Hotspots for Vessel-to-Vessel and Vessel-to-Fix Object Accidents Along the Great Lakes Seaway

by

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AUTHOR'S DECLARATION

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

I understand that my thesis may be made electronically available to the public.

ABSTRACT

This research focuses on the freight vessel accidents occurring on the Great Lakes Seaway (GLS) extending from Rimouski (on the St. Lawrence) to Sault Ste. Marie (connecting Lake Huron to Lake Superior). Over the past decade, an average of 112 vessel accidents per year have been reported along the GLS, 20% of which took place as a result of groundings and collisions with other vessels. The vast majority of these accidents took place on river and canal/lock segments of the seaway. Freight vessel accidents along the GLS tend to be clustered at specific unsafe locations. In this research, locations with high vessel accident occurrence are referred to as hotspots. The first step in vessel accident reduction is to identify hotspots along the GLS, which then become prime candidates for future safety intervention initiatives. Given the rare and random nature of vessel accidents, the identification of hotspots needs to be based on robust site-specific prediction models. This research presents an empirical Bayes prediction model developed for the Great Lakes Seaway (GLS) that considers four types of accident scenarios: vessel-to-vessel (VV) and vessel-to-fix objects (VF) for river and canal/lock sections. Hotspot sites are determined using two risk tolerance thresholds: 95th percentile exceedance (high risk sites) and 85th percentile exceedance (moderate and high-risk sites). For the 95th percentile threshold and VV accidents, a total of five hotspots were identified over the 1600 km length of the GLS being studied (excluding lake or port areas). Of the designated hotspot sections, 10 km (60.6% of the total hotspot length) were located along natural river courses and the rest at canals/locks. For VF accidents, all of the high-risk hotspots were located at canal/lock sections (a total of 15.5 km). Reducing the threshold to 85th percentile resulted in a 7.8% increase in seaway length that is designated as a hotspot. VV and VF accidents were combined and for these accidents, hotspots were obtained for the 95th and 85th percentile thresholds. For the 95th percentile a total of five sections (14 km, 0.88% of the seaway) were identified as hotspots, and for the 85th percentile the number of hotspots were increased to 16 sections (47.72 km, 3% of the seaway). These unsafe locations were also compared with observed historical accidents along the GLS, and the location of the observed accidents were found to be consistent with hotspot designated sections along the GLS for both thresholds.

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CHAPTER 1

INTRODUCTION

The United Nations Conference on Trade and Development (UNCTAD) predicts a significant increase in world trade much of it creating an increase in waterborne activity (Asariotis et al., 2011). This is likely to result in an increase in the number of accidents involving waterborne freight transit. To reduce these accidents a systematic approach needs to be undertaken that considers both their potential frequency of occurrence as well as their severity (loss of life, environmental damage, and financial losses). In Canada, according to the Transportation Safety Board of Canada, an average of between 75 and 150 vessel accidents per year were reported in inland waters between 2000 and 2013. These resulted in a significant number of fatalities and personal injuries as well as severe environmental impacts (Statistical Summary, Marine Occurrences 2013). A reduction in inland freight vessel accidents becomes an important goal for national freight transportation safety.

The goal of accident reduction becomes especially important for managing safety along the Great Lakes Seaway. The economic impact of accidents taking place on the GLS can be quite significant. For example, in June 19, 2015, a cruise ship hit a concrete wall in the Eisenhower Lock in the St. Lawrence River. This caused the injury of 29 people and a 42 hour closure of the seaway. The cost of this closure was $25,000 in commerce per hour, according to the marine traffic officials (Boatnerd.com, 2015).

1.1 PROBLEM STATEMENT

The reduction of vessel accidents requires insights into two fundamental safety issues. First, which sites are unsafe and second, how best to make these sites safer. Unsafe sites have been referred to in literature as “hotspots” (Miranda-Moreno et al., 2005). The primary rationale for identifying hotspots is to identify those locations where accidents are most likely to occur such that we have a greater chance of employing strategies to prevent these accidents in the future. The idea is to focus scarce safety funds where they are most likely to be effective. Once we have done that we can investigate how best to improve the safety at those sites.

The observational data alone cannot be used to rank sites since (as illustrated in Figure 1.1) accidents are random events that tend to fluctuate from year to year.

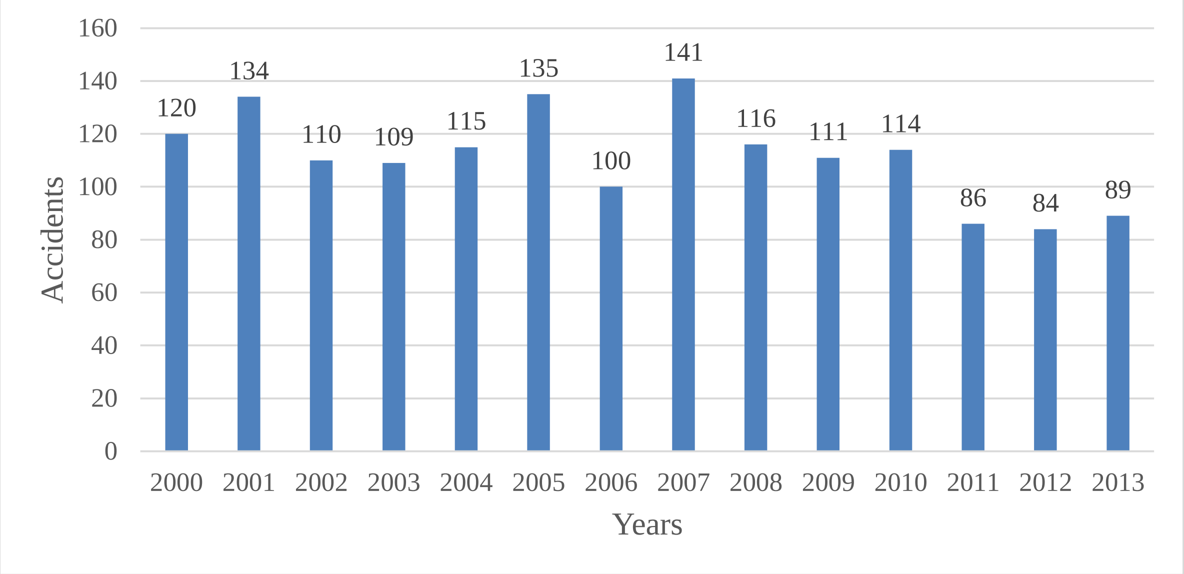

Figure 1.1 Number of Vessel Accidents Occurred in the GLS per Year

Along the GLS vessel accident frequency between 2000 and 2013 varied from a low 84 in 2012 to a high of 141 in 2007. The accidents illustrated in this figure comprise all accidents in the GLS including ports, open lakes area, rivers and canals. From Figure 1.1, we note that no appreciable reduction in the frequencies are observed over the 14 year period for the GLS, despite the implementation of several improvements addressing safety operations and standards that meet or exceed international water transport protocols.

At a site specific level similar fluctuations over time can be observed although the vast majority of sites will show no accidents despite having potential safety problems. This speaks to the rare nature of accident occurrence at the individual location level (see Figure 1.2). Hence, observable frequency data is not always useful to identify locations where safety intervention may be warranted. For this, we require robust models of accident prediction that are able to establish the potential for accident occurrence over an extended period of time (Shahdah, 2014).

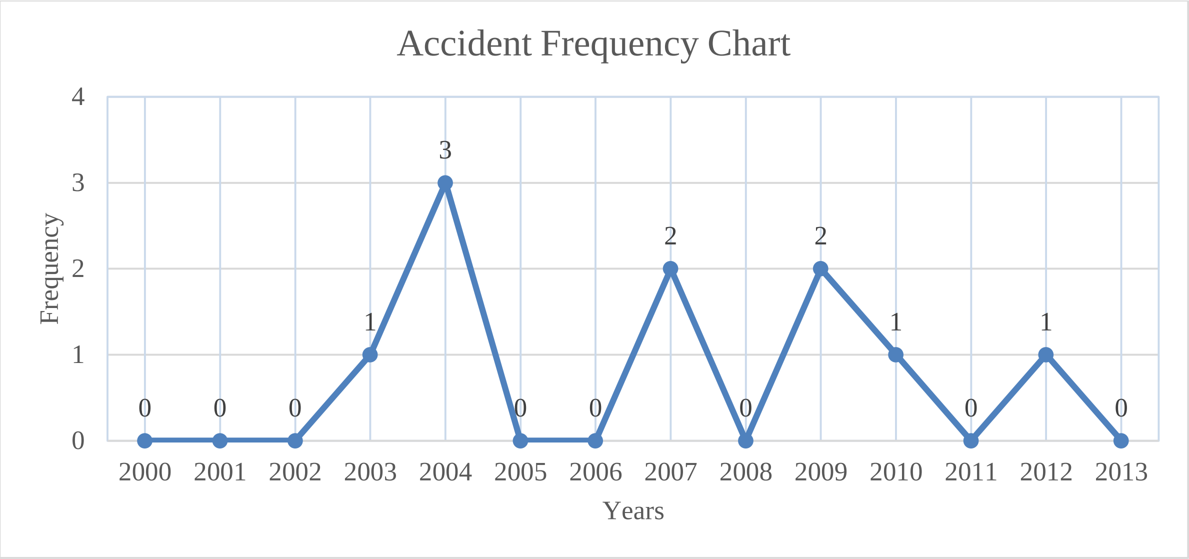

Figure 1.2 Yearly Accident Frequency Chart of the Highest Risk Site along the GLS

Random effects could make identifying hotspots more difficult. It is therefore, important to have models to help isolate these hotspots despite random effects. For instance, consider that we have two different areas. One has more accidents than the other and therefore, needs more attention. The reason that it has more accidents could be due to navigation problems or that the location itself is the issue (such as being near a port city with higher traffic). Alternately, the majority of the accidents in that location might have occurred only on one day and on all other days the area was safe. In this case, the accidents would have occurred randomly and it would not be defined as a hotspot.

For these circumstances we need a model to control for random effects in vessel accident occurrence. Such a model can account statistically for different factors that influence accident occurrence, such as the width and length of the navigation channel, natural obstructions, weather, traffic, and wind conditions. The difficulty in developing these models is how to incorporate factors such that they are not subject to a mixture of problems associated with the statistical approach such as collinearity or correlation among the variables, statistical significance, and regression to the mean bias.

1.2 RESEARCH OBJECTIVES

The main purpose of this thesis is to identify unsafe sites for inland waterborne transport, and can be expressed in terms of three specific objectives:

1. Develop models for accident prediction and hotspot identification.
2. Develop a vessel accident prediction model using empirical exposure data.
3. Apply the model to a major water transport system and identify the hotspots.

In this research, the accident prediction models are calibrated using data on vessel accidents and traffic volumes from the Great Lakes Seaway. These models are subsequently used to identify hotspots along a selected segment of the GLS that consists of river and canal/locks sections.

This GLS case study includes only river and canal/locks sections between Rimouski and Sault Ste. Marie. Despite the importance of severity or consequences in freight vessel accidents the hotspots identified in this research are based solely on an estimation of the expected "frequency of vessel accidents". The focus of the research is on the GLS inland seaway, and the results of this study are limited essentially to traffic and the operational characteristics of this seaway. The issue of transferability of the results to the other major inland waterways in the world is outside of the scope of this research.

1.3 ORGANIZATION OF THESIS

The remainder of this thesis has been organized into six chapters. **Chapter 2** presents existing prediction models for freight vessel transport. It demonstrates the need of prediction models in hotspot identification and examines the models that have been used in highway traffic safety. **Chapter 3** shows the analysis of accidents along the Great Lakes Seaway by defining the exposures. **Chapter 4** presents the Empirical Bayes Model and the parameters used for estimation and validations for the Great Lakes Seaway. **Chapter 5** highlights the Great Lakes Seaway hotspots by examining the model results and output statistics through sensitivity analysis. Finally, **Chapter 6** summarizes the findings from the results and gives recommendations about the observed safety problems and future studies.

CHAPTER 2
LITERATURE REVIEW

2.1 ACCIDENT AND RISK ANALYSIS FOR MARINE TRANSPORTATION

There is some research on marine transportation safety, which focuses on probabilistic risk analysis, statistical analysis, and simulation modelling. For example, a risk assessment for oil tankers using Fault Tree Analysis for collisions and groundings has been done. As a result, it found that the main reasons for these collisions and groundings were due to the following reasons: violations of the Convention on the International Regulations for Preventing Collision at Sea (COLREG), interpretation failure, lack of communication between vessels, and improper Bridge Resource Management (Ugurlu et al., 2015). Another example of research on risk assessment was done using the Structural Equation Modelling (SEM) approach to find the variables contributing to marine accidents (Mullai, and Paulsson, 2011). Still other research used the Bayesian Belief Network model integrating the Human Factors Analysis and Classification System (HFACS) with risk analysis (Trucco et al., 2008). The HFACS was also used to analyze collisions and highlight the contribution of improper Bridge Resource Management on vessel accidents (Chauvin et al., 2013). Using a mathematical method, the probability of vessel accidents in a channel with uniform width, was researched by Kuroda (Kuroda et al., 1982). Another researcher analyzed historical accidents which occurred in the port of Hong Kong using the Negative Binominal Regression model, and the results showed that heavy traffic increased the probability of having collisions (Yip, 2008). Fishing vessel accidents were analysed using the Binominal model and found that as wind speed increased, the probability of having accidents went up. The same research also found that the smaller the size of the fishing vessel the higher the likelihood of accidents (Jin, and Thunberg, 2005).

There were also some studies, which applied simulation approaches to marine safety. For example, the geographical characteristics of the Bosporus were used to develop a simulation model, which estimates the probability of having vessel accidents (Otay, and Ozkan, 2003). Moreover, a stochastic model for vessel accidents resulting from oil tanker traffic was created (Tan, and Otay, 1998).

In all of the previous studies on marine transportation there has been a lack of focus on hotspot identification for inland freight vessels. The variables pertaining to inland water versus open water or ports differ. Similarly, the characteristics of freight vessels compared to other types of vessels such as passenger or fishing vessels is also significantly different. As a result, and due to the high level of inland freight traffic, a study focusing on this specific perspective is warranted. Historically hotspot identification methods have been used in highway traffic safety studies. This research will evaluate the applicability of using these models to determining the hotspots in the inland waters of the GLS.

2.2 HOTSPOT IDENTIFICATION METHODS IN HIGHWAY TRAFFIC SAFETY

The frequency distribution of accidents usually fluctuates from year-to-year, which makes identifying hotspots based solely on observed frequencies unreliable. For one year, accidents at a given site could be high (unsafe), while for another year they could be low (safe). To account for these observed fluctuations in the yearly accident data, it becomes necessary in hotspot identification to develop rigorous and statistically sound prediction models for application to specific sites.

Several hotspot identification methods were analyzed in previous research (Montella, 2010). Seven Hotspot Identification (HSID) methods were compared in this study namely; Crash Frequency (CF), Crash Rate (CR), Equivalent Property Damage Only Crash Frequency (EPDO), Proportion Method (P), Empirical Bayes estimate of total-crash frequency (EB), Empirical Bayes estimate of severe-crash frequency (EBs), and the Potential For Improvement Method (PFI).

2.2.1 Previous Methods

2.2.1.1 Crash Frequency Method

Crash Frequency (CF) method is a simple and straightforward method to identify hotspots. In this method, based on the observed crash frequencies, sites are ranked in descending order. When completed, a value of crashes per year per km can be obtained by dividing the total number of crushes into the segment length and the available timeframe of data. The top ranked sites can then be identified for further analysis (Cheng, and Washington, 2008).

2.2.1.2 Crash Rate Method

In the Crash Rate (CR) method, the number of crashes is divided by the traffic volume and this value is used to rank the segments (Cheng, and Washington, 2008). The CR method assumes that there is a linear relation between crashes and exposure (Hauer, 1997).

2.2.1.3 Equivalent Property Damage Only Method

The Equivalent Property Damage Only (EPDO) method ranks each section based on a combined cost and severity score (Montella, 2010). For example, the weight factor for U.S. fatal traffic motor-vehicle crashes (with a cost of $4,008,900) is 542, for injuries (with a cost of $82,600) the weight factor is 11, and for property damage only (PDO) (with a cost of $7,400) the weight factor is 1 (FHWA 2013).

2.2.1.4 Proportion Method

The Proportion (P) method is used to rank sites based on the probability of having a specific crash type (rear-end, snowy road, night-time, etc.) greater than the threshold. In this method, the Bernoulli Trial Formula in equation [2.1] is used to find the probability of having a specific crash type. It is equal to the proportion of the crash type. Based on equation [2.1], the probability of having less than x accidents for n trials for the comparison group (p) can be calculated (Montella, 2010).

$$P(X \leq x-1, n; p) = B(x-1, n; p) = \sum_{i=0}^{x-1} \frac{n!}{(n-i)! \times i!} \times p^i \times (1-p)^{n-i} \qquad [2.1]$$

2.2.2 Crash Prediction Model

In the EB, EBs, and PFI methods, a crash prediction model (CPM) is used to estimate the expected number of crashes for the analysis period (Hauer, 1997). CPM is a mathematical formula, which explains the relationship between the safety level of a section and the variables that impact the determination of that level. These variables, which significantly impact accident rates, however, cannot have a correlation to one another (Eenink et al., 2008).

Based on the previous research, it can be concluded that it is more appropriate to use a non-linear relationship between traffic exposure and crashes in traffic safety analysis (Hauer, 1997; Persaud, 2001; Usama, 2014).

Equation [2.2] shows the typical linear regression model in which E(y) is the expected number of crashes in a specific segment (Hauer, 1997).

$$E(y) = \beta + \beta_1 . x_1 + \beta_2 . x_2 + \ldots + \beta_y . x_y + \varepsilon \qquad [2.2]$$

where β, β_1, β_2, and β_y are the coefficients, x_1, x_2, and x_y are the independent variables and ε is the error.

The alternative non-linear regression model, which is shown in equation [2.3], can be used for CPM calculations (Hauer, 1997).

$$E(y) = \beta . \exp(\beta_1 . x_1 + \beta_2 . x_2 + \ldots + \beta_y . x_y) + \varepsilon \qquad [2.3]$$

To fit the models in equation [2.2] and [2.3], linear regression analysis can be used. The error in our models is assumed to follow the normal distribution. The error is a constant value for each value of the independent variables. It is known that the crashes in our models are positive discrete values, which do not follow the normal distribution. Therefore, CPMs tend to follow the Generalized Linear Model (GLM) (Usama, 2014). The most common underlying distributions in the GLM are Poisson and Negative Binominal (NB) regression models (Miaou, and Lum, 1994; Poch and Mannering, 1996).

2.2.2.1 Poisson and NB Models for Underlying Distributions

It is known that the crash occurrences mostly follow the Poisson distribution (Persaud et al., 1999; Kononov, and Allery, 2003; Usama, 2014). Equation [2.4] below shows the typical Poisson distribution.

$$P(X = y_i) = \frac{\mu_i^{y_i} \times e^{-\mu_i}}{y_i!} \qquad [2.4]$$

$$X \sim Poisson, Var(X) = \mu \qquad [2.5]$$

$P(X = y_i)$ shows the probability of having y number of crashes in the period i, and μ_i is the expected number of crashes in the same period. In the Poisson process, it is assumed that the variance is equal to the mean. However, this assumption may not consistently be correct. In this case, the variance can be greater than the mean (Lord et al., 2005). The reason is that the crash data could be over-dispersed due to some uncertainties, which cannot be measured in the model (Hauer, 1997; Washington et al., 2010; Mitra and Washington, 2007, Usama, 2014). Specifically, differences between the observed number of crashes and the predicted number of crashes from the results of the Poisson process could be higher than what we expect (Hauer, 1997). To solve this problem, researchers use Negative Binominal (NB) distribution where the variance is the non-linear function of the mean. Using NB may represent a widely distributed number of crashes more accurately than the Poisson distribution (Hauer, 1997). NB form is;

$$P(Y_i, \mu_i, \emptyset\,) = \frac{\gamma(y_i + \emptyset^{-1})}{\gamma(\emptyset^{-1}) \times y_i!} \times \left(\frac{1}{1+\emptyset\mu_i}\right)^{\emptyset^{-1}} \times \left(\frac{\emptyset\mu_i}{1+\emptyset\mu_i}\right)^{y_i} \qquad [2.6]$$

$$Y_i \sim NB(\mu_i, \emptyset) \qquad [2.7]$$

with

$$E(Y_i) = \mu, and\ Var(Y_i) = \mu + \emptyset\mu^2 \qquad [2.8]$$

where

μ_i = expected number of crashes at site i.

y_i = observed number of crashes at site i.

γ = gamma function.

$\emptyset$ = dispersion parameter which is greater than zero for NB distribution.

2.2.2.2 Generalized Linear Model

We can categorize both Poisson and NB models as part of Generalized Linear Model (GLM) family. A GLM consists of three features (Everitt, and Hothorn, 2006):

1. An error distribution, which gives the distribution of dependent variables such as the number of crashes (Usama, 2014). For analysis of variance and multiple regression, error terms follow the normal distribution. For log-regression, error terms follow binominal distribution (Everitt and Pickles, 2000; Everitt and Hothorn, 2006).
2. A link function, g, which shows how independent variables' linear function is related to the expected value. Equation [2.9] shows the link function;

$$g(\mu) = \beta + \beta_1 x_1 + \cdots + \beta_n x_n \tag{2.9}$$

3. A variance function, which shows us how the variance of the variables connects to the mean.

Equation [2.10] shows the variance function for the GLM. When $V(\mu) = 1$ and $\emptyset = \sigma^2$, the error distribution follows the Normal Distribution and variance does not depend on the mean. When $V(\mu) = \mu(1 - \mu)$ and $\emptyset = 1$, the distribution is Binominal. The distribution also follows Poisson when $V(\mu) = \mu$ and $\emptyset = 1$ (Everitt and Hothorn, 2006).

$$Var(response) = \emptyset V(\mu) \tag{2.10}$$

2.2.2.3 Goodness of Fit Tests

To understand the goodness of fit, there are three criteria (Hardin and Hilbe, 2007; Washington et al., 2010; Lord, and Park, 2008).

1. Akaike's Information Criterion (AIC) (Akaike, 1998):

$$AIC = \frac{-2lnL(Y_x)+2P}{N} \qquad [2.11]$$

where

$lnL(Y_x)$ = log likelihood of model Y.

P = the number of parameters.

N = the number of observations.

In the model decisions, the model with the lowest AIC value means the best fit (Lord, and Park, 2008).

2. The models parameters' statistical significance value, which is usually accepted to be 5%.
3. The dispersion parameter, which can be found by dividing residual deviance into the degrees of freedom. In this criterion, dispersion parameter should be close to 1 for the model, which is expected not to be over-dispersed (McGullagh and Nelder, 1989). Equation [2.12] shows the deviance for the Poisson distribution (Usama, 2014);

$$D = \sum_{i=1}^{n}(y_i \log\left(\frac{y_i}{\mu_i}\right) - (y_i - \mu_i)) \qquad [2.12]$$

2.2.2.4 Empirical Bayes Model

In the Empirical Bayes (EB) procedure, the CPM is used to estimate the expected number of crashes (prior estimation) based on the variables which are believed to have a significant effect on the model. Following this, the expected number of crashes is combined with the observed historical crashes (data likelihood), which occurred in the same site (Hauer, 1997; Montella, 2010). To estimate the expected EB crashes (Hauer, 1997; Usama, 2014);

$$\lambda_i = E(\mu_i \backslash y_i) = \alpha_i \times \mu_i + (1-\alpha_i) \times y_i \qquad [2.13]$$

with, $$E(\lambda_i) = \lambda_i \; and \; Var(\lambda_i) = (1-\alpha_i) \times E(\lambda_i) \qquad [2.14]$$

where

λ_i =expected number of EB crashes for the site i.

μ_i =expected number of crashes for the site i(from CPM model).

y_i =observed crashes for the site i.

α_i =weight factor for the site i.

Calculated mean and variance from the equation [2.8] can be used to obtain α_i in equation [2.15] for the NB model.

$$\alpha_i = \frac{E(y_i)}{Var(y_i)+E(y_i)} \qquad [2.15]$$

2.2.2.5 Empirical Bayes Severe Crashes Model

Empirical Bayes Severe Crashes (EBs) model is similar to the EB model. The only difference in this model is that the EB expected number of severe crashes are taken into account. The model follows the same structure as the EB model. (Montella, 2010).

2.2.2.6 Potential for Improvement Method

To obtain the Potential for Improvement (PFI) method, we need to subtract the EB expected crash frequency and the crash frequency (calculated from the CPM) (Persaud et al., 1999). When the PFI is greater than 0, that means the site experiences more crashes than expected and it is the reverse when PFI is lower than 0 (Montella, 2010). The typical formula for PFI is;

$$PFI_i = \lambda_i - \mu_i = \alpha_i \times \mu_i + (1-\alpha_i)y_i - \mu_i \qquad [2.16]$$

2.2.3 Alternative Hotspot Identification Methods

There are also other models that have been used for hotspot identification in traffic safety. Currently, simulation models that aim to assess the safety performance of drivers are being used in road safety. These models also have the ability to measure the level of conflict that is correlated with crash statistic (Young et al., 2014). Understanding the driver's behaviour is critical in simulation models and some research has been done to assess the crash potential at intersections by using micro simulation methods (Saccomanno and Cunto, 2006). In marine transportation, this approach is costly since there is limited simulation software and the software that does exist does not meet the realistic demands of the simulation (due to extreme variances in vessel characteristics).

Spatial analysis methods are other HSID methods, which have been used in road safety (Flahaut et al., 2003; Loo et al., 2011). The most common models are the Local Spatial Autocorrelation (LSA) method and the Kernel Density Estimation (KDE) method. "In the LSA method each spatial unit is assigned with an LSA index that evaluates the level of spatial inter-dependence between the observed crashes at neighbouring spatial units." (Yu et al., 2014) KDE is a method, which makes no inferences about the probability distributions of the variables being assessed, and is used to determine the probability frequency of a random variable (Yu et al., 2014). Similar to LSA method, each spatial unit has a local crash density estimation. In these methods, the section is identified as a hotspot if the estimated value of LSA or KDE exceeds the threshold. These spatial methods were compared with the EB model by using the Segment Consistency Test, the Method Consistency Test (MCT) and the False Identification Test (FIT). As a result, the EB method was found to be the best fit according to MCT and FIT (Yu et al., 2014).

Another alternative to the EB approach is the Full Bayes (FB) method. This method has been used by several other researchers (Li et al., 2013; Miranda-Moreno and Fu, 2007). It was found that the FB method requires less data and deals better with uncertainty (Persaud et al., 2010). Although the FB method has some advantages, it is complex and therefore, unpopular with many researchers (Persaud and Lyon, 2007).

2.3 MODEL DESICION

Based on the findings of the previously mentioned researchers, it can be concluded that there is no accurate and robust HSID method for water transportation. It is therefore, necessary to develop a HSID model specifically applicable to inland water transportation for freight vessels.

In HSID methods, it is possible to have false negatives and false positives during the site ranking (Cheng, and Washington, 2005). False negatives are observed when an actual unsafe site is deemed by the model to be safe due to inaccurately determined low crash frequencies. Conversely, in a false positive the model determines there to be a high crash frequency at an actual safe site. This problem is also known as Regression to the Mean (RTM) treatment bias (Hauer, 1996; Persaud et al., 1999; Park and Saccomanno, 2007; Elvik, 2008). Specifically, when a variable is extreme (significantly higher or lower than the mean) in the first measurement, it will tend to be closer to the mean in its second measurement. As a result, the data has a tendency to return towards the mean (Hauer, 1997).

To assess the advantages and disadvantages of different HSID methods, researchers use four quantitative tests. They are Site Consistency Test, Method Consistency Test, Total Rank Differences Test, and Total Score Test respectively (Cheng, and Washington, 2008; Montella, 2010). Results shows that EB is the most consistent and reliable method for HSID since it deals with RTM and over-dispersion problems (Hauer, 2001). Consequently, the EB model will be used in this research to identify hotspots in the GLS (specifically pertaining to rivers and canal/locks) for freight vessels.

CHAPTER 3

FEATURES OF THE GREAT LAKES SEAWAY

3.1 FACTS ABOUT THE GREAT LAKES SEAWAY

The Great Lakes Seaway is a large inland waterway linking the Gulf of the St. Lawrence to the headwaters of Lake Superior (Thunder Bay), with a total distance of approximately 3700km. Since 1959, more than 2.5 billion tonnes of cargo estimated at US$375 billion have moved to and from Canada, the United States, and nearly fifty other nations by water. About 25% of this traffic travels to and from overseas ports (especially European ports), with the remainder being shipped through the internal Great Lakes Seaway (The Economic Impacts of the Great Lakes-St. Lawrence Seaway System, 2011).

The focus of this model is to predict vessel accidents on a portion of the GLS extending for 1600 km from Rimouski (St. Lawrence River) to the canal/lock systems at Sault Ste. Marie. A significant percentage of GLS freight movement and accident occurrence takes place along this segment of the GLS. In 2013 alone, a total of 28,560,000 gross tonnes of freight was transported along this segment by about 2768 vessels (The St. Lawrence Seaway Traffic Report, 2013).

3.1.1 GLS Locks

There are 17 locks between Montreal and Sault Ste. Marie to make inland vessel transportation possible along the GLS (see Figure 3.1). Seven of these locks (St. Lambert, Cote Ste. Catherine, Lower and Upper Beauharnois, Snell, Eisenhower and Iroquois) are located on the St. Lawrence River in the section between Montreal and Lake Ontario. Two locks, (the Snell and Eisenhower Locks) are operated by the U.S. government. The GLS Development Corporation is responsible for operating the five locks along the St. Lawrence River and the eight locks located on the Welland Canal, which connects Lake Ontario to Lake Erie. The remaining two locks (the Poe and MacArthur Locks) are located on the U.S. side of Sault Ste. Marie, and are operated by the St. Mary’s River Vessel Traffic Service (VTS). These locks refer to as the Soo Locks have different geometric features than the other GLS locks. The Poe Lock is the largest at 366 meters in length, 33.5 meters in width and 9.8 meters in depth. The MacArthur Lock is 244 meters long, 24.4 meters wide and 9.4 meters deep. The other 15 locks of the GLS comprise a combined length of 233.5 meters, with an average width and depth of 24.4 meters and 9.1 meters, respectively.

Figure 3.1 The GLS Map with Major Ports and Locks *(Source: Wilkinson Social Studies, 2015)*

3.1.2 Major Ports in the GLS

The vessel traffic from the top 5 major Canadian ports has been listed in Table 3.1. This is according to the St. Lawrence Seaway traffic report for 2013 for the vessels that used the lock systems in the Welland Canal and the St. Lawrence River (Montreal to Lake Ontario). Table 3.2 on the other hand, shows the major United States ports traffic along the GLS. The locations of major Canadian and U.S. GLS ports are shown in Figure 3.1 (The St. Lawrence Seaway Traffic Report, 2013).

Table 3.1 Major Canadian Ports in the GLS for Inland Lock Traffic

Canadian Ports	**Shipments**	**Total Cargo Tonnes**	**%**
Inbound:			
Hamilton	489	7,840,955	16.6
Quebec City	230	5,852,925	12.4
Montreal	132	1,786,745	3.8
Baie Comeau	52	1,284,553	2.7
Tracy/Sorel	95	1,260,093	2.7
Total	998	18,025,271	38.2
Outbound:			
Thunder Bay	244	4,857,828	10.3
Port Cartier	115	3,056,909	6.5
Hamilton	125	2,075,076	4.4
Sarnia	168	1,625,718	3.4
Goderich	62	1,206,879	2.6
Total	714	12,822,410	27.2

Table 3.2 Major U.S. Ports in the GLS for Inland Lock Traffic

United States Ports	Shipments	Total Cargo Tonnes	%
Inbound:			
Toledo	106	1,946,898	10
Detroit	112	882,356	4.6
Cleveland	231	800,523	4.1
Burns Harbour	53	508,473	2.6
Ashtabula	19	301,158	1.6
Total	521	4,439,408	22.9
Outbound:			
Superior	150	4,019,741	20.7
Toledo	84	1,839,845	9.5
Duluth	81	1,382,060	7.1
Ashtabula	38	1,008,389	5.2
Sandusky	37	993,036	5.1
Total	390	9,243,071	47.6

It can be seen that the traffic for the U.S. ports is relatively low compared to that of the Canadian ports. For 2013, 68% of the total vessel traffic traveling through the GLS locks in the Welland Canal and the St. Lawrence River is responsible for carrying 71% of the total goods coming into Canadian ports (The St. Lawrence Seaway Traffic Report, 2013).

Canadian ports traffic data for 2011, which has been obtained from Transport Canada, also indicates general domestic and international vessel traffic movement along the GLS. Table 3.3 shows the major Canadian ports for the total vessel activity along the GLS.

Table 3.3 Major Canadian Ports in the GLS for Total Shipments

Canadian Ports	Shipments	%
Inbound		
Montreal	1,974	20.50
Quebec	1,101	11.44
Kingston	983	10.21
Hamilton	594	6.17
Windsor	476	4.94
Total	5,128	53.26
Outbound		
Montreal	1,927	20.25
Quebec	1,115	11.71
Kingston	983	10.33
Hamilton	546	5.74
Sarnia	490	5.15
Total	5,061	53.17

Based on the data, it can be concluded that almost 32% of the total vessel activities occurred in the Port Montreal (20.5%) and the Port Quebec (11.5%). This data also shows that major vessel traffic for international shipments is mostly accessed through the Port Montreal and Port Quebec.

3.2 ACCIDENT TYPES AND VESSEL TYPES

The Transportation Safety Board of Canada (TSB) provides a Marine Occurrence Report[1], which divides occurrences into two categories - incidents and accidents. Incidents include a wide spectrum of events such as, a person falling overboard, cargo shift, bottom contact without grounding, loss of cargo overboard, intentional anchoring or grounding or beaching to avoid accident, release of dangerous goods, traffic conflicts not resulting accidents, any threat to safety caused by the failure of navigation equipment. For vessel accidents to occur the following conditions must apply: a collision between vessel, a vessel striking another object, grounding, sustaining damage that affects the vessel's seaworthiness or renders it unfit for its purpose, an explosion, foundering, vessels gone missing, fire, sinking, capsizing, or an abandoned vessel. The primary focus of this research is restricted to reportable vessel accidents.

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[1] http://www.tsb.gc.ca/eng/incidents-occurrence/marine/1808E-20140926.pdf

There are several different types of vessels such as, pleasure craft, cargo vessel, tanker, barge, passenger vessel, and fishing vessel. This research focuses on only freight vessels namely, cargo vessels, tankers, and barges.

Barges are flat-bottomed boats, which are mostly used to carry goods on rivers or canals. There are two different types of barges: self-propelled barges and tugboat propelled. Tugboats are small but powerful vessels used to tow barges. Cargo vessels can carry solid or liquid goods and they mostly have a crane or other equipment to load or unload their goods. Tankers are merchant vessels, which transport liquids or gases in bulk. In the marine industry, freight vessels are categorized based on their size or ton deadweight (DWT). The smallest category is Small Handy Size, which is between 20,000 to 28,000 DWT while the largest category is Ultra Large Crude Carrier (ULCC) is between 320,000 and 550,000 DWT. The largest category able to carry goods on the GLS, due to the size restrictions of the locks, is the Seawaymax. The Seawaymax class has a 225.6 meter length, 23.8 m width, a draft of 8.08 m and a 35.5 meter height from the waterline. The larger sized vessels can be used for inland water transportation on the GLS, but cannot be used to access the locks.

3.2.1 Freight Vessels' Characteristics

It should be noted that freight vessels have limited maneuverability and slower reaction times (increased stopping distance in case of emergency) especially in the narrow part of a channel or canal due to their massive structure (Landsburg et al., 1983; Ming et al., 2013). Also, when the vessel slows down, it does not steer well because the rudder needs the flow of water to function effectively.

Furthermore, adverse weather conditions may cause accidents. It is possible to be dragged by the effect of tide and wind if a vessel is traveling too slowly. Therefore, each vessel must maintain a certain speed based on its own characteristic. When there is limited visibility vessels are operated only by their navigation systems and it might be difficult to observe other smaller vessels that do not have a computerized navigation signal (Gray et al., 2003). The effect of environmental factors on freight vessel accidents on the GLS will be discussed in the Section 3.3.1 pertaining to accident data collection.

3.2.2 Causes of Vessel Accidents

The main focus in our research deals with groundings and collisions along the river and canal/lock sections of the GLS. Collisions include those between two vessels and those between a vessel and a fixed object. Grounding is the term used when a vessel runs aground or makes contact with the seabed. Grounding accidents have been combined with collisions with fixed objects. Based on the previous research on marine accidents, common factors on groundings and collisions are shown in Figure 3.2.

TSB Canada[2] classifies the accidents and then investigates them according to their classification code as per the Occurrence Classification Policy.

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[2] http://www.bst-tsb.gc.ca/eng/lois-acts/evenements-occurrences.asp

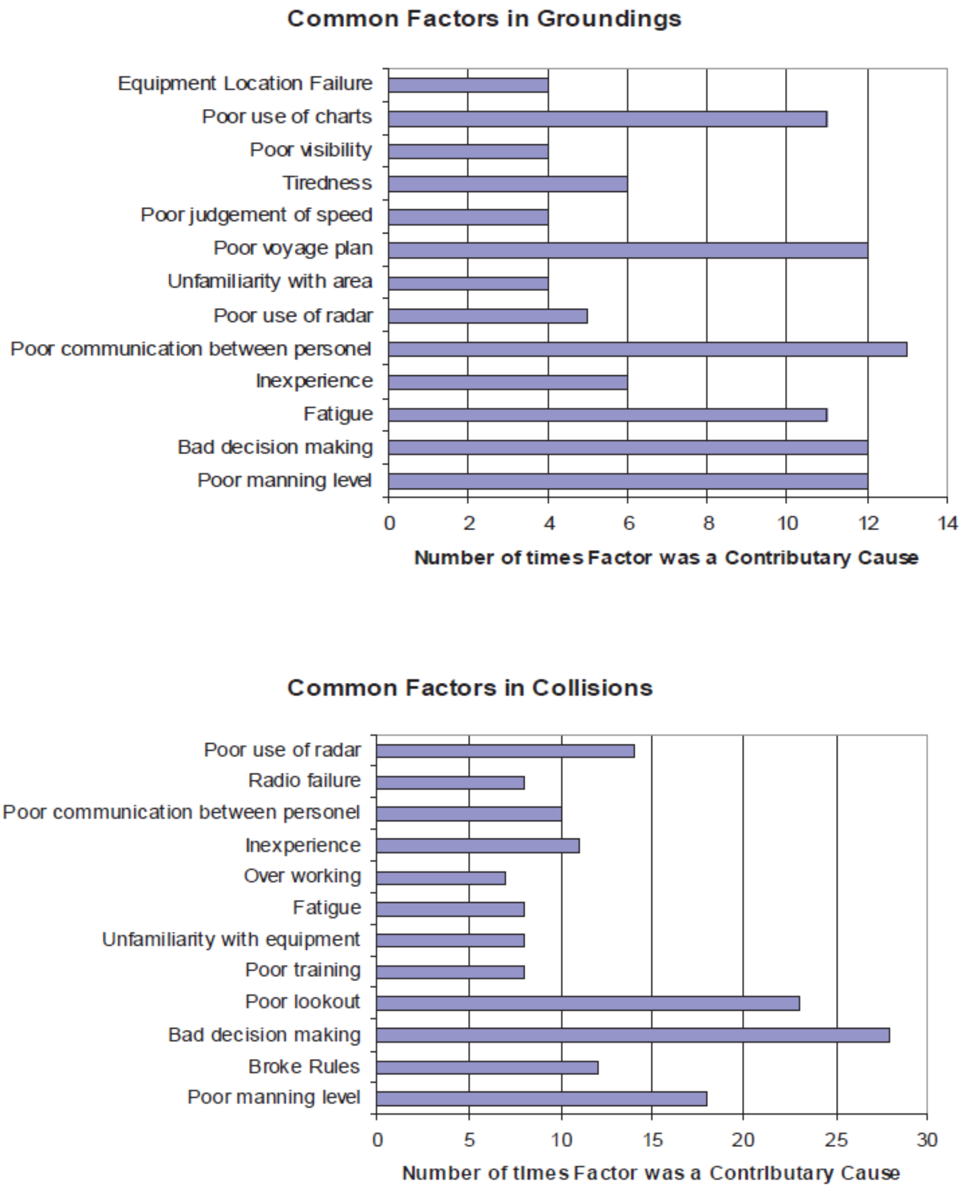
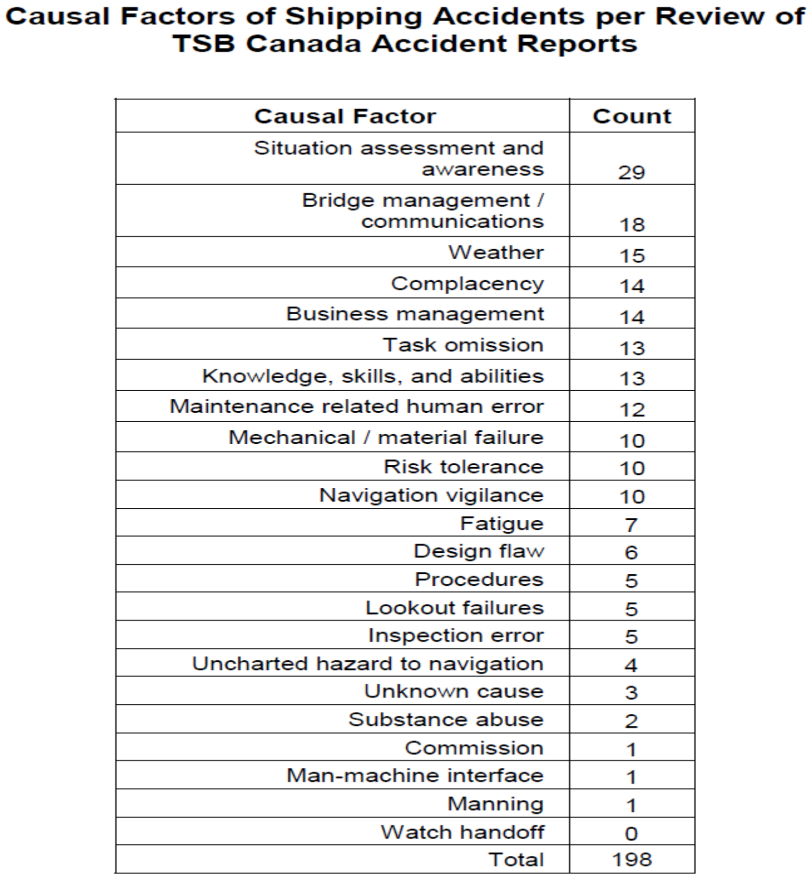


Figure 3.2 Common Factors in Groundings and Collisions *(Source: Ziarati, 2007)*

According to the Figure 3.2 poor decision-making plays a critical role in both grounding and collisions, i.e. Vessel collisions with fixed objects. Poor communication and poor voyage planning are also important contributing factors for groundings while poor lookout significantly impacts the number of collisions. Based on the top reasons for collisions and groundings, it can be surmised that the main reason for these type of accidents is mainly due to human error. Figure 3.3 also confirms that 84% of the accidents that are investigated by the Transportation Safety Board of Canada (TSB) are caused by human error (Baker, and Seah, 2004). TSB Canada also collects data on GLS accidents in U.S. waters.



Causal Factors of Shipping Accidents per Review of TSB Canada Accident Reports

Causal Factor	Count
Situation assessment and awareness	29
Bridge management / communications	18
Weather	15
Complacency	14
Business management	14
Task omission	13
Knowledge, skills, and abilities	13
Maintenance related human error	12
Mechanical / material failure	10
Risk tolerance	10
Navigation vigilance	10
Fatigue	7
Design flaw	6
Procedures	5
Lookout failures	5
Inspection error	5
Uncharted hazard to navigation	4
Unknown cause	3
Substance abuse	2
Commission	1
Man-machine interface	1
Manning	1
Watch handoff	0
Total	198

Figure 3.3 Casual Factors of Marine Accidents from TSB Reports *(Source: Baker, and Seah, 2004)*

3.3 MODEL DATA INPUT

In this section, the nature of vessel accidents along the GLS are discussed. Also discussed are, detailed information about the historical traffic data and route selection.

3.3.1 Accident Data

Accident data for the entire GLS was obtained from TSB Canada for the years between 2000 and 2013. Between those years, there were a total of 1667 vessel (all vessel types included) accidents on the GLS. 1046 (63%) of these accidents involved barges, cargo vessels and tankers. When the accidents occurring in the channel, river and canal/lock sections are filtered out, the number of accidents was reduced to 507 (30%). As a result, 302 (18%) freight vessel accidents occurred involving grounding and collision. This means 60% of freight vessel accidents on the GLS river and canal sections are groundings and collisions. TSB Canada data also includes the occurrence date, occurrence time, time zone, vessel flag, longitude, latitude, name of the vessel, near location description, area type, DWT, wind speed, light conditions, sea state and a summary of the accident. Appendix A shows the classification of accidents for each type of vessel that have been researched in this thesis. The appendix also includes the environment conditions during the accidents. Specifically the light conditions, sea state and wind conditions. Environment Canada's website[3] was used to obtain wind speed and light conditions for the missing data. Occurrence time was checked and filtered to identify light conditions (daytime or nighttime). For the wind condition, the wind speed between 0 and 12 knots (22.22 km) was designated as "light", between 12 knots (22.22 km) and 20 knots (37.04 km) was designated as "moderate", and the speeds more than 20 knots (37.04 km) was designated as "strong". For the sea state, waves less than 1.25 meters were labelled as "calm", 1.25 to 4 meters as "moderate" and more than 4 meters as "high". High sea state also included ice patches, ice covered section and strong tide or rips. Determination of the bin sizes for the above environmental factors have been set based on the data provided by TSB Canada. The GLS was categorized according to 4 zones: St. Lawrence River from Rimouski-Lake Ontario (Zone 1), Welland Canal (Zone 2), Detroit River and St. Clair River (Zone 3), and St. Mary's River (Zone 4).

As mentioned, freight vessel collisions shown in Appendix A consist of vessels colliding with fixed objects and vessel-to-vessel collisions. Of these vessel-to-vessel collisions, 26 accidents took place in zone 1, 18 accidents occurred in zone 2, 4 accidents in zone 3, and 3 accidents in zone 4. It is critical to understand that if a freight vessel collides with another freight vessel this is considered as two vessels involved in the collision as per our research. If a freight vessel collides with another type of vessels (not a freight vessel) this is counted as one collision. This determination gives a more accurate exposure (vessel-km accident ratio) in the model results. From the accident tables (in Appendix A), it can be observed that most of the accidents occurred

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[3] https://weather.gc.ca/canada_e.html

when the wind was light, sea state was calm. Also, almost all zone accidents occurred equally in daytime and nighttime. This can help us to understand that weather conditions and light conditions do not have significant effects on freight vessel accidents as there are restriction on the seaway in terms of having dangerous weather conditions. For instance, the St. Lawrence River (between Montreal and Lake Ontario) and the Welland Canal are usually closed during the winter (the end of December to the beginning of April) depending on the water surfaces' conditions (The St. Lawrence Seaway Traffic Report, 2013). This differs for the other sections of the seaway. Closures on the GLS during the winter may help us to understand why the environmental conditions do not have significant effect on accidents.

Figure 3.4 shows that majority of accidents occurred in zone 1 (the St. Lawrence River) while zone 4 has only 5% of the total accidents.

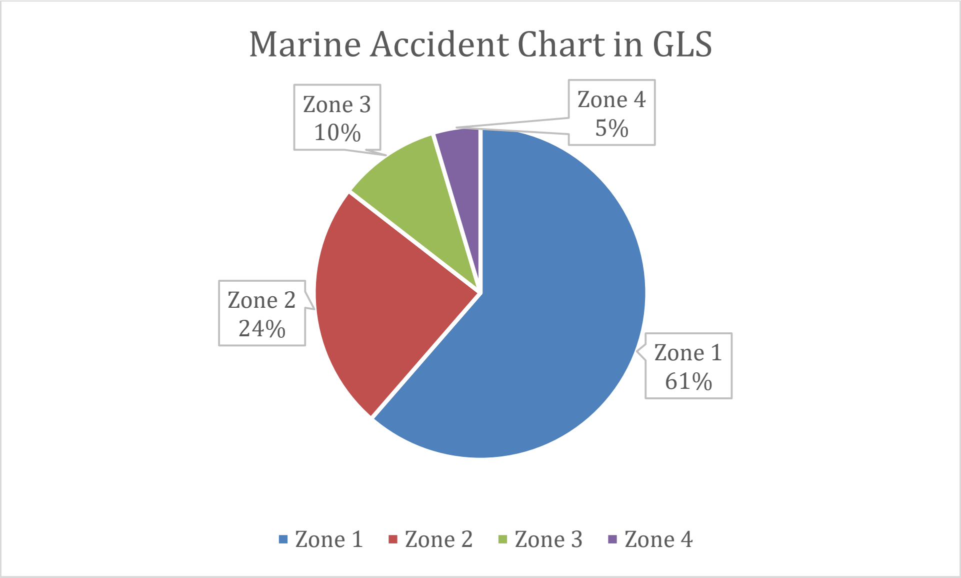

Figure 3.4 Analyzed Zones' Proportion of Marine Accidents in the GLS

3.3.2 Traffic Data and Route Selection

Vessel traffic data for the GLS was collected from different sources. Canal shipment data (Canal sections of the St. Lawrence River and Welland Canal) were extracted from the GLS Management Corporation Annual Reports for the period 2000 to 2013. River vessel traffic along the seaway between Montreal and Kingston was assumed to be similar to canal traffic in the same vicinity, since separate data on river traffic volumes was not available. For the Rimouski-Quebec, Quebec-Montreal, Detroit River, and St. Clair River segments, we obtained traffic data from the Canadian Coast Guard Marine Communications and Traffic Service for 12 years between 2002 and 2013. For the St. Mary River segment, traffic data was obtained from the US Coast Guard. Table 3.4 below shows the average yearly freight vessel traffic for each zone.

Table 3.4 Average Annual Traffic for Each Zone in the GLS

Zones	Section	Average Annual Traffic by Section
Zone 1	Rimouski-Quebec	12284
	Quebec-Montreal	14588
	Montreal-Lake Ontario	2324
Zone 2	Welland Canal	2694
Zone 3	Detroit River	2540
	St. Clair River	4708
Zone 4	St. Mary River	4494

In this analysis, to obtain the length and the width of the GLS, one week of freight vessel Automatic Identification System (AIS) data was used. There are online sources[4] that collect AIS data for vessels. From the online sources, we can get some information about vessels such as speed of the vessel, direction, destination, vessel type, characteristics of the vessel, and position history. Several freight vessels' position history was collected for a week and was put into ArcGIS software (ESRI, 2012) to determine which route they use on the GLS. Also, bathymetric gridded

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[4] http://www.marinetraffic.com/

data for the GLS was used to determine which proportion of the river is useful for marine transportation. Table 3.5 shows a sample of the vessel position history data.

Table 3.5 Sample Vessel Position Data Obtained from AIS Data

Timestamp	AIS Source	Speed	Longitude	Latitude	Course
2014-08-10 1:25	T-AIS	18.40	-67.37149	49.13534	61.00
2014-08-10 1:22	T-AIS	18.30	-67.39185	49.12794	61.00
2014-08-10 1:19	T-AIS	18.40	-67.40601	49.12253	55.00
2014-08-10 1:17	T-AIS	18.50	-67.41892	49.11681	55.00
2014-08-10 1:15	T-AIS	18.60	-67.43170	49.11101	55.00
2014-08-10 1:11	T-AIS	19.00	-67.48860	49.08527	55.00
2014-08-10 1:04	T-AIS	19.00	-67.50781	49.07662	55.00
2014-08-10 1:01	T-AIS	19.10	-67.52780	49.06763	55.00
2014-08-10 0:58	T-AIS	19.20	-67.54807	49.05871	56.00
2014-08-10 0:55	T-AIS	19.20	-67.56825	49.04985	56.00
2014-08-10 1:01	T-AIS	19.10	-67.52780	49.06763	55.00
2014-08-10 0:58	T-AIS	19.20	-67.54807	49.05871	56.00
2014-08-10 0:55	T-AIS	19.20	-67.56825	49.04985	56.00

The term “downbound” is used for vessels in the Great Lakes region moving towards the Atlantic Ocean. The term “upbound” describes vessels that are heading away from the Atlantic Ocean (United States Coast Guard, 2010). Vessels usually follow the same route in the GLS for upbound and downbound traffic. However, there are some sections along the GLS where opportunity allows for upbound and downbound traffic lanes to differentiate in order to minimize the risk of collisions along the GLS route.

Figure 3.5 shows the entrance part of the Detroit River from the Lake Erie side where the upbound traffic uses the east side of the Bois Blanc Island while the downbound traffic uses the west side of the island. The same exception occurs in the St. Mary River between Munuscong Lake and Lake Nicolet. In this segment, vessels use the east side of the Neebish Island for upbound traffic and the west side for the downbound traffic. Since we have the regional traffic data, it is assumed that the upbound and the downbound traffic is equally distributed in these sections for our calculation purposes.

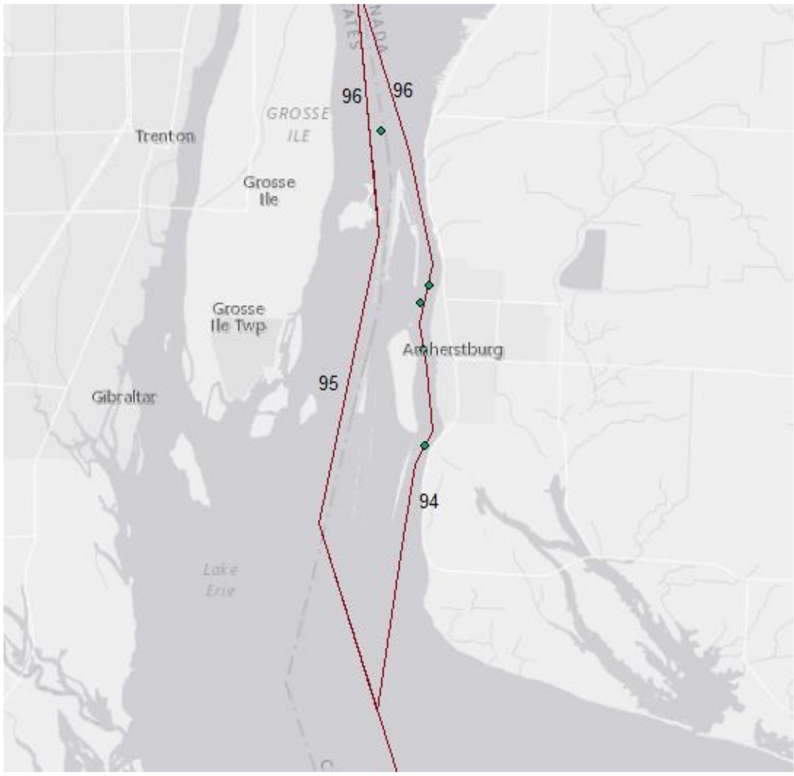


Figure 3.5 Detroit River's Upbound and Downbound Vessel Route

For much of its length, the GLS consists of 1,440 km of river sections and 160 km of canals and locks. This is the length of the GLS which is of interest in this research, i.e. excluding lakes and port locations. While there are sections of the seaway near the Gulf of the St. Lawrence with widths in excess of 80 km, much of the St. Lawrence (700 km of length) consists of narrower river sections and canal/lock sections with widths ranging from 60 m to 5 km. Restrictions to vessel movement caused by a reduction in channel width can be a major cause of vessel accidents along the GLS.

For the section selection, the geography of the GLS was considered. For instance, curvy routes, narrow parts, straight routes, segments with islands, segments with locks or canal entrances were given different length designations, as they might differently influence the effect on vessel accidents. Section length was kept to 1 km if there was a lock on the canal and canal segments were kept shorter than river segments since they are narrower than the river. The usable route for vessels was calculated to determine the average width of the section. When there is an island on the GLS, the width of that segment was calculated between the land and island on the side of the waterway which the vessels use (see Figure 3.6). As a result of the above criteria, the length of the seaway was divided into 109 geographic sections using ArcGIS software. Of these, 38 sections were canals and locks and 71 natural river courses (see Figure 3.7).

Figure 3.6 Sample Vessel Route and Usable Width of the Section

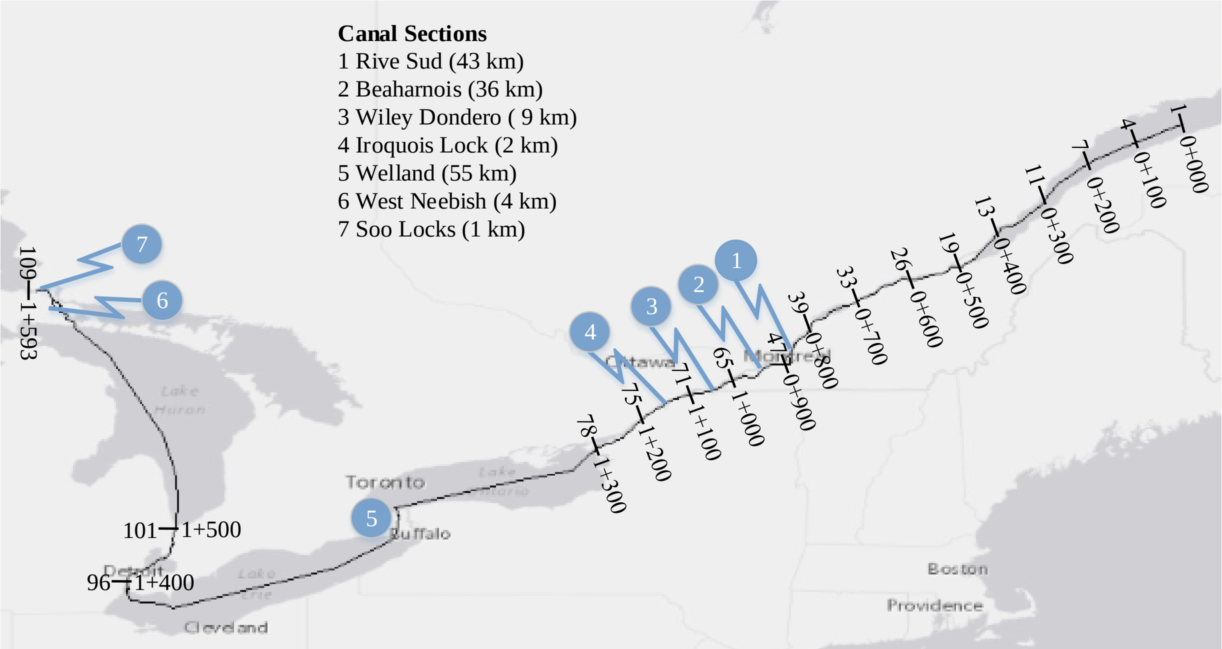


Figure 3.7 The GLS from Rimouski to Sault Ste. Marie with Mileage Offsets

It is important to mention that the sections on the lakes in Figure 3.7 are not taken into account. The mileage offsets in this figure exclude the segments on the lakes themselves although the route taken on the lake is illustrated. If vessels carry goods to ports on the lakes they follow different routes.

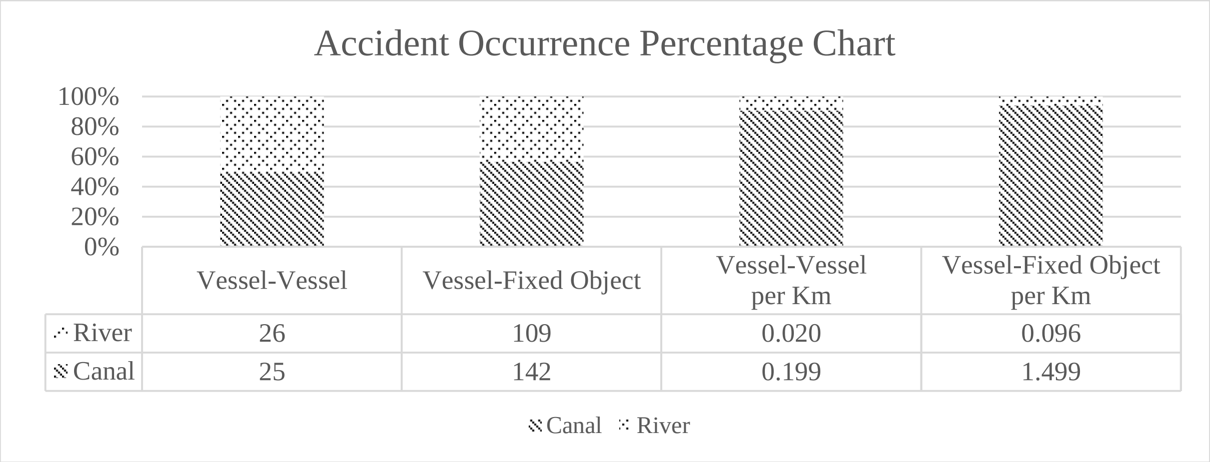
Table 3.6 provides some insights into which sections of the GLS are canal-lock sections and which are river sections.

Table 3.6 Sectioning Table with Their Zones

Zone #	Sections	
	River	**Canal/lock**
1	1-45, 58, 59, 65, 66, 70-72, 74-78	46-57, 60-64, 67-69, 73
2	NA	79-93
3	94-102	NA
4	103, 105-107, 109	104, 108

3.4 CLASSIFICATION OF ACCIDENTS FOR MODEL DEVELOPMENT

As explained previously, only freight vessel accidents as reported by the TSB along the selected segment of the GLS have been considered in this research. Between 2000 and 2013 there were 302 such accidents, which have been classified by two types of impact: Vessel-to-Vessel (VV) and Vessel-to-Fixed Object (VF). VF accidents include scenarios, such as, running aground or hitting a fixed object (natural or man-made). Canals and locks are man-made routes specifically designed for vessel traffic while the river sections are natural. Therefore, as illustrated in Figure 3.8, these VV and VF accidents have been further classified into the two navigation channel types: rivers and canal/locks.



	Vessel-Vessel	Vessel-Fixed Object	Vessel-Vessel per Km	Vessel-Fixed Object per Km
River	26	109	0.020	0.096
Canal	25	142	0.199	1.499

Figure 3.8 Percentage of Marine Accident Occurrences in the GLS between 2000 and 2013

For the 14 year period between 2000-2013, about 50% of VV accidents were found to take place at canal/locks sections and the remainder along river sections. Of the 251 VF accidents, 142 took place at canals and locks, while 109 took place along river sections (roughly equally split). However, river sections of the GLS represent a total length of 1,440 km as compared to only 160 km for canals and locks. Hence, on a route-km basis, most VF accidents tend to be concentrated at canals and locks (approx. 94%). This is expected given the narrower width involved and the restriction on vessel maneuverability, which is likely to increase collision with the sides of the navigation channel.

CHAPTER 4

VESSEL ACCIDENT PREDICTION MODEL

4.1 MODEL SELECTION

As explained in Chapter 2, an EB model approach has been adopted in this study for site-specific vessel accident prediction. The EB approach has been examined and explored by several researchers and was found to provide reliable site-specific results (with reduced over-dispersion error and regression-to-the-mean bias) (Persaud et al., 2002; Hauer et al., 2002; Miranda-Moreno et al., 2005). In the EB approach, the best estimate of expected vessel accidents at a specific site is obtained by combining two sources of inference:

1. Historically observed accidents (y) for a specific site (or GLS section)
2. Expected accident frequency for similar sites obtained from a calibrated safety performance function (SPF) or prior.

By combining these two sources, a site-specific annual expectation of accidents (λ_i) or a posterior expected value is obtained, such that:

$$\lambda_i = E(\mu_i \mid \mathrm{y}_i) = \alpha_i \cdot \mu_i + (1-\alpha_i) \cdot y_i \quad [4.1]$$

with, $$E(\lambda_i) = \lambda_i, \text{ and } Var(\lambda_i) = (1-\alpha_i) \cdot E(\lambda_i) \quad [4.2]$$

where

λ_i = EB expected annual accident frequency at site i,

μ_i = expected annual accident frequency at similar sites (i.e., from SPFs),

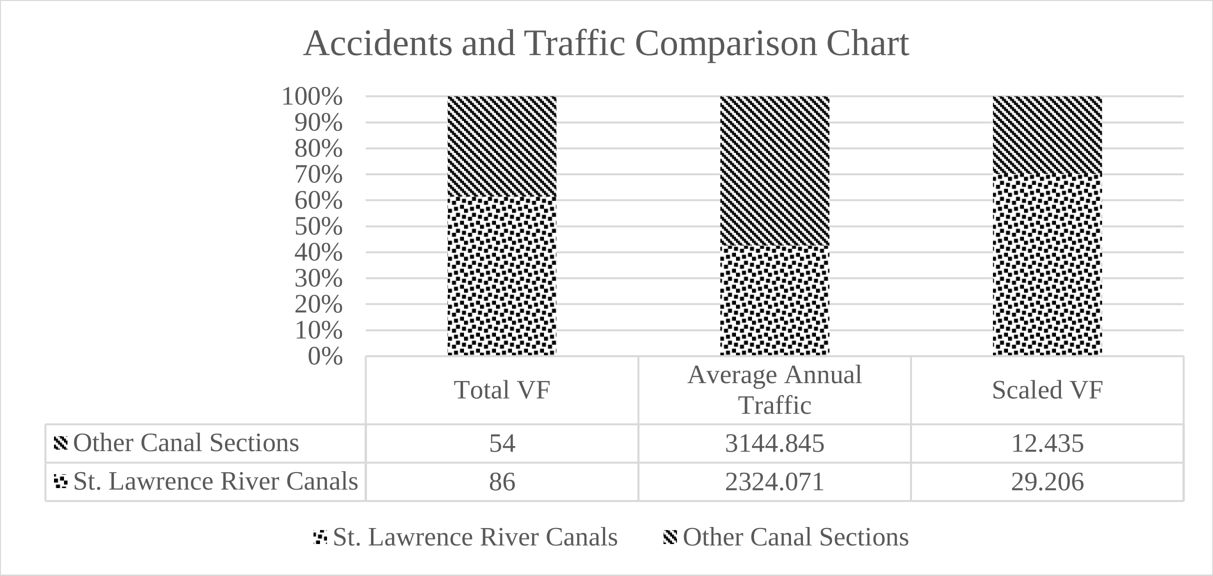
y_i = observed crash frequency in n years at site i, and

α_i = weight factor.

The weight factor α_i is estimated from the mean and variance of the SPF, such that:

$$\alpha_i = \frac{E(y_i)}{Var(y_i) + E(y_i)} \qquad [4.3]$$

A number of SPF expressions were investigated in this study for the GLS data for different geometric and operational input factors. The expressions that yielded the best statistical results included: section width (km), section length (km) and annual vessel passages. A separate "regional affiliation" term was introduced for VF models to reflect larger regional navigation features along the GLS (i.e. river and canal sections over the length of the St. Lawrence or at linkages between the Great Lakes). When we checked the annual average traffic and yearly VF accident data for canal-lock sections of the St. Lawrence River and other canal sections in the GLS, we found an inconsistency in the vessel accident occurrence rates per-km. From Figure 4.1 we note that there is more traffic in the Great Lakes sections but fewer accidents than the St. Lawrence sections. When this was scaled on a section length basis, this incontinency became more pronounced.



	Total VF	Average Annual Traffic	Scaled VF
▨ Other Canal Sections	54	3144.845	12.435
▩ St. Lawrence River Canals	86	2324.071	29.206

Figure 4.1 Accident and Traffic Comparison Chart between the Zone 1 Canals and Other Canals

A separate "regional affiliation" term was introduced to explain for the above discrepancy in the number of VF accidents between zones of the GLS. It was explained in Chapter 3 that the human errors have a significant impact on vessel accidents. There might be a navigational problem or management problem in that region, which cause more accidents. Another factor that may contribute to the increase of accidents in the St. Lawrence River canals despite less traffic in this area compared to the other canal sections are the number of canal entrance points. The bulk of VF accidents in a canal occur at the canal entrance (see Figure 4.2). Due to the geometric nature of the St. Lawrence River there are four canal sections separated by portions of river. As a result, there are eight canal entrance points along this seaway. On the other hand, other GLS canals consist of a continuous uniform nature (same width and geometry through their length), and therefore, have only two entrances to these sections. In the research, this difference between the St. Lawrence and Great Lakes was accounted for by a regional input term. In the model, this term has been designated as binary, i.e. 1 for the St. Lawrence canals (canals in zone 1) and 0 for the other canals (canals in zone 2, 3, and 4) of the GLS.

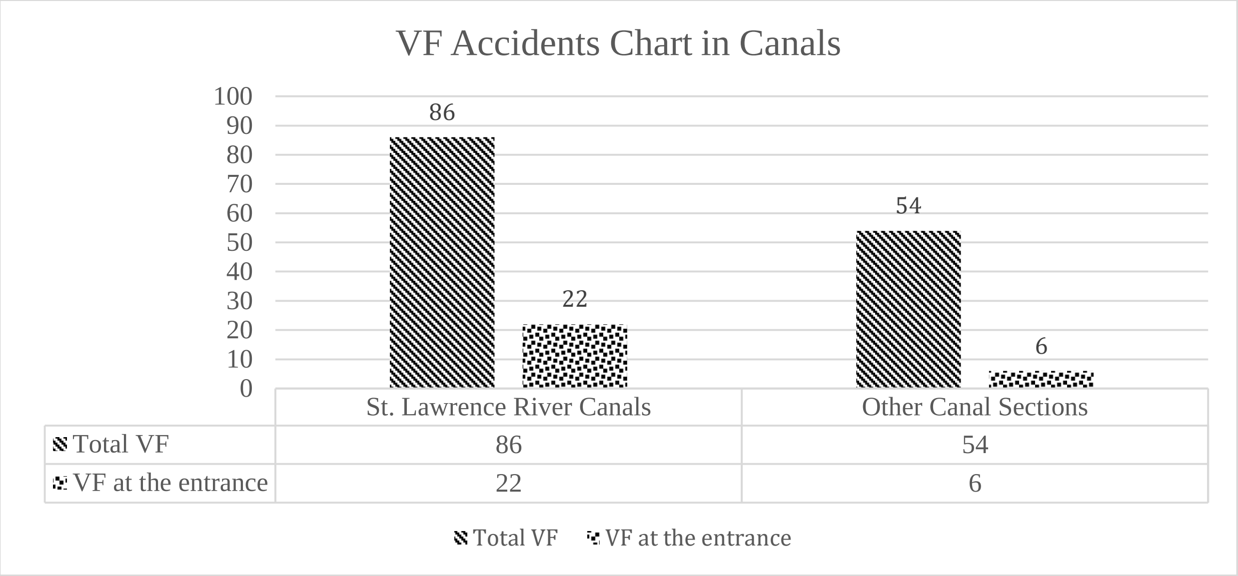


Figure 4.2 VF Proportion between Canals and Canal Entrances for Zone 1 and Other Zones

R-software (R, 2013) was used to fit various Generalized Linear Models (Poisson and Negative Binominal) for VV and VF impact types. These expressions are of the form:

$$\ln(E(\mathrm{y}_i)) = \beta_1 + \beta_2 \times \ln(\frac{T_{(x-z)} \times L_i}{W_i}) \qquad [4.4]$$

$$\ln(E(\mathrm{y}_i)) = \beta_1 + \beta_2 \times \ln(\frac{T_{(x-z)} \times L_i}{W_i}) + \beta_3 \times D_{\mathrm{var(i)}} \qquad [4.5]$$

where

y_i = observed crash frequency in n years at section i

$T_{(x-z)}$ = Total number of freight vessel traffic in the years between x and z.

L_i = length of the section i

W_i = average width of the section i

$D_{var(i)}$ = region effect at the section i

The GLM-NB distribution was found to yield better results for VF accidents in river sections, while a GLM-Poisson distribution was found to yield better results for the VF accidents in river sections and all VV models. A detail discussion of R-software model results is provided in Appendix H. From the investigated accident reports and accident history data it was concluded that other variables such as, sea state, wind and time had no significant effect on the vessel accident frequency along the GLS.

Table 4.1 summarizes the organization of the GLS vessel accident/traffic data for input into the SPF and the EB posterior. The EB posterior makes use of the SPF or prior input data and separate observational data for data likelihood. This table illustrates the data inputs for the two types of vessel impact model (VV and VF) and two GLS section types (rivers and canals/locks). Eight (8) years of data between 2002 and 2009 was used to fit various GLM for VV accidents on the river sections. These data were used to establish the EB prior or SPF function. The best fit GLM for the posterior was established using 4 years of data between 2010 and 2013 for the data likelihood or observational component of the model.

Table 4.1 Data for SPF (Prior) and Data Likelihood Inputs by Type of Accident and Section

	VV		**VF**	
Section Type	**Prior**	**Data likelihood**	**Prior**	**Data likelihood**
River	2002-2009	2010-2013	2002-2009	2010-2013
Canal/Lock	2000-2007	2010-2013	2000-2005	2010-2013

Table 4.2 shows the prior model inputs for the Welland Canal sections for demonstration purposes. There are 8 locks on the Welland Canal and the average width of the canal sections range from 100 meters to 470 meters. For the VF model, a regional affiliation term (Dvar) was designated as 0 for zone 2, 3 and 4 canal sections and value of 1 for zone 1 canal sections. For VV canal section there is no regional affiliation term on the GLS. For other sections' prior inputs have been summarized in Appendix D.

Table 4.2 Prior Model Inputs for Zone 2

Zone 2 (Welland Canal) Canal Sections								
Section	Length (km)	Width (km)	VV (2000-2007)			VF (2000-2005)		
			Traffic	Accident	Dvar	Traffic	Accident	Dvar
79	3	0.47	21995	0	NA	16084	1	0
80	4	0.18	21995	2	NA	16084	4	0
81	1	0.2	21995	0	NA	16084	2	0
82	1	0.125	21995	0	NA	16084	4	0
83	5	0.24	21995	3	NA	16084	4	0
84	4.5	0.1	21995	2	NA	16084	1	0
85	5	0.16	21995	2	NA	16084	4	0
86	5	0.16	21995	0	NA	16084	3	0
87	5	0.2	21995	0	NA	16084	0	0
88	5	0.24	21995	0	NA	16084	0	0
89	5	0.23	21995	0	NA	16084	0	0
90	5	0.24	21995	0	NA	16084	0	0
91	4	0.2	21995	0	NA	16084	2	0
92	2.5	0.11	21995	2	NA	16084	1	0
93	3.5	0.2	21995	0	NA	16084	0	0

4.2 SPF AND EB PREDICTION MODEL RESULTS

Table 4.4 and 4.5 summarize the SPF results for river and canal/lock sections, respectively. Separate models were calibrated for VV and VF impact types. The ratio of the residual deviance to the degrees of freedom yielded a dispersion parameter, which measures the degree of over-dispersion or unexplained variation in the observed site accident data as compared to what the model predicts. A value of 1 for this parameter suggest no over-dispersion and the model is assumed to fully capture the site-specific variation in accident frequency (McGullagh, and Nelder, 1989).

It is important to mention that both Poisson and NB models have been applied to different prior data (4, 6 and 8 years) and the best models were chosen based on the criteria (significance of the values, AIC value, and dispersion parameter) that have been explained in Chapter 2. For example, Table 4.3 shows both Poisson and NB model results on the same section and over the same years.

Table 4.3 Sample Poisson and NB Model Results for Model Decision

Outputs	**VV River Poisson**		**VV River NB**	
	coefficient	**p-value**	**coefficient**	**p-value**
β1	-10.014	0.003	-10.820	0.006
β2	0.694	0.007	0.758	0.012
Residual Deviance	60.64		44.836	
Degrees of freedom	69		69	
AIC	97.835		97.858	
Dispersion parameter	0.875		0.650	

It can be seen from the Table 4.3 that both β1 and β2 significance values are less than 5% value and AIC parameters are similar. However, the dispersion parameter in Poisson model is statistically better (closer to 1) than NB model in terms of having a better fit. In this case, choosing the Poisson model gives us better results.

For the river section in Table 4.4, the degree of dispersion for VV and VF accidents was found to be 0.875 and 1.085, respectively, and for these models both Poisson and NB distributions were considered acceptable. In this research, we selected a NB link function for the VF accidents in the river, and a Poisson link function for the VV accidents in the river model based on the significance of the input factors in Equation 4.4 and 4.5.

Table 4.4 Prior Model Results from R-Statistical Software for VV and VF Accidents in River Sections

Outputs	VV River		VF River	
	coefficient	p-value	coefficient	p-value
β1	-10.014	0.003	-7.922	0.001
β2	0.694	0.007	0.623	0.001
Residual Deviance	60.640		74.912	
Degrees of freedom	69		69	
AIC	97.835		184.220	
Dispersion parameter	0.875		1.085	

For canal-lock, the SPF VV and VF expressions yielded dispersion parameters of 1.061 and 2.312, respectively, suggesting that for VF accidents the data is slightly over-dispersed. Analysis of both Poisson and NB link functions, however, yielded statistically more robust inputs for the Poisson link function. Hence, in this research a Poisson link function was used for canal/lock accident prediction for both VV and VF accident types. From Table 4.4 and Table 4.5, we can conclude that all the variable parameters in the fitted expressions were highly significant at the 5% level.

Table 4.5 Prior Model Results from R-Statistical Software for VV and VF Accidents on Canal-Lock Sections

Outputs	VV Canal/Lock		VF Canal/Lock	
	coefficient	p-value	coefficient	p-value
β1	-21.736	0.001	-6.112	0.018
β2	1.616	0.002	0.517	0.011
β3	---	---	0.586	0.029
Residual Deviance	38.189		80.950	
Degrees of freedom	36		35	
AIC	62.863		157.020	
Dispersion parameter	1.061		2.312	

It should be noted, that the SPF for VF accidents in canal/locks includes a regional affiliation term that distinguishes the St. Lawrence River segments of the GLS from segments connecting the Great Lakes (i.e. Welland, Detroit River, St. Clair River and St. Mary's River).

The data likelihood component of the EB posterior makes use of data from a 4 year period (2010-13) for both VV and VF accidents at rivers and canal/lock sections (Table 4.1). The four year period for data likelihood is considered sufficient to capture long term year-to-year variations in the observed accident frequencies (Hauer et al., 2002).

In total there are 109 river and canal/lock sections over the entire length of the GLS. For demonstration purposes a 58.5 Km stretch of the GLS, along the Welland Canal has been selected in this thesis to report the posterior estimates of expected frequencies for both VV and VF accident types. The results are summarized in Table 4.6. For these results, the prior μ and the posterior $\sum E(\mu/y)$ have been reported for a combined 4 year period, as have the number of observed accidents. VAR(y) was calculated based on the section's dispersion parameter by using the summation of 4 years of data. To obtain the 4-year estimate, each year's expectation was summed (∑E(μ/y)) for VV and VF accidents. For other sections of the GLS posterior model results have been summarized in Appendix E.

Table 4.6 EB Model Results for Zone 2

Zone 2 (Welland Canal) Canal Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
79	1	1.366	4.313	0.240	1.088	0	0.010	0.000	0.989	0.010
80	2	2.604	15.679	0.142	2.086	0	0.078	0.007	0.923	0.072
81	0	1.204	3.350	0.264	0.318	1	0.007	0.000	0.993	0.014
82	1	1.535	5.448	0.220	1.118	0	0.015	0.000	0.984	0.015
83	1	2.518	14.666	0.147	1.222	0	0.071	0.005	0.930	0.066
84	2	3.751	32.534	0.103	2.181	0	0.245	0.064	0.794	0.195
85	5	3.106	22.310	0.122	4.769	0	0.136	0.020	0.874	0.119
86	0	3.106	22.310	0.122	0.380	0	0.136	0.020	0.874	0.119
87	1	2.767	17.711	0.135	1.239	0	0.095	0.010	0.909	0.086
88	0	2.518	14.666	0.147	0.369	0	0.071	0.005	0.930	0.066
89	0	2.574	15.326	0.144	0.370	2	0.076	0.006	0.926	0.219
90	0	2.518	14.666	0.147	0.369	0	0.071	0.005	0.930	0.066
91	0	2.466	14.059	0.149	0.368	0	0.066	0.005	0.934	0.062
92	1	2.634	16.047	0.141	1.230	0	0.081	0.007	0.921	0.075
93	2	2.301	12.245	0.158	2.048	2	0.053	0.003	0.946	0.158

From Table 4.6, it can be seen that the number of expected accidents is in the range between the observed accidents and the posterior results based on the weight factor (α). Specifically, for VF accidents the reference population is so diverse (Var(y)>> ∑μ), resulting in a very small α value. In this case, the reference population exerts little influence in our estimation (EB results are closer to the observed accidents). This is completely opposite for VV accidents. VV expected accidents over 4 years are closer to the posterior results due to its high weight factor. Another conclusion regarding this table is that the expected number of VF accidents are greater than the VV accidents.

CHAPTER 5

ANALYSIS OF THE GLS HOTSPOTS

5.1 HOTSPOT CRITERIA AND SCALING

The 85th and 95th percentiles were obtained based on the distribution of 4 years' total expected values per section divided by section length and the 4-year total volume and multiplied by 100,000 for scaling. The 85th and 95th percentile represents the expected 4-year total number of accidents that is exceeded 15% and 5% of the time for all the GLS sections. These expectations reflect higher than average values for seaway conditions. For this research, sections with an expected number of accidents exceeding the 85th and 95th percentiles were deemed to be hotspots for the period 2010-13. These thresholds were determined somewhat arbitrarily using the researchers discretion as to what was deemed to be high risk. The upper 5% (high-risk) or 15% (moderate-risk) of the distribution indicates an unacceptable risk as compared to the other sections of the GLS. The 85th and 95th percentile expected 4-year number of VV accidents is 0.19 and 0.41 respectively. For VF accidents the 85th and 95th percentile values were found to be 3.26 and 7.29, respectively. Figure 5.1 and Figure 5.2 displays the distribution for the expected number of accidents for all of the GLS sections along with the 85th and 95th percentile thresholds. The expected 4-year total for scaled VV and VF accidents can be seen in Appendix F.

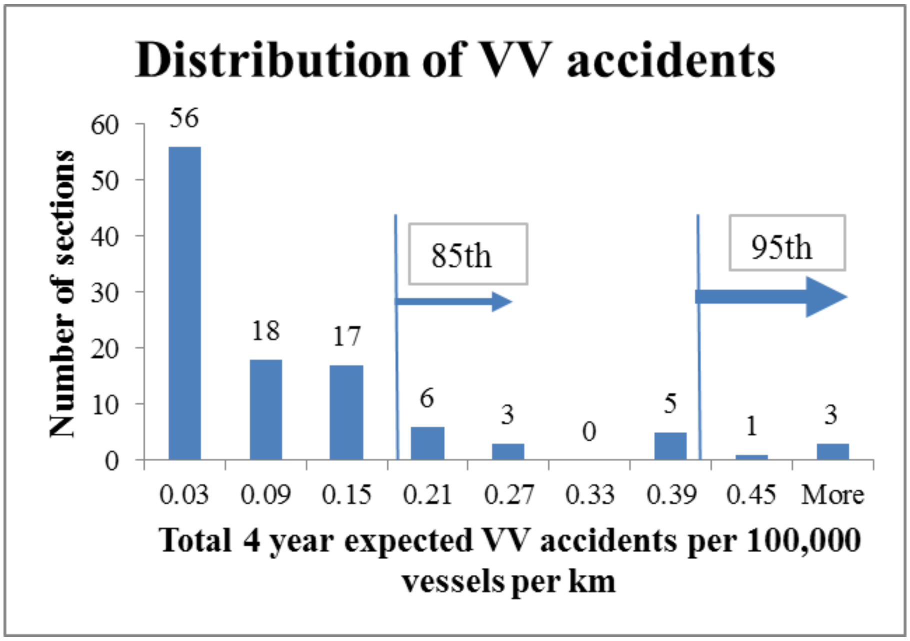


Figure 5.1 Distribution of Scaled Expected VV Accidents in the GLS

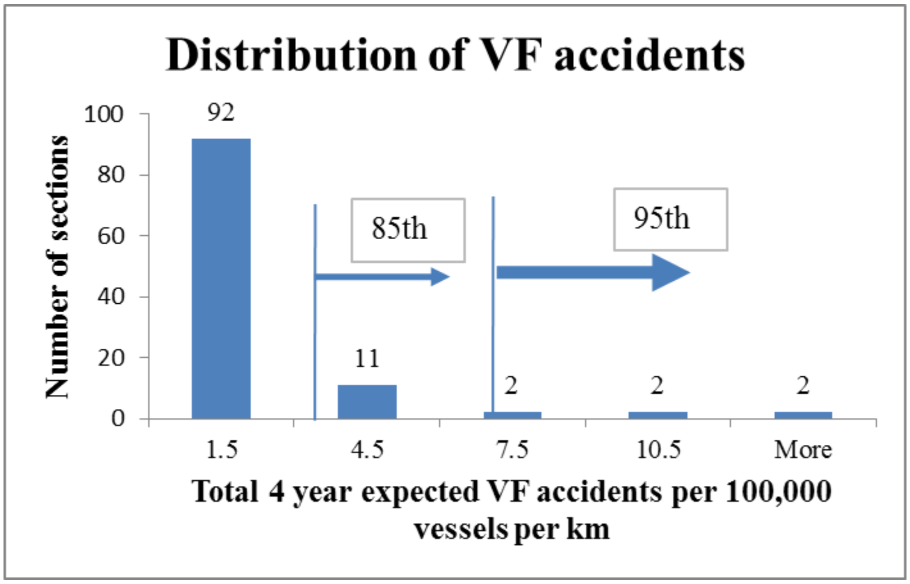


Figure 5.2 Distribution of Scaled Expected VF Accidents in the GLS

5.2 HOTSPOTS BASED ON ACCIDENT TYPES

Table 5.1 provides a list of the GLS hotspots for the 95th percentile (dark red) and 85th percentile (light red) thresholds for VV and VF accidents. The table includes information on mileage offset, section type, and E(μ/y)/4 yr. For the higher risk 95th percentile threshold a total of 5 sections (16.5 km, 1.03% of the seaway) were identified as hotspots for VV accidents, and 6 sections (15.5 km, 0.97% of the seaway) for VF accidents. These hotspots are identified out of a total of 109 sections considered (1600 km) along the GLS. A total of 10 sections (31 km, 1.94% of the seaway) were identified as hotspots when both types of accidents (VV and VF) were combined.

For the lower risk threshold of 85th percentile, the number of hotspots increased to 16 sections for VV (96.76 km or 6.07% of the GLS length) and 17 sections for VF (50.72 km, 3.18% of the GLS length). A total of 25 sections (123.98 km, 7.78% of the seaway) were identified as hotspots when both VV and VF accidents were combined into a single model. Reducing the threshold by 10% has had the effect of adding 15 sections to the list of hotspots for all accident types. Seven of these hotspots were isolated sections (48.73 Km), while 8 hotspots (44.25 km) were found to be extensions of the 95th percentile sites.

Table 5.1 Hotspot Results for VV and VF Accidents in the Great Lakes Seaway

Section #	Mileage Offsets (km)	Location	Section Type	VV Accidents		VF Accidents	
				E(μ/y) per km*10^5	% value	E(μ/y) per km*10^5	% value
46	00+899	St. Lawrence River	Canal	0.117	67.20	4.624	90.90
47	00+900	St. Lawrence River	Canal-lock	0.417	95.40	32.263	99.00
48	00+903	St. Lawrence River	Canal	0.070	56.30	4.374	89.00
52	00+918	St. Lawrence River	Canal	0.042	40.00	3.691	86.30
53	00+919.5	St. Lawrence River	Canal-lock	0.144	75.40	8.760	94.50
60	00+967	St. Lawrence River	Canal-lock	0.407	93.60	10.684	97.20
67	01+080	St. Lawrence River	Canal-lock	0.551	97.20	4.102	87.20
69	01+088	St. Lawrence River	Canal-lock	0.551	97.20	4.102	87.20
70	01+098	St. Lawrence River	River	0.201	85.40	0.438	59.00
73	01+146	St. Lawrence River	Canal-lock	0.147	78.10	20.575	98.10
79	01+318	Welland Canal	Canal	0.032	30.90	3.411	84.50
80	01+322	Welland Canal	Canal-lock	0.170	82.70	4.906	92.70
82	01+324	Welland Canal	Canal-lock	0.140	73.60	10.513	96.30
84	01+333.5	Welland Canal	Canal-lock	0.407	92.70	4.559	90.00
85	01+338.5	Welland Canal	Canal-lock	0.224	87.20	8.972	95.40
86	01+343.5	Welland Canal	Canal	0.224	87.20	0.714	69.00
89	01+358.5	Welland Canal	Canal	0.412	94.50	0.696	67.20
92	01+370	Welland Canal	Canal-lock	0.282	90.00	4.630	91.80
93	01+373.5	Welland Canal	Canal	0.424	96.30	5.504	93.60
94	01+384.25	Detroit River	River	0.380	91.80	0.843	72.70
95	01+394.25	Detroit River	River	0.602	99.00	1.146	79.00
98	01+440.25	Detroit River	River	0.270	89.00	0.886	75.40
103	01+529.42	St. Mary's River	River	0.283	90.90	0.700	68.10
104	01+533.64	St. Mary's River	Canal	0.183	83.60	3.537	85.40
105	01+540.48	St. Mary's River	River	0.215	86.30	1.137	78.10

Table 5.1 indicates the hotspots for rivers and canal/locks for the 95th and 85th percentile thresholds. For the 95th percentile threshold, canal and lock sections are decidedly less safe than river sections, although the actual kilometres designated as hotspots are significantly greater for the 85th percentile. The table represents the total linear distance in kilometres from the start point for both VV and VF hotspots. For the 95th percentile threshold, 9 hotspot sections were found to be located on canals and one hotspot on a river course. For 85th percentile value, the number of

hotspots increased to 19 for canals and 6 for river sections. Although there are more hotspot segments on canals than rivers for the 85th percentile, the total route length of river hotspots is greater than for canals (see Figure 5.3).

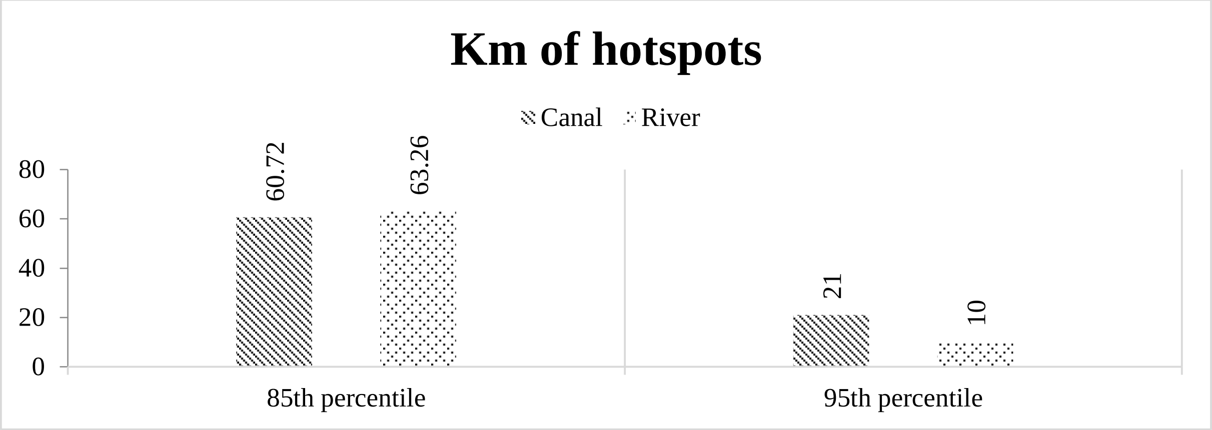


Figure 5.3 Km of Hotspots on Canal/Lock and River

A factor that significantly affects the expected number of accidents (VV and VF) on the GLS is the navigable portion of the channel width. The average navigable width of channels along the GLS is 13.83 km, while the average width of the hotspot sections for the 85th percentile is 0.54 km and only 0.17 km for the 95th percentile. These finding demonstrate that as the width of the section decreases, the risk of accidents increases significantly.

Table 5.2 indicates the number of hotspot sections and their length in kilometres for four different zones of the GLS. Both 85th and 95th percentile thresholds are shown. The highest risk sites tend to be located in the Detroit St. Clair River sections followed closely by the St. Lawrence River. This is especially true if adjustments are made to consider the section length and the concentration of risk. The highest expected number of hotspots are found along the St. Lawrence for both 95th and 85th percentiles.

Table 5.2 Number and Km of Hotspots on Each Zone

Zone	Number of Hotspots		Km of Hotspots	
	85th percentile value	95th percentile value	85th percentile value	95th percentile value
St. Lawrence River	10	6	33	11.5
Welland Canal	9	3	33.5	9.5
Detroit River-St. Clair River	3	1	40.75	10
St. Mary's River	3	0	16.73	0

By reducing the threshold from 95th percentile to 85th, all we have accomplished is that we increased the area that comes under hotspot designation, but the locations are more or less the same. Sections that are classified under the 95th percentile value are a subset of sections classified under the 85th.

Hotspot identification models can also be used as an input into cost-effective analysis. We do not have any indication of the cost of intervention to rectify these hotspots in order to make them safer. However, we can speculate the cost of intervention in a simple model that the cost will be proportional to the length of the hotspot. By applying a 10% reduction in threshold (from 95th to 85th percentile) we increase the number of hotspots and thereby, increase the cost required to rectify the hotspots. In this research, increasing the safety intervention by reducing the threshold 10%, increased the total length of hotspots by 300%. As a result, reduction in the acceptable safety criteria by 10% may cost us 300% more.

Figure 5.4 shows the hotspot locations on the Welland Canal (Zone 2). The thin line corresponds to hotspots based on the 85th percentile, while the thicker line corresponds to hotspots for the 95th percentile for selected sections of the GLS. This figure illustrates that a 10% reduction in threshold (95 to 85th percentile) yields an extension of the hotspots zones along the segments, and that hotspots identified for the 95th percentile tend to be located within the length of channel hotspot for the 85th percentile. For canal sections most of the high-risk sites (at 95th percentile) are found at the canal entrance/exit points; whereas for the lower 85th percentile, these hotspot zones tend to be extended over the length of the canal. Also, it can be noted that adjacent sections to the 95th percentile hotspots tend to encompass the 85th percentile hotspots as well.

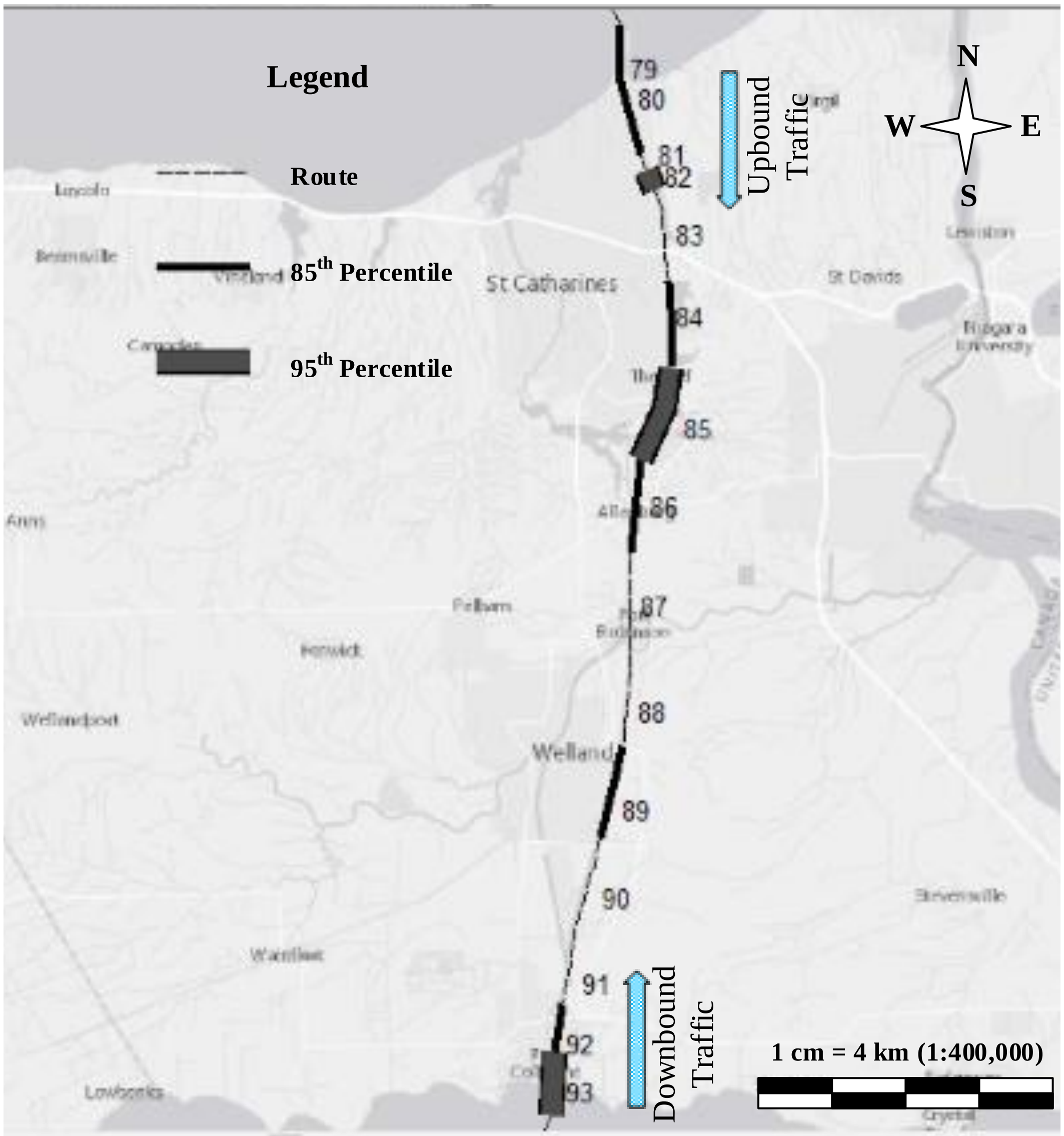


Figure 5.4 Hotspot Locations on the Welland Canal

5.2.1 Illustration of the Top 5 Hotspots for VV Accidents

In this segment the top five highest risk sections for only VV accidents are illustrated on the maps to follow. The top five sections namely are 95, 69, 67, 93 and 47 respectively. Detailed information about these sections can also be seen on the previously shown Table 5.1.

Section 95 is located on the south Detroit River and it is identified as the highest risk hotspot location for VV accidents. The length of this section is 10 km and the average width is 247 m. It can be seen from Figure 5.5 that section 94 is the entrance of the Detroit River which is used by vessels for upbound traffic. On the other hand section 95 is the exit for this downbound traffic.

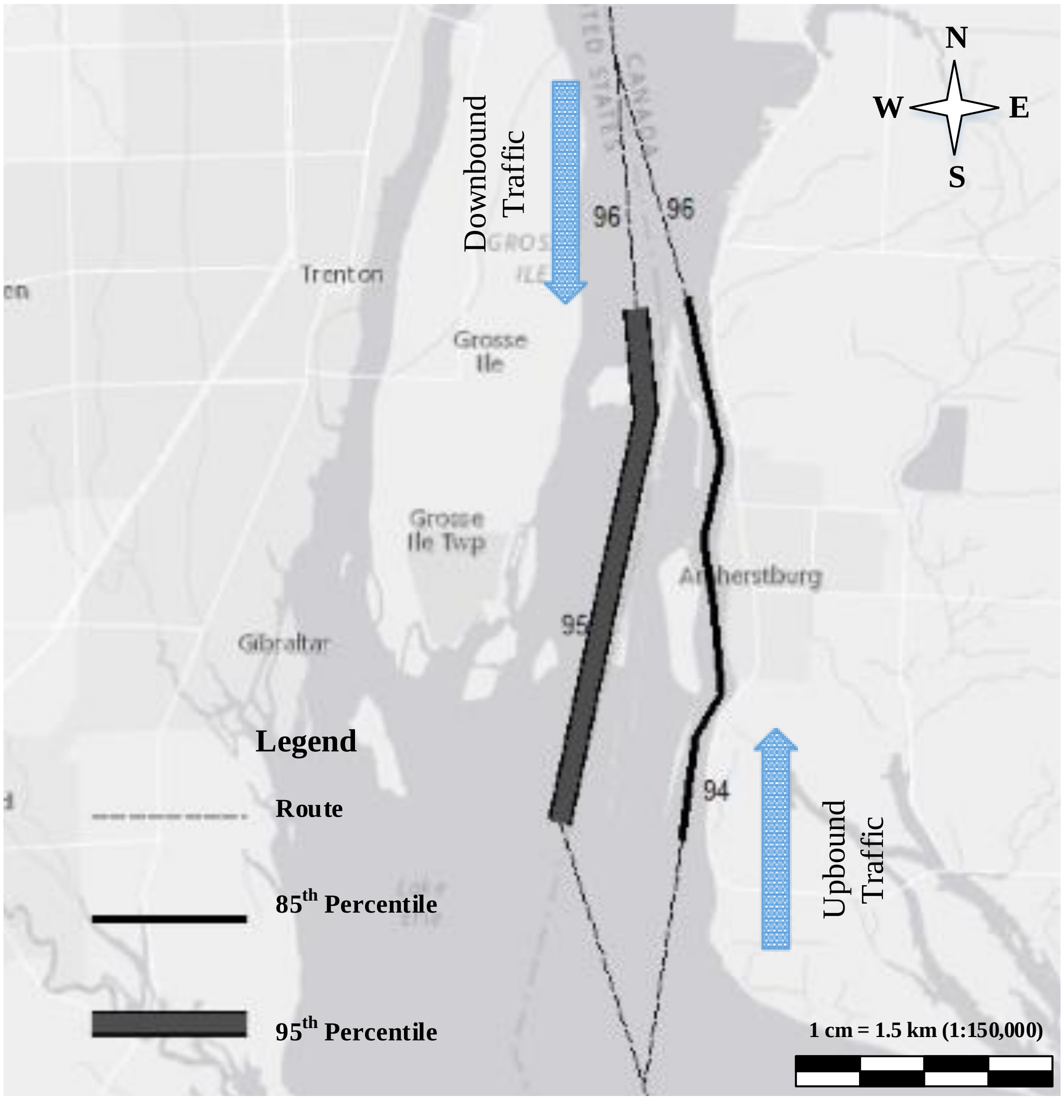


Figure 5.5 Rank 1 Hotspot for VV (Detroit River Entrance)

Section 69 is second highest risk section for VV accidents and it is located in the St. Lawrence River (Wiley Dondero Canal). This section is a canal section which includes the Eisenhower Lock. The length of this section is 1 km and the average width is 50 meters. It is critical to know that Section 70 is also identified as a hotspot for 85th percentile threshold VV accidents (see Figure 5.6).

Figure 5.6 Rank 2 Hotspot for VV (West Wiley Dondero Canal)

The Section 67 in Figure 5.7 is also located in Wiley Dondero Canal and have similar characteristics with section 69 since it includes Snell Lock. The length on this section is 1 km and the width is 55 meters. Connected sections were not identified as hotspots, so this might show that the east entrance of Wiley Dondero Canal is safer than the west entrance.

Figure 5.7 Rank 3 Hotspot for VV (East Wiley Dondero Canal)

Section 93 (see Figure 5.8) is located in the south Welland Canal nearby to Port Colborne. This section connects Lake Erie to the Welland Canal (Lock 8-Section 92) and its length and width are 3.5 km and 200 m respectively. In the Welland Canal, there are a total of 2 hotspots for VV accident based on 95th percentile threshold. The number of total hotspots increases to 8 sections for 85th percentile threshold.

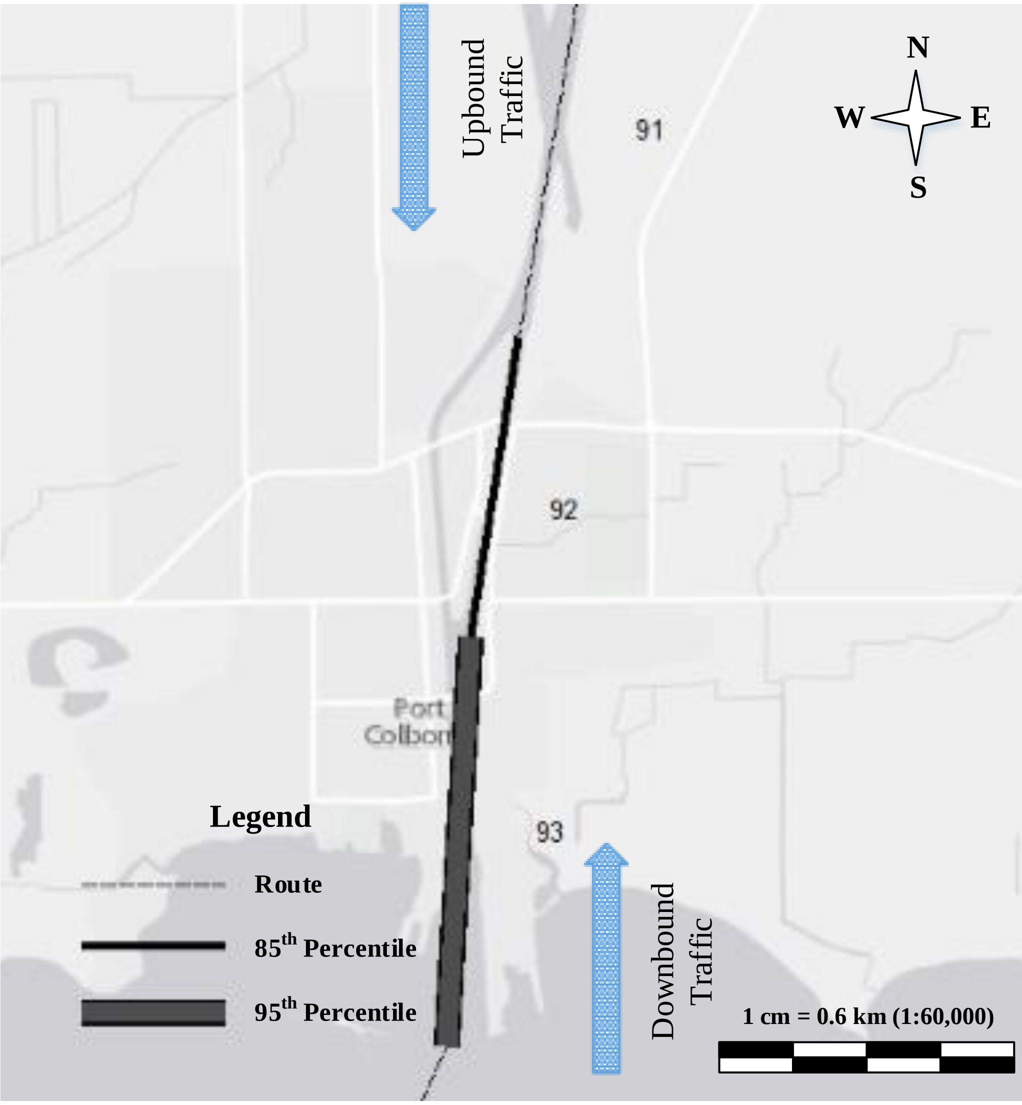


Figure 5.8 Rank 4 Hotspot for VV (South Entrance of the Welland Canal)

Section 47 is the 5th ranked hotspot location for VV accidents (see Figure 5.9). This 1 km length of section is located in Canal de la Rive Sud, Montreal and it includes the St. Lambert Lock. The average width of this section is 60 m. It can be noted that the sections adjacent to this highly ranked hotspot do not follow the trend of being in the 85th percentile and are relatively safer areas for VV accidents.

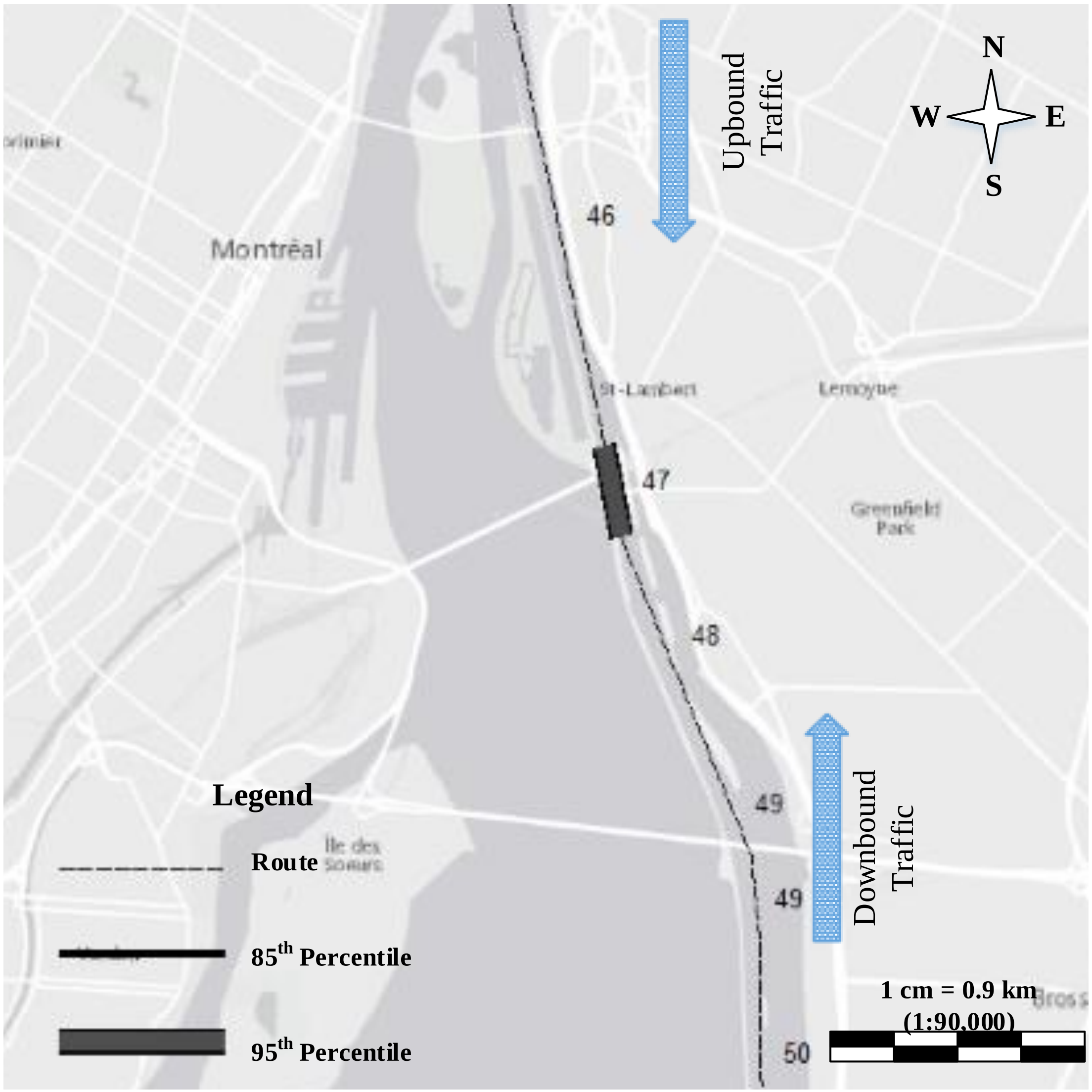


Figure 5.9 Rank 5 Hotspot for VV (North Rive Sud Canal, Montreal)

Except for Section 47, it can be seen that all of the other four highest ranked hotspot sections are located at the entrance points of the rivers or canals. This demonstrates the effect that funnelling or narrowing of the channel has on VV accidents and the important role that this factor plays.

5.2.2 Illustration of Top 5 Hotspots for VF Accidents

The top five highest risk sections for VF accidents are illustrated on the maps below. These include Section 47, 73, 60, 82 and 85 respectively. Since they have different characteristics, VF and VV accident types result to different hotspot sections. However, there are some sections that are both hotspots for VV and VF accidents.

Section 47 in Figure 5.10 is the highest risk section for VF accidents. This section was also identified as a hotspot for VV accidents in the previous segment. The main difference in this section is that the connected or adjacent sections (Section 46 and 48) are also identified as hotspots for VF accidents.

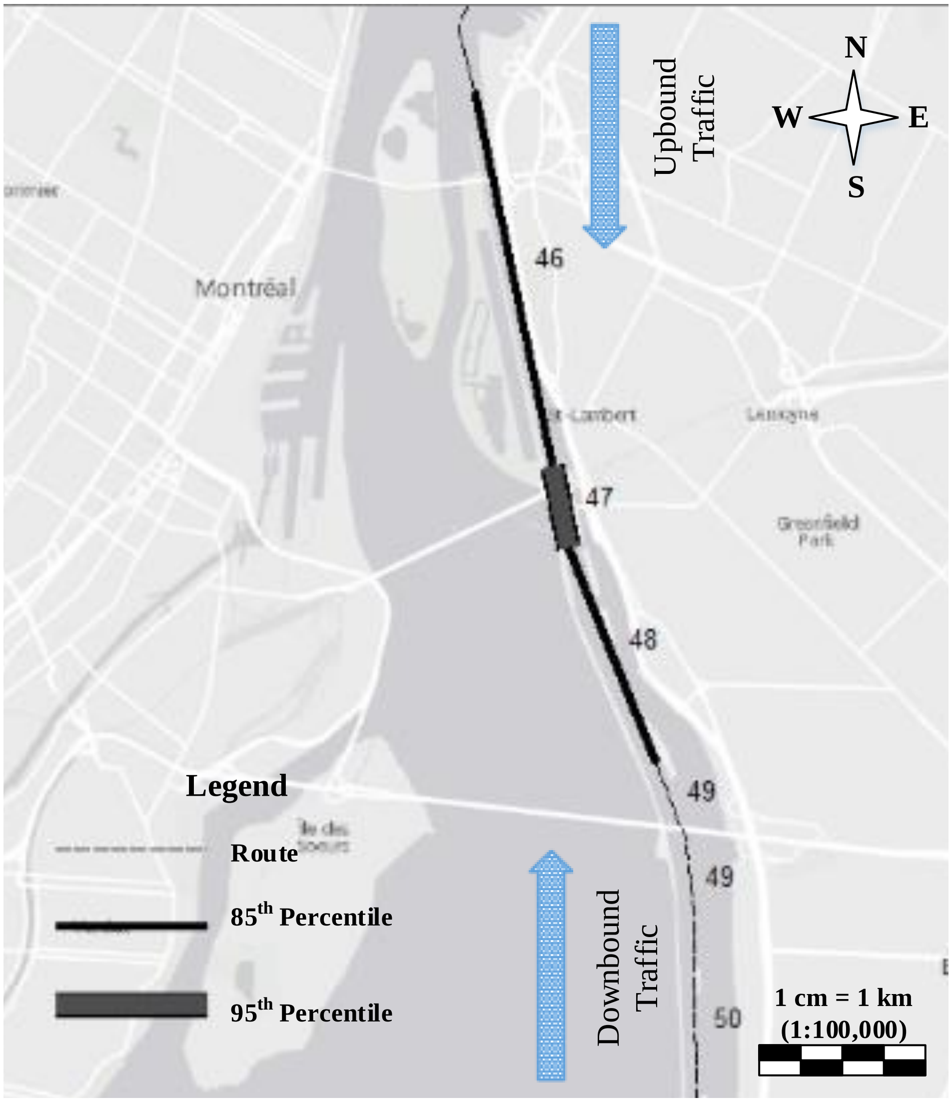


Figure 5.10 Rank 1 Hotspot for VF (North Rive Sud Canal, Montreal)

Section 73 in Figure 5.11 covers the Iroquois Lock with its 2 km length and 150 m width. This section is a small canal section along the St. Lawrence River. The sharp reduction of the width from 1200 m to 150 m is the most important contributing factor to being identified as a hotspot.

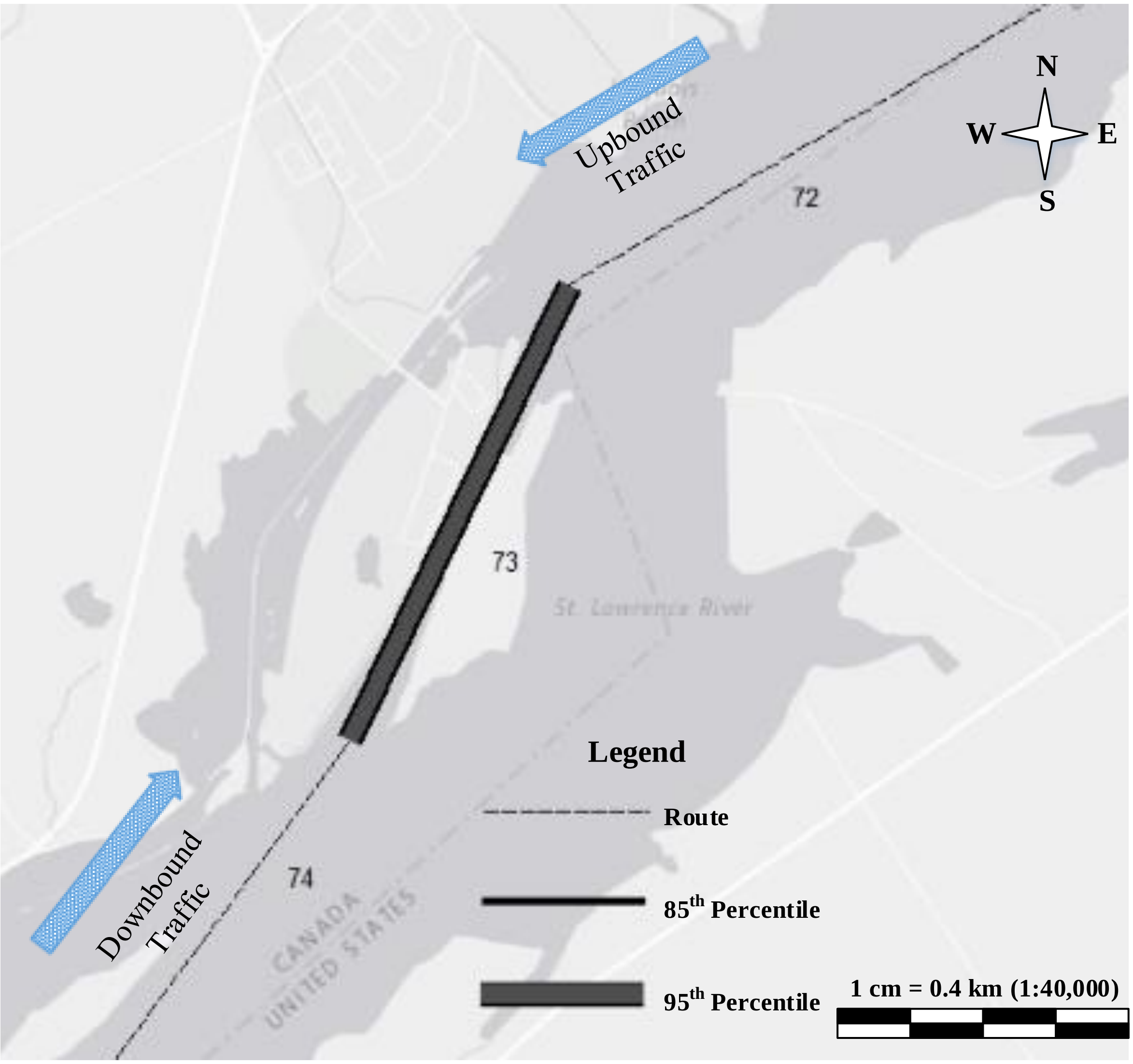


Figure 5.11 Rank 2 Hotspot for VF (Iroquois Lock)

Section 60 in Figure 5.12 connects the St. Lawrence River to the Beauharnois Canal which contains the Upper Beauharnois Lock. The length of this section is 5 km with its 100 m average width. The other sections were not identified as hotspot in this segment.

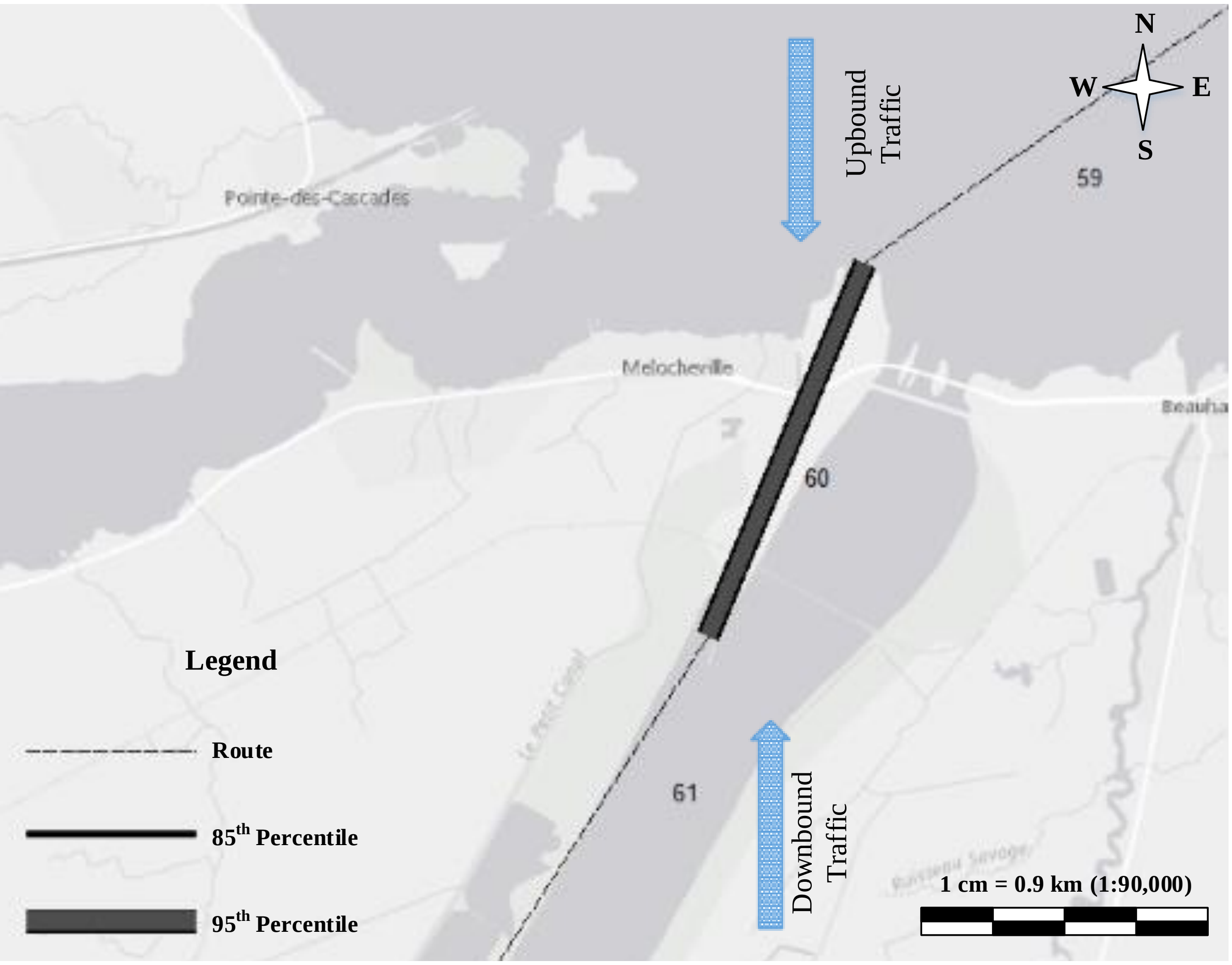


Figure 5.12 Rank 3 Hotspot for VF (Upper Beauharnois Canal)

There are only 2 VF hotspots on the Welland Canal for the 95th percentile value. These sections are shown in Figure 5.13 and Figure 5.14. The lengths of Section 82 and 85 are 1 and 5 km and the widths are 125 m and 160 m respectively. Section 82 includes Lock 2 while Lock 7 is located in the Section 85. It can be seen that Section 84 in Figure 5.14 is also a hotspot for 85th percentile threshold.

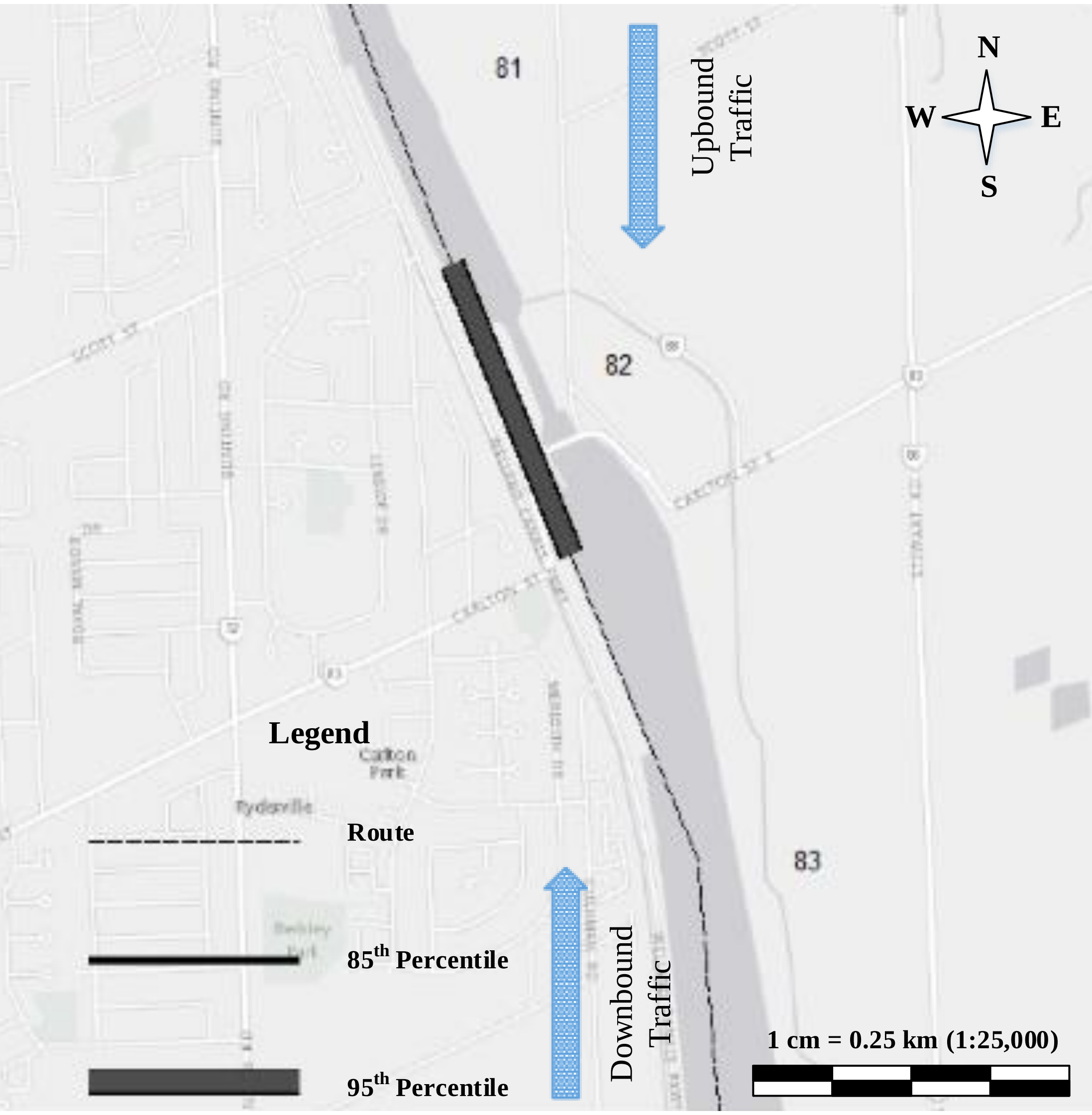


Figure 5.13 Rank 4 Hotspot for VF (Welland Canal, Lock 2)

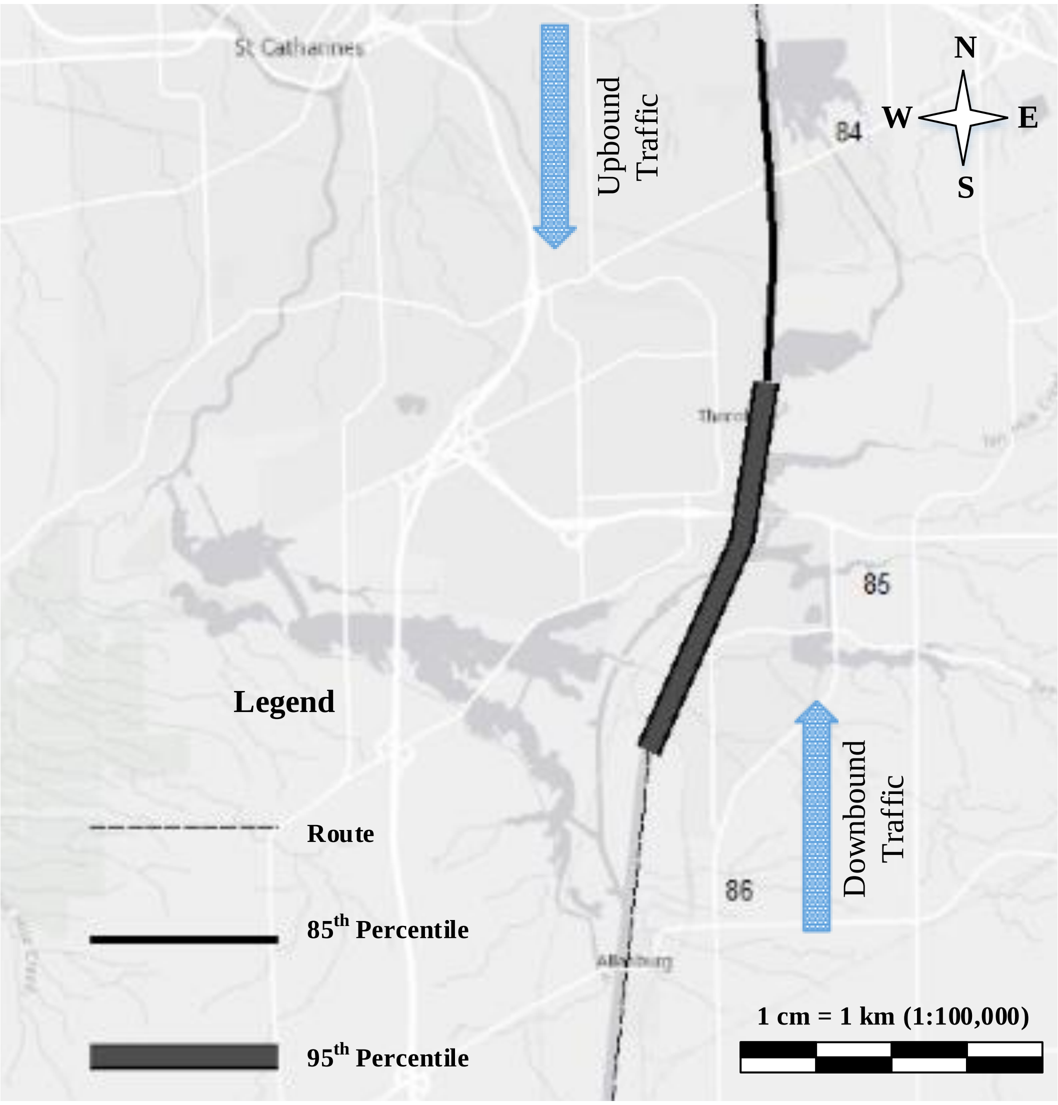


Figure 5.14 Rank 5 Hotspot for VF (Middle Welland Canal with Lock 7)

Figures in this part show that all of the top five highest risk sections for VF accidents are located in canals. Specifically, three of these sections (8 km combined) are located along the St. Lawrence River and the other two sections (a total of 6 km) are in the Welland Canal. All of these sections contain locks, demonstrating how sections with narrowing segments on the GLS are a significantly higher risk area for vessels having VF accidents.

5.3 HOTSPOTS BASED ON TOTAL ACCIDENTS

In the previous segment, it was explained how hotspots are classified based on the accident type. It is critical to determine hotspot sections for VV and VF accident in order to take precautions to reduce these specific accident types along the GLS. However, we might also want consider the total risk of an expected accident along the GLS. It can be seen in Table 5.1 that the number of expected VF accidents is significantly higher than the expected VV accidents. Therefore we considered that combining the two accident types might give us different variation of hotspots. Moreover, it was hypothesised that a section, which was identified as a hotspot for VV accident, might not be a hotspot when analyzed using the total number of expected accidents (due to the small number of VV accidents).

The scaling criteria (100,000 volume per km) which was used to identify hotspots was also used with the combined accidents. For the combined accidents the 85th and 95th percentile thresholds were found to be 3.58 and 9.05, respectively. Figure 5.15 illustrates these thresholds on a distribution for the expected number of accidents for all of the GLS sections.

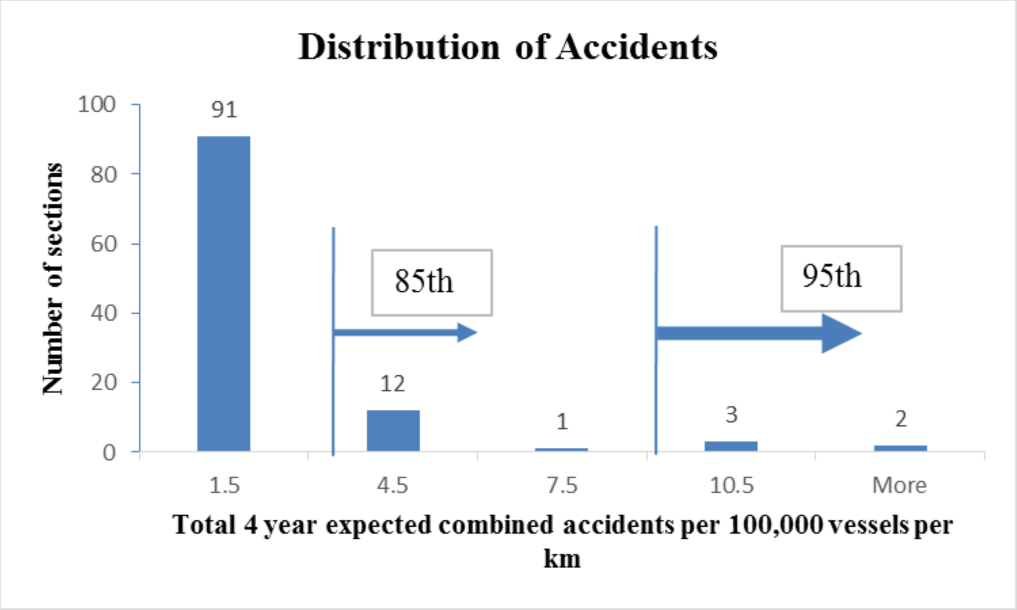


Figure 5.15 Distribution of 4 Years' Total Expected Number of Accidents

The list of these hotspots is provided in Table 5.3 for the 95th percentile and the 85th percentile thresholds. For the higher risk 95th percentile threshold a total of 5 sections (14 km, 0.88% of the seaway) were identified as hotspots, and 16 sections (47.72 km, 3% of the seaway) for 85th percentile threshold. Reducing the threshold by 10% has had the effect of adding 11 sections to the list of hotspots. Seven of these hotspots were isolated sections (a total of 17.22 km), while four hotspots (a combined 16.5 km) were found to be adjacent to the 95th percentile sites.

Table 5.3 Hotspots for Combined Accidents in the GLS

Section #	Mileage Offsets (km)	Location	Section Type	Accidents	
				E(μ/y) per km*10^5	% value
46	00+899	St. Lawrence River	Canal	4.741	90
47	00+900	St. Lawrence River	Canal-lock	32.680	99
48	00+903	St. Lawrence River	Canal	4.443	87.2
52	00+918	St. Lawrence River	Canal	3.733	86.3
53	00+919.5	St. Lawrence River	Canal-lock	8.903	94.5
60	00+967	St. Lawrence River	Canal-lock	11.091	97.2
67	01+080	St. Lawrence River	Canal-lock	4.653	88.1
69	01+088	St. Lawrence River	Canal-lock	4.653	88.1
73	01+146	St. Lawrence River	Canal-lock	20.723	98.1
80	01+322	Welland Canal	Canal-lock	5.076	92.7
82	01+324	Welland Canal	Canal-lock	10.653	96.3
84	01+333.5	Welland Canal	Canal-lock	4.966	91.8
85	01+338.5	Welland Canal	Canal-lock	9.196	95.4
92	01+370	Welland Canal	Canal-lock	4.912	90.9
93	01+373.5	Welland Canal	Canal	5.927	93.6
104	01+533.64	St. Mary's River	Canal	3.721	85.4

Figure 5.16 clearly shows that all of the hotspots are located on canal sections presumably since these sections are the narrowest portions of the GLS. The average navigable width of channels along the GLS is 13.83 km, while the average width of the hotspot sections for the 85th percentile is 0.176 km and only 0.128 km for the 95th percentile.

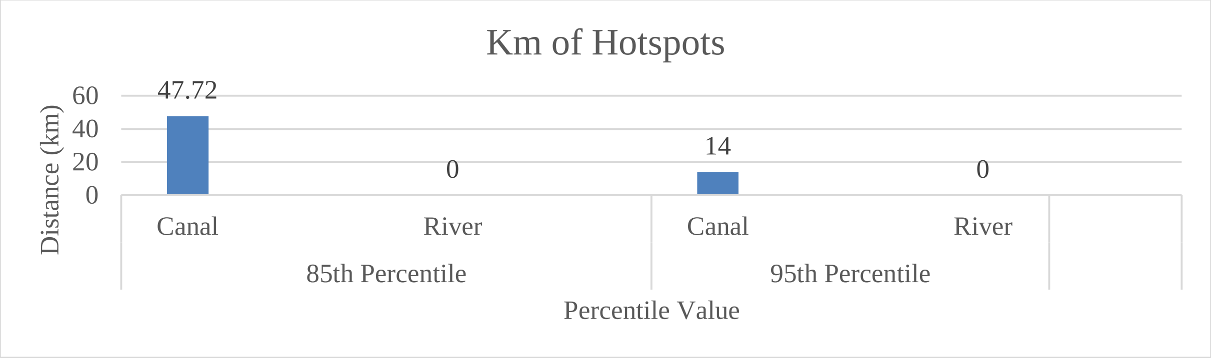


Figure 5.16 Km of Hotspots on Canal and River for Combined Accidents

Table 5.4 indicates the number of hotspot sections and their length in km for four different zones of the GLS. The highest risk sites tend to be located in the St. Lawrence River canal sections followed closely by the Welland Canal. This is especially true if adjustments are made to consider the section length and the concentration of risk. The Detroit River and the St. Clair River sections appear to be safer when utilizing the total combined accident data (since there are no hotspots).

Table 5.4 Number and Km of Hotspots on Each Zone

Zone	Number of Hotspots		Km of Hotspots	
	85th percentile value	95th percentile value	85th percentile value	95th percentile value
St. Lawrence River	9	3	23	8
Welland Canal	6	2	20.5	6
Detroit River-St. Clair River	0	0	0	0
St. Mary's River	1	0	4.22	0

When we consider the cost-effective analysis for the hotspots based on the combined accidents, it can be concluded that reducing the threshold 10% resulted in a 240% increase in the length of total hotspots. This is compared to 300% when we identified hotspots for VV and VF accidents. Moreover, the length of hotspots increased from 31 km (at 95th percentile) to 123.98 km (at 85th percentile) for VV and VF accidents. The length of hotspots for the combined accidents is relatively shorter, decreasing to14 km (at 95th percentile) and to 47.72 km (at 85th percentile).

5.4 COMPARING HOTSPOTS TO HISTORICAL ACCIDENT LOCATIONS

In this chapter, hotspot locations were identified for VV and VF accidents separately and in combination. For the combined accidents, we obtained five hotspots for the 95th percentile threshold and 16 hotspots for the 85th percentile threshold.

In this discussion, hotspot locations for the combined predicted accidents are compared to the observed historical accident locations. The observed accident data has been obtained for a 10 year period between 2000 and 2009. Since there are not enough accidents, the hotspot locations were compared with the data that was used to identify the model and determine the unsafe sites. For this comparison, to be independent, the data used as part of the data likelihood component in the EB model should not be the same as the data used in the historical accident comparison. Hence, the 4 years of observed accident data should not encompass the years between 2010 and 2013. Since a separate set of accident data outside this period was not available, we compared the historical accident frequencies for 2010-2013 to the expected values obtained from the SPF prior of the EB prediction model. The SPF function used in this comparison is a cross-sectional model for the VV and VF combined accidents over the entire seaway. Also, in the interest of creating statistical symmetry the following data was not used in our SPF model: VV and VF river accidents in 2000 and 2001, VV canal accidents in 2008 and 2009, and VF canal accidents between 2006 and 2009 (see Table 4.1 for more information). As a result of these omissions we are more likely to have an objective comparison.

Figure 5.17, and Figure 5.18 show the historical observed accidents in Zone 1 (the St. Lawrence River). Also, the 95th percentile hotspot locations can be seen in these figures. There are three hotspot locations in the St. Lawrence River namely section 47, 60, and 73. The total number of historical accidents in these sections for the years between 2000 and 2009 are 5, 13, and 16 respectively. In the St. Lawrence River a total of 148 freight vessel accidents occurred between the selected years. 34 of these accidents (23% of the total St. Lawrence River accidents and 15%

of the entire GLS accidents) occurred only in these three hotspot locations. The total length of these sections is only 8 km, which is only 0.6% of the length of the St. Lawrence River.

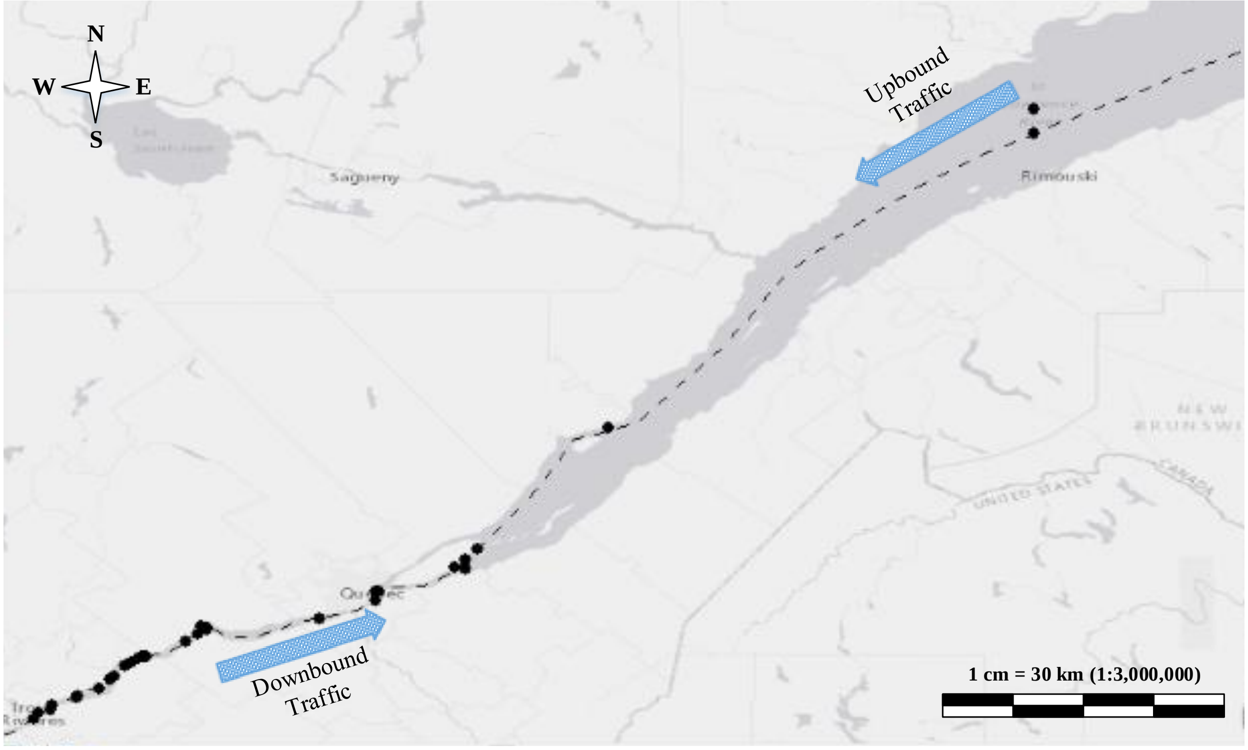


Figure 5.17 Observed Accidents between Rimouski and Trois-Rivieres

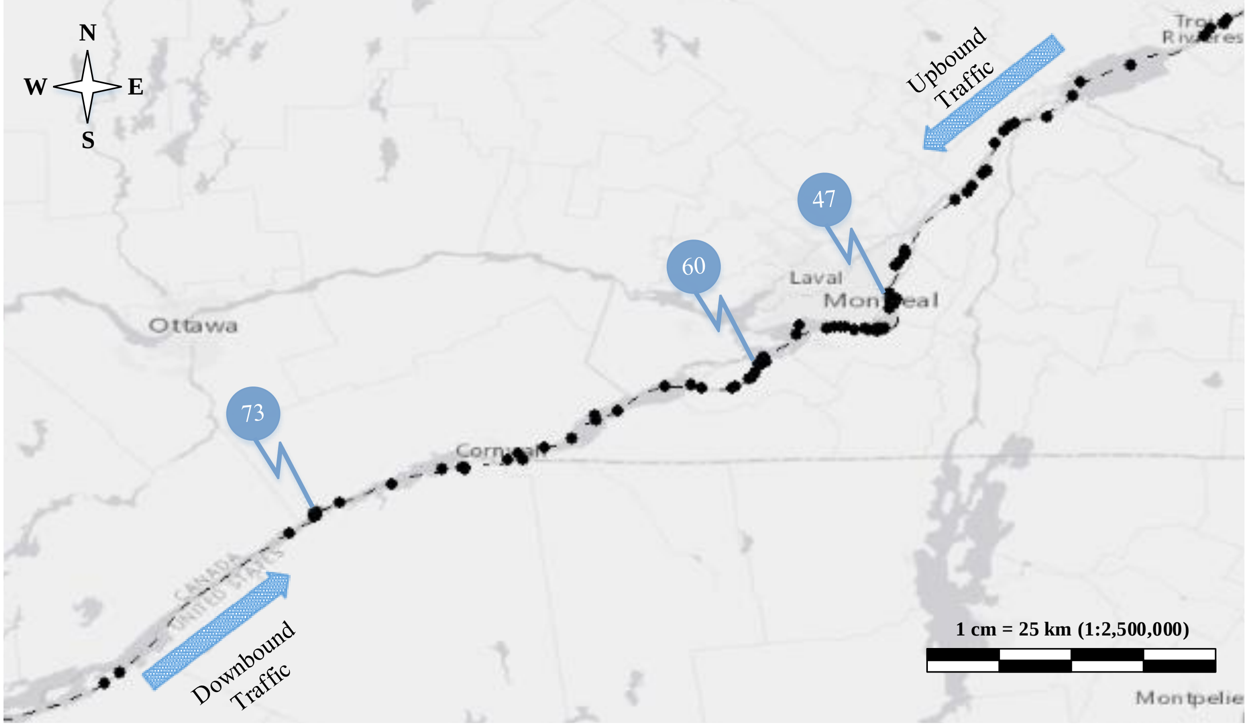


Figure 5.18 Observed Accidents between Trois-Rivieres and Lake Ontario

Figure 5.19 shows the Welland Canal's observed historical accidents between 2000-2009. Two of the five hotspots in the 95th percentile are located in this zone namely, Section 82, and 85. The number of observed accidents is 6 and 9 respectively. 29% of total accidents (15 accidents out of 51) in the Welland Canal occurred only in these two hotspot locations (representing 7% of the entire GLS). The total length of the hotspots is 6 km and this is 10% of the total length of the Welland Canal (6 km out of 58.5 km).

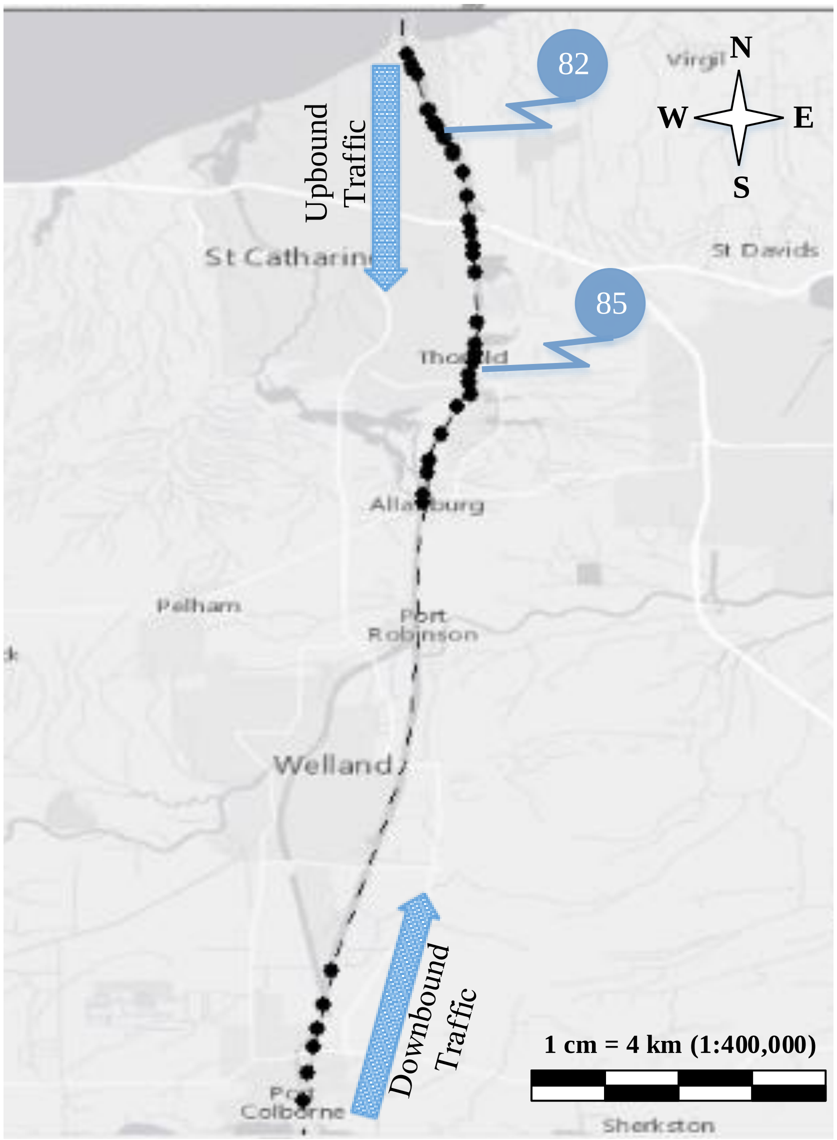


Figure 5.19 Observed Accidents in the Welland Canal

Figure 5.20 also shows the historical observed accidents in the Detroit and St. Clair River while Figure 5.21 shows the accident locations in the St. Mary's River. 24 accidents occurred in the Detroit and St. Clair River and only 14 in the St. Mary's River. In these sections there is no 95th percentile hotspot and these two zones (Zone 3, and 4) are safer than the other zones in the GLS.

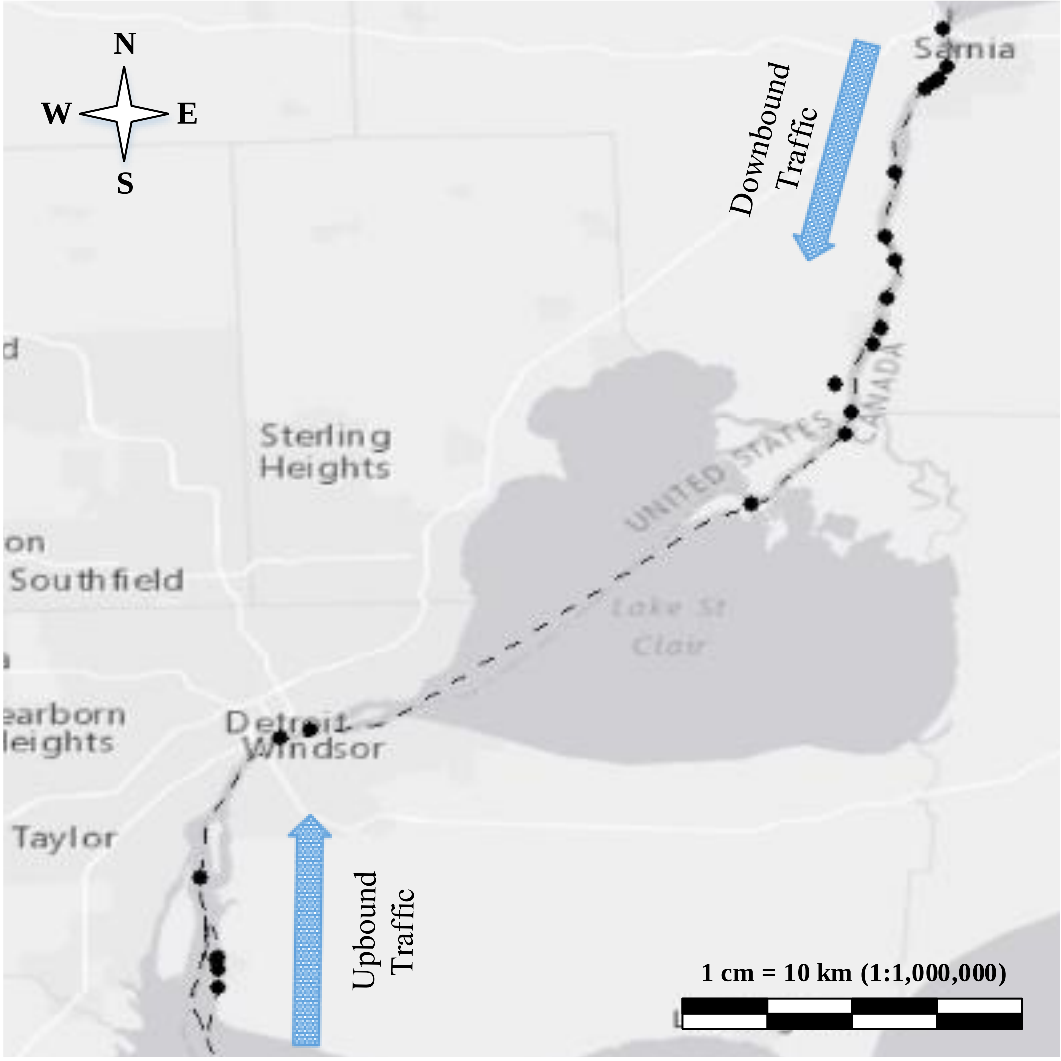


Figure 5.20 Observed Accidents in Detroit and St. Clair River

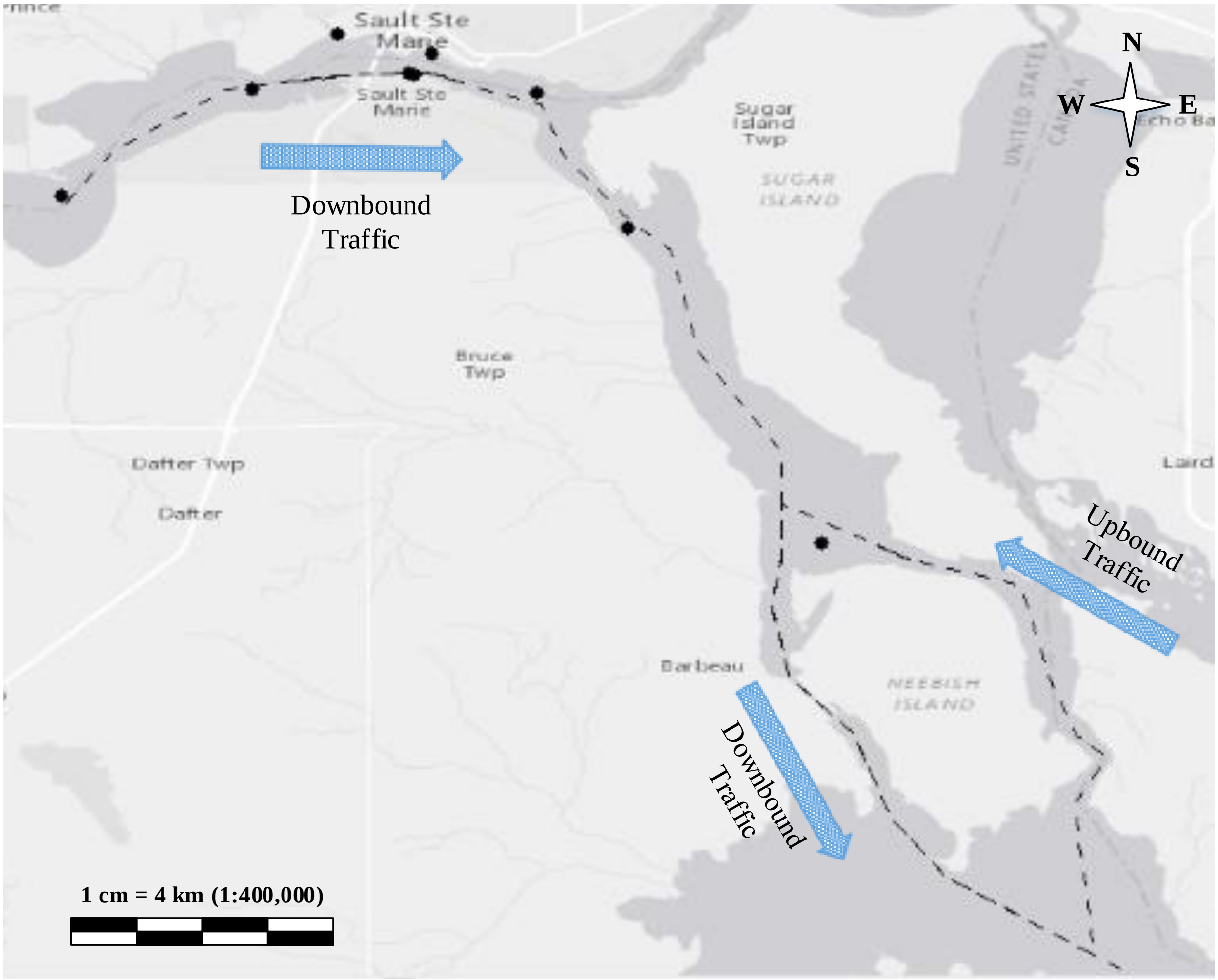


Figure 5.21 Observed Accidents in St. Mary's River

There are 5 hotspot sites identified for the 95th percentile threshold of the combined accidents namely, section 47, 73, 60, 82 and 85. 21% of the total 234 accidents occurred only in these sections for the years between 2000 and 2009. 10% reduction in the threshold added 11 more unsafe sites. These sites are Section 53 (7 observed accidents), 93 (1 observed accident), 80 (8 observed accidents), 84 (4 observed accidents), 92 (3 observed accidents), 46 (2 observed accidents), 67 (no accidents), 69 (3 observed accidents), 48 (5 observed accidents), 52 (6 observed accidents), and 104 (no accidents) respectively. The hotspot sections for the 85th percentile threshold of combined accidents experienced 88 of the total 234 accidents (38%).

As a result, historical accidents along the Great Lakes Seaway tend to take place along the sections where the EB model predicted safety issues, demonstrating the model's consistency. Therefore, when introducing safety countermeasures for these model predicted "unsafe sites" we are most certain to create initiatives, which will be cost-effective and will produce safer sites. The reduction in tolerance from the 95th to 85th percentile has had the effect of increasing the area that comes under definition of a hotspot. If we see these accidents as being targeted by countermeasures, then by reducing the tolerance from 95th to 85th percentile there is a significant increase in the number of accidents within the "unacceptable threshold". This increased number of unacceptable accidents may increase the profile of these accidents and thereby, the safety budget needed to reduce them.

CHAPTER 6

CONTRIBUTIONS AND FUTURE WORK

6.1 MAJOR CONTRIBUTIONS

The EB approach adopted in this research has provided a robust objective basis for predicting vessel accidents along the Great Lakes Seaway. Four types of prediction models were developed for different types of accidents and navigable channel features: namely vessel-to-vessel collisions for river and canal/lock sections and vessel-to-fix objects collisions for river and canal/lock sections. The major explanatory factors in these prediction models (statistically significant at the 5% level) were: vessel volume (number of vessels per year traversing each section), length of section (in km) to account for exposure, navigable channel width (in km), and for vessel-to-fix object accidents a dummy variable to account for regional affiliation.

The application of the model for the GLS hotspot identification necessitated the introduction of risk tolerance criteria to guide decisions as to when safety intervention is warranted. In the absence of these criteria, we have selected the expected number of accidents that are exceeded at least 5 and 15% of the time in the expected accident distribution that results from the model (the 95th and 85th percentile thresholds). The expected accident values were calculated based on 4 years' total expected accidents and scaled for the traffic volume and length of navigation channel. These values serve as the high and moderate tolerance levels for hotspot identification.

The application of the EB crash prediction models yielded 5 VV hotspots for a total length of 16.5 km, and 6 VF hotspots for a total length of 15.5 km, assuming the higher risk 95th percentile threshold. For the lower risk 85th percentile threshold, 16 VV hotspots (96.76 km) and 17 VF hotspots (50.72 km) were identified. For the 95th percentile threshold of VV and VF accidents, canals and locks were found to be more unsafe than river sections. A total of 9 hotspots were found on canals and one hotspot on a river section. For the 85th percentile threshold, the number of hotspots increased to 19 for canals and 6 for river sections. The model suggested that a reduction in risk threshold from 95 to 85 resulted in an increased length of the GLS channel hotspots of about 300%. However, the general locations of these hotspots along the route remained similar in nature. In fact, the 95th percentile hotspots were included as a subset in the 85th percentile hotspots.

Since there were a relatively small number of expected VV accidents, all accident types (VV and VF) in river and canal/lock sections were combined. These sections were scaled with the same criteria and the 95th and 85th percentile values were calculated for all vessel accidents. As a result, 5 sections (14 km, 0.88% of the seaway) in the GLS were identified as hotspots for the 95th percentile threshold, which increased to 16 sections (47.22 km, 3% of the seaway) for the 85th percentile threshold. All of these hotspots were located in canal/lock sections and specifically in sections of the St. Lawrence River and the Welland Canal.

A consistency was observed between the location of hotspots identified by the models and observed accidents for similar types of accidents along the GLS. Hence, it appears that the application of the EB model for predicting vessel accidents correctly highlights the GLS locations where accidents have been reported over a number of years. The application of the model allays concerns that observed accidents have been deemphasized in identifying problem locations. For the GLS at least this does not appear to be the case. The model introduced in this research provides a reliable, cost-effective method for allocating scarce safety budget resources to those GLS locations where these funds have the greatest potential to return safety dividends.

6.2 FUTURE WORK

In this research, unsafe sites were identified specifically for VV and VF accidents and combined accident types. However, there are a number of other processes that can be applied and factors that might also be considered to develop a greater understanding of hotspots. These processes are as follows:

1. The issue of appropriate countermeasures and their effectiveness is considered to be outside the scope of this research. However, with the identified unsafe locations in this research, the nature and causes of likely or historical accidents can be investigated, and the appropriate countermeasures can be developed for accident reduction. Specifically, for VV accidents, traffic related safety countermeasures could be introduced such as traffic control strategies or different types of signage. For the VF accidents, geometric solutions can be applied on the hotspot locations (for example, increasing the width, lighting the canal sides, using buoys to mark unsafe locations and navigating vessels, etc.). Also, safety policies can be reconsidered based on unsafe locations since these few locations encompass the majority of observed accidents. Additionally, cost-effective research can be done in the identified hotspot location due to the fact that there might be different economic implications between dealing with canal/locks versus rivers sections.

2. After any improvement is conducted (such as, increasing the width or changing the safety policy) in the unsafe site of the GLS, an observational before-and-after analysis along with a simulation can be utilized to measure the effectiveness of the countermeasure with respect to vessel accident reduction.

3. There is a lack of simulation software for inland water transportation safety, and the current models are not easily accessible. They are also mostly limited to one type for example oil tankers, and fail to reflect unique maneuverability issues specific to certain types of vessels and navigation channels that would have significant effect on safety. Future simulation models will need to take these vessel characteristics into account for different types of vessels. Simulation model for inland transportation can be developed to simulate the vessel interactions by type of vessel navigating restricted channels and under adverse weather conditions. This suggests an opportunity to integrate observational prediction and simulation models to better identify hotspots and tailor appropriate intervention strategies.

4. Severity of accidents is an important issue in inland water transportation, especially when dangerous goods are involved. The research discussed in this thesis has not addressed the issue of vessel accident severity. Hotspots obtained from the expected number of accidents may differ from hotspots obtained when health and environmental impacts are considered.
5. Simulation methods can be also used to obtain non-freight vessel (passenger vessel, ferries, pleasure craft, etc.) traffic data to determine how they are affecting the freight vessel accident occurrences. Thereby, we can evaluate the risk better by encompassing all types of vessel interactions on the inland waters.
6. In this research there was a lack of predicted correlation between the total traffic volume and the observed accidents in the St. Lawrence River canals. This discrepancy was compensated for, by using the regional affiliation term. For future work, these canal sections can be investigated to determine if there is another possible reason rather than geometric differences, which cause more accidents. Also, canal entrance accidents can be analyzed specifically to find the true underlying reason behind that problem.
7. The transferability of these results to other inland navigation channels needs to be investigated. The scope of this research has been limited to vessel accident prediction along the Great Lakes Seaway.

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APPENDICES

APPENDIX A: OBSERVED FREIGHT VESSEL ACCIDENTS AND THEIR PERCENTAGES FOR ENVIRONMENTAL CONDITIONS

A.1- Number of Observed Freight Vessel Accidents and Their Percentages for Environmental Conditions in Zone 1

Zone 1 (St. Lawrence River)			Accident Type								Zone 1 Total			
			Collision				Grounding							
Vessel Type			Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total
# of accidents			4	93	8	105	8	65	8	81	12	158	16	186
%			3.810	88.571	8	100	9.877	80.247	9.877	100	6.452	84.946	8.602	100
Light Conditions	Day	# of accidents	1	51	5	57	3	34	6	43	4	85	11	100
		%	0.952	48.571	5	54.286	3.704	41.975	7.407	53.086	2.151	45.699	5.914	53.763
	Night	# of accidents	3	42	3	48	5	31	2	38	8	73	5	86
		%	2.857	40	3	45.714	6.173	38.272	2.469	46.914	4.301	39.247	2.688	46.237
Sea State	Calm	# of accidents	4	92	8	104	7	59	7	73	11	151	15	177
		%	3.810	87.619	8	99.048	8.642	72.840	8.642	90.123	5.914	81.183	8.065	95.161
	Moderate	# of accidents	0	1	0	1	1	2	1	4	1	3	1	5
		%	0	0.952	0	0.952	1.235	2.469	1	4.938	0.538	1.613	1	2.688
	High	# of accidents	0	0	0	0	0	4	0	4	0	4	0	4
		%	0	0	0	0	0	4.938	0	4.938	0	2.151	0	2.151
Wind	Light	# of accidents	4	63	5	72	8	50	6	64	12	113	11	136
		%	3.810	60	5	68.571	9.877	61.728	7.407	79.012	6.452	60.753	5.914	73.118
	Moderate	# of accidents	0	14	0	14	0	9	2	11	0	23	2	25
		%	0	13.333	0	13.333	0	11.111	2.469	13.580	0	12.366	1.075	13.441

Zone 1 (St. Lawrence River)			Accident Type								Zone 1 Total			
			Collision				Grounding							
Vessel Type			Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total
	Strong	# of accidents	0	16	3	19	0	6	0	6	0	22	3	25
		%	0	15.238	3	18.095	0	7.407	0	7.407	0	11.828	2	13.441

A.2- Number of Observed Freight Vessel Accidents and Their Percentages for Environmental Conditions in Zone 2

Zone 2 (Welland Canal)			Accident Type								Zone 2 Total			
			Collision				Grounding							
Vessel Type			Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total
# of accidents			2	65	2	69	0	3	0	3	2	68	2	72
%			2.899	94.203	3	100	0	100	0	100	2.778	94.444	3	100
Light Conditions	Day	# of accidents	0	39	1	40	0	3	0	3	0	42	1	43
		%	0	56.522	1	57.971	0	100	0	100	0	58.333	1	59.722
	Night	# of accidents	2	26	1	29	0	0	0	0	2	26	1	29
		%	2.899	37.681	1	42.029	0	0	0	0	2.778	36.111	1	40.278
Sea State	Calm	# of accidents	2	64	2	68	0	3	0	3	2	67	2	71
		%	2.899	92.754	3	98.551	0	100	0	100	2.778	93.056	3	98.611
	Moderate	# of accidents	0	1	0	1	0	0	0	0	0	1	0	1
		%	0	1.449	0	1.449	0	0	0	0	0	1.389	0	1.389
	High	# of accidents	0	0	0	0	0	0	0	0	0	0	0	0
		%	0	0	0	0	0	0	0	0	0	0	0	0
Wind	Light	# of accidents	1	50	2	53	0	2	0	2	1	52	2	55
		%	1.449	72.464	3	76.812	0	100	0	66.667	1.389	72	3	76.389
	Moderate	# of accidents	1	10	0	11	0	0	0	0	1	10	0	11
		%	1.449	14.493	0	15.942	0	0	0	0	1.389	13.889	0	15.278
	Strong	# of accidents	0	5	0	5	0	1	0	1	0	6	0	6
		%	0	7.246	0	7.246	0	100	0	33.333	0	8.333	0	8.333

A.3- Number of Observed Freight Vessel Accidents and Their Percentages for Environmental Conditions in Zone 3

Zone 3 (Detroit and St. Clair River)			Accident Type								Zone 3 Total			
			Collision				Grounding							
Vessel Type			Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total
# of accidents			1	7	1	9	5	14	2	21	6	21	3	30
%			11.111	77.778	11	100	23.810	66.667	9.524	100	20	70	10	100
Light Conditions	Day	# of accidents	1	4	1	6	1	9	1	11	2	13	2	17
		%	11.111	44.444	11	66.667	4.762	42.857	4.762	52.381	6.667	43.333	6.667	56.667
	Night	# of accidents	0	3	0	3	4	5	1	10	4	8	1	13
		%	0	33.333	0	33.333	19.048	23.810	5	47.619	13.333	27	3	43.333
Sea State	Calm	# of accidents	1	7	1	9	5	13	1	19	6	20	2	28
		%	11.111	77.778	11	100	23.810	61.905	4.762	90.476	20	67	6.667	93.333
	Moderate	# of accidents	0	0	0	0	0	1	0	1	0	1	0	1
		%	0	0	0	0	0	4.762	0	4.762	0	3.333	0	3.333
	High	# of accidents	0	0	0	0	0	0	1	1	0	0	1	1
		%	0	0	0	0	0	0	5	4.762	0	0	3	3.333
Wind	Light	# of accidents	1	6	1	8	4	12	1	17	5	18	2	25
		%	11.111	66.667	11	88.889	19.048	57.143	4.762	80.952	16.667	60	6.667	83.333
	Moderate	# of accidents	0	0	0	0	0	1	0	1	0	1	0	1
		%	0	0	0	0	0	4.762	0	4.762	0	3.333	0	3.333
	Strong	# of accidents	0	1	0	1	1	1	1	3	1	2	1	4
		%	0	11.111	0	11.111	4.762	4.762	5	14.286	3.333	7	3	13.333

A.4- Number of Observed Freight Vessel Accidents and Their Percentages for Environmental Conditions in Zone 4

Zone 4 (St. Mary’s River)			Accident Type								Zone 4 Total			
			Collision				Grounding							
Vessel Type			Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total	Barge	Cargo	Tanker	Total
# of accidents			2	3	0	5	1	7	1	9	3	10	1	14
%			40	60	0	100	11.111	77.778	11.111	100	21.429	71.429	7.143	100
Light Conditions	Day	# of accidents	1	0	0	1	0	3	1	4	1	3	1	5
		%	20	0	0	20	0	33.333	11.111	44.444	7.143	21	7.143	35.714
	Night	# of accidents	1	3	0	4	1	4	0	5	2	7	0	9
		%	20	60	0	80	11.111	44.444	0	55.556	14.286	50	0	64.286
Sea State	Calm	# of accidents	2	3	0	5	1	7	1	9	3	10	1	14
		%	40	60	0	100	11.111	77.778	11.111	100	21.429	71.429	7.143	100
	Moderate	# of accidents	0	0	0	0	0	0	0	0	0	0	0	0
		%	0	0	0	0	0	0	0	0	0	0	0	0
	High	# of accidents	0	0	0	0	0	0	0	0	0	0	0	0
		%	0	0	0	0	0	0	0	0	0	0	0	0
Wind	Light	# of accidents	1	2	0	3	0	5	1	6	1	7	1	9
		%	20	40	0	60	0	55.556	11.111	66.667	7.143	50	7.143	64.286
	Moderate	# of accidents	0	0	0	0	0	2	0	2	0	2	0	2
		%	0	0	0	0	0	22.222	0	22.222	0	14.286	0	14.286
	Strong	# of accidents	1	1	0	2	1	0	0	1	2	1	0	3
		%	20	20	0	40	11.111	0	0	11.111	14.286	7.143	0	21.429

APPENDIX B: OBSERVED ACCIDENT DATA

B.1- Observed VV Accident Data for 109 GLS Sections

VV Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
1	00+030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	00+060	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	00+090	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	00+120	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2
5	00+135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	00+165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	00+205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	00+235	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	00+255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	00+275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	00+305	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	00+365	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	00+405	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	00+430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	00+455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	00+465	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	00+480	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
18	00+495	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	00+510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VV Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
20	00+526	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	00+534	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
22	00+545	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
23	00+555	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	00+575	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
25	00+595	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	00+607	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	00+622	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	00+642	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
29	00+659	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
30	00+674	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	00+680	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	00+686	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	00+706	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
34	00+716	0	0	0	0	0	0	0	1	0	2	0	0	0	0	3
35	00+730	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	00+766	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
37	00+771	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	00+787	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	00+801	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	00+819	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	00+826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	00+835	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	00+857	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VV Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
44	00+869	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	00+894	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
46	00+899	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	00+900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	00+903	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	00+905	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	00+908.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	00+914.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	00+918	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	00+919.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	00+925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	00+930.5	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
56	00+933.5	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
57	00+937.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	00+947	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	00+962	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	00+967	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	00+977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	00+984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	00+991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	00+998	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2
65	01+038	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	01+079	0	0	0	1	0	0	0	0	0	0	0	2	0	0	3
67	01+080	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VV Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
68	01+087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	01+088	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	01+098	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	01+123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	01+144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	01+146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	01+161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	01+201	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	01+241	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	01+274	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	01+315	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	01+318	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	01+322	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
81	01+323	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
82	01+324	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
83	01+329	0	0	0	0	0	1	2	0	0	0	0	0	0	0	3
84	01+333.5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
85	01+338.5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
86	01+343.5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
87	01+348.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	01+353.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	01+358.5	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
90	01+363.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	01+367.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VV Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
92	01+370	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
93	01+373.5	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
94	01+384.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	01+394.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	01+400.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	01+420.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	01+440.25	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
99	01+461.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	01+481.25	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
101	01+504.25	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
102	01+523.75	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
103	01+529.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
104	01+533.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105	01+540.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
106	01+560.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107	01+575.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108	01+578.48	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
109	01+593.48	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
Total		5	1	5	5	5	6	2	6	4	4	2	3	3	0	51

B.2- Observed VF Accident Data for 109 GLS Sections

VF Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
1	00+030	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	00+060	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	00+090	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	00+120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	00+135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	00+165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	00+205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	00+235	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	00+255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	00+275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	00+305	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	00+365	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	00+405	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
14	00+430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	00+455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	00+465	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	00+480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	00+495	1	0	0	1	0	0	2	0	0	0	0	0	0	0	4
19	00+510	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
20	00+526	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

VF Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
21	00+534	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
22	00+545	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	00+555	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	00+575	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	00+595	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	00+607	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	00+622	0	1	0	0	0	0	1	1	0	0	0	0	0	0	3
28	00+642	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
29	00+659	1	1	0	0	0	1	1	1	0	0	0	0	0	0	5
30	00+674	1	0	0	1	1	0	0	0	0	0	0	0	0	0	3
31	00+680	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	00+686	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
33	00+706	0	0	1	0	0	1	0	0	0	0	0	1	0	0	3
34	00+716	0	0	0	0	0	0	0	0	1	0	1	0	1	0	3
35	00+730	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
36	00+766	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
37	00+771	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	00+787	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
39	00+801	0	0	1	0	0	0	1	0	0	0	0	0	2	0	4
40	00+819	0	0	1	0	0	0	0	0	0	1	0	0	0	0	2
41	00+826	0	2	0	0	0	0	1	0	0	0	1	0	1	0	5
42	00+835	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
43	00+857	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2
44	00+869	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	00+894	0	0	2	0	0	0	1	1	0	0	1	1	0	0	6
46	00+899	1	0	0	0	0	1	0	0	0	0	0	2	0	0	4

VF Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
47	00+900	0	1	2	0	0	0	0	0	0	2	0	0	1	2	8
48	00+903	2	0	0	1	0	1	1	0	0	0	1	0	0	0	6
49	00+905	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	00+908.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	00+914.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	00+918	1	0	0	0	1	1	1	2	0	0	0	0	1	0	7
53	00+919.5	1	2	0	0	0	0	0	3	1	0	0	0	1	0	8
54	00+925	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2
55	00+930.5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
56	00+933.5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
57	00+937.5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
58	00+947	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
59	00+962	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	00+967	1	3	1	0	3	2	0	2	1	0	0	1	1	3	18
61	00+977	0	1	0	0	0	1	2	0	0	0	0	0	0	0	4
62	00+984	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2
63	00+991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	00+998	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
65	01+038	1	0	0	0	1	1	0	0	0	1	1	1	0	0	6
66	01+079	1	0	0	0	0	0	2	0	0	1	2	0	0	0	6
67	01+080	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	01+087	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	01+088	1	0	1	0	0	0	1	0	0	0	0	0	0	0	3
70	01+098	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
71	01+123	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2
72	01+144	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1

VF Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
73	01+146	0	2	2	2	1	1	5	2	1	0	1	1	0	2	20
74	01+161	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
75	01+201	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
76	01+241	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	01+274	0	0	0	0	1	1	0	0	0	0	1	0	0	0	3
78	01+315	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	01+318	0	0	0	0	1	0	1	0	0	0	0	0	0	1	3
80	01+322	0	0	0	1	3	0	0	0	0	2	1	0	1	0	8
81	01+323	1	0	0	0	1	0	0	0	0	1	0	0	0	0	3
82	01+324	1	0	2	0	0	1	0	0	1	0	1	0	0	0	6
83	01+329	0	0	1	1	2	0	0	1	0	0	1	0	0	0	6
84	01+333.5	0	0	0	0	1	0	0	0	1	0	2	0	0	0	4
85	01+338.5	0	0	1	2	0	1	1	1	1	0	0	2	3	0	12
86	01+343.5	0	2	0	0	1	0	0	0	0	0	0	0	0	0	3
87	01+348.5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
88	01+353.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	01+358.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	01+363.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	01+367.5	0	1	0	0	1	0	0	0	1	0	0	0	0	0	3
92	01+370	0	1	0	0	0	0	0	0	0	0	0	0	1	0	2
93	01+373.5	0	0	0	0	0	0	1	0	0	0	1	0	0	1	3
94	01+384.25	1	0	0	2	0	0	0	1	0	0	0	0	0	0	4
95	01+394.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	01+400.25	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
97	01+420.25	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
98	01+440.25	1	0	0	0	0	0	0	0	1	0	1	0	1	0	4

VF Accidents																
Section	**Mileage Offsets (km)**	**Years**														
		2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**Total**
99	01+461.25	0	0	1	0	0	0	0	1	0	0	0	0	1	0	3
100	01+481.25	0	1	0	0	1	1	0	1	0	0	0	0	0	0	4
101	01+504.25	0	0	2	0	0	0	0	0	1	0	1	0	0	0	4
102	01+523.75	0	0	1	0	0	1	2	0	1	0	0	0	0	0	5
103	01+529.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
104	01+533.64	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
105	01+540.48	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
106	01+560.48	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
107	01+575.48	0	0	1	0	0	1	0	1	1	0	0	0	0	0	4
108	01+578.48	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
109	01+593.48	0	0	0	0	0	1	1	0	0	0	0	1	0	0	3
Total		20	19	28	14	22	19	26	19	14	10	20	13	17	10	251

APPENDIX C: HISTORICAL FREIGHT VESSEL TRAFFIC DATA

Year	Freight Vessel Traffic						
	Zone 1			Zone 2	Zone 3		Zone 4
	Section 1-21 (Rimouski-Quebec)	Section 22-45 (Quebec-Montreal)	Section 46-78 (Montreal-Lake Ontario)	Section 79-93 (Welland Canal)	Section 94-98 (Detroit River)	Section 99-102 (St. Clair River)	Section 103-109 (St. Mary River)
2000	NA	NA	2548	2858	NA		5332
2001	NA	NA	2235	2791	NA		4595
2002	9961	11606	2253	2550	2510	3324	4724
2003	12016	13114	2199	2493	2896	3700	4917
2004	12522	15293	2236	2627	3186	5421	4727
2005	12350	15410	2320	2765	3082	5251	4681
2006	11089	15547	2581	2928	3034	5458	4815
2007	11421	14852	2463	2983	2656	5080	4843
2008	12586	15336	2280	2810	2396	5005	4709
2009	11869	13956	1866	2285	1762	3650	3222
2010	11378	14417	2251	2573	2269	4385	4161
2011	12917	15432	2477	2704	2202	4508	4152
2012	14109	14759	2491	2724	1992	4247	4160
2013	15191	15336	2337	2629	2489	6468	3871

APPENDIX D: PRIOR INPUT DATA FOR EACH GLS ZONE

D.1- Prior Input Data for Zone 1 River Sections

Zone 1 (St. Lawrence River) River Sections								
Section	**Length (km)**	**Width (km)**	**VV (2002-2009)**			**VF (2002-2009)**		
			Traffic	**Accident**	**Dvar**	**Traffic**	**Accident**	**Dvar**
1	30	72	93814	0	NA	93814	0	NA
2	30	80.5	93814	0	NA	93814	0	NA
3	30	69	93814	0	NA	93814	0	NA
4	30	68	93814	1	NA	93814	0	NA
5	15	72	93814	0	NA	93814	0	NA
6	30	50.3	93814	0	NA	93814	0	NA
7	40	44.3	93814	0	NA	93814	0	NA
8	30	35	93814	0	NA	93814	0	NA
9	20	27	93814	0	NA	93814	0	NA
10	20	30	93814	0	NA	93814	0	NA
11	30	14	93814	0	NA	93814	0	NA
12	60	24	93814	0	NA	93814	0	NA
13	40	5	93814	0	NA	93814	0	NA
14	25	30.5	93814	0	NA	93814	0	NA
15	25	17	93814	0	NA	93814	0	NA
16	10	11	93814	0	NA	93814	0	NA
17	15	5.53	93814	1	NA	93814	0	NA
18	15	6.6	93814	0	NA	93814	3	NA
19	15	4.05	93814	0	NA	93814	0	NA
20	16	2.82	93814	0	NA	93814	0	NA
21	8	2.33	93814	1	NA	93814	1	NA
22	11	2.3	115114	1	NA	115114	0	NA

Zone 1 (St. Lawrence River) River Sections

Section	Length (km)	Width (km)	VV (2002-2009)			VF (2002-2009)		
			Traffic	Accident	Dvar	Traffic	Accident	Dvar
23	10	2.2	115114	0	NA	115114	0	NA
24	20	4.33	115114	1	NA	115114	0	NA
25	20	6.02	115114	0	NA	115114	0	NA
26	12	6.3	115114	0	NA	115114	0	NA
27	15	4.17	115114	0	NA	115114	2	NA
28	20	3.98	115114	2	NA	115114	1	NA
29	17	3.87	115114	0	NA	115114	3	NA
30	15	4.5	115114	0	NA	115114	2	NA
31	6	4.39	115114	0	NA	115114	0	NA
32	6	5.95	115114	0	NA	115114	1	NA
33	20	3.97	115114	2	NA	115114	2	NA
34	10	2.57	115114	3	NA	115114	1	NA
35	14	2.66	115114	0	NA	115114	0	NA
36	36	13.2	115114	2	NA	115114	1	NA
37	5	9.175	115114	0	NA	115114	0	NA
38	16	12.265	115114	0	NA	115114	2	NA
39	14	2.99	115114	0	NA	115114	2	NA
40	18	2.218	115114	0	NA	115114	2	NA
41	7	1.38	115114	0	NA	115114	1	NA
42	9	3.27	115114	0	NA	115114	1	NA
43	22	1.4	115114	0	NA	115114	1	NA
44	12	2.13	115114	0	NA	115114	0	NA
45	25	1.52	115114	1	NA	115114	4	NA
58	9.5	7.87	18198	0	NA	18198	2	NA
59	15	7.26	18198	0	NA	18198	0	NA
65	40	7.31	18198	0	NA	18198	3	NA
66	41	2.3	18198	1	NA	18198	3	NA

Zone 1 (St. Lawrence River) River Sections								
Section	Length (km)	Width (km)	VV (2002-2009)			VF (2002-2009)		
			Traffic	Accident	Dvar	Traffic	Accident	Dvar
70	10	1.02	18198	0	NA	18198	0	NA
71	25	2.46	18198	0	NA	18198	1	NA
72	21	1.46	18198	0	NA	18198	1	NA
74	15	1.15	18198	0	NA	18198	1	NA
75	40	2.33	18198	0	NA	18198	0	NA
76	40	2.41	18198	0	NA	18198	0	NA
77	33	1.05	18198	0	NA	18198	2	NA
78	41	3.82	18198	0	NA	18198	0	NA

D.2- Prior Input Data for Zone 1 Canal Sections

Zone 1 (St. Lawrence River) Canal Sections								
Section	**Length (km)**	**Width (km)**	**VV (2000-2007)**			**VF (2000-2005)**		
			Traffic	**Accident**	**Dvar**	**Traffic**	**Accident**	**Dvar**
46	5	0.24	18835	0	NA	13791	2	1
47	1	0.06	18835	0	NA	13791	3	1
48	3	0.28	18835	0	NA	13791	4	1
49	2	0.48	18835	0	NA	13791	0	1
50	3.5	0.366	18835	0	NA	13791	0	1
51	6	0.82	18835	0	NA	13791	0	1
52	3.5	0.41	18835	0	NA	13791	3	1
53	1.5	0.137	18835	0	NA	13791	3	1
54	5.5	0.225	18835	0	NA	13791	1	1
55	5.5	0.213	18835	2	NA	13791	1	1
56	3	0.21	18835	2	NA	13791	1	1
57	4	0.38	18835	0	NA	13791	1	1
60	5	0.1	18835	0	NA	13791	10	1
61	10	1.45	18835	0	NA	13791	2	1
62	7	1.48	18835	0	NA	13791	2	1
63	7	1.52	18835	0	NA	13791	0	1
64	7	1.43	18835	0	NA	13791	1	1
67	1	0.05	18835	0	NA	13791	0	1
68	7	0.38	18835	0	NA	13791	0	1
69	1	0.05	18835	0	NA	13791	2	1
73	2	0.15	18835	0	NA	13791	8	1

D.3- Prior Input Data for Zone 2 Canal Sections

Zone 2 (Welland Canal) Canal Sections								
Section	**Length (km)**	**Width (km)**	**VV (2000-2007)**			**VF (2000-2005)**		
			Traffic	**Accident**	**Dvar**	**Traffic**	**Accident**	**Dvar**
79	3	0.47	21995	0	NA	16084	1	0
80	4	0.18	21995	2	NA	16084	4	0
81	1	0.2	21995	0	NA	16084	2	0
82	1	0.125	21995	0	NA	16084	4	0
83	5	0.24	21995	3	NA	16084	4	0
84	4.5	0.1	21995	2	NA	16084	1	0
85	5	0.16	21995	2	NA	16084	4	0
86	5	0.16	21995	0	NA	16084	3	0
87	5	0.2	21995	0	NA	16084	0	0
88	5	0.24	21995	0	NA	16084	0	0
89	5	0.23	21995	0	NA	16084	0	0
90	5	0.24	21995	0	NA	16084	0	0
91	4	0.2	21995	0	NA	16084	2	0
92	2.5	0.11	21995	2	NA	16084	1	0
93	3.5	0.2	21995	0	NA	16084	0	0

D.4- Prior Input Data for Zone 3 River Sections

Zone 3 (Detroit and St. Clair River) River Sections								
Section	**Length (km)**	**Width (km)**	**VV (2002-2009)**			**VF (2002-2009)**		
			Traffic	**Accident**	**Dvar**	**Traffic**	**Accident**	**Dvar**
94	10.75	0.562	10761	0	NA	10761	3	NA
95	10	0.247	10761	0	NA	10761	0	NA
96	6	2.6	21522	0	NA	21522	0	NA
97	20	1.28	21522	0	NA	21522	1	NA
98	20	1.08	21522	0	NA	21522	1	NA
99	21	0.82	36889	0	NA	36889	2	NA
100	20	1.08	36889	1	NA	36889	3	NA
101	23	1	36889	1	NA	36889	3	NA
102	19.5	0.88	36889	1	NA	36889	5	NA

D.5- Prior Input Data for Zone 4 River and Canal Sections

Zone 4 (St. Mary River) River Sections								
Section	**Length (km)**	**Width (km)**	**VV (2002-2009)**			**VF (2002-2009)**		
			Traffic	**Accident**	**Dvar**	**Traffic**	**Accident**	**Dvar**
103	5.67	0.983	18319	0	NA	18319	0	NA
105	6.84	1.38	18319	0	NA	18319	0	NA
106	20	1.22	18319	0	NA	18319	1	NA
107	15	1.45	36638	0	NA	36638	4	NA
109	15	2.35	36638	2	NA	36638	2	NA
Zone 4 (St. Mary River) Canal Sections								
Section	**Length (km)**	**Width (km)**	**VV (2000-2007)**			**VF (2000-2005)**		
			Traffic	**Accident**	**Dvar**	**Traffic**	**Accident**	**Dvar**
104	4.22	0.16	19317	0	NA	14488	0	0
108	3	0.2	38634	1	NA	28976	1	0

APPENDIX E: EXPECTED 4 YEARS' TOTAL EB RESULT FOR EACH ZONE

E.1- Expected 4 Years' Total EB Result for Zone 1 River Sections

Zone 1 (St. Lawrence River) River Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
1	0	0.314	0.107	0.746	0.234	0	0.092	0.007	0.926	0.085
2	0	0.293	0.093	0.759	0.222	0	0.085	0.006	0.931	0.079
3	0	0.322	0.113	0.741	0.239	0	0.094	0.008	0.924	0.087
4	0	0.325	0.115	0.739	0.240	0	0.095	0.008	0.923	0.088
5	0	0.204	0.045	0.819	0.167	0	0.059	0.003	0.951	0.056
6	0	0.392	0.167	0.701	0.275	0	0.115	0.012	0.908	0.105
7	0	0.508	0.280	0.645	0.327	0	0.151	0.020	0.884	0.133
8	0	0.492	0.262	0.652	0.321	0	0.146	0.019	0.887	0.129
9	0	0.449	0.219	0.672	0.302	0	0.133	0.015	0.896	0.119
10	0	0.420	0.192	0.687	0.289	0	0.124	0.013	0.902	0.112
11	0	0.870	0.823	0.514	0.448	0	0.263	0.060	0.813	0.214
12	0	0.958	0.997	0.490	0.470	0	0.290	0.074	0.798	0.231
13	0	1.979	4.251	0.318	0.629	0	0.612	0.328	0.651	0.399
14	0	0.478	0.248	0.658	0.315	0	0.142	0.018	0.890	0.126
15	0	0.688	0.514	0.572	0.394	0	0.206	0.037	0.847	0.175
16	0	0.510	0.282	0.644	0.328	0	0.151	0.020	0.883	0.134
17	0	1.008	1.104	0.477	0.481	0	0.306	0.082	0.789	0.241
18	0	0.903	0.885	0.505	0.456	0	0.273	0.065	0.807	0.220
19	1	1.224	1.627	0.429	1.096	0	0.373	0.122	0.754	0.281
20	1	1.597	2.770	0.366	1.218	0	0.491	0.211	0.699	0.343
21	0	1.168	1.481	0.441	0.515	0	0.356	0.111	0.763	0.271

Zone 1 (St. Lawrence River) River Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
22	0	1.542	2.580	0.374	0.577	0	0.473	0.196	0.707	0.335
23	0	1.493	2.422	0.381	0.570	0	0.458	0.184	0.714	0.327
24	0	1.509	2.471	0.379	0.572	0	0.463	0.188	0.712	0.329
25	0	1.228	1.638	0.429	0.526	0	0.375	0.123	0.753	0.282
26	0	0.868	0.819	0.515	0.447	0	0.262	0.060	0.814	0.213
27	0	1.291	1.809	0.416	0.538	0	0.394	0.136	0.744	0.293
28	0	1.590	2.744	0.367	0.583	0	0.489	0.209	0.700	0.342
29	0	1.462	2.321	0.387	0.565	0	0.448	0.176	0.718	0.322
30	0	1.231	1.645	0.428	0.527	0	0.375	0.123	0.753	0.283
31	0	0.706	0.541	0.566	0.400	0	0.212	0.039	0.844	0.179
32	0	0.584	0.370	0.612	0.357	0	0.174	0.027	0.868	0.151
33	1	1.592	2.753	0.366	1.217	0	0.489	0.210	0.700	0.343
34	2	1.356	1.995	0.405	1.739	0	0.415	0.150	0.734	0.304
35	1	1.636	2.907	0.360	1.229	0	0.503	0.222	0.694	0.349
36	0	1.086	1.281	0.459	0.498	0	0.330	0.095	0.776	0.256
37	0	0.398	0.172	0.698	0.278	0	0.117	0.012	0.907	0.106
38	0	0.686	0.511	0.573	0.393	0	0.205	0.037	0.848	0.174
39	2	1.521	2.513	0.377	1.820	0	0.467	0.191	0.710	0.331
40	0	2.144	4.989	0.301	0.644	0	0.665	0.387	0.632	0.420
41	2	1.599	2.777	0.365	1.854	0	0.492	0.212	0.699	0.344
42	0	1.092	1.296	0.457	0.500	0	0.332	0.096	0.775	0.257
43	0	3.236	11.371	0.222	0.717	0	1.017	0.905	0.529	0.538
44	0	1.707	3.165	0.350	0.598	0	0.526	0.242	0.685	0.360
45	2	3.330	12.036	0.217	2.288	0	1.047	0.960	0.522	0.546
58	0	0.208	0.047	0.816	0.170	0	0.060	0.003	0.950	0.057
59	0	0.291	0.092	0.760	0.221	0	0.085	0.006	0.931	0.079

Zone 1 (St. Lawrence River) River Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
65	2	0.534	0.309	0.633	1.072	0	0.159	0.022	0.878	0.139
66	2	1.114	1.348	0.453	1.599	2	0.339	0.100	0.771	0.719
70	0	0.768	0.640	0.545	0.419	0	0.231	0.047	0.832	0.192
71	1	0.785	0.669	0.540	0.884	0	0.236	0.049	0.829	0.196
72	0	0.975	1.032	0.486	0.474	0	0.295	0.076	0.795	0.234
74	0	0.917	0.913	0.501	0.460	0	0.277	0.067	0.805	0.223
75	1	1.088	1.286	0.458	1.041	0	0.331	0.096	0.776	0.256
76	0	1.066	1.233	0.464	0.494	0	0.323	0.092	0.779	0.252
77	1	1.587	2.734	0.367	1.216	0	0.488	0.208	0.701	0.342
78	0	0.812	0.716	0.531	0.432	0	0.244	0.052	0.824	0.201

E.2- Expected 4 Years' Total EB Result for Zone 1 Canal Sections

Zone 1 (St. Lawrence River) Canal Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
46	2	4.283	42.437	0.092	2.209	0	0.060	0.004	0.941	0.056
47	3	3.817	33.689	0.102	3.083	0	0.042	0.002	0.958	0.040
48	1	3.037	21.328	0.125	1.254	0	0.020	0.000	0.979	0.020
49	0	1.863	8.028	0.188	0.351	0	0.004	0.000	0.995	0.004
50	0	2.863	18.962	0.131	0.376	0	0.017	0.000	0.982	0.017
51	0	2.493	14.375	0.148	0.368	0	0.011	0.000	0.988	0.011
52	1	2.700	16.860	0.138	1.235	0	0.014	0.000	0.985	0.014
53	1	3.071	21.812	0.123	1.256	0	0.021	0.000	0.978	0.021
54	0	4.653	50.069	0.085	0.396	0	0.077	0.006	0.924	0.071
55	0	4.787	52.990	0.083	0.397	0	0.084	0.008	0.918	0.077
56	0	3.524	28.722	0.109	0.385	0	0.032	0.001	0.967	0.031
57	0	3.009	20.941	0.126	0.378	0	0.020	0.000	0.979	0.019
60	5	6.737	104.981	0.060	5.105	0	0.245	0.064	0.794	0.194
61	0	2.418	13.521	0.152	0.367	0	0.010	0.000	0.990	0.010
62	0	1.989	9.153	0.179	0.355	0	0.005	0.000	0.994	0.005
63	0	1.962	8.904	0.181	0.354	0	0.005	0.000	0.995	0.005
64	0	2.025	9.484	0.176	0.356	0	0.006	0.000	0.994	0.006
67	0	4.194	40.682	0.093	0.392	0	0.056	0.003	0.944	0.053
68	0	4.019	37.364	0.097	0.390	0	0.049	0.003	0.951	0.046
69	0	4.194	40.682	0.093	0.392	0	0.056	0.003	0.944	0.053
73	4	3.400	26.744	0.113	3.932	0	0.029	0.001	0.970	0.028

E.3- Expected 4 Years’ Total EB Result for Zone 2 Canal Sections

Zone 2 (Welland Canal) Canal Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
79	1	1.366	4.313	0.240	1.088	0	0.010	0.000	0.989	0.010
80	2	2.604	15.679	0.142	2.086	0	0.078	0.007	0.923	0.072
81	0	1.204	3.350	0.264	0.318	1	0.007	0.000	0.993	0.014
82	1	1.535	5.448	0.220	1.118	0	0.015	0.000	0.984	0.015
83	1	2.518	14.666	0.147	1.222	0	0.071	0.005	0.930	0.066
84	2	3.751	32.534	0.103	2.181	0	0.245	0.064	0.794	0.195
85	5	3.106	22.310	0.122	4.769	0	0.136	0.020	0.874	0.119
86	0	3.106	22.310	0.122	0.380	0	0.136	0.020	0.874	0.119
87	1	2.767	17.711	0.135	1.239	0	0.095	0.010	0.909	0.086
88	0	2.518	14.666	0.147	0.369	0	0.071	0.005	0.930	0.066
89	0	2.574	15.326	0.144	0.370	2	0.076	0.006	0.926	0.219
90	0	2.518	14.666	0.147	0.369	0	0.071	0.005	0.930	0.066
91	0	2.466	14.059	0.149	0.368	0	0.066	0.005	0.934	0.062
92	1	2.634	16.047	0.141	1.230	0	0.081	0.007	0.921	0.075
93	2	2.301	12.245	0.158	2.048	2	0.053	0.003	0.946	0.158

E.4- Expected 4 Years' Total EB Result for Zone 3 River Sections

Zone 3 (Detroit and St. Clair River) River Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑µ**	**∑Var(y)**	**α**	**∑E(µ/y)**	**∑y**	**∑µ**	**∑Var(y)**	**α**	**∑E(µ/y)**
94	0	0.725	0.571	0.559	0.406	0	0.218	0.041	0.840	0.183
95	0	1.157	1.454	0.443	0.513	0	0.352	0.109	0.764	0.269
96	1	0.299	0.097	0.755	0.471	0	0.087	0.007	0.929	0.081
97	0	0.985	1.053	0.483	0.476	0	0.298	0.078	0.793	0.237
98	2	1.095	1.302	0.457	1.587	1	0.333	0.097	0.775	0.483
99	1	2.178	5.152	0.297	1.350	0	0.676	0.400	0.628	0.425
100	0	1.780	3.439	0.341	0.607	0	0.549	0.264	0.675	0.371
101	1	2.037	4.506	0.311	1.323	0	0.631	0.349	0.644	0.407
102	0	1.991	4.302	0.316	0.630	0	0.616	0.332	0.650	0.400

E.5- Expected 4 Years’ Total EB Result for Zone 4 River Sections

Zone 4 (St. Mary River) River Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
103	0	0.500	0.272	0.648	0.324	0	0.148	0.019	0.885	0.131
105	1	0.455	0.225	0.669	0.635	0	0.135	0.016	0.895	0.120
106	0	0.959	0.999	0.490	0.470	0	0.290	0.074	0.797	0.231
107	0	1.109	1.336	0.454	0.503	0	0.337	0.099	0.772	0.260
109	1	0.821	0.732	0.529	0.905	0	0.247	0.053	0.822	0.203

E.6- Expected 4 Years’ Total EB Result for Zone 4 Canal Sections

Zone 4 (St. Mary River) Canal Sections										
Section #	**VF accident results**					**VV accident results**				
	∑y	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**	**∑y**	**∑μ**	**∑Var(y)**	**α**	**∑E(μ/y)**
104	1	2.483	14.259	0.148	1.220	0	0.068	0.005	0.933	0.063
108	0	2.654	16.291	0.140	0.372	0	0.083	0.007	0.919	0.077

APPENDIX F: EXPECTED 4 YEARS' TOTAL SCALED VV AND VF ACCIDENTS WITH % VALUE BY SECTION

Section #	Mileage Offsets (km)	Region	Section Type	VV Accidents		VF Accidents	
				E(μ/y) per km*10^5	% value	E(μ/y) per km*10^5	% value
1	00+030	St. Lawrence River	River	0.005	1.80	0.015	1.80
2	00+060	St. Lawrence River	River	0.005	0.90	0.014	0.90
3	00+090	St. Lawrence River	River	0.005	2.70	0.015	3.60
4	00+120	St. Lawrence River	River	0.005	3.60	0.015	4.50
5	00+135	St. Lawrence River	River	0.007	6.30	0.021	8.10
6	00+165	St. Lawrence River	River	0.007	5.40	0.017	6.30
7	00+205	St. Lawrence River	River	0.006	4.50	0.015	5.40
8	00+235	St. Lawrence River	River	0.008	9.00	0.020	7.20
9	00+255	St. Lawrence River	River	0.011	14.50	0.028	12.70
10	00+275	St. Lawrence River	River	0.010	13.60	0.027	10.90
11	00+305	St. Lawrence River	River	0.013	17.20	0.028	11.80
12	00+365	St. Lawrence River	River	0.007	7.20	0.015	2.70
13	00+405	St. Lawrence River	River	0.019	19.00	0.029	13.60
14	00+430	St. Lawrence River	River	0.009	11.80	0.023	10.00
15	00+455	St. Lawrence River	River	0.013	16.30	0.029	14.50
16	00+465	St. Lawrence River	River	0.025	22.70	0.061	25.40
17	00+480	St. Lawrence River	River	0.030	28.10	0.060	24.50
18	00+495	St. Lawrence River	River	0.027	23.60	0.057	20.90
19	00+510	St. Lawrence River	River	0.035	32.70	0.136	37.20
20	00+526	St. Lawrence River	River	0.040	38.10	0.142	38.10
21	00+534	St. Lawrence River	River	0.063	52.70	0.120	35.40

Section #	Mileage Offsets (km)	Region	Section Type	VV Accidents		VF Accidents	
				E(μ/y) per km*10^5	% value	E(μ/y) per km*10^5	% value
22	00+545	St. Lawrence River	River	0.051	48.10	0.087	28.10
23	00+555	St. Lawrence River	River	0.055	50.00	0.095	30.90
24	00+575	St. Lawrence River	River	0.027	24.50	0.048	17.20
25	00+595	St. Lawrence River	River	0.024	21.80	0.044	16.30
26	00+607	St. Lawrence River	River	0.030	27.20	0.062	26.30
27	00+622	St. Lawrence River	River	0.033	31.80	0.060	23.60
28	00+642	St. Lawrence River	River	0.029	25.40	0.049	18.10
29	00+659	St. Lawrence River	River	0.032	30.00	0.055	20.00
30	00+674	St. Lawrence River	River	0.031	29.00	0.059	21.80
31	00+680	St. Lawrence River	River	0.050	43.60	0.111	34.50
32	00+686	St. Lawrence River	River	0.042	41.80	0.099	31.80
33	00+706	St. Lawrence River	River	0.029	26.30	0.102	32.70
34	00+716	St. Lawrence River	River	0.051	47.20	0.290	50.90
35	00+730	St. Lawrence River	River	0.042	40.90	0.146	39.00
36	00+766	St. Lawrence River	River	0.012	15.40	0.023	9.00
37	00+771	St. Lawrence River	River	0.035	33.60	0.093	30.00
38	00+787	St. Lawrence River	River	0.018	18.10	0.041	15.40
39	00+801	St. Lawrence River	River	0.040	37.20	0.217	45.40
40	00+819	St. Lawrence River	River	0.039	36.30	0.060	22.70
41	00+826	St. Lawrence River	River	0.082	58.10	0.442	60.00
42	00+835	St. Lawrence River	River	0.048	42.70	0.093	29.00
43	00+857	St. Lawrence River	River	0.041	39.00	0.054	19.00
44	00+869	St. Lawrence River	River	0.050	45.40	0.083	27.20
45	00+894	St. Lawrence River	River	0.036	35.40	0.153	40.00
46	00+899	St. Lawrence River	Canal	0.117	67.20	4.624	90.90
47	00+900	St. Lawrence River	Canal-lock	0.417	95.40	32.263	99.00

Section #	Mileage Offsets (km)	Region	Section Type	VV Accidents		VF Accidents	
				E(μ/y) per km*10^5	% value	E(μ/y) per km*10^5	% value
48	00+903	St. Lawrence River	Canal	0.070	56.30	4.374	89.00
49	00+905	St. Lawrence River	Canal	0.023	20.90	1.836	80.90
50	00+908.5	St. Lawrence River	Canal	0.050	44.50	1.123	77.20
51	00+914.5	St. Lawrence River	Canal	0.019	20.00	0.643	64.50
52	00+918	St. Lawrence River	Canal	0.042	40.00	3.691	86.30
53	00+919.5	St. Lawrence River	Canal-lock	0.144	75.40	8.760	94.50
54	00+925	St. Lawrence River	Canal	0.136	71.80	0.753	70.00
55	00+930.5	St. Lawrence River	Canal	0.147	77.20	0.754	70.90
56	00+933.5	St. Lawrence River	Canal	0.109	65.40	1.343	80.00
57	00+937.5	St. Lawrence River	Canal	0.051	46.30	0.989	76.30
58	00+947	St. Lawrence River	River	0.063	51.80	0.187	43.60
59	00+962	St. Lawrence River	River	0.055	50.90	0.154	40.90
60	00+967	St. Lawrence River	Canal-lock	0.407	93.60	10.684	97.20
61	00+977	St. Lawrence River	Canal	0.010	12.70	0.384	56.30
62	00+984	St. Lawrence River	Canal	0.008	10.00	0.531	61.80
63	00+991	St. Lawrence River	Canal	0.008	8.10	0.530	60.90
64	00+998	St. Lawrence River	Canal	0.009	10.90	0.533	62.70
65	01+038	St. Lawrence River	River	0.036	34.50	0.280	49.00
66	01+079	St. Lawrence River	River	0.183	84.50	0.408	58.10
67	01+080	St. Lawrence River	Canal-lock	0.551	97.20	4.102	87.20
68	01+087	St. Lawrence River	Canal	0.069	55.40	0.584	63.60
69	01+088	St. Lawrence River	Canal-lock	0.551	97.20	4.102	87.20
70	01+098	St. Lawrence River	River	0.201	85.40	0.438	59.00
71	01+123	St. Lawrence River	River	0.082	57.20	0.370	55.40
72	01+144	St. Lawrence River	River	0.117	66.30	0.236	46.30
73	01+146	St. Lawrence River	Canal-lock	0.147	78.10	20.575	98.10

Section #	Mileage Offsets (km)	Region	Section Type	VV Accidents		VF Accidents	
				E(μ/y) per km*10^5	% value	E(μ/y) per km*10^5	% value
74	01+161	St. Lawrence River	River	0.156	80.00	0.321	52.70
75	01+201	St. Lawrence River	River	0.067	54.50	0.272	48.10
76	01+241	St. Lawrence River	River	0.066	53.60	0.129	36.30
77	01+274	St. Lawrence River	River	0.108	64.50	0.385	57.20
78	01+315	St. Lawrence River	River	0.051	49.00	0.110	33.60
79	01+318	Welland Canal	Canal	0.032	30.90	3.411	84.50
80	01+322	Welland Canal	Canal-lock	0.170	82.70	4.906	92.70
81	01+323	Welland Canal	Canal	0.136	72.70	2.992	83.60
82	01+324	Welland Canal	Canal-lock	0.140	73.60	10.513	96.30
83	01+329	Welland Canal	Canal	0.124	68.10	2.300	81.80
84	01+333.5	Welland Canal	Canal-lock	0.407	92.70	4.559	90.00
85	01+338.5	Welland Canal	Canal-lock	0.224	87.20	8.972	95.40
86	01+343.5	Welland Canal	Canal	0.224	87.20	0.714	69.00
87	01+348.5	Welland Canal	Canal	0.162	81.80	2.331	82.70
88	01+353.5	Welland Canal	Canal	0.124	68.10	0.694	65.40
89	01+358.5	Welland Canal	Canal	0.412	94.50	0.696	67.20
90	01+363.5	Welland Canal	Canal	0.124	68.10	0.694	65.40
91	01+367.5	Welland Canal	Canal	0.145	76.30	0.865	73.60
92	01+370	Welland Canal	Canal-lock	0.282	90.00	4.630	91.80
93	01+373.5	Welland Canal	Canal	0.424	96.30	5.504	93.60
94	01+384.25	Detroit River	River	0.380	91.80	0.843	72.70
95	01+394.25	Detroit River	River	0.602	99.00	1.146	79.00
96	01+400.25	Detroit River	River	0.151	79.00	0.876	74.50
97	01+420.25	Detroit River	River	0.132	70.90	0.266	47.20
98	01+440.25	Detroit River	River	0.270	89.00	0.886	75.40
99	01+461.25	St. Clair River	River	0.103	61.80	0.328	53.60

Section #	Mileage Offsets (km)	Region	Section Type	VV Accidents		VF Accidents	
				E(μ/y) per km*10^5	% value	E(μ/y) per km*10^5	% value
100	01+481.25	St. Clair River	River	0.095	60.90	0.155	41.80
101	01+504.25	St. Clair River	River	0.090	60.00	0.293	51.80
102	01+523.75	St. Clair River	River	0.105	62.70	0.165	42.70
103	01+529.42	St. Mary's River	River	0.283	90.90	0.700	68.10
104	01+533.64	St. Mary's River	Canal	0.183	83.60	3.537	85.40
105	01+540.48	St. Mary's River	River	0.215	86.30	1.137	78.10
106	01+560.48	St. Mary's River	River	0.142	74.50	0.288	50.00
107	01+575.48	St. Mary's River	River	0.106	63.60	0.205	44.50
108	01+578.48	St. Mary's River	Canal-lock	0.156	80.90	0.758	71.80
109	01+593.48	St. Mary's River	River	0.083	59.00	0.369	54.50

APPENDIX G: EXPECTED 4 YEARS' TOTAL SCALED COMBINED ACCIDENTS WITH % VALUE BY SECTION

Section #	Mileage Offsets (km)	Region	Section Type	Accidents	
				E(µ/y) per km*10^5	% value
1	00+030	St. Lawrence River	River	0.020	1.8
2	00+060	St. Lawrence River	River	0.019	0.9
3	00+090	St. Lawrence River	River	0.020	2.7
4	00+120	St. Lawrence River	River	0.020	3.6
5	00+135	St. Lawrence River	River	0.028	7.2
6	00+165	St. Lawrence River	River	0.024	6.3
7	00+205	St. Lawrence River	River	0.021	4.5
8	00+235	St. Lawrence River	River	0.028	8.1
9	00+255	St. Lawrence River	River	0.039	11.8
10	00+275	St. Lawrence River	River	0.037	10.9
11	00+305	St. Lawrence River	River	0.041	12.7
12	00+365	St. Lawrence River	River	0.022	5.4
13	00+405	St. Lawrence River	River	0.048	14.5
14	00+430	St. Lawrence River	River	0.033	9
15	00+455	St. Lawrence River	River	0.042	13.6
16	00+465	St. Lawrence River	River	0.086	20
17	00+480	St. Lawrence River	River	0.090	21.8
18	00+495	St. Lawrence River	River	0.084	19
19	00+510	St. Lawrence River	River	0.171	35.4
20	00+526	St. Lawrence River	River	0.182	36.3
21	00+534	St. Lawrence River	River	0.183	37.2
22	00+545	St. Lawrence River	River	0.138	30
23	00+555	St. Lawrence River	River	0.150	32.7
24	00+575	St. Lawrence River	River	0.075	17.2
25	00+595	St. Lawrence River	River	0.067	16.3
26	00+607	St. Lawrence River	River	0.092	23.6
27	00+622	St. Lawrence River	River	0.092	24.5
28	00+642	St. Lawrence River	River	0.077	18.1
29	00+659	St. Lawrence River	River	0.087	20.9
30	00+674	St. Lawrence River	River	0.090	22.7
31	00+680	St. Lawrence River	River	0.161	33.6
32	00+686	St. Lawrence River	River	0.141	31.8
33	00+706	St. Lawrence River	River	0.130	28.1
34	00+716	St. Lawrence River	River	0.341	48.1
35	00+730	St. Lawrence River	River	0.188	38.1
36	00+766	St. Lawrence River	River	0.035	10
37	00+771	St. Lawrence River	River	0.128	27.2
38	00+787	St. Lawrence River	River	0.059	15.4
39	00+801	St. Lawrence River	River	0.256	43.6

Section #	Mileage Offsets (km)	Region	Section Type	Accidents	
				E(μ/y) per km*10^5	% value
40	00+819	St. Lawrence River	River	0.099	26.3
41	00+826	St. Lawrence River	River	0.524	58.1
42	00+835	St. Lawrence River	River	0.140	30.9
43	00+857	St. Lawrence River	River	0.095	25.4
44	00+869	St. Lawrence River	River	0.133	29
45	00+894	St. Lawrence River	River	0.189	39
46	00+899	St. Lawrence River	Canal	4.741	90
47	00+900	St. Lawrence River	Canal-lock	32.680	99
48	00+903	St. Lawrence River	Canal	4.443	87.2
49	00+905	St. Lawrence River	Canal	1.859	80.9
50	00+908.5	St. Lawrence River	Canal	1.173	76.3
51	00+914.5	St. Lawrence River	Canal	0.662	64.5
52	00+918	St. Lawrence River	Canal	3.733	86.3
53	00+919.5	St. Lawrence River	Canal-lock	8.903	94.5
54	00+925	St. Lawrence River	Canal	0.888	67.2
55	00+930.5	St. Lawrence River	Canal	0.902	68.1
56	00+933.5	St. Lawrence River	Canal	1.453	79
57	00+937.5	St. Lawrence River	Canal	1.040	73.6
58	00+947	St. Lawrence River	River	0.250	42.7
59	00+962	St. Lawrence River	River	0.209	40.9
60	00+967	St. Lawrence River	Canal-lock	11.091	97.2
61	00+977	St. Lawrence River	Canal	0.394	50.9
62	00+984	St. Lawrence River	Canal	0.539	60
63	00+991	St. Lawrence River	Canal	0.537	59
64	00+998	St. Lawrence River	Canal	0.541	60.9
65	01+038	St. Lawrence River	River	0.317	46.3
66	01+079	St. Lawrence River	River	0.592	61.8
67	01+080	St. Lawrence River	Canal-lock	4.653	88.1
68	01+087	St. Lawrence River	Canal	0.653	63.6
69	01+088	St. Lawrence River	Canal-lock	4.653	88.1
70	01+098	St. Lawrence River	River	0.639	62.7
71	01+123	St. Lawrence River	River	0.452	54.5
72	01+144	St. Lawrence River	River	0.353	49
73	01+146	St. Lawrence River	Canal-lock	20.723	98.1
74	01+161	St. Lawrence River	River	0.476	56.3
75	01+201	St. Lawrence River	River	0.339	47.2
76	01+241	St. Lawrence River	River	0.195	40
77	01+274	St. Lawrence River	River	0.494	57.2
78	01+315	St. Lawrence River	River	0.162	34.5
79	01+318	Welland Canal	Canal	3.444	84.5
80	01+322	Welland Canal	Canal-lock	5.076	92.7
81	01+323	Welland Canal	Canal	3.128	83.6
82	01+324	Welland Canal	Canal-lock	10.653	96.3
83	01+329	Welland Canal	Canal	2.424	81.8

Section #	Mileage Offsets (km)	Region	Section Type	Accidents	
				E(μ/y) per km*10^5	% value
84	01+333.5	Welland Canal	Canal-lock	4.966	91.8
85	01+338.5	Welland Canal	Canal-lock	9.196	95.4
86	01+343.5	Welland Canal	Canal	0.938	70
87	01+348.5	Welland Canal	Canal	2.493	82.7
88	01+353.5	Welland Canal	Canal	0.818	65.4
89	01+358.5	Welland Canal	Canal	1.108	74.5
90	01+363.5	Welland Canal	Canal	0.818	65.4
91	01+367.5	Welland Canal	Canal	1.011	71.8
92	01+370	Welland Canal	Canal-lock	4.912	90.9
93	01+373.5	Welland Canal	Canal	5.927	93.6
94	01+384.25	Detroit River	River	1.223	77.2
95	01+394.25	Detroit River	River	1.747	80
96	01+400.25	Detroit River	River	1.027	72.7
97	01+420.25	Detroit River	River	0.398	51.8
98	01+440.25	Detroit River	River	1.156	75.4
99	01+461.25	St. Clair River	River	0.431	53.6
100	01+481.25	St. Clair River	River	0.249	41.8
101	01+504.25	St. Clair River	River	0.384	50
102	01+523.75	St. Clair River	River	0.269	44.5
103	01+529.42	St. Mary's River	River	0.983	70.9
104	01+533.64	St. Mary's River	Canal	3.721	85.4
105	01+540.48	St. Mary's River	River	1.352	78.1
106	01+560.48	St. Mary's River	River	0.429	52.7
107	01+575.48	St. Mary's River	River	0.311	45.4
108	01+578.48	St. Mary's River	Canal-lock	0.914	69
109	01+593.48	St. Mary's River	River	0.452	55.4

APPENDIX H: R-SOFTWARE INPUTS AND OUTPUTS

H.1- R-Software Inputs

```
>A4=read.csv("C:/Users/bircan/Desktop/Thesis Analysis/Ranalysis/River2.csv")
> A5=read.csv("C:/Users/bircan/Desktop/Thesis Analysis/Ranalysis/Canal2.csv")
> A4$Traffic6L=A4$Traffic6*A4$L
> A4$Traffic8L=A4$Traffic8*A4$L
> A4$Traffic6LW=A4$Traffic6L/A4$W
> A4$Traffic8LW=A4$Traffic8L/A4$W
> A4$lnTraffic6LW=log(A4$Traffic6LW,base=exp(1))
> A4$lnTraffic8LW=log(A4$Traffic8LW,base=exp(1))
> A5$Traffic6L=A5$Traffic6*A5$L
> A5$Traffic8L=A5$Traffic8*A5$L
> A5$Traffic6LW=A5$Traffic6L/A5$W
> A5$Traffic8LW=A5$Traffic8L/A5$W
> A5$lnTraffic6LW=log(A5$Traffic6LW,base=exp(1))
> A5$lnTraffic8LW=log(A5$Traffic8LW,base=exp(1))
> model3_pos=glm(formula=Acc8VV~lnTraffic8LW,family=poisson(link="log"),data=
A4)
> model4_pos=glm(formula=Acc8VF~lnTraffic8LW,family=poisson(link="log"),data=A
4)
> model4_nb=glm.nb(formula=Acc8VF~lnTraffic8LW,data=A4)
> model7_pos=glm(formula=Acc8VV~lnTraffic8LW,family=poisson(link="log"),data=
A5)
> model10_pos=glm(formula=Acc6VF~lnTraffic6LW+Dvar,family=poisson(link="log")
,data=A5)
```

H.2- R-Software Outputs for the Chosen Models

VV River Model

```
> summary(model3_pos)

Call:
glm(formula = Acc8VV ~ lnTraffic8LW, family = poisson(link = "log"),
    data = A4)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.4062  -0.8053  -0.5927  -0.3620   2.6879

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)  -10.0140     3.3160  -3.020  0.00253 **
lnTraffic8LW   0.6942     0.2553   2.719  0.00655 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for poisson family taken to be 1)

    Null deviance: 68.845  on 70  degrees of freedom
Residual deviance: 60.389  on 69  degrees of freedom
AIC: 97.835

Number of Fisher Scoring iterations: 6
```

VF River Model

```
> summary(model4_nb)

Call:
glm.nb(formula = Acc8VF ~ lnTraffic8LW, data = A4, init.theta = 2.825388983,
    link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.6190  -1.0854  -0.7026   0.3709   2.2312

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   -7.9229     2.0968  -3.779 0.000158 ***
lnTraffic8LW   0.6234     0.1636   3.810 0.000139 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(2.8254) family taken to be 1)

    Null deviance: 91.681  on 70  degrees of freedom
Residual deviance: 74.912  on 69  degrees of freedom
AIC: 184.22

Number of Fisher Scoring iterations: 1


              Theta:  2.83
          Std. Err.:  2.33

 2 x log-likelihood:  -178.22
```

VV Canal Model

```
> summary(model7_pos)

Call:
glm(formula = Acc8VV ~ lnTraffic8LW, family = poisson(link = "log"),
    data = A5)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.8165  -0.8917  -0.4963  -0.2657   2.3674

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -21.7366     6.8211  -3.187  0.00144 **
lnTraffic8LW   1.6166     0.5181   3.120  0.00181 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for poisson family taken to be 1)

    Null deviance: 50.907  on 37  degrees of freedom
Residual deviance: 38.189  on 36  degrees of freedom
AIC: 62.863

Number of Fisher Scoring iterations: 6
```

VF Canal Model

```
> summary(model10_pos)

Call:
glm(formula = Acc6VF ~ lnTraffic6LW + Dvar, family = poisson(link = "log"),
    data = A5)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.2793  -1.6715  -0.4907   0.7202   3.0928

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)   -6.1125     2.5914  -2.359   0.0183 *
lnTraffic6LW   0.5173     0.2023   2.557   0.0106 *
Dvar           0.5865     0.2689   2.181   0.0292 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

    Null deviance: 89.013  on 37  degrees of freedom
Residual deviance: 80.950  on 35  degrees of freedom
AIC: 157.02

Number of Fisher Scoring iterations: 5
```