Aquatic Invasive Species Early Detection and Rapid Response- Assessment of Chemical Response Tools

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Sommer Abdel-Fattah

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Executive Summary

Research on aquatic invasive species has been an important and productive part of the research conducted in an attempt to protect the Great Lakes. Through time the majority of this research has focused on the chemical control of invasive fishes. Early efforts to develop chemical control techniques for common carp and other nuisance fishes expanded in the 1960s resulting in highly successful effort to control the invasive sea lamprey in the Great Lakes. These efforts, in cooperation with the Great Lakes Fishery Commission created an emphasis on extending chemical control talents to newly established nonindigenous species in the Great Lakes, and recently, to assessments of taxon-specific chemicals and integrated control of invasive fishes such as those by Dawson and Kolar (2004). Using these types of studies scientists can develop models to predict potential fish invaders in the Great Lakes and have the capability to conduct risk assessments on what types of chemicals can be used to mitigate invasive species risk. It is particularly important to develop selective chemical treatments that will minimize the impacts to non-target species.

This study identifies current and potential invaders in the Great Lakes and provides chemical solutions and applications methods in order to develop a more responsive and strategic rapid response.

This report outlines chemical which have scientifically been proven to be effective against invaders and discusses use and application, public health and water quality, non-target impacts and their registration status in Canada and the United States.

In order to understand the use of chemicals as pesticides, the registering process, and the registering agencies requirements have been extensively documented within the report. The conclusion discusses some improvements that would be implemented to align US and Canadian regulations and registering processing through joint review.

Scientists continue to have unique capabilities in chemical control methodologies and regulatory affairs. Research conducted on aquatic invasive species needs to be responsive to the imposing threats while strictly adhering to the governmental restrictions.

To manage invasive species, early detection and rapid response is vital. Finding new invasive species before they spread widely or become established allows us to try to eliminate populations as soon as possible. If it’s not possible to eliminate them, early response could make control measures more effective and reduce their costs.

Chapter 1

Introduction

The introduction and spread of non-native species in marine and freshwater environments is a worldwide problem that is increasing in frequency. Aquatic Invasive Species (AIS) are introduced through various pathways including: ballast water from shipping and in shellfish transfers. AIS can cause extensive damage to ecosystems and the economies which they depend upon. This report focuses on introduced species into the Laurentian Great Lakes.

Invasion by non-native species is one of the most challenging environmental issues facing natural resource managers today. Nonindigenous invasive species which have been labelled exotics, nuisance species and alien species, all share the common characteristic of "introduction into an environment in which they did not evolve and thus usually have no natural enemies to limit their reproduction and spread" (Westbrooks, 1998). In this report these species are termed **aquatic invasive species (AIS)** for uniformity. These pests can alter the number and distribution of native species and have broad economic and societal impacts extending far beyond the shoreline of residents and recreational users. In their native habitat, where they have genetically evolved, these organisms may not be high risk to local habitats, however, when aquatic and terrestrial species are transported to ecosystems outside their range, problems can be caused disturbing the balance of natural ecosystems by altering population, community, and ecosystem structure and function.

The Great Lakes ecosystem has been subject to AIS invasions since the settlement of the region by Europeans. Since the 1800s, at least 185 known aquatic invasive organisms established themselves in the Great Lakes. The estimated rate of invasion is one new organism annually (Bright, 1998). The bulk of these organisms are plants, fish, algae, mollusks and oligochaetes, mostly native to Eurasia; and the Atlantic Coast. There are many invasive species that have a high probability of entering the Great Lakes region; such as European perch, roach, tench and killer shrimp which have been included within this report.

The single largest source of unintentional introductions has resulted from maritime commerce, with AIS transport occurring via ocean vessels originating in foreign ports. Some species attached themselves to the hulls of ships, while others were carried in ballast water taken on by ships in foreign ports for stability. It is standard operating procedure for ships embarking from ports around the world to take on large quantities of coastal water to lower the vessel to a safer position in the water. As they make their journey organisms carried in the water in their ballast tanks can be displaced (Glassner-Shwayder, 2000). These organisms include, among others, pathogens, plants, zooplankton, molluscs and fish that may remain suspended in the water column of ballast or sink down into the sediment on the bottom of the tank. When ships reach their destinations, these species are released when ballast water is discharged. Some of the most harmful biological invaders transported via shipping include the sea lamprey, zebra mussel, ruffe, round goby and spiny waterflea.

There are three main methods of controlling invasive species -- physical, chemical and biological. Physical control involves putting up barriers to prevent invasive species from geographically expanding, or physically removing a species from its new habitat. Dredging, dams, traps, electrical fields, mechanical barriers, and trenching are examples of barriers used to prevent invasive species from entering new areas. Methods of physically removing invasive species from new habitats include mechanical harvesting, hand-pulling plants, and cutting and destroying infested material. Chemical control involves applying poisons or pesticides to eliminate invasive species. When used properly, these pesticides have little effect on native species and ecosystems. Biological control uses a living organism to reduce or eliminate the population of the invasive species. The organism may eat the invasive species or cause it to become diseased. Control agents often must be brought from the original habitat of the invasive species. Proposals for biological control must be carefully assessed to ensure the control species does not become invasive and cause as much damage as the species to be controlled.

Of these options chemical solutions are often more practical particularly within the aquatic environment where physical barriers will impact many other species and biological controls may not be available. Mechanical removal of species may be difficult or impossible with small invertebrates, and pathogens.

It is critical to support continued research aimed at documenting the wide array of AIS impacts, as well as to find ways to prevent additional introductions, control aquatic invaders already established and prevent their spread. The ultimate goal of AIS research should be directed towards management action facilitating the prevention and control of aquatic invasive species. The uncertainties and risks associated with prevention and control programs also must be considered when working towards ameliorating problems, particularly with the application of chemicals to control aquatic invaders and the potential for new biological and ecological problems.

A detailed list of focus priority species for this report are available in Table 1.

Table 1: Priority Invasive Species and Associated Chemical Control Tools

Priority Invasive Species List

Tier 1 = established, harmful, non-native
Tier 2 = potential invader

Grouping	Tier	Name	Taxon	Species	Chemical Control Tools
Fish	1	sea lamprey	Petromyzontidae	*Petromyzon marinus*	TFM,Bayer 73,Rotenone,Antimycin and Bayluscide®
	2	bighead carp	Cyprinidae	*Hypophthalmichthys nobilis*	Rotenone and Antimycin
	2	black carp	Cyprinidae	*Mylopharyngodon piceus*	Rotenone and Antimycin
	2	grass carp	Cyprinidae	*Ctenopharyngodon idella*	Rotenone-laced bait such as Prentox®
	1	rudd	Cyprinidae	*Scardinius erythrophthalmus*	Rotenone and Lime
	2	tench	Cyprinidae	*Tinca tinca*	Rotenone and Antimycin
	2	roach	Cyprinidae	*Rutilus rutilus*	Rotenone and Antimycin
	1	white perch	Moronidae	*Morone americana*	Rotenone

	1	european perch	Percidae	*Perca fluviatilis*	Rotenone
	1	Eurasian ruffe	Percidae	*Gymnocephalus cernus*	Rotenone,antimycin,TFM and Bayluscide®
	2	monkey goby	Gobiidae	*Neogobius fluviatilis*	Rotenone
	1	round goby	Gobiidae	*Neogobius melanostomus*	Rotenone
	1	tubenose goby	Gobiidae	*Proterorhinus semilunaris*	Rotenone
	1	northern snakehead	Channidae	*Channa argus*	Rotenone
Zooplankton	1	fish-hook waterflea	Cladocera	*Cercopagis pengoi*	Chlorine
	1	spiny waterflea	Cladocera	*Bythotrephes longimanus*	Chlorine
Aquatic Plants	2	brazilian elodea	Hydrocharitaceae	*Egeria densa*	Diquat(Reward®), Fluridone
	1	curly-leaf pondweed	Potamogetonaceae	*Potamogeton crispus*	Diquat, copper with diquat,endothall,fluridone,imazamox
	1	eurasian water milfoil	Haloragaceae	*Myriophyllum spicatum*	Copper complexes,2,4-D,diquat,fluridone,imazamox,penoxsulam,endothall, triclopyr Glyphosate(Roundup, Rodeo), Imazapyr(Habitat) Diquat (Reward®)
	1	common reed	Phragmites	*Phragmites australis*	
	1	water soldier	Hydrocharitaceae	*Stratiotes aloides*	
	1	european frog-bit	Hydrocharitaceae	*Hydrocharis morsusranae*	2,4-D,diquat,imazamox and imazapyr
	2	hydrilla	Hydrocharitaceae	*Hydrilla verticillata*	Copper complexes, diquat, copper with diquat, endothall, fluridone, imazamox and penoxsulam
	1	purple loostrife	Lythraceae	*Lythrum salicaria*	Glyphodsate,Triclopyr-TEA
	1	water chestnut	Trapaceae	*Trapa natans*	2,4-D
Macro invertebrates	1	Echinogammarus	Amphipoda	*Echinogammarus ischnus*	No known chemical, biocides can aid
	2	killer shrimp*	Amphipoda	*Dikerogammarus villosus*	No current method known, can be killed by biocides
	1	New Zealand mud snail	Gastropoda	*Potamopyrgus antipodarum*	Copper sulphate,Hyamine and hydrogen peroxide, TFM, Bayluscide®
	1	quagga mussel	Dreissenidae	*Dreissena rostriformis bugensis*	Zequanox,chlorine
	1	zebra mussel	Dreissenidae	*Dreissena polymorpha*	Zequanox,chlorine
Pathogens	1	Microsporidia	Microsporidia	*Heterosporis* spp.	Fumagillin DCH
	1	Myxosporidian	Myxozoa	*Sphaeromyxa sevastopoli*	No current method known
	1	Salmonid whirling disease	Protozoa	*Myxobolus cerebralis*	Calcium Cyanide, Quicklime(CaO),Calcium cyanamide with Chlorine gas
	1	Viral hemorrhagic septicemia (VHS)	Rhabdoviridae	*Viral hemorrhagic septicemia virus*	Virkon Aquatic, Iodophor, hypochlorite with some slaked lime (at high concentrations)
Phytoplankton	1	cylindro blue-green algae or Cylindrospermopsis	Cyanobacteria	*Cylindrospermopsis raciborskii*	Endothall (Hydrothol 191®), copper sulphate or complexed copper products

Chapter 2: Aquatic Invasive Species Chemical Controls

There are many ways to manage invading non-native species including biological control agents such as insects, fish and pathogens as a means to weaken and suppress invading species, mechanical to remove aquatic species from water bodies or wetlands and chemical eradication.

This section will examine common chemical controls, their use and regulation status. Chemical controls were highlighted based on the target species of eradication taken from the Great Lakes Panel on Aquatic Nuisance Species list of high priority species. Some species were added as expected new invaders; these include monkey goby, European perch, tench, roach and killer shrimp. Chemical controls discussed include piscicides, lampricides, molluscicides, herbicides, algaecides and pathogen chemical controls. For the purpose of this report, registered chemical controls will be focused and discussed in detail.

Registration guarantees that the product has gone through strict approval processes from the governing bodies. The Ontario Ministry of the Environment and Health Canada's Pest Management Regulatory Agency (PRMA) is Canada's governing body and the Environmental Protection agency is the US reviewing agency for product approval. After approval the product is required to be labelled, which is approved as part of the registration process. The label contains the conditions of registration which, along with the PCPA and regulations, govern the use of the product. In effect, therefore, the label is a legislative document. Use of a product in a manner that is inconsistent with the directions or limitations on the label is prohibited. Any control product offered for sale in Canada or the US must bear the approved label for that country.

This document will outline specific chemical controls, as well as the regulatory processes in both Canada and the US and outline how to get a new pesticide registered through the corresponding agencies.

All information about registration came directly from the EPA and PMRA sites and direct communication. Registration status for Canada was from Health Canada's label search and for the US this information was from EPA's ECOTOX database.

2.0 Piscicides

Piscicides have been applied to ponds, lakes, streams, and rivers to control nuisance fishes for decades (Dawson and Kolar, 2003). Only two general piscicides (Rotenone and Antimycin) and two selective piscicides (TFM and Bayluscide®) are currently registered for use in the United States. Rotenone and Antimycin are also registered in Canada; however, TFM and Bayluscide are registered only for use against lamprey and thus will be discussed in more detail as lampricides.

2.1 Rotenone

Target AIS: Carp, northern snakeheads, Rudd, tench, roach, Eurasian ruffed, round goby, monkey goby, white perch, and European perch

Rotenone is the main piscicide used internationally for eradicating and controlling pest fishes in freshwaters (Rowe, 2003). Rotenone is a general use fish toxicant (Marking, 1992). Chemical eradication using rotenone has been used for fisheries management in Canada and the USA since the 1930s (Finlayson et al. 2002).

2.1.1 Use and Application

Rotenone is a compound found naturally in some plant species roots and it is toxic to fish and insects at concentrations higher than 1 ug/l (Conover, Simmonds, and Whalen, 2007). Rotenone inhibits a process at the cellular level making it impossible for fish to use the oxygen absorbed in the blood and needed in the release of energy during respiration. Rotenone is a general use piscicide, and as such is toxic to many types of fish, and has been effective against Carp. Rotenone and Antimycin are the only registered piscicides available to potentially control Asian carps in the United States without considerable additional expense. Where concentrations of juvenile Asian carps are high, rotenone might be a useful tool (Rowe, n.d.).

Other high priority invasive species that are susceptible to eradication by rotenone include northern snakeheads, rudd (Rowe, n.d.), tench, roach, Eurasian ruffed, round goby, monkey goby, white perch, and European perch.

Rotenone is applied either as a powder, or as a liquid. Rotenone is very water insoluble, comparable to oil. Liquid formulations of rotenone contain additional materials (dispersants and emulsifiers such as naphthalene, and methylnaphthalenes) that aid in the dispersal of rotenone throughout the water column (Conover et al., 2007).

Commercial products contain only 2.5% to 5% of rotenone, thus, the actual concentration in the water is only 0.012 to 0.250 parts per million (ppm) of rotenone. The commercial products are most commonly applied at a concentration 1.0 to 2.0 ppm which equates to 0.025 to 0.100 ppm of actual rotenone; however treatment rates can range from 0.5 to 10.0 ppm. It is labelled for use in lakes and running waters (i.e., streams and rivers). Rotenone has the advantage that it degrades rapidly especially in sunlight (Conover et al., 2007).

To determine when the water is safe to restock fish, the simplest test used by most fishery specialists is to place several fish in a cage and hold them in the treated water for several days. If they survive, the water is safe. Analytical techniques can also be used to determine how much rotenone is still present. Generally, restocking can occur within a few weeks of treatment, with the lakes being typically monitored for invertebrate recovery (Conover et al., 2007).

There have been rare instances in which this chemical has been used selectively. Willis and Ling (2000), describe a technique for using rotenone to control non-native mosquitofish in wetlands containing native black mudfish, a species twice as resistant to rotenone as mosquitofish. However, a limited number of studies (Henderson, 1976; Marking and Bills 1981, Chapman et al., 2003) have shown that bighead, grass, and silver carps are not especially susceptible to rotenone compared with published toxicity values of most other fish (Marking and Bills, 1976; Berger et al., 1969), making selectivity a challenging option. Another technique to improve the selectiveness of this toxin is by using poisoned baits.

In specific areas where black or grass carps are especially problematic, control using Piscicide baits should be attempted. Piscicide-laced baits, such as Prentox®, represent a special application of Rotenone. Poisoned baits have been used to control grass carp (Rowe, 1999; Thomas, 2004) and common carp (Rach et al., 1994). These applications require training the target fish on unpoisoned bait followed by application of the poisoned bait. The baiting technique is cannot guarantee complete removal of carp with poisoned bait, and mortality of non-target fishes sometimes occurs (Gehrke, 2003; Rowe, 2003).Use of rotenone-laced bait such as Prentox® for grass carp may be useful if specific areas where grass carp are problematic can be identified. The extremely strong crushing teeth of black carp allow them to crush food items that cannot be crushed by any native North American fish of similar size, minimizing the risk to other fish. Ideally, such bait should be of a size and character that would not easily break down to smaller pieces which then could be consumed by non-target organisms. It seems possible that baits for black carp could also be devised (Conover et al., 2007).

The use of biological controls is not recommended at this time as a strategy for controlling feral population of Asian carps. The introduction of biological controls such as disease agents, parasites, or predators to reduce or eliminate Asian carps is not likely to be fruitful and it is not recommended (Conover et al, 2007). There are no known diseases or parasites that are likely to effectively control Asian carps that are completely specific to Asian carps (Kolar et al., 2007). It is also unlikely that any predator could be found that would prey only on Asian carps.

The American Fisheries Society has published a manual for the use of rotenone in fisheries management (Finlayson et al., 2000).

2.1.2 Public Health and Water Quality

Millions of dollars were spent on research to determine safety of rotenone prior to registration by the U.S. Environmental Protection Agency (EPA). The EPA concluded that the use of rotenone for fish control does not present a risk of unreasonable adverse effects to humans and the environment when used according to label instructions. The National Academy of Sciences has suggested a safe level in drinking water of 0.014 ppm of rotenone. These safe levels assume a lifetime exposure to rotenone. For comparison, most rotenone treatments result in exposure levels within the range of 0.012 to 0.25 ppm of rotenone, but rotenone generally persists for no longer than a few weeks, making lifetime exposure highly unlikely. Tolerances for rotenone in drinking and irrigation water have not yet been established by EPA even though the studies required for setting tolerances have been completed. As a result, water containing residues of rotenone cannot be legally allowed for use as a domestic water source or on crops (Conover et al., 2007).

The hazard associated with drinking water containing rotenone is very slight because of the low concentration of rotenone used in the treatment (0.012 to 0.25 ppm of rotenone) and the rapid breakdown of rotenone. Estimates on the oral toxicity to humans are 0.023 to 0.039 ounces of rotenone per pound of body weight. Hence, a 160 pound person would have to drink more than 23,000 gallons of water treated at 0.25 ppm of rotenone at one time to receive an effect. Liquid rotenone formulations contain trace amounts of the carcinogen trichloroethylene (TCE) (Conover et al., 2007). However the TCE concentration in water immediately following treatment (less than 0.005 ppm of TCE) is below the level permissible in drinking water (0.005 ppm of TCE), and these levels dissipate within a few days (Conover et al, 2007).

The ability of rotenone to move through soil is low. Monitoring studies in ground waters adjacent to treatment areas have found no contamination associated with rotenone treatments (Conover et al., 2007).

2.1.3 Non-Target Species Impacts

Recent studies have revealed that the effects of rotenone on non-target species is far lower than originally believed. All animals including fish, insects, birds and mammals have natural enzymes in the digestive tract that neutralize rotenone, and the absorption of rotenone is inefficient. Fish (and larval forms of amphibians and aquatic invertebrates) are more susceptible because rotenone is readily absorbed directly into their blood through their gills. Studies have shown that amphibians and invertebrates will repopulate an area when rotenone neutralizes (Conover et al., 2007).

2.1.4 Registration Status

Rotenone is registered for use in the U.S. and Canada. Rotenone is readily available on the commercial market.

2.2 Antimycin

Target AIS: Asian Carp, Ruffe and Round Goby, Tench, Roach, Sea Lamprey

Antimycin is a general use fish toxicant (Marking 1992). It is a Restricted Use Pesticide registered by EPA for piscicidal uses. Derived as a fermentation product from *Streptomyces* mold, the chemical is applied directly to water to renovate recreational fish populations and to remove scaled fish from catfish fingerling and food-fish production ponds (EPA, 2007).

Antimycin is not just one compound; it has four major and four minor components. The manufacture of antimycin includes fermentation and refinement processes that affect its composition and quality. Some of the terms used to refer to antimycin are listed below (EPA, ECOTOX, 2011):

• Antimycin A
• Antimycin A1
• Antimycin A3
• 3-methylbutanoic acid 3-[[3-(formylamino)-2-hydroxybenzoyl]amino]-8-hexyl-2,6-dimethyl-4,9-dioxo-1,5-dioxonan-7-yl ester
• Isovaleric acid, 8-ester with 3-formamido-N-(7-hexyl-8-hydroxy-4,9-dimethyl-2,6-dioxo-1,5-dioxonan-3-yl) salicylamide
• Blastmycin

Fintrol is the formulation of antimycin currently registered and available in North America, sold in 240-mL volumes of a 23% concentrate (weight/weight) in acetone, with 240 mL of diluents (acetone-surfactant mix). The weight of active ingredient is very low because of its high potency. The concentrate and diluent are mixed just prior to application. The advantages of using antimycin are that it is rapidly biodegraded, it can be detoxified using potassium permanganate and fishes cannot detect the compound so they do not evade exposure (EPA, 2007).

2.2.1 Use and Application

Antimycin has two broad uses as a piscicide: fish management program use and aquaculture use. Environmental factors such as water body size, pH, temperature, and, in lotic environments, flow rate and gradient affect the amount of antimycin and number of application sites that must be used to achieve the desired concentration. Chemical treatments are expensive and treatment of large rivers is not logistically or economically feasible.

The compound is applied to water to achieve treatment concentrations up to 25 parts per billion (ppb) by a drip-feed device which is part of a drip station, or by backpack sprayer, boat bailer, or other hand-held sprayer. Drip stations are typically used in streams and rivers inaccessible to boat traffic. Backpack sprayers may be used to supplement drip stations or other application devices in areas with poor water circulation such as stagnant pools. Backpack sprayers are used in areas where water depth is 1 foot or less. Boat bailers are used in larger water bodies such as ponds and rivers. Deeper water bodies may require the use of a pump mechanism to ensure adequate mixing throughout the water column. Antimycin can be dispensed through a perforated hose stretching the length of the water column, or delivered through the boat's propeller wash using a pump mechanism. In aquaculture (catfish production), antimycin can be applied at concentrations up to 25 ppb to achieve a "complete kill" or at concentrations up to 10 ppb to achieve a "selective kill." Selective kills are performed after stocking fingerlings to eliminate only smaller or more sensitive species that compete for food and resources and may reduce the yields of commercial farmers (Conover et al., 2007).

Asian Carp, ruffed, tench, roach and round goby can be readily killed by antimycin. Ruffe are more sensitive to antimycin and rotenone than yellow perch, but similar in sensitivity to brown trout, so selective treatments with those compounds is unlikely (Boogaard et al,. 1996). A bottom release formulation of antimycin has been developed that could reduce concentrations of ruffed in deep water with minimal impact on non-target fishes, although this formulation is unregistered (Conover et al., 2007).

There have been rare instances in which this chemical has been used selectively. Burress and Luhning (1969) and Cumming (1975) used antimycin to remove scaled fish from production ponds without affecting channel catfish. Radonski (1967) used antimycin to eliminate yellow perch while leaving the remaining fish unharmed. Because bighead, grass, and silver carps are more sensitive to antimycin than channel catfish in production ponds, it is useful in aquaculture. The contact time required killing bighead, grass, and silver carps using rotenone and antimycin requires further investigation. No field testing in open waters has been conducted to specifically target bighead, grass, or silver carps; the sensitivity of black carp to antimycin and rotenone (Conover et al., 2007).

2.2.2 Public Health and Water Quality

Dietary and or recreational exposure to antimycin may occur by consuming, wading, or fishing, in treated water. Occupational exposure may occur by mixing, loading, or applying the product. Thus, fish cannot be harvest from the exposed area for 12 months after treatment. Drinking water intakes within the treatment area must be closed until monitoring samples demonstrate antimycin levels are below the limit of detection (0.015 μg/L). The area must also be restricted to public access for 7 days after treatment. The registrant must submit a detailed standard operating procedures manual. Because the toxicological effects of antimycin on humans cannot be estimated, the EPA made the conservative assumption that exposure from consuming treated water may pose risks of concern. To mitigate the potential risks, flowing water from treatment areas must be deactivated with potassium permanganate and any drinking water intakes within the treatment area must be closed during treatment and until monitoring samples demonstrate antimycin levels are below the limit of detection (0.015 ppb). Deactivation with potassium permanganate is also used to purify drinking water (Conover et al., 2007).

There is limited data available on the toxicity to humans (USEPA, 2007). Finlayson et al. (2002) identified conjunctivitis as a possible consequence when applying the treatment, and recommended the use of safety glasses when handling the product.

2.2.3 Non-Target Species Impacts

Treatments may adversely affect imperilled native species such as the federally endangered pallid sturgeon; and treatments would require public and regulatory agency support. Because treating waters with these chemicals to control wild Asian carps would require using concentrations that would also kill many native species, rotenone and antimycin should be considered for removing Asian carps only when sensitive native species are not present or are of insignificant concern (Conover et al., 2007).

In invertebrates, treatment concentrations of 25 ppb would exceed acute risk levels of concern. To ensure chronic exposure does not occur, deactivation with potassium permanganate is necessary to minimize exposure to non-target aquatic animals.

Where antimycin is used to remove scaled fish from aquaculture ponds, treatment concentrations are considerably lower than 25 ppb to ensure that the health/survival of the crop is not impaired. Therefore, the likelihood of either acute or chronic effects in non-target animals from the use of antimycin in aquaculture is low, particularly since the treated water is typically retained within the aquaculture facility (Conover et al., 2007).

Based on laboratory data, aquatic invertebrates and fish appear to demonstrate comparable sensitivity to antimycin. However, field studies in high-gradient mountain streams deactivated with potassium permanganate suggest that aquatic invertebrate populations are temporarily affected by antimycin. Sampling conducted several months to a year after treatment indicates that aquatic invertebrate abundance and diversity were similar to pre-treatment levels. Even in streams where antimycin was not deactivated with potassium permanganate, invertebrate drift and survival was not significantly affected during or immediately after 8-hr treatments at 10 ppb (Conover et al., 2007).

EPA estimated toxicity, exposure, and risk to avian and mammalian terrestrial organisms. Data were not available to evaluate the risk of antimycin exposure to non-target insects or terrestrial plants; however, given the ways in which antimycin is applied, exposure is expected to be minimal. At 25ppb Antimycin is moderately toxic to mammals following acute oral exposure; however, it is not likely it will be significant in their food sources (EPA, 2007).

2.2.4 Registration Status

Antimycin is registered only in the U.S., and would require a special permit for use in Canada. Antimycin was discovered in 1945 and was first registered as a fish toxicant in 1960 (Conover et al., 2007). Antimycin is primarily used to control Asian carp in the United States. In the US, there is one registered product that contains antimycin A (Fintrol-® Concentrate, EPA Registration Number 39096-2, Aquabiotics Corp.) (Ecotox, 2011). This product is classified as a Restricted Use Pesticide (RUP) due to aquatic toxicity and the need for highly specialized applicator training. Furthermore, the bottom release formulation is not registered and could only be used under emergency or experimental use permits.

Antimycin is not available on the commercial market and the supply is quite limited.

2.3 TFM and Bayluscide Piscicides

Target AIS: Ruffe, Round goby, and Tubenose goby

TFM and Bayluscide are registered piscicides in the U.S. TFM is a restricted use lampricides, and would require a special permit for use against ruffe, although a chemical may be applied in the U.S. "against any target pest not specified on the labelling if the application is to the ... site specified on the labelling" (Section 2(ee) of the U.S. Federal Insecticide, Fungicide, and Rodenticide Act). This would allow use in the U.S. waters of the Great Lakes at concentrations permitted for application against sea lamprey. Boogaard et al. (1996) concluded that treatment with TFM or Bayluscide could "control ruffe populations with limited adverse effects on native species". Higher concentrations of TFM would be required to eradicate ruffe than to eradicate sea lampreys (Boogaard et al., 1996) and thus is receiving authorization to use may be difficult. TFM is not available on the commercial market. TFM and Bayluscide may not be ideal for general use because there is a need to avoid using these chemicals in any way that may jeopardize Sea lamprey control.

2.4 Management Decisions: General Piscicides Benefits and Alternatives

Antimycin and rotenone (CAS Number 83-79-4, EPA PC Code 071003) are the only two broad spectrum piscicides registered in the United States and Canada. Antimycin and rotenone each appear to have niche uses, although both can be applied in a variety of situations. In general, antimycin is used to repopulate native, threatened, or endangered trout species in streams, by eliminating non-native fish species, particularly in high-altitude alpine lakes and streams because it is effective in cold alpine waters and where pH is low. In addition, this piscicide may be used at low concentrations, which makes it easy to transport to isolated or hard to reach mountain streams. Rotenone is most often used in standing water, such as large lakes and reservoirs. It is typically applied to improve or maintain sport fisheries, and to eliminate unwanted species in rearing ponds. The costs of rotenone and antimycin A are similar. For water bodies requiring partial or complete kill of certain fish species, rotenone and antimycin are effective.

Although some uses of rotenone and antimycin coincide, they are not direct replacements for each other. Antimycin is more toxic than rotenone and, because of the smaller quantities required, is sometimes preferred for use in remote locations not accessible by vehicles (i.e. foot or helicopter access only). Depending on the fish species, antimycin is up to 10 times more toxic and requires shorter contact times than rotenone (6 h versus 18 h) (Finlayson et al., 2002).

There are a variety of unregistered general and selective piscicides as provided in Table 2.

Table 2. List of Registered and Un-Registered Piscicides

Registered Piscicides	
General Piscicides	Rotenone Antimycin
Selective Piscicides	TFM Bayluscide®

Unregistered Piscicides		
General	Ammonia	Ozone
	Aqualin	Phostoxin®
	Baythroid®	Polychlorpinene
	Bleaching powder and urea	Potassium permanganate
	Calcium hypochlorite	Salicylanilide I
	Copper sulphate	Saponins
	Croton seed powder	Sodium cyanide
	Cunaniol	Sodium fluoride
	Dieldrin	Sodium hydroxide
	Endosulfan	Sodium nitrite
	Endrin	Sodium pentachlorophenate
	Juglone	Sumithion®
	Lime	Tobacco waste
	Limil	Toxaphene
Selective Piscicides	DANEX-80	
	DDVP	
	Dibrom®-malathion	
	Euphorbia antiquorum extract	
	GD-174	
	Guthion®	
	Malathion	
	Phosphamidon	
	Sodium sulfite	
	Squoxin	
	Thanite	
	Toxaphene	
Toxic Baits	Rotenone	
	Antimycin	
	Calcium carbide	
	Ichthyothereol	

3.0 Lampricides

Lampricides are chemicals designed to target the larvae of lampreys in river systems before their recruitment as parasitic adults. Common use lampricides include 3-trifluoromethyl-4-nitrophenol (TFM), and Bayluscide, registered piscicides Antimycin and Rotenone can also be affective in eradicating lampreys. Lampricides can be problematic for amphibians such which often share the same habitats. Also, some more "primitive" species of fish, such as the Sturgeon in the Great Lakes are sensitive to chemicals such as TFM.

Table 3 provides the names and types of lampricides.

Table 3. List of Common Use Lampricides

Lampricides	
TFM	Sea Lamprey Larvicide TFM Bar
Bayluscide	Bayluscide® Wettable Powder Bayluscide® Granular Sea Lamprey Larvicide Bayluscide® Emulsifiable Concentrate
Antimycin	Fintrol® Concentrate Fintrol® Granular Antimycin
Rotenone	Rotenone 5% and Rotenone 2.5% Synergized Liquid Powdered Rotenone 5-7.5%
Toxic Baits	Antimycin Impregnated Bait Rotenone Impregnated Bait Calcium Carbide Impregnated Bait

3.1 TFM (3-trifluoromethyl-4-nitrophenol)

Target AIS: Sea Lamprey, Ruffe

A search for a selective larval lampricide began in 1951. Over the next 7 years more than 6,000 chemicals were screened for selective toxicity and 3-trifluoromethyl-4-nitrophenol (TFM) was identified as the most effective (Applegate et al., 1961). The sea lamprey control program, administered by the Great Lakes Fishery Commission, has involved the use of TFM since 1958 (Howell et al., 1961). About 175 Great Lakes streams are treated at regular intervals with TFM to kill larval sea lampreys.

3.1.1 Use and Application

The toxicity of TFM to sea lampreys and other aquatic organisms is influenced by alkalinity, pH, turbidity, temperature, dissolved oxygen, and the presence of other toxic substances (Dawson et al., 1975; Marking and Bills, 1985). Because toxicity is strongly correlated to alkalinity and because alkalinity is quite stable in any given stream, alkalinity measurements have been widely used to help predict the concentrations of lampricides needed to effectively treat a stream.

Through biological assessments and careful TFM use, the Great Lakes Fishery Commission and its agents have successfully reduced sea lamprey populations in the Great Lakes by 90%. Sea lampreys are most vulnerable during their larval stage. Because TFM is effective when it is used to target larval sea lampreys in streams, TFM is applied to streams, not to the open waters of the Great Lakes (Seelye, n.d.). Despite the success of TFM, it is a costly control method. In recent years the combination of improved analytical and predictive techniques has allowed treatment crews to reduce lampricide concentrations by about 20% (Seelye, n.d.).

3.1.2 Public Health and Water Quality

TFM is not harmful to humans or other mammals at the concentration applied. TFM does not bioaccumulate in the aquatic environment and it breaks down in a matter of days.

3.1.3 Non-target Species Impacts

In the sea lamprey control program, TFM cause some mortalities of Oligochaeta and Hirudinea, immature forms of Ephemeroptera, and certain Trichoptera, Simuliidae, and Amphibia. The combination of TFM and Bayluscide may affect some Pelecypoda and Gastropoda, but its overall effects on invertebrates are probably less than those of TFM alone (Busiahn, 1996). The dose needed to eliminate sea lampreys, TFM is nontoxic or has minimal effects on aquatic plants, other fish, and wildlife (Seelye, n.d.). Extensive and controlled laboratory testing has shown a considerable variability in sensitivity to TFM amongst non-target species. Among the 15 teleosts examined by Boogaard et al. (2003), the most sensitive were members of the catfish family, Ictaluridae (black bullhead, channel catfish, tadpole madtom). This group has a similar sensitivity to TFM as juvenile white sturgeon and are killed by TFM concentrations ranging from 1.3 to 1.7 sea lamprey MLC. Adult mudpuppies are also in this category. Salmonids (rainbow trout, brown trout, lake trout, Atlantic salmon) are less sensitive and can be killed at concentrations 3–5 MLC. The least sensitive groups are the Centrarchidae (bluegill, green sunfish, smallmouth bass), and the Percidae (yellow perch) which are killed at TFM concentrations 6–8 MLC. In these studies all fish tested were young-of-the-year juveniles (1–2 g body mass) while the mudpuppies were adults. An earlier study on the toxicity of TFM to bullfrogs (Kane et al., 1993) showed that larvae are about 10 times more sensitive than adults. In this study the authors attributed their result to greater uptake of TFM from the water by larvae than adults.

The impact on non-target species can be reduced by closely controlling the concentration of TFM applied and by applying TFM during the right season (after the spawning run, for instance). In the Great Lakes, long term studies have shown no traces of TFM in fish even in cases where several treatments had been made in streams tributary to the lakes in which the fish were caught (Seelye, n.d.).

The most recent changes in treatment philosophy have emphasized the protection of sensitive and/or endangered species. A species particularly vulnerable to TFM is the endangered species the lake sturgeon (Acipenser fluvescens) which in its early life stages (< 10 mm length) is actually more sensitive to TFM than sea lamprey larvae of similar size.

3.1.4 Registration Status

TFM (3-trifluoromethyl-4-nitrophenol) is a selective lampricide approved for use in the United States by the USEPA to control sea lamprey in the Great Lakes and Lake Champlain. This compound is also registered as a lampricide by the Agriculture Canada and has met or surpassed all criteria for application in Great Lakes streams.

TFM is a restricted use lampricides, meant only for use against lamprey in Canada.TFM is not available on the commercial market, but is produced only for the Great Lakes Fishery Commission for sea lamprey control under contract with two suppliers.

3.2 Bayluscide®

Target AIS: Sea lamprey, ammocoetes, mud snails, ruffe, and round goby

The Great Lakes Fishery Commission has used 2',5-dichloro-4-nitrosalicylanilide (Bayluscide or Bayer 73) since 1963 (Howell et al., 1964). Bayluscide can be used as an additive to TFM that increases the effectiveness of TFM as a lampricide. This chemical, used either singly or in combination with TFM, decreases the sea lamprey population to levels that permit acceptable survival of lake trout and other valuable fishes in the Great Lakes (Seelye et al., n.d.)

Worldwide, however, niclosamide is used primarily as a molluscicide (WHO, 2003) and is recommended by WHO for control of schistosome-bearing snails' (WHO, 2003), because of its high toxicity to aquatic snails (Tchounwou et al., 1991). It is also used as an antihelminthic in humans, livestock and pets (WHO, 2003).

3.2.1 Use and Application

In areas where TFM is not effective (i.e., the St. Mary's River and in lentic areas), a different lampricide-granular Bayluscide-is used. Granular Bayluscide is a time-released lampricide that coats a grain of sand. The lampricide is applied to sea lamprey larval "hot spots" and dissolves above those spots to remove the larvae (Seelye, n.d.).

Niclosamide is 100% lethal to larval sea lamprey at 0.06–0.15 mg/L, depending on water hardness and is more toxic to free-swimming adult sea lamprey (adults), than burrowed sea lampreys (larvae) (Nettles et al., 2001). WHO (2003) recommends that: 'For environmental applications against snails 0.6–1.0 mg/L is effective.

Delayed-release and/or pelleted formulations of Bayluscide® are available and have been used in the USA to selectively reduce populations of bottom-associated fish species such as the round goby (Neogobius melanostomus). Avoidance response tests indicated that the round goby was unable to detect the compound (Schreier et al., 2001). Also, research on minimum effective contact times indicated that exposure to Bayluscide® for a few minutes is lethal to the round goby (Schreier et al., 2001).

3.2.2Public Health and Water Quality

Given the limited use and tight control maintained by the U.S. Fish and Wildlife Service during applications of lampricides, Bayluscide presents minimal risk to human health and safety of the environment. Niclosamide is relatively non-toxic to humans. Occasional gastrointestinal upset is the only side effect reported (WHO, 2003). Skin irritation is sometimes reported in workers applying niclosamide, but this is thought to be caused by formulation ingredients other than niclosamide (WHO, 2003).

Niclosamide (2′, 5-dichloro-4′-nitrosalicylanilide), the active ingredient of Bayluscide, degrades rapidly in natural water and sediment systems, however, the rate of degradation is very slow in autoclaved samples. This difference suggests that degradation under laboratory conditions is dependent on microbial activity and hydrolysis plays a minor role in degradation of niclosamide. The major degradation product of niclosamide has been reported to be aminoniclosamide (2′,5-dichloro-4′-aminosalicylanilide), which represented more than 50% of the residues extractable from sediments (Boogaard et al, 2003). Significantly more of the chemical is adsorbed to sediments with higher organic content and at lower pH's.

3.2.3 Non-Target Species Impacts

The toxicity to sea lampreys and other aquatic organisms is influenced by alkalinity, pH, turbidity, temperature, dissolved oxygen, and the presence of other toxic substances (Dawson et al., 1975; Marking and Bills, 1985). Doses of Bayluscide® used to kill sea lampreys can also kill rainbow trout under certain water quality conditions (Nettles et al., 2001). Salmonids are also more susceptible than other species (Nettles et al., 2001). Niclosamide is toxic to all fish species at 0.5 mg/L and to zooplankton and aquatic vegetation at higher concentrations (WHO, 2003). In general, hard-bodied invertebrates such as insect larvae and crustaceans are much less susceptible to niclosamide than the soft-bodied invertebrates such as molluscs, leeches, and annelid worms (Nettles et al., 2001).

The uptake of residues by most invertebrates exposed to niclosamide is fairly rapid and equilibrium is reached within 24 hours. About 90% of the accumulated residues were lost within 48 hours after the organisms were transferred to clean flowing water. As with invertebrates, fish rapidly accumulate and eliminate residues of niclosamide. Three distinct residues were isolated from the extracts of edible fillet tissue; parent niclosamide, the glucuronide conjugate of niclosamide, and the sulphate ester of niclosamide (Clearwater et al., 2008).

Aquatic plants and agricultural crops do not appear to be adversely affected. Bayluscide was originally developed as a molluscicide to eliminate snails. Therefore, molluscs are extremely sensitive to Bayluscide (Boogaard et al., 2003).

Oral, dermal, and ocular administration of Bayluscide to mammals resulted in no clinical signs of systemic toxicity. Tests of the chronic effects of Bayluscide indicated that it is not mutagenic or carcinogenic. Bayluscide is not persistent in the environment; it breaks down in natural water and sediment systems (Clearwater et al., 2008).

Granular Bayluscide is likely to induce mortalities among oligochaetes, microcrustaceans, chironomids, and pelecypods, however, no evidence exists that the lampricides have caused the catastrophic decline or disappearance of any species (Gilderhus and Johnson, 1980).

3.2.4 Registration Status

Bayluscide® is currently registered for use in the United States by the USEPA. It is a selective piscicide that is registered only for use to control sea lamprey in the Great Lakes and Lake Champlain.

It must be noted that registration for Bayluscide 5% granular molluscicide Bayluscide 5% granular molluscicide has been cancelled, and only Bayluscide 70% wettable powder--sea lamprey larvicide Bayluscide 70% wettable powder--sea lamprey larvicide is registered and only for restricted use.

3.3 Management Decisions: General Lampricides Benefits and Alternatives

In most cases TFM and Bayluscide are used together to increase effectiveness of sea lamprey control. Bayluscide can be used as an additive to TFM that increases the effectiveness of TFM. These chemical, used either singly or in combination, decreases the sea lamprey population to levels that permit acceptable survival of lake trout and other valuable fishes in the Great Lakes

4.0 Molluscicides

Several chemical treatments provide some control of snails and mussels with limited effects on fish (Terhune et al., 2002). TFM and Bayluscide are effective chemical control methods to eradicate snails and mussels, they will be briefly mentioned here, however, specific details are available under lampricides. This section will discuss liming, chlorination, and a new biocide, Zequanox. Copper sulphate is another control option, however most literature has discarded it as a management tool due to its ecological effects and as such it will not be included in discussion.

4.1Bayluscide and TFM molluscicides

In 1963 the molluscicide niclosamide (Bayluscide®) was found to be selectively toxic to ammocoetes, in mixtures with TFM as well as alone (Howell et al,. 1964). Formulated for bottom release, niclosamide is used to treat slow moving waters where TFM is largely ineffective. Because of its irritant properties, niclosamide stimulates molluscs to come out of their burrows. Details of TFM and Bayluscide effects on public health, water quality, non-target species effects and registration status are available in section 3.1 and 3.2.

4.2 Lime

Target AIS: grass carp, rudd, and tench

Formulations of lime include calcium carbonate ($CaCO_3$) also called limestone, calcium oxide (CaO), commonly called quicklime or burnt lime and calcium hydroxide ($Ca(OH)_2$) known as hydrated lime or slaked lime. $Ca(OH)_2$ is preferred for pest control operations (Clearwater et al., 2008).

Lime addition is used to increase the pH and alkalinity of water or soils to lethal concentrations for the target organisms (Clearwater, 2006). The most likely mechanism of toxicity is that extreme changes in water chemistry cause direct physical damage to the gills of most aquatic organisms and disrupt respiration and iono-regulation. Macrophytes will also be physically damaged by extreme alkalinity (Piper et al., 1998).

4.2.1 Use and Application

Lime can be applied to the dried pond bottom or the water surface. When used to eradicate pest aquatic organisms it is added as hydrated lime to water at high applications rates sufficient to increase pH > 2 for 4–5 days (Clearwater, 2006). More moderate applications of lime are used to manipulate pond water and soil chemistry to enhance aquaculture operations (Boyd and Tucker, 1998; Mazik and Parker, 2001; Wedemeyer, 2001).

Liming is a non-specific treatment and will kill most aquatic organisms present; therefore this approach is appropriate only in water bodies where it is acceptable to completely disrupt the aquatic ecosystem such as small, enclosed human-made ponds with limited outflow.

Lime application at low rates causes minor to moderate changes in soil and water chemistry and is known as ‘pond conditioning’. Liming with limestone is used to increase the pH of acidic soils and enhance organic decomposition. Limestone is less soluble than other forms of lime and therefore changes pond chemistry slowly, with less risk to the aquaculturist. Increased alkalinity will stabilise the pH of pond water, which can vary from pH 6 to pH 10 during the day if the alkalinity is less than 20 mg $CaCO_3$/L (Wurts and Masser, 2004).

At high application rates, burnt lime or hydrated lime (which is more soluble than limestone) can be used to ‘disinfect’ ponds by temporarily increasing soil or water pH and alkalinity to levels sufficient to kill any parasites and disease micro-organisms present (Piper et al., 1998). However, some pathogens, including those that cause human disease, are not be affected by high pH (Mazik and Parker, 2001).

Lime can also be used to eradicate aquatic pest species, by application at exceedingly high rates to increase the pH of pond water to lethal levels (Clearwater, 2006). In order to be effective against most aquatic species the pH must be increased to pH 12 for at least 24 h, as some species, are resistant to exposures of 12 hours to water with a high pH (> 9.5).

Lime may also be ineffective against organisms that can avoid or limit their exposure (e.g. by burrowing). Macrophytes will probably be killed or damaged by these extreme liming treatments (Piper et al., 1998). Burnt and hydrated lime are more soluble than limestone and thus are preferable when a rapid change in pH and alkalinity is required. Burnt lime is more soluble, but also more caustic than hydrated lime (Clearwater, 2006).

The use of lime to eradicate aquatic pests has not been systematically studied, thus the effect of factors such as application rate, the exposure time required to kill pest species, pest species resistance, and recovery rates of treated water bodies are unknown (Clearwater, 2006).

Liming has been used in success eradication against gambusia, goldfish, grass carp, gudgeon, koi carp, rudd, and tench (Dykzeul and Young, 2001; IFS 2003; David, 2003; Barnes, 2005).

Eradication attempts of crustaceans (marron and yabbies) were less successful as they were resistant when pH was < 12. These results led to the recommendation that in order to ensure the effective eradication of all pest organisms the pH should be increased to pH 12 for at least 24 h or for 4–5 days if resistant species are present. The pH and alkalinity can be measured and used to determine when to restock (Clearwater, 200).

4.2.2 Human Health and Water Quality

Burnt lime and hydrated lime are much more soluble in water than limestone and therefore are used in liming operations when pond sterilisation and pest eradication are the goals (Boyd & Tucker, 1998). However, burnt lime is a strongly caustic agent which may cause severe irritation of the skin and mucous membranes (Budavari et al., 1989); therefore, from a human health perspective most operators will prefer to work with hydrated lime (rather than burnt lime).

Hydrated lime can also irritate the skin and mucous membranes but is significantly less caustic and reactive than burnt lime. In addition, burnt lime is more unstable than hydrated lime and will absorb CO2 and water from air; therefore, it must be stored in dry, air-tight conditions. Personal protective equipment is required when handling burnt or hydrated lime.

The major advantage of using lime for pest eradication is that even though high application rates of lime will have a large impact on a water body, lime is not considered a persistent toxin (especially by the general public), even though its effects could last for months. Lime is a naturally occurring compound, consisting of some of the most abundant elements on earth, in compounds that are highly abundant (Boyd and Tucker, 1998). However, liming of eutrophic waters can cause precipitation of phosphorus; which will remain on the sediment after treatment (Wang et al., 2005).

4.2.3Non-Target Species Impacts

Lime is a general toxicant. The majority of aquatic animals, including macrophytes would be killed by caustic injury to the gills and other delicate respiratory and dermal surfaces, which is likely to inflict pain and it is recommended that a cautious approach is taken.

As liming is likely to inflict pain, most fishes and large invertebrates should be removed from the water body prior to lime treatment so that the pest species can be sorted out and euthanized. The high pH will also be dangerous to other organisms (e.g. birds) until it is reduced; and as such access to the treated water body will have to be prevented. Decaying organic matter resulting from lime treatment could cause anoxic conditions in the treated water body. As pH and alkalinity may not decrease to acceptable levels for an extended post-treatment period, it may be necessary to dilute the water or neutralise pH and alkalinity (Clearwater, 2006).

4.2.4 Registration Status

All formulations of Lime mentioned above are EPA approved. Numerous formulations of lime are approved by Health Canada Pesticide Regulatory Management Agency.

4.3 Chlorination

Target AIS: zebra mussels, spiny waterflea

Chlorination effects can be provided by a range of compounds—the hypochlorites of sodium, potassium, or calcium; chlorine and chlorine dioxide gases; and sodium chlorite—and their toxic properties can be used to control zebra mussels and related nuisance mollusc species.

The cost-effective oxidizing activity of chlorine has made it the most commonly used compound for all types of water disinfection and biofouling control in North America, and it has been used in potable water treatment since the beginning of the 1900's (Van Benschoten et al., 1993).

4.3.1Use and Application

Chlorination, primarily via sodium hypochlorite, has dominated the chemical control of zebra mussel in both Europe and North America, and remains the least expensive and most popular method of removal. Chlorine is able to kill or prevent settling of planktonic veliger larvae in raw water piping systems. In general, chlorine treatment for zebra mussel control should be applied at the most suitable time, for the shortest period, and at the lowest concentration to be efficacious (Jenner and Janssen-Mommen, 1993). However, adult mussels will close at concentrations of from 1 to 2 mg/L and remain closed for up to 2 weeks. Concentrations >2 mg/L of chlorine would effectively kill mussels as well as eliminate eggs and larvae of common carp and rainbow smelt.

4.3.2 Public Health and Water Quality

Chlorine is non-persistent in water and has potential for use in reclamation of water supply reservoirs where other toxicants may be forbidden. The ease of neutralizing chlorine with sodium thiosulfate is an additional advantage. Chlorination under certain conditions can result in formation of deleterious by-products, and its release into the environment is closely regulated by a number of states. There has been concern that the cumulative effects of extensive chlorine use for zebra mussel control in large rivers in North America could be problematic due to toxicity to non-target organisms and formation of trihalomethanes. Chlorination byproducts—"chlorinated hydrocarbons"—cause a wide range of reproductive, developmental, and behavioural dysfunctions, including miscarriages, birth defects and cancers. Although chlorine discharge into natural water bodies is already regulated, it is possible that it may be prohibited or severely restricted in the future. However, to date, these products provide the most effective and low-cost control in the majority of situations (United States Environmental Protection Agency, 1999).

4.3.3 Non-Target Impacts

Chlorine has a high acute toxicity to aquatic life, with concentrations as low as 0.29 parts per million killing trout and 0.71 to 0.82 ppm killing sunfish.

Chlorination by-products formed by the reaction with organic material have been associated with cancer in animals.

4.3.4 Registration Status

Chlorine oxide and chlorine dioxide are approved for use by the EPA. Numerous chlorine containing compounds and sodium hypochlorate compounds are approved for use in Canada as well as many other oxidizing agents that can be used.

The International Joint Commission has called for a phase out of the production and use of chlorine and chlorine-containing compounds due to the carcinogenic risks.

4.4 Zequanox

Target AIS: zebra mussels, quagga mussels

Extensive laboratory screening trials of more than 700 bacterial strains identified a North American isolate, strain CL145A of *Pseudomonas fluorescens*, to be lethal to Zebra and Quagga mussels. Of the strains that have been laboratory tested, only *Pf*-CL145A has been found to be highly lethal, i.e., at dosages that produce >90% adult zebra and quagga mussel kill and 100% larval kill. *Pseudomonas fluorescens* is worldwide in distribution and is present in all North American water bodies. In nature, it is a harmless bacterial species that is found protecting the roots of plants from plant diseases. New York State Museum research has shown that the *Pf*-CL145A strain of this species may be used to control *Dreissena* species (Molloy, 2002). A patent for this purpose has been issued in both the United States (Molloy, 2001) and Canada (Molloy, 2004). Commercial products have been developed by Marrone Bio Innovations which are marketed as Zequanox®, and contain dead cells, thus further reducing environmental concerns (Marrone Bio Innovations, 2010).

4.4.1 Use and Application

When a zebra or quagga mussel ingests artificially high densities of Pf-CL145A, compounds within these bacterial cells destroy the mussel's digestive system. Dead cells are equally as lethal as live cells, providing clear evidence that the mussels die from natural compounds not from infection (Marrone Bio Innovations, 2010).

4.4.2 Non-Target Species Impacts

Research trials have shown that Zequanox is quite effective at controlling invasive mussels. Toxicology tests have demonstrated it is safe to mammals, to the environment and to important native, aquatic species. Research trials have proven Zequanox to be safe for important aquatic species (Marrone Bio Innovations, 2010) including, but not limited to:

- water fleas, Daphnia
- freshwater shrimp, Hyalella
- native blue mussel, Mytilus and native freshwater clams
- fathead minnows
- mallard ducks
- brown trout
- sunfishs

4.4.3Registration Status

In 2007, Marrone Bio Innovations entered into a commercial partnership with the New York State Museum. The Ontario Ministry of the Environment and Health Canada's Pest Management Regulatory Agency as well as the US EPA are currently reviewing the product for approval.

Final regulatory approval of Zequanox in both the US and Canada is anticipated in 2011 (Rackl, P. Communication).

4.5 Management Decisions: General Molluscicides Benefits and Alternatives

Hydrated lime, copper sulphate, and copper sulphate with citric acid can be effective in eliminating snails that live along pond margins (Conover et al., 2007). Bayluscide®, rock salt (NaCl), and copper sulphate can be effective options for treating some whole ponds (Kelly, 2000). Hydrated lime and copper sulphate cannot be used in ponds with low alkalinity and Bayluscide can only be used to control snails in ponds with no fish (Terhune et al., 2003). Moreover, these compounds are not approved for use as a molluscicide. Therefore, it is not legal to use these for snail control (Conover et al., 2007).

Liming of a water body to eliminate aquatic pest species is a non-specific treatment option best suited for artificial environments such as human-made ponds and aquaculture. A lime treatment would cause significant disruption to a natural water body, including the requirement to decrease water volumes pre-treatment and to net and trap most fishes or large invertebrates. This negatively effects of this disruption would have to be weighed against the benefits of the elimination of a pest species.

Chlorine has a number of important advantages: it is relatively inexpensive, it works in most raw water systems, it is toxic at low concentrations and quickly loses toxicity without bioaccumulating, and it can be applied with simple mechanisms. However, there are several drawbacks to the chlorination process. The transport and storage of gaseous or liquefied chlorination products involve hazards, and their corrosive properties can harm system components, so that they all require special handling. Discharge also presents problems because carcinogenic trihalomethanes may be formed where organic compounds are present in water. Adsorbable organic halides (AOX) may also be formed, but do not present risks. Differences in water quality may incur extra costs where discharge concentrations may be unpredictable due to varying chlorine demand.

Once Zequanox is fully registered it will be an effective technique for mussel control. It is a new biocide, using natural components which are safe for the surrounding environment. A list of other oxidizing and non-oxidizing molluscicides is available in Table 4.

Table 4. List of Oxidizing and Nonoxidizing Molluscicides, from US Army Zebra Mussel Chemical control Guide.

Chlorination	
Nonchlorine Oxidizing Chemicals	Bromine ACTI-BROM Potassium Permanganate CAIROX ZM
Nonoxidizing Molluscicides	Quaternary and Polyquaternary Ammonium Compounds BULAB 6002 Calgon H-130M CLAM-TROL

	MACROTROL 9210 VeliGON Aromatic Hydrocarbons BULAB 6009 MEXEL 432 Endothall EVACä Metals and Their Salts Copper Ions MacroTech Potassium Compounds

5.0 Herbicides

Aquatic herbicides are chemicals specifically formulated for use in water to kill or control aquatic plants. Aquatic herbicides are sprayed directly onto floating or emergent aquatic plants or are applied to the water in either a liquid or pellet form. Systemic herbicides are capable of killing the entire plant. Contact herbicides cause the parts of the plant in contact with the herbicide to die, but leaving the roots able to re-grow. Non-selective, broad spectrum herbicides will generally affect all plants that they come in contact with. Selective herbicides will affect only some plants (often dicots - broad leafed plants like Eurasian watermilfoil will be affected by selective herbicides whereas monocots like Brazilian elodea may not be affected). Most aquatic plants are monocots.

In some cases, non-toxic dyes or colourants can be used to prevent or reduce aquatic plant growth by limiting sunlight penetration, similar to fertilization. These products include Aquashade, Blue Springs, and Crystal Blue and other products are available (AgriLife Communications, 2011). However, dyes do not enhance the natural food chain and may suppress success of the pond and thus are not discussed in this report.

5.1 Fluridone

Target AIS: Eurasian watermilfoil, curly-leaf pondweed, elodea, and hydrilla

Fluridone is a systemic herbicide. It was discovered in the mid-1970s and was soon shown to be effective for the control of submersed plants. This herbicide was registered by the EPA for use in water in 1986. Fluridone is a carotenoid pigment inhibitor; loss of carotenoids in plants allows ultraviolet light to destroy chlorophyll, thus killing the plant by starving it. It does not control algae. This aquatic herbicide is available as liquid and as slow- and fast-release pellet formulations. Trade names for fluridone products include Sonar®, Avast, and Whitecap® and come in liquid and granular formulations (AgriLife Communications, 2011). These are broad spectrum, systemic herbicides. Systemic herbicides are absorbed and move within the plant to the site of action.

5.1.1 Use and Application

Fluridone is a slow-acting systemic herbicide used to control Eurasian watermilfoil, curly-leaf pondweed, elodea and other underwater plants. It may be applied as a pellet or as a liquid. Fluridone is effective on submersed plants where there is little water movement and an extended time for the treatment. Its use is most applicable to whole-lake or isolated bay treatments where dilution can be minimized. It is not effective for spot treatments of areas less than five acres. It is slow-acting and may take six to twelve weeks before the dying plants fall to the sediment and decompose. When used to manage Eurasian watermilfoil, fluridone is applied several times during the spring/summer to maintain a low, but consistent concentration in the water.

Granular formulations of fluridone are effective when treating areas of higher water exchange or when applicators need to maintain low levels over long time periods. Although fluridone is considered to be a broad spectrum herbicide, when used at very low concentrations, it can be used to selectively remove Eurasian watermilfoil (AgriLife Communications, 2011).

Fluridone application rates for plant control are much lower than are those for other herbicides: µg/l (ppb) compared to mg/l (ppm). However, contact time required to control target weeds is measured in weeks or months rather than hours or days. Fluridone concentrations in the water must remain for 45-80 or more days for optimum long term control of hydrilla. Fluridone controls a broad spectrum of aquatic plants, but can be somewhat selectively used based on timing of application. Late winter or early spring fluridone treatments seem to provide the best selectivity for hydrilla control, as hydrilla begins robust growth while most non-target native plants are still dormant (AgriLife Communications, 2011).

It is typically applied to the whole water body because it requires a contact time of 45 days to be effective. The labels permit single treatments of up to 90 ppb for whole lake treatments and 150 ppb for partial lake treatments, with a maximum cumulative application of 150 ppb per growth cycle (EPA, 2004).

5.1.2 Public Health and Water Quality

The drinking water risks were calculated for both fluridone and its major degradate because fluridone degrades to N-methyl Formamide (NMF) in water. All drinking water exposures are below the EPA's level of concern. There is a possibility that swimmer exposures could occur following fluridone applications to recreational lakes, however, all swimmer exposure estimates are low and does not occur on a long-term basis. All of the aggregate risks from dietary, drinking water including metabolites, and recreational exposures to fluridone are below the EPA's level of concern and no risk mitigation is required (EPA, 2004).

Fluridone is a Toxicity Category III for acute dermal and eye irritation, and Toxicity Category IV for acute oral, acute inhalation and dermal irritation. There was no indication of reproductive or neurotoxicant effects from fluridone in the reviewed studies. Fluridone is classified as not likely to be carcinogenic to humans (EPA, 2004).

5.1.3 Non-Target Species Impacts

Some native aquatic plants, especially pondweeds, are minimally affected by low concentrations of fluridone. Fluridone has a half-life in water of approximately 20 days; much longer but highly variable in sediments. This herbicide does not accumulate in fish or zooplankton and does not affect algae. It has a low toxicity to fish (EPA, 2004).

5.1.4 Registration Status

Fluridone is both registered by Canada and the U.S.

5.2 2-4-D

Target AIS: Eurasian watermilfoil

There are two formulations of 2,4-D approved for aquatic use. The granular formulation contains the low-volatile butoxy-ethyl-ester formulation of 2,4-D (Trade names include AquaKleen®, Weeder64 and Navigate®). The liquid formulation contains the dimethylamine salt of 2,4-D (Trade names include DMA*4IVM).

5.2.1 Use and Application

2,4-D is a relatively fast-acting, systemic, selective herbicide used for the control of Eurasian watermilfoil and other broad-leaved species. Both the granular and liquid formulations can be effective for spot treatment of Eurasian watermilfoil. 2,4-D has been shown to be selective to Eurasian watermilfoil when used at the labelled rate, leaving native aquatic species relatively unaffected. By court-order the butoxy-ethyl-ester formulation of 2,4-D cannot be used in waters with threatened and endangered salmon-bearing waters in the Pacific Northwest.

The principal use is for the control of broad leaf weeds in crops but also for the control of aquatic weeds. In the US where it was the third most used pesticide in the early to mid 1990s, over 31,000 tonnes of 2,4-D was used annually (Bureau of National Affairs, 1993).

5.2.2 Public Health and Water Quality

2,4-D is a WHO Class II 'moderately hazardous' pesticide. It has a lethal dose of 50% at 375mg/kg in the rat suggesting a similar level of toxicity in humans (WHO, 1996).

Occupational exposure to 2,4-D has produced serious eye and skin irritation. Other symptoms of 2,4-D poisoning include nausea, weakness and fatigue, and in some cases neurotoxic effects including inflammation of nerve endings (Cornell University, 1994). Some medical reports describe victims of acute exposure to 2,4-D having severe and sometimes long lasting or even permanent symptoms. These include diarrhoea, temporary loss of vision, respiratory tract irritation, confusion, numbness and tingling, bleeding and chemical hypersensitivity (Shearer, 1990).

Phenoxy acid herbicides have been linked with soft tissue sarcomas, but the Canadian authorities have concluded that data do not suggest a positive link with 2,4-D (Interdepartmental Executive Committee on Pest Management, 1994). However, the International Agency for Research on Cancer (IARC) has classified 2,4-D among as a class 2B carcinogen-possibly carcinogenic to humans (WHO, 1987), concluding that there was limited evidence in humans and animals.

2,4-D has also been classified as an endocrine disrupter, and significant chromosomal damage occurred in human cells cultured in the presence of 2,4-D.

2,4-D has low soil sorbtion and a high potential for leachability. It has been detected in groundwater supplies in a number of US States and in Canada. Its high potential for water contamination has led to the inclusion of 2,4-D in the EC Priority Candidate List of chemicals to be considered for inclusion among the chemicals most tightly controlled to prevent water pollution.

5.2.3 Non-Target Species Impacts

Some formulations of 2,4-D are highly toxic to fish. Aquatic invertebrates do not in general seem to be very sensitive to 2,4-D. Moderate exposure of honey bees to 2,4-D severely impaired reproduction. Toxicity to birds is low to moderate (EPA, 2003).

Long term exposure to 2,4-D can affect different animals in a wide variety of ways. Rats for example were found to be largely unaffected when fed moderately large amounts in their diet over long periods, although signs of kidney pathology were demonstrated. Dogs however died when fed smaller amounts over shorter periods (EPA, 2003).

5.2. 4Registration Status

2-4-D is both Canada and US approved.

5.3Triclopyr-TEA

Target AIS: Eurasian watermilfoil, purple loosestrife

A trade name for triclopyr is Renovate3®. There are two formulations of triclopyr. It is the TEA formation of triclopyr that is registered for use in aquatic or riparian environments.

Triclopyr is a chloropyridinyl compound herbicide used against woody and herbaceous weeds. Most triclopyr is sold as a triethylamine salt (abbreviated TEA) or butoxyethyl ester (abbreviated BEE) derivative of the parent chemical, triclopyr acid. Triclopyr is sold under names such as Access, Crossbow, ET, Garlon, Grazon, PathFinder, Redeem, Rely, Remedy, and Turflon. It is often mixed other herbicides like 2,4-D to target a greater range of plant pests.

Renovate is a liquid triclopyr formulation that is effective on Eurasian watermilfoil. It is a selective broadleaf, systemic herbicide. Systemic herbicides are absorbed and move within the plant to the site of action. Systemic herbicides tend to act more slowly than contact herbicides. An aquatically registered surfactant will improve the effectiveness of triclopyr.

5.3.1Use and Application

The triclopyr formulation, Renovate, is specifically labelled for use in and around standing water sites, such as marshes, wetlands and the banks of ponds and lakes.

Triclopyr, applied as a liquid, is a relatively fast-acting, systemic, selective herbicide used for the control of Eurasian watermilfoil and other broad-leaved species such as purple loosestrife. Triclopyr can be effective for spot treatment and is relatively selective to Eurasian watermilfoil when used at the labelled rate. Many native aquatic species are unaffected by triclopyr.

Triclopyr is very useful for purple loosestrife control since native grasses and sedges are unaffected by this herbicide. Death of plants treated with triclopyr occurs slowly, usually within 3-5 weeks. When applied directly to water, Ecology has imposed a 12-hour swimming restriction to minimize eye irritation.

5.3.2Public Health and Water Quality

Triclopyr BEE, TEA, and acid are slightly toxic in oral and dermal routes of exposure. Inhalation is practically non-toxic. Triclopyr TEA is a corrosive eye irritant and triclopyr BEE is only a slight eye irritant (EPA, 1998). Triclopyr is excreted relatively quickly. A study in which humans ingested triclopyr found more than 80% of the chemical excreted within two days. Exposing the skin and eyes to triclopyr may cause redness. Inhalation may cause coughing (National Institute for Occupational Safety and Health, 2006).

Triclopyr mimics auxin, a natural plant hormone, causing an auxin overdose 1000 times greater than natural levels. This interferes with hormonal balance, eventually causing death of the plant. Triclopyr has a low toxicity to grasses, but can harm conifers in high doses (California Department of Pesticide Regulation, 1997).

Triclopyr BEE and triclopyr TEA rapidly degrade into the parent chemical, triclopyr acid, after application. Thus, although triclopyr BEE has a higher affinity for soil, both chemicals are considered to be moderately to slightly mobile in soil (California Department of Pesticide Regulation, 1997). Triclopyr acid is slightly toxic to birds, and practically non-toxic to most other animals. Triclopyr TEA is only slightly toxic to birds and marine invertebrate organisms. Triclopyr BEE is slightly toxic to birds, and moderately to highly toxic to fish and other marine species (EPA, 1998).

5.3.3 Non-Target Species Impacts

Tests on animals have found that long term exposure to triclopyr can cause changes in the liver and kidney. A significant increase in breast tumour frequency was observed in female rats and mice that were fed triclopyr (National Pesticide Information Center, 2011).

5.3.4 Registration Status

Renovate is the only formulation of triclopyr registered by the US EPA as an aquatic herbicide. The other formulation Garlon 4 is a butoxyethyl ester formulation with 4 lb/gal acid equivalent and this formulation is not registered for aquatic use (EPA, n.d.). Renovate is also approved for use in Canada.

5.4 Diquat

Target AIS: Hydrilla, Eurasian watermilfoil, curly-leaf pondweed, Brazilian elodea, algae, Frog's Bit

A trade name for diquat is Reward®. Reward is a liquid diquat formulation that has been effective on curly-leaf pondweed, elodea and is more effective if mixed with a copper compound. It is a contact herbicide. Contact herbicides act quickly and kill all plants cells that they contact but do not kill the roots. It is applied as a liquid. Typically diquat is used primarily for short term (one season) control of a variety of submersed aquatic plants. It is very fast-acting and is suitable for spot treatment. However, turbid water or dense algal blooms can interfere with its effectiveness.

5.4.1 Use and Application

Diquat alone does not provide effective control of hydrilla; however when mixed with chelated coppers, at a rate of two gallons of diquat and four gallons of chelated copper per surface acre, effective, albeit temporary, control of hydrilla is provided. For submerged weeds such as hydrilla, watermilfoils, naiads and others, use 1 to 2 gallons Reward per surface acre applied either as an invert emulsion or deliver diluted Reward to near the bottom of the water body with weighted hoses. The addition of copper-based herbicides will improve control of Hydrilla. Diquat quickly "disappears" from the water column. This disappearance is largely attributed to adsorption to suspended particulate matter, sediments and aquatic plants as well as uptake by aquatic plants. Diquat is not toxic to fish at rates well above those used for weed control. Diquat and copper are not often considered for large scale hydrilla control because repetitive treatments are labour intensive with a high cumulative cost. Repeated annual treatments also require an increased amount of copper to be introduced into the system.

5.4.2 Public Health and Water Quality

Because diquat is a non-selective herbicide, it affects target as well as non-target plants. Diquat must be monitored closely because it accumulates in sediment and soil after each application; however, the most current risk assessments indicate that diquat is not biologically available when bound to sediment and soil.

5.4.3 Non-Target Species Impacts

Diquat is highly toxic to some invertebrates and moderately toxic to birds and amphibians. However, if diquat is applied at standard rates and the mitigations included in the FSEIS are followed, then diquat is relatively safe to use in the environment. Decision makers may want to consider that some data gaps remain regarding diquat. Toxicological studies have not been completed for many aquatic species. Data regarding diquat's persistence in sediment and soil is only reflected over a 40 year time period. The environmental impacts of diquat accumulating in soil and sediment beyond that time have not been investigated.

5.4.4 Registration Status

Diquat is approved for use in Canada and the US. In Canada it is more frequently used for Crop protection.

5.5 Imazapyr

Target AIS: phragmites and floating-leaved plants

The most common trade name for imazapyr is Habitat®. The active ingredient, imazapyr, is also marketed in compounds by the trade names, Chopper, Arsenal, and Assault. This systemic broad spectrum, slow-acting herbicide, applied as a liquid, is used to control emergent plants like spartina, reed canarygrass, and phragmites and floating-leaved plants like water lilies. Imazapyr does not work on underwater plants such as Eurasian watermilfoil. Although imazapyr is a broad spectrum, non-selective herbicide, a good applicator can somewhat selectively remove targeted plants by focusing the spray only on the plants to be removed.

5.5.1 Use and Application

Imazapyr is a non-selective broad-spectrum systemic herbicide, absorbed by the foliage & roots, with rapid transfer to the xylem & phloem to the meristematic regions, where it accumulates and causes disruption of protein synthesis. This leads to interference in DNA synthesis and cell growth of the plants. The result of exposure is death of new leaves.

Aquatic applications of imazapyr can be made as a liquid. Application methods include aerial and application to water via boat. Aqueous imazapyr formulations may be mixed with surfactants or oils for application. Applications to smaller areas may be made with handheld equipment, including backpack sprayers, sprinkling cans, and handgun sprayers.

Terrestrial applications of imazapyr consist of ground and aerial spray, as well as granular broadcast applications. Granular formulations may also be mixed with fertilizers, surfactants or oils for application. Applications to smaller areas may be made with handheld equipment, such as backpack granular spreaders, sprinkling cans, and handgun sprayers. Aqueous imazapyr formulations may be mixed with surfactants or oils or mixed with other herbicides and fertilizers.

The recommended application rate of imazapyr is 1.5 lbs a.e./acre on non-crop areas and aquatic sites.

5.5.2 Public Health and Water Quality

The primary route of potential harm to humans would occur during the application process. If contact occurs, imazapyr is irritating to the eyes and can cause rashes, redness and swelling at the site of exposure. The amount of the product needed to produce an acute effect is relatively large. Imazapyr is not a carcinogen and has no known reproductive effects. One primary breakdown product of Imazapyr is quinolinic acid which is irritating to the eyes, respiratory system, and skin. It is also a neurotoxin and can cause symptoms similar to those in Huntington's chorea such as loss of coordination and trembling.

In soils, imazapyr is persistent. The EPA reports that the half-life of imazapyr is 17 months. If applied to soil, imazapyr is expected to have very high mobility and thus is likely to contaminate water. Studies have detected imazapyr in surface as well as groundwater.

5.5.3 Non-Target Species Impacts

Imazapyr by its nature does not distinguish between the plants it eradicates. Thus, rare and endangered plants are particularly at risk from exposure to the herbicide. The EPA has stated that studies on the effects of imazapyr to macroinvertebrate communities did not yield effects.

5.5.4 Registration Status

Imazapyr is registered in Canada and the US.

5.6 Endothall

Target AIS: curly-leaf pondweed, Hydrilla, and Brazilian elodea, mussels (in cooling towers)

Endothall was first used in agriculture as a plant desiccant. This active ingredient is comprised of only carbon, hydrogen and oxygen. A trade name for the dipotassium salt of endothall is Aquathol®. Endothall is in the dicarboxylic acid class of chemicals. Endothall is applied as either a dipotassium salt or an N, N-dimethylalkylamine salt. Endothall acid is not directly applied to use sites; it is formed as a breakdown product resulting from application of the salt forms. The amine salt is the only form applied terrestrially, while both the dipotassium and amine salt are applied to aquatic use sites. The amine salt is also used to control algae and invasive molluscs in cooling towers.

The majority of endothall is used in aquatic environments. Endothall acid is a selective contact herbicide. Endothall acid works by disrupting plant cell membranes and interfering with plant respiration, by affecting protein and lipid biosynthesis.

5.6.1 Use and Application

Endothall is a fast-acting non-selective contact herbicide which destroys the vegetative part of the plant but generally does not kill the roots. Endothall may be applied in a granular or liquid form. Endothall compounds are used primarily for short term (one season). However, there has been some recent research that indicates that when used in low concentrations, endothall can be used to selectively remove exotic weeds; leaving some native species unaffected. Because it is fast acting, endothall can be used to treat smaller areas effectively. Maximum single application rates are 5 ppm for aquatic applications. Application rates of both the salt forms of endothall are expressed as acid equivalents (ae) to equalize the application rates in terms of the acid.

Aquathol K, and Aquathol Super K are dipotassium salts of endothall and come in both liquid and granular formulations. These endothall products have been effective on curly-leaf pondweed and can be mixed with copper compounds for additional effectiveness. Hydrothol 191 is an alkylamine salt of endothall and is also available as liquid and granular formulations. It is a contact herbicide and has also effective on curly-leaf pondweed.

5.6.2 Public Health and Water Quality

In the human health risk assessment during registration, chronic dietary risks (food and drinking water) do not exceed the level of concern, although drinking water risk for infants less than one year old is concerning. However, the EPA believes that this risk estimate is the result of conservative assumptions. Aggregate risks (food, drinking water, and residential exposure) also do not exceed the Agency's level of concern. To ensure that endothall exposures from drinking water do not result in risks of concern, the Agency is requiring that direct applications to water not be applied less than 600 feet from an active drinking water intake.

For terrestrial uses of endothall, all risks calculated for short-term and intermediate-term occupational exposures are below the Agency's level of concern with the exception of mixing and loading liquids for aerial applications. Technical endothall is classified as a severe dermal irritant. The EPA requires that workers mixing and loading liquids for aerial applications wear respirators (EPA, 2005). All risks for short-term and intermediate-term exposures from mixing, loading, and applying liquid formulations to aquatic use sites are below the Agency's level of concern if precautions are taken (EPA, 2005). All risks for short-term exposures from loading and applying granular formulations for aquatic applications are below the Agency's level of concern when workers wear protective equipment. For intermediate-term exposures from loading and applying granular formulations for aquatic applications, risks are of concern to the Agency.

All occupational risks from use of endothall as a biocide in cooling towers are below the Agency's level of concern. The Agency has classified endothall as "not likely to be carcinogenic to humans" based on the lack of evidence of carcinogenicity in mice or rats (EPA, 2005).

5.6.3 Non-Target Species Impacts

Ecological risks were identified as a result of endothall use in terrestrial and aquatic settings. To potentially reduce risks to non-target plants and organisms, the EPA requires that endothall labels differentiate application rates for small and large applications of endothall dipotassium salt. Labels will specify that higher rates are only to be used for small, spot treatments, and lower rates are to be used for larger treatments.

Hydrothol can be toxic to fish. The inorganic salt, normally used at rates of 2-3 ppm in water, is not toxic to adult fish, eggs or fry at rates of 100-800 ppm depending on fish species. The amine salt is 2-3 times more active on plants, but 200-400 times more toxic to fish than the inorganic salt. The amine salt is toxic to fish at 0.5 ppm and carries and EPA label warning not to use it where fish are an important resource. Therefore, the amine salt is not used by itself for large scale hydrilla control.

5.6.4Registration Status

Endotholl is registered in Canada and the US. In addition, the use of N, N-dimethylalkylamine salt in lakes, streams, and ponds is limited to algae, Hydrilla, bur-weed, Elodea canadensis, and Brazilian elodea by the US EPA.

5.7 Imazamox

Target AIS: Purple loosestrife

Clearcast is a liquid imazamox formulation. It is a broad spectrum, systemic herbicide. An aquatically registered surfactant is needed for application. The commercial formulations include Beyond, Clearcast, Clearmax, and Raptor.

5.7.1 Use and Application

Only one formulation of imazamox, Clearcast, is labeled for forestry and other non-crop applications. In both terrestrial and aquatic applications, Clearcast is applied at rates of 0.125-0.5 lb a.e./acre. In aquatic applications, the maximum application rate for Clearcast is also limited by water depth, and the maximum target concentration is 500 ppb (equivalent to 500 μg/L or 0.5 mg/L). In broadcast applications, Clearcast is labeled for both ground and aerial (fixed wing or helicopter) applications. In aquatic applications, Clearcast may be applied either to the water surface for the control of emergent weeds or below the water surface for the control of submersed vegetation.

Applications of Clearcast must be made with an adjuvant which may consist of a nonionic surfactant, methylated seed oil or vegetable oil concentrates or silicone-based surfactants. Clearcast is labeled for the control of numerous terrestrial target species, including ryegrass, Johnsongrass, purple loosestrife, and purple or yellow sedge.

5.7.2 Public Health and Water Quality

Imazamox is relatively non-toxic by oral and inhalation routes, slightly toxic by the dermal route, non-to-slightly irritating to the skin, and slightly-to-moderately irritating to the eye. Imazamox is not a dermal sensitizer. Imazamox is only moderately persistent, and it degrades aerobically in the soil to a non-herbicidal metabolite which is immobile or moderately mobile. Imazamox also degrades by aqueous photolysis. Imazamox is mobile however the terminal soil metabolite is moderately mobile to immobile. Leaching of imazamox in the field studies was very limited. Imazamox is metabolized under aerobic soil conditions.

5.7.3 Non-Target Species Impacts

Test results indicate that imazamox is practically nontoxic to avian species, finfish, aquatic invertebrates, and honeybees following acute exposure.

5.7.4 Registration Status

Imazamox was introduced in Europe in 1995, granted a conditional registration in the United States in 1997, and granted an unconditional registration in the United States in 2001 (Tomlin 2004; U.S. EPA/OPP 1997). The conditional registration in the United States was issued to American Cyanamid. Currently, all active formulations in the United States are registered to BASF. BASF also holds all registrations for Imazamox in Canada.

5.8 Glyphosate

Target AIS: Purple loosestrife, and Phragmites

Trade names for aquatic products with glyphosate as the active ingredient include Rodeo®, AquaMaster®, and AquaPro®. This systemic broad spectrum herbicide is used to control floating-leaved plants like water lilies and shoreline plants like purple loosestrife. Glyphosate does not work on underwater plants such as Eurasian watermilfoil. The herbicide glyphosate is the active ingredient of several commercial products including Rodeo, Roundup, Roundup Pro, Roundup Ultra, and Accord.

5.8.1 Use and application

Glyphosate is generally applied as a liquid to the leaves. Although glyphosate is a broad spectrum, non-selective herbicide, a good applicator can somewhat selectively remove targeted plants by focusing the spray only on the plants to be removed. Plants can take several weeks to die and a repeat application is often necessary to remove plants that were missed during the first application.

At present, the only practical method for controlling moderate to large populations of Phragmites is the use of the EPA approved herbicide Rodeo, active ingredient glyphosate. When used according to the manufacturer's label instructions, this product has been shown to be safer and more effective than all other alternatives. Additional environmental protection can be afforded by proper timing of application and the selection of conservative application equipment. Recruitment of replacement vegetation is greatly enhanced by removing dead Phragmites either by burning or mowing.

Rodeo is a very specific product formulation of the herbicide glyphosate which has been approved by the EPA for controlling many species of undesirable plants growing in or near sensitive aquatic environments. Glyphosate (N- (phosphonomethyl) glycine) is a non-selective systemic herbicide that kills or injures actively growing plants when applied to green tissue. The compound is rapidly translocated throughout the plant body where it interferes with the biosynthesis of aromatic compounds at points of growth. Since the specific enzyme inhibited by the action of glyphosate is localized in plastids, only organisms having this pathway and plastids are affected. All plants have plastids and the shikimate pathway; animals do not. Thus, the mode of action of glyphosate is specific to plants.

Roundup Ultra II, Weathermax (Monsanto) is a white, crystalline organophosphate salt (C3H8NO5P) that causes extremely broad spectrum plant mortality primarily due to the inability of most plant species to rapidly metabolize the chemical to non-toxic forms. It is readily absorbed into the treated plants from the leaves to the roots and shoot apices where the meristematic growth cells are located. The chemical inhibits 5-enolpyruvylshikimate-3 phosphate synthase (EPSPS) which is a key enzyme in the shikimatebiosynthetic pathway. The enzyme is essential in the production of aromatic amino acids, auxin, phytoalexins, folic acid, lignin, plastoquinones and numerous secondary products required by plants.

5.8.2 Public Health and Water Quality

In brief, the compound does not bioaccumulate in aquatic food chains and exhibits very low toxicity to achlorophyllous organisms including bacteria, fungi, and animals. Glyphosate is non-volatile, immobilized is most soils, and is rapidly removed from the environment by chemical bonding with soil particles and microbial degradation. Abundant toxicological data exists showing glyphosate to be safe when used according to label instructions.

5.8.3 Non-Target Species Impacts

Roundup is relatively harmless to animals since they lack the shikimate pathway.

5.8.4 Registration Status

Control of Phragmites has been occurring in dry municipal ditches throughout Southwestern Ontario over the past 20 years using glyphosate products. Licensed pesticide applicators can legally use Roundup Ultra II to target Phragmites in wetlands and on beaches as long as surface water is not present during time of application. Glyphosate is registered in Canada and the US.

5.9 Management Decisions: General Herbicides Benefits and Alternatives

In the case of herbicides, management decisions will be based on the target pest, costs as well as the size of the area to be targeted.

In large (3+ acre) patches of target growth in open wetland and marsh areas that are removed from valuable landscaping features (such as residential lots, managed turf, plantings, etc), the most common method of application is aerial application (by helicopter) using the product Habitat®.

Habitat Herbicide should be applied at a rate of 48 oz./acre plus 1% Methylated Seed Oil as a surfactant with a volume of 15 Gallons of water per Acre. For phragmites it should be applied in Mid-summer (late June) through fall (October) while the phragmites is still actively growing. Aerial application is an excellent control method to control especially in areas that are inaccessible to ground equipment or boats. It is expected that there will be a need to spot treat plants that were not controlled by the initial treatment in the 1-3 years following the application. If follow-up spot treatments are conducted, this should result in long-term control, with small maintenance treatments being made periodically as phragmites in re-introduced.

Where there are only small patches of growth in open wetland areas away from desirable trees and landscaping features (at least 2.5 drip lines away from desirable trees, and at least 100 feet away from landscaping features such as managed turf, landscaping plants, etc.) a hand-held wand application from a spray system mounted on ground vehicles or boats is best. Backpack sprayers can also be used. Habitat Herbicide in this case would be applied at a rate of 2% v/v plus 1% v/v methylated seed oil as a surfactant and approx. 20 gallons of water per acre. This is also a very effective treatment for phragmites. Follow-up spot treatments will be necessary, but complete control of an individual patch can be achieved over time. Habitat is soil active, so applications that are made near or under desirable trees (especially hardwoods such as oak, blackgum, sweetgum, red maple and willow) can result in damage to the nearby tree. It is important to keep the spray away from the foliage of desirable trees, and from any areas where the roots of desirable trees may be present. The application of Habitat Herbicide should be made by state certified aquatic pest control applicators.

Small patches growing near desirable trees and landscaping can be treated with Clearcast® Herbicide and Rodeo® Herbicide. Clearcast should be applied at a rate of 1% v/v plus Rodeo Herbicide at a rate of 1% plus 1% v/v methylated seed oil as a surfactant with 50 gallons of water per acre. Because these treatments are being made near desirable trees or landscape features, products such as Clearcast and Rodeo are good choices. Clearcast has been recently labelled as an aquatic herbicide, and early trial work is showing excellent control of phragmites, with safety for use around desirable hardwoods such as oak and bald cypress. When a tank mix of Clearcast and Rodeo is used, the treatment will not provide foliar selectivity, so careful treatment will need to be necessary to avoid spray contact of green foliage and stems of desirable tree and plant species. Follow-up treatments will be necessary, but the overall infestation can be reduced over time.

These costs are estimates and will vary from site to site depending on treatment rates, water depths, amount of notification needed, difficulty of access to the site, and other factors. Approximate costs for one acre herbicide treatment: Glyphosate: $300, Fluridone: $900 to $1,000, Endothall: $650, 2,4-D: $300-600, Diquat: $300 to $400.

Two benefits of treating hydrilla with fluridone are the amounts and duration of hydrilla control which are possible from one application. Large scale treatments have provided up to five acres of control for each acre treated for as long as two growing seasons. While initial treatment costs are as high as $750 per acre treated, the costs per acre of hydrilla controlled over a two year period are often less than $100. Because it requires a long contact time for optimum efficacy, fluridone's cost effectiveness decreases in fast-flowing waters where larger amounts are required to compensate for dilution. Because fluridone disperses so readily throughout waterbodies, spot or partial treatments also are difficult due to dilution (EPA, 2004).

Glyphosate is an effective tool against floating water plants such as purple loosestrife. When used according to the manufacturer's instructions, this product has been shown to be safer and more effective than all other alternatives.

One danger with any chemical control method is the chance of oxygen depletion after the treatment caused by the decomposition of the dead plant material. Oxygen depletions can kill fish in the pond. If the pond is heavily infested with weeds it may be possible (depending on the herbicide chosen) to treat the pond in sections and let each section decompose for about two weeks before treating another section.

6.0 Algaecides

Target AIS: Cylindro blue-green algae

Currently there is no non-toxic, sustainable method to control blue-green algae in aquaculture ponds. However, using chemical algaecides such as copper sulphate and certain chelated or complexed copper products or endothall may prevent bluegreen algae.

6.1 Endothall - Amine Salt

A trade name for the amine formulation of endothall is Hydrothol 191®. Hydrothol 191® is a rapidly acting non-selective contact herbicide or algaecide. In Washington Hydrothol 191® may only be used at very low concentrations for filamentous algae control or cyanobacteria control (blue-green algae) in selected water bodies. Several treatments each season may be needed to control algae/cyanobacteria. Hydrothol 191® has a high acute toxicity to fish and must be used with extreme care. Because of fish impacts, Ecology does not allow concentrations higher than 0.2mg a.e./L of Hydrothol 191®. Unlike copper compounds that are also used for algae control, Hydrothol 191® does not accumulate in sediments and breaks down rapidly.

Details of Endothall effects on public health, water quality, non-target species effects and registration status are available in section 5.0 on herbicides.

6.2 Peroxygen-based Granular Algaecide

Trade names include GreenClean® and Pak27®. These are peroxygen-based granular algaecides, more commonly sodium percarbonate, used for the prevention and control of algae in ponds, streams, irrigation systems, ornamental pools, and fountains. Areas being treated with these products must be closed to recreational activities during and for two-hours after treatment.

6.2.1Use and Application

Sodium percarbonate rapidly dissolves in water and dissociates into sodium, carbonate and hydrogen peroxide. Acute ecotoxicity tests with fish and water fleas revealed LC50 values of 71 and 4.9 mg/l. The available data show that the observed aquatic toxicity of sodium percarbonate can be explained by the formation of hydrogen peroxide. Because sodium percarbonate dissociates into sodium, carbonate and hydrogen peroxide, the environmental risk assessment is based on the risk assessment of the individual components.

Sodium has a low toxicity and the emitted amount of sodium is relatively low compared to background concentrations and therefore the emitted amount of sodium will not have an effect on the aquatic organisms of the receiving water.

6.2.2 Public Health and Water Quality

Sodium percarbonate has a low acute toxicity via the oral and dermal. The existing animal data on acute toxicity show that sodium percarbonate has a local effect. In animal tests, used to predict impacts on humans, a slight irritating effect on the skin was reported for solid sodium percarbonate and it was highly irritating to the rabbit eye. However, sodium percarbonate did not have sensitising properties in a test with guinea pigs.

When consumers are exposed to sodium percarbonate, neither hydrogen peroxide nor sodium carbonate will be systemically available due to their effective degradation or neutralisation in the body. Consequently it is to be expected that the concentration of hydrogen peroxide and sodium in the blood and the pH of the blood will not be increased. Therefore, neither sodium percarbonate itself nor hydrogen peroxide or carbonate will reach the organs or the foetus and there is no risk for systemic, developmental or reproductive toxicity. With regard to genotoxicity and carcinogenicity the properties of sodium percarbonate also resemble those of hydrogen peroxide and it can be concluded that there is no concern for humans with regard to a possible genotoxicity or carcinogenicity of sodium percarbonate. The only critical endpoint for sodium percarbonate seems to be local irritation.

6.2.3 Non-Target Species Impacts

Shurtleff devised testing to identify toxicity of fish (Shurtleff, 1989a) and invertebrates (Shurtleff, 1989b) to sodium percarbonate. He found that Sodium percarbonate rapidly dissolves in water and dissociates into sodium, carbonate and hydrogen peroxide. Acute ecotoxicity tests with fish and water fleas revealed LC50 values of 71 and 4.9 mg/l. The available data show that the observed aquatic toxicity of sodium percarbonate can be explained by the formation of hydrogen peroxide.

6.2.4 Registration Status

No records of registration could be found for Canada or the U.S.

6.3 Copper Sulphate and Copper Compounds

Other common names for copper sulphate include bluestone (due to the colour of the product), copper sulphate, cupric sulphate and blue vitriol. Cutrine Plus, K-Tea, Captain, and Clearigate are all chelated or compound copper herbicides and can be used in a mixture with Reward or Aquathol K. Copper algaecides are not selectively toxic to odour-producing blue-green algae. Copper also interacts strongly with other water quality variables, and one important consequence of those interactions is that copper products become more toxic to fish and algae as water hardness and alkalinity decrease.

6.3.1 Application and Use

Agriculture and Agri-Food Canada insist that copper treatments are a temporary solution to problems with cyanobacteria. The treatment does not deal with the root problem for the growth of cyanobacteria, algae, and plants. Prairie ponds and lakes experience prolific algae growth because the water is nutrient-rich. Typically, ponds and lakes have very high phosphorus concentrations which serve as a nutrient for cyanobacteria, algae, and aquatic plants. Copper is toxic to most types of cyanobacteria at concentrations ranging from 0.06 to 0.25 mg Cu/L. When cyanobacteria are killed by a copper treatment, toxins may be released in high concentrations. Before using the water as an animal drinking water supply, wait at least 14 days after treatment to allow time for potential toxins to degrade (Agriculture and Agri-Food Canada, 2011).

The best plan to minimize cyanobacteria, algae, and aquatic plant problems incorporates good watershed management. The goal is to prevent nutrient inputs into the water such phosphorus, nitrogen, animal waste, fertilizers, soil particles, and silt. Each of these act as fertilizers for algae and aquatic plants (Agriculture and Agri-Food Canada, 2011).

6.3.2 Public Health and Water Quality

Copper sulphate treatments cause poor water quality. Increased aeration is required in copper treated ponds than in untreated ponds. Copper can accumulate in the sediments of treated ponds, with a relatively large fraction of the copper in the sediment initially present in a potentially bioavailable form. In addition, due to their potential adverse environmental impacts, there may be local regulations in place restricting the use of algaecides.

The Pest Management Regulatory Agency (PMRA) of Health Canada has found that use of copper sulphate based algaecides poses no significant hazard to swimmers. When used according to the label directions, copper sulphate algaecide should not cause skin irritation. Skin irritation could occur if not handled properly.

Drinking water is regulated well below toxic levels for humans. The Canadian guideline is a maximum copper concentration of 1.0 mg Cu/L to avoid taste and staining problems (Agriculture and Agri-Food Canada, 2011).

6.3.3 Non-Target Species Impacts

Treatment of ponds with algaecides chemicals can result in beneficial algae also being removed. Algaecides or chlorination may cause the algal cells to burst and this can cause toxins to be released into the water. In addition, when algae decompose, the phosphorus stored in the algal cells is released into the water. The released phosphorus is available to fuel new algae growth.

Agriculture and Agri-Food Canada relate that at certain concentrations, copper is toxic to algae, plants, and many other organisms and green algae growth sometimes increases several weeks after treatment. This occurs because too many beneficial organisms are also killed. For example, zooplankton eat green algae, keeping their populations at lower levels. When too many zooplankton are killed, green algae re-establish and soon grow to a high population density, since they have less predator organisms to limit their growth. Copper treatments always disrupt biological life in a dugout ecosystem.

Copper is poisonous to Rainbow trout at concentrations of approximately 0.04 mg Cu /L (Agriculture and Agri-Food Canada, 2011).

6.3.4 Registration Status

TeckCominco, Nalco and Phelps Dodge hold current registrations for use of granular copper sulphate as an algaecide. They were first registered in 1991. TeckCominco is the only company currently marketing in Canada. Numerous copper formulations are registered through the EPA.

7.0 Pathogen Control

Invasive pathogens currently in the Great Lakes include myxosporidian, salmonid whirling disease, the parasite Microsporidea and the hemorrhagic septicemia virus (VHSV). There are currently no widely used documented treatments for these pathogens; thus some possible remedies have been suggested. Salmonid whirling disease is thought to be disinfected with liming.

Myxosporidian:

Myxosporidian and microsporidian parasitic infections are very frequent in major carp species. Reports of large-scale mortalities of fry and fingerlings of carp species are common due to such infections. Several species of Myxosporidia have been found to infect all the carp species and form cysts on the body surface, fins, gills and internal organs such as the kidney and spleen. However, when large numbers of oocysts are present on the gills, breathing of the fish is adversely affected (Dey, Kumar and Mishra, 1988). Renal infections lead to the damage of most of the renal tubules in the form of vacuolar degeneration of the tubular epithelial cells (Dykova, 1978).

There is no known effective treatment against myxosporodiosis. Spores released from the infected and dead fishes remain viable for quite a long period in the pond bottom before they infect new hosts. Infected fish should immediately be removed and, if possible, the pond should immediately be dried and disinfected. In undrainable ponds where drying is not at all possible, the pond should be disinfected with chlorinated lime.

Microsporidea

Kent and Dawe (1994) investigated the use of Fumagillin DCH to eradicate Microsporea. It has been used to control other microsporean and myxosporean diseases of fishes, and the efficacy of this drug. Chinook salmon were experimentally infected with L. salmonae in seawater tanks. At 1 week post initial exposure, 2 tanks of 12 fish each were fed Fumagillin DCH and 2 other tanks of exposed fish were maintained as non-treated controls. None of the surviving 22 Fumagillin-treated fish exhibited L. salmonae infections when examined at 44 days post initial exposure, while 13 of 21 untreated fish were infected. This preliminary study suggests that Fumagillin DCH may be a useful therapeutant for controlling L. salmonae infections.

Viral Hemorrhagic Septicemia (VHS)

Viral hemorrhagic septicemia (VHS) is a deadly infectious fish disease caused by the Viral hemorrhagic septicemia virus (VHSv) (Elsayed, E., M. Faisal, M. Thomas, G Whelan, W. Batts, and J. Winton, 2006). It has caused large fish kills in the Great Lakes Basin (Skall et al. 2005).

VHSv is not a human pathogen as it cannot replicate in warm-blooded animals and rapidly dies at human body temperatures. There are no concerns with respect to human health with this pathogen and it cannot infect humans if they eat fish with the pathogen. However, VHS is a reportable animal disease that requires notification of the US Department of Animal and Plant Health Inspection Service (USDA-APHIS), the Canadian Food Inspection Agency (CFIA), as well as the OIE (International Organization for Animal Health). The USDA-APHIS has issued emergency orders that restrict live fish movement over state and national boundaries (U.S. Department of Agriculture, 2006).

The current disease status of VHSv Isolate IVb by the Great Lakes Fishery Commission – Great Lakes Fish Health Committee's (GLFHC) Great Lakes Model Fish Health Program is as an emergency disease. It is in the process of being changed to a restricted disease, as it is now endemic to the Great Lakes. Emergency diseases under this program are required to be eradicated from infected and adjacent waters (Whelan, Gary, 2006).

In 2008, the Great Lakes Fishery Commission came to consensus on a recommended iodophor treatment protocol that is known to not kill cool water eggs but should be effective in killing VHSv. Experiments are pending on whether the virus is definitively killed by the GLFHC recommended protocol (Whelan, Gary, 2006). The DNR has used this protocol for more than three years for cool water eggs to reduce the transmission risk. In the Western United States, salmon eggs are routinely surface disinfected with iodophor (an iodine compound) at or after water hardening to eliminate vertical (parent to egg) VHSv transmission and this chemical has been demonstrated to be effective (Finley, 1978). The reason this topical disinfection is effective is that the virus does not penetrate the egg and stays on the outside. Ovadine® is the only PVP Iodine product approved in Canada for fish egg surface disinfection. Ovadine® is a non-staining, non-corrosive buffered 10% polyvinylpyrrolidone-iodine complex (PVP Iodine) which provides 1% available iodine. In Canada, this product is a Health Canada approved pharmaceutical specifically formulated for use in aquaculture as a fish egg disinfectant for salmonids of the genera *Salmo* and *Onchorhynchus* or as a general sanitizer (Syndel Laboratories Ltd. (a), 2011). Another EPA-approved disinfectant proven effective against VHS is Virkon AQUATIC. The active ingredient in Virkon aquatic is Potassium monopersulfate. In Canada, this product has been available in Canada since December 2006 as a general disinfectant and is Health Canada approved for use in aquaculture. Chlorine bleach kills the VHS virus, but in concentrations that are much too caustic for ordinary use.

Virkon Aquatic is a disinfecting solution with efficacy against fish viruses, bacteria, fungi, and molds. Virkon Aquatic is EPA registered (except in California where registration is pending) for disinfecting of environmental surfaces associated with aquaculture including boats, nets, boots, waders, dive suits, hoses, brushes, hard surfaces and other similar equipment. Virkon Aquatic solution is fast acting, colorless, fragrance free, non corrosive, and non-irritating to skin and eyes. The ingredients have been selected for their ability to degrade quickly within the environment (Syndel Laboratories Ltd. (b), 2011).

There is a large need for rapid detection tools and for new tools to track the disease within a fish population. Currently, it takes 28 days to certify fish are VHSv free which greatly handicaps management efforts. There are no treatments at this time to stop horizontal (fish to fish) transmission or to treat infected fish. Extreme control measures may be needed, which may include infected lot destruction (Whelan, Gary, 2006).

Pathogen Therapy

Pathogen Therapy can be applied in two ways, by external or internal (through diet).

There are two methods of application of external treatments.

Immersion in chemical solution: The most common method of administering therapeutic agents to fish is immersion in water soluble compounds. Depending on the available facilities, severity and nature of the disease and local conditions, three types of immersion treatments are suitable. These are baths in lower concentration of chemicals ranging from short to prolonged periods and dips where the fish are dipped into a chemical solution of high concentration for a very short period ranging from a few seconds to 5 minutes. Indefinite bath is suitable for pond treatment where the chemical is applied at a low concentration for an indefinite period and the chemical is allowed to gradually dissipate or detoxify naturally.

Swabs: Swabbing is application of drugs when dealing with individual fish with localized external infections.

Treatment via diet: This method is usually applied for treating the systemic bacterial diseases or gut parasites by incorporation of the drug into the feed. Loss of appetite is one of the first signs of a disease and hence in such cases the use of drugs in proper doses through supplementary feeding becomes difficult. Leeching of drug is another problem. If some of the water soluble drugs are properly mixed with vegetable oil prior to its final mixing with the feed, such losses may be minimised. Generally, feeding medicated feed is considered to be a prophylactic rather than a therapeutic measure.

8.0 Biocides and Small Invertebrates

Target AIS: Zebra Mussel, the Eurasian Ruffe, amphipod, and Spiny Water Flea

Ship ballast water has become the dominant vector for non-indigenous species introduction to the Laurentian Great Lakes. In 2004, the adoption of ballast water management and discharge standards by the International Maritime Organization (IMO) aimed at reducing the risk of further invasions (Kelly and Kazumi, 2007).

Different techniques have been established, such as salinity shock. Exchanged ballast water must have a salinity of >30 parts per thousand, which should kill most freshwater organisms during exchange (Kelly and Kazumi, 2007). The salinity shock from open ocean water would have minimized the risk of introduction for the Zebra Mussel, the Eurasian Ruffe, and the amphipod. Raised salinity would have been less effective in preventing the introduction of resting eggs of the Spiny Water Flea. All of the representative species would be inactivated using oxidizing biocides. Although such treatment technologies could reduce densities to a low enough point that the total number of organisms remaining in a given ballast tank may still be sufficiently high to enable the establishment of viable populations (Kelly and Kazumi, 2007).

Treatment Technology Development

Treatment of ballast water to reduce or eliminate the biota it contains has been the primary focus of efforts to address the ballast water issue. Many different technologies are being tested for their applicability, either alone or in combination, including filtration, ultracentrifugation, and exposure to intense ultraviolet light (UV), ozone, heat, oxygen removal, ultrasound, and use of biocides such as hypochlorite, gluteraldehyde, and commercial products such as SeaKleenTM.

The use of ozone as a biocide (ozonation) has been tested in a full scale application on board a U.S. oil tanker with promising results. Other biocides such as hypochlorite and gluteraldehyde are known to be effective against many biota including many microbes. Gluteraldehyde and hypochlorite are likely impractical for treatment of the large volumes of water in full ballast tanks on board typical transoceanic ships. Biocides have more likely utility in treating NOBOB tanks where the residual water volume is small. However, laboratory-based studies have shown that these biocides may be less effective on biota buried in sediments, unless the sediment can be stirred-up and resuspended (IAGLR, 2002). The presence of organic matter also reduces the effective concentration of hypochlorite, thus requiring a higher initial concentration. In addition, the shipping industry has concerns about the effects of hypochlorite on the coatings and steel of ballast tanks. Chloride ion is very reactive with exposed iron and the concern is that regular use of hypochlorite would increase the rate of deterioration of the ballast tank structure. In addition, the environmental community, and some regulatory agencies are concerned, if not resistant, to the idea of discharging biocide-laden ballast water to the environment. In some cases, such as gluteraldehyde and ozone, the biocide will break down into non-toxic chemicals, mainly water and carbon dioxide, while still in the ballast tank or shortly after exposure to sunlight (IAGLR, 2002).

Although several of these treatment approaches show promise, no one technology appears on the horizon as a "silver bullet." All have limitations that make them less than 100% effective. Some presently have serious practical limitations that must be overcome or which may ultimately make them unusable, such as large size, high power requirements, costs, and maximum achievable treatment rate. With time and money, engineering solutions are likely for many of these problems, but perhaps one of the largest hurdles in the future may be finding adequate test platforms for technologies that are ready for on-board testing (IAGLR, 2002).

Chapter 3: Using an Approved Chemical Tool

Canada Regulation

Pesticides are carefully regulated in Canada through a program of pre-market scientific assessment, enforcement, education, and information dissemination. These activities are shared among federal, provincial/territorial and municipal governments, and are governed by various Acts, regulations, guidelines, directives and by-laws. It is a complex process, in which regulators at all levels work together towards helping protect Canadians from any risks posed by pesticides and ensuring that pest control products are effective. In Ontario, all pesticides must be federally registered under the Pest Control Products Act (PCPA) by Health Canada – Pest Management Regulatory Agency and provincially classified in accordance with the requirements under the Pesticides Act and Regulation 63/09. This section describes pesticide use and sale regulation on the Federal, Provincial and Municipal levels.

Federal Governance

The Pest Management Regulatory Agency (PMRA) of Health Canada has the mandate to protect human health, safety and the environment by minimizing risks, while providing Canadians access to the pest management tools they require for agriculture, forestry, industry, and personal use.

The PMRA of Health Canada is responsible for the following components:
• Pest Control Products Act (PCPA) and Regulations
• Pesticide registration and re-evaluation
• Human Health and Safety
• Environmental impact
• Value/efficacy assessment
• Alternative strategies
• Compliance and enforcement

Importing and Selling Pesticides

Pesticides imported into, sold or used in Canada are regulated nationally under the Pest Control Products Act and Regulations (PCPA). The PMRA is responsible for administering this legislation, registering pest control products, re-evaluating registered products and setting maximum residue limits under the Food and Drugs Act. Companies that wish to have the right to sell a pest control product in Canada must submit detailed information and data to be evaluated by the PMRA. Companies must provide all the scientific studies necessary for determining that the product is acceptable in terms of safety, merit and value. Depending on the complexity of the submission, a complete evaluation can take anywhere from a number of weeks, to a year or more. The evaluation results either in the product being granted registration and allowed for sale and use in Canada, or in the product being refused registration.

PMRA's Alternative Strategies and Regulatory Affairs Division develops and implements federal policy and legislation for pest control products, and works with other government bodies, grower groups, research facilities and industry to facilitate information exchange. Cooperative efforts include:

- Integrated Pest Management Partnership Projects;
- Initiatives to facilitate access to new technologies (e.g. microbials, pheromones);
- Participation within international bodies such as the North American Free Trade Agreement (NAFTA) and the Organization for Economic Cooperation and Development (OECD) for the development of risk reduction policies, joint reviews and the harmonization of data requirements; and for cooperation with international initiatives such as Persistent Organic Pollutants (POPs) and Prior Informed Consent (PIC) policies.
- Working with other governmental departments and the Federal/Provincial/Territorial Committee on pesticide-related issues;
- Active involvement with agriculture, forestry, aquaculture and other sectors to identify and manage problems using sustainable pest management practices.

Working with other federal and provincial ministries, PMRA regional offices promote and verify compliance with the PCP Act through investigations, inspections and consultations.
They have the mandate to investigate the use, sale and importation of products; perform on-site inspection of usage and storage of products; do soil, crop and product sampling; and to educate individuals, local officials and grower groups as to regulatory requirements. Where contraventions of the Act or regulations occur, appropriate enforcement measures may be taken.

Provincial/Territorial Governance

Only pesticides that are registered for use under the PCPA may be imported into, sold or used in Canada. However, the provinces and territories may regulate the sale, use, storage, transportation and disposal of registered pesticides in their jurisdictions as long as the measures they adopt are consistent with any conditions, directions and limitations imposed under the PCPA or other federal legislation. A province or territory may prohibit the use of a registered pesticide in its jurisdiction, or it may add more restrictive conditions on the use of a product than those established under the PCPA. However it may not authorize the use of a product that has not been approved under the PCPA, and may not relieve the user of the obligation to comply with conditions, directions and limitations imposed under the PCPA. The provincial government regulates:

- Transportation, sale, use, storage/disposal
- Training/certification and licensing of applicators/vendors
- Spills/accidents
- Permits/use restrictions
- Compliance and enforcement

Provinces and Territories administer a pesticides management program that includes education and training programs, the licensing/certification of applicators, vendors and growers, and issuing permits for certain pesticide uses. Other important roles – carried out in cooperation with PMRA regional offices - are those of enforcement and compliance monitoring, and response to spills or accidents.

Sale and Use

On the Provincial level, pesticide product class designations (domestic, commercial, restricted) are reviewed and/or products are assigned to schedules to limit the sale and use of certain products to the appropriate individuals/operators who are trained to use them. Provincial/territorial regulatory departments can establish additional requirements for the safe handling and management of pesticides to meet local needs/conditions. Retail pesticide vendors and pesticide applicators are required to be trained and licensed to ensure that products are used responsibly. Pesticide applications on public land, and by Pest Control Operators (PCO) on residential property, require the posting of signs in most provinces. Compliance and enforcement Provincial authorities set fines, revoke/refuse licences, issue warnings, issue control orders etc.

In Ontario, aquatic herbicides are classified as nondomestic pesticide products (Class 3 or 4). Pesticide vendors may sell an aquatic herbicide to only those persons that possess the appropriate licence and/or permit. Persons who hold an Aquatic Vegetation exterminator licence may purchase a Class 3 or 4 herbicide for aquatic plant control. However, as described above, a permit is required unless the exterminator is performing a water extermination on premises they own or occupy or on premises that are owned or occupied by their full-time employer and the extermination is being done in, on, or over surface water that is wholly contained on those premises and the water body does not discharge, directly or indirectly (other than by percolation) into any water or watercourse.

There are situations where a person may be exempt from both the requirement for an Aquatic Vegetation exterminator licence and a permit (e.g. a person owns or occupies the property, or is a full time employee of the person that owns or occupies the property, upon which a water extermination is to occur, and the water body is wholly contained within the boundaries of that property and has no direct or indirect outflow). However, in order for a vendor to sell a non-domestic product (Class 3 or 4) to the person that person will require a letter signed by an MOE Director confirming that the person is exempt from requiring a exterminator licence and permit to purchase a Class 3 or 4 product for aquatic plant control.

Using pesticides in aquatic environments

A water exterminator's licence and a water extermination permit are required for anyone seeking to apply a pesticide to lakes, ponds, rivers, streams or wetlands to control an invasive species. The Ontario Ministry of the Environment reviews and approves water extermination permits for the use of pesticides in aquatic environments. The Pesticides Act and Ontario Regulation 914 provide the provincial regulatory framework and outline requirements for training, licensing, permits and pesticide classification (Ministry of Natural Resources, 2011).

Qualified farmers are permitted to purchase and use Class 3 and 4 pesticides for land extermination only on their own farmland (Ontario Ministry of Agriculture, Food and Rural Resources, 2010).

A person does not require an MOE permit to apply appropriately labelled Class 3, 4, 5, 6 or 7 pesticides in a drainage ditch to control plants that emerge from or float on the surface of the water if the drainage ditch does not contain moving water at the time of the extermination. A "drainage ditch" is defined in Regulation 63/09 as an artificial watercourse, added to the natural land drainage system, primarily to collect and convey water and that, for some period each year, does not contain moving water (Ontario Ministry of Agriculture, Food and Rural Resources, 2010).

Permits

Applicators can be required to obtain use permits for restricted class pesticides (e.g. for application by air, fumigation, or for aquatic use), that set out strict conditions for use in the province/territory (e.g. the requirement for buffer zones).

Beginning Spring 2010 all applicants for permits to use aquatic herbicides in open water bodies (e.g. lakes and rivers) in Ontario are required to submit documentation that the proposed application will be performed by an appropriately licensed water exterminator (Aquatic Vegetation Class) or that the applicant is exempt from licensing due to ownership or occupation of the proposed treatment area. This change is consistent with the current requirements outlined in Ontario Regulation 63/09 of the Pesticides Act.

This represents a change in practice for some waterfront property owners who may have previously obtained a permit without having to retain the services of a licensed exterminator.

If the applicant cannot demonstrate that they meet the licensing or licensing exemption requirements prescribed under the Pesticide Act and Regulation 63/09, the ministry will return the permit application and advise the applicant of the available options for aquatic plant control:

- obtain a water exterminator's licence (Aquatic Vegetation Class);
- retain the services of a person that is an appropriately licensed water exterminator; or
- use alternative approved methods for aquatic plant control, such as mechanical harvesting.

The operational change only applies to permits issued for use of aquatic herbicides on open water bodies. The operational change will not affect the processing of other types of water extermination permits as appropriate exterminator licensing requirements are already in place for these permits.

Section 7(2) of the Pesticides Act prescribes that no person shall perform a water extermination unless the person is the holder of a permit issued by the ministry or is exempt under the regulations.

Section 82 of Regulation 63/09 prescribes the licensing requirements for water exterminations. Section 83 of Regulation 63/09 prescribes the exemptions from requiring a water exterminator's licence and/or permit for the performance of a water extermination.

For open water bodies (e.g. a lake or river) the regulation prescribes that the person performing the extermination must possess a valid ministry permit and water exterminator's licence (Aquatic Vegetation Class). The regulation does provide an exemption from the exterminator licensing requirement if the applicant can demonstrate that they, or their full-time employer, own or occupy the area to be treated.

In 2009 the ministry undertook an internal review of the current aquatic herbicide permit program. The results of the review indicated that the ministry could improve its regulatory oversight of aquatic herbicide permits by ensuring that applicants for open water body treatments (e.g. lakes and rivers) demonstrate that they possess the appropriate water exterminator licence or meet the licensing exemptions prescribed in Regulation 63/09 under the Pesticides Act.

Restricting aquatic herbicide use to appropriately licensed exterminators is consistent with current pesticide legislation, will ensure that pesticides are only used by individuals with specific knowledge in the safe and proper use of pesticides, and is consistent with other initiatives undertaken by the ministry to enhance pesticide management and reduce public exposure to toxins.

When reviewing applications for aquatic herbicide permits, the ministry takes a number of factors into consideration to ensure protection of human health and the environment, including the protection of drinking water sources.

The ministry, in consultation with Ontario Ministry of Natural Resources (MNR), the federal Department of Fisheries and Oceans (DFO) and other partner agencies, has developed detailed guidelines for aquatic plant control. The ministry routinely consults with MNR, DFO and other government agencies with jurisdiction for aquatic plant control and the protection of fish habitat before issuing aquatic herbicide permits.

A ministry permit imposes strict conditions with respect to type and quantity of federally approved product that can be used, the size of area that may be treated, and the date of application and notification of adjacent property owners (Ministry of the Environment, 2010).

Municipal Governance

The Municipal Government is responsible for By-laws for municipal (and, in some cases, private/residential) lands only.

US Regulation

EPA and the states (usually that state's agriculture office) register or license pesticides for use in the United States. EPA receives its authority to register pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). States are authorized to regulate pesticides under FIFRA and under state pesticide laws. States may place more restrictive requirements on pesticides than EPA; however, pesticides must be registered both by EPA and the state before distribution. EPA also regulates pesticides imported for use in the U.S. and participates in a wide variety of international activities, such as regulatory agreements and coordination activities.

Evaluating Potential New Pesticides and Uses

Federal law requires that before selling or distributing a pesticide in the United States, a person or company must obtain registration, or license, from EPA. Most states conduct a review of the pesticide label to ensure that it complies with federal labelling requirements and any additional state restrictions of use. States may require the registration of pesticides and inert ingredients that are considered safe are exempt from the requirements of registration.

Minor Uses, Experimental Use, Special Local Needs and Emergency Situations

Minor uses of pesticides are those for which the total United States production for a crop is fewer than 300,000 acres. Minor use also applies to pesticide uses which do not provide sufficient economic incentive for a registrant to support initial or continuing registrations. The EPA coordinates activities between EPA, United States Department of Agriculture (USDA) and the Department of Health and Human Services (DHHS), and expediting registrations for minor use pesticides.

States have authority under Section 24(c) of FIFRA to add uses to pesticides based on special local needs. Other federal agencies or an authorized state official may request that EPA allow the use of an unregistered active ingredient or an additional use for a registered pesticide to respond to an emergency for a specific period of time. Under emergency circumstances a specific pesticide can be temporarily exempt from the full requirements of registration, to deal with an emergency. EPA can issue Experimental Use Permits for pesticides that are not federally registered for aquatic use. EPA uses these permits to accumulate information necessary to register a pesticide under Section 3 of FIFRA for aquatic use. A pesticide manufacturer must be working toward a Section 3-registration or state registration in order to be eligible for a EUP.

Review of Registered Pesticides and Enforcing Pesticide Requirements

EPA ensures that each registered pesticide continues to meet the highest standards of safety to protect human health and the environment. The Agency has several programs to ensure the review of registered pesticides, including re-registration, tolerance reassessment, registration review, and special review (EPA, 2011).

Pesticide producing establishments must be registered with EPA under Section 7 of FIFRA. EPA regional offices administer the registration of pesticide producing establishments (EPA, 2011).

States may be delegated primary enforcement responsibility for pesticide use violations. The states have this authority when they have adopted and are implementing pesticide use regulations or when they have entered into a cooperative agreement with EPA (EPA, 2011).

Permits

On November 27, 2006 EPA issued a final rule clarifying two specific circumstances in which a Clean Water Act (CWA) permit is not required to apply pesticides to or around water. They are: 1) the application of pesticides directly to water to control pests; and 2) the application of pesticides to control pests that are present over or near water, where a portion of the pesticides will unavoidably be deposited to the water to target the pests (EPA, 2011).

The action put into effect a rule that confirms EPA's past operating approach that pesticides legally registered under FIFRA for application to or near aquatic environments, and legally applied to control pests at those sites, are not subject to NPDES permit requirements. The rule became effective on January 26, 2007.

Clarifying when the CWA applies to pesticide use is critical in efforts to prevent or respond to an infestation of mosquitoes that may carry the West Nile virus, or to control an invasive species that may damage valuable natural resources (EPA, 2011).

Chapter 4: Process for Registration of New Pest Control Products

It is important that those involved in managing aquatic systems have as many different tools as possible for the control and eradication of non-native aquatic species. This section explains the process involved to develop and register a pesticide in both the United States and Canada.

United States

The need to regulate pesticides became apparent in the late 1940s. In 1947, Congress passed the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) that regulated the licensing and application of pesticides, primarily for agriculture. Initially, the U.S. Department of Agriculture (USDA) was given the responsibility of registering pesticides. The responsibility passed to the EPA when it was created in 1970. Amendments to FIFRA were made in 1980 and 1988, with the latter amendment requiring that all pesticides registered before 1984 undergo a reregistration process since testing methodology had improved significantly. Congress passed the Food Quality Protection Act in 1996, which placed emphasis on chemicals used directly on food and crops. At this time, risk assessments were made mandatory to evaluate the cumulative effects from pesticides of similar modes of action, provided special consideration for infants, elderly, and other sensitive groups. The EPA established a program to determine the endocrine disrupting characteristics of pesticides, and required reassessments of pesticide tolerances (Dawson and Kolar, 2003).

Before registering a new pesticide or new use for a registered pesticide, EPA must first ensure that the pesticide, when used according to label directions, can be used with a reasonable certainty of no harm to human health and the environment. To make such determinations, EPA requires more than 100 different scientific studies and tests. Where pesticides may be used on food or feed crops, EPA also sets tolerances (maximum pesticide residue levels) for the amount of the pesticide that can remain in or on foods.

It is estimated that from initial discovery through developmental research to final product, the development of a pesticide can take 8 to 10 years and cost $35 to $50 million (American Crop Protection Association, 2001). Registration tests can cost up to $10 million (USDA, 2002). The number and types of tests required depends on the intended use and the risk associated with potential exposure. Crops and large use aquatic pesticides have the greatest stringency on testing.

There are three types of registrations that may be granted by the EPA. The most common registration is a full, or Section 3(c), registration (EPA, 2011). Section 3 registrations require a full battery of data to support the registration and are renewed on an annually. This type of registration is usually obtained by the product manufacturer (Dawson and Kolar, 2003).

The second type of registration is the Special Local Needs, or Section 24(c) registration (EPA, 2011). These types of registrations generally cover situations where individual states apply for registration of an additional use of a federally registered pesticide, or a new end-use product to meet special needs. In most instances this involves a currently registered pesticide and thus minimal additional data requirements are necessary for registration. Applications for special local needs registrations must be accompanied by an unreasonable adverse effects assessment. Special local needs registrations are also renewed on an annual basis.

The final type of registration is a Section 18 Emergency Exemption. Section 18 registrations are sought when a control need is identified in which registered pesticides will not be effective.

Occasionally, requests are made for pesticides for which registrations have been cancelled. In situations where an emergency exemption is required, the EPA has the authority to grant an exemption to a state or federal agency (Dawson and Kolar, 2003).

All data submitted to support the registration of a pesticide must meet strict standards of record-keeping and documentation known as Good Laboratory Practice (GLP) guidelines. Failure to comply with these guidelines not only will result in rejection of the submitted data, but can also result in fines and/or imprisonment

Development of a pesticide is generally a lengthy process and involves the broad steps of (1) developing a treatment strategy, (2) developing a specific chemical, (3) developing formulations of that chemical, (4) producing, and (5) registering the chemical and formulations of the chemical (Dawson and Kolar, 2003). In the pages that follow, the components of each of these steps will be discussed.

Developing a Treatment Strategy

It is important in developing a chemical control strategy to have a sound understanding of the biology of the organism to be controlled, including the organism's life cycle, breeding habits, and habitat preferences. This will allow for identification of a life stage that is particularly susceptible to chemical control (Dawson and Kolar, 2003).

Labour-intensive screening of thousands of chemicals may be necessary to identify a taxon-specific chemical to control the specific invasive species. Screening may involve models based on the actions of specific classes of chemicals that are available to help identify candidates. In addition to biological activity and effectiveness, ease of handling, safety, and cost should be considered (Dawson and Kolar, 2003).

Toxicity Screening

Once the candidate chemicals have been selected, toxicity screening is initiated to define an effective concentration range over which mortality of the target life stage can be achieved (Lennon and Walker 1964). The types of toxicity tests that can be used in this phase are described in a guide from the American Society of Testing Materials (1980). The number of concentrations initially tested is a matter of convenience. Six concentrations, each differing by a factor of 10, is an appropriate starting point. If no mortality is observed at the highest concentration or total mortality is observed at the lowest concentration, the range should be adjusted and a new test conducted. This procedure is repeated until mortality is observed at the highest concentration and not at the lowest concentration. Effective concentrations are then refined by further toxicity testing on the target organism within this concentration range. Toxicity testing on phylogenetically diverse non-target organisms is done to determine which of these may be sensitive to the chemical at the concentrations effective on the target organism. If any non-target organisms are determined to be sensitive at the concentrations toxic to the target organism, then subsequent toxicity screening is conducted to determine if there is a concentration range over which mortality of the target organism may be achieved with minimal mortality to non-target organisms (Dawson and Kolar, 2003).

The decision to develop a particular chemical or group of chemicals as should be based primarily on sound science, and economic considerations.

Safety Considerations

Perhaps the most important consideration is safety. From a human safety perspective, the chemical must be safe to pesticide applicators as well as to those who may come into contact with it following applications. Additionally, non-target organisms exposed to the pesticide or to its degradation products should not be adversely affected. The pesticide label provides explicit instructions on the application methods, dose or application rates, and on its safe use. Safety considerations include protective clothing for applicators, applicator training, instructions and warning statements regarding specific hazards, restrictions on water usage during and after treatment, environmental warnings, proper storage and disposal of containers, and procedures for handling spills.

Registration Process

Once the decision to develop a pesticide has been made, the process of registration with the EPA begins with a series of long-term research studies. These studies provide data related to product chemistry, animal toxicology, residues in food and feed, environmental fate, ecological effects, and efficacy. It is possible through modeling that the requirements for some studies may be satisfied or waived (Dawson and Kolar, 2003).

The EPA places submitted data into two categories: data submitted to support the registration of the active ingredient of the pesticide (generic data) and data submitted to support the registration of a specific formulation of the active ingredient (product-specific data) (Dawson and Kolar, 2003).

Field Testing and Experimental Use Permits

A critical component of the registration process is field testing. This usually begins late in the registration process because field testing generally requires an experimental use permit and data generated during the registration phase are used to support the application for the permit. Field testing occurs on large-scale plots under normal conditions and should cover all proposed uses. Data from field trials must be submitted to the EPA and are also subject to GLP standards. It is at this point in the pesticide development process that a manufacturing source for the active ingredient and formulations is explored if one does not already exists. Manufacturing process development studies are conducted once a manufacturer is identified. This is in preparation for full production of the pesticide once the registration has been granted by the EPA (Dawson and Kolar, 2003).

Product Chemistry, Toxicological, and Environmental Assessments

Tests conducted to satisfy product chemistry requirements center on the physical characteristics of the active ingredient and the formulated products. For example, tests include solubility in water and organic solvents, color, melting point, boiling point, octanol-water partition coefficient, and storage stability. Which tests are required depends on the nature of the active ingredient and the formulation and the manner in which the formulation will be used. For example, a test to determine viscosity would not be required if the product is a solid.

Toxicological assessments in mammals to ensure human safety and minimize harm to other non-target organisms are made to determine the acute effects of single doses, the chronic effects from long-term exposures, mutagenic effects, and carcinogenic effects. Acute studies examine the toxicity from oral exposure, dermal exposure, and inhalation. Acute eye and dermal irritation studies are also generally required. Subchronic tests involve 90-day feeding studies and dermal exposure studies that run from 21 to 28 days. Developmental and reproduction studies are also conducted. Finally, there is a battery of studies conducted to determine potential mutagenic, carcinogenic, and neurotoxic effects (Dawson and Kolar, 2003).

Environmental testing determines the fate of the chemical in water and soil. Some examples of environmental fate studies are hydrolysis, aerobic or anaerobic aquatic or soil metabolism, and photolysis. Studies of this type are generally conducted with radiolabeled material so that the fate of the parent chemical and its’ degradates can be followed. Use of radiolabeled chemicals can be costly depending on the ease of their synthesis (Dawson and Kolar, 2003).

Residue Chemistry and Residue Tolerances

Pesticide residue studies are conducted to determine whether residues would persist in an organism that could potentially be consumed by humans. In the case of registration of a piscicide, residue studies in fish or shellfish are generally required. Livestock and plant metabolism studies may also be required if water from a treated stream or pond could potentially be used for irrigation or watering livestock. If it is practical to place use restrictions on treated pond or stream water, the livestock or plant metabolism studies may be waived by the EPA. As a general rule, the first set of these studies should focus on determining the qualitative nature of the residues in the exposed organisms (Dawson and Kolar, 2003). Once this is known, field studies are conducted to determine levels of the residues that might be expected from a typical treatment. An assessment of the biological activity of the residues is made, and studies are conducted on those residues that might cause toxicity. The EPA will then set residue tolerances for the food portion of the organism on the basis of those studies. It is the responsibility of the manufacturer or registrant to demonstrate that the residues in a commodity are at levels that provide a reasonable margin of safety for human consumption. Monitoring is conducted and any food or feed commodities having residues that exceed the tolerance are destroyed. For a piscicide, it is not likely that residue tolerances would be set unless the piscicide is used on a contained food fish that will be shipped to market. Tolerance enforcement is the responsibility of the FDA (Dawson and Kolar, 2003).

Risk Assessment

Risks from the use of pesticides (American Crop Protection Association 2001) are assessed by the equation: Risk = Hazard × Exposure. Toxicology studies provide estimates of the hazards and the residue studies provide estimates of the exposures. In determining the risk associated with pesticide use, the EPA estimates the Reference Dose, also known as the Acceptable Daily Intake (ADI). This factor is arrived at by taking the No Observable Effect Level determined from animal feeding studies and dividing by a safety factor, usually 100 or greater. The ADI is taken as the amount of residue that can be ingested by the average person every day for a lifetime with a reasonable expectation of no ill effects. Typically the ADI is set well below levels that affect the most sensitive test animals. Considering that residue tolerances are also set such that residue exposures from all sources fall well below the ADI, a significant margin of safety is incorporated into the risk estimate (Dawson and Kolar, 2003).

The Federal Registration Package

The process of conducting the appropriate tests to support the registration of a pesticide takes 6 to 7 years and typically results in the accumulation of several thousands of pages of data. Registration packages are reviewed by the scientific and administrative branches of the EPA's Office of Pesticide Program; the process of review can take 6 months to 1 year for each individual piece of the submission. While the review is in progress, the registrant begins preparations for pesticide production. A product label will be approved once the data supporting the registration are judged to be adequate by the EPA (Dawson and Kolar, 2003).

The process of pesticide registration may differ by state agencies. Some states do not conduct full data reviews. Rather, they rely on the assessment of the EPA decisions. For each of these states, registration of a pesticide requires payment of an annual registration fee, ranging from $35 to $70, along with a completed application form containing information regarding the registrant's name and address, the name of the pesticide, the EPA registration number, and a complete copy of the pesticide label. Statutes of all states contain clauses that indicate that the state may request additional information or data in making its assessment (Dawson and Kolar, 2003).

Production

Identification of Sponsor

A sponsor, as defined by GLP guidelines, can be (1) a person who initiates and supports a study by provision of financial or other resources; (2) a person who submits a study to the EPA in support of an application for a research or marketing permit; and (3) a testing facility, if it both initiates and actually conducts the studies (40 CFR Part 160). Therefore, the sponsor of a pesticide can be either the manufacturer of a chemical or a third party.

Manufacturers of such chemicals are not usually motivated to register the product for use as a piscicide because it is a minor use and is not profitable and because more tests are required for a chemical used on water. Guiding the registration of a piscicide consequently falls on the party interested in the registration from financial and technical perspectives. Once identified, the sponsor has the responsibility to secure and provide funding to develop and register the piscicide and monitor all testing facilities involved in the conduct of registration studies for regulatory compliance and for study progress. The sponsor also has the responsibility of securing funding to produce the active ingredient and formulations. Once registered, the sponsor is responsible for maintaining the registrations of the active ingredients and formulations with the EPA and the states (Dawson and Kolar, 2003).

Manufacturing

The producer of a piscicide may be willing to manufacture the piscicide and formulations of the piscicide to the specifications of the party interested in the registration. If not, then it will be necessary for the registrant to identify an additional facility that can manufacture the formulation (Dawson and Kolar, 2003).

It is possible to have more than one manufacturer of the active ingredient under contract so that a constant source is available and costs can be controlled.

Labels and Product Classification

Registrations of products fall into two broad classifications: manufacturing-use products (MUP) and end-use products (EUP). Manufacturing-use products may either be the active ingredient or a formulation, if that formulation is used in the production of yet another formulation. The product label for such a material will specifically state that the product is an MUP and can only be used in the production of another product. End-use products are formulations that are only used to control pests and may not be used in the production of another formulation unless a specific registration and label have been developed for that purpose (Dawson and Kolar, 2003).

Registration Maintenance

Once an active ingredient and formulations of the active ingredient have been registered, activities turn toward registration maintenance. The registrant remains in contact with the EPA to pay annual fees, to renew the registrations, and provide any additional information that the EPA may require. One important aspect of registration maintenance is the monitoring and reporting of unreasonable adverse effects of the pesticide that falls under Section 6(a)(2) of FIFRA. The EPA has defined unreasonable adverse effects as any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide (EPA, 2011). Information on the adverse effects rule could result in the suspension or cancellation of a product. It is more likely that it will only be used to modify the terms and conditions of the registration on the basis of a review of the risks and benefits.

The burden of submission of adverse effects information falls solely on the registrant of a product, and only information that is additional and factual must be submitted. Any pertinent information that comes to the attention of the registrant directly, or to any party under contract to the registrant so that the registrant might reasonably be expected to receive the information, must be submitted. For example, if a study finds that a pesticide causes tumours in an avian species and the registrant, or an agent for the registrant, becomes aware of the information, then a 6(a)(2) report must be filed with the EPA (Dawson and Kolar, 2003). The information must be factual. For instance, if someone is alleged to have become ill after swimming in a pond treated with a pesticide and the allegation is reported by a neighbour or friend, that in itself is not sufficient to warrant a 6(a)(2) report. On the other hand, if the person is treated medically for the condition and the symptoms are consistent with expected toxicity, a 6(a)(2) report to the EPA is required provided the incident is reported by the attending physician to an appropriate authority (Dawson and Kolar, 2003).

Costs to maintain pesticide registrations vary from year to year and are based on appropriation legislation. Fee caps are also set by the appropriation legislation, and for this year the caps were set at $70,000 for the first 50 registrations and a maximum of $121,000 (Dawson and Kolar, 2003).

Laboratories for Development of Regulatory Data

There are numerous laboratories in the United States that generate regulatory data for submissions to the EPA. Due to the diversity of data required to register a pesticide, there is no single laboratory that can conduct all of the required studies. Most laboratories have expertise in one particular field. Whichever laboratories are chosen to perform the required studies, it is imperative that a careful review of the laboratories' capabilities and study proposals be conducted. Because the studies will be submitted to regulatory agencies, it will be necessary to review the quality assurance capabilities and GLP conformance of the laboratories. Laboratories that can conduct the appropriate field studies for environmental or residue studies are less easily identified. The additional effort required to conduct studies in the field that conform to GLP is not usually undertaken by most contract laboratories (Dawson and Kolar, 2003).

Time Line and Cost Estimates

Actual times will vary depending on the chemical selected and the registration requirements. As stated above, conducting all the studies required to register a pesticide can take 8-10 years and can cost up to $10 million (Dawson and Kolar, 2003). To register a piscicide, the time line may be closer to 5 years and the cost closer to $5 million. If the active ingredient is one that is already registered, the actual final time required and cost associated with registration will depend on the availability of data from the current registrant. While it is desirable to form a cooperative agreement with the producer of a chemical to register their product as a piscicide, by law they are required to cooperate and supply the data if requested (Dawson and Kolar, 2003).

CANADA: Registration of Pest Control Products

The Pest Management Regulatory Agency (PMRA) of Health Canada is responsible for the Pesticide registration and re-evaluating registered products and setting maximum residue limits under the *Food and Drugs Act*. Companies that wish to have the right to sell a pest control product in Canada must submit detailed information and data to be evaluated by the PMRA. Companies must provide all the scientific studies necessary for determining that the product is acceptable in terms of safety, merit and value. Depending on the complexity of the submission, a complete evaluation can take anywhere from a number of weeks, to a year or more. The evaluation results either in the product being granted registration and allowed for sale and use in Canada, or in the product being refused registration. The steps for registration are outlined below. All information is provided by PRMA email interviews and PRMA main website.

Screening

Before a submission is evaluated for health and environmental considerations, and for its value, efficacy, it is first examined by Screening Officers of the PMRA's Submission Management and Information Division (SMID). The purpose of the initial screening is to make sure that submissions meet the format, content and fee requirements of the Agency before they are sent for detailed evaluation. The screening process ensures that only complete, accurate and standardized submissions are brought forward for assessment. To this end, the Agency provides to industry detailed pre-submission guidance on administrative procedures and data requirements. In the Screening Unit, preliminary analyses of the studies are also carried out in order to determine if they are acceptable and whether they comply with international protocols.

Evaluation of pest control product

The PMRA's Health Evaluation Division (HED) has three main areas: The Toxicological Evaluation Sections, The Occupational Exposure Assessment Section and The Food Residue Exposure Assessment Section.

The Toxicological Evaluation Sections identify possible human health effects of pesticides, and establish the levels at which humans can be exposed to the products without any harm. Studies assessed include short and long-term, carcinogenicity (the capacity to cause cancer), genotoxicity (the capacity to cause damage to chromosomes), and teratogenicity (the capacity to produce fetal malformations), among others. These toxicology sections are responsible for setting Acceptable Daily Intakes (ADI) -- the amount of a compound that can be consumed daily for a lifetime with no adverse effects. ADIs always have safety factors built in, ranging from 100 to 1000. These safety factors are designed to take into account the potential differences in response, both within the same species (i.e., adults versus enfants) and between species (i.e., animals versus humans).

The **Occupational Exposure Assessment Section (OEAS)** performs exposure assessments on all new active ingredients and all major new uses of a pesticide in order to determine how much exposure to a pesticide could occur in a typical day. These assessments take into account the different exposures that people could have to pesticides, such as those who work with the pesticides (formulators, applicators, and farmers) and bystanders (people working or living near where a pesticide is used). They also take into consideration the differing exposures that adults and children would have. Data considered include residues found in air and on surfaces indoors and outdoors following application in domestic, commercial, and agricultural situations. Routes and duration of exposure, and the species tested in toxicity studies are also considered. Assessments of the effectiveness of personal protective equipment are often performed, and wearing such equipment can be required as a condition of registration.

The **Food Residue Exposure Assessment Section (FREAS)** evaluates every submission where a product could come in contact with food, including field crops, meat and dairy products, and processed foods. These evaluations are conducted in order to set the maximum residue limits (MRLs) for pesticides on food, both domestic and imported under the *Food and Drug Act*. Dietary Risk Assessments (DRAs) are also carried out to assess the potential daily intake of pesticide residues from all possible food sources.
DRAs take into account the different eating patterns of infants, toddlers, children, adolescents and adults, and so include a detailed evaluation of the foods and drinks that infants and children consume in quantity such as fruits and fruit juices, milk and soya products.

The Federal agency by delivering a notice in writing, may request an applicant to provide other information in support of the application within the time and in the form specified in the notice.

During an evaluation, the applicant has the burden of persuading PRMA that the health and environmental risks and the value of the pest control product are acceptable; and the Minister shall consider the information provided by the applicant in support of the application and may consider additional information, but the Minister shall give the applicant a reasonable opportunity to make representations in respect of the additional information before completing the evaluation.

In evaluating the health and environmental risks of a pest control product and in determining whether those risks are acceptable, the Minister shall apply a scientifically based approach; and in relation to health risks. Among other relevant factors, consider available information on aggregate exposure to the pest control product, namely dietary exposure and exposure from other non-occupational sources, including drinking water and use in and around homes and schools, and cumulative effects of the pest control product and other pest control products that have a common mechanism of toxicity,

(ii) apply appropriate margins of safety to take into account, among other relevant factors, the use of animal experimentation data and the different sensitivities to pest control products of major identifiable subgroups, including pregnant women, infants, children, women and seniors, and

(iii) in the case of a threshold effect, if the product is proposed for use in or around homes or schools, apply a margin of safety that is ten times greater than the margin of safety that would otherwise be applicable under subparagraph (ii) in respect of that threshold effect, to take into account potential pre- and post-natal toxicity and completeness of the data with respect to the exposure of, and toxicity to, infants and children unless, on the basis of reliable scientific data, the Minister has determined that a different margin of safety would be appropriate.

In determining whether the health and environmental risks and the value of a pest control product are acceptable, the Minister may, in accordance with the regulations, if any, take into account information regarding the risks and value of other pest control products that are registered for the same use.

The Minister shall, before making the determination, give the applicant a reasonable opportunity to make representations in respect of the information referred to in that subsection.

When making a decision regarding the registration of a pest control product, the Minister shall, if necessary, specify any maximum residue limits and health risks for the product or for its components or derivatives that the Minister considers appropriate in the circumstances. Relevant factors include available information on

(i) aggregate exposure to the pest control product, namely dietary exposure and exposure from other non-occupational sources, including drinking water and use in and around homes and schools,

(ii) cumulative effects of the pest control product and other pest control products that have a common mechanism of toxicity, and

(iii) the different sensitivities to pest control products of major identifiable subgroups, including pregnant women, infants, children, women and seniors; and

(*b*) in the case of a threshold effect, apply a margin of safety that is ten times greater than the margin of safety that would otherwise be applicable in respect of that threshold effect, to take into account potential pre- and post-natal toxicity and completeness of the data with respect to the exposure of, and toxicity to, infants and children, unless, on the basis of reliable scientific data, the Minister has determined that a different margin of safety would be appropriate.

The Minister may, by delivering a notice in writing, require a registrant to compile information, conduct tests and monitor experience with the pest control product for the purpose of obtaining additional information with respect to its effects on human health and safety or the environment or with respect to its value; and to report the additional information to the Minister within the time and in the form specified in the notice.

Environment

The Environmental Assessment Division (EAD) evaluates data on the environmental chemistry and toxicology of products, as well as their environmental fate i.e., what happens to the pesticide once it enters the environment. To address environmental concerns that may arise from the intended use of a product, EAD also makes recommendations for restrictions on use that would lessen risk. This could include label statements outlining buffer zones, timing and frequency of applications, rate at which the product can be applied, etc. As with the other PMRA divisions, EAD maintains contact with their counterparts in other federal and provincial government departments and in other countries so that they have access to the most up-to-date information, standards and protocols.

Laboratory Services

The PMRA's Laboratory scientists evaluate the product chemistry data that companies must provide as part of submissions for registering any pest control product. This ISO accredited laboratory also performs approximately 1500 guarantee, formulation and residue analyses every year in support of the PMRA's compliance investigations and microcontaminant, guarantee, and misuse inspection programs.

Value/efficacy assessments

An applicant for registration of a pesticide must establish that the product has merit and value for the purposes claimed when the product is used according to label directions. Product Sustainability and Coordination Division (PSCD) evaluators carry out these assessments, which include determining the efficacy or effectiveness of the product at various doses. This helps establish the lowest effective rate at which pesticides can be applied, and contributes to the minimizing of risks to health and the environment, crop damage and resistance problems. These assessments have led to many Canadian products having up to 50 per cent lower label use rates than the same products in other countries. Efficacy assessments also help protect users from deceptive claims regarding the effectiveness of pest control products. The "value" aspect of the assessment is linked to efficacy, and looks at whether the product improves crop yield, reduces damage by pests etc., depending on the intended use of the product.

Decisions

New Products: Once all the component parts of a submission have been evaluated, PMRA determines whether or not a product should be granted registration. Only if there is sufficient scientific evidence to show that a product does not pose unacceptable health or environmental risks and that it serves a useful purpose will a decision to register be made. A registration is normally granted for a term of five years, subject to renewal.
However, the term will be limited to less than five years where it is determined that the risks or value should be reviewed after a specified period. In all cases, conditions of registration are specified, including detailed use instructions, so that the product can be used safely. PMRA can also recommend to the Minister that registration be refused.

Registered Products: After a product is registered, PMRA may re-evaluate the products resulting in changes to the use pattern, label statements, or classification of a product in order to ensure that the risks and value of that product remain acceptable. Where it is determined that the risks to human health or the environment are no longer acceptable, or that the product is without value for its intended purpose, the registration is refused.

After considering any information reported, the Minister shall determine whether a special review of the registration of the pest control product as well as ask for public consultation.

If the Minister considers that the health and environmental risks and the value of the pest control product are acceptable after any required evaluations and consultations have been completed, the Minister shall register the product or amend its registration in accordance with the regulations, if any, by specifying the conditions relating to its manufacture, handling, storage, transport, import, export, packaging, distribution, use or disposal, including conditions relating to its composition and, subject to subsection, its label; assigning a registration number to the product in the case of a new registration and, where the Minister considers it appropriate, in the case of an amendment; and specifying the period for which the registration or amended registration is valid, which period may be either finite or indefinite. The Minister shall deny an application if the Minister does not consider that the health or environmental risks of a pest control product are, or its value is, acceptable.

The Minister shall then specify, as a condition of registration, the requirement for product safety information, including a material safety data sheet for the product, to be provided to workplaces where the pest control product is used or manufactured.

Once the product is registered, the registrant of a pest control product shall, as a condition of registration, record, retain and report to the Minister information on sales of the product in the form and manner directed by the Minister. The obligation to retain and report sales information continues to apply to a former registrant after that product ceases to be registered.

Re-evaluation and Special Review

The Minister may initiate the re-evaluation of a registered pest control product if the Minister considers that, since the product was registered, there has been a change in the information required, or the procedures used, for the evaluation of the health or environmental risks or the value of pest control products of the same class or kind. Re-evaluation of a pest control product is initiated by the Minister delivering a notice in writing to the registrant explaining the reasons for initiating the re-evaluation and, if considered necessary by the Minister, requiring the registrant to provide information in the form and within the period specified in the notice.

After the re-evaluation is initiated, the Minister shall deliver a notice to federal and provincial government departments and agencies whose interests and concerns are affected by the federal regulatory system requesting them to provide, in the form and within the period specified in the notice, information in respect of the health and environmental risks and the value of the product that is under re-evaluation.

The Minister shall initiate a special review of the registration of a pest control product if a federal or provincial government department or agency has provided information to the Minister that relates to the health or environmental risks or the value of the product and if, after considering the information provided, the Minister has reasonable grounds to believe that the health or environmental risks of the product are, or its value is, unacceptable.

The Minister may cancel or amend the registration of a pest control product if the registrant fails to satisfy a requirement or in the course of a re-evaluation or special review, the Minister has reasonable grounds to believe that the cancellation or amendment is necessary to deal with a situation that endangers human health or safety or the environment.

Other Grounds for Cancellation or Amendment

A registrant who intends to discontinue the sale of a pest control product for one or more uses for which it is registered shall notify the Minister of that intention in the form and manner directed by the Minister. The Minister may deliver a notice in writing to the registrant requiring the registrant to explain the reasons for the discontinuation.

If a registrant fails to pay a fee, fine, penalty, charge or cost that the registrant is liable to pay under or in relation to this Act, the Minister may cancel or amend any registration in the registrant's name; and refuse to consider any application made by the registrant under this Act. Before taking any action in relation to charges or costs, the Minister shall give the registrant a reasonable opportunity to make representations.

Joint Review

There have been efforts to harmonize the environmental data requirements under NAFTA for registration of Chemical Pesticides. The Pest Management Regulatory Agency (PMRA) and the United States Environmental Protection Agency (EPA) are committed to establishing a process that will enable joint reviews or worksharing of pesticide evaluations on a regular basis. For efficient worksharing, harmonization is necessary in a number of areas including data requirements, test guidelines for the generation of data, and evaluation methodologies (Health Canada, 1997).

The achievement of harmonizing environmental data requirements for the registration of the major agricultural and forestry uses of chemical pesticides in Canada and the United States is one more positive step on the road toward harmonization. Harmonization reduces costs to applicants and facilitates simultaneous registration of pesticides in Canada and the United States (Health Canada, 1997).

Impediments still remain, however, to optimum worksharing of environmental reviews, i.e., requirements for field dissipation studies, test guidelines and exposure and risk assessment methodologies. These are currently being addressed under the North American Free Trade Agreement (NAFTA) Technical Working Group on Pesticides.

Announced at the March 1996 meeting of the NAFTA Technical Working Group on Pesticides in Washington, D.C., the environmental data requirements for the registration of the major agricultural and forestry uses of chemical pesticides in Canada and the United States have, essentially, now been harmonized (Health Canada, 1997). This paper explains the process and rationales by which this important harmonization step was achieved.

Canadian data requirements for environmental chemistry and fate of chemical pesticides, as specified in Trade Memorandum T-1-255, were compared with those proposed by the U.S. EPA in 40 Code of Federal Regulations Part 158 Subparts D and N. Differing requirements were then examined in terms of their importance to the determination of environmental risk based on the experience of evaluating numerous chemical pesticides over more than a decade (Health Canada, 1997).

Some changes were made in order to harmonize requirements; for example, Canada required bioaccumulation studies in earthworms and later deleted it as it was not included in the U.S. process. The PMRA did not frequently request data on bioaccumulation in earthworms, except for terrestrial and forestry uses for pesticides with a potential to bioaccumulate. The triggers for this requirement were based on the potential for exposure, the log of the octanol/water partition coefficient (log K_{ow})$\geq$3, accumulation in non-target aquatic organisms, and persistence in soil. The EPA did not have this requirement. For the majority of cases, the PMRA will use the log K_{ow} $\geq$3, the bioconcentration/bioaccumulation in fish, and the metabolism data in plants, rats, cows, goats and chickens to assess potential for bioaccumulation in other organisms (Health Canada, 1997).

The PMRA also required adsorption/desorption and either soil-column leaching or soil thin layer chromatography (TLC) data for terrestrial, seed treatment, and forestry uses, but one of either adsorption/desorption or soil-column leaching or soil TLC data for greenhouse and domestic (residential) uses, and only adsorption/desorption data for aquatic uses. The EPA required either adsorption/desorption or soil-column leaching data for all of these uses. In most cases, experience has shown that either adsorption/desorption or soil-column leaching data would suffice to assess potential mobility in soil (Health Canada, 1997). The PMRA will continue to accept soil TLC data where these data are generated using internal standards. The PMRA will continue to require only adsorption/desorption data for aquatic uses because leaching data are not relevant to the aquatic use pattern. In another effort to blend Canadian and U.S. policies, the EPA has **extended the requirements for aquatic biotransformation from aquatic to terrestrial uses where runoff to aquatic sites is of concern.** The new EPA requirements will allow the Agency to predict the impact of pesticides on aquatic environments (including sediment) due to runoff from terrestrial use. These requirements are closer to the PMRA's requirements for aquatic biotransformation for all terrestrial, aquatic and forestry uses (Health Canada, 1997).

The PMRA required data on aerobic and anaerobic biotransformation at two temperatures (3-8°C and 20-30°C) in soil for terrestrial and forestry uses and in natural water/sediment systems for terrestrial, aquatic and forestry uses, while the EPA required these data at one temperature in the higher range (18-30°C) (Health Canada, 1997). In most cases, biotransformation data from only a higher temperature will permit an adequate assessment of pesticide behaviour in soil and natural water. Past evaluation of data generated at low and high temperatures has shown that there is generally a two-to-threefold decrease in transformation rate for a 10°C decrease in temperature. The PMRA will, however, continue to require low-temperature anaerobic aquatic biotransformation data on a case-by-case basis for pesticides that may contaminate groundwater or bottom sediments. This issue will be discussed further through the OECD Test Guideline development process. The PMRA has deleted the low temperature requirement for aerobic and anaerobic soil and aerobic aquatic studies (Health Canada, 1997).

The PMRA has deleted the requirement to conduct toxicity studies on soil microorganisms. Over the years, the results of studies on toxicity to soil microorganisms were never pivotal in reaching a decision on whether to register a pesticide. Most data generally indicated no effect on the endpoint tested or transient short-term effects (Health Canada, 1997).

The EPA has changed the use-pattern classification of seed treatments from an indoor use to a terrestrial food/feed crop use category which results in a change in data requirements. With the exception of seed treatments, the broad use patterns designated by the EPA and the PMRA were compatible. The PMRA regarded seed treatments as a special terrestrial, i.e., agricultural use pattern requiring a reduced dataset, whereas the EPA considered them an indoor use. After reviewing the toxicity and persistence data of pesticides on seeds, the EPA concluded that they needed additional data to estimate exposure of these pesticides to the environment. This will provide additional data for more accurately estimating exposure and will achieve harmonization with both Canada and the United Kingdom (Health Canada, 1997).

These changes have aided in simplifying the application process, particularly for those applying for both Canada and US registration and applying for joint review.

Chapter 5: Summary

Native species are needed to maintain or enhance an aquatic system. However, noxious species often degrade aquatic systems to a degree that may require eradication to protect and maintain established beneficial uses. The prevention, control, and eradication of noxious species needs to be given a high priority in the development of lake and watershed management plans and may require extensive control measures.

The 1987 amendments to the Federal Clean Water Act required the development and implementation of programs designed to reduce or eliminate the introduction of toxic substances to our nation's waters. In addition, new scientific evidence concerning the potential impacts that certain toxic substances may have on human and aquatic life have increased public awareness regarding the intentional introduction of toxic substances to surface waters, even in situations where their introduction may enhance the uses of a water body. Thus, a more thorough review and analysis of the benefits of aquatic pesticides relative to the potential risks to human and environmental health is warranted. Through this process, managers can make informed selections of methods for reducing water quality issues and meeting long-term management goals.

Management plans help to ensure that proven control methods will be implemented for the long-term management of the water body and those problems such as nutrient enrichment and sediment loading, which often are the cause of accelerated plant and algae growth, are addressed. Planning further assures that aquatic plant managers will not rely on aquatic plant control methods that may only address the symptoms of such problems.

When choosing an aquatic pesticide some important considerations need to be made. These include results of toxicological studies for aquatic species native and threatened, and long-term environmental impacts regarding persistence. When considering endangered Species, special consideration is given to salmonids and other listed species under the Endangered Species Act (ESA).

Invasive Aquatic Plant Control

The environmental impacts of many chemicals were evaluated for noxious and nuisance aquatic plant control. Currently, the chemical herbicides diquat, endothall (Hydrothol® 191 and Aquathol®), fluridone, glyphosate, Triclopyr, copper compounds and 2,4-D have been approved as chemical alternatives to aquatic plant control. Integrated pest management is the preferred method of control.

Having a variety of control methods available provides the flexibility necessary to control nuisance populations of native as well as invasive non-native species in situations where it is also desirable to maintain other beneficial water uses.

In regard to public waters, a wide range of participation is essential for the benefit of all users. However, in the case of new infestations of noxious (non-native) and invasive plants, early control may be necessary. Addressing the potential loss of habitat or habitat disruption from aquatic plant control strategies must also considered in implementation of any aquatic plant management program, particularly wetlands, which are sometimes overlooked as a key component of aquatic systems. The value and function of wetlands is increasingly being recognized and must be incorporated into any comprehensive lake or vegetation management plan.

Aquatic plants appear in many shapes and sizes. Some float on the water surface, while others grow completely underwater. They grow wherever water is persistent, in rivers, streams, lakes, wetlands, coastlands or marine waters. The presence of native species is natural and normal in lakes and other water bodies because they provide important links in aquatic life systems. In large quantities, however, plants can interfere with water uses. Non-native aquatic plants and excessive plant nutrients are often a threat to the health of the aquatic environment. The removal of non-native aquatic plants from the aquatic system is often desirable and even necessary to enhance water quality and protect beneficial uses. The US Army Corp of Engineers (2011) has provided a list of advantages and disadvantages to chemical weed control as seen below.

Advantages of Chemical Weed Control

- Aquatic herbicide application can be less expensive than other aquatic plant control methods.
- Aquatic herbicides are easily applied around underwater obstructions and structures, such as docks.
- Aquatic herbicides can be applied directly to problem areas of all size scales.
- Aquatic herbicides are deemed safe by USEPA for intended use when used as directed.

Disadvantages of Chemical Weed Control

- Some herbicides have swimming, drinking, and water use restrictions.
- Herbicide use may have unwanted impacts to people who use the water and to the environment.
- Non-targeted plants as well as nuisance plants may be adversely impacted by some herbicides.
- Depending on the herbicide used, it may take several days to weeks or several treatments during a growing season before the herbicide controls or kills treated plants.
- Rapid-acting herbicides like Aquathol may cause low oxygen conditions to develop as plants decompose. Low oxygen conditions may result in fish kills.
- To be most effective, herbicides must be applied to specific stages of the plants, (i.e. young shoots, flowering stages).
- Some expertise in using herbicides is necessary in order to be successful and to avoid unwanted impacts. Therefore, permits are required for certain types of herbicides.
- Many people have strong feelings against using herbicides in water. Having the public involved and educated in the treatment process is beneficial.
- Some local jurisdictions have policies forbidding or discouraging the use of aquatic herbicides. As policies change, control practices must adjust.

Invasive Fish Control

In maintaining viable recreational fisheries it is important to protect native fish from invasive species. The introduction of non-native species has lead to impaired fisheries as a result of competition, predation, or alteration of key parts of ecosystems. Piscicides can be effectively used to control fish whose populations may have become imbalanced or may have otherwise impaired the fishery. Two general use registered piscicides include antimycin and rotenone.

Both rotenone and antimycin may be used when all fish in a body of water are to be eliminated, with subsequent stocking of desired fish to rehabilitate the fishery. More frequently, antimycin is used as a selective piscicide on certain kinds of fish as described in its use in catfish aquaculture ponds. At the labelled application rates, antimycin has limited effects on macroinvertebrate fauna, thus allowing for a more rapid repopulation of fish that depend heavily on a macroinvertebrate food supply.

According to the EPA, antimycin is generally used "to repopulate native, threatened, or endangered trout species in streams by eliminating non-native fish species, particularly in high altitude alpine lakes and streams because it is effective in cold alpine waters and where pH is low. In addition, this piscicide may be used at low concentrations, which makes it easy to transport to isolated streams.

Rotenone is most often used in standing water, such as large lakes and reservoirs, and that it was often applied to maintain sport fisheries, and sample fish populations (USEPA 2006b). Rotenone has also been used to aid in the restoration of threatened and endangered trout species (Finlayson, et al., 2001).

Conversely, antimycin is not as effective as rotenone in large bodies of standing water primarily because of its short persistence and the difficulty of dispersing the product throughout the water column. The Fintrol Concentrate label states that it is designed for use in running water, streams, and shallow waters.

Pfeifer et al (2001), stated that the greatest value of antimycin is its property to be degraded extremely rapidly when it comes in contact with sunlight and strong oxygenation. As a result, it does not need to be detoxified before reaching downstream fish populations when it is used in high altitude streams and lakes having outlets with steep stream gradients.

Antimycin does not have as serious an impact on aquatic invertebrates as rotenone (Finlayson et al., 2002). Antimycin is often thought of as a costly pesticide. However, in EPA's alternatives analysis, it was determined that the cost, based upon 1998 data, was comparable to rotenone on the basis of treating a specific amount of water. The cost of antimycin was estimated to be about \$47/acre. Rotenone cost was found to be \$2-13 per acre-foot at unspecified "low rates" and \$45-

137 at high rates (USEPA, 2006b). Antimycin A may be more costly per unit volume of product, but it requires much lower application rates than rotenone.

There are a variety of molluscicides available. TFM and Bayluscide have shown to be effective lampricides and are largely in use in the Great Lakes.

Copper sulphate can be effective options for treating some whole pond. Hydrated lime and copper sulphate cannot be used in ponds with low alkalinity and Bayluscide can only be used to control snails in ponds with no fish (Terhune et al., 2003). Liming of a water body to eliminate aquatic pest species is a non-specific treatment but is best suited for artificial environments such as human-made ponds and aquaculture. Chlorine is relatively inexpensive, it works in most raw water systems, and it is toxic at low concentrations and quickly loses toxicity without bioaccumulating. Zequanox is an effective technique for mussel control that is natural and safe for the surrounding environment.

There are currently limited treatments for pathogens and small invertebrates, but biocide treatment can help prevent their spread.

A full overview of the pests, their chemical control and water quality issues is available in appendix A

Chapter 6: Conclusion

Control tends to be a focal point of many non-indigenous species initiatives. Aquatic Nuisance Species can be controlled by several general methods, including chemical, biological, mechanical or physical, and habitat management practices. Proper evaluation and use of selective chemicals may provide effective control of aquatic invaders with a minimum of ecological hazard or other side-effects.

Before considering any control tool, the local ecosystems need to be thoroughly understood particularly for presence of endangered or protected species. All possible options need to be reviewed in order to choose the best tool for the selected site. States or provinces may have their own prohibition, standards or guidelines for use of chemical tools) and must be checked for up to date registration status, and local use restrictions as these may change from time to time.

Management decisions need to consider application safety, public health and water quality issues, and non-target impacts and labels on products must be strictly followed.

To aid in a solution that will not have a large impact on existing species an examination of species within the targeted region is necessary and when possible it is best to chose selective pesticides.

There are some improvements to be made in respect to information available to the public. With respect to rapid response in the Great Lakes, there should be some clear bi-national standards established rather than needing to confer with two sets of regulatory guidelines. Although it is complicated working in adjacent water, the application of Bayluscide to control Sea Lampreys in the shared St. Marys River, is evidence that it can also prove to be highly successful. To improve this, further alignment of PMRA and EPA standards for registering new pesticides should be established. Joint registration of chemicals should be encouraged to aid in the management decision making process. Aligning these guidelines might also be necessary to improve the suite of chemical tools available in addition to using the ones already registered.

All efforts should be made towards precautionary measures to prevent further invasion into the Great Lakes. No single method is likely to provide the necessary control of aquatic nuisance species. Hence, a comprehensive control strategy involving a combination of techniques referred to as Integrated Pest Management (IPM) is usually necessary for an effective control program. Most control methods have at least some environmental risk.

Affordable and effective control often requires a prompt response to an infestation before the organism becomes established or widely dispersed. Therefore, when a reasonable chance exists that a newly detected non-indigenous aquatic species could become a nuisance, a quick determination of whether control is essential.

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