# EXAMINATION OF POTENTIAL ENVIRONMENTAL IMPACTS ON SURFACE WATER ASSOCIATED WITH CRANBERRY FARMING IN NEWFOUNDLAND AND LABRADOR AND DEVELOPMENT OF BEST MANAGEMENT PRACTICES FOR IMPACT MITIGATION

by

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## ABSTRACT

The commercial cranberry industry has a significant economic impact in North America, with cranberry sales of $89.6 million in Canada in 2014. However, there is growing concern about elevated levels of pesticides and nutrients downstream from cranberry farms and the associated risks to water quality and aquatic life. The present study will identify potential environmental impacts and develop best management practices (BMPs) for the growing cranberry industry in the Canadian province of Newfoundland and Labrador (NL).

Bi-weekly upstream, on-farm, and downstream water sampling was conducted at 6 farms in NL from June to November of 2011 and 2012. Water quality testing assessed levels of 69 pesticides and 11 additional parameters. Nine soil samples were analyzed for 122 pesticides and 4 additional parameters. Probability, linear and exponential regression, and correlational analyses were carried out to assess data. ANOVA and Tukey tests were run to determine significance between sites, and descriptive statistics were evaluated.

The only significant difference between upstream and downstream sites over all farms was a decrease downstream compared to upstream for pH. The most frequently detected pesticide was diazinon, with 15 detections at both upstream and downstream sites. The only other pesticide detection downstream aside from 3 instances of trace amounts of historical use pesticides was a single detection of carbaryl. None of the nine soil samples taken at the downstream locations contained any detectable levels of

pesticides. The lack of significant differences in water samples between downstream and upstream sites for pesticides and nutrients, as well as no detected pesticides in soil samples, suggests current on-farm practices in the studied farms have been fairly effective in mitigating risk to downstream surface water and soil in NL during the sampling period. However, the frequent detection of diazinon off the farm shows there may be room for improving management practices for cranberry farming in the province.

An in depth analysis of BMPs at Deadman's Bay cranberry farm found that many of the fifteen key BMPs introduced in the present study were already implemented at the farm, but that there was a need to adopt or modify some other BMPs or their combinations. Implementing the recommended BMPs at sites throughout NL will enable the provincial cranberry industry to minimize economic costs and environmental impacts.

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## Table of Content

## List of Tables

# List of Figures

## List of Symbols and Abbreviations

NL Newfoundland and Labrador

DB Deadmans Bay

TN Terra Nova

SC Stephenville Crossing

BH Botwood Highway

GFW Grand Falls Windsor

BF Bishop's Falls

BMPs Best Management Practices

DT Degradation Time

LD Lethal Dose

LC Lethal Concentration

NOEC No Observed Effect Concentration

$K_{oc}$ Sorption Coefficient

TDS Total Dissolved Solids

BOD Biological Oxygen Demand

IPM Integrated Pest Management

# Chapter 1: Introduction

## 1.1 Background

The North American cranberry (*Vaccinium macrocarpon*) is a major crop for commercial cultivation, particularly in the north-eastern United States and eastern Canada (Scott, 2010). The commercial cranberry industry has a significant economic impact in North America, with an estimated value of $254 million in the United States in 2014 (NASS, 2015), and sales of $89.6 million by Canadian cranberry farmers in 2014 (Statistics Canada, 2015).

With markets for cranberries growing worldwide, several studies have been conducted to evaluate potential downstream environmental effects of cranberry cultivation. Studies in the north-eastern United States have found that pesticides and fertilizers that were applied on cranberry farms were present in downstream surface water, including phosphorus (Eichner et al., 2012), diazinon (Davis, 1997; Rountry, 2008), carbaryl (Davis, 1997; Rountry, 2008), and numerous additional contaminants. In some cases the concentrations of these compounds were high enough to have potential negative impacts on some forms of aquatic life (Davis, 1997; Rountry, 2008). In a study by the U.S. Geological Survey (USGS, 2005) in Wisconsin, it was concluded that pesticide levels entering nearby lakes were not high enough to be acutely toxic to fish, but that further research on the pesticide’s effects on lakes and aquatic biology was required. Since acidic soils of cranberry bogs tend to be especially low in phosphorus (Hanson, 2007), large quantities of phosphorus application on cranberry farms may pose a particularly high risk of downstream contamination which can lead to eutrophication and algal blooms in phosphorus limited environments.

The Agriculture and Lands Branch (Branch), Department of Fisheries and Land Resources, Government of Newfoundland and Labrador, has been researching and developing a cranberry industry since the late 1990s, when the Provincial Government established pilot sites throughout the province to evaluate potential for development of the cranberry industry in the province. Since the beginning of this project, five cranberry developments have been established, including one research site managed by the province and four private sector sites. Pre-commercialization began in 1996, with expansion of four existing private sites, including 10 acres in Terra Nova, 4 acres in Frenchman's Cove, 4 acres in Stephenville Crossing, and 5 acres in Stephenville (Branch, 2016). Research and development activities have shown that cranberry producers can produce quality fruit and yields that are competitive with the industry best. Farm gate value in Newfoundland and Labrador in 2014 was $122,000, with marketed production of 482 tons. In 2015, Newfoundland and Labrador's total cultivated area and bearing area for cranberries was 300 acres and 112 acres, respectively (Statistics Canada, 2016). In 2014, a $7 million federal-provincial-territorial program was announced to develop the industry in Newfoundland and Labrador further, with the intent of creating jobs in rural communities and diversifying the economy ( Branch, 2016).

The exponential increase in cranberry field development in Newfoundland and Labrador from 33 acres in 2007 to over 330 acres in 2016 (various stages of development) has raised many concerns as to how this development is affecting the environment, particularly the impacts associated with chemical use of fertilizers and pesticides (insecticides, fungicides and herbicides) on surface water quality. Given these potential environmental risks, it is possible that future growth and expansion of the industry may be influenced, and thus research is required to inform on the actual impacts of these types of developments.

Given the vast amounts of peatland that exists in the province (shown in Figure 1.1), opportunities exist to increase production of cranberries, with the ultimate goal being commercialization. Newfoundland and Labrador has a competitive advantage in the cranberry industry, as it has many essential preconditions, particularly: the ability to successfully produce fruit, large areas of available bogs, available market for product, genetically pure (disease, weed and insect free) material, and strong government support. It is absolutely feasible, therefore, to have a viable and sustainable cranberry industry in the province, capable of generating significant direct and indirect social and economic benefits.

The cranberry industry in Newfoundland and Labrador is one that is faced with great opportunities and challenges. While it has the potential to contribute significantly to the province's economy and social well-being, the potential environmental risks associated with development can negatively affect surface water quality (Saad, 2005). Therefore, it is essential to increase research capacity in this area in order to support the continued development and expansion of this agribusiness in a way that is environmentally responsible. As with any sector within the agriculture and agrifoods industry, the province strives to support a cranberry industry that is sustainable. As such, the quality of life of the producers, communities, profitability of the farming operation, and protection of the environment must all be taken into consideration.

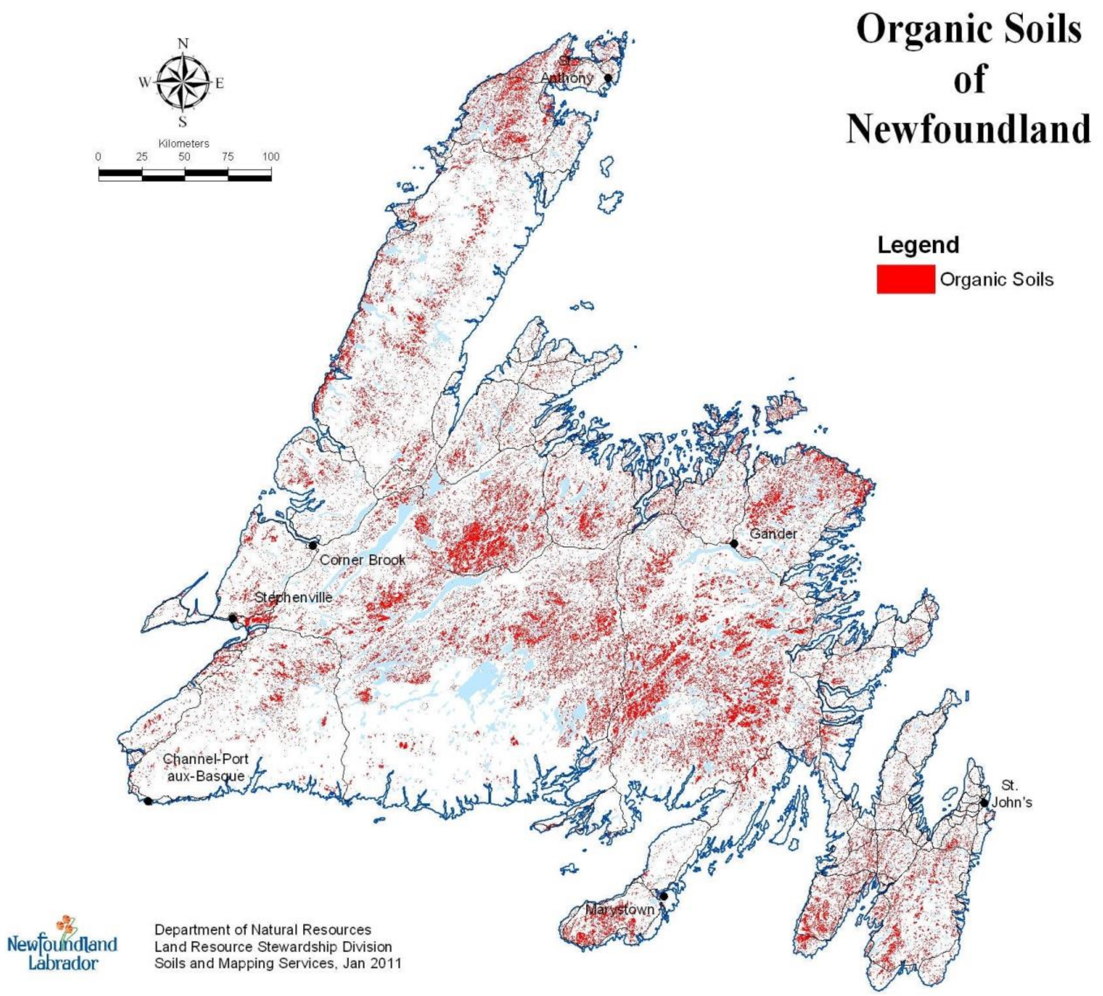


Figure 1.1 Organic Soils map of Newfoundland, visualizing the 4 million acres of peatland (shown in red) across the island of Newfoundland.

## 1.1 Objectives

To our knowledge there has been no comprehensive study in Canada on the environmental impacts of cranberry farming on surface water, so the present study will likely be the first of its kind in Canada. A proactive approach has been taken in this research project in anticipation of the future repercussions this may have on the industry. Specifically, the objective of the research is to identify the potential environmental impacts by pesticide and fertilizer contamination of downstream surface water and soil quality associated with cranberry development. Based on those findings and the current literature on best management practices (BMPs) for cranberry farming, alternate BMPs will be considered for mitigation of potential impacts and support of environmental sustainability.

This research will provide direct benefits to the agriculture industry. Founded in a strong science-based approach, the results of this work will provide a platform for future decisions surrounding the industry, and subsequently improve awareness, economic viability, efficiency, competitiveness, productivity and sustainability of the sector. Additionally, recommendations of best management practices to minimize surface water quality degradation will ensure that farming activities are in line with current environmental regulations.

### 1.3 Funding and Partnerships

Funding for this project has been provided through the Canada-Newfoundland and Labrador Agriculture Research Initiative (ARI), a federal/provincial cost shared program on a 60:40 federal-provincial basis, with the federal contribution being provided by Agriculture and Agri-food Canada (AAFC), and the provincial portion through the Agriculture Research and Development Program, Agriculture and Lands Branch, Department of Fisheries and Land Resources. ARI funding was used for field technician/assistant salaries, equipment, field logistics and sample analysis. Water sample analysis was conducted by Maxxam Analytics, Bedford, Nova Scotia.

Financial support was also provided by the former Institute for Biodiversity, Ecosystem Science and Sustainability (IBES), Sustainable Development and Strategic Science Branch, Department of Environment and Conservation, Government of Newfoundland and Labrador.

### 1.4 Thesis Outline

In the following chapter, Chapter 2: Literature Review, there is an overview of the cranberry industry globally and in Newfoundland and Labrador, identification of environmental impacts of cranberry farming and risk agents to downstream environments, and review of previous studies on the environmental impacts of cranberry farming.

Chapter 3: Site Investigations and Methods, outlines the characteristics of the farms and sites used in the present study, pesticide and fertilizer application schedules used on the farms, water and soil sampling protocols, and statistical methods used to analyze water and soil data.

Chapter 4: Analyses of Parameters and Trends for Cranberry Farms, includes sections on probability analysis, regression analysis, correlation between parameters, descriptive statistics, and tests for significance between upstream, on-farm, and downstream sites.

Chapter 5: Cranberry Farming BMPs and General Discussion, consists of an introduction to fifteen BMPs for cranberry farming in Newfoundland and Labrador, an in depth analysis of existing BMPs at DB cranberry farm, and an assessment of the need for new BMPs in Newfoundland and Labrador.

Chapter 6: Conclusions and Recommendations, summarizes the present study, makes conclusions and recommendations for the cranberry industry in Newfoundland and Labrador, and provides direction for future research.

**1.5 Summary**

The commercial cranberry industry has a significant economic impact in North America (NASS, 2015; Statistics Canada, 2015), with growing global markets (Eichner et al., 2012). However, multiple studies have found that pesticides and fertilizers applied on cranberry farms are entering downstream water, with potentially harmful environmental impacts. With limited study on environmental impacts of cranberry farms in Canada, and a growing industry in Newfoundland and Labrador, the present study will play a central role in the future of the industry in Newfoundland and Labrador by identifying potential environmental impacts and developing best management practices.

# Chapter 2: Literature Review

## 2.1 Overview of the Cranberry Industry at Provincial and Global Scales

The North American cranberry (*Vaccinium macrocarpon*) is a fruit native to North America (Pollack, 2001) that is a major crop for commercial cultivation, particularly in the north-eastern United States and eastern Canada (Scott, 2010). The world's largest commercial cranberry producer is the United States, with an estimated value of $385.5 million. Within the US, Wisconsin produces the majority of cranberries, with other producers including Massachusetts, New Jersey, Oregon, and Washington (NASS, 2015). In 2006, only 19% of cranberries were produced outside of the US, including 10,000 acres in Canada and 1,000 acres in Chile (Sandler, 2008). In Canada, international demand and rising consumption has spurred on a rapidly increasing cranberry industry in recent years. Between the 2006 and 2011 censuses the cranberry became the 4th largest fruit crop in Canada, surpassing raspberries, strawberries, and peaches. During this time, cranberry farm area increased in Quebec by 112.1% and in British Columbia by 61%. All of the Atlantic Canadian provinces became greater players in the industry during these years, with an increased cranberry farm area in each province (Statistics Canada, 2012). Canadian production was estimated at a total of 86,286,000 kg of cultivated cranberries in 2011, with the majority coming from Quebec (50,573,000 kg) and British Columbia (27,414,000 kg). Other Canadian provinces harvesting cranberries include Ontario, New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland

and Labrador (See Table 1; Dorff, 2014). In 2014 Canadian cranberry farmers sold $89.6 million of cranberries, a dip of 5.1% compared to 2013 sales (Statistics Canada, 2015). There are 15 cranberry farms in operation in Newfoundland and Labrador (CBC News, 2014), but the total quantity produced by Newfoundland and Labrador has been suppressed to meet the confidentiality requirements of the *Statistics Act* (Dorff, 2014). Table 2.1 shows the total number of cranberries harvested on farms in each Canadian province in 1940 and 2011.

Table 2.1: Cranberries harvested in each Canadian province in 1940 and 2011 (modified from Dorff, 2014)

| **Province** | **Cranberries, Wild (unmanaged, kg)** | **Cranberries, Cultivated (managed, kg)** | |
|---|---|---|---|
| | **1940** | **1940** | **2011** |
| Newfoundland and Labrador | .. | .. | X |
| Prince Edward Island | 27,898 | 1,642 | 357,000 |
| Nova Scotia | 19,805 | 86,878 | 1,472,000 |
| New Brunswick | 26,967 | 3,036 | 6,024,000 |
| Quebec | 13,953 | 1,197 | 50,573,000 |
| Ontario | 13,219 | 1,129 | X |
| Manitoba | 8,899 | 0 | .. |
| Saskatchewan | 17,030 | 27 | .. |
| Alberta | 27,364 | 159 | .. |
| British Columbia | 2,233 | 2,778 | 27,414,000 |
| **Canada** | **157,368** | **96,846** | **86,286,000** |

.. = not available for reference period
X = suppressed to meet confidentiality requirements of Statistics Act

## 2.2 Environmental Impacts on Surface Water

Cranberry production requires large amounts of water for harvesting, irrigation, and frost protection. Cranberry farmers utilize lakes and streams as their main sources of water (Hinterleitner, 2006). To achieve maximum cranberry production, crops also require application of fertilizers and pesticides (Hinterleitner, 2006)**.** Plant nutrients nitrogen and phosphorus are added as fertilizers to crops to increase yields, and pesticides are applied to crops to prevent losses in crop yield and quality. However, if these risks agents make their way to the ambient environment they may impact aquatic life and human health (Saad, 2005). After use in cranberry bogs, water drains back to the lakes and streams, potentially carrying risk agents applied on the farm including nitrogen, phosphorus, and pesticides out into lakes and streams (Saad, 2005). In comparison to surface water, it is less likely that nutrients and pesticides from cranberry bogs will enter groundwater because of the barrier to movement of water down through the soils by the alternating sand and organic matter layers and the dense fibrous root system of the cranberry vines. Another reason why contaminants are less likely to enter groundwater is that wetland cranberry bogs are typically located in low lying areas for which groundwater is effluent, and as the water table moves above the land surface the water and contaminants will be discharged into water bodies surrounding the bogs (Mahr and Moffitt, 1993; Sandler, 1991). Reasons for the reduced chance of these chemicals entering groundwater include the high organic matter of cranberry bog soil which creates an impervious barrier that separates the bog from the main aquifer, although this can vary by case and location based on geological conditions and persistence of chemicals. The high rate of water use, application of fertilizers and pesticides, and close proximity of cranberry bogs to surface water increase potential for nutrient and pesticide contamination of downstream surface water (Hinterleitner, 2006)**.** Figure 2.1, shows one downstream site in Terra Nova.

Figure 2.1: Water downstream from a cranberry bog in the Terra Nova region, with water flowing into Terra Nova Lake

## 2.3 Risk Agents to Surface Water

### *2.3.1 Nutrients*

Fertilizer application plays an important role in cranberry production because access to nitrogen, phosphate, and potassium is essential for growth of all plants (Eilers, 2010).

The acidic soils of cranberry bogs tend to be particularly low in phosphorus, so farmers need to add phosphorus to increase cranberry production (Hanson, 2007). Most fertilizers applied to cranberry fields contain nitrogen, phosphate, and potassium, with varying ratios of each (Sandler, 2008). Standard recommendations for fertilizer application on cranberry bogs are 3.5-11 kg/hectare per year nitrogen, maximum 20 lb/acre per year phosphate, and 40-120 lb/acre per year potassium (DeMoranville, 2008). However, nutrients that are applied on farms and are transported to the ambient environment is a source of economic loss for farmers, and may impact the surrounding environment (Eilers, 2010). The use of high quantities of fertilizers paired with the water from the annual cranberry harvest floods creates the problem of runoff containing high concentrations of nutrients with the potential of contaminating downstream water (DiBiasio, 2013). Figure 2.2 shows nutrient inputs, outputs, and transport processes for agricultural land.

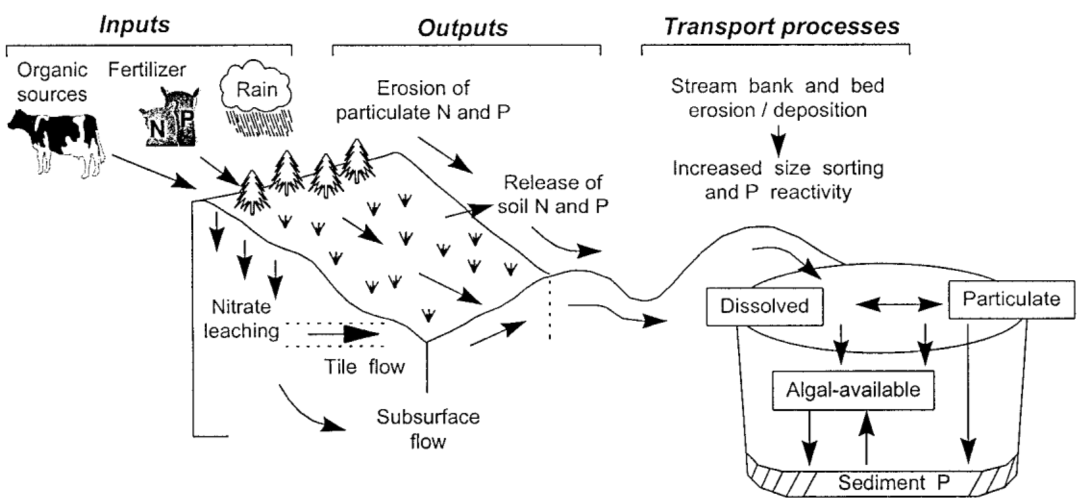


Figure 2.2: Inputs, outputs, and transport processes of nutrients from agricultural land (from Carpenter, 1992)

Phosphate and nitrogen that is transported by water into surface water and groundwater may cause overgrowth of algae or other plant material and result in eutrophication (Eilers, 2010). A 2008 study (Dodds, 2009) determined that a conservative estimate of the financial cost of freshwater contamination by nutrients from anthropogenic sources in the United States was $2.2 billion per year, including $44 million for recovery of threatened and endangered species of surface water inputs. Nonpoint inputs including runoff from agriculture is the major source of water degradation (U.S. EPA, 1990). In pond and lake ecosystems the limiting nutrient is usually phosphorus (Eichner, 2012). Plant organic matter generally has a phosphorus to nitrogen to carbon ratio by weight of 1P : 7N : 40C (Wetzel, 1983). Additions of phosphorus can lead to eutrophication and algal blooms, and if nitrogen and carbon are present in excess the phosphorus has the potential to produce up to 500 times its own weight in phytoplankton or algae. Nitrogen is less commonly the nutrient that limits growth in freshwater ponds, but in cases where there are high phosphorus loads with no nitrogen inputs nitrogen can then be the limiting nutrient to plant growth (Eichner, 2012).

Eutrophication, the enrichment of an ecosystem with nutrients, can have numerous negative effects on aquatic ecosystems including the increased growth of algae that degrades water quality for drinking, fisheries, and other uses. In freshwater, blooms of cyanobacteria contribute to water-related problems including summer fish kills (Palmstrom, 1988). When cyanobacteria die they release neurotoxins and hepatotoxins which may pose a serious human health risk when ingested (Lawton, 1991). Eutrophication causes the loss of habitats, including aquatic plant beds in marine and freshwater environments (Jeppesen, 1998), and is also a factor in the loss of aquatic biodiversity (Seehausen, 1997).

A study in Wisconsin (Garrison, 2005) investigated historical eutrophication of Musky Bay in response to cranberry farming and residential development. Musky Bay was eutrophic at the time of the study, containing dense aquatic plant growth and a floating algal mat, with commercial cranberry farms on its southeastern and southwestern parts, and residential homes on its northern and eastern shores. Sediment cores were analyzed from two sites within the bay and one site within the main lake to identify temporal and causal relations of eutrophication by comparing sampling data with historical records of the construction and expansion of the cranberry bogs and shoreline residential homes. Cranberry farms were constructed at the southeastern location in 1939 and southwestern location in the early 1940s. Both farms were expanded over time, reaching their present size by 1980 and 1986 for the southeastern and southwestern farms, respectively. For residential homes, construction started on the bay between 1914 and 1932, reaching a total of 31 houses on the bay by 1971. The remaining houses were built between 1971 and 2001, reaching a total of 37 houses on the bay by the time of the study. The researchers determined that both cranberry farming and residential development were impacting water quality of the bay, but identified five pieces of evidence for why cranberry farms were the most significant source of nutrient enrichment in the bay during the previous 60 years: 1) ambient nutrient concentrations started increasing around 1939, coinciding with initial cranberry farm construction; 2) ambient nutrient concentrations increased sooner in the sampled core close to the cranberry farm compared to the core sampled closer to the residential development; 3) the eutrophic indicator *S. construens* var. *binodis* increased more in the core near the cranberry farm compared to the core near the residential development; 4) the floating algal mat was not in the bay historically, but rather formed within the last decade, meaning the formation of the mat corresponded to the beginning of the southeastern cranberry farm's aerial fertilizer application; 5) increases in potassium concentrations within the last decade also aligned with the beginning of aerial fertilizer application.

*2.3.1.1 Nitrogen, Nitrate, Nitrite*

Incomplete uptake of nitrogen by crops means that after autumn harvest some inorganic nitrogen will remain in the soil which may pose environmental risks. Therefore, a main goal for a cranberry farmer is to determine the optimal amount of nitrogen needed as fertilizer to produce healthy crops without creating excess inorganic nitrogen. By submitting soils for laboratory testing, a farmer can determine current soil N and P levels. Accounting for current nutrient levels and the crop to be grown, a Fertilizer Management Specialist will recommend a quantity of a fertilizer that contains the appropriate nutrient ratio to provide the required levels of each nutrient. Applying optimal amounts will minimize nitrogen losses to the environment, and subsequently risks to the environment and human health (Eilers, 2010).

Nitrate pollution poses a direct health risk to humans and other mammals. At high concentrations nitrate in water can be toxic, with studies linking high concentrations to methemoglobinemia in infants (Sandstedt, 1990). Since nitrate is soluble in water it is likely to enter surface water through runoff and tile drainage and move through soil into groundwater (Drury, 2009). High nitrate levels in surface waters can increase algae growth and eutrophication, leading to deterioration of aquatic life (Guy, 2008) as well as human health impacts (Chambers, 2001).

From natural nitrogen sources, it is estimated that 203 Tg N yr-1 (1 Tg = 1 Billion kg) moves from the atmosphere into marine and terrestrial ecosystems through biological nitrogen fixation, primarily by un-reactive molecular nitrogen being reduced to ammonium compounds. In comparison, the level of nitrogen fixation through human activities including agriculture and burning of fossil fuels is so large that in the last century it has doubled the global cycling of nitrogen (anthropogenic = 210 Tg N yr-1; Fowler et al., 2013). Agriculture is the primary source of reactive nitrogen discharged into the environment, contributing 84 percent of ammonia (U.S. EPA, 2010), 73 percent of nitrous oxide (U.S. EPA, 2010), and 54 percent of nitrate (Smith 1997).

*2.3.1.2 Phosphorus*

Phosphorus is an important nutrient for plant and animal growth but applications of this nutrient as fertilizer may lead to soil saturation of phosphorus and the resulting movement of phosphorus to water bodies (Eilers, 2010). Over application of phosphorus on agricultural soils is common, and contributes to excessive runoff into water bodies (Cordell, 2008). Rosmarin (2004) estimated that out of the 1 billion tonnes of phosphorus mined since 1950, close to 250 million tonnes has ended up in water bodies or is buried in landfills. When excessive amounts of phosphorus enters surface water it will contribute to eutrophication of rivers and lakes and to *Cyanobacteria* blooms, resulting in decreased water quality and limitations on water use (Eilers, 2010). Phosphorus in water is not directly toxic to humans and animals, but can indirectly cause toxic effects in freshwater due to algal blooms or anoxic conditions (Carpenter, 1998).

*2.3.2 Pesticides*

Worldwide in 2007 there was an estimated 5.2 billion pounds of pesticides sprayed, with the largest contributors being herbicides (39% of total), insecticides (18% of total), and fungicides (10% of total). The United States accounted for 22% of the total worldwide pesticide use in 2007 (U.S. EPA, 2013). Pesticide use is an effective way to control weeds, insects and diseases, but pesticides applied on cranberry bogs may enter the ambient environment and contaminate surface water (Eilers, 2010). Figure 2.3 shows the processes involved in pesticide transport through the environment. Pesticides that enter surface water may cause ecological impacts including direct kills of fish and other organisms, impediments to reproduction, growth, and development, and bioaccumulation and biomagnification. The extent to which these impacts occur is dependent in part upon both the toxicity of the pesticide used and the exposure scenario, including the quantity of the pesticide used and the application timing and method (Environment Canada, 2011). In Canada, although some surface water monitoring programs are in place throughout the country, many pesticides that are used in agriculture and have the potential to cause toxic effects downstream still do not have specific water quality guidelines established (Eilers, 2010).

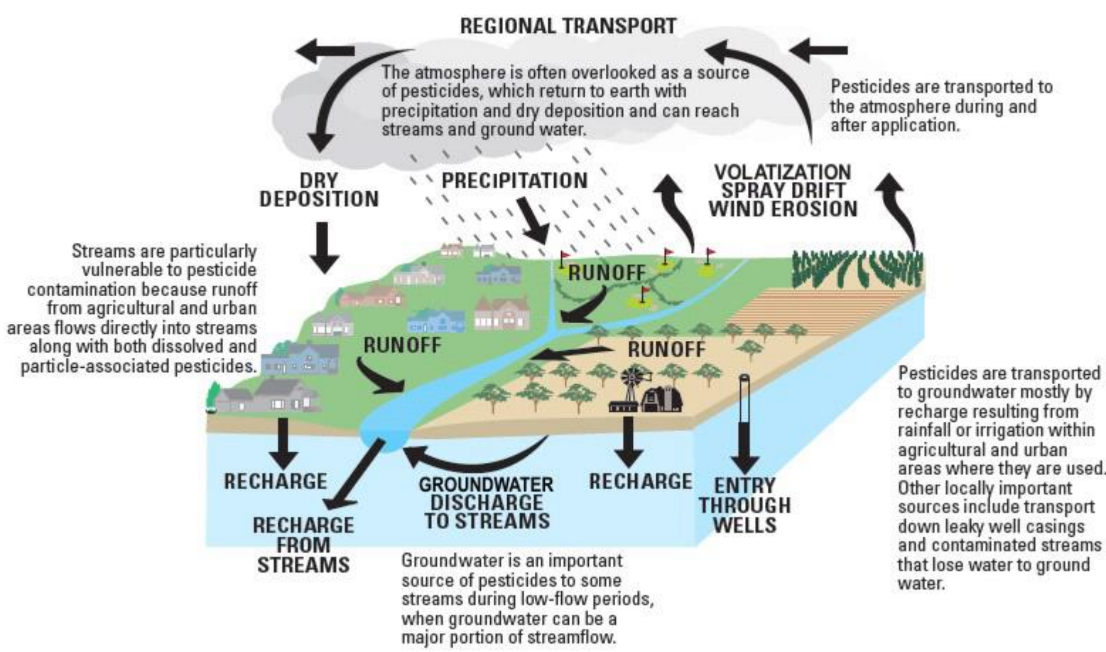


Figure 2.3 Pesticide transport in the environment (modified from Gilliom, 2005)

The amount of a specific pesticide entering the ambient environment is partially dependent upon the physical and chemical factors of a pesticide that controls its mobility and persistence. These factors promote the transport of some pesticides out into the ambient environment while limiting the amount of other pesticides leaving the cranberry bog (Phillips, 2004). In addition to mobility and persistence of particular pesticides, many other factors can influence pesticide transport into ambient environment including the timing and rate of application, physical characteristics of watersheds, and storm characteristics (Phillips, 2004).

Pesticides that have been recommended to producers for use on cranberry farms in Newfoundland and Labrador include diazinon, carbaryl, chlorothalonil, dichlobenil, napropamide, mesotrione, glyphosate, clopyralid, fluazifod-P- butyl and S-isomer, sethoxydim, and methoxyfenozide (L. Madore, personal communication, December 7, 2015). Pesticides that have actually been applied at Newfoundland and Labrador cranberry developments since 2011 include at a minimum: diazinon, carbaryl and chlorothalonil, although, with the exception of Deadmans Bay cranberry farm (application schedule outlined in Chapter Three), specific pesticide application information was not obtained from the other farms due to the potential of incomplete records. Table 2.2 shows characteristics of carbaryl, diazinon, and chlorothalonil involved in determining fate in the environment including solubility, half-life, sorption coefficient, and vapor pressure.

Table 2.2: Characteristics of carbaryl, diazinon, and chlorothalonil determining fate in the environment.

| Pesticide | Solubility (mg/L) | Half-life | Sorption coefficient ($K_{oc}$) | Vapor pressure (mm Hg) |
|---|---|---|---|---|
| Diazinon | 60[a] | 70 hrs to 12 weeks (surface water); 10 to 200 days (soil)[b] | 1,000[a] | $6 \times 10^{-5}$[a] |
| Carbaryl | 120[a] | 21 days (surface water)[e]; 4 to 72 days (soil)[c] | 300[a] | $1.2 \times 10^{-6}$[a] |
| Chlorothalonil | 0.81[d] | < 8 hrs (surface water); 30 – 90 days (soils)[d] | 850 – 7000[d] | $5.72 \times 10^{-7}$[d] |

[a] Wauchope et al, 1992
[b] ATSDR, 2011
[c] NPIC, 2003
[d] Syngenta Crop Protection, 2003
[e] Xu, 2002

*2.3.2.1 Diazinon*

Diazinon is an insecticide used to protect crops including fruits and vegetables, and its main mode of toxicity is inhibition of cholinesterases in the nervous system (EPA, 2005). In surface water diazinon has a half-life ranging from approximately 70 hours to 12 weeks, with its persistence strongly dependent on environmental conditions including pH, temperature, and presence of microorganisms (ATSDR, 2008). In soil diazinon has a half-life ranging from 10 to 200 days (ATSDR, 2008). Table 2.3 provides Degradation Time ($DT_{50}$; the amount of time it takes for 50% of a compound to degrade in soil or water), Lethal Dose ($LD_{50}$; the dose required to kill 50% of a population of exposed test animals), and general information on diazinon and carbaryl.

In the United States Environmental Protection Agency's (EPA; 2005) review of studies relating to the acute toxicity of diazinon in surface water, they found toxicity to freshwater animals had been previously determined for 13 invertebrate species, 10 fish species and one amphibian species. Acute toxicity values in these studies ranged from

Table 2.3: Chemical properties, functions, $DT_{50}$ $LD_{50,}$ and $LC_{50}$ for diazinon, carbaryl, and chlorothalonil (modified from Chowdhury, 2012).

| Compound | Formula and CAS No | Chemical Class and Function | $DT_{50}$ (days) | $LD_{50}$ (mg/kg) | $LC_{50}$ (mg/L) |
|---|---|---|---|---|---|
| Diazinon | $C_{12}H_{21}N_2O_3PS$; 333-41-5 | Organophosphorus; Insecticide[a] | 7-15[a] | Rabbit: 1,160-1,340[a] | Freshwater fish: 0.09 – 7.8 (acute)[b] |
| Carbaryl | $C_{12}H_{11}NO_2$; 63-25-2 | Insecticide, plant growth regulator, nematicide[a] | 0.15-35[a] | Rats: 50-500[a] | Freshwater fish: 0.25 – 20 (96 hr)[c] |
| Chlorothalonil | $C_8C_{14}N_2$; 1897-45-6 | Chloronitriles, fungicide, metabolic process inhibitor[d] | 30 – 90 (soils); < 0.33 (surface water)[e] | Rats: > 10,000 (oral) Rabbits: > 10,000 (dermal)[d] | Channel catfish: 0.43; Bluegill: 0.3; Rainbow Trout: 0.25[f] |

[a] Chowdhury, 2012
[b] NPIC, 2009
[c] NPIC, 2000
[d] British Columbia Ministry of Agriculture, Food, and Fisheries, 2004
[e] Syngenta Crop Protection, 2003
[f] EXTOXNET, 1996

0.25 μg/L for the cladoceran, *Ceriodaphnia dubia*, to 11,640 μg/L for planaria, *Dugesia tigrina*. Table 2.4 shows toxicity levels of diazinon and carbaryl to algae, aquatic invertebrates, and fish, and No Observed Effect Concentration (NOEC) values for both pesticides, presented in a more recent aquatic risk assessment (Vryzas, 2011), although other pesticides relevant to the present study including chlorothalonil were not assessed in the aquatic risk assessment. This table shows that both diazinon and carbaryl are especially toxic to aquatic invertebrates. In comparison to $LD_{50}$ which is the dose of a compound required to kill 50% of a population of exposed test animals, the NOEC provided in the table is the highest level of a compound for which there were no observable adverse effects (e.g. decreases in growth or reproduction) to the most sensitive species tested.

Table 2.4: Toxicity levels (ug/L) of diazinon and carbaryl to algae, aquatic invertebrates, and fish (modified from Vryzas, 2011).

| Compound | Algae | Aquatic Invertebrates | Fish | NOEC |
|---|---|---|---|---|
| Diazinon | 6400 | 0.56 | 700 | 0.56 |
| Carbaryl | 600 | 6 | 210 | 6 |

*2.3.2.2 Carbaryl*

Carbaryl is an insecticide used on crops including fruits and vegetables to control various pests such as moths, ants, and mosquitoes. Carbaryl does not dissolve well in water and sticks to soil, but is widely used and can persist in surface water for a long time under the right environmental conditions (NPIC, 2003). Carbaryl is highly toxic to aquatic invertebrates including shrimp, and stoneflies, and ranges from slightly to highly toxic for numerous fish species. Carbaryl's half-life ranges from 4 to 72 days in soil, but breaks down more quickly in flooded, sandy, or well aerated soils (NPIC, 2003). In Water, photolysis degrades carbaryl with a half-life of 21 days (Xu, 2002).

The toxic mode of action for carbaryl is inhibition of the enzyme acetylcholinesterase (AChE) at synaptic junctions in the nervous system. AChE breaks down the neurotransmitter acetylcholine, and its inhibition results in the accumulation of acetylcholine in the nerve synapses, leading to continual firing of nerve pulses throughout the nervous system. The accumulation of acetylcholine can result in uncontrolled movement, paralysis, convulsions, and possible death (EPA 2012).

In EPA's (2012) review of studies relating to toxicity of carbaryl in surface water they found that toxicity to 60 freshwater species representing 47 genera had been previously determined. Acute toxicity values ranged from 3.175 µg/L for the stonefly (*Isogenus sp.*) to 27,609 µg/L for the catfish (*Clarias batrachus*).

*2.3.2.3 Chlorothalonil*

Chlorothalonil is an organochlorine fungicide used on crops including vegetables and small fruits, and is used to control fruit rots in cranberry bogs. Chlorothalonil is highly toxic to aquatic organisms including fish and invertebrates. The $LC_{50}$ dose for chlorothalonil exposure is 0.43 mg/L for channel catfish, 0.3 mg/L for bluegills, and 0.25

mg/L for rainbow trout (EXTOXNET, 1996). This fungicide is moderately persistent, with a half-life ranging from one to three months in aerobic soils (EXTOXNET, 1996), but less than 8 hours in surface water (Syngenta Crop Protection, 2003). Chlorothalonil has a solubility of 0.81 mg/L, a $K_{oc}$ of 850 – 7000, and a vapor pressure of $5.72 \times 10^{-7}$ mm HG (Syngenta Crop Protection, 2003). Since Chlorothalonil has a low solubility, there is an increased probability that if this chemical enters surface water it will be adsorbed on soil and living organisms. Chlorothalonil's low vapor pressure means it should not be readily volatised into air, decreasing the likelihood of transport of this pesticide at long distances, and therefore reducing exposure to humans and animals.

### *2.3.3 Water Quality Parameters*

Both physical and chemical parameters of water samples were analyzed in the present study.  Physical parameters include electrical conductivity, total dissolved solids, pH, temperature and turbidity.  Chemical parameters include orthophosphate, organophosphorous pesticides, organochlorinated pesticides, nitrogen (ammonia nitrogen), biological oxygen demand (BOD), nitrate-nitrogen,nitrite-nitrogen, and nitrate-nitrogen + nitrite-nitrogen.  Since regional differences in precipitation can influence the amount of contaminants entering downstream water (Environment Canada, 2011), precipitation data during the sampling periods was collected from Environment Canada climate stations proximal to the studied cranberry farms in Terra Nova National Park, Stephenville, and Badger. With increased precipitation there is an increased potential for contaminants to enter downstream water through runoff, soil erosion, and leaching to groundwater (Environment Canada, 2011).

On each of the six farms, water samples were taken bi-weekly at upstream, on-farm, and downstream sites from June to November 2011 and 2012 to encompass growing and harvest seasons. Data for each parameter were combined and averaged for all farms. Six cranberry farms in Newfoundland and Labrador were investigated for the purpose of this research: Stephenville Crossing (SC), Deadmans Bay (DB), Botwood Highway (BH), Grand Falls- Windsor (GFW), Bishop's Falls (BF), and Terra Nova (TN). The characteristics of each farm are discussed in section 3.1.

**2.4 Review of Relevant Studies in the Literature**

In this section 6 key background studies are reviewed, focusing on downstream impacts of nutrient and pesticide application on cranberry farms. These studies were selected for review because they are some of the few studies focusing specifically on the environmental effects of cranberry farming. In addition, these studies focus on some of the pollutants of interest to our study, which include nitrogen, phosphorus, diazinon, carbaryl, and chlorothalonil. Eichner et al. (2012) investigated water quality in a Plymouth, Massachusetts pond, which was impaired primarily due to high nutrient levels from cranberry bogs and other sources. This study determined the phosphorus load to the pond and evaluated best management practices such as minimizing phosphorus fertilizer application on cranberry farms. In Anderson (2006) a PhD research project was conducted to look at pesticide and nutrient effects of a cranberry farm on downstream ground and surface water in northern Wisconsin. Diazinon and various other pesticides were applied to the farm, and downstream water quality was monitored. Several recommendations were made for reducing downstream contamination, including finding pesticides with shorter half-lives. In a study by Washington State Department of Ecology (Davis, 1997; Rountry, 2008), they investigated pesticide contamination of a ditch system collecting runoff from 900 acres of cranberry bogs in Grayland/North Cove Washington. Their objectives were to determine extent and severity of pesticide contamination, impacts on aquatic life, and effectiveness of best management practices. The USGS conducted a study (USGS, 2005) in northern Wisconsin to address resident's concerns that pesticides used on cranberry bogs were affecting the water quality and biology of these downstream lakes and streams in the region. To address these concerns the USGS collected water and sediment samples from four nearby lakes and water samples from a nearby river. They analyzed samples for dozens of pesticides including diazinon, carbaryl, and chlorothalonil. Canadian studies on the effects of cranberry farms on downstream water quality are lacking, with no Canadian studies found during our search of the literature. However, we have reviewed a study from Environment Canada (Kuo, 2012), and although there are no cranberry farms located in close proximity to the water bodies tested in this study, we included this research to provide a sense of which/how much of 80 different pesticides exist near an active agricultural zone in Canada. In their study, the researchers monitored the occurrence and concentration of pesticide residue in farm runoff and the aquatic environment near farms in Okanagan Valley, British Columbia, a region accounting for 43.5% of the pesticides sold in the province in 2003.

### *2.4.1 Article 1- Summary of Report titled Water Quality and Management Options Assessment and Phosphorus Mitigation Program for Cranberry Bogs on White Island Pond (Eichner et al., 2012)*

In this report, Eichner et al. (2012) summarized a study that was done to address local water concerns of White Island Pond, a 291 acre freshwater pond in Plymouth, Massachusetts. The pond consists of a 167 acre eastern basin and a 124 acre western basin. The eastern basin has four cranberry bogs along its shoreline – 2 in the north, 1 in the east, and 1 in the south by the stream discharging from the basin. The Massachusetts Department of Environmental Protection (MassDEP) had previously reviewed water quality data in the pond, determining that elevated phosphorus levels were the main cause of water quality impairments in the pond. MassDEP had concluded that a total phosphorus concentration limit of 19µg/L was needed to restore White Island Pond (MassDEP, 2010)**.**

The White Island Pond project was a comprehensive study, involving collecting water quality, soil, and plant tissue samples to analyze for nutrients; collecting stream volumetric flow samples; developing phosphorus and water budgets; evaluating phosphorus mitigation strategies for adjacent bogs and within the pond; developing designs for systems to reduce phosphorus levels from bog outflows and to restore the pond; and encouraging growers to reduce phosphorus fertilizer application.

The operators of the two cranberry bogs along the northern shoreline of the pond – A.D. Makepeace Company (ADM) and Federal Furnace Cranberry Company (FF) - both agreed to participate in a pilot program with the goal of developing and implementing practices to reduce discharge of nutrients from cranberry bogs and meet water quality standards. The ADM bog has a bog surface of 38 acres, and the FF bog has a bog surface of 50 acres.

## Water Quality Data

Monthly pond samples were collected between July 22, 2009 and November 30, 2010, and weekly stream samples were also collected at two pond outlet locations. Water samples were analyzed for 16 parameters, including total phosphorus (TP), total nitrogen (TN), and chlorophyll a. A review of the 2009 and 2010 data confirmed that the pond had degraded water quality due to elevated phosphorus levels. Total phosphorus concentrations in the east basin during the summer (June – September) averaged 53µg/L (north) and 59µg/L (middle). For TN, average summer surface concentrations in the pond exceeded USEPA's ecoregion specific recommended maximum of 0.32mg/L (U.S. EPA, 2001) at all three sampling stations, with readings of 0.97mg/L, 0.90mg/L, and 0.65mg/L. Average chlorophyll a concentrations, an indicator of nutrient enrichment, exceeded recommended limits at all stations for 2009 and 2010. The average ratios of N to P showed that phosphorus was the limiting nutrient, confirming project management targets should focus primarily on phosphorus.

## Phosphorus Management Model/ Budget

Since phosphorus was determined to be the limiting nutrient, a phosphorus budget was developed to account for all sources of phosphorus entering the pond, which was used to evaluate options for pond restoration. They reviewed the phosphorus mass in the pond, and also all potential sources they could contribute to this mass. Phosphorus mass in the pond was determined by water column sampling of phosphorus levels and pond volume. For the phosphorus budget inputs, project staff selected properties on the upgradient shoreline of the pond, within 300ft of the shoreline. It was determined that, not including the cranberry bogs, the overall annual phosphorus load to the east basin was between 61 and 82kg. This included wastewater loading of 48kg/yr to 50kg/yr, lawn fertilizer loading of 0kg/yr to 4kg/yr, bird loading of 0kg/yr to 0.5kg/yr, and atmospheric loading of 3kg/yr to 6kg/yr.

## Cranberry Bogs Loading

Reviewing water quality and discharge data, it was found that the ABM and FF bogs combined added an annual phosphorus mass to the east basin of 2.7kg in 2009, 16.6kg in 2010, and 0.25kg in 2011. A key reason for this variation between years is that the pumping system at FF was not able to prevent releases to the pond on several occasions (e.g. heavy rain). Including the cranberry phosphorus additions, the total annual watershed loading to the east basin was estimated at 64kg to 85kg in 2009, 78kg to 99kg in 2010, and 61kg to 82kg in 2011. Therefore, the two cranberry bogs were contributing 0.4% to 17% to the annual phosphorus load for the east basin.

## Cranberry Bogs Best Management Practices

Prior to this study, the ADM and FF cranberry bogs implemented a series of strategies for limiting phosphorus impacts to the east basin. These strategies included limiting application of phosphorus fertilizer starting in 2008, reducing area of the ADM bog by removing a 17 acre bog cell from production, and collecting in-bog water and discharging it upland at FF. It was concluded that these strategies reduced annual phosphorus inputs from the bogs between 86% and 97% in each of 2009, 2010, and 2011, compared to pre-2007 levels. Out of the implemented steps, it was the phosphorus fertilizer application reduction that had the largest impact, as opposed to removing the 17 acre bog cell from production and collecting in-bog water and discharging it upland at FF. In 2005 to 2007 the yearly fertilizer application between the two bogs was a total of 893kg. In 2009 to 2011 that level was reduced by 84%, with yearly application of 142kg. The removal of one bog cell from ADM production eliminated the potential fertilizer application of 5.4kg.

## Conclusions and Recommendations

White Island Pond’s water quality is impaired due to excessive phosphorus loads. A set of recommendations were set out to ensure pond water quality meets regulatory standards. Due to the complexity and uncertainty levels of the ponds ecosystem, it was recommended that an adaptive management plan be developed and implemented. The purpose of this plan is to set out goals for water quality, water levels, use goals, and acceptable land use characteristics, as well as financial and technical responsibilities. It was also recommended to maintain a regular pond monitoring program.

#### *2.4.2 Article 2- Summary of Doctoral Thesis Titled "Cranberry Marsh Nutrient and Pesticide Effects on Receiving Lake and Groundwater" (Anderson, 2006)*

Anderson (2006) completed a doctoral thesis project to assess impacts of a cranberry farming operation in northern Wisconsin on water quality and biological integrity due to pesticide and nutrient movement into groundwater and lake receiving waters and sediments. Pesticides applied on the cranberry farm were chlorpyrifos, an organophosphorus insecticide, and tebufenozide, a member of the class of insecticide chemicals called diacylhydrazines. The pesticide application schedule consisted of chlorpyrifos in June 1999, and tebufenozide in July 1999 and July 2001. In previous years various chemicals including diazinon and dichlobenil had also been applied. After each pesticide application water was contained on the cranberry farm for 7-10 days, before being released to receiving waters. In Cranberry Lake, the lake receiving the discharge, five sites were investigated- a site at mid-lake, outlet, inlet, near the discharge gate, and at the furthest point across the lake.

## Methods

To assess pesticide movement and effects, three methods were used including acute toxicity tests on ambient water and sediment, in-situ tests using caged fathead minnows, and chemical analyses. For acute toxicity tests they used the organisms *Ceriodaphnia dubia* and fathead minnows. For sediment toxicity tests they took samples at mid-lake, inlet, and outlet sites and performed a 10 day sediment toxicity test using the amphipod *Hyalella azteca*, and the larval midge *Chironomus tentans*. After 10 days, sediments were sieved and *H. azteca* survival and *C. tentans* survival and growth were determined. For in-situ tests, 30 fathead minnows were placed into a cage and lowered into mid water column at each site one day before water release from the farm. The number of surviving minnows was determined at 0, 8, 24, and 48 hours post release in 1999 and 2001, with an added 4 hour count in 2001. For chemical analysis, they took water and sediment samples at the mid-lake site before pesticide application in summer 1999 and tested for various pesticides. Water samples were taken again at 4h post release of water from the marsh after chlorpyrifos application in 1999. In 2001, after tebufenozide application four pre-release water samples and 15 post release water samples were analyzed. They also assessed groundwater by testing a well for 17 pesticides (not including tebufenozide) and general water quality parameters (e.g. nitrogen, ammonia, nitrate) in May 2002.

# Results

## a) *Acute Toxicity and In-Situ tests*

Chlorpyrifos- For the pesticide chlorpyrifos, toxicity tests were performed pre and post water release in 1999. None of the samples were found to be toxic to *C. dubia*. However, the 24h post release sample at the outlet site was found to be toxic to fathead minnows, with 0% survival. Finding toxic effects at this site showed that the pesticide was being transported across the lake.

Tebufenozide- For the pesticide tebufenozide, toxicity tests in 1999 found no toxic effects. However, in the in-situ test the minnows had 0% survival at the inlet site 8h post water discharge (other sites had 80-100% survival at pre release, 8h, 24h, and 48h). Toxicity tests in 2001 found that samples at the discharge site were toxic to both *C. dubia* and fathead minnows in all samples in the first hour, with the lowest survival rate occurring for both at 30m (0% survival), and toxic effects remained at 24h and 48h. Also in 2001, samples at the outlet site were toxic to *C. dubia* at 2h, 24h, and 48h, with a minimum 10% survival rate at 80m. At the inlet site, samples were toxic to fathead minnows, with decreased survival to 10% at 100m, returning to 100% survival by 120m. At withdrawal and mid-lake sites, samples were toxic to fathead minnows at 240m (70% and 30% survival, respectively).

*b) Sediment Toxicity Tests*

*H. azteca*- None of the sediment toxicity tests showed significant effects on survival of *H. azteca*

*C. tentans*, Aug 2000- There was a significant reduction in survival in *C. tentans* at a site located in a bay beyond the outlet site, decreasing to 82% weight of control. There was a significant decrease in growth at the mid-lake site, and at a site located in a bay beyond the outlet site, decreasing to 68% and 75% respectively.

*C. tentans*, Oct 2000- There were no significant effects on survival for *C. tentans*. However, growth at mid-lake reduced to 82% of control weight.

*c) Chemistry*

Water samples taken prior to pesticide application in 1999 had residual dichlobenil amounts ranging from 0.29 to 0.86 pg/L for mid-lake and inlet sites (LOD = 0.034 pg/L ). Diazinon levels were below detection limits at all sites (LOD = 0.061 pg/L). After the 1999 chlorpyrifos application, one sample at the inlet site collected 4h after water discharge had 0.068 pg/L chlorpyrifs (LOD = 0.015 pg/L). In 2001, samples were taken after tebufenozide application and this pesticide was not detected in any samples (LOD = 3.1 pg/L).

*d) <u>Groundwater</u>*

Seventeen pesticides were tested for and none were detected. Fourteen general water quality parameters were tested and all were below detection limits except for barium (7.5 pg/L), chromium (2.1 pg/L), nickel (1.7 pg/L), and nitrate as N (0.14 pg/L).

<u>Conclusions and Recommendations</u>

The authors recommended either a) finding pesticides with half-lives shorter than that of tebufenozide (67 days for photodegradation in water) so that it could degrade within the 7-10 day holding period before the water is discharged into the lake, or b) creating a holding area for the water that would give the pesticides enough time to degrade before being released into Cranberry Lake. If alternate pesticides with shorter half-lives are selected that would increase the importance of an effective and diligent pest management program with frequent scans of cranberry plants for insects to ensure appropriate timing of pesticide application that matches up with when insects of concern are present.

*2.4.3 Articles 3 and 4- Summary of Washington State Department of Ecology's Research on Cranberry Bogs (Davis, 1997; Rountry, 2008)*

A study in Grayland/ North Cove Washington (Davis, 1997) investigated pesticide contamination of a ditch system collecting runoff from 900 acres of cranberry bogs. The north ditch, Grays Harbor County Drainage No. 1 (GHDD-1), discharges into South Bay of

Grays Harbor. The south ditch, Pacific County Drainage Ditch No. 1 (PCDD-1), discharges into Willapa Bay.

The objectives of the study were to determine extent and severity of pesticide contamination from cranberry farming, determine the impact on aquatic life, and evaluate the effectiveness of measures implemented to reduce pesticide concentration in the drainage ditches. Water, tissue, and sediment samples were collected to investigate pesticide contamination extent and severity. Bioassays were conducted on water from drainage ditches and sediment samples were collected for assessment of benthic assemblages to investigate the impact on aquatic life and/or wildlife.

## Methods

### 1) *Water Sampling*

Samples were collected downstream of bog drainages that flow into the drainage ditches. Weekly samples were collected May 13-August 19 1996, with peak insecticide application periods occurring in early May, mid-July, and early August. Daily samples were collected for 4-5 days immediately following peak pesticide applications. All samples were analyzed for organophosphorus insecticides, and one sample during each peak application period was also analyzed for chlorinated pesticides, nitrogen-containing pesticides, sulfur-containing pesticides, pyrethrins, chlorinated herbicides, and other target compounds including carbaryl. Measurements were also taken for total suspended solids (TSS), total organic carbon (TOC), temperature, pH, conductivity, and flow.

*2) Sediment Sampling*

Sediment samples were collected at four sites in the GHCDD-1 ditch, and three sites in the PCDD-1 ditch. All samples were collected between August 27-29, 1999. Sediments were analyzed for 133 compounds including chlorinated pesticides and PCBs, and organophosphorus pesticides.

## Results/ Discussion

*1) Water Sampling*

Eight organophosphorus pesticides were detected from samples in the two ditches, with six of the pesticides detected in both ditches. Azinphos-methyl, chlorpyrifos, and diazinon were the pesticides that were most frequently detected in both ditches. Azinphos-methyl levels exceeded USEPA water quality critera of 0.01 ug/L for all but 1 of the detections from GHCDD-1 and 21 of 26 detections from PCDD-1. Chlorpyrifos levels did not exceed Washington State standards from any sample from GHCDD-1, but did exceed standards for 17 of 26 detections from PCDD-1. For diazinon there were no state or federal criteria available for comparison, but 25 of 26 detections from GHCDD-1 and 17 of 25 from PCDD-1 exceeded chronic criteria of 0.04µg/L calculated by the California Department of Fish and Game, and 20 detections from GHCDD-1 and 10 detections from PCDD-1 exceeded the acute criteria of 0.08µg/L.

Fifteen additional pesticides, including 12 herbicides and 3 insecticides, were detected in samples analyzed for the larger range of target compounds. Carbaryl was detected in both ditches in May and July, exceeding the National Academy of Sciences recommended maximum concentration of 0.02 ug/L. 4,4'-DDD was found at GHCDD-1 in May and July, and at PCDD-1 in all samples, exceeding Washington State criteria of 0.001 ug/L in all cases. The herbicides napropamide, norflurazon, and 2,4-D were also detected in all samples from both ditches.

All conventional parameters including temperature, pH, TOC, and TSS were within acceptable levels and state criteria.

*2) Sediment Sampling*

Fifteen pesticides and/or breakdown products were detected from 7 of the 8 sampling sites, including nine chlorinated pesticides, three organophosphorus insecticides, and three herbicides. The chlorinated pesticides have been banned for years, but the other six compounds were still being used on cranberry bogs at the time of this study. DDT and/or its breakdown products, and dichlobenil were detected in all seven samples. Other detected pesticides that were found in both ditches include diazinon, chlorpyrifos, and napropamide. All detections of aldrin, 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT were above the Provincial Sediment Quality Guidelines for lowest effect level, indicating these compounds may adversely affect some sediment-dwelling organisms. Two diazinon samples and one chlordane sample exceeded New York State criteria for sediment.

Conclusions

It was concluded that in both ditches organophosphorus pesticide concentrations in water remained high enough throughout the entire study to potentially have a negative impact on some aquatic life. Additionally, the pesticide levels detected in tissue samples after peak pesticide applications are high enough to cause acute mortality to indigenous aquatic organisms, with numerous detections of insecticides exceeding $LC_{50}$ values for representative invertebrates.

*2.4.4 Article 5- U.S. Geological Survey (USGS), 2005, Wisconsin*

In 2004-2005 a study was conducted in northern Wisconsin to address resident's concerns that pesticides used on cranberry bogs were affecting the water quality and biology of downstream lakes and streams in the region. To address these concerns the USGS collected water and sediment samples from four nearby lakes and water samples from the Trout River. Great Corn Lake, Little Corn Lake, and Little Trout Lake were selected because of their close proximity and hydraulic connection to the cranberry bogs, while Ike Walton Lake was chosen as a reference lake that was not affected by cranberry operations.

Samples were analyzed for dozens of pesticides including those typically or historically used on cranberry bogs in the region such as carbaryl, diazinon, chlorothalonil, chlorpyrifos, nonflurazon, p,p'-DDT, p,p'-DDE, and 2,4-D. The objective of the study was to quantify concentrations of pesticides applied on cranberry bogs in the nearby lakes and sediments.

The USGS detected ten pesticides in the collected water samples. Eight of the pesticides detected in water samples were herbicides and two (carbaryl and diazinon) were insecticides. Of the pesticides detected in water samples, five were applied on cranberry bogs (carbaryl, diazinon, 2,4-D, napropamide, and norflurazon).

The most commonly detected pesticide of those applied on cranberry bogs was norflurazon. Norflurazon was not detected in samples from the reference lake, but was detected in 100 percent of the other lake samples. Norflurazon was also the pesticide detected at the highest concentrations in lake samples from Great Corn Lake, with a maximum detection concentration of 2.7 µg/L.

Three pesticides (carbaryl, diazinon, and 2,4-D) were only detected in Little Trout Lake samples. Carbaryl and 2,4-D were detected at concentrations near or lower than the USGS reporting limits. Diazinon was detected in all Little Trout Lake samples at concentrations up to six times the reporting limit.

The authors concluded that pesticides from cranberry bogs were in fact entering nearby lakes. They concluded that concentrations would have to be much higher than those measured in water samples during their study to be acutely toxic to fish. However, they felt they could not conclude that pesticides were having no effect on lakes and aquatic biology, and recommended further study to identify chronic effects to aquatic organisms.

*2.4.5 Article 6- Environment Canada, 2012, British Columbia*

In 2012, Environment Canada published a pesticide monitoring study (Kuo, 2012) for Okanagan Valley, British Columbia. Large quantities of pesticides have been applied in Okanagan Valley for decades to control agricultural pests, with 43.5% of the pesticides sold in BC in 2003 being applied in this region.

Methods

In their study they monitored the occurrence and concentration of pesticide residue in farm runoff and the aquatic environment near farms, and conducted a risk assessment for the detected pesticide levels. They took runoff and sediment samples from farm ditches/small streams, and exit points of runoff from the farms. Eighty and 63 pesticides were selected for monitoring from surface water and sediment, respectively. The authors picked these pesticides to monitor based on pesticide sales and use patterns, evaluation of local crop types, top 9 insecticides, fungicides, and herbicides sold in the region, published information on environmental toxicity, persistence in the environment, and analytical capabilities.

Results

The monitoring study showed that residues of agricultural pesticides were present in both farm runoff and ditch sediments. Residues of DDT and its breakdown products 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene (DDE) and 1,1-dichloro-2,2-BIS (p-chlorophenyl)ethane (DDD), were detected in ditch sediment samples, despite being banned in Canada for use over 30 years ago. In total, 40 of the 80 pesticides monitored were detected in runoff water in Okanagan Valley, including endosulfan-sulfate, the most frequently detected pesticide. For the top selling chemicals in the Okanagan Valley, detections were made for five of the top nine insectides, one of the top nine fungicides, and three of the top nine herbicides. Diazinon was detected in 16 water runoff samples, with a mean value of 18.369 ng/L, and some samples exceeded the 100 ng/L guideline for protection of aquatic life (BCMOE Water Quality Objective). Chlorothalonil was detected in 19 water runoff samples, with a mean of 0.107 ng/L, but no levels were detected that approached the guideline of 180 ng/L (Canadian Environmental Quality Guideline). Table 2.5 shows the concentrations and frequencies of detection for the pesticides detected in runoff water.

Conclusions

The authors concluded that pesticides commonly applied to crops in the area, including organochlorine, nitrogen containing, and organophosphate pesticides, were detected in runoff and downstream small stream water, with levels of diazinon exceeding guidelines for protection of aquatic life.

### 2.5 Summary

The cranberry industry in Canada has been increasing rapidly in recent years (Statistics Canada, 2012), with farmers cranberry sales of $89.6 million in Canada in 2014 (Statistics Canada, 2015). Cranberry production requires the use of large quantities of water, and application of pesticides and fertilizers (Hinterleitner, 2006). Studies that have been done to evaluate potential environmental impacts of farming have found applied

Table 2.5 Frequency, mean, and range of detection of various pesticides in runoff water from Environment Canada's 2012 study (Kuo, 2012) in British Columbia, shown in order of number of detections.

| Compound | Frequencies | Mean (Range; ng/L) | Guidelines (ng/L) |
|---|---|---|---|
| Endosulphan - Sulphate | 22 | 2.297 (0.027 – 14) | 20[c] |
| MCPA | 20 | 1.553 (0.132 – 8.14) | 2600[b] |
| Chlorothalonil | 19 | 0.107 (0.015 – 0.294) | 180[b] |
| Hexachlorobenzene | 19 | 0.064 (0.014 – 0.124) | 10[d] |
| Metolachlor | 19 | 0.146 (0.091 – 0.238) | 7800[d] |
| α-Endosulfan | 19 | 1.904 (0.05 – 15.6) | 20[c] |
| Simazine | 18 | 13.061 (0.454 – 84.4) | 10000[a,b] |
| β-Endosulfan | 17 | 2.426 (0.326 – 16) | 20[c] |
| Diazinon | 16 | 18.369 (0.088 – 214) | 100[a] |
| Desethylatrazine | 14 | 2.038 (0.034 – 8.61) | none |
| Dieldrin | 14 | 0.479 (0.025 – 2.89 | 4[d] |
| MCPP | 13 | 1.833 (0.055 - 12.3) | none |
| Dacthal | 13 | 0.050 (0.004 – 0.095) | none |
| Atrazine | 11 | 2.893 (0.15 – 20.6) | 1800[b] |
| 2,4-D | 10 | 5.831 (0.612 – 23.8) | 4000[a] |
| Alachlor | 9 | 0.274 (0.14 – 0.292) | none |
| Permethrins | 9 | 90.235 (0.133 – 0.405) | none |
| Diazinon-Oxon | 9 | 3.164 (0.027 – 20) | none |
| Dicamba | 8 | 0.506 (0.056 – 2.27) | 10000[d] |
| α-HCH | 5 | 0.066 (0.02 – 0.071) | none |
| γ-HCH | 5 | 0.277 (0.044 – 0.249) | none |
| Phosmet | 5 | 0.545 (0.021 – 1.06) | none |
| Azinphos-Methyl | 4 | 7.320 (0.699 – 25.5) | 5[c] |
| Hexazinone | 4 | 0.589 (0.037 – 1.65) | none |
| Flutriafol | 3 | 0.510 (0.171 – 0.549) | none |
| Pendimethalin | 3 | 1.485 (0.187 – 1.96) | none |
| Dimethoate | 3 | 9.243 (1.17 – 17.5) | 6200[b] |
| Metribuzin | 2 | 0.217 (0.145 – 0.289) | 1000[b] |
| Aldrin | 2 | 0.039 (0.016 – 0.062) | 1[c] |
| Captan | 2 | 3.880 (3.43 – 4.33) | 1300[b] |
| β-HCH | 2 | 0.430 (0.263 – 0.597) | none |
| Quintozene | 2 | 0.046 (0.017 – 0.075) | none |
| Linuron | 2 | 5.580 (1.87 – 6.53) | 70000[b] |
| Bromoxynil | 1 | 2.34 | 5000[b] |
| Endrin | 1 | 0.016 | 3[c] |
| Heptachlor | 1 | 0.011 | 10[d] |
| Heptachlor-Epoxide | 1 | 0.015 | 10[d] |
| Chlorpyriphos | 1 | 0.134 | 3.5[a,b] |

[a] – BCMOE Water Quality Objective
[b] – CCME, Canadian Environmental Quality Guideline
[c] – Ontario MOE Objective/ International Joint Commission criteria to protect aquatic life
[d] – Canadian Water Quality Guidelines

pesticides and fertilizers in downstream surface water, in some cases at levels high enough to pose a risk to aquatic life.

In Eichner et al., 2012, it was found that two cranberry bogs added an annual phosphorus mass to the east basin of 0.25 – 16.6kg, contributing 0.4% to 17% to the annual phosphorus load for the east basin. By limiting application of phosphorus fertilizer, reducing area of a bog by removing a 17 acre bog cell from production, and collecting in-bog water and discharging it upland annual phosphorus inputs from the bogs were reduced between 86% and 97% in each of 2009, 2010, and 2011, compared to pre-2007 levels.

In Anderson (2006), a project assessing cranberry farming operations in Wisconsin, results from acute toxicity and in-situ tests, sediment toxicity tests, surface water and groundwater analysis brought the author to recommend the need to either find pesticides with shorter half-lives or create a holding area for the water that would give the pesticides enough time to degrade before being released into downstream water.

Washington State Department of Ecology's research on cranberry bogs (Davis, 1997; Rountry, 2008) investigated pesticide contamination of a ditch system collecting runoff from 900 acres of cranberry bogs. They detected eight organophosphorus pesticides and 15 additional pesticides in the ditches, in some cases exceeding USEPA water quality criteria. It was concluded that in the ditches organophosphorus pesticide concentrations in water remained high enough throughout the entire study to potentially have a negative impact on some aquatic life.

A study by the U.S Geological Survey (2005) on the impact of cranberry bogs on downstream water quality in Wisconsin detected ten pesticides in the collected water samples, including five pesticides that were applied on cranberry farms. They concluded that concentrations would have to be much higher than those measured in water samples during their study to be acutely toxic to fish. However, they felt they could not conclude that pesticides were having no effect on lakes and aquatic biology, and recommended further study to identify chronic effects to aquatic organisms.

# Chapter 3: Site Investigations and Methods

## 3.1 Farm/ Site Characteristics

This study investigated environmental effects at 6 cranberry farms in Newfoundland and Labrador, Canada. Farm locations included Stephenville Crossing (SC), Botwood Highway (BH), Grand Falls –Windsor (DFW), Bishops Falls (BF), Deadman's Bay (DB), and Terra Nova (TN).

Stephenville Crossing is located on the west coast of Newfoundland, approximately 75km southwest of the city of Corner Brook. The 30-year (1981 to 2010) daily average temperature at Environment Canada's Stephenville weather station, approximately 15 km from Stephenville Crossing, is 5.0 °C. The 30-year daily average temperature was calculated by first calculating an average for each individual month based on daily values, then calculating normal values as the mean for each month from all the individual months in the 30 year period, and then finally calculating the annual normal values as the mean of the monthly normal values (all 30-year averages and 30-year totals presented below were calculated using this same procedure). The mean daily maximum is 8.7 °C, and the mean daily minimum is 1.2 °C. The mean total annual precipitation is approximately 1340.4 mm. For the months June to November, the water sampling period for the present study, the 30-year daily average temperature is 9.5 °C and the 30-year mean annual precipitation is 725.8 mm (Environment Canada, 2015; Section 5.2 includes a more in depth look at precipitation data).

Botwood Highway, Grand Falls – Windsor, and Bishops Falls are located in central Newfoundland, approximately 80-100 km west of the town of Gander. The 30-year (1981 to 2010) daily average temperature at Environment Canada's Wooddale/Bishops Falls weather station, within approximately 20 km of all three central Newfoundland cranberry farms, is 4.4 °C. The mean daily maximum is 9.2 °C, and the mean daily minimum is -0.5 °C. The mean total annual precipitation is approximately 1108.4 mm. For the months June to November, the 30-year daily average temperature is 11.0 °C and the 30-year mean annual precipitation is 593.7 mm (Environment Canada, 2015).

Terra Nova and Deadman's Bay are located on the east coast of Newfoundland, with Terra Nova located on the western edge of Terra Nova National Park, and Deadman's Bay located further north on the shore of Bonavista Bay. The 30-year (1981 to 2010) daily average temperature at Environment Canada's Port Blandford weather station, approximately 15 km south of the town of Terra Nova, is 5.0 °C. The mean daily maximum is 10.4 °C, and the mean daily minimum is -0.4 °C. The mean total annual precipitation is approximately 988.3 mm. For the months June to November, the 30-year daily average temperature is 11.5 °C and the 30-year mean annual precipitation is 495.8 mm. The 30-year (1981 to 2010) daily average temperature at Environment Canada's Musgrave Harbour weather station, approximately 25 km west of Deadman's Bay, is 4.4 °C. The mean daily maximum is 8.2 °C, and the mean daily minimum is 0.7 °C. The mean total annual precipitation is approximately 1043.1 mm. For the months June to November, the 30-year daily average temperature is 10.6 °C and 30-year mean annual precipitation is 551.7 mm (Environment Canada, 2015). Figure 3.1 shows a map of Canada, with Newfoundland and Labrador located on the east coast of the country. Figure 3.2 shows a map of the Island of Newfoundland with the locations of each of the six farms within the province. Figures 3.3 – 3.8 shows an aerial view of each of the 6 farms and the water sampling locations at each farm.

### 3.2 Pesticide and Fertilizer Application Records

Chemicals recommended to producers for use on cranberry farms in Newfoundland include diazinon, carbaryl, chlorothalonil, dichlobenil, napropamide, mesotrione, glyphosate, clopyralid, fluazifod-P- butyl and S-isomer, sethoxydim, and methoxyfenozide (L. Madore, personal communication, December 7, 2015). Out of the six cranberry farms monitored in the present study, the only application schedule that was able to be obtained was the pesticide application schedule at DB for 2011 and 2012. No other application schedules are presented here, largely because of the potential of insufficiently detailed records. It was also not possible to obtain records from the other farms on what pesticides and fertilizers were used and the total annual amounts used.

At DB, pesticides and fertilizers were applied to a total area of 8 acres. Chemicals were applied in 2011 from June 24$^{th}$ to August 23$^{rd}$, and in 2012 from July 4$^{th}$ to August 10$^{th}$. Table 3.1 shows the application schedule for pesticides and fertilizers at DB in 2011 and 2012.

Since it is possible that a host of historically used pesticides beyond those recommended and applied on Newfoundland's cranberry farms in the present day may still exist in surface water proximal to the farms, a wide range of 69 organophosphorus and organochlorinated pesticides were tested for in this study.

Table 3.1 Application schedule of pesticides and fertilizers at DB cranberry farm in 2011 and 2012.

| Date | Pesticide/Fertilizer | Quantity |
|---|---|---|
| June 24th, 2011 | Bravo 500 (containing 500g/L chlorothalonil) | 30L |
| June 24th, 2011 | Diazinon 500 EC (containing 500g/L diazinon) | 14L |
| June 29th, 2011 | Devrinol 10-G (containing 10% (by weight) napropamide) | 80kg |
| July 19th, 2011 | Ferbam 76 WDG (containing 76% (by weight) Ferbam) | 20kg |
| July 21th, 2011 | 12-10-13 (N-P-K fertilizer) | 150kg |
| July 26th, 2011 | 12-10-13 (N-P-K fertilizer) | 277kg |
| August 10th, 2011 | 12-10-13 (N-P-K fertilizer) | 317kg |
| August 17th, 2011 | Sevin XLR Plus (containing 466g/L carbaryl) | 24L |
| August 18th, 2011 | Ferbam 76 WDG (containing 76% (by weight) Ferbam) | 20kg |
| August 23rd, 2011 | 12-10-13 (N-P-K fertilizer) | 272.4kg |
| July 4th, 2012 | Ferbam 76 WDG (containing 76% (by weight) Ferbam) | 20kg |
| July 4th, 2012 | Sevin XLR Plus (containing 466g/L carbaryl) | 25L |
| July 12th, 2012 | 12-10-13 (N-P-K fertilizer) | 163.44kg |
| July 31st, 2012 | 12-10-13 (N-P-K fertilizer) | 363.2kg |
| August 1st, 2012 | Diazinon 500 EC (containing 500g/L diazinon) | 30L |
| August 10th, 2012 | 295.1kg 12-10-13 (N-P-K fertilizer) | 295.1kg |

### 3.3 Water Sampling

Water sampling was conducted on each of the six cranberry farms over two field seasons (2011 and 2012). On each farm, water samples were collected at three strategically selected sites:

- **site 1**- water entering cranberry field
- **site 2**- water on cranberry field (from a drainage ditch for DB, GFW, and TN; from an on-farm pond for SC, BH, and BF)

- **site 3**- water exiting cranberry field

By sampling at these three sites, environmental impacts associated with chemical use can be compared along three gradients, namely, source water, site water, and effluent. The source water site (Site 1) functions as an experimental control since it is not exposed to fertilizers or pesticides from the cranberry farm (under the assumption that aerial application at the farms did not reach as far as Site 1), and thus measurements of water quality parameters here will provide background levels for comparison purposes. It is hypothesized that the water samples collected on the cranberry field (Site 2) contains detectable concentrations of chemicals, subject to temporary or intermittent chemical use. Site 2 water samples provide data representing levels of chemicals indicative of the operation where applications of pesticides and fertilizers have been made. Samples from the effluent site (Site 3) will provide data on the levels of contaminants escaping from the farm and entering downstream surface water.

Parameters tested- Water samples were sent to an off-site laboratory to test for nitrate-nitrogen, carbonaceous BOD, nitrate-nitrogen + nitrite-nitrogen, nitrite-nitrogen, nitrogen (ammonia nitrogen), orthophosphate, organophosphorus pesticides, and organochlorinated pesticides (An example of a reporting sheet for all laboratory tested parameters is provided in the appendix). Parameters tested on-site include electrical conductivity, total dissolved solids, pH, temperature, and turbidity.

Sample frequency- At each of the upstream, on-farm, and downstream sites, on-site measurements were conducted and 9 water samples were collected for lab analysis bi-weekly starting in June and ending in November of 2011 and 2012.

Sampling procedure- A multiparameter meter (Hanna Model HI9829) and a turbidity meter (Hanna Model HA-98703) were used to collect on-site data. The multiparameter meter was used to measure temperature, pH, turbidity, and conductivity, and the turbidity meter was used only to measure turbidity.  Grab samples were also taken using a design consisting of a 1.2m metal pole with a plastic bottle attached to its end. The author stood on shore and used the pole to take a water sample from water near the surface, and then emptied the samples into a clean container (both amber glass and plastic bottles) for shipping to the laboratory.

Each site required: six 2L amber glass bottles; one 500ml plastic bottle, one 250ml plastic bottle, and one 100ml amber glass bottle with sulfuric acid.

Each sample was taken 1.2m from the water's edge where applicable, 15cm deep. All samples were shipped by courier in large coolers, packed in ice.

Care was taken to clean meters and bottles between each site as to not contaminate any of the samples. Samples were delivered (on-ice) to Maxxam Analytics, Bedford, Nova Scotia, immediately following sample collection. Laboratory QA/QC samples consisted of method blanks, blank spikes, matrix spikes, laboratory duplicates (all 1 in 20 samples or 1 in batch, whichever was most frequent), and surrogate recovery (included in every sample for pesticide analyses).

**3.4 Soil Sampling**

Three soil samples were taken in 2011: TN - Aug. 30; GFW – Aug 31; and DB  – Sept. 29. 6 soil samples were taken in 2012; DB- Oct. 30; TN- Oct. 31; BF- Oct. 31; GFW- Nov. 1; SC - Nov. 2; and BH Nov. 15. Each sample was representative of a $314m^2$ circle of land. Soil was collected at

5 locations within the $314m^2$ circle, mixed together into a single sample, placed into a 250ml glass jar, and shipped to the laboratory for analysis. An auger was used to collect the samples, each sample at a depth of 0-30cm. Samples were taken outside the farm just west of Site 2 at TN, between Site 2 and Site 3 (closer to Site 3) at GFW, close to Site 3 just outside the pond at BH, between Site 2 and Site 3 (closer to Site 3) at DB, just west of Site 3 at SC, and close to Site 3 at BF (soil sampling location for each farm is shown in Figures 3.3 to 3.8). Laboratory testing included the parameters ammonia-N, nitrate + nitrite, phosphate, moisture, and 122 different pesticides. Soils were dried before testing, so all values given are referring to dry weight.

### 3.5 Statistical Analysis and Modelling of Results

Probability analyses were carried out using JMP statistical software to test for distributional assumptions for each of the 12 studied parameters, grouping data together for each parameter over all years and all sites. Running a distributional analysis in JMP for a particular parameter would create a table comparing the fit of 11 distributions for that parameter, and the best fit distribution was selected from these options and graphed.

Linear and exponential regression analyses were conducted based on daily levels of each parameter to establish parameter trends at upstream, on-farm, and downstream sites for each of the six farms.

A correlational analysis was completed to determine the correlations between each two parameters over all sites and years. Correlational analysis was done using JMP to run a Matched Pairs analysis, comparing all possible pairs between the parameters.

Descriptive statistics were calculated over all sites and years for each parameter. Statistics included in the analysis were Total Number of Samples (N), Mean, Median, Maximum, Minimum, Guidelines (accepted criteria (when available)), Standard Deviation, Standard Error, and Relative Span (RS).

Significance of the differences between sites was determined for each parameter, grouping all data for a parameter over all farms into 3 groups (upstream, on-farm, and downstream), running an ANOVA to identify significant differences between sites, with $P > 0.05$, and running a Tukey Test to determine specifically which of the 3 groups were significantly different from the others. Individual comparisons were made to determine significance between upstream, on-farm, and downstream sites at each of the 6 individual farms.

### 3.6 Summary

In the present study, the environmental effects of cranberry farming were investigated at 6 farms in Newfoundland and Labrador, Canada. Bi-weekly water sampling was conducted on each farm at upstream, on-farm, and downstream sites from June to November of 2011 and 2012 to evaluate differences between sites. Water quality testing assessed levels of 80 parameters, including 69 pesticides. Nine total soil samples were collected during the sampling period, testing for ammonia-N, moisture, nitrate + nitrite, phosphates, and 122 different pesticides. Probability, linear and exponential regression, and correlational analyses were carried out to assess data. ANOVA and Tukey tests were run to determine significance between sites, and descriptive statistics were evaluated.


Figure 3.1 Map of Canada, showing Newfoundland and Labrador on the east coast of the country (coloured purple; Natural Resources Canada, 2006).

# Cranberry Site Water Sampling Locations

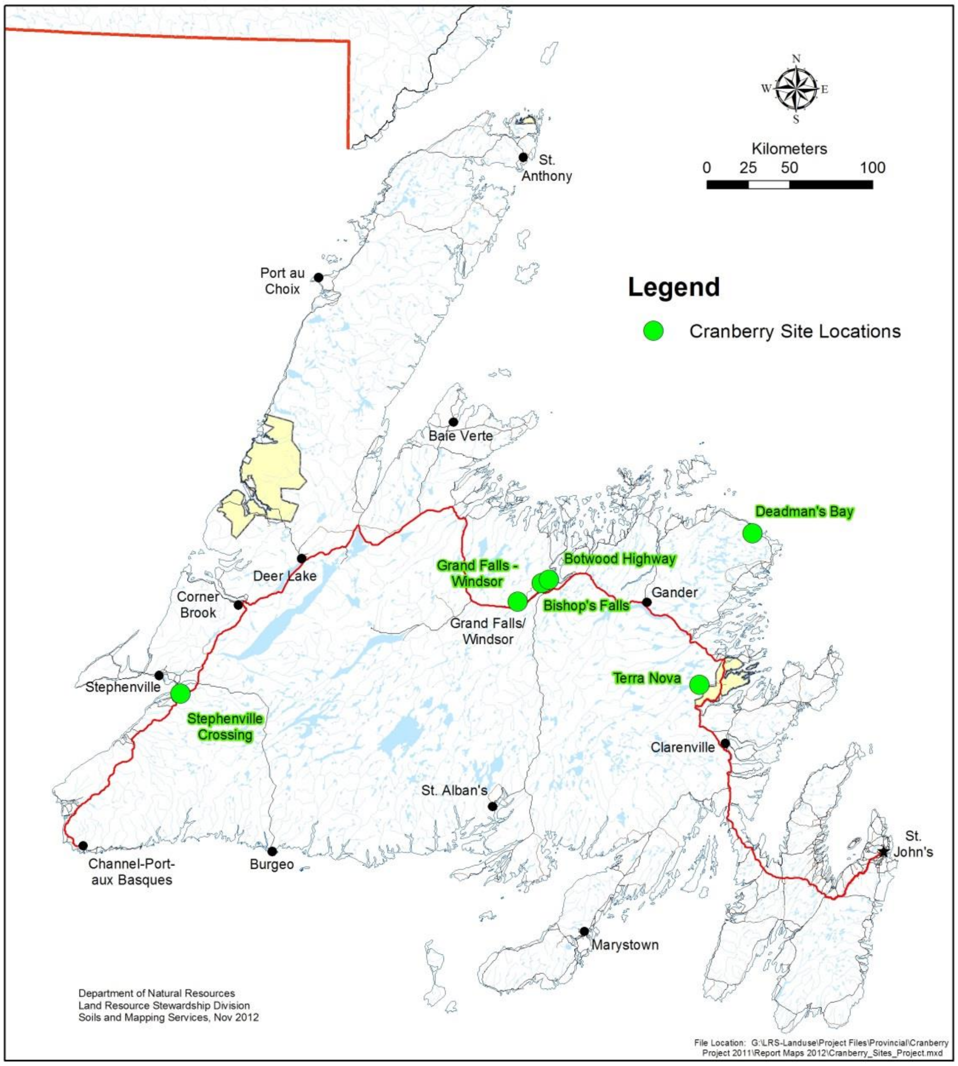


Figure 3.2 Map of the Island of Newfoundland showing the six cranberry water sampling sites, including Stephenville Crossing (SC), Grand Falls – Windsor (GFW), Bishop's Falls (BF), Botwood Highway (BH), Deadman's Bay (DB), and Terra Nova (TN) (Map created by Land Resource Stewardship Division, Department of Fisheries, Forestry and Agrifoods, Government of Newfoundland and Labrador).

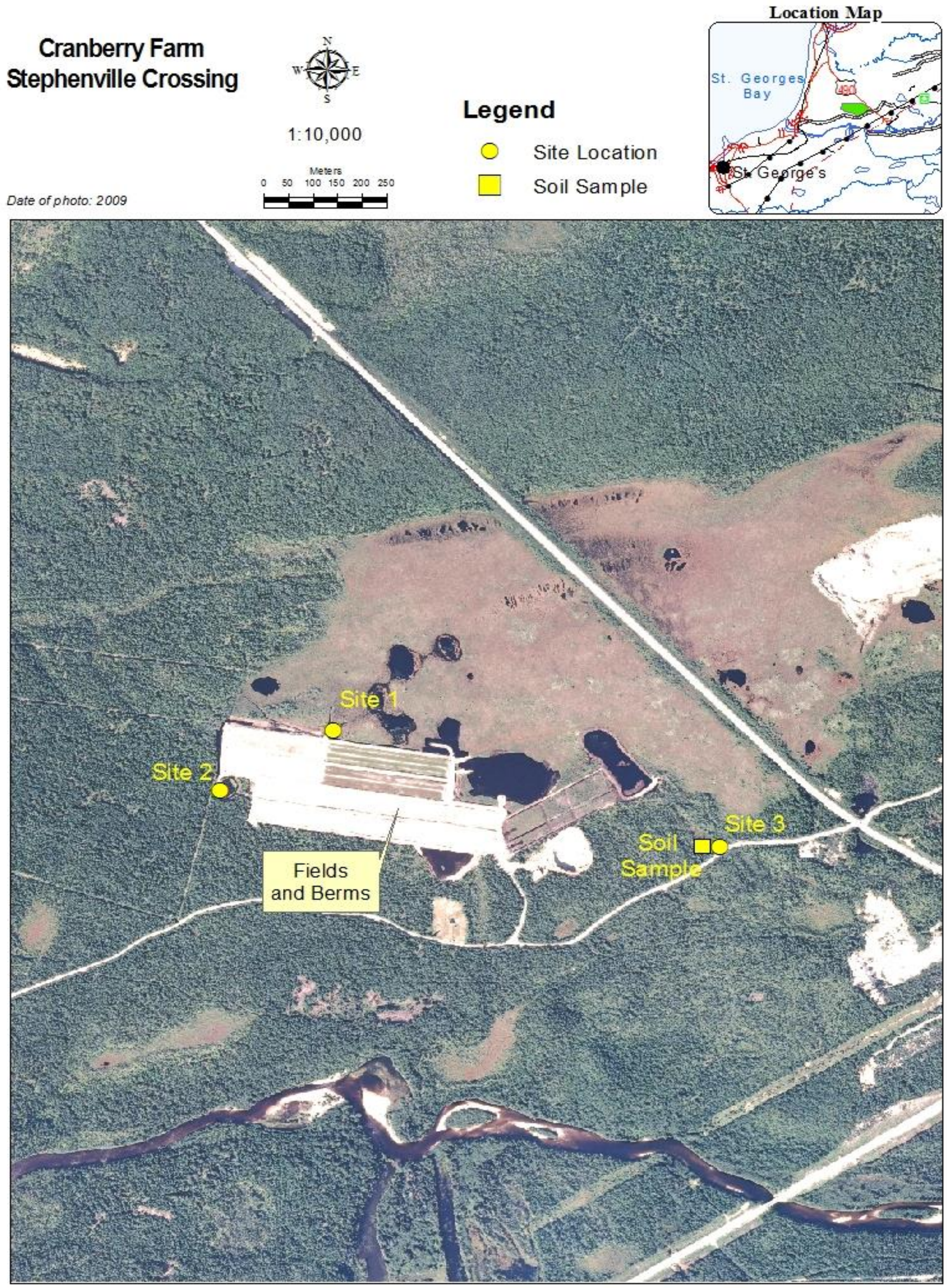


Figure 3.3 Cranberry Farm, Stephenville Crossing (SC) Map created by Land Resource Stewardship Division, 2012.

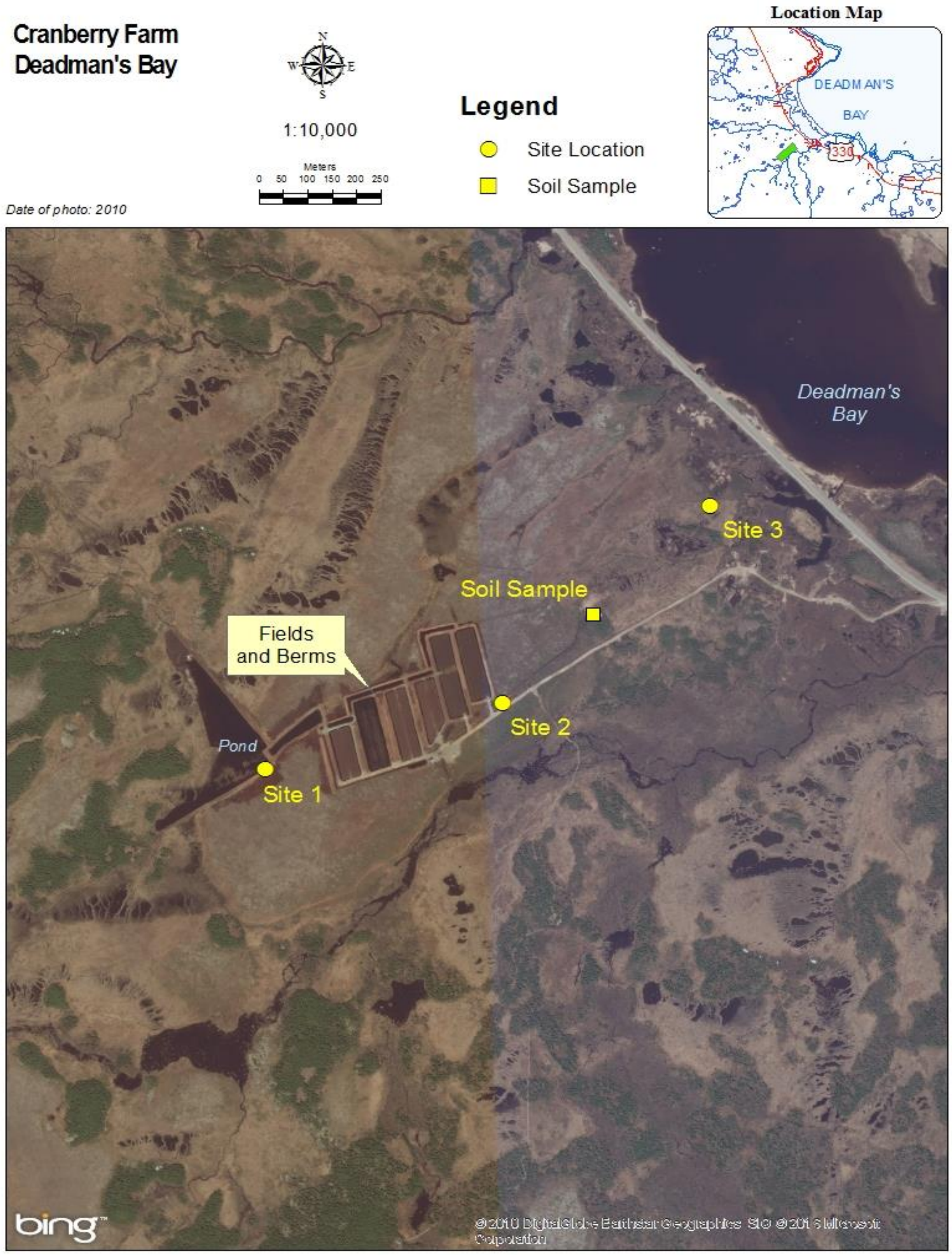


Figure 3.4 Cranberry Farm, Deadmans Bay (DB) Map created by Land Resource Stewardship Division, 2012.

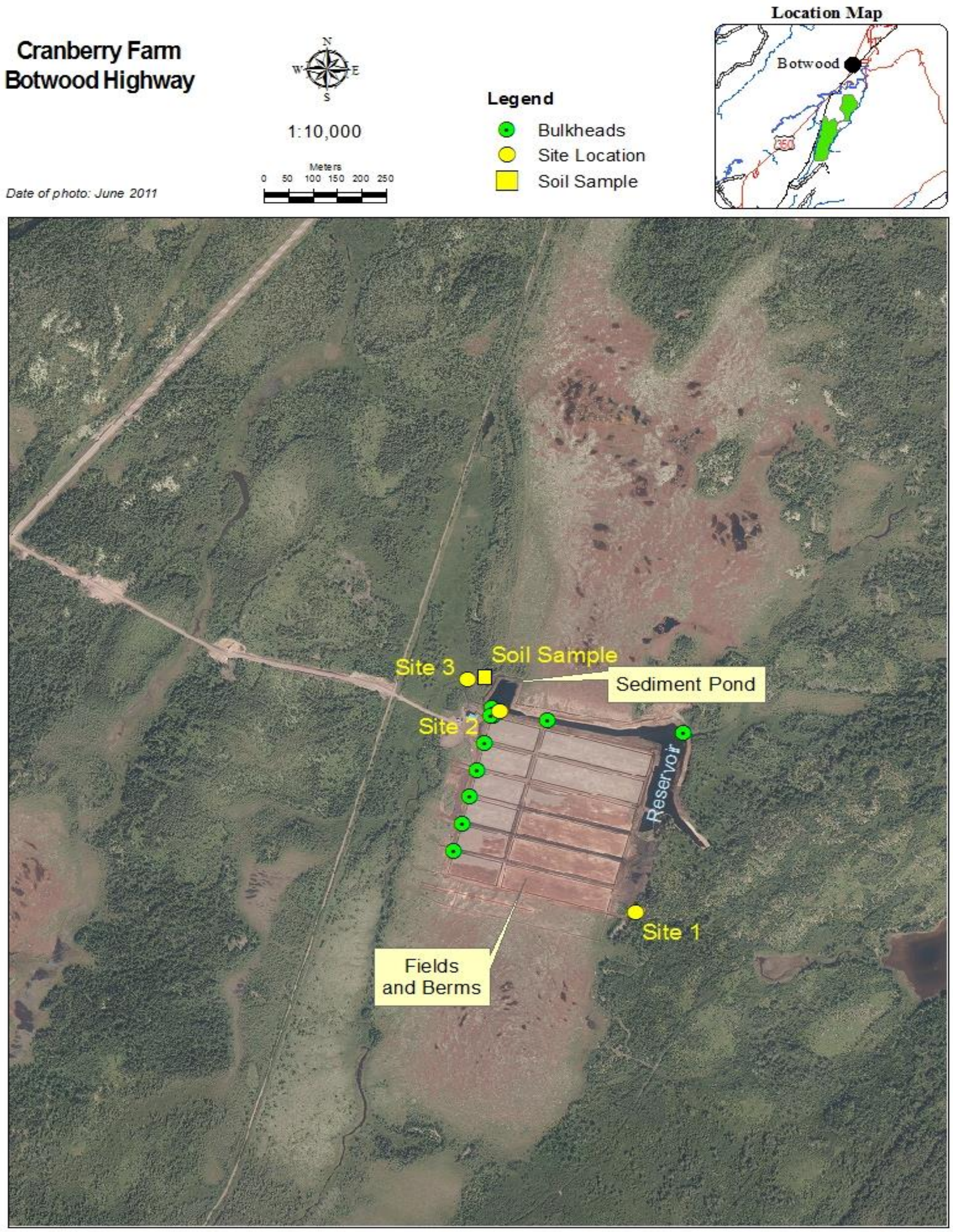


Figure 3.5 Cranberry Farm, Botwood Highway (BH) Map created by Land Resource Stewardship Division, 2012.

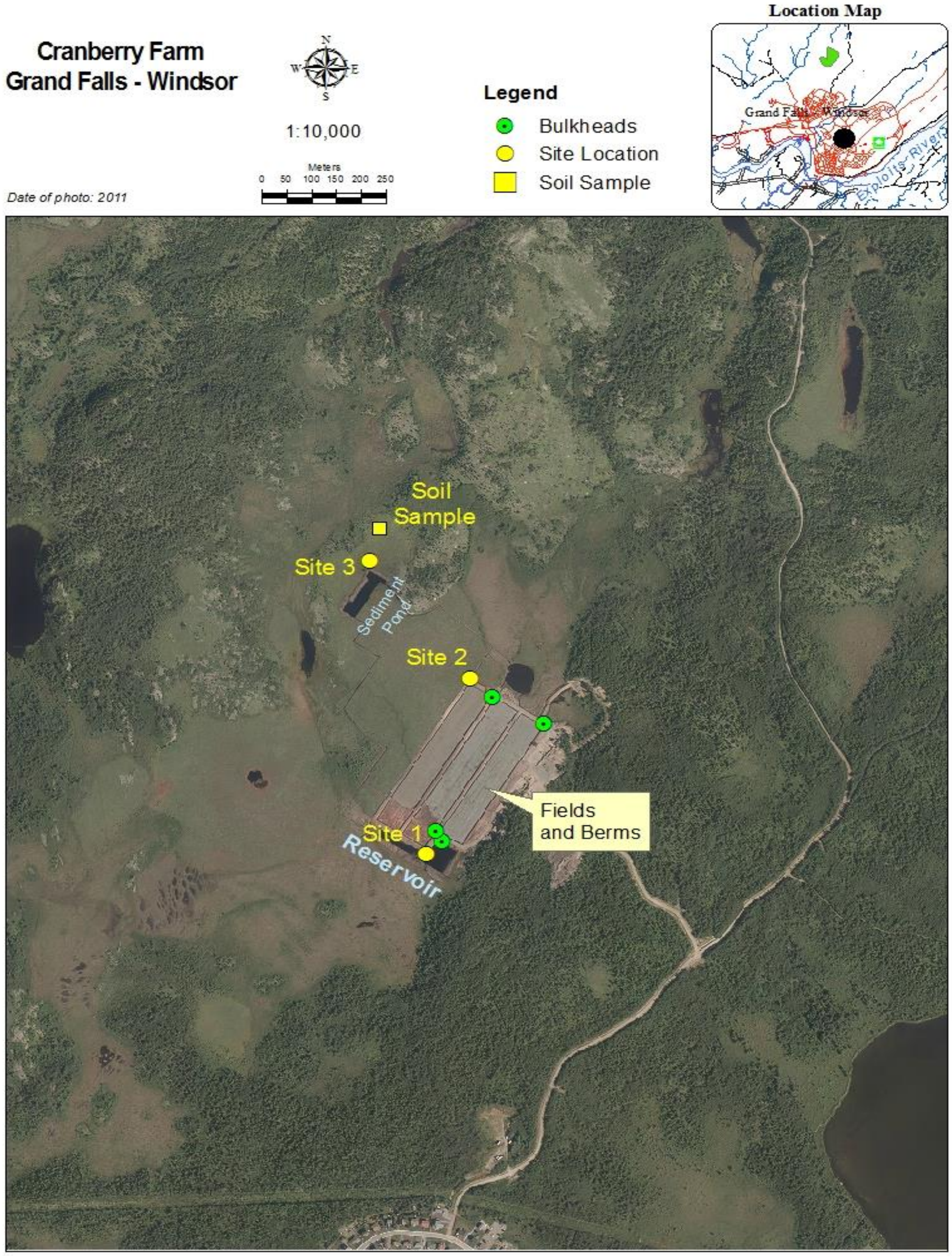


Figure 3.6 Cranberry Farm, Grand Falls-Windsor (GFW) Map created by Land Resource Stewardship Division, 2012.

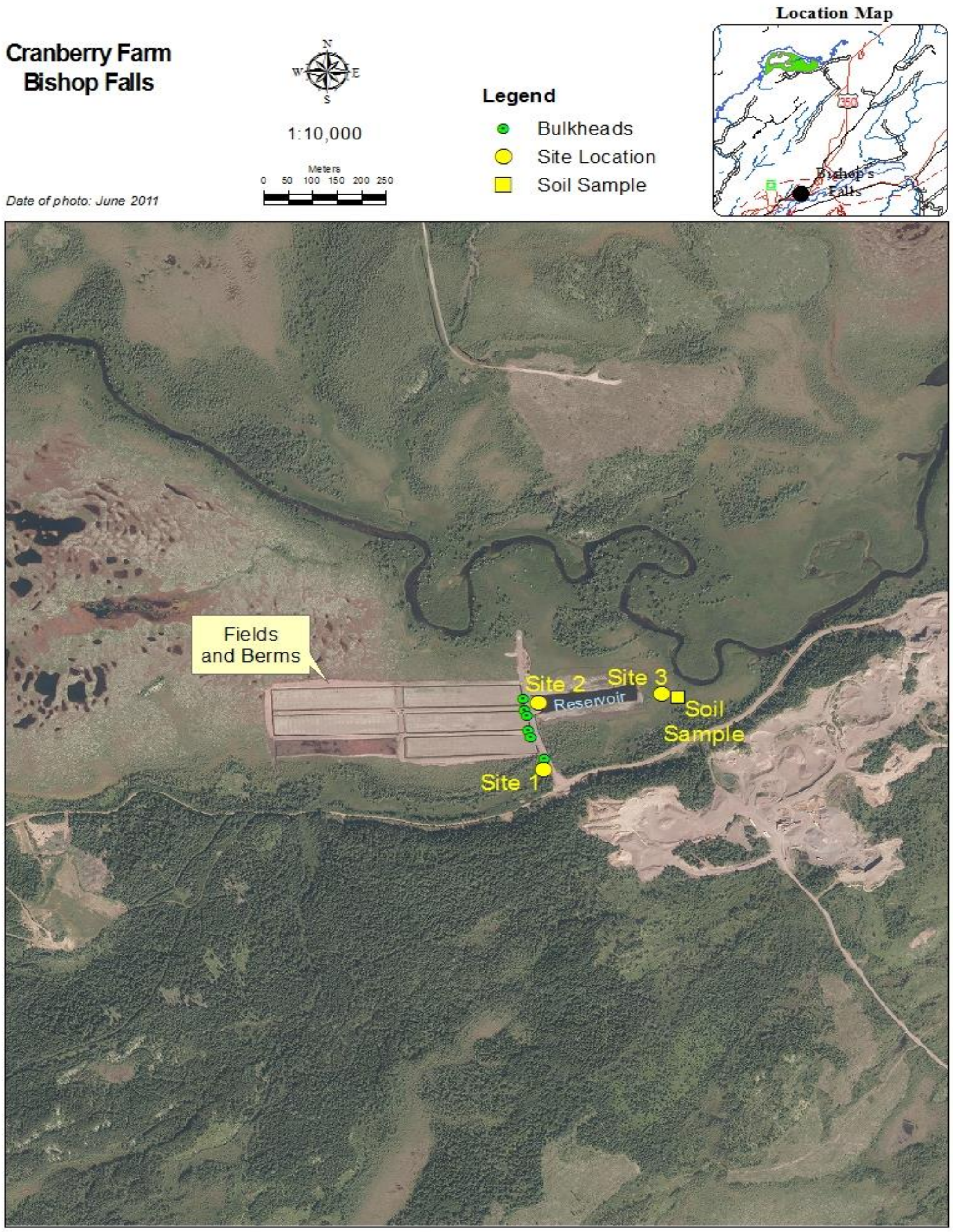


Figure 3.7 Cranberry Farm, Bishops Falls (BF) Map created by Land Resource Stewardship Division, 2012.

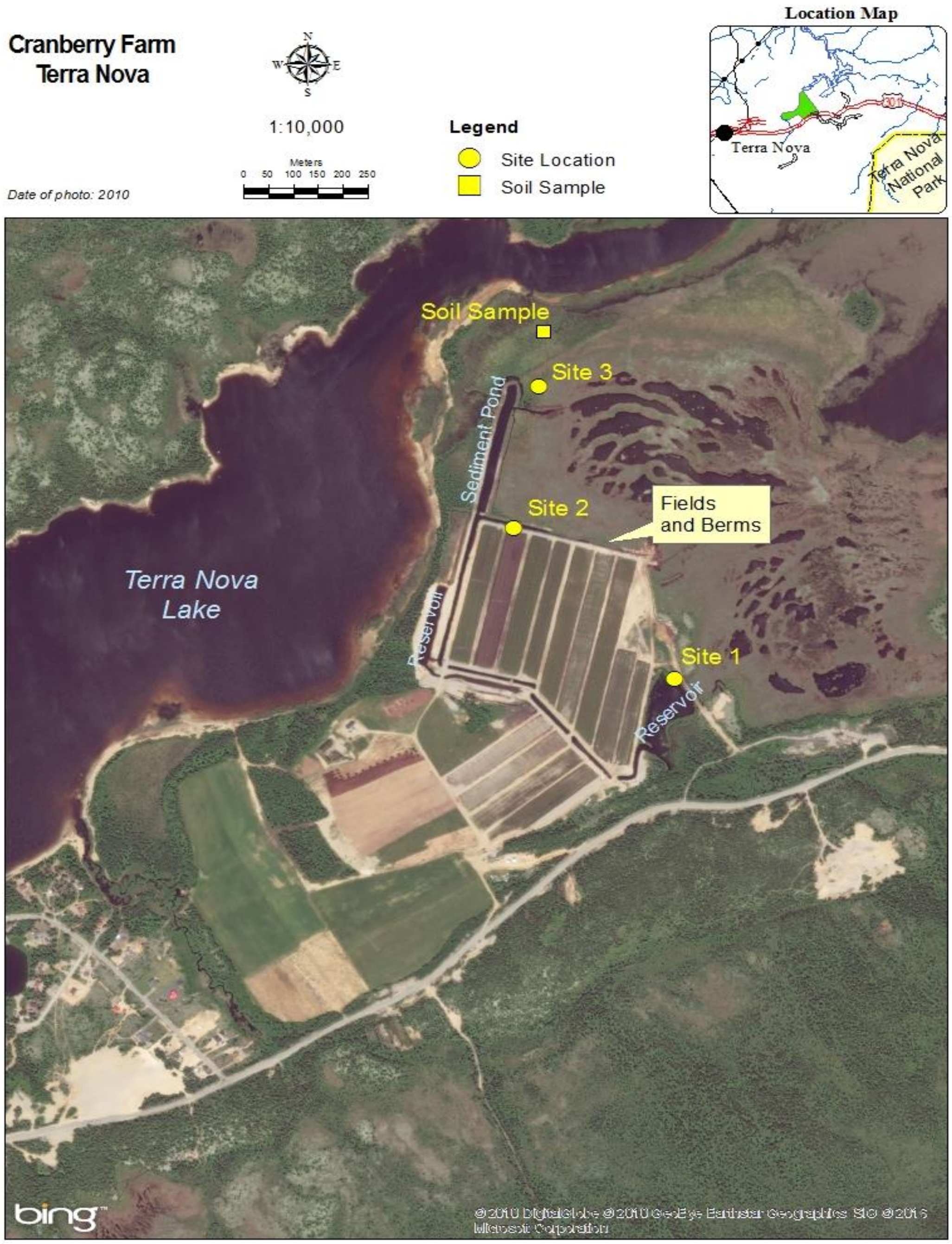


Figure 3.8 Cranberry Farm, Terra Nova (TN) Map created by Land Resource Stewardship Division, 2012.

# Chapter 4: Analyses of Parameters and Trends for Cranberry Farms

## 4.1 Descriptive Statistics

Descriptive statistics were calculated over all sites and years for temperature, pH, turbidity, TDS, and conductivity. Statistics included in the analysis were Total Number of Samples (N), Mean, Median, Maximum, Minimum, Guidelines (accepted criteria (when available)), Standard Deviation, Standard Error, and Relative Span (RS). Temperature values ranged from 1.84°C to 27.58°C, with a mean of 15.04°C and an N of 317. pH values ranged from 3.37 to 9.02, with a mean of 6.33 and an N of 308. Turbidity values ranged from 0.22 NTU to 80.1 NTU, with a mean of 2.96 NTU and an N of 316. TDS values ranged from 6 ppm to 217 ppm, with a mean of 31.58 ppm and an N of 319. Conductivity values ranged from 0.013 mS/cm to 0.63 mS/cm, with a mean of 0.065 and an N of 319. Table 4.1 shows descriptive statistics for temperature, pH, turbidity, TDS, and conductivity. Diazinon, nitrogen (ammonia nitrogen, organophosphate, carbonaceous BOD, nitrate-nitrogen + nitrite-nitrogen, nitrate-nitrogen, and nitrite-nitrogen were not included in the calculation of descriptive statistics over all sites and years due to the lack of data points (>50% “no-detection” values), but these parameters were tested for significant differences between upstream, on-farm, and downstream sites in subsequent sections of this chapter.

Quantiles were calculated for temperature, pH, turbidity, TDS, and conductivity over all sites and years. Table 4.2 shows the Minimum, 10%, 25%, Median, 75%, 90%, and Maximum values for each parameter.

Table 4.1 Descriptive statistics for temperature, pH, turbidity, TDS, and conductivity over all years and all sites.

[a]-Health Canada Canadian Drinking Water Standard

| Parameter | Temperature (ºC) | pH | Turbidity (NTU) | TDS (ppm) | Conductivity (mS/cm) |
|---|---|---|---|---|---|
| N | 317 | 308 | 316 | 319 | 319 |
| Mean | 15.04 | 6.33 | 2.96 | 31.58 | 0.065 |
| Median | 15.79 | 6.49 | 1.8 | 28 | 0.057 |
| Minimum | 1.84 | 3.37 | 0.22 | 6 | 0.013 |
| Maximum | 27.58 | 9.02 | 80.1 | 217 | 0.63 |
| Guidelines | - | - | - | 500[a] | - |
| SD | 6.05 | 1.03 | 5.53 | 20.9 | 0.053 |
| SE | 0.34 | 0.06 | 0.31 | 1.17 | 0.003 |
| Relative Span (RS) | 1.02 | 0.41 | 2.69 | 1.36 | 1.3 |

Table 4.2 Quantiles for temperature, pH, turbidity, TDS, and conductivity over all sites and years.

| Parameter | Minimum | 10% | 25% | Median | 75% | 90% | Maximum |
|---|---|---|---|---|---|---|---|
| **Temperature (ºC)** | 1.84 | 6.49 | 9.82 | 15.79 | 19.77 | 22.53 | 27.58 |
| **pH** | 3.37 | 4.86 | 5.63 | 6.49 | 7.06 | 7.52 | 9.02 |
| **Turbidity (NTU)** | 0.22 | 0.77 | 1.13 | 1.8 | 2.72 | 5.61 | 80.1 |
| **TDS (ppm)** | 6 | 12 | 21 | 28 | 39 | 50 | 217 |
| **Conductivity (mS/cm)** | 0.013 | 0.025 | 0.042 | 0.057 | 0.077 | 0.099 | 0.63 |

Not including Diazinon, out of all 68 pesticides that were tested in the present study, there were only a total of 12 detections in water samples over all farms and years. Carbaryl was detected a total of 3 times, including 2 times on the farm with levels of 340 ug/L at DB and 16 ug/L at TN, and 1 time downstream with a level of 5 ug/L at TN. No other pesticide was detected more than 2 times, only in trace amounts, with the majority likely being from historic agricultural use (e.g. DDT) rather than present day use on cranberry farms. Table 4.3 shows more detailed information on the pesticides that were detected throughout the study. It should be noted that, not including Diazinon, there were no pesticide detections whatsoever at 3 of the 6 farms included in the study.

For the 9 soil samples, there were no detections of any pesticides or nitrite at any site. Ammonia – N was detected in 4 of 9 samples, with a maximum of 36 mg/kg at GFW. Moisture ranged from 19% at TN to 95% at GFW. Nitrate was detected in 6 of 9 samples, with a maximum detection of 24 mg/kg at GFW. Phosphate analysis was only done for 4 samples, ranging from 0.08 mg/kg at GFW and TN to 2.1 mg/kg at BH. At the DB farm, the soil samples were collected five and eleven weeks after the final chemical application in 2011 and 2012, respectively. The application schedules from other farms were unavailable, but if all farms used similar timelines then pesticide and nutrient soil parameters may have been increased earlier in the season relative to the values shown in the present analysis. Table 4.4 shows results from the analysis of the 9 soil samples taken throughout 2011 and 2012.

Table 4.3 Pesticide detections in water samples over all sites (69 pesticides were tested in total).

| Pesticide Name | Total # of Detections | | Levels (ug/L) | Standard Deviation (ug/L) | Location |
|---|---|---|---|---|---|
| | 2011 | 2012 | | | |
| Diazinon | 36 | 38 | 0.02 - 367 | 20.02 | Detections at upstream and on-farm site at SC, and all sites at DB, GFW, and TN |
| Carbaryl | 3 | 0 | 340, 16, 5 | 190.32 | DB on-farm; TN on-farm; TN downstream |
| Daconil | 1 | 0 | 5.4 | - | DB on-farm |
| a-BHC | 1 | 0 | 0.1 | - | DB downstream |
| Aroclor 1254 | 1 | 0 | 0.07 | - | DB upstream |
| 2,4 DDT + 4, 4 DDD | 0 | 2 | 0.015, 0.047 | 0.023 | WR on-farm; TN upstream |
| 4,4 DDE | 0 | 2 | 0.012, 0.027 | 0.011 | WR on-farm; TN upstream |
| o,p-DDT | 0 | 1 | 0.1 | - | DB downstream |
| p,p-DDT | 0 | 1 | 0.22 | - | DB downstream |

Table 4.4 2011 and 2012 Soil Sample Analysis (ND= No Detections, - = no analysis)

| | SC | DB | | BH | GFW | | BF | TN | | std |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Date** | Nov 2, 2012 | Sep 29, 2011 | Oct 30, 2012 | Nov 15, 2012 | Aug 30, 2011 | Nov 1, 2012 | Oct 31, 2012 | Aug 30, 2011 | Oct 31, 2012 | - |
| **Ammonia-N (mg/kg)** | ND | 13 | 13 | 22 | ND | 36 | ND | ND | ND | 10.86 |
| **Moisture** | 92% | 92% | 89% | 91% | 95% | 92% | 55% | 22% | 19% | 31.58% |
| **Nitrate (mg/kg)** | 27 | ND | 1.6 | 2.2 | ND | 24 | 2.5 | ND | 1.6 | 12.19 |
| **Nitrite (mg/kg)** | ND | ND | ND | ND | ND | ND | ND | ND | ND | - |
| **Phosphate (mg/kg)** | - | 0.5 | - | 2.1 | 0.08 | - | - | 0.08 | - | 0.96 |
| **Pesticides** | ND | ND | ND | ND | ND | ND | ND | ND | ND | - |

## 4.2 Probability analysis

Probability analyses were carried out using JMP statistical software to test for distributional assumptions for each of the 12 studied parameters. Data for each parameter was grouped together over all years and all sites. Seven parameters, including diazinon, nitrogen (ammonia nitrogen), organophosphate, carbonaceous BOD, nitrate-nitrogen, nitrite-nitrogen, and nitrate-nitrogen + nitrite-nitrogen, had frequent (>25%) "no-detection" data values. For these parameters, the "no detection" values were eliminated from probability analysis. On the other hand, temperature, pH, turbidity, TDS, and conductivity all had continuous readings. Running a distributional analysis in JMP for a particular parameter would create a table comparing the fit of 11 distributions for that parameter. Table 4.5 shows the distribution comparison table for temperature.

Table 4.5 Fit of 11 distributions for the temperature parameter, tested using JMP.

**Compare Distributions**

| Show | Distribution | Number of Parameters | -2*LogLikelihood | AICc |
|---|---|---|---|---|
| ☐ | Normal 3 Mixture | 8 | 1969.58119 | 1986.04872 |
| ☐ | Normal 2 Mixture | 5 | 1981.99292 | 1992.18584 |
| ☑ | Weibull | 2 | 2031.53514 | 2035.57335 |
| ☐ | Extreme Value | 2 | 2031.53514 | 2035.57335 |
| ☐ | Johnson Sl | 3 | 2036.22004 | 2042.29671 |
| ☐ | Normal | 2 | 2039.35597 | 2043.39418 |
| ☐ | GLog | 3 | 2039.35439 | 2045.43106 |
| ☐ | Johnson Su | 4 | 2039.35564 | 2047.48384 |
| ☐ | Gamma | 2 | 2067.3895 | 2071.42772 |
| ☐ | LogNormal | 2 | 2109.06054 | 2113.09875 |
| ☐ | Exponential | 1 | 2352.3821 | 2354.3948 |

The best fit distribution with low Number of Parameters, to avoid overfitting, and low AICc (Akaike Information Criterion with correction for small sample size), to ensure a high quality model compared to other options, was selected and graphed. For temperature, Weibull distribution was the best fit. Figure 4.1 shows temperature's Weibull continuous fit model on a histogram, and provides an outlier box plot displaying the $25^{th}$ quantile to $75^{th}$ quantile within the box and the median sample value as a horizontal line through the box.

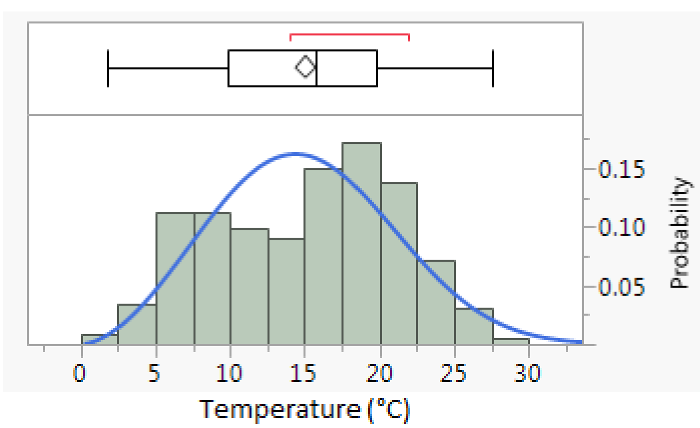


Figure 4.1 Histogram and outlier box plot showing the distribution of temperature (°C) over all years and sites.

For pH, Weibull distribution was the best fit. Figure 4.2 shows pH's Weibull continuous fit model on a histogram, and provides an outlier box plot.

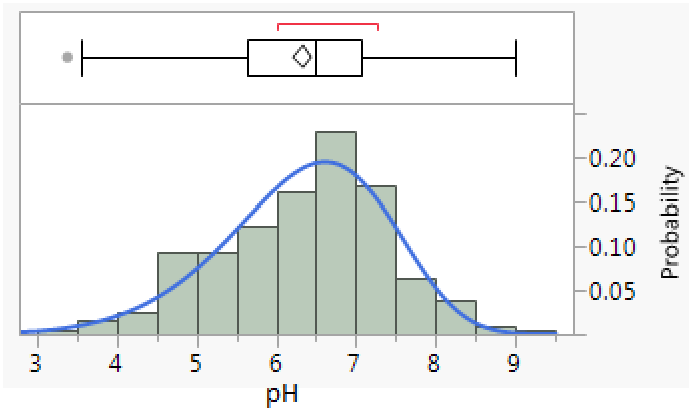


Figure 4.2 Histogram and outlier box plot showing the distribution of pH over all years and sites (Weibull distribution).

Table 4.6 shows the best fitting distribution for each of the 12 studied parameters. The Johnson Sl distribution was the best fit for 6 parameters – TDS, nitrogen (ammonia nitrogen), organophosphate, nitrate-nitrogen + nitrite-nitrogen, nitrate-nitrogen, and nitrite-nitrogen. The Johnson Su distribution was the best fit for 3 parameters – turbidity, diazinon, and carbonaceous BOD. The other three parameters were temperature and pH, with Weibull distributions, and conductivity, with a LogNormal distribution.

## 4.3 Regression analysis

Seven of the 12 tested parameters had >50% "no-detection" values and were not modeled for regression analysis due to the lack of data points. For the total 366 samples across all years and sites there were 195 "no-detection" values for nitrogen (ammonia nitrogen; 53%), 252 "no-detection" values for nitrate-nitrogen (69%), 274 "no-detection" values for organophosphate

Table 4.6 Distribution for all parameters with data from all years and all sites grouped together for each parameter.

| Parameter | Distribution | # of Equation Parameters | -2*LogLikelihood | AICc |
|---|---|---|---|---|
| Temperature | **Weibull** | 2 | 2031.54 | 2035.57 |
| pH | **Weibull** | 2 | 885.36 | 889.40 |
| Turbidity | **Johnson Su** | 4 | 1124.98 | 1133.11 |
| TDS | **Johnson Sl** | 3 | 2619.39 | 2625.46 |
| Conductivity | **LogNormal** | 2 | -1319.63 | -1315.59 |
| Diazinon | **Johnson Su** | 4 | 12.92 | 21.50 |
| Nitrogen (ammonia nitrogen) | **Johnson Sl** | 3 | -460.95 | -454.80 |
| Organophosphate | **Johnson Sl** | 3 | -1529.12 | -1522.86 |
| Carbonaceous BOD | **Johnson Su** | 4 | -160.02 | -150.59 |
| Nitrate-nitrogen + Nitrite-nitrogen | **Johnson Sl** | 3 | -168.30 | -162.08 |
| Nitrate-nitrogen | **Johnson Sl** | 3 | -172.62 | -166.40 |
| Nitrite-nitrogen | **Johnson Sl** | 3 | -418.15 | -410.65 |

(75%), 293 “no-detection” values for diazinon (80%), 333 “no-detection” values for carbonaceous BOD (91%), and 346 “no-detection” values for nitrite-nitrogen (95%).

Temperature, pH, turbidity, TDS, and conductivity did not have any “no-detection” values. Linear and exponential regression models were created for these five parameters at each individual site to identify their interactions with time. Regression models for all parameters were found to have low predictability and have not been presented here. For each parameter's 36 models (18 sites x 2 years), pH had 6 models with an $R^2 > 0.5$ and 0 models with an $R^2 > 0.8$, turbidity had 7 models with an $R^2 > 0.5$ and 0 models with an $R^2 > 0.8$, TDS had 4 models with an $R^2 > 0.5$ and 0 models with an $R^2 > 0.8$, and conductivity had 5 models with an $R^2 > 0.5$ and 0 models with an $R^2 > 0.8$. Temperature had all 36 models with an $R^2 > 0.5$ and 22 models with an $R^2 > 0.8$, but due to the fact that the yearly sampling periods began in July and ended in November it was to be expected that there would naturally be a downward temperature trend during that time.

### 4.4 Correlations between parameters

The 7 parameters that had >50% "no-detection" values were not included in correlational analysis due to the lack of data points. For the other 5 parameters, namely temperature, pH, turbidity, TDS, and conductivity, the correlations between each two parameters were determined over all sites and years. Correlational analysis was done using JMP to run a Matched Pairs analysis, comparing all possible pairs between the 5 tested parameters. The only strong relationship was found to be between conductivity and TDS, with a correlation of 0.958. Figure 4.3 provides a scatterplot showing the linear relationship between conductivity and TDS. After removing 3 outliers for the conductivity and TDS correlational analysis the correlation between these parameters increased to 0.999. Two of the removed outlier values were sampled on July 20th, 2011 at GFW, and the other was from October 1st, 2012 at TN. Figure 4.4 provides the updated scatterplot for TDS and conductivity with the 3 outliers removed, showing the clear positive linear relationship between these two parameters.

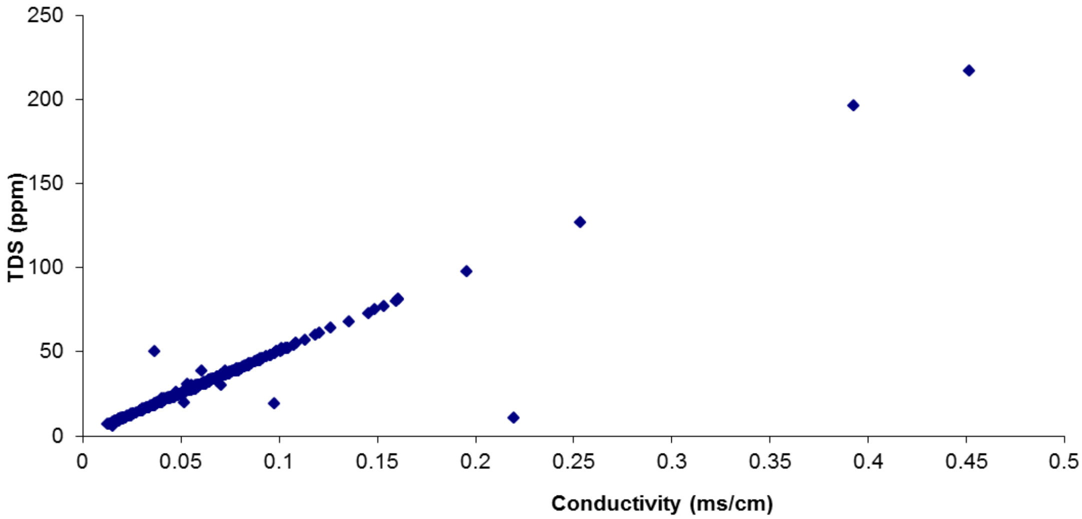


Figure 4.3 Scatterplot with TDS (ppm) on y-axis and conductivity (mS/cm) on x-axis showing a correlation between parameters of 0.958 (N=314).

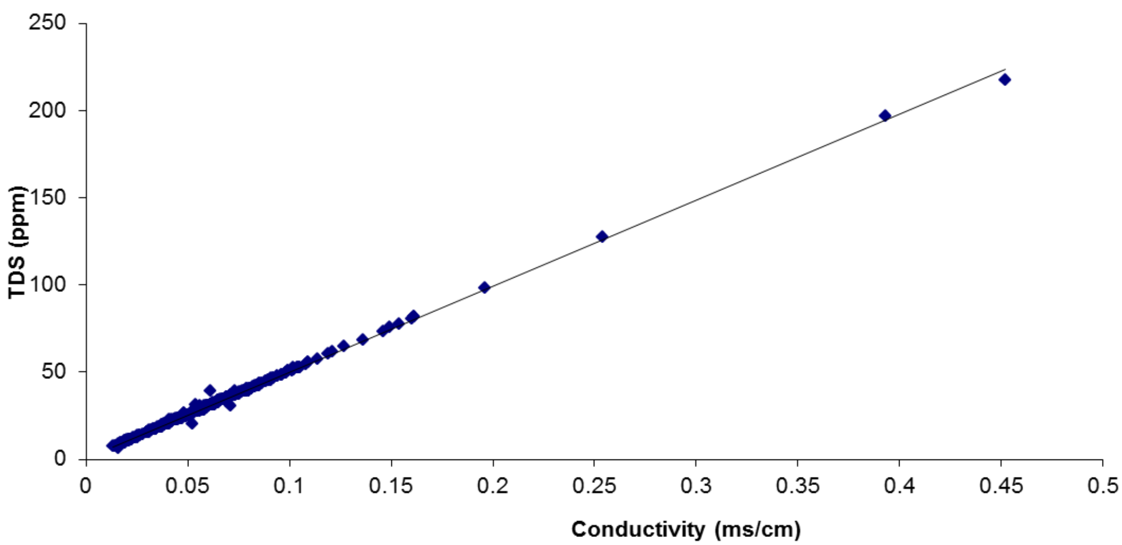


Figure 4.4 Scatterplot of relationship between TDS and conductivity with 3 outliers removed (Correlation = 0.999; N=311).

There was a weak relationship between all other parameters, with correlations ranging from |0.005| to |0.164|. Table 4.7 shows the correlations between temperature, pH, turbidity, TDS, and conductivity.

Table 4.7 Correlations between temperature, pH, turbidity, TDS, and conductivity over all sites and all years (correlations above 0.5 are shown in bold; N = 304 for pH, N=314 for other parameters (3 outliers removed for the TDS-conductivity relationship; missing pH values for TN – Site 1 - 2011)).

| Parameter | Temperature | pH | Turbidity | TDS | Conductivity |
|---|---|---|---|---|---|
| **Temperature** | - | -0.011 | 0.164 | -0.05 | -0.051 |
| **pH** | -0.011 | - | -0.005 | 0.13 | 0.125 |
| **Turbidity** | 0.164 | -0.005 | - | 0.031 | 0.024 |
| **TDS** | -0.05 | 0.13 | 0.031 | - | **0.999** |
| **Conductivity** | -0.051 | 0.125 | 0.024 | **0.999** | - |

## 4.5 Tests for significant differences between upstream, on-farm, and downstream sites

### *4.5.1 Comparisons over all farms*

Significance of the differences between sites was determined for each parameter, grouping all data for a parameter over all farms into 3 groups - upstream, on-farm, and downstream. The JPM program was used to run an ANOVA to identify any significant differences between sites, with $P > 0.05$. If there was a significant difference, a Tukey Test was run to determine specifically which of the 3 groups were significantly different from the others.

There was no difference between sites for temperature, TDS, conductivity, diazinon, and carbonaceous BOD. For pH, downstream levels were significantly reduced compared to both upstream and on-farm readings, but there was no statistically significant difference between upstream and on-farm. The downstream pH mean was 6.05, compared to 6.45 upstream and 6.50 on-farm. Figure 4.5 provides pH boxplots for each site, showing the significantly lower pH level at Site 3 (downstream) compared to Site 1 (upstream; P = 0.0148) and Site 2 (on-farm; P = 0.0038).

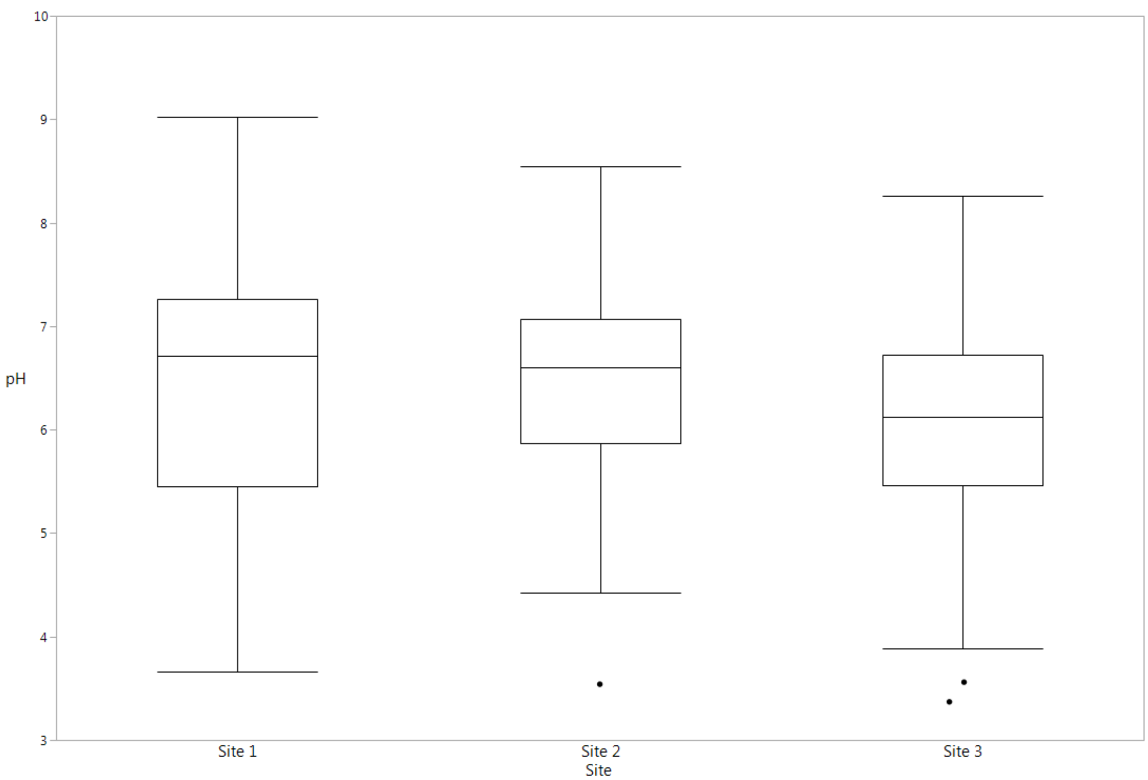


Figure 4.5: pH boxplots for each site, comparing distribution and mean of Site 1 (upstream), Site 2 (on-farm), and Site 3 (downstream).

For turbidity, nitrogen (ammonia nitrogen), organophosphate, nitrate-nitrogen + nitrite-nitrogen, nitrate-nitrogen, and nitrite-nitrogen, levels were significantly increased on-farm compared to both upstream and downstream, but there was no statistically significant difference between upstream and downstream. At the downstream site for each of these parameters, levels either returned close to the upstream baseline levels (turbidity, organophosphate) or returned all the way to the upstream baseline levels (nitrogen (ammonia nitrogen), nitrate-nitrogen + nitrite-nitrogen, nitrate-nitrogen, nitrite-nitrogen). For example, the on-farm nitrogen (ammonia nitrogen) mean was 0.215 mg/L, compared to 0.117 mg/L upstream and 0.109 mg/L downstream. Figure 4.6 provides nitrogen (ammonia nitrogen) boxplots for each site, showing the significantly higher nitrogen (ammonia nitrogen) level at Site 2 (on-farm) compared to Site 1 (upstream; $P = 0.0025$) and Site 3 (downstream; $P = 0.0006$). Out of the parameters with significant differences, nitrogen (ammonia nitrogen), organophosphate, nitrate-nitrogen + nitrite-nitrogen, nitrate-nitrogen, and nitrite-nitrogen had a high proportion of “no-detection” values. For these parameters, significance was tested both with and without the “no-detection” values included. There was a significant difference in both scenarios for all parameters except for organophosphate and nitrite-nitrogen, for which were only significant with the “no-detection” values included. In cases in which both scenarios were significant – nitrogen (ammonia nitrogen), nitrate-nitrogen + nitrite-nitrogen, and nitrate-nitrogen – results without the “no-detection” values were used for final analysis. For organophosphate and nitrite-nitrogen, results with the “no-detection” values included were used for final analysis. Organophosphate and nitrite-nitrogen only had 7 and 2 upstream detections respectively, compared to 61 and 15 on-site detections, so this made it difficult to make statistical comparisons of mean values between sites for these parameters. Table 4.8 shows the means and statistical significance of upstream, on-farm, and downstream sites for all 12 parameters.

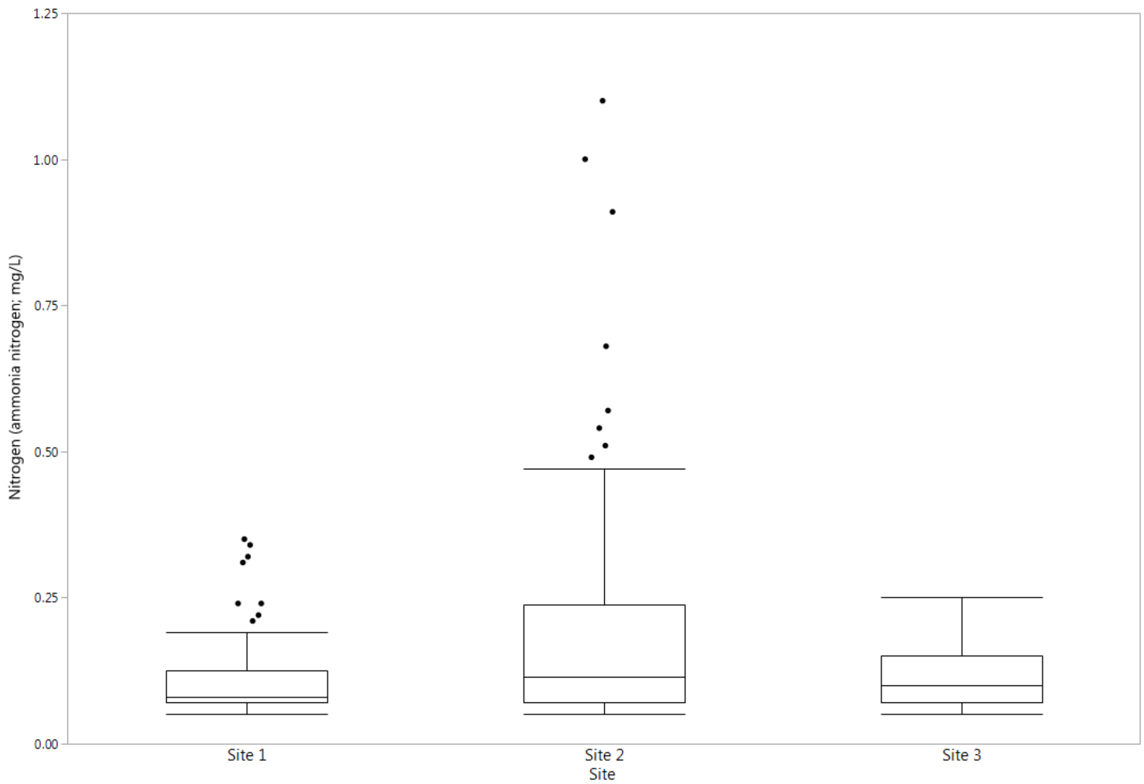


Figure 4.6: Nitrogen (ammonia nitrogen) boxplots for each site, comparing distribution and mean at Site 1 (upstream), Site 2 (on-farm), and Site 3 (downstream) (all "no-detection" values removed from analysis).

*4.5.2 Comparisons between sites at each individual farm*

Individual comparisons were made between upstream, on-farm, and downstream sites at each of the 6 individual farms by using the Tukey test to identify the source of the difference.

<u>*Farm SC*</u>

At Farm SC the on-farm site mean value of 0.128 ug/L was significantly higher than the downstream site mean value of 0.01 ug/L for diazinon (P=0.0365), and the on-farm site mean value of 0.113 mg/L was significantly higher than the upstream site mean value of 0.028 ug/L for nitrate-nitrogen (P=0.0364). For pH there was an increased reading on-farm of 6.60 relative to both the upstream mean of 5.87 (P=0.0432) and the downstream mean of 5.01 (P<0.0001),

Table 4.8: Means, statistical significance, and standard deviation of upstream, on-site, and downstream sites for all 12 parameters over all sites. $^{*}$ = significantly different from upstream site; $^{\alpha}$ = significantly different from on-farm site

| Parameter | Upstream Mean | Upstream std | On-Farm Mean | On-Farm std | Downstream Mean | Downstream std |
|---|---|---|---|---|---|---|
| Temperature (ºC) | 15.03 | 6.07 | 15.15 | 6.06 | 14.93 | 6.06 |
| pH | 6.45 | 1.01 | 6.50 | 1.01 | $6.05^{*\alpha}$ | 1.01 |
| Turbidity (NTU) | 2.07 | 3.37 | $3.66^{*}$ | 3.37 | $2.48^{\alpha}$ | 3.37 |
| TDS (ppm) | 30.49 | 20.80 | 35.21 | 20.80 | 29.0 | 20.80 |
| Conductivity (mS/cm) | 0.061 | 0.051 | 0.075 | 0.052 | 0.06 | 0.051 |
| Diazinon (mg/L) | 0.198 | 42.99 | 9.47 | 42.98 | 0.395 | 42.99 |
| Nitrogen (ammonia nitrogen) (ug/L) | 0.117 | 0.148 | $0.215^{*}$ | 0.155 | $0.109^{\alpha}$ | 0.151 |
| Organophosphate (ug/L) | 0.008 | 0.043 | $0.026^{*}$ | 0.043 | $0.012^{\alpha}$ | 0.043 |
| Carbonaceous BOD (mg/L) | 3.64 | 3.56 | 5.52 | 3.55 | 4.79 | 3.55 |
| Nitrate-nitrogen + Nitrite-nitrogen (ug/L) | 0.169 | 0.236 | $0.344^{*}$ | 0.236 | $0.149^{\alpha}$ | 0.232 |
| Nitrate-nitrogen (ug/L) | 0.166 | 0.224 | $0.335^{*}$ | 0.224 | $0.148^{\alpha}$ | 0.226 |
| Nitrite-nitrogen (ug/L) | 0.006 | 0.004 | $0.007^{*}$ | 0.004 | $0.005^{\alpha}$ | 0.004 |

and the upstream site was significantly increased relative to downstream (P=0.0147). Figure 4.7 provides boxplots for Farm SC diazinon levels for each site, showing the significantly higher diazinon level at Site 2 (on-farm) compared to Site 3 (downstream). The Site 1 boxplot shows that there were numerous diazinon detections at the upstream site, despite there not being any known diazinon sources applied further upstream. In contrast, there was not a single detection of diazinon at the downstream site. The finding that compared to upstream, diazinon levels were elevated on-farm but not downstream indicates the existing BMPs at Farm SC were effective at containing diazinon on the farm and minimizing the impact of applied pesticides on the downstream environment.

*Farm DB*

At Farm DB there was an increase of the on-farm site organophosphate mean of 0.021 mg/L compared to both the upstream site mean of 0.0056 mg/L (P=<0.0001) and the downstream site mean of 0.0064 mg/L (P<0.0001). The upstream site had a significantly higher nitrogen (ammonia nitrogen) mean of 0.113 mg/L compared to the on-farm site mean of 0.074 mg/L (P=0.0238). For diazinon, there was 1 detection out of 19 samples upstream, 0.2 ug/L on September 1, 2011, 12 detections out of 19 samples on-farm, including 9 out of 10 in 2011 and 3 out of 9 in 2012, and 1 out of 19 samples downstream, 0.47 ug/L on July 19, 2011. Other detections of pesticides at DB included only a single detection of six different pesticides, all in 2011. Aroclor 1254 was detected upstream at 0.07 ug/L on August 3, o,p-DDT was detected downstream at 0.1 ug/L on August 9, p,p-DDT was detected downstream at 0.22 ug/L on August 9, carbaryl was detected on-farm at 340 ug/L on August 18, a-BHC was detected downstream at 0.1 ug/L on September 19, and daconil was detected on-farm at 5.4 ug/L on October 26. The finding that carbaryl and daconil were only detected on-farm, and that diazinon was detected on-farm 12 times compared to only once downstream, suggests that existing BMPs have been effective in containing pesticides on the farm. However, the detection of diazinon downstream at 0.47 ug/L on July 19, 2011 is cause for further investigation of alternative BMPs for containing pesticides on the farm, as this detection is approaching the 0.56 ug/L level found by Vryzas (2011) to be toxic to aquatic invertebrates even though our sample was taken close to one month after June 24 application. The presence of a-BHC, aroclor 1254, o,p-DDT, and p,p-DDT in the environment were likely the result of historic use, as these compounds were not applied on the farm in recent years.

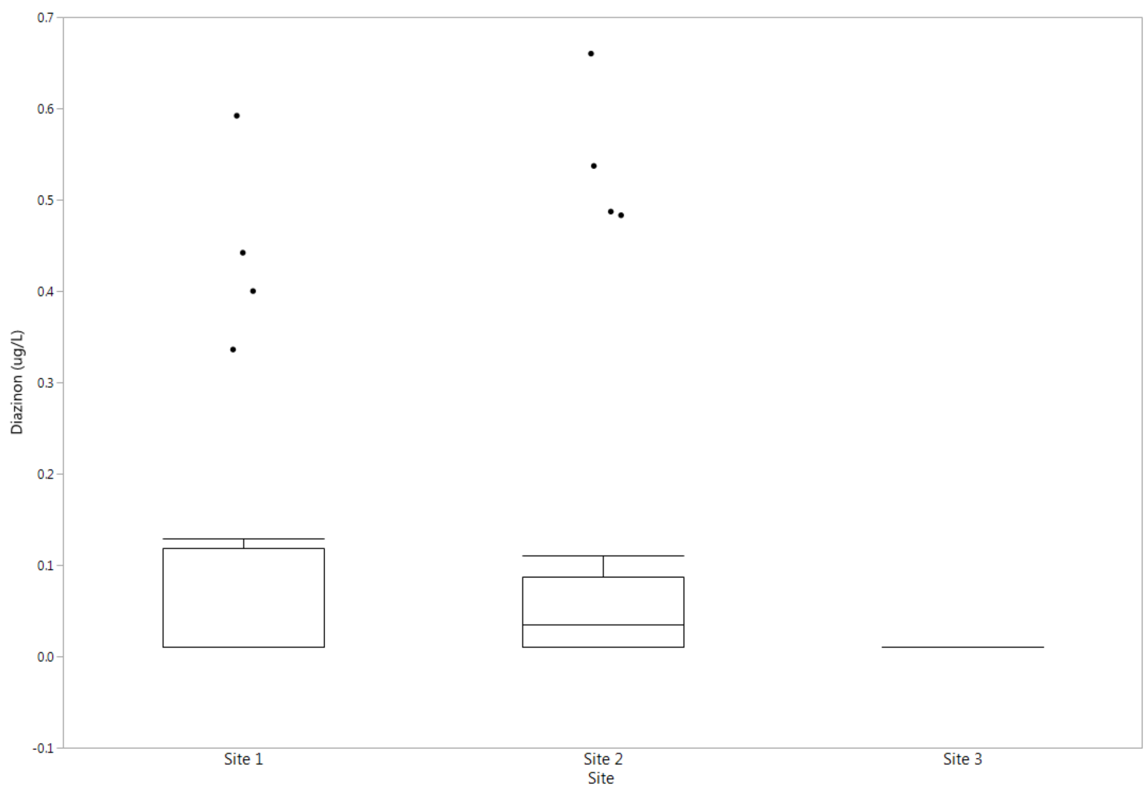


Figure 4.7: Boxplots for Farm SC diazinon levels for each site, comparing distribution and mean at Site 1 (upstream), Site 2 (on-farm), and Site 3 (downstream) (“no-detection” values included in analysis).

*Farm BH*

At Farm BH there was an increased measurement of conductivity (P=0.0022), turbidity (P=0.0198), and TDS (P=0.0013) at the downstream site compared to the upstream site, with a conductivity measurement of 0.092 mS/cm downstream and 0.060 mS/cm upstream, a turbidity measurement of 2.51 NTU downstream and 1.42 NTU upstream, and a TDS measurement of 46.6 ppm downstream and 29.9 ppm upstream. TDS (P=0.004) and conductivity (P=0.0066) were also significantly increased downstream relative to on-farm, with on-farm measurements of 31.6 ppm and 0.063 mS/cm, respectively.

*Farm GFW*

At Farm GFW there was an increase on-farm compared to both upstream and downstream for organophosphate (P<0.0001, upstream; P<0.0001, downstream), nitrogen (ammonia nitrogen; P=0.0001, upstream; P=0.0004, downstream), nitrite-nitrogen (P=0.0001, upstream; P=0.0002, downstream), nitrate-nitrogen (P<0.0001, upstream; P=0.0005, downstream), TDS (P<0.0001, upstream; P<0.0001, downstream), turbidity (P=0.0001, upstream; P=0.0041, downstream), and conductivity (P<0.0001, upstream; P<0.0001, downstream). The mean values for these differences are 0.388 mg/L on-farm compared to 0.005 mg/L upstream and 0.0059 mg/L downstream for organophosphate, 0.283 mg/L on-farm compared to 0.054 mg/L upstream and 0.071 mg/L downstream for nitrogen (ammonia nitrogen), 0.388 mg/L on-farm compared to 0.05 mg/L upstream and 0.125 mg/L downstream for nitrate-nitrogen, 0.0119 mg/L on-farm compared to 0.005 mg/L upstream and 0.0053 mg/L downstream for nitrite-nitrogen, 43.29 ppm on-farm compared to 22.65 ppm upstream and 24.18 ppm downstream for TDS, 3.75 NTU on-farm compared to 1.56 NTU upstream and 2.09 NTU downstream for turbidity, and 0.09 mS/cm on-farm compared to 0.045 mS/cm upstream and 0.045 mS/cm downstream for conductivity. For pH, the upstream mean of 7.06 was significantly increased relative to both the on-site mean of 6.61 (P=0.0247) and the downstream mean of 6.60 (P=0.0234). Figure 4.8 provides boxplots for Farm GFW nitrogen (ammonia nitrogen) levels for each site, showing the significantly higher nitrogen (ammonia nitrogen) level at Site 2 (on-farm) compared to Site 1 (upstream) and Site 3 (downstream).

*Farm BF*

At Farm BF there was an increase at the on-farm site compared to the downstream site for nitrate-nitrogen (P=0.0138), TDS (P=0.018), and pH (P=0.0023). The mean values for these differences are 0.276 mg/L on-farm compared to 0.029 mg/L downstream for nitrate-nitrogen, 49.0 ppm on-farm compared to 29.1 ppm downstream for TDS, and 7.10 on-farm compared to 6.41 downstream for pH. For pH there was also a significant increase of the upstream site mean value of 6.97 compared to the downstream site (P=0.016).

*Farm TN*

At Farm TN there was an increase of the on-farm site compared to the upstream site for organophosphate (P=0.0344) and TDS (P<0.0001). The mean values for these differences are 0.028 mg/L on-farm compared to 0.005 mg/L upstream for organophosphate, and 22.71 ppm on-farm compared to 11.12 ppm upstream for TDS. For TDS there was also a significant difference at the on-farm site compared to the downstream site mean values of 9.94 ppm (P=0.0002).

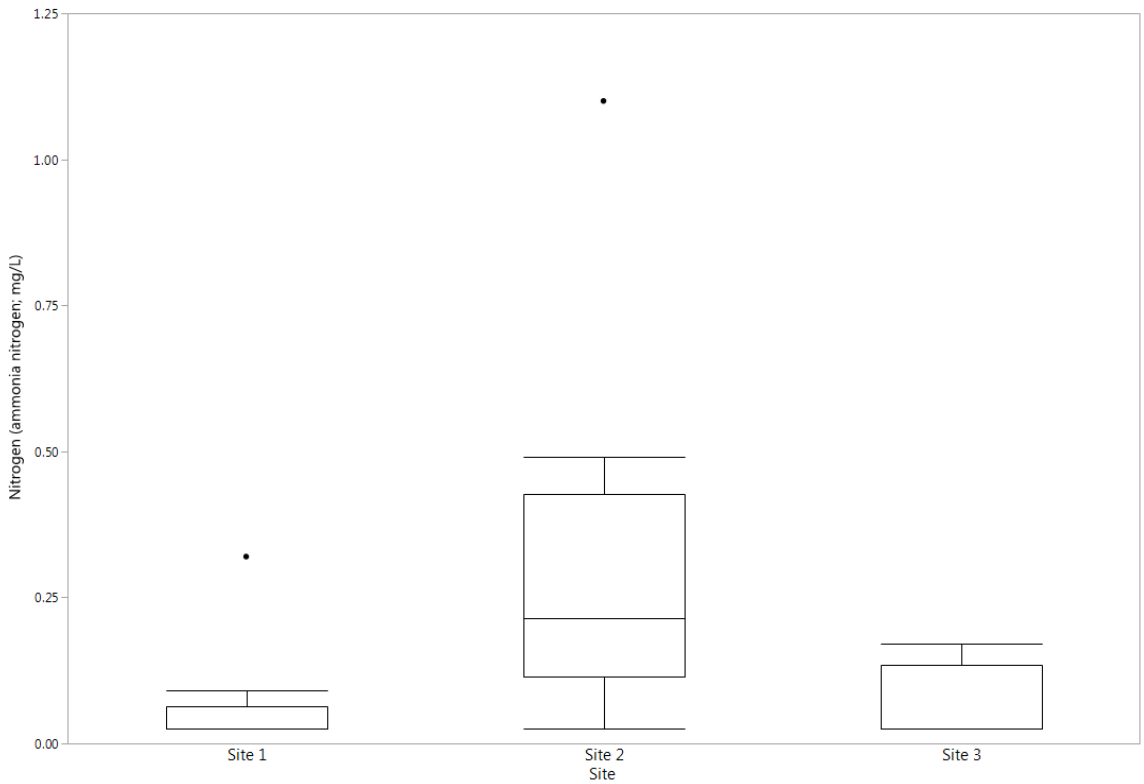


Figure 4.8: Boxplots for Farm GFW nitrogen (ammonia nitrogen) levels for each site, comparing distribution and mean at Site 1 (upstream), Site 2 (on-farm), and Site 3 (downstream) ("no-detection" values included in analysis).

**4.6 Summary**

In Chapter Four, probability, linear and exponential regression, and correlational analyses were carried out to assess data. ANOVA and Tukey tests were run to determine significance between sites, and descriptive statistics were evaluated. Grouping data for diazinon over all farms into 3 groups, upstream, on-farm, and downstream, it was found that there was no difference between sites. There was a significant increase on-farm compared to both upstream and downstream for turbidity, nitrogen (ammonia nitrogen), organophosphate, nitrate-nitrogen + nitrite-nitrogen, nitrate-nitrogen, and nitrite-nitrogen, a significant decrease in pH downstream compared to both upstream and on-farm levels for pH, and no difference between sites for temperature, TDS, conductivity, and carbonaceous BOD. ANOVA and Tukey tests were also conducted for each farm individually to identify significant differences between each set of upsteam, on-farm, and downstream sites. Looking at each farm individually, there were frequent significant differences on-farm compared to both upstream and downstream, but the only significant differences between upstream and downstream were a significantly lower pH at Farm GFW and Farm E downstream compared to upstream, and significantly decreased levels of conductivity, turbidity, and TDS downstream compared to upstream. Given the differences between downstream sites compared to on-farm and upstream sites, and differences between individual farms, BMPs will be evaluated in the following chapter to identify BMPs that have been effective at containing chemicals on the farms and additional BMPs that could further improve environmental performance at these farms. The findings from the evaluation of BMPs will act as a set of guidelines for minimizing the impact of cranberry farming on downstream surface water at farms inside and outside of Newfoundland and Labrador.

# Chapter 5: Cranberry Farming Best Management Practices and General Discussion

## 5.1 Overview of Best Management Practices for Cranberry Farming

There are a wide range of best management practices for cranberry farming that when implemented will minimize risk of agricultural operations to the environment while maintaining or improving farm productivity. The process of Environmental Farm Planning educates Canadian producers, providing information on agri-environmental issues, and how to assess environmental risks and mitigate those risks on an individual farm basis (Eilers, 2010). This section will outline various practices for mitigating environmental impacts of cranberry farming using pesticide, nutrient, irrigation, flooding, and landscape management strategies.

### *5.1.1 Pest Management*

#### *5.1.1.1 Integrated Pest Management*

On cranberry farms it is necessary to manage insect pests, weeds, and diseases effectively (MDARD, 2016). An Integrated Pest Management (IPM) program monitors, prevents, and controls pests and environmental conditions that could otherwise have serious economic impacts (US.EPA, 2009). IPM practices for cranberry farms manage pests by utilizing biological, chemical, and cultural control practices. Insect, weed, disease, and nutrient management are all key components of IPM. The process of IPM relies on judgement and adaptability, including the basic components of education, monitoring, and decision making (UMASSa, 2010). Under IPM, sprays are not the only answer to protect crops, and should only be used as an option when warranted by sufficient numbers or impact of pests (Le Duc, 2004). A key component of IMP for cranberry farming is monitoring the pest population and influencing factors to ensure control options are only used if pest populations reach a threshold level or if conditions on the farm are favorable for pest reproduction and growth. All appropriate methods should be utilized, with a combination of techniques being preferable to reliance on any one option. When chemicals are applied, selective chemicals should be used rather than broad spectrum pesticides (Maurice, 2000). By eliminating application of broad based chemicals, the presence of natural predators of pests will not be impacted (Le Duc, 2004). The best management approach is the least disruptive one that does not interfere with positive components of the cranberry farm's system. Fungi are the primary cause of disease on cranberry plants, responsible for rot of roots and fruit, and blight on the leaves. Plant or berry damage is commonly the first indication of the disease in the cranberry beds (Maurice, 2000).

Successful pest protection techniques include the selective use of flooding, sanding, baiting and nematodes (MDARD, 2016). Sanding involves application of 1.2 to 2 cm of sand to ice covering cranberry fields in winter. In spring this sand will cover cranberry plant stems and leaf residues, aiding in formation of new stems and roots, ensuring plants are healthy and less vulnerable to insects (Le Duc, 2004). IPM practices recommended by the University of Massachusetts Cranberry Station include education by regularly attending relevant workshops on IPM, use of monitoring techniques (e.g. sweep netting; pheromone traps) to estimate action thresholds, cultural practices (e.g. flooding; sanding) to manage pests, horticultural practices to optimal soil drainage, and crop phenology for evaluating timing of strategies for managing insects and diseases (see Figure 5.1; UMASSa, 2010).

*5.1.1.2 Insect Management*

When insect pests infest cranberry beds, cultural and chemical practices may be needed to limit economic damage (MDARD, 2016). Two important components of an effective monitoring program are implementing a consistent monitoring schedule and collecting data (Le Duc, 2004). Monitoring methods enable pest identification on cranberry farms so the potential for damage can be evaluated (Maurice, 2000). The presence or absence of insects can be determined by utilizing IPM techniques, such as weekly to biweekly visits made to the bog with a sweep net. The net is swept through the bog in a set pattern and upon completion; the insects collected in the net are identified and counted. A certain threshold amount of insects are acceptable. When these threshold values are exceeded, then action to protect the crop is considered (L. Madore, personal communication, December 7, 2015). Another technique involves using pheromone traps that attract male insects by giving off a synthetic pheromone. Pheromone traps give information on presence or absence of target pests on cranberry farms, and aids in predicting timing of the next generation of larvae (Maurice, 2000). In Eastern Canada, pheromone traps are utilized for identifying the presence of Cranberry Fruitworm, Black-headed Fireworm, Sparganothis Fruitworm, and Cranberry Girdler (Le Duc, 2004). By using IPM practices to monitor pest populations, it is possible to use spot treatments and optimize treatment timing (MDARD, 2016).

In Madore, 2010, four pest species of interest to the cranberry industry in Newfoundland were investigated, including the Black-headed Fireworm (Rhopobota naevana), the Cranberry Girdler (Chrysoteuchia topiaria), the Sparganothis Fruitworm (Sparganothis sulphureana), and the Cranberry Fruitworm (Acrobasis vaccinii). Populations of these species were monitored on five farms throughout the province. Sweep netting and pheromone trapping were used to monitor populations from 2006 to 2009. It was found that the Black-headed Fireworm was detected across the province, with the highest populations found during sweep net monitoring of the studied species. The Cranberry Girdler was found to be well distributed across the province. Few specimens of Sparganothis Fruitworm were found in 2006 and 2007, but in 2008 specimens were found sporadically via both sweep netting and pheromone trapping, with higher concentrations at east coast sites compared to west coast sites. The Cranberry Fruitworm was found to be distributed throughout the province, with low populations of larvae found throughout the province for the three years of monitoring.

Sweep netting found higher populations of Black-headed Fireworm and Cranberry Fruitworm compared to other species, so Madore concluded that these two species had the potential to cause higher crop damage. Of the four studied species, the Black-headed Fireworm and Cranberry Fruitworm were the only species to reach their action threshold, although the Black-headed Fireworm had only a moderate population in most locations but a high population on the west coast of Newfoundland. Madore concluded that as a result of the action thresholds being met for the Black-headed Fireworm and Cranberry Fruitworm that IPM should be put in place on all cranberry farms throughout Newfoundland and Labrador.

To monitor for Black-headed Fireworms, monitoring for larvae should begin in late April, and more extensive visual sweeps should begin one to two weeks after larvae are seen for the first time. Pheromone traps for monitoring flight of Black-headed Fireworm moth should be setup in the middle of May, counting the number of moths weekly. Ten days to two weeks after the number of moths reaches a maximum, or 3 weeks after first catching a moth, field edges and known hot-spots should begin to be searched (Maurice, 2000). For the Cranberry Fruitworm, infested cranberries can be found between late July and mid-September (Le Duc, 2004). Pheromone traps giving off Cranberry Fruitworm pheromone attracts male Cranberry Fruitworm moths. Most Cranberry Fruitworm eggs are found at the calyx end of cranberries that are located in weedy areas, on edges of beds and ditches, and on cranberries sticking up above the vine canopy (Maurice, 2000). Table 5.1 shows monitoring chronology for various cranberry pests including the Cranberry Fruitworm and Black-headed Fireworm.

Flooding cranberry beds in spring for one month assists in controlling the Cranberry Fruitworm population. Alternatively, a flooding lasting 24 to 48 hours from bud break to bud elongation helps control the Black-headed Fireworm population (Le Duc, 2004). In situations where chemicals must be applied to mitigate insect damage to cranberry plants, it is important to avoid resistance by rotating insecticides and using insecticides in conjunction with biological and cultural control options (MDARD, 2016).

*5.1.1.3 Pesticide Management*

Pesticides are chemical compounds that, despite posing potential environmental impacts, are in most cases necessary for economic viability of cranberry farming (Le Duc, 2004). Pesticides are applied on cranberry farms only when required, such as when it is determined by field scouting that a threshold is approaching for economic damage (Eilers, 2010). The frequency of application of any particular pesticide would be dictated according to the need. For example, insecticides are not to be applied if insects are not present. The same with fungicides and the herbicides, although some growers spray fungicides pre-emptively, in an effort to prevent fungal outbreaks (L. Madore, personal communication, December 7, 2015).

Table 5.1 Monitoring chronology for various cranberry pests, including the Cranberry Fruitworm and Black-headed Fireworm (modified from Le Duc, 2004).

| Pest | Bud break | | Bloom | Fruit set | Fruit development and maturation<br>Bud development |
|---|---|---|---|---|---|
| | May | June | July | August | September |
| Cranberry girdler | Inspection of visible signs of damage | Installation of traps and checking of traps once a week | Inspection of adults in flight | | Inspection of larvae<br>Infested areas reddish or brownish |
| Cranberry fruitworm | Installation of traps and checking of traps at least once a week | Calculation of percent fruit set | | Premature reddening of fruit<br>Viable eggs | |
| Blackheaded fireworm | Inspection of larvae on stems; sweep net monitoring | Infested areas where plants look burned<br>Leaves tied together with silk | Installation of traps and checking of traps at least once a week | Fruit pierced or eaten, tied together with silk | |
| Sparganothis fruitworm | Installation of traps and checking of traps at least once a week<br>Sweep net monitoring | Leaves tied together with silk | | Fruit pierced, eaten, redden prematurely | |

Only when all other control options are ruled out should pesticides be considered for use, and when pesticides are used they should be used according to the label instructions only. Similarly, fungicide and herbicide needs are evaluated with IPM techniques, alternatives are considered when certain thresholds are exceeded, and appropriate actions are taken (L. Madore, personal communication, December 7, 2015). In addition to following pesticide label instructions, current material safety data sheets should be made accessible, and detailed pesticide application records should be kept (UMASSc, 2010). When selecting pesticides to apply on a cranberry farm, toxicity, risk to non-target organisms, risk to downstream environments, and persistence should all be considered (MDARD, 2016). Questions that should be asked before applying pesticides on cranberry farms include will spaying pesticides do more harm than good?; will spraying be a smart financial decision?; has the problem been accurately evaluated, and have all other options been attempted? (Le Duc, 2004).

It is required that all pesticides be registered by the Pest Management Regulatory Agency of Health Canada before use in Canada. It is through the registration process that the purpose of the chemical is demonstrated, and its application timing and restrictions are documented. All precautions for the use of the chemical are clearly identified and labelled, such as the maximum single application rate, pre-harvest intervals, any restricted entry intervals after application, and the maximum number of applications, for example. Only products registered and approved for use on cranberries should be utilized on the crop, and when used, they should be applied according to the label instructions. Applied pesticides are not to be returned directly to the receiving watercourse, but rather held within the cranberry bed for as long as possible. This approach should minimize any potential water contamination concerns (L. Madore, personal communication, December 7, 2015).

Product substitution, application rate reduction, and shift of application date have been found to be effective options for reducing downstream environmental impacts (Reichenberger et al., 2007). The most feasible mitigation strategy may be changes in application. Product substitution would include a shift from the typically used synthetic chemical pesticides to biological pesticides, which come from biological material including plants, animals, and bacteria. Pesticide education for farmers is another possible mitigation strategy (Watson, 2013).

Pesticide application equipment must be properly calibrated to ensure appropriate amounts of chemicals area being applied, minimizing economic losses and risks to downstream water.

Additionally, the application sprayer must be shut off when the boom crosses over waterways or ditches. Pesticides should not be applied in excessive winds above 8km/h because that will significantly increase non-target application and reduce uniformity of application (MDARD, 2016).

*5.1.2 Nutrient Management*

Nutrient management is defined as managing the amount, source, placement, form, and timing of the application of plant nutrients to the soil (USDA, 2006). For cranberry farms, a nutrient management plan ensures the nutrients applied are equal to the uptake of the cranberry crop, minimizing the excess nutrients available to be lost via run-off into downstream water (Colquhoun, 2010). Optimal nutrient management makes it possible to apply nutrients efficiently, minimizing nutrient losses to the environment while at the same time ensuring high quality crops with optimal yield (Eilers, 2010). Nutrient management plans must be adhered to, or excess nutrient loading can occur when applied fertilizer exceeds the needs of the soil (Bradford et al., 2008). In these cases nutrients may contaminate groundwater and surface water, especially after rain and snowmelt (Chander et al., 2005).

Emissions of nitrogen to the environment can be limited by following rate, timing, and method best management practices for nitrogen application. Farmers should take into account all other sources of nitrogen (e.g. carryover from previous crops) when determining application rate, ensure nitrogen is applied as close to the time that it is required by the crops as realistically possible, and inject nutrients into the soil to minimize runoff into downstream water (Ribaudo, 2011). Applying nutrients between bud break and the end of August ensures timing availability of nutrients with when cranberry plants can utilize the nutrients. Alternatively, applying nutrients in the fall or early spring increases the potential for leaching (Colquhoun, 2010). The longer the time is between fertilizer application and plant uptake, the better the chance is of losing nutrients to downstream surface or ground water (UMASSd, 2010). Ribaudo (2011) found that two-thirds of U.S. cropland is not meeting each of the rate, timing, and method best management practices criteria for good nitrogen management, and recommended a number of policy approaches including financial incentives, regulation, and nitrogen management as a condition of eligibility for farm programs.

Education is a key component of nutrient management. Two central practices for more efficient fertilizer use include soil testing and tissue testing, enabling application of fertilizer more in line with plant requirements (Ribaudo, 2011). Soil nutrient testing allows farmers to align their crop nutrient requirements with nutrient levels in soil and applied fertilizers (Eilers, 2010). Soil testing for organic matter content and pH should be completed every 2-4 years, and tissue testing for mineral content should be completed every 1-4 years (UMASSd, 2010). Measuring pH every 2-4 years ensures soils remain in the 4.0 to 5.5 range, the optimal pH for nutrient utilization and plant growth. In cases where pH rises above 5.5, application of sulfur may be required to lower soil pH (Colquhoun, 2010). (Ribaudo (2011)) found that at farms applying commercial nitrogen exclusively, farmers who tested their soil applied 33.5kg per acre less than farmers who did not do soil testing, and reducing application of nitrogen was the most effective practice for decreasing the amount of nitrogen entering the ambient environment. Cranberry beds located on organic soils may need as little as 4.5kg per acre per year, whereas beds on sandy soils may require as much as 27kg per acre per year. Assessing tissue nitrogen levels, vine growth, yields, and previous nutrient application, the appropriate amount of nutrient requirements can be determined (Colquhoun, 2010).

Research on cranberry beds in Wisconsin and Massachusetts have shown that no more than 22kg/ha of phosphorus is required each season for established beds with tissue phosphorus in the adequate range of 0.1% phosphorus (DeMoranville et al., 2009). It is common practice for cranberry farmers in North America to pick fertilizers based mainly on their nitrogen requirements, with little consideration of phosphorus content. Many commonly used fertilizers can deliver more than 35kg/ha of phosphorus each season when applied for nitrogen needs. Applying fertilizers in this fashion has the potential to create high phosphorus loading in cranberry soils (DeMoranville et al., 2009).

The high levels of iron and aluminum in acidic cranberry soils leads to extensive binding of phosphorus as iron and aluminum phosphates in the soil (Davenport et al., 1997). It has been shown that phosphorus can be released from these compounds when flooded soils become anaerobic (Shahandeh et al., 1994), likely creating spikes of phosphorus in downstream surface water**.**

In DeMoranville's (2009) study, all cranberry bogs had at least 20kg/ha of phosphorus applied in 2002. At Site 1 in 2002 they found cranberry yield actually increased with reduction in the phosphorus levels applied, and the same thing occurred at Site 2 when phosphorus levels were decreased there in 2006. At Site 3, yield stayed constant with decreased phosphorus application.

DeMoranville also found that water quality improved with reduction in phosphorus application, with the largest improvement occurring at Site 1. After three years of phosphorus reduction at

Site 1, phosphorus levels in flood discharges decreased from 0.377mg/L to 0.097mg/L. When water was held on site for 10-12 days before discharging, it was found that anaerobic conditions developed and, regardless of how much fertilizer was applied, the phosphorus was released from soil. The authors concluded that decreasing fertilizer application to 20kg/ha phosphorus or less does not decrease cranberry yield, and that to minimize output of phosphorus from bogs phosphorus applications should not exceed 22kg/ha, and water should not be held on site for more than 10 days.

The vast majority of phosphorus entering surface water enters during large storm events from lands that combine high erosion and surface water runoff characteristics with high soil phosphorus levels. Most effective regulation and management of phosphorus runoff will focus primarily on these land areas (Carpenter, 1992). For transport management, cover crops, retention ponds, contour tillage, terracing, conservation tillage, buffer strips, and riparian zones can minimize nutrient transport to surface water by erosion and runoff. However, nutrient sources to soil must also be decreased, or nutrients will continue to accumulate in the soil (Carpenter, 1992). Nutrient management practices recommended by the University of Massachusetts Cranberry Station include education by attending workshops, keeping good records and modifying program based on plant responses, managing floods to minimize phosphorus discharge, conducting tissue tests on a regular basis to assess nutrient levels in the plants, and applying nitrogen as ammonia nitrogen (UMASSd, 2010). Cranberry plants have a preference for ammonium nitrogen over nitrate nitrogen, and ammonia nitrogen adsorbs to soil so is less prone to leaching compared to nitrate nitrogen (Colquhoun, 2010).

*5.1.3 Water Management*

*5.1.3.1 Containing Water on Farm*

One of the features of a cranberry bog is its tremendous ability to control water flow on site. Besides rice production, few other types of agriculture have such a high degree of control over the water flow to and from their production acreage. This provides cranberry growers a decisive advantage over other forms of agriculture, in their ability to hold water onsite after critical pesticide applications. For example if a specific pesticide calls for a two week holding period prior to release, a cranberry farmer can adhere to this rule, regardless of the weather (L. Madore, personal communication, December 7, 2015). Nevertheless, it is still important for chemical applicators to do their best to anticipate weather because application close in time to heavy rainfall can increase the quantity of pesticides and fertilizers running off from the cranberry beds and eventually reaching downstream water (MDARD, 2016).

The cranberry beds themselves may be considered to be a temporary storage area for water. A system of ditches and dikes control water movement in and out of the cranberry beds (MDARD, 2016). The perimeter ditches are two feet deep around the beds, and the soil pore space exceeds 50% of the soil volume. Therefore each bed has approximately a foot of water storage, for a total of 67.5 acre feet of water storage in the cranberry beds themselves. This storage volume is critical, as it allows the pesticides to be fully contained, during their entire half-life periods.  After water leaves the beds, it could be stored in a tailwater pond and again recycled, or released into the natural drainage system (B. Brazil, personal communication, February 17, 2016). Prior to applying chemicals, water levels in ditches must be lowered as much as possible to allow absorption of the chemicals to vegetation and sediment in the ditches, thus increasing holding time of the contaminated water (MDARD, 2016).

The authors of Anderson (2006; see summary on pages 31-35 of the present document) concluded that the results from their study provided evidence that pesticides discharged into Cranberry Lake from the cranberry marsh are present in the receiving water at toxic levels. They concluded that discharged water was moving through the lake in approximately 24 hours, and was adversely affecting organisms in its path. They recommended either a) finding pesticides with half-lives shorter than that of tebufenozide (67 days for photodegradation in water) so that it could degrade within the 7-10 day holding period before the water is discharged into the lake, or b) creating a holding area for the water that would give the pesticides enough time to degrade before being released into Cranberry Lake.

In 2008, an article was published (Rountry, 2008;) to evaluate efforts to reduce pesticide contamination in the drainage ditches nearby cranberry bogs in Washington that were the focus of previous studies by Washington State's Department of Ecology (see summary of earlier research on pages 35-39 of the present report). Subsequent to the water sampling in 1996, the Department of Ecology implemented a non-regulatory, multi-goal approach, developing performance measures to achieve their desired environmental, financial, and social improvements. They found that the most effective BMPs for keeping pesticides out of the ditches was to isolate perimeter ditches at the bog. This was done by using exterior treated wood as lining and covering for the perimeter ditches, which blocked entry of pesticides into the ditch. Water samples from these covered ditches were found to have dramatically reduced pesticide concentrations. When possible, irrigation water containing pesticide residues was contained on-site, giving the pesticides adequate time to degrade before releasing the water into the drainage ditches. In some cases carbon filters were installed to treat irrigation water before being released. A 2005 survey showed that cranberry farmers found that their use of BMPs actually improved farm profitability by lowering chemical input costs. Implementation of BMPs enabled all goals set in 1998 to be achieved, including reducing concentration of pesticides in the ditches by 50% in two years. Diazinon and chlorpyriphos concentrations were reduced by 96% in two years.

Water resource protection and enhancement practices recommended by the University of Massachusetts Cranberry Station include ensuring water supply is adequate for production needs, using tailwater recovery and holding ponds, holding harvest water long enough for sediments to settle before water discharge, and reducing water level in ditches before applying chemicals (UMASSe, 2010).

#### *5.1.3.2 Flooding*

Flooding is done on cranberry beds in the fall to harvest berries, in the winter for frost protection, and in the spring for pest control, frost removal from soil, and protection of plants from frost. Flooding cranberry beds when the soil surface layer has frozen in the early winter covers the plants in ice, minimizing damage from cold, windy weather. Waiting for the soil surface layer to freeze before winter flooding reduces potential for water loss via seepage (MDARD, 2016). Research has shown that fall (Averill, 1997) and spring (DeMoranville, 2008) floods on cranberry farms reduces insect and weed populations. The harvest flood water should be held in the cranberry beds for a minimum of one day, and then slowly released from the beds (MDARD, 2016).

90% of cranberry farmers in Wisconsin use a “flow through” system for irrigation and flooding, in which water is pumped from a water source, used directly on cranberry beds, and then discharged back to the lake, potentially carrying with it pesticide and nutrient residues. Some cranberry farmers are now starting to use “tailwater recovery” systems, consisting of a settling pond on site that collects the water to be used for irrigation and flooding. The water is given time to settle, and is then pumped into a reservoir for later use, making it possible to meet water quality and quantity requirements for cranberry farming. Tailwater recovery systems effectively control pollutant discharges, matching the policy of the Wisconsin Cranberry Growers’ Association to implement closed systems on cranberry farms to minimize freshwater use and prevent discharge of pesticides and nutrients into surface water (Hanson, 2007).

*5.1.3.3 Irrigation*

Irrigation management plans begin with the cranberry farmer assessing each component of water use on the farm and identifying potential areas for reducing water use (Colquhoun, 2010). Water management practices for conserving water and protecting the environment include controlled drainage and subsurface drainage systems. Controlled drainage using existing drainage pipes can decrease the levels of pesticides and nutrients lost to the environment while maintaining appropriate water table levels, and sub-irrigation can potentially meet cranberry irrigation requirements while minimizing costs and environmental impacts. (Elmi, 2010).

Sprinkler irrigation systems protect cranberry plants from frost damage in the spring and fall, supply water to the plants during their growing season, and apply chemicals. For the irrigation system to work most effectively it is essential to ensure there is a uniform application rate of

0.1 to 0.15 inches per hour. If this isn't the case then some cranberry plants will receive too much or too little water. Uniformity of the irrigation systems should be tested on a regular basis because it may be impacted by a whole host of factors including sprinkler rotation speed, different sprinkler elevations, wear, and wind. Irrigation rates should incorporate rainfall amounts, so irrigation water applied will be decreased near rainfall events (MDARD, 2016).

*5.1.4 Landscape Management*

Landscape management strategies that can reduce groundwater and surface water pesticide and nutrient loads include buffer strips, constructed wetlands, and an erosion control plan.

*5.1.4.1 Constructed Wetlands*

Wetlands are areas that are covered with a flood of ground or surface water that is sufficient for supporting widespread vegetation that is typically adapted for saturated soil conditions (U.S. EPA, 2005). Constructed wetlands are wetlands that are human made for restoring habitat or for reducing runoff, and have been found to be an effective method for reducing pesticide loads to surface water (Watson, 2013). Studies of constructed wetlands have found them to be an effective practice for filtering water coming from agricultural land, although experience with them on cranberry farms has been limited to date (UMASSe, 2010). Constructing wetlands is an effective option for containing nitrogen and phosphate on cranberry farms because wetlands trap and remove these nutrients via sediment absorption, uptake by helophyte vegetation, and decomposition by microorganisms (Raisin, 1995; Mitsch, 2000; Kang, 2002; Jordan, 2003). The use of constructed wetlands has many benefits including improving downstream water quality, constricting flooding, providing stream shading, and providing habitat for a wide range of species (Lowrance, 1983; Peterjohn, 1984).

The ability of wetlands to filter out reactive nitrogen depends on a number of factors, including size of the wetlands, hydrologic characteristics, and seasonal weather conditions (Ribaudo, 2011). In rivers, lakes, and wetlands the nutrient $NO^3$ is converted to $N^2$ (process of denitrification), reducing flow of nitrogen downstream (Jansson et al., 1994). Restoring wetlands and floodplains is one way to increase denitrification, and thereby decrease downstream pollution. Restoration is a highly cost-effective method for reducing nonpoint nitrogen pollution (Gren, 1995). Figure 5.1 presents a visualization of the relationship between uplands, riparian zones, wetlands, and downstream surface water.

#### *5.1.4.2 Vegetated Treatment*

Buffer strips are strips of vegetation located by a body of water that can reduce runoff into that water (Watson, 2013). Buffer strips reduce erosion, contain pollutants, and provide habitat for various species (Eilers, 2010). These strips of vegetation remove pesticides, nutrients, and sediment from runoff water by filtration, adsorption, absorption, deposition, infiltration, decomposition, and volatilization. Buffer strips protect downstream water from nutrient and pesticide contamination primarily by filtering the water that passes through or over the buffer strips (U.S. EPA, 2005).

Nitrogen loses to surface water bodies may be reduced by implementing land management practices including use of filter strips or riparian buffers. Buffer strips have the ability to extract nitrogen from both ground and surface water (Mayer, 2005). Mayer et al. (2005) estimated that buffer strips can remove 74 percent of nitrogen that passes through the root zone of the buffer strips. In Ribaudo (2011) it was found that less than 10% of crops in the United States that did

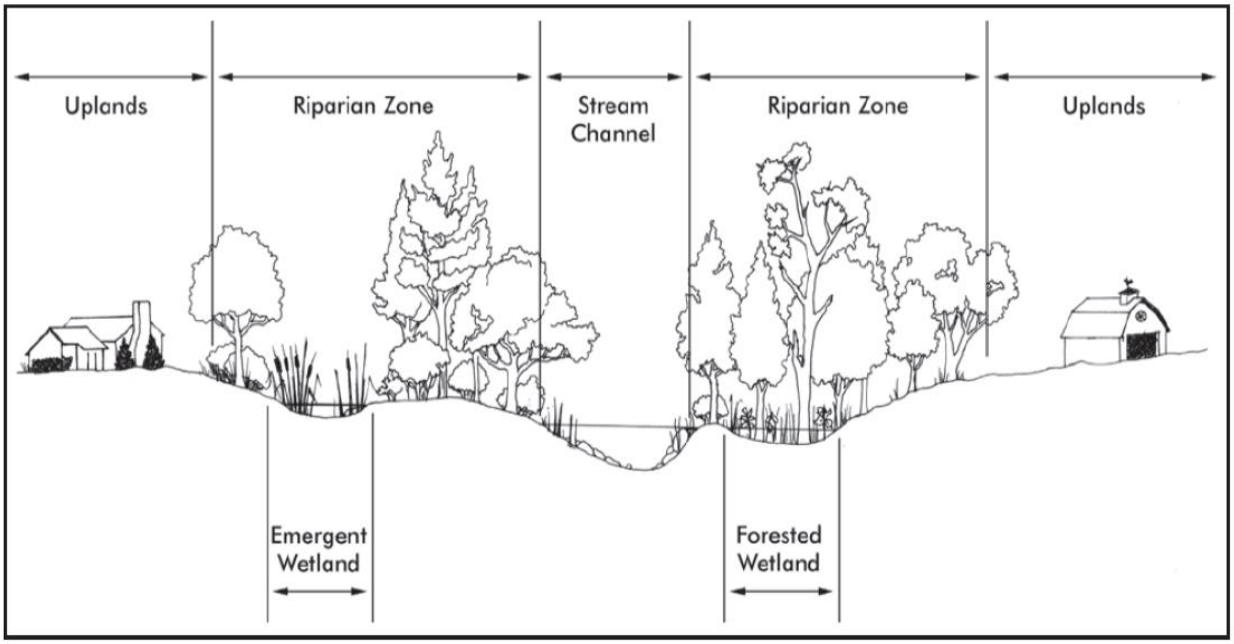


Figure 5.1 Relationship between uplands, riparian zones, wetlands, and downstream surface water (U.S. EPA, 2005)

not meet rate, timing, or method criteria were using filter strips that could have mitigated nitrogen losses to downstream surface water. How much of an impact buffer strips have depends largely on the density of vegetation, size of buffer, and hydrologic conditions (Dosskey, 2005; Dosskey, 2007). Buffer strips are often used alongside of other preventative measures for protecting downstream environments, including reduction in chemical application on the farm, collection of runoff, or reduction in soil erosion (U.S. EPA, 2005). To make implementation of buffer strips more cost effective, cranberry farmers can use buffer strips containing plant species that can be monetized (Eilers, 2010).

### *5.1.4.3 Erosion Control*

Soil can be a carrier of nutrients and pesticides, something of particular concern on cranberry farms since these farms are typically located nearby to sensitive water bodies and wetlands (UMASSb, 2010). Therefore, implementing an erosion control plan is another strategy for mitigating risk of cranberry farms to downstream environments. Ditch banks erode with a mix of high velocity water and saturated unstable soils. Soils can be stabilized by utilizing grass or other vegetation on ditch banks (MDARD, 2016). Establishing grass or other vegetation on dikes will stabilize the soil and reduce waterlogging Cranberry vines or other vegetation on ditch sidewalls increases soil stability. If bank and ditch erosion is not adequately addressed it will result in the loss of ditch and canal functionality (UMASSb, 2010). Using grass or sand on cranberry berms is also an effective measure for reducing wind damage. Installation of rock cover, geofabric or geogrid material, or riprap can also mitigate erosion (MDARD, 2016). Compared to many other crops, farming cranberries typically does not cause significant amounts of off-site erosion, and a number of practices recommended for erosion reduction are normal practices for cranberry farming. For example, cranberry bogs are located on nearly level or slightly depressed landscapes, water flow through bogs is strictly controlled, and sediment ponds minimize sediment discharge to the downstream environment. In cranberry farming, sediment eroded by water and wind is primarily a result of infrequent events such as land clearing, new bog construction, and ditch cleaning and maintenance (UMASSb, 2010). Practices recommended by the University of Massachusetts Cranberry Station for erosion and sediment control include creating an erosion control plan before starting construction, protecting disturbed areas from runoff and keep runoff velocity as low as possible, inspect and maintain sediment and erosion control structures on a regular basis, and check areas that have embankment protection installed and evaluate for accelerated weathering or displacement (UMASSb, 2010). Table 5.2 summarizes the BMPs discussed in this chapter, providing the fundamental BMPs for cranberry farming.

### 5.2 Evaluation of BMPs and Conclusions for Cranberry Farming in Newfoundland

Out of the six cranberry farms monitored in the present study, the most detailed information on BMPs is available for the government operated DB farm. DB will be evaluated here for the effectiveness of existing BMPs for containing pesticides and nutrients within the farm boundaries, and alternative BMPs will be recommended where appropriate.

At DB, diazinon was detected in 12 of 19 samples on-farm, compared to only 1 of 19 samples downstream. Carbaryl and daconil were each detected a single time on the farm, each at the relatively high levels of 340  ug/L and 5.4 ug/L, respectively, but neither were detected downstream in any samples. The finding that carbaryl and daconil were only detected on-farm, and that diazinon was detected on-farm 12 times compared to only once downstream, suggests that existing BMPs at DB have been effective in containing pesticides on the farm. However, the detection of diazinon downstream at 0.47 ug/L on July 19, 2011 is cause for further investigation of alternative BMPs for containing pesticides on the farm at DB, as this detection is approaching the 0.56 ug/L level found by Vryzas (2011) to be toxic to aquatic invertebrates even though our sample was taken close to one month after June 24 application. The presence of a-BHC, aroclor 1254, o,p-DDT, and p,p-DDT in the environment near DB was determined to be the result of historic use, as these compounds were not applied on the farm in recent years.

Table 5.2 Fundamental BMPs for cranberry farming

| **Fundamental BMPs for Cranberry Farming** |
|---|
| Ensure relevant workshops and educational materials are available to pesticide and fertilizer applicators |
| Utilize sweep nets and pheromone traps to monitor pests and estimate action thresholds |
| Use non-pesticide pest protection techniques when possible such as flooding, sanding, baiting, and nematodes |
| Apply pesticides only after reaching threshold for economic damage |
| When using pesticides, use according to label instructions only |
| When selecting pesticides, take into account toxicity, risk to non-target organisms, risk to downstream environments, half-life, and persistence |
| Time pesticide and fertilizer application to avoid floods and precipitation events to the extent possible |
| Time fertilizer application to ensure nutrients are available when plants are able to utilize them |
| Ensure no excess pesticides or fertilizers are applied, and that they are applied to the entire crop uniformly |
| Perform soil testing for organic matter content and pH every 2-4 years and tissue testing for mineral content every 1-4 years |
| Monitor cranberry plant responses to fertilizers and adjust application program accordingly |
| Use tailwater ponds to store water after it leaves cranberry beds. Contain water for 7-10 days to give adequate time for pesticides to break down before being released to environment |
| Use subirrigation or drip irrigation to minimize runoff |
| Utilize landscape management options including constructed wetlands, buffer strips, and riparian buffers |
| Implement erosion control measures such as use of grass or sand on the berms to reduce wind damage |

*5.2.1 Existing BMPs at DB Farm*

An insect monitoring program was implemented by the Agrifoods Development Branch's Pest Management Specialist for the years 2006-2008, involving weekly sweep netting and pheromone traps. This program monitored the Blackheaded Fireworm, Cranberry Fruitworm, Cranberry Girdler, and Sparganothis Fruitworm at DB and three additional commercial cranberry farms throughout the province. Only when all other pest control options were ruled out were pesticides considered for use. When pesticides were used at DB, they were used according to the label instructions only. Similarly, fungicide and herbicide needs were evaluated with IPM techniques, alternatives were considered when threshold levels of pests were exceeded, and appropriate actions were taken. Infestation of cutworms was the primary issue at DB and required pesticide application. The color of leaves and shapes of plants were monitored for pest damage. One week pesticide applicators courses were offered each winter at various locations throughout Newfoundland, including training on Integrated Pest Management. Both individuals involved in chemical application at DB completed pesticide applicators courses and were licensed to apply products. In 2011, chemicals were applied from June 24$^{th}$ to August 23$^{rd}$, and in 2012 chemicals were applied from July 4$^{th}$ to August 10$^{th}$ (see Chapter 3 for detailed application schedule). The 12-10-13 fertilizer ratio was determined by reviewing soil test reports for pH levels and related factors. Since DB was a well-established farm by the start of the present study in 2011, less N was applied compared to what was required when the farm was established in 2002. Cranberry growth was monitored and in the event of stunted grown additional fertilizer would have been added. However, cranberries always grew well at DB, so additional fertilizer was not required regularly. Since cranberries always grew well at DB it is likely the soil was tested on an infrequent basis.

Erosion was a problem at DB because the sphagnum bog would dry out and be impacted by wind action. Despite erosion being a concern, no erosion mitigation measures were implemented at DB (B. Brazil, personal communication, February 17, 2016).

The yearly harvests at DB were done in October, and the farms were flooded before harvest in mid-October and after harvest for frost in November. A gravity feed system was used, flooding the highest beds first and then releasing water to subsequent beds. There was no flooding over banks during the flooding process. Application of fertilizer was avoided for approximately 1 month prior to harvest, meaning there was no fertilizer application done in close time proximity to flooding. Application of both pesticides and nutrients at DB was timed to avoid large precipitation events as much as possible. There was a water reservoir at a higher elevation of the farm above the beds and a sediment pond down below the beds that water would naturally drain into. Water was not held on the farm manually, but the sediment ponds would contain water and allow the water to slowly enter the downstream environment over time. Around each of the beds there were berms of peat moss that assisted in containing water on the farm. Sprinkler system irrigation was used at DB, in contrast to subirrigation which is used at most sites throughout Newfoundland. The timing of irrigation use was highly weather dependent. Weather and plant growth were both monitored and irrigation was used appropriately based on those factors (B. Brazil, personal communication, February 17, 2016).

*5.2.2 Temporal comparison of application schedule to daily and monthly precipitation data*

This section will compare the pesticide and fertilizer application dates at DB cranberry farm with precipitation data from Environment Canada to determine whether or not chemical application timing could be altered to reduce pesticide and nutrient runoff caused by precipitation events. Chemicals were applied at DB between June 24$^{th}$ to August 23$^{rd}$ 2011, and July 4$^{th}$ to August 10$^{th}$ 2012. The 30-year (1981 to 2010) mean monthly precipitation at Musgrave Harbour weather station, approximately 25 km west of Deadman's Bay, for June, July, and August are 74.6mm, 81.6mm, and 92.6mm respectively. This data shows that June and July near DB typically has less precipitation compared to the overall 86.9mm average monthly rainfall, while August near DB typically has more precipitation compared to the average month. Therefore, special care should be taken to limit pesticide and nutrient application in August because chemicals may be at higher risk of entering downstream environments during this month of higher than average precipitation. Environment Canada stopped collecting data at the Musgrave Harbour weather station in 2009, so it was not possible to compare the present study's application schedule for 2011-2012 with individual precipitation events in Musgrave Harbour during the same time period. The only daily precipitation data available within 50km of Deadman's Bay for the time period of the present study was from Environment Canada's Indian Bay B.B. weather station, located approximately 40km south of Deadman's Bay. Daily data at the Indian Bay B.B. station was available for June 2011 but was unavailable for the remainder of our water sampling period. In June 2011, 30L of Bravo 500 (containing 500g/L chlorothalonil) and 14L of Diazinon 500 EC (containing 500g/L diazinon) was applied on June 24$^{th}$, and 80kg of Devrinol 10-G (containing 10% (by weight) napropamide) was applied on June 29$^{th}$. Timing of these chemicals were well timed to avoid the major precipitation event on June 20$^{th}$-21$^{st}$ involving 62.4mm of rain, with 0.0mm of precipitation falling from June 23$^{rd}$-30$^{th}$. Therefore, based on the limited daily precipitation data available for the time period of the present study, it appears that chemical application timing at DB could not have been improved to better avoid precipitation events, at least during June 2011.

### *5.2.3 Temporal comparison of application schedule to downstream water data*

Throughout the June to November water sampling periods in 2011 and 2012 there were no parameters at DB that had a significant difference downstream compared to upstream. There was an increase of the on-farm site organophosphate mean of 0.021 mg/L compared to both the upstream site mean of 0.0056 mg/L (P=<0.0001) and the downstream site mean of 0.0064 mg/L (P<0.0001). The upstream site had a significantly higher nitrogen (ammonia nitrogen) mean of 0.113 mg/L compared to the on-farm site mean of 0.074 mg/L (P=0.0238).

Diazinon was applied June 24$^{th}$ 2011 (14L) and August 1 2012 (30L). At the first water testing measurement of 2011 on July 5$^{th}$ there was no diazinon detected downstream. At the second testing on July 19$^{th}$ diazinon was detected downstream at 0.47ug/L, although no diazinon had been applied in the period between the first and second water measurement. There were no detections of diazinon downstream for the remainder of the year. In 2012, although on-farm diazinon measurements increased after the August 1$^{st}$ application for both August water samples, 0.23ug/L on August 9$^{th}$ and 0.27ug/L on August 23$^{rd}$, there was no diazinon detected downstream during the entire June to November sampling period. For carbaryl, there was only a single detection at DB over all sites during the entire sampling period. On August 18$^{th}$, 2011, 340 ug/L of carbaryl was detected at the DB on-farm site, but there were no detected levels at the upstream and downstream sites. The previous day, August 17$^{th}$, was when the only application of carbaryl for the year at DB took place, applying 24L of Sevin XLR Plus, containing 466 g/L carbaryl. At the September 1$^{st}$ sampling date, the first samples taken at DB subsequent to the carbaryl detection on August 18$^{th}$, carbaryl levels at upstream, on-farm, and downstream sites were all below detection limits.

Nutrients were applied July 21$^{st}$, July 26$^{th}$, August 10$^{th}$, and August 23$^{rd}$ in 2011, and July 12$^{th}$, July 31$^{st}$, and August 10$^{th}$ in 2012. For both years there was no elevation downstream of nitrogen, phosphate, BOD nitrate, or nitrite after fertilizer application. Based on the results of water sampling data that showed there were no significant differences downstream compared to upstream in levels of any tested pesticide or nutrient, it appears that the best management practices implemented at DB were effective in mitigating risk to downstream surface water from pesticides and nutrients that were applied at DB cranberry farm.

*5.2.4 Conclusions and Recommendations for improving BMPs at DB*

Since there was no significant difference at DB in downstream surface water compared to upstream surface water for any parameter evaluated in the present study, the existing BMPs such as the IPM program, providing education for pesticide applicators, and avoiding application of pesticides and nutrients immediately prior to major precipitation events appear to be effective in minimizing risk to the downstream environment. However, the single detection of diazinon downstream at 0.47 ug/L on July 19, 2011 is concerning, as this detection is approaching the 0.56 ug/L level found by Vryzas (2011) to be toxic to aquatic invertebrates. The finding of diazinon at this level in the downstream environment close to one month after the June 24 application of diazinon at DB provides evidence that diazinon is persisting in the environment for an extended period of time. One area that may be able to be improved at DB to further mitigate losses of chemicals to the environment is a transition away from irrigation using heads at the surface and towards sub-irrigation and drip irrigation. Sub-irrigation is used at most cranberry farms in Newfoundland and Labrador (B. Brazil, personal communication, February 17, 2016), and transitioning to this irrigation option at farms that still use surface sprinkler systems may be an effective option for minimizing water use and risk to downstream environments. Further research is required on the feasibility of various irrigation systems such as drip irrigation in Newfoundland and Labrador and the related environmental and economic costs. In addition to altering irrigation practices, there is room for improvement at DB in soil nutrient testing and erosion control measures. More care should be taken in adhering to the recommended yearly soil testing, and testing results should be considered when determining chemical application schedules. Implementing erosion control measures such as use of grass or sand on the berms to reduce wind damage is an additional practice that should be implemented. Table 5.3 summarizes key BMPs used at DB for minimizing downstream environmental impacts, as well as additional measures that could be implemented to further mitigate degradation of downstream surface water.  A potential area of focus for future research would be a more in depth analysis of downstream soil contamination, since the present study included extensive surface water sampling, but an analysis of only 9 total soil samples over all 6 farms. Additionally, potential contamination to downstream groundwater should be evaluated in future research.

Table 5.3 Summary of key BMPs for reducing contamination of downstream surface water at DB, and recommendations of additional measures for further mitigating impacts.

| **Key BMPs at DB** |
|---|
| Weekly use of sweep netting and pheromone traps for pest identification |
| Educating farmers with one week pesticide applicator courses |
| Optimizing pesticide and nutrient application timing, avoiding application for 1 month prior to flooding, and avoiding application before large precipitation events |
| A sediment pond was located downstream of the cranberry beds to contain pesticides and fertilizers on the farm |
| Berms of peat moss surrounded cranberry beds, assisting in containing chemicals on the farm |
| **BMPs for Alteration or Implementation at DB** |
| Implement erosion control plan, using grass or sand on berms to reduce wind action |
| Ensure strict adherence to recommended yearly soil testing, and consider results when planning nutrient application schedule |
| Consider switching from surface sprinkler system to subirrigation or drip irrigation |

*5.2.5 BMPs comparisons between DB and other Newfoundland and Labrador cranberry farms*

Compared to the Branch's operation of DB farm during 2011 and 2012, much less information is available on the BMPs used at the five privately owned cranberry farms evaluated in the present study. For diazinon levels downstream, DB's 0.028ug/L average and 0.47ug/L maximum is higher than all farms except for TN. At farm's SC, BH, and BF there was not a single detection of diazinon downstream in 2011 or 2012, and at GFW there was a 0.019ug/L average and 0.126ug/L maximum. Conversely, TN had higher levels of diazinon compared to DB, with a

0.275ug/L average and 2.31ug/L maximum. Compared to other downstream sites, DB downstream water had average or below average levels of organophosphate, carbonaceous BOD, and nitrate-nitrogen + nitrite, but above average levels of nitrogen (ammonia nitrogen). For these four nutrient related parameters, BF was most effective and BH was least effective in mitigating losses to downstream surface water.

Over all parameters, BF was most effective at containing pesticides and nutrients on the farm and minimizing environmental damage downstream. Future research should investigate implemented BMPs at BF in more detail and test these BMPs at other farms throughout the province to ensure a sustainable cranberry industry in the province of Newfoundland. Out of the six farms, precipitation was by far the highest at SC during the June to August pesticide and nutrient application period, receiving a total of 352.9mm during these months on average from 1981 to 2010, compared to 248.8mm at DB during the same time period. Given such a high level of precipitation at SC it should be highlighted that the BMPs were effective at this site, with no downstream detections of diazinon.

Cranberry farms throughout Newfoundland and Labrador should implement the fundamental BMPs for cranberry farming identified in Table 5.2. Special attention should be given throughout the province to the recommended BMPs implementations for DB (shown in Table 5.3), including erosion control plans, appropriate soil testing, and a shift from surface sprinkler systems to subirrigation or drip irrigation systems. Since in the present study diazinon was by far the most frequently detected pesticide in downstream surface water throughout the province, it should be re-evaluated whether or not diazinon is the optimal pesticide to be using on cranberry farms in the province, or if there is a preferable pesticide with a shorter half-life and reduced toxicity to aquatic life. The Black-headed Fireworm and Cranberry Fruitworm appear to be the insects of greatest concern to the cranberry industry in Newfoundland, so IPM strategies should incorporate monitoring and preventative measures for these insects. A survey should be conducted, asking cranberry farmers to indicate whether or not they are taking advantage of educational materials and workshops relating to environmental protection, if they would attend additional workshops if offered, and to what extent they incorporate environmental factors into their decision-making.

**5.3 Summary**

Stakeholders in Newfoundland and Labrador's cranberry industry can minimize environmental impacts of cranberry farming by implementing appropriate pest management, nutrient management, water management, and landscape management BMP. In Chapter Five, 15 key BMPs were introduced for mitigating the environmental impacts of cranberry farming in the province. An in depth analysis of practices at DB cranberry farm found that the vast majority of the key BMPs were implemented at the farm, but that there was a need for an erosion control plan, appropriate soil testing, and a shift to subirrigation or drip irrigation systems. Implementing the recommended BMPs at sites throughout Newfoundland and Labrador will ensure the provincial cranberry industry minimizes economic and environmental operational costs.

# Chapter 6: Conclusions and Recommendations

## 6.1 Conclusions

The commercial cranberry industry has a significant economic impact in North America (NASS, 2015; Statistics Canada, 2015), with an estimated value of $254 million in 2014 the United States (NASS, 2015), and growing global markets (Eichner et al., 2012). Cranberry production requires the use of large amounts of water, and application of fertilizers and pesticides (Hinterleitner, 2006). Studies in the north-eastern United States have found that pesticides and fertilizers that were applied on cranberry farms were present in downstream surface water, including phosphorus (Eichner et al., 2012), diazinon (Davis, 1997; Rountry, 2008), carbaryl (Davis, 1997; Rountry, 2008), and numerous additional contaminants. With limited research on environmental effects of cranberry farming in Canada, and a growing industry in Newfoundland, the present study will play a central role in the future of the industry in the province by identifying potential environmental impacts and developing best management practices.

The two primary objectives of the present study were to:

1) Identify the potential environmental impacts associated with cranberry development on downstream surface water in Newfoundland and Labrador, Canada
2) Develop best management practices to mitigate potential impacts and support environmental sustainability.

The environmental effects of cranberry farming were investigated at 6 cranberry farms throughout Newfoundland. Weekly to bi-weekly water sampling was conducted on each farm at upstream, on-farm, and downstream sites from June to November of 2011 and 2012 to evaluate differences between sites. Water quality testing assessed levels of 80 parameters, including 69 pesticides. Nine total soil samples were collected during the sampling period, testing for 122 pesticides, ammonia-N, moisture, nitrate + nitrite, and phosphates. Probability, linear and exponential regression, and correlational analyses were carried out to assess data. ANOVA and Tukey tests were run to determine significance between sites, and descriptive statistics were evaluated.

Grouping surface water data for a parameter over all farms into 3 groups, upstream, on-farm, and downstream, it was found that there was a significant increase on-farm compared to both upstream and downstream for turbidity, nitrogen (ammonia nitrogen), organophosphate, nitrate-nitrogen + nitrite-nitrogen, nitrate-nitrogen, and nitrite-nitrogen, a significant decrease in pH downstream compared to both upstream and on-farm levels for pH, and no difference between sites for temperature, TDS, conductivity, diazinon, and carbonaceous BOD. The on-farm nitrogen (ammonia nitrogen) mean was 0.215 mg/L, compared to 0.117 mg/L upstream and 0.109 mg/L downstream. The on-farm organophosphate mean was 0.026 mg/L, compared to 0.008 mg/L upstream and 0.012 mg/L downstream. ANOVA and Tukey tests were also conducted for each farm individually to identify significant differences in surface water quality between each set of upsteam, on-farm, and downstream sites. Looking at each farm individually, there were frequent significant differences on-farm compared to both upstream and downstream, but the only significant differences between upstream and downstream sites were a significantly lower pH at GFW and BF downstream compared to upstream, and significantly decreased levels of conductivity, turbidity, and TDS downstream compared to upstream at BH. At BH, conductivity was 0.060mS/cm upstream and 0.092mS/cm downstream, turbidity was 1.42 NTU upstream and 2.51 NTU downstream, and TDS was 29.9ppm upstream and 46.6ppm downstream. None of the nine total soil samples taken over the 6 farms, all taken from downstream locations, contained detectable levels of pesticides. The lack of significant differences in water samples between downstream and upstream sites for pesticides, nitrogen (ammonia nitrogen), organophosphate, and nitrate-nitrogen + nitrite-nitrogen, as well as no detected pesticides in soil samples, suggests current on-farm practices have been effective in containing potential contaminates on the farms and mitigating risk to downstream surface water and soil in Newfoundland and Labrador.

Stakeholders in Newfoundland and Labrador's cranberry industry can further reduce environmental impacts of cranberry farming by implementing appropriate pest management, nutrient management, water management, and landscape management BMP. Fifteen key BMPs were introduced for mitigating the environmental impacts of cranberry farming in the province. The 15 key BMPs for cranberry farming in Newfoundland and Labrador identified in Chapter Five were:

1) Ensure relevant workshops and educational materials are available to pesticide and fertilizer applicators
2) Utilize sweep nets and pheromone traps to monitor pests and estimate action thresholds
3) Use non-pesticide pest protection techniques when possible such as flooding, sanding, baiting, and nematodes
4) Apply pesticides only after reaching threshold for economic damage
5) When using pesticides, use according to label instructions only

6) When selecting pesticides, take into account toxicity, risk to non-target organisms, risk to downstream environments, half-life, and persistence
7) Time pesticide and fertilizer application to avoid floods and precipitation events to the extent possible
8) Time fertilizer application to ensure nutrients are available when plants are able to utilize them
9) Ensure no excess pesticides or fertilizers are applied, and that they are applied to the entire crop uniformly
10) Perform soil testing for organic matter content and pH every 2-4 years and tissue testing for mineral content every 1-4 years
11) Monitor cranberry plant responses to fertilizers and adjust application program accordingly
12) Use tailwater ponds to store water after it leaves cranberry beds. Contain water for 7-10 days to give adequate time for pesticides to break down before being released to environment
13) Use sub-irrigation or drip irrigation to minimize runoff
14) Utilize landscape management options including constructed wetlands, buffer strips, and riparian buffers
15) Implement erosion control measures such as use of grass or sand on the berms to reduce wind damage

An in depth analysis of practices at DB cranberry farm found that the majority of the 15 key

BMPs were implemented at the farm. Recommendations given for DB farm included implementing an erosion control plan, ensuring appropriate soil testing was done every 2-4 years, and shifting to sub-irrigation or drip irrigation systems. It is recommended that the 15 identified BMPs for cranberry farming in Newfoundland be implemented throughout the province to ensure the provincial cranberry industry minimizes economic and environmental operational costs.

## 6.2 Contributions and Recommendations

The present study was the first in depth study of environmental impacts of cranberry farming in Newfoundland and Labrador, and to our knowledge the first study of its kind in Canada. The vast majority of previous studies have been conducted in the Northeastern United States, so this study provides rare insight into environmental impacts of the cranberry industry outside that region, where the industry is less established and there are different climatic conditions. Considering the size of economic impacts of the cranberry industry on the Canadian economy, with $89.6 million in sales in Canada in 2014 (Statistics Canada, 2015), the present study will aid policymakers in Newfoundland and Labrador and throughout Canada in their decision making to ensure the growing industry can maximize profits by effectively managing pest damage, while at the same time avoiding degradation of the environment. The present study provides evidence that the effects of the cranberry industry to downstream surface water in Newfoundland and Labrador is relatively minor, with the vast majority of parameters not having a significant difference downstream compared to upstream at any farm. By establishing the BMPs recommended in the present thesis report, these downstream impacts can be further mitigated, ensuring a sustainable cranberry industry in Newfoundland and Labrador into the future.

Since in the present study diazinon was by far the most frequently detected pesticide in downstream surface water, it should be re-evaluated whether or not diazinon is the optimal pesticide to be using on cranberry farms in the province, or if there is a preferable pesticide with a shorter half-life and reduced toxicity to aquatic life. The present study identified BF as the farm most effectively mitigating downstream environmental impacts. Future research could involve doing a test run of BMPs from BF at poorer performing farms while monitoring downstream surface water at these farms to compare parameter levels with new BMPs to levels presented in the present study under existing BMPs strategies. Studies of longer duration with more frequent monitoring are desired to provide a more in depth analysis of how contaminants from cranberry operations are breaking down in the environment and their risk to aquatic life. Since it was not possible to obtain chemical application schedules for some farms included in the present study, selection of farms for future studies should be based partially on the ability to obtain application schedules at those farms. This would make it possible to plan the sampling schedule around the application schedule in all cases, complete a correlational analysis between application date and downstream parameter levels at all farms, and get an improved picture of how quickly chemicals are degrading in the environment. The scope of the present study focused on the effects of cranberry farming on downstream surface water and soil quality, so a potential area of focus for future research would be an in depth analysis of the impact of cranberry farming on groundwater quality. Additionally, further research is required on the feasibility of various irrigation systems such as drip irrigation on cranberry farms in Newfoundland and Labrador and the related environmental and economic costs.

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# Appendix

## **A.1.** Example of Maxxam Analytics Reporting Sheets

### Water Quality Reports

NL Dept of Natural Resources
Client Project #:
Site Location:TN,FP
Your P.O. #: PO 211028119
Sampler Initials:

Maxxam Job #: B1D4009
Report Date: 2011/09/21

**RESULTS OF ANALYSES OF WATER**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maxxam ID | | | KS9887 | | KS9889 | | |
| Sampling Date | | | 8/30/2011 | | 8/31/2011 | | |
| COC Number | | | N/A | | N/A | | |
| | | | | | | | |
| | **Units** | **Criteria A** | **TN SITE#3** | **RDL** | **FP SITE#2** | **RDL** | **QC Batch** |
| **Calculated Parameters** | | | | | | | |
| Nitrate-Nitrogen | mg/L | **10** | ND | 0.05 | 0.08 | 0.05 | 2601772 |
| **Inorganics** | | | | | | | |
| Carbonaceous BOD | mg/L | - | ND | 5 | ND | 3 | 2600683 |
| Nitrate-Nitrogen + Nitrite-Nitrogen | mg/L | - | ND | 0.05 | 0.08 | 0.05 | 2609078 |
| Nitrite-Nitrogen | mg/L | **1** | ND | 0.01 | ND | 0.01 | 2609081 |
| Nitrogen (Ammonia Nitrogen) | mg/L | - | ND | 0.05 | 0.06 | 0.05 | 2610762 |
| Orthophosphate (P) | mg/L | - | ND | 0.01 | 0.11 | 0.01 | 2609077 |
| **Subcontracted Analysis** | | | | | | | |
| Subcontract Parameter | N/A | - | ATTACHED | N/A | ATTACHED | N/A | 2602682 |

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
EDL = Estimated Detection Limit
QC Batch = Quality Control Batch
Criteria A: Guideline - Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ), Health Canada, Dec. 2010.

A= Maximum Acceptable Concentration (MAC) - established for substances that are known or suspected to cause adverse effects on health. When exceeded, minimum action required is immediate resampling. If continuous exceedance occurs, the local authority responsible for drinking water supplies should be consulted concerning appropriate corrective action.

C= Aesthetic Objectives (AO) - apply to characteristics of drinking water that can affect its acceptance by consumers or interfere with practices for supplying good quality water. If a concentration is well above an AO, then there is a possibility of a health hazard.

Note 1 Turbidity guideline value of 0.3 NTU based on conventional treatment system. For slow sand or diatomaceous earth filtration 1.0 NTU and for membrane filtration 0.1 NTU.
Note 2 Aluminium guideline value of 0.1 mg/L is for treatment plants using aluminium-based coagulants, 0.2mg/L applies to other types of treatment systems.

NL Dept of Natural Resources
Maxxam Job #: B1D4009
Report Date: 2011/09/21

Client Project #:
Site Location: TN/FP
Your P.O. #: PO 211028119
Sampler Initials:

**ORGANOPHOSPHORUS PESTICIDES BY GC-MS (WATER)**

| Maxxam ID | | | KS9887 | KS9889 | | |
|---|---|---|---|---|---|---|
| Sampling Date | | | 8/30/2011 | 8/31/2011 | | |
| COC Number | | | N/A | N/A | | |
| | | | | | | |
| | **Units** | **Criteria A** | **TN SITE#3** | **FP SITE#2** | **RDL** | **QC Batch** |
| **Pesticides & Herbicides** | | | | | | |
| Demeton-S | ug/L | **-** | ND | ND | 2 | 2605823 |
| Dichlorvos | ug/L | **-** | ND | ND | 2 | 2605823 |
| Dimethoate | ug/L | **20** | ND | ND | 2 | 2605823 |
| Fenchlorophos (Ronnel) | ug/L | **-** | ND | ND | 2 | 2605823 |
| Fonofos | ug/L | **-** | ND | ND | 2 | 2605823 |
| Metolachlor | ug/L | **50** | ND | ND | 5 | 2605823 |
| Mevinphos | ug/L | **-** | ND | ND | 2 | 2605823 |
| Phosmet | ug/L | **-** | ND | ND | 2 | 2605823 |
| Triallate | ug/L | **-** | ND | ND | 5 | 2605823 |
| Trifluralin | ug/L | **45** | ND | ND | 5 | 2605823 |
| Atrazine | ug/L | **-** | ND | ND | 1 | 2605823 |
| Diazinon | ug/L | **20** | 3 | ND | 2 | 2605823 |
| Malathion | ug/L | **190** | ND | ND | 2 | 2605823 |
| Parathion Ethyl | ug/L | **50** | ND | ND | 2 | 2605823 |
| Parathion Methyl | ug/L | **-** | ND | ND | 2 | 2605823 |
| Simazine | ug/L | **10** | ND | ND | 2 | 2605823 |
| Aldicarb | ug/L | **9** | ND | ND | 5 | 2605823 |
| Bendiocarb | ug/L | **40** | ND | ND | 2 | 2605823 |
| Carbaryl | ug/L | **90** | ND | ND | 5 | 2605823 |
| Carbofuran | ug/L | **90** | ND | ND | 5 | 2605823 |
| Cyanazine (Bladex) | ug/L | **10** | ND | ND | 5 | 2605823 |
| Prometryne | ug/L | **-** | ND | ND | 1 | 2605823 |
| Chlorpyrifos (Dursban) | ug/L | **90** | ND | ND | 2 | 2605823 |
| Terbufos | ug/L | **1** | ND | ND | 1 | 2605823 |
| Phorate | ug/L | **2** | ND | ND | 1 | 2605823 |
| Guthion (Azinphos-methyl) | ug/L | **20** | ND | ND | 1 | 2605823 |
| Ethion | ug/L | **-** | ND | ND | 1 | 2605823 |
| Fenthion | ug/L | **-** | ND | ND | 1 | 2605823 |
| **Surrogate Recovery (%)** | | | | | | |
| 2-Fluorobiphenyl | % | - | 72 | 66 | | 2605823 |
| D14-Terphenyl (FS) | % | - | 84 | 85 | | 2605823 |
| D5-Nitrobenzene | % | - | 76 | 68 | | 2605823 |

ND = Not detected

N/A = Not Applicable
RDL = Reportable Detection Limit
EDL = Estimated Detection Limit
QC Batch = Quality Control Batch
Criteria A: Guideline - Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ), Health Canada, Dec. 2010.

A= Maximum Acceptable Concentration (MAC) - established for substances that are known or suspected to cause adverse effects on health. When exceeded, minimum action required is immediate resampling. If continuous exceedance occurs, the local authority responsible for drinking water supplies should be consulted concerning appropriate corrective action.

C= Aesthetic Objectives (AO) - apply to characteristics of drinking water that can affect its acceptance by consumers or interfere with practices for supplying good quality water. If a concentration is well above an AO, then there is a possibility of a health hazard.

Note 1 Turbidity guideline value of 0.3 NTU based on conventional treatment system. For slow sand or diatomaceous earth filtration 1.0 NTU and for membrane filtration 0.1 NTU.
Note 2 Aluminium guideline value of 0.1 mg/L is for treatment plants using aluminium-based coagulants, 0.2mg/L applies to other types of treatment systems.

Maxxam Job #: B1D4009
Report Date: 2011/09/21

NL Dept of Natural Resources
Client Project #:
Site Location: TN/FP
Your P.O. #: PO 211028119
Sampler Initials:

**ORGANOCHLORINATED PESTICIDES BY GC-ECD (WATER)**

| Maxxam ID | | | KS9887 | KS9889 | | |
|---|---|---|---|---|---|---|
| Sampling Date | | | 8/30/2011 | 8/31/2011 | | |
| COC Number | | | N/A | N/A | | |
| | | | | | | |
| | **Units** | **Criteria A** | **TN SITE#3** | **FP SITE#2** | **RDL** | **QC Batch** |
| **Pesticides & Herbicides** | | | | | | |
| Aldrin | ug/L | - | ND | ND | 0.005 | 2604066 |
| alpha-BHC | ug/L | - | ND | ND | 0.005 | 2604066 |
| beta-BHC | ug/L | - | ND | ND | 0.005 | 2604066 |
| delta-BHC | ug/L | - | ND | ND | 0.005 | 2604066 |
| a-Chlordane | ug/L | - | ND | ND | 0.005 | 2604066 |
| g-Chlordane | ug/L | - | ND | ND | 0.005 | 2604066 |
| Chlordane (Total) | ug/L | - | ND | ND | 0.005 | 2604066 |
| o,p-DDD | ug/L | - | ND | ND | 0.005 | 2604066 |
| p,p-DDD | ug/L | - | ND | ND | 0.005 | 2604066 |
| o,p-DDD + p,p-DDD | ug/L | - | ND | ND | 0.005 | 2604066 |
| o,p-DDE | ug/L | - | ND | ND | 0.005 | 2604066 |
| p,p-DDE | ug/L | - | ND | ND | 0.005 | 2604066 |
| o,p-DDE + p,p-DDE | ug/L | - | ND | ND | 0.005 | 2604066 |
| o,p-DDT | ug/L | - | ND | ND | 0.005 | 2604066 |
| p,p-DDT | ug/L | - | ND | ND | 0.005 | 2604066 |
| o,p-DDT + p,p-DDT | ug/L | - | ND | ND | 0.005 | 2604066 |
| DDT+ Metabolites | ug/L | - | ND | ND | 0.005 | 2604066 |
| Dieldrin | ug/L | - | ND | ND | 0.005 | 2604066 |
| Endosulfan I (alpha) | ug/L | - | ND | ND | 0.005 | 2604066 |
| Endosulfan II | ug/L | - | ND | ND | 0.005 | 2604066 |
| Endosulfan sulfate | ug/L | - | ND | ND | 0.005 | 2604066 |
| Total Endosulfan | ug/L | - | ND | ND | 0.005 | 2604066 |
| Endrin | ug/L | - | ND | ND | 0.005 | 2604066 |
| Endrin aldehyde | ug/L | - | ND | ND | 0.005 | 2604066 |
| Endrin ketone | ug/L | - | ND | ND | 0.005 | 2604066 |
| Heptachlor | ug/L | - | ND | ND | 0.005 | 2604066 |
| Heptachlor epoxide | ug/L | - | ND | ND | 0.005 | 2604066 |
| Hexachlorobenzene | ug/L | - | ND | ND | 0.005 | 2604066 |
| Lindane | ug/L | - | ND | ND | 0.003 | 2604066 |
| Methoxychlor | ug/L | **900** | ND | ND | 0.01 | 2604066 |
| Mirex | ug/L | - | ND | ND | 0.005 | 2604066 |
| Octachlorostyrene | ug/L | - | ND | ND | 0.005 | 2604066 |
| Total PCB | ug/L | - | ND | ND | 0.05 | 2604066 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Aroclor 1016 | ug/L | - | ND | ND | 0.05 | 2604066 |
| Aroclor 1221 | ug/L | - | ND | ND | 0.05 | 2604066 |
| Aroclor 1232 | ug/L | - | ND | ND | 0.05 | 2604066 |
| Aroclor 1242 | ug/L | - | ND | ND | 0.05 | 2604066 |
| Aroclor 1248 | ug/L | - | ND | ND | 0.05 | 2604066 |
| Aroclor 1254 | ug/L | - | ND | ND | 0.05 | 2604066 |
| Aroclor 1260 | ug/L | - | ND | ND | 0.05 | 2604066 |
| Toxaphene | ug/L | - | ND | ND | 0.2 | 2604066 |
| **Surrogate Recovery (%)** | | | | | | |
| 2,4,5,6-Tetrachloro-m-xylene | % | - | 58 | 59 | | 2604066 |
| Decachlorobiphenyl | % | - | 100 | 96 | | 2604066 |

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
EDL = Estimated Detection Limit
QC Batch = Quality Control Batch
Criteria A: Guideline - Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ), Health Canada, Dec. 2010.

A= Maximum Acceptable Concentration (MAC) - established for substances that are known or suspected to cause adverse effects on health. When exceeded, minimum action required is immediate resampling. If continuous exceedance occurs, the local authority responsible for drinking water supplies should be consulted concerning appropriate corrective action.

C= Aesthetic Objectives (AO) - apply to characteristics of drinking water that can affect its acceptance by consumers or interfere with practices for supplying good quality water. If a concentration is well above an AO, then there is a possibility of a health hazard.

Note 1 Turbidity guideline value of 0.3 NTU based on conventional treatment system. For slow sand or diatomaceous earth filtration 1.0 NTU and for membrane filtration 0.1 NTU.
Note 2 Aluminium guideline value of 0.1 mg/L is for treatment plants using aluminium-based coagulants, 0.2mg/L applies to other types of treatment systems.

Results relate only to the items tested.

## Soil Quality Reports

Maxxam Job #: B2H4415
Report Date:
2012/12/03

NL Dept of Natural Resources
Client Project #:

Site Location:
Your P.O. #: 211028119
Sampler Initials:

**RESULTS OF ANALYSES OF SOIL**

| | | | | |
|---|---|---|---|---|
| Maxxam ID | | PN0849 | | |
| Sampling Date | | 10/30/2012 | | |
| COC Number | | N/A | | |
| | | | | |
| | **Units** | **DEADMAN'S BAY** | **RDL** | **QC Batch** |
| **Inorganics** | | | | |
| Ammonia-N | mg/kg | 13 ( 1 ) | 2.8 | 3036268 |
| Moisture | % | 89 | 1 | 3034033 |
| Nitrate (N) | mg/kg | 2.9 | 0.25 | 3031396 |
| Nitrate + Nitrite | mg/kg | 2.9 | 0.25 | 3036987 |
| Nitrite (N) | mg/kg | ND | #### | 3036989 |
| **Subcontracted Analysis** | | | | |
| Subcontract Parameter | N/A | ATTACHED | N/A | 3035769 |

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
EDL = Estimated Detection Limit
QC Batch = Quality Control Batch
( 1 ) Soil duplicate 30.8% RPD is acceptable. (Soil RPD limit <35%)

**PESTICIDES BY GC-MS (SOIL)**

| Maxxam ID | | FA0581 | | |
|---|---|---|---|---|
| Sampling Date | | 2012/10/30 | | |
| | UNITS | DEADMAN'S BAY (PN0849-01R) | RDL | QC Batch |
| **PESTICIDE RESIDUE** | | | | |
| 2,4'-DDT + 4,4'-DDD | ug/g | <0.15(1) | 0.15 | 6360667 |
| 4,4'-DDE | ug/g | <0.75(1) | 0.75 | 6360667 |
| 4,4'-DDT | ug/g | <0.30(1) | 0.30 | 6360667 |
| 4,4'-methoxychlor | ug/g | <0.75(1) | 0.75 | 6360667 |
| a-BHC | ug/g | <0.15(1) | 0.15 | 6360667 |
| Acephate | ug/g | <0.75(1) | 0.75 | 6360667 |
| a-Chlordane | ug/g | <0.15(1) | 0.15 | 6360667 |
| Alachlor | ug/g | <0.75(1) | 0.75 | 6360667 |
| Aldrin | ug/g | <0.75(1) | 0.75 | 6360667 |
| Aspon | ug/g | <0.15(1) | 0.15 | 6360667 |
| Atrazine | ug/g | <0.45(1) | 0.45 | 6360667 |
| Azinophos methyl (Guthion) | ug/g | <0.75(1) | 0.75 | 6360667 |
| Azinphos ethyl | ug/g | <0.75(1) | 0.75 | 6360667 |
| b-BHC | ug/g | <0.15(1) | 0.15 | 6360667 |
| Benfluralin | ug/g | <0.30(1) | 0.30 | 6360667 |
| Bromacil | ug/g | <0.30(1) | 0.30 | 6360667 |
| Bromophos | ug/g | <0.15(1) | 0.15 | 6360667 |
| Bromophos-ethyl | ug/g | <0.75(1) | 0.75 | 6360667 |
| Butylate | ug/g | <0.30(1) | 0.30 | 6360667 |
| Captan | ug/g | <1.5(1) | 1.5 | 6360667 |
| Carbophenothion | ug/g | <0.15(1) | 0.15 | 6360667 |
| Chlorbenside | ug/g | <0.75(1) | 0.75 | 6360667 |
| Chlorfenson(ovex) | ug/g | <0.30(1) | 0.30 | 6360667 |
| Chlorfenvinphos(e/z) | ug/g | <0.15(1) | 0.15 | 6360667 |
| Chlormephos | ug/g | <0.75(1) | 0.75 | 6360667 |
| Chlorothalonil (Daconil) | ug/g | <0.30(1) | 0.30 | 6360667 |
| Chlorpropham | ug/g | <0.30(1) | 0.30 | 6360667 |
| Chlorpyrifos | ug/g | <0.15(1) | 0.15 | 6360667 |
| Chlorpyriphos-methyl | ug/g | <0.45(1) | 0.45 | 6360667 |
| Chlorthiophos | ug/g | <0.45(1) | 0.45 | 6360667 |
| Cyanazine (Bladex) | ug/g | <0.45(1) | 0.45 | 6360667 |
| Cyanophos | ug/g | <0.75(1) | 0.75 | 6360667 |
| Dacthal | ug/g | <0.75(1) | 0.75 | 6360667 |
| d-BHC | ug/g | <0.15(1) | 0.15 | 6360667 |
| Demeton | ug/g | <0.30(1) | 0.30 | 6360667 |

## PESTICIDES BY GC-MS (SOIL)

| Maxxam ID | | FA0581 | | |
|---|---|---|---|---|
| Sampling Date | | 2012/10/30 | | |
| | **UNITS** | **DEADMAN'S BAY (PN0849-01R)** | **RDL** | **QC Batch** |
| Desethyl-atrazine | ug/g | <0.45(1) | 0.45 | 6360667 |
| Desmetryn | ug/g | <0.45(1) | 0.45 | 6360667 |
| Diallate(e/z) | ug/g | <0.15(1) | 0.15 | 6360667 |
| Diazinon | ug/g | <0.30(1) | 0.30 | 6360667 |
| Dichlobenil | ug/g | <0.75(1) | 0.75 | 6360667 |
| Dichlofenthion | ug/g | <0.30(1) | 0.30 | 6360667 |
| Dichlofluanid | ug/g | <0.30(1) | 0.30 | 6360667 |
| Dichloran | ug/g | <0.75(1) | 0.75 | 6360667 |
| Dichlorvos + Naled | ug/g | <0.75(1) | 0.75 | 6360667 |
| Dicofol | ug/g | <0.75(1) | 0.75 | 6360667 |
| Dicrotophos | ug/g | <0.75(1) | 0.75 | 6360667 |
| Dieldrin | ug/g | <0.30(1) | 0.30 | 6360667 |
| Dimethoate | ug/g | <0.30(1) | 0.30 | 6360667 |
| Dioxathion | ug/g | <0.30(1) | 0.30 | 6360667 |
| Diphenylamine | ug/g | <0.75(1) | 0.75 | 6360667 |
| Disulfoton (Di-Syston) | ug/g | <0.30(1) | 0.30 | 6360667 |
| Endosulfan I | ug/g | <1.5(1) | 1.5 | 6360667 |
| Endosulfan II | ug/g | <0.30(1) | 0.30 | 6360667 |
| Endosulfan Sulfate | ug/g | <0.15(1) | 0.15 | 6360667 |
| Endrin | ug/g | <1.5(1) | 1.5 | 6360667 |
| Endrin Aldehyde | ug/g | <0.60(1) | 0.60 | 6360667 |
| Endrin ketone | ug/g | <0.60(1) | 0.60 | 6360667 |
| EPN | ug/g | <0.75(1) | 0.75 | 6360667 |
| Eptam | ug/g | <0.75(1) | 0.75 | 6360667 |
| Ethalfluralin | ug/g | <0.75(1) | 0.75 | 6360667 |
| Ethion | ug/g | <0.75(1) | 0.75 | 6360667 |
| Fenitrothion | ug/g | <0.30(1) | 0.30 | 6360667 |
| Fensulfothion | ug/g | <0.30(1) | 0.30 | 6360667 |
| Fenthion | ug/g | <0.30(1) | 0.30 | 6360667 |
| Folpet | ug/g | <1.5(1) | 1.5 | 6360667 |
| Fonofos | ug/g | <0.75(1) | 0.75 | 6360667 |
| g-Chlordane | ug/g | <0.15(1) | 0.15 | 6360667 |
| Heptachlor | ug/g | <0.30(1) | 0.30 | 6360667 |
| Heptachlor epoxide | ug/g | <0.15(1) | 0.15 | 6360667 |
| Hexachlorobenzene | ug/g | <0.45(1) | 0.45 | 6360667 |
| Hexazinone | ug/g | <0.75(1) | 0.75 | 6360667 |

**PESTICIDES BY GC-MS (SOIL)**

| Maxxam ID | | FA0581 | | |
|---|---|---|---|---|
| Sampling Date | | 2012/10/30 | | |
| | UNITS | DEADMAN'S BAY (PN0849-01R) | RDL | QC Batch |
| Iodofenphos | ug/g | <0.15(1) | 0.15 | 6360667 |
| Iprodione | ug/g | <0.75(1) | 0.75 | 6360667 |
| Isofenphos | ug/g | <0.30(1) | 0.30 | 6360667 |
| Lindane (BHC), gamma- | ug/g | <0.15(1) | 0.15 | 6360667 |
| Malaoxon | ug/g | <1.5(1) | 1.5 | 6360667 |
| Malathion | ug/g | <0.15(1) | 0.15 | 6360667 |
| Metalaxyl | ug/g | <0.30(1) | 0.30 | 6360667 |
| Methamidophos | ug/g | <0.75(1) | 0.75 | 6360667 |
| Methidathion | ug/g | <0.30(1) | 0.30 | 6360667 |
| Metolachlor | ug/g | <0.30(1) | 0.30 | 6360667 |
| Metribuzin (Sencor) | ug/g | <0.75(1) | 0.75 | 6360667 |
| Mevinphos (Phosdrin) | ug/g | <0.75(1) | 0.75 | 6360667 |
| Mirex | ug/g | <0.30(1) | 0.30 | 6360667 |
| Nitrofen | ug/g | <0.75(1) | 0.75 | 6360667 |
| o,p'-DDD | ug/g | <0.15(1) | 0.15 | 6360667 |
| o,p'-DDE | ug/g | <0.15(1) | 0.15 | 6360667 |
| Omethoate | ug/g | <0.75(1) | 0.75 | 6360667 |
| Parathion | ug/g | <0.75(1) | 0.75 | 6360667 |
| Parathion methyl | ug/g | <0.30(1) | 0.30 | 6360667 |
| Pentachloronitrobenzene | ug/g | <0.75(1) | 0.75 | 6360667 |
| Permethrin | ug/g | <0.75(1) | 0.75 | 6360667 |
| Phorate (Thimet) | ug/g | <0.30(1) | 0.30 | 6360667 |
| Phosalone | ug/g | <0.75(1) | 0.75 | 6360667 |
| Phosmet | ug/g | <0.45(1) | 0.45 | 6360667 |
| Phosphamidon | ug/g | <0.75(1) | 0.75 | 6360667 |
| Pirimicarb | ug/g | <0.75(1) | 0.75 | 6360667 |
| Pirimiphos-ethyl | ug/g | <0.30(1) | 0.30 | 6360667 |
| Pirimiphos-methyl | ug/g | <0.30(1) | 0.30 | 6360667 |
| Procymidone | ug/g | <0.75(1) | 0.75 | 6360667 |
| Profenophos | ug/g | <0.75(1) | 0.75 | 6360667 |
| Profluralin | ug/g | <0.30(1) | 0.30 | 6360667 |
| Prometryn | ug/g | <0.45(1) | 0.45 | 6360667 |
| Pronamide | ug/g | <0.75(1) | 0.75 | 6360667 |
| Propazine | ug/g | <0.30(1) | 0.30 | 6360667 |
| Propiconazole | ug/g | <0.30(1) | 0.30 | 6360667 |
| Pyrazophos | ug/g | <0.30(1) | 0.30 | 6360667 |

## PESTICIDES BY GC-MS (SOIL)

| Maxxam ID | | FA0581 | | |
|---|---|---|---|---|
| Sampling Date | | 2012/10/30 | | |
| | **UNITS** | **DEADMAN'S BAY (PN0849-01R)** | **RDL** | **QC Batch** |
| Quinalophos | ug/g | <0.45(1) | 0.45 | 6360667 |
| Ronnel | ug/g | <0.75(1) | 0.75 | 6360667 |
| Simazine | ug/g | <0.15(1) | 0.15 | 6360667 |
| Stirophos | ug/g | <0.30(1) | 0.30 | 6360667 |
| Sulfotepp | ug/g | <0.30(1) | 0.30 | 6360667 |
| Tecnazene | ug/g | <0.75(1) | 0.75 | 6360667 |
| Terbufos | ug/g | <0.75(1) | 0.75 | 6360667 |
| Terbuthylazine | ug/g | <0.30(1) | 0.30 | 6360667 |
| Terbutryne | ug/g | <0.30(1) | 0.30 | 6360667 |
| Tetradifon | ug/g | <0.30(1) | 0.30 | 6360667 |
| Tolylfluanid | ug/g | <0.75(1) | 0.75 | 6360667 |
| Triadimefon | ug/g | <0.75(1) | 0.75 | 6360667 |
| Triallate | ug/g | <0.30(1) | 0.30 | 6360667 |
| Trifluralin | ug/g | <0.75(1) | 0.75 | 6360667 |
| Vinclozolin | ug/g | <0.30(1) | 0.30 | 6360667 |
| **Surrogate Recovery (%)** | | | | |
| 2-FLUOROBIPHENYL (sur.) | % | 71 | N/A | 6360667 |
| D5-NITROBENZENE (sur.) | % | 61 | N/A | 6360667 |
| p,p'-DDE13C12 (sur.) | % | 137(2) | N/A | 6360667 |
| TERPHENYL-D14 (sur.) | % | 137 | N/A | 6360667 |
| Triphenyl phosphate (sur.) | % | 50 | N/A | 6360667 |

## PHYSICAL TESTING (SOIL)

| Maxxam ID | | FA0581 | | |
|---|---|---|---|---|
| Sampling Date | | 2012/10/30 | | |
| | **UNITS** | **DEADMAN'S BAY (PN0849-01R)** | **RDL** | **QC Batch** |
| **Physical Properties** | | | | |
| Moisture | % | 89 | 0.30 | 6353508 |

## ORGANOPHOSPHORUS PESTICIDES BY GC-MS (SOIL)

| | | | | |
|---|---|---|---|---|
| Maxxam ID | | PN0849 | | |
| Sampling Date | | 2012/10/30 | | |
| COC Number | | N/A | | |
| | | | | |
| | **Units** | **DEADMAN'S BAY** | **RDL** | **QC Batch** |
| **Pesticides & Herbicides** | | | | |
| Bendiocarb | ug/g | ND | 50 | 3038015 |
| Demeton-S | ug/g | ND | 50 | 3038015 |
| Dichlorvos | ug/g | ND | 50 | 3038015 |
| Dimethoate | ug/g | ND | 50 | 3038015 |
| Fenchlorophos (Ronnel) | ug/g | ND | 50 | 3038015 |
| Fonofos | ug/g | ND | 50 | 3038015 |
| Metolachlor | ug/g | ND | 100 | 3038015 |
| Mevinphos | ug/g | ND | 50 | 3038015 |
| Phosmet | ug/g | ND | 50 | 3038015 |
| Triallate | ug/g | ND | 50 | 3038015 |
| Trifluralin | ug/g | ND | 50 | 3038015 |
| Fenthion | ug/g | ND | 50 | 3038015 |
| Ethion | ug/g | ND | 50 | 3038015 |
| Guthion (Azinphos-methyl) | ug/g | ND | 50 | 3038015 |
| Phorate | ug/g | ND | 50 | 3038015 |
| Terbufos | ug/g | ND | 50 | 3038015 |
| Aldicarb | ug/g | ND | 50 | 3038015 |
| Atrazine | ug/g | ND | 50 | 3038015 |
| Carbaryl | ug/g | ND | 50 | 3038015 |
| Carbofuran | ug/g | ND | 50 | 3038015 |
| Cyanazine (Bladex) | ug/g | ND | 50 | 3038015 |
| Diazinon | ug/g | ND | 50 | 3038015 |
| Parathion Ethyl | ug/g | ND | 50 | 3038015 |
| Parathion Methyl | ug/g | ND | 50 | 3038015 |
| Prometryne | ug/g | ND | 50 | 3038015 |
| Malathion | ug/g | ND | 50 | 3038015 |
| Simazine | ug/g | ND | 50 | 3038015 |
| Chlorpyrifos (Dursban) | ug/g | ND | 50 | 3038015 |
| **Surrogate Recovery (%)** | | | | |
| 2-Fluorobiphenyl | % | 51 | | 3038015 |

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

ORGANOCHLORINATED PESTICIDES BY GC-ECD (SOIL)

| Maxxam ID | | PN0849 | | |
|---|---|---|---|---|
| Sampling Date | | 2012/10/30 | | |
| COC Number | | N/A | | |
| | | | | |
| | Units | DEADMAN'S BAY | RDL | QC Batch |
| **Pesticides & Herbicides** | | | | |
| Aldrin | ug/g | ND | 0.020 | 3037797 |
| a-Chlordane | ug/g | ND | 0.020 | 3037797 |
| g-Chlordane | ug/g | ND | 0.020 | 3037797 |
| Chlordane (Total) | ug/g | ND | 0.020 | 3037797 |
| o,p-DDD | ug/g | ND | 0.020 | 3037797 |
| p,p-DDD | ug/g | ND | 0.020 | 3037797 |
| o,p-DDD + p,p-DDD | ug/g | ND | 0.020 | 3037797 |
| o,p-DDE | ug/g | ND | 0.020 | 3037797 |
| p,p-DDE | ug/g | ND | 0.020 | 3037797 |
| o,p-DDE + p,p-DDE | ug/g | ND | 0.020 | 3037797 |
| o,p-DDT | ug/g | ND | 0.020 | 3037797 |
| p,p-DDT | ug/g | ND | 0.020 | 3037797 |
| o,p-DDT + p,p-DDT | ug/g | ND | 0.020 | 3037797 |
| DDT+ Metabolites | ug/g | ND | 0.020 | 3037797 |
| Dieldrin | ug/g | ND | 0.020 | 3037797 |
| Lindane | ug/g | ND | 0.020 | 3037797 |
| Endosulfan I (alpha) | ug/g | ND | 0.020 | 3037797 |
| Endosulfan II | ug/g | ND | 0.020 | 3037797 |
| Total Endosulfan | ug/g | ND | 0.020 | 3037797 |
| Endrin | ug/g | ND | 0.020 | 3037797 |
| Heptachlor | ug/g | ND | 0.020 | 3037797 |
| Heptachlor epoxide | ug/g | ND | 0.020 | 3037797 |
| Hexachlorobenzene | ug/g | ND | 0.020 | 3037797 |
| Methoxychlor | ug/g | ND | 0.050 | 3037797 |
| Aroclor 1016 | ug/g | ND | 0.15 | 3037797 |
| Aroclor 1221 | ug/g | ND | 0.30 | 3037797 |
| Aroclor 1232 | ug/g | ND | 0.15 | 3037797 |
| Aroclor 1242 | ug/g | ND | 0.15 | 3037797 |
| Aroclor 1248 | ug/g | ND | 0.15 | 3037797 |

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

ORGANOCHLORINATED PESTICIDES BY GC-ECD (SOIL)

| | | | | |
|---|---|---|---|---|
| Maxxam ID | | PN0849 | | |
| Sampling Date | | 2012/10/30 | | |
| COC Number | | N/A | | |
| | | | | |
| | **Units** | **DEADMAN'S BAY** | **RDL** | **QC Batch** |
| Aroclor 1254 | ug/g | ND | 0.15 | 3037797 |
| Aroclor 1260 | ug/g | ND | 0.15 | 3037797 |
| Aroclor 1262 | ug/g | ND | 0.15 | 3037797 |
| Aroclor 1268 | ug/g | ND | 0.15 | 3037797 |
| Total PCB | ug/g | ND | 0.30 | 3037797 |
| alpha-BHC | ug/g | ND | 0.020 | 3037797 |
| beta-BHC | ug/g | ND | 0.020 | 3037797 |
| delta-BHC | ug/g | ND | 0.020 | 3037797 |
| Endosulfan sulfate | ug/g | ND | 0.020 | 3037797 |
| Endrin aldehyde | ug/g | ND | 0.020 | 3037797 |
| Endrin ketone | ug/g | ND | 0.020 | 3037797 |
| Mirex | ug/g | ND | 0.020 | 3037797 |
| Octachlorostyrene | ug/g | ND | 0.020 | 3037797 |
| Toxaphene | ug/g | ND | 0.80 | 3037797 |
| **Surrogate Recovery (%)** | | | | |
| 2,4,5,6-Tetrachloro-m-xylene | % | 113 | | 3037797 |
| Decachlorobiphenyl | % | 106 | | 3037797 |

ND = Not detected
N/A = Not Applicable
RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

## **A.2.** Linear and Exponential Models

Table A1: 2011 linear and exponential models for temperature, pH, conductivity, turbidity, and tds at each site. For each parameter, only the best fit model out of the linear and exponential models is presented.

| Parameter | Farm and Site | Best Fit Model | Model | $R^2$ |
|---|---|---|---|---|
| temp | A1 | linear | y = -0.103x + 4255 | $R^2$ = 0.7097 |
| temp | A2 | linear | y = -0.1078x + 4451.2 | $R^2$ = 0.693 |
| temp | A3 | linear | y = -0.0789x + 3262 | $R^2$ = 0.6066 |
| temp | B1 | linear | y = -0.1204x + 4925.3 | $R^2$ = 0.6399 |
| temp | B2 | linear | y = -0.1103x + 4511.5 | $R^2$ = 0.6088 |
| temp | B3 | linear | y = -0.0869x + 3559.7 | $R^2$ = 0.5201 |
| temp | C1 | linear | y = -0.1101x + 4505.1 | $R^2$ = 0.9381 |
| temp | C2 | linear | y = -0.1357x + 5551.2 | $R^2$ = 0.8127 |
| temp | C3 | linear | y = -0.1187x + 4856.3 | $R^2$ = 0.8709 |
| temp | D1 | linear | y = -0.1543x + 6365.7 | $R^2$ = 0.8858 |
| temp | D2 | linear | y = -0.159x + 6559 | $R^2$ = 0.8215 |
| temp | D3 | linear | y = -0.1609x + 6638.2 | $R^2$ = 0.9069 |
| temp | E1 | linear | y = -0.1309x + 5403.8 | $R^2$ = 0.8215 |
| temp | E2 | linear | y = -0.1352x + 5583.1 | $R^2$ = 0.8486 |
| temp | E3 | linear | y = -0.1057x + 4366.4 | $R^2$ = 0.9432 |
| temp | F1 | linear | y = -0.1294x + 5341.4 | $R^2$ = 0.7307 |
| temp | F2 | linear | y = -0.1218x + 5028.7 | $R^2$ = 0.7478 |
| temp | F3 | linear | y = -0.1185x + 4894.6 | $R^2$ = 0.7991 |
| pH | A1 | exp | $y = 2E\text{-}24e^{0.0014x}$ | $R^2$ = |

| | | | | |
|---|---|---|---|---|
| | | | | 0.4055 |
| pH | A2 | exp | $y = 1E-13e^{0.0008x}$ | $R^2 = 0.3027$ |
| pH | A3 | exp | $y = 2E+21e^{-0.001x}$ | $R^2 = 0.2071$ |
| pH | B1 | exp | $y = 4E-68e^{0.0038x}$ | $R^2 = 0.4025$ |
| pH | B2 | exp | $y = 1E-53e^{0.003x}$ | $R^2 = 0.3485$ |
| pH | B3 | exp | $y = 4E-88e^{0.005x}$ | $R^2 = 0.4309$ |
| pH | C1 | exp | $y = 2E+17e^{-0.001x}$ | $R^2 = 0.0433$ |
| pH | C2 | exp | $y = 3E+08e^{-4E-04x}$ | $R^2 = 0.19$ |
| pH | C3 | exp | $y = 0.0024e^{0.0002x}$ | $R^2 = 0.0303$ |
| pH | D1 | exp | $y = 5E-13e^{0.0007x}$ | $R^2 = 0.6783$ |
| pH | D2 | exp | $y = 37333e^{-2E-04x}$ | $R^2 = 0.0103$ |
| pH | D3 | exp | $y = 1E-17e^{0.001x}$ | $R^2 = 0.5311$ |
| pH | E1 | exp | $y = 3E+15e^{-8E-04x}$ | $R^2 = 0.3381$ |
| pH | E2 | exp | $y = 1E+14e^{-7E-04x}$ | $R^2 = 0.3368$ |
| pH | E3 | exp | $y = 2306.9e^{-1E-04x}$ | $R^2 = 0.0097$ |
| pH | F1 | exp | $y = 8E-23e^{0.0013x}$ | $R^2 = 0.2369$ |
| pH | F2 | exp | $y = 5E-12e^{0.0007x}$ | $R^2 = 0.0713$ |
| pH | F3 | exp | $y = 3E-13e^{0.0007x}$ | $R^2 = 0.2828$ |
| Turbidity | A1 | linear | y = 0.0064x - 261.43 | $R^2 = 0.181$ |
| Turbidity | A2 | linear | y = -9E-05x + 4.9428 | $R^2 = 0.0004$ |
| Turbidity | A3 | linear | y = -0.006x + 248.49 | $R^2 = 0.3963$ |
| Turbidity | B1 | linear | y = 0.056x - 2281.9 | $R^2 = 0.5694$ |
| Turbidity | B2 | linear | y = 0.0041x - 163.79 | $R^2 = 0.0016$ |
| Turbidity | B3 | linear | y = -0.0024x + 97.941 | $R^2 = 0.0542$ |
| Turbidity | C1 | linear | y = -0.0044x + | $R^2 = 0.0533$ |

| | | | | |
|---|---|---|---|---|
| | | | 182.99 | |
| Turbidity | C2 | linear | y = 0.0139x - 564.92 | $R^2$ = 0.23 |
| Turbidity | C3 | linear | y = -0.0155x + 634.37 | $R^2$ = 0.413 |
| Turbidity | D1 | linear | y = -0.0085x + 353.41 | $R^2$ = 0.1335 |
| Turbidity | D2 | linear | y = -0.0305x + 1258.8 | $R^2$ = 0.4087 |
| Turbidity | D3 | linear | y = -0.0058x + 240.02 | $R^2$ = 0.0399 |
| Turbidity | E1 | linear | y = 0.0058x - 235.87 | $R^2$ = 0.0492 |
| Turbidity | E2 | linear | y = 0.0058x - 235.87 | $R^2$ = 0.0492 |
| Turbidity | E3 | linear | y = -0.0035x + 146.2 | $R^2$ = 0.0266 |
| Turbidity | F1 | linear | y = 0.0024x - 96.264 | $R^2$ = 0.0006 |
| Turbidity | F2 | linear | y = -0.0317x + 1321.6 | $R^2$ = 0.0026 |
| Turbidity | F3 | linear | y = -0.0006x + 27.97 | $R^2$ = 0.0009 |
| TDS | A1 | exp | $y = 2E\text{-}37e^{0.0021x}$ | $R^2$ = 0.5449 |
| TDS | A2 | exp | $y = 2E\text{-}62e^{0.0035x}$ | $R^2$ = 0.4647 |
| TDS | A3 | exp | $y = 2E\text{-}64e^{0.0036x}$ | $R^2$ = 0.5996 |
| TDS | B1 | exp | $y = 1E\text{-}35e^{0.002x}$ | $R^2$ = 0.1836 |
| TDS | B2 | exp | $y = 1E\text{-}56e^{0.0032x}$ | $R^2$ = 0.5663 |
| TDS | B3 | exp | $y = 5E\text{-}37e^{0.0021x}$ | $R^2$ = 0.3671 |
| TDS | C1 | exp | $y = 7E\text{+}16e^{-9E\text{-}04x}$ | $R^2$ = 0.0318 |
| TDS | C2 | exp | $y = 7E\text{-}26e^{0.0015x}$ | $R^2$ = 0.0587 |
| TDS | C3 | exp | $y = 5E\text{-}36e^{0.0021x}$ | $R^2$ = 0.0475 |
| TDS | D1 | exp | $y = 5E\text{-}30e^{0.0017x}$ | $R^2$ = 0.3927 |
| TDS | D2 | exp | $y = 431.4e^{-6E\text{-}05x}$ | $R^2$ = 5E-05 |
| TDS | D3 | exp | $y = 9E\text{+}37e^{-0.002x}$ | $R^2$ = 0.0664 |
| TDS | E1 | exp | $y = 5E\text{+}93e^{-0.005x}$ | $R^2$ = 0.3339 |

| | | | | |
|---|---|---|---|---|
| TDS | E2 | exp | $y = 5E+93e^{-0.005x}$ | $R^2 = 0.3339$ |
| TDS | E3 | exp | $y = 3E+62e^{-0.003x}$ | $R^2 = 0.0858$ |
| TDS | F1 | exp | $y = 2E-28e^{0.0016x}$ | $R^2 = 0.309$ |
| TDS | F2 | exp | $y = 1E-36e^{0.0021x}$ | $R^2 = 0.0167$ |
| TDS | F3 | exp | $y = 3E-06e^{0.0004x}$ | $R^2 = 0.0086$ |
| Conductivity | A1 | linear | y = 0.0001x - 5.4362 | $R^2 = 0.5135$ |
| Conductivity | A2 | linear | y = 0.0003x - 10.595 | $R^2 = 0.4793$ |
| Conductivity | A3 | linear | y = 0.0002x - 8.1177 | $R^2 = 0.6139$ |
| Conductivity | B1 | linear | y = 0.0001x - 5.2051 | $R^2 = 0.2907$ |
| Conductivity | B2 | linear | y = 0.0002x - 6.6121 | $R^2 = 0.4659$ |
| Conductivity | B3 | linear | y = 0.0001x - 5.3998 | $R^2 = 0.3866$ |
| Conductivity | C1 | linear | y = -5E-05x + 2.2276 | $R^2 = 0.0373$ |
| Conductivity | C2 | linear | y = 8E-05x - 3.2416 | $R^2 = 0.0491$ |
| Conductivity | C3 | linear | y = 0.0004x - 15.499 | $R^2 = 0.1219$ |
| Conductivity | D1 | linear | y = 8E-05x - 3.1547 | $R^2 = 0.4112$ |
| Conductivity | D2 | linear | y = -0.0002x + 7.6123 | $R^2 = 0.2342$ |
| Conductivity | D3 | linear | y = 3E-05x - 1.3393 | $R^2 = 0.0637$ |
| Conductivity | E1 | linear | y = -0.0004x + 16.561 | $R^2 = 0.2987$ |
| Conductivity | E2 | linear | y = -0.0021x + 87.832 | $R^2 = 0.2769$ |
| Conductivity | E3 | linear | y = -0.0002x + 9.71 | $R^2 = 0.0863$ |
| Conductivity | F1 | linear | y = 4E-05x - 1.486 | $R^2 = 0.38$ |
| Conductivity | F2 | linear | y = -3E-05x + 1.4431 | $R^2 = 0.0025$ |
| Conductivity | F3 | linear | y = 1E-05x - 0.3991 | $R^2 = 0.0187$ |

Table A2: 2012 linear and exponential models for temperature, pH, conductivity, turbidity, and tds at each site. For each parameter, only the best fit model out of the linear and exponential models is presented.

| Parameter | Farm and Site | Best Fit Model | Model | R2 |
|---|---|---|---|---|
| temp | A1 | linear | y = -0.164x + 6768.3 | $R^2$ = 0.9339 |
| temp | A2 | linear | y = -0.1755x + 7242.4 | $R^2$ = 0.9342 |
| temp | A3 | linear | y = -0.1426x + 5887.3 | $R^2$ = 0.9516 |
| temp | B1 | linear | y = -0.0903x + 3731.9 | $R^2$ = 0.6018 |
| temp | B2 | linear | y = -0.0727x + 3006.7 | $R^2$ = 0.6281 |
| temp | B3 | linear | y = -0.1086x + 4484 | $R^2$ = 0.778 |
| temp | C1 | linear | y = -0.1273x + 5255.6 | $R^2$ = 0.8796 |
| temp | C2 | linear | y = -0.1591x + 6566.1 | $R^2$ = 0.891 |
| temp | C3 | linear | y = -0.1644x + 6783.2 | $R^2$ = 0.9271 |
| temp | D1 | linear | y = -0.1685x + 6954.4 | $R^2$ = 0.8246 |
| temp | D2 | linear | y = -0.1356x + 5600.8 | $R^2$ = 0.7088 |
| temp | D3 | linear | y = -0.1467x + 6056.2 | $R^2$ = 0.7987 |
| temp | E1 | linear | y = -0.131x + 5406.7 | $R^2$ = 0.8796 |
| temp | E2 | linear | y = -0.1476x + 6090.2 | $R^2$ = 0.8746 |
| temp | E3 | linear | y = -0.1405x + 5798 | $R^2$ = 0.9017 |
| temp | F1 | linear | y = -0.1755x + 7240.3 | $R^2$ = 0.8688 |
| temp | F2 | linear | y = -0.1436x + 5927.8 | $R^2$ = 0.917 |
| temp | F3 | linear | y = -0.1683x + 6945.1 | $R^2$ = 0.8952 |
| pH | A1 | exp | $y = 5E\text{-}68e^{0.0038x}$ | $R^2$ = 0.4784 |
| pH | A2 | exp | $y = 7E\text{-}36e^{0.002x}$ | $R^2$ = 0.3488 |
| pH | A3 | exp | $y = 2E\text{+}19e^{-0.001x}$ | $R^2$ = 0.2525 |

| | | | | |
|---|---|---|---|---|
| pH | B1 | exp | $y = 4E\text{-}87e^{0.0049x}$ | $R^2 = 0.7152$ |
| pH | B2 | exp | $y = 2E\text{-}59e^{0.0033x}$ | $2E\text{-}59e^{0.0033x}$ |
| pH | B3 | exp | $y = 6E\text{-}37e^{0.0021x}$ | $R^2 = 0.2425$ |
| pH | C1 | exp | $y = 1E\text{-}08e^{0.0005x}$ | $R^2 = 0.1137$ |
| pH | C2 | exp | $y = 6E\text{-}33e^{0.0018x}$ | $R^2 = 0.6848$ |
| pH | C3 | exp | $y = 7E\text{-}24e^{0.0013x}$ | $R^2 = 0.3164$ |
| pH | D1 | exp | $y = 5E\text{-}28e^{0.0016x}$ | $R^2 = 0.4243$ |
| pH | D2 | exp | $y = 4E+14e^{-8E\text{-}04x}$ | $R^2 = 0.1411$ |
| pH | D3 | exp | $y = 3E\text{-}12e^{0.0007x}$ | $R^2 = 0.2157$ |
| pH | E1 | exp | $y = 1E\text{-}37e^{0.0021x}$ | $R^2 = 0.5366$ |
| pH | E2 | exp | $y = 1E\text{-}15e^{0.0009x}$ | $R^2 = 0.1588$ |
| pH | E3 | exp | $y = 1E\text{-}32e^{0.0018x}$ | $R^2 = 0.5231$ |
| pH | F1 | exp | $y = 6E\text{-}29e^{0.0016x}$ | $R^2 = 0.1584$ |
| pH | F2 | exp | $y = 1E\text{-}14e^{0.0008x}$ | $R^2 = 0.2345$ |
| pH | F3 | exp | $y = 1E\text{-}04e^{0.0003x}$ | $R^2 = 0.0175$ |
| Turbidity | A1 | exp | $y = 7E\text{-}71e^{0.0039x}$ | $R^2 = 0.1328$ |
| Turbidity | A2 | exp | $y = 6E+73e^{-0.004x}$ | $R^2 = 0.17$ |
| Turbidity | A3 | exp | $y = 2E+308e^{-0.022x}$ | $R^2 = 0.7847$ |
| Turbidity | B1 | exp | $y = 3E\text{-}78e^{0.0044x}$ | $R^2 = 0.5362$ |
| Turbidity | B2 | exp | $y = 9E+138e^{-0.008x}$ | $R^2 = 0.1875$ |
| Turbidity | B3 | exp | $y = 1E+267e^{-0.015x}$ | $R^2 = 0.4068$ |
| Turbidity | C1 | exp | $y = 8E\text{-}12e^{0.0006x}$ | $R^2 = 0.0029$ |
| Turbidity | C2 | exp | $y = 4E+17e^{-1E\text{-}03x}$ | $R^2 = 0.0198$ |
| Turbidity | C3 | exp | $y = 0.0083e^{0.0001x}$ | $R^2 = 7E\text{-}05$ |
| Turbidity | D1 | exp | $y = 2E\text{-}51e^{0.0028x}$ | $R^2 = 0.0372$ |
| Turbidity | D2 | exp | $y = 8E+18e^{-0.001x}$ | $R^2 = 0.0081$ |
| Turbidity | D3 | exp | $y = 3E+49e^{-0.003x}$ | $R^2 = 0.0872$ |
| Turbidity | E1 | exp | $y = 2E+249e^{-0.014x}$ | $R^2 = 0.5107$ |
| Turbidity | E2 | exp | $y = 1E+255e^{-0.014x}$ | $R^2 = 0.712$ |
| Turbidity | E3 | exp | $y = 3E+151e^{-0.008x}$ | $R^2 = 0.3107$ |
| Turbidity | F1 | exp | $y = 2E+308e^{-0.021x}$ | $R^2 = 0.7192$ |
| Turbidity | F2 | exp | $y = 2E+308e^{-0.025x}$ | $R^2 = 0.735$ |
| Turbidity | F3 | exp | $y = 1E+07e^{-4E\text{-}04x}$ | $R^2 = 0.0028$ |
| TDS | A1 | exp | $y = 1E\text{-}78e^{0.0045x}$ | $R^2 = 0.1033$ |

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|---|---|---|---|---|
| TDS | A2 | exp | $y = 6E-63e^{0.0036x}$ | $R^2 = 0.1103$ |
| TDS | A3 | exp | $y = 2E-30e^{0.0017x}$ | $R^2 = 0.3696$ |
| TDS | B1 | exp | $y = 7E-130e^{0.0073x}$ | $R^2 = 0.2906$ |
| TDS | B2 | exp | $y = 4E-40e^{0.0023x}$ | $R^2 = 0.1218$ |
| TDS | B3 | exp | $y = 4E-55e^{0.0031x}$ | $R^2 = 0.4993$ |
| TDS | C1 | exp | $y = 1E+65e^{-0.004x}$ | $R^2 = 0.1553$ |
| TDS | C2 | exp | $y = 4E-12e^{0.0007x}$ | $R^2 = 0.0062$ |
| TDS | C3 | exp | $y = 7E+90e^{-0.005x}$ | $R^2 = 0.458$ |
| TDS | D1 | exp | $y = 3E-05e^{0.0003x}$ | $R^2 = 0.0179$ |
| TDS | D2 | exp | $y = 3E+135e^{-0.007x}$ | $R^2 = 0.4783$ |
| TDS | D3 | exp | $y = 2E+49e^{-0.003x}$ | $R^2 = 0.2254$ |
| TDS | E1 | exp | $y = 2E+67e^{-0.004x}$ | $R^2 = 0.3434$ |
| TDS | E2 | exp | $y = 7E+267e^{-0.015x}$ | $R^2 = 0.7729$ |
| TDS | E3 | exp | $y = 2E+09e^{-4E-04x}$ | $R^2 = 0.0086$ |
| TDS | F1 | exp | $y = 5E+18e^{-1E-03x}$ | $R^2 = 0.0124$ |
| TDS | F2 | exp | $y = 3E+106e^{-0.006x}$ | $R^2 = 0.4874$ |
| TDS | F3 | exp | $y = 4E+27e^{-0.001x}$ | $R^2 = 0.0725$ |
| Conductivity | A1 | exp | $y = 6E-83e^{0.0045x}$ | $R^2 = 0.1067$ |
| Conductivity | A2 | exp | $y = 1E-70e^{0.0038x}$ | $R^2 = 0.1485$ |
| Conductivity | A3 | exp | $y = 3E-40e^{0.0021x}$ | $R^2 = 0.4065$ |
| Conductivity | B1 | exp | $y = 1E-134e^{0.0074x}$ | $R^2 = 0.2854$ |
| Conductivity | B2 | exp | $y = 5E-42e^{0.0022x}$ | $R^2 = 0.1236$ |
| Conductivity | B3 | exp | $y = 2E-60e^{0.0033x}$ | $R^2 = 0.5346$ |
| Conductivity | C1 | exp | $y = 2E+61e^{-0.003x}$ | $R^2 = 0.1455$ |
| Conductivity | C2 | exp | $y = 9E-18e^{0.0009x}$ | $R^2 = 0.0091$ |
| Conductivity | C3 | exp | $y = 9E+88e^{-0.005x}$ | $R^2 = 0.4648$ |
| Conductivity | D1 | exp | $y = 3E-05e^{0.0002x}$ | $R^2 = 0.0038$ |
| Conductivity | D2 | exp | $y = 2E+130e^{-0.007x}$ | $R^2 = 0.4741$ |
| Conductivity | D3 | exp | $y = 2E+49e^{-0.003x}$ | $R^2 = 0.2459$ |
| Conductivity | E1 | exp | $y = 1E+62e^{-0.004x}$ | $R^2 = 0.3021$ |
| Conductivity | E2 | exp | $y = 6E+269e^{-0.015x}$ | $R^2 = 0.7739$ |
| Conductivity | E3 | exp | $y = 804991e^{-4E-04x}$ | $R^2 = 0.0076$ |
| Conductivity | F1 | exp | $y = 2E+14e^{-9E-04x}$ | $R^2 = 0.0098$ |

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|---|---|---|---|---|
| Conductivity | F2 | exp | $y = 5E+107e^{-0.006x}$ | $R^2 =$ 0.5025 |
| Conductivity | F3 | exp | $y = 1E-211e^{0.0117x}$ | $R^2 =$ 0.2563 |