field during irrigation (Solomon, Potenski, et al., 2002); therefore, intensity of a potential worker exposure may be medium in this scenario.

The impact of the irrigation method is influenced by the water source and is further influenced by the frequency workers are exposed to the activity, emphasizing the need for an FMEA-style approach to integrate all three factors. For example, farms that use treated water for irrigation as compared to untreated water sources will have a lower chance of a potential worker exposure regardless of the irrigation method utilized. However, workers on farms that use untreated water sources will experience variable exposure depending on the irrigation method utilized. In this case, untreated water sources with spray or surface irrigation methods are expected to lead to higher exposure versus untreated water sources with drip or subsurface irrigation methods. The number of times during a specific period that workers are exposed to irrigation activity can also contribute to the degree of exposure. Workers may be faced with exposures many times a day, increasing the risk, or rarely exposed and decreasing the risk.

This interplay between hazards is a significant consideration when assessing the potential exposure that migrant farmworkers face in this agricultural setting. The use of an FMEA is valuable as it helps to integrate different variables for overall risk consideration. It provides a means for prioritizing risk based on a variety of contributing factors. The FMEA as a tool allows for multi-dimensional analysis in a structured approach and can be applied to examine complex situations or scenarios. In this work it was applied to explore the potential of migrant farmworker exposure to enteric pathogens in the SAWP occupational setting. This is the first study that utilizes FMEA as a framework to facilitate evaluation of potential exposure of migrant farmworkers in the SAWP to enteric pathogens, highlighting areas of concern for possible risk mitigation. Very high and high RPN values warrant the implementation of controls such as enhanced PPE during irrigation, or administrative controls such as removing workers from the fields during irrigation and scheduling work outside of those periods. Alternatively, control can include the use of treated irrigation water, the modification of an irrigation method or the combination of both. Evaluation of the RPN values through a risk matrix is discussed in section 4.4.1. Application of FMEA to explore potential exposure in an occupational setting is novel and bridges thinking from engineering risk analysis to public health and occupational health and safety.

FMEA, however, could not be conducted for all the hazards and hazardous situations identified due to lacking data on the severity of contamination and/or potential intensity of exposure for certain hazards and hazardous situations. Evaluation of the hazards and hazardous situations identified is summarized in a spectrum of concern risk matrix for the range of exposures tied to each of the identified hazards and hazardous situations (section 4.4.2).

4.4 Evaluation of Migrant Farmworker Health Risks

Two risk matrices were developed for evaluation of migrant farmworker health risks attributable to enteric pathogens. An evaluation matrix was generated to evaluate the results of the FMEA carried out for the combination of irrigation water sources and methods (section 4.4.1). Additionally, a spectrum of concern risk matrix was also developed for the range of exposures tied to each of the identified hazards and hazardous situations from Figure 4-2 (section 4.4.2). The spectrum of concern matrix integrates the understanding of the identified hazards with the potential exposure pathways to measure a relative spectrum of concern ranging from very low to very high for a potential exposure, which can be used as guidance by risk assessors.

4.4.1 FMEA Evaluation Matrix

The FMEA evaluation matrix summarizes all of the possible results of RPN based on the three factors of severity, intensity and frequency. Values of RPN were split into five categories to characterize the potential risk of an exposure. Categories were defined as very low, low, medium, high and very high and corresponded to a range of values and a colour code. Very low values ranged from 1-4, low values ranged from 5-12, medium values ranged from 13-24, high values ranged from 25-63 and very high values ranged from 64-125. The summarized FMEA evaluation matrix is below in Table 4-6. The split between the range of RPN values was arbitrary and was used to help characterize the different levels of potential risk. Characterization of the risk helps to prioritize high risk scenarios and can also help to focus potential mitigation strategies. After the risk is characterized mitigation strategies can follow; this is specific to the scenario and can vary widely depending on the assessment and judgment of the assessor. Types of mitigation strategies include risk avoidance or removal, transfer or limitation of the hazards for risk reduction, or acceptance of the risk.

Alternatively, in some FMEAs it is possible to only focus on the highest values of RPN or to determine an RPN threshold where action will only be taken for values at or above the threshold. The use of the matrix to show the gradation of risk, even if arbitrary, is valuable because it summarizes everything in one tool for review and risk management. The FMEA evaluation matrix can be used to identify at a quick glance the very high and high values and the drivers leading to it (severity, intensity, or frequency). Given that information, scenarios of higher RPN values can be managed by changing any or all of the factors of severity, intensity or frequency. In this application, the severity can be reduced by using a treated water source for irrigation, the intensity can be reduced by using a subsurface or drip irrigation method and the frequency can be reduced by removing the workers during irrigation or irrigating at different times or less frequently.

The matrix is not a quantitative representation of hazards; rather it is a qualitative assessment providing a relative comparison of risk. The developed matrix at minimum is a high-level tool to distinguish between very high and very low risks. Relative risk ranges defined in the matrix can also help prioritize potential action by differentiating between immediate action or acceptably low risk for adequate resource planning and overall risk management (Vatanpour, Hrudey, & Dinu, 2015). As such, despite the limitations of risk matrices, users can utilize the matrix to inform and highlight areas of concern to support decision-making.

Table 4-6: FMEA Evaluation Matrix

1-4	5-12	13-24	25-63	64-125
VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH

INTENSITY	FREQUENCY					SEVERITY
	Never	Rarely	Occasionally	Often	Always	
Very Low	1	2	3	4	5	1
Low	2	4	6	8	10	
Medium	3	6	9	12	15	
High	4	8	12	16	20	
Very High	5	10	15	20	25	
Very Low	2	4	6	8	10	2
Low	4	8	12	16	20	
Medium	6	12	18	24	30	
High	8	16	24	32	40	
Very High	10	20	30	40	50	
Very Low	3	6	9	12	15	3
Low	6	12	18	24	30	
Medium	9	18	27	36	45	
High	12	24	36	48	60	
Very High	15	30	45	60	75	
Very Low	4	8	12	16	20	4
Low	8	16	24	32	40	
Medium	12	24	36	48	60	
High	16	32	48	64	80	
Very High	20	40	60	80	100	
Very Low	5	10	15	20	25	5
Low	10	20	30	40	50	
Medium	15	30	45	60	75	
High	20	40	60	80	100	
Very High	25	50	75	100	125	

4.4.2 Spectrum of Concern Matrix for identified Hazards and Hazardous Situations

The spectrum of concern matrix was developed to address all of the hazards and hazardous situations within each of the four categories identified from Figure 4-2. The FMEA could not be conducted for all of the hazards and hazardous situations identified due to lacking data and lots of variability, and so the FMEA evaluation matrix could not be used to evaluate the potential risk of an exposure from all of the hazards and hazardous situations. Evaluation was instead summarized in a spectrum of concern risk matrix for the range of exposures tied to each of the identified hazards and hazardous situations, also ranging from very low to very high. The spectrum of concern matrix is developed to be used as a guide for risk assessors.

The hazards and hazardous situations identified all contribute to a potential exposure or exacerbate an existing one; however, their impact can be variable depending on the exposure scenario, the frequency of the activity leading to exposure and the controls in place. To be able to assess this variability; a guidance matrix was created to determine the range of concern from a potential exposure. Similar to the FMEA matrix the range varied from very low, low, medium, high and very high. Each hazard or hazardous situation was assigned a possible range of concern the rationale for assignment was supported through discussion of the literature, ways workers can be exposed, and examples of lower and higher scenarios based on the hazard or hazardous situation under review. Rationale supported through discussion of the literature focused on three drivers of risk. It examined if there was an increased exposure to enteric pathogens given the environment, if there was an increased potential for secondary transmission given the situation and finally if there was an increased potential consequence to health given the hazard or hazardous situation. The finalized guidance spectrum of concern matrix is summarized in Table 4-7, Table 4-8, Table 4-9 and Table 4-10 below.

The spectrum of concern matrix is a valuable tool because it provides a form of evaluation for subjective items that can vary widely from one situation to another. The tool also provides the risk assessor the flexibility to assess the situation while still providing some guidance supported through literature. This process also engages the assessor to start considering possible risk management strategies as hazards are identified. The tool would be used as a supporting guidance document alongside the risk assessment template (Appendix B) to be completed by risk assessors. Risk assessors might use the form during an inspection where they will review each of the items and identify a concern level based on the situation with guidance from the spectrum of concern matrix. There is also potential for further development, where the guidance criteria ranges can be updated as more information becomes available.

Table 4-7: Spectrum of Concern Matrix – Agriculture Environmental Factors

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	**Considerations in Risk Scoring**	**Rationale/ Justification**	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Animal sanitation and waste management	• Degree of potential contamination • Degree of exposure to contamination • Frequency of activity	Animal waste is a source of enteric pathogens (Aw, 2018). Workers assigned job tasks that include the sanitation or management of animals and animal waste can face potential exposure situations. The degree of contamination present is dependent of the magnitude of exposure, given the assigned task. Concerns can vary from very high for workers involved in the sanitation of animal waste on a frequent basis or with limited PPE to medium for workers involved in the same task but on a less frequent basis or with full PPE. PPE reduces the risk of a potential exposure; however, it doesn't change the fact that the job inherently exposes workers to a very high degree of contamination. Hence, since PPE is the lowest on the hierarchy of controls for protection from hazards in the workplace, the lower bound of the spectrum is medium.			Medium – Very High (if applicable)		
Handling of raw animal products	• Degree of potential contamination • Degree of exposure to contamination • Frequency of activity	Raw animal products are a source of enteric pathogens (Cancino-Padilla et al., 2017; Sobsey et al., 2011). Workers assigned job tasks handling raw animal products such as raw milk and eggs can face potential exposure situations. Concerns can vary from very high if there is a chance a worker can consume directly or accidentally raw products to medium if the chance is minimized in the handling process through mechanisms of control.			Medium – Very High (if applicable)		
Care of and contact with animals	• Degree of potential contamination (water source) • Degree of exposure to contamination • Frequency of activity	Zoonotic pathogens that can cause enteric illness are pathogens that originate in animal sources (Centers for Disease Control and Prevention, 2021). The burden of zoonotic disease has been shown to be much higher for people in the agricultural setting with exposure to domestic and farm animals (Klumb et al., 2020). Workers assigned tasks that include the care of and contact with animals as part of their job duties can face potential exposure situations due to the degree of contamination. Concerns can vary from very high concern situations that include workers coming in direct contact with waste, or saliva of an infected animal with no PPE. High concerns can include situations where workers come in indirect contact with areas where animas live and roam or objects and surfaces that may have been contaminated such as barns or animal food and water trays (Centers for Disease Control and Prevention, 2021). Medium concerns include situations where workers are in contact with animals but are provided with PPE or are dealing with animals less often.			Medium – Very High (if applicable)		

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	**Considerations in Risk Scoring**	**Rationale/ Justification**	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Manure applications to fields	• Manure best practices applied • Time of application • Source of manure • Soil characteristics: type, moisture content, pH • Application process	Animal manure is a source of enteric pathogens (Beuchat, 2006; Iwu and Oko, 2019; Sobsey et al., 2011; Stine et al., 2005). Workers assigned job tasks handling, preparing, or applying manure can face potential exposure situations. Concerns can vary from very high concern situations that include workers handling raw manure that is unmanaged, to medium situations include workers handling managed manure with full PPE. PPE reduces the risk of a potential exposure; however, it doesn't change the fact that the job inherently exposes workers to a very high degree of contamination. Since PPE is the lowest on the hierarchy of controls for protection from hazards in the workplace, the lower bound of the spectrum is medium.			Medium – Very High (if applicable)		
Crop planting, harvesting and management	• Crop type • Crop growth location • Frequency of activity	Crop type and growth location can present workers with varying levels of a potential exposure to enteric pathogens. Crop types with a large surface area that can trap and hold moisture, such as lettuce, are prone to higher pathogen contamination (Jones & Shortt, 2010). There is also evidence of strong pathogen-produce combinations associated with major foodborne outbreaks (Anderson et al., 2011). Farms with crops growing close to or at ground level (e.g., lettuce and cabbage) present a higher potential of contamination versus raised crops (Solomon et al., 2002; World Health Organization, 2016).	Very Low – High				
Preparation and application of reconstituted pesticides	• Degree of potential contamination (water source)	Reconstituted pesticides can potentially become a source of enteric pathogens. Pesticides reconstituted with untreated water sources can support microbial growth and survival, although not all pathogenic (Ng et al., 2005). Untreated water used to reconstitute pesticides was also found to include human norovirus (Verhaelen et al., 2013). Workers assigned job tasks handling, preparing, or applying reconstituted pesticides can face potential exposure situations. Concerns could vary from high concern situations that include reconstituting pesticides with untreated water to very low concerns if pesticides are reconstituted with sterile water.	Very Low – High				
Irrigation water sources and methods used	• Degree of potential contamination (water source) • Degree of exposure to contamination (irrigation method) • Frequency of activity	Irrigation water sources and the methods of irrigation used on site can present workers with varying levels of a potential exposure to enteric pathogens. Concerns can vary from very low to very high. Municipally treated water sources present a very low concern while the use of untreated irrigation water represents an important exposure pathway to enteric pathogens depending on the degree of contamination, frequency, and duration of exposures (Dickin et al., 2016; Pachepsky et al., 2011). The movement and transfer of pathogens are also influenced by the irrigation method used. The microbiological risk is highest with flood and overhead/spray/sprinkler methods and is reduced with subsurface and drip methods.	Very Low – Very High				

Table 4-8: Spectrum of Concern Matrix – Infrastructure Factors

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	**Considerations in Risk Scoring**	**Rationale/ Justification**	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Access to hygiene facilities for handwashing and laundry	• Number and location of handwashing facilities in worksite and time allotted for breaks • Water source for handwashing facility • Availability of laundry facilities • Number and functionality of washers/dryers	Good hand hygiene is an important tactic in breaking the chain of transmission and, in particular, reducing the incidence of gastrointestinal infection (Bloomfield et al.,2007; Monaghan and Hutchison.,2016). Workers lacking hygiene facilities for handwashing face potential exposure situations from contaminated crops via hand-to-mouth contact or from secondary transmission from one person to another through contact via contaminated hands or surfaces. Very high concern situations include workers directly consuming food with highly contaminated hands due to lacking hygiene stations, while medium concern situations include workers contaminating surfaces or objects with contaminated hands and low concern situations include workers who have access to adequate handwashing stations with enough time to use them. Contaminated textiles and fabrics with infective body substances may contribute to an exposure (Centers for Disease Control and Prevention, 2015). Workers with lacking laundry facilities can face potential exposure; pathogens can be transmitted from contaminated textiles and fabrics via direct contact or through aerosols of contaminated lint. Very high concerns situations include workers not having access to laundry facilities, while medium concern situations include workers who have occasional access to laundry facilities, and low concern situations include workers who have adequate access to laundry facilities.		Low – Very High			
Access to appropriate toilet facilities within living and working sites	• Living site: quantity and cleanliness • Worksite: quantity, proximity, and cleanliness	Inadequate sanitation facilities such as toilets are a major factor in several infectious diseases including enteric disease (World Health Organization, 2019b). Workers lacking adequate sanitation facilities face exposure situations from contaminated hands or surfaces or through secondary transmission from one person to another. Very high concern situations include defecation in or near the field if workers do not have access to a toilet at the worksite or living site, while medium concern situations can include having access to a toilet facility but without access to a sink and clean running water to wash afterwards. Low concern situations include access to a sanitation facility with a toilet, sink and clean running water in both the worksite and living site.		Low – Very High			
Occupational densities in living and working sites	• Number of people living and working in close contact • Worker health records	Crowding in these living spaces can exacerbate the spread of close contact infectious diseases such as enteric diseases (Baker et al., 2013; World Health Organization, 2021) by facilitating secondary transmission from one person to another via contaminated hands and surfaces. Depending on the degree of crowding, based on the number of people living in close contact and record of worker illness situations can be a very high concern.		Low – Very High			

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	**Considerations in Risk Scoring**	**Rationale/ Justification**	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Proximity to animal sites and manure storage	• Capacity to be tracked into worksite and/or living site, or transported by flies, etc.	Sites with proximity to sources of pathogenic microorganisms, (e.g., storage of managed manure, animal rearing sites) pose a microbial health hazard to workers by supporting a pathway of exposure and enabling cross-contamination from the worksite into the living site via contaminated hands, shoes or clothing. Close contact to domestic animals in rural agricultural areas were linked to the prevalence of *Cryptosporidium* in a community (Sahimin et al., 2018). Workers living in close proximity to sources of pathogenic microorganisms, (e.g., storage of managed manure) face potential exposure situations through intra-household pathogen transmission, exposure to animal feces (Chard et al., 2020) or location factors such drainage. Concerns can be low if there is enough separation between sites, adequate drainage and mechanisms for cleaning up before moving into the living site. Concerns can be high if sites are close, there is poor drainage and no mechanisms for workers to clean up after work.		Low – High (if applicable)			
Suitable separation barriers in the living site	• Separation between sleeping, kitchen and bathrooms • Separation between bathroom kitchen	The lack of suitable barriers for hygiene segregation can present a risk of air-borne dissemination of microorganisms when flushing as well as associated contamination of surfaces that may spread microorganisms within the living areas (Barker and Jones, 2005). Workers living in locations with limited hygiene barriers between bathrooms, food preparation areas and sleeping areas can face a potential exposure situation. Concerns can be very low if there are adequate barriers and can range to high concern situations if no barriers exist especially from bathrooms.		Low – High			
Access to food storage, refrigeration, & preparation space	• Adequate food storage refrigeration and preparation space for all workers	Not having access to a refrigerator has been shown to triple the probability of getting a gastrointestinal disorder from consumption of unprotected food among migrant farmworkers (Frisvold et al., 1988). Workers with inadequate access to food storage, refrigeration and food preparation space can face potential exposure situations from the consumption of contaminated food. Concerns can be very low if there are adequate amenities that will protect food and water but can range to very high as lacking amenities can lead to a direct exposure through consumption of contaminated food and water.	Very Low – Very High				
Variable access to drinking water (municipally supplied, private wells, storage tanks)	• Water source in living site • Water source in worksite	Sources of drinking water on site can present workers with varying levels of a potential exposure to enteric pathogens, depending on the water source (World Health Organization, 2017). Workers with varying drinking water sources can face a potential exposure situation through direct consumption depending on the water source. Concerns can be very low for municipally supplied drinking water off a distribution system, to high for untreated private water systems, and very high if workers use inappropriate sources (i.e., surface water) if availability in worksite is poor.	Very Low – Very High				

Table 4-9: Spectrum of Concern Matrix – Occupational Factors

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	**Considerations in Risk Scoring**	**Rationale/ Justification**	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Availability of personal protective equipment	• Type of activity • Type of PPE uses • Frequency of activity	PPE is an element of control for protection from hazards in the workplace. Equipment such as gloves, masks and safety shoes are worn by workers to reduce the risk from exposure to hazards (Canadian Centre for Occupational Health & Safety, 2021a). Workers with varying access to PPE can face potential exposure situations depending on the activity and the type of PPE required. Concerns can be low to very high if PPE is missing in the workplace. Low concern situations include activities that may not require PPE due to low hazard such as picking produce from raised crops irrigated with treated water. Medium concerns can be associated with activities that do not have a high chance of an enteric exposure but still expose workers to a hazard. Very high concern situations can include handling fresh manure (source of enteric pathogens) with no PPE. The level of concern can change depending on the activity, type of PPE used and the frequency of the activity.		Low – Very High			
Provision of job-specific health and safety training	• Type of job-specific training offered	The delivery of job-specific training helps minimize the risk from exposure by ensuring that workers are aware of the hazards they face in the workplace and provides them with the tools necessary to protect themselves and their co-workers (Canadian Centre for Occupational Health & Safety, 2021a). Workers with varying levels of job-specific health and safety training can face potential exposure situations depending on the hazard associated with the job activity. Concerns can vary from low to very high, low concern situations can include workers provided with all the job-specific training required. Depending on the hazard, a potential exposure can be a very high concern if workers are not provided with the job-specific training required to protect themselves and others, especially because they are likely to face specific job hazards more frequently.		Low – Very High			
Provision of standardized health and safety training	• Type of standard training offered	The delivery of standard workplace training such as Workplace Hazardous Materials Information System training helps minimize the risk from exposure by ensuring that workers are aware of the hazards they face in the workplace and provides them with the tools necessary to protect themselves and their co-workers (Canadian Centre for Occupational Health & Safety, 2021a). Workers with varying levels of standardized health and safety training can face potential exposure situations depending on the hazard associated with the job activity. Concerns can vary from low to high; standard training may not specifically cover hazards faced by workers that can lead to an enteric exposure, so concern is high but can be low if the type of standard training does cover how to deal with an enteric exposure, and/or if there is adequate job-specific health and safety training.		Low – High			

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	Considerations in Risk Scoring	Rationale/ Justification	Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (5)
Application of workplace health and safety protocols	• Variability of protocols	Workplace health and safety protocols including standards, procedures processes, and the use of joint health and safety committees are key to ensuring safe workplaces by identifying hazards and improving conditions (McLaughlin et al., 2014). Workers with missing or inconsistent protocols, standards or procedures can face potential exposure situations depending on the hazard associated with the job activity. Very low concern situations can be the lack of procedures around duties that do not pose a potential enteric exposure to workers such as administrative tasks or the operation of machinery. High concern situations can include the lack of procedures or standards around high exposure situations like the handling of manure.	Very Low – High				
Assigned job duties and clear understanding of job constraints	• Assigned job duties • Limits of job duties	Depending on the assigned tasks, workers can face potential exposure situations with a high degree of contamination. If workers are unaware of the hazards associated with their assigned job tasks, then they might carry out activities that are more hazardous. If workers are unaware of the limits of their job, they may carry out activities that are outside of the limits of their responsibilities, potentially facing new or unfamiliar exposure situations. Concerns can vary from very low if tasks do not present workers with a potential enteric exposure, to very high if tasks for example include the management or sanitation of animal waste without the worker understanding the hazards associated with the task and taking the precautions needed to protect themselves.	Very Low – Very High				
Applicability of employment labour standards	• Application of employment standards	The application of employment standards can act a control by stipulating hours of work and overtime to control the number of hours a worker is potentially exposed to a hazard (Ontario Ministry of Labour Training and Skills Development, 2016). Migrant farmworker entitlements under the Employment Standards Act have been characterized as limited, with workers excluded from aspects related to minimum wage, and hours of work (McLaughlin et al., 2014; Vosko et al., 2019). Workers with limited entitlements can face exposure situations depending on the aspect of the standard. Low concern situations can be issues with minimum wage that does not contribute to a potential exposure situation; a very high concern situation can be an infected worker going to work without the opportunity to take a sick day, potentially infecting other workers.		Low – Very High			
Frequency of inspections	• Kind of inspections • Number of inspections	Inspections are key to workplace health and safety; they help prevent injuries and illnesses by identifying existing and potential hazards (Canadian Centre for Occupational Health & Safety, 2021e). Concerns can vary from low to very high concerns. Situations of low concern can be inspection related to the exterior of housing. While a very high concern situation could be the inspection and testing of water wells used for drinking water. Infrequent inspection and testing can lead to a potential exposure situation if a drinking water contamination is not identified. Review of inspection history will lead to continuous improvement.		Low – Very High			

Table 4-10: Spectrum of Concern Matrix – SAWP Management Factors

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	**Considerations in Risk Scoring**	**Rationale/ Justification**	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Language barriers	• Workers' ability to communicate in English • Access to interpreters and translators • Employer ability to communicate in workers' language (e.g., Spanish, French)	Language and communication barriers limit workers from communicating health concerns and seeking out appropriate help (Migrant Worker Health Expert Working Group, 2020). Concerns can vary from very low to medium depending on how well workers are able to communicate their health risk. Low concern situations can include when health concerns are obvious to practitioners and no clear communication is needed or if the worker can rely on a translator to help communicate concerns. Medium concern situations are when workers are unable to communicate a health concern and it goes unresolved impacting worker health. Risk assessors can further investigate the impacts of this factor through discussion with workers and their overall experience in managing health concerns.	Very Low – Medium				
Access to migrant farmworker support programs	• Support groups (volunteers, grassroot organizations, etc.)	It has been shown that the presence of volunteer groups and grassroot organizations provided workers with empowerment and facilitation of access to things such as compensation, resources and healthcare during their tenure (Canadian Council for Refugees, 2018). Workers unable to promptly manage health concerns ultimately prolongs the process of managing or controlling potential infectious enteric disease spread. Workers with access to support programs can quickly deal with a health issue, making it a very low concern, while workers who do not may deal with health issues in other ways (e.g., calling doctors in the country of origin or reaching out to friends or family so concern is medium.	Very Low – Medium				
Access to transportation	• Worker freedom of mobility	Social determinants of health can include the level of literacy, access to transportation, and healthy workplaces (Bhatt and Bathija, 2018). Workers with limited access to transportation can face increased consequences to of a potential infection if they are not able to get to a health care facility to deal with it. Concern can vary from very low if they have access to independent transportation without relying on the employer to high if they don not have access to transportation or must rely on the employer.	Very Low – High				

Hazards and Hazardous Situations		Guidance Criteria	Risk Rank – Potential Spectrum of Concern				
Factor	**Considerations in Risk Scoring**	**Rationale/ Justification**	**Very Low (1)**	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Possibility of repatriation or discontinuation from participation in the program	• Program parameters, including the repatriation clause and the naming systems (review at time of assessment)	Workers receive closed work permits tied to one employer under SAWP guidelines, preventing them from seeking other employment during their stay in Canada (Hennebry and McLaughlin, 2012). This legal arrangement puts migrant farmworkers in a predicament where they may feel obligated to tolerate workplace harassment, unsafe or unprotected work, and injuries and illnesses due to fear of losing employment or legal status (Hennebry & McLaughlin, 2016). Under these guidelines, employers also have access to the option of worker repatriations (Human Resources and Skills Development Canada, 2020). There is lots of variability around this item, depending on the level of risk tolerance a worker is willing to accept, potentially leading to a possible exposure situation.	Very Low – Very High				
Employer-employee dynamics and confidentiality	• Relationship between employer and employee	Workers are inherently disempowered from refusing unsafe work or asking for PPE given the fragile state of their temporary status and the employer–employee power dynamic including things such as the repatriation clause or the naming system (McLaughlin et al., 2014). Given the employer–employee dynamic, workers may choose not to involve employers when seeking health care given the privacy and confidentiality issues that may result from relying on an employer to provide transportation to the hospital or offer translation services (Hennebry and Preibisch, 2008). There is lots of variability around this item depending on the relationship between the worker and the employer, with varying impacts on exacerbating an existing exposure situation.	Very Low – Very High				
Temporary legal status (closed work visa tied to one employer)	• SAWP parameters	Under the SAWP guidelines, workers receive closed work permits tied to one employer, preventing them from seeking other employment during their stay in Canada (Hennebry and McLaughlin, 2012). This legal arrangement puts migrant farmworkers in a predicament where they may feel obligated to tolerate workplace harassment, unsafe or unprotected work, and injuries and illnesses due to fear of losing employment, or legal status (Hennebry & McLaughlin, 2016). There is lots of variability around this item, depending on the level of risk tolerance a worker is willing to accept, potentially leading to a possible exposure situation.	Very Low – Very High				
Access to health care	• Language • Transportation • Third party intervention (**Note**: language and transportation factors from above impact this factor)	Workers' inability to independently access medical care can be one of the major contributors to health risks (Preibisch and Otero, 2014) by elevating the likelihood and consequence of infection in congregate settings when issues are unresolved medically. Workers who have access to health care can have health issues resolved quickly and the level of concern from a potential enteric exposure is very low. However, workers who face barriers to health care due to transportation, confidentiality issues, or language barriers can face high concerns from a potential enteric exposure if illness is not dealt with and potentially spreading and infecting other workers.	Very Low – Very High				

4.5 Application of Risk Assessment Principles for Risk-Informed Framework Development

The tools developed as part of the overall framework to identify and evaluate the health hazards facing migrant farmworkers and to explore potential mitigation strategies are founded in application of risk assessment principles. Discussion of the risk assessment tools applied based on the designed methodology outlined in Figure 3-1 and ways for further development in the migrant farmworker context is detailed in the sections below. Discussion of the value of applying the systems theory approach to build the transmission network is detailed in section 4.5.1 and is followed by how it can be used as a starting point for further development including both quantitative and qualitative analysis (section 4.5.2). Currently the framework is preliminarily evaluated with support of epidemiological evidence discussed in section 4.5.3. Additionally, discussion of how the framework highlights the existing systemic issues that pre-date the COVID-19 pandemic, allowing for enabled pathogen pathways and the spread of infectious disease within this occupational setting, is detailed in section 4.5.4.

4.5.1 Risk Framework Development – Integration of Systems Theory

Utilization of the systems theory approach provided the structure necessary to bring together an array of different hazards leading to a potential migrant farmworker infection. The approach allowed for clear problem formulation to identify the limits of the assessment using the conceptual model based on thinking from systems identification, valuable insights beyond the individual nodes within the transmission network, and development of a framework that could be used to inform effective decision-making. Using this approach in the migrant farmworker context helped to identify what was in scope and what was considered out of scope for consideration. The approach also helped with creating connections between the many possible identified hazards in scope leading to potential exposure.

The overall transmission network (Figure 4-5) provided a clear visualization of the overlap between the worksites and the living sites specific to the migrant farmworker setting. This highlights the potential for elevated rates of cross-contamination in the absence of hygiene and sanitation barriers and controls.

The resulting transmission network describes the movement of pathogens in this setting in a form that is usable and presentable. The organization of the network also allows for the ability to explore different mitigation strategies to assess effectiveness. The network provides a clear and simple outline highlighting areas where hazards can emerge and where control strategies can be introduced. Some

HACCP principles were applied to introduce control points along active pathogen pathways with prescribed mitigation strategies to impede pathogen transfer, in addition to providing a location where current strategies can be continuously examined for improvement.

4.5.2 Potential Applications of Framework – Quantitative and Qualitative Applications of the Transmission Network

The transmission network presented in this work covering all three source modules (section 4.2.2) offers a starting point for more in-depth analysis, either quantitative or qualitative. For example, the relative impact of specific hazards and the associated pathways leading to a possible infection can be quantitively or semi-quantitatively evaluated given targeted data that looks at the rate of infection from exposure to a hazard. The transmission network also presents an opportunity for further qualitative work by identifying existing behaviours that enable certain pathogen pathways, such as specific job duties or barriers to the uptake of certain control measures such as PPE. The transmission network can also be used for evaluating the effect of new interventions by observing possible exposures through a specific pathway before and after implementation of an intervention.

In its most fundamental form, the network can represent a very simple Markov chain, which is an approach that relies on the outcomes of a previous event to determine the probability of a future event (Gagniuc, 2017). The current network does not capture a quantitative value of probability for transitions from one node to another; however, it provides a structure for further development to do so given sufficient data and based on the example in section 4.2.2 (Figure 4-6). Quantitative data for elements within the network can include surveillance data with plausible causes of infection (contaminated food/water, interaction with animals, interaction with an infected human) in addition to health records identifying the impact of worker enteric illness, as well as information on the effect of possible controls. Data can be analyzed, and a relative numerical probability based on the data available can be assigned to each pathway moving from one node to another allowing for the ability to semi-quantify the probability of worker infection through any given pathway. The structure also provides the ability to quantify the relative contributions to total exposure by different exposure pathways (Goddard et al., 2020). Development of a Markov chain would be an ideal outcome; however, limitations still exist because there would be uncertainty in the interpretations of the data collected. Additionally, the possibility of a potential exposure is not an isolated event and is influenced by many factors. Although limitations exist, the use of a Markov chain to further explore and quantify the risk from exposure in the migrant farmworker context is a direction worth exploring.

The developed network can also be used for further qualitative work and analysis. The transmission network can potentially be used as a starting point to explore a specific problem or hypothesis given a clear problem definition and adequate supporting data. It can be used to help understand empirical observations and emergent behaviour within the scope of work and to investigate the effectiveness of specific control point locations and strategies (Canan, 2018). For example, the use of PPE as a control point in the network with a prescribed mitigation strategy to impede the risk from exposure may be more effective if offered and mandated by the employer versus needing to be provided by the worker (McLaughlin et al., 2014). Understanding which control measures to introduce and where to apply them has the potential to reduce risks of exposure, leading to greater protection of worker health and general public health. These scenarios can be developed and explored further using the transmission network as a starting point for discussion and analysis.

Overall, the transmission network can be used as a starting point for quantitative or qualitative applications. Additional data specific to migrant farmworker health and ways they are exposed to enteric pathogens can help refine the network and provide a more nuanced understanding of pathogen dynamics as well as the spread of infectious disease in this environment.

4.5.3 Preliminary Evaluation of Migrant Farmworker Health Risks

As part of the risk assessment process, evaluation of the risk is usually determined based on analysis of quantitative data in the risk analysis step. However, in the absence of sufficient and relevant data for quantitative evaluation of the health risks within the overall developed framework, a preliminary evaluation was conducted based on epidemiological evidence of enteric disease (Hertz-Picciotto, Wartenberg, & Simon, 1995).

Although reported outbreaks of enteric diseases specifically in the migrant farmworker setting are sparse given challenges with reporting and outbreak surveillance, there is evidence of widespread issues with gastrointestinal illnesses. Data collected from 2006–2010 by the Norfolk General Hospital in Simcoe, Ontario from 888 migrant farmworker visits showed that gastrointestinal illnesses were the second highest diagnosis at 13% (McLaughlin et al., 2012). Analyzed repatriation data (Orkin et al., 2014) showed that the second highest reason for repatriation was gastrointestinal illnesses (26.5%), only closely behind musculoskeletal disorders (27.7%). In an American case study with 367 farmworker participants, it was also found that the probability of workers reporting gastrointestinal illnesses was increased by 60% in the absence of field sanitation such as access to toilets. Based on the baseline survey of workers interviewed, the probability of a worker with average characteristics (as defined in the study) reporting an illness increased from 13.1% to 20.9% when there was no access to a toilet facility while working in the field (Frisvold et al., 1988). Additional data collected by the OHCOW during migrant farmworker health clinics between 2007–2011 also highlights gastrointestinal illnesses among 454 workers as a main diagnosis (12.1%). Gastrointestinal illnesses were slightly behind skin (13.7%) and eye (14.5%) concerns with the number one diagnosis being attributable to musculoskeletal disorders at 29.5%. The findings are consistent with the Norfolk Hospital (McLaughlin et al., 2012) and analyzed repatriation data (Orkin et al., 2014). It should be noted here that the clinics address non-urgent concerns, which may not always capture the self-limiting nature of enteric disease. Generally, the lack of outbreak data among this population can be tied to a multitude of reasons: Outbreaks may go unrecognized because of a smaller number of workers at SAWP locations resulting in low case counts, the endemic and often self-limiting nature of the diseases (Bischoff et al., 2012), the legal status of farmworkers leading to barriers in accessing healthcare, or due to challenges related to reporting and surveillance where most migrant farmworker cases are not reported to public health. The evidence from these studies, however, is indicative of the health risks attributable to enteric pathogens in this occupational setting, and the combination of risk tools as part of the overall framework developed in this work can be used as a basis to perform risk assessments for the realized health risks.

4.5.4 Implications of the Framework for Understanding the Transmission of Disease – The COVID-19 Pandemic Case

The tools developed as part of the framework can potentially be used for enhancing the understanding of parallel transmission routes leading to the spread of other forms of infectious disease. More broadly the spread of disease within this occupational setting was highlighted because of the COVID-19 pandemic. At the onset of a country-wide shut down and border closures in March of 2020, agricultural employers highlighted the need for migrant farmworkers for the upcoming growing season and requested exceptions for their entry into Canada. Simultaneously, migrant farmworker advocates and expert groups cautioned on the potential health risks workers may experience given existing issues related to close living quarters, limited hygiene facilities and barriers to healthcare (Migrant Worker Health Expert Working Group, 2020; Migrant Workers Alliance for Change, 2020). Concerns were almost immediately realized with widespread transmission of COVID-19 and outbreaks resulting in over 2,230 positive total cases and four deaths in a little over a year (Mojtehedzadeh, 2021).

Tracking of COVID-19 cases has been one of the few ways in which the health status of workers has been monitored and publicly shared. In addition to information on the number of positive COVID-19 cases among workers, major Canadian media outlets such as the Toronto Star, National Post and the Globe and Mail were also publicly sharing the working and living conditions of migrant farmworkers and the role they play in supporting Canadian food security (Grant, 2020; Grant & Blaze Baum, 2020; Martell & Johnson, 2020; Perkel, 2021). The widespread transmission of COVID-19 has clearly highlighted some of the underlying factors that pre-date and exacerbate the risk associated with the coronavirus disease. Although the focus of this work was on enteric disease, factors contributing to the spread of COVID-19 such as close living quarters with inability to isolate, limited hygiene facilities and barriers to healthcare are the same factors that also contribute to the transmission of enteric disease. As such COVID-19 provides the corroborating evidence for some of the issues raised and contributing factors highlighted in this work.

The interest specifically in enteric disease stems from uniqueness of the migrant farmworker occupational setting. Sources of enteric pathogens are inherently present in this setting given hazards such as the handling or use of managed manure, the role requirement tied to animal care and sanitation, or exposure to potentially contaminated irrigation water sources. The exposure to sources of enteric pathogens coupled with the elevated risk from cross-contamination and secondary transmission from one person to another given infrastructure factors can contribute to a potential worker exposure to an enteric pathogen.

Overall, changes due to the COVID-19 pandemic to the SAWP requirements (Government of Canada, 2020) have generally been associated with quarantine measures including advances in the COVID-19 testing protocols requiring workers to get tested 72 hours before a flight to Canada. Changes, however, have not included any drastic program reforms such as implementing a national housing guideline—a key factor in tackling the transmission of infectious disease by addressing issues related to crowding and access to sufficient hygiene facilities (Migrant Worker Health Expert Working Group (MWH - EWG), 2020). While this framework was created with enteric disease in mind, the overall structure highlights the significance of identifying factors and enabled pathogen pathways leading to the spread of infectious disease broadly in this setting.

Chapter 5
Conclusions and Recommendations

5.1 Conclusions

This research was focused on advancing the understanding of the health risks associated with enteric disease that face migrant farmworkers in Canada's Seasonal Agricultural Worker Program (SAWP) through application of a science-based approach using risk assessment principles. The work focused on identifying and evaluating hazards and hazardous situations that contribute to enteric pathogen exposures relevant to migrant farmworkers in the SAWP occupational setting through the development of risk-based tools offering a framework to explore potential mitigation strategies.

This work applies engineering risk analysis methods for occupational health and safety to assess migrant farmworkers' exposure to enteric pathogens. This is novel and bridges thinking from engineering risk analysis to public health and occupational health and safety. The outputs of this work including the guidance spectrum of concern matrix (section 4.4.2) and Appendix B provide tools to assess the risks pertaining to enteric disease in this occupational setting, which are currently not accounted for in the SAWP and housing inspection standards. The use of a systems theory approach to understand the health impacts on migrant farmworkers in this occupational setting is also novel and contributes to systems engineering through a unique application. Systems modelling is a basic principle that can be used in engineering and social sciences, bringing together a complex set of components within identified boundaries. In this application it was a way to bring together varying types of hazards and hazardous situations along with potential exposure pathways to evaluate the impact on migrant farmworker health. Additionally, this work has implications on public health review and surveillance, as it highlights migrant farmworkers as a population at a potentially elevated risk to enteric disease, emphasizing the need for further disease surveillance and reporting.

The main conclusions from this work are the following:

1. **Evidence of Health Risk Posed by Enteric Pathogens**
    - While outbreak-related data of enteric illness among migrant farmworker populations in Canada are sparse, given the endemic and self-limiting nature of the disease, there is epidemiological evidence of gastrointestinal illnesses, that comprise one of the highest diagnoses of disease among migrant farmworkers. Migrant farmworkers are more likely to be exposed to hazards attributable to enteric pathogens given their occupational setting. Increased exposures contribute to an increased likelihood of a potential enteric infection, emphasizing the need to evaluate the health risk associated with enteric disease facing migrant farmworkers.
2. **Identified Hazards Contributing to Potential Exposures**
    - Sources of biological hazards in the agricultural setting (e.g., animal feces, contaminated irrigation water sources) and hazardous situations leading to exposure to enteric pathogens (e.g., missing PPE, barriers to accessing health care) in the migrant farmworker occupational setting contribute to a potential worker enteric infection
3. **Overlap of the Working and Living Areas**
    - The potential of exposure to enteric pathogens leading to the spread of infectious enteric diseases is exacerbated in the migrant farmworker setting as a result of overlap between the working and living areas, emphasizing the need for targeted hygiene and sanitation control points as a mitigation strategy.
4. **Cross-Contamination Pathways**
    - Cross-contamination pathways are important pathogen pathways that need to be evaluated in the migrant farmworker occupational setting given the overlap of the working and living sites. Ignoring the impact from cross-contamination can characteristically understate the overall probability tied to a potential worker enteric infection.
5. **Risk Assessment Methodology and Application of Systems Theory Approach**
    - Preliminary evaluation of the migrant farmworker health risks attributable to enteric pathogens can be assessed using risk assessment methodologies. Risk assessment

methodology as an approach can be used to identify hazards, and a systems theory approach can be integrated to mechanistically describe exposure to the hazards from source to potential worker exposure within the SAWP occupational setting.

6. **Infected Worker**

   - An infected worker becomes a potential source of enteric pathogens within congregate living quarters in the absence of adequate infrastructure including hygiene facilities and hygiene segregation barriers.

7. **Risk of Enteric Illness**

   - Migrant farmworkers in the SAWP occupational setting face increased risk to enteric illnesses. While COVID-19 highlighted the health risks and more broadly the spread of infectious disease in the migrant farmworker occupational setting, enteric disease is a persistent risk facing workers due to their occupational setting.

Overall, this work highlights three major elevated health risks associated with enteric disease facing migrant farmworkers. Migrant farmworkers experience elevated exposures to enteric pathogen sources given their occupational setting and job requirements. Additionally, migrant farmworkers face elevated potential exposure pathways given the overlap between their working and living areas allowing for additional cross-contamination pathways. Finally, migrant farmworkers experience elevated consequences to a potential enteric infection given barriers related to accessing health care services during their tenure in Canada. These elevated health risks are evident in the epidemiological data; however, quantification of risk is difficult to determine given the lack of available data concerning migrant farmworker health. The following section below highlights recommendations for better understanding and mitigating the migrant farmworker health risks associated with enteric disease.

5.2 Recommendations

Key recommendations based on findings from this work are:

1. controlling the frequency and magnitude of exposure to sources of enteric pathogens in the agricultural setting; a potential mitigation strategy that can be utilized to meet this recommendation includes:
   - utilizing micro irrigation methods such as drip and subsurface mechanisms, which limit the amount of water on crop surfaces (Beuchat, 2006; Solomon, Potenski, et al., 2002), this approach can be applied in the migrant farmworker context and can contribute to controlling the magnitude of a possible exposure to enteric pathogens in an untreated irrigation water source (section 4.1.1).
2. limiting the impact from exposure pathways associated with infrastructure in the working and living sites; a potential strategy that can mitigate the impact of a potential exposure pathway and is based on findings from this work includes:
   - providing adequate hydration and hygiene stations within a reasonable and accessible distance, as well as instituting hygiene segregation barriers (section 4.1.2 and 4.2.2.3)
3. protecting workers in the worksites through the implementation of occupational controls; a specific mitigation strategy that is based on findings from this work includes:
   - identification of hazards associated with enteric disease as part of the inspection process through use of the guidance spectrum of concern matrix (section 4.4.2)
   - the recommendation to develop and institute specific training related to Water Hygiene and Sanitation (WASH) for both workers and employers (section 4.1.3).
     - Training modules relevant to employers can include education on what constitutes clean drinking water and ensuring its supply, while training modules relevant to the workers can include hand hygiene and hygiene promotion in shared living spaces as part of the onboarding process.

4. reducing the consequence from a potential enteric infection; a strategy that can be used to meet this recommendation can include:
    - applying public health strategies such as health promotion and education, improved disease surveillance and health data collection specifically in the migrant farmworker occupational setting, potential data sources can include:
        - Health records describing migrant farmworker enteric illnesses prior to and during their stay in Canada
        - Workplace injury and illness records
        - Repatriation data

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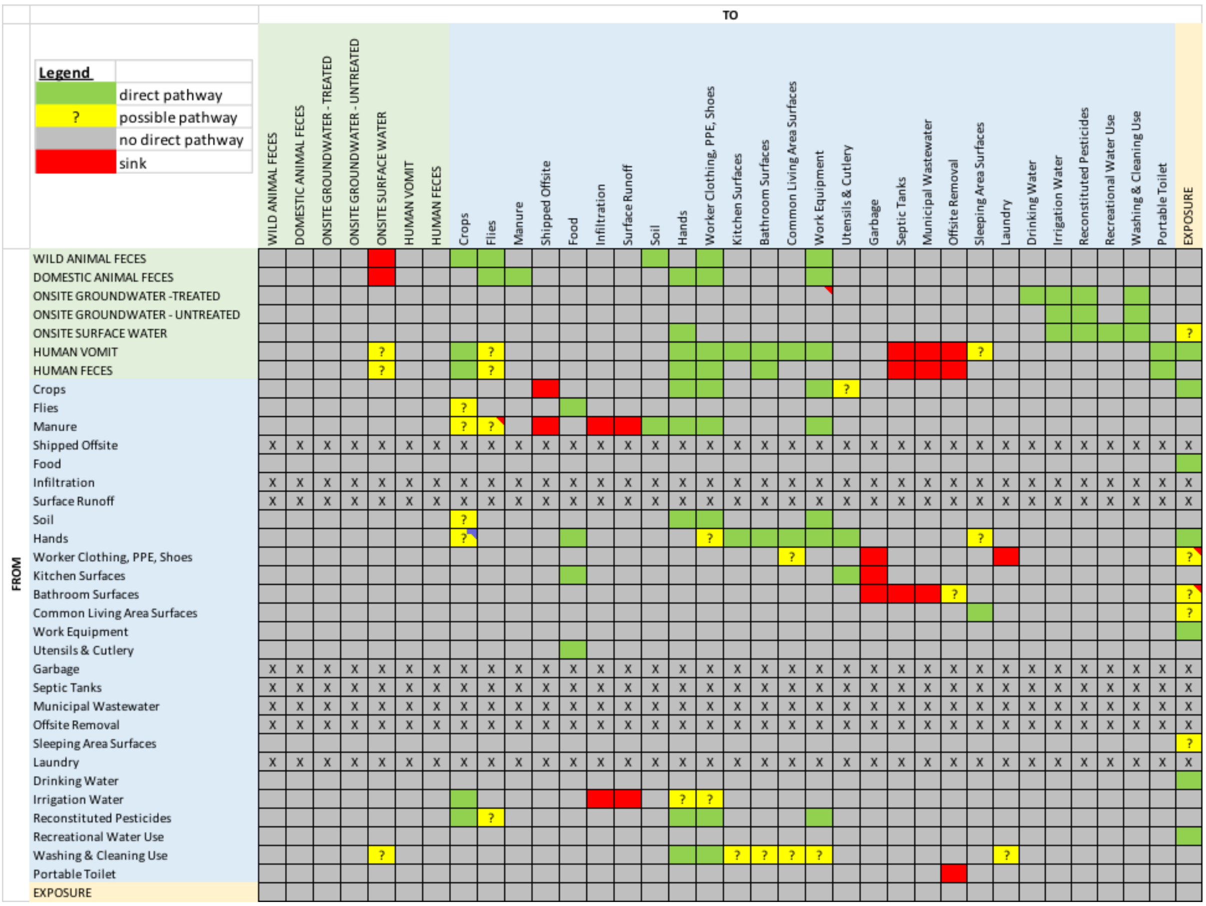
Appendix A

Transmission Network Verification Matrix Describing the Movement of Pathogens in the Network from One Node to Another



Appendix B – Risk Assessment Template

Hazard and Hazardous Situations		Guidance Criteria		Potential Concern Ratings					
Category	Factor	Considerations in Risk Scoring	Expected Spectrum of Concern	(1) Very Low	(2) Low	(3) Medium	(4) High	(5) Very High	Risk Management
Agriculture Environmental Factors	Animal sanitation and waste management (if applicable)	• Degree of potential contamination • Degree of exposure to contamination • Frequency of activity	Medium – Very High						
	Handling of raw animal products (if applicable)	• Degree of potential contamination • Degree of exposure to contamination • Frequency of activity	Medium – Very High						
	Care of and contact with animals (if applicable)	• Degree of potential contamination • Degree of exposure to contamination • Frequency of activity	Medium – Very High						
	Manure applications to fields (if applicable)	• Source of manure • Manure best practices applied • Application process • Time of application • Soil characteristics: type, moisture content, pH	Medium – Very High						
	Crop planting, harvesting and management	• Crop type • Crop growth location • Frequency of activity	Very Low – High						
	Preparation and application of reconstituted pesticides	• Degree of potential contamination (water source)	Very Low – High						
	Irrigation water sources and methods used	• Degree of potential contamination (water source) • Degree of exposure to contamination (irrigation method) • Frequency of activity	Very Low – Very High						

Hazard and Hazardous Situations		Guidance Criteria		Potential Concern Ratings					
Category	Factor	Considerations in Risk Scoring	Expected Spectrum of Concern	(1) Very Low	(2) Low	(3) Medium	(4) High	(5) Very High	Risk Management
Infrastructure Factors	Access to hygiene facilities for handwashing and laundry	• Number and location of handwashing facilities in worksite, allotted break time • Water source for handwashing facility • Availability, functionality of laundry facilities	Low – Very High						
	Access to appropriate toilet facilities within living and working sites	• Living site: quantity and cleanliness • Worksite: quantity, proximity, and cleanliness	Low – Very High						
	Occupational densities in living and working sites	• Number of people living and working in close contact	Low – Very High						
	Proximity to animal sites and manure storage (if applicable)	• Capacity to be tracked into worksite and/or living site, or transported by flies, etc.	Low – High						
	Suitable separation barriers in the living site	• Separation between sleeping and kitchen and bathroom areas • Separation between bathroom and kitchen	Low – High						
	Access to food storage, refrigeration, & preparation space	• Adequate food storage, refrigeration and preparation space for all workers	Very Low – Very High						
	Variable access to drinking water Variable access to drinking water (municipally supplied, private wells, storage tanks)	• Water source in living site • Water source in worksite	Very Low – Very High						

Hazard and Hazardous Situations		Guidance Criteria		Potential Concern Ratings					
Category	**Factor**	**Considerations in Risk Scoring**	**Expected Spectrum of Concern**	**(1) Very Low**	**(2) Low**	**(3) Medium**	**(4) High**	**(5) Very High**	**Risk Management**
Occupational Factors	Availability of personal protective equipment	• Type of activity • Type of PPE uses • Frequency of activity	Low – Very High						
	Provision of job-specific health and safety training	• Type of job specific training offered	Very Low – Very High						
	Provision of standardized health and safety training	• Type of standard training offered	Low – High						
	Application of workplace health and safety protocols	• Variability of protocols	Very Low – High						
	Assigned job duties and clear understanding of job constraints	• Assigned job duties • Limits of job duties	Very Low – Very High						
	Applicability of employment labour standards	• Application of employment standards	Low – Very High						
	Frequency of inspections	• Number of inspections • Kind of inspections	Low – Very High						

Hazard and Hazardous Situations		Guidance Criteria		Potential Concern Ratings					
Category	**Factor**	**Considerations in Risk Scoring**	**Expected Spectrum of Concern**	**(1) Very Low**	**(2) Low**	**(3) Medium**	**(4) High**	**(5) Very High**	**Risk Management**
SAWP Management Factors	Language barriers	• Workers' ability to communicate in English • Access to interpreters and translators • Employer ability to communicate in workers' language (e.g., Spanish, French)	Very Low – Medium						
	Access to migrant farmworker support programs	• Support groups (volunteers, grassroot organizations, etc.)	Very Low – Medium						
	Access to transportation	• Worker freedom of mobility	Very Low – High						
	Possibility of repatriation or discontinuation from participation in the program	• Program parameters, including the repatriation clause and the naming systems (review at time of assessment)	Very Low – Very High						
	Employer-employee dynamics and confidentiality	• Relationship between employer and employee	Very Low – Very High						
	Temporary legal status (closed work visa tied to one employer)	• SAWP parameters	Very Low – Very High						
	Access to health care	• Language • Transportation • Third party intervention (**Note**: language and transportation factors from above impact this factor)	Very Low – Very High						