Mitigating dissemination of bioterrorism agents in Canadian food distribution systems

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IMPORTANT INFORMATIVE STATEMENTS

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Abstract

A systems-based approach combining the capacity to capture, store, manage and analyze data in a Geographical Information System (GIS), predictive microbiology and risk modeling was applied in the development of tools for the identification of vulnerabilities and the measurement of risks associated with contamination of the Canadian distribution system with microbiological threat agents. The approach was validated through a detailed examination of the Canadian ready-to-eat lettuce sector. Relevant data was collected and integrated with ArcGIS, and a simulation model developed with Arena™ event simulation software was designed to predict the fate of contaminated lettuce during storage and shipping, to identify areas at risk as time progresses, and to estimate the population affected by the events. The simulation model incorporates mathematical equations that predicts the fate microbiological threats and accommodates shipping delays and temperature profiles at each stage to calculate growth, survival, or die-off in the packaged lettuce during storage and shipping, until the point of sale at retail. A user interface was designed to dynamically display the predicted risk across the Canadian distribution system. The simulation tool has been termed the Canadian GIS-based Risk Assessment, Simulation and Planning (CanGRASP) tool for food safety. A scenario involving contamination of lettuce with *E. coli* O157:H7 is presented to show how geographic zones affected by a contamination event are identified and the proportion of the population potentially affected by the event over time.

Résumé

Afin de concevoir des outils de détection des vulnérabilités et de mesure des risques associés à la contamination du réseau de distribution canadien par des agents microbiologiques potentiellement dangereux, on a eu recours à la microbiologie prédictive et à la modélisation des risques, des méthodes axées sur les systèmes permettant de regrouper, de stocker, de gérer et d'analyser des données dans un système d'information géographique (SIG). On a validé cette approche dans le cadre d'un examen approfondi du marché de la laitue prête à manger au Canada. On a recueilli et regroupé les données pertinentes au moyen du système ArcGIS et on a conçu un modèle de simulation à l'aide du logiciel de simulation d'événements Arena™ afin de prédire l'évolution de la laitue contaminée pendant son entreposage et son transport, de cerner les secteurs à risque à mesure que le temps passe et d'estimer combien de personnes seront touchées par l'incident. Le modèle de simulation s'appuie sur des équations mathématiques pour prédire l'évolution des agents microbiologiques et pour établir le temps de transport et les profils de température à chaque étape de manière à calculer la croissance, la survie ou la mortalité des agents dans la laitue emballée pendant l'entreposage et le transport, et jusqu'au moment de la vente dans le commerce de détail. On a conçu une interface utilisateur permettant l'affichage dynamique des risques prédits dans l'ensemble du réseau de distribution canadien. On a appelé cet outil de simulation « l'outil canadien d'évaluation, de simulation et de planification des risques à partir d'un SIG pour la salubrité des aliments » ou « CanGRASP ». On a présenté un scénario mettant en scène une contamination de laitue avec la bactérie E. coli O157:H7 afin de montrer comment on détermine les zones géographiques touchées par une contamination et la proportion de la population qui sera potentiellement touchée au fil du temps.

Executive summary

Introduction or background: Intentional contamination of food with microbiological agents is a realistic threat with unpredictable and potentially catastrophic consequences to public health and the national economy. Canadian food systems incorporate many independent production, processing, transportation, distribution and retail channels that deliver a profusion of foods to consumers in distant markets, often within a matter of hours or days. Consequently, the identification of vulnerabilities and the measurement of risks associated with contaminated food commodities must be accomplished in consideration of complex elements along the farm-to-fork chain. The purpose of the research presented herein was to apply a systems-based approach for the assessment of risk in complex food chains to allow the development of tools that can predict the dissemination of contaminated food along temporal and geographic planes and the implied risk to public health. Specific objectives were developed in consideration of the need to improve the capacity for immediate response to national emergencies affecting the food supply.

Results: The main deliverable from the research is a prototype risk simulation model which has been termed the Canadian GIS-based Risk Assessment, Simulation and Planning tool for Food Safety (CanGRASP). The tool can be used to map the spatial distribution of contaminated food at any point along the distribution chain and predict public health impacts for specific regions of Canada. Development of the tool was achieved through: the design and assembly of a relational database which captures relevant data on processing facilities, transportation and distribution systems; selection of appropriate computerized mapping tools to display the dissemination of contaminated food along temporal and geographic planes; validation of mathematical models that predict the behavior of microbiological threats at each stage and along the chain; and integration of these components in an overall risk simulation model. The performance of CanGRASP and the validity of the approach were demonstrated experimentally with ready-to-eat (RTE) lettuce, a product amenable to the widespread dissemination of infectious microorganisms in the Canadian food system.

Significance: The research summarized in this report demonstrated the value of a practical systems-based approach for the assessment of risks associated with intentional contamination of food in the Canadian distribution system. The main deliverable, CanGRASP, significantly improves the ability to identify vulnerabilities and assess risks associated with contamination of the food supply with microbiological threat agents.

Future plans: The current CanGRASP prototype operates in a desktop environment that includes protected geo-databases, licensed modeling software and ArcGIS tools needed for analysis and mapping purposes. Plans are underway to transition the simulation and mapping capabilities of the current version from a desktop operation to a distributed, secure multi-user server based operation to ensure accessibility by mandated personnel in federal, provincial, regional or municipal agencies.

CRTI 07-0234RD

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Acknowledgements

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1 Introduction

1.1 Background

International risk assessment exercises have shown that intentional contamination of food systems with chemical, biological, radiological or nuclear (CBRN) agents is a realistic threat, with unpredictable and potentially catastrophic consequences to public health and national economies. The Canadian food system incorporates many independent production, processing, transportation, distribution and retail channels that deliver a profusion of fresh or processed foods to consumers in distant markets, often within a matter of hours or days. Hence the identification of vulnerabilities and the measurement of risks associated with contamination of specific commodities or products in the Canadian food system must be accomplished in consideration of complex elements along the farm-to-fork continuum. Current strategies for the assessment of vulnerabilities to the food system rely on estimates of the relative public-health consequences expected from various product-threat agent-contamination scenarios for foods deemed "most at risk". This approach has proven practical for readily traceable and highly regulated foods derived from stable production systems, centralized processing facilities and established distribution channels. For example, credible threat vulnerability assessments of the milk supply are feasible given the extent of knowledge about this efficient and well monitored supply chain. Furthermore, the availability of survival/decay data for chemical or microbiological threats or threat surrogates in milk enhances the accuracy of scenario-based risk assessments. In contrast, there is a dearth of reliable data to support assumptions about the fate of CBRN threats in other commodities that contribute to the Canadian food system, many of which are sourced or processed in disparate locations prior to distribution through poorly defined channels. Alternative means are clearly needed to identify and assess vulnerabilities inherent to these foods.

The identification of vulnerabilities and the measurement of risks associated with contamination of specific products in a food system must be accomplished by taking into consideration the complexity of the farm-to-fork continuum (Allard, 2002). Several modelling approaches were recently developed to analyse food safety risks in food supply chains. Vialette et al. (2005) used meta-analysis of food safety information based on a combination of relational databases associated with quantitative microbiology models. Jacxsens et al. (2010) proposed a conceptual approach to analyse the complexity of the climate change and globalization challenge on the fresh produce supply chain. Laguerre et al. (2012) identified the need to improve the design and management of the cold chain, proposed combined deterministic and stochastic approaches to predict the evolution of food products along the cold chain, and used these approaches to evaluate the effect of the product's evolution on its microbial safety (Flick et al., 2012; Hoang et al., 2012). Over the past few years, the Sym'Previus project (Couvert et al., 2005; Couvert et al., 2006; Haemmerlé et al., 2007; Hignette et al., 2008; Buche et al., 2011, Coroller et al., 2012; Destercke et al., 2013) has led to the development of two software tools to help manage food safety. These include: (1) a database containing information on the behavior of microorganisms and natural contaminants in foods, that can be queried with a specifically developed system (MIEL) allowing formulation of interrogations on specific foods and microorganisms; (2) a user-

friendly software tool that simulates the growth of microorganisms in a food matrix. In the Sym'Previus project, a semi-automatic acquisition tool, called @WEB, retrieves scientific documents from the Web. Moreover, a flexible querying system using the domain ontology to simultaneously scan local and Web data was developed in order to feed the predictive modeling tools available in the Sym'Previus platform.

Although geographic information systems (GIS) have been used for many years as a tool to model and assess risks (Aagaard-Hansen et al. 2009), few examples are found of GIS being used to model food safety risks. GIS were used to identify vulnerable areas where non-time/temperature dependant contaminants were transferred into food chains (Van Der Perk et al. 2001) or to build clusters of producers and to map optimized routes for delivery systems (Bosona and Gebresenbet 2011). In the broader context of distribution systems, models involving time-based risk assessment or decision support systems to quantify risk have been proposed for the transportation of hazardous materials or dangerous substances (Romano and Romano 2009). However, there are few examples of the use of GIS to model the dispersal of specific commodities in food distribution systems on a national scale and to map consequent risks in affected populations.

1.2 The systems-based approach

The assessment of risk in well-defined or comparatively simple food supply chains could be achieved using information derived from investigation of causes or conditions leading to past disruptions or accidents. Such analysis may not be possible if the chain is highly complex or in the absence of retrospective analyses or data. Here a systems-based approach for the assessment of vulnerabilities to threats directed at the chain may be more appropriate. According to this view a complex food chain can be defined as a series of interacting, interrelated or interdependent elements or parts that are organized and integrated to form a unified whole to achieve the objective, specifically to deliver safe food to consumers. In the present context, a systems-based approach would require the ability to map the dissemination of the commodity along geographic and temporal planes together with the development of appropriate mathematical tools to predict the probability of threat survival and dispersion at discrete stages and along the entire farm-to-fork continuum. The tools could then be used to enhance risk-based decision making for the identification of specific vulnerabilities. This capability would vastly improve pre-event planning by helping to identify vulnerabilities, potential impacts, and assist in the design of intervention and risk management strategies. It would also contribute significantly to response capability by streamlining the ability to intercept and contain potentially contaminated product, predicting potential impacts to ensure appropriate resources are available, and through the identification of effective point (s) of intervention for a range of contamination scenarios.

2 Purpose

The purpose of the research presented herein was to demonstrate the value of a practical systems-based approach for the assessment of risk in complex Canadian food chains. Key elements of the strategy included: the acquisition and compilation of data (processing facilities, transportation and distribution systems) for the development of computerized mapping tools to predict the dissemination of contaminated food along temporal and geographic planes; the development of validated mathematical models to predict threat behavior at each stage and along the entire chain; and the design of decision making tools to identify strategies needed to verify model performance. The performance of the tools and the validity of the approach were demonstrated experimentally with ready-to-eat (RTE) lettuce, a product amenable to the widespread dissemination of infectious microorganisms.

The project addressed CRTI priority area 7 (Safety of the Food System). Specific gaps that were directly addressed by this proposal included: the analysis of food system vulnerabilities; modelling strategies to determine critical intervention points and their effectiveness and the generation of essential new knowledge about the behaviour of bacterial, viral and parasitic threat agents in the food production-to-consumption continuum. In addition, the project indirectly assessed existing food related risk, threat and vulnerability assessment modeling, methodologies and systems, which were also identified by CRTI as a gap. Furthermore, lessons learned and tools developed here could have were developed in consideration of direct application in dealing with catastrophic, non- deliberate contamination events (due to natural disasters, weather related effects etc.).

3 Methodology

3.1 Overall approach

The objective to devise a practical approach to the identification of vulnerabilities and the measurement of risks associated with microbiological threat agents was demonstrated through a detailed analysis of the packaged, RTE lettuce production/distribution chain. This food product was selected for study because it is widely distributed in the Canadian retail system and is known to be vulnerable to contamination with hazardous microorganisms. A simulation model that can predict and map the public health impact implied by contamination was developed from information and elements shown in Figure 1. Methodological detail associated with the collection of relevant data and the design of individual models is given below.

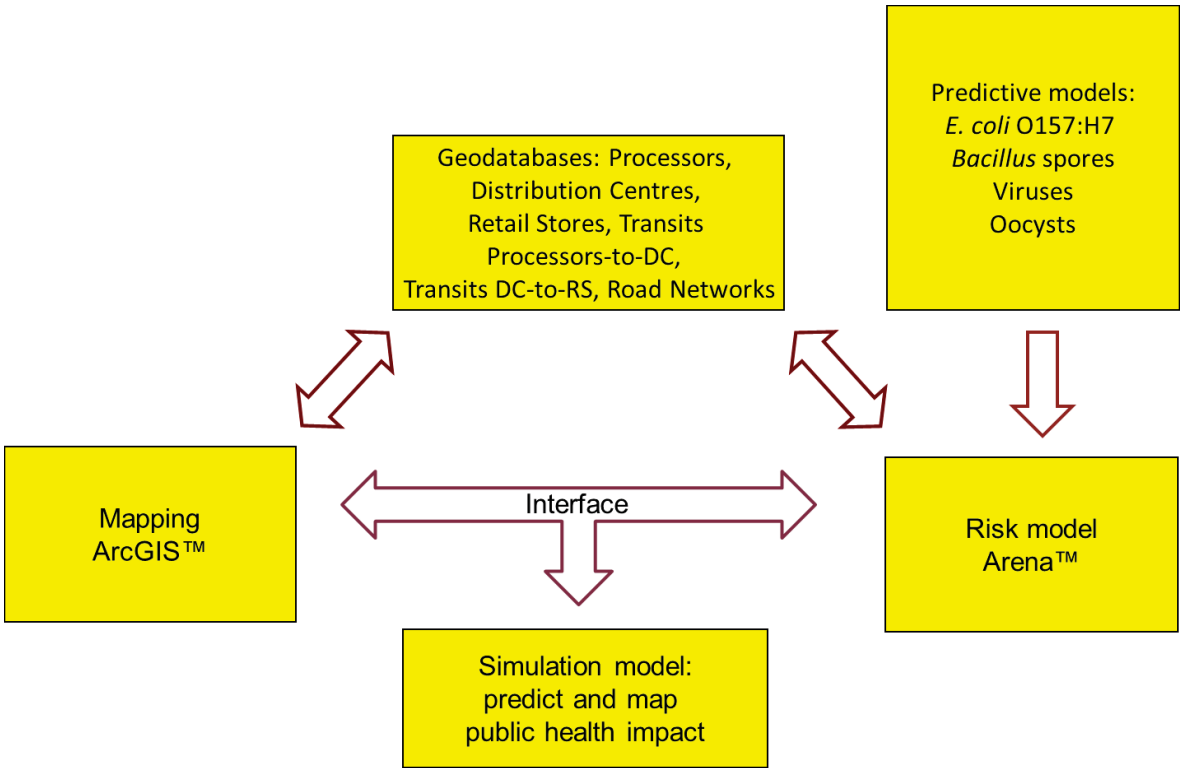


Figure 1. Information and models assembled to construct an overall model to simulate the dissemination of microbiological threats in a Canadian RTE lettuce distribution chain.

3.2 Assembly of the geo-database

The design and construction of a relational database was required to store and manage the heterogeneous data needed to characterize the flow of packaged RTE lettuce through the distribution systems of the major retail chains in Canada. The data required included:

- Location of processors, origin of lettuce supplied to each processor (both domestic and imported), quantities processed on a seasonal basis for the domestic retail sector, distribution centres being supplied by each processor, probability of shipment to each

distribution centre, time spent in storage at processor, and temperature of salads during storage at processor;

- Transit time between each processor and distribution centre, and product temperature during transit;
- Location of retail distribution centres, quantities received (both domestic and imports) on a seasonal basis, probability of shipment to each retail store serviced by distribution centre, time spent in storage at distribution centre, and temperature during storage at the distribution centre;
- Transit time between each distribution centre and retail store, and temperature during transit; and
- Locations of retail stores, distribution centre supplying each retail store, quantities received on a seasonal basis, time spent in storage at retail, and temperature in retail storage.

In addition to these data, the database needed to include provincial and municipal data layers, transportation routes and demographic data. The flow diagram in Figure 2 illustrates the relational database structure that was constructed for this project. Two constraints were integrated into the database: 1) each distribution centre is supplied by no more than three processors; 2) each retail store is supplied by a single produce distribution centre.

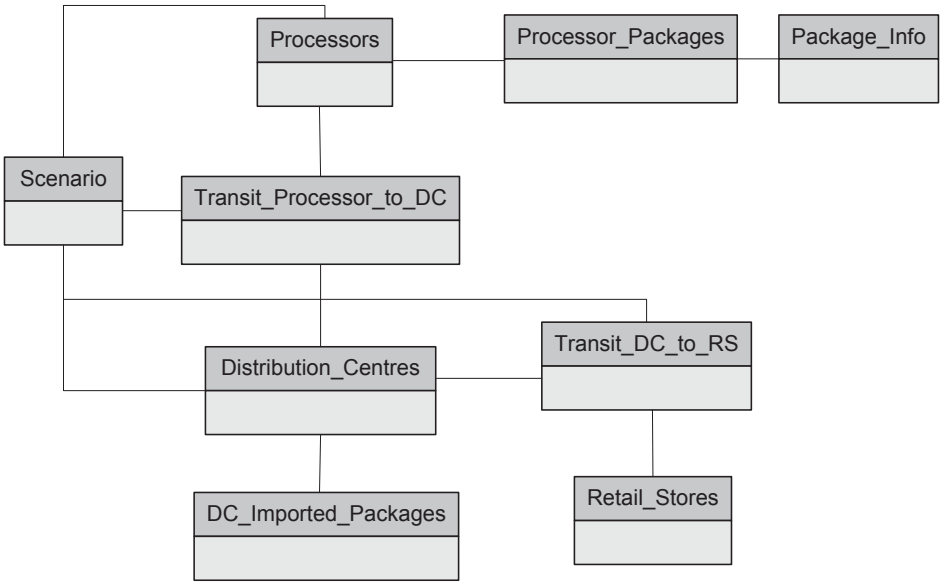


Figure 2. Relational database structure used to characterize the flow of packaged RTI lettuce through the Canadian retail distribution system.

3.2.1 Collection of time-temperature profiles

Information on the time-temperature exposure of the product through each step of the distribution system was required to estimate the growth or death of microbial contaminants. Therefore, time-temperature profiles of RTE lettuce were collected in a typical Canadian retail distribution system consisting of five stages: storage at the processing plant, transportation to a distribution centre,

storage at the distribution centre, transportation to a retail store, and storage at the retail store. Nine cases of ready-to-eat baby leaf lettuce (six 454 g packages per case) were followed from processing to retail in four separate trials carried out during both winter and summer. Cases were handled according to standard practice at each stage of the distribution system. The processor, distribution centre, and retail stores were the same for all trials. Lettuce temperatures were recorded using hypodermic thermocouple probes (Model HYP1-3-1/2-T-G-60-SMP-M, Omega Engineering, Laval, QC) connected to miniature temperature recorders (Hobo U12-014, Hoskin Scientific, Montreal, QC). The cases were distributed evenly in the pallet (Figure 3) to examine the effect of position on produce temperature. The thermocouples were imbedded in the stem of a piece of lettuce in the centre of instrumented packages immediately after processing and temperatures were recorded at 5-minute intervals until the cases were opened for retail display. In addition, air temperatures surrounding the cases were recorded with miniature temperature and relative humidity recorders (Hobo U23-002, Hoskin Scientific, Montreal, QC). These were often used to estimate the start and finish times of each step of the supply chain.

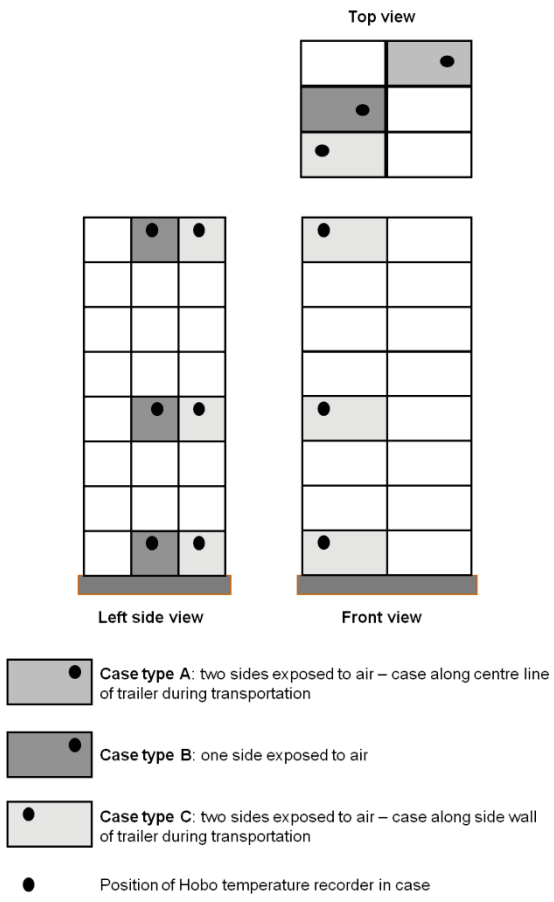


Figure 3. Position of nine instrumented cases of ready-to-eat baby leaf lettuce in a pallet (three instrumented cases per layer – types A, B and C; three instrumented layers per pallet – bottom, middle, top)

3.3 Fate of microbiological surrogates in RTE lettuce in the farm-to-fork chain

Biosafety considerations preclude or restrict experimentation with human pathogens in field, pilot plant or laboratory settings. Consequently, surrogate microorganisms representative of four broad classes of potential microbiological threat agents were used to examine the fate of such agents along the farm-to-fork chain. Selection of the surrogates was based on information available in the scientific literature or from data obtained through experimentation with strains available in participating laboratories. The final list of surrogates is given in Table 1. Methods used to detect each surrogate in lettuce were derived from the scientific literature or were adapted for the purpose. Where needed, predictive models were developed to estimate growth, survival or die-off of the surrogates under variable conditions of time and temperature.

Table 1. Microbiological threat agent surrogates and methods used for their recovery from lettuce tissues.

Class of threat	Surrogates	Detection in lettuce
Virus	Murine norovirus 1 Clone CW3 (MNV-1) Washington, University School of Medicine, St. Louis, MO	Recovery by filtration, detection by plaque forming assay or Real-time reverse transcription PCR (Baert et al, 2008)
Parasite	*Eimeria papillata* Culture collection at CFIA, Centre for Foodborne and Animal Parasitology, Saskatoon, SK	Conventional parasitological methods (oocyst flotation); rDNA (PCR) using primers developed in-house.
Gram negative bacterium	*E. coli* O157:H7 ATCC 700728, stx - isolate	Nalidixic acid resistance, detection on Sorbitol MacConkey Agar containing cefixime and tellurite supplement and 25 ug/mL nalidixic acid (Bezanson et al, 2011)
Bacterial spore	*Bacillus atrophaeus* ATCC 9372	Heat shock at 80ºC in nutrient broth followed by most probable number; Confirmation by PCR using primers in Saikaly et al, 2007.

3.3.1 Fate of the surrogates in field lettuce

Field experiments were performed at the Pacific Agri-Food Research Centre, Summerland, BC and the Atlantic Food and Horticulture Research Centre in Kentville, NS to determine the fate of the surrogates inoculated onto field lettuce. Individual plots of Romaine lettuce separated by 2 m wide buffer zones were inoculated with 10^6 CFU *E. coli* O157:H7/ml, 10^7 PFU murine norovirus 1, 10^6 CFU *Bacillus atrophaeus* /ml and 10^5 *Eimeria papillata* oocysts suspended in water four weeks after transfer of seedlings to the field. The inoculum was applied as evenly as possible to

all plants by walking back and forth along the length of the rows while dispensing the bacterial suspension from a watering can held at a height of cm above the plant canopy. This enabled application at an approximate rate of two liters per row.

Lettuce samples were collected immediately after inoculation and for up to three weeks thereafter. Samples consisted of three heads collected at random w by cutting plant stocks with a sterile knife at a distance of 2.5-3.0 cm above ground. The leaves from each head were separated and approximately 225 g of randomly selected leaves were transferred to sterile plastic bags. The samples were refrigerated and distributed to participating laboratories for analysis.

Count data were analyzed by the Weibull survival function:

$$\text{Log } Nt/N0 = -(t/\text{delta})p$$

where N0 is the cell count (CFU/ g-1) at t=0, delta is the time required for the first log reduction, and p is the shape parameter ($p<0$ for a tailing curve, or $p=0$ for a straight line. This model is commonly used to quantify microbial decline resulting from treatments such as heat or exposure to chemicals (Mafart et al, 2002). It can describe three different curve shapes: (i) an initial rapid decline, changing to a tailing-off at low cell numbers ($p<0$); (ii) log-linear kinetics ($p=1$); and, (iii) a shoulder prior to inactivation ($p>0$).

Non-linear regression was performed using GraphPad Prism 5.03 for Windows (GraphPad Software, San Diego, USA). Goodness-of-fit was determined using r2. Akaika's Information Criteria (AIC) was used to determine if the best-fit values for the two parameters differed between data sets. AIC is used in cases where the F-test is inappropriate for model comparisons i.e. when the models in question are not nested. Standard output from Prism also includes 95% prediction limits, which define the region around the curve where 95% of future data points should be found.

3.3.2. Sampling system

A sampling strategy that considered the numbers of plants available for analysis and test sensitivity was developed in Excel™ to calculate the number of samples required to achieve the desired level of confidence. An electronic copy of the spreadsheet file is attached to the report and an example of a calculation output id provided in Appendix 4.

3.3.3. Fate of the surrogates during processing

Processing was performed in the pilot plant at the Pacific Agri-Food Research Centre in Summerland, BC. Cut lettuce was processed in a 400 l stainless steel flume operated at 4 ºC with 70 ppm (free) chlorine. The final de-watering stage was performed in a commercial lettuce centrifuge operated at 200 rpm for 2 minutes. Romaine lettuce obtained from a local supplier was trimmed and cut into 4x4 cm pieces. Inoculum suspended in distilled water was mixed with 5 kg cut lettuce to achieve inoculation levels of 10^5 CFU *E. coli* O157:H7/g, 10^4 PFU murine norovirus 1/g, 10^5 CFU *Bacillus atrophaeus* /g and 10^3 *Eimeria papillata* oocysts/g. The inoculated batch was processed and twenty five 25 g samples were removed from the centrifuge for analysis. Chlorine level was adjusted to 70 ppm and nine additional5 kg batches of un-inoculated lettuce were processed according to this schedule without changing the wash water in the flume. Samples were removed after de-watering as before and were distributed to respective laboratories for analysis. Figure 4 provides a schematic overview of the experiment.

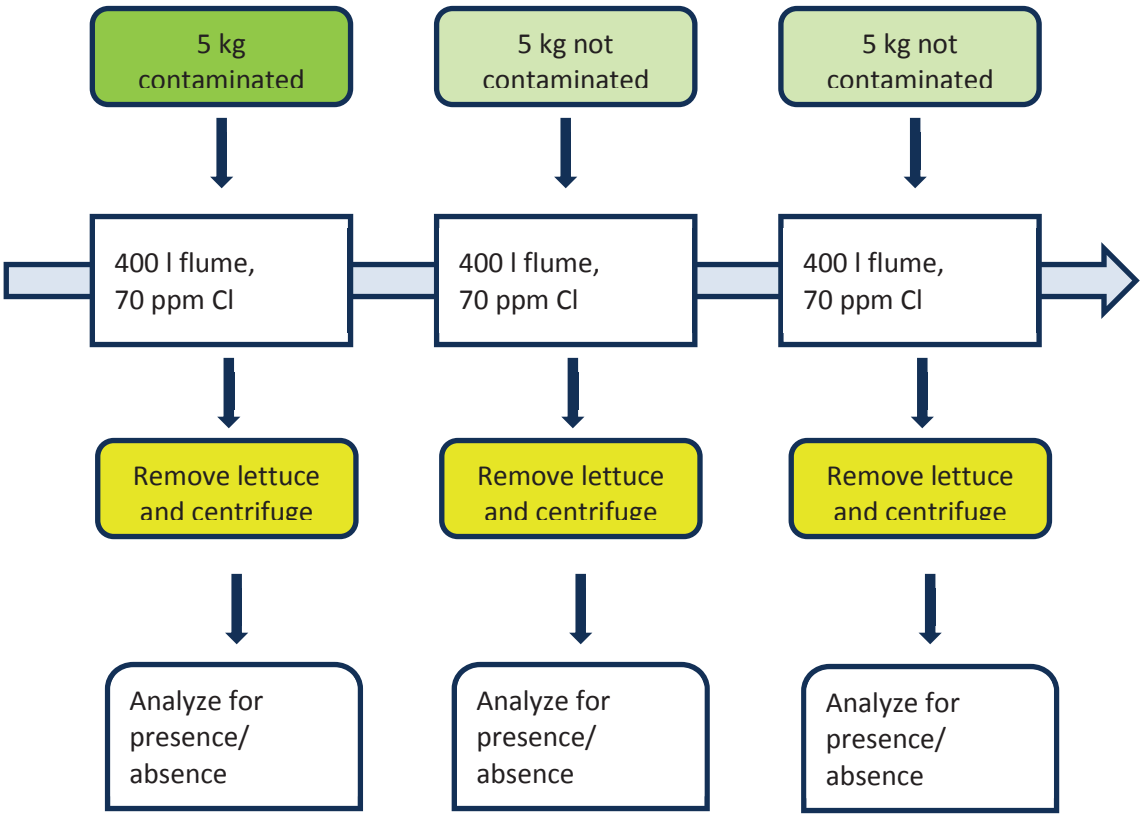


Figure 4. Flow diagram for the processing scheme applied in pilot plant trials. Nine successive 5 kg batches were processed after the initial contaminated batch.

3.3.4. Fate of the surrogates in packaged lettuce

The surrogates were inoculated on RTE packaged lettuce to examine behaviour during storage at refrigeration temperatures. In separate experiments, Romaine lettuce cut into 4x4 cm pieces was inoculated with the surrogate. The inoculated lettuce was plunged in a cold (4 ºC) NaOCl solution (70 ppm free Cl) for two minutes. The lettuce was then spun in a home salad spinner to remove excess water. Samples (50g) were packed in PDZ 961 film (oxygen permeability: 6000-8000 cm^{-3} m^{-2} 24 h, 1 atm at 23 ºC, carbon dioxide permeability: 19000-22000 cm^{-3} m^{-2} 24 h, 1 atm at 23 ºC) and were stored at 5 ºC and 12 ºC. Samples were periodically withdrawn and analysed using methods given in Table .

3.3.5. Dynamic growth-death model for *E. coli* O157:H7 in packaged lettuce.

Unlike the other surrogate microorganisms used in this work *E. coli* O157:H7 can multiply in packaged RTE lettuce at growth permissive temperatures. Hence a dynamic model that predicts behaviour under the range of temperatures likely to be encountered in the food distribution system was needed for the overall simulation model. Literature data on behaviour of this

pathogen on fresh-cut lettuce was taken from published graphs by digitization, published tables or from personal communications. A three-phase growth function was fitted to the data from 14 studies, and a square root model for growth rate (μ) as a function of temperature was derived. Variability in the published data were incorporated into the growth model by the 95% prediction limits. A linear die-off function was fitted to the data from 13 studies, and the resulting die-off rate constant was selected to give fail-safe predictions.

3.4 Mapping and analysis using GIS

A geographic information system (GIS) and associated ArcGIS Network Analyst Tools were used to calculate transit times with transportation information for Canada. First, a road network consisting of a system of interconnected road elements, such as lines connecting points, was prepared. Each element was defined based on a multi-level hierarchy of road classifications, such as highways, major roads and local streets. The hierarchy can take into account the network attributes for each class such as speed limit, barriers, turn restrictions and one-way restrictions. The total transit time was calculated as the sum of the network transit time, from each origin (e.g. processor or distribution centre) to each destination (e.g. distribution centre or retail outlet), a delay time depending on the destination, and an average unloading time when multiple drop offs are done during retail delivery.

The identification of vulnerabilities and measurement of risks associated with the contamination of food systems by biological agents requires an accessibility analysis to identify those areas that are at immediate risk as time progresses and estimates of the population affected by the contamination event. Accessibility is defined as the ease with which a target location can be reached from a particular location or by an individual at that location. In this study, retail outlets were the target locations. Based on a literature review, food accessibility analysis using GIS can be based either on a Density Analysis Approach, where a retail store service area is defined using buffer method and spatial clustering, or based on a Proximity Approach where the accessibility is estimated by measuring distances or travel times.

In our study, a spatial method based on a proximity approach was used to determine accessibility since proximity to a retail outlet usually correlates with consumer patronage. Using a GIS to investigate travel times, the most straightforward approach is one that studies the road network and analyzes the distance and speed of travel to different outlets. The spatial approach used to measure accessibility, considered transport usage characteristics of people in different areas:

- Accessibility criterion in rural areas: The zone of influence (or service area) of a retail outlet was delineated as the area within 30 minutes driving time.

- Accessibility criterion in urban areas: The zone of influence of a retail outlet was delineated as the area within a 5 km travel distance.

To estimate the demographic characteristics of each zone of influence, or identify the population associated with each retail store, ArcGIS Spatial Analyst was used to create a geographic intersection of the census tract polygon boundaries with each service area map. Then, population densities were calculated for each census tract by dividing the total population within a census tract by the total land area of the census tract. The population of each zone of influence polygon was calculated by multiplying the surface area of the polygon by the population density for the

census tract in which the zone of influence polygon was located. It should be noted that when a zone of influence intersects several census tracts, the population is calculated by considering the densities of each intersected census tract.

3.5 Development of the risk simulation model

A risk model was developed using the approach shown in Figure 1. The model utilizes the predictive microbiology models and the geodatabases of processing, transportation, distribution and retailing information, to predict the distribution of contaminated product and the public health impact, as a function of time. The risk model was created with Arena™ discrete event simulation software application from Rockwell Automation. The Arena software was selected to develop the risk model since it is a tool that was originally designed to model, simulate and analyze "supply chains, manufacturing, processes, logistics, distribution and warehousing, and service systems." (Arena user's guide, 2010), and as such was extremely robust at handling simulations similar to those in the current model. The software, like ArcGIS (used for the mapping component) and Microsoft Access (used for the database component) has an Object Model, allowing them to be integrated using Microsoft Visual Basic. The integration of the three components with a user interface on the front end was the final objective of the project.
The Arena risk model was created to simulate the fate of lettuce from entry at processor (bulk) to exit at retail (bag) (Figure 5). The model was designed to begin with bulk lettuce and simulate the packaging of the product, the delays and temperature profiles encountered during storage and shipping, as well as the shipping logistics as they exist in the Canadian retail distribution system. Using predictive equations based on the type of contamination (bacteria, virus, parasites, or spores), the model was designed to calculate growth, survival, or die-off in the packaged lettuce during storage and shipping, until retail display.

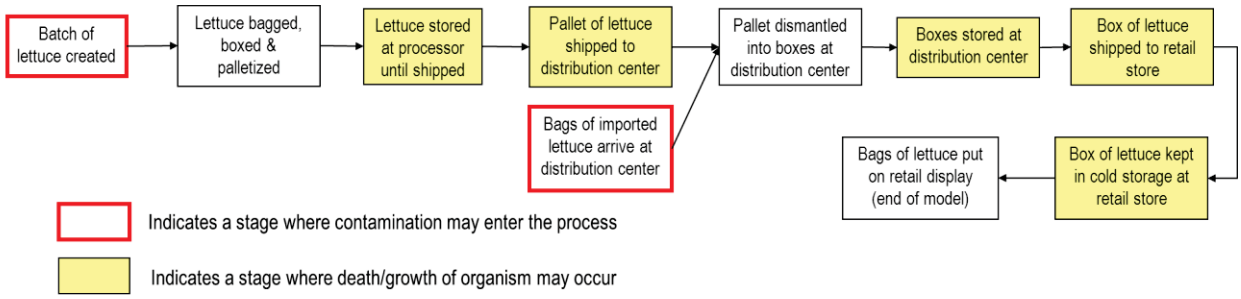


Figure 5: Lettuce supply chain events incorporated into Arena model

As only contaminated product is of interest in determining potential risk to consumers, packaged lettuce which is free of contamination was not simulated within the Arena simulation. The model simulates batches of lettuce at only those Processors and/or Importers indicated by the user to have contaminated product in a given scenario. The model stops simulating batches from those processors once the specified amount of contaminated lettuce has entered the supply chain.
The conceptual flow of Figure 5 was translated into the Arena simulation software to create the base Arena model flow shown in Figure 6. The model is separated into six subsystems for

simulating both the physical movement of packaged lettuce in the supply chain and the contamination levels within packages due to the time and temperature profiles experienced during storage and transit. The subsystems have been colour coded to ease explanation of the model supplied in an appendix to the report. The risk model looks at individual packages of lettuce along the entire chain keeping track of their attributes including: the processor that produced it; the distribution centre it travelled through; the mass of the package; the time and temperature history of the package; the retail location it was delivered to; the type of contamination it contains and its level along the entire chain. The final output from the model is a Microsoft Access database containing the attributes of the individual bag which can be utilized for analysis by the ArcGIS tools incorporated in the overall simulation tool.

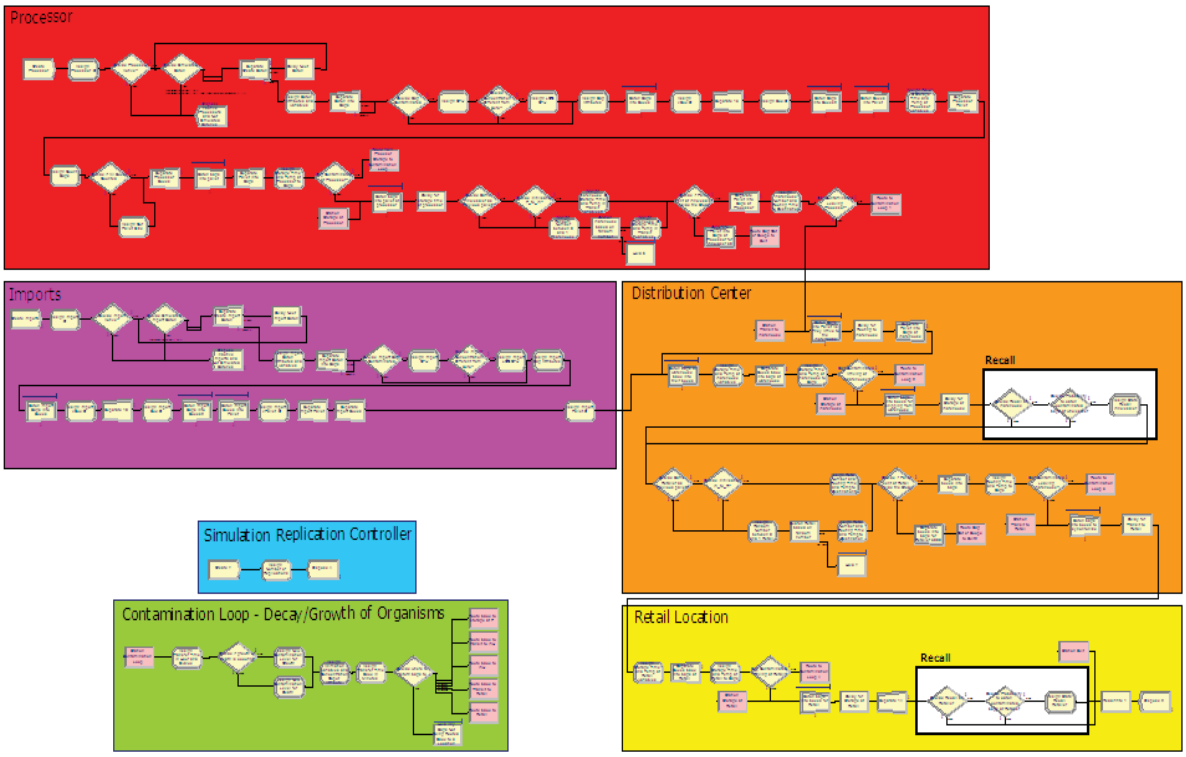


Figure 6: Arena™ model flow

An approach was developed to estimate the public health risk associated with a contamination event given the definition of zones of influence and populations associated with each retail outlet. Direct estimates of infection rates would require a significant amount of information on the dose-response relationship and detailed knowledge about consumer purchasing and handling practices. A risk index, as opposed to the exact or absolute risk, was developed as an alternative to provide a metric to gauge the potential relative risk associated with a contamination scenario in various retail locations. The risk index incorporates: population density around a retail location; proportion of product that is contaminated; and average level of contamination in the product. In many ways, these components capture the basic definition of risk being a function of the probability of an event (prevalence and concentration of contamination) and severity of the event (population density around a site) (Hashemi Beni et al., 2012).

The risk index (RI) shown in Equation 1 is therefore a function of three factors: RI_1 (population density parameter); RI_2 (prevalence of contamination parameter); and RI_3 (average level of contamination parameter);

$$RI = RI_1 \times RI_2 \times RI_3 \qquad \text{Eq.1}$$

The first factor (RI_1) is calculated by either linearly (Eq. 2a) or log-linearly (Eq. 2b) translating the number of people potentially exposed to a retail location into a risk index multiplier. The two options (linear and log-linear) were explored in order to enhance the discrimination available in the risk index since the potential population exposed to a retail location had a very large range, up to approximately 840,000, but with the majority, up to 80% of the stores, with an exposed population of less than 110,000.

$$RI_1 = m \times P + b \qquad \text{Eq. 2a}$$

$$RI_1 = m \times \log(P) + b \qquad \text{Eq. 2b}$$

Where:
m = parameter describing the rate of change of RI_1 relative to population
P = Population around retail store (option 1: actual population, option 2: log population)
b = intersect of the curve

The second parameter (RI_2) is simply the prevalence of contaminated product at the retail location (Equation 3). This parameter scales the index up or down so that when there is no contamination the value is 0 and in the unlikely event that all the product is contaminated the value is 1. The number of contaminated packages at a retail location is estimated from the simulation model incorporating contaminated volumes and supply chain logistics.

$$RI_2 = prev \qquad \text{Eq. 3}$$

Where:
prev = Prevalence of contaminated product (contaminated packages / total number of packages)

Finally, the third parameter (RI_3) shown in Equation 4 is calculated by using a log function to convert average concentration into a risk index multiplier. The logarithmic function was selected since it is more conservative than the alternative and simpler linear function because it increases the risk multiplier at a faster rate at lower concentration values.

$$RI_3 = u \times \log(C) + d \qquad \text{Eq. 4}$$

Where:
u = parameter describing the rate of change of RI_3 relative to average log concentration
C = Average contamination concentration
d = Intercept of the curve
The specific parameter values used in Equations 2 and 4 were estimated based on the range desired for the risk index (y-axis) and the corresponding x-axis (population potentially exposed or average concentration). The range of values and corresponding parameters are summarized below:

Equation 2a (RI_1) – Linear				
	Pop.	RI_1	Parameter (m)	Parameter (b)
Min	1	0	5.95×10^{-6}	-5.95×10^{-6}
Max	840,000	5		

Equation 2b (RI_1) – Log				
	Log Pop.	RI_1	Parameter (m)	Parameter (b)
Min	0	0	0.8446	0
Max	5.92	5		
Equation 4 (RI_3)				
	Log Conc.	RI_3	Parameter (u)	Parameter (d)
Min	0	1	0.8	1.00
Max	5	5		

Figure 7 illustrates the calculation of the Risk Index (RI) incorporating the three components: RI_1, RI_2 and RI_3 in a scenario where there is a range of populations potentially exposed (1 – 500,000), the prevalence of contamination at all sites is assumed to be 0.2 (RI_2 = 0.2) and the average concentration in contaminated product is assumed to be 3 log CFU (RI_3 = 3.4). In this situation, a retail location with 10,000 potential people exposed would get assigned a risk index score of 0.07 (assuming a linear population function) or 2.4 (assuming a log population function), while a retail location with 1,000 potential people exposed would get assigned a risk index score of 0.01 (assuming a linear population function) or 1.79 (assuming a log population function).

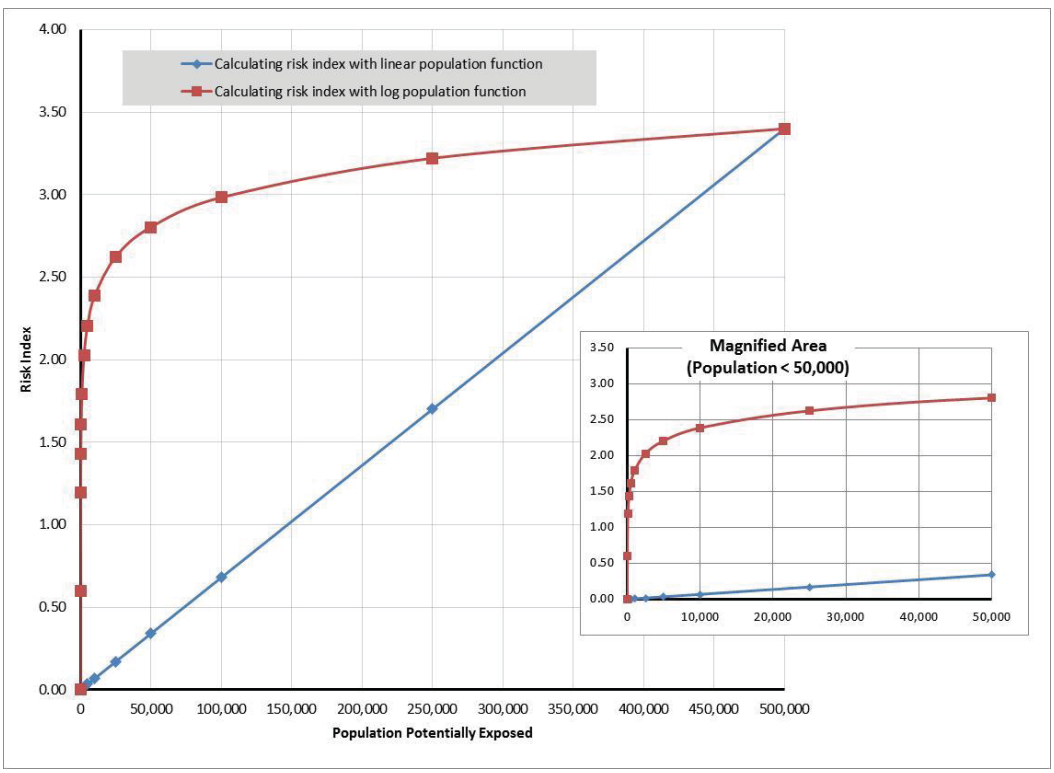


Figure7: Illustration of how the risk index varies with the size of the potentially exposed population (RI_2 = 0.2, RI_3 = 3.4)

Unlike this simple example however, the final risk index calculation varies by retail location based on the fact that some locations will receive contaminated product while others will not, and

in some locations even if they have the same proportion of contaminated product the level of contamination will be different. Obviously the number of people potentially exposed will vary from location to location as well.

3.6 Model Integration and Design of the Overall Simulation Model

Virtual Basic (VB) programming was used to integrate the Arena risk model, Microsoft Access databases and ArcGIS in a single interface to develop an overall simulation tool (Figure 8).

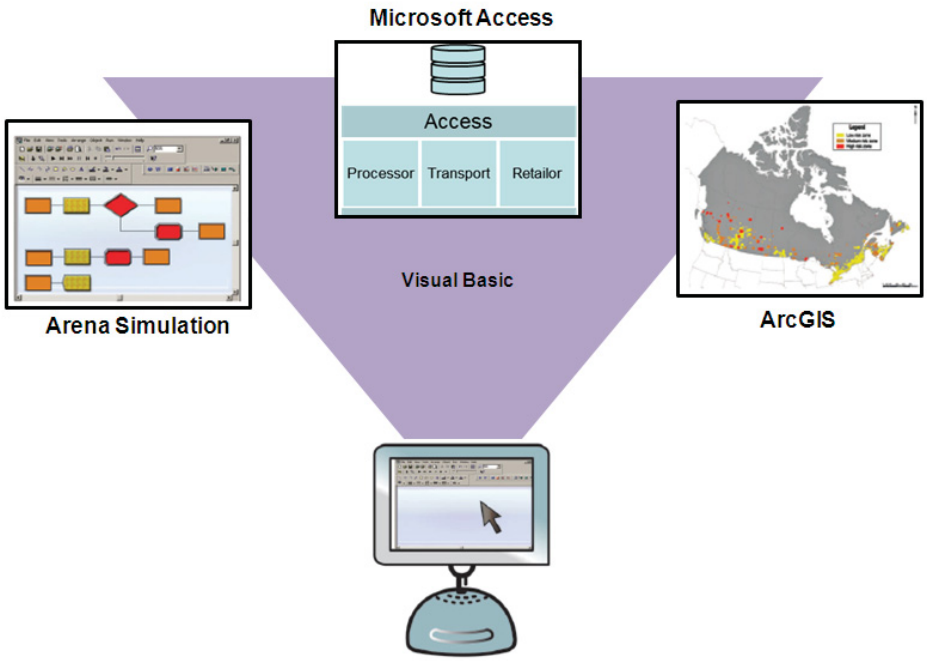


Figure 8: Conceptual relationships of components composing the integrated simulation tool.

The interface was designed to allow simulations based on scenarios derived from parameters chosen by the user including:

- Season when contamination event occurs
- Number of replications to perform during simulation
- Type of contamination (Viruses, Parasites, Gram-negative bacteria, Bacterial spores)
- Source(s) of contamination (Processor or Distribution Centre)
- Kilograms contaminated at each source
- Level of concentration at each source (CFU/kg)
- If a recall will occur for the product, the time the recall begins and how effective the recall is at the Distribution Centre or Retail

The simulation model delivers the results in the form of an Access database for analysis with ArcGIS. ArcGIS tools were developed to allow a user to calculate, for each retail location receiving contaminated product, the mean contamination level on any given day, the prevalence of the contamination, the population potentially affected by the incident, and the risk index. ArcGIS is then used to map the spatial distribution of contaminated product over time and show the public health impact.

4 Results

4.1 Assembly of the geo-database

The heterogeneous data collected to characterize the Canadian retail distribution system for RTE lettuce was assembled in a Microsoft Access™ database to provide an interface for the Arena™ simulation software. The Network Analyst extension tools in ArcGIS were used to calculate distances between sets of origins and destinations, such as the distances between the processors and distribution centers, or the distances between the distribution centers and the retailers. A shapefile based network dataset was created from the transportation layer. Temperature distributions were derived from measurements in two Canadian distribution chains during the summer and winter. An example is provided in Figure 9 which shows profiles measured in a distribution chain consisting of five stages: storage at the processing plant, transportation to a distribution centre, storage at the distribution centre, delivery and retail storage.

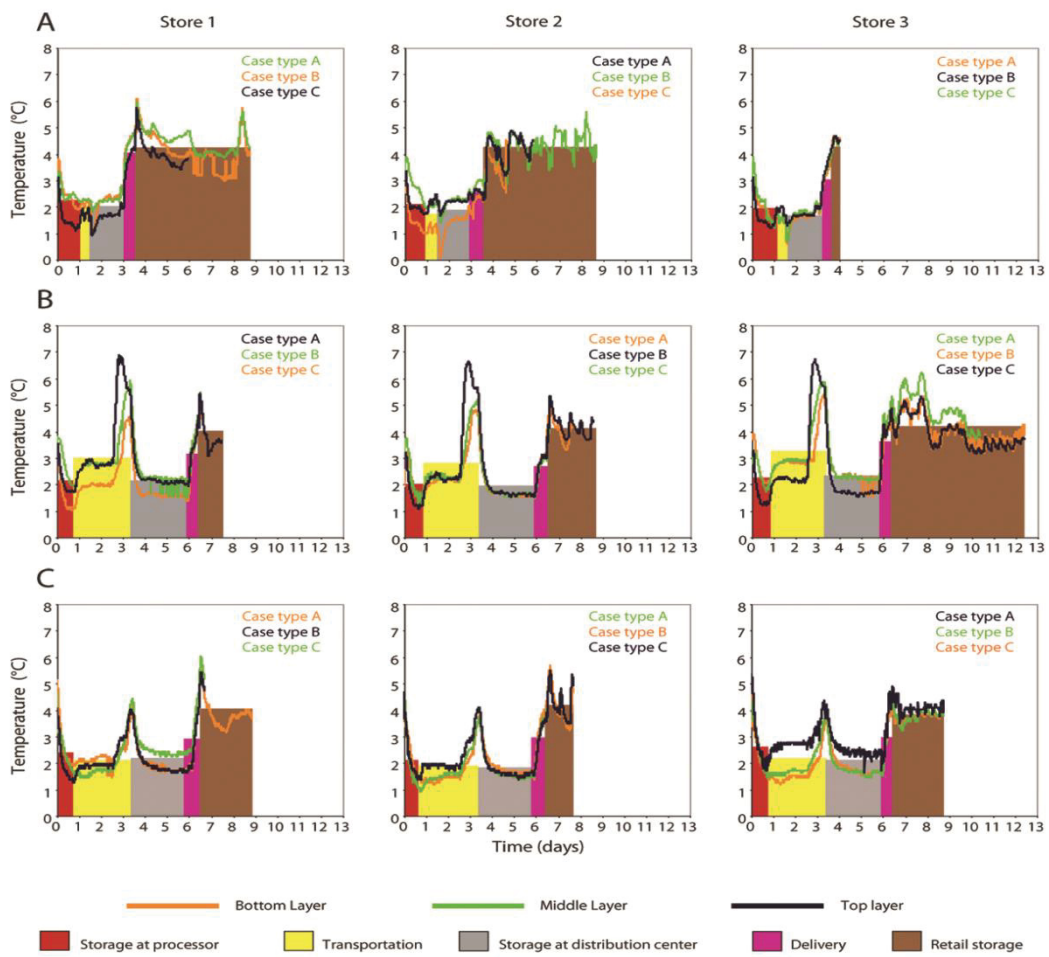


Figure 9. Temperature profiles measured on three occasions (A, B, & C) in a distribution system for RTE lettuce. Coloured rectangles indicate duration of each step (width of rectangle) and mean temperature of the three cases for each step (height of rectangle).

Measurements performed in commercial distribution systems showed that temperatures fluctuate during transportation but were comparatively well maintained during storage. There were also differences between seasons which are reflected in the database which includes seasonal temperature profiles. Details of the database architecture, assembly and access are provided in Appendix 1.

4.2 Fate of the surrogates on field lettuce

Field trials were conducted over two successive seasons at the Pacific Agri-Food Research Centre in Summerland, BC and the Atlantic Food and Horticulture Centre in Kentville, NS, to model the fate of the surrogate microorganisms on field lettuce. Murine norovirus 1 inoculated at a level of 10^6 PFU/g was detected sporadically on lettuce leaves one week post-inoculation in both sites over two years of experimentation. There is a dearth of information about the survival of viruses in agricultural crops grown under field conditions. To our knowledge, the present represents the first attempt to examine the fate of Murine norovirus 1 on leafy vegetables. The outcome suggests that the virus is highly susceptible to the harsh conditions encountered in the agricultural environment. Exposure to ultraviolet light, extremes of temperature, periodic episodes of drought followed by precipitation are known to influence the survival of microorganisms in the plant phylosphere (Brandl, 2006).

Eimeria papillata oocyst counts on lettuce also decreased over time in both sites, although the decline was linear and very gradual. Oocyst numbers were converted to log values, then the log of the surviving population at time=t was calculated as:

$$\log S_t = \log \frac{N_t}{N_0}$$

where Nt and N0 are number of oocysts g-1 at time=t and time=0, respectively. Data were then fitted with a Weibull decline function:

$$\log S_t = -\left(\frac{t}{\delta}\right)^p$$

where δ is the time required for the first log reduction, and p is the shape parameter (p<1 for a tailing curve, p>1 for a shoulder prior to inactivation, or p=1 for a straight line).
Non-linear regression was performed using GraphPad Prism 6.01 for Windows (GraphPad Software, San Diego, USA). Simulated output was calculated using @RISK 6.1. An @RISK™ spreadsheet was constructed to simulate the decline in oocyst numbers, with the prediction limit used as the source of variability. The initial number of oocysts was simulated using a Triangle distribution with low, mean, and high values defined to give a reasonable range of input values (Table ; cell B6). The change in log oocyst numbers (cell B12) was simulated using the parameter values (Table 2; cells B7&8) for the Weibull model and the time in days selected (cell B9). Over the range of the experimental times, the prediction limit varied from a low of 1.01 (log oocyst g^{-1}) at t=0 to 1.05 at t=28d (Figure 10), so to simplify the model, an average value of 1.03

was used in the simulation to introduce the range of the prediction limit (cell B10). This variability was added to the fixed value calculated for the log change in oocyst numbers using a Triangle distribution to concentrate the range of variability closer to the mean value (Table 1; cell B11). The final log oocyst numbers g^{-1} were calculated using an Excel® Mimimum function to prevent the value from being greater than N0 (cell B13).

Table 2. Structure of @RISK™ simulation for Eimeria papillata *oocysts on field lettuce*

	Location	Function or value
Initial log oocysts g^{-1}	B6	RiskTriang(1,2,3)
δ	B7	12.0
p	B8	0.996
Day	B9	User selected (7, 14, 21, 28)
PL	B10	1.02
Log Change	B11	-(B9/B7)^B8
PL added	B12	B11+RiskTriang(-B10,0,B10)
Final log oocysts g^{-1}	B13	Min(B6+B12,B6)

PL, 95% prediction limit

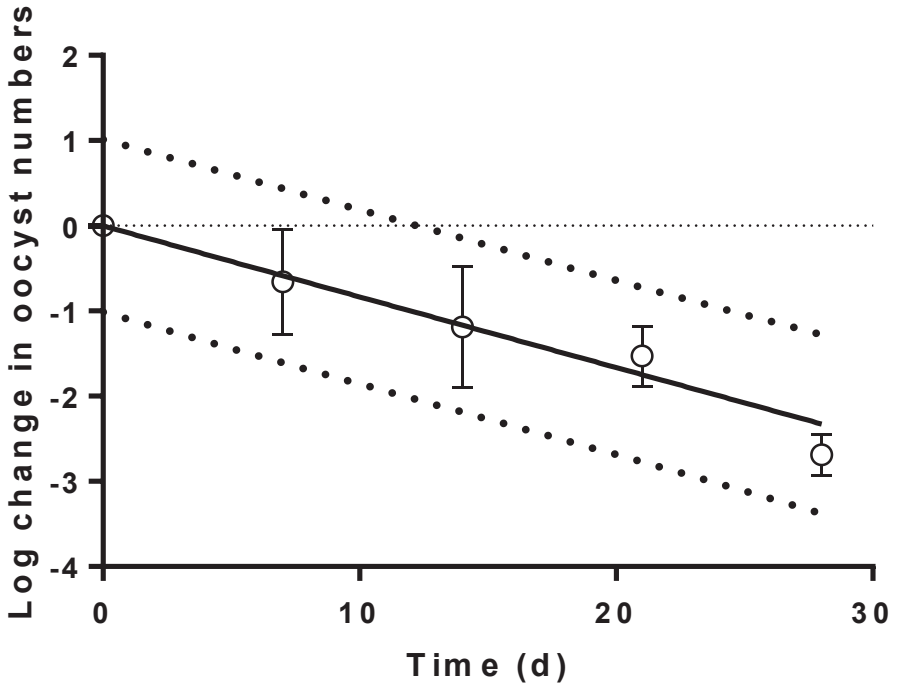


Figure10 . Simulated (100) data points incorporating variation in data compared to regression line and 95% prediction limits for Eimeria papillata *oocysts on field lettuce.*

The predicted change in oocyst population over a period of three weeks was approximately 1.5 log, which is indicative of far greater stability in the production environment than that observed

for Murine norovirus 1. As Figure 10 shows, the decline in oocyst population was linear over the course of the experiments. It must be stressed here that populations were measured in samples of uniform weight collected over variable periods of time after inoculation. Up to 80% of the ultimate fresh weight of lettuce plants is produced in the three weeks before harvest maturity (Zink and Yamaguchi, 1963) at a rate that is influenced by the combined effects of temperature, light levels, soil type and nutrition (Dufault et al., 2006). Consequently, samples collected after inoculation were removed from plants that underwent growth leading to progressive and variable differences in the surface area to weight ratio of the leaves. The implied sample asymmetry undoubtedly introduced a bias to the measurement of oocyst populations. Furthermore, wind and precipitation likely contributed to mechanical removal from the plant surface. Hence it is likely that the decline in oocyst populations was not due to loss in viability.

Bacillus atropheus spore data were subjected to similar analysis. Spore numbers were converted to log values, the log of the surviving population at time=t was calculated and data were fitted with the Weibull decline function as described for *Eimeria papillata* above. An @RISK™ spreadsheet was constructed to simulate the decline in spore numbers, with the population limit was used as the source of variability. The initial number of spores was simulated using a Triangle distribution with low, mean, and high values defined to give a reasonable range of input values (Table ; cell B6). The change in log spore numbers (cell B12) was simulated using the parameter values (Table ; cells B7&8) for the Weibull model and the time in days selected (cell B9). Over the range of the experimental times, the population limit varied from a low of 2.0 (log spores g^{-1}) at t=0 to 2.03 at t=21d (Figure 11), so to simplify the model, an average value of 2.02 was used in the simulation to introduce the range of the population limit (cell B10). This variability was added to the fixed value calculated for the log change in spore numbers using a Triangle distribution to concentrate the range of variability closer to the mean value (Table 3; cell B11). The final log spore numbers g^{-1} were calculated using an Excel® Mimimum function to prevent the value from being greater than N0 (cell B13).

Table 3. Structure of @RISK™ simulation for Bacillus atrophaeus *spores on field lettuce*

	Location	Function or value
Initial log spores g^{-1}	B6	RiskTriang(1,2,3)
δ	B7	6.63
p	B8	0.638
Day	B9	User selected (7, 14, 21)
PL	B10	2.02
Log Change	B11	-(B9/B7)^B8
PL added	B12	B11+RiskTriang(-B10,0,B10)
Final log spores g^{-1}	B13	Min(B6+B12,B6)

PL, 95% prediction limits

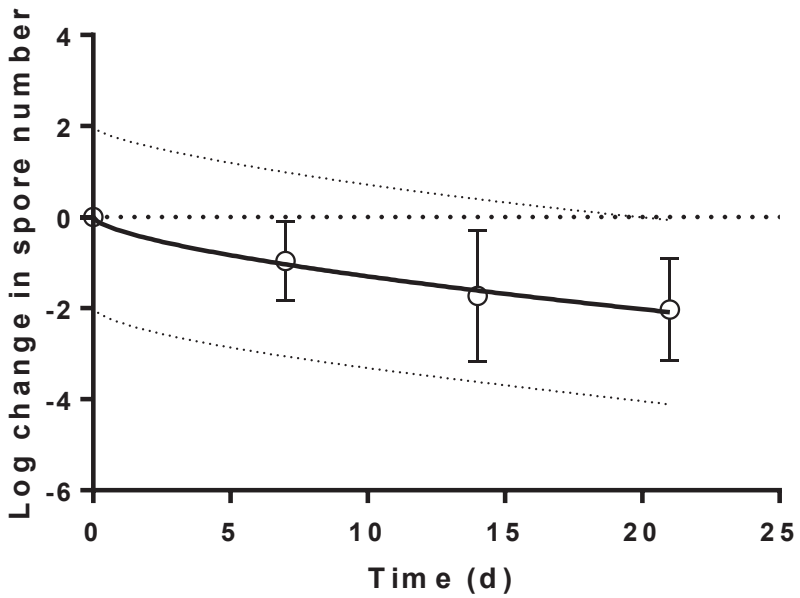


Figure 11. Simulated (100) data points incorporating variation in data compared to regression line and 95% prediction limits for Bacillus atrophaeus *spores on field lettuce.*

Decay of *Bacillus atrophaeus* spores on lettuce was nearly linear and the predicted change in spore populations over a period of three weeks was approximately 1.5 log g^{-1}, which mirrored the decay rate observed for *Eimeria papillata* oocysts. In parallel with measurements of oocyct populations, plant growth and the influence of abiotic factors undoubtedly influenced spore population estimates derived from samples collected over the time course of the experiments. In addition, *Bacillus* endospores are also known resists stresses encountered in the natural environment. Hence this work provided strong evidence that both protozoan oocysts and Gram-positive bacterial endospores can remain viable for several weeks on field lettuce.

E. coli O157:H7 populations also fell on lettuce. An initial, rapid rate of decline was followed by a long "tailing" period during which *E. coli* O157:H7 was consistently recovered by enrichment for up to three weeks post-inoculation. The data sets collected at both experimental sites and from recently published studies (Erickson et al., 2010; Moyne et al., 2011) were used for model development. A total of 73 points over the range of 0 to 21days, and the mean and standard deviation (SD) for each of the time points with the regression line and the prediction limits (broken lines; range within which 95% of future data points should fall) are shown in Figure 12. The response shows that the majority (>85%) of the cells are sensitive, resulting in an initial rapid drop in log cell numbers of 0.629 d^{-1}. The tailing is due to a small proportion (<15%) of the cells which die off at a slower rate of 0.078 log cfu d^{-1}. An @RISK model was constructed to simulate the decline in cell numbers, with 95% prediction limits used as the source of variability, and output from 100 iterations of the model is shown in Figure 13. The large circles are output from one iteration, while the other 99 iterations are shown as smaller circles. The simulated log reductions are localized near the regression line, with fewer simulated points appearing close to the limit of the simulation range.

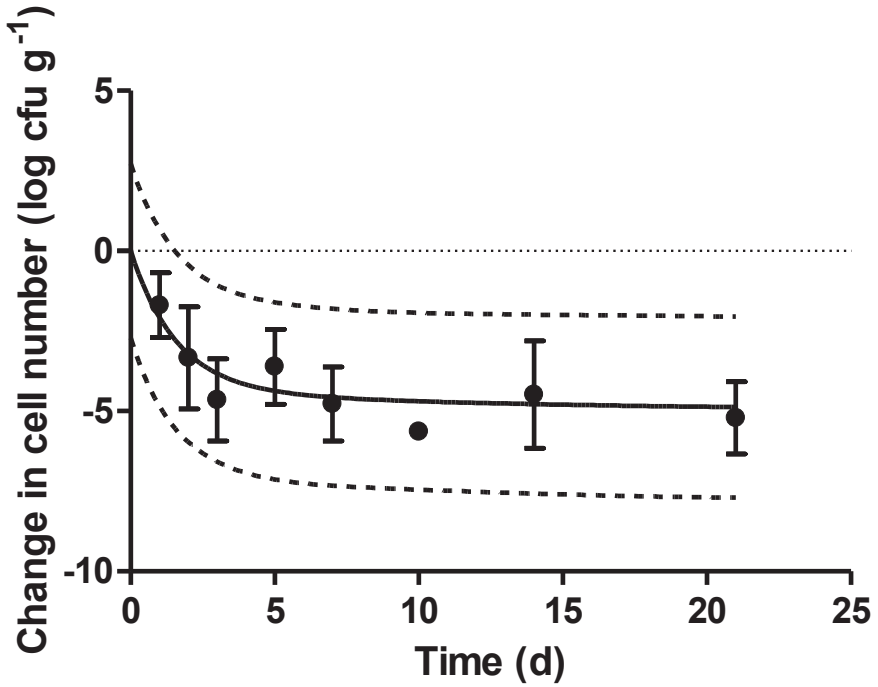


Figure 12. Fitting of field data for E. coli O157:H7 with the two-phase exponential decay function. Regression model is indicated by the solid line, bars indicate standard deviations and broken lines represent the 95% prediction limits.

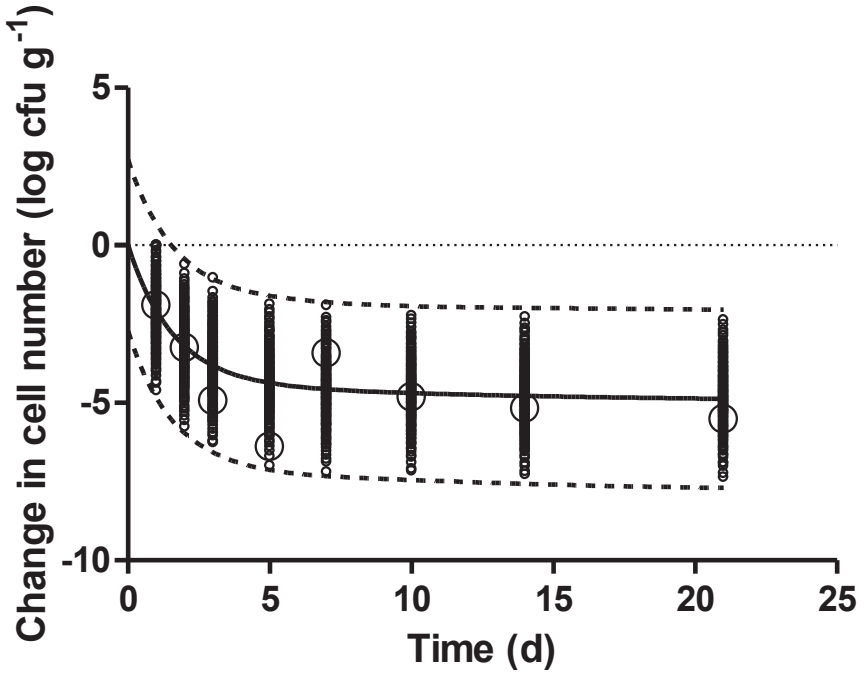


Figure13 . Simulated output from the @RISK model for decay of E. coli O157:H7.

E. coli O157:H7 cells clearly decay at a faster rate than *Eimeria papillata* oocyst on field lettuce. However, low levels of viable cells persisted for up to three weeks post-inoculation.

4.3 Fate of the surrogates during processing

The experiment was designed to verify survival of the surrogates during a standard commercial process for RTE lettuce and to assess the risk of transfer to successive batches after the introduction of contaminated raw material in the production environment. Results presented in Table 4 shows that *E. coli* O157:H7 was detected in the 10th batch of processed lettuce. *E. coli* O157:H7 is sensitive to the antimicrobial effects of chlorine and would be rapidly inactivated in the aqueous phase. However, attachment to plant tissues is known to increase the resistance of bacterial cells to a range of sanitizers, a phenomenon that is believed to promote survival during processing. The persistence of *E. coli* O157:H7 during processing of RTE lettuce was recently examined in detail by Pérez-Rodríguez et al (2011). These authors have attributed the phenomenon to adhesion of the species to small pieces of lettuce tissue that are not removed from the flume between successive batches.

gradual dilution effect may further reduce the number of spores/oocysts in the process water.

Table 4: Number of lettuce samples positive for the presence of four surrogate microorganisms in nine successive batches of lettuce processed after the introduction of a single contaminated batch of lettuce.

Surrogate species	**Wash number**									
	1*	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
E. coli O157:H7	5/5	5/5	4/5	3/5	1/5	5/5	1/5	0/5	3/5	1/5
Bacillus atrophaeus	5/5	5/5	5/5	5/5	5/5	3/5	3/5	3/5	3/5	1/5
Eimeria papillata	5/5	4/5	4/5	0/5	0/5	1/5	1/5	0/5	0/5	0/5
Murine norovirus 1	5/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5

* Batch was inoculated with each surrogate species.

The Murine norovirus 1 surrogate used for the present work is also sensitive to the effects of chlorine but survived a standard process for RTE lettuce. This finding is in agreement with previous research on the disinfection of leafy vegetables which has shown that chlorine-based sanitizers reduce, but not eliminate, viruses on the surface of fresh produce (Gulati et al, 2001; Nowak et al, 2011). However, Murine norovirus 1 was absent from all samples analysed after the initial contamination event. In contrast with *E. coli* O157:H7, the risk of virus transfer during processing of RTE lettuce appears to be low.

Bacillus atrophaeus spores and *Eimeria papillata* oocysts are highly resistant to chlorine and were expected to survive exposure to the concentration used in the process water. Results in Table show that *Bacillus atrophaeus* was recovered from each batch of lettuce, although the

number of positive samples declined after batch 6. *Eimeria papillata* oocysts were detected consistently in batches 2 and 3 but only sporadically thereafter. Hence, both surrogates survived and persisted in the RTE lettuce processing environment. However, processing successive batches likely led to a gradual reduction in the number of spores or oocysts available to re-contaminate lettuce.

Although the scientific literature contains occasional reference to the fate of various classes of human pathogens in fresh fruit and vegetable processing, there have been no attempts to compare the relative risk of survival and persistence in the processing environment. The present established that the comparatively resistant bacterial spores and protozoan oocysts survive exposure to chlorinated water and may re-contaminate successive batches of product. The persistence of *E. coli* O157:H7 was unexpected given the state of knowledge when the proposal was prepared. This problem has since received considerable interest from a research group led by Dr. Fernando Pérez-Rodríguez at the University of Cordoba, Spain, who have developed a model to predict the fate of the species in successive batches of processed lettuce. Dr. Pérez-Rodríguez kindly agreed to apply his model to simulate the risk of cross-contamination in successive batches of lettuce processed under the conditions used for the present work. Here we examined the effect of three initial *E. coli* O157:H7 populations the risk of contamination in 250 g bags of RTE lettuce processed after the introduction of a contaminated batch of lettuce (Figure 14). As expected, the number of contaminated bags of lettuce decreased with time but the results of this analysis showed that the proportion remain significant even when the initial level of contamination is low. The infectious dose for *E. coli* O157:H7 is believed to ≤10 cells (Tuttle et al, 1999). Hence the introduction of a single contaminated batch in the processing environment could significant amplify the threat to public health.

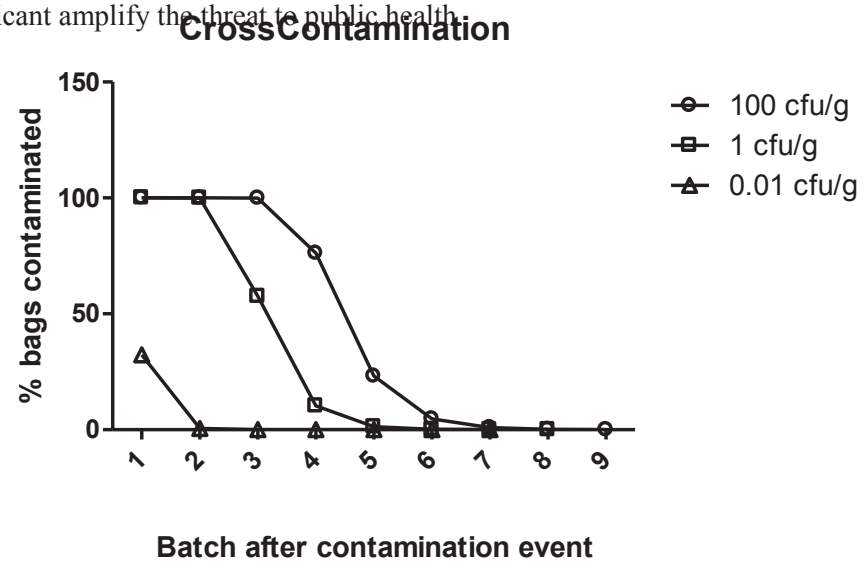


Figure 14: Predicted percentage of 250 g bags of lettuce contaminated with E. coli O157:H7 in successive batches of RTE lettuce. Results of predictions for three initial level of contamination are shown.

4.4 Fate of the surrogates in packaged lettuce

The surrogates were inoculated onto packaged RTE lettuce to establish their fate during refrigerated storage. *Bacillus atrophaeus* spores concentrations were unchanged in RTE Romaine

lettuce stored at 5 ºC and 12 ºC and there was no evidence of germination over a two week storage period. A similar result was found with *Eimeria papillata* oocysts, a species that is unable to replicate outside a host. Hence, populations of both *Bacillus atrophaeus* spores and *Eimeria papillata* oocysts remained stable in refrigerated RTE lettuce.

Noroviruses have been reported to survive in extra-intestinal environments. Experiments were carried out on stainless steel disks, soil, water and intact lettuce leaves to examine the stability of the surrogate strain selected for this work. Data summarized in Figure shows that Murine norovirus 1 was very stable in water. Infectious virus was recovered from stainless steel disks and in soil for 6-7 weeks after inoculation. In contrast, it was no longer detected after two weeks on raw lettuce. Reasons for the comparatively poor survival on lettuce tissues are unclear.

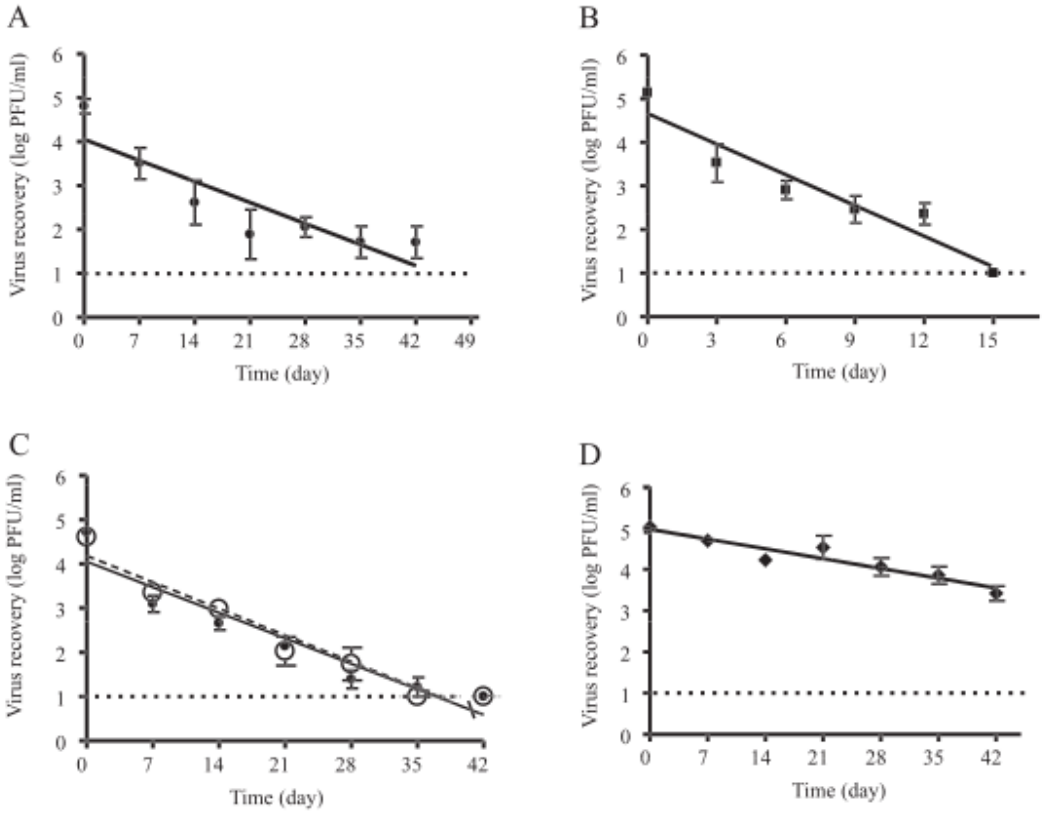


Figure 15. Survival of MNV-1 on or in (A) stainless steel disks, (B) lettuce, (C) soil, and (D) water at room temperature. The dashed line indicates the limit of detection of the plaque assay (10 PFU).

Survival of Murine norovirus 1was also examined in packaged RTE lettuce. The laboratory procedures used in these investigations were meant to simulate a commercial process, including a chlorine sanitation step at concentrations used in the processing trials described in section 4.3. Under these conditions, the virus was not detected in RTE lettuce by the plaque assay and intermittently using the more sensitive RT-PCR method after two days in the package. These findings indicate that stresses incurred during processing of RTE lettuce inactivate Murine norovirus 1.

4.4.1. Dynamic growth-death model for *E. coli* O157:H7.

Mechanical damage during harvesting and processing of RTE lettuce induce leakage of nutrients from plant cells in sufficient quantities to support cell division of Gram-negative species such as *E. coli* O157:H7 at growth permissive temperatures (Delaquis et al., 2007). Consequently, the ability to predict the fate of *E. coli* O157:H7 in packaged lettuce must account for periods where growth can occur. The minimum growth temperature for *E. coli* O157:H7 in vitro appears to be near 6ºC and growth in packaged leafy vegetables below this temperature is highly unlikely. However conflicting experimental outcomes have been reported when *E. coli* O157:H7 is introduced to leafy vegetable tissues stored below 6ºC. We therefore collected all available data on behaviour of this pathogen in RTE lettuce from published graphs by digitization, published tables or from personal communications, and data collected by project participants to develop a growth/death model.

The three-phase linear model of Buchanan et al. (1997) was used to fit log-transformed growth data. This model expresses the lag, exponential, and stationary phases as straight lines, where the growth rate is a constant during the exponential phase, but equal to zero during the lag and stationary phases. The equations for fitting with non-linear regression are given in the form used by GraphPad Prism 5.03 for Windows (GraphPad Software, San Diego, CA):

$$logNt= if(t<tL,logN0,if(t>=tm,logNm,logN0+R*(t-tL)))$$

$$R=(logNm-logN0)/(tm-tL)$$

where: Nt=cell number (cfu g-1), R=growth rate (log cfu g-1 h-1), tL=time delay before growth commences (lag), N0=cfu g-1 at t=0, Nm=Maximum Population Density (MPD; cfu g-1), tm=time at which the MPD is reached, and μ (the growth rate in units of ln cfu g-1 h-2) is R*2.303.

A log-linear model for die-off was fitted to the log transformed cell numbers by linear regression using GraphPad Prism 5.03. The datasets were normalized to N0=0, and the initial point was forced through (0,0) giving the following model:

$$logNt=-R*t$$

and k=R*2.303 is the die-off coefficient in units of ln cfu g-1 h-1.

The dynamic combined model for pathogen growth and death which excludes both the lag and the maximum population density is described by equation logNt=-R*t. The calculation of rate, which is conditionally defined as either growth or death, depending on the cut-off temperature (set at 5 ºC) is given by:

$$dNt/dt=Rate*Nt$$

$$Rate = if (T>5, Growth, Death)$$

$$Growth = (b*(T-Tmin))2$$

$$Death = -k$$

The combined growth-death model successfully predicted pathogen behaviour under both isothermal and non-isothermal conditions when compared to new published data (McKellar and Delaquis, 2011).

4.5 Overall Simulation Tool

The overall simulation tool is referred to as CanGRASP - Canadian GIS-based Risk Assessment, Simulation and Planning for Food Safety. Documentation for the Arena™ risk model is provided in Appendix 2. The current version of the model includes a predictive equation for *Escherichia coli* O157:H7. The interface serves as a portal to the simulation model and GIS, through a control box, and consists of three tabs (Figure 16).

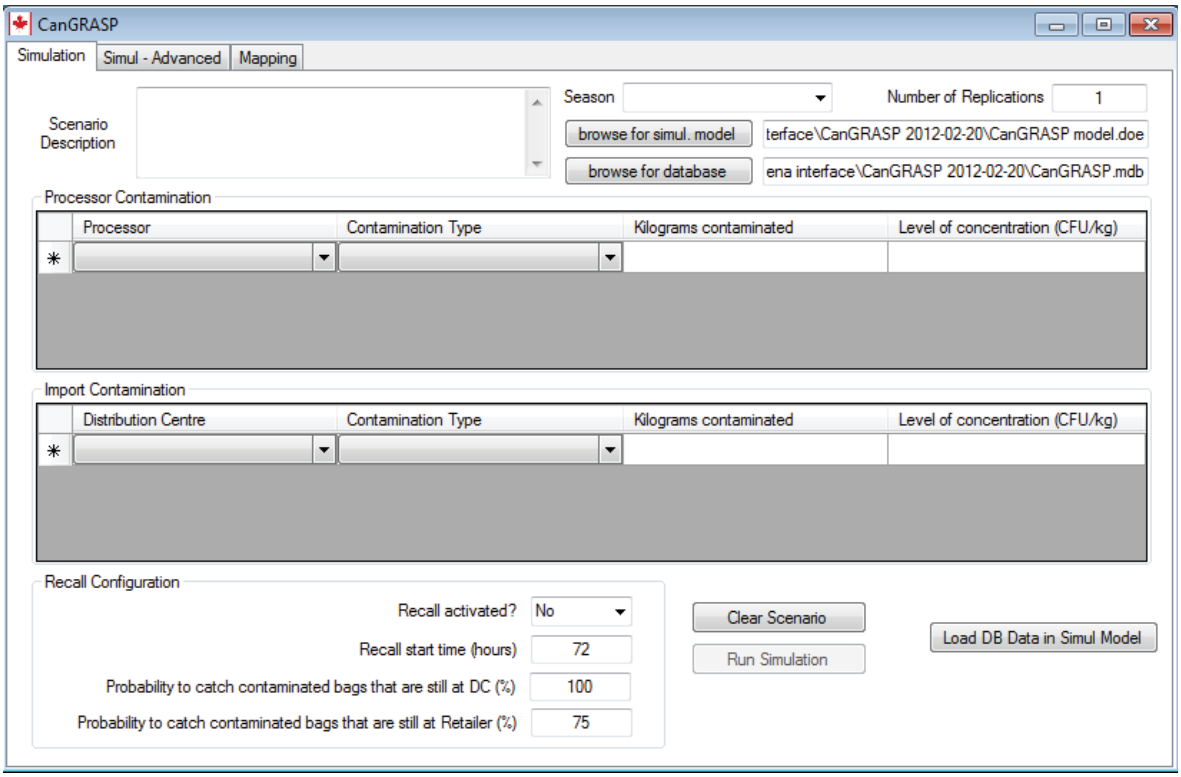


Figure 16: The CanGRASP User Interface (Simulation Tab Shown)

The Simulation tab allows a user to define the parameters for a defined contamination scenario. By clicking on the "Run Simulation" button on the Simulation tab, Arena simulates and tracks the contamination event in the food distribution system.

The CanGRASP user interface also includes an advanced simulation tab (Figure 17), in which the user may specify the probability of routing consecutive pallets/boxes at a location to the same destination and may add a specific temperature abuse at a particular step in the distribution system.

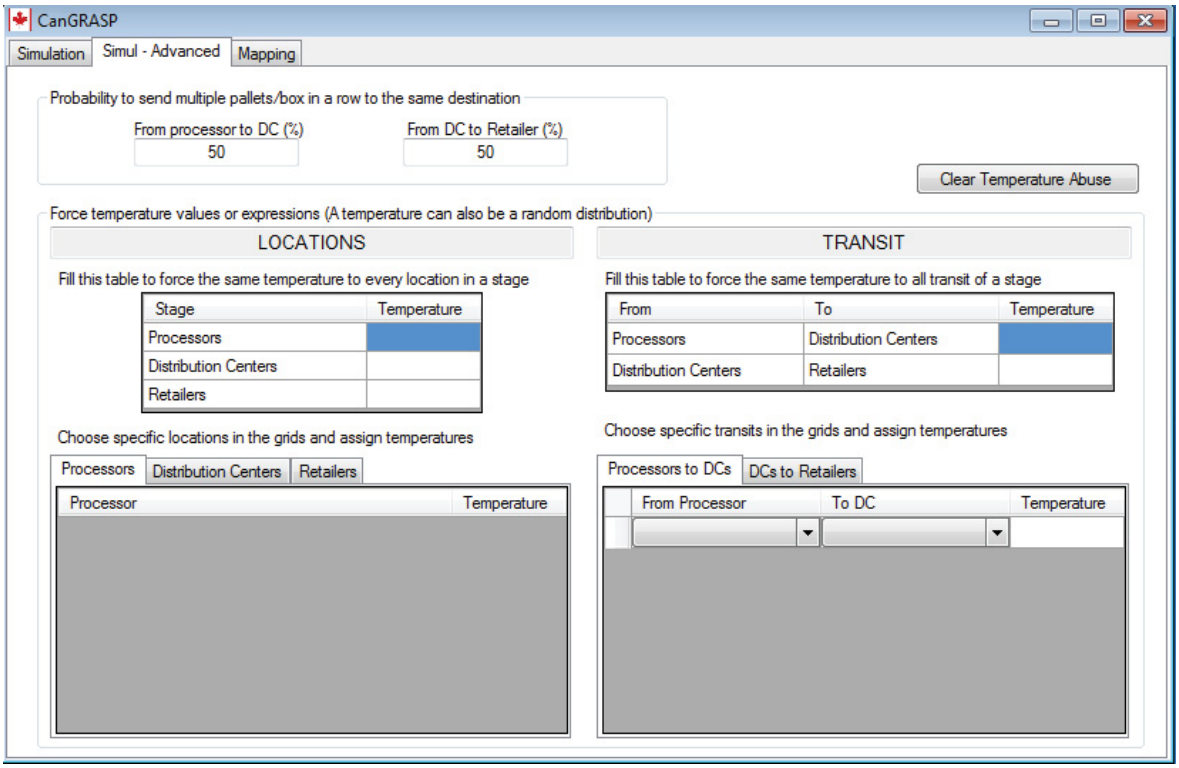


Figure 17: The CanGRASP User Interface (Advanced Simulation Tab Shown)

The parameters required for a simulation are set in the "Simulation" and "Simul – Advanced" tabs (Figures 6 and 7). These tabs allow the user to select several parameters:

- Season when contamination event occurs
- Number of times the simulation is to be replicated
- Stage where contamination enters the system: processor or distribution centre
- Type of contamination: virus, parasite, gram negative bacteria, bacteria spore
- Kilograms contaminated
- Level of concentration of the contaminant
- Recall configuration: recall activation, recall start time, probability to catch contaminated product at distribution centre, probability to catch contaminated product at retail
- Probability to send multiple pallets/box in a row to the same destination: from processor to distribution centre, from distribution centre to retail store
- Specific temperature or temperature distribution for a location: applied to every location in a stage, or applied to a specific location
- Specific temperature for a transit step: applied to all transits in a stage, or applied to a specific transit.

Combining these parameters with the other information that Arena reads directly from the Canadian retail distribution system geodatabase (GEODB_CAN.mdb), a simulation is run. Then the simulation results are analyzed and mapped using GIS. The "Mapping" tab (Figure 18) of the CanGRASP interface accesses CanGRASP tools in ArcGIS that automatically analyze the

simulation results, dynamically map the spatial distribution of contaminated product over time, and quantify its public health impact.

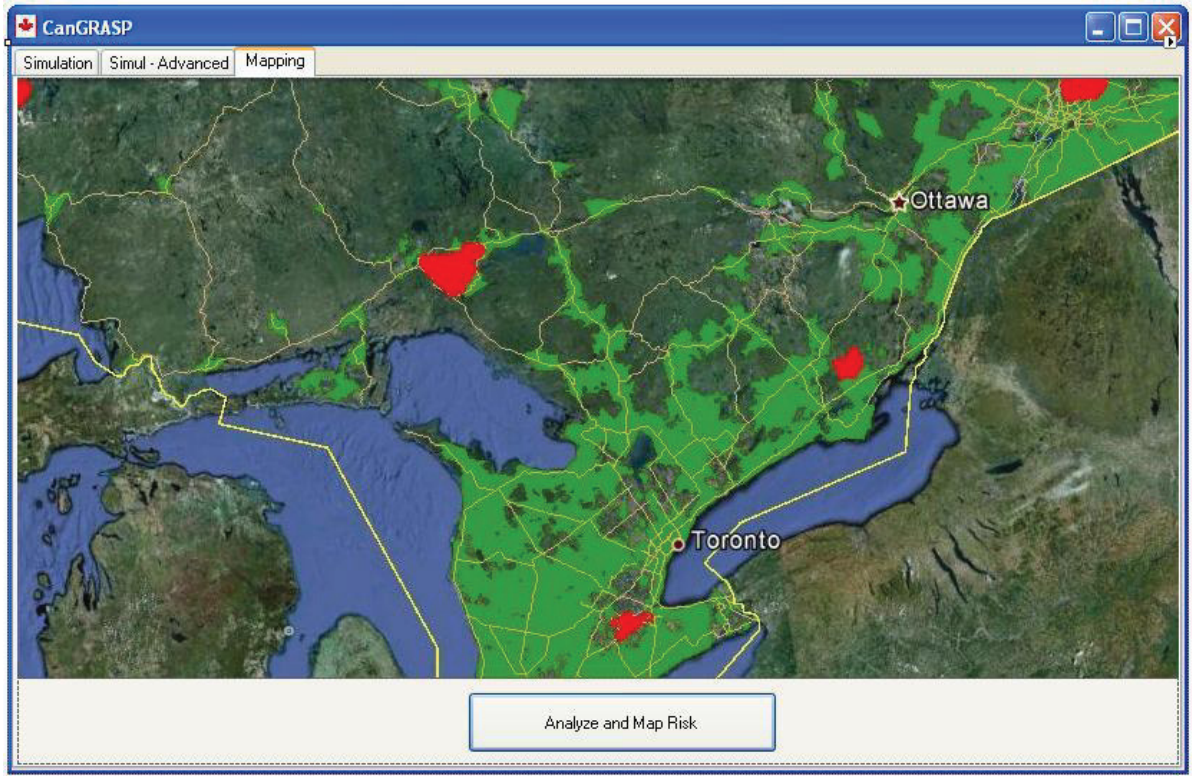


Figure 18: The CanGRASP User Interface (Mapping Tab Shown)

The following sub-sections describe the tool's input and output data. The input data (details on the contamination scenario) and the output data (location of contaminated product on a daily basis for the duration of the contamination scenario) are stored in separate tables created in the CanGRASP Output geodatabase saved on the shared drive in St-Hyacinthe (qcsthyafil1\common\Recherche\VilleneuveSe\ Géomatique\CanGRASP\Simulation Outputs).

4.5.1 Scenario

The Scenario table is filled in by the CanGRASP integrated simulation tool based on the parameters selected or entered in the "Simulation" and "Simul – Advanced" tabs of the interface. The table includes the values of the attributes used by CanGRASP to assess food safety risks in a Canadian retail distribution system. A separate Scenario table with unique name (e.g. Scenario_PrTA120214_3) is created for each simulation. The table's name matches the unique name of the simulation results table (e.g. Simulation_Result_PrTA120214_3) and the mapping results table (e.g. Mapping_Result_PrTA120214_3). The nomenclature used to define a unique name for each simulation includes four parts: 1) the source of contaminated product (Pr=Domestic processor or Dc=Packaged product imported by distribution centre); 2) the selection of a specific temperature abuse as part of the scenario (TA); 3) the date the simulation was run (YYMMDD): and 4) the rank of the simulation when several similar simulations are run on the same date (_#). The fields included in the Scenario table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Scenario_Desc	String	Description of scenario including whether or not temperature abuse occurred and, when occurring, how much and where it occurred
Season	String	Season when contamination incident occurs
No_of_Reps	Integer	Number of replications of simulation
ID	Integer	ID of processor or distribution centre where contamination incident is initiated, or ID of processor, distribution centre, retail store or transit step where temperature abuse occurs
Contam_Type	String	Contamination type (virus, parasites, gram negative bacteria, spores, etc.)
Vol_Contam	Double	Quantity of contaminated product (kg)
Conc_Contam	Double	Level of concentration in contaminated product (CFU/kg)
T_Abuse	Double	Forced temperature used during simulation (°C)
Recall	String	Recall activated? (Yes or No)
Recall_Start	Double	Time when the recall is started (h)
Prob_Stop_DC	Double	Probability to catch contaminated packages that are still at DC (%) (e.g. effectiveness of the recall at the distribution centre)
Prob_Stop_RS	Double	Probability to catch contaminated packages that are still at RS (%) (e.g. effectiveness of recall at the retail store)
Prob_sub_Pro_DC	Double	Probability that processor will send multiple pallets/box in a row to the same distribution centre (%)
Prob_sub_DC_RS	Double	Probability that distribution centre will send multiple pallets/box in a row to the same retail store (%)

4.5.2 Simulation_Result

The Simulation_Result table is created in the output database. A separate table is created for each simulation executed with the CanGRASP tool. Each table has a unique name (e.g. Simulation_Result_PrTA120214_3) that matches the unique name of the table describing the simulated scenario (e.g. Scenario_PrTA120214_3). The table includes the values of the attributes used by ArcGIS to calculate the spatial distribution of contaminated product over time and quantify its public health impact. The fields included in the Simulation_Result table are:

Attribute name	Data type	Description
BagID	Integer	Identification number given to each package of fresh-cut lettuce produced by a processor during a simulation
BatchID	Integer	Identification number given to each batch of fresh-cut lettuce packaged by a processor during a simulation

Attribute name	Data type	Description
BoxID	Integer	Identification number given to each box of packaged fresh-cut lettuce assembled by processor during a simulation
PalletID	Integer	Identification number given to each pallet of boxed fresh-cut lettuce assembled by a processor during a simulation
ProcessorID	Integer	Identification number used in Arena tool for each processor (= Pro_Arena_ID in GEODB_CAN.mdb)
WarehouseID	Integer	Identification number used in Arena tool for each distribution centre (= DC_Arena_ID in GEODB_CAN.mdb)
RetailerID	Integer	Identification number used in Arena tool for each retail store (= Retail_Arena_ID in GEODB_CAN.mdb)
ReplicationID	Integer	Identification number given to each replication of a simulation
BagVolume_kg	Double	Mass of fresh-cut lettuce in a package (kg)
ArrivalTime	Integer	Time when package was filled at processor (e.g. Initial time) (h)
CycleTime	Double	Time when package was placed in retail display case (e.g. Final time) (h)
Recalled	Integer	Recall status of lettuce pack (0=Pack which travelled the entire supply chain; 1=Pack recalled at distribution centre; 2=Pack recalled at retail store)
ContaminationType	Integer	Type of contamination selected for the simulation (1=Viruses; 2=Parasites; 3=Gram negative bacteria; 4=Bacteria spores)
InitialConcentration_LOG_CFU_perBag	Double	Initial concentration of the contamination after packaging at processor (CFU/pack)
TimeProcessor_hrs	Double	Time packaged lettuce spends in processor's storage prior to shipment to distribution centre (h)
TemperatureProcessor	Double	Temperature of packaged lettuce during storage at processor (°C)
ContaminationProcessor_LOG_CFU_perBag	Double	Concentration of the contamination after storage at the processor (CFU/pack)
TimeTransit_P_W_hrs	Double	Time packaged lettuce spends in transit between processor and distribution centre (h)
TemperatureTransit_P_W	Double	Temperature of packaged lettuce during transit between processor and distribution centre (°C)
ContaminationTransit_P_W_LOG_CFU_perBag	Double	Concentration of the contamination after transit between processor and distribution centre (CFU/pack)
TimeWholesaler_hrs	Double	Time packaged lettuce spends in storage at distribution centre prior to delivery to retail store (h)

Attribute name	Data type	Description
TemperatureWholesaler	Double	Temperature of packaged lettuce during storage at distribution centre (°C)
ContaminationWholesaler_LOG_CFU_perBag	Double	Concentration of the contamination after storage at the distribution centre (CFU/pack)
TimeTransit_W_R_hrs	Double	Time packaged lettuce spends in transit between distribution centre and retail store (h)
TemperatureTransit_W_R	Double	Temperature of packaged lettuce during transit between distribution centre and retail store (°C)
ContaminationTransit_W_R_LOG_CFU_perBag	Double	Concentration of the contamination after transit between distribution centre and retail store (CFU/pack)
TimeRetailer_hrs	Double	Time packaged lettuce spends in retail store walk-in cooler prior to display in store (h)
TemperatureRetailer	Double	Temperature of packaged lettuce during storage in retail store walk-in cooler (°C)
ContaminationRetailer_LOG_CFU_perBag	Double	Concentration of the contamination just prior to retail display (CFU/pack)

4.5.3 Mapping_Result

The CanGRASP mapping tools allow results to be presented in table, map, image or video format. The Simulation_Analysis table is created in the output database by CanGRASP tools developed in ArcGIS. The table includes the risk index values for retail stores having received contaminated product and the population that is potentially at risk of purchasing contaminated product. A separate table with unique name is created for each simulation scenario (e.g. Simulation_Analysis_PrTA120214_3). The table's name matches the unique name of the table describing the simulated scenario (e.g. Scenario_PrTA120214_3). The fields included in the Simulation_Analysis table are:

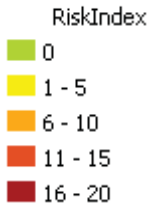
Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Retail_ID	Integer	ID of retail stores having displayed contaminated packages of lettuce
DC_ID	Integer	ID of distribution centre having supplied the contaminated packages of lettuce
Processor_ID	Integer	ID of processor associated with the contaminated packages of lettuce
ReplicationID	Integer	Identification number given to each replication of a simulation
Date_Model	Date	Date specified for start of contamination event
No_day	Integer	Number of days between start of contamination event and time when contaminated packages of lettuce are placed in the retail store's display

Attribute name	Data type	Description
Frequency	Integer	Number of contaminated packages of lettuce displayed in retail store on day "No_day" of contamination event
Mean_ContaminationLevel	Double	Average concentration of the contamination in the contaminated packages displayed in one day (CFU/pack)
Sum_Prevalence	Double	Number of contaminated packages of lettuce displayed in retail store on day "No_day" divided by the quantity of packaged lettuce received daily by each retail store, within a banner. When there is no contamination the value is 0 and in the unlikely event that all the product is contaminated the value is 1.
Population_Affected	Double	Affected population calculated based on the population density in a service area covering a 5 km distance (in urban areas) or a 20 min drive (in rural regions) from each store using the road network
Risk_Index	Integer	Gauge of potential relative risk associated with the presence of contaminated packages in the retail store's display

The Mapping_Result maps are created by the CanGRASP tools developed in ArcGIS. These maps present the zones where consumers are at risk of purchasing contaminated product over time. These zones are color coded according to a dynamic risk index, to identify those areas that are at greatest immediate risk as time progresses (for each day), and to estimate the population affected by these contamination events.

Each map includes several information layers such as main roads, provincial boundaries, lakes and water ways, etc. In addition to this data, each map presents a layer showing the influence zones of retail stores. These zones are color coded based on a risk index. The scale consists of five color levels indicating the potential relative risk associated with a contamination scenario:

- *Green*: no risk
- *Yellow*: low risk
- *Orange*: moderate risk
- *Red*: high risk
- *Dark Red*: severe risk



By analyzing the simulation results, CanGrasp tools create maps presenting the daily spread of contaminated product across the food distribution network and the risk level associated with each retail outlet. Figure 19 provides an example of zones in British Columbia where consumers are at risk of purchasing contaminated product over time for a hypothetical contamination scenario. These maps can be exported to video or image format.

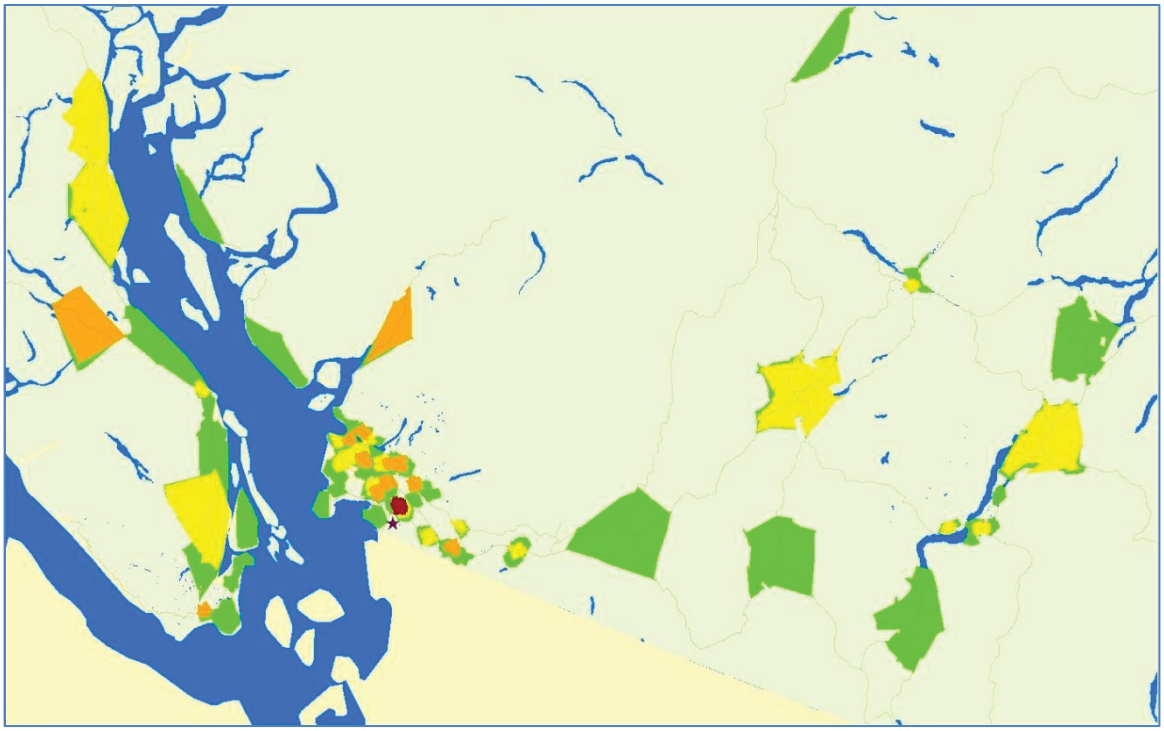


Figure 19. Example of a map created with the "Mapping Result" tool in CanGRASP.

4.2 Example scenario

The following contamination scenario was constructed to illustrate the predictive and mapping capabilities implicit to the CanGRASP tool. During summer, 3600 kg of lettuce packaged by a processor in the province of Quebec is contaminated with 100 cfu/g of *E. coli* O157:H7. The processor supplies packaged lettuce to 7 of the distribution centres in the database. The 7 distribution centres are from two separate retail chains and supply product to a total of 1227 retail stores located in Ontario, Quebec and Atlantic Canada. During the simulated contamination event, contaminated product was distributed to 5 of the 7 distribution centres. The 5 distribution centres supplied contaminated product to 294 retail stores over a 12-day period. The initial concentration of the packaged lettuce at the processor was 4.4 ± 0.1 log cfu/pack with minimum and maximum concentrations respectively being 4.1 and 4.7 log cfu/pack. The average concentration of *E. coli* O157:H7 in the contaminated packs at the end of each step in the supply chain is shown in Table 5. The range of time and temperature the contaminated product experiences in each step of the supply chain during this simulated contamination event is presented in Table 6. The number of stores displaying contaminated product during each day of the simulation contamination event are summarized in Table 7.

Table 5. Range of E. coli *O157:H7 contamination in packs at each step of the supply chain during this simulated contamination event.*

Step	**Concentration of contamination (log cfu/pack)**		
	Avg. ± Std. dev.	**Min**	**Max**
Processor storage	4.5 ± 0.3	2.0	5.2
Transportation from processor to DC	4.5 ± 0.3	2.0	5.7
Distribution centre (DC) storage	4.4 ± 0.4	2.0	5.6
Transportation from DC to RS	4.4 ± 0.4	1.9	6.0
Retail store (RS) storage	4.4 ± 0.6	-0.7	8.8

Table 6. Range of storage and transit times and product temperatures for all components of the supply chain.

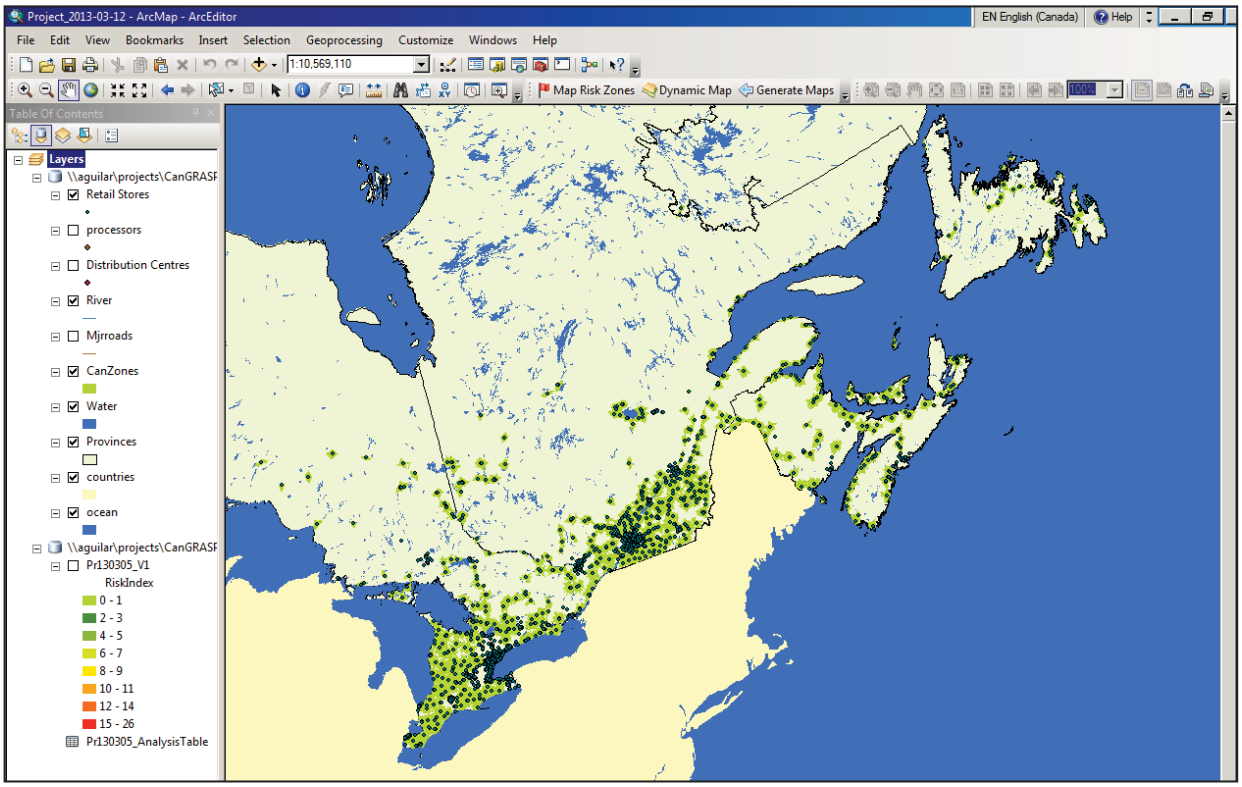
Step	**Time (h)**			**Temperature (°C)**		
	Avg. ± Std. dev.	**Min**	**Max**	**Avg. ± Std. dev.**	**Min**	**Max**
Processor storage	38 ± 14	10	56	5.3 ± 0.8	3.4	7.2
Transportation from processor to DC	26 ± 23	4	68	4.6 ± 1.3	1.4	6.6
Distribution centre (DC) storage	23 ± 20	10	61	3.0 ± 1.0	-0.3	8.0
Transportation from DC to RS	12 ± 3	8	29	5.8 ± 2.5	-3.3	13.7
Retail (RS) storage	36 ± 45	0	174	4.7 ± 1.6	-0.7	10.2

Table 7. Spread of predicted contamination event over time

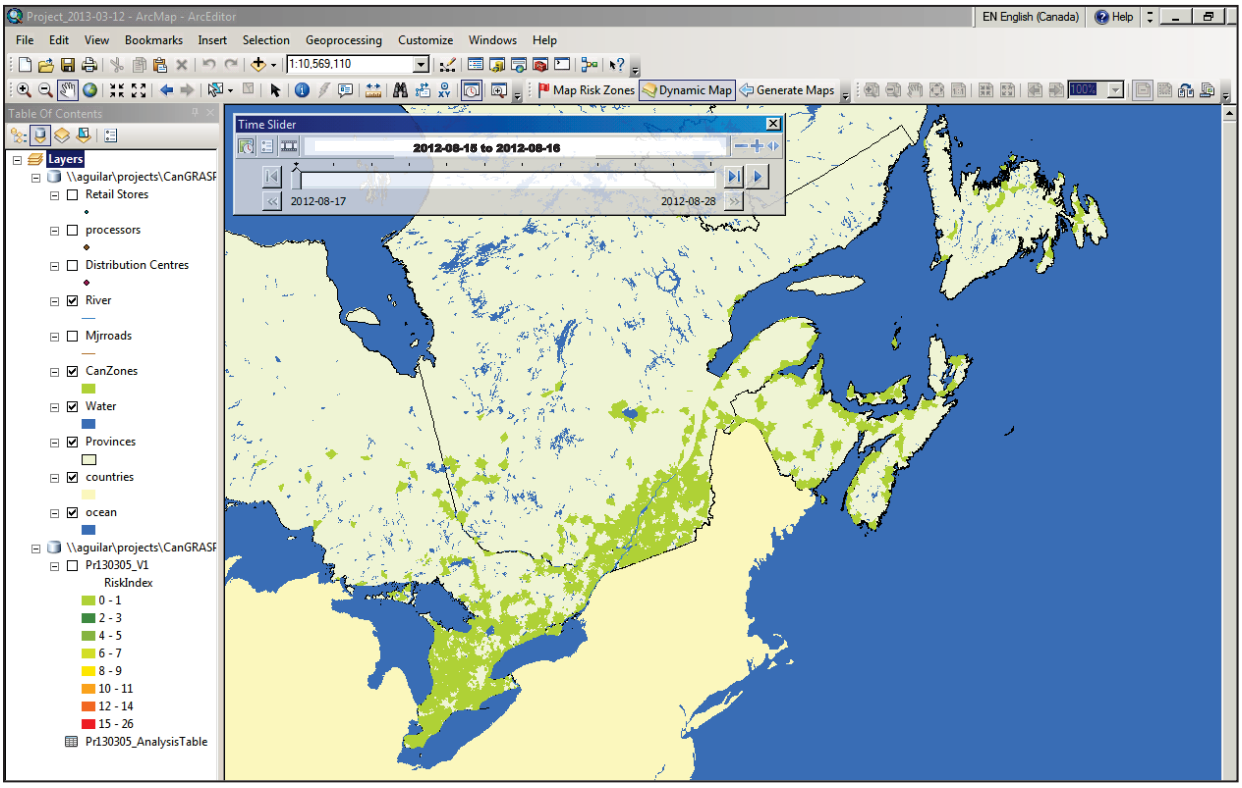
Day after event	**No. of stores displaying contaminated packs**	**Population at risk of purchasing contaminated packs**	**Contamination per store (log cfu/pack)**		**Average prevalence (%)**
			Avg.	**Max**	
1	0	0	0.0	0.0	0.0
2	0	0	0.0	0.0	0.0
3	38	3,033,603	4.6	4.9	13.2
4	117	7,017,816	4.5	5.0	15.4
5	137	7,149,489	4.5	5.1	15.0
6	134	7,317,927	4.6	5.3	17.3
7	95	4,695,597	4.7	5.6	16.6
8	67	3,913,125	4.9	5.8	13.4
9	43	3,014,743	4.9	5.5	14.3
10	43	1,933,815	6.8	8.4	11.1
11	35	1,565,699	5.3	6.4	12.7
12	11	751,069	5.1	5.9	15.0
13	7	374,876	6.1	6.7	12.2
14	1	42,842	5.7	5.7	4.9
15	0	0	0.0	0.0	0.0

The model predicted a fourteen-day *E. coli* 0157:H7 outbreak. By analyzing the prediction model results using GIS, the daily spread of contaminated product across the food distribution network and the risk level for each retail outlet can be quickly calculated (Table 3). On Day 0, 100% of the contaminated packs were shipped from Processor A to Distribution Centres B and C. Retail Chain B received 60.5% of contaminated packs while Retail Chain C received 39.5%. Contaminated packs remained on the retail outlet shelves from Day 3 to Day 14. Average prevalence of contaminated packs in retail outlets involved varied between 4.9 to 17.3%, depending of the day. In the next step estimates of the level of risk and the portion of population associated with the contamination event were calculated and the results were displayed in time using the mapping tool within CanGRASP. The timed series below shows the screen display the risk associated with specific retail zones in the geographic area affected by the contamination event.

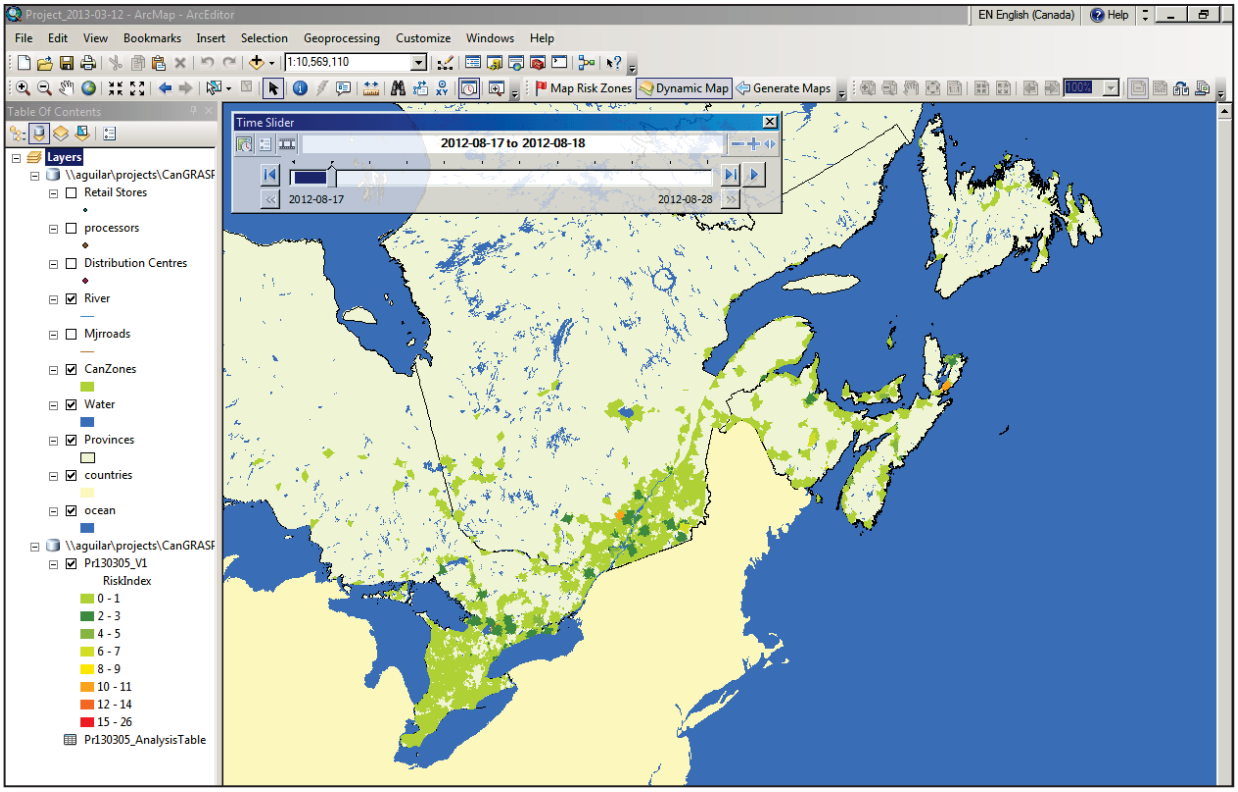
Retail outlets potentially affected by the contamination event and their zones of influence are displayed on the map. The zones of influence are green as the risk is 0.



Day 1: None of the outlets have received contaminated product



Day 2: Some contaminated products have reached retail, risk index increases.



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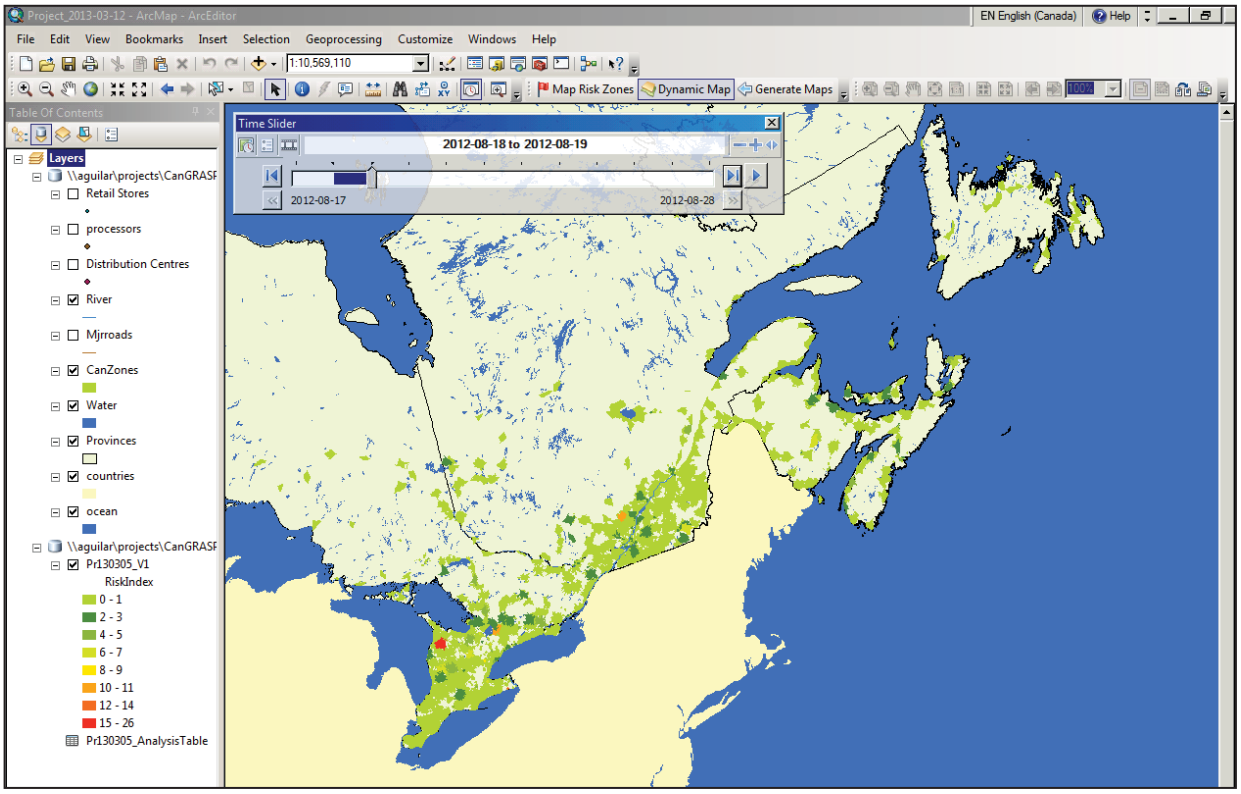
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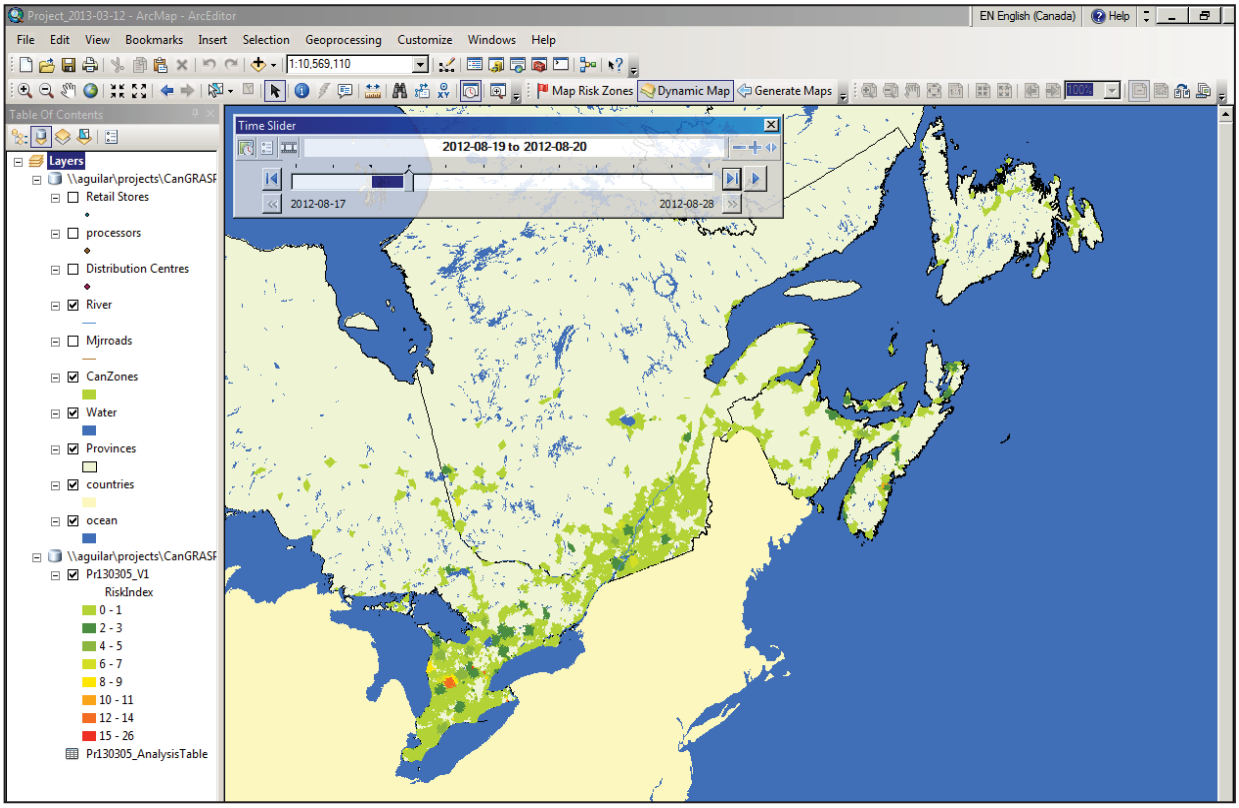
Day 4: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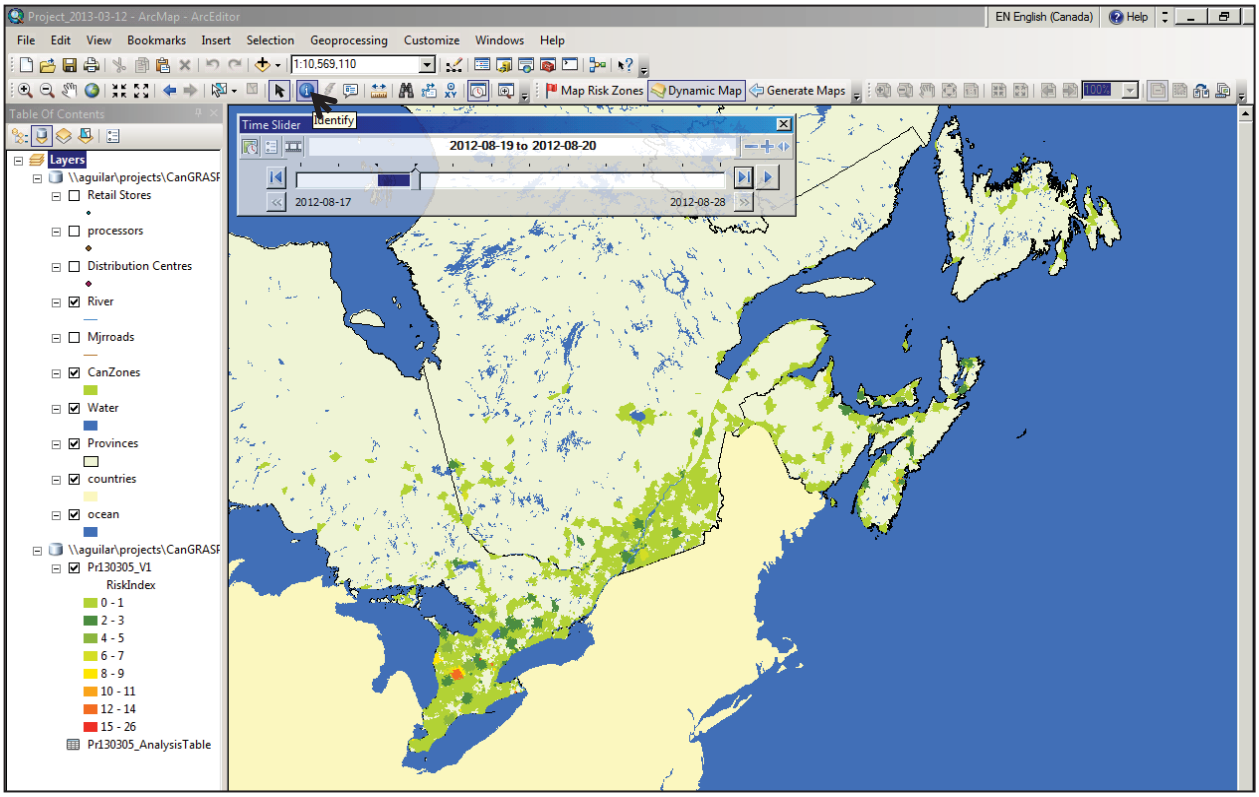
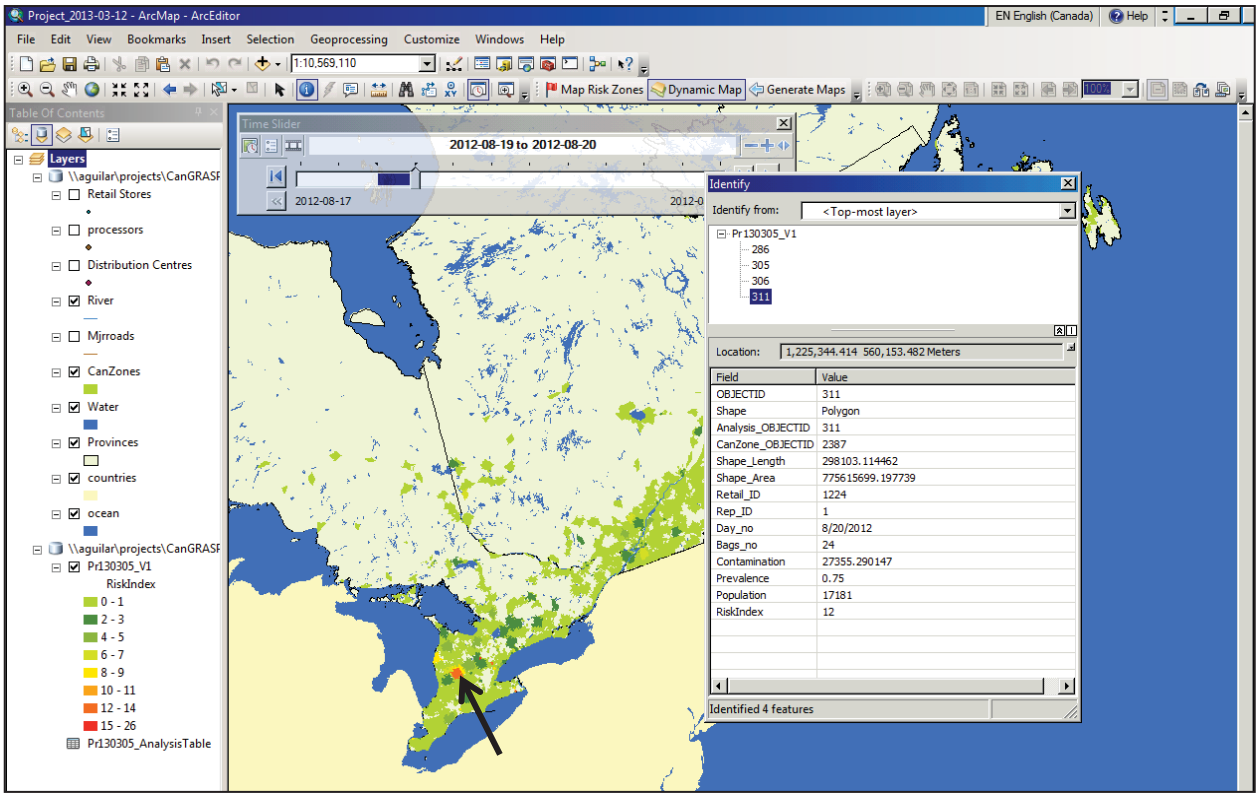
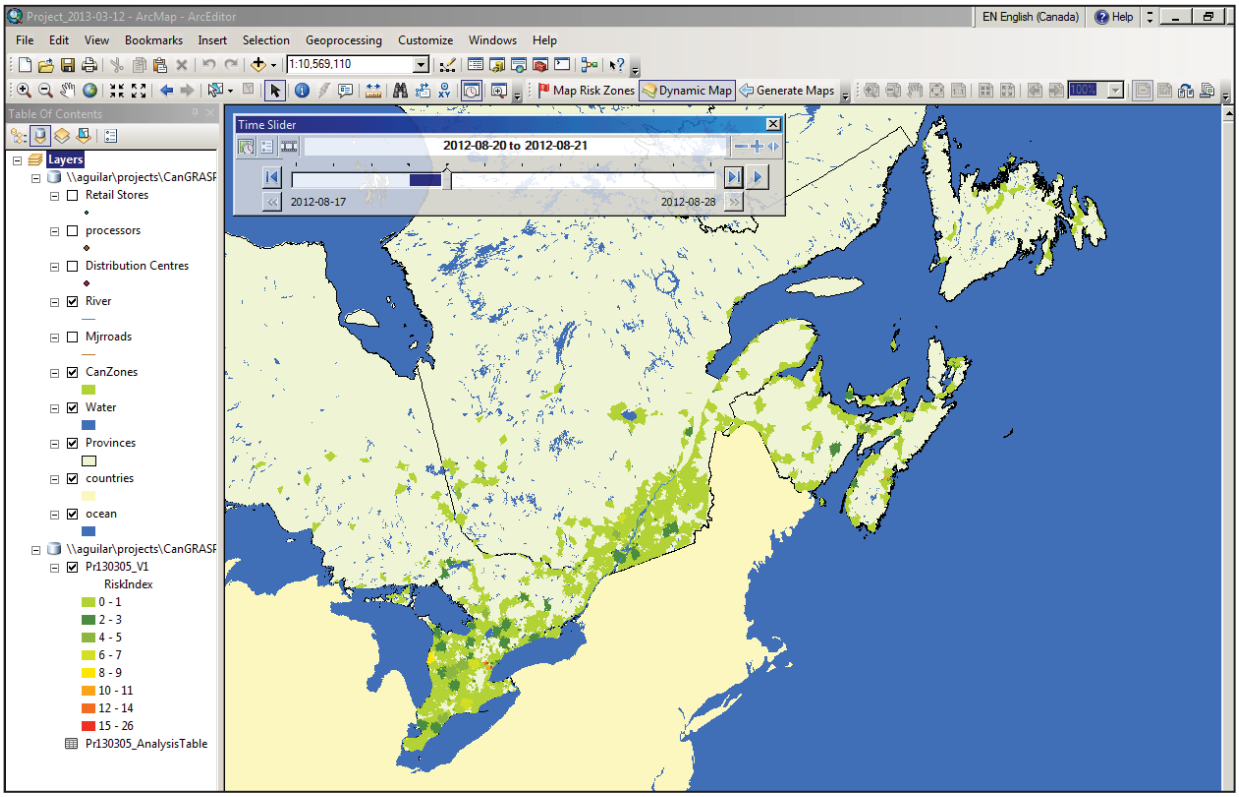
Day 5:



Day 6: Call out box showing information about a high risk retail zone.



Day 7: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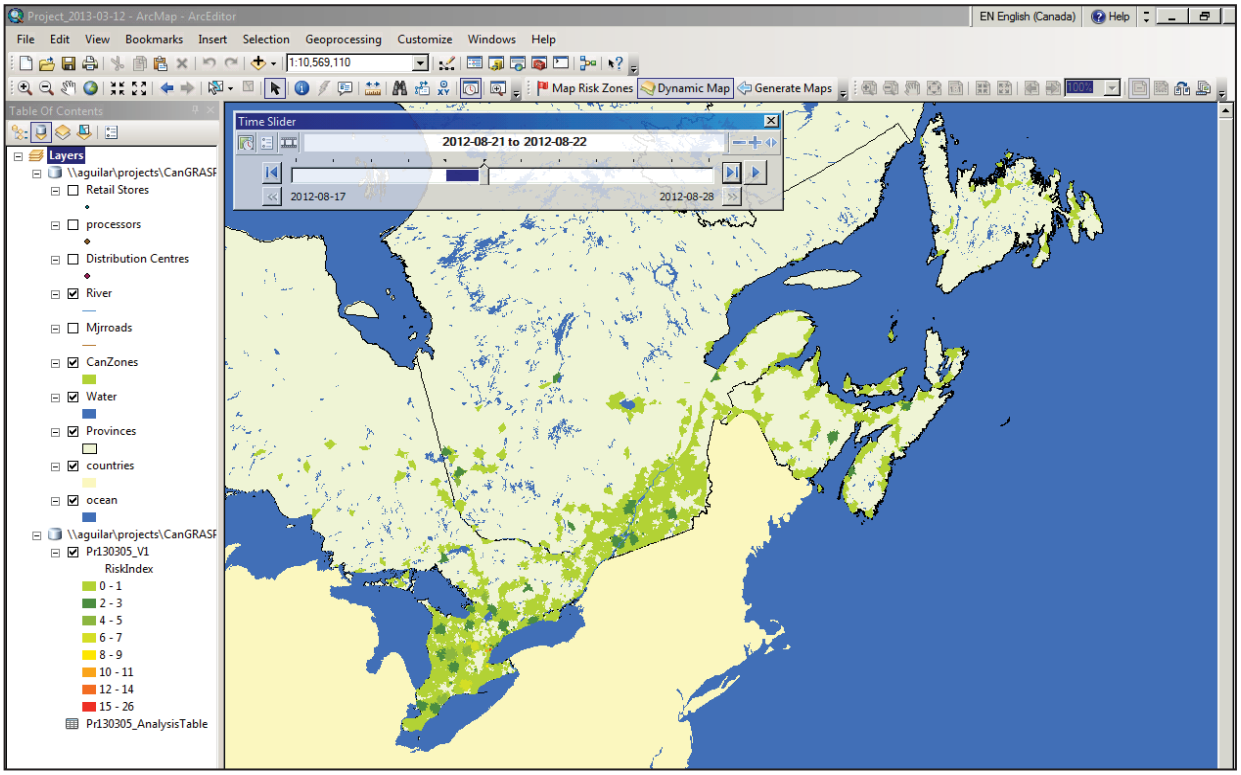
Day 8: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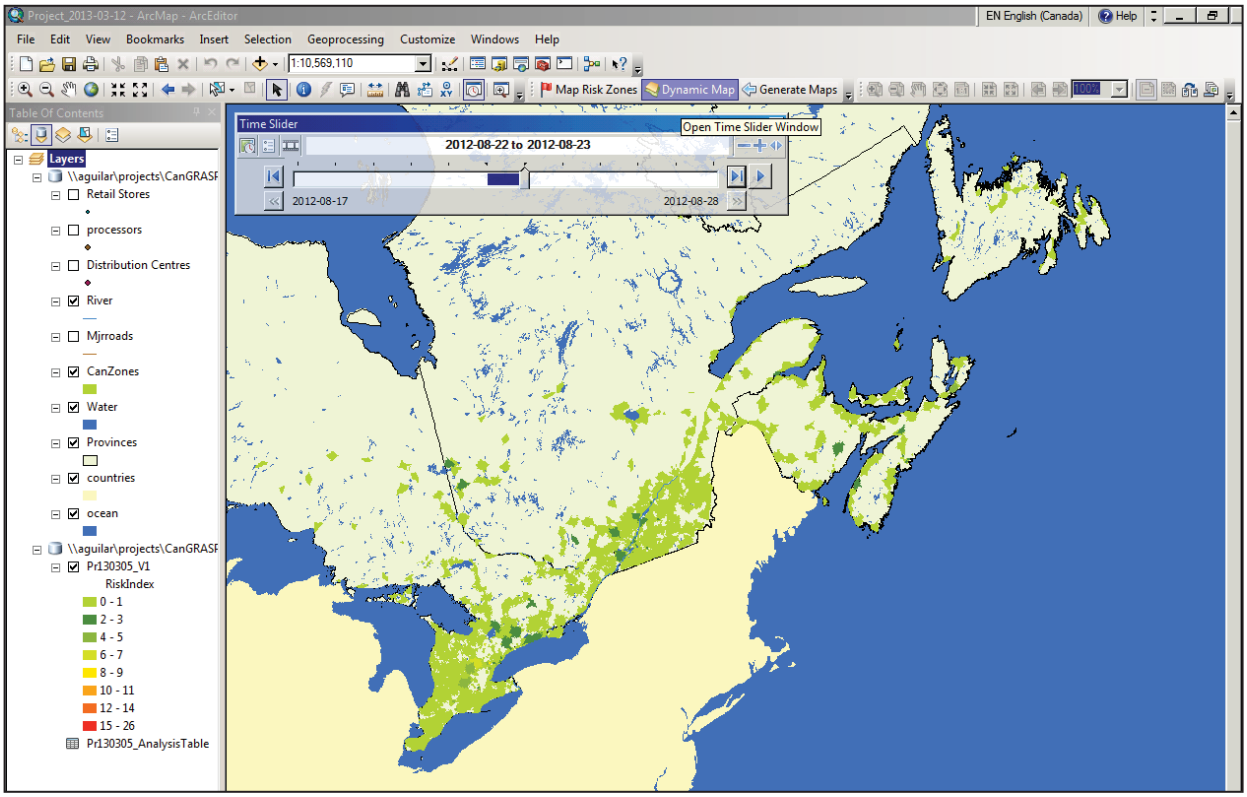
Day 9: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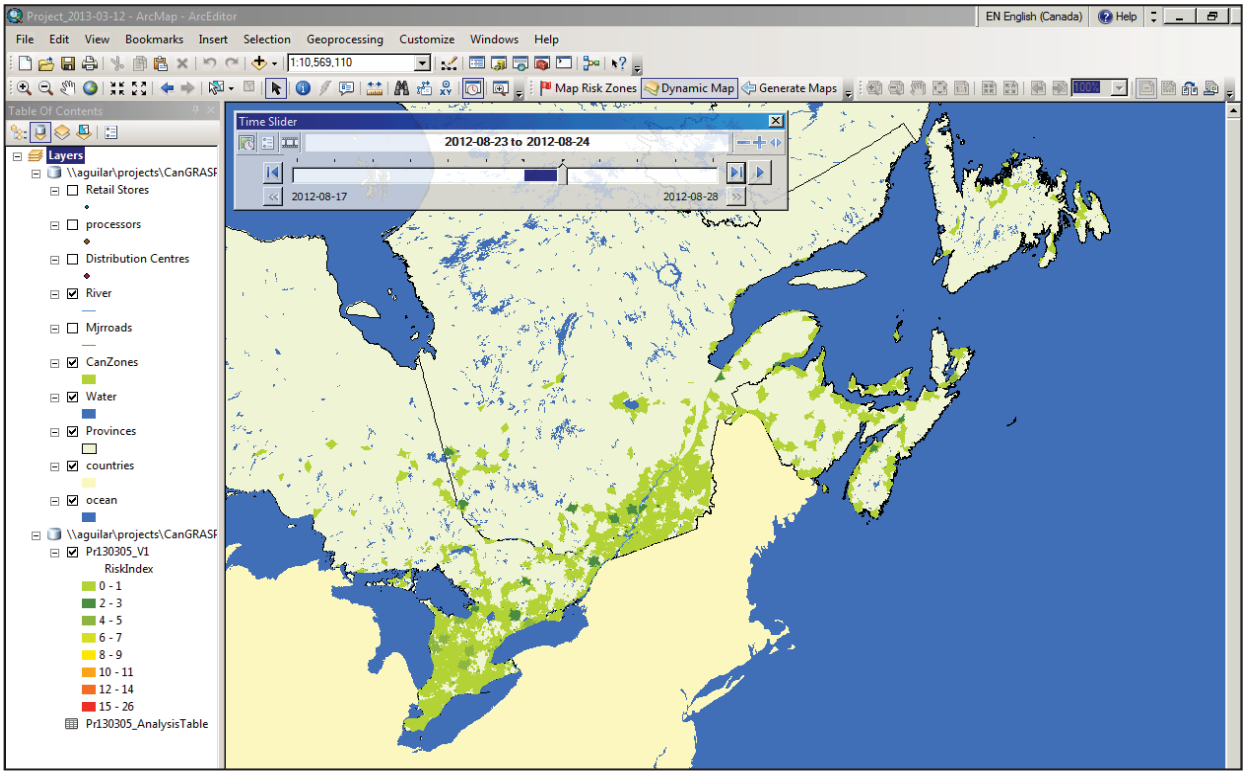
Day10: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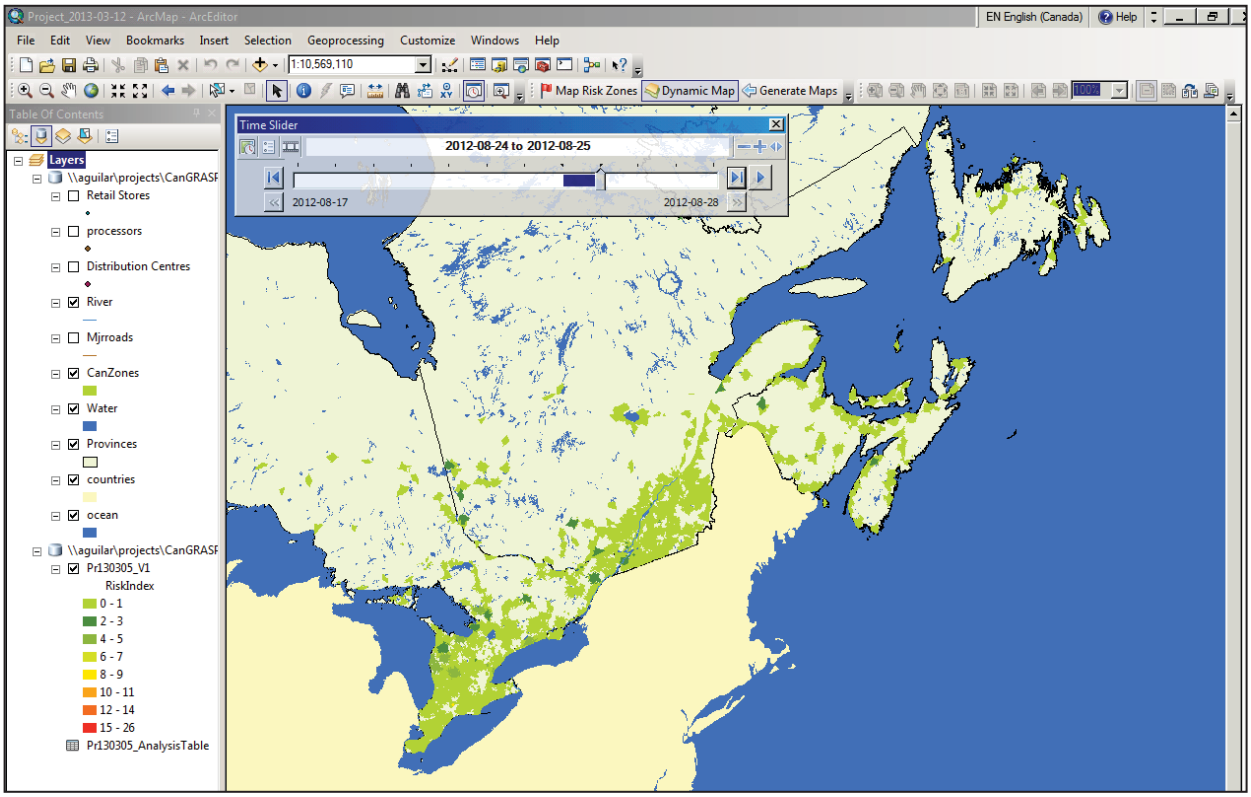
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Pr130305_V1
RiskIndex
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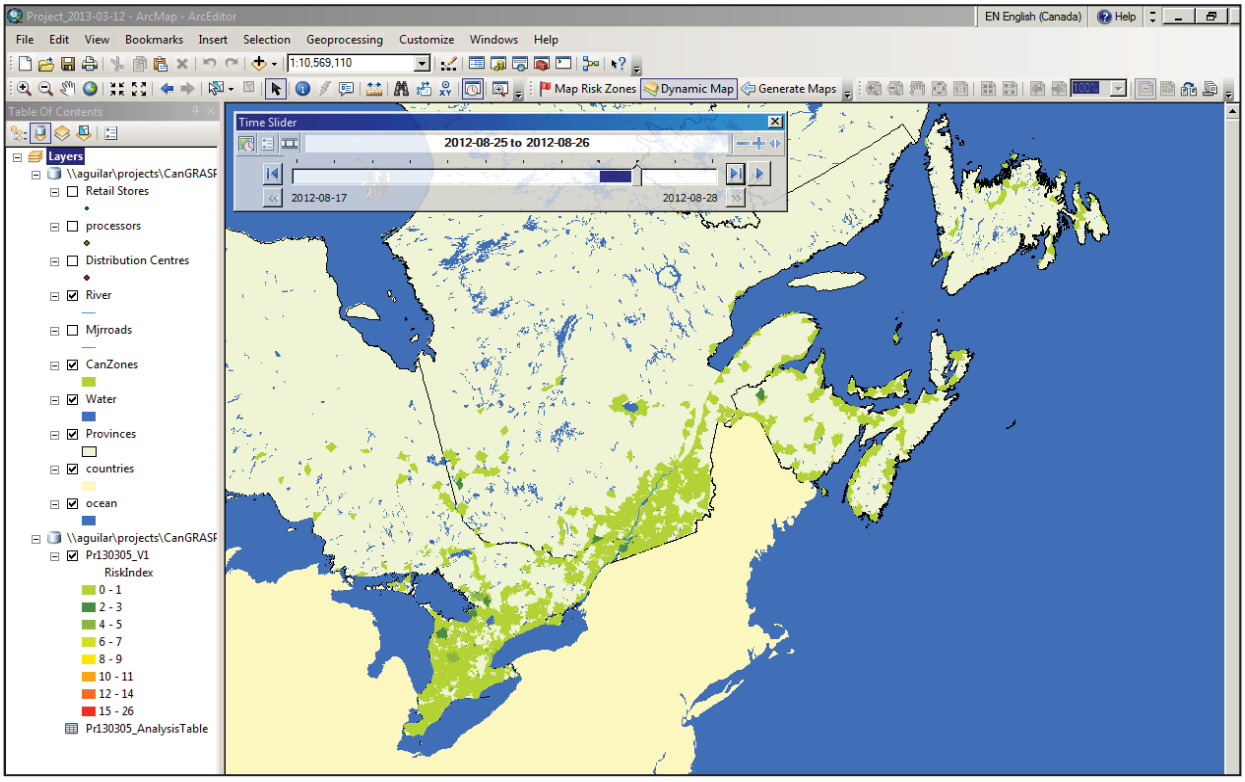
12 - 14
15 - 26
Pr130305_AnalysisTable
Time Slider
2012-08-24 to 2012-08-25
2012-08-17
2012-08-28

Day 12:


Project_2013-03-12 - ArcMap - ArcEditor
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Map Risk Zones
Dynamic Map
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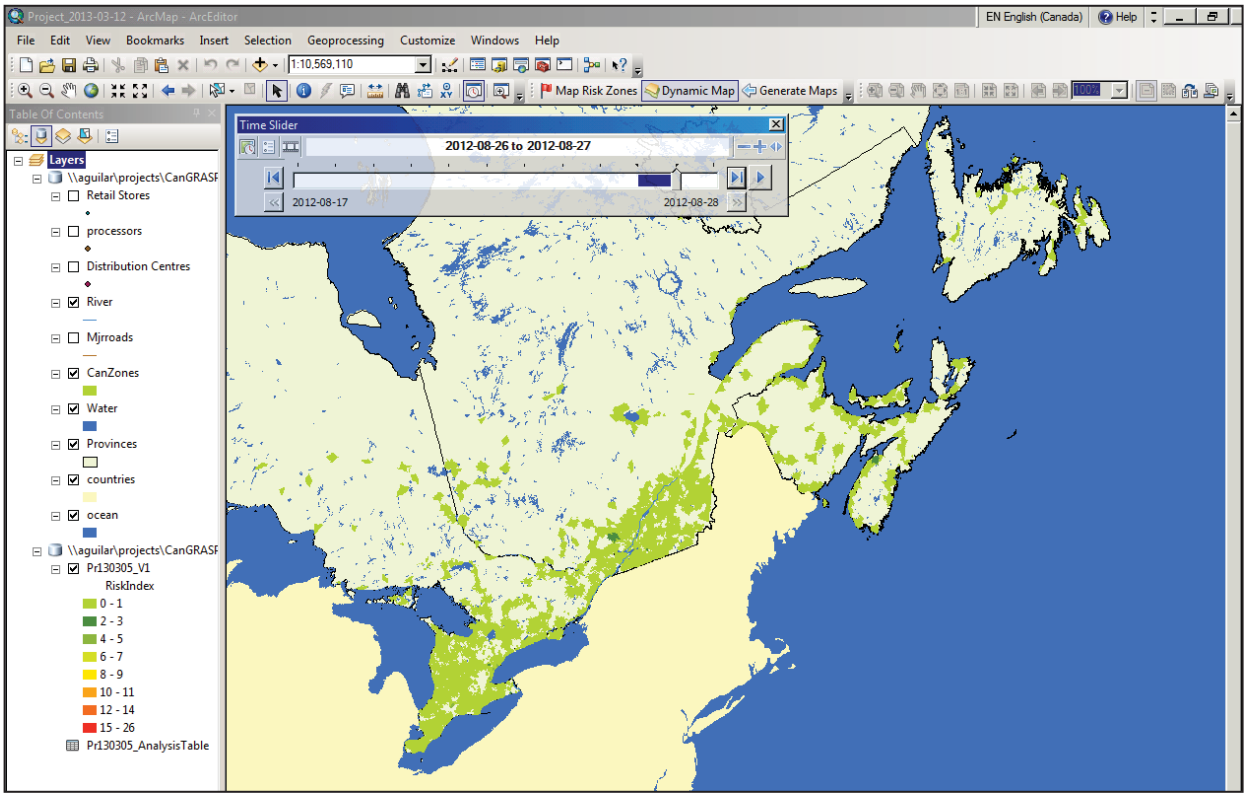
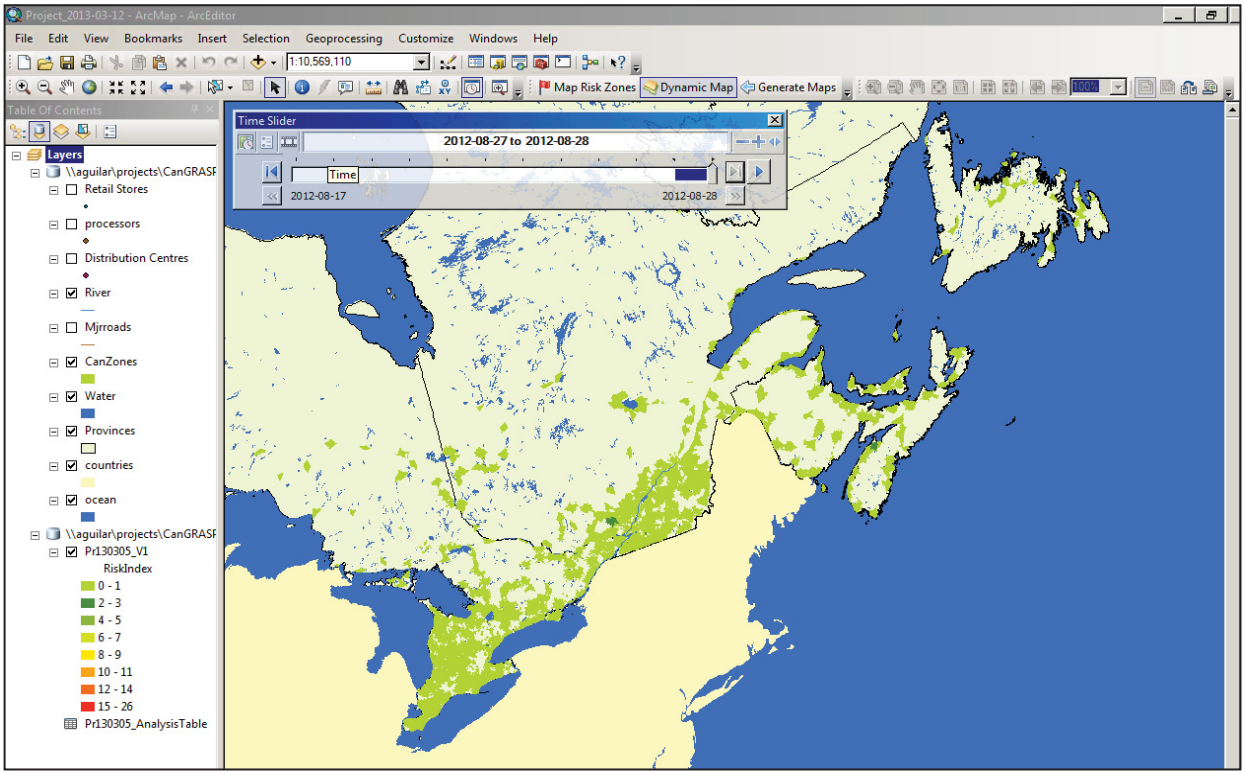
Pr130305_AnalysisTable
Time Slider
2012-08-25 to 2012-08-26
2012-08-17
2012-08-28

Day 13:



Day 14: Last day with contaminated product on the retail shelves.



The risk illustrated in these figures is one of the analyses that can be conducted for such a scenario. However, other analyses would be possible, resulting in different maps. For example, it would have been possible to compare the spread of contaminated packs in different retail chains and to compare, for each chain, the spread of contaminated product and the population affected. Examples of the types of additional queries that could be considered include:

- Time based query: as an example if a contamination event occurs in a processing plant at location A at time T1, using this tool, the spread of the contaminated product across the food distribution network can be quickly predicted. Then, it is possible to answer such questions: how widely distributed the product will be at T2, what level of contamination can be expected at T3 when conditions favouring growth are present, and what the public health impact might be at T4.
- Distance based query: For instance, distribution centre A servicing a territory within close proximity could be compared to distribution centre B servicing a larger more remote territory. If contaminated product were delivered to both distribution centres, it would be possible to compare the risks involved in both situations as a result of differences in transit times and possibly longer exposure to higher temperatures.
- Season based query: A scenario involving contaminated product arriving at distribution centre A during the summer could be compared to the same scenario occurring during the other seasons e.g. the winter. Since warmer product temperatures expected during summer months could result in higher levels of contamination in the product, the risks associated with seasonal differences in product temperatures could be compared.
- Territory based query: as an instance distribution centre A servicing a smaller densely populated region could be compared to distribution centre B servicing a larger less densely populated region. In a scenario involving contaminated produce being delivered to both distribution centres, the risks associated with the spread of contaminated product could be compared depending on the size of the territory covered and the population associated with each territory.

Hence the CanGRASP simulation tool makes it possible to perform detailed studies of the public health impact of a contamination event involving microbiological threat agents in RTE lettuce distributed through Canadian retail chains. With the assembly of suitable data bases, this approach could be extended to any food product. A tutorial was prepared to assist the user with the use and application of the tool within CanGRASP (Appendix 3).

5 Transition and Exploitation

The current prototype of CanGRASP operates in a desktop environment that includes protected geo-databases, licensed modeling software and ArcGIS tools needed for analysis and mapping purposes. A reliable more robust solution is clearly needed to provide access to stakeholders. The design and assembly of an integrated solution that accommodates the CanGRASP interface, geo-databases, simulation model and mapping tools through a secure mechanism will ensure the protection of confidential or sensitive information in the databases, access to updated data, and functionality needed to facilitate use of the tool. Consequently, a new proposal was submitted to AAFC Science and Technology Branch with the objective to develop a method for transferring the simulation and mapping capabilities of the current tool from a desktop operation to a distributed multi-user server based operation, to ensure user accessibility regardless of their location and organization. This will involve defining the needs of different categories of end users (risk assessment professionals, first responders, modelling specialists, research scientists), developing a distributed multi-user version of the CanGRASP tool, testing the operability of the tool with a selection of end users and making necessary improvements, and developing a mechanism for updating the distribution system geo-databases on an annual basis. The multi-user version of CanGRASP will be designed to provide common access to and operability by personnel at AAFC, CFIA, PHAC, DND, HC, and provincial, regional or municipal agencies.

The new version of CanGRASP will be developed in two phases. The first phase will involve the development of a distributed multi-user solution that will be validated and tested with a group of selected users from a number of federal departments or agencies (AAFC, PHAC, CFIA, HC and DND) who are eligible to view data from the protected geo-databases. The first phase will deliver critical requirements to enable users of the tool to fully test its capabilities and demonstrate its value. The second phase will involve improving the tool, based on the lessons learned and results of the first phase, and incorporating a method to limit data access capabilities depending on the type of users. The second phase will also include fixing any deficiencies or adding necessary enhancements identified during testing. The first phase will therefore result in a tool that effectively meets the needs of eligible end users within federal departments or agencies while the second will result in a refined and enhanced tool that meets the needs of a broader group of end users, including those in provincial, regional or municipal agencies. As part of ensuring effective transfer of the technology, end-users and stakeholders will be engaged throughout these phases to ensure approaches will provide the required accessibility, functionality, performance and security for the tool. This will include engagement in prototyping and testing phases to ensure the operability of the tool. Communicating and promoting the capabilities of the tool to stakeholders will be undertaken through workshops, seminars or webinars that engage identified government and/or industry contacts. During the development of the tool, appropriate use of web service(s) and web page(s) to initiate simulation and retrieve post simulation analysis results will be examined. Map visualization options for both novice and advanced users will be considered. Departmental or Government of Canada standards related to geospatial data, web accessibility, and information management will be addressed, as determined to be applicable.

6 Conclusion

The project summarized herein addressed CRTI priority area 7 (Safety of the Food System), specifically gaps in food related risk, threat and vulnerability assessment modeling, methodologies and systems. Research objectives were developed in consideration of the need for improved tools to deal with deliberate contamination of the food supply with microbiological threat agents, or catastrophic non- deliberate contamination events (due to natural disasters, weather related effects, for example.). A systems-based approach for the assessment of risk in complex Canadian food chains was used in the development of a risk simulation model termed the Canadian GIS-based Risk Assessment, Simulation and Planning tool for Food Safety (CanGRASP). The report describes key elements of the strategy employed to this end including: the acquisition and compilation of data (processing facilities, transportation and distribution systems) in a relational geo-database for the development of computerized mapping tools to predict the dissemination of contaminated food along temporal and geographic planes; the development of mathematical tools that predict microbiological threat behavior; and the design of the overall simulation tool to dynamically map the spread of contaminated food in the Canadian distribution system.

The architecture of the geo-database described in the report was designed to allow integration with GIS and the Arena™ modeling software used to develop the overall simulation tool. The geo-database can accommodate data for the characterization of distribution systems for any food commodity in its present format and is therefore immediately available for the purpose. The linked mapping interface provides means to visualize the location of contaminated food in the distribution system, areas at risk as time progresses and estimates of the population affected by the event. In addition, the interface was designed with query tools that provide links to diverse and detailed information (location, contaminated product location, volumes, population statistics, etc). Hence the interface provides both the means to quickly display risks associated with an event to accommodate urgent applications in a response setting and enhanced analytical capability to support the development of mitigation strategies in the preparedness domain.

Microbiological threats in foods are generally classified under four broad classes of microorganisms including viruses, protozoa, Gram-negative bacteria and bacterial sporeformers. The prototype version of the CanGRASP simulation tool delivered with this report includes a predictive equation for Gram-negative bacteria which, unlike other classes of threat, are capable of growth in foods. Consequently, the predictive model developed through experimentation with the surrogate bacterium *E. coli* O157:H7 considers the potential for survival, decay or growth under the variable conditions encountered in commercial distribution systems. This represents a significant improvement over previous approaches employed in the identification of vulnerabilities and the estimation of risk that tend to rely on broad assumptions about survival or decay based on static presence/absence data. The modeling approach herein delivers more realistic predictions of microbiological threat behaviour in food distribution systems.

Moreover, the proposed approach revealed important new considerations for the identification of vulnerabilities to microbiological threats in food distribution systems and the development of

apposite simulation models. The validity of the approach was demonstrated experimentally with ready-to-eat (RTE) lettuce. A review of available epidemiological data indicated that this product is amenable to the widespread dissemination of bacterial hazards and the scientific literature contains frequent mention of a role in the dissemination of enteric viruses. The Murine norovirus 1 surrogate for enteric viruses was used in a limited number of previous studies that examined survival during the production and processing of RTE leafy vegetables. In our hands, the virus survived poorly in RTE lettuce under conditions that simulated commercial processing and distribution practices, observations that are indicative of a low risk of dissemination through this food commodity. Furthermore, experimentation with the protozoan and bacterial spore-former surrogates provided data indicative of stability that could not be deduced from available sources of information. These observations illustrate the uncertainty that can be introduced by reliance on assumptions or data that have not been validated experimentally and underline the merit of the approach used for the identification of microbiological vulnerabilities and risks in the present work.

The prototype CanGRASP tool developed through this work provides the ability to simulate and dynamically display public health outcomes associated with microbiological contamination of the food supply. It was used to examine contamination scenarios in an actual Canadian distribution system and to provide realistic estimates of the implied risks to public health, which represents a significant improvement in response capacity. The current prototype operates in a desktop environment but was designed to favour transition to a server based operation to enable access by stakeholders tasked with the identification and resolution of threats to the food supply. The latter will be the focus of future work.

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Annex B PROJECT PERFORMANCE SUMMARY

PROJECT PERFORMANCE SUMMARY

Technical Performance Summary:

The objectives of the work identified in the Project Charter are listed below. A statement of achievement follows each objective:

1. A compilation of nation-wide data on production, importation, distribution, processing and retailing systems into databases that can be interfaced with computerized vulnerability assessment software – *The objective was completed as planned. A relational database accessible by modeling software was designed to store the relevant data.*
2. The development of an interactive, GIS-based tool to enable mapping the origin, transportation routes and ultimate destination of lettuce in the Canadian marketplace – *The objective was completed as planned. The interface was designed to allow simulations based on scenarios derived from range of parameters chosen by the user and delivers the results in the form of an Access database for analysis with ArcGIS.*
3. The design of an expert system to assist in the design of sampling strategies that accommodate a range of contamination scenarios at each stage along the farm-to-fork chain. – *A system was developed to support the sampling strategies needed for field studies. However, the range of difference in survivability of the surrogates during subsequent steps along the chain (from full survival of bacterial endospores and protozoan oocysts to complete eradication of the virus) reduced the need for additional sampling scheme development. Hence this objective was partially fulfilled.*
4. The selection of appropriate surrogate viral, bacterial and parasitic microorganisms through laboratory-based confirmation of recovery from and survival in soil, water, plant and contact surfaces to test the performance of the expert system. – *The objective was completed as planned.*
5. Field and pilot plant based experimentation to provide data for the development of mathematical models that predicts the rate of decay or expansion for microbiological threats. *The objective was completed as planned.*
6. The development/testing of a tool that predicts the fate of viral, bacterial or parasitic threats along the chain; assessment of risks associated with variable contamination scenarios. The development of the predictive tool is the final outcome of the research project. *The objective was completed as planned. The prototype CanGRASP tool developed through this work provides the ability to simulate and dynamically display public health outcomes associated with microbiological contamination of the food supply. It was used to examine contamination scenarios in an actual Canadian distribution system and to provide realistic estimates of the implied risks to public health, which represents a significant improvement in response capacity. A two year proposal was submitted to foster transition from a desktop environment to a web-based platform. It is anticipated that the tool will become widely available to stakeholders at that time.*

Schedule Performance Summary:

The project end-date in the original Project Charter was March 12, 2012. While the first CanGRASP prototype was delivered on time the project team requested and extension to fine tune some of the associated tools and to test the prototype. This work was supported by funding from AAFC.

Cost Performance Summary: Budgets were distributed to the partners in accordance with the budget shown below:

Partner	Budget Element	Fiscal Year (08/09)	Fiscal Year (09/10)	Fiscal Year (10/11)	Fiscal Year (11/12)	TOTALS
Lead Federal Department – AAFC	Labour	$38,000.00	$143,000.00	$161,000.00	$114,250.00	$456,250.00
	Equipment	$5,250.00	$17,000.00	$7,000.00	$6,250.00	
	Lab O&M	$17,000.00	$31,000.00	$39,000.00	$26,000.00	
	Overhead	$12,000.00	$32,820.00	$36,750.00	$25,395.00	
	Travel	$19,750.00	$22,800.00	$21,000.00	$10,800.00	
	Contracts	$0.00	$5,000.00	$15,000.00	$10,000.00	
	Other (specify)			$2,000.00	$2,000.00	
	Total	$92,000.00	$251,620.00	$281,750.00	$194,695.00	$820,065.00
Lead Federal Department – (CFIA)	Labour	$0.00	$31,000.00	$52,000.00	$51,500.00	$134,500.00
	Equipment	$6,000.00	$1,000.00	$1,000.00	$1,000.00	
	Lab O&M	$12,500.00	$24,000.00	$24,000.00	$12,500.00	
	Overhead	$3,450.00	$9,300.00	$12,450.00	$10,425.00	
	Travel	$4,500.00	$6,000.00	$6,000.00	$4,500.00	
	Contracts					
	Other (specify)					
	Total	$26,450.00	$71,300.00	$95,450.00	$79,925.00	$273,125.00
Other Federal Department(s)- (PHAC)	Labour	$36,500.00	$73,000.00	$73,000.00	$32,000.00	$214,500.00
	Equipment	$5,000.00	$5,000.00	$5,000.00	$0.00	
	Lab O&M	$7,500.00	$14,000.00	$14,000.00	$7,500.00	
	Overhead	$7,650.00	$14,400.00	$14,400.00	$7,725.00	
	Travel	$2,000.00	$4,000.00	$4,000.00	$2,000.00	
	Contracts				$10,000.00	
	Other (specify)					
	Total	$58,650.00	$110,400.00	$110,400.00	$59,225.00	$338,675.00
Other Federal Department(s)- (HC)	Labour	$12,000.00	$24,000.00	$24,000.00	$12,000.00	$72,000.00
	Equipment	$0.00				
	Lab O&M	$7,500.00	$14,000.00	$14,000.00	$7,500.00	
	Overhead	$3,075.00	$5,925.00	$5,925.00	$3,075.00	
	Travel	$1,000.00	$15,000.00	$1,500.00	$1,000.00	
	Contracts					
	Other (specify)					
	Total	$23,575.00	$45,425.00	$45,425.00	$23,575.00	$138,000.00
CRTI Total Funding		$200,675.00	$478,745.00	$533,025.00	$357,420.00	**$1,569,865.00**

The project allocation was $1,569,994. Total expenditures over the course of the project were 1,565,154, $4,480 were returned to CRTI. No significant cost variance were encountered.

Annex C Publications, Presentations, Patents

Scientific manuscripts:

- Fallahi, S and Mattison, K. 2011. Evaluation of murine norovirus persistence in environments relevant to food production and processing. Journal of Food Protection. 74:1847-51.

- Hashemi Beni, L, Villeneuve, S, LeBlanc, DI and Delaquis, P. 2011. A GIS-based approach in support of an assessment of food safety risks. Transactions in GIS. 15:95-108.

- McKellar, R and Delaquis, P. 2011. Development of a dynamic growth-death model for *Escherichia coli* O157:H7 in minimally processed leafy green vegetables. International Journal of Food Microbiology. 51:7-14.

- McKellar, RC, LeBlanc, DI, Lu, J and Delaquis, P. 2012. Simulation of *Escherichia coli* O157:H7 behaviour in fresh-cut lettuce under dynamic temperature conditions during distribution from processing to retail. Foodborne Pathogens and Disease 9:239-244.

- Hashemi Beni, L, Villeneuve, S, LeBlanc, DI, Côté, K, Fazil, A, Otten, A, McKellar, R and Delaquis, P. 2012. Spatio-temporal assessment of food safety risks in Canadian food distribution systems using GIS. Spatial and Spatio-temporal Epidemiology. 3:215-223.

- Bergeron-Quirion, S, Villeneuve, S, LeBlanc, DI, and Delaquis, P. 2012. Thermophysical properties and thermal behavior of leafy vegetables packaged in clamshells. Journal of Food Engineering 113:27-32.

In preparation:

- McKellar, RC, LeBlanc, DI, Peréz Rodríguez, F and Delaquis, P. 2012. Comparative simulation of *Escherichia coli O157:H7* behaviour in packaged fresh-cut lettuce distributed in a typical Canadian cold chain in the summer and winter. Food Control.
- McKellar, RC, Peréz Rodríguez, F, Harris, LJ, Moyne, A-l, Blais, B, Topp, E, Bezanson, G, Bach, S and Delaquis, P. 2012. A predictive mathematical model for *Escherichia coli* O157:H7 on field lettuce. Food Microbiology.

Student theses/reports:

- O'Halloran, M. 2009. Mitigating Dissemination of Bioterrorism Agents in Canadian Food Systems: Preliminary work for Mapping Cluster. PHAC, Guelph.

- Frame. C. 2009. Evaluation of DNA Extraction Methods of *Bacillus atrophaeus* Spores and Quantification of Recovered DNA using Quantitative Real-Time PCR. AAFC, Summerland
- Dussault, V. 2010. Stratégies d'atténuation de la diffusion d'agents de bioterrorisme dans le système alimentaire canadien : Analyse du réseau de distribution canadien. Rapport de travail, AAC, St Hyacinthe.
- Tan, B. 2010. Effects of Storage Temperature and Duration on *Bacillus spp.* Spore and Vegetative Cell Populations in Lettuce Tissues. Co-op report, AAFC, Summerland.
- Gomez, L. 2010. Effect of time and temperature on the fate of *Bacillus atrophaeus* in field lettuce and in soil. Co-op report, AAFC, Summerland.
- Fallahi S . 2011. Evaluation of norovirus persistence in environments relevant to food production and processing. MsSc thesis, University of Ottawa.
- Alisa Abozina. 2011. Determining the persistence of *Bacillus atrophaeus* in field Romaine lettuce and soil. Co-op report, AAFC, Summerland.
- Haghnegahdar, Ghazal. 2011. Optimization of PCR for the Recovery of *Bacillus atrophaeus* from Environmental Samples. Co-op report, AAFC, Summerland.

Conference/oral presentations:

- Delaquis, P. 2010. A systems-based approach for the assessment of microbiological threats to the food supply. Second Annual Meeting, BASELINE Project (GAN 222738) Annual meeting, Feb. 25-6, Brest, France. (oral presentation)
- Delaquis, P. 2010. The complexity of the food supply: Farm to fork. Biological Threat Prevention – The Global Food Supply Chain – Workshop. Sept 8-10, Ottawa, ON (oral presentation)
- Delaquis, P. 2009. Mitigating dissemination of bioterrorism agents in Canadian food systems. Europe-Canada Food and Health & Food Safety and Security. Second Twinning Workshop, Oct. 20-21, Guelph, ON. (oral presentation)
- Delaquis, P, Bach, S, LeBlanc, DI, Brassard, J, Houde, A, Villeneuve, S, Bezanson, G, Diarra, M, Topp, E, Blais, B, Gajadhar, A, Bisaillon, J-R, Fazil, A, Gilmour, M, Mattison, K, and Bidawid, S 2009. A systems-based approach for the assessment of microbiological threats to the food supply. Federal Food Safety Research and Nutrition Meeting, Nov. 4-5, Ottawa, ON. (oral presentation, abstract).
- Hashemi Beni, L, Villeneuve, S, LeBlanc, D, Dussault, V, Henry, M, and Delaquis, P. 2010. A GIS-based Approach in Support of Assessment of Food Safety Risks. Federal Food Safety Research and Nutrition Meeting, Nov. 3-4, Ottawa, ON. (poster, abstract)

- Fallahi, S, Bezanson, G, Brassard, J, Delaquis, P, Houde, A and Mattison, K. 2010. Evaluation of murine norovirus environmental stability. Federal Food Safety Research and Nutrition Meeting, Nov. 3-4, Ottawa, ON. (poster, abstract)

- LeBlanc, DI, Lu, J, Taylor, M, Goguen, B and Delaquis, P. 2010. Retail supply chain time-temperature data in support of food safety risk assessment. Federal Food Safety Research and Nutrition Meeting, Nov. 3-4, Ottawa, ON. (poster, abstract)

- Fallahi, S, Bezanson, G, Brassard, J, Delaquis, P, Houde, A and Mattison, K. 2012. Long-term Stability of Norovirus on Farm and Agriculturally-relevant Environments. Meeting of the International Association of Food Protection, July 30 – August 3 Milwaukee, WI, USA (abstract, poster).

- Fazil, A, Otten, A, Hashemi Beni, L, Villeneuve, S, McKellar, R, l Delaquis, P et LeBlanc, DI. 2012. Développement d'un outil de simulation permettant de prédire les risques de santé publique associés aux dangers microbiologiques présents dans le système canadien de distribution des aliments. AQIA Annual Meeting, Sept 9, 2012 (poster, abstract).

- Bergeron-Quirion, S, Villeneuve, S, LeBlanc, DI, and Delaquis, P. 2012. Predicting the temperature of leafy vegetables packaged in clamshells during distribution in the cold chain. 50th National Conference of the Canadian Institute of Food Science and Technology (CIFST): Innovation meets Commercialization, Niagara Falls, ON, Canada, May 27-29, 2012. (poster, abstract)

- Bergeron-Quirion, S, Villeneuve, S, LeBlanc, DI, and Delaquis, P. 2012. Thermophysical properties of pre-washed baby-leaf lettuce and brassica greens packaged in clamshells. 11th Conference of Food Engineering (CoFE 2012), National Conference Center, Leesburg, VA, USA, April 2-4, 2012. (poster, abstract)

- Fazil, A, Otten, A, Hashemi Beni, L, Villeneuve, S, McKellar, R, Delaquis, P., and LeBlanc, DI 2012. Development of a simulation tool to predict the public health risks associated with microbiological hazards in Canadian food distribution systems. 50th National Conference of the Canadian Institute of Food Science and Technology (CIFST): Innovation meets Commercialization, Niagara Falls, ON, Canada, May 27-29, 2012. (poster, abstract)

- Villeneuve, S, Hashemi Beni, L, Côté, K, LeBlanc, DI, Fazil, A, Otten, A, McKellar, R, and Delaquis, P. 2012. Development of an interactive modeling tool to predict the risks associated with contaminated fresh-cut lettuce in Canadian Distribution Systems. 99th Annual Meeting of the International Association of Food Protection (IAFP), Rhode Island Convention Center, Providence, RI, USA, July 22-25, 2012. (oral presentation, abstract)

- Delaquis, P, Bezanson, G, McKellar, R and Gajadhar, A. 2012. Fate of protozoan oocysts (*Eimeria ppaillata)* on lettuce in field plots. 99th Annual Meeting of the International Association of Food Protection (IAFP), Rhode Island Convention Center, Providence, RI, USA, July 22-25, 2012.

Webinar:

- Delaquis, P. 2009. Mitigating dissemination of bioterrorism agents in Canadian food systems. Webinar presented to the Canadian Produce Manufacturer's Association membership, March 25, 2009.

Appendix 1.

Canadian retail distribution system geo-database for RTE lettuce

The following is an overview of the data available in the Canadian retail distribution system database for RTE lettuce (GEODB_CAN.mdb). It includes description, source and limits of the data. Each sub-section represents a separate table created in the geodatabase (mdb) saved on the shared drive in St-Hyacinthe (qcsthyafil1\common\Recherche\VilleneuveSe\Géomatique\CanGRASP\ Distribution system database). Each table in the database file is a separate sheet in the MS Excel file available in the same folder on the shared drive (DB_CAN_2012-09-19.xlsx).

1. Scenario

The Scenario table is filled in by the CanGRASP (Canadian GIS-based Risk Assessment, Simulation and Planning for Food Safety) integrated simulation tool. The table includes the values of the attributes used by CanGRASP to assess food safety risks in a Canadian retail distribution system. A separate Scenario table is created for each simulation. The fields included in the Scenario table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Scenario_Desc	String	Description of scenario including whether or not temperature abuse occurred and, when occurring, how much and where it occurred
Season	String	Season when contamination incident occurs
No_of Reps	Integer	Number of replications of simulation
ID	Integer	ID of processor or distribution centre where contamination incident is initiated, or ID of processor, distribution centre, retail store or transit step where temperature abuse occurs
Contam_Type	String	Contamination type (virus, parasites, gram negative bacteria, spores, etc.)
Vol_Contam	Double[1]	Quantity of contaminated product (kg)
Conc_Contam	Double[1]	Level of concentration in contaminated product (CFU/kg)
T_Abuse	Double[2]	Forced temperature used during simulation (°C)
Recall	String	Recall activated? (Yes or No)
Recall_Start	Double[2]	Time when the recall is started (h)
Prob_Stop_DC	Double[2]	Probability to catch contaminated packages that are still at DC (%) (e.g. effectiveness of the recall at the distribution centre)

Attribute name	Data type	Description
Prob_Stop_RS	Double[2]	Probability to catch contaminated packages that are still at RS (%) (e.g. effectiveness of recall at the retail store)
Prob_sub_Pro_DC	Double[2]	Probability that processor will send multiple pallets/box in a row to the same distribution centre (%)
Prob_sub_DC_RS	Double[2]	Probability that distribution centre will send multiple pallets/box in a row to the same retail store (%)

[1]Value fixed at 2 decimal places
[2]Value fixed at 1 decimal place

2. Package_Info

The Package_Info table describes the various package sizes manufactured by Canadian lettuce processors, or imported by Canadian distribution centres, and their grouping and stacking format. The fields included in the Package_Info table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Pack_Type	Integer	Unique identifier for each type of package
Mass_per_pack_g	Integer	Mass of fresh-cut lettuce in a package (g)
Packs_per_box	Integer	Number of packages in a box
Boxes_per_pallet	Integer	Number of boxes stacked on a pallet
Mass_per_box_kg	Double[1]	Total mass of fresh-cut lettuce in a box (kg)

[1] Value fixed at 3 decimal places

Fifteen different package types (identified as Pack_Type 1 to 15) were reported being manufactured by domestic processors during a survey of Canadian lettuce processors conducted in 2009. Although all processors specified the Mass_per_pack_g for each Pack_Type being produced, not all specified the Packs_per_box or Boxes_per_pallet. The number of Packs_per_box and the number of Boxes_per_pallet were assumed for Pack_Type 1, 4, 5 and 7 (see "Package_info" table).
The RTE lettuce available in Canadian retail stores that is processed abroad and imported by the distribution centres may or may not be adequately characterized by the descriptions included for Pack_Type 1 to 15. Assembling a complete list of imported package types was not feasible because of the large number of SKUs (stock keeping units) handled by each distribution centre. After consulting the web sites of several lettuce processors in the U.S.A, three different pack types (identified as Pack_Type 16 to 18) were defined to describe imported minimally processed lettuce. The Mass_per_pack_g selected for Pack_Type 16 to 18 represent small, medium and large size packages commonly available in retail stores. The numbers of Packs_per_box and the number of Boxes_per_pallet, selected for the three imported package types, were obtained from the website of an American processor producing all three pack sizes (see "Package_Info" table).

Mass_per_box_kg is a calculated value determined with the following equation:

$$\text{Mass\_per\_box\_kg} = \frac{\text{Mass\_per\_pack\_g} \times \text{Packs\_per\_box}}{1000\ g/kg}$$

3. Processor_Packages

The Processor_Packages table describes the proportion of each Pack_Type manufactured by all domestic processors. The fields included in the Processor_Packages table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Processor_ID	Integer	Unique number given to each domestic processor
Pack_Type	Integer	Unique identifier for each type of package
Proportion_Pro	Double[1]	Proportion of each Pack_Type produced yearly by each processor for the retail sector (%)

[1] Value fixed at 1 decimal place

The different package types manufactured by each processor were reported during a survey of Canadian lettuce processors conducted in 2009. Since Processor_ID 2 did not specify the proportion of each package type being produced, it was assumed that each type was produced in equal proportions.

4. Lettuce_processors

The Lettuce_processors table includes the list of Canadian lettuce processors that prepare RTE leafy greens for the food retail sector. The list consists of five processors spread in three provinces (Quebec, Ontario and British Columbia). The Lettuce_processors table describes the location of each processor, the product processed, the origin and destination of the product, quantities processed on a seasonal basis, and time-temperature data for the packaged product during storage at the processor. The fields included in the Lettuce_processors table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Processor_ID	Integer	Unique number given to each domestic processor
Pro_Arena_ID	Integer	Identification number used in Arena program for each processor

Attribute name	Data type	Description
Processor_name	String	Name of processor
Address	String	Street address
City	String	City
Province	String	Newfoundland = NF; Nova Scotia = NS; Prince Edward Island = PE; New Brunswick = NB; Quebec = QC; Ontario = ON; Manitoba = MB; Saskatchewan = SK; Alberta = AB; British Columbia = BC
Postal_code	String	Postal code
Latitude	Double	Latitude
Longitude	Double	Longitude
Product_processed	String	Types of leafy greens processed
KG_REC_SP	Double[1]	Quantity of leafy greens delivered to processing plant in spring (both produced by processor and purchased) (kg)
KG_REC_SU	Double[1]	Quantity of leafy greens delivered to processing plant in summer (both produced by processor and purchased) (kg)
KG_REC_F	Double[1]	Quantity of leafy greens delivered to processing plant in fall (both produced by processor and purchased) (kg)
KG_REC_W	Double[1]	Quantity of leafy greens delivered to processing plant in winter (both produced by processor and purchased) (kg)
DOM_PROD_SP	Integer	% of leafy greens delivered to processing plant in spring that is produced in Canada (0 to 100%)
DOM_PROD_SU	Integer	% of leafy greens delivered to processing plant in summer that is produced in Canada (0 to 100%)
DOM_PROD_F	Integer	% of leafy greens delivered to processing plant in fall that is produced in Canada (0 to 100%)
DOM_PROD_W	Integer	% of leafy greens delivered to processing plant in winter that is produced in Canada (0 to 100%)
PRODUCTION_REGION	String	Regions where domestically produced leafy greens are purchased
LOCAL_GROWERS	Integer	Number of growers from each region that supply domestically grown leafy greens to processor
IMPORT_SP	Double[1]	% of leafy greens purchased during spring that is imported (0 to 100%)

Attribute name	Data type	Description
IMPORT_SU	Double[1]	% of leafy greens purchased during summer that is imported (0 to 100%)
IMPORT_F	Double[1]	% of leafy greens purchased during fall that is imported (0 to 100%)
IMPORT_W	Double[1]	% of leafy greens purchased during winter that is imported (0 to 100%)
KG_PROD_SP	Double[1]	Quantity of RTE leafy greens produced during spring e.g., 13 weeks (kg)
KG_PROD_SU	Double[1]	Quantity of RTE leafy greens produced during summer e.g., 13 weeks (kg)
KG_PROD_F	Double[1]	Quantity of RTE leafy greens produced during fall e.g., 13 weeks (kg)
KG_PROD_W	Double[1]	Quantity of RTE leafy greens produced during winter e.g., 13 weeks (kg)
EXPORT_SP	Double[1]	% of total production that is exported during spring (0 to 100%)
EXPORT_SU	Double[1]	% of total production that is exported during summer (0 to 100%)
EXPORT_F	Double[1]	% of total production that is exported during fall (0 to 100%)
EXPORT_W	Double[1]	% of total production that is exported during winter (0 to 100%)
DOM_RET_SP	Double[1]	% of domestic sales that are sold to retail versus food service during spring (0 to 100%)
DOM_RET_SU	Double[1]	% of domestic sales that are sold to retail versus food service during summer (0 to 100%)
DOM_RET_F	Double[1]	% of domestic sales that are sold to retail versus food service during fall (0 to 100%)
DOM_RET_W	Double[1]	% of domestic sales that are sold to retail versus food service during winter (0 to 100%)
KG_DOM_RET_SP	Double[2]	Quantity of RTE leafy greens produced during spring for the domestic retail market (kg/season)
KG_DOM_RET_SU	Double[2]	Quantity of RTE leafy greens produced during summer for the domestic retail market (kg/season)
KG_DOM_RET_F	Double[2]	Quantity of RTE leafy greens produced during fall for the domestic retail market (kg/season)

Attribute name	Data type	Description
KG_DOM_RET_W	Double[2]	Quantity of RTE leafy greens produced during winter for the domestic retail market (kg/season)
PROD_RATE_SP	Double[2]	Rate of RTE leafy greens produced per hour during spring for the domestic retail market (kg/h) (Note: assuming processing 24 hours per day, 7 days a week)
PROD_RATE_SU	Double[2]	Rate of RTE leafy greens produced per hour during summer for the domestic retail market (kg/h) (Note: assuming processing 24 hours per day, 7 days a week)
PROD_RATE_F	Double[2]	Rate of RTE leafy greens produced per hour during fall for the domestic retail market (kg/h) (Note: assuming processing 24 hours per day, 7 days a week)
PROD_RATE_W	Double[2]	Rate of RTE leafy greens produced per hour during winter for the domestic retail market (kg/h) (Note: assuming processing 24 hours per day, 7 days a week)
T_PRO_SP	String	Temperature distribution of RTE leafy greens while stored at processor during spring (estimated from time-temperature trials) (°C)
T_PRO_SU	String	Temperature distribution of RTE leafy greens while stored at processor during summer (estimated from time-temperature trials) (°C)
T_PRO_F	String	Temperature distribution of RTE leafy greens while stored at processor during fall (estimated from time-temperature trials) (°C)
T_PRO_W	String	Temperature distribution of RTE leafy greens while stored at processor during winter (estimated from time-temperature trials) (°C)
ST_PRO_SP	String	Range of time processed lettuce spends in processor's storage prior to shipment to distribution centre during spring (estimated from time-temperature trials) (min)
ST_PRO_SU	String	Range of time processed lettuce spends in processor's storage prior to shipment to distribution centre during summer (estimated from time-temperature trials) (min)

Attribute name	Data type	Description
ST_PRO_F	String	Range of time processed lettuce spends in processor's storage prior to shipment to distribution centre during fall (estimated from time-temperature trials) (min)
ST_PRO_W	String	Range of time processed lettuce spends in processor's storage prior to shipment to distribution centre during winter (estimated from time-temperature trials) (min)
BOX_PER_SEAS_SP	Double[1]	Calculated number of boxes of packaged leafy greens produced for domestic retail market during spring (e.g. 13 weeks) (box/season)
BOX_PER_SEAS_SU	Double[1]	Calculated number of boxes of packaged leafy greens produced for domestic retail market during summer (e.g. 13 weeks) (box/season)
BOX_PER_SEAS_F	Double[1]	Calculated number of boxes of packaged leafy greens produced for domestic retail market during fall (e.g. 13 weeks) (box/season)
BOX_PER_SEAS_W	Double[1]	Calculated number of boxes of packaged leafy greens produced for domestic retail market during winter (e.g. 13 weeks) (box/season)
BOX_PER_W_SP	Double[1]	Calculated number of boxes of packaged leafy greens produced per week during spring (box/week)
BOX_PER_W_SU	Double[1]	Calculated number of boxes of packaged leafy greens produced per week during summer (box/week)
BOX_PER_W_F	Double[1]	Calculated number of boxes of packaged leafy greens produced per week during fall (box/week)
BOX_PER_W_W	Double[1]	Calculated number of boxes of packaged leafy greens produced per week during winter (box/week)
AVG_Packs_per_Box	Double[2]	Average number of packs per box produced by processor (Packs/box)

[1] Value fixed at 0 decimal places
[2] Value fixed at 1 decimal place

The values of several attributes in the Lettuce_processors table were obtained during a survey of Canadian lettuce processors conducted in 2009. These include: 1) the quantity of leafy greens

delivered to each processing plant on a seasonal basis (KG_REC_*X*); 2) the percentage of this quantity that is produced in Canada (DOM_PROD_ *X*) versus the quantity that is imported (IMPORT_ *X*); 3) the domestic production regions (PRODUCTION_REGION); 4) the number of domestic growers (LOCAL_GROWERS); 5) the quantity of RTE leafy greens produced on a seasonal basis (KG_PROD_ *X*); and 6) the percentage of the total production that is exported (EXPORT_ *X*) versus sold domestically to retail (DOM_RET_ *X*). Note: *X* used in the attribute names indicated previously represents all four seasons (e.g. SP, SU, F or W).
Several of the attributes in the Lettuce_processors table are calculated values. The equations used to calculate the values of each of these attributes are listed below. When attributes vary depending on the season, *X* used in the attribute name must be replaced by one of the four seasons (e.g. SP, SU, F or W).

$$\text{KG\_DOM\_RET\_}X = \text{KG\_PROD\_}X \times \frac{(100 - \text{EXPORT\_}X)}{100} \times \frac{\text{DOM\_RET\_}X}{100}$$

$$\text{PROD\_RATE\_}X = \frac{\text{KG\_DOM\_RET\_}X}{(91.25\ days\ per\ season \times 24\ h\ per\ day)}$$

$$\text{BOX\_PER\_SEAS\_}X = \text{KG\_DOM\_RET\_}X \times \sum_{\text{Pack\_Type}} \frac{\text{Proportion\_Pro}}{\text{Mass\_per\_box\_kg}} \times \frac{1}{100}$$

$$\text{BOX\_PER\_W\_}X = \frac{\text{BOX\_PER\_SEAS\_}X}{13\ weeks\ per\ season}$$

$$\text{AVG\_Packs\_per\_Box} = \sum_{\text{Pack\_Type}} (\text{Proportion\_Pro} \times \text{Packs\_per\_box}) \times \frac{1}{100}$$

5. Transit_Processor_to_DC

The Transit_Processor_to_DC table identifies the distribution centres being supplied by each domestic processor, the probability of supplying product to each distribution centre, the transit time between the processor and the distribution centre, and time-temperature data for the packaged product during transit. The fields included in the Transit_Processor_to_DC table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Transit_ID	Integer	Unique number given to the transit between a processor and a distribution centre
Processor_ID	Integer	Unique number given to each domestic processor
Pro_Arena_ID	Integer	Identification number used in Arena program for each processor

Attribute name	Data type	Description
DC_ID	Integer	Unique number given to each distribution centre
DC_Arena_ID	Integer	Identification number used in Arena program for each distribution centre
Prob_Pro_DC	Double[1]	Probability of RTE leafy greens produced by a processor to be shipped to a retail distribution centre.
SUM_Prob_Pro_DC	Double[1]	Sum of probability values associated with each processor
Transp_Pro_DC	Integer	Time required for transportation from processor to distribution centre - based on optimum route and speeds set for the various segments of the route (min)
MinDelay_Pro_DC	Integer	Minimum time spent in transport trailer either before leaving processing plant or before being unloaded at distribution centre (estimated from time-temperature trials) (min)
MaxDelay_Pro_DC	Integer	Maximum time spent in transport trailer either before leaving processing plant or before being unloaded at distribution centre (estimated from time-temperature trials) (min)
MinTransit_Pro_DC	Integer	Minimum time required for transportation of processed lettuce from processor to distribution centre (Attribute no longer used to characterize the Transit_Time_Pro_DC)
MaxTransit_Pro_DC	Integer	Maximum time required for transportation of processed lettuce from processor to distribution centre (Attribute no longer used to characterize the Transit_Time_Pro_DC)
Transit_Time_Pro_DC	String	Range of time required for transit of processed lettuce from processor to distribution centre (min)
T_Pro_DC_SP	String	Temperature distribution of RTE leafy greens during transit from processor to distribution centre during spring (estimated from time-temperature trials) (°C)
T_Pro_DC_SU	String	Temperature distribution of RTE leafy greens during transit from processor to distribution centre during summer (estimated from time-temperature trials) (°C)

Attribute name	Data type	Description
T_Pro_DC_F	String	Temperature distribution of RTE leafy greens during transit from processor to distribution centre during fall (estimated from time-temperature trials) (°C)
T_Pro_DC_W	String	Temperature distribution of RTE leafy greens during transit from processor to distribution centre during winter (estimated from time-temperature trials) (°C)
Delay_prob0	Integer	Transit time for the first time step of the continuous distribution statement describing the Transit_Time_Pro_DC (min)
Delay_prob1	Integer	Transit time for the second time step of the continuous distribution statement describing the Transit_Time_Pro_DC (min)
Delay_prob2	Integer	Transit time for the third time step of the continuous distribution statement describing the Transit_Time_Pro_DC (min)
Delay_prob3	Integer	Transit time for the fourth time step of the continuous distribution statement describing the Transit_Time_Pro_DC (min)
Delay_prob4	Integer	Transit time for the fifth time step of the continuous distribution statement describing the Transit_Time_Pro_DC (min)
Delay_prob5	Integer	Transit time for the sixth time step of the continuous distribution statement describing the Transit_Time_Pro_DC (min)

[1] Value fixed at 3 decimal places

The probability values (Prob_Pro_DC) were obtained during a survey of Canadian lettuce processors conducted in 2009. When the processor did not specify the proportion allocated to each distribution centre supplied, it was assumed that each retail chain received an equal proportion of the processor's production regardless of the number of distribution centres being supplied for each individual retail chain. When the processor did not specify the proportion allocated to individual distribution centres of the same chain, the probability calculated for each distribution centre (DC) was based on the total quantity of packaged leafy greens received per week (BOX_PER_W_DC_*X*), for all four seasons combined, as reported by or calculated for each DC. *Note: The probability values (Prob_Pro_DC) need to be revised when changes are made to the database, namely when the distribution centres supplied by a processor are modified, or when the volumes allocated to distribution centres are updated, or when the number of retail stores supplied by a distribution centre is corrected.*

The time required for transportation from the processor to the distribution centre (Transp_Pro_DC) was calculated using the "Calculate Transit Time" tool in CanGRASP. The

fastest path option was used as it was assumed that processors use the quickest route to reach their destination rather than the shortest one in distance (see Section 2.11).
The transit time between a processor and a distribution centre (Transit_Time_Pro_DC) is comprised of two parts: the transportation time (Transp_Pro_DC) and any time spent in the transport trailer either before leaving the processor or before being unloaded at the distribution centre (hereafter referred to as delay time). The delay time was estimated from time-temperature data recorded during trials conducted in a commercial retail distribution chain in 2010 and 2011. The delay time varied significantly from trial to trial and ranged from a minimum value (MinDelay_Pro_DC) to a maximum value (MaxDelay_Pro_DC). A continuous distribution statement was calculated for the delay times recorded during both series of time-temperature trials. For each Transit_ID, the related transportation time was added to each time step in the continuous distribution statement of the delay time to obtain the continuous distribution statement of the transit time (Transit_Time_Pro_DC).
The Delay_prob# attributes are calculated values consisting of the sum of the transportation time (Transp_Pro_DC) and individual time steps of the continuous distribution statement describing the delay time. The Delay_prob# values are concatenated together with the probabilities associated with each time step to obtain the continuous distribution statement for the transit time (Transit_Time_Pro_DC).

6. Distribution_centres

The Distribution_centres table lists the produce distribution centres of five major food retail chains in Canada. (Note: Partial information is also included on a sixth major food retail chain). There are a total of 27 produce distribution centres spread across nine of the ten Canadian provinces. The Distribution_centres table describes the location of each produce distribution centre, the total number of cases of RTE leafy greens received by each distribution centre on a seasonal basis, the proportion of product that is produced locally versus imported, the average number of packs per case for domestic and imported product, and time-temperature data for the product during storage at the distribution centre. The fields included in the Distribution_centres table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
DC_ID	Integer	Unique number given to each distribution centre
DC_Arena_ID	Integer	Identification number used in Arena program for each distribution centre
GROUP_NAME	String	Name of retail chain
Distribution_Centre_Name	String	Name of distribution centre
Address	String	Street address
City	String	City

Attribute name	Data type	Description
Province	String	Newfoundland = NF; Nova Scotia = NS; Prince Edward Island = PE; New Brunswick = NB; Quebec = QC; Ontario = ON; Manitoba = MB; Saskatchewan = SK; Alberta = AB; British Columbia = BC
Postal_code	String	Postal code
Latitude	Double	Latitude
Longitude	Double	Longitude
BOX_PER_W_DC_SP	Integer	Total quantity of RTE leafy greens received by each distribution centre on a weekly basis during spring (box/week)
BOX_PER_W_DC_SU	Integer	Total quantity of RTE leafy greens received by each distribution centre on a weekly basis during summer (box/week)
BOX_PER_W_DC_F	Integer	Total quantity of RTE leafy greens received by each distribution centre on a weekly basis during fall (box/week)
BOX_PER_W_DC_W	Integer	Total quantity of RTE leafy greens received by each distribution centre on a weekly basis during winter (box/week)
LOCAL_DC_SP	Double[1]	% of RTE leafy greens that is received from Canadian processors during spring - calculated based on data provided by processors (0 to 100%)
LOCAL_DC_SU	Double[1]	% of RTE leafy greens that is received from Canadian processors during summer - calculated based on data provided by processors (0 to 100%)
LOCAL_DC_F	Double[1]	% of RTE leafy greens that is received from Canadian processors during fall - calculated based on data provided by processors (0 to 100%)
LOCAL_DC_W	Double[1]	% of RTE leafy greens that is received from Canadian processors during winter - calculated based on data provided by processors (0 to 100%)
IMPORT_DC_SP	Double[1]	% of RTE leafy greens received by the distribution centre that is imported – Spring (0 to 100%)

Attribute name	Data type	Description
IMPORT_DC_SU	Double[1]	% of RTE leafy greens received by the distribution centre that is imported – Summer (0 to 100%)
IMPORT_DC_F	Double[1]	% of RTE leafy greens received by the distribution centre that is imported – Fall (0 to 100%)
IMPORT_DC_W	Double[1]	% of RTE leafy greens received by the distribution centre that is imported – Winter (0 to 100%)
IMPORT_RATE_DC_SP	Double[1]	Rate of receiving of imported RTE leafy greens at the distribution centre during spring (kg/h) (Note: assuming receiving 24 hours per day, 7 days a week)
IMPORT_RATE_DC_SU	Double[1]	Rate of receiving of imported RTE leafy greens at the distribution centre during summer (kg/h) (Note: assuming receiving 24 hours per day, 7 days a week)
IMPORT_RATE_DC_F	Double[1]	Rate of receiving of imported RTE leafy greens at the distribution centre during fall (kg/h) (Note: assuming receiving 24 hours per day, 7 days a week)
IMPORT_RATE_DC_W	Double[1]	Rate of receiving of imported RTE leafy greens at the distribution centre during winter (kg/h) (Note: assuming receiving 24 hours per day, 7 days a week)
AVG_Packs_per_Box_IMP	Double[1]	Average number of packages per box imported by distribution centre (Packs/box)
AVG_Packs_per_Box_DOM	Double[1]	Average number of packages per box received by distribution centre from domestic processors (Packs/box)
T_DC_SP	String	Temperature distribution of RTE leafy greens while stored at distribution centre during spring (estimated from time-temperature trials) (°C)
T_DC_SU	String	Temperature distribution of RTE leafy greens while stored at distribution centre during summer (estimated from time-temperature trials) (°C)

Attribute name	Data type	Description
T_DC_F	String	Temperature distribution of RTE leafy greens while stored at distribution centre during fall (estimated from time-temperature trials) (°C)
T_DC_W	String	Temperature distribution of RTE leafy greens while stored at distribution centre during winter (estimated from time-temperature trials) (°C)
ST_DC_SP	String	Range of time RTE leafy greens spend in distribution centre's storage, during spring, prior to delivery to retail store (estimated from time-temperature trials) (min)
ST_DC_SU	String	Range of time RTE leafy greens spend in distribution centre's storage, during summer, prior to delivery to retail store (estimated from time-temperature trials) (min)
ST_DC_F	String	Range of time RTE leafy greens spend in distribution centre's storage, during fall, prior to delivery to retail store (estimated from time-temperature trials) (min)
ST_DC_W	String	Range of time RTE leafy greens spend in distribution centre's storage, during winter, prior to delivery to retail store (estimated from time-temperature trials) (min)

[1] Value fixed at 1 decimal place

The total quantities of RTE leafy greens received by each distribution centre (BOX_PER_W_DC_SP, BOX_PER_W_DC_S, BOX_PER_W_DC_F, and BOX_PER_W_DC_W) were obtained during a survey of Canadian produce distribution centres conducted in 2011. Responses were received from 22 of the 27 produce distribution centres servicing the five retail chains included in the database. Approximate quantities were assigned to the 5 distribution centres for which no values were obtained during the survey (DC_ID 60, 61, 64, 79 and 83).

Several of the attributes in the Distribution_centres table are calculated values. The equations used to calculate the values of each of these attributes are listed below. When attributes vary depending on the season, *X* used in the attribute name must be replaced by one of the four seasons (e.g. SP, SU, F or W).

$$\text{LOCAL\_DC\_}X = \frac{\sum_{\text{Processors supplying DC}}(\text{Prob\_Pro\_DC} \times \text{BOX\_PER\_W\_}X)}{\text{BOX\_PER\_W\_DC\_}X} \times 100$$

$$\text{IMPORT\_DC\_}X = 100 - \text{LOCAL\_DC\_}X$$

$$\text{IMPORT\_RATE\_DC\_}X = \text{BOX\_PER\_W\_DC\_}X \times \frac{\text{IMPORT\_DC\_}X}{100} \times \frac{\sum_{\text{Pack\_Type}}\left(\frac{\text{Proportion\_DC} \times \text{Mass\_per\_box\_kg}}{100}\right)}{7\ days\ per\ week \times 24\ h\ per\ day}$$

$$\text{AVG\_Packs\_per\_Box\_IMP} = \sum_{\text{Pack\_Type}} (\text{Proportion\_DC} \times \text{Packs\_per\_box}) \times \frac{1}{100}$$

$$\text{AVG\_Packs\_per\_box\_DOM} = \frac{\sum_{\text{Processors supplying DC}}\left[\text{Prob\_Pro\_DC} \times \frac{\sum_{X=\text{SP}}^{X=\text{W}}(\text{BOX\_PER\_W\_}X)}{4} \times \text{AVG\_Packs\_per\_Box}\right]}{\sum_{\text{Processors supplying DC}}\left[\text{Prob\_Pro\_DC} \times \frac{\sum_{X=\text{SP}}^{X=\text{W}}\text{BOX\_PER\_W\_}X}{4}\right]}$$

7 DC_Imported_Packages

The DC_Imported_Packages table describes the proportion of each Pack_Type imported by each distribution centre. The fields included in the DC_Imported_Packages table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
DC_ID	Integer	Unique number given to each distribution centre
Pack_Type	Double	Unique identifier for each type of package
Proportion_DC	Double	Proportion of each Pack_Type imported yearly by each distribution centre (%)

Assembling a complete list of imported package types for each produce distribution centre was not feasible because of the large number of SKUs (stock keeping units) handled by each. After consulting the web sites of several lettuce processors in the U.S.A, three different pack types (identified as Pack_Type 16 to 18 and representing small, medium and large size packs) were used to describe imported minimally processed lettuce. Since distribution centres did not specify the proportion of each pack type being imported, it was assumed that each pack type was ordered in equal proportions.

8 Transit_DC_to_RS

Individual retail stores receive produce from a single distribution centre. The Transit_DC_to_RS table identifies the retail stores being supplied by each distribution centre, the probability of product being shipped from a distribution centre to each retail store, the transit time between the distribution centre and the retail store, and time-temperature data for the packaged product during transit. The fields included in the Transit_DC_to_RS table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Transit_ID	Integer	Unique number given to the transit between a distribution centre and a retail store
DC_ID	Integer	Unique number given to each distribution centre
DC_Arena_ID	Integer	Identification number used in Arena program for each distribution centre
Retail_ID	Integer	Unique number given to each retail store
Retail_Arena_ID	Integer	Identification number used in Arena program for each retail store
Prob_DC_RS	Double[1]	Probability of RTE leafy greens to be shipped from a distribution centre to a retail store
SUM_Prob_DC_RS	Double[1]	Sum of probability values associated with each distribution centre
Transp_DC_RS	Integer	Time required for transportation from distribution centre to retail store - based on optimum route and speeds set for the various segments of the route (min)
MinUnloading_DC_RS	Integer	Minimum time spent unloading trailer during delivery to retail stores (e.g. Minimum number of retail stores on a trailer's delivery route X 20 min per retail store) (min) - (Note: 20 min unloading time per store is based on time reported by one distribution centre)
AvgUnloading_DC_RS	Integer	Average time spent unloading trailer during delivery to retail stores (e.g. Average number of retail stores on a trailer's delivery route X 50 min per retail store) (min) (Note: 50 min unloading time per retail store is based on time-temperature trials)
Delay_prob0	Integer	Transit time for the first time step of the continuous distribution statement describing the Transit_Time_DC_RS (min)

Attribute name	Data type	Description
Delay_prob1	Integer	Transit time for the second time step of the continuous distribution statement describing the Transit_Time_DC_RS (min)
Delay_prob2	Integer	Transit time for the third time step of the continuous distribution statement describing the Transit_Time_DC_RS (min)
Delay_prob3	Integer	Transit time for the fourth time step of the continuous distribution statement describing the Transit_Time_DC_RS (min)
Transit_Time_DC_RS	String	Range of time required for transit of processed lettuce from distribution centre to retail store (min)
T_DC_RS_SP	String	Temperature distribution of RTE leafy greens during transit from distribution centre to retail store during spring (estimated from time-temperature trials) (°C)
T_DC_RS_SU	String	Temperature distribution of RTE leafy greens during transit from distribution centre to retail store during summer (estimated from time-temperature trials) (°C)
T_DC_RS_F	String	Temperature distribution of RTE leafy greens during transit from distribution centre to retail store during fall (estimated from time-temperature trials) (°C)
T_DC_RS_W	String	Temperature distribution of RTE leafy greens during transit from distribution centre to retail store during winter (estimated from time-temperature trials) (°C)

[1] Value fixed at 4 decimal places

The territory serviced by each DC was obtained during a survey of Canadian produce distribution centres conducted in 2011. An approximate territory was assigned for each of the three produce distribution centres for which no information was provided during the survey (DC_ID 60, 61, and 64).

The probability of RTE leafy greens being shipped from a distribution centre to a retail store (Prob_DC_RS) was calculated with the following equation. Note: For attributes varying based on the season, *X* used in the attribute name must be replaced by one of the four seasons (e.g. SP, SU, F or W).

$$\text{Prob\_DC\_RS} = \frac{\sum_{X=\text{SP}}^{X=\text{W}} \text{BOX\_PER\_W\_RS\_}X}{\sum_{X=\text{SP}}^{X=\text{W}} \text{BOX\_PER\_W\_DC\_}X}$$

The time required for transportation from the distribution centre to the retail store (Transp_DC_RS) was calculated using the "Calculate Transit Time" tool in CanGRASP. The fastest path option was used as it was assumed that processors use the quickest route to reach their destination rather than the shortest one in distance. The road network used for this calculation consists of a system of interconnected road elements. Each element was defined based on a multi-level hierarchy of road classifications, as described in Section 2.5 Transit_Processor_to_DC.
The transit time between a distribution centre and a retail store (Transit_Time_DC_RS) is comprised of three parts: the transportation time (Transp_DC_RS), the unloading time at the retail store, and a delay consisting of any time spent in the transport trailer either before leaving the distribution centre or before being unloaded at the retail store. The unloading and delay times were estimated from time-temperature data recorded during trials conducted in a commercial retail distribution chain in 2010 and 2011. An average unloading time of 50 min per retail store was calculated for deliveries monitored during these trials. Since delivery trailers often drop off orders at several retail stores along a delivery route, the unloading time calculated for each Transit_ID was equal to the average unloading time (e.g. 50 min) multiplied by the average number of retail stores per route as reported by the distribution centres during a survey conducted in 2011. The delay time varied significantly from trial to trial therefore a continuous distribution statement was calculated for the delay times recorded during both series of time-temperature trials. For each Transit_ID, the related transportation and unloading times were added to each time step in the continuous distribution statement of the delay time to obtain the continuous distribution statement of the transit time.
The Delay_prob# attributes are calculated values consisting of the sum of the transportation time (Transp_Pro_DC), the unloading time (AvgUnloading_DC_RS) and individual time steps of the continuous distribution statement describing the delay time. The Delay_prob# values are concatenated together with the probabilities associated with each time step to obtain the continuous distribution statement for the transit time (Transit_Time_DC_RS).

9 Retail_stores

The Retail_stores table includes the retail stores of five major food retail chains in Canada. (Note: Partial information is also included on the retail stores of a sixth major food retail chain). There are a total of 2969 retail stores, in this table, spread across ten Canadian provinces and two territories. The Retail_stores table describes the location of each retail store, the retail chain affiliated with each store, the produce distribution centre servicing each retail store, the population that would be affected by a contamination incident in each retail store, the quantity of RTE leafy greens received by each banner of retail store on a weekly and daily basis, and time-temperature data for the product during storage at the retail store. The fields included in the Retail_stores table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Retail_ID	Integer	Unique number given to each retail store
Retail_Arena_ID	Integer	Identification number used in Arena program for each retail store
GROUP_NAME	String	Name of retail chain

Attribute name	Data type	Description
Retail_Name	String	Name of retail banner
Address	String	Street address
City	String	City
Province	String	Newfoundland = NF; Nova Scotia = NS; Prince Edward Island = PE; New Brunswick = NB; Quebec = QC; Ontario = ON; Manitoba = MB; Saskatchewan = SK; Alberta = AB; British Columbia = BC; Northwest Territories = NT; Yukon = YT
Postal_code	String	Postal code
Latitude	Double	Latitude
Longitude	Double	Longitude
DC_ID	Integer	ID of distribution centre supplying the retail store
AffPop	Double[1]	Affected population calculated based on the population density in a service area covering a 5 km distance (in urban areas) or a 20 min drive (in rural regions) from each store using the road network
BOX_PER_W_RS_SP	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a weekly basis during spring (box/week)
BOX_PER_W_RS_SU	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a weekly basis during summer (box/week)
BOX_PER_W_RS_F	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a weekly basis during fall (box/week)
BOX_PER_W_RS_W	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a weekly basis during winter (box/week)
PACKS_PER_D_RS_SP	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a daily basis during spring (Packs/day)
PACKS_PER_D_RS_S	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a daily basis during summer (Packs/day)
PACKS_PER_D_RS_F	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a daily basis during fall (Packs/day)

Attribute name	Data type	Description
PACKS_PER_D_RS_W	Integer	Quantity of RTE leafy greens received by each retail store, within a banner, on a daily basis during winter (Packs/day)
T_RS_SP	String	Temperature distribution of RTE leafy greens while held in retail store walk-in cooler during spring (estimated from time-temperature trials) (°C)
T_RS_SU	String	Temperature distribution of RTE leafy greens while held in retail store walk-in cooler during summer (estimated from time-temperature trials) (°C)
T_RS_F	String	Temperature distribution of RTE leafy greens while held in retail store walk-in cooler during fall (estimated from time-temperature trials) (°C)
T_RS_W	String	Temperature distribution of RTE leafy greens while held in retail store walk-in cooler during winter (estimated from time-temperature trials) (°C)
ST_RS_SP	String	Range of time processed lettuce spends in retail store walk-in cooler prior to being moved to retail display area during spring (estimated from time-temperature trials) (min)
ST_RS_SU	String	Range of time processed lettuce spends in retail store walk-in cooler prior to being moved to retail display area during summer (estimated from time-temperature trials) (min)
ST_RS_F	String	Range of time processed lettuce spends in retail store walk-in cooler prior to being moved to retail display area during fall (estimated from time-temperature trials) (min)
ST_RS_W	String	Range of time processed lettuce spends in retail store walk-in cooler prior to being moved to retail display area during winter (estimated from time-temperature trials) (min)

[1] Value fixed at 0 decimal places

The initial list of retail stores was obtained from the authors of the Scotia Capital 2008 report "Store Locator: A Proximity Analysis of over 2,500 Grocery Stores". This list included the location, with longitudinal and latitudinal coordinates, of stores from five major food retail chains

across Canada. In 2011, the list of retail stores was verified and corrected based on information provided on each retail chain's web site. Because of continuous changes in the food retail sector (e.g. new stores being built, existing stores being sold and opening under new banners, or stores closing), the information in the Retail_stores table will need to be verified and updated on an annual basis. When corrections are made in the Retail_stores table, related corrections to the Transit_DC_to_RS table need to be considered.

The total quantities of RTE leafy greens received by each retail store within a banner (BOX_PER_W_RS_SP, BOX_PER_W_RS_S, BOX_PER_W_RS_F, and BOX_PER_W_RS_W) were calculated based on data provided by Canadian produce distribution centres during a survey conducted in 2011.

The quantity of individual packages of RTE leafy greens received by each retail store on a daily basis during each season is calculated with the following equations. When attributes vary depending on the season, *X* used in the attribute name must be replaced by one of the four seasons (e.g. SP, SU, F or W).

$$\text{PACKS\_PER\_D\_RS\_}X = \text{BOX\_PER\_W\_RS\_}X \times \frac{\left[\frac{\text{IMPORT\_DC\_}X}{100} \times \text{AVG\_Packs\_per\_Box\_IMP} + \frac{\text{LOCAL\_DC\_}X}{100} \times \text{AVG\_Packs\_per\_Box\_DOM}\right]}{7\ days\ per\ week}$$

10 Other Data

In addition to the distribution system data, some information such as, transportation routes, demographic data and provincial and municipal data layers are included in the database.

The Canada 2011 Census data is used to estimate the demographic characteristics of each zone of influence, or identify the population associated with each retail store. Since the rule used to calculate the zone of influence of each retail store depended on whether the store was located in an urban or rural area, the Statistics Canada definition of urban versus rural was used. According to Statistics Canada, an urban area in Canada is an area with a population of at least 1,000 people where the density is no fewer than 400 persons per square km^2 (Statistics Canada 2009). Rural areas include all territory lying outside urban areas. In the Census data, each urban area is given an urban area code (UAUID) whereas for rural areas this code is null.

Transportation or road network data is used to calculate the transit times between processors and distribution centres as well as between distribution centres and retail stores. The road network was built based on a multi-level hierarchy of road classifications, such as highways, major roads and local streets, as shown in the following table.

CLASSROUTE	CLASS_NUM	Speed	Speed_RU
Highway	1	90	85
Ramp	2	50	50
Local Road/Street	3	45	30
Local / semi-private	3	45	30
Collector Roads	4	45	30

Express Road (Arterial)	5	80	45
Reserved public transport	6	0.00001	0.00001
Service road	7	0.00001	0.00001
Artery	8	80	30
Local / unknown	9	45	30
Service road	10	0.00001	0.00001
Path	11	0.00001	0.00001
Winter	12	70	50

Appendix 2:

CanGRASP Arena Model Documentation

The model was developed using Arena Discrete Event Simulation Software to simulate the fate of lettuce from entry at processor (bulk) to exit at retail (bag) (Figure 20:). The model starts with bulk lettuce and simulates:

- Packaging (different sizes);
- Storage and shipping delays (time and temperature);
- Shipping logistics (processor to distribution centre to retail locations).
-

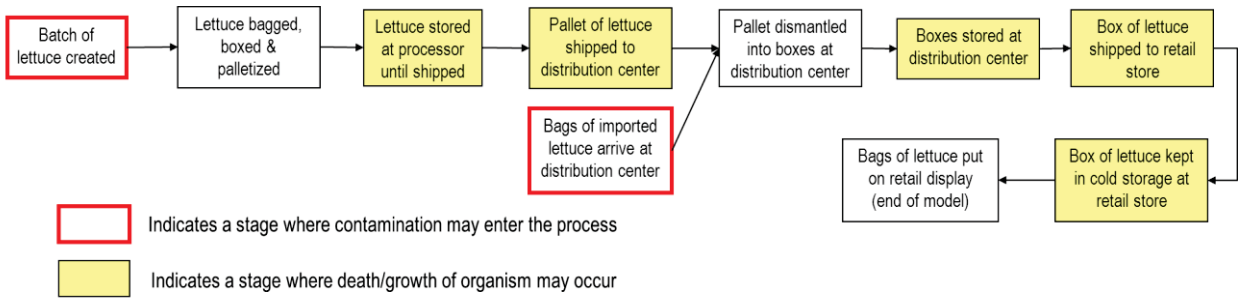


Figure 20: Lettuce supply chain events incorporated into Arena model

Using predictive equations based on the type of contamination (bacteria, virus, parasites, or spores), the model calculates growth, survival, or die-off in the packaged lettuce during storage and shipping, until the point of sale at retail.

A population accessibility analysis was conducted to identify those areas that are at immediate risk as time progresses, and estimate the population affected by the contamination event. A zone of influence is determined for each retail location using a 30 minute driving time for rural areas and 5 km travel distance for urban areas. The population associated with each retail location is calculated, using ArcGIS Spatial Analyst, by intersecting the zone of influence polygon with the census tract.

A Risk Index (RI) was developed to provide a metric to gauge the potential public health risk associated with a contamination scenario in various retail locations. The Risk Index incorporates the population density around a retail location, the proportion of product that is contaminated, and the average level of contamination in the product (Hashemi Beni et al., 2012). The Risk Index is used by ArcGIS to classify the zone around each retail store based on the relationship between population, prevalence and concentration.

The integrated simulation tool (CanGRASP, Canadian GIS-based Risk Assessment, Simulation and Planning for Food Safety), consists of a three-tab user interface. The simulation tab (Figure 21) allows the user to select several parameters for simulation:

- Season when contamination event occurs
- Number of replications to perform during simulation
- Type of contamination (Viruses, Parasites, Gram-negative bacteria, Bacteria spores)
- Source(s) of contamination (Processor or Distribution Centre)
- Kilograms contaminated at each source
- Level of concentration at each source (CFU/kg)
- If a recall will occur for the product, the time the recall begins and how effective the recall is at the Distribution Centre or Retail

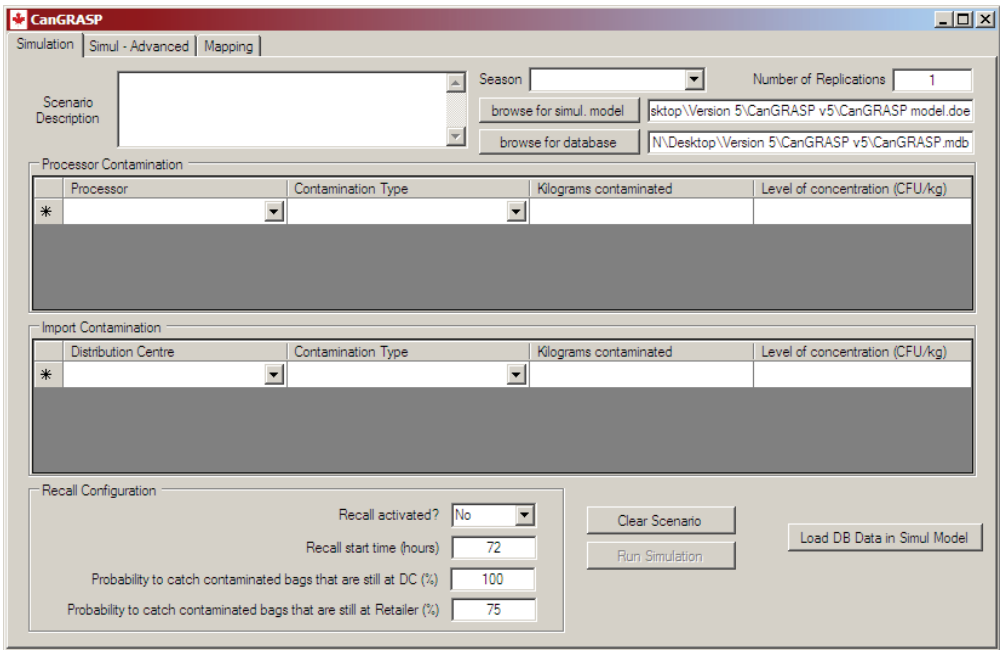


Figure 21: CanGRASP User Interface (Simulation Tab Shown)

The CanGRASP user interface also includes an advanced simulation tab (Figure 22), in which the user may specify:

- Probability of routing consecutive pallets/boxes at a location to the same destination (separate fields for Process to Distribution Centre and Distribution Centre to Retail)
- Temperature profiles occurring during storage and/or transit (a temperature may be set for all lettuce at a certain step in the supply chain, or temperature may be indicated for specific locations and/or transit routes)

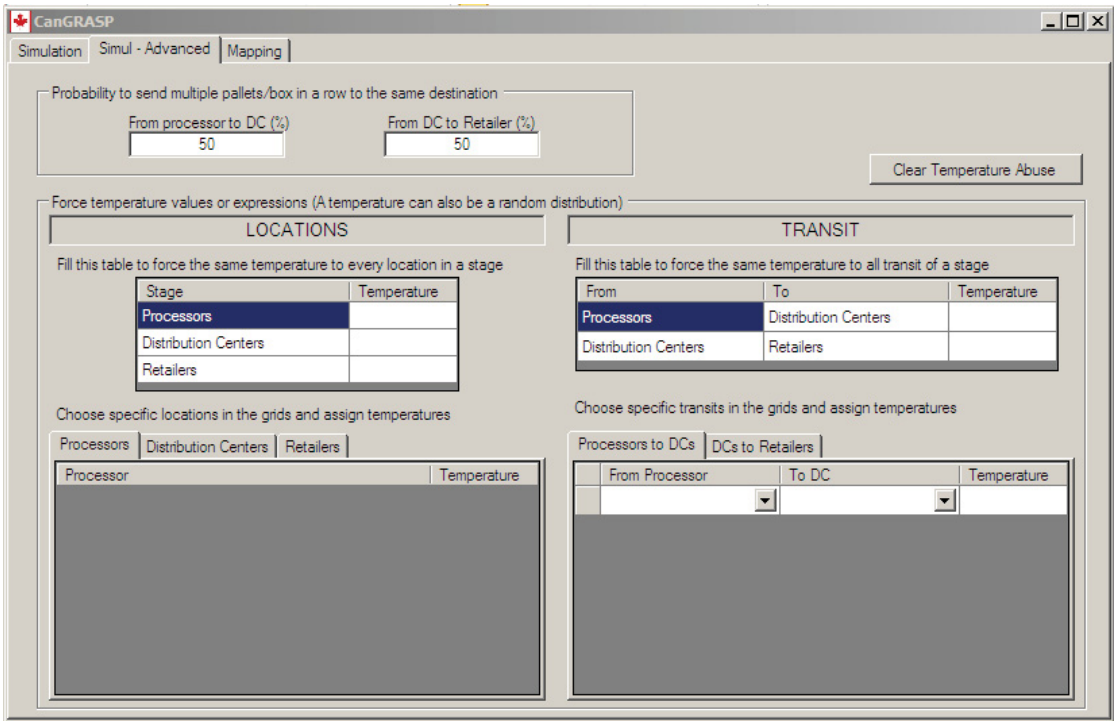


Figure 22: CanGRASP User Interface (Advanced Simulation Tab Shown)

Once the user has entered information for the desired scenario, the Run Simulation button allows the inputs to be used by Arena through Visual Basic (VB) programming. The Arena file is automatically run and outputs the results to an Access database for analysis with ArcGIS. After the simulation is run, the mapping tab is used to access ArcGIS tools that automatically analyse the simulation results, dynamically map the spatial distribution of contaminated product over time, and quantify its public health impact.

Using the Identify tool on the mapping tab of the user interface, a user can click on one retail location and obtain the mean contamination level at that location on that day, the prevalence of the contamination, the population potentially affected by the incident, and the risk index.

As only contaminated product is of interest in determining potential risk to consumers, packaged lettuce which is free of contamination is not considered within the Arena simulation. The model simulates batches of lettuce at only those Processors and/or Importers indicated by the user to have contaminated product in a given scenario. The model stops simulating batches from those processors once the specified amount of contaminated lettuce has entered the supply chain.

The conceptual flow of was translated into the Arena simulation software to create the base Arena model flow of Figure 23. The model is separated into six subsystems for simulating both the physical movement of packaged lettuce in the supply chain and the contamination levels within packages due to the time and temperature profiles experienced during storage and transit. The subsystems have been colour coded to ease explanation of the model and it is assumed the reader is familiar with the Arena simulation environment.

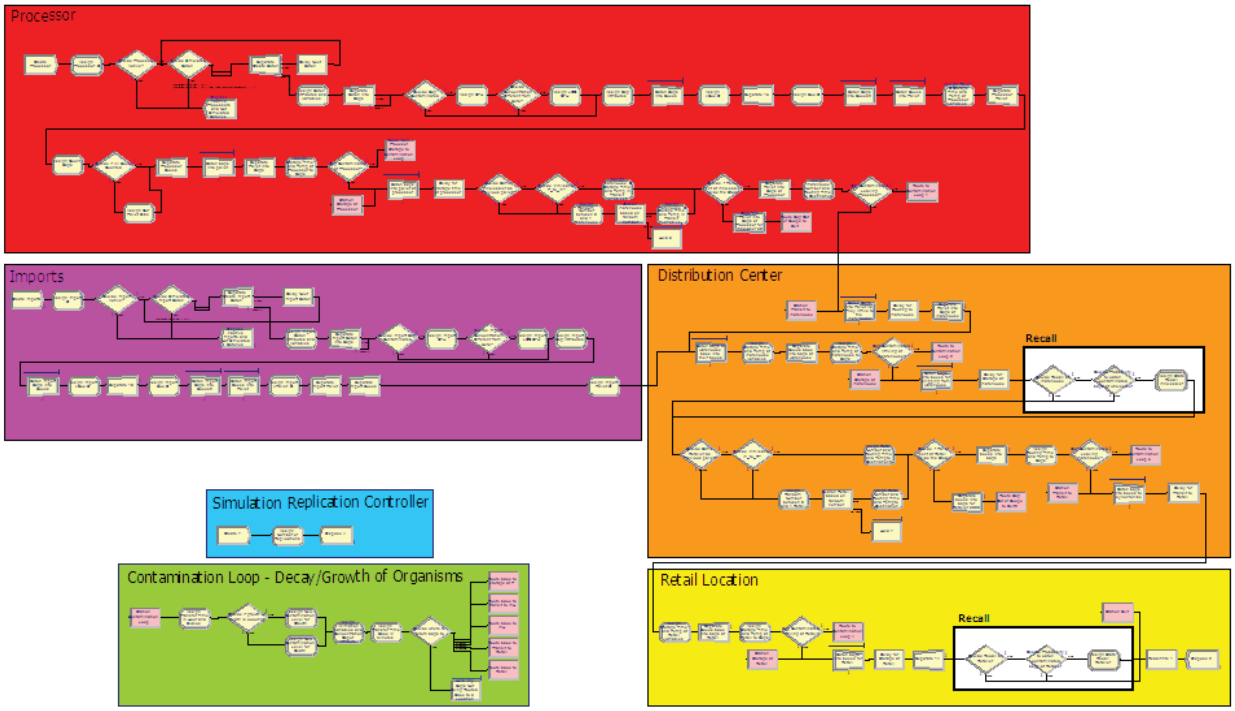


Figure 23: Arena Model Flow

The Simulation Replication Controller module (indicated in blue within Figure 23 and separately in Figure 24), is a logic-based sub-system which sets the number of replications to be performed. Typical use of Arena would have the user set the number of replications through the Run>Setup menu tab, but for the tool the replications are set through the CanGRASP User Interface, requiring the number of replications to be provided to Arena with a logic entity.

i. A create module creates one entity at time zero in the simulation.
ii. The logic entity enters an assign module, where the number of replications, MREP (Arena variable for maximum number of replications) are set:
    - MREP = vSimulationTime(4)
iii. The logic entity is then removed from the simulation with a dispose module.

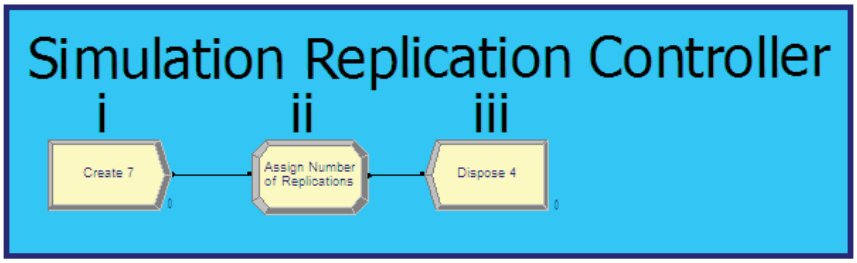


Figure 24: Simulation Replication Controller Subsystem

Domestic lettuce and imported bulk lettuce are introduced within the model's Processor system (indicated in red within Figure 23). The model flow within the Processor system is listed

below, with module numbers corresponding to those labelled within Figure 25: Processor Subsystem.

1. An entity is created for each Processor that exists in the database. These entities are created at time 0.0001, rather than at the initiation of the model simulation, to allow for modules i-iii in the Simulation Replication Controller to be completed before simulating the lettuce product. The number of entities created is set as UBOUNDROW("expProcessorInput"), the number of rows in the expression expProcessorInput (equivalent to the number of Processors data exists for in the Canadian supply chain).
2. Each Processor is assigned an attribute to identify them by a unique number and an attribute for the type of contamination present in the batch of lettuce within an assign module.
    - vIndex = vIndex+1
    - aProcessor = vIndex
    - aContaminationType = vContamination(aProcessor,1)
3. A decide module is used to determine if a Processor is active in the simulation, based on the production level of the Processor in the season as recorded in the industry survey. If a Processor is inactive in that season, it is removed from the simulation (even if the user specified contaminated lettuce). The value tested for in the 2-way by condition decide module is:
    - expProcessorInput(aProcessor,3*vSimulationTime(7)) > 0
4. The Processor entity has now entered a logic loop to create batches of lettuce from an active Processor. The first step is a decide module to determine if a batch should be created, based on the amount of contaminated lettuce the Processor was indicated to have and the amount already packaged within the simulation. If all lettuce at a Processor has been packaged the Processor entity is disposed of. If there is remaining lettuce to package, the entity moves on in the logic loop. The conditions tested in the N-way by condition decision module are:
    - vbOnlyContaminated(1) == 0
    - vbOnlyContaminated(1) == 1 .and. vContamination(aProcessor,2) > 0
5. A separate module then creates a duplicate entity, considered the batch entity within the model. The Processor entity remains within the logic loop, while the batch entity (holding the same attributes as its parent Processor entity) exits the logic loop.
6. The Processor entity is then held in a delay module for 1 hour, at which time it returns to the decide module #4 and is directed to either be removed or create another batch of packaged lettuce.
7. After creation, the batch entity is given several attributes within an assign module:
    - vBatchID = vBatchID+1, since the variable is not set at the beginning of the simulation, it holds the default Arena value of 0, resulting in the first batch entity initiating the consecutive values at 1.
    - aBatchID = vBatchID, assigning a unique identification number to the batch represented by the entity.
    - aBatchVolume = expProcessorInput(aProcessor,vSimulationTime(7)*3), which points to a row and column, respectively within the expression ProcessorInput. vSimulationTime(7) points to row 7 of the SimulationTime variable, the cell

representing the season the simulation takes place during; multiplying this value by 3 is a pointer to the correct column for each Processor's hourly production rate (for example, the seasons are represented as 1,2,3,4 for spring, summer, fall and winter, respectively and the production rates for these seasons are found in columns 3,6,9 and 12, respectively).

- aBagVolumeID = DISC(expProcessorInput(aProcessor,13), 1, expProcessorInput(aProcessor,14), 2, expProcessorInput(aProcessor,15), 3, expProcessorInput(aProcessor,16), 4, expProcessorInput(aProcessor,17), 5, expProcessorInput(aProcessor,18), 6, expProcessorInput(aProcessor,19), 7, expProcessorInput(aProcessor,20), 8, expProcessorInput(aProcessor,21), 9, expProcessorInput(aProcessor,22), 10, expProcessorInput(aProcessor,23), 11, expProcessorInput(aProcessor,24), 12, expProcessorInput(aProcessor,25), 13, expProcessorInput(aProcessor,26), 14, expProcessorInput(aProcessor,27), 15, expProcessorInput(aProcessor,28), 16, expProcessorInput(aProcessor,29), 17, expProcessorInput(aProcessor,30), 18, expProcessorInput(aProcessor,31), 19, expProcessorInput(aProcessor,32), 20), a discreet distribution based on the cumulative probabilities of bag size in columns 13 through 32 of expProcessorInput, representing the 20 bag sizes noted in the industry survey. It is assumed that a batch is only made up of one bag size, since it represents a short period of production time (1 hour).
- aBagVolume = vBagSizes(aBagVolumeID,1), as the first column of the BagSizes variable holds the volume, in kilograms, each bag ID represents.
- vNumberOfBagsInBatch = ANINT(aBatchVolume / aBagVolume), calculated as the integer value of the batch volume divided by the bag volume.
- aArrivalTime = TNOW, a universal Arena function to assign the model's current time stamp to the attribute. This may be used to track the bag's movement by time with the output results.

8. The batch entity then enters a separate module, in which duplicate entities are created, the number created is calculated as vNumberOfBagsInBatch-1, so that when the original and duplicates enter the next module there are as many entities as the calculated value for the number of bags in the batch (the batch entity has now become a bag entity). All bag entities retain the attributes that were assigned to the parent batch entity.
9. All bag entities enter a decide module to determine which bags are contaminated and assign contamination accordingly. This is done with the if statement, if(vContamination(aProcessor,2)>0), to determine if there is contaminated product at the Processor the bag originated from. Column two of the Contamination variable represented the volume in kilograms of the contaminated product the user specified before simulation. If there is contamination entities are sent to module #10, if not they proceed to module #13.
10. If the contaminated volume is greater than zero, the bag enters an assign module where the contamination level of the bag, aContamination is set as:
    - aConcentration= POIS(aBagVolume*vContamination(aProcessor,3)), vContamination(aProcessor, 3) points to the level of contamination within a contamination batch, with units of CFU/kg.

    The assign module also adjusts the volume of contamination held as:

- vContamination(aProcessor,2) = vContamination(aProcessor,2) – aBagVolume

This allows for the previous decide module to stop labelling bag entities as contaminated once the user specified volume of contaminated lettuce has been packaged within the simulation.

11. The bag entity then enters a decide module to determine if the concentration within the bag was set to a value above zero, as the Poisson distribution will allow for zero values. Bags with a concentration value of zero are sent to module #13, others continue to module #12.
12. Bag entities with aConcentration set above zero enter an assign module, to convert the concentration value to a log value:
    - aConcentration = LOG(aConcentration).

    Since the aConcentration attribute represents a bag's concentration based on its current point in the distribution chain, the attribute aInitialConcentration is introduced to hold a record of the bag's initial concentration:
    - aInitialConcentration = aConcentration

    A binary attribute, abConcentration is also set to one, to easily indicate the bag is contaminated at the point of packaging:
    - abConcentration = 1
13. All bag entities then enter an assign module, where a unique bag identification number is assigned, in the same method as was done for batch numbers.
    - vBagID = vBagID+1,
    - aBagID = vBagID.

The bag entities now go through a series of modules that simulate the bags being packaged into boxes and pallets for shipping so that the model realistically simulates bags produced consecutively being shipped together, and the effect this aspect of the distribution chain has on the spread of contaminated bags to Canadian consumers. Due to the nature of assigning attributes within Arena, the entities are batched and separated several times, to allow attributes to be assigned to each individual entity.

14. The bags enter a batch module, where entities are batched by attribute aProcessor and the batch size is set to vBagSizes(aBagVolumeID,2), as the second column in the bag size variable holds data regarding the number of bags packaged per box based on the volume of the bags considered.
15. All box entities are then directed to an assign module, where the variable vBoxID is set to vBoxID+1. The attribute is not set at this time as it needs to be applied to the individual bag entities since applying an attribute the batched box entity will not bwe stored by the bags once the boxes are separated.
16. The box entities enter a separate module, where the batch is split into the original bag entities (with the member attributes set to retain their original entity values).
17. The bag entities enter an assign module, where aBoxID is set, allowing the bags to be identified by the box they are packaged within:
    - aBoxID = vBoxID
18. The bag entities again enter a batch module, being batched by attribute aBoxID to batch sizes of vBagSizes(aBagVolumeID,2), replicating the initial batch into boxes module.

19. The box entities enter another batch module, again batched by attribute aProcessor and with batch sizes of vBagSizes(aBagVolumeID,3), as the third column in the bag size variable holds data regarding the number of boxes shipped per pallet based on the volume of the bags considered.
20. An assign module is used to assign variables values relevant to the pallet entity:
    - vPalletID = vPallet ID + 1
    - vTime = expProcessorInput(aProcessor, 3*(vSimulationTime(7) – 1) + 2)
    - vTemp = expProcessorInput(aProcessor, 3*(vSimulationTime(7) – 1) + 1)
    - vCurPalletBoxCount = NG, NG is a pointer within Arena for the number of entities in the grouped entity
21. vCurPalletSize = 1000000
22. The pallet entity is then split back into box entities with a separate module, with the members retaining their original entity attribute values.
23. The box entities then enter an assign module for counting the number of bags contained on the pallet:
    - vCurPalletSize = vCurPalletSize + NG
    - vCurPalletBoxCount = vCurPalletBoxCount – 1
24. A decide module is used to determine if all of the boxes on a pallet have been counted, with the condition if vCurPalletBoxCount > 0. If the condition is true, not all boxes have yet been counted and the box entity is directed to a separate module (#25), if the condition is false the box entity is directed to an assign module (#24).
25. An assign module is used to adjust the variable for the number of bags on a pallet once the last box for the current pallet passes through the decide module of #23, with the equation vCurPalletSize = vCurPalletSize – 1000000. This adjustment removes the place holder value of one million that was given in module #20.
26. All box entities are then divided back into bag entities with a separate module, all members retain their original entity attribute values.
27. The individual bags are then batched into a pallet with size equivalent to vCurPalletSize.
28. The pallet entity is split back into bag entities with a separate module, with all entities retaining their original attribute values.
29. The bag entities enter an assign module so that the pallet attributes may be assigned:
    - aPalletID = vPalletID
    - aTime = vTime
    - aTemp = vTemp
    - aoTimeTempCon(1) = aTime/60
    - aoTimeTempCon(2) = aTemp
    - aPalletSize = vCurPalletSize
30. The bags then enter a decide module, to determine if individual bags are contaminated so that they may be routed to the contamination loop (Figure 27) to determine the new contamination levels based on the time and temperature experience of the bag while at the Processor. The check within the module is if abContaminatedBag == 1, so that those bags identified in module #12 as contaminated are routed to the contamination loop. Uncontaminated bags do not enter the contamination loop module calculations.
31. Bag entities identified as contaminated enter a route module and are sent to the Contamination Loop station, with a routing time of zero minutes.

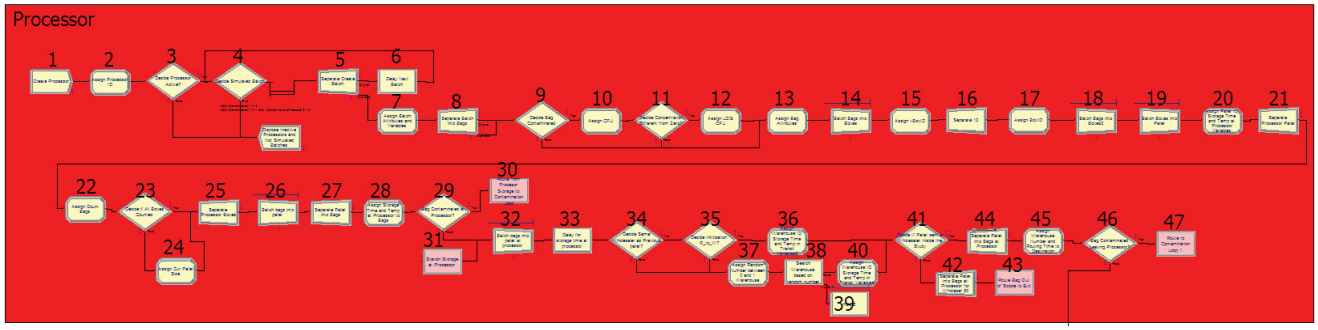


Figure 25: Processor Subsystem

Rather than creating modules for calculating changes in a bag's contamination level at all storage and transit stages within the model, a single set of modules was created and used to perform these calculations when required, shown in Figure 27: Contamination Loop Subsystem. The route and station modules available in the advanced transfer toolbar of Arena are utilized for moving bag entities from the supply chain systems to the contamination loop and back. Routing times of zero hours are applied for all transfers, so the transfer of the bags does not affect the timing they experience when simulating the supply chain.

The calculations made to calculate contamination levels are given by equations 1-2b below. The values of variables x,b,T_{min} and k_{max} are based on the type of organism being considered and are stored in the Arena expressions for the model. More details on these equations and corresponding variable values are provided in the microbiological studies section of the report.

$$\log N = \log N_0 + (R*t/x) \quad (1)$$

$$R = \text{if}(T>5, R_{Growth}, R_{Death}) \quad (2)$$

$$R_{Growth} = (b*(T-T_{min}))^2 \quad (2a)$$

$$R_{Death} = -k_{max} \quad (2b)$$

a. Contaminated bag entities arrive at the contamination loop station module.
b. An assign module is used to convert the time attribute from units of minutes to hours, as well as set the B variable required for the calculations, which varies with the type of contamination being modelled.
    - aTime = aTime/60
    - vBValue = expBInput(aContaminationType)
c. A decide module determines if the bag will experience an increase or decrease in the concentration of contamination, based on the temperature it experiences during the specific stage of storage or transit it is in. The determination is made with the statement aTemp > expGrowthDeathTemp(aContaminationType), as this expression holds the threshold temperature value where decay of an organism no longer occurs and the potential for growth exists.
    - If the temperature is above the threshold, the bag is sent to an assign module for calculating the rate of growth and also calculating the new concentration value for the organism contaminating the product:
        - vRate = (vBValue*(aTemp-expTMin(aContaminationType)))**2

        - aConcentration = aConcentration + (vRate*aTime/expXConstant(aContaminationType))
    - If the temperature is below the threshold, the bag is sent to an assign module for calculating the rate of decay and also calculating the new concentration value for the organism contaminating the product:
        - vRate = expDeathRate(aContaminationType,3) + LOGN(expDeathRate(aContaminationType,1), expDeathRate(aContaminationType,2))
        - aConcentration = aConcentration – (vRate*aTime/expXConstant(aContaminationType))

d. Once the current concentration level is calculated for the bag entity, variable and attribute values needed for the animation results are set within an assign module:
    - voContamination(aStep,1) = voContamination(aStep,1)+1
    - voContamination(aStep,2) = voContamination(aStep,2) + 10**aConcentration
    - voContamination(aStep,3) = LOG(voContamination(aStep,2)/voContamination(aStep,3))
    - voContamination(aStep,4) = voContamination(aStep,4) + aBagVolume
    - aoTimeTempCon(aStep*3) = aConcentration
e. The time value for the current step is then calculated back to units of minutes with an assign module:
    - aTime = aTime*60
f. A decide module determines which stage in the supply chain a bag entity should be returned to, based on the aStep value which is unique to each step, using the N-way by condition option for the type of decision.
g. As a fail-safe, if the aStep value of a bag entity does not equal an integer from 1 through 5, the bag is sent to a hold module.
h. Bag entities which have an aStep value of 1,2,3,4 and 5 are sent to route modules and sent to stations for storage at Processor, transit from Processor to Distribution Center (DC), storage at DC, transit from DC to Retail and storage at Retail, respectively. All routing times are set to zero hours.

The animation mentioned in module *d* above is not shown in Figure 23, but can be seen in the main Arena window, to the right of the subsystems. The animation of Figure 26 allows the user to view the movement of contaminated bags within the supply chain at all five steps and an average level of contamination. The animation is not intended to be used in the final CanGRASP Tool, but was useful during design iterations and debugging of the Arena model component of CanGRASP.

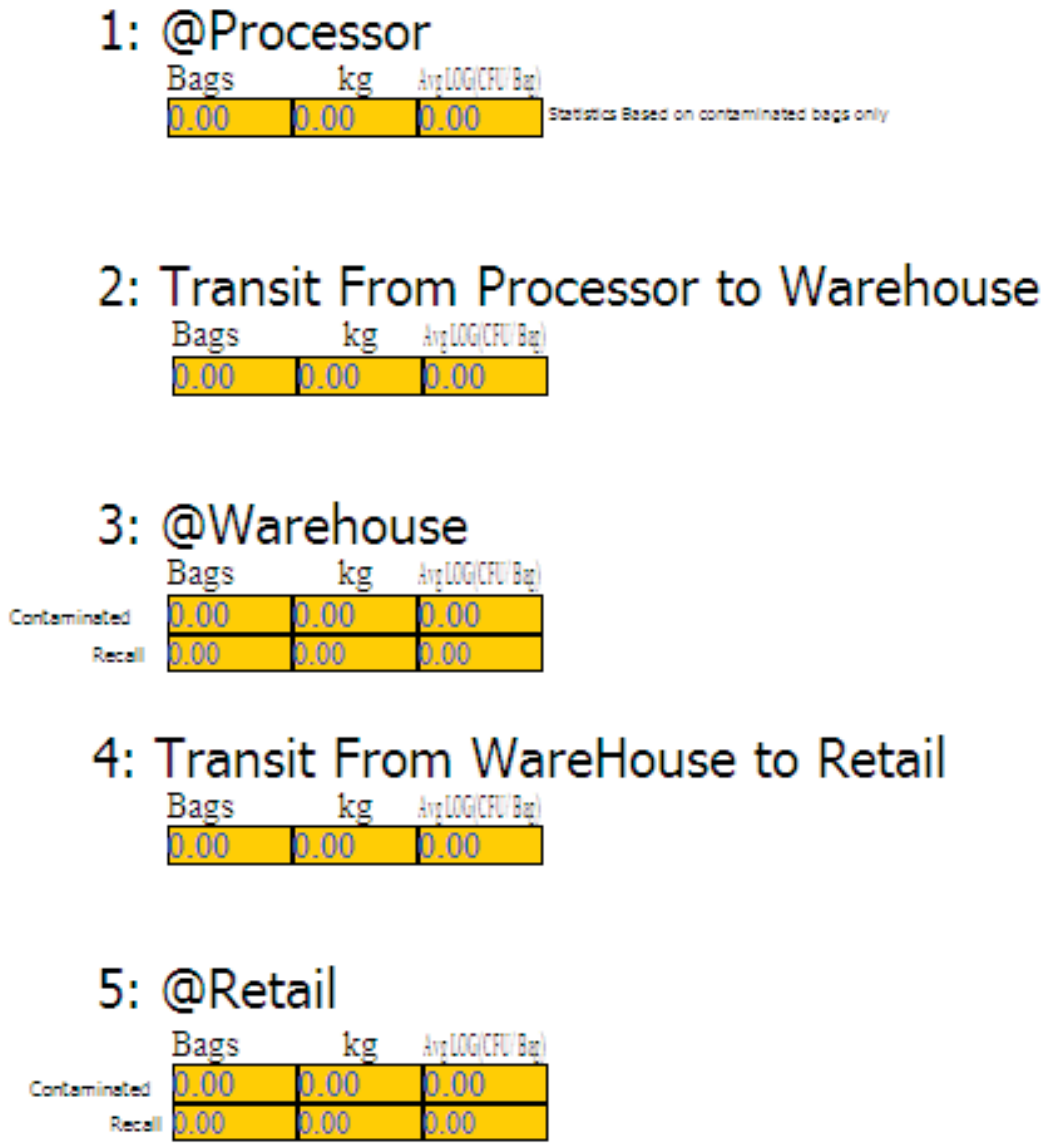


Figure 26: In-model Animation of Bag Statistics

It is important to note that the third step in the supply chain for the simulation, the Distribution Center, is referenced by the acronym DC in the written description of the model, but in the Arena annotation is referred to as Warehouse, Wholesaler or W. The change to DC was to be consistent with other building blocks of the tool, such as the Access database. The terms are interchangeable within the report.

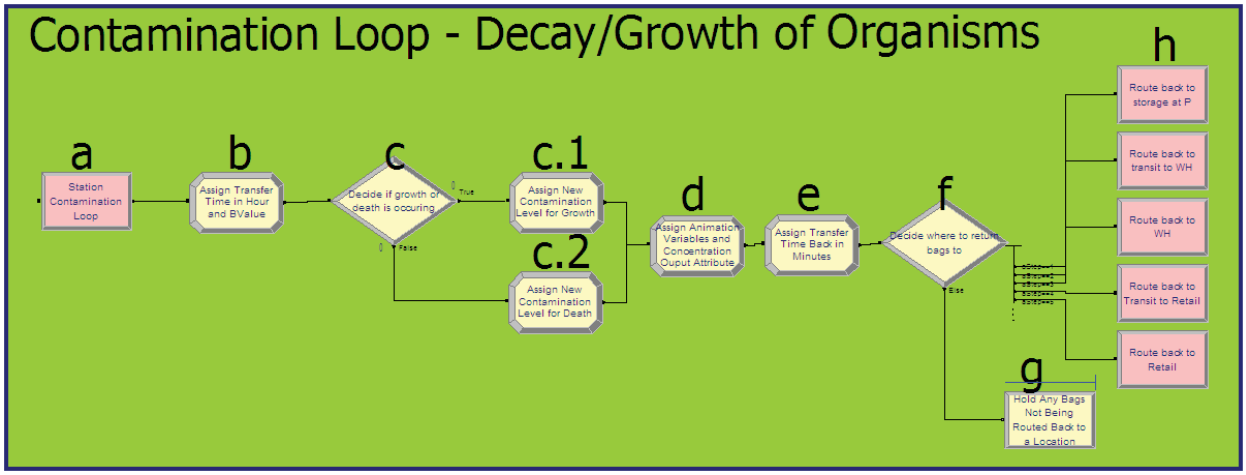


Figure 27: Contamination Loop Subsystem

31. Contaminated bag entities arrive at the storage at Processor station once completing the contamination loop.
32. Bag entities that were determined to be free from contamination in module #29, as well as contaminated bags arriving at the station of module #31 enter a batch module. The bags are batched by attribute value aPalletID, in a batch size equivalent to aPalletSize. This results in all bags on a common pallet being combined for simulating storage time at the Processor and shipping to the DC.
33. Pallet entities enter a delay module, simulating the time delay due to storage at the Processor. The delay time is set to aTime (with units of minutes).
34. A decide module is utilized to determine if a pallet will be shipped to the same DC as the previous pallet shipped from the same Processor. This is to simulate the reality of shipping orders to one DC with consecutive production, in the interest of efficiency for the Processor and how this practice in manufacturing may affect the spread of contamination. The probability of pallets following the previous pallet is set but the user, with a default of 50%. The decision is made 2-way by chance, with a percent truth set as vProbSameDestination(1).
35. Pallet entities which were determined to follow the previous pallet's destination then enter a second decide module. The module checks that vWarehouse(aProcessor) <> 0, creating a fail-safe in the event that a pallet has not yet left the Processor the pallet is originating from in the current simulation. If this module was not included, the first pallet from each Processor would have the possibility of being assigned a value for vWarehouse of zero, in module #45.
36. If vWarehouse is not equal to zero, the pallet entity enters an assign module, to set the variables for transit to the DC:
    - vTime = expTransit_P_W_Time(aProcessor,vWarehouse(aProcessor))
    - vTemp = expTransit_P_W_Temp(10*(vSimulationTime(7)-1)+aProcessor, vWarehouse(aProcessor))
37. If the pallet entity does not follow the shipping path of the previous pallet in #34 or is determined to be the first pallet shipped from a Processor in #35 then it is sent to an

assign module to randomly determine the DC it will be shipped to. A random number from 0 through 1 is assigned as:

- aRandNum = UNIF(0,1)

38. A search module is then used to determine the DC, using the number generated in the previous module, with a search condition of aRandNum <= vTransit_P_W_Prob(aProcessor, J). A starting value of zero and an ending value of UBOUNDCOL("vTransit_P_W_Prob") specified.
39. In the event a DC is not determined in #38, the pallet entity is sent to a hold module as a fail-safe.
40. Once a DC is found in #38, the pallet entity enters an assign module, to set the variables for transit to the DC:
    - vWarehouse(aProcessor) = J
    - vTime = expTransit_P_W_Time(aProcessor, vWarehouse(aProcessor)
    - vTemp = expTransit_P_W_Temp(10*(vSimulationTime(7)-1) + aProcessor, vWarehouse(aProcessor))
41. All pallet entities enter a decide module to verify that the DC assigned falls within the scope of the tool's dataset, as was done for the Processor in module #3. This is accomplished by verifying vWarehouse(aProcessor) <> UBOUNDCOL("Transit_P_W_Prob").
42. If the DC is determined to not meet the conditions of #41, the pallet entity is sent to a separate module to split the pallet into the original bag entities.
43. The bag entities no longer within the simulation scope enter a route module which sends them to the Exit Station (module #117), with a route time of zero hours.
44. Pallet entities determined to ship to a DC within the scope of the simulation in #41 enter a separate module, splitting the pallet into the original bag entities for the purpose of assigning attributes.
45. The bag entities enter an assign module, to assign the DC and transit attributes previously set as variables for their pallet, reset aStep to a value of 2 (representing that the entities are now in the second stage of the supply chain, transit to the DC) and to assign output file attributes for the transit to DC stage:
    - aWarehouse = vWarehouse(aProcessor)
    - aTime = vTime
    - aTemp = vTemp
    - aStep = 2
    - aoTimeTempCon(4) = aTime/60
    - aoTimeTempCon(5) = aTemp
46. A decide module is used as the final Processor Subsystem module, determining as in module #29 if individual bags are contaminated so that they may be routed to the contamination loop (Figure 27). The check within the module is if abContaminatedBag == 1.
47. Contaminated bags enter a route module which sends them to the contamination loop with a route time of zero hours. The bag entity then follows modules a-h in the contamination loop as previously described.
48. Contaminated bags in stage 2 of the supply chain (aStep=2), are routed out of the contamination loop to a station module representing their arrival at the DC. The

subsequent module and first module in the DC Subsystem (Figure 29) for these bag entities will be module #73.

The model considers both domestically packaged lettuce, as modelled with in the Processor Subsystem of Figure 25, and foreign packed lettuce imported to Canada, as modelled in Figure 18. Since both of these subsystems feed into the DC Subsystem of Figure 29, the Import Subsystem (Figure 28) is described prior to continuing the supply chain path of the bag entities from the Processor as they enter the DC Subsystem. While bags appear to be simulated at the foreign processor or Importer, there is no accounting for growth or death of microorganisms in the imported bags of lettuce until the time and temperature profile for storage at the DC is introduced in the DC Subsystem.

49. An entity is created for each foreign processor (Importer) importing contaminated packages of lettuce within the scenario. These entities are created at time 0.0002, to allow for the Simulation Replication Controller modules and the creation of Processor entities to be completed before simulating the imported lettuce product. The number of entities created is set as UBOUNDROW("expImportInput").
50. Each Importer is assigned an attribute to identify them by a unique number and an attribute for the type of contamination present in the lettuce within an assign module.
    - vIndexImport = vIndexImport+1
    - aImport = vIndexImport
    - aContaminationType = vContaminationImport(aImport,1)
    - aWarehouse = aImport

Since data collection for the industry survey was done with domestic Processors and Distribution Centers, the imported package lettuce volumes originated from the DCs providing responses to the survey, rather than from the foreign Processor or Importer. This means that the data available for development of the simulation was simply the volume of prepackage lettuce arriving at domestic DCs through import. Therefore, the import entities do not represent true foreign processors, but rather placeholders for the imports into each DC. For example, Importer 1 corresponds to the packaged lettuce imported to DC 1, as DC 1 indicated in the industry survey.

51. The Importer entity enters a decide module to determine if the Importer is active within the simulation based on the production level of the Importer in the season as recorded in the industry survey. If an Importer is inactive in that season, it is removed from the simulation (even if the user specified contaminated lettuce). If the Importer is active, it enters a logic loop consisting of modules #52, 54 and 55 in which batches are created. The condition in the module is set as expImportInput(aImport,vSimulationTime(7)) > 0.
52. Importer entities determined to be active in the simulation move to a second decide module to determine if a batch should be simulated. Entities continue on to batch simulation in module #54 if one of the following conditions is satisfied. The first conditions relates to the user indicating that all product should be modelled (vbOnlyContaminated = 0, not only contaminated); the second condition relates to the user indicating only contaminated product should be modelled and that there is contaminated product at the importer still to package.
    - vbOnlyContaminated(1) == 0
    - vbOnlyContaminated(1) == 1 .and. vContaminationImport(aImport,2) > 0

53. If an entity is determined to not be active in the simulation in #51, or that a batch should not be simulated in #52, the entity is sent to a dispose module and removed from the simulation.
54. Importer entities that are to have batches created enter a separate module which creates a duplicate entity, considered the batch entity within the model. The Importer entity remains within the logic loop, while the batch entity (holding the same attributes as its parent Importer entity) exits the logic loop to module #56.
55. The Importer entity is then held in a delay module for 1 hour, at which time it returns to the decide module #52 and is directed to either be removed or create another batch of packaged lettuce.
56. After creation, the batch entity is given several attributes within an assign module:
    - vBatchID = vBatchID + 1
    - aBatchID = vBatchID
    - aBatchVolume = expImportInput(aImport,vSimulationTime(7))
    - aBagVolumeID = DISC(expImportInput(aImport,5), 1, expImportInput(aImport,6), 2, expImportInput(aImport,7), 3, expImportInput(aImport,8), 4, expImportInput(aImport,9), 5, expImportInput(aImport,10), 6, expImportInput(aImport,11), 7, expImportInput(aImport,12), 8, expImportInput(aImport,13), 9, expImportInput(aImport,14), 10, expImportInput(aImport,15), 11, expImportInput(aImport,16), 12, expImportInput(aImport,17), 13, expImportInput(aImport,18), 14, expImportInput(aImport,19), 15, expImportInput(aImport,20), 16, expImportInput(aImport,21), 17, expImportInput(aImport,22), 18, expImportInput(aImport,23), 19, expImportInput(aImport,24), 20)
    - aBagVolume = vBagSizes(aBagVolumeID,1)
    - vNumberOfBagsInBatch = ANINT(aBatchVolume / aBagVolume)
    - aArrivalTime = TNOW
57. The batch entity then enters a separate module, in which duplicate entities are created, the number created is calculated as vNumberOfBagsInBatch-1, so that when the original and duplicates enter the next module there are as many entities as the calculated value for the number of bags in the batch (the batch entity has now become a bag entity). All bag entities retain the attributes that were assigned to the parent batch entity.
58. All bag entities enter a decide module, to determine which bags are contaminated, and assign contamination accordingly. This is done with the if statement, if(vContamination(aImport,2)>0), to determine if there is contaminated product at the Importer the bag originated at. Column two of the Contamination variable represented the volume in kilograms of the contaminated product the user specified before simulation.
59. If the contaminated volume is greater than zero, the bag enters an assign module where the contamination level of the bag, aContamination, is set with the Poisson distribution to POIS(aBagVolume*vContaminationImport(aImport,3)). vContaminationImport(aImport, 3) points to the level of contamination within a contamination batch, with units of CFU/kg. The assign module also adjusts the volume of contamination held as vContaminationImport(aImport,2) to be the current value, less the volume of the bag entity. This allows for the previous decide module to stop labelling bag entities as

contaminated, once the user specified volume of contaminated lettuce has been packaged within the simulation:

- vContaminationImport(aImport,2) = vContaminationImport(aImport,2) - aBagVolume

60. The bag entity then enters a decide module to determine if the concentration within the bag was set to a value above zero, as the Poisson distribution will allow for zero values, the frequency of which is determined by the concentration and bag volume product.
61. Bag entities with aConcentration set above zero enter an assign module, to convert the concentration value to a log value, by setting aConcentration to LOG(aConcentration). Since the aConcentration attribute represents a bag's concentration based on its current point in the distribution chain, the attribute aInitialConcentration is introduced and set to aConcentration, to hold a record of the bag's initial concentration. A binary attribute, abConcentration is also set to one, to easily indicate the bag is contaminated at the point of packaging.
62. All bag entities are then directed to an assign module from either module #58 or #61, where a unique bag identification number is assigned, in the same method as was done for batch numbers.
    - vBagID = vBagID+1,
    - aBagID = vBagID.
63. The bags enter a batch module, where entities are batched by attribute aImport and the batch size is set to vBagSizes(aBagVolumeID,2), as the second column in the bag size variable holds data regarding the number of bags packaged per box based on the volume of the bags considered.
64. All box entities are then directed to an assign module, where the variable vBoxID is set to vBoxID+1.
65. The box entities enter a separate module, where the batch is split into the original bag entities (with the member attributes set to retain their original entity values).
66. The bag entities enter an assign module, where aBoxID is set equal to vBoxID, allowing the bags to be identified by the box they are packaged within.
67. The bag entities again enter a batch module, being batched by attribute aBoxID to batch sizes of vBagSizes(aBagVolumeID,2), replicating the initial batch into boxes module.
68. The box entities enter another batch module, again batched by attribute aImport and with batch sizes of vBagSizes(aBagVolumeID,3), as the third column in the bag size variable holds data regarding the number of boxes shipped per pallet based on the volume of the bags considered.
69. An assign module is used to assign variables values relevant to the pallet entity:
    - vPalletID = vPallet ID + 1
70. The pallet entity is then split back into box entities with a separate module, with the members retaining their original entity attribute values.
71. The box entity is then split back into bag entities in a separate module, with the members retaining their original entity attribute values.
72. As the final module of the Imports Subsystem, an assign module is used to set the pallet ID attribute to each bag entity. Import bag entities:
    - aPalletID = vPalletID

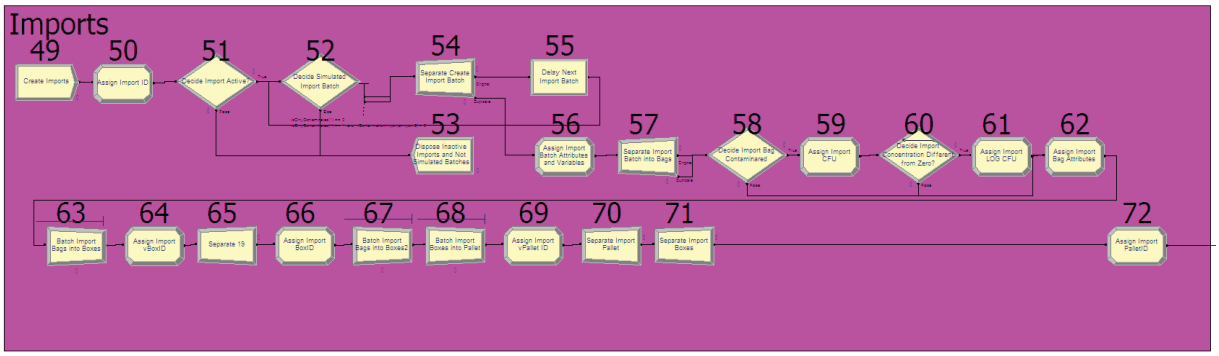


Figure 28: Imports Subsystem

73. Domestically packaged bags of lettuce arrive in a batch module from modules #46 and #48, the bag entities are combined once again into their pallet entity to simulate the delay time for shipping. The batch size is set as aPalletSize and they are batched by attribute aPalletID.
74. The Pallet entity enters a delay module, with a delay time in minutes of aTime. This delay represents the time the pallet experiences during shipping from the Processor to DC, which is based on the geographical locations and a travel time calculated using GIS software.
75. The pallet entity enters a separate module where the batch is split into the original bag entities, with all entities retaining their original attributes.
76. All simulated bag entities enter a batch module, with domestically packaged product arriving from module #75 and imported packages arriving from module #72. The bags are batched into their previously determined boxes, with a batch size of vBagSizes(aBagVolumeID,2) and are batch by attribute aBoxID.

In the Processor Subsystem variables and attributes were often applied to a pallet as a whole (all bags on a pallet experiencing the same time, temperature and destination), to reflect the fact that complete pallets are typically shipped to DCs. In the DC Subsystem(Figure) however, variables and attributes are often applied to boxes, rather than pallets or bags. It was discovered through the industry survey that pallets are typically dismantled at the DC, with various numbers of boxes being shipped to Retailers.

77. The box entity enters an assign module to set the time and temperature profile the bags within the box will experience while at the DC:
    - vTemp = expWholesalerInput(aWarehouse, vSimulationTime(7)*2-1)
    - vTime = expWholesalerInput(aWarehouse, vSimulationTime(7)*2)
78. The box entity enters a separate module so that individual bag entities may have attributes applied. The batch is split with entities retaining their original values.
79. An assign module is used to set DC relevant attributes to each bag entity:
    - aTime = vTime
    - aTemp = vTemp
    - aStep = 3
    - aoTimeTempCon(7) = aTime/60
    - aoTimeTempCon(8) = aTemp

80. Each bag entity enters a decide module to determine if it is contaminated, with the condition abContaminatedBag == 1.
81. Bags determined to meet the condition in module #80 and are therefore contaminated enter a route module and are directed to the contamination loop, following modules a-h as previously described to determine the new concentration level in the bag after storage at the DC.
82. Contaminated bags return from the contamination loop to a station module representing storage at the DC when they are labelled as in step 3 of the supply chain (aStep = 3).
83. Contaminated bags from station module #82 and uncontaminated bags from decision module #80 all enter a batch module, to return the bag entities to box entities. They are batched by attribute aBoxID in batch sizes of vBagSizes(aBagVolumeID,2).
84. The box entities enter a delay module to simulate the time spent in storage at the DC, with the delay time set as aTime.
85. The box entity then enters the recall logic of module #85-87. A decision module determines if a recall has occurred in the simulation, with the condition vRecall(1) == 1 .and. TNOW > vRecall(2). If a recall is specified by the user, vRecall(1), a binary variable, is set to one, and the user specified time for recall to begin is stored in vRecall(2).
86. If a recall has been initiated as determined in module #85, the box entity enters a second decision matrix, to determine if the box is captured in the recall. The user specifies the probability of recalled product being removed from the supply chain at both the DC and a retail location, storing the values in vRecall. A decision module therefore places a probability of vRecall(3) for a box entity to be recalled, and 1-vRecall(3) for it to be missed in the recall while at the DC.
87. Boxes which are recalled while at the DC, from module #86, enter an assign module to set recall variables for the output file, and the attribute aRecalled to mark the bag as recalled at the DC. Bags continue in the supply chain during the simulation, so that a quick assessment of the recall's effectiveness within the supply chain can be done, looking at where the bags would have been consumed and at what concentration levels if the recall was not conducted.
    - voRecall(1,1) = voRecall(1,1) + 1
    - voRecall(1,2) = voRecall(1,2) + aConcentration
    - voRecall(1,3) = voRecall(1,2)/voRecall(1,1)
    - voRecall(1,4) = voRecall(1,4) + aBagVolume
    - aRecalled = 1
88. Box entities arrive at a decision module from #85 when a recall has not been initiated, from #86 when a recall is initiated but the box is not captured, and from #87 when a box is captured in a recall. As in module #34 at the Processor, a decide module is utilized to determine if a box will be shipped to the same Retailer as the previous box shipped from the same DC. The probability of pallets following the previous pallet is set but the user, and the module's condition specified as 2-way by chance with a probability of vProbSameDestination(2).
89. Box entities which were determined to follow the previous box's destination then enter a second decide module. The module checks that vRetail(aWarehouse) <> 0, creating a fail-safe in the event that a box has not yet left the DC the box is originating from in the

current simulation. If this module was not included, the first box from each DC would have the possibility of being assigned a value for vRetail of zero, in module #88.

90. If vRetail is not equal to zero in #89, the box entity enters an assign module, to set the variables for transit to the Retailer:
    - vTime = expTransit_W_R_Time(vRetail(aWarehouse))
    - vTemp = expTransit_W_R_Temp(vRetail(aWarehouse),vSimulationTime(7))
91. Box entities that do not follow the previous box in module #88, or are found to be the first box leaving a DC in #89 are directed to a set of modules to determine the Retailer the box will be shipped to, similar to the method used in modules #37-40 in the Processor subsystem. The box entity enters an assign module to randomly determine the Retailer it will be shipped to. A random number from 0 through 1 is assigned as:
    - aRandNum = UNIF(0,1)
92. A search module is then used to determine the Retailer, using the number generated in the previous module, with a search condition of aRandNum <= (vTransit_W_R_Prob(J,2) * (vTransit_W_R_Prob(J,1)==aWarehouse)). A starting value of zero and an ending value of UBOUNDCOL("vTransit_W_R_Prob") specified.
93. In the event a retailer is not determined in #92, the pallet entity is sent to a hold module as a fail-safe.
94. Once a Retailer is found in #92, the box entity enters an assign module, to set the variables for transit to the Retailer:
    - vRetail(aWarehouse) = J
    - vTime = expTransit_W_R_Time(vRetail(aWarehouse))
    - vTemp = expTransit_W_R_Temp(vRetail(aWarehouse),vSimulationTime(7))
95. All box entities enter a decide module to verify that the Retailer assigned falls within the scope of the tool's dataset, as was done for the Processor in module #3 and DC in module #41. This is accomplished by verifying vRetail(aWarehouse) <> UBOUNDROW("vTransit_W_R_Prob").
96. If the Retailer is determined to not meet the conditions of #95, the box entity is sent to a separate module to split the box into the original bag entities.
97. The bag entities no longer within the simulation scope enter a route module which sends them to the Exit Station (module #117), with a route time of zero hours.
98. Box entities determined to ship to a Retailer within the scope of the simulation in #95 enter a separate module, splitting the box into the original bag entities for the purpose of assigning attributes.
99. The bag entities enter an assign module, to assign the Retailer and transit attributes previously set as variables for their box, reset aStep to a value of 4 (representing that the entities are now in the fourth stage of the supply chain, transit to the Retailer) and to assign output file attributes for the transit to retail stage:
    - aRetail = vRetail(aWarehouse)
    - aTime = vTime
    - aTemp = vTemp
    - aStep = 4
    - aoTimeTempCon(10) = aTime/60
    - aoTimeTempCon(11) = aTemp

100. A decide module is used to determine if individual bags are contaminated so that they may be routed to the contamination loop (Figure 27). The check within the module is if abContaminatedBag == 1.
101. Contaminated bags enter a route module which sends them to the contamination loop with a route time of zero hours. The bag entity then follows modules a-h in the contamination loop as previously described.
102. Contaminated bags in stage 4 of the supply chain (aStep=4), are routed out of the contamination loop to a station module representing their arrival at retail. The subsequent module for these bag entities will be module #103.
103. Uncontaminated bags from module #100 and contaminated bags returning from the contamination loop to module #102 then enter a batch module, to batch bag entities back into their box entity for shipping to retail. The batch size is set as vBagSizes(aBagVolumeID,2), and bags are batched by attribute aBoxID.
104. The final module in the DC subsystem of Figure is a delay module, representing the time delay introduced during shipping from the DC to retail. The delay time is set as aTime in minutes. The box entities leave this module to enter the Retail Location subsystem of Figure 30.

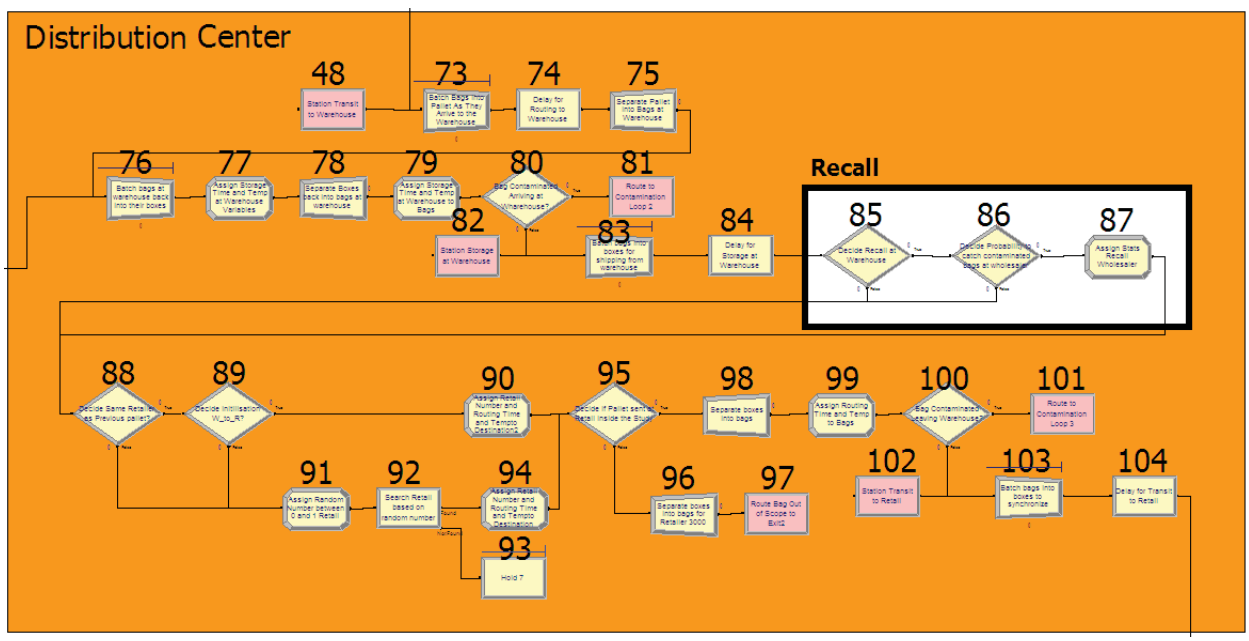


Figure 29: Distribution Center Subsystem

The simulation flow for bags in retail is shown as the yellow subsystem within Figure 23, and in more detail in Figure 30. It is assumed that changes in concentration levels may change during storage at retail based on the time and temperature profiles a bag endures, but that the concentration at the time of retail display is the concentration a Canadian consumer is exposed to at the time of consumption. No modelling occurs for the packaged lettuce after the time of display at retail.

105. The box entities arrive at an assign module, the first in the retail location subsystem (Figure 30), where the time and temperature the bags will experience at the Retailer are set:

- vTemp = expRetailerInput(aRetail, 1 + 2*(vSimulationTime(7)-1))
- vTime = expRetailerInput(aRetail, 2*vSimulationTime(7))

106. The box entity is then split into the original bag entities with a separate module. All entities retain their original attribute values.
107. An assign module is used to set retail location specific attributes to the bag entity:
    - aTime = vTime
    - aTemp = vTemp
    - aStep = 5
    - aoTimeTempCon(13) = aTime/60
    - aoTimeTempCon(14) = aTemp
108. A decide module is used to determine if individual bags are contaminated so that they may be routed to the contamination loop (Figure 27). The check within the module is if abContaminatedBag == 1.
109. Contaminated bags enter a route module which sends them to the contamination loop with a route time of zero hours. The bag entity then follows module a-h in the contamination loop as previously described.
110. Contaminated bags in stage 5 of the supplychain (aStep=5), are routed out of the contamination loop to a station module representing storage at retail.
111. Contaminated bags arriving at module #110 and uncontaminated bags from module #108 all arrive at a batch module that batches bag entities into their box entity for storage at retail. The batch size is set as vBagSizes(aBagVolumeID,2) and the bags are batched by attribute aBoxID.
112. The box entity enters a delay module, representing the time the box and bags it contains, spend in the retailer's storage before display. The delay time is specified as aTime in minutes.
113. The box is then split back into the original bag entities with a separate module and all entities retain their original values.
114. The bag entity then enters the recall logic of module #114-116. A decision module determines if a recall has occurred in the simulation, with the condition vRecall(1) == 1 .and. TNOW > vRecall(2). If a recall is specified by the user, vRecall(1), a binary variable, is set to one, and the user specified time for recall to begin is stored in vRecall(2).
115. If a recall has been initiated as determined in module #114, the bag entity enters a second decision matrix, to determine if the bag is captured in the recall. The user specifies the probability of recalled product being removed from the supply chain at both the DC and a retail location, storing the values in vRecall. A decision module therefore places a probability of vRecall(4) for a bag entity to be recalled, and 1-vRecall(4) for it to be missed in the recall while at retail.
116. Bags which are recalled while at retail, from module #115, enter an assign module to set recall variables for the output file, and the attribute aRecalled to mark the bag as recalled at Retailer. Bags continue in the supply chain during the simulation, so that a quick assessment of the recall's effectiveness within the supply chain can be done, looking at where the bags would have been consumed and at what concentration levels if the recall was not conducted.
    - voRecall(2,1) = voRecall(2,1) + 1

- voRecall(2,2) = voRecall(2,2) + aConcentration
- voRecall(2,3) = voRecall(2,2)/voRecall(2,1)
- voRecall(2,4) = voRecall(2,4) + aBagVolume
- aRecalled = 2

117. Module #117 is a station module, referred to as Station Exit. Bags arrive here from route modules #43 and #97 when pallets and boxes were determined to be shipped to DCs and retailers, respectively, outside of the simulation dataset.

118. All bag entities pass through the readwrite module, which writes the following data to an Access output file:
    - aBagID
    - aBatchID
    - aBoxID
    - aPalletID
    - aProcessor
    - aWarehouse
    - aRetail
    - NREP
    - aBagVolume
    - aArrivalTime
    - TNOW
    - aRecalled
    - aContaminationType
    - aInitialConcentration
    - aoTimeTempCon(1)
    - aoTimeTempCon(2)
    - aoTimeTempCon(3)
    - aoTimeTempCon(4)
    - aoTimeTempCon(5)
    - aoTimeTempCon(6)
    - aoTimeTempCon(7)
    - aoTimeTempCon(8)
    - aoTimeTempCon(9)
    - aoTimeTempCon(10)
    - aoTimeTempCon(11)
    - aoTimeTempCon(12)
    - aoTimeTempCon(13)
    - aoTimeTempCon(14)
    - aoTimeTempCon(15)
    -

119. The final module of the simulation is a dispose module, where bag entities are removed as they arrive at the end of the supply chain. This removal from the system signals their purchase at retail by a Canadian consumer.

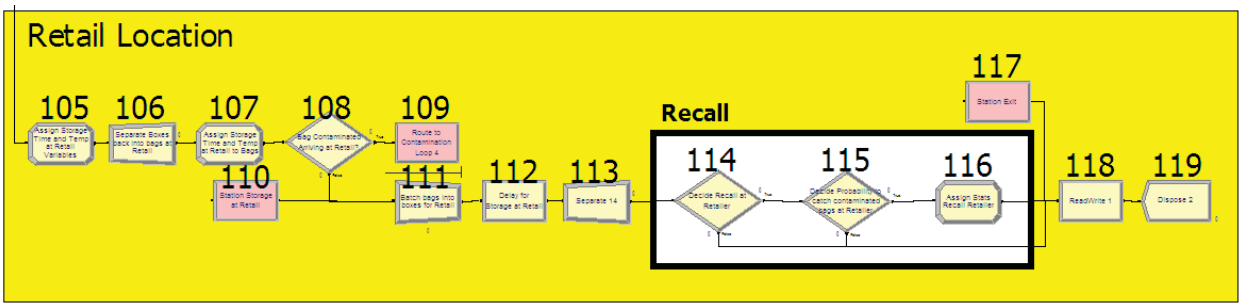


Figure 30: Retail Location Subsystem

Attribute, variable & expression tables:
The following tables provide details on the attributes, variable and expressions used within the Arena model. Tables 8 and 9 provide descriptions of each attribute, variable and expression used within the Arena model. Tables10 through 16 are used to describe some of the more complicated variables, mainly those utilizing the matrix function within Arena. Similarly, Tables 17 through 27 are used to describe some of the more complicated expressions.

Table 8: List of Attributes assigned to Entities within the Arena Model

Attribute	Rows*	Description
aArrivalTime		indicates the time within the model the package was created, units of hours
aBagID		unique number assigned to each package for identification
aBagVolume		volume (kg) of package
aBatchID		unique number assigned to batches, for identification of packages from the same batch
aBatchVolume		volume (kg) of lettuce in the batch
abContaminatedBag		binary attribute, with 1 denoting a bag of packaged lettuce contaminated
aBoxID		unique number assigned to a box, for identification of packages from the same box
aConcentration		current concentration within a package, may have units of CFU or logCFU depending on the module being examined.
aContaminationType		coding for the type of contamination within a package (1 for a virus, 2 for parasite, 3 for gram negative bacteria and 4 for bacterial spore)
aImport		unique number assigned to Importer to identify packages' supply chain
aInitialContentration		initial concentration (log CFU) within a package
aoTimeTempCon	15	attribute matrix which stores output attributes to be read to an

		Access file at the end of simulation. Values for time (hours), temperature (°C) and concentration (log CFU) for each of the 5 stages during the supply chain are listed in the attribute.
aPalletID		unique number assigned to pallets, for identification of packages from the same pallet
aPalletSize		number of bags on a pallet
aProcessor		unique number assigned to each Processor to identify packages' supply chain
aRandNum		Random number between 0 and 1, generated for use in modules #38 and #92 when determining the Distribution Center or Retailer, respectively, that a bag will travel to
aRecalled		a value that indicates if a package was recalled during the supply chain and if so where (0 = not recalled, 1 = recalled at DC, 2 = recalled at retail)
aRetail		unique number assigned to each Retailer to identify packages' supply chain
aStep		indicates which step of the supply chain a bag is currently in (1=Processor, 2=Transit from Processor to DC, 3 = DC, 4 = Transit from DC to Retailer, 5 = Retail)
aTemp		temperature a package is experiencing in the current step (°C)
aTime		time a package remains in the current step (most often in units of minutes, converted to hours for the contamination loop and returned to minutes)
aWarehouse		unique number assigned to each Warehouse to identify packages' supply chain

* - attributes with an unspecified quantity of rows have a default value of 1, as in Arena

Table 9: List of Variables within Arena Model

Variable	Rows*	Columns*	Set prior to simulation?	Description
vBagID				A unique number assigned to each bag, stored as this variable for calculation and then set to the attribute
vBagSizes				Variable matrix containing data for each of the 20 possible bag sizes within the model, columns represent volume in kg, bags per box and boxes per pallet.
vBatchID				A unique number assigned to each batch, stored as this variable for calculation and then set to the attribute
vbOnlyContaminated				A binary value to indicate that only contaminated product is simulated in the model
vBoxID				A unique number assigned to each box, stored as this variable for calculation and then set to the attribute

vBValue				Variable used to hold the current B value for the growth equation during the contamination loop
vContamination				Variable matrix containing contaminated product data for each of 10 possible processors within the model. Columns represent coding for the type of contamination, volume of contaminated lettuce per processor in kg, and the level of contamination in CFU/kg as entered by the user.
vContaminationImport				Variable matrix containing data for each of 50 possible importers (one for each DC within the model). Columns represent coding for the type of contamination, volume of contaminated lettuce per processor in kg, and the level of contamination in CFU/kg as entered by the user.
vCurPalletBoxCount				Holds the current value for the number of boxes on the current pallet
vCurPalletSize				Holds the total number of bags on the current pallet, used to set aPalletSize
vIndex				Variable used to assign unique numbers to processors as the entities are created in the model
vIndexImport				Variable used to assign unique numbers to importers as the entities are created in the model
vNumberOfBagsInBatch				Variable used to calculate the number of bags in a specific batch so the processor entity may create the correct number of bag entities
voContamination				Variable used to hold values displayed in the Arena animation as the model runs, concerning all contaminated bags. Rows represent the 5 possible steps within the supply chain, while columns are for number of bags, total contamination (CFU), average log CFU/bag and total mass of lettuce.
voRecall				Variable used to hold values displayed in the Arena animation as the model runs, concerning all recalled bags. Rows represent the two steps recall may occur in (DC and retail), while columns are for number of bags, total contamination (CFU), average log CFU/bag and total mass of lettuce.
vPalletID				A unique number assigned to each pallet, stored as this variable for calculation and then set to the attribute.
vProbSameDestination				The probability of pallets following the previous pallet at the Processor or boxes following the previous box at the DC. This is to simulate the reality of shipping orders to one DC with consecutive production, or one retailer with consecutive product received, and how this practice in manufacturing may affect the spread of contamination
vRate				Variable used to hold the current rate value for the growth or death calculations during the contamination loop
vRecall				Variable matrix containing the user specified data for a recall during simulation. Rows represent whether a

				recall is to occur, the time for a recall to begin, the probability of catching a bag at the DC and the probability of catching a bag at retail.
vRetail				Variable representing the retail location a box will be shipped to, held here until set to the attribute aRetail
vSimulationTime				Variable containing the simulation settings entered by the user.
vTemp				Variable used to store the current temperature a bag, box or pallet will experience in a particular stage of the supply chain, then set to the attribute (°C)
vTime				Variable used to store the amount of time a bag, box or pallet will spend in a particular step of the supply chain, then set to the attribute (hours)
vTransit_P_W_Prob				Variable to hold the probability of a pallet being shipped from a specific Processor (represented individually by the 10 rows) to a specific DC (represented individually by the 50 columns)
vTransit_W_R_Prob				Variable to hold the probability of a box being shipped from a specific DC to a specific Retail Location. The 3000 rows represent individual retailers, and since each store is supplied by only one DC, the first column contains a value equivalent to aWarehouse for the supplying DC. The second column then contains the percentage of the supplying DC's product that is sent to the specific retailer.
vWarehouse				Variable representing the DC a pallet will be shipped to, held here until set to the attribute aWarehouse.

* - variables with an unspecified quantity of rows/columns have a default value of 1, as in Arena

Table 10: vBagSizes

	Volume of the bag (kg)	**No. of bags/box when packaged at Processor**	**No. of boxes/pallet when packaged at Processor**
Bag Size 1			
Bag Size 2			
Bag Size 3			
.			
.			
Bag Size 20			

Table 11: vbOnlyContaminated

Binary value to simulate all or only contaminated product (**1**=only contaminated, 0=all)
Unused cell

The format of Table12 is a product of earlier versions of the Arena model and user interface. Initial designs allowed for the user to indicate if all or only contaminated product should be modelled within Arena. During design iterations and refinement of the user interface it was decided that to create a more user friendly tool the run time should be minimized and that this could best be done by eliminating the option to simulate all product. Therefore, the second cell of vbOnlyContaminated is not utilized within the model and the value in the first cell is always 1, there is no option for the user to alter this on the interface.

Table 12: vContamination

	Coding for type of contamination 1 = virus, 2 = parasite, 3 = gram negative bacteria 4 = bacterial sporeformer	**Volume of contaminated lettuce at the Processor (kg)**	**Level of contamination within the lettuce (CFU/kg)**
Processor 1			
Processor 2			
Processor 3			
.			
.			
.			
Processor 10			

Table 13: vContaminationImport

	Coding for type of contamination 1 = virus, 2 = parasite, 3 = gram negative bacteria 4 = bacterial sporeformer	**Volume of contaminated lettuce at the Importer (kg)**	**Level of contamination within the lettuce (CFU/kg)**
DC 1			
DC 2			
DC 3			
.			
.			
.			
.			
.			
DC 50			

Table14: vProbSameDestination

Probability that a pallet leaving a Processor *x* will be shipped to the same DC as the last pallet to ship from Processor *x*
Probability that a box leaving DC *y* will be shipped to the same Retailer as the last box to ship from DC *y*

Table 15: vRecall

Binary value to indicate if a recall occurs in the simulation (1=recall, 0=no recall)
Time (hours after simulation begins) that a recall will occur at
robability for a contaminated bag to be captured at a DC once a recall is initiated
robability for a contaminated bag to be captured at the Retailer once a recall is initiated

Table16: vSimulationTime

Unused cell
Unused cell
Unused cell
Number of replications
Unused cell
Unused cell
Code for season of the year (1,2,3,4 for spring, summer, fall and winter, respectively)
Unused cell

The format of Table 16 is a product of earlier versions of the Arena model and user interface. Initial designs allowed for user inputs that are no longer relevant. For instance, a simulation time in days was requested, but the final version runs for the period of time required for all contaminated product to be put on display at retail or recalled, making this input obsolete and the first cell in which is original resided also obsolete. The references to the fourth and seventh row however were very numerous and it was more practical to keep the 8 row variable than adjust so many references within the Arena model.

Table 17: vTransit_P_W_Prob (only some cells filled as examples, matrix follows simply pattern of data)

	DC 1	**DC 2**	**DC 3**	**…**	**DC 50**
Processor 1	Probability of pallet leaving P1 being shipped to DC 1				Probability of pallet leaving P1 being shipped to DC 50
Processor 2	Probability of pallet leaving P2 being shipped to DC 1				
Processor 3	Probability of pallet leaving P3 being shipped to DC 1				
.	.				
.	.				
Processor 10	Probability of pallet leaving P10 being shipped to DC 1				Probability of pallet leaving P10 being shipped to DC 50

Table 18: vTransit_W_R_Prob

	DC supplying the Retailer	Percent of the DC's product that is sent to the Retailer
Retailer 1		
Retailer 2		
Retailer 3		
.		
.		
Retailer 2999		
Retailer 3000		

Table 19: List of Expressions within Arena Model (all expressions set prior to simulation)

Expression	Rows*	Columns*	Description
expBInput			The B values required for calculating growth, unique value for each type of contamination
expDeathRate			The $-k_{max}$ value corresponding to the death rate, unique value for each type of contamination. This variable is represented by a shifted log normal distribution: the columns hold the mean, standard deviation and shift, respectively.
expGrowthDeathTemp			The temperature (°C) above which growth occurs, below death occurs, unique value for each type of contamination
expImportInput			Inputs specific to lettuce being imported to the supply chain. The 50 rows represent importers (one for each DC which can receive imported product), while columns 1-4 represent the hourly production during each season for an importer and columns 5-24 represent the proportion of product imported in each of the 20 different bag sizes the model allows.
expProcessorInput			Inputs specific to lettuce being produced at each of the 10 possible Processors (1 row for each Processor's data). Columns 1-12 represent seasonal data for the temperature and time experienced by product and the hourly production rate. Columns 13-32 represent the proportion of product packaged in each of the 20 different bag sizes the model allows.

expRetailerInput			Inputs specific to time and temperature experience by product stored at each Retailer. Each row represents a specific retail location, with season temperatures in columns 1,3,5 and 7; seasonal time delays of storage in columns 2, 4, 6 and 8 (seasons spring, summer, fall and winter, respectively).
expTMin			The T_{min} variable value of the rate equation for growth. A unique value for each of the 10 possible contamination types.
expTransit_P_W_Temp			Values for the temperature (°C) experienced by product during transit from a specific Processor to a specific DC. The 50 DCs are represented by columns, while the 10 Processors have 4 values each (one for each season) represented in separate rows.
expTransit_P_W_Time			Values for the time delay (hours) experienced by product for transit from a specific Processor to a specific DC. The 50 DCs are represented by columns, while the 10 Processors are represented in separate rows.
expTransit_W_R_Temp			Values for the temperature (°C) experienced by product during transit to a specific retailer. The 3000 Retailers are represented in separate rows, while the columns represent the temperatures experienced for spring, summer, fall and winter, respectively. There is no need to represent DCs in this expression, as each retail store only receives from one specific DC.
expTransit_W_R_Time			Values for the time delay (hours) experienced by product for transit from its DC to a specific Retailer.
expWholesalerInput			Inputs specific to time and temperature experience by product stored at each DC. Each row represents a specific DC, with season temperatures in columns 1,3,5 and 7; seasonal time delays of storage in columns 2, 4, 6 and 8 (seasons spring, summer, fall and winter, respectively).
expXConstant			The X variable value of the equation for calculating concentration based on the time and temperature experience it has during a stage of the supply chain. A unique value for each of the 10 possible contamination types.

* - expressions with an unspecified quantity of rows/columns have a default value of 1, as in Arena

Table 20: expDeathRate

	Mean value of K_{max}	**Standard deviation of K_{max}**	**Shift for log normal distribution of K_{max}**
Contamination Type 1			
Contamination Type 2			
.			
.			
Contamination Type 10			

Table 21: expImportInput

	Production rate in spring (kg/hr)	**Production rate in spring (kg/hr)**	**Production rate in spring (kg/hr)**	**Production rate in spring (kg/hr)**	**product packaged as bag size 1**	**...**	**product packaged as bag size 20**
Importer 1							
Importer 2							
.							
.							
Importer 50							

Table 22: expProcessorInput

	Temp (°C) at Processor in Spring	**Time (min) spent at Processor in Spring**	**Production rate in Spring (kg/hr)**	**…** ***[6 columns for data concerning summer and fall]***	**Temp (°C) at Processor in Winter**	**Time (min) spent at Processor in Winter**	**Production rate in Winter (kg/hr)**	**Proportion of product packaged as bag size 1**	**Proportion of product packaged as bag size 2**	**…**	**Proportion of product packaged as bag size 20**
Processor 1											
Processor 2											
.											
.											
.											
Processor 10											

Table 23: expRetailerInput

	Temp (°C) spring storage	Time (hr) spring storage	Temp (°C) summer storage	Time (hr) summer storage	Temp (°C) fall storage	Time (hr) fall storage	Temp (°C) winter storage	Time (hr) winter storage
Retailer 1								
Retailer 2								
.								
.								
.								
Retailer 3000								

Table 14: expTransit_P_W_Temp

	DC 1	**DC 2**	.	.	.	**DC 50**
P1 Spring	Temp (°C) during transit P1 to DC 1 in spring	Temp (°C) during transit P1 to DC 2 in spring				Temp (°C) during transit P1 to DC 50 in spring
P1 Summer	Temp (°C) during transit P1 to DC 1 in summer	Temp (°C) during transit P1 to DC 2 in summer				Temp (°C) during transit P1 to DC 50 in spring
P1 Fall	Temp (°C) during transit P1 to DC 1 in fall	Temp (°C) during transit P1 to DC 2 in fall				Temp (°C) during transit P1 to DC 50 in spring
P1 Winter	Temp (°C) during transit P1 to DC 1 in winter	Temp (°C) during transit P1 to DC 2 in winter				Temp (°C) during transit P1 to DC 50 in spring
P2 Spring	Temp (°C) during transit P2 to DC 1 in spring	Temp (°C) during transit P2 to DC 2 in spring				Temp (°C) during transit P2 to DC 50 in spring
.						
.						

P10 Fall	Temp (°C) during transit P10 to DC 1 in fall	Temp (°C) during transit P10to DC 2 in fall				Temp (°C) during transit P10 to DC 50 in fall
P10 Winter	Temp (°C) during transit P10 to DC 1 in winter	Temp (°C) during transit P10 to DC 2 in winter				Temp (°C) during transit P10 to DC 50 in winter

Table 25: expTransit_P_W_Time

	DC 1	**DC 2**	.	.	.	**DC 50**
Processor 1	Time (hr) for transit from P1 to DC 1	Time (hr) for transit from P1 to DC 2				Time (hr) for transit from P1 to DC 50
Processor 2	Time (hr) for transit from P2 to DC 1	Time (hr) for transit from P2 to DC 2				Time (hr) for transit from P2 to DC 50
.						
.						
.						
Processor 10	Time (hr) for transit from P10 to DC 1	Time (hr) for transit from P10 to DC 2				Time (hr) for transit from P10 to DC 50

Table 26: expTransit_W_R_Temp

	Spring Temp (°C)	**Summer Temp (°C)**	**Fall Temp (°C)**	**Winter Temp (°C)**
Retailer 1				
Retailer 2				
.				
.				
Retailer 3000				

Table 27: expWholesalerInput

	Temp (°C) spring storage	Time (hr) spring storage	Temp (°C) summer storage	Time (hr) summer storage	Temp (°C) fall storage	Time (hr) fall storage	Temp (°C) winter storage	Time (hr) winter storage
DC 1								
DC 2								
.								
.								
.								
DC 50								

Appendix 3:

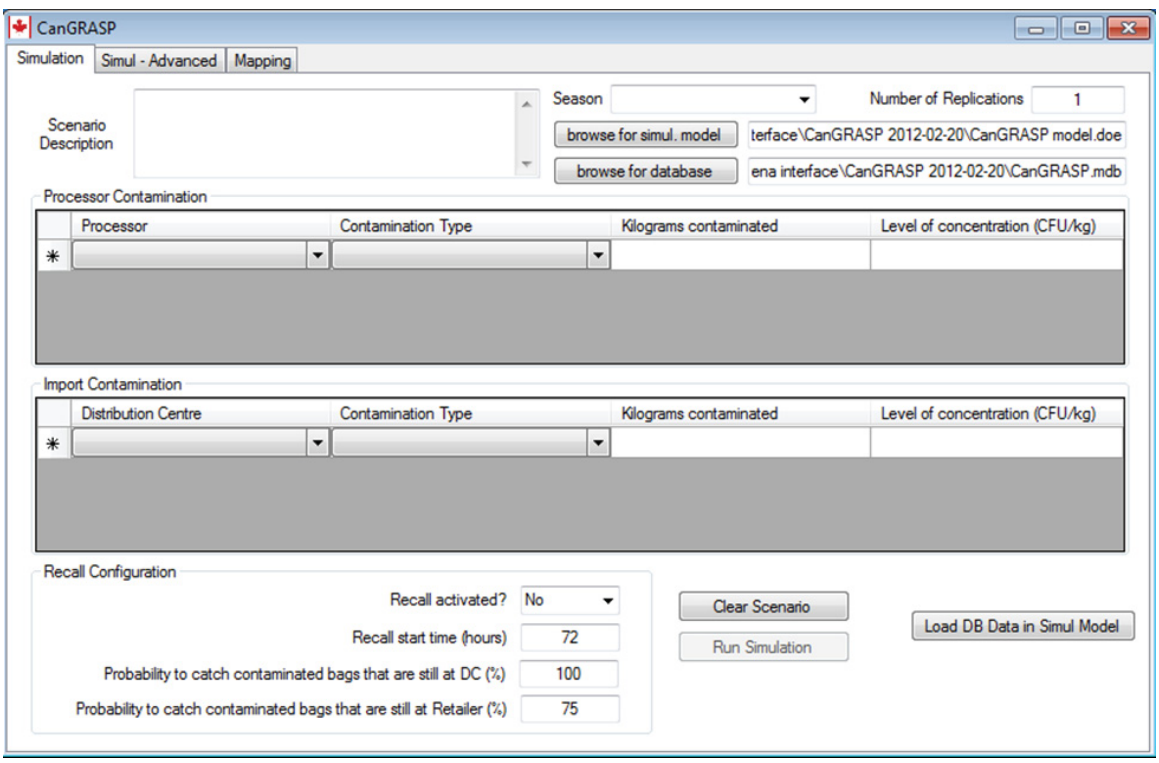
CanGRASP Tutorial: Interface and Tools

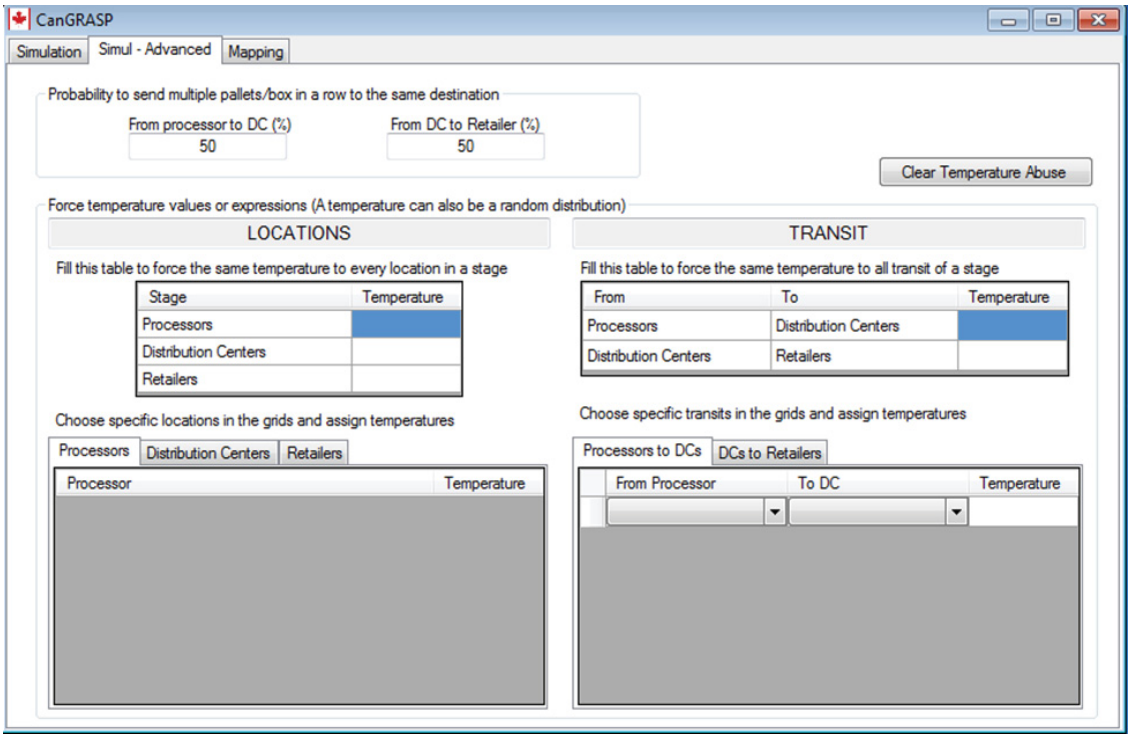
1. CanGRASP Interface

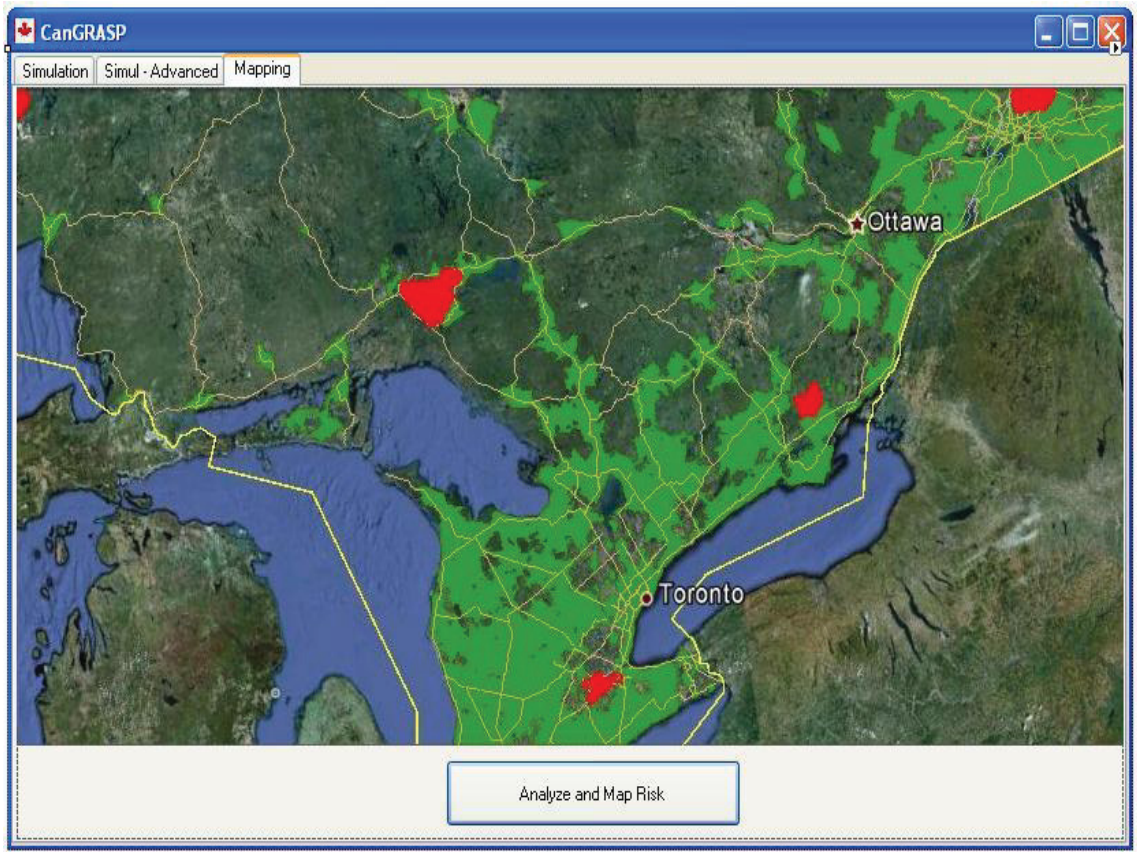
CanGRASP (Canadian GIS-based Risk Assessment, Simulation and Planning for Food Safety) is an integrated simulation tool consisting of a simulation model (Arena) and GIS (ArcGIS) accessed through an interface implemented in Visual Basic.Net. The interface is composed of three tabs: Simulation, Simul-Advanced and Mapping

The Simulation tab allows a user to define a contamination scenario while the Simul-advanced tab allows the user to define other simulation parameters as well as specify temperature abuse occurrences in selected segments of the distribution system. By clicking on the "Run Simulation" button on the Simulation tab, Arena is used to simulate and track the contamination event in the food distribution system.

The Mapping tab allows the user to analyze and map the results of the simulated contamination event. By clicking on the "Analyze and Map Risk" button on the Mapping tab, the simulation results can be analyzed in ArcGIS and prepared for visualization. ArcGIS has been customized and new tools developed to meet specific requirements. The CanGRASP GIS tools analyze the simulation results and calculate the potential impact of the contamination event by determining the geographic zones and the population affected by the event. These zones are then color coded, according to a dynamic risk index, to identify the ones that are at greatest immediate risk as time progresses.

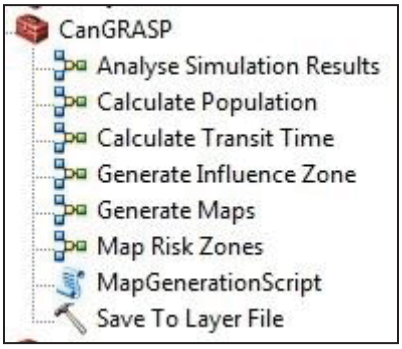






2. CanGRASP Spatial Analysis Toolbox

A CanGRASP toolbox was developed in ArcGIS which contains Spatial Analysis tools for analyzing accessibility to each retail store and identifying the influence zone and the population associated to each retail store. In addition the tools in the CanGRASP toolbox allow users to analyse the simulation results, and create the risk maps. There is also a tool to calculate transit time between processors and distribution centers and between distribution centers and retail stores.



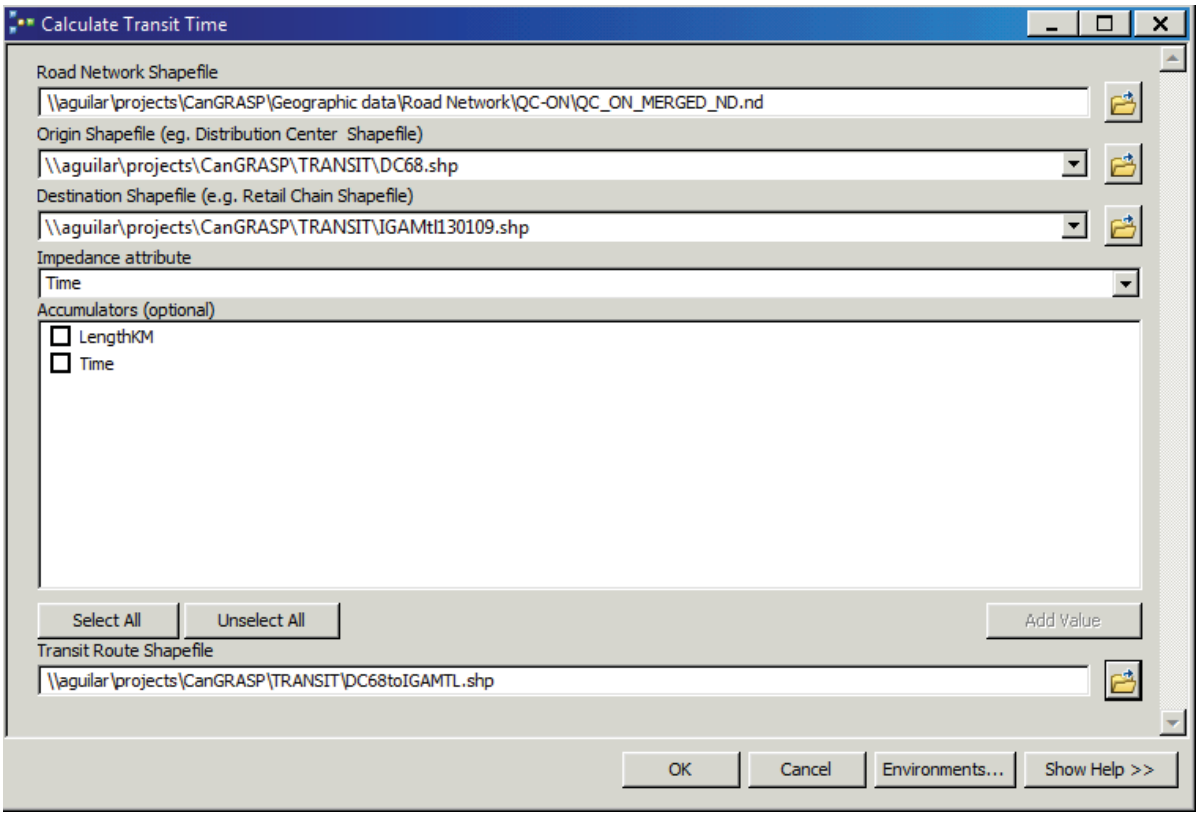
How to add CanGRASP toolbox to ArcToolbox

1. Click on ArcToolbox window and open it
2. Right Click on ArcToolbox and click "add Toolbox"
3. Select CanGRASP Tools.tbx in \\aguilar\projecs\CanGRASP\Model\New model\Model\ and Click Open

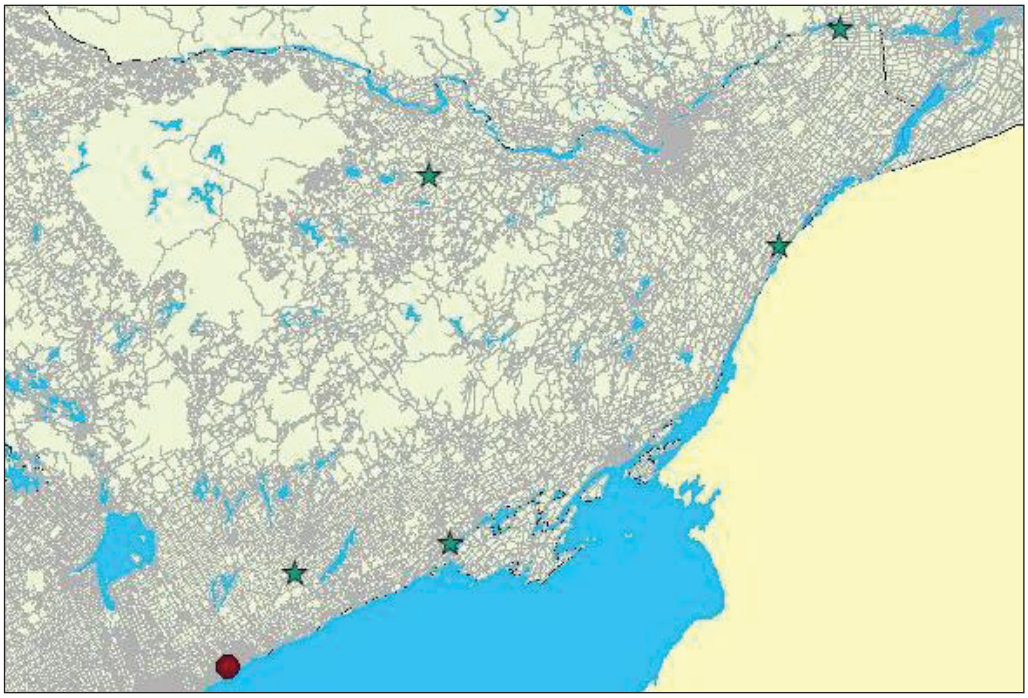
Notes:

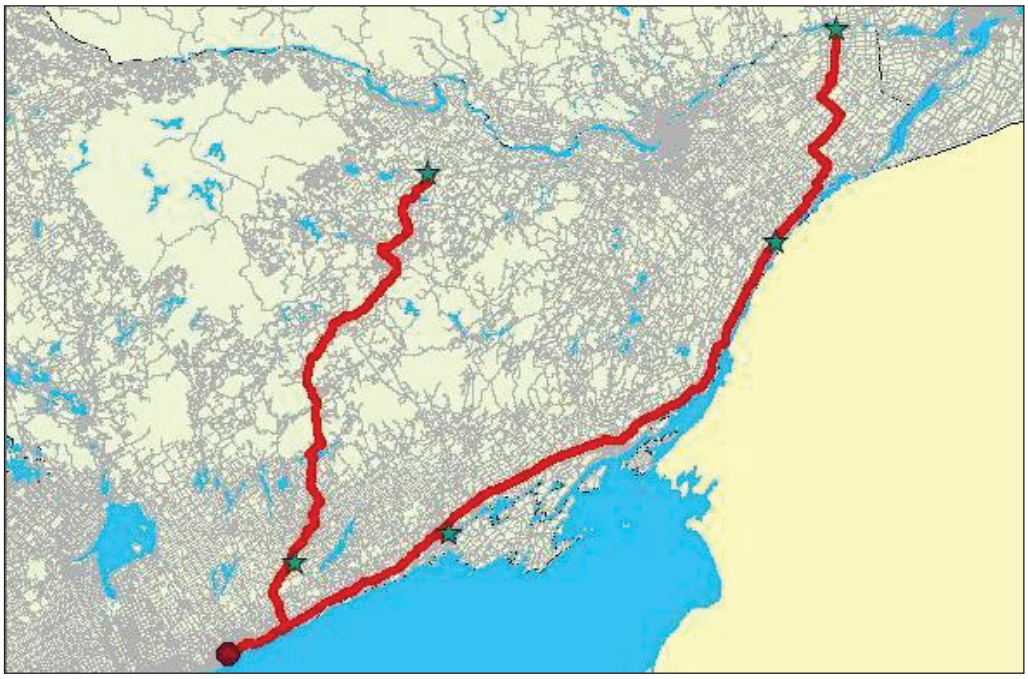
- An ArcGIS licence version 10 or higher is required to run the tools. Network Analyst toolbox is also needed to run the Calculate Transit Time and Generate Influence Zone tools. Make sure to activate the Network Analyst by clicking on the Customize button and selecting Extensions. In the Extensions window, make sure there is a check mark next to Network Analyst.
- Make sure you have a temporary folder in the C:\ drive (i.e. C:\Temp) to keep intermediate and temporary files that the tools create.
- Don't use space or "-" for the name of any files.
- Create a CanGRASP folder on your C:\ drive and make sure you have the Project map (Project.mxd) in this folder. The CanGRASP interface is programmed to open this map (C:\CanGRASP\Project.mxd) when you click on Analyze and Map Risk on the Mapping tab.

2.1. Calculate Transit Time



General Description: Calculates travel time between an origin (processor or distribution centre) and many destinations (distribution centres or retail stores) based on a Road Network.
Road Network Shapefile: Road network shapefile for the region where the transit times are being calculated.
Origin Shapefile: Shapefile of processor location (e.g. Processor Shapefile) or shapefile of distribution centre location (e.g. Distribution Centre shapefile) in region where the transit times are being calculated.
Note: the origin shapefile contains one point (e.g. one processor or one distribution center)
Destination Shapefile: Shapefile of distribution centre locations or retail store locations, for a specific retail chain, in region where the transit times are being calculated.
Note: the destination shapefile contains one or more points (e.g. many distribution centers or many retail stores)
Impedance: Attribute used to calculate transit time. For this tool, this attribute is always the shortest time.
Accumulators (Optional): Values to appear in Transit Time Table – Options include Distance in km (LengthKM option), Time in minutes (Time option), or both.
Transit Route shapefile: Shapefile of roads selected for transit time calculation. Specify the name of the shapefile to be created with this tool and the directory where this shapefile will be saved. Don't use space or "-" for the name of the shapefile.
Example: Distribution centre A (red dot) supplies retail stores 1, 2, 3, 4 and 5 (green stars) (top figure). Using Calculate Transit Time, the fastest route and travel time between DC A and each retail store is calculated (bottom figure).





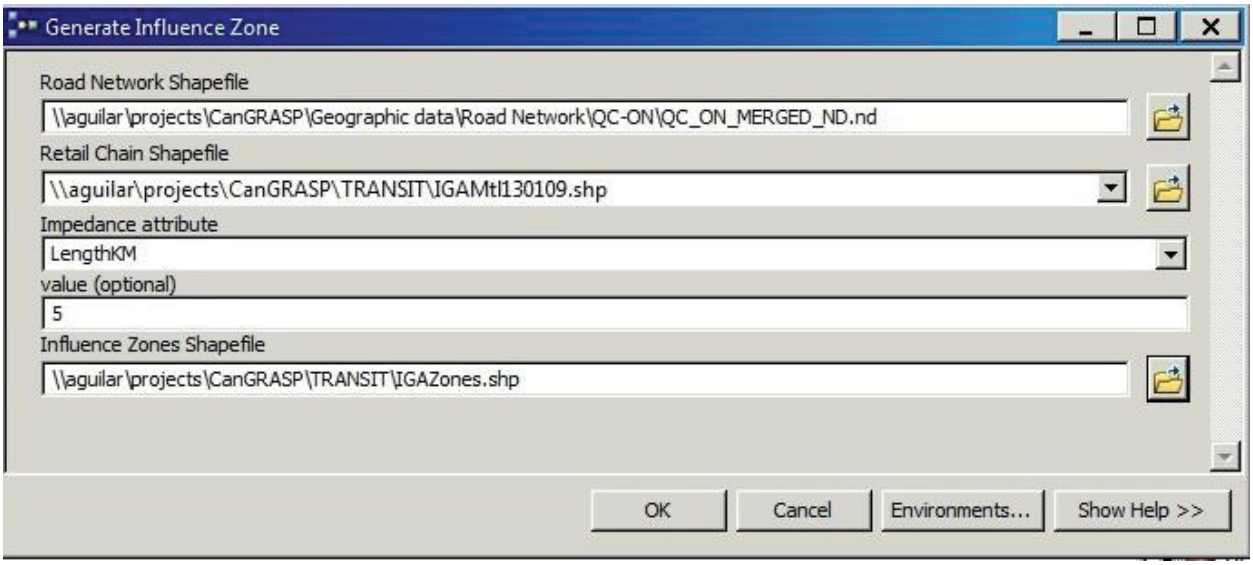
Note: To create a shapefile of a single processor (or distribution centre),

- Right click on the Processors (or Distribution Centres) layer in the Table of Contents of your map
- Click on Open Attribute Table
- Select (e.g. highlight) the processor (or distribution centre) to use for the Origin Shapefile

- Close the Attribute Table
- Right click on the Processors (or Distribution centres) layer in the Table of Contents
- Click on Data \ Export Data
- In the Export Data Window, select where the shapefile will be saved and name the shapefile (\\aguilar\projects\CanGRASP\TRANSIT\filename.shp)

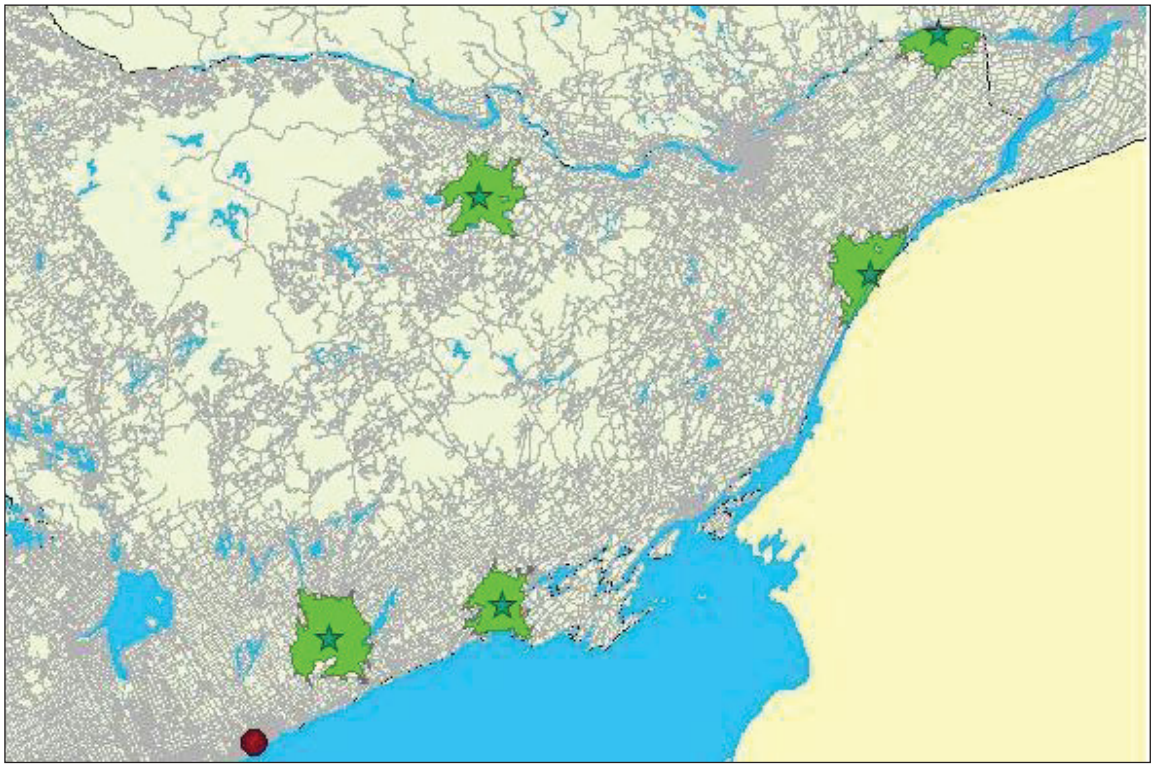
Note: To create a shapefile with several distribution centres or retail stores, repeat the same procedure as above but select (or highlight) several distribution centres or retail stores when you are at third step.

2.2. Generate Influence Zone tool

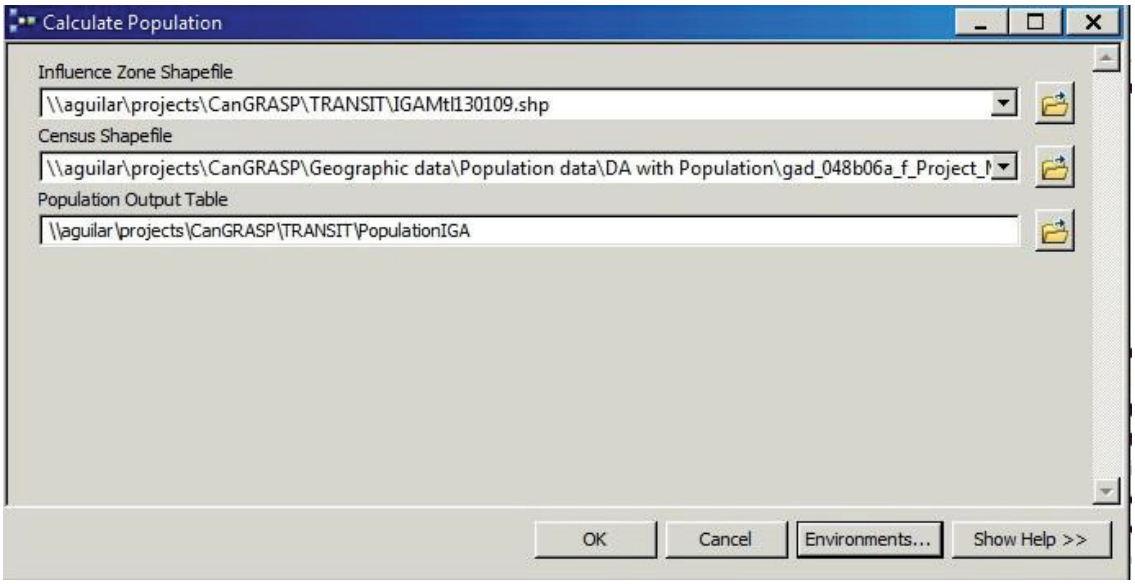


General description: Prepares a shapefile of polygons or zones around each retail store to define the population pool likely to purchase product at each retail store. The influence zone can be calculated based on time to drive to the retail store or based on distance to the retail store.
Road Network shapefile : Road network shapefile for the region where the influence zones are being calculated.
Retail Chain shapefile : Shapefile of retail store locations for a specific chain in region where the influence zones are being calculated.
Impedance: Attribute used to calculate influence zones. Attribute can be Time in minutes or Distance in km.
Value: Value of the Impedance attribute used for the calculation of influence zones.
Influence Zones shapefile: Specify the name of the shapefile to be created with this tool and the directory where this file will be saved.

Example: The zone of influence of retail stores 1, 2, 3, 4 and 5 was calculated using the Generate Influence Zone tool. The green-colored areas in the figure below are within a 5 km travel distance to each retail store which is located in an urban region.

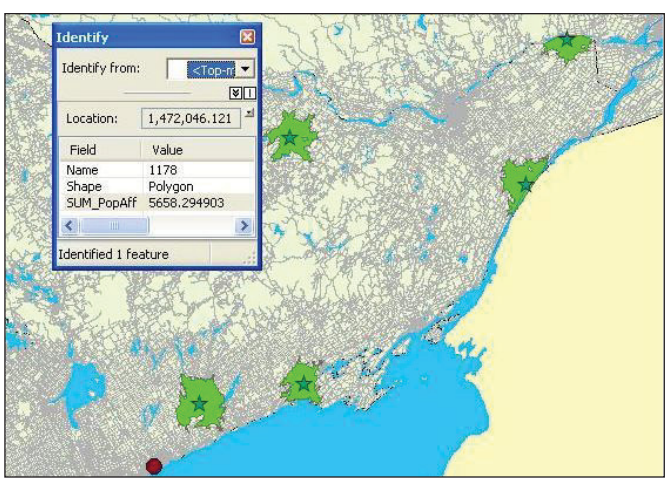


2.3 Calculate Population tool

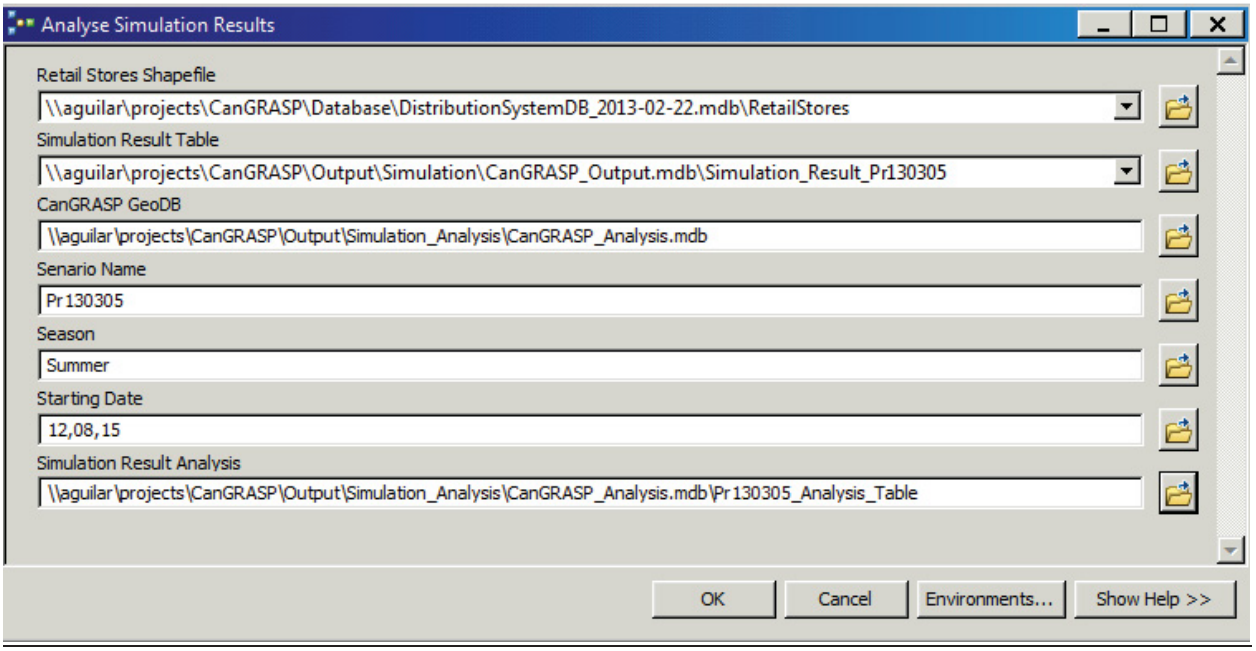


General Description: Calculates the population in the influence zone defined for each retail store.
Influence Zones shapefile: Shapefile of polygons or zones, around each retail store, delimiting the population pool likely to purchase product at each retail store. Shapefile created with the "Influence Zone" tool.
Census shapefile: Census population data file used to calculate the population of each influence zone.
Population Table: Results table of the population calculated for each influence zone. Specify the name of the results table to be created with this tool and the directory where this file will be saved.

Example: The population associated with each retail store is calculated based on the intersection of the census tract polygon boundaries with each influence zone. The population information is assigned to each retail store and can be viewed in the attribute table.



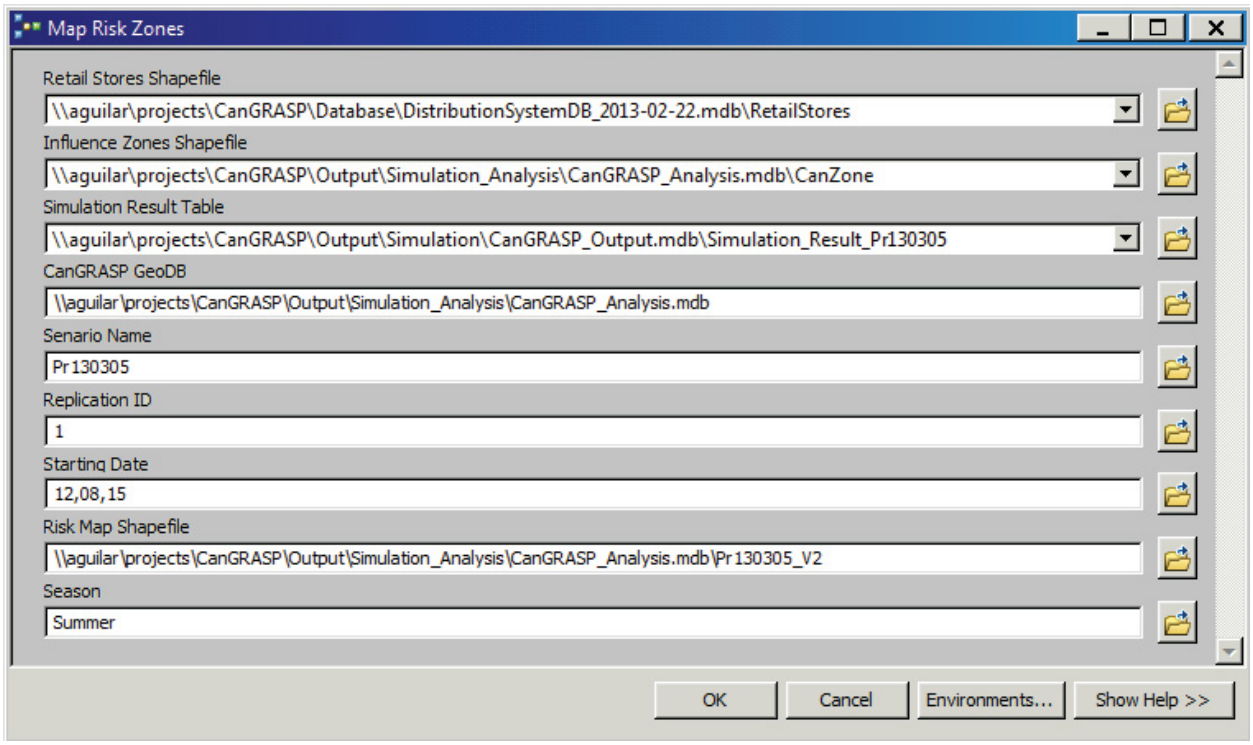
2.4 Analyse Simulation Results tool



General Description: Analyses the output of a simulation and prepares a table specifying the location of contaminated packs on a daily basis, their mean contamination level, their prevalence and the resulting risk index.
Retail Stores Shapefile: Shapefile of all retail store locations.
Simulation Result Table: Location of the CanGRASP_Output.mdb file that has the simulation results for the scenario being analyzed.
CanGRASP GeoDB: Geodatabase where will be stored the results calculated with the Analyse Simulation Results tool.
Scenario Name: Name of scenario in the CanGRASP_Output.mdb file that has the simulation results
Season: Season selected for the simulation in the CanGRASP simulation interface. The season entered must be identical with that selected during simulation to make sure that the appropriate seasonal data is used in the calculation of the Risk Index. (Note: Always use an uppercase letter for the first letter of season e.g., Spring, Summer, Fall, Winter).
Starting Date: The start date of the simulated scenario (Note: the format for the date should be YY-MM-DD or YY,MM,DD)
Simulation Result Analysis Table: Specify the name of the results table to be created with this tool
Example: The Simulation Result Analysis table includes the list of retail stores with contaminated product in their display cases on each date.

OBJECT	RetailerI	Replicati	Date_Model	FREQUENCY	MEAN_Contamin	SUM_Prevalence	population	Risk_Index
17	1052	4	5/24/2012	6	4591.557631	0.177968	44421	3
18	1052	4	5/27/2012	8	815.986095	0.237291	44421	3
24	1058	4	5/22/2012	6	6023.432271	0.177968	65122	3
25	1058	4	5/23/2012	6	7906.619006	0.177968	65122	3
30	1063	4	5/27/2012	8	1299.841334	0.237291	9357	3
35	1073	4	5/25/2012	8	1341.977593	0.237291	286256	4
43	1075	4	5/23/2012	6	6529.246706	0.177968	200335	3

2.5 Map Risk Zones tool:



General Description: Analyses the output of a simulated contamination event and prepares a map that shows the spatial distribution and the public health risk associated with the contaminated product. The resulting map can be queried for information on each retail location and can be viewed as a dynamic animation to compare daily results.

Retail Stores Shapefile: Shapefile of all retail store locations.

Influence Zones shapefile : Shapefile of polygons or zones, around each retail store, delimiting the population pool likely to purchase product at each retail store. Shapefile created with the "Influence Zone" tool. Note: Make sure to select the CanZone shapefile in the CanGRASP geodatabase (e.g. Output\Simulation_Analysis\CanGRASP_Analysis.mdb) rather than the CanZone in the distribution system database (e.g. Database\DistributionSystemDB_2013-02-22.mdb).

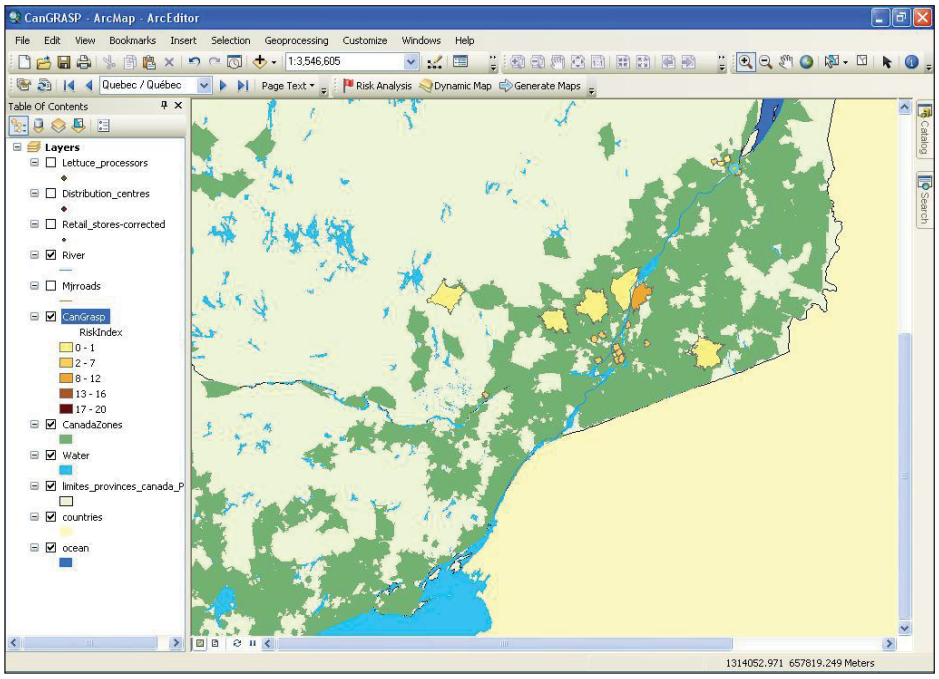
Simulation Result Table: Location of the CanGRASP_Output.mdb file that has the simulation results for the scenario being analyzed and mapped.

CanGRASP GeoDB: Geodatabase where the results calculated with the Analyse Simulation Results tool were stored.

Scenario Name: Name of scenario in the CanGRASP_Output.mdb file that has the simulation results
Replication ID: Replicate number of the scenario to be mapped.
Starting Date: The start date of the scenario (Note: the format for the date should be YY-MM-DD or YY,MM,DD)
Risk Map Shapefile: Specify the name of the shapefile to be created with this tool
Season: Season selected for the simulation in the CanGRASP simulation interface. The season entered must be identical with that selected during simulation to make sure the appropriate seasonal data are used in the calculation of the prevalence of contaminated product and the risk index. (Note: Always use an uppercase letter for the first letter of season e.g., Spring, Summer, Fall, Winter).
Note: When the Map Risk Zones tool is run, a Risk Map layer is added to the map. To view the zones at risk on each day of the contamination event, the time must be enabled on the Risk Map's layer.

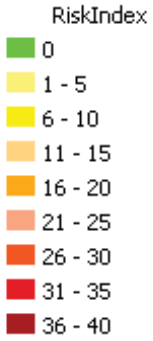
- Right click on the Risk Map layer just created and select Properties.
- In the Time tab of the Layer Properties window,
    - Verify that there is a check mark next to "Enable time on this layer".
    - Make sure the Time Field selected is Day_no and the Time Step Interval is 1 day.
    - Click on Apply then on OK.
- On the Time Slider, click on the "Options" button.
    - In the Time Slider Option window, click on the Time Extent tab and make sure that the Risk Map layer that you just created is selected in "Restrict full time extent to".

Example: The results maps present the zones where consumers are at risk of purchasing contaminated product over time.



These zones are color coded according to a dynamic risk index, to identify those areas that are at greatest immediate risk as time progresses (for each day), and to estimate the population affected

by these contamination events. These zones are color coded based on a risk index. The scale consists of many color levels indicating the potential relative risk associated with a contamination scenario, such as:



or

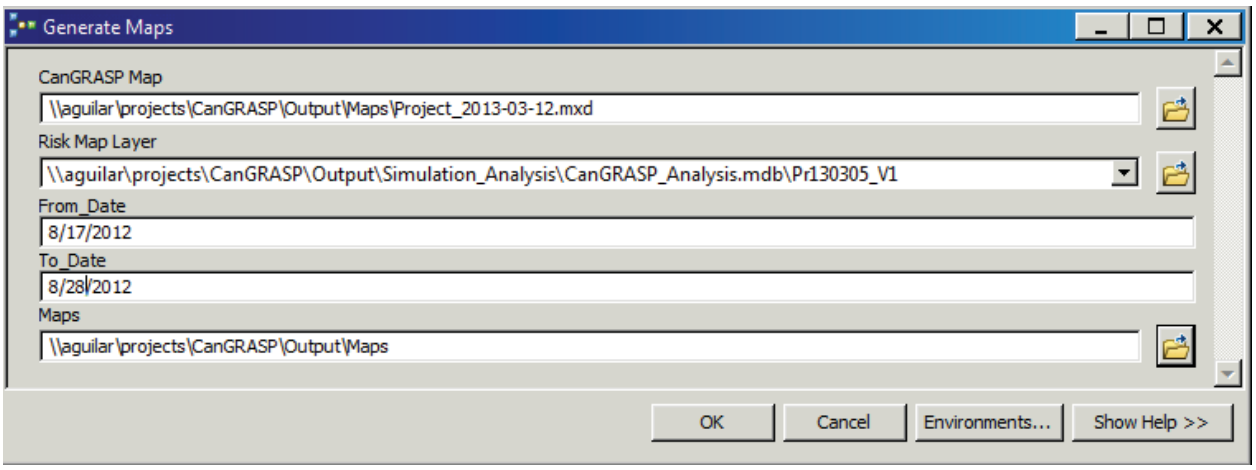
- *Green*: no risk
- *Yellow*: low risk
- *Orange*: moderate risk
- *Red*: high risk
- *Dark Red*: severe risk

When using the ArcGIS Identify tool and clicking on one of the colored zones, a table will be displayed that lists various information about the zone including the risk index for retail stores having received contaminated product and the population that is potentially at risk of purchasing contaminated product. The fields included in this table are:

Attribute name	Data type	Description
OBJECTID	Integer	Specific to ArcInfo®
Retail_ID	Integer	ID of retail stores having displayed contaminated packages of lettuce
RepID	Integer	Identification number given to each replication of a simulation
Day_no	Date	Date during simulated contamination event for which data is reported in table.
Bags_no	Integer	Number of contaminated packages of lettuce displayed in retail store on ”Day_no” during contamination event
Contamination	Double	Average concentration of the contamination in the contaminated packages displayed in one day (CFU/pack)
Prevalence	Double	Number of contaminated packages of lettuce displayed in retail store on day “Day_no” divided by the quantity of packaged lettuce received daily by each retail store, within a banner. When there is no contamination the value is 0 and in the unlikely event that all the product is contaminated the value is 1.

Attribute name	Data type	Description
Population	Double	Affected population calculated based on the population density in a service area covering a 5 km distance (in urban areas) or a 20 min drive (in rural regions) from each store using the road network
RiskIndex	Integer	Gauge of potential relative risk associated with the presence of contaminated packages in the retail store's display

2.6 Generate Map tool



General Description: Exports an image (in .png format) of specific daily maps from the Risk Map shapefile.
Note: The map generated for each day will look exactly like the image on the screen. Therefore, you need to zoom in to the required area before generating the map to obtain the view required. Before clicking on the Generate Maps tab, right click on the layer for which maps need to be generated and select "Zoom to layer".
CanGRASP Map: Name of map that has the Risk Map layer from which will be generated the images
Risk Map Layer: Select layer of the Risk Map shapefile
From_Date: Specify the date for which the results will start to be mapped.
To_Date: Specify the date until which the results will be mapped.
Maps: Specify the folder where the images will be saved.

Appendix 4: Example of an output from the sampling system.

$n_{cochran} = 4PQ/L^2$ where L is the interval (+/-) into which the true population proportion lies 95% of the time

$n_{cochran} = Z^2PQ/L^2$ where an exact measure of Z is used instead of 4 for 95% confidence level. Other confidence levels can be used

$n_{cochran} = Z^2PQ/L^2/Se$ where impact of test sensitivity is included. Test specificity is assumed to be 1

fpc = $n_0/1+(n_0-1)/N$ (finite population correction). Can also use the reciprocal which is $1/(1/n_0 + 1/N)$

Confidence level	95%	Z =	-1.95996
Test sensitivity =	75%		
Probability of detecting in plant =	75%		
P =	50%	Q =	50%
L or e =	10%	P lower range =	40%
n_0 =	171	P high range =	60%
Number of lettuce plants available =	500		
Average size of a plant in grams =	500		
Amount required for analytical method in grams =	25		
N =	10000		
$n_{cochran}$ with fpc =	127		
$n_{cochran}$ with reciprocal =	127		

$n_{puri} = N/(1+(e^2 (N-1)/Z^2 PQ))$

$n_{puri} = N/(1+(e^2 (N-1)/Z^2 PQ))/Se$ where Se is considered

n_{puri} =	143

6 sampling periods of 30 plants = 180

Random sampling

Sampling Period 1	Day 0
Sampling Period 2	Week 1
Sampling Period 3	Week 2
Sampling Period 4	Week 3
Sampling Period 5	Week 4
Sampling Period 6	Week ?