THE DEVELOPMENT OF RISK-BASED SPILL MANAGEMENT CRITERIA RELATED TO THE BENEFICIAL USE IMPAIRMENTS IN THE ST. CLAIR RIVER

by

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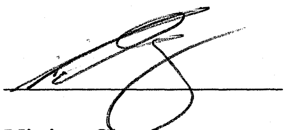

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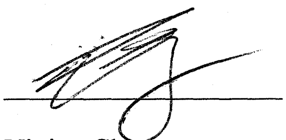

Vivian Cheng

Abstract

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Master of Applied Science and Management, 2010

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Spills to the St. Clair River have caused the water treatment plant (WTP) intakes to shut down numerous times. A set of risk-based spill management criteria is developed to evaluate existing and future spill prevention and control measures in the policy planning stage. It estimates the explicit risk of a WTP shutdown due to the violation of the drinking water quality guidelines in a two-year period. The risk is determined by the joint probability of occurrence of the smallest spill chemical event mass and the smallest low flow condition. Land-based benzene and vinyl chloride spills are found to have caused the highest number of WTP shutdown occurrences. Based on the spill data from 1988-1997 and 1998-2007, the risk of WTP shutdown in a two-year period due to benzene spills is 86% and 50%, respectively; and vinyl chloride spills is 17% and 9%, respectively. The study concludes that the risk of WTP shutdown due to spills has been decreasing in the St. Clair River over the past 20 years.

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Lastly, and most importantly, my deepest gratitude to my lovely parents.

Dedication

To Wayne—whose love, encouragement, understanding, forbearance, and confidence in my aptitude I am so thankful to have.

To Tuk—who spent many hours by my desk.

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List of Acronyms

IJC	International Joint Commission
GLWQ	Great Lakes Water Quality Agreement
AOC	Areas of Concern
AOR	Area of Recovery
BUI	Beneficial Use Impairment
CEPA	Canadian Environmental Protection Act
CFA	Canadian Fisheries Act
CRIC	Canadian RAP Implementation Committee
COA	Canadian-Ontario Agreement
Cs of A	Certificates of Approval
CV	Coefficient of Variance
OCWA	Ontario Clean Water Act
EESLAA	Environmental Enforcement Statute Law Amendment Act
OEPA	Ontario Environmental Protection Act
MAC	Maximum Acceptable Concentration
MISA	Municipal/Industrial Strategy for Abatement
MOE	Ministry of the Environment
ODWQS	Ontario Drinking Water Quality Standards
ORIS	Occurrence Report Information System
OWRA	Ontario Water Resources Act
RAP	Remedial Action Plan
SAC	Spills Action Centre
OSDWA	Ontario Safe Drinking Water Act
SLEA	Sarnia-Lambton Environmental Association
SPP	Source Protection Plan

WIFN	Walpole Island First Nation
WTP	Water Treatment Plant

1.0 Introduction

1.1 Problem Definition

The Great Lakes are a major receptacle for spill contaminants resulting from anthropogenic activities. Land-based spills (hereafter termed spills) are frequently found in highly urbanized areas. Spills take on many forms, but oils, chemicals, and wastes comprise the majority of the water pollution in the Great Lakes Basin. Spills affect the physical, chemical, and biological characteristics of the receiving water, resulting in algal bloom, increased water treatment costs, impairments to drinking water quality, and the degradation of fish and wildlife populations and habitats.

The issue of spills is commonly associated with their frequency and environmental impact in a geographical area. Situating beside the St. Clair River is the City of Sarnia, which is Ontario's most highly industrialized area. Spills to the St. Clair River corridor were one of the highest for all areas in the Great Lakes Basin in the 1990s (International Joint Commission, 2006). As a result, the local drinking water has been greatly affected (Binational Advisory Council, 1991). Concerns over the safety of the local surface water supply from the St. Clair River are signified by the numerous shutdowns of the water intakes along the river and its tributaries when spills occur (Binational Advisory Council, 1991). Despite more stringent government spill policy and regulation, the trend of spills continues to fluctuate in the new millennium in the St. Clair River corridor. Water intake shutdown due to spills remains a concern for residents and the local jurisdictions, since no studies have yet quantified its risk. Furthermore, in the absent of a risk-based spill study, it is difficult to evaluate the effectiveness of any existing and future spill management programs.

1.2 Context

Two pieces of legislation govern the responsibility shared between Canada and United States regarding the Great Lakes water quality: the *International Boundary Water Treaty Act* and the *Great Lakes Water Quality Agreement*. The two countries committed to protect and work cooperatively on issues regarding the common boundary of their waterways by signing the Boundary Water Treaty Act (the Treaty) in 1909. The Treaty established the International Joint Commission (IJC) and the Water Quality Board to address the matters and projects affecting the health of the Great Lakes. The Great Lakes Water Quality Agreement (GLWQA) (1972) reaffirms the countries' obligation and rights under the Treaty. The amendment to the GLWQA in 1978 improves the pollution abatement, control, and prevention policy of the Great Lakes. It also recognizes the need to restore and maintain the physical, biological, and chemical integrity of the Great Lakes Basin Ecosystem through the implementation of water quality standards, regulatory requirements, and research programs. The GLWQA specifically deals with persistent toxic substances, hazardous substances, and oils that enter into the Great Lakes System (International Joint Commission, 2008).

The IJC spearheads the implementation of the GLWQA. It identified 43 watersheds in the Great Lakes Basin with ecosystem degradation symptoms as described in the GLWQA, which are referred to as Areas of Concern (AOC). Figure 1.1 is a map of all AOC locations. Among the 43 AOC, 12 are located in Canada, 26 in the U.S, and 5 are binational areas. Since 1985, three areas have been delisted as AOC (2 within Canada). Many of the remaining AOC, such as the Niagara River, St. Lawrence River, Toronto and Region Area, and St. Clair River are still experiencing drinking water consumption, or taste and odour problems due to spills (Binational Advisory Council, 1991; Ministry of the Environment and Energy, 1992; Niagara Peninsula Conservation Authority, 2009; Metro Toronto and Region Remedial Action Plan, 1994).

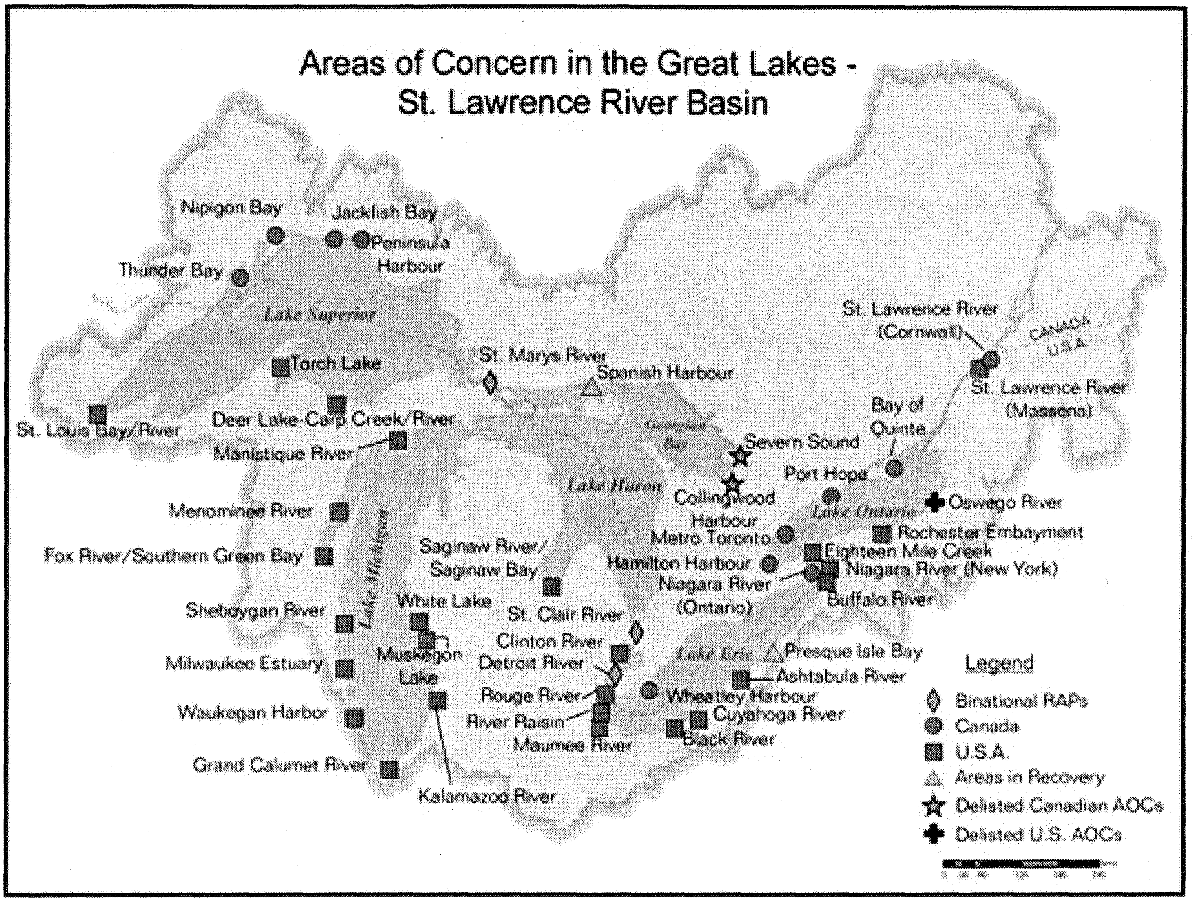

Figure 1.1 Map of the Areas of Concern (U.S. Environmental Protection Agency, 2009)

Pursuant to the GLWQA, each AOC has to develop a Remedial Action Plan (RAP). *Annex 2* of the GLWQA stipulates a remediation process that must occur through the three RAP stages: the first RAP report determines the severity of the pollution sources and effects; the second report identifies the goals and remedial actions; and the third report documents the implementation of remedial measures, which would deem the AOC in full recovery. The GLWQA describes 14 symptomatic ecosystem degradation indicators, which are referred to as "impairments of beneficial uses" or BUIs. A list of the BUIs is shown in Table 1.1. Each AOC is required to identify and document the remedial actions required in order to restore the 14 BUIs and other environmental issues identified in the RAP Stage One report.

Table 1.1 Beneficial Use Impairments (BUIs) for Areas of Concern in the Great Lakes Water Quality Agreement

Beneficial Use Impairment
Restrictions on fish and wildlife consumption
Tainting of fish and wildlife flavour
Degradation of fish and wildlife populations
Fish tumours or other deformities
Bird or animal deformities or reproductive problems
Degradation of benthos
Restrictions on dredging activities
Eutrophication or undesirable algae
Restrictions on drinking water consumption, or taste and odour problems
Beach closings
Degradation of aesthetics
Degradation of phytoplankton and zooplankton populations
Added costs to agriculture or industry
Loss of fish and wildlife habitat

The St. Clair River RAP Stage One and Two reports identified the area as having drinking water consumption impairments, or taste and odour problems due to spills. Table 1.2 shows the number of spills in the St. Clair River area between 1974 and 2005. As a result of some of these spills, the water treatment plants (WTPs) located downstream from the City of Sarnia on the Canadian border experienced sporadic periods of closures as spill plumes travel through the river, subsequently elevating the chemical parameters in the raw water supply to beyond the safe consumption level (The Binational Public Advisory Council, 1991; The Binational Public Advisory Council, 1995; Lake St. Clair Canadian Watershed Coordination Council, 2005).

Table 1.2 Spills record between 1974 and 2005

Year	No. of Spills	References
1974-1985	11	The Binational Public Advisory Committee, 1991
1986-1989	400	St. Clair River Stage 2 Remedial Action Plan Water Use Goals, Remedial Measure and Implementation Strategy, 1995
1991-2006	700	Walpole Island First Nation "*Request for Proposal-Macomb County Health Department Drinking Water Protection Project Manager, Macomb County Health Department, Mount Clemens, Michigan, 2006*" (Golder Associates, 2008)
2002-2005	11	International Joint Commission, 2006

The Walpole Island First Nation (WIFN) WTP and the Town of Wallaceburg WTP were closed on two occasions in the early 1990s due to spills of polyethylene diethyl ether and ethylbenzene. The massive power outage in August 2003 affected a spill monitoring system at an industrial facility in Sarnia which led to two consecutive spills of vinyl chloride monomer totalling 132 kg, and caused the WIFN WTP to shut down (International Joint Commission, 2006). A year later, another major spill of 157,500 L of methyl ethyl keytone caused both WTPs to shut down for three to four days (Ministry of the Environment, 2005). The problem of the WTP shutdowns was not limited to the Canadian side of the St. Clair River. Michigan experienced 12 shutdowns in the period between 1978 and 1990 (The Binational Public Advisory Committee, 1991). The Canadian RAP Implementation Committee (CRIC) for the St. Clair River AOC is investigating the WTPs shutdown issue. The delisting criterion for the drinking water BUI in the St. Clair River AOC is to have "no treatment plant shutdowns due to exceedences [*sic*] of drinking water guidelines over a two year period" (Canadian Remedial Action Plan Implementation Committee, 2007, p. 7, 24). Policy administrators should consider the explicit risk of WTP shutdowns in a two-year period prior to removing this BUI.

1.3 Research Rationale

The motivation for this study is to investigate whether spill management based on water intake shutdowns as suggested by the CRIC for the St. Clair River AOC is an appropriate strategy. The tainted drinking water crises in Ontario from Walkerton to the Kashechewan First Nation and the subsequent enactment of the *Clean Water Act* and *Safe Drinking Water Act* demonstrate that society is much more responsive to environmental issues if they are found to pose risks to human lives, health, and safety. Therefore, a case study for the St. Clair River AOC should be done to determine the risk of shutdown of the local water intakes. If water quality managers determine that the risk is significant, a direct relationship between spills and drinking water should be applied when developing management strategies for both.

1.4 Purpose and Objectives

The purpose of this study is to investigate risk-based spill management criteria by associating spills to municipal water intake shutdowns. The objective of the study is to develop a methodology to establish risk-based spill management criteria based on spills characteristics and receiving water conditions.

The proposed methodology includes the following steps:

1) Statistical analysis of the spill record;
2) Statistical analysis of the WTP shutdown record; and
3) Risk analysis of WTP shutdowns due to spills.

The criteria are used to evaluate the effectiveness of spill management measures. It quantifies the risk in terms of the spill frequency and environmental impact, for example water intake shutdown. Local policy administrators can apply this methodology to plan for risk-based spill management strategies relating to drinking water consumption, or taste and odour problems. The risk analysis can be executed on a regular basis when spill and water intake shutdown information become available. Hence, such an exercise can determine the performance of existing and future spill management measures by evaluating and comparing their risks. To demonstrate this methodology, a case study of the St. Clair River AOC is presented. Local data from the St. Clair River AOC, including spills, shutdown data, St. Clair river hydrologic information, and WTP operation protocols are analyzed.

1.5 Study Area

The St. Clair River stretches 64km between the southern tip of Lake Huron and Lake St. Clair in Southwestern Ontario. Lands along the river are dominated mainly by agriculture, except near Port Huron and Sarnia (The Binational Public Advisory Council, 1991). Sarnia is known to have a high density of petroleum refineries and chemical manufacturers. Figure 1.2 shows a map of the St. Clair River AOC. The St. Clair River has a broad delta region near Lake St. Clair which branches off to other tributaries. The WIFN and Town of Wallaceburg have water intakes located in the delta region, downstream from Sarnia. The Town of Wallaceburg is located approximately 40km from the City of Sarnia (Murru, M., personal communication, 2009). The plant's water intake is located in Chenal Ecarté, a distributary of the St. Clair River (Environmental Canada, 1994). The WIFN community is located approximately 50km downstream from the City of Sarnia with a population of about 4,000 within the Township of Wallaceburg (Kicknosway, S., personal communication, 2009). The WIFN's water intake is located in the St. Clair River.

The St. Clair River AOC is an area of watershed that is shared by Canada and the United States. Figure 1.2 delineates the entire AOC boundary. The case study examines spills that occur on the Canadian side of the AOC, including the stretch along the St. Clair River between Sarnia, Wallaceburg, and WIFN.

1.6 Organization

The research report is comprised of six chapters. Chapter 1 is the introduction to the report. Chapter 2 reviews the current state of knowledge related to spills in the Canadian context and the St. Clair River AOC related to spill frequency, spill legislation and definitions, drinking water quality parameters, as well as spill notification and WTP shutdown protocols. Chapter 3 describes the development of the risk-based spill management criteria. Chapter 4 presents the data compilation and spill characteristics. Chapter 5 demonstrates the application of the risk-based spill management criteria at the St. Clair River AOC. Chapter 6 concludes the study with findings and recommendations for future research.

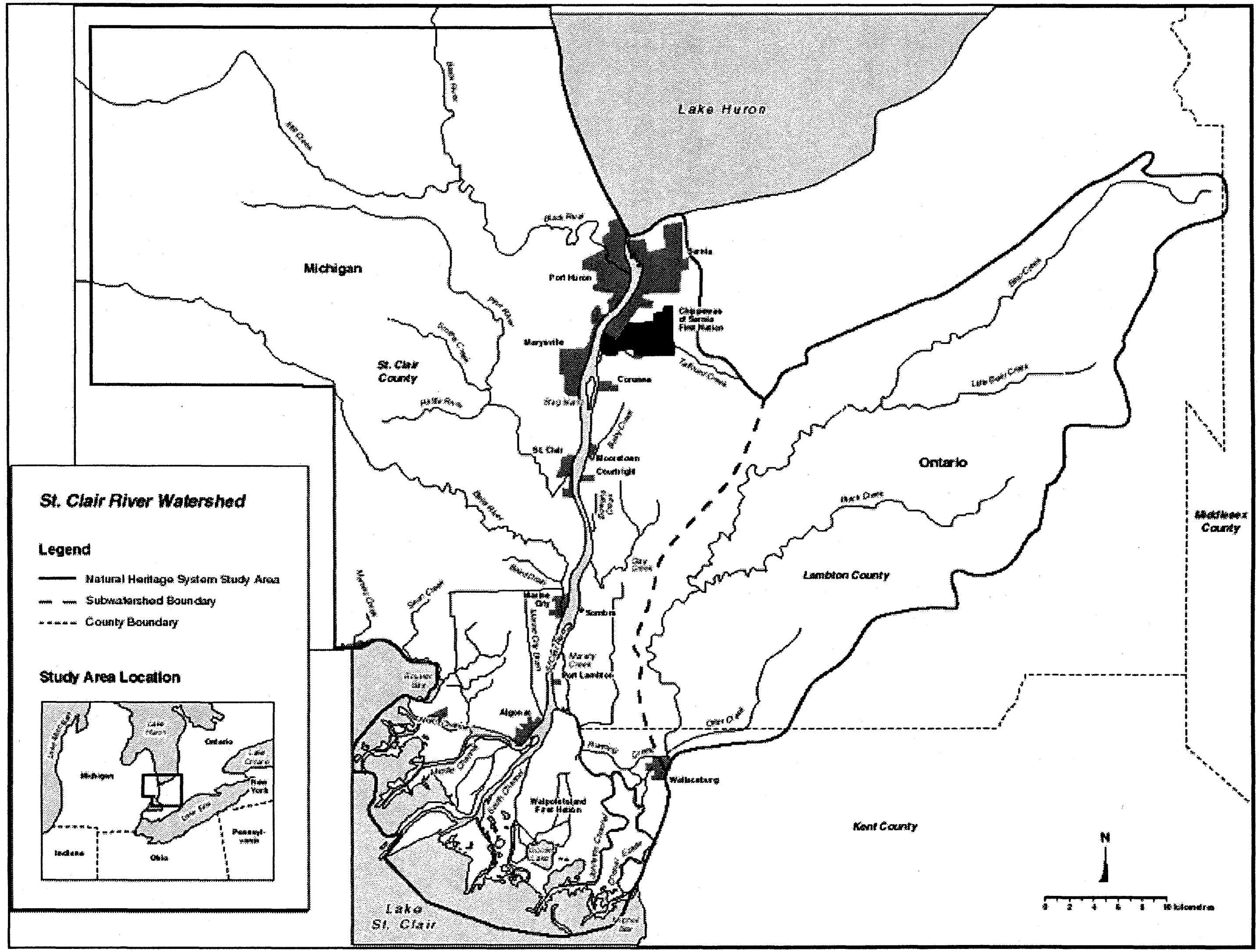

Figure 1.2 Boundary of the St. Clair River AOC (The Binational Public Advisory Council, 1991)

2.0 Current State of Knowledge

2.1 A snapshot of the spills trend in the Great Lakes System between 1990 and 2004

A study called "Report on Spills in the Great Lakes Basin, with a Special Focus on the St. Clair-Detroit River Corridor" by the IJC, a binational authority that manages the water quality of the Great Lakes, reviewed the issue of spills in the Great Lakes and the connecting river corridors (International Joint Commission, 2006). The study examined Canadian and American spills from 1990 to 2004 and concluded that spills occurred along the shorelines, in tributary waters, and in the open water of the lakes from human-related activities. Sources of spills were navigational traffic, land transportation, and recreational activities (p. 29), as well as overflows and discharges from industrial outfalls, combined sewers, and municipal waste water treatment plants (p. 11). These spills contributed to a large amount of the pollution in the Great Lakes Basin. Spills, according to the study, included substances, such as gasoline, diesel, asphalt, hydraulic oil, ammonia, chlorine, pesticides, industrial waste, and effluent (p. 34). The IJC categorized the spills into "oils and hydrocarbons", "chemicals", "waste", and "others" (ibid.). From data between 1990 and 2004, American spills were mainly comprised of oil-based substances, while Canadian spills were mostly chemical-based (pp. 36-37). A major source of Canadian spills was industrial land use, whereas American spills were often caused by marine transportation. The report found that spills continued to occur in densely populated areas with frequent commercial and industrial activities (p. 30).

Figure 2.1 is an excerpt from the IJC study on the number of Canadian spills reported in the Great Lakes between 1990 and 2004. Lake Ontario had the most Canadian spills, which reflects how the distribution of population density and industrial land pattern relate to the number of spills

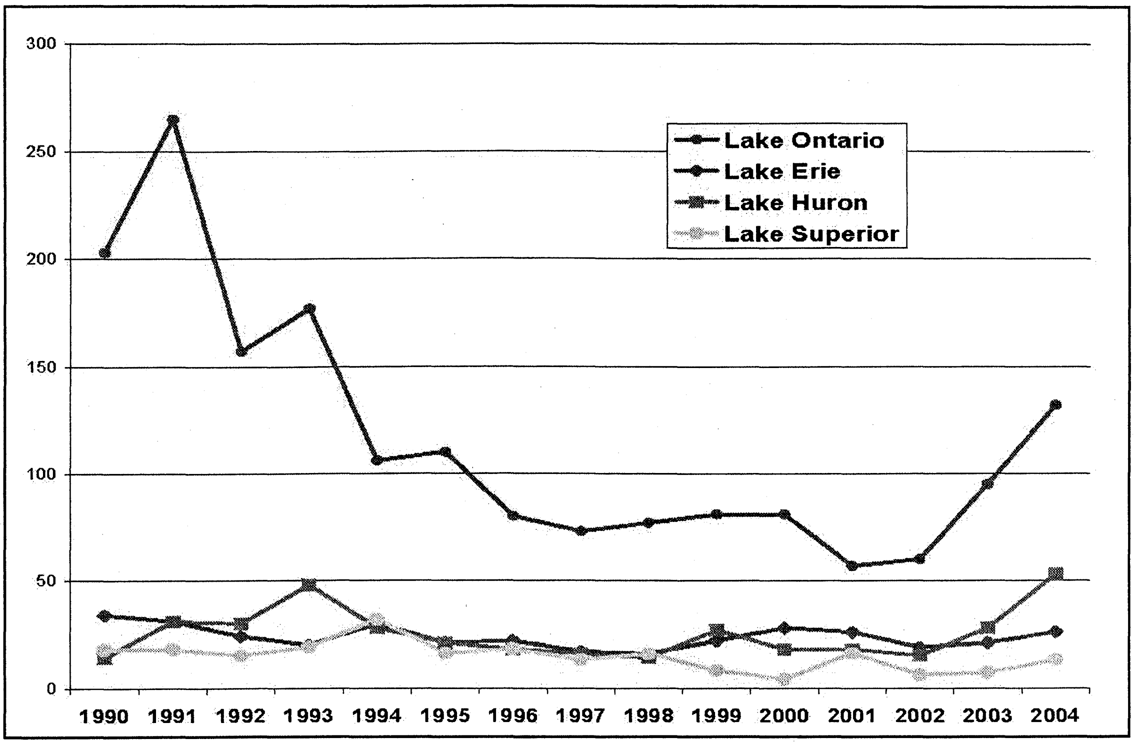

Figure 2.1 The number of Canadian spills reported in the Great Lakes between 1990 and 2004 (International Joint Commission, 2006, p. 33)

(International Joint Commission, 2006, p. 30). Figure 2.2 and Figure 2.3 are also excerpts from the IJC report, which show the number of spills in the Great Lakes river corridors. Figure 2.2 shows that the St. Mary's River, St. Lawrence River, and the St. Clair River had a high number of Canadian spills in the early 90's. The number of spills generally declined from 1990 to 2000. The St. Lawrence River experienced a fluctuation of spill incidents between 1998 and 2004. The St. Clair River also experienced a resurgence of spills in 2000 and 2004. Figure 2.3 shows the number of Canadian spills compared to American spills in the St. Clair River-Detroit River corridor. Industrial activities and marine traffic along the river corridors have contributed to a greater number of spills reported in these rivers than any other rivers in the Great Lakes Basin (p. 31). The number of Canadian spills to the St. Clair River is higher than those of the American's between 1900 and 2004.

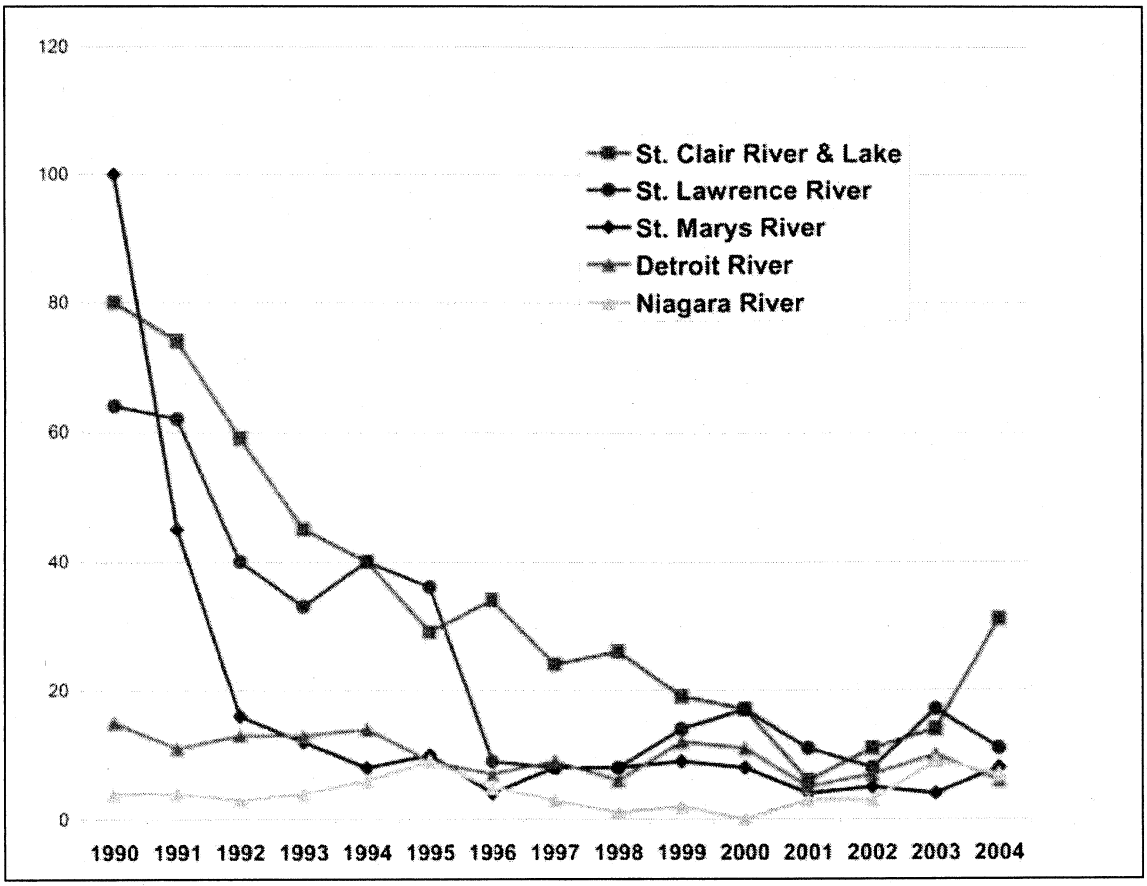

Figure 2.2 The number of Canadian spills reported in the Great Lakes river corridors between 1990 and 2004 (International Joint Commission, 2006, p. 32)

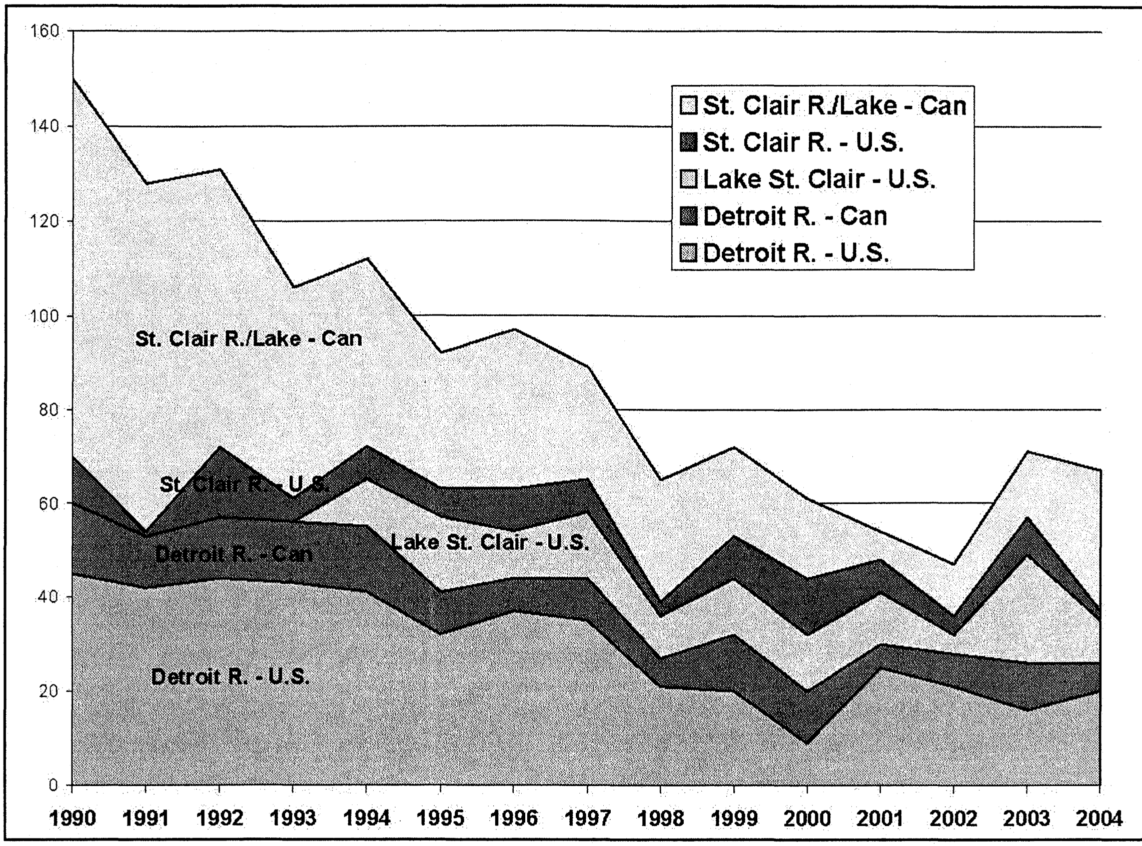

Figure 2.3 The number of spills reported in the St. Clair-Detroit River corridor between 1990 and 2004 (International Joint Commission, 2006, p. 30)

2.2 Spill Management Criteria in the Context of Federal and Provincial Environmental Legislation and Municipal By-laws

Spills are byproducts of anthropogenic activities, which enter into the environment in many forms. Spills are managed under the major pieces of environmental legislation in Canada and Ontario. The Canadian Environmental Protection Act (CEPA), Canadian Fisheries Act (CFA), Ontario Environmental Protection Act (OEPA), Ontario Water Resources Act (OWRA), and Ontario Clean Water Act (OCWA) sanction the discharge of substances and materials that would cause irreversible negative impacts on environmental and human health. Table 2.1 is a summary of the references to spills under the legislation. Entrenched in the law are mechanisms to control and prevent the release of pollutants from human-related activities.

The following sections review how the law governs spills and how it defines the hazards and threats of spills on environmental and human health.

Table 2.1 References to spills in the major pieces of Canadian and Ontario environmental legislation

Definition	Source	Characteristic
CEPA: "release" (s. 3(1))	spray, inject, inoculate, abandon, deposit, leak, seep, pour, emit, empty, throw, dump, place, and exhaust (s. 3)	toxicity, anthropogencity, persistency and bioaccumulation (s. 92.1); an uncontrolled, unplanned or accidental release (s. 193)
CFA: "deposit" (s. 34)	any substances	deleterious to fish and fish habitats (s. 34(1) (a), (b))
OEPA: "discharge" (s. 91(1), 92))	from or out of a structure, vehicle or other container (s. 91(1))	cause adverse effects (s. 1(1))
OWRA: "discharge" (s. 1(1), s. 1(3)(b))	any substances	cause harm or interfere with the consumption of the water (s. 1(3)(b)) and degradation in the appearance, taste and odour of the water (s. 1(3)(c))
OCWA: "drinking water threats" (s. 1)	multiple sources of contaminant discharges, non-point sources of contaminants, and naturally occurring contaminants from land use activities and conditions (s. 1)	adversely affect on the quality of any water used as a source of drinking water (s. 1)

2.2.1.1 Canadian Environmental Protection Act

The CEPA (1999) associates spills with the release of "toxic" and harmful substances. The act defines toxicity in terms of the quantity and concentration of substances that have the potential to cause immediate or long-term effects to human life or health, biological diversity, and the environment (s. 64). The risks to environmental and human health are assessed based on "the hazards posed by the substances and the likelihood of exposure that persons, organisms, and environment will come into contact with the substances" (Environment Canada, 2004). The act stipulates a system of regulating substances that are manufactured in Canada. It identifies and assesses their toxicity, anthropogencity, persistency, and bioaccumulation characteristics throughout the substances' life cycle (s. 92.1, 93). Toxic substances that are found on the *List of Toxic Substances* (Schedule 1, CEPA, 1999) are subject to "virtual elimination" (s. 65(3)). In essence, the act requires the releases of toxic and harmful substances to be below "the lowest concentration that can be accurately measured using sensitive but routine sampling and analytical methods" (Government of Canada, 2009a).

2.2.1.2 Canadian Fisheries Act

The CFA (1985) protects the Canadian water for fish to spawn, nurse, rear, migrate, and find food to sustain their life process (s. 34(1)). It prohibits deleterious substances to be "deposited" into the fisheries waters by means of "discharging, spraying, releasing, spilling, leaking, seeping, pouring, emitting, emptying, throwing, dumping or placing" (ibid.). Merriam-Webster Dictionary defines deleterious as "harmful often in a subtle or unexpected way" (deleterious, 2009). The CFA defines a deleterious substance as any quantity or concentration that would degrade or alter the quality of water to cause a deleterious effect on fish, fish habitats, and the use of fish (s. 34(1)). The act controls substances that a person may deposit into the water and the activities that may be harmful to the fish or fish habitat. Regulations, such as the Metal Mining Effluent Regulations (SOR/2002-222)), Meat and Poultry Products Plant Liquid Effluent Regulations (C.R.C., c. 818), Pulp and Paper Effluent Regulations (SOR/92-269), and Petroleum Refinery Liquid Effluent Regulations (C.R.C., c. 828) control the discharge of wastewaters from these industries. The threat to fish and fish habitats are assessed based on a class of deleterious substances prescribed in the regulations (Petroleum Refinery Liquid Effluent Regulations, Schedule I). The parameters include the acute lethality of the effluent, pH level, volume (Pulp and Paper Effluent

Regulations, Schedule I), the biochemical oxygen demanding matter, and the quantity of total suspended solids (Meat and Poultry Products Plant Liquid Effluent Regulations, Schedule I).

2.2.1.3 Ontario Environmental Protection Act

The OEPA (1990) regulates the discharge of wastes and storm water directly into rivers and lakes through the means of deposit, emission, leak, and addition (s. 1, 27(3.1-3.2)). It regulates the discharge in terms of the source and concentration through the licensing of permits and the Certificates of Approval (Cs of A) (s. 1.6(1)). Unregulated discharges are considered spills, which are defined as "discharge[s] into the natural environment, from or out of a structure, vehicle or other container, and that is abnormal in quantity or quality in light of all the circumstances of the discharge." (Part X, s. 91(1)). The act prohibits the discharge of pollutants and contaminants that have an "adverse effect" on the quality of the environment, which would impact negatively on human use of the environment and human health (s. 1, 91(1)). Prohibited by the act are adverse effects that include:

- harm or material discomfort to persons;
- the impairment of the safety of persons;
- injury or damage to property or to plant or animal life;
- loss of enjoyment of normal use of property; and
- interference with the normal conduct of business (ibid.).

By virtue, the OEPA requires the reporting of "any accidental, abnormal or inadvertent release of a pollutant discharged into the natural environment from or out of a man-made container" (Spills Action Centre, 2007, p. 2). A person who causes or allows the discharge of contaminants into the natural environment is required to notify the Ministry of the Environment (MOE) (s. 15(1)) and the Spills Action

Centre (SAC) (Classification and Exemption of Spills and Reporting of Discharges, O. Reg. 678/98, Part II). Some forms of spills are exempted from being reported, which include the following (Classification and Exemption of Spills and Reporting of Discharges, O. Reg. 678/98, Part I):

- discharges that are approved by the Cs of A;
- potable water from reservoir and municipal water main discharge from natural events;
- planned maintenance spills with no present risk to public safety and adverse effects;
- transport cargo, vehicles, and electrical utilities of spilled fluid 100 liters or less with no likelihood of entering into any waters, drainage structures, and causing adverse effects; and
- gasoline and associated products from plants, marina, retail, and private outlets with 100 liters or less and 25 liters or less in public accessible areas.

Spills are definitely reportable when they cause adverse effects, are committed deliberately, are not remediated immediately, or are likely to enter any waters as defined under the OWRA (see the following section) in quantity greater than the exempted limit (Exemption of Spills and Reporting of Discharges, O. Reg. 678/98, Part I). The OEPA deals with spills in particular from industrial and municipal sources in Ontario.

The Municipal/Industrial Strategy for Abatement (MISA) program manages the major toxic contaminants contributors from the petroleum, pulp and paper, metal mining, industrial minerals, metal casting, organic chemical manufacturing, inorganic chemical manufacturing, inorganic chemical, iron and steel, electric power generation, and municipal waste sectors (Ministry of the Environment, 2007a). MISA regulations, promulgated between 1993 and 1995, require the regular monitoring and reporting of effluent and storm water quality (ibid.). A number of petroleum, inorganic chemical, and organic chemical manufacturing facilities located in the St. Clair River AOC are included in the list of MISA facilities (Schedule 1, Effluent Monitoring-Inorganic Chemical Sector; Schedule 1, Effluent Monitoring-Organic Chemical

Manufacturing Sector; Schedule 1, Effluent Monitoring- Petroleum Sector). The effluent regulations prescribe a list of substances which need to be monitored. The parameters include the acute lethality and chronic toxicity limits for aquatic species, as well as effluent volume at the point of discharge from sewers and outfalls (Effluent Monitoring- Inorganic Chemical Sector; Effluent Monitoring-Organic Chemical Manufacturing Sector; Effluent Monitoring-Petroleum Sector). MISA facilities are also required to prepare spill prevention and contingency plans under section 91.1 of the OEPA.

The enactment of the *Environmental Enforcement Statute Law Amendment Act* (EESLAA) in 2005 provided the MOE with enhanced authority to prevent spills from the MISA facilities. The EESLAA enables the MOE to require the development of spill prevention and contingency plans for toxic substances through a Director or Officer order to a specific class of person (Environmental Protection Act, s. 18(1), 91.1), as well as to have the administrative right to impose fines, in addition to the right to prosecute the director of an operation (Environmental Enforcement Statute Law Amendment Act s. 182.1). Under the *Spill Prevention and Contingency Plan*, *O. Reg. 224/07*, the MISA industries must exercise risk management "to reduce the risk of discharge into the natural environment or to prevent or minimize an adverse effect where a discharge has occurred" (Ministry of the Environment, 2007b, p. 3). Chemicals that are listed under the "Environmental Penalties-Code of Toxic Substances" which are inherently toxic and persistent or bioaccumulative when released into the natural environment must be managed through spill prevention and contingency planning (Ministry of the Environment, 2007b, p. 10). The regulation imposes the identification of spill hazards that are reasonably foreseeable at the plant or related to the operation of the plant with the potential to cause harm or have adverse effects (Spill Prevention and Contingency Plan, s. 5(1)). The adverse effects are determined based on the sensitivity and vulnerability of the natural and man-made features, such as the surface water protection zone defined under subsection 2(1) of the *Clean Water Act* (s. 5(1)). The spill prevention and contingency plans are required to be implemented in all MISA facilities by the end of 2008.

2.2.1.4 Ontario Water Resources Act

The OWRA (1990) is intended to protect, conserve, and manage the water of Ontario for the well-being of the environment, society, and economy (s. 0.1). In terms of protecting human and environmental health, the act regulates the discharge of drainage, storm water, commercial wastes, and industrial wastes, which are collectively referred to as "sewage" (s. 1). Persons conducting sewage work, that involves the "collection, transmission, treatment and disposal of sewage" from on shore or bank, are required to obtain approval from the MOE, otherwise the discharge of sewage is prohibited (s. 30(1)). In essence, any facilities that generate wastes are subject to the licensing of discharges in Ontario. The OWRA regulates the discharge of sewage if they can cause injury to or interfere with the living organisms and individuals who come into contact with the water or the soil and sediment in the water (s. 1). Materials are deemed impairments if they are scientifically proven to be toxic to the aquatic environment or can degrade the appearance, taste or odour of the water (s. 3). For the protection of the public water supply, the act can enforce an area where swimming, bathing, water-taking, and the discharging and remaining of any material that may impair the quality of water are prohibited (s. 33(1)).

2.2.1.5 Ontario Clean Water Act

The *Ontario Clean Water Act* (OCWA) (2006) was enacted pursuant to the recommendations made by Justice Dennis O'Connor's in the inquiry to the Walkerton Tragedy provides a policy management mechanism to eliminate drinking water threats. Bacterial contamination of the Town of Walkerton groundwater due to agricultural runoff resulted in the death of seven people and caused sickness in 1,346 people (Ministry of the Environment, 2007c). The purpose of the OCWA is to regulate and prohibit "drinking water threats" from multiple sources of contaminant discharges, non-point sources of contaminants, and naturally occurring contaminants from land use activities and conditions that have the potential to adversely affect the quality of any water used as a source of drinking water (s. 1). Every well and intake location is subject to risk assessment under the act as they are the entry points of raw water supply to the drinking water system (s. 4, 15(2)). Currently, local municipalities are conducting risk assessment exercises to prepare for reporting of the risk analysis as required under O. Reg. 287/07. The steps and scope of the risk assessment are further explained by the MOE in a risk assessment guiding module (2006). Ultimately, a Source Protection Plan (SPP) will be developed for every watershed in the Great Lakes Basin in Ontario to guide and restrict development activities within the source protection area (s. 48). Local conservation, planning, and health authorities will enforce the SPP (s. 57). Management criteria for source water protection have yet to be created.

Spills are associated with land use activities such as the storage, transport, and handling of sewage, waste, and agricultural materials, which can be a threat to the drinking water supply (Ministry of the Environment, 2008). Surface water intake zones are identified as one of the vulnerable areas in the OCWA (s. 2). The MOE guiding document on the risk assessment for surface water intake zones recommends that the nature of the threat (e.g. spills) be characterized by its "treatability, frequency (how often the issue occurs), duration (how long the issue lasts) and magnitude (e.g. range of concentrations of the contaminant)" (Ministry of Environment, 2006b, p. 18). It is also necessary to assess the risk on human health, the optimal operational level of the WTPs, and the aesthetic characteristics of water, such as odour and taste (ibid.).

The threats characteristics are prioritized with the following risk assessment criteria (Ministry of the Environment, 2006b, p. 19):

1. "Contaminant affects human health and exceeds a benchmark (for issues) and the contaminant cannot be treated at the local plant because it doesn't [*sic*] have the process means (e.g. nitrate) or the issue is related to an incident resulting in plant closures, e.g. frequent spills".

2. "Contaminant affects human health and exceeds a benchmark (for issues) and the contaminant can be treated at the local plant (e.g. PCE)".
3. "Contaminant affects human health and is trending upwards (for issues) toward a benchmark and cannot be treated at the plant e.g. nitrate".
4. "Contaminant poses an indirect threat to human health and cannot be treated at the plant e.g. high phosphorous possibly resulting incyanobacteria (blue-green algae) blooms".

The MOE guiding document suggests the vulnerability of the surface water intake can be affected by the depth of the intake from the top of the water surface, length of the intake from shoreline, and the historical water records indicating the number of past incidences exceeding the water quality guidance/standards (Ministry of the Environment, 2006a, p. 19). The risk of drinking water contamination would be based on the likelihood of the contaminant in concern reaching the water intake under the presence of spills (Ministry of the Environment, 2006b, p. 8).

2.2.2 Municipal Spills Management Mechanisms

The local municipalities have responsibilities that are delegated by the provincial government. Some of these responsibilities include providing infrastructures and services to ensure the adequate management and minimization of sewage and waste, protecting natural areas and their functions, and safeguarding public health and safety in cities and towns (Planning Act, s. 2(f), (g), (o)). Municipalities deal with spills commonly through the use of sewer by-laws.

Li and McAteer (2000) examined the issue of spills in the urban areas of the Golden Horseshoe. The authors estimated that an average 1,050 L of spilled oil escaped to the air, land, and water per day in the Golden Horseshoe between 1988 and 1997. They found that 31% of the reported spills potentially affected watercourses and 53% potentially polluted the soil. The study estimated that 6.84 million litres of oil are spilled in the Golden Horseshoe; one-fifth traveled to the "urban drainage system" through the combined sewers, storm sewers, and tributaries in the watershed.

Spill control and response by-laws are part of the municipal jurisdiction to address the spills issue. Municipal sewer by-laws restrict the disposal of hazardous wastes, heavy metal, and toxins into the sewer system. Their purpose is "to establish legal and enforceable limits on materials which may result in untreated sewage and other pollutants entering Lake Ontario" (Region of Peel, 2009). Some municipalities are also equipped to respond to spill complaints and monitor sewer use by commercial and industrial facilities (Di Caro, 2007). Han (2008) presented an internet survey of the types of spill management tools used by regional municipalities in the Golden Horseshoe. Table 2.2 shows the summary of the result. According to the study, within the Golden Horseshoe, seven of the nine municipalities had sewer by-laws and four of the nine had a spill response team. The author concluded that most municipalities use sewer by-laws as a tool to control untreated discharges from entering the man-made and natural drainage system.

Table 2.2 Regional municipal spill management mechanisms in the Golden Horseshoe (Han, 2008)

Regional Municipality	**Sewer by-law**	**Spill Response Team**
Dufferin	x	x
Durham	✓	x
Halton	✓	✓
Niagara	✓	x
Northumberland	x	x
Peel	✓	✓
Toronto	✓	✓
Waterloo	✓	✓
York	✓	x

2.2.3 Overview of the Literature on Spill Management Criteria in the Federal, Provincial and Municipal Environmental Legislation

Each piece of the environmental legislation has a different definition with reference to spills depending on its purpose and objective. Together they provide a broad description as to “what is a spill?” Common in the legislation is the sanctioning of illicit and accidental releases that have adverse and deleterious effects on human health through the use water for drinking, fish for food, and land for conducting businesses. Spills are regulated based on the substances’ toxicity, anthropogencity, persistency, and bioaccumulation characteristics.

Spills management as described in the legislation has been focused on regulating the level of contamination exposed to human, wildlife, and aquatic species. In the mid ‘80s and early ‘90s environmental legislation targeted point source control through the licensing of discharge approvals and permits under CFA, OWRA, and OEPA’s MISA program. The regulations permitted discharges in quality and quantity that were deemed safe for human and aquatic species. Municipalities created the sewer by-laws to prevent industrial and commercial hazardous discharges from entering the watershed. As anthropogenic pollution became more prevalent the legislation targeted releases that are highly hazardous to human and environmental health. The principle of pollution prevention through risk management emerged through the amendment of CEPA (1999). The act stipulated a system of assessing the health risk of substances, and subsequently prohibited the manufacturing of those that are found to be high-risk or toxic. Risk management is now required in MISA facilities and industries that use toxic substances, as well as for the protection of drinking water sources under the OEPA and OCWA (O. Reg. 224/07 and O. Reg. 287/07).

The OCWA is the only legislation that identifies spills as a threat to source water and water intake locations. WTP shutdown is characterized as a high priority threat under the act. At the time of the research the literature did not have any information on the exact methodology of evaluating the threats and vulnerabilities in the surface water intake zones in the St. Clair River. It is also unclear what the spill management criteria are from the result of the risk assessment.

2.3 Water Treatment Plant Operation

The shutdown of the water intakes is closely tied to the operation of the WTP. The literature shows that the Wallaceburg WTP and WIFN WTP were frequently affected by spills in the St. Clair River AOC (Binational Public Advisory Council, 1991; Binational Public Advisory Council, 1995). The following sections explore the circumstances that can trigger a WTP shutdown. In addition to the literature review, personal interviews with the WTP operators at the City of Toronto Hogan Plant, Town of Wallaceburg, WIFN WTP, and SAC staff supply some anecdotal operational protocols, providing an inside view as to what happen when spills occur.

2.3.1 Drinking Water Standard in Ontario

Safe drinking water requires some forms of water treatment. The provincial government has jurisdiction over local water distribution (s.92, The Canadian Constitution Act, 1867). The OWRA regulates water use, water quality, and point source pollution. The *Ontario Water Quality Objectives* under the OWRA set chemical parameters for disease-causing bacteria, toxic chemicals, and radioactive substances in the drinking water, which are referred to as Maximum Acceptable Concentrations (MAC) (Greenbaum and Wellington, 2008, p. 446).

The municipal drinking water quality standards are set out in the *Ontario Drinking Water Quality Standards* (ODWQS) under the *Safe Drinking Water Act* (OSDWA). The Ministry of Health determines, based on national and international standards, the level of chemical concentrations that are safe for human consumption. Regulation 169/03, Schedule 2 of the ODWQS set out the MAC for chemicals in a drinking water distribution system. The regulations on the testing and sampling of the drinking water are stated in O. Reg. 170/03 of the OSDWA. Water testing is done on an annual or quarterly basis (O. Reg. 170/03). Any exceedences of MAC parameters in the distribution system are required to be reported to the Medical Officer of Health and the SAC within 24 hours (OSDWA, s. 15.1-9(2)). The OSDWA and its regulations do not mention WTP shutdown as a result of water quality exceedences.

2.3.2 The Reporting of Spills and Water Treatment Plant Shutdown Protocols

In Ontario, the SAC is the government agency that responds to spills. Pursuant to the GLWQA and *Annex 4* of the *Canada-Ontario Agreement* (COA), the SAC was established to respond, track, and analyze spills as part of a national 24-hour emergency notification system. The public is required to report spills under Part X of the OEPA (see Section 2.2.1.3). The SAC follows a set of spill procedure cards when it receives a spill report. An example of a response card is shown in Appendix I for spills to the watercourse. The SAC has a total of 58 cards corresponding to different types of spills (Bowering, V., personal communication, 2008). The general spill response protocol involves first finding out about the magnitude of the spill and the type of contaminants involved. Depending on the size and the potential impact of the spill, Environment Canada, the polluter, MOE District Branch, local health unit, WTP operator, and downstream water users may be contacted. The Environmental Science and Standards Division and the Environmental Monitoring and Reporting Branch at the MOE District Branch are responsible for sampling and tracking the size, time, and direction of the spill plume. Subsequently, WTPs downstream from a spill may be ordered to shut down (Bowering, V., personal communication, 2008). The local Medical Officer of Health is responsible for making the shutdown decision based on "the substance, estimated quantity of the spill, the estimated time for the chemical plume to reach the WTP intake, and the relevant water quality guideline and any possible health reactions from ingestion of the contaminant" (International Joint Commission, 2006; Kicknosway, S., personal communication, 2009). The duration of a shutdown is dependent on the testing and sampling of the water at the intake before it is re-opened (Chin I., personal communication, 2008; Kicknosway, S., personal communication, 2009; Murru, M., personal communication, 2009).

According to the Sarnia-Lambton Environmental Association (SLEA), a voluntary environmental co-operative consisting of 19 local industries, industries may require to notify the MOE and seek advice from the officials when there is a change in operation conditions (Sarnia-Lambton Environmental Association, 2008). Spills notifications indicate there are alterations in the operation processes that are not likely to have adverse effects on the environment. The situations may include the following (ibid.):

- a loss of material from a process-no discharge to the environment;
- a change in treatment plant operating conditions, leading to an upward trend of discharge or one or more substances, but still within permissible limits; or
- discharged from storm run-off, within permissible limits.

A "prolonged shutdown" occurs in cases of spills and scheduled maintenance. In such instances, the MOE may ask the WTP operator to continue to operate and monitor the water parameters closely for exceedances when it receives spill notifications from industries upstream from the intake (Kicknosway, S., personal communication, 2009). From personal interviews with the WTP operators, the author of this study compiles the general WTP shutdowns conditions in Figure 2.4 (Chin I., personal communication, 2008, Kicknosway, S., personal communication, 2009; Murru, M., personal communication, 2009). Non-scheduled shutdown may take place when the WTP is notified that an incident has occurred. It needs to be emphasized that, at times, the decision to close a water intake may be based on the WTP operator and manager's perception of risk. For example, the vinyl chloride spill during the massive power outage in August 2003 resulted in communities along the St. Clair River having to close their water intakes. However, the intakes downstream were actually not closed until several days after the fact when the company responsible reported the spills (Kicknosway, S., personal communication, 2009; Murru, M., personal communication, 2009). Meanwhile, municipal sewage overflows which occurred during the blackout also impacted the water quality in the river, and subsequently added to the perceived health risk that led to the decision to shut down the intakes (International Joint Commission, 2006).

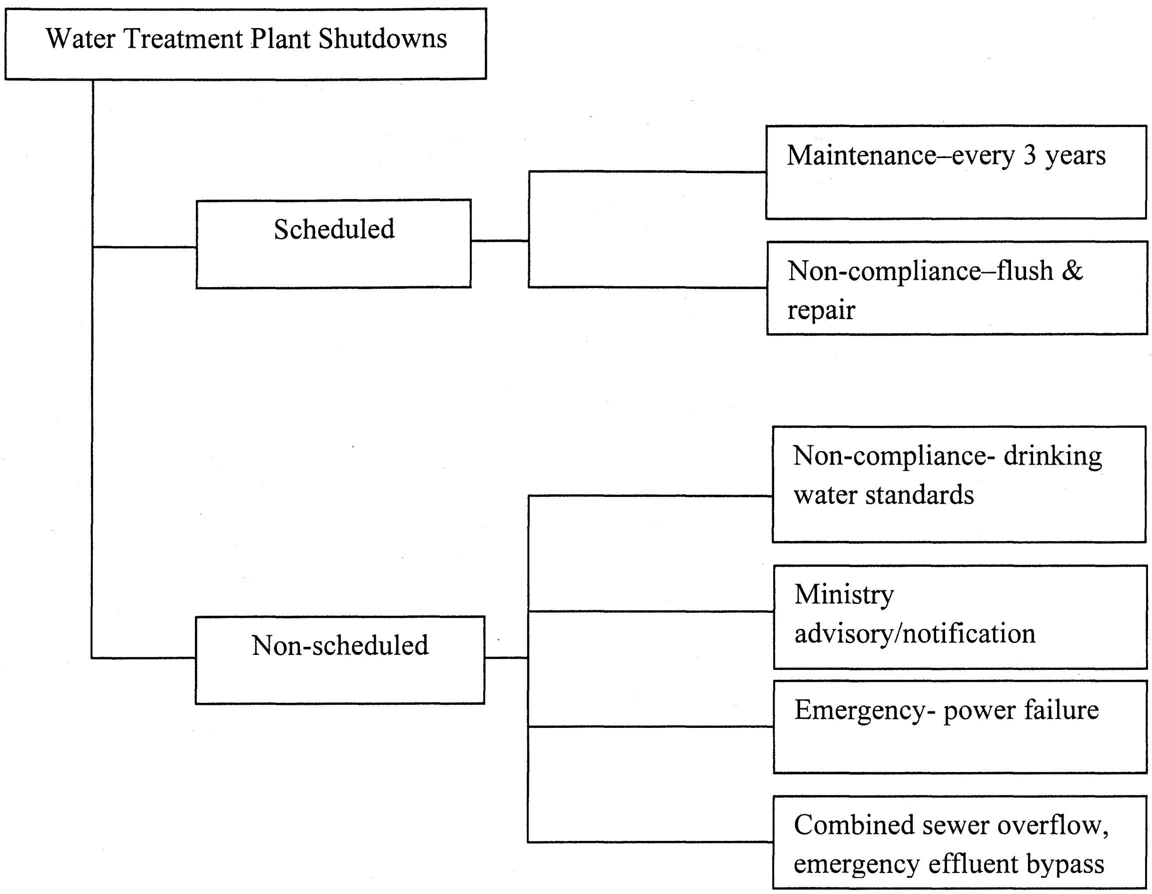

Figure 2.4 Conditions for scheduled and non-scheduled WTP shutdowns

2.3.3 The Monitoring of Industrial Spills in the St. Clair River

The report by Golder Associates (2008) titled "Evaluation of Raw Water Monitoring For The Wallaceburg Water Treatment Plant", discussed the raw water quality and monitoring situation in the Town of Wallaceburg WTP. The report provided several insights into the monitoring situation in the St. Clair River. It indicated that along the Canadian side of the St. Clair River, the SLEA has a monitoring station located downstream from the City of Sarnia for its own research and monitoring purposes. The study stated that, since 1988, the MOE has developed several spill models to predict the movement of spills in the St. Clair River. The spill models provide rapid assessment of the spill situation based on the measured data in the river. The exercise is able to inform the WTPs downstream of any potential or imminent shutdowns. The models simulate the lateral mixing of river, spill rates, duration of the spill to determine the arrival time of the spill plume and the peak concentration of the contaminates (Golder Associates, 2008, pp. 11-12). For the protection of the water intake, the report recommended monitoring the water quality by either installing a new upstream station, utilizing the water quality data collected by the SLEA, or the data from the State of Michigan Drinking Water Protection Program.

2.3.4 Overview of the Literature on Water Treatment Plant Operation in Ontario and St. Clair River AOC

The operation of WTPs relies on sampling and testing of the raw water supply at the intake to ensure the safety of the distribution system is as per the OSDWA regulations. However, unlike receiving water quality monitoring, the systematic testing and sampling required under the OSDWA are not done on a continuous basis. Since there is currently no receiving water monitoring in place on the Canadian side of the St. Clair River, there is no means to detect the contaminants before reaching the intakes. When shutdowns occur, some are resulted from planned maintenance and repair, while others are non-scheduled and caused by a breach in chemical safety parameters at the intake.

Spills trigger different response depending on their severity. Spill response protocols are used by both the public and industrial sectors to facilitate recovery efforts. The SAC spill response includes spill modeling to determine the possibility of contaminants reaching an intake. Without being able to detect the contamination level in the receiving water in real-time, spill response is based on the projection of spill modeling and risk perceptions. Ultimately, the Officer of Health and the WTP operational manager decide whether an intake should be shut down after a spill.

2.4 Measuring the Restoration Progress Through the RAP Process

The administration of listing and delisting of BUIs, such as the drinking water BUI in the St. Clair River AOC, follows a three-stage development of the RAPs. Stage One identifies the level of environmental degradation and the conditions of the BUIs in the individual AOC (Binational Advisory Council, 1991; Ministry of the Environment and Energy, 1992). Stage Two evaluates the restoration and protection strategies of the AOC, including the BUI delisting criteria or targets (Environment Canada, 2008a). Stage Three documents the implementation and monitoring of the rehabilitation actions and confirms that the beneficial uses have been restored (ibid.). The RAP process is systematically linked to the delisting criteria, which are targets for restoring the beneficial uses of the water and the AOC.

A U.S. Policy Committee's document titled "Restoring United States Areas of Concern: Delisting Principles and Guidelines" (2001) described how to explain the restoration progress of the BUIs (pp. 6-8). The Committee suggested a normative interpretation of the interim steps between Stage Two and Stage Three (ibid.). For example, the delisting of one BUI from a list of all impairments is evidence of improvement. Similarly, the delisting of BUIs in parts of an AOC or parts of the watershed is also a sign of progress. Beneficial uses can be considered for delisting when:

- the delisting criteria are met;
- pollution source causing the BUI is controlled or removed;
- the impairments are no longer caused by human-related activities; and
- the impairments are not limited to a local geographical area but a lake-wide or region-wide condition (Environment Canada, 2008b).

An AOC reaches a milestone when it is re-designated to an Area of Recovery (AOR) (U.S. Environmental Protection Agency, 2001, pp. 8-9). This is a point in the restoration process where the AOC ecosystem is responsive to the actions taken; and that time is needed for a complete natural recovery. From this point forward in the RAP process, the state of recovery is no longer gauged by the delisting criteria (ibid., p. 9). An AOR is required to implement monitoring and prevention strategies to "reduce the risk of future degradation and to insure recovery can proceed" (ibid.). The implementation of rehabilitation initiatives needs time for full restoration. Stage Three of the RAP documents this process.

2.4.1 The Delisting Criteria

The application of the delisting criteria is to set targets for restoring the AOC in the initial stages of the RAP. The guidelines for listing and delisting are shown in Appendix II. These guidelines were initially developed from a scientific symposium in 1988 (Hartig et al., 1997, p. 715), subsequently they were revised and adopted by the IJC to assist "in reviewing the RAPs, make recommendations on listing new areas of concern, and assist governments and RAP teams in reaching agreement on the problems and cleanup benchmarks" (ibid.).

Despite the publication of the guiding document on delisting by the U.S. Policy Committee (2001), the Michigan Department of Environmental Quality believed still more guidance is needed on the specific criteria for delisting the BUIs (Michigan Department of Environmental Quality, 2006, p. 4), given most of the U.S. AOC are located within its jurisdiction. Hartig et al. (2008) suggested that quantitative targets should be applied to the BUI delisting criteria to describe the desired future restored states (p. 14). The authors reviewed the 50 environmental indicators used for the ecological recovery in the Detroit River-Western Lake Erie corridor. The study evaluated the measure of progress in the Detroit River AOC. The authors found that only 32% of the indicators have quantitative targets or measurable endpoints (p. 15).

They suggested that quantitative targets should be used to track the restoration management efforts and progress (Ibid.).

The author of this study further explored Hartig et al.'s (2008) claim that there is an insufficient number of quantitative BUI delisting criteria in the AOC. She reviewed the delisting criteria of 31 of the 43 AOC and her findings concurred with that of the authors'.

There are a total of 434 delisting criteria for the 14 BUIs in 43 AOC. The delisting criteria were obtained from the Great Lakes Commission (2004). The author of this study found that nearly half of the BUIs were declared as "not impaired" in the AOC; and among the remaining BUIs, 30% of those delisting targets were not yet defined, 6% had qualitative targets, 12% had measurable restoration targets, and 7% had measurable restoration and a time target.

Measurable or quantitative targets usually specify the rehabilitation of certain chemical, physical or biological parameters of the BUI. An example of a quantitative delisting criterion is "The N:P ratio measured in Saginaw Bay is at least 29:1…indicating that conditions once favoring blue-green algal populations responsible for former taste and odor problems in drinking water withdrawn from the bay are no longer present" (Great Lakes Commission, 2004). The review of the delisting criteria and a summary of the author's findings are described in more detail in Appendix III.

2.4.2 The Delisting Criterion for Drinking Water Impairment in the St. Clair River AOC

The current delisting criterion for the drinking water BUI in the St. Clair River AOC consists of a quantitative restoration and time target: "no treatment plant shutdowns due to exceedences [*sic*] of drinking water guidelines over a two year period" (St. Clair River Canadian RAP Implementation Committee, 2007, p. 23). Stage One of the St. Clair River AOC RAP identified numerous accounts of intake shutdowns due to industrial spills to the St. Clair River (Binational Public Advisory Council, 1991, p. 213). In particular, the Wallaceburg WTP and the WIFN WTP were most affected on the Canadian side of the river (ibid.).

Between the period of 1995 and 1997 there was no record of spills causing a WTP shutdown (Canadian Watershed Coordination Council, 2008, p. 36). The intention of the CRIC then was to remove the drinking water impairment in the Stage One RAP Update report (Mayne, 2005, p. 63). However, five large spills occurred between 2000 and 2004 and the subsequent WTP shutdowns at the WIFN and Town of Wallaceburg caused the delisting criterion to remain (Canadian Watershed Coordination Council, 2008, p.36-37; Mayne, 2005, p. 64). Public concerns over the delisting criterion mounted. The Ontario Public Advisory Council, an entity that represents the public and gives advice to the government of Canada and Ontario in the remedial action planning of the Great Lakes, questioned how the drinking water impairment delisting criterion could ensure the restoration of the AOC from industrial spills (Jackson, 2006, p. 34). In 2007, the St. Clair River CRIC recommended that the delisting criterion should be re-assessed and, if necessary, revised to consider the recent spills (p. 23).

2.4.3 Overview of the Literature on the Delisting of Areas of Concerns

The RAPs and delisting criteria together provide a framework to measure the restoration progress of the BUIs and AOC. The listing criteria define the severity of the environmental degradation and the delisting criteria set the restoration targets. The delisting process is an adaptive management exercise which implements restoration strategies while being responsive to the recovery progress of the ecosystem health. The literature discusses the need to apply more quantitative delisting criteria to measure current and future restoration efforts. However, the time required to achieve the quantitative targets is not always considered. Quantitative targets are rendered ineffective and implausible if the local environmental conditions are continually threatened by pollution sources—as in the case of spills in the St. Clair River AOC. It is therefore necessary to consider the risk of violation when evaluating the effectiveness of quantitative targets. Such an analysis can facilitate the delisting of the BUIs and AOC. As in the case of the St. Clair River AOC, the risk of WTP shutdown due to spills should be assessed before delisting can be considered.

2.5 Conclusion on the Current State of Knowledge

The recent enactment of the OCWA broadens the protection of source water to non-point source discharges, whereas before the legislation focused on managing spills from point source releases. A review of the government spills policy and regulation suggests that spills abatement, control, and prevention have become increasingly stringent over time. This contributes to a significant decrease of spills over the past 20 years in the Great Lakes Basin, including the St. Clair River. However, the threat of spills continues to be a serious environmental and health safety concern and the risk of intake shutdowns remains not quantified.

The existing approach to determining the possibility of intake shutdowns is through spill modeling. The MOE spill model simulates a reported spill to study if a specific intake is under threat. The spill modeling is only conducted after a spill incident has occurred. This type of deployment is intended for spill response and warning WTP operators of shutdowns. The risk of intake shutdowns over time requires the modeling of all possible spills and hydrological conditions that would cause a violation of water quality safety limits at the intake. The literature shows that currently no spill modeling is being used to determine the risk of intake shutdowns in the St. Clair River AOC.

The OCWA is the only legislation that links spills to intake shutdowns. It establishes intake shutdown as a high-threat characteristic to drinking water quality but it does not differentiate the threat priority in terms of the number of shutdowns over time. The CRIC explicitly associates spills to water intake shutdowns. Its drinking water BUI delisting criterion is being applied only in the St. Clair River AOC.

Presently, the St. Clair River AOC CRIC is considering the revision of the drinking water consumption delisting criterion. This is an opportunity to investigate the development of quantitative spill management criteria by directly linking water quality to intake shutdowns. By doing so, the local spill management strategy can address the issue of shutdowns by directly considering the amount of risk the intakes is exposed to. The proposed methodology uses statistical analysis to determine the risk of water intake shutdown over a two-year period.

3.0 Method and Data

3.1 Approach and Scope

This chapter discusses the approach and methodology for developing risk-based spill management criteria. The methodology is applied through a case study at the St. Clair River AOC to determine the risk of local WTP shutdowns. For the St. Clair River AOC, the delisting criterion for drinking water BUI is to have no WTP shutdown due to drinking water guideline exceedences in a two-year period. However, the delisting criterion does not explicitly consider the risk of violating the drinking water quality safety limits. Without a risk-based analysis it is difficult to evaluate whether the existing spill abatement programs are effective in removing the drinking water BUI.

On shore spills contribute to surface water pollution via end-of-pipe discharges and storm runoff. Spill management can work toward limiting the number of end-of-pipe discharges and overflows, as well as placing monitoring devices in the receiving water to detect non-point spills. This study suggests a spill management strategy that is based on the risk of water intake shutdowns.

The development of risk-based spill management criteria should consider the characteristics of the spills and receiving water, such as the following:

- density of contaminants;
- magnitude of the spill;
- weather conditions; and
- receiving water hydrological characteristics.

A study by Li tilted "A GIS planning model for urban oil spill management" (2001) concludes, after mapping all the reported oil spills in the Great Toronto Area, that spills have no significant spatial pattern or variation in their seasonal distribution. The study suggests that spills happen randomly in time and space. As for the characteristic of the receiving water, such as the flow, is likely to be subject to general seasonal fluctuations due to rain storms and ice retardation, but the amount of fluctuation and the inter-event time are stochastic in nature. Since the flow of the receiving water and spills both occur randomly in time and space, the impacts of spills at the receiving water are probabilistic. The risk of a spill occurrence is defined as the probability of an occurrence over a certain period of time. Receiving water-based spill management criteria can be specified by:

i. Probability of spilled chemical concentrations in the receiving water exceeding the provincial water quality objectives per year;

ii. Risk of spilled chemical concentrations in the receiving water exceeding the provincial water quality objectives over a certain period of time;

iii. Probability of beneficial use violation per year; and

iv. Risk of benefit use violation over a certain period of time.

The proposed risk-based spill management approach is appropriate for policy planning stages. With its application, water quality managers can determine the acceptable risk and evaluate how effective current and future abatement programs are based on the reduced risk. Additionally, the risk approach can be used to determine whether the receiving water quality is restored to a satisfactory level. Such a risk-based analysis is bound by the assumptions that spills are released on or near the shoreline and that spill plumes travel and disperse uniformly in the receiving water. Local spill and receiving water characteristics should also be examined to confirm their stochastic nature. For the St. Clair River AOC, there are two probabilistic criteria that should be applied to the delisting of the drinking water BUI due to spills:

i. Probability of non-scheduled WTP shutdown per year; and

ii. Risk of non-scheduled WTP shutdown over a two-year period.

The following section describes the methodology for the above criteria.

3.2 Method

In order to relate spills to WTP shutdown the following steps are necessary:

i. Analysis of spill events and WTP shutdown characteristics:

The cause and effect of spills in the study area are identified by analyzing the statistical properties of the spill event and shutdown characteristics (for example, annual number of spills or shutdown event, spill volumes and masses, causes, and environmental impact).

ii. Analysis of receiving water characteristics:

Statistical analysis identifies the properties of the low flow data of the receiving water.

iii. Identification of common chemical parameters among spills:

The provincial water quality objectives, safe drinking water criteria, and WTP shutdown events provide the common parameters. Spill chemicals in Step i, which caused previous WTP shutdowns or violated the safe drinking water criteria, are identified for the Step iv calculations.

iv. Determination of the relationships between spilled chemicals and receiving water characteristics:

In order to determine the effect of a chemical spill at the water intake, a detailed simulation of the spill occurrence, in terms of the mixing and the transport of the chemicals from the point of entry to the intake must be performed. The conditions under which there can be a shutdown involve numerous variables. Since the spill occurrence and the receiving water characteristics are stochastic, the water quality at the WTP intake is also stochastic. The probability of a shutdown must be determined by conducting a Monte-Carlo simulation to account for the multiple variables or conditions. Such a task is onerous and does not provide an efficient "first-cut" analysis for the policy planning stage. An alternative approach is to utilize the previous shutdown records and the associated flows as proposed in this study. From these data, the smallest spilled chemical event mass (m) and the smallest low flow (q) are selected to represent the worst combination which may cause a WTP to shut down. By assuming the spilled chemical event mass and the associated low flows are statistically independent, the probability of shutdown per spill event is the product of their marginal probabilities as given below.

$$P_s = P[M=>m] * P[Q=<q] \quad (1)$$

in which

P_s is the probability of shutdown per spill event;

$P[M=>m]$ is the probability of a spilled chemical event mass equal or greater than m;

$P[Q=<q]$ is the probability of a low flow equal or less than q;

m is the lowest spill event mass which has caused a previous shutdown; and

q is the smallest low flow of a previous shutdown event.

The risk of a shut down in n years can be estimated by the following equations:

$$P = P_s * \# \textit{ spills events/year} \quad (2)$$

$$Risk = 1 - (1 - P)^n \quad (3)$$

It should be noted that this approach provides a conservative risk estimate, as the joint probability of the smallest spilled chemical event mass and the smallest low flow may be smaller than P_s.

3.3 Source of Data

The SAC, SLEA, and Environment Canada provided the spill and river flow information for the St. Clair River AOC case study. The SAC supplied excerpts of the spill data from 1988 to 2007 from its Occurrence Report Information System (ORIS). Spills in the SAC data are categorized into five material groupings: “oils”, “chemicals”, “wastes”, “gases”, and “other materials”. The focus of this study is on chemical spills. Spill events consisting of chemical materials from 1988 to 2007 were extracted from the SAC ORIS data for further analysis and manipulation. The SLEA provided the chemical spill data that contain spill events to the river and WTPs shutdowns from 1986 to 2005. The daily and monthly mean flow for the St. Clair River from 1988 to 2007 originated from Environment Canada’s data that were collected by taking a conventional current meter or acoustic doppler current profiler. The flow was determined by using a stage-fall discharge equations from eight different gauge pairs. The average flow from these eight equations was used to determine the monthly and daily mean flow (Thompson, A., personal communication, 2009).

4.0 Data Compilation and Spills Characteristics

4.1 Organization of Data

The SAC chemical spill data are divided in sets of 1988-2002 and 2003-2007 with the following common descriptive categories:

- Year
- Month
- Day
- Quantity
- Unit
- Quantity in Liters
- Percent concentration
- Concentration details
- Details
- Region
- Address
- Chemical
- Chemical Family
- Corporation
- Sector
- Cause
- Municipality
- Environmental Impact

For the purposes of the analysis, the density (g/ml) and mass (kg) were added to each record of chemical spill.

The SLEA data consist of a chronological list of chemical spills to the St. Clair River and records of WTP shutdowns associated with each spill. The SLEA data consist of the following variables:

- Year
- Date
- Material
- Quantity
- Reportable Spill
- Discharge Classification
- Shutdown

In the SLEA data, the nature of the spills is described under "Reportable Spills" and "Discharge Classification". Spill incidents that are beyond ordinary circumstances are considered as reportable. They include those discharges that are classified as exceedences of the Cs of A or MISA parameters (Edwardson, D., personal communication, 2009).

4.2 Chemical Spills Characteristics

The following sections present the results of the spill statistical analysis based on the spills reported to the SAC. The author of this study examined the chemical spill characteristics by the year, mass, cause, sector, and environmental impact. Records with either no quantity, an unknown quantity, or a quantity that could not be accurately estimated were disregarded. In cases where only the volume was specified, the density of the chemical was used to convert the value from volume (l) to mass (kg).

4.2.1 Annual Statistics

The frequency of chemical spills was calculated based on the number spill events in the SAC data. Figure 4.1 shows that the number of spills decreased significantly from over 100 spills to below 20 spills in the period between 1988 and 1999. Records in the SAC data include spills to roads, parking lots, curbs, soil, surface water, and air; from tanks, trucks, rail cars, pipes, hoses, and other sources. The number of spills rose in 2000 and increased to just below 40 spills in 2007. Table 4.1 shows the spill statistics between 1988 and 2007. The first four columns show the proportion of spill events with and without spill mass for each year. It should be noted that, in this analysis, 44-89% of spills are unaccounted for each year since some of the spill event masses were missing in the SAC data. For spills with mass, the SAC data did not provide the proportion of spills that were cleaned up subsequent to the incidence.

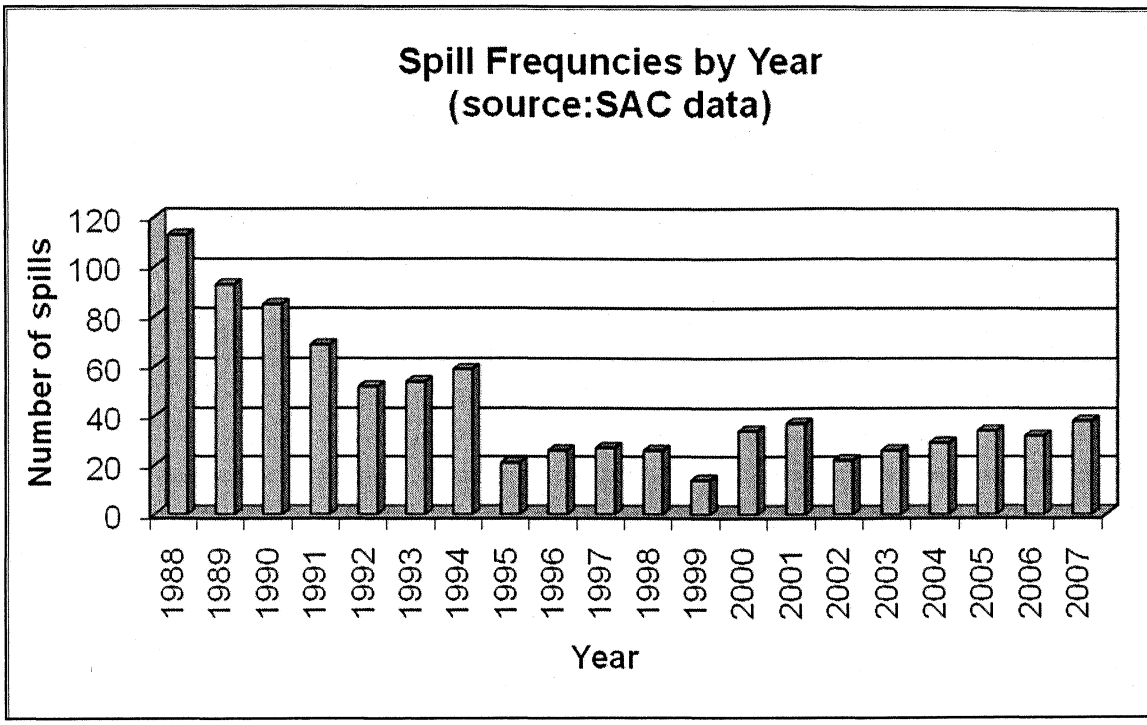

Figure 4.1 Chemical spill frequencies by year (SAC data)

A total of 4,661,605 kg of chemicals were spilled in the St. Clair River AOC. The spill event mass ranged between 0.01kg and 2,286,000kg. The significant variance indicates that spills are likely to be episodic rather than chronic. In the new millennium, the number of spills dramatically decreased to 10 events or less but episodes of significant spills still occurred.

Table 4.1 Annual chemical spills statistics for the St. Clair River AOC (SAC data)

Year	Total No. of Spills	No. of Spills with Mass	% of Total Spills	Annual Spill Mass (kg)	Avg. Spill Event Mass (kg)	Max. Spill Event Mass (kg)	Min. Spill Event Mass (kg)	Std. Dev.
1988	113	40	35%	881,151	14,569	857,803	0.50	164,484
1989	93	45	48%	240,037	15,008	132,100	0.80	157,514
1990	85	40	47%	2,332,052	14,458	2,286,000	0.50	157,334
1991	69	37	54%	32,352	4,402	25,600	1.10	53,799
1992	52	29	56%	34,685	4,306	11,460	1.70	53,784
1993	54	25	46%	25,818	4,525	5,400	0.90	52,674
1994	59	19	32%	6,038	1,700	2,604	0.90	4,433
1995	21	9	43%	36,490	317	30,000	0.50	2,607
1996	26	10	38%	1,495	5,137	1,294	0.40	56,268
1997	27	7	26%	206	487	45	1.60	2,309
1998	26	5	19%	3,853	818	3,316	1.00	1,059
1999	14	2	14%	13,203	690	13,000	202.50	3,537
2000	34	10	29%	872,262	4,190	867,000	0.40	56,935
2001	37	4	11%	507	28	430	5.00	79
2002	22	4	18%	11,258	4,022	10,733	2.60	53,781
2003	26	11	42%	8,255	718	2,904	5.00	787
2004	29	4	14%	128,624	32,156	10,733	2.60	62,462
2005	34	6	18%	1,037	173	909	0.40	362
2006	32	10	31%	13,213	1,202	7,020	0.90	2,274
2007	38	18	47%	19,069	1,020	10,707	0.01	2,446
Total	891	335	38%	4,661,605				
Avg.	85	32	34%	443,962	5,496	213,953	11	44,446

4.2.2 The Causes of Spills Statistics

Based on the frequency of spills, the top three causes of chemical spills in the St. Clair River AOC were due to Valve/Fitting Leak/Failure, Unknown, and Process Upset. However, if the causes of spills were analyzed in terms of the spill event mass, as shown in Tables 4.2a-b, Valve/Fitting Leak/Failure, Pipe Line Leak, and Discharge/Bypass to Watercourse had the greatest spill mass, consisting of 25%, 15%, and 11%, respectively, of the total spill event mass between 1988 and 2007. Prevention efforts should focus on eliminating the risk of spills due to these causes.

Table 4.2a The causes of chemical spills in the St. Clair River AOC (SAC data)

Cause	Total Number of Spills	Number of Spills with Mass	Total Spill Mass (kg)	Average Annual Spill Mass (kg)	Maximum Spill Event Mass (kg)	Minimum Event Mass (kg)
Valve/Fitting Leak/Failure	158	84	80,085	4,749	25,009	950
Unknown	109	17	12,945	1,178	3,334	540
Process Upset	103	25	38,349	3,651	25,649	1,534
Pipe Line Leak	92	50	25,703	4,121	11,897	742
Discharge/By pass to Watercourse	87	38	1,098,408	109,840	864,408	28,164
Container Leak, Fuel Tanks, Barrels	74	27	2,292,351	208,396	2,286,984	91,694
Discharge To Air	60	20	22,990	4,598	7,592	1,177
Other Discharges	51	15	24,996	1,981	11,032	1,515
Over Flow	48	16	19,254	2751	15,033	1,203

Table 4.2b The causes of chemical spills in the St. Clair River AOC (SAC data)

Cause	Total Number of Spills	Number of Spills with Mass	Total Spill Mass (kg)	Average Annual Spill Mass (kg)	Maximum Spill Event Mass (kg)	Minimum Event Mass (kg)
Start Ups/ Shutdowns/ Interruptions	25	9	17,657	2,522	17,072	2,199
Pipe/Hose Leak	24	10	880,907	176,181	867,880	110,113
Other Cause	19	3	3,300	1,999	3,498	1,010
Tank Leak (Surface)	16	8	4,681	2341	4,662	2,341
Transport Accident	14	7	235	59	141	34
Cooling System Leak	10	5	127,992	25,598	1,745	21,332
De-railing	1	1	950	950	950	950
Total*	891	335	4,650,803	550,915	4,146,886	265,498

*Tabulation from Tables 4.2a-b

4.2.3 Chemical Spills by Sector Statistics

Chemical spill events in the St. Clair River AOC between 1988 and 2007 were analyzed. Spills with mass from the SAC were divided into two time periods, 1988-2002 and 2003-2007. Figure 4.2 shows that between 1988 and 2002 the Chemical sector was responsible for most of the chemical spills, followed by the Petroleum and General Manufacturing sector at 47%, 20%, and 19%, respectively. Table 4.3 shows 64% of chemical spills from the Chemical sector were caused by Valve/Fitting Leak/Failure, Discharge/Bypass to Watercourse, and Pipe Line Leak. In the Petroleum sector, Pipe Line Leak and Valve/Fitting Leak/Failure accounted for 29% and 23% of the chemical spills, respectively. The issue of

Valve/Fitting Lake/Failure, Pipe Line Leak, and Discharge/Bypass to Watercourse contributed to 51% of the chemical spills in the General Manufacturing sector.

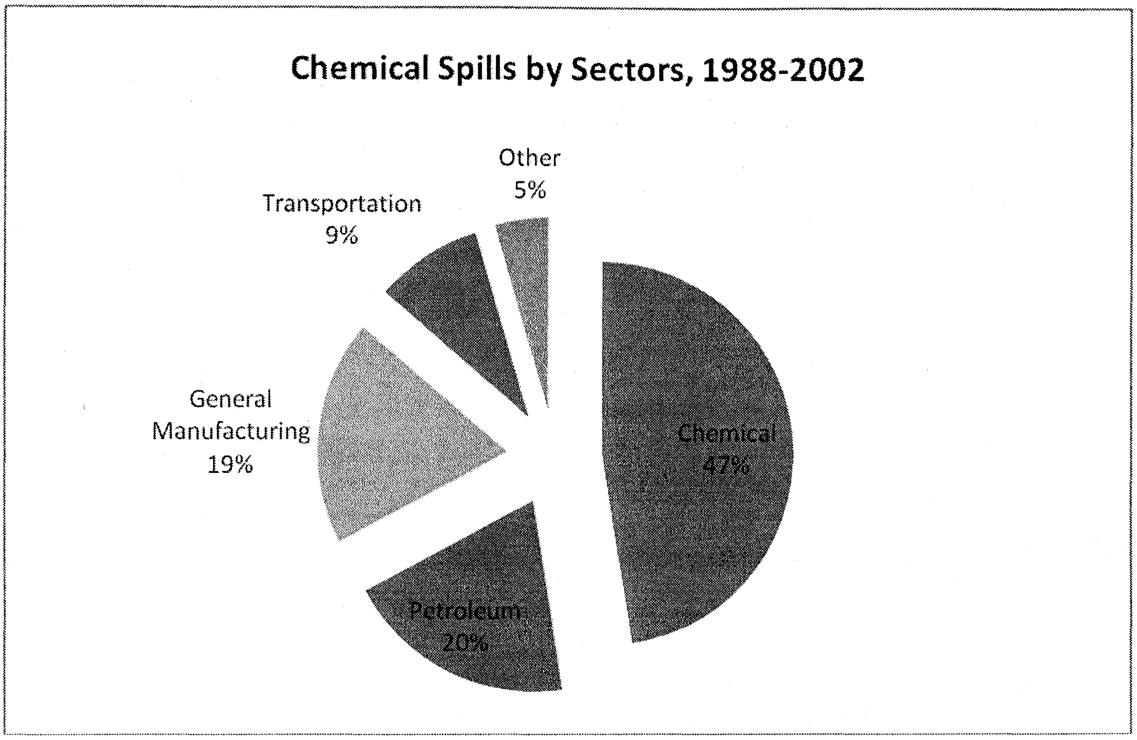

Figure 4.2 Chemical spill frequencies by sectors 1988-2002 (SAC data)

The sector information was categorized differently in 2003-2007, likely due to the need to accurately portray the spills from specific chemical industries. Figure 4.3 shows that nearly half of the chemical spills in the St. Clair River AOC between 2003 and 2007 were from the MISA facilities. The Petroleum Refineries and Organic Chemicals Manufacturing sector were each responsible for 23% of the chemical spills. The Inorganic Chemicals Manufacturing sector was accountable for 6% of the chemical spills in this period. Table 4.4 shows 70% of spills in the Petroleum Industry were caused by Discharge to Air, Pipe/Hose Leak, and Start Ups/Shutdowns/Interruptions.

Table 4.3 The causes of spills by sectors 1988-2002 (SAC data)

1988-2002					
	Chemical	Petroleum	General Manufacturing	Trans-portation	Other
Container Leak, Fuel Tanks, Barrels	12	4	3	1	5
Cooling System Leak	0	2	3	0	0
De-railing	0	0	0	1	0
Discharge/By pass to Watercourse	21	7	8	2	0
Discharge To Air	0	0	0	0	0
Other Discharges	3	2	6	0	0
Pipe/Hose Leak	2	0		0	2
Transport Accident	3	1	0	2	1
Over Flow	6	5	2	3	0
Pipe Line Leak	21	16	9	3	1
Process Upset	15	4	4	0	0
Start Ups/ Shutdowns/ Interruptions	1	2	3	0	0
Tank Leak (Surface)	1	0		0	1
Unknown	6	0	2	2	2
Valve/Fitting Leak/Failure	44	13	12	12	0
Other Cause	0	0	2	0	1
Total	135	56	54	26	13

In the Organic Chemical Manufacturing sector, Discharge to Air and Unknown causes contributed to 45% and 18% of the chemical spills, respectively. The issue of Pipe/Hose Leak and Discharge to Air were responsible for 67% of the chemical spills in the Inorganic Chemical Manufacturing sector. Non-MISA plants contributed to spills due to Discharge to Air.

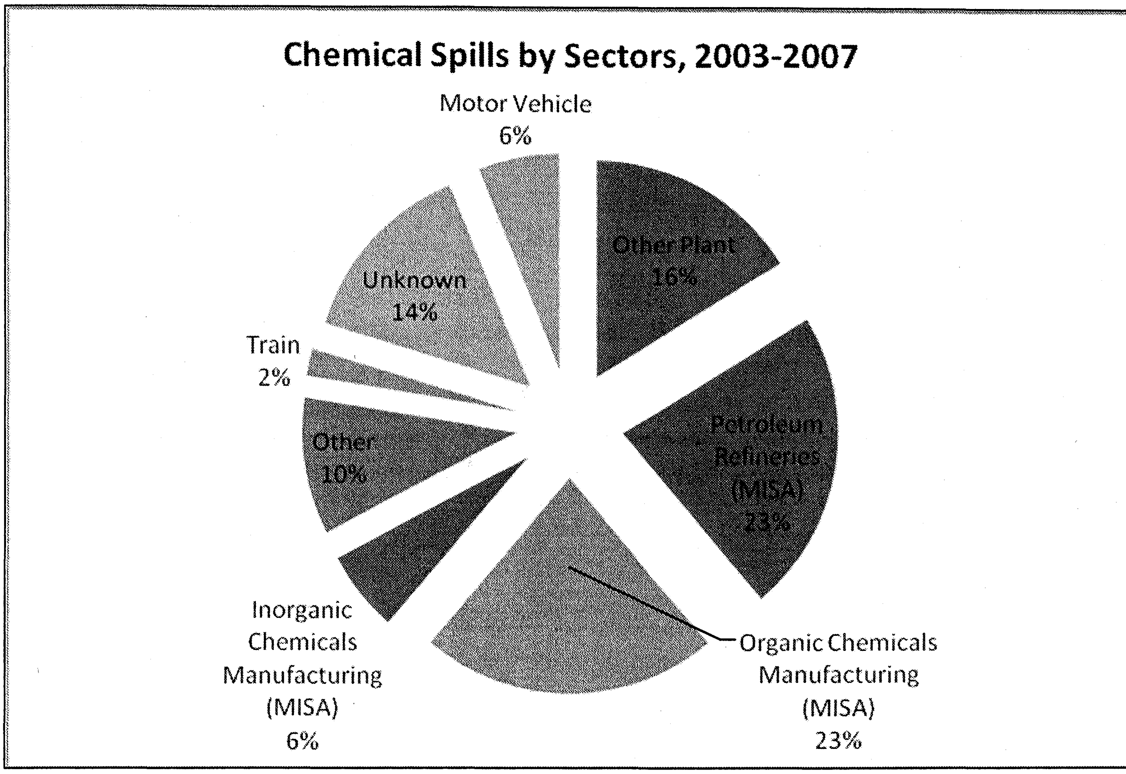

Figure 4.3 Chemical spill frequencies by sectors 2003-2007 (SAC data)

Table 4.4 The causes of spills by sectors 2003-2007 (SAC data)

2003-2007								
	Other Plant (Non-MISA)	Petroleum Refineries (MISA)	Organic Chemicals Manuf. (MISA)	Inorganic Chemicals Manuf. (MISA)	Other	Train	Unknown	Motor Vehicle
Container Leak, Fuel Tanks, Barrels	0	0	0	0	0	0	0	0
Cooling System Leak	0	1	0	0	0	0	0	0
De-railing	0	0	0	0	0	0	0	0
Discharge/By pass to Watercourse	0	0	1	0	0	0	0	0
Discharge To Air	6	2	5	1	2	0	3	0
Other Discharges	0	1	1	0	1	0	0	0
Pipe/Hose Leak	0	2	0	1	0	0	1	0
Transport Accident	0	0	0	0	0	0	0	0
Over Flow	0	0	0	0	0	0	0	0
Pipe Line Leak	0	0	0	0	0	0	0	0
Process Upset	0	0	1	0	0	0	0	1
Start Ups/ Shutdowns/ Interruptions	0	2	1	0	0	0	0	0
Tank Leak (Surface)	0	0	0	0	0	0	0	0
Unknown	2	2	2	1	2	1	3	0
Valve/Fitting Leak/Failure	0	1	0	0	0	0	0	2
Other Cause	0	0	0	0	0	0	0	0
Total	8	11	11	3	5	1	7	3

4.2.4 Environmental Impact Statistics

The environmental impacts caused by the chemical spills in the St. Clair River AOC include "Water Courses and Surface Water", "Soil and Vegetation", "Air", "Multi Media & Human Health and Safety", and "Other". Figure 4.4 shows the proportion of all chemical spills by the receiving medium. The author found that chemical spills mainly affected other media that were not specified in the SAC data. Otherwise, spill have most impact on Air, Water Courses and Surface Water, Soil and Vegetation, and followed by Multi Media and Human Health and Safety.

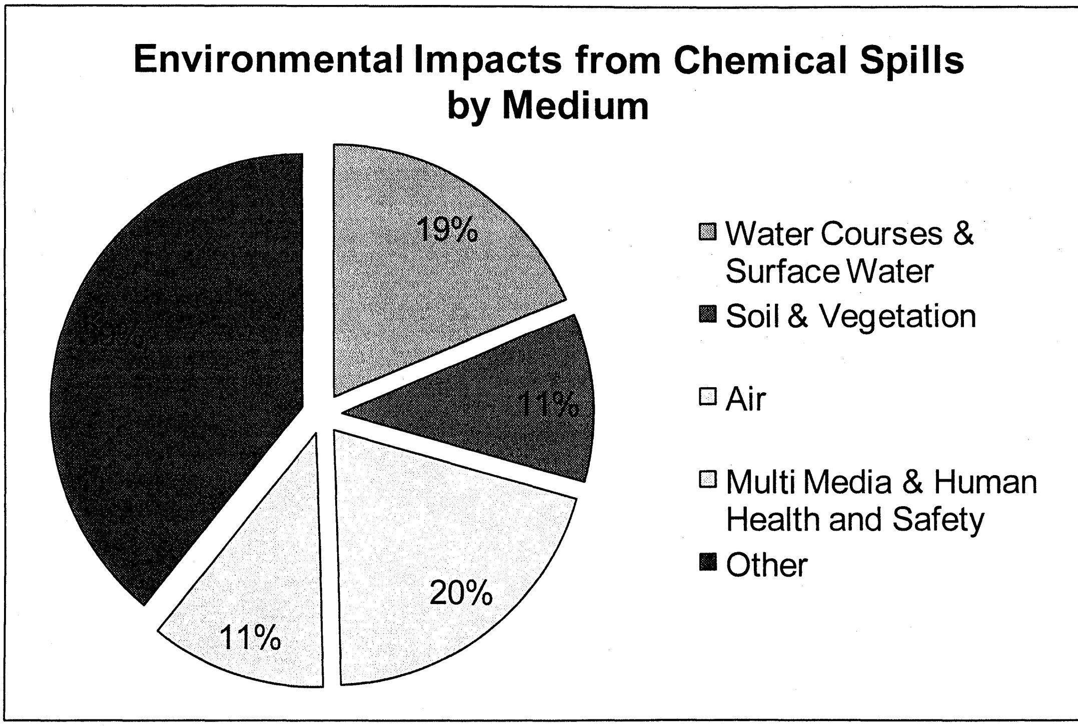

Figure 4.4 Environmental impacts of chemical spills (SAC data)

4.3 Water Treatment Plant Shutdown Statistics

There are three public WTPs located in the St. Clair River AOC that provide drinking water to local residents. Both the Sarnia-Lambton and the WIFN have water intakes located in the St. Clair River. The

Town of Wallaceburg WTP has an intake in the Chenal Ecarté, a distributary of the St. Clair River. The Sarnia-Lambton water intake is located at Port Huron, upstream from the City of Sarnia where the density of industrial activities is the highest in Ontario. The literature review indicated that the Wallaceburg and WIFN WTPs were shut down in the past due to spills. Both the SAC and SLEA data do not specify the names of the WTPs. It is assumed that the Wallaceburg and WIFN WTPs are included in the shutdown data, although the shutdown of other intakes, such as those of industrial facilities' may also be included in the data.

The focus of this part of the analysis is based on the frequency of shutdowns in the period between 1988 and 2007 due to chemical spills. The SLEA data provide the annual number of shutdowns and the names of the chemicals responsible. The chemicals associated with the shutdowns are then referenced in the SAC data to determine their spill characteristics in terms of the spill frequencies, causes, and environmental impacts.

4.3.1 Annual Shutdown Statistics

Shutdown information was extracted from the SAC data based on chemical spills to the river. Table 4.5 shows an excerpt of the reported dates and chemicals of WTP shutdowns. Similarly, the shutdown information was retrieved from the SLEA data. Table 4.6 shows an excerpt of the reported dates and chemicals in the SLEA data. The author found that the SLEA data recorded 24 shutdowns between 1988 and 2005 and the SAC data recorded 3 shutdowns between 1988 and 2007. No shutdowns were recorded in 1995-2002 and no data were available between 2006 and 2007 from the SLEA data. Figure 4.5 shows the annual number of shutdowns, according to the SLEA data.

Table 4.5 SAC shutdown record between 1988 and 2007

Year	Month	Day	Chemical	Environmental Impact
1990	7	20	vinyl chloride monomer (VCM)	Water course or lake
1990	9	4	acrylonitrile (vinyl cyanide)	Water course or lake
1990	10	30	ethylbenzene	Water course or lake

Table 4.6 An excerpt of the SLEA shutdown record between 1988 and 2005

Year	Date	Material	Material	Material	Material	Shut down
2004	29-Oct	benzene	toluene	xylenes		yes
2004	23-May	styrene	ethylbenzene	benzene	toluene	yes
2004	23-May	oily water				yes
2004	23-May	TSS				yes
2004	29-Apr	naphtha				yes
2004	5-Mar	caustic soda				yes
2004	16-Feb	determined to be pentane, butane & 2-methyl butane				yes
2004	1-Feb	MEK / MIBK				yes
2003	14-Aug	vinyl chloride	incidents treated as single reportable spill			yes
1994	05-Nov	ethylbenzene				yes
1993	08-Sep	benzene	cyclohexane			yes
1993	09-Feb	benzene				yes
1992	23-Jul	*false benzene*				*yes*
1992	20-Mar	isobutylene				yes
1992	19-Mar	isobutylene				yes
1992	21-Jan	toluene	xylene	benzene	ethylbenzene	yes
1991	10-Jul	acrylonitrile				yes
1991	07-May	ethyl benzene				yes
1990	06-Nov	ethyl benzene	styrene	benzene	toluene	yes
1990	30-Oct	ethylbenzene				yes
1989	17-Oct	diethylbenzene				yes
1989	22-Mar	selexol				yes
1989	23-Feb	regen eff				yes
1988	25-May	ammonia	acrylonitrile	MOEE as 96001		yes

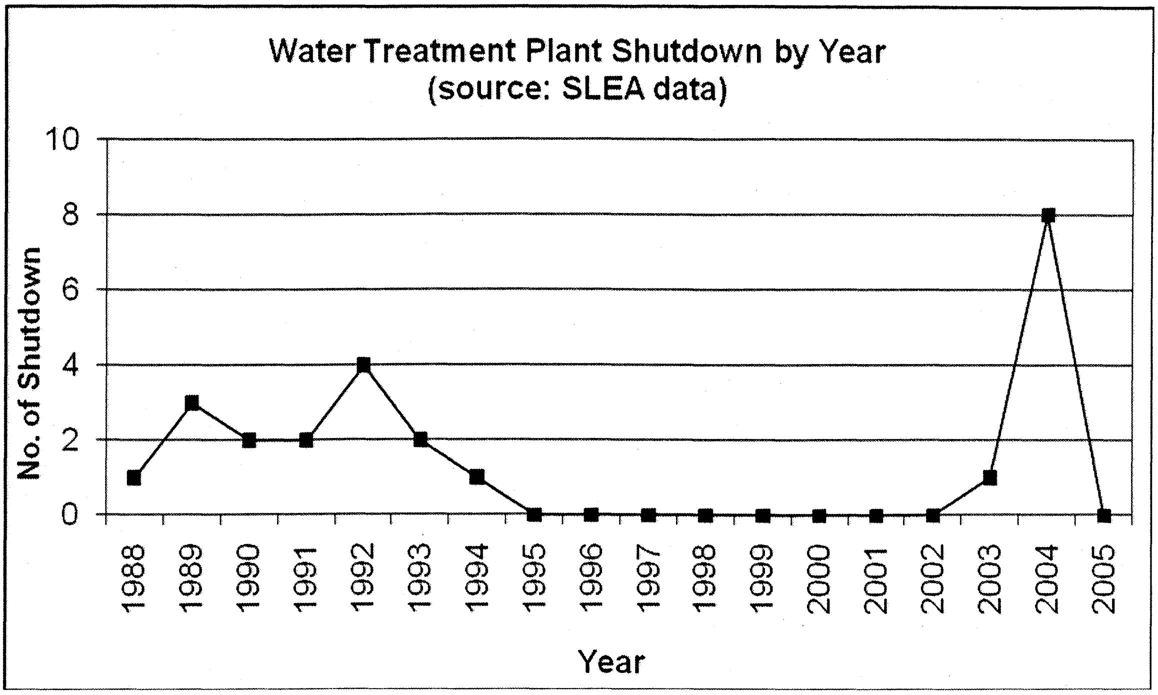

Figure 4.5 Annual number of shutdowns (SLEA data)

4.3.2 Chemical Statistics

The section presents the findings on the analysis of the chemicals that have spilled to the St. Clair River and subsequently caused shutdowns. Among the chemicals in the SLEA data, 14 were selected and cross-referenced in the SAC data. The author found that the SAC data contain 12 of the 14 chemicals recorded in the SLEA data. However, only 8 of the 12 chemicals were recorded with spill mass, as is shown in Table 4.7.

Table 4.7 Chemicals recorded to have caused a WTP shutdown

	Chemicals recorded to have caused a WTP shutdown (SLEA data)	SAC database	SAC Spill Record with Mass
1	2-Methyl Butane		
2	Acrylonitrile (Vinyl Cyanide)	✓	
3	Ammonia	✓	
4	Benzene	✓	✓
5	Butane	✓	
6	Caustic Soda (Sodium Hydroxide)	✓	✓
7	Diethylbenzene		
8	Ethylbenzene	✓	✓
9	Isobutene (Isobutylene)	✓	✓
10	Methyl Ethyl Ketone	✓	✓
11	Pentane	✓	
12	Styrene	✓	✓
13	Toluene	✓	✓
14	Vinyl Chloride (chloroethylene)	✓	✓

The eight chemicals referenced in the SAC data were analyzed for their spill occurrences, causes of spill, and environmental impacts. It should be noted that the following analysis of the eight specific chemicals include spills that had environmental impact to all media (e.g. to air, soil, and surface water). Again the proportion of spills that were recovered was not provided in the SAC data.

The total number of spill occurrences is shown in Figure 4.6. Vinyl Chloride and benzene had the highest spill frequencies with mass. The number of WTP shutdowns associated with the particular chemical (from the SLEA data) is shown in Figure 4.6 to indicate the proportion of spill occurrences and WTP shutdowns.

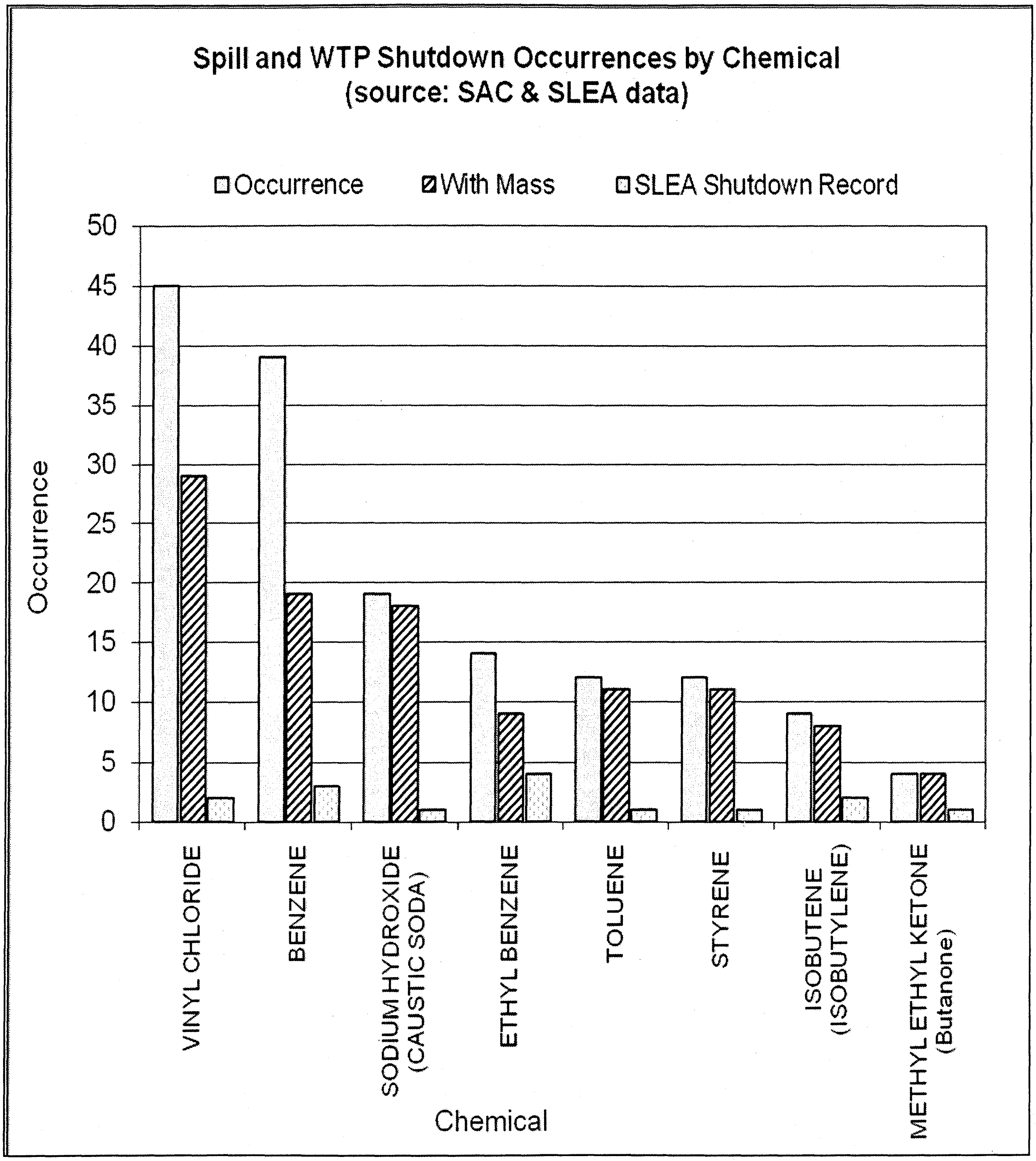

Figure 4.6 Spill and WTP shutdown occurrences by chemical (SAC and SLEA data)

4.3.3 Causes of Spills

The causes of spills for the eight chemicals were analyzed using the SAC data. The SLEA data are not part of the statistics being presented within because they did not contain information on the causes of the chemical spills.

Table 4.8 shows that Discharge/Bypass to Water Courses was responsible for 97% of all benzene spill mass. Over Flow contributed to almost 59% of all ethylbenzene spill mass. Majority of the toluene spill mass came from Pipe/Hose Leaks. Cooling System Leaks were responsible for 92% all methyl ethyl ketone spill mass. Vinyl chloride was mostly spilled via Other Discharges and due to Valve Fitting/Leak/Failures, which accounted for 72% of its total spill mass.

Table 4.8 Chemical spill mass by causes (SAC data)

Cause	Benzene (kg)	Ethyl-benzene (kg)	Caustic Soda (Sodium Hydroxide) (kg)	Isobutene (Isobutylene) (kg)	Methyl Ethyl Keytone (Butanone) (kg)	Styrene (kg)	Toluene (kg)	Vinyl Chloride (kg)
Container Leak, Fuel Tanks, Barrels	698	1	3	0	0	182	0	0
Cooling System Leak	50	0	0	1,745	125,843	0	0	0
Discharge/Bypass To Water Courses	40,269	69	7,328	0	0	5	0	24
Discharge To Air	0	0	0	500	0	0	0	150
Other Discharges	46	1	120	0	11,026	0	0	6,000
Pipe/Hose Leak	0	0	0	0	0	0	868,734	1
Other Transport Accident	0	0	0	0	0	0	16	0
Over Flow	119	144,00	632	0	0	0	31	0
Pipe Line Leak	110	1569	12,481	7,891	0	5	5,691	33
Process Upset	0	1	66	0	0	0	0	3,948
Start Ups/ Shutdowns/ Interruptions	12	0	0	0	0	0	0	0
Tank Leak (Surface)	0	4,728	4,662	0	0	0	0	0
Unknown	40	18	21	32	8	20	0	1
Valve/Fitting Leak/Failure	122	3,755	13,116	0	0	6,674	1,840	4,745
Total	41,466	24,542	38,429	10,168	136,877	6,886	876,312	14,902

4.3.4 Environmental Impact

The environmental impacts caused by the eight specific chemicals are shown in Figure 4.7. The SAC data categorized the environment impacts into “Water Courses and Surface Water”, “Soil and Vegetation”, “Air”, “Multi Media and Human Health and Safety”, and “Other”. The author found that the eight specific chemicals mainly affected other media that were not specified in the SAC data. Otherwise, 28% of the spills caused by these chemicals had significant impact on Water Courses and Surface Water.

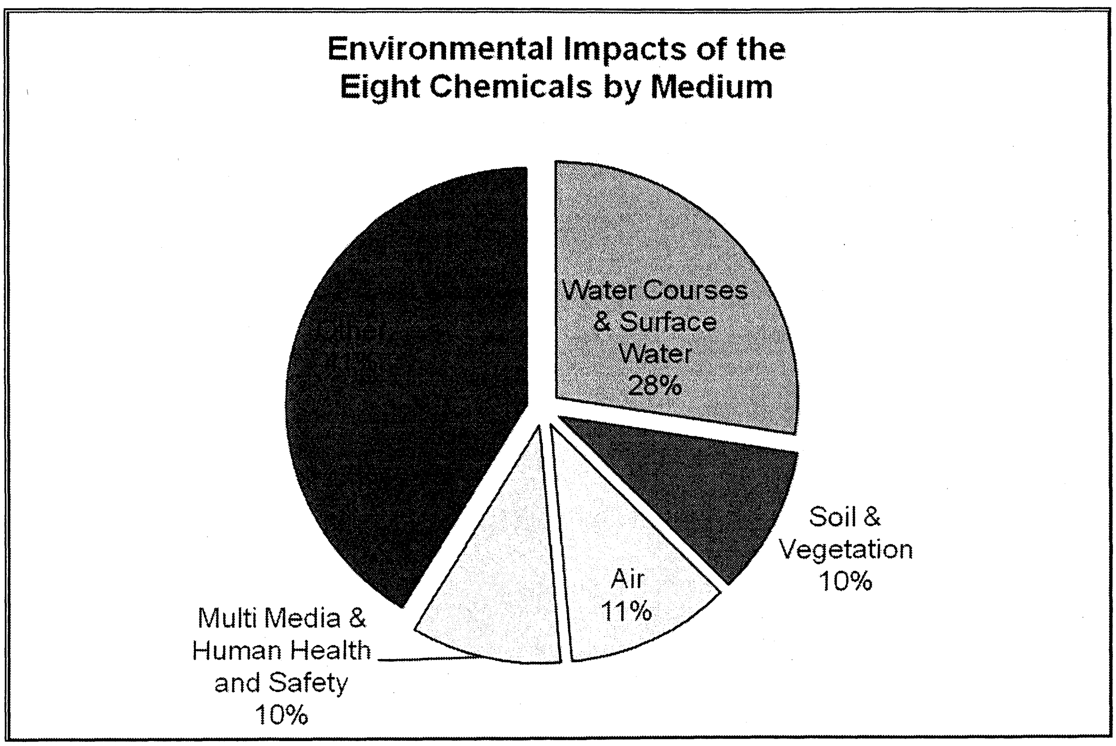

Figure 4.7 Environmental impacts of the eight chemicals (SAC data)

4.3.5 Drinking Water Quality Analysis

According to the CRIC, the delisting criterion for the drinking water BUI is to have no treatment plant shutdown due to exceedences of drinking water guidelines in a two-year period. As stated in the literature review, the Canadian and Ontario water quality guidelines and drinking water quality standards regulate a list of organic and inorganic chemicals with different quantitative parameters. The standards and guidelines set out the Maximum Acceptable Concentration (MAC) for the chemicals shown in Table 4.9. WTP shutdown may occur when the water quality at the intake exceeds the MAC. The literature review also indicated that emergency events such as CSOs, effluent bypasses, and power outages can trigger shutdowns due the possibility of MAC exceedences. The WTP operator's decision to shutdown can be based on the scientific evidence, as well as his or her perception of the health risk in the receiving water. A shutdown of the WTP appears to be a cautionary procedure to prevent the possible contamination of the drinking water supply distribution system.

Table 4.9 shows that the Provincial Water Quality Objectives regulates six of the eight chemicals, which were reported to cause shutdowns in the St. Clair River AOC in the past 20 years. The Ontario Drinking Water Standards and the Canadian Drinking Water Quality Guidelines exclude the regulation on methyl ethyl keytone and styrene, which are regulated under the Ontario Water Quality Objectives.

Given the high number of benzene and vinyl chloride spills in the St. Clair River AOC in the past 20 years, it is appropriate to analyze their risks of exceeding the drinking water quality guidelines. Chapter 5 presents the statistical analysis and the risk of shutdown due to benzene and vinyl chloride spills.

Table 4.9 Maximum Acceptable Concentrations

	Spill Chemical	Provincial Water Quality Objectives	Ontario Drinking Water Standards	Canadian Drinking Water Quality Guidelines
1	Benzene	0.1 mg/L	0.005 mg/L	0.005 mg/L
2	Caustic Soda (Sodium Hydroxide)	-	-	-
3	Ethylbenzene	0.008 mg/L	0.0024 mg/L*	0.0024 mg/L*
4	Isobutene (Isobutylene)	-	-	-
5	Methyl Ethyl Ketone	0.4 mg/L	-	-
6	Styrene	0.004 mg/L	-	-
7	Toluene	0.0008 mg/L	0.024 mg/L*	0.024 mg/L*
8	Vinyl Chloride (chloroethylene)	0.6 mg/L	0.002 mg/L	0.002 mg/L

* aesthetic objectives

5.0 Treatment Plant Shutdown Risk Analysis Results

5.1 Risk Analysis

Spills can occur at any locations and have the potential to enter the receiving water and cause WTP shutdowns. The risk analysis examines the spills that have the most likelihood to cause a shutdown by focusing on spills that directly entered or impacted the watercourses in the St. Clair River AOC. As stated in Chapter 4, benzene and vinyl chloride had the highest spill occurrences in the St. Clair River AOC. The risk analysis focuses on these two chemicals and determines the risk of WTP shutdown for the periods of 1988-1997 and 1998-2007. The time periods are intended to reflect the changes in the spill control and abatement practices enforced under the law. As discussed in the literature review, spill regulations have become more stringent since 1988. Spill control and prevention milestones in the study period include the:

- General Effluent Monitoring Regulations, 1988;
- OEPA and OWRA, 1990;
- MISA Program and regulations, 1993-1995;
- EESLAA, 2005;
- OCWA, 2006;
- Spill Prevention and Contingency Plan for MISA facilities, 2007.

When examining the risk of shutdown, it is important to consider the stationary properties of the shutdown time series. The probability of spills, in the scope of this study, is dependent on the number of companies that are in operation throughout the study period. In the past 20 years, several companies that were responsible for major chemical spills have either since completely shut down, ceased operations, or downsized (Edwardson, D., personal communication, 2009). In 2007, eight of the eleven large facilities that existed in 1988 in the St. Clair River AOC remain in full operation.

5.2 Statistical Analysis of Variables

The risk analysis is preceded by a series of statistical exercises which examines the nature and relationship between the spills and river flow. The following section presents the results of the statistical exercises which are used to estimate the risk of WTP shutdowns.

5.2.1 Spills and Flow Independence

The relationship between spill event mass and the river flow needs to be established in order to verify the assumption of independence. Figure 5.1 and Figure 5.2 show the scatter plots of mass of spills and river flow for benzene and vinyl chloride spills, respectively. The correlation coefficient (R^2) of benzene spill mass and river flow is 0.0016 with a sample size of 31. They can be considered as statistically independent. The correlation coefficient (R^2) for vinyl chloride is 0.17 with a sample size of only eight records. While it is difficult to confirm their independency at this sample size, it is assumed that they are statistically independent.

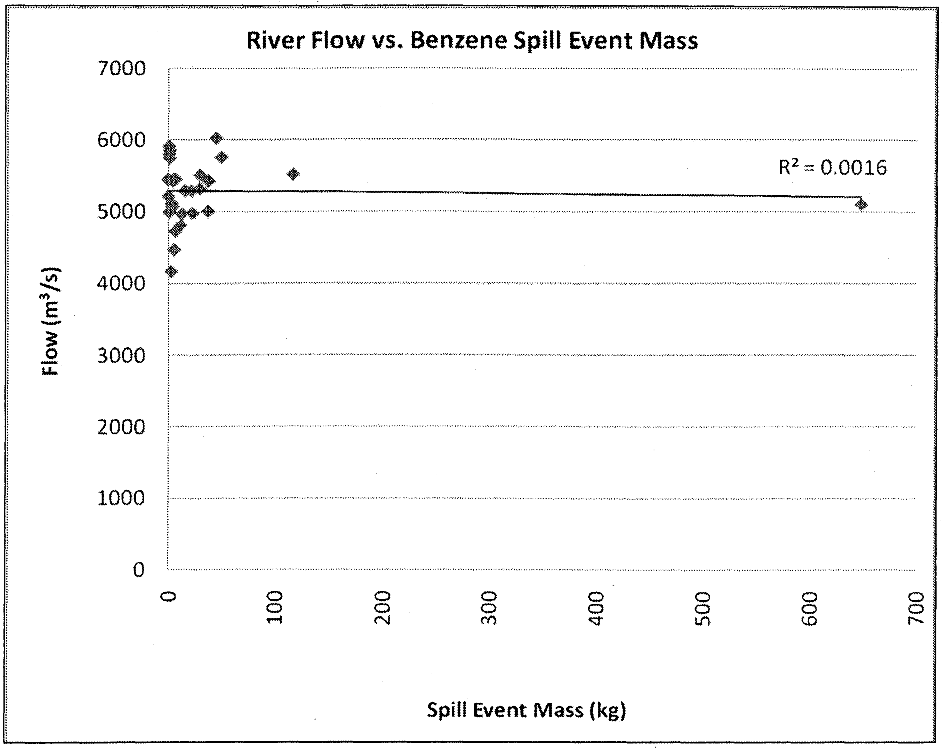

Figure 5.1 The scatter plot of benzene spill event mass and river flow

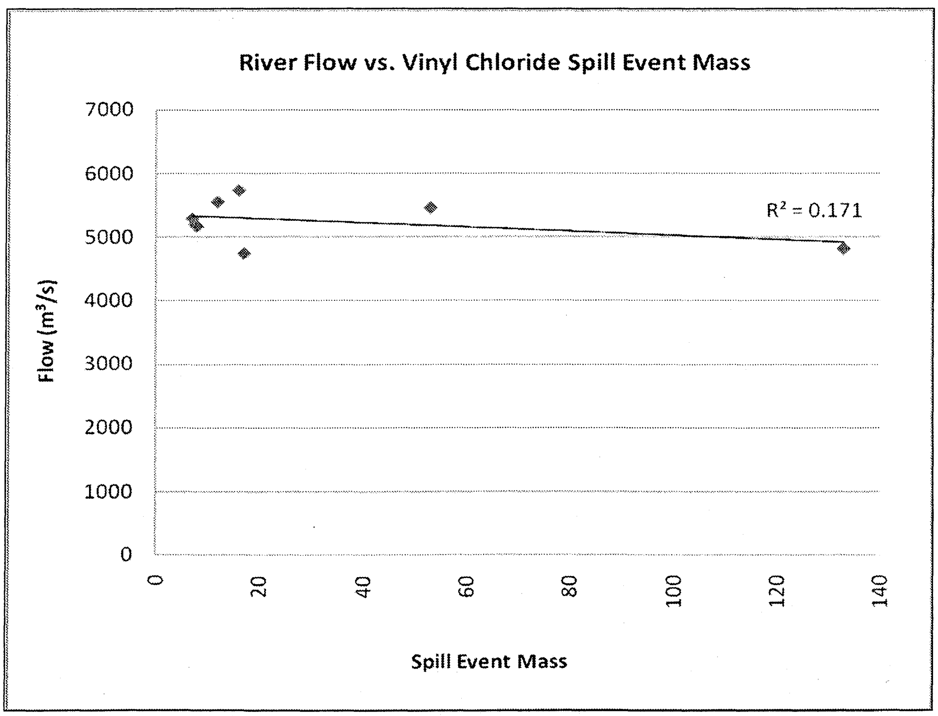

Figure 5.2 The scatter plot of vinyl chloride spill event mass and river flow

5.2.2 River Low Flow

Since the flow regime in the St. Clair River is likely subject to seasonal fluctuation due to rainfall and ice retardation, the purpose of the flow regime statistical exercise is to determine the variance of the low flow. The author of this study examined the flow by using Environment Canada's stage-fall discharge monthly mean flow. River flows for each of the twelve months from 1900 to 2007 were compared based on the coefficient of variance (CV).

Table 5.1 shows that in the analysis period, February has lowest flow, follows by January and March. Furthermore, the monthly mean flow varies the most in the months of January to March with a *CV* ranging from 11% to 15%. These statistics indicate that over the past 108 years the flow in the St. Clair River fluctuates the most in the late winter.

In order to reconcile the variation of the flow for the month of January to March, the author of this study obtained the stage-fall discharge daily mean flow from Environment Canada. Figure 5.3 to Figure 5.5 show the daily flow duration curves for the months of January to March. For all three months, the daily mean flow recorded a higher magnitude than the monthly mean flow for the same duration. For instance, the flow duration curves of daily and monthly flow for January and February can vary about $500m^3/s$, while they remain almost the same for the month of March. In order to obtain a conservative estimate of the risk of shutdowns from the St. Clair River AOC, the daily flow from 1988 to 2007 were used to determine the annual low flow probability in the St. Clair River. For the month of March, the two curves are similar. Apparent from the flow duration curves is that the monthly mean flow tends to reflect a lower flow for the St. Clair River, which can infer more spills to the probability of WTP shutdowns in the proposed risk-based approach.

Table 5.1 Monthly mean flow (m^3/s) statistics

January	
MAX.	6060 m^3/s
MIN.	3060 m^3/s
AVG.	4498 m^3/s
STD.	663 m^3/s
CV	14.74%

February	
MAX.	5720 m^3/s
MIN.	3000 m^3/s
AVG.	4398 m^3/s
STD.	673 m^3/s
CV	15.31%

March	
MAX.	5830 m^3/s
MIN.	3510 m^3/s
AVG.	4819 m^3/s
STD.	565 m^3/s
CV	11.73%

April	
MAX.	6260 m^3/s
MIN.	3600 m^3/s
AVG.	5110 m^3/s
STD.	520 m^3/s
CV	10.81%

May	
MAX.	6370 m^3/s
MIN.	4390 m^3/s
AVG.	5322 m^3/s
STD.	498 m^3/s
CV	9.36%

June	
MAX.	6430 m^3/s
MIN.	4420 m^3/s
AVG.	5419 m^3/s
STD.	500 m^3/s
CV	9.22%

July	
MAX.	6570 m^3/s
MIN.	4500 m^3/s
AVG.	5483 m^3/s
STD.	509 m^3/s
CV	9.28%

August	
MAX.	6630 m^3/s
MIN.	4530 m^3/s
AVG.	5491 m^3/s
STD.	512 m^3/s
CV	9.32%

September	
MAX.	6600 m^3/s
MIN.	4460 m^3/s
AVG.	5446 m^3/s
STD.	513 m^3/s
CV	9.42%

October	
MAX.	6740 m^3/s
MIN.	4420 m^3/s
AVG.	5392 m^3/s
STD.	502 m^3/s
CV	9.31%

November	
MAX.	6650 m^3/s
MIN.	4390 m^3/s
AVG.	5337 m^3/s
STD.	495 m^3/s
CV	9.27%

December	
MAX.	6230 m^3/s
MIN.	3990 m^3/s
AVG.	5159 m^3/s
STD.	504 m^3/s
CV	9.77%

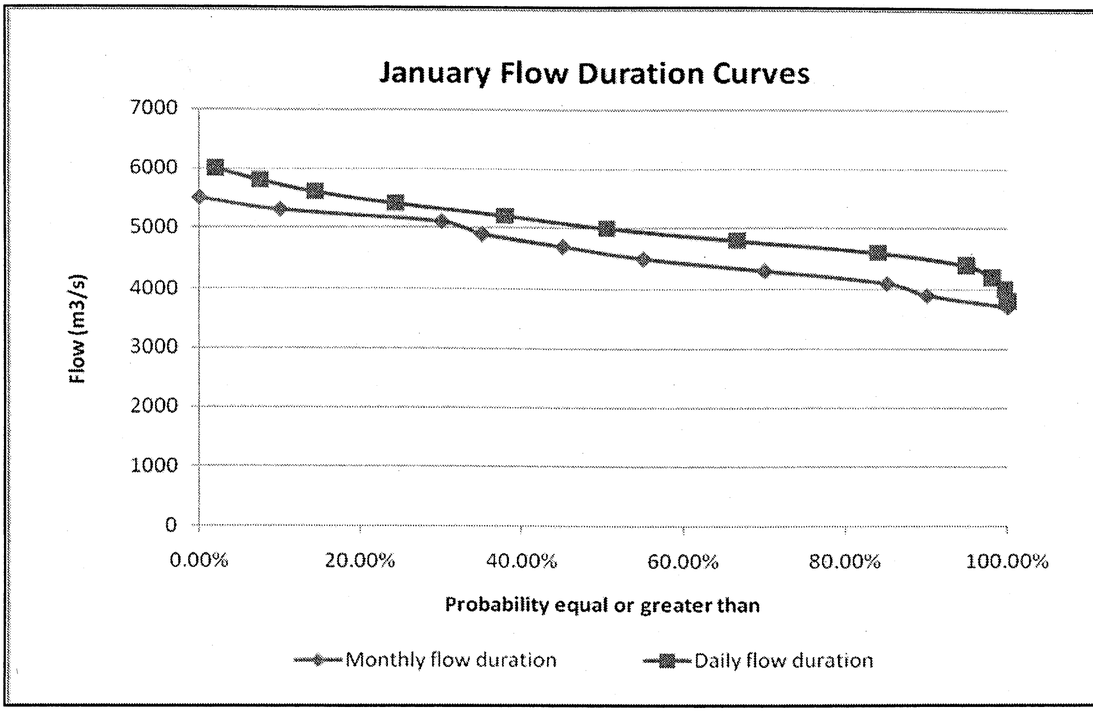

Figure 5.3 Flow duration curve for January

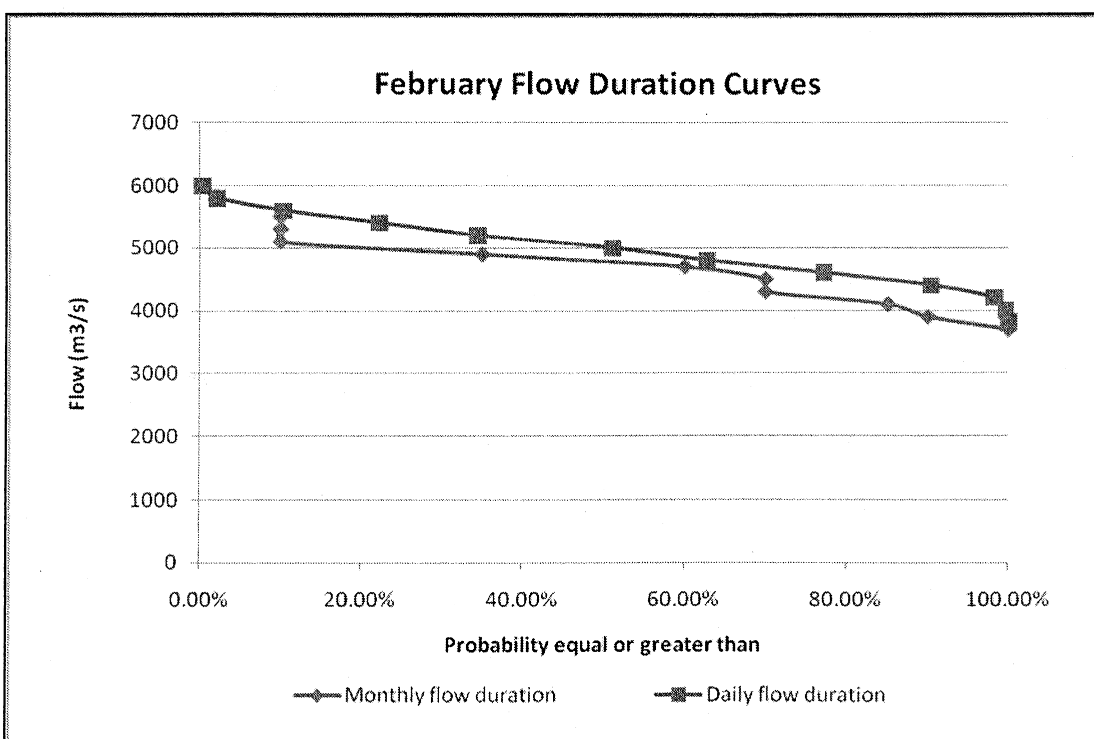

Figure 5.4 Flow duration curve for February

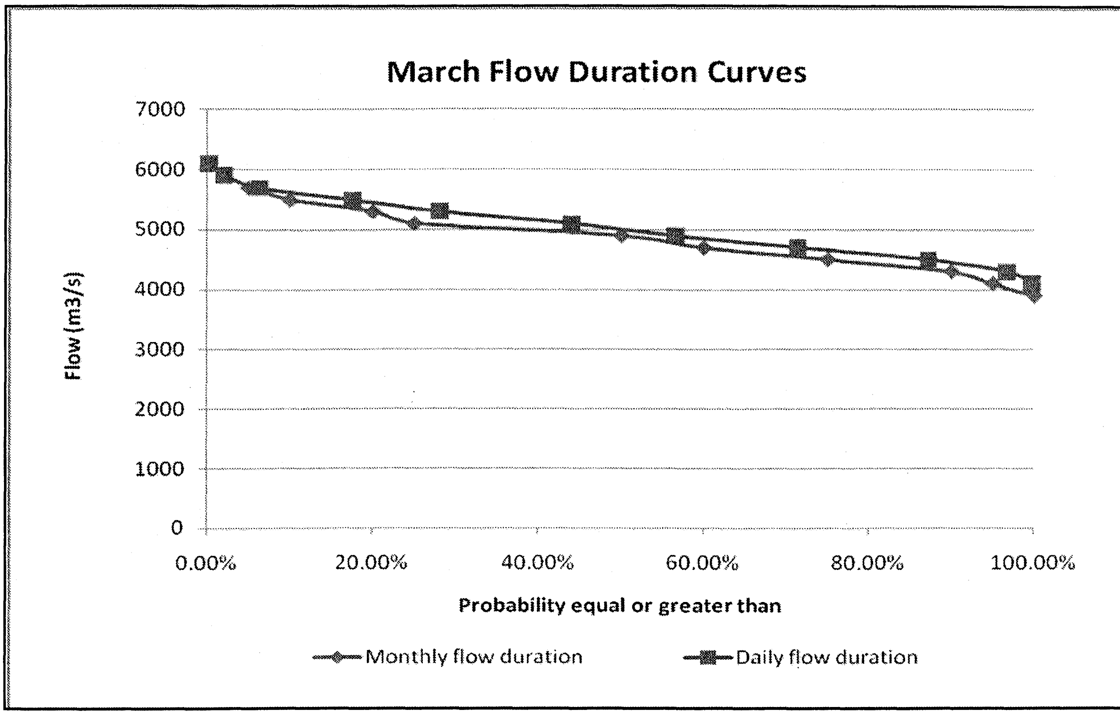

Figure 5.5 Flow duration curve for March

For the purposes of risk calculations, the daily mean flow was used to determine the annual low flow in the St. Clair River. The lowest flow in each year from 1988 to 2007 was selected, creating an annual low flow of 20 records.

5.2.3 Probability Distribution of the Annual Low Flow, Benzene Spills, and Vinyl Chloride Spills

Distribution fitting is necessary for determining the probability distribution of the random variables in the risk calculation. Statistical tests and visual inspection were used to determine the appropriate distribution curves for each of the random variables. The distribution fitting exercise examines the characteristics of the annual low flow and benzene and vinyl chloride spill event mass (using the Chi-squared test, probability plots, Kolmogorov–Smirnov test, and visual inspection) to determine the appropriate probability distribution. The results of the exercise are shown in Appendix IV. The author of this study found that the:

- annual low flow was normally distributed;
- benzene spill event mass in the SAC data was log-normally distributed;
- benzene spill event mass in the SLEA data was log-normally distributed;
- vinyl Chloride spill event mass in the SAC data was log-normally distributed; and
- vinyl Chloride spill event mass in the SLEA data was log-normally distributed.

5.2.4 Inter-event Time Between Spills

The time between spills is one measure of spills frequencies. One of the concerns regarding high spill frequencies is the accumulative effects of consecutive spills in a short period of time. Appendix V shows the inter-event time (day) between the benzene and vinyl chloride spills in the SAC and SLEA data. In general, spills of similar chemicals rarely occur more than once on any given day. Only one exception of such an incident was recorded in the SAC data for benzene spills on May 31, 1989. However, spills do occur closely to each other on occasion. The SLEA data recorded two benzene spills and one vinyl chloride spill that occurred on consecutive days in December, 1989 and July, 1992, respectively. Otherwise, the records in the SAC and SLEA data show that spills normally occur at least seven days apart. The accumulative effects between inter-event time and spills on water quality require additional research, which is beyond the scope of this study.

5.3 Risk of Benzene Spills

The risk of WTP shutdown due to benzene spills in a two-year period was determined using the spill date, spill quantity (kg), and the corresponding river daily mean flow in Table 5.2.

Table 5.2 SLEA shutdown record for benzene spills and the corresponding St. Clair River daily mean flow provided by Environment Canada

Date	Mass (kg)	Flow (m^3/s)
6-Nov-1990	22.00	*5230.00
21-Jan-1992	648.00	5096.31
23-Jul-1992	Unknown	5382.97
9-Feb-1993	117.00	5509.19
8-Sep-1993	50.00	5911.37
23-May-2004	Unknown	*4869.96
29-Oct-2004	7.00	4723.71

* Month average is used when day average is not available

5.4 Risk Analysis Using the SAC Data

There were a total of 12 records of benzene spills to the watercourses in the SAC data from 1988 to 1997. An excerpt of the benzene spill records from the SAC data is found in Appendix VI. Namely five companies were responsible for all the benzene spills. These companies continue to operate to date, although some have since amalgamated with different companies and continue to operate under different company names. Table 5.3 shows the benzene spills to the water courses in the St. Clair River AOC from the SAC data.

Table 5.3 Benzene spill to the water courses in St. Clair River AOC (SAC data)

Date	Mass (kg)
2-Sep-1988	79.11
31-May-1989	3.00
31-May-1989	3.52
20-Jul-1989	40170.30
28-Sep-1989	5.27
5-Dec-1989	40.00
26-Jul-1990	5.00
23-Jul-1992	12.20
9-Feb-1993	117.00
3-Jun-1993	1.40
8-Sep-1993	50.00
2-Jan-1996	45.00

It was indicated in the previous section of this study that the SAC data did not provide any shutdown record for benzene spills. An assumption was made to use the SLEA shutdown dates and the corresponding SAC benzene spills for calculating the risk of shutdown. A shutdown was identified by cross-referencing the SLEA shutdown dates with the corresponding SAC benzene spill date and event mass. There were two shutdowns, February 9, 1993 and September 8, 1993 between 1988 and 1997. There were no benzene spills recorded by the SAC between 1998 and 2007.

A conservative estimate of the probability of a shutdown is the probability of spills with mass equal to or greater than the smallest spills mass that triggered a previous shutdown and river flow equal to or less than the smallest flow that triggered a previous shutdown. The probability distribution curves of spill event mass and river flow were fitted with theoretical probability distributions. Figures 5.6 and Figure

5.7 show the probability distribution curves for benzene spill event mass (of the 12 spill events) and annual low flow in the SAC data between 1988 and 2007, respectively. It was determined that the log-normal probability distribution was generally appropriate for describing the spill event mass and normal probability distribution for describing the annual low flow.

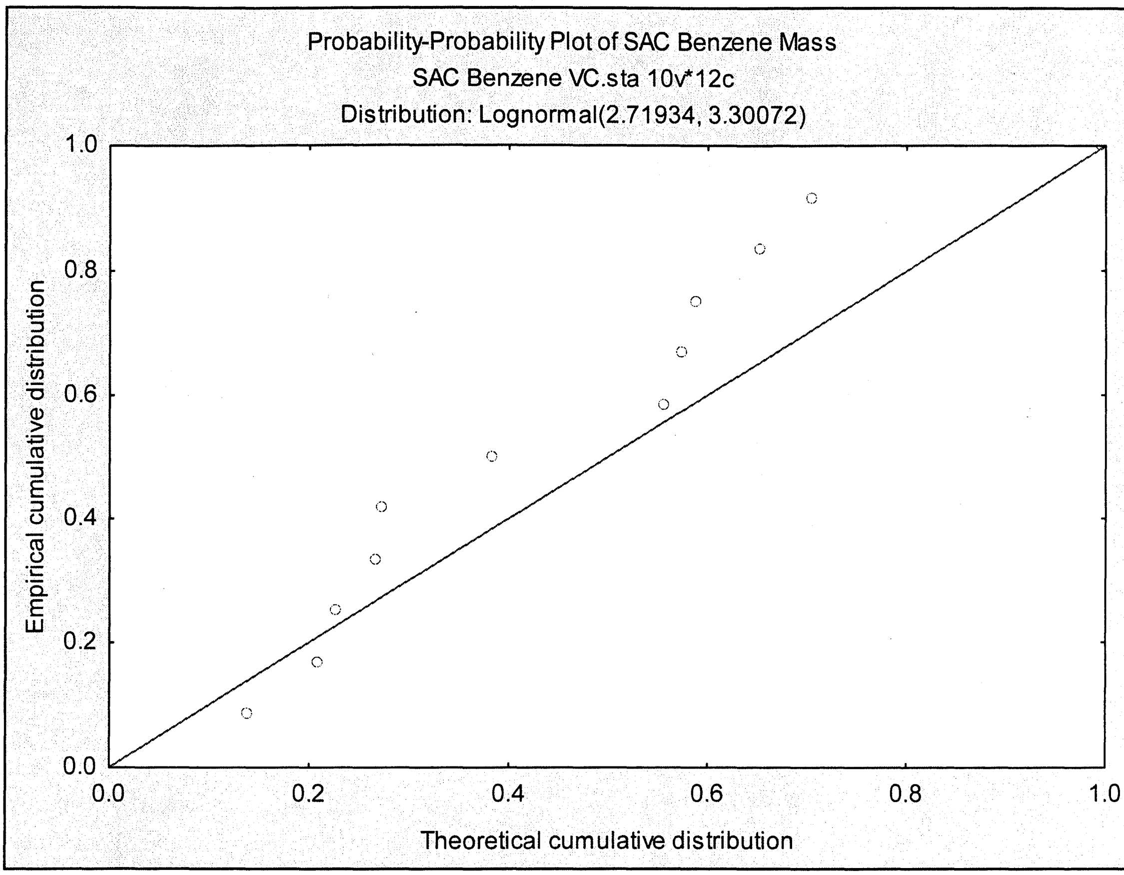

Figure 5.6 Log-normal probability distribution fitting of benzene spill event mass recorded by the SAC

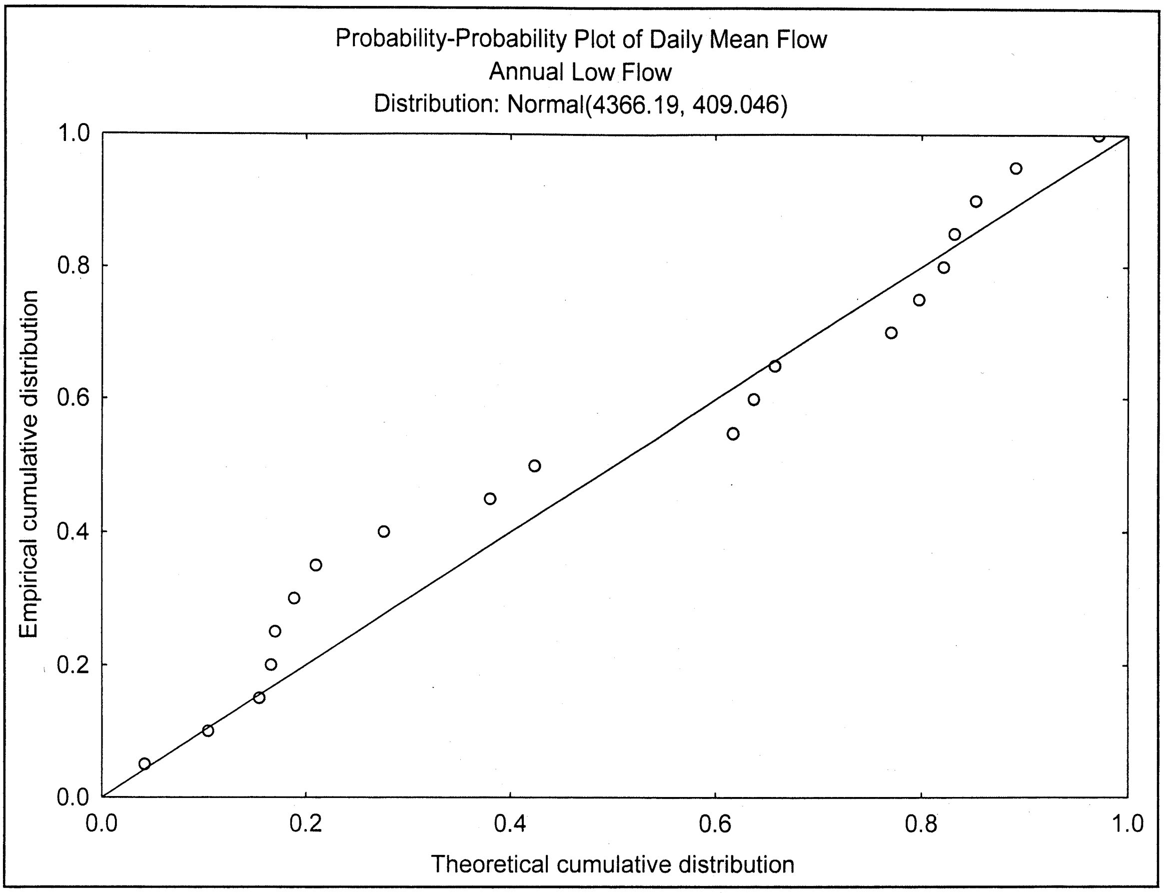

Figure 5.7 Normal probability distribution fitting of annual daily low flow recorded by the Environment Canada

Using the SAC data between 1988 and 1997, the probability of shutdown per event can be determined by the joint probability of benzene spill event mass (*M*) and annual low flow (*Q*) as follows:

$$P[shut\ down\ per\ event] = P[Q{=}{<}5509.19\frac{m^3}{s}] * P[M{=}{>}50KG] = 0.99*0.41{=}0.41$$

The probability of shut down per year:

$$P[shut\ down\ per\ year] = P[shut\ down\ per\ spill\ event] * \frac{\#\ events}{year} = 0.41 * \frac{12}{10} = 0.49$$

The risk (*R*) of benzene spill in a two-year period can be estimated by:

$$R = 1 - (1 - P[shut\ down\ per\ year])^n$$

in which n is the period of consideration in years. Using the SAC data between 1988 and 1997, the risk of WTP shutdown over 2, 3, 4, and 5-year periods is shown in Table 5.4.

Table 5.4 The risk of WTP shutdown based on benzene spills recorded by the SAC between from 1988 and 1997

Risk of WTP shutdown in 2 year	74%
Risk of WTP shutdown in 3 year	87%
Risk of WTP shutdown in 4 year	93%
Risk of WTP shutdown in 5 year	97%

The risk of WTP shutdown due to benzene spills in a two–year period is 74% based on the number of spills recorded by the SAC between 1988 and 1997.

5.4.1 Risk Analysis Using the SLEA Data

There were a total of 31 benzene spills to the St. Clair River between 1988 and 2007 in the SLEA data. Table 5.5 shows the benzene spill dates and event masses recorded in the SLEA data.

Table 5.5 Benzene spills to the St. Clair River in 1988-2007 (SLEA data)

Date	Mass (kg)
2-Sep-1988	38
20-Jul-1989	0.1
2-Aug-1989	6
28-Sep-1989	4.5
5-Dec-1989	30
6-Dec-1989	16
19-Dec-1989	37.4
27-Apr-1990	1
4-May-1990	0.5
26-Jul-1990	5
6-Nov-1990	22
24-Jan-1991	3.5
2-Feb-1991	23
23-Dec-1991	7
21-Jan-1992	648

Date	Mass (kg)
8-Jul-1992	4.7
12-Jul-1992	30
9-Feb-1993	117
2-Jun-1993	1.4
8-Sep-1993	50
16-Jan-1994	1.3
2-Jan-1996	45
23-Aug-1996	1.3
8-Sep-1996	1.54
14-Mar-1999	4.1
16-Dec-2000	6
1-Nov-2001	13
22-Nov-2001	11.7
12-May-2002	4.33
3-Mar-2003	3
29-Oct-2004	7

The probability distribution of spill event mass was fitted with the log-normal distributions as shown in Figure 5.8. It was determined that the log-normal probability distribution was generally appropriate for describing the spill event mass recorded by the SLEA. As indicated in Figure 5.7, the annual low flow had the normal probability distribution.

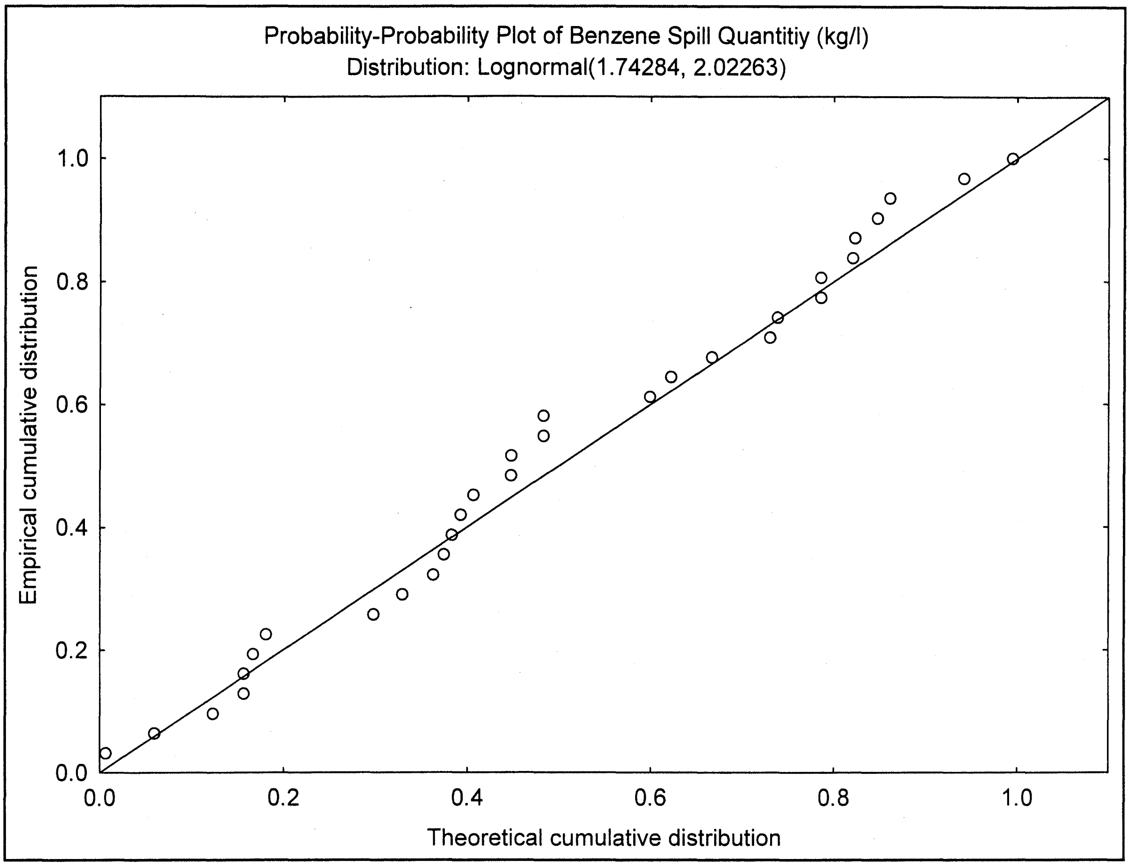

Figure 5.8 Log-normal probability distribution fitting of benzene spill event mass recorded by the SLEA

Using the SLEA data between 1988 and 1997, the probability of shutdown per even can be determined by the joint probability of benzene spill event mass (M) and annual low flow (Q) as follows:

$$P[\textit{shut down per event}] = P[Q{=}{<}5096.31\frac{m^3}{s}] * P[M{=}{>}22KG] = 0.96*0.27=0.26$$

The probability of shut down per year:

$$P[\textit{shut down per year}] = P[\textit{shut down per spill event}] * \frac{\#\,events}{year} = 0.26 * \frac{24}{10} = 0.62$$

The risk (R) of benzene spill in a two year period can be estimated by

$$R = 1 - (1 - P[\textit{shut down per year}])^n$$

in which n is the period of consideration in years. Using the SLEA data between 1988 and 1997, the risk of the risk of WTP shutdown over 2, 3, 4, and 5-year periods is shown in Table 5.6.

Table 5.6 The risk of WTP shutdown based on benzene spills recorded by the SLEA between1988 and 1997

Risk of WTP shutdown in 2 year	86%
Risk of WTP shutdown in 3 year	95%
Risk of WTP shutdown in 4 year	98%
Risk of WTP shutdown in 5 year	99%

The risk of WTP shutdown due to benzene spills in a two-year period is 86% based on the number of spills recorded by the SLEA between 1988 and 1997.

For the period of 1998-2007, the probability of shutdown per event can be determined by the joint probability of benzene spill event mass (M) and annual low flow (Q) as follows:

$$P[shut\ down\ per\ event] = P[Q=<4723.71\frac{m^3}{s}] * P[M=>7KG] = 0.81*0.52=0.42$$

The probability of shut down per year:

$$P[shut\ down\ per\ year] = P[shut\ down\ per\ spill\ event] * \frac{\#\ events}{year} = 0.42*\frac{7}{10} = 0.29$$

The risk (R) of benzene spill in a two year period can be estimated by:

$$R = 1 - (1 - P[shut\ down\ per\ year])^n$$

In which *n* is the period of consideration in years. Using the SLEA data between 1998 and 2007, the risk of the risk of WTP shutdown over 2, 3, 4, and 5-year periods is shown in Table 5.7.

Table 5.7 The risk of WTP shutdown based on benzene spills recorded by the SLEA between 1998 and 2007

Risk of WTP shutdown in 2 year	50%
Risk of WTP shutdown in 3 year	65%
Risk of WTP shutdown in 4 year	75%
Risk of WTP shutdown in 5 year	83%

The risk of WTP shutdown due to benzene spills in a two-year period is 50% based on the number of spills recorded by the SLEA between 1998 and 2007.

5.5 Risk Analysis of Vinyl Chloride

The risk of WTP shutdown due to vinyl chloride spills in a two-year period was determined using the spills date, spill quantity (kg), and the corresponding river flow in Table 5.8.

Table 5.8 SLEA WTP shutdown record for vinyl chloride spills and the corresponding St. Clair River daily mean flow provided by Environment Canada

Date	Mass (kg)	Flow (m^3/s)
20-Jul-1990	53.00	5462.53
14-Aug-2003	133.00	4747.13

5.5.1 Risk Analysis Using the SAC Data

There were five vinyl chloride spills recorded by the SAC between 1988 and 1997 and one between 1998 and 2007, as shown in Table 5.9. An excerpt of the vinyl chloride spill records from the SAC data is found in Appendix VI. These spills all reportedly impacted the watercourses in the St. Clair River AOC.

Table 5.9 Vinyl chloride spills to the water courses in the St. Clair River AOC (SAC data)

Date	Mass (kg)
20-Jul-1990	17.00
13-Aug-1990	1200.00
10-Mar-1991	7.90
2-Jun-1991	16.00
7-Jan-1995	7.00
14-Aug-2003	100.00

As indicated, the SAC data did not provide any shutdown records due to vinyl chloride spills. An assumption was made to use the SLEA shutdown dates and the corresponding SAC vinyl chloride spills for calculating the risk of shutdown. A shutdown was identified by cross-referencing the SLEA shutdown dates with the corresponding SAC vinyl chloride spill date and event mass. There were two shutdowns, July 20, 1990 and August 14, 2003 between 1988 and 1997. However, the reported spill masses of these data sets were not identical. For instance, July 20, 1990 spill mass recorded by the SAC and SLEA are of 17kg and 53kg, respectively. Such discrepancy will yield a significant difference in the risk calculation. As a result, it was not possible to determine the risk for the period between 1988 and 1997. The following section shows the risk calculation for the period between 1998 and 2007.

The probability distribution curves of spill event mass and river flow were fitted with theoretical probability distributions. Figure 5.9 shows the probability distribution curves for vinyl chloride spill mass (of the 6 spill events recorded by the SAC) between 1998 and 2007. Given the limited number of data points, it was determined that the log-normal probability distribution was generally appropriate for describing the vinyl chloride spill event mass. The annual low flow had the normal probability distribution as shown in Figure 5.7.

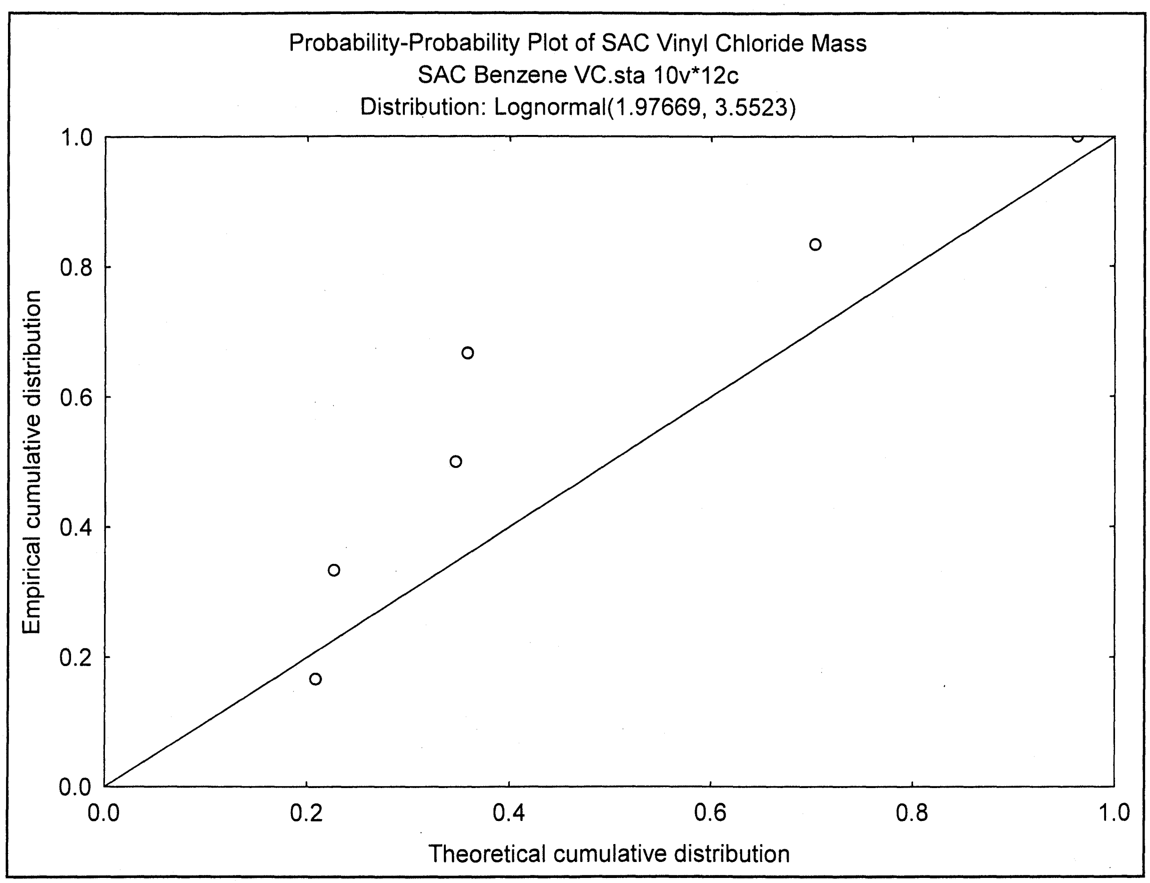

Figure 5.9 Log-normal probability distribution fitting of vinyl chloride spill event mass recorded by the SAC

Using the SAC data between 1998 and 2007, the probability of shutdown per event can be determined by the joint probability of vinyl chloride spill event mass (M) and annual low flow (Q) as follows:

$$P[shut\ down\ per\ event] = P[Q=<4747.13\frac{m^3}{s}] * P[M=>133KG] = 0.82*0.25=0.21$$

The probability of shut down per year:

$$P[shut\ down\ per\ year] = P[shut\ down\ per\ spill\ event] * \frac{\#\ events}{year} = 0.21*\frac{1}{10} = 0.02$$

The risk (R) of benzene spill in a two year period can be estimated by:

$$R = 1 - (1 - P[shut\ down\ per\ year])^n$$

In which n is the period of consideration in years. Using the SAC data between 1998 and 2007, the risk of WTP shutdown over 2, 3, 4, and 5-year periods is shown in Table 5.10.

Table 5.10 The risk of WTP shutdown based on vinyl chloride spills recorded by the SAC between 1998 and 2007

Risk of WTP shutdown in 2 year	4%
Risk of WTP shutdown in 3 year	6%
Risk of WTP shutdown in 4 year	8%
Risk of WTP shutdown in 5 year	10%

The risk of WTP shutdown due to vinyl chloride spills in a two-year period is 4% based on the number of spills recorded by the SAC between 1998 and 2007.

5.5.2 Risk Analysis Using the SLEA Data

There were 8 vinyl chloride spills to the St. Clair River recorded by the SLEA between 1988 and 2007. Table 5.11 shows the vinyl chloride spill dates and event masses. The probability distribution curve of vinyl chloride spill mass was fitted with theoretical probability distributions as shown in Figure 5.10. Given such a limited number of data points, it was found that the log-normal probability distribution was generally appropriate for describing the spill event mass. As indicated in Figure 5.7, the annual low flow had the normal probability distribution.

Table 5.11 Vinyl chloride spills to the St. Clair River in 1988-2007 (SLEA data)

Date	Mass (kg)
4-Feb-1989	7.60
20-Jul-1990	53.00
10-Mar-1991	7.90
2-Jun-1991	16.00
9-Aug-1991	11.90
7-Jan-1995	7.00
14-Aug-2003	133.00
16-Aug-2003	17.00

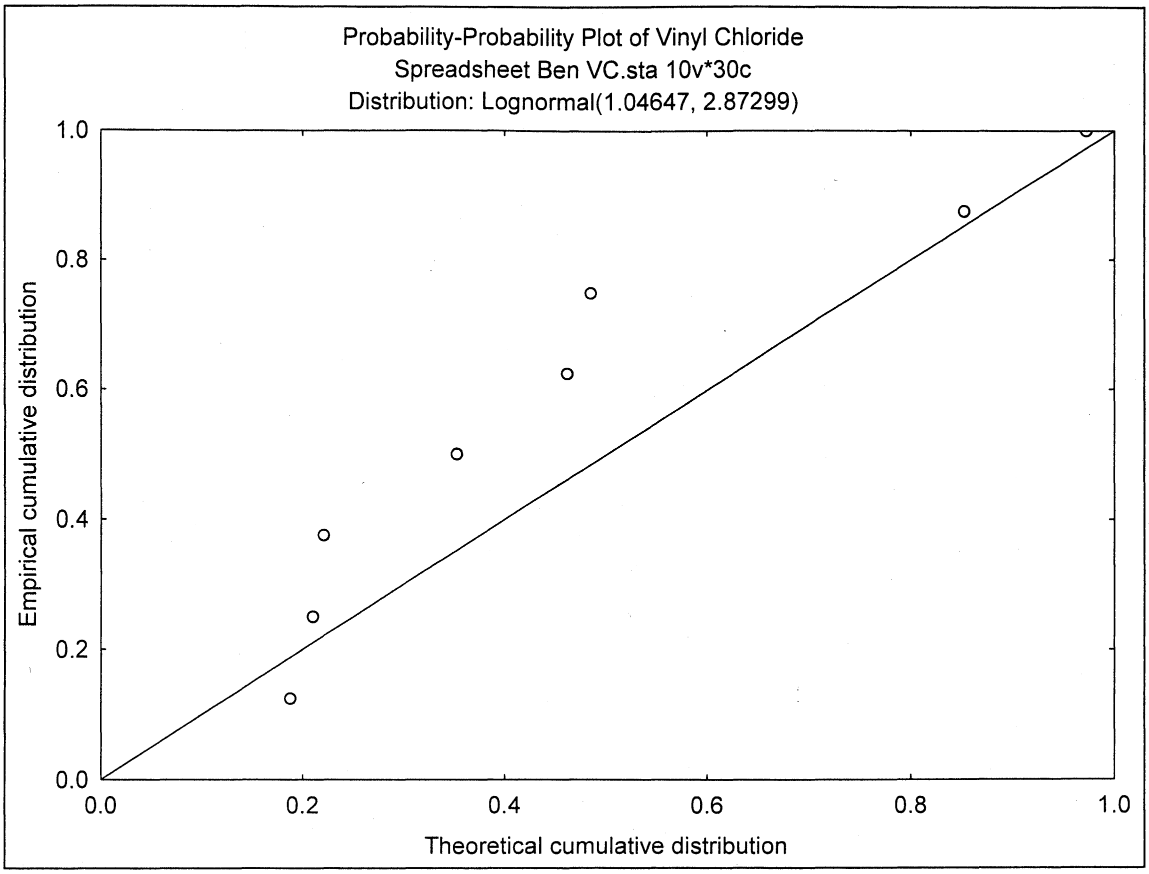

Figure 5.10 Log-normal probability distribution fitting of vinyl chloride spill event mass recorded by the SLEA

Using the SLEA data between 1988 and 1997, the probability of shutdown per even can be determined by the joint probability of vinyl chloride spill event mass (M) and annual low flow (Q) as follows:

$$P[shut\ down\ per\ event] = P[Q=<5462.53\frac{m^3}{s}] * P[M=>53KG] = 0.99*0.15= 0.15$$

The probability of shut down per year:

$$P[shut\ down\ per\ year] = P[shut\ down\ per\ spill\ event] * \frac{\#\ events}{year} = 0.15*\frac{6}{10} = 0.09$$

The risk (R) of benzene spill in a two year period can be estimated by

$$R = 1 - (1 - P[shut\ down\ per\ year])^n$$

in which n is the period of consideration in years. Using the SLEA data between 1988 and 1997, the risk of the risk of WTP shutdown over 2, 3, 4, and 5-year periods is shown in Table 5.12.

Table 5.12 The risk of WTP shutdown based on vinyl chloride spills recorded by the SLEA between 1988 and 1997

Risk of WTP shutdown in 2 year	17%
Risk of WTP shutdown in 3 year	25%
Risk of WTP shutdown in 4 year	31%
Risk of WTP shutdown in 6 year	38%

The risk of WTP closure due to vinyl chloride spills in a two-year period is 17% based on the number of spills recorded by the SLEA between 1988 and 1997.

For the period of 1998-2007, the probability of shutdown per event can be determined by the joint probability of benzene spill event mass (M) and annual low flow (Q) as follows:

$$P[shut\ down\ per\ event] = P[Q{=}{<}4747.13\frac{m^3}{s}] * P[M{=}{>}133KG] = 0.82*0.27 = 0.22$$

The probability of shut down per year:

$$P[shut\ down\ per\ year] = P[shut\ down\ per\ spill\ event] * \frac{\#\ events}{year} = 0.22*\frac{2}{10} = 0.04$$

The risk (R) of benzene spill in a two year period can be estimated by:

$$R = 1 - (1 - P[shut\ down\ per\ year])^n$$

In which n is the period of consideration in years. Using the SLEA data between 1998 and 2007, the risk of the risk of WTP shutdown over 2, 3, 4, and 5-year periods is shown in Table 5.13.

Table 5.13 The risk of WTP shutdown based on vinyl chloride spills recorded by the SLEA between 1998 and 2007

Risk of WTP shutdown in 2 year	9%
Risk of WTP shutdown in 3 year	13%
Risk of WTP shutdown in 4 year	17%
Risk of WTP shutdown in 6 year	20%

The risk of WTP shutdown due to vinyl chloride spills in a two-year period is 9% based on the number of spills recorded by the SLEA between1998 and 2007.

5.6 Risk Analysis Summary

From the risk calculations, it is found that the risk of shutdown is strongly affected by the number of spills in the period of analysis. In order to investigate the sensitivity of the risk calculations, the benzene and vinyl chloride spills which occurred between 1988 and 2007 are divided up into 5, 10, 15, and 20-year intervals.

Table 5.14 and Table 5.15 show the risk of shutdown in a two-year period based on the benzene and vinyl chloride spill events recorded by the SAC and SLEA at a 5-year interval. Table 5.16 and Table 5.17 show the risks at a 10-year interval. Notable are the projected risks of shutdown at 0%. The risk is null if no spill events are recorded in the time interval. It is possible to observe the risks for each chemical relative to the time period.

Table 5.14 The risk of shutdown in two years due to benzene spill events at a 5-year interval

SAC data 5-year interval	
Benzene spill risk	Year 2
1988-1992	0%
1993-1997	55%
1998-2002	0%
2003-2007	0%

SLEA data 5-year interval	
Benzene spill risk	Year 2
1988-1992	99%
1993-1997	35%
1998-2002	0%
2003-2007	31%

Table 5.15 The risk of shutdown in two years due to vinyl chloride spill events at a 5-year interval

SAC data 5-year interval	
Vinyl chloride spill risk	Year 2
1988-1992	0%
1993-1997	0%
1998-2002	0%
2003-2007	2%

SLEA data 5-year interval	
Vinyl chloride spill risk	Year 2
1988-1992	28%
1993-1997	0%
1998-2002	0%
2003-2007	17%

Table 5.16 The risk of shutdown in two years due to benzene spill events at a 10-year interval

SAC data 10-year interval	
Benzene spill risk	Year 2
1988-1997	74%
1998-2007	43%

SLEA data 10-year interval	
Benzene spill risk	Year 2
1988-1997	86%
1998-2007	50%

Table 5.17 The risk of shutdown in two years due to vinyl chloride spill events at a 10-year interval

SAC data 10-year interval	
Vinyl chloride spill risk	Year 2
1988-1997	0%
1998-2007	4%

SLEA data 10-year interval	
Vinyl chloride spill risk	Year 2
1988-1997	17%
1998-2007	9%

The risk of shutdown can also be presented based on the number of spill events in succession of 5, 10, 15, and 20-year intervals from 1988 to 2007. Table 5.18 and Table 5.19 show the risk of shutdown for the benzene and vinyl chloride spill events in a 5, 10, 15, and 20-year interval respectively.

Table 5.18 Risk of shutdown in two years due to benzene spill events at 5, 10, 15, 20-year intervals beginning from 1988 to 2007

SAC data	
Benzene spill risk	Year 2
5-year analysis (1988-1992)	0%
10-year analysis (1988-1997)	74%
15-year analysis (1988-2002)	55%
20-year analysis (1988-2007)	43%

SLEA data	
Benzene spill risk	Year 2
5-year analysis (1988-1992)	99%
10-year analysis (1988-1997)	86%
15-year analysis (1988-2002)	73%
20-year analysis (1988-2007)	86%

Table 5.19 Risk of shutdown in two years due to vinyl chloride spill events at 5, 10, 15, 20-year intervals beginning from 1988 to 2007

SAC data	
Vinyl chloride spill risk	Year 2
5-year analysis (1988-1992)	0%
10-year analysis (1988-1997)	0%
15-year analysis (1988-2002)	0%
20-year analysis (1988-2007)	3%

SLEA data	
Vinyl chloride spill risk	Year 2
5-year analysis (1988-1992)	28%
10-year analysis (1988-1997)	17%
15-year analysis (1988-2002)	12%
20-year analysis (1988-2007)	10%

Table 5.20 and Table 5.21 show the risk of a shutdown caused by benzene and vinyl chloride spill events in 5, 10, 15, and 20-year intervals retrospectively from 2007 to 1988. It is noted that the risk of shutdown is decreasing from 1988 to 2007.

Table 5.20 Risk of a shutdown in two years due to benzene spill events at 5, 10, 15, 20-year intervals beginning from 2007 to 1988

SAC data	
Benzene spill risk	Year 2
5-year analysis (2003-2007)	0%
10-year analysis (1998-2007)	0%
15-year analysis (1993-2007)	43%
20-year analysis (1988-2007)	43%

SLEA data	
Benzene spill risk	Year 2
5-year analysis (2003-2007)	30%
10-year analysis (1998-2007)	50%
15-year analysis (1993-2007)	56%
20-year analysis (1988-2007)	86%

Table 5.21 Risk of shutdown in two years due to vinyl chloride spill events at 5, 10, 15, 20-year intervals beginning from 2007 to 1988

SAC data	
Vinyl chloride spill risk	Year 2
5-year analysis (2003-2007)	2%
10-year analysis (1998-2007)	4%
15-year analysis (1993-2007)	5%
20-year analysis (1988-2007)	20%

SLEA data	
Vinyl chloride spill risk	Year 2
5-year analysis (2003-2007)	17%
10-year analysis (1998-2007)	9%
15-year analysis (1993-2007)	9%
20-year analysis (1988-2007)	10%

6.0 Conclusions and Recommendations

6.1 A Summary of Findings

The major findings of the study are listed below:

1. Effective quantitative BUI delisting targets should consider the risk of violating the restoration targets.
2. Risk management should be considered in the recovery process of the AOC.
3. Risk-based spill management criteria should be used to evaluate the effectiveness of spill prevention and control programs.
4. In order to accurately evaluate the risk of WTP shutdowns due to spills, Monte-Carlo simulations and spill modeling of the fate of the spilled chemicals from the source to the WTP intake should be undertaken.
5. A conservative probabilistic approach for estimating the risk of WTP shutdowns due to spills is to determine the probability of the joint occurrence of the smallest spilled chemical event mass and the smallest low flow rate.
6. Spill management regulations have become more stringent in the past two decades.
7. Spill management regimes are shifting from recovery actions to abatement and risk reduction protocols.
8. Spills are a threat to source water and water intake locations. WTP shutdown is categorized as a high threat priority under the OCWA.
9. Non-scheduled WTP shutdowns are typically associated with non-compliance with drinking water standards, Ministry advisory or notification, emergency power failure, combined sewer overflow, and emergency effluent bypass.

10. Receiving water monitoring is a valuable tool for detecting spills and providing early warnings for vulnerable water supply features, such as WTP intakes.
11. Chemical spills in the St. Clair River AOC decreased from over 100 spills to below 20 spills from 1988 to 1999, and increased again to 40 spills in 2007.
12. The top three causes of chemical spills in the St. Clair River AOC were due to Valve/Fitting Leak/Failure, Unknown Causes, and Process Upset based on the total number of occurrences.
13. From 1988 to 2002, the Chemical sector in the St. Clair River AOC was responsible for most of the chemical spills, followed by the Petroleum and General Manufacturing sector at 47%, 20%, and 19%, respectively.
14. Valve/Fitting Leak/Failure, Discharge/Bypass to Watercourse, and Pipe Line Leak were responsible for 64% of chemical spills from the Chemical sector from 1988 to 2002.
15. The Petroleum Refineries and Organic Chemicals Manufacturing sector each were responsible for 23% of the chemical spills in the St. Clair River AOC in 2003-2007.
16. Discharge to Air, Pipe/Hose Leak, and Start Ups/Shutdowns/Interruptions were responsible for 70% of the chemical spills in the St. Clair River AOC from 2003 to 2007.
17. 61% of all chemical spills in the St. Clair River AOC have an impact on Air, Water Courses and Surface Water, Soil and Vegetation, and Human Health and Safety.
18. The SLEA data had 24 shutdown records in the period between 1988 and 2005, while the SAC data had 3.
19. According to the SAC data, benzene and vinyl chloride had the highest number of occurrences with mass in the St. Clair River AOC.
20. Discharge/Bypass to Water Courses was responsible for 97% of all benzene spills.
21. Other Discharges and Valve Fitting/Leak/Failures contributed to 72% of all vinyl chloride spills.
22. The Provincial Water Quality Objectives impose MAC on 6 of the 14 chemicals that have been found to cause past WTP shutdowns in the St. Clair River AOC.

23. The Provincial Water Quality Objectives, Ontario Drinking Water Standards, and the Canada Drinking Water Guidelines all have MACs for benzene, ethylbenzene, toluene, and vinyl chloride.
24. River flow in the St. Clair River fluctuates the most in the months of January to March.
25. Daily mean flow is more representative of the actual flow in the St. Clair River when the flow duration curves of the daily mean flow are compared to those of the monthly mean flow.
26. The normal probability distribution may be used to describe the annual low flow in the St. Clair River and the log-normal probability distribution may be used to describe the chemical spill event masses in the St. Clair River AOC.
27. The risk of WTP shutdown due to benzene spills in a two-year period is 86% and 50%, according to the SLEA data from 1988 to1997 and 1998 to 2007, respectively.
28. The risk of a WTP shutdown due to vinyl chloride spills in a two-year period is 17% and 9%, based on the SLEA data from 1988 to 1997 and 1998 to 2007, respectively.
29. The risk of a WTP shutdown due to benzene spills in a two-year period is 74% and 43%, according to the SAC data from 1988 to 1997 and 1998 to 2007, respectively.
30. The risk of a WTP shutdown due to vinyl chloride spills in a two-year period is 0% and 4%, based on SLEA data from 1988 to 1997 and 1998 to 2007, respectively.
31. The risk of WTP shutdown due to spills has been decreasing over the past 20 years.
32. Further research is required to determine the significance of the risk level presented in this study. One method is to use the costs and benefits analysis.

6.2 Concluding Remarks

The result of the risk analysis suggests that there is a strong link between spills and water intake shutdowns in the St. Clair River AOC. On one hand, local spill management should consider the explicit possibility of intake shutdowns due to spills. The development of risk-based spill management as proposed in this study uses statistical analysis to study historical spills to determine the risk. Despite the trend of spills has been decreasing in the past 20 years, the statistical analysis shows that spills are episodic in their frequencies and magnitudes. Spill abatement strategies should focus not only on spill frequency but spill event mass as well. On the other hand, water quality parameters should consider chemicals which are often found in spills. For example, the chemical, isobutene is currently not part of any Canadian safe water quality parameters (Table 4.8). Chemicals that are found to occur frequently and with large spill mass should also be suspected for requiring water quality safety limits.

The development of risk-based spill management criteria provides a risk estimate for a specific time period. One advantage to this application is that it is able to quantify the risk by using a relatively simple calculation. Another advantage is that it now enables the AOC to evaluate the BUIs progress on a time-sensitive basis based on the risk of violation for BUIs. However, as shown in section 5.6, the risk can greatly vary depending on the analysis period. From this study, it is observed from past spill records that spill frequency was highest in the late '80s and early '90s. If the risk analysis period only focuses on the years where the number of spills is the highest, the risk of violation is high. Yet, if the risk analysis period is "stretched out" to the years where the general trend of spills is in a decrease, the result of the risk is comparatively lower. Therefore, it is important to select an analysis period that is representative of the current spill trend. Alternatively, a comparison of the risks, as presented in section 5.6, should be reviewed with a clear understanding of the spill frequency in each analysis period.

This study introduces the concept of risk-based spill management by using intake shutdowns. The risks presented in the study are initial estimates. The accuracy of the risks can be further refined by examining the stochastic nature of the spill and receiving water characteristics. The current study focuses on the statistical analysis rather than on the chemical and geo-physical simulation of the movement of the contaminant in the water. Future studies should consider spill modeling that formulates all possible conditions under which an intake can be shutdown. Such a study will provide a more realistic account of spill behaviour in the river. The risks provided in this study should therefore be used as a general benchmark.

6.3 Recommendations

Beyond the scope of this study is the research required to determine the actual acceptable risk. Costs and benefits analysis is one common tool that is used to evaluate the appropriate risk level. The incremental reduction in the risk of WTP shutdowns induces the marginal costs and benefits. Further research is required to determine the monetary value of the specific consequences of spills and WTP shutdowns. It is important to examine the value of the actual and less tangible commodities, such as the cost of re-starting the WTP, the loss of water pressure in the water treatment system, local fish habitat destruction, and tax payers' confidence in the local drinking water supply. Figure 6.1 shows the marginal costs and benefits curve where ideally the point of intersection would indicate the optimal risk level. Without such an analysis, it would be difficult to determine the acceptable risk.

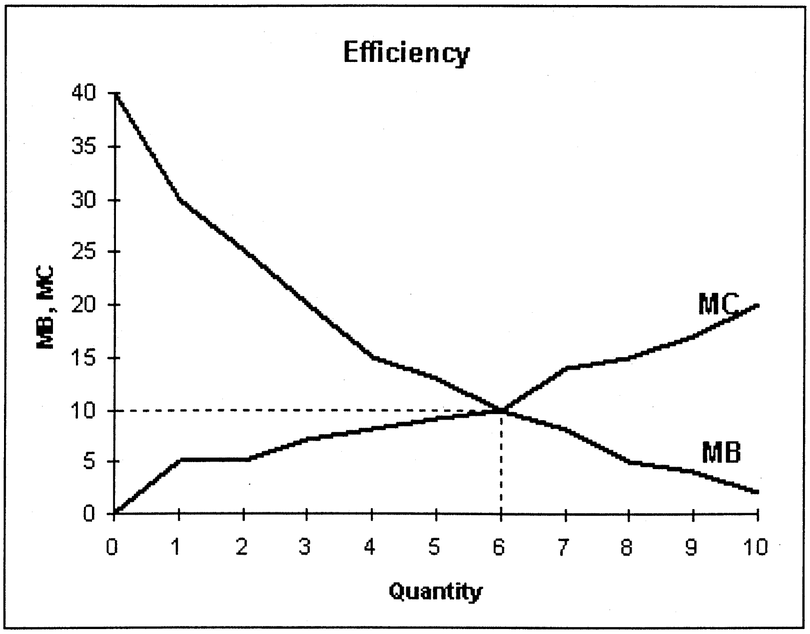

Figure 6.1 The marginal costs and benefits curve (Cooper and Weekes, 1983)

In addition, future research should stem from improved spill data. This study reveals that the existing spill records do not provide the amount of material that is recovered after each spill. The information can improve the accuracy of the spill statistical analysis. Also, the analysis shows that there are discrepancies between the two sources, especially regarding the previous shutdowns. The SAC data consistently show a fewer number of spill events for benzene and vinyl chloride compared to the SLEA record. Lastly, it is difficult to obtain shutdown records from specific WTPs, hence making it difficult to cross-reference any spill events by date and mass, as well as to confirm the occurrences of shutdowns. WTPs shutdown records should be made readily available to the CRIC for assessment and review purposes.

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Appendix I SAC Spill Response Procedure Card

Below is an example of a SAC spill response procedure card (Bowering, V., personal communication, August 19, 2008).

Spills to Watercourses *

For all Spills to the Great Lakes and their Interconnecting Channels – see also Card <u>11</u>, <u>20</u> and <u>21</u>

During Business Hours SAC Officers are to Contact the District/Area Office for <u>ALL SPILLS</u>

Card 10

Additional questions following Primary Assessment - <u>Card 3</u>:

<u>Reporting Details</u>

1. Name of watercourse?
2. Location of spill on watercourse?
3. Flow of watercourse?
4. Is the impacted part of the watercourse accessible by land?
5. Is there a water treatment plant downstream?
6. Name of conservation authority?
7. Has municipality been notified?

<u>Note:</u>

- *If fish or waterfowl kill, also see <u>Card 39</u>.*
- *If pesticides involved, also see <u>Card 17</u>.*
- *If manure spill, also see <u>Card 42-C</u>.*
- *For all spills to Great Lakes or their Interconnecting Channels, also see <u>Card 11</u>, and as applicable Cards <u>20</u> and <u>21</u>.*

→ **Is the size and type of spill potentially hazardous, e.g., threatens health, safety, environment?**

No → Complete report and forward to MOE District Office

Yes → SAC Actions

A sewage bypass due to equipment failure, power failure or abnormal occurrence such as flood conditions.

<u>Note:</u> Sewage bypasses/overflow are often weather related, and are almost always directed to the nearest surface watercourse.

→

- MOE <u>Procedure F-5-1</u> requires the plant operator to notify SAC and the local health unit. SAC may assist with notification if this action appears to be necessary.
- Note intent of items #3 to 5 in the SAC Actions to the right.
- **Note** <u>Card 34</u>.

<u>SAC Actions:</u>

1. Ensure Police, Fire Dept, and Works Dept. are notified as required.
2. During business hours contact district office. Off hours determine need to dispatch ERP as per "call-out criteria" (note <u>Card 1-C</u>) with any route directions established by police or other authority in charge on-site.
3. Contact local health unit if the spill has the potential to impact public health or private drinking water users.
4. Contact WTP's if they may be affected. See 'Surface Water Intakes Municipal <u>WTP's</u> binder for municipal systems. If water intakes are to be closed, then notify <u>SDWB DW Compliance Operations Coordinator</u> , see 'Drinking Water Management Division' binder. See "Other Agencies" binder, Health Canada section for drinking water health threats to First Nations and federal facilities. Note <u>Card 38-E</u> for DWMD support and <u>Card 56</u> for First Nations.
5. For a major fish kill or significant watercourse impairment, contact Environment Canada (<u>Card 24</u>), possibly MNR (<u>Card 23</u>), and park & conservation authorities. See also <u>Card 24</u> for spills of "National Interest".
6. For spills from a vessel, notify Env. Canada and the CCG*, note Cards <u>11</u>, <u>20</u> and <u>21</u>.
7. If the release threatens to cross a boundary (Provincial or International), notify the neighbouring jurisdiction environmental contacts, Environment Canada see Card 24 and CCG**. Note <u>Card 35</u> and "Other Government Agencies" contact sheets (harbour authorities and US contacts also noted in <u>Card 11</u>).
8. If report suggests that there is likely a need for addition MOE support refer to <u>Card 57</u>. Brief SAC management.
9. If water intakes are to be closed **NOTE** <u>Card 53</u> **EMO-PEOC**.
10. If workers are affected, contact MOL as per MOL procedures.
11. For media support, brief MOE Communications (see also <u>Card 7</u>).
12. For incidents that involve sinking of vessels, vehicles, aircraft and equipment contact <u>MOL Diving Notification Centre</u>

*Essentially all surface waters, including tributary streams, wetlands, ponds, lakes, etc.
**In addition to verbally notifying CCG also fax the report to 519-383-1879

Last Revised: June 20, 2008

Appendix II Beneficial Use Impairments Listing/Delisting Guidelines

Tables II.1-5 show the criteria for listing and delisting the use impairments in the AOCs (Hartig et al., 1997, p. 715).

Table II.1 Guidelines for listing and delisting the use impairments

Use Impairments	Listing guidelines	Delisting Guidelines
Restrictions on fish and wildlife consumption	When contaminant levels in fish or wildlife populations exceed current standards, objectives, or guidelines or public health advisories are in effect for human consumption of fish or wildlife. Note: Contaminant levels in fish and wildlife must be due to contaminant input from watershed.	When contaminant levels in fish and wildlife populations do not exceed current standards, objectives or guidelines and no public health advisories are in effect for human consumption of fish or wildlife. Note: Contaminant levels in fish and wildlife must be due to contaminant input from watershed. When survey results confirm no tainting of fish or wildlife flavor.
Tainting of fish and wildlife flavor	When ambient water quality standards, objectives, or guidelines, for the anthropogenic substance(s) known to cause tainting, are being exceeded or survey results have identified tainting of fish or wildlife flavor.	When survey results confirm no tainting of fish or wildlife flavor.

Table II.2 Guidelines for listing and delisting the use impairments

Use Impairments	Listing guidelines	Delisting Guidelines
Degraded fish and wildlife populations	When fish and wildlife management programs have identified degraded fish or wildlife populations due to a cause within the watershed. In addition, this use will be considered impaired when relevant, field-validated fish or wildlife bioassays with appropriate quality assurance/quality controls confirm significant toxicity from water column or sediment contaminants.	When environmental conditions support healthy, self-sustaining communities of desired fish and wildlife at predetermined levels of abundance that would be expected from the amount and quality of suitable physical, chemical, and biological habitat present. An effort must be made to ensure that fish and wildlife objectives for areas of concern are consistent with Great Lakes ecosystem objectives and Great Lakes Fishery Commission fish community goals. Furthermore, in the absence of community structure data, this use will be considered restored when fish and wildlife bioassays confirm no significant toxicity from water column or sediment contaminants.
Fish tumours or other deformities	When the incidence rates of fish tumors or other deformities exceed rates at unimpacted control sites or when survey data confirm the presence of neoplastic or preneoplastic liver tumors in bullheads or suckers.	When the incidence rates of fish tumors or other deformities do not exceed rates at unimpacted control sites and when survey data confirm the absence of neoplastic or preneoplastic liver tumors in bullheads or suckers.

Table II.3 Guidelines for listing and delisting the use impairments

Use Impairments	Listing guidelines	Delisting Guidelines
Bird or animal deformities or reproductive problems	When wildlife survey data confirm the presence of deformities (e.g. cross-bill syndrome) or other reproductive problems (e.g. egg-shell thinning) in sentinel wildlife species.	When the incidence rates of deformities (e.g. cross-bill syndrome) or reproductive problems (e.g. egg-shell thinning) in sentinel wildlife species do not exceed background levels in inland control populations.
Degradation of benthos	When benthic macroinvertebrate community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when toxicity (as defined by relevant, field-validated bioassays with appropriate quality assurance/quality controls) of sediments-associated contaminants at a site is significantly higher than controls.	When benthic macroinvertebrate community structure does not significantly diverge from unimpacted control sites of comparable physical and chemical characteristics. Furthermore, in the absence of community structure data, this use will be considered restored when toxicity of sediment-associated contaminants is not significantly higher than controls.
Restrictions on dredging activities	When contaminants in sediments exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities.	When contaminants in sediments do not exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities.

Table II.4 Guidelines for listing and delisting the use impairments

Use Impairments	Listing guidelines	Delisting Guidelines
Eutrophication or undesirable algae	When there are persistent water quality problems (e.g. dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, etc.) attributed to cultural eutrophication.	When there are no persistent water quality problems (e.g. dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, etc.) attributed to cultural eutrophication.
Restrictions on drinking water consumption or taste or odor problems	When treated drinking water supplies are impacted to the extent that: 1) densities of disease-causing organisms or concentrations of hazardous/toxic chemicals or radioactive substances exceed human health standards, objectives, or guidelines; 2) taste and odour problems are present; or 3) treatment needed to make raw water suitable for drinking is beyond the standard treatment used in comparable portions of the Great Lakes which are not degraded (i.e. settling, coagulation, disinfection).	For treated drinking water supplies; 1) when densities of disease-causing organisms or concentrations of hazardous/toxic chemicals or radioactive substances do not exceed human health standards, objectives, or guidelines; 2) when taste and odour problems are absent; and 3) when treatment needed to make raw water suitable for drinking does not exceed standard treatment.
Beach closings	When water commonly used for total body contact or partial body contact recreation exceed standards, objectives, or guidelines for such use.	When water commonly used for total body contact or partial body contact reaction do not exceed standards, objectives, or guidelines for such use.

Table II.5 Guidelines for listing and delisting the use impairments

Use Impairments	Listing guidelines	Delisting Guidelines
Degradation of aesthetics	When any substance in water produces a persistent objectionable deposit, unnatural colour or turbidity, or unnatural odour (e.g. oil slick, surface scum).	When the waters are devoid of any substance that produces a persistent objectionable deposit, unnatural colour or turbidity, or unnatural odour (e.g. oil slick, surface scum).
Degradation of phytoplankton and zooplankton populations	When phytoplankton or zooplankton community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when relevant, field validated phytoplankton or zooplankton bioassays (e.g. *Ceriodaphnia*; algal fractionation bioassays) with appropriate quality assurance/quality controls confirm toxicity in ambient waters.	When phytoplankton or zooplankton community structure does not significantly diverge from unimpacted control sites of comparable physical and chemical characteristics. Furthermore, in the absence of community structure data, this use is considered restored when plankton bioassays confirm no toxicity in ambient waters.
Added costs to agriculture or industry	When there are additional costs required to treat the water prior to use for agricultural purposes (i.e. including but not limited to, livestock watering, irrigation and crop-spraying) or industrial purposes (i.e. intended for commercial or industrial applications and noncontact food processing).	When there are no additional costs required to treat the water prior to use for agricultural or industrial purposes (as defined above).

Table II.6 Guidelines for listing and delisting the use impairments

Use Impairments	Listing guidelines	Delisting Guidelines
Loss of fish and wildlife habitat	When fish and wildlife management goals have not been met as a result of loss of fish and wildlife habitat due to a perturbation in the physical, chemical, or biological integrity of the boundary waters, including wetlands.	When the amount of physical, chemical and biological habitat required to meet fish and wildlife management goals has been achieved and protected.

Appendix III A Review of AOC Delisting Criteria

The author of this study obtained the delisting criteria of 31 AOC from the Great Lakes Commission (2003). The purpose of the review is to find out how many delisting criteria have quantitative and measurable targets. Tables III.1-4 are summaries of the types of delisting criteria found in the AOC.

There were a total of 434 delisting criteria and they were categorized into types, each type was represented by a symbol as shown in Table III.1. An example of a quantitative delisting criterion is "The N:P ratio measured in Saginaw Bay is at least 29:1...indicating that conditions once favoring blue-green algal populations responsible for former taste and odor problems in drinking water withdrawn from the bay are no longer present" (Great Lakes Commission, 2003). Terms such as "enhance", "improve", "remediate" and "restore" were considered as qualitative description if no measurable targets were mentioned. An example of the Measurable Restoration Target with Time Target is "Three consecutive years of testing for E. coli bacteria, an indicator of the presence of harmful microorganisms, confirm that state water quality standards for full-body recreation are being met" (Ibid.). Table III.2 shows the 14 BUIs stated in the GLWQA. Table III.3 charts the type of delisting criteria observed for the 14 BUIs at the 31 AOC. Table III.4 summaries the result of the review.

Table III.1 Symbols representing the types of delisting criteria

Legend	Types of Delisting Criteria
□	Qualitative/ Measurable Target
♦	Target Not Yet Defined
—	Not Impaired
●	Measurable Restoration Target
■	Measurable Restoration and Time Target

Table III.2 The 14 BUIs stated in the GLWQA

No.	Beneficial Use Impairment
1	Restrictions on fish and wildlife consumption
2	Tainting of fish and wildlife flavour
3	Degradation of fish and wildlife populations
4	Fish tumours or other deformities
5	Bird or animal deformities or reproductive problems
6	Degradation of benthos
7	Restrictions on dredging activities
8	Eutrophication or undesirable algae
9	Restrictions on drinking water consumption, or taste and odour problems
10	Beach closings
11	Degradation of aesthetics
12	Degradation of phytoplankton and zooplankton populations
13	Added costs to agriculture or industry
14	Loss of fish and wildlife habitat

Table III.3 The types of delisting criteria observed in the 31 AOC

	Areas of Concern	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Ashtabula River	♦	—	♦	●	♦	♦	♦	♦	■	■	♦	♦	♦	□
2	Black River	♦	—	♦	♦	—	♦	♦	♦	♦	♦	♦	—	—	♦
3	Buffalo River	♦	—	—	♦	—	♦	♦	—	—	—	—	—	—	♦
4	Clinton River	♦	—	♦	—	—	♦	♦	♦	—	♦	♦	—	—	♦
5	Cuyahoga River	♦	—	♦	—	—	♦	♦	♦	—	♦	♦	♦	—	♦
6	Deer Lake	●	—	—	—	—	—	♦	—	—	—	—	—	—	—
7	Detroit River	■	♦	—	●	—	●	●	—	●	●	□	—	—	●
8	Eighteenmile Creek	♦	—	—	—	—	♦	♦	—	—	—	—	—	—	—
9	Fox River/ Lower Green Bay	♦	—	♦	—	♦	♦	♦	♦	♦	♦	♦	♦	—	—
10	Grand Calumet River	●	●	■	●	♦	♦	♦	♦	●	■	●	♦	♦	□
11	Kalamazoo River	□	—	□	—	□	□	□	—	—	□	□	—	—	□
12	Manistique River	●	—	—	—	—	●	●	—	—	●	—	—	—	□
13	Maumee River	♦	—	♦	♦	—	♦	♦	♦	♦	♦	♦	—	—	♦
14	Menominee River	♦	—	♦	—	—	♦	♦	—	—	♦	—	—	—	♦
15	Milwaukee Estuary	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦	♦
16	Muskegon Lake	●	—	●	—	—	■	□	●	♦	●	□	—	—	●
17	Niagara River (US)	♦	—	—	♦	—	♦	♦	—	—	—	—	—	—	♦
18	Oswego River	♦	—	●	—	—	—	—	●	—	—	—	—	—	□
19	Presque Isle Bay	—	—	—	♦	—	—	♦	—	—	—	—	—	—	—
20	River Raisin	□	♦	□	—	●	□	□	●	—	□	□	—	—	□
21	Rochester Embayment	●	—	●	—	●	●	●	●	—	■	■	■	—	■
22	Rouge River	●	♦	■	♦	■	■	■	—	—	●	♦	—	—	■
23	Saginaw River/Bay	●	■	●	—	●	■	—	■	■	■	■	■	—	■
24	Sheboygan River	♦	♦	♦	♦	♦	♦	♦	♦	—	—	—	♦	—	—
25	St. Clair River (US)	●	—	—	—	●	●	—	—	—	■	■	—	—	—
26	St. Lawrence River (US)	♦	—	—	—	—	—	—	—	—	—	—	—	—	♦
27	St. Louis River	♦	—	♦	♦	—	♦	♦	♦	—	♦	♦	—	—	♦
28	St. Marys River	●	—	●	●	—	●	●	■	—	■	□	—	—	●
29	Torch Lake	●	—	—	—	—	♦	♦	—	♦	—	♦	—	—	♦
30	Waukegan Harbor	—	—	—	—	—	●	●	—	—	●	—	□	—	●
31	White Lake	■	—	■	—	—	■	●	■	♦	—	♦	—	—	■

Table III.4 A summary of the types of delisting criteria observed in the 31 AOC

Legend	Delisting criteria	Count	%
□	Qualitative/ Measurable Target	24	6
♦	Target Not Yet Defined	132	30
—	Not Impaired	194	45
●	Measurable Restoration Target	52	12
■	Measurable Restoration and Time Target	32	7
Total delisting criteria		434	100

Appendix IV Distribution Fitting Summaries

Statistical analysis was performed for the annual low flow, benzene, and vinyl chloride spill mass. Each set of data went through the following exercise to determine the best fit distribution curve. The distribution curve fitting was based on a combination of the following:

- a comparison of the mean and variance value purely on empirical grounds;
- a comparison of the observed frequency and the expected frequency between the model and data to determine if there were substantial discrepancies;
- the Chi-Squared goodness of fit test to determine whether the discrepancies were significant;
- a comparison of the data values and theoretical distribution values using probability plots;
- the Kolmogorov–Smirnov test to compare between the data and theoretical cumulative relative frequencies; and
- visual inspection of the distribution on the probability plots.

The statistical analysis is computed by using the software "Statistica". The following are the statistical analysis summaries for each variable.

Annual Low Flow

Variable	Descriptive Statistics (Annaul Low Flow.sta)									
	Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Variance	Std.Dev.	Skewness
Daily Mean Flow	20	4366.190	4387.698	Multiple	1	3660.279	5146.889	167318.8	409.0462	0.080119

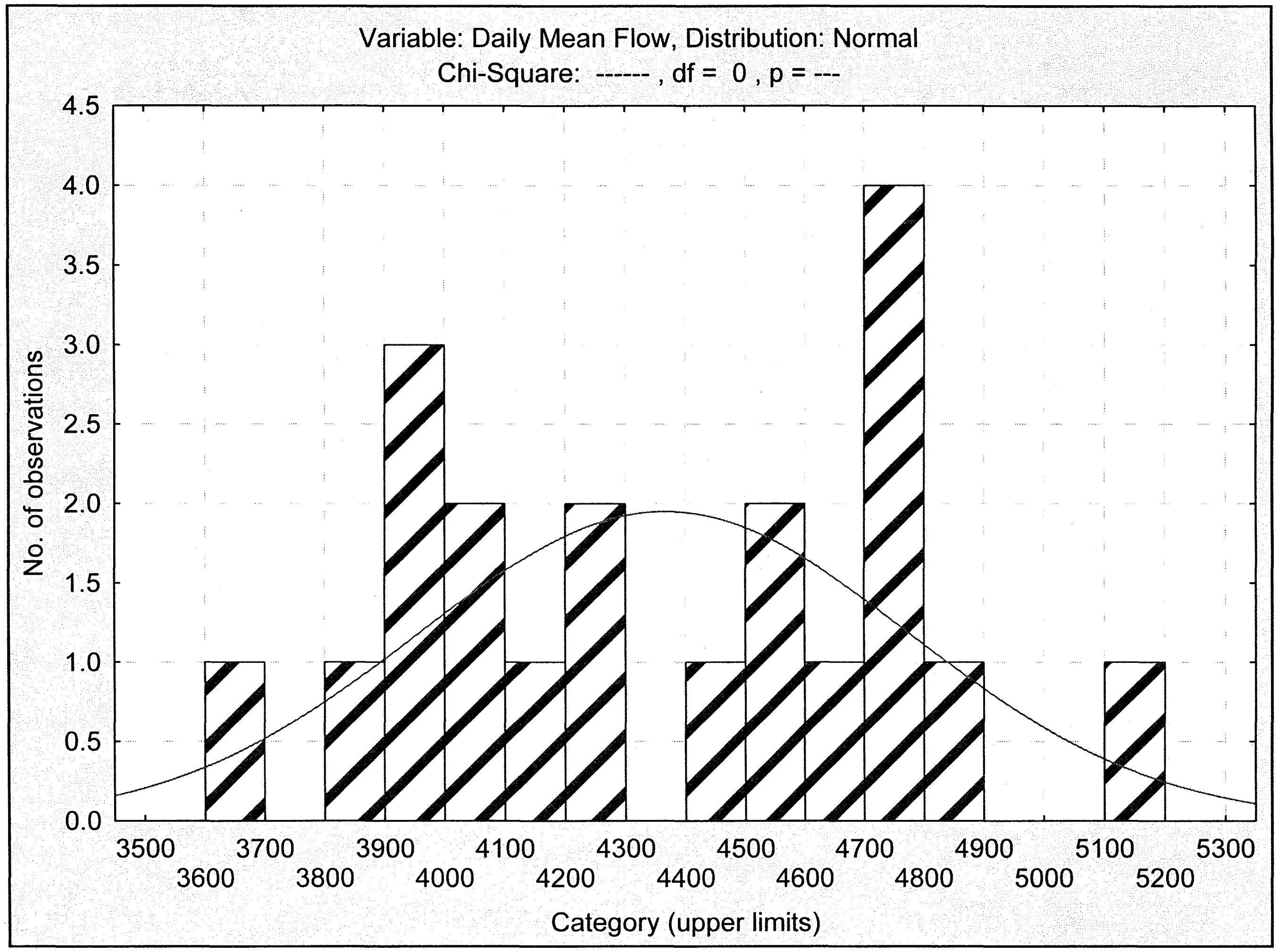
Category	Frequency table: Daily Mean Flow (Annaul Low Flow.sta) K-S d=.14016, p> .20; Lilliefors p> .20 Shapiro-Wilk W=.95472, p=.44448								
	Count	Cumulative Count	Percent of Valid	% of all Cases	Cumulative % of All	Expected Count	Cumulative Expected	Percent Expected	Cumulative % Expected
3400.000<x<=3600.000	0	0	0.00000	0.00000	0.0000	0.610526	0.61053	3.05263	3.05263
3600.000<x<=3800.000	1	1	5.00000	5.00000	5.0000	1.052532	1.66306	5.26266	8.31529
3800.000<x<=4000.000	4	5	20.00000	20.00000	25.0000	2.043585	3.70664	10.21793	18.53322
4000.000<x<=4200.000	3	8	15.00000	15.00000	40.0000	3.138672	6.84532	15.69336	34.22658
4200.000<x<=4400.000	2	10	10.00000	10.00000	50.0000	3.813426	10.65874	19.06713	53.29371
4400.000<x<=4600.000	3	13	15.00000	15.00000	65.0000	3.665310	14.32405	18.32655	71.62026
4600.000<x<=4800.000	5	18	25.00000	25.00000	90.0000	2.786956	17.11101	13.93478	85.55504
4800.000<x<=5000.000	1	19	5.00000	5.00000	95.0000	1.676333	18.78734	8.38166	93.93670
5000.000<x<=5200.000	1	20	5.00000	5.00000	100.0000	0.797584	19.58492	3.98792	97.92462
Missing	0	20	0.00000	0.00000	100.0000				

Number of valid cases:20

Observed mean = 4366.190273, Observed variance = 167318.822221

Distribution: Normal

Parameters: Mean = 4366.190, Variance = 167318.8



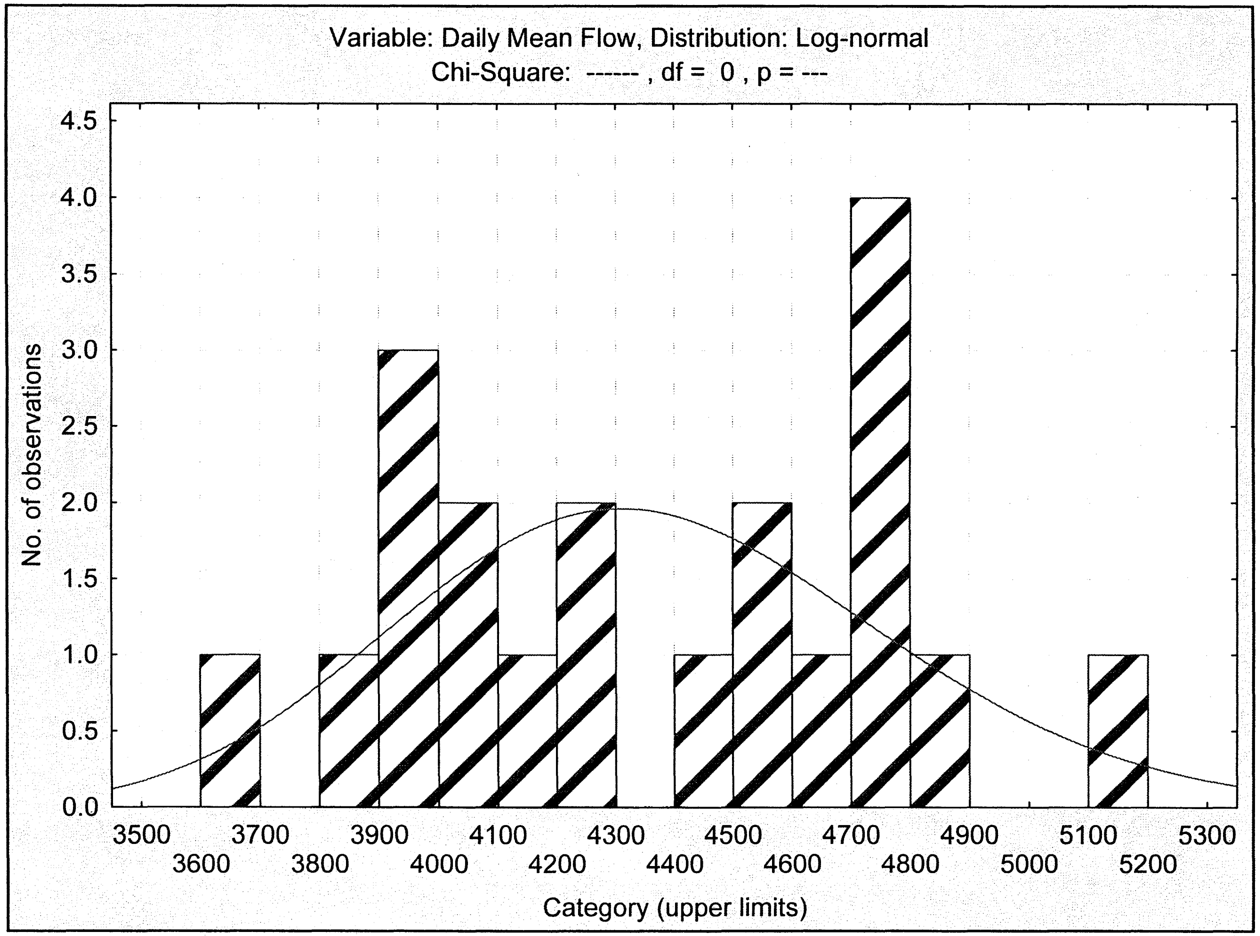
Upper Boundary	Variable: Daily Mean Flow, Distribution: Normal (Annaul Low Flow.sta) Chi-Square: ------ , df = 0 , p = ---								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 3600.00000	0	0	0.000000	0.0000	0.610526	0.61053	3.052631	3.0526	-0.61053
3700.00000	1	1	5.000000	5.0000	0.423360	1.03389	2.116800	5.1694	0.57664
3800.00000	0	1	0.000000	5.0000	0.629172	1.66306	3.145861	8.3153	-0.62917
3900.00000	1	2	5.000000	10.0000	0.881052	2.54411	4.405259	12.7206	0.11895
4000.00000	3	5	15.000000	25.0000	1.162534	3.70664	5.812669	18.5332	1.83747
4100.00000	2	7	10.000000	35.0000	1.445381	5.15202	7.226903	25.7601	0.55462
4200.00000	1	8	5.000000	40.0000	1.693291	6.84532	8.466454	34.2266	-0.69329
4300.00000	2	10	10.000000	50.0000	1.869191	8.71451	9.345956	43.5725	0.13081
4400.00000	0	10	0.000000	50.0000	1.944235	10.65874	9.721175	53.2937	-1.94423
4500.00000	1	11	5.000000	55.0000	1.905534	12.56428	9.527669	62.8214	-0.90553
4600.00000	2	13	10.000000	65.0000	1.759776	14.32405	8.798882	71.6203	0.24022
4700.00000	1	14	5.000000	70.0000	1.531338	15.85539	7.656692	79.2770	-0.53134
4800.00000	4	18	20.000000	90.0000	1.255618	17.11101	6.278090	85.5550	2.74438
4900.00000	1	19	5.000000	95.0000	0.970100	18.08111	4.850500	90.4055	0.02990
5000.00000	0	19	0.000000	95.0000	0.706233	18.78734	3.531163	93.9367	-0.70623
5100.00000	0	19	0.000000	95.0000	0.484453	19.27179	2.422263	96.3590	-0.48445
5200.00000	1	20	5.000000	100.0000	0.313131	19.58492	1.565657	97.9246	0.68687
< Infinity	0	20	0.000000	100.0000	0.415075	20.00000	2.075377	100.0000	-0.41508

Number of valid cases:20

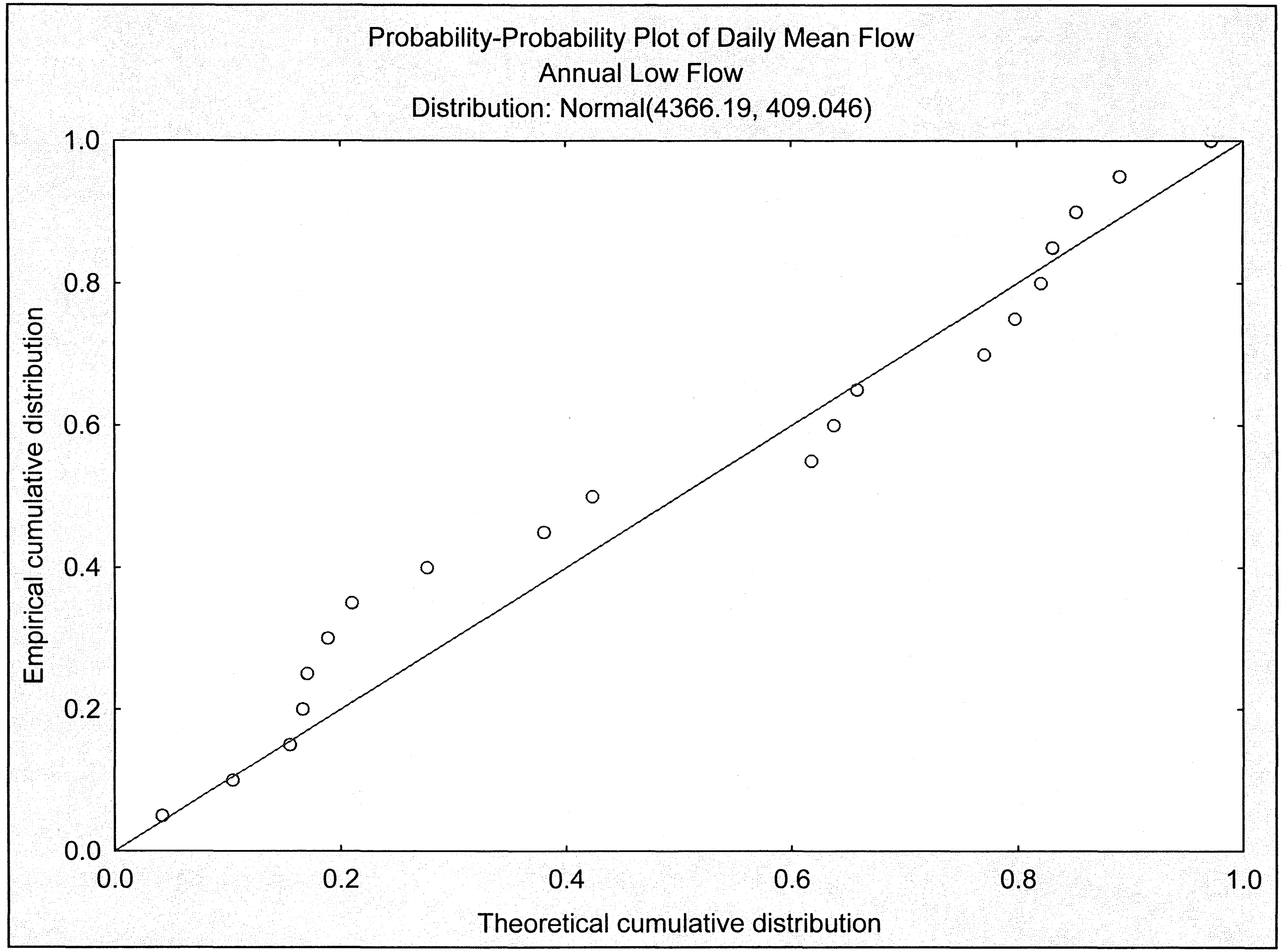
Observed mean = 4366.190273, Observed variance = 167318.822221

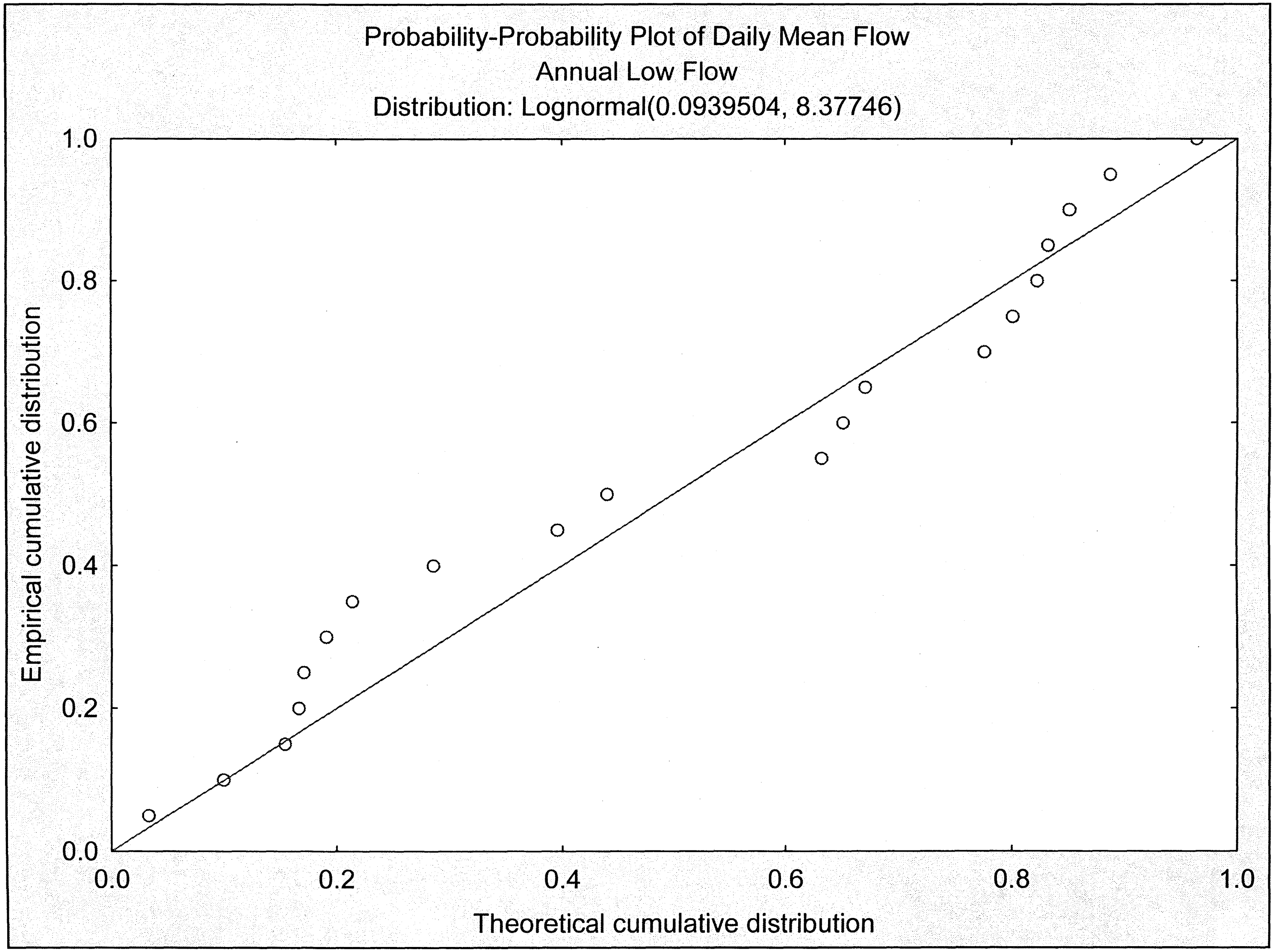
Distribution: Log-normal

Parameters: Mean = 8.377463, Variance = .8827E-2



Upper Boundary	Variable: Daily Mean Flow, Distribution: Log-normal (Annaul Low Flow.sta) Chi-Square: ------ , df = 0 , p = ---								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 3600.00000	0	0	0.000000	0.00000	0.445062	0.445066	2.225310	2.22533	-0.445066
3700.00000	1	1	5.000000	5.00000	0.413526	0.858589	2.067628	4.29299	0.58647
3800.00000	0	1	0.000000	5.00000	0.657692	1.516288	3.288460	7.5814	-0.657699
3900.00000	1	2	5.000000	10.00000	0.955121	2.471400	4.775603	12.35700	0.044888
4000.00000	3	5	15.000000	25.00000	1.274850	3.746255	6.374250	18.73133	1.725155
4100.00000	2	7	10.000000	35.00000	1.573347	5.319600	7.866735	26.59800	0.426655
4200.00000	1	8	5.000000	40.00000	1.805221	7.124822	9.026106	35.6241	-0.80522
4300.00000	2	10	10.000000	50.00000	1.935317	9.06014	9.676584	45.3007	0.064688
4400.00000	0	10	0.000000	50.00000	1.947534	11.00767	9.737668	55.03833	-1.947533
4500.00000	1	11	5.000000	55.00000	1.847407	12.855088	9.237035	64.2754	-0.84741
4600.00000	2	13	10.000000	65.00000	1.658335	14.51341	8.291677	72.5671	0.341666
4700.00000	1	14	5.000000	70.00000	1.413741	15.927155	7.068703	79.63588	-0.41374
4800.00000	4	18	20.000000	90.00000	1.148393	17.07554	5.741964	85.3777	2.85161
4900.00000	1	19	5.000000	95.00000	0.891583	17.967133	4.457917	89.83566	0.10842
5000.00000	0	19	0.000000	95.00000	0.663457	18.630599	3.317287	93.15299	-0.663466
5100.00000	0	19	0.000000	95.00000	0.474441	19.105033	2.372207	95.5251	-0.47444
5200.00000	1	20	5.000000	100.00000	0.326834	19.431866	1.634171	97.15933	0.67317
< Infinity	0	20	0.000000	100.00000	0.568139	20.000000	2.840695	100.00000	-0.56814

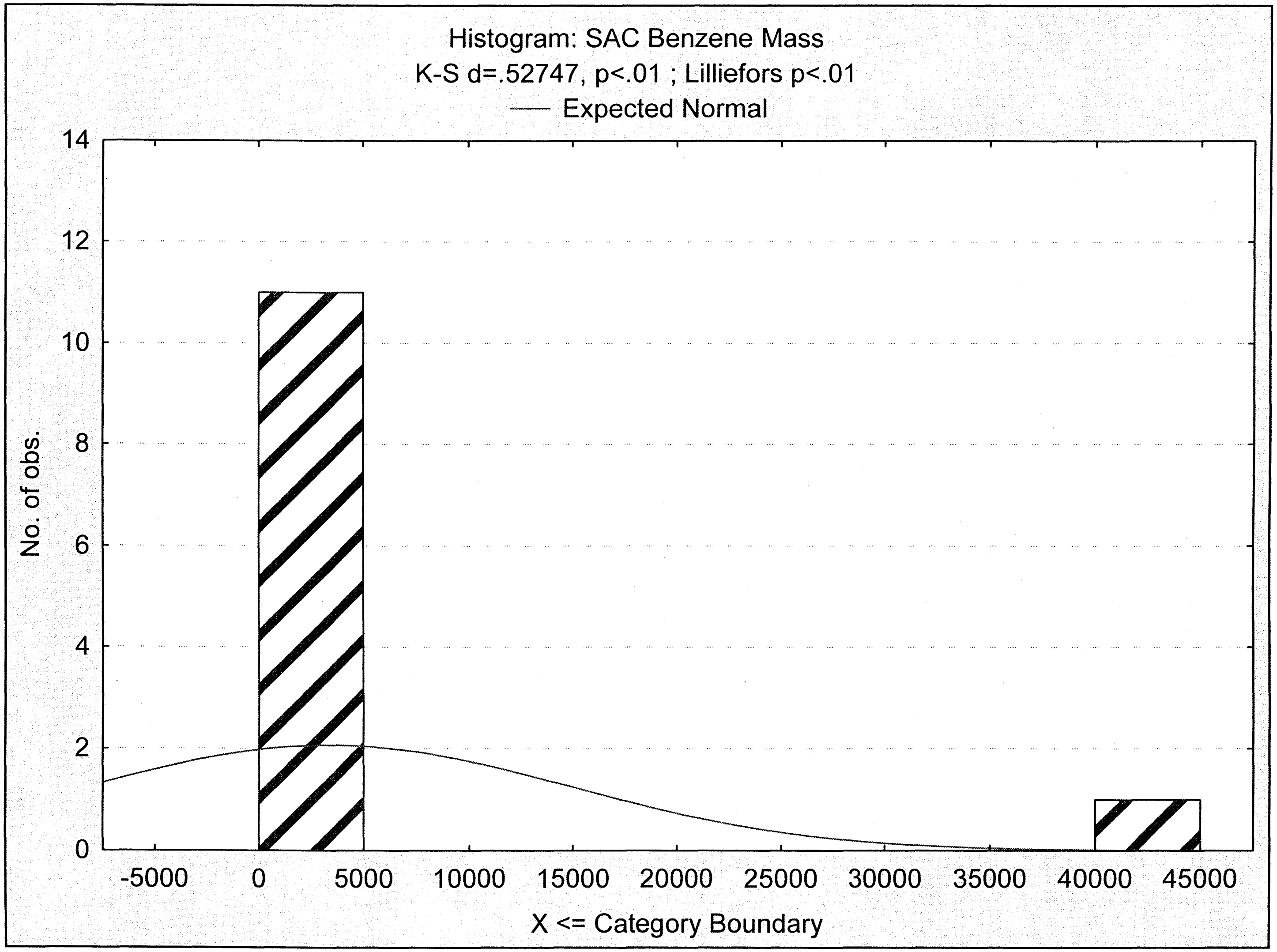

Probability-Probability Plot of Daily Mean Flow
Annual Low Flow
Distribution: Normal(4366.19, 409.046)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0

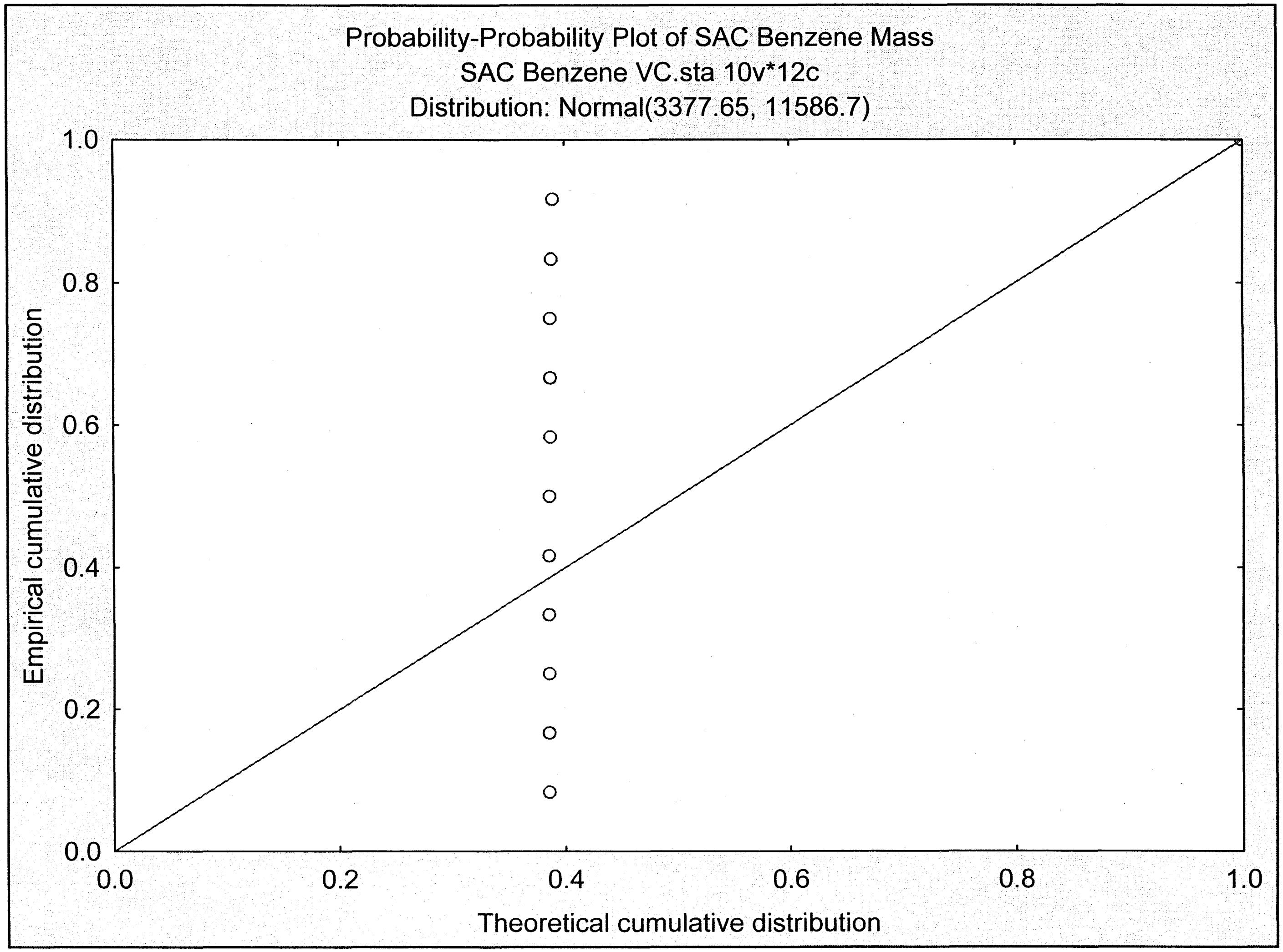

Probability-Probability Plot of Daily Mean Flow
Annual Low Flow
Distribution: Lognormal(0.0939504, 8.37746)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0

Benzene Spill Mass, SAC Data

Variable	Descriptive Statistics (SAC Benzene VC.sta) Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Variance	Std.Dev.	Skewness
SAC Benzene Mass	12	3377.65C	26.1000C	Multiple	1	1.40000C	40170.3C	13425245E	11586.74	3.464041

Category	Frequency table: SAC Benzene Mass (SAC Benzene VC.sta) K-S d=.52747, p<.01 ; Lilliefors p<.01 Shapiro-Wilk W=.32944, p=.00000 Count	Cumulative Count	Percent of Valid	Cumul % of Valid	% of all Cases	Cumulative % of All	Expected Count	Cumulative Expected	Percent Expected	Cumulative % Expected
-5000.00<x<=0.000000	0	0	0.00000C	0.0000C	0.00000C	0.0000C	4.623967	4.62397	38.53306	38.53306
0.000000<x<=5000.000	11	11	91.66667	91.6667	91.66667	91.6667	2.044157	6.66812	17.03464	55.5677C
5000.000<x<=10000.00	0	11	0.00000C	91.6667	0.00000C	91.6667	1.926097	8.59422	16.05081	71.61851
10000.00<x<=15000.00	0	11	0.00000C	91.6667	0.00000C	91.6667	1.510827	10.10505	12.59022	84.20873
15000.00<x<=20000.00	0	11	0.00000C	91.6667	0.00000C	91.6667	0.986548	11.0916C	8.22123	92.42997
20000.00<x<=25000.00	0	11	0.00000C	91.6667	0.00000C	91.6667	0.536265	11.62786	4.46887	96.89884
25000.00<x<=30000.00	0	11	0.00000C	91.6667	0.00000C	91.6667	0.242652	11.87051	2.0221C	98.92094
30000.00<x<=35000.00	0	11	0.00000C	91.6667	0.00000C	91.6667	0.091393	11.96191	0.76161	99.68254
35000.00<x<=40000.00	0	11	0.00000C	91.6667	0.00000C	91.6667	0.028652	11.99056	0.23876	99.92131
40000.00<x<=45000.00	1	12	8.33333	100.000C	8.33333	100.000C	0.007476	11.99803	0.0623C	99.98361
Missing	0	12	0.00000C		0.00000C	100.000C				


Histogram: SAC Benzene Mass
K-S d=.52747, p<.01 ; Lilliefors p<.01
Expected Normal
No. of obs.
0
2
4
6
8
10
12
14
-5000
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
X <= Category Boundary


Probability-Probability Plot of SAC Benzene Mass
SAC Benzene VC.sta 10v*12c
Distribution: Normal(3377.65, 11586.7)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0

Number of valid cases:12

Observed mean = 3377.650333, Observed variance = 134252458.017852

Distribution: Normal

Parameters: Mean = 3377.650, Variance = 134252E3

Upper Boundary	Variable: SAC Benzene Mass, Distribution: Normal (SAC Benzene VC.sta) Chi-Square: ------ , df = 0 , p = ---									
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 0.00000	0	0	0.00000	0.0000	4.623967	4.62397	38.53306	38.5331	-4.62397
5000.00000	11	11	91.66667	91.6667	2.044157	6.66812	17.03464	55.5677	8.95584
10000.00000	0	11	0.00000	91.6667	1.926097	8.59422	16.05081	71.6185	-1.92610
15000.00000	0	11	0.00000	91.6667	1.510827	10.10505	12.59022	84.2087	-1.51083
20000.00000	0	11	0.00000	91.6667	0.986548	11.09160	8.22123	92.4300	-0.98655
25000.00000	0	11	0.00000	91.6667	0.536265	11.62786	4.46887	96.8988	-0.53626
30000.00000	0	11	0.00000	91.6667	0.242652	11.87051	2.02210	98.9209	-0.24265
35000.00000	0	11	0.00000	91.6667	0.091393	11.96191	0.76161	99.6825	-0.09139
40000.00000	0	11	0.00000	91.6667	0.028652	11.99056	0.23876	99.9213	-0.02865
< Infinity	1	12	8.33333	100.0000	0.009443	12.00000	0.07869	100.0000	0.99056

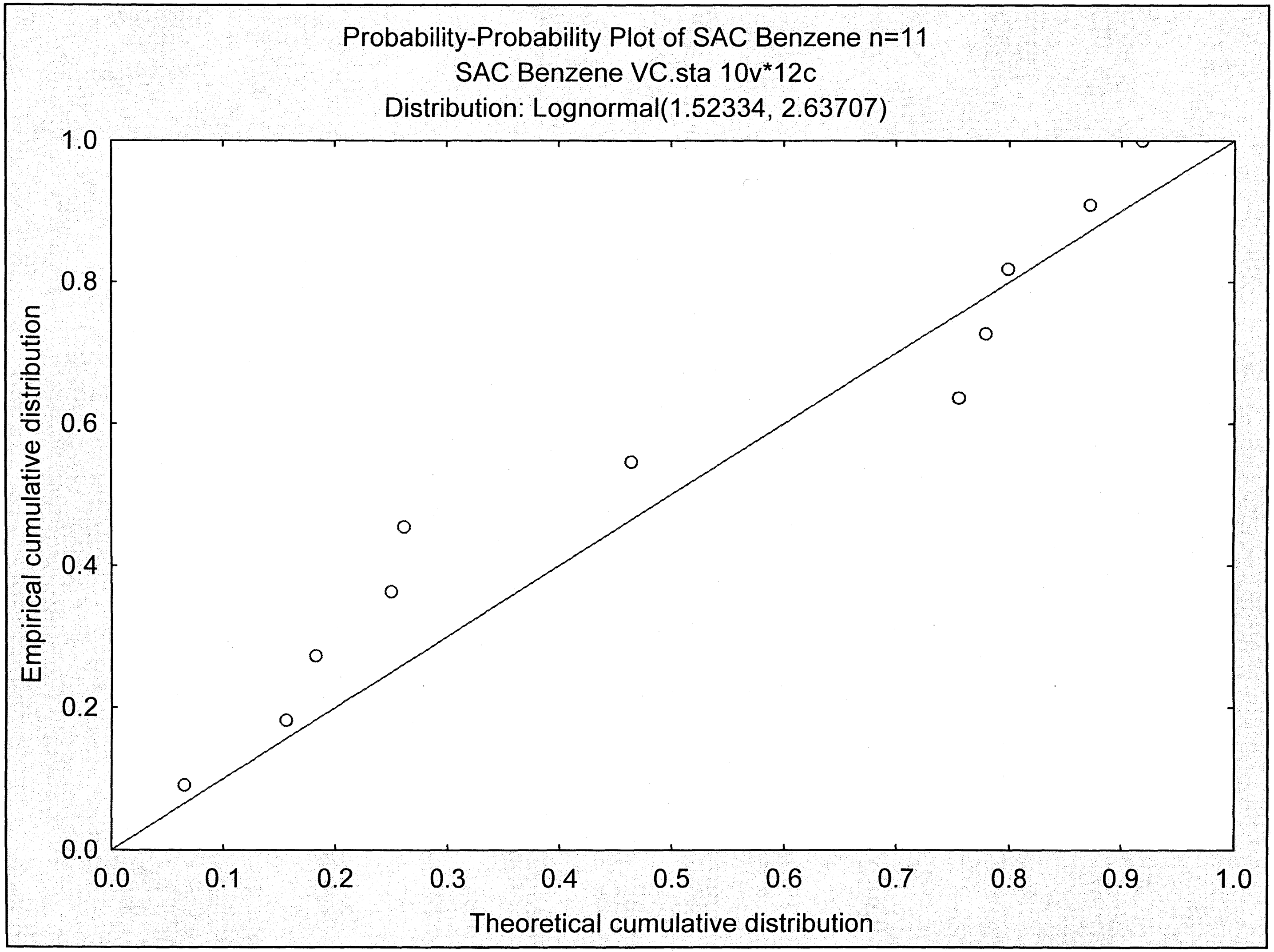
Number of valid cases:12

Observed mean = 3377.650333, Observed variance = 134252458.017852

Distribution: Log-normal

Parameters: Mean = 3.300722, Variance = 7.394790

Upper Boundary	Variable: SAC Benzene Mass, Distribution: Log-normal (SAC Benzene VC.sta) Chi-Square: ------ , df = 0 , p = ---								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 0.00000	0	0	0.00000	0.0000	0.00000	0.00000	0.00000	0.0000	0.000000
5000.00000	11	11	91.66667	91.6667	11.66955	11.66955	97.24628	97.2463	-0.669553
10000.00000	0	11	0.00000	91.6667	0.15185	11.82140	1.26540	98.5117	-0.151848
15000.00000	0	11	0.00000	91.6667	0.05729	11.87870	0.47745	98.9891	-0.057294
20000.00000	0	11	0.00000	91.6667	0.03023	11.90893	0.25192	99.2410	-0.030230
25000.00000	0	11	0.00000	91.6667	0.01866	11.92759	0.15553	99.3966	-0.018664
30000.00000	0	11	0.00000	91.6667	0.01265	11.94023	0.10538	99.5020	-0.012645
35000.00000	0	11	0.00000	91.6667	0.00911	11.94935	0.07596	99.5779	-0.009115
40000.00000	0	11	0.00000	91.6667	0.00687	11.95622	0.05724	99.6351	-0.006868
< Infinity	1	12	8.33333	100.0000	0.04378	12.00000	0.36485	100.0000	0.956218


Probability-Probability Plot of SAC Benzene n=11
SAC Benzene VC.sta 10v*12c
Distribution: Lognormal(1.52334, 2.63707)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0
0.1
0.3
0.5
0.7
0.9

Vinyl Chloride Spill Mass, SAC Data

Variable	Descriptive Statistics (SAC Benzene VC.sta) Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Variance	Std.Dev.	Skewn
SAC Vinyl Chloride Mass	6	224.650C	16.5000C	Multiple	1	7.00000C	1200.00C	229570.1	479.134E	2.420

Category	Frequency table: SAC Vinyl Chloride Mass (SAC Benzene VC.sta) K-S d=.43596, p<.20 ; Lilliefors p<.01 Shapiro-Wilk W=.54786, p=.00010 Count	Cumulative Count	Percent of Valid	% of all Cases	Cumulative % of All	Expected Count	Cumulative Expected	Percent Expected	Cumulative % Expected
-200.000<x<=0.000000	0	0	0.0000C	0.00000C	0.0000C	1.917496	1.917496	31.95827	31.95827
0.000000<x<=200.0000	5	5	83.3333	41.66667	41.6667	0.959412	2.876908	15.99020	47.94847
200.0000<x<=400.0000	0	5	0.0000C	0.00000C	41.6667	0.979934	3.856843	16.33224	64.28071
400.0000<x<=600.0000	0	5	0.0000C	0.00000C	41.6667	0.842965	4.699808	14.04942	78.33013
600.0000<x<=800.0000	0	5	0.0000C	0.00000C	41.6667	0.610718	5.310526	10.17863	88.50876
800.0000<x<=1000.000	0	5	0.0000C	0.00000C	41.6667	0.372635	5.683161	6.21058	94.71934
1000.000<x<=1200.000	1	6	16.6667	8.33333	50.0000C	0.191482	5.874643	3.19137	97.91072
Missing	6	12	100.0000C	50.00000C	100.0000C				

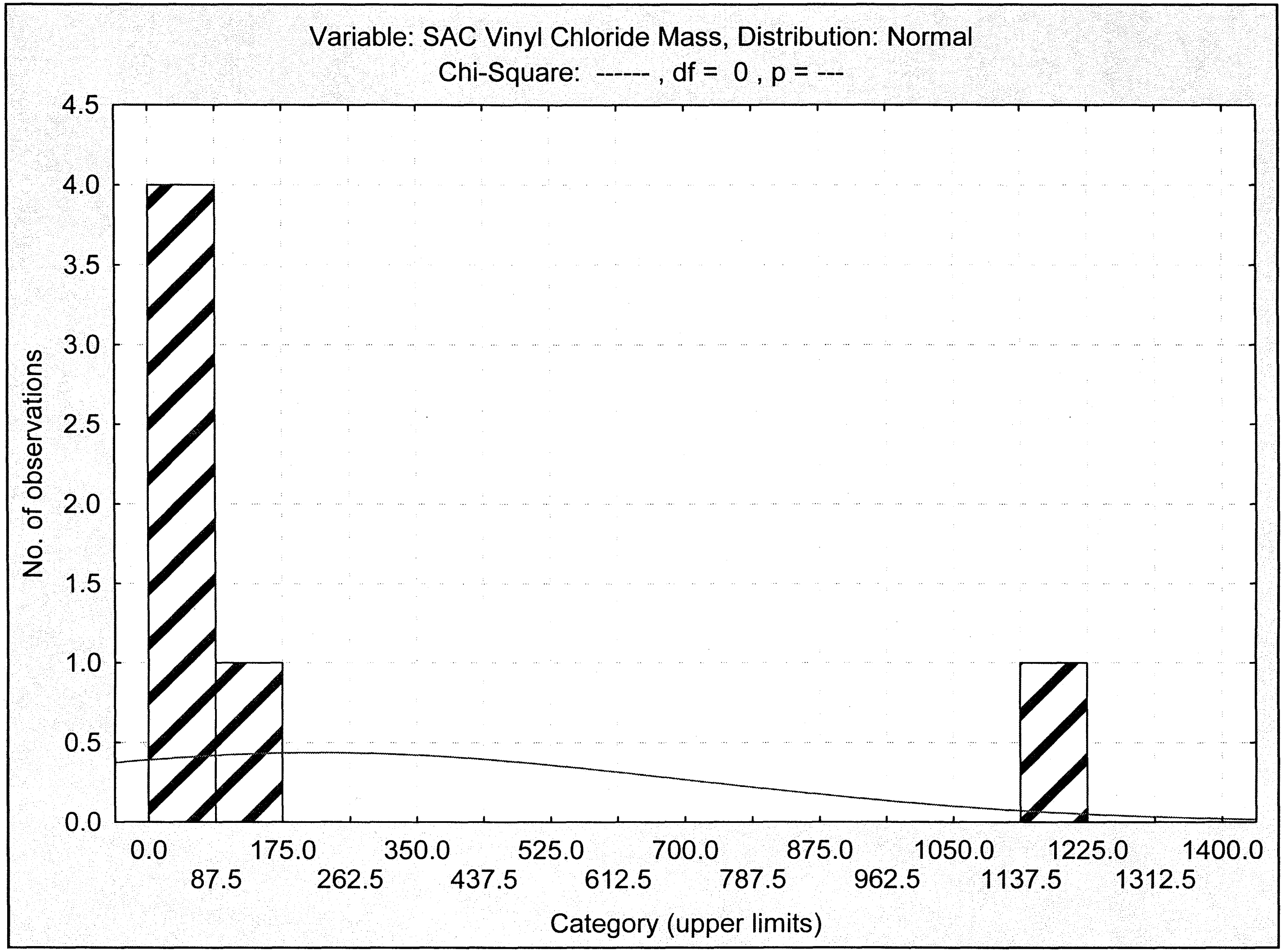
Number of valid cases:6

Observed mean = 224.650000, Observed variance = 229570.135000

Distribution: Normal

Parameters: Mean = 224.6500, Variance = 229570.1

Upper Boundary	Variable: SAC Vinyl Chloride Mass, Distribution: Normal (SAC Benzene VC.sta) Chi-Square: ------ , df = 0 , p = --- Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 87.50000	4	4	66.66667	66.6667	2.324071	2.324071	38.73452	38.7345	1.675929
175.00000	1	5	16.66667	83.3333	0.428331	2.752403	7.13886	45.8734	0.571669
262.50000	0	5	0.00000	83.3333	0.436491	3.188894	7.27486	53.1482	-0.436491
350.00000	0	5	0.00000	83.3333	0.430257	3.619151	7.17095	60.3192	-0.430257
437.50000	0	5	0.00000	83.3333	0.410238	4.029389	6.83730	67.1565	-0.410238
525.00000	0	5	0.00000	83.3333	0.378356	4.407745	6.30594	73.4624	-0.378356
612.50000	0	5	0.00000	83.3333	0.337537	4.745283	5.62562	79.0880	-0.337537
700.00000	0	5	0.00000	83.3333	0.291272	5.036555	4.85454	83.9426	-0.291272
787.50000	0	5	0.00000	83.3333	0.243127	5.279682	4.05211	87.9947	-0.243127
875.00000	0	5	0.00000	83.3333	0.196301	5.475983	3.27168	91.2664	-0.196301
962.50000	0	5	0.00000	83.3333	0.153309	5.629292	2.55516	93.8215	-0.153309
1050.00000	0	5	0.00000	83.3333	0.115817	5.745109	1.93028	95.7518	-0.115817
1137.50000	0	5	0.00000	83.3333	0.084631	5.829740	1.41052	97.1623	-0.084631
1225.00000	1	6	16.66667	100.0000	0.059820	5.889559	0.99699	98.1593	0.940180
1312.50000	0	6	0.00000	100.0000	0.040899	5.930459	0.68165	98.8410	-0.040899
< Infinity	0	6	0.00000	100.0000	0.069541	6.000000	1.15902	100.0000	-0.069541



Variable: SAC Vinyl Chloride Mass, Distribution: Normal
Chi-Square: ------ , df = 0 , p = ---
No. of observations
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
87.5
175.0
262.5
350.0
437.5
525.0
612.5
700.0
787.5
875.0
962.5
1050.0
1137.5
1225.0
1312.5
1400.0
Category (upper limits)

Number of valid cases:6

Observed mean = 224.650000, Observed variance = 229570.135000

Distribution: Normal

Parameters: Mean = 224.6500, Variance = 229570.1

	Variable: SAC Vinyl Chloride Mass, Distribution: Normal (SAC Benzene VC.sta) Chi-Square: ------ , df = 0 , p = ---								
Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 140.00000	5	5	83.33333	83.33333	2.579297	2.579297	42.98828	42.98833	2.420703
280.00000	0	5	0.00000	83.33333	0.696606	3.275903	11.61010	54.5984	-0.696606
420.00000	0	5	0.00000	83.33333	0.673646	3.949549	11.22744	65.8258	-0.673646
560.00000	0	5	0.00000	83.33333	0.598495	4.548045	9.97492	75.8007	-0.598495
700.00000	0	5	0.00000	83.33333	0.488510	5.036555	8.14184	83.9426	-0.488510
840.00000	0	5	0.00000	83.33333	0.366328	5.402883	6.10547	90.0480	-0.366328
980.00000	0	5	0.00000	83.33333	0.252377	5.655260	4.20628	94.2543	-0.252377
1120.00000	0	5	0.00000	83.33333	0.159739	5.814998	2.66231	96.9166	-0.159739
1260.00000	1	6	16.66667	100.0000	0.092887	5.907885	1.54811	98.4647	0.907113
< Infinity	0	6	0.00000	100.0000	0.092115	6.000000	1.53525	100.0000	-0.092115

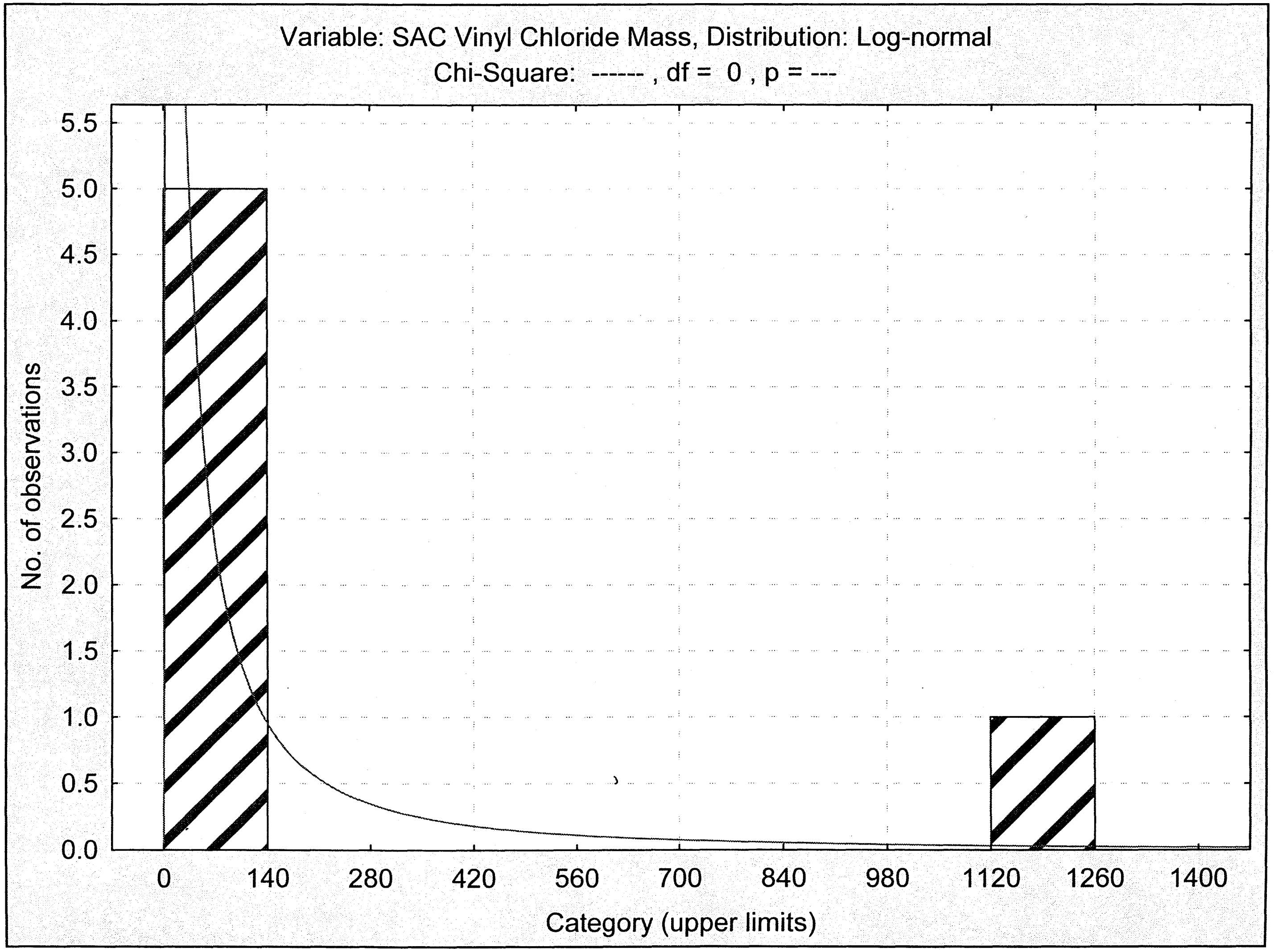
Number of valid cases:6

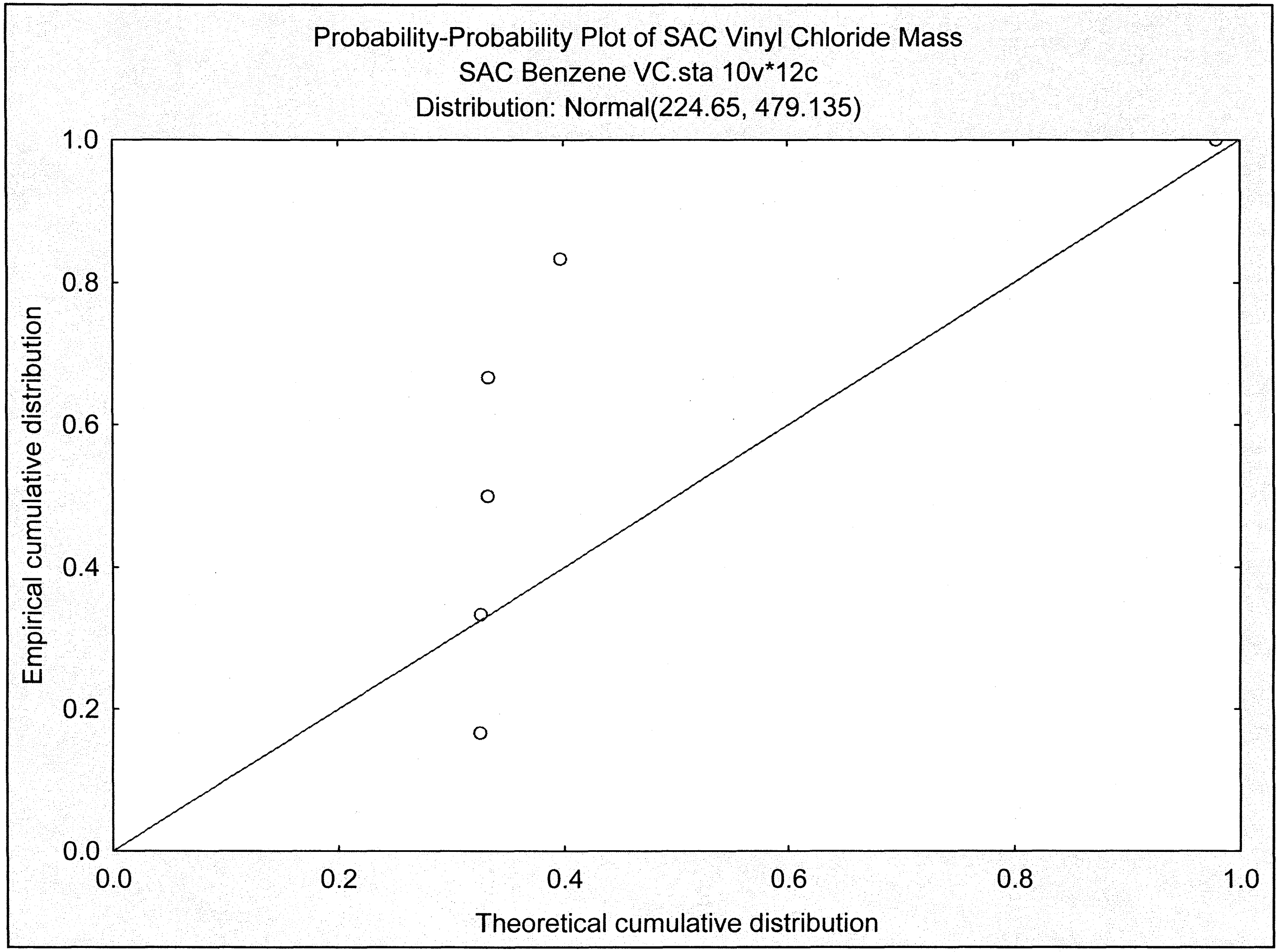
Observed mean = 224.650000, Observed variance = 229570.135000

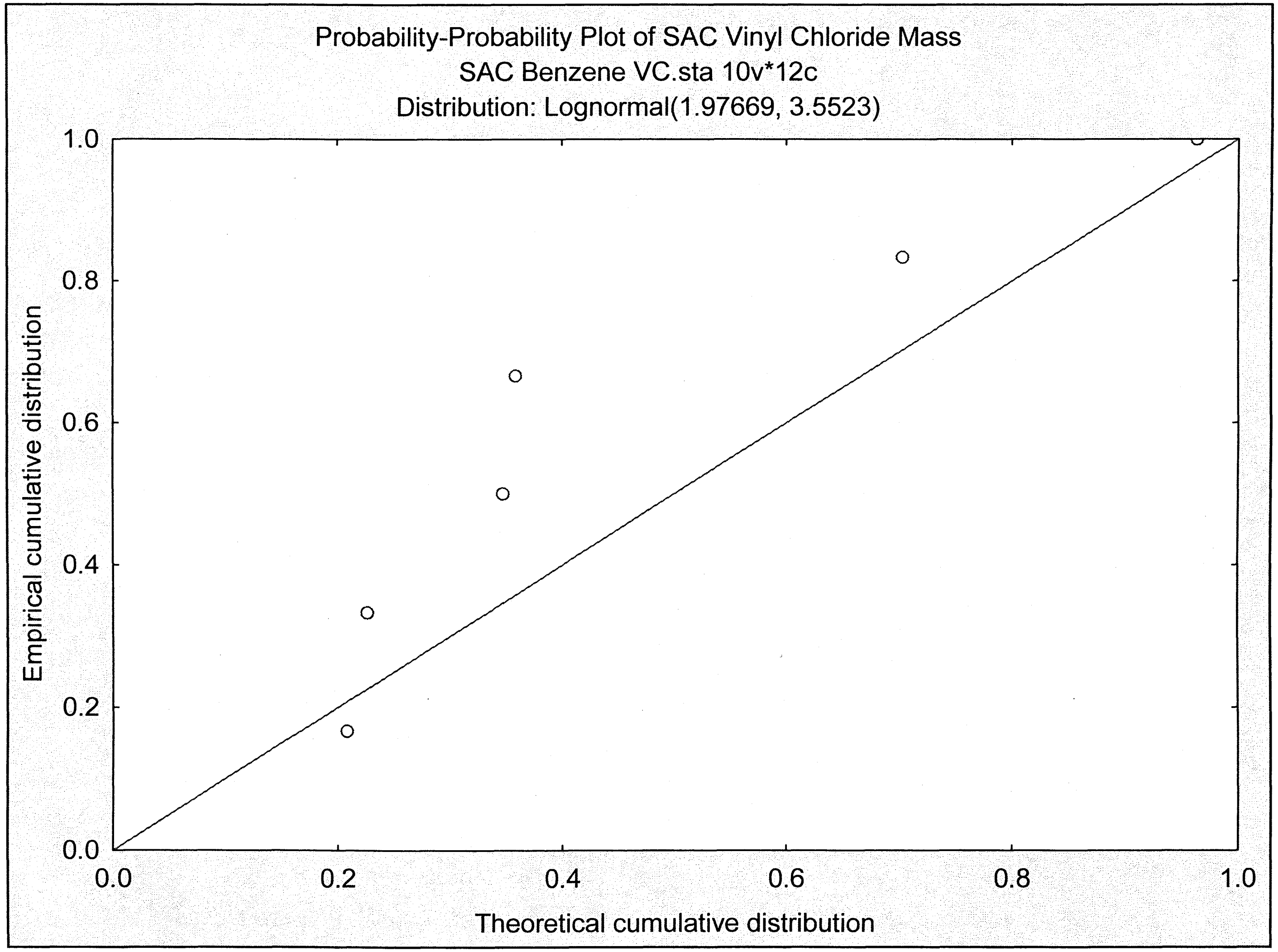
Distribution: Log-normal

Parameters: Mean = 3.552304, Variance = 3.907290

Upper Boundary	Variable: SAC Vinyl Chloride Mass, Distribution: Log-normal (SAC Benzene VC.sta) Chi-Square: ------ , df = 0 , p = ---								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 140.00000	5	5	83.33333	83.3333	4.553576	4.553576	75.89293	75.8929	0.446424
280.00000	0	5	0.00000	83.3333	0.570121	5.123697	9.50202	85.3949	-0.570121
420.00000	0	5	0.00000	83.3333	0.251830	5.375527	4.19717	89.5921	-0.251830
560.00000	0	5	0.00000	83.3333	0.143682	5.519208	2.39470	91.9868	-0.143682
700.00000	0	5	0.00000	83.3333	0.093046	5.612255	1.55077	93.5376	-0.093046
840.00000	0	5	0.00000	83.3333	0.065098	5.677353	1.08497	94.6226	-0.065098
980.00000	0	5	0.00000	83.3333	0.048006	5.725359	0.80009	95.4226	-0.048006
1120.00000	0	5	0.00000	83.3333	0.036784	5.762143	0.61307	96.0357	-0.036784
1260.00000	1	6	16.66667	100.0000	0.029023	5.791166	0.48372	96.5194	0.970977
< Infinity	0	6	0.00000	100.0000	0.208834	6.000000	3.48056	100.0000	-0.208834


Variable: SAC Vinyl Chloride Mass, Distribution: Log-normal
Chi-Square: ------ , df = 0 , p = ---
No. of observations
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
0
140
280
420
560
700
840
980
1120
1260
1400
Category (upper limits)

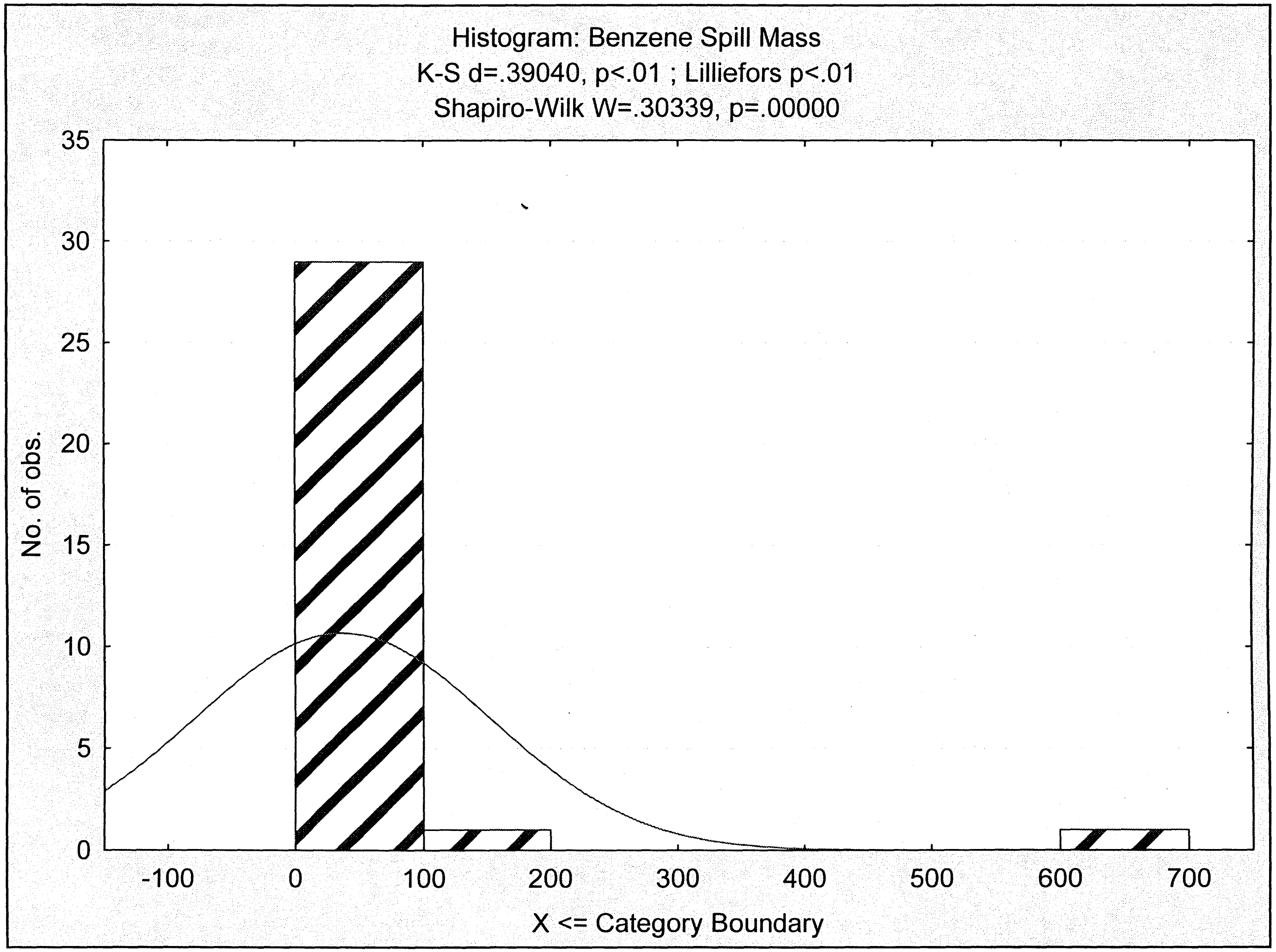

Probability-Probability Plot of SAC Vinyl Chloride Mass
SAC Benzene VC.sta 10v*12c
Distribution: Normal(224.65, 479.135)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0


Probability-Probability Plot of SAC Vinyl Chloride Mass
SAC Benzene VC.sta 10v*12c
Distribution: Lognormal(1.97669, 3.5523)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0

Benzene Spill Mass, SLEA Data

Variable	Descriptive Statistics (SLEA Benzen spills with annaul low monthly.sta)									
	Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Variance	Std.Dev.	Skewness
Benzene Spill Mass	31	36.88290	6.000000	Multiple	2	0.100000	648.0000	13415.60	115.8257	5.228805

Category	Frequency table: Benzene Spill Mass (SLEA Benzen spills with annaul low monthly.sta) K-S d=.39040, p<.01 ; Lilliefors p<.01 Shapiro-Wilk W=.30339, p=.00000								
	Count	Cumulative Count	Percent of Valid	% of all Cases	Cumulative % of All	Expected Count	Cumulative Expected	Percent Expected	Cumulative % Expected
-100.000<x<=0.000000	0	0	0.00000	0.00000	0.0000	11.62741	11.62741	37.50777	37.5078
0.000000<x<=100.0000	29	29	93.54839	93.54839	93.5484	10.29268	21.92009	33.20220	70.7100
100.0000<x<=200.0000	1	30	3.22581	3.22581	96.7742	6.61474	28.53483	21.33788	92.0479
200.0000<x<=300.0000	0	30	0.00000	0.00000	96.7742	2.10701	30.64184	6.79681	98.8447
300.0000<x<=400.0000	0	30	0.00000	0.00000	96.7742	0.33152	30.97337	1.06942	99.9141
400.0000<x<=500.0000	0	30	0.00000	0.00000	96.7742	0.02565	30.99901	0.08273	99.9968
500.0000<x<=600.0000	0	30	0.00000	0.00000	96.7742	0.00097	30.99998	0.00313	99.9999
600.0000<x<=700.0000	1	31	3.22581	3.22581	100.0000	0.00002	31.00000	0.00006	100.0000
Missing	0	31	0.00000	0.00000	100.0000				


Histogram: Benzene Spill Mass
K-S d=.39040, p<.01 ; Lilliefors p<.01
Shapiro-Wilk W=.30339, p=.00000
No. of obs.
35
30
25
20
15
10
5
0
-100
0
100
200
300
400
500
600
700
X <= Category Boundary

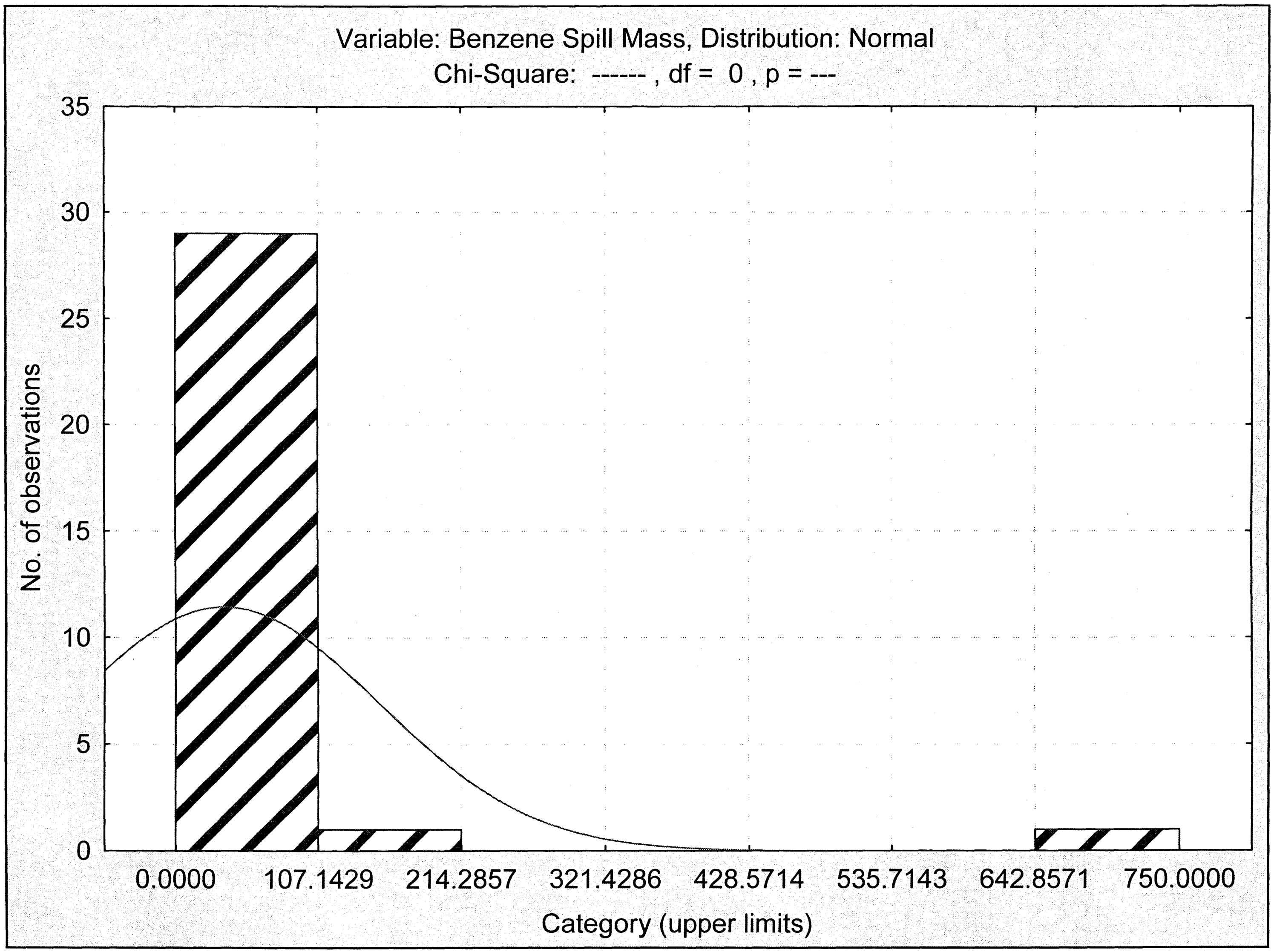
Number of valid cases:31

Observed mean = 36.882903, Observed variance = 13415.598848

Distribution: Normal

Parameters: Mean = 36.88290, Variance = 13415.60

	Variable: Benzene Spill Mass, Distribution: Normal (SLEA Benzen spills with annaul low monthly.sta) Chi-Square: ------ , df = 0 , p = ---								
Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 107.14286	29	29	93.54839	93.5484	22.56620	22.56620	72.79420	72.7942	6.43380
214.28571	1	30	3.22581	96.7742	6.48681	29.05301	20.92518	93.7194	-5.48681
321.42857	0	30	0.00000	96.7742	1.72963	30.78264	5.57946	99.2988	-1.72963
428.57143	0	30	0.00000	96.7742	0.20619	30.98883	0.66514	99.9640	-0.20619
535.71429	0	30	0.00000	96.7742	0.01091	30.99974	0.03519	99.9992	-0.01091
642.85714	0	30	0.00000	96.7742	0.00025	31.00000	0.00082	100.0000	-0.00025
< Infinity	1	31	3.22581	100.0000	0.00000	31.00000	0.00001	100.0000	1.00000


Variable: Benzene Spill Mass, Distribution: Normal
Chi-Square: ------ , df = 0 , p = ---
No. of observations
35
30
25
20
15
10
5
0
0.0000
107.1429
214.2857
321.4286
428.5714
535.7143
642.8571
750.0000
Category (upper limits)

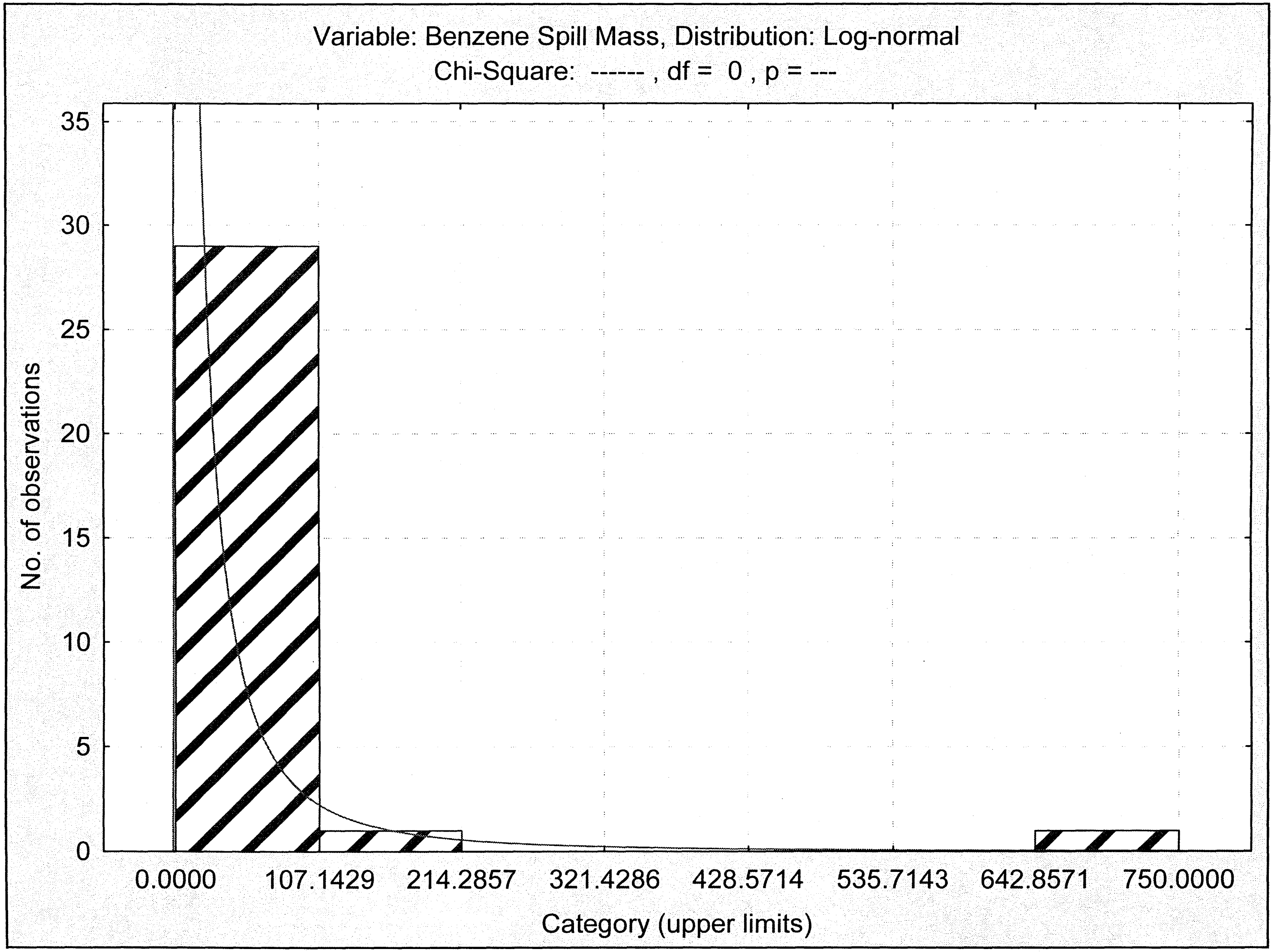
Number of valid cases:31

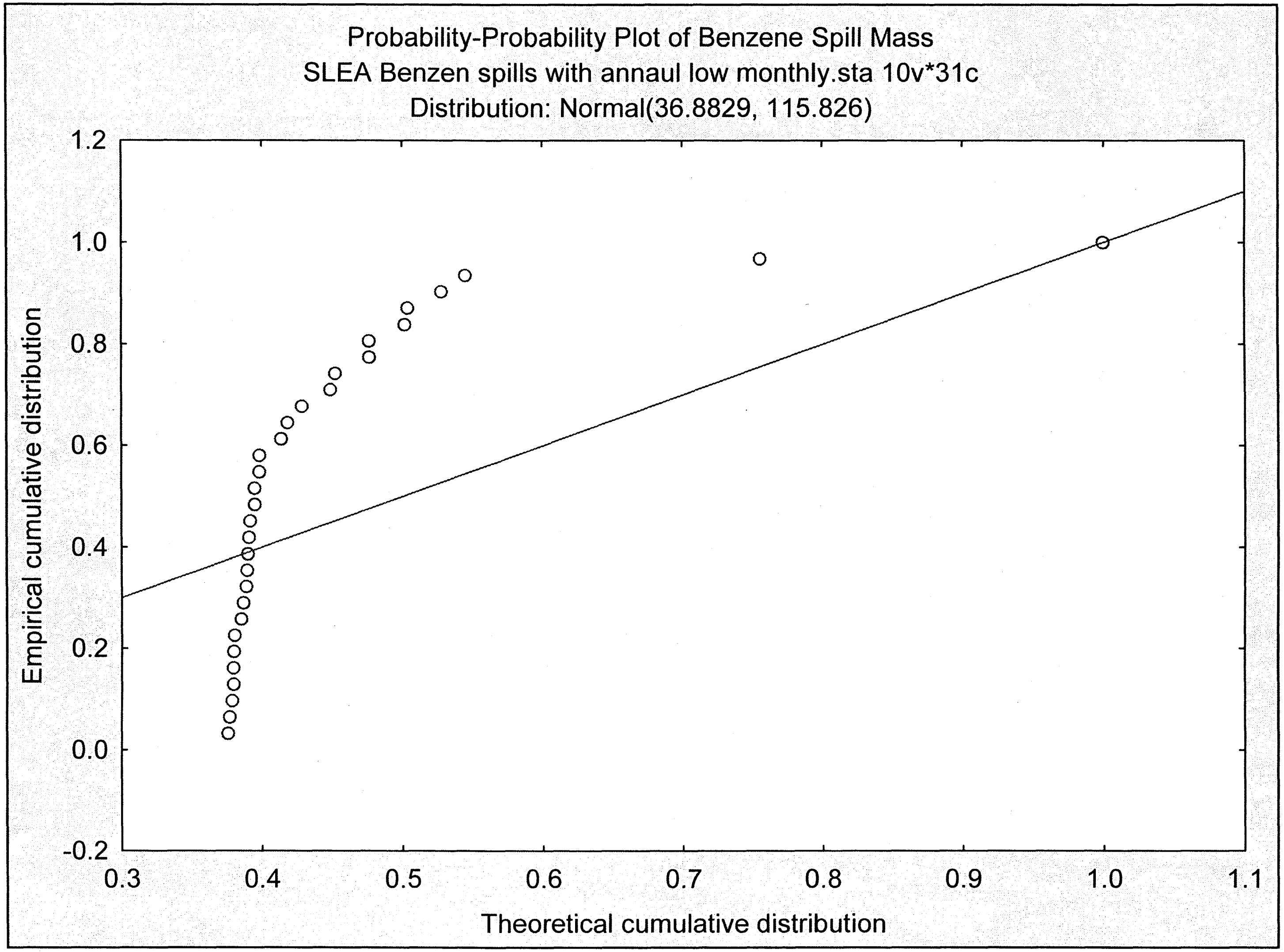
Observed mean = 36.882903, Observed variance = 13415.598848

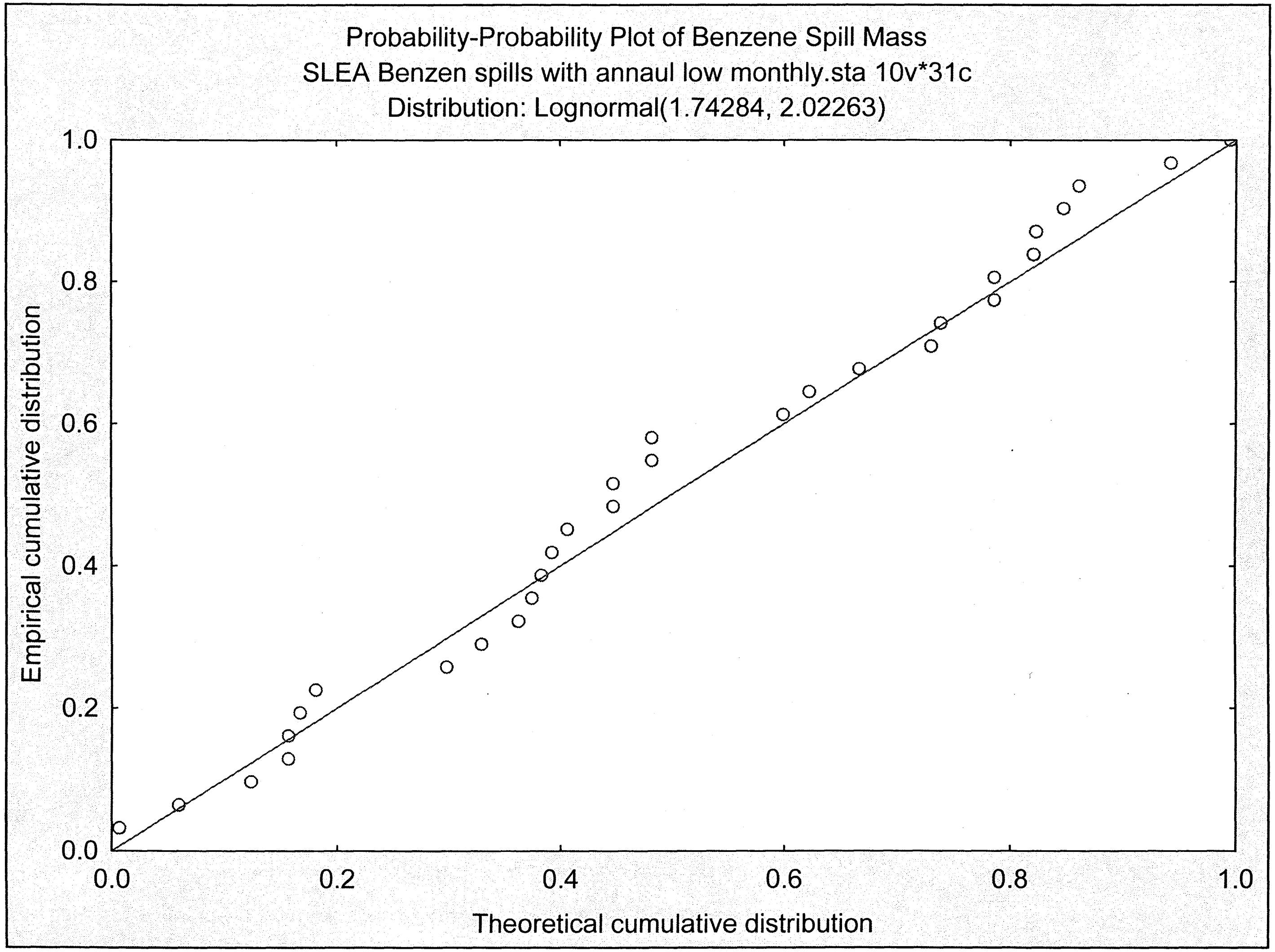
Distribution: Log-normal

Parameters: Mean = 2.022634, Variance = 3.037478

	Variable: Benzene Spill Mass, Distribution: Log-normal (SLEA Benzen spills with annaul low monthly.sta) Chi-Square: ------ , df = 0 , p = ---								
Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 107.14286	29	29	93.54839	93.5484	29.01348	29.01348	93.59187	93.5919	-0.013478
214.28571	1	30	3.22581	96.7742	1.13446	30.14794	3.65955	97.2514	-0.134459
321.42857	0	30	0.00000	96.7742	0.36509	30.51303	1.17772	98.4291	-0.365093
428.57143	0	30	0.00000	96.7742	0.16900	30.68203	0.54517	98.9743	-0.169002
535.71429	0	30	0.00000	96.7742	0.09335	30.77538	0.30113	99.2754	-0.093350
642.85714	0	30	0.00000	96.7742	0.05739	30.83277	0.18512	99.4605	-0.057386
< Infinity	1	31	3.22581	100.0000	0.16723	31.00000	0.53945	100.0000	0.832770


Variable: Benzene Spill Mass, Distribution: Log-normal
Chi-Square: ------ , df = 0 , p = ---
No. of observations
0
5
10
15
20
25
30
35
0.0000
107.1429
214.2857
321.4286
428.5714
535.7143
642.8571
750.0000
Category (upper limits)


Probability-Probability Plot of Benzene Spill Mass
SLEA Benzen spills with annaul low monthly.sta 10v*31c
Distribution: Normal(36.8829, 115.826)
Empirical cumulative distribution
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Theoretical cumulative distribution


Probability-Probability Plot of Benzene Spill Mass
SLEA Benzen spills with annaul low monthly.sta 10v*31c
Distribution: Lognormal(1.74284, 2.02263)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0

Vinyl Chloride Spill Mass, SLEA data

Variable	Descriptive Statistics (Vinyl Chloride Spill.sta)									
	Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Variance	Std.Dev.	Skewness
Vinyl Chloride Spill Mass	8	31.6750C	13.9500C	Multiple	1	7.00000C	133.000C	1903.905	43.6337E	2.276362

Category	Frequency table: Vinyl Chloride Spill Mass (Vinyl Chloride Spill.sta) K-S d=.38169, p<.15 ; Lilliefors p<.01 Shapiro-Wilk W=.64094, p=.00048								
	Count	Cumulative Count	Percent of Valid	% of all Cases	Cumulative % of All	Expected Count	Cumulative Expected	Percent Expected	Cumulative % Expected
-20.0000<x<=0.000000	0	0	0.00000C	0.00000C	0.0000C	1.87153C	1.87153C	23.39412	23.39412
0.000000<x<=20.00000	6	6	75.0000C	60.0000C	60.000C	1.284597	3.156127	16.05747	39.45159
20.00000<x<=40.00000	0	6	0.00000C	0.00000C	60.000C	1.44912C	4.605248	18.11401	57.5656C
40.00000<x<=60.00000	1	7	12.5000C	10.0000C	70.000C	1.329795	5.935043	16.62244	74.18804
60.00000<x<=80.00000	0	7	0.00000C	0.00000C	70.000C	0.99267C	6.927713	12.40838	86.59641
80.00000<x<=100.0000	0	7	0.00000C	0.00000C	70.000C	0.602775	7.530488	7.53469	94.1311C
100.0000<x<=120.0000	0	7	0.00000C	0.00000C	70.000C	0.297728	7.828216	3.7216C	97.8527C
120.0000<x<=140.0000	1	8	12.5000C	10.0000C	80.000C	0.119612	7.947828	1.49515	99.3478E
Missing	2	10	25.0000C	20.0000C	100.000C				

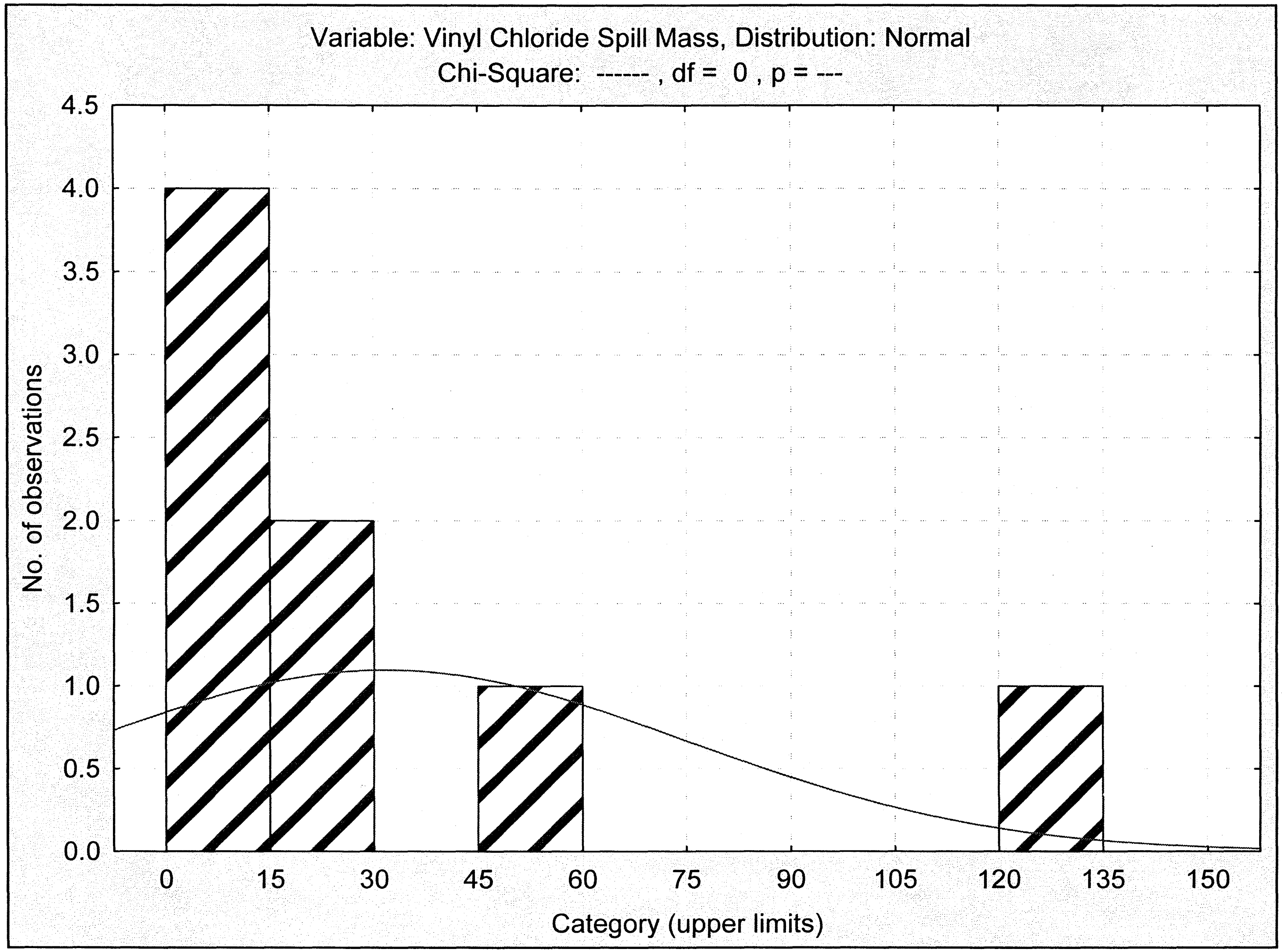
Number of valid cases:8

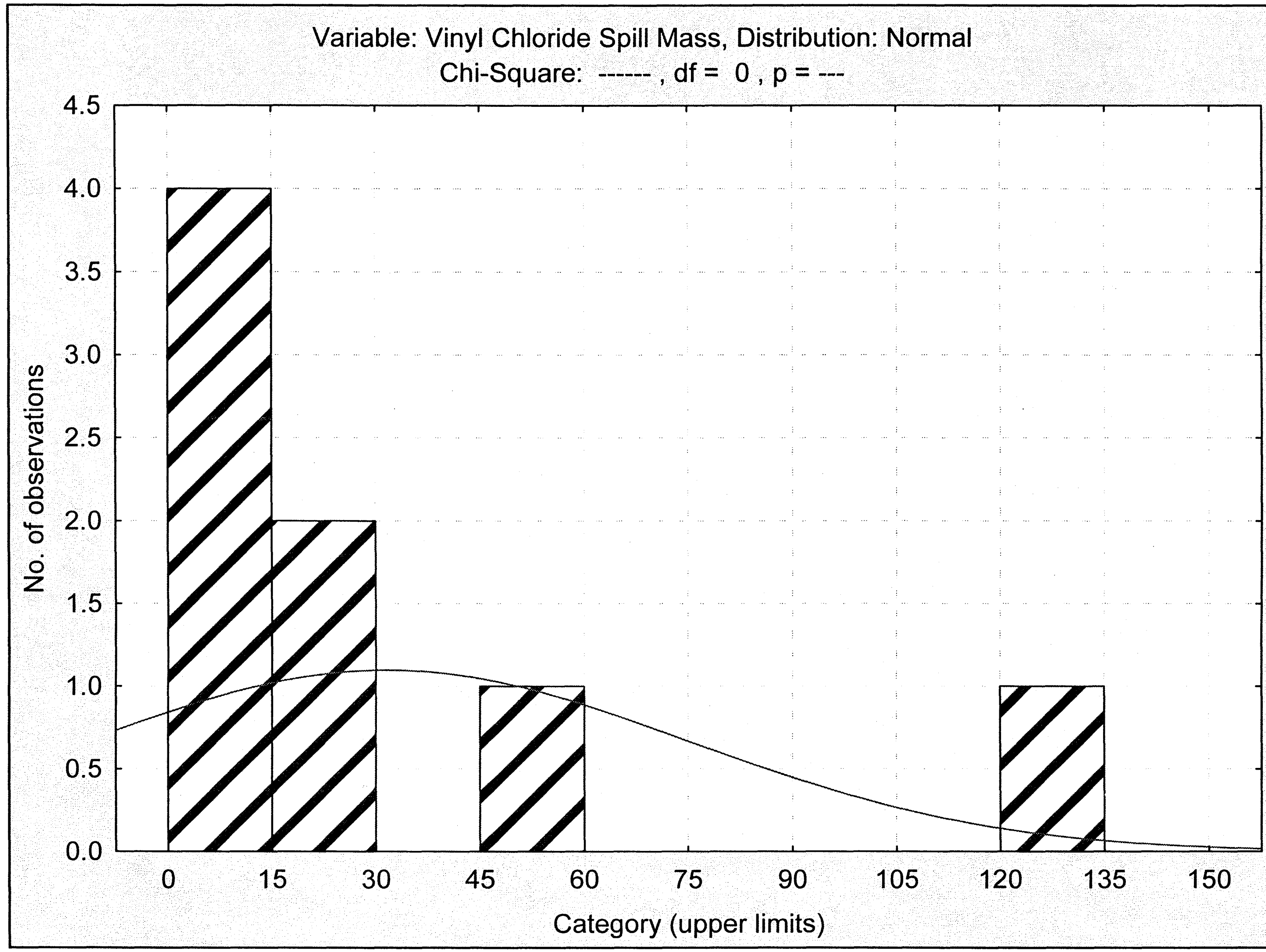
Observed mean = 31.675000, Observed variance = 1903.905000

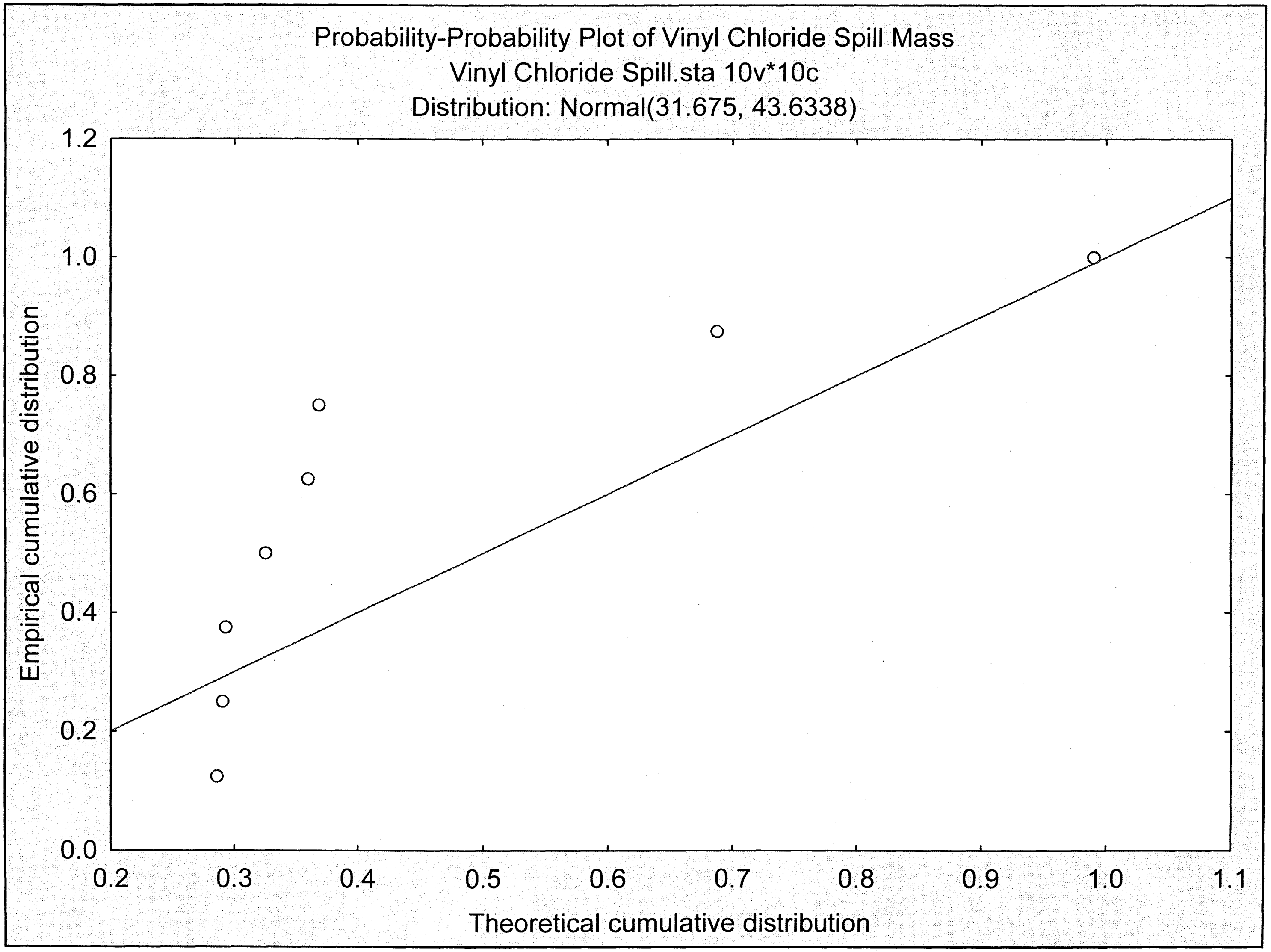
Distribution: Normal

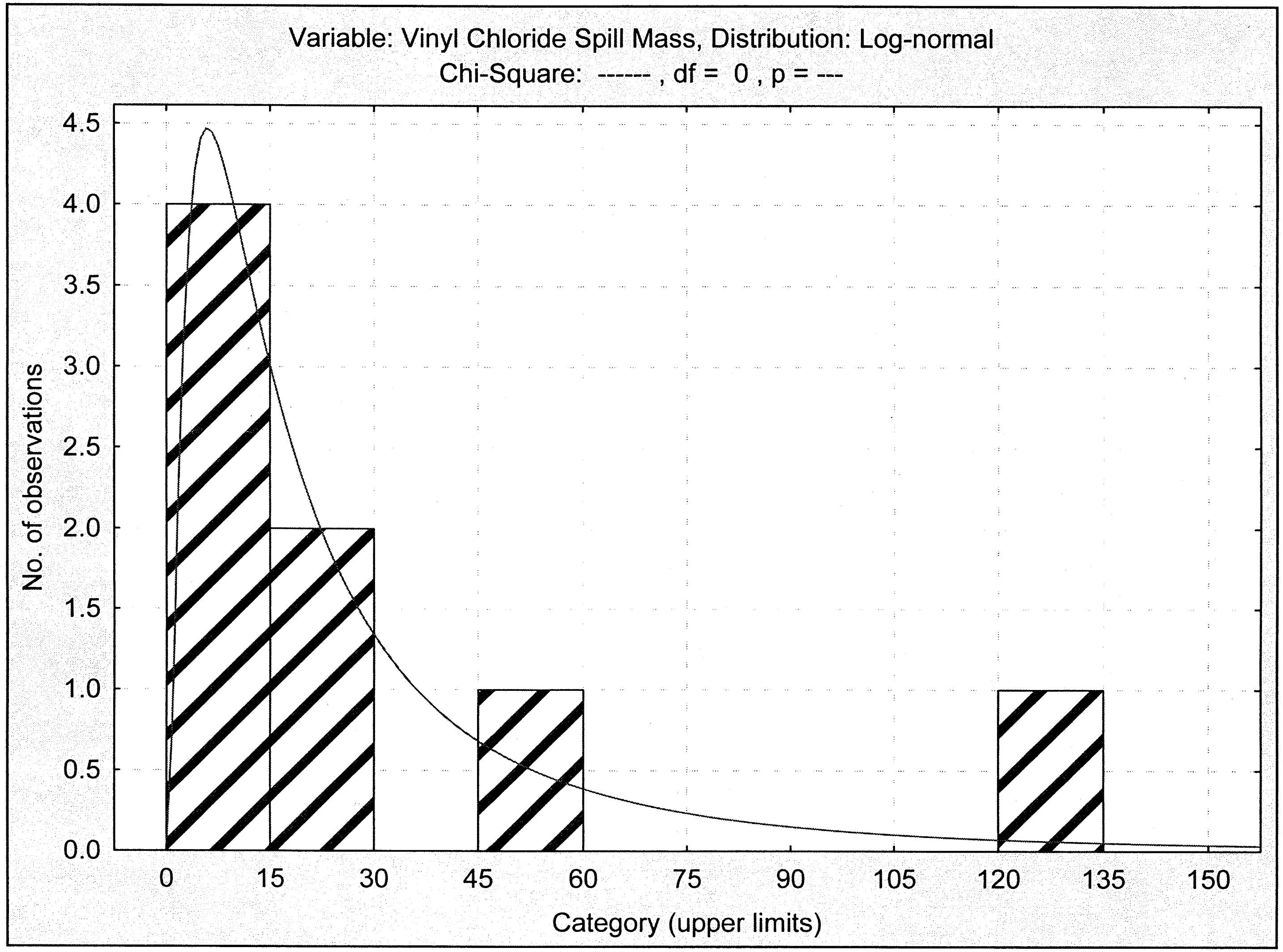
Parameters: Mean = 31.67500, Variance = 1903.905

	Variable: Vinyl Chloride Spill Mass, Distribution: Normal (Vinyl Chloride Spill.sta) Chi-Square: ------ , df = 0 , p = ---									
Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
<= 15.00000	4	4	50.00000	50.0000	2.809376	2.809376	35.11720	35.1172	1.19062
30.00000	2	6	25.00000	75.0000	1.068138	3.877514	13.35173	48.4689	0.93186
45.00000	0	6	0.00000	75.0000	1.082187	4.959702	13.52734	61.9963	-1.08219
60.00000	1	7	12.50000	87.5000	0.975341	5.935043	12.19177	74.1880	0.02466
75.00000	0	7	0.00000	87.5000	0.781969	6.717012	9.77461	83.9626	-0.78197
90.00000	0	7	0.00000	87.5000	0.557699	7.274710	6.97123	90.9339	-0.55770
105.00000	0	7	0.00000	87.5000	0.353822	7.628532	4.42278	95.3567	-0.35382
120.00000	0	7	0.00000	87.5000	0.199684	7.828216	2.49605	97.8527	-0.19968
135.00000	1	8	12.50000	100.0000	0.100247	7.928463	1.25308	99.1058	0.89975
< Infinity	0	8	0.00000	100.0000	0.071537	8.000000	0.89421	100.0000	-0.07154


Variable: Vinyl Chloride Spill Mass, Distribution: Normal
Chi-Square: ------ , df = 0 , p = ---
No. of observations
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
15
30
45
60
75
90
105
120
135
150
Category (upper limits)


Variable: Vinyl Chloride Spill Mass, Distribution: Normal
Chi-Square: ------ , df = 0 , p = ---
No. of observations
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
15
30
45
60
75
90
105
120
135
150
Category (upper limits)


Probability-Probability Plot of Vinyl Chloride Spill Mass
Vinyl Chloride Spill.sta 10v*10c
Distribution: Normal(31.675, 43.6338)
Empirical cumulative distribution
Theoretical cumulative distribution
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1


Variable: Vinyl Chloride Spill Mass, Distribution: Log-normal
Chi-Square: ------ , df = 0 , p = ---
No. of observations
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
15
30
45
60
75
90
105
120
135
150
Category (upper limits)

Appendix V Spill Inter-event Time

The frequencies of spills are indicated by the number of days between the spill occurrences. Tables V.1-4 show the inter-event time (day) of the benzene and vinyl chloride spills in the SAC and SLEA data.

Table V.1 Inter-event time for benzene spills (SAC data)

Benzene spills (SAC data)		
Date	Mass (kg)	Inter-event Time (day)
2-Sep-1988	79.11	-
31-May-1989	3.00	271
31-May-1989	3.52	0
20-Jul-1989	40170.30	50
28-Sep-1989	5.27	70
5-Dec-1989	40.00	68
26-Jul-1990	5.00	233
23-Jul-1992	12.20	728
9-Feb-1993	117.00	201
3-Jun-1993	1.40	114
8-Sep-1993	50.00	97
2-Jan-1996	45.00	846

Table V.2 Inter-event time for benzene spills (SLEA data)

Benzene spills (SLEA data)		
Date	Mass (kg/l)	Inter-event time (day)
2-Sep-1988	38	-
20-Jul-1989	0.1	321
2-Aug-1989	6	13
28-Sep-1989	4.5	57
5-Dec-1989	30	68
6-Dec-1989	16	1
19-Dec-1989	37.4	13
27-Apr-1990	1	129
4-May-1990	0.5	7
26-Jul-1990	5	83
6-Nov-1990	22	103
24-Jan-1991	3.5	79
2-Feb-1991	23	9
23-Dec-1991	7	324
21-Jan-1992	648	29

Benzene spills (SLEA data) (continue)		
Date	Mass (kg/l)	Inter-event time (day)
8-Jul-1992	4.7	169
12-Jul-1992	30	4
9-Feb-1993	117	212
2-Jun-1993	1.4	113
8-Sep-1993	50	98
16-Jan-1994	1.3	130
2-Jan-1996	45	716
23-Aug-1996	1.3	234
8-Sep-1996	1.54	16
14-Mar-1999	4.1	917
16-Dec-2000	6	643
1-Nov-2001	13	320
22-Nov-2001	11.7	21
12-May-2002	4.33	171
3-Mar-2003	3	295
29-Oct-2004	7	606

Table V.3 Inter-event time for vinyl chloride spills (SAC data)

Vinyl chloride spills (SAC data)		
Date	Mass (kg)	Inter-event Time (day)
20-Jul-1990	17.00	-
13-Aug-1990	1200.00	24
10-Mar-1991	7.90	209
2-Jun-1991	16.00	84
7-Jan-1995	7.00	1315
14-Aug-2003	100.00	3141

Table V.4 Inter-event time for vinyl chloride spills (SLEA data)

Vinyl chloride spills (SLEA data)		
Date	Mass (kg)	Inter-event Time (day)
4-Feb-1989	7.60	-
20-Jul-1990	53.00	531
10-Mar-1991	7.90	233
2-Jun-1991	16.00	84
9-Aug-1991	11.90	68
7-Jan-1995	7.00	1247
14-Aug-2003	133.00	3141
16-Aug-2003	17.00	2

Appendix VI Excerpts of Benzene and Vinyl Chloride Spill Records from the SAC Data

Tables VI.1-2 are excerpts of the benzene and vinyl chloride spills from the SAC data in 1988-2007 for the St. Clair River AOC.

Table VI.1 Benzene spills (SAC data)

Date	Mass (kg)	Source	Sector	Cause	Environmental Impact
2-Sep-1988	79.11	Pipe Line	Chemical	Discharge /Bypass To Watercourse	Water course or lake
31-May 1989	3.00	Pipe Line	Chemical	Discharge /Bypass To Watercourse	Water course or lake
31-May-1989	3.52	Pipe Line	Chemical	Discharge /Bypass To Watercourse	Water course or lake
20-Jul-1989	40170.30	Petroleum Refinery	Petroleum	Discharge /Bypass To Watercourse	Water course or lake
28-Sep-1989	5.27	Pipe Line	Chemical	Discharge /Bypass To Watercourse	Water course or lake
5-Dec-1989	40.00	Pipe Line	Chemical	Unknown	Water course or lake
26-Jul-1990	5.00	Other Plant	Chemical	Valve/Fitting Leak/Failure	Water course or lake
23-Jul-1992	12.20	Other Plant	General Manufacturing	Start Ups/Shut Downs/Interruptions	Water course or lake
9-Feb-1993	117.00	Other Plant	General Manufacturing	Valve/Fitting Leak/Failure	Water course or lake
3-Jun-1993	1.40	Other Plant	General Manufacturing	Other Discharges	Water course or lake
8-Sep-1993	50.00	Other Plant	General Manufacturing	Cooling System Leak	Water course or lake
2-Jan-1996	45.00	Other Plant	General Manufacturing	Other Discharges	Water course or lake

Table VI.2 Vinyl chloride spills (SAC data)

Date	Mass (kg)	Source	Sector	Cause	Environmental Impact
20-Jul-1990	17.00	Other Plant	Chemical	Valve/Fitting Leak/Failure	Water course or lake
13-Aug-1990	1200.00	Other Plant	Chemical	Valve/Fitting Leak/Failure	Water course or lake
10-Mar-1991	7.90	Other Plant	Chemical	Discharge /Bypass To Watercourse	Surface Water Pollution
2-Jun-1991	16.00	Other Plant	Chemical	Discharge /Bypass To Watercourse	Water course or lake
7-Jan-1995	7.00	Other Plant	Chemical	Valve/Fitting Leak/Failure	Water course or lake
14-Aug-2003	100.00	Other Plant	Chemical	Process Upset	Surface Water Pollution