Assessing the Economic Value of Protecting the Great Lakes: Invasive Species Prevention and Mitigation

Final Report

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Executive Summary

The Great Lakes have long been recognized as a vital cross-boundary resource for Canadians and Americans alike. Studies have consistently shown investments in the health of the Great Lakes to be attractive. This report focuses on one specific threat to the Great Lakes ecosystem: Aquatic Invasive Species (AIS). Once established, AIS are extremely difficult to control. Canada and Ontario have made commitments to address the threat of AIS. The *Ontario Biodiversity Strategy* (2005-2010) targets AIS prevention, early detection, rapid response and management and control.

The objective of this study is to undertake an economic analysis that will provide a better understanding of the economic value (to Ontario) of protecting the Great Lakes by preventing the establishment of AIS. The specific objective of this study is to gain an understanding of the magnitude of the impacts of an invasion relative to the costs of preventive measures. Two species groups are examined using a case study approach to assess costs: zebra mussels costs of invasion; and, Asian carp costs of prevention.

The study was conducted in three main phases:

1) *Estimate Costs Associated with Preventing Asian Carp from Entering the Great Lakes;*
2) *Estimate Environmental Damages and Economic Costs of Zebra Mussels in the Ontario;*
3) *Discuss the Value of Prevention and the Estimated Economic Impacts of AIS.*

We adopt the Total Economic Value (TEV) framework to determine the full range of societal costs attributable to the zebra mussel invasion to date. Our case study of Asian carp prevention costs takes into account those costs associated with physical barriers, control and removal activities, studies and increased enforcement of regulations. Indirect costs are discussed qualitatively.

The analysis of economic costs of zebra mussels includes only the Ontario side of the Great Lakes (with the exception of Lake Superior since it has not been affected by zebra mussels to date). The main tributaries to the lakes are also included but smaller tributaries are excluded. Asian carp are threatening the Great Lakes from the Mississippi River system therefore the majority of prevention costs for the control of Asian carp is being paid by the US government and neighbouring US States.

Costs are converted to 2009 Canadian dollars, unless stated otherwise and capital project costs are annualized. Therefore, we calculate the current annualized value of Asian carp prevention costs and zebra mussel impacts. We use a social discount rate of 3.5% to annualize capital costs and impacts.

This study employs an analysis of economic welfare not a distributional analysis of costs of benefits. Therefore our analysis evaluates costs and benefits that accrue to stakeholders as a whole. Although some costs and benefits apply specifically to particular stakeholders, several costs and benefits may be redistributed to society as a whole, such as increased fee rates for residential water, electricity, or taxes.

Asian Carp

Four carp species native to Asia are currently found in the Mississippi watershed, three of which are known to have established breeding populations in the watershed. The Mississippi River is hydrologically connected to the Great Lakes by the Chicago Area Waterway System (CAWS), including the Chicago Ship and Sanitary Canal (CSSC). The most likely pathway for invasion is through the CAWS, so prevention measures have had two primary foci: the construction of physical barriers and deterrents within the CAWS; and, the removal of Asian carp from the vicinity of constructed barriers. In addition, effort and funding are being allocated to research.

The total annual cost for prevention activities is approximately $20.5 million, with costs distributed roughly evenly among physical barrier construction/maintenance (36%), control/removal (32%) and studies (29%). Increased enforcement activities account for 2% of costs. As these costs are actual incurred and reported costs, no uncertainty analysis is performed.

Recent multiple discoveries of Asian Carp DNA on the Great Lakes side of the barriers and the June 2010 capture of a bighead carp upstream of electric barriers may indicate that current prevention strategies are not 100% effective, although conclusive evidence is not available about the nature of these breaches. Current spending aimed at preventing Asian carp from entering the Great Lakes may not be sufficient to prevent an invasion.

Zebra Mussels

Zebra mussel impacts on food webs and fish populations contribute to economic losses to recreational and commercial fishing (Pimentel, 2005) and cause impairment to industrial, municipal, hydro electric, and nuclear power plant water intakes, clogging pipes and causing decreased water flow and reduced plant efficiency (O'Neill, 1997; Colautti et al, 2006). Increased algae growth associated with zebra mussels can also result in impairment to recreational boating and swimming beaches, taste and odor problems in drinking water supplies, and blocked water-intake pipes during storm events (USGA, 2008) as well as other use impacts including farm irrigation and golf courses.

Exhibit 1 presents the results of the uncertainty analysis on the cost data for the zebra mussel infestation, as annualized values.

Exhibit 1 Summary of the Total Annualized Costs with Uncertainty Analysis Results

	Low*	Mean*	High*
Residential Water	$21,103,930	$24,355,209	$27,571,510
Industrial Water	$1,488,706	$2,223,433	$2,941,593
Golf Courses	$11,943	$14,308	$16,735
Recreational Fishing	$2,363,521	$2,856,629	$3,344,868
Commercial Fishing and Aquaculture	$500,775	$599,894	$699,171
Recreational Boating	$37,112,280	$44,233,155	$51,388,449
Navigational Boating	$871,959	$1,044,882	$1,220,191
Power Generation	$6,884,591	$7,646,884	$8,378,534
TOTAL	**$75,198,160**	**$82,974,395**	**$90,879,145**

* These result show combinations of outcomes and the columns are not additive. That is, the total low column may be a combination of the minimum costs and the maximum costs for different categories and any number of combinations in between.

The total impact ranges from $75M to $91M and impacts resulting from operational inconveniences and ecosystem function are additional costs of the zebra mussel invasion that could not be monetized. Non-extractive use values such as wildlife watching, and ecosystem service values such as habitat function, cannot be monetized because there is no data quantifying the link between zebra mussels and changes in these uses. In addition, option and non-use values may constitute a large portion of the total economic costs of the zebra mussel invasion, but the value of such impacts has not been estimated in the literature.

Comparison and Policy Implications

This analysis has taken a purposely simplified approach so that clear conclusions can be drawn from the findings. The analysis looks at only two species, identified through discussion with the client: one that has, so far, been prevented from invading; and, the other that has successfully invaded. We examine relatively well-defined costs and (foregone) benefits of each without a requirement for hypothetical extrapolations regarding invasion (or not) of species and related speculation on impacts. Such a hypothetical analysis would require assumptions about the rate and extent of invasion and direct and indirect impacts; a scenario-based approach to capture the potential range of impacts would be warranted and would require considerably more time and resources than available for this study.

Notwithstanding the limitations associated with this study, the results clearly show that costs associated with preventing entry of Asian carp are a fraction of the mitigation costs associated with the current zebra mussel invasion ($20M: $83M) even though many zebra mussel invasion costs could not be monetized. Furthermore, the estimated cost of the zebra mussel invasion represents only a fraction of the total Great Lakes Basin costs, as impacts to the U.S. from the zebra mussel invasion were purposely excluded from the analysis. From a risk mitigation perspective, the analysis can be used to justify prevention costs in the range of those currently spent on Asian Carp, and higher, given the importance of protecting the Great Lakes Basin ecosystem from severe alteration. As a general approach, where costs of prevention are less than the estimated economic impacts of an invasion, expenditures up to the cost of the economic impacts can be justified since the return on the investment will be positive. Where the costs of invasion are unknown, which will be typical of AIS that have not yet invaded, the zebra mussel costs can be used as a precautionary basis for estimating the impacts of those AIS with the potential to significantly alter the Great Lakes Basin ecosystem.

Given the uncertainty surrounding the effects of Asian carp (and other potential invaders) on the Great Lakes system, the enormous impact associated with the zebra mussel (and other established AIS) in the Great Lakes, and the relative magnitude of prevention costs compared to mitigation costs, we can conclude that a focus on prevention of future invasions is warranted where scientists suspect ecosystem alterations will result in significant changes to the Great Lakes Basin ecosystem.

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1 Introduction

1.1 Project Context

The Great Lakes have long been recognized as a vital cross-boundary resource for Canadians and Americans alike. The International Joint Commission, established in 1909, assists governments in addressing pressing issues in these waters, such as those related to water quality, water levels, water flows, invasive species management, and ecosystem integrity. The Great Lakes Water Quality Agreement (GLWQA) commits Canada and the United States to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem and includes a number of objectives and guidelines to achieve these goals. Since 1971, Canada and Ontario have worked together under a series of agreements to protect the Great Lakes. The Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) establishes an action plan and clear roles and responsibilities between federal and provincial ministries, and helps Canada to meet its obligations under the GLWQA. Key priority areas in COA are: cleaning up Areas of Concern (AOCs); reducing harmful pollution; and, dealing with lake-wide environmental issues, including protecting and restoring aquatic habitats in rivers and nearshore areas.

Studies have consistently shown investments in the health of the Great Lakes to be attractive. For example, *America's North Coast: A Benefit-Cost Analysis of a Program to Protect and Restore the Great Lakes* (Buchsbaum et al., 2007) found that a present value investment of $26 billion in Great Lakes restoration would result in a long term economic benefit of at least $50 billion and short-term benefits of between $30 billion and $50 billion, primarily for the U.S. Great Lakes region. On the Canadian side of the Great Lakes ecosystem, the report *Monetary Benefits of Hamilton-Halton Watershed Stewardship Program (1994-2002): Cost Savings and Economic Benefits* (2003) found that the incurred costs of rehabilitation projects represented only 10% of the total economic benefits on average.

This report focuses on one specific threat to the Great Lakes ecosystem: Aquatic Invasive Species. Because it is difficult to predict the likelihood of non-native species invading the Great Lakes ecosystem, or the economic impact of a successful invasion, a case study approach is used to illustrate the relative costs of preventing invasions and mitigating the impacts of established invaders. The purpose is not to compare the impacts of the two species but to understand the relative magnitudes of costs to assess whether prevention efforts for one known species are the same as, more than, or less than, the impact costs of a second known species. Also, assessing the costs to Ontario of a known successful invader (i.e. zebra mussels) provides a useful benchmark to gauge appropriate levels of effort for prevention where an invading species would have the potential to significantly alter the Great Lakes ecosystem.

1.2 Background

Aquatic Invasive Species (AIS) are defined as "a non-native species whose introduction will likely cause (or has already caused) damage to the host ecosystem, existing species therein, the economy or human well-being".[1] Once established, AIS are extremely difficult to control. During the past two centuries, invasive species have significantly changed the Great Lakes ecosystem. In turn, the changes have had broad economic and social impacts for those that rely on the system for food, as a water source, and for recreation. According to the U.S. Environmental Protection Agency, at least 25 non-native species of fish have entered the Great Lakes since the

[1] Fisheries and Oceans Canada, http://www.dfo-mpo.gc.ca/science/enviro/ais-eae/index-eng.htm

1800s, along with many non-native species of plants (USEPA, 2009). AIS tend to degrade native habitat, outcompete native species, and disturb food webs. These changes can result in negative economic and social consequences. To date, damage to commercial and recreational fisheries of the Great Lakes has been among the most pronounced of these consequences.

In some cases, effects have been felt directly by human users of the Great Lakes ecosystem. For example, fouling of water intakes by invasive zebra mussels has increased maintenance costs for those industries and municipalities which take water from the Great Lakes. Since their establishment, zebra mussels have also caused serious disruptions to the Great Lakes ecosystem. Disruptions include damage to the health of commercially valuable fish stocks, such as previously compromised whitefish populations,[2] and changes in natural nutrient cycles, an impact with potentially far-reaching and imperfectly understood consequences.

New species with the potential to become AIS in the Great Lakes are constantly being identified by scientists. For example, the Asian carp is currently threatening to invade the Great Lakes system from the Mississippi watershed and considerable efforts are being made to prevent breeding populations from successfully establishing themselves in the Great Lakes Basin.

1.2.1 AIS Management in Ontario

Ontario is a signatory to the Joint Strategic Plan for Management of Great Lakes Fisheries, which is a collaborative approach between Canada and the U.S. and a product of the 1955 Convention on Great Lakes Fisheries. The Great Lakes Fishery Commission (GLFC) coordinates fisheries research and exotic species control, in particular the sea lamprey. The GLFC is also a forum for Ontario and the eight U.S. states on the Great Lakes to discuss and make joint decisions about Great Lakes fisheries management.[3]

In September 2004, the Government of Canada introduced *An Invasive Alien Species Strategy for Canada*. This strategy aims to minimize the risk of invasive alien species to the environment, economy and society, and to protect environmental values such as biodiversity and sustainability. The strategy emphasizes four strategic goals:

- To prevent harmful intentional and unintentional introductions
- To detect and identify new invaders in a timely manner
- To respond rapidly to new invaders
- To manage established and spreading invaders through eradication, containment, and control.

To implement this strategy in aquatic habitat, the Government of Canada and partners developed *A Canadian Action Plan to Address the Threat of Aquatic Invasive Species.* This strategy advocates that the most effective approach to dealing with AIS involves managing the pathways through which invasive species enter and spread through Canadian waters. These pathways include shipping, recreational and commercial boating, the use of live bait, the aquarium/water garden trade, live food fish, unauthorized introductions and transfers, and canals and water diversions.

[2] Environment Canada NWRI, Research into Action to Benefit Canadians, Zebra Mussels, Nutrients and the "Dead Zone": The Great Lakes Debate, ec.gc.ca/inre-nwri/default.asp?lang=En&n=832CDC7B&xsl=articlesservices,viewfull&po=0E367B85

[3] See www.glfc.org

The *Ontario Biodiversity Strategy* (2005-2010) advocates implementing the *Canadian Action Plan* in Ontario through the following actions:

- Preventing introductions of invasive species through the identification and management of high risk pathways (e.g. ballast water, nurseries) and bans on the importing of high risk species (e.g. Asian carp)
- Improving capability to assess risks of invasions
- Building capability to quarantine where necessary
- Enhancing early detection capacity, especially in high risk areas
- Taking rapid action to eradicate invasive pests; and
- Limiting the spread/impacts of invasive pests that cannot be eradicated.

These actions target (in order of significance): AIS prevention; early detection; and, rapid response and management and control, as once AIS are established they are typically virtually impossible to eradicate.

1.3 Project Objectives and Scope

The objective of this study is to undertake an economic analysis that will provide a better understanding of the economic value (to Ontario) of protecting the Great Lakes of preventing the establishment of AIS. The specific objective of this study is to examine costs and (foregone) benefits associated with specific AIS to gain an understanding of the magnitude of the impacts of an invasion relative to the costs of preventive measures. Impacts of two species groups in particular are examined using a case study approach:

- The economic costs (to Ontario) caused by invasive mussels of the *Dreissena* genus, specifically the zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena rostriformis*)
- The costs of current intervention strategies to prevent invasion of “Asian carp”, focusing on Bighead Carp (*Hypophalmichthys nobilis)* and Silver Carp (*Hypophalmichthys molitrix*).

Note that for the purposes of this paper, the two *Dreissenid* species are referred to generically as ‘‘zebra mussels.’’ The two species are closely related and ecologically similar. They have also invaded the Great Lakes in close succession, resulting in the similar ecological and economic costs. See Benson et al., 2010.

The scope of this study has been defined such that speculation regarding hypothetical situations is not necessary. For instance, speculation on what the economic benefits would be had zebra mussels not successfully invaded, or the economic costs incurred if Asian Carp do invade, are not within the scope of analysis. Instead, the economic valuation is based on the current status of the two species of interest: zebra mussels which have successfully invaded the Great Lakes Basin; and, Asian Carp which, to date, have been successfully prevented from colonizing within the Basin.

1.4 Study Boundaries

1.4.1 Geographic Location

The analysis of economic costs of zebra mussels includes only the Ontario side of the Great Lakes, with the exception of Lake Superior since it has not been affected by zebra mussels to date. The main tributaries to the lakes are also included but smaller tributaries are excluded.

We restrict our analysis to the main tributaries as there is high certainty that they are infested with zebra mussels, whereas the status of smaller tributaries is often unknown.

To estimate the value of zebra mussel impacts to Ontario, we use cost data from Ontario and, where data are limited, we transfer relevant costs from U.S. States. In estimating the economic costs of zebra mussels, the key stakeholders affected include Ontario residents, Ontario (Great Lakes area) tourists, the Canadian Federal government, the Ontario provincial government, Ontario municipal governments and Ontario industries and businesses in the Great Lakes area.

Asian carp are threatening the Great Lakes from the Mississippi River system. Therefore, the majority of prevention costs for the control of Asian carp is being paid by the US government and neighbouring US States. We calculate the total economic costs paid by both Canadian and American governments and other various stakeholders within the Mississippi River watershed for activities associated with preventing the Asian carp from entering the Great Lakes and spreading within the Basin. The key stakeholders include the US state and federal governments, the City of Chicago, the Ontario provincial government and the Canadian federal government.

1.4.2 Time frame for Analysis

For Asian Carp prevention costs we assess costs from 2002 to 2010, including planned expenditures and expenditures on measures with co-benefits in terms of preventing other species migrations to and from the Great Lakes Basin. For zebra mussel impact costs we assess costs that have been incurred since the species incursion into the Ontario Great Lakes. We present our results as annual costs in 2009 Canadian dollars. In the case of capital projects, estimated service life is used to annualize costs.

1.4.3 Intervention and Mitigation Measures

We use a case study approach to determine the range of societal costs for each of the two species:

- We adopt the Total Economic Value (TEV) framework (see Section 2.2) to account for the full range of societal costs attributable to the zebra mussel invasion to date. Because this case study analysis is limited to incurred costs, as indicated above, estimating the costs of prevention of potential zebra mussel infestations is not attempted.

- Our case study of Asian carp prevention costs takes into account those costs associated with: construction of physical barriers; biological control and removal activities; undertaking studies related directly to barrier improvement, control and removal; and, costs associated with increased enforcement of regulations. Indirect costs, such as property value changes due to mitigation measures, are discussed qualitatively. Again, because our analysis is limited to incurred costs, estimation of the potential costs of invasion of Asian carp is not attempted.

1.5 Overview of this Report

This report is organized into six sections, including this introduction section. The subsequent sections include:

Section 2 – Approach and Methodology

In this section, we present our overall methodological approach and we outline the steps taken in our analysis. Our valuation approach is described using a total economic value (TEV) framework. We also describe our economic analysis approach and the methodology used for conducting uncertainty analysis.

Section 3 – Analysis: Asian Carp Prevention Costs

This section begins by presenting background information on Asian Carp. Costs to prevent Asian Carp migration into the Ontario Great Lakes are described with a detailed analysis of total direct costs, categorized by type of expenditure. Finally, we provide information on the assumptions, limitations, and uncertainties involved in this analysis.

Section 4 – Analysis: Zebra Mussel Impact Costs

This section begins by presenting background information on Zebra Mussels. Ecological and economic costs of zebra mussel infestation are described. We present an overview of the common mitigation measures for zebra mussels. A cost assessment calculates impact costs for each impact category, presented according to the TEV framework. Finally, we provide a summary of the assumptions, limitations, and uncertainties involved in this analysis.

Section 5 –Results

We provide the results of the Asian Carp and the Zebra Mussel cost analyses, including results of a uncertainty analysis for zebra mussel impact costs. Tables are used to show the total annualized costs for each cost category, and the sum of all costs for Asian Carp and for Zebra Mussels.

Section 6 – Discussion

In this section, we discuss some conclusions drawn from this study and possible implications of our results for future funding decisions and policy development on invasive species prevention and management.

2 Approach and Methodology

2.1 Overview of Approach

To draw comparisons between the two species through the case studies, we identify the costs of Asian carp prevention in parallel with analyzing the costs of the zebra mussel infestation. These values are then compared to illustrate the scope and scale of the relative costs of AIS pertinent to Ontario. A qualitative discussion of the two situations also sheds light on the relative implications of AIS.

The study is conducted in three main phases.

1) Estimate Costs Associated with Preventing Asian Carp from Entering the Great Lakes

We review and assess the total current annual costs for preventing Asian carp invasion into the Great Lakes. Analysis focuses on the Chicago Area Waterways System (CAWS), the primary site of invasion pressure. Current costs are annualized and aggregated to calculate a total cost of prevention activities. Indirect costs and potential future costs are discussed separately.

2) Estimate the Environmental Damages and Economic Costs of Zebra Mussels in the Ontario

We review and assess current human and environmental impacts of zebra mussels in the Great Lakes. We identify the economic value of impacts caused by zebra mussels and present these costs on a per unit basis where possible (*i.e.* per house, facility, boat). Cost data are obtained for Ontario and Great Lakes U.S. states using the cost-transfer approach for data sources in the U.S. Impacts and economic values are presented according to the use categories defined in the TEV framework (see Section 2.2). Costs are annualized and aggregated to derive an estimate of the total annual costs of zebra mussels to Ontario.

3) Discuss the Value of Prevention and the Estimated Economic Costs of AIS

We summarize the results of our analysis. We discuss the scope and scale of reported impacts and costs and comment on their relevance and implications. In our discussion, we include intangible values described in Phases 1 and 2 as well as external prevention/impact costs, such as indirect costs to society or costs accrued outside of Ontario, such as those in the U.S.

As the Great Lakes ecosystem is extremely complex, the impacts of an invasion cannot be predicted with any certainty. As a consequence, estimating the costs and benefits of preventing a future invasion would layer uncertain cost values over unknowable benefits. The case study approach described above represents a purposely simplified approach employed to avoid hypothetical situations and to minimize guesswork and uncertainty. The goal is to illustrate the magnitude of a prevention cost alongside the magnitude of a mitigation cost. This comparison is done at a level of detail suitable to inform strategic level policy decisions pertaining to AIS policy and investment in Ontario.

2.2 Total Economic Value Framework

We use the Total Economic Value (TEV) framework to identify, quantify and where possible monetize the full range of costs associated with invasive zebra mussels. The economic valuation method was chosen over alternative approaches because it encompasses a robust taxonomy for assessing links between biological impacts and economic values.

As discussed in Section 2.1, the analysis of Asian carp is limited to current costs. As current impacts on the Great Lakes are virtually non-existent and the effects of an invasion are uncertain, use of the TEV framework to evaluate forgone benefits is not appropriate.

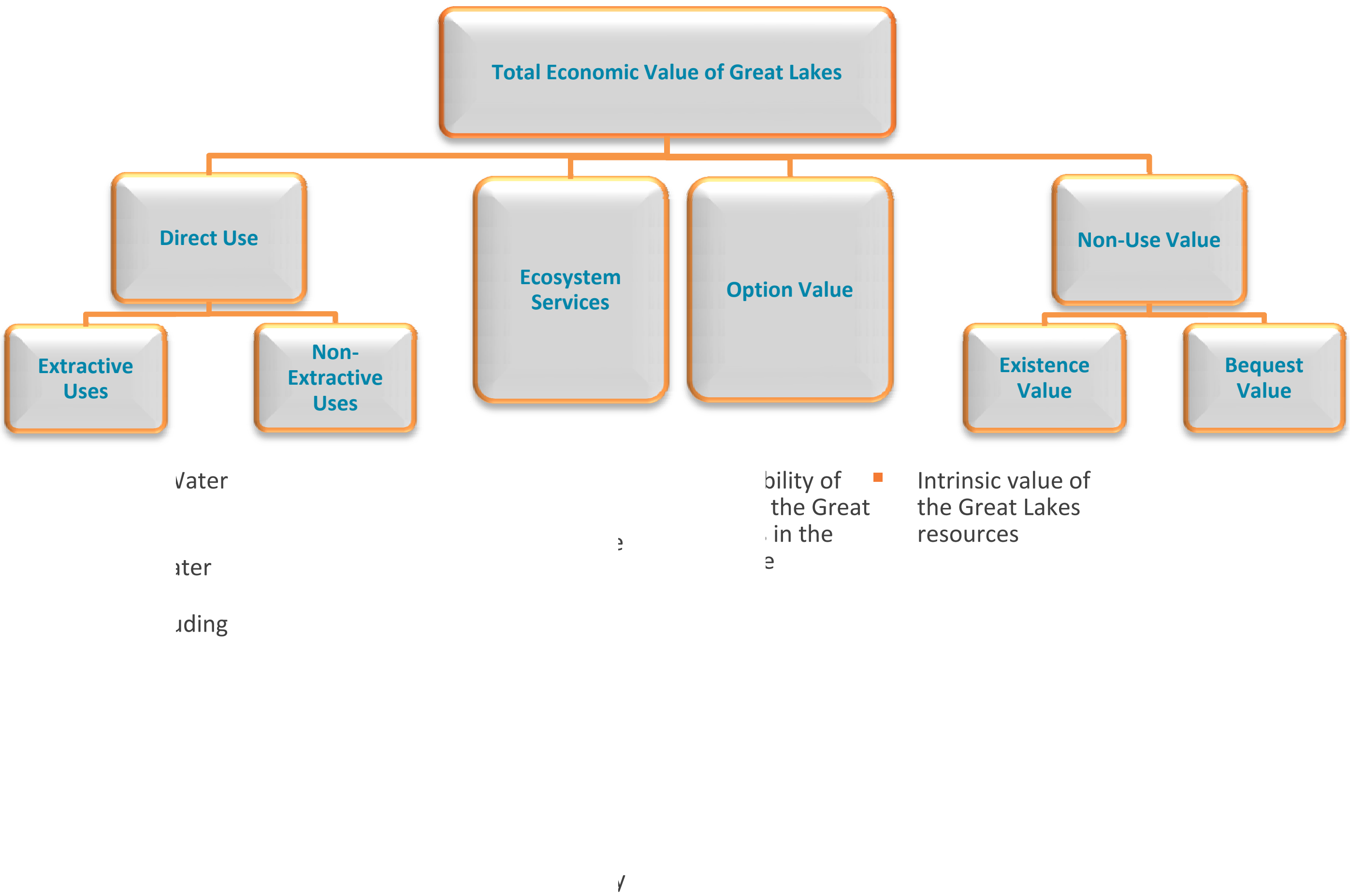
Zebra mussels impact a wide variety of potential benefits to society. Although valuing these impacts is a challenge, conceptually the total economic costs of the zebra mussels are equivalent to the total WTP to avoid these impacts by all of the relevant stakeholders. It should be noted that most of the impacts associated with zebra mussels are valued using control, treatment, and maintenance expenditures. Individuals, governments and businesses may be willing to pay more than they are currently paying to avoid these impacts. Therefore, our results should be interpreted as conservative since they represent a lower bound estimate of the total economic costs of zebra mussels.

The type of benefits that zebra mussels impact can be categorized using the TEV framework, shown in Exhibit 2. This framework considers that the costs attributable to the AIS species consist of direct-use values, indirect use values (specifically, ecosystem services), option values and non-use values:

- Direct use values reflect the direct use of the resource, such as fishing, water use for power generation, and water use by agricultural and industrial/commercial users (Tietenberg, 2006).
- Indirect use values include ways in which the lakes benefit communities by providing services such as waste assimilation and habitat. These indirect use categories can also be thought of as ecosystem services.[4]
- Option value refers to the option of using specific benefits impacted by zebra mussels in the future, even if they are not being used today.
- Non-use values include existence and bequest values. Existence value recognizes that some Ontarians may be prepared to pay something for the protection of the Great Lakes from the effects of zebra mussels even if they do not currently use the Great Lakes. Bequest value recognizes that decisions on the Great Lakes Basin should also take into account the value of leaving it undamaged for future generations. Exhibit 2 illustrates the type of benefits that may be impacted by the zebra mussels within the TEV framework.

[4] It is important to note that not all ecosystem services are indirect uses and not all indirect uses are ecosystem services. Clearly, all the goods and services provided by the Great Lakes ultimately come from the ecosystem. In the context of this report, we use the term "ecosystem services" to categorize indirect uses in order to communicate the more natural foundations of these services.

Exhibit 2 Total Economic Value Framework for Great Lakes Invasive Species



2.3 Economic Analysis Approach

This section provides a brief outline of the general economic approach used in this analysis. Our approach is to first identify the full range of costs then, where possible, quantify them and, finally, to use economic valuation approaches to develop monetary values. In this analysis, dollars are used as the common numeraire so that values under the TEV categories can be easily compared. All values presented in this report are converted to 2009 Canadian dollars, unless stated otherwise.[5] With these inputs, the TEV of the Great Lakes can be presented using a common method (economic valuation) and metric (dollars).

The approach used to evaluate the economic costs of zebra mussels aggregates the impacts of zebra mussels to the Ontario Great Lakes, according to the TEV framework. The approach used to evaluate the current prevention costs of Asian carp in the Great Lakes aggregates the costs of specific interventions. Our main analysis presents the results as current annualized economic

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[5] This conversion was done using Statistics Canada data on the Canadian Price Index (v41693271). Data accessed from CANSIM using CHASS. Values were converted into Canadian dollars using Purchasing Power Parity (PPP) conversion factors from the OECD (http://www.oecd.org/department/0,3355,en_2649_34357_1_1_1_1_1,00.html).

values. To present current annualized economic values, it is necessary to separate upfront costs from ongoing annual costs. We then annualize initial values to develop total annualized values for both the economic costs of zebra mussels and the costs of preventing Asian Carp from entering the Great Lakes.

Initial values are annualized using the following formula:

$$AIV = IV \times \frac{r}{1-(1+r)^{-n}}$$

where AIV is the annualized initial value, IV is the initial value, r is the social discount rate and n is the number of years in the analysis.

The total annualized value includes the sum of the annualized initial values and the ongoing annual values.

$$Total\ Annualized\ Value = Annualized\ Initial\ values + Ongoing\ Annual\ Values$$

In the case of control measures, we may use the cost-transfer approach (Rossi et al., 2004). This approach is analogous to the benefit-transfer approach but applies to control and mitigation costs. Because the objective of this analysis is to calculate the total annual economic costs of zebra mussels to Ontario, we rely on average unit costs as opposed to marginal unit costs.[6]

Results are presented as current annualized costs. This implies the following assumptions:

1) The ecological extent and impacts of the zebra mussels remain the same as when the underlying studies were undertaken.
2) The real costs of annual control measures have not changed since the data were collected.

2.3.1 Discount Rate

The choice of a Social Discount Rate (SDR) is an important and controversial policy decision in cost benefit analysis. For our study, we considered the two main approaches that exist for calculating the discount rate:

- The social opportunity cost rate of capital
- The social time preference rate

The social opportunity cost rate of capital is usually identified as the real rate of return earned on a marginal project in the private sector. The social time preference rate is the rate at which society is willing to trade off between present and future consumption. This rate takes into account factors other than the economic opportunity cost of funds and is often used for circumstances where environmental goods and services are substantial.

Current “interim” guidelines from the Treasury Board Secretariat (TBS) use a weighted social opportunity cost rate of capital approach to recommend a SDR of 8% with sensitivity rates of 3% and 10%. However, this choice has been severely criticized for not reflecting relevant theoretical and empirical literature.

[6] In traditional cost-benefit analysis, the marginal values of benefits are compared to the marginal costs. However, when estimating total costs, the use of average costs is appropriate.

There is now widespread agreement that the most appropriate method for calculating the SDR is through the use of an optimal growth rate model. Using this method, the SDR depends on three primary variables and is formulated as:

$$SDR = d + e*g$$

The first term, ***d***, is the utility discount rate ("pure preference for utility in the present over the future" Boardman et al. (2009). The latter product term is composed of ***e***, the elasticity of marginal utility with respect to consumption (i.e. the absolute value of the rate at which the marginal value of consumption decreases as per-capita consumption increases) and ***g***, the growth in per-capita consumption.

Using this approach, Boardman et al. (2009) proposes that Canada should use a SDR of 3.5% with sensitivity rates of 2% and 5% for intragenerational projects. This SDR is a real, before-inflation rate. To arrive at a central SDR estimate for Canada of 3.5%, Boardman et al. (2009) use values of ***d*** = 1, ***e*** = 1.5 and ***g*** = 1.7.

The research and policy trend in other countries also supports using a relatively low social discount rate. In the US, Moore et al. (2004) propose a SDR of 3.5% in many circumstances. The United Kingdom government has recently lowered their recommended SDR from 6% to 3.5% (HM Treasury (2003)). Finally, in France, a reduction in the SDR from 8% to 4% has recently been recommended by a group of experts commissioned by the ministry of Finance (Lebegue et al. (2005)).

For the purpose of this economic analysis, we use a SDR of 3.5%. We feel this SDR appropriately reflects both the specific circumstances of the economic analysis and the recent theoretical and empirical literature.

2.4 Uncertainty Analysis Approach

A risk-based analysis was conducted to ensure that the final results (net present value) reflect the uncertainty in key input variables. To account for the inherent uncertainties involved, Monte Carlo simulations using @Risk Software were performed.[7] This approach integrates uncertainty into the analysis as opposed to relying on *ex post* sensitivity analysis to test the robustness of the results. This approach allows us to describe a distribution of possible economic benefits rather than specific point estimates. This analysis is important to test the robustness of the results for changes in various variables. In addition, the range of outcomes that the net benefit falls within can then be identified, and the risk of a negative outcome (costs > benefits) better understood.

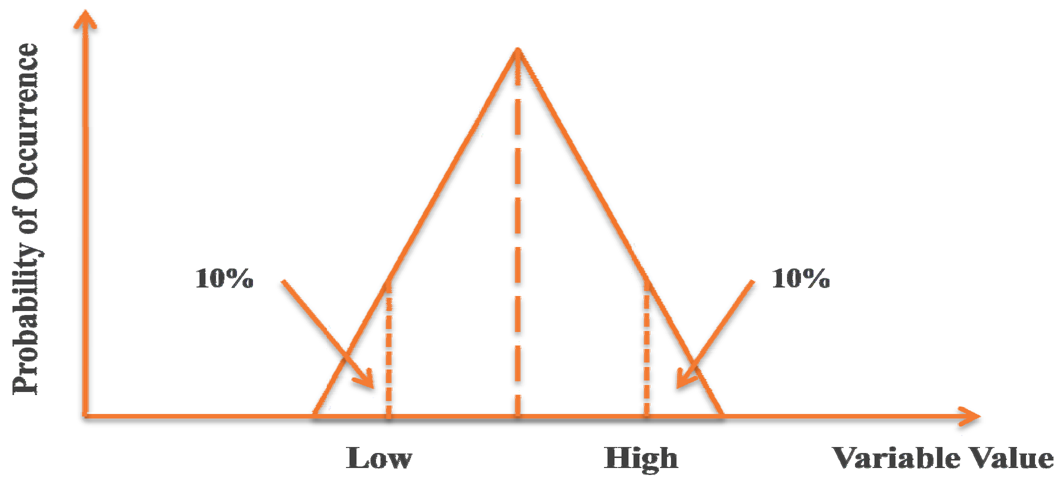
Uncertainty is factored into the analysis through the definition of uncertainty ranges around key variables. In the cases where we have a range of values, we use these as our low and high values, with the average as the most likely. In the cases where we have single point estimates, we use this as the most likely and add/subtract 25% to arrive at our high/low estimates. Thus, uncertainty is factored into our analysis by considering a range of possible values.

[7] http://www.palisade.com/risk/

To keep the analytics of @Risk simple, we use the RiskTrigen function.[8] This triangular distribution function specifies three points: one at the most likely, one at the specified bottom percentile and one at the specified top percentile. The percentile values give the percentage of the total area under the triangle that falls to the left of the entered point. Using this distribution, we attach small probabilities that the costs and benefits will fall beyond our high or low estimates.

Exhibit 3 presents a graphical representation of the probability distribution of the RiskTrigen function. The variable values are distributed along the X-axis and the probability of occurrence is represented on the Y-axis. As shown, the central dashed line has the highest probability of occurrence and the probability of occurrence decreases as the variable values move further away from this central estimate.

Exhibit 3 The RiskTrigen Function in @Risk



[8] The RiskTrigen function was chosen over alternative distribution functions (normal, gamma etc) for its simplicity, and because it does not have 'tails'. That is to say, the RiskTrigen function does not allow variable values that are far outside the low and high estimated values.

3 Analysis: Asian Carp Prevention Costs

3.1 Introduction

Several carp species native to Asia are considered invasive species in the United States. Four of these species - black carp (*Mylopharyngodon piceus*), bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idella*), and silver carp (*Hypophthalmichthys molitrix)*, collectively referred to as "Asian carp" - are of specific concern.

Asian carp can grow up to 1.8 metres in length and weigh 70 kg (Conover et al., 2007). To support this large mass, Asian carp can eat up to 40% of their body weight per day. The specific diet of Asian carp is varied by species: black carp feed primarily on mollusks, bighead carp feed primarily on zooplankton, grass carp prefer submerged plants and soft leaves and silver carp filter feed primarily on phytoplankton. The appetites of Asian carp support growth of up to 2-3 kg per year in temperate climates. Lifetime egg production per female varies per species but ranges from 50,000 to 5,000,000. Asian carp have a maturity age of 2-10 years depending on the species, water temperature and diet (Conover et al., 2007).

Asian carp were originally imported to North America in the 1960's and 1970's as a means of biological control of aquatic plants and algae. The first documented shipments of Grass carp to the United States occurred in 1963, with documented escapes into the Mississippi watershed following shortly afterwards. By 1974, the Arkansas Game and Fish Commission had introduced more than 380,000 Grass Carp into over 100 lakes in the Mississippi watershed through a hatchery and stocking program. The first known introduction of three other Asian Carp species occurred in 1974 when a fish farmer imported several individuals. The Arkansas Game and Fish Commission subsequently ran a successful breeding program for both Silver and Bighead Carp during the late 1970s. It is likely that individuals raised as part of this breeding program escaped into the Mississippi watershed. Additional escapes from fish farms are thought to have occurred during flooding in the early 1990s.[9] All four species are

Mutually Beneficial Interaction Between AIS

Work is currently underway to explore the interaction between three nuisance species, including the two AIS examined in this report: bighead carp, zebra/quagga mussels and bluegreen algae.

Bluegreen algae blooms have increased markedly in the Great Lakes since the invasion of *Dreissenid* mussels, as the mussels avoid consuming bluegreen algae (Vanderploeg et al., 2001). It is thought that these blooms may act as a food source for the filter-feeding bighead carp, thereby enhancing their chances of establishing and spreading should they reach the Great Lakes. It is also thought that bluegreen algae blooms may be enhanced by interaction with bighead and silver carp (USEPA et al, 2010).

Great Lakes Restoration Initiative funding is presently being used to explore these interactions, with a current emphasis on bighead carp interactions.

[9] See http://www.jsonline.com/news/wisconsin/29194474.html for a summary of Asian carp imports and escapes.

currently found in the Mississippi watershed. Bighead, grass and silver carp are known to have established breeding populations in the watershed.[10]

The Mississippi and Great Lakes watersheds are hydrologically connected by the Chicago Area Waterway System (CAWS), including the Chicago Ship and Sanitary Canal (CSSC), which is used to transport freight between the Great Lakes & the Mississippi River and to convey treated wastewater south from the city of Chicago. In recent years, Asian carp, particularly the filter-feeding bighead and silver species, have progressed northward up the Mississippi system. Policy makers, biologists and engineers are currently focusing resources on the CSSC in an effort to prevent Asian Carp from entering the Great Lakes. Sections 3.3 and 3.4 outline the costs associated with this effort.

3.2 Potential Impacts

As breeding populations of Asian Carp have not established in the Great Lakes watershed, the ecological and economic costs of an invasion of Asian carp are unknown. However experts expect that that introduction of Asian carp into the Great Lakes ecosystem would threaten the sport and commercial fisheries - industries that combined are worth an estimated $550 million/year to Ontario's economy.[11] These ecological and economic damages could exceed those caused by previous sea lamprey and zebra mussel invasions (USEPA et al 2010). There are also possible implications for other watershed uses such as recreational boating & waterfowl hunting.[12]

Benefits Associated with Asian Carp

Asian carp have been used for several decades in North American aquaculture for algae control. They are often raised alongside catfish on US farms for this purpose, then sold for human consumption at the end of the production cycle.

A pair of 1998 studies estimated the net benefit of stocking bighead carp with catfish at US$108-$183/acre, while a separate 1998 study estimated net profit from bighead carp raised in catfish ponds at US$371/acre.

(Source: Conover et al, 2007)

3.3 Prevention Measures

To date, the identified pathway of single specimens collected in the Canadian Great Lakes have come from the live food fish industry (DFO, 2004). However, as indicated in Section 1 above, this report is based on a case study approach of costs of prevention. Therefore, for consistency and comparability, we analyze only the costs of preventive measures untaken by the United States for Asian Carp. From the perspective of the U.S. government, invasion of the Great Lakes watershed *via* the artificial hydraulic connections between the Great Lakes and Mississippi watersheds, in particular the CAWS, poses the most significant risk for invasion pathway. As a result, American prevention measures have had two primary foci: the construction of physical barriers and deterrents within the CAWS; and, the

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[10] Conover et al, 2007.

[11] These figures come from Ontario's Ministry of Natural Resource's website http://www.mnr.gov.on.ca/en/Business/GreatLakes/2ColumnSubPage/STEL02_173913.html

[12] Silver carp have been known to jump up to 10 feet out of the water when frightened by the sound of boat motors sometimes injuring boaters and water-skiers. Asian carp feeding habits may also lead to the degradation of waterfowl production areas. See, for example, http://www.asiancarp.org/documents/asiancarp.pdf

removal of Asian carp both upstream and downstream of these barriers for monitoring purposes and in order to reduce propagule pressure.[13] Significant effort and funding are also being allocated to research in support of these efforts.

3.3.1 Summary of Current Prevention Measures

Costs for actions undertaken to prevent Asian carp from invading the Great Lakes have been drawn from a number of sources. Two principal sources include:

- *Asian Carp Control Strategy Framework* (USEPA et al., 2010)
  - Outlines actions which are underway, funded or planned.
- *Management and Control Plan for Bighead, Black, Grass and Silver Carps in the United States* (Conover et al., 2007)
  - Estimates costs for a number of recommended actions, many of which have been completed or are presently underway.

Exhibit 4, below, summarizes measures for the prevention of Asian carp invasion which are currently underway along with their implementation year and costs. Activities for which funds have been allocated but not yet spent are included with a note. A number of measures have been recommended at an estimated cost, but funds have not been committed. These are identified with *italics and grey highlights*. Indirect costs are not included. Two cost estimates for the implementation of comprehensive prevention strategies are provided for comparison.

Exhibit 4 Costs of Prevention Measures for Asian Carp

Description of Prevention Activity	Time	Source	Cost ($US)
Physical Barriers			
Construction of "Barrier I" on CSSC at Romeoville Illinois.	2002	Conover et al, 2007	$2.2 M
Barrier I upgrade	2008	Conover et al, 2007	$5.5 M (pre-construction estimate)
Total Barrier I construction, operation and upgrade costs	2006-2008	CSSC Dispersal Barrier Advisory Panel, 2009	$ 5.0 M
Construction of Barrier IIA	2007	USACE 2009	$8.5 M (through FY 2007)
Construction of Barrier IIB	2010	USEPA et al, 2010	$17.0 M (construction partially complete)
Yearly Operation & Maintenance of Barriers IIA & IIB (estimated)	2007	Conover et al, 2007	$450,000/ yr
Construction of Des Plaines River and Illinois & Michigan Canal Barriers	2010	USEPA et al, 2010	$4.5 M (funded, contract awarded April 2010.)[14]

[13] Propagule pressure is defined as "the quality, quantity and frequency of invading organisms". Higher propagule pressure tends to increase the probability of a successful invasion (see Simberloff, 2009)

[14] Funded for 2010 at $13.2 M, winning bid valued at $4.5 M. See https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=eee06c62a5eac1f6d454ddf48a592591&_cview=0

Description of Prevention Activity	Time	Source	Cost ($US)
Strobe/Sound Projector Array/Acoustic Bubble Curtain (planned pilot)	*2010*	*CSSC Dispersal Barrier Advisory Panel, 2010*	*$15.0 M*
Barrier Effectiveness Testing	2010	USEPA et al, 2010	$400,000
Modification of Structural Operations	*2010*	*USEPA et al, 2010*	*$ unknown*
"Current barrier & Rapid Response Cost"	2010	O'Keefe, 2010 (unpublished)	$25-46 M
"Develop & implement redundant barrier systems within the CSSC"	*20 years (recommended 2007)*	*Conover et al, 2007*	*$18 M over 20 years*
Control and Removal			
Removal / Containment of Carp previously stocked for biological control (proposed)	*2007*	*Conover et al, 2007*	*$2.0 M/yr*
Targeted Removal within Chicago Area Waterway System	2010	USEPA et al, 2010	$2.0 M
Downstream Commercial fishing to reduce propagule pressure	2010	USEPA et al, 2010	$300,000
Promotion of Commercial Fishing & Commercial Market Development	2010	USEPA et al, 2010	$3.0 M
Monitoring, Testing and Contract Fishing (adjacent to and upstream of electrical barriers)	2010	USEPA et al, 2010	$2.6 M
Rotenone Application	2010	Miller, 2010	$3.0 M[15]
Studies & Planning			
Barrier Efficacy Study	2009	USEPA et al, 2010	$1.1 M
"Great Lakes and Mississippi River Inter-basin Study"[16]	2010-2012	USEPA et al, 2010	$1.0 M
Inter-basin Transfer Feasibility Study exploring hydraulic pathways	2010	USEPA et al, 2010	$500,000
Barrier Effectiveness Study Using Tagged Fish	2010	USEPA et al, 2010	$400,000

[15] Cost for December 2009 Rotenone Application. Marc Miller, Director Illinois Department of Natural Resources: Testimony to the Illinois Senate Committee on Energy and Natural Resources, February,25, 2010. Available online [http://asiancarp.org/documents/ILLINOIS%20ASIAN%20CARP%20CONTROL%20EFFORTS_Senate.pdf]
[16] Initial phases focused on Chicago Area Waterways & Asian Carp migration. See Action 2.2 (pp 18 and Appendix A of report).

Description of Prevention Activity	Time	Source	Cost ($US)
Study to Evaluate Tow Boats & Barges as Vector for Asian Carp	2010	USEPA et al, 2010	$500,000
Study to Evaluate Seismic technology to control Asian Carp	2010	USEPA et al, 2010	$200,000
Research re: Asian Carp Attraction Pheromones	2010	USEPA et al, 2010	$300,000
Research re: Identification of Selective Toxicants	2010	USEPA et al, 2010	$300,000
Research re: Toxicant Delivery Mechanisms	2010	USEPA et al, 2010	$200,000
Development of Oral Toxicant Delivery Platforms	2010-2011	USEPA et al, 2010	$1.6 M
Study re: reducing Asian Carp Food Sources *via* Nutrient Removal	2010-2012	USEPA et al, 2010	$1.0 M
Enforcement			
Additional enforcement of existing invasive species laws, listing of Bighead Carp as "injurious species".	2010	USEPA et al, 2010	$400,000
Estimated Costs for Comprehensive Strategies			
Full implementation of "Management and Control Plan for Bighead, Black, Grass and Silver Carps in the United States"	*2007*	*Conover et al, 2007*	*$286 M over 20 years*
Measures ensuring AIS (including, but not limited to Asian Carp) are not introduced to the Great Lakes through Canals and Waterways	*2005*	*GLRC Strategy, 2005.*	*$225 M over 5 years*

3.3.2 Potential Economy-wide Costs

In addition to those costs discussed in the preceding section, two recent studies (Taylor and Roach, 2010 and Schweiterman, 2010) have examined the broader economic impact of permanent hydrologic and ecological separation of the Great Lakes and Mississippi watersheds by closing the CSSC. This approach has been suggested by ecologists and environmental non-governmental organizations, and has been the subject of ongoing legal action among several Great Lakes States.

Schweiterman in particular provides an analysis of the economy-wide impact of closure of the CSSC. Although many of the costs identified are beyond the scope of the present analysis, they are presented in Exhibit 5 below in order to serve as information for an upper limit estimate of the financial impact of potential Asian carp prevention measures in the United States in general and the Chicago area in particular.

Exhibit 5 Potential Costs Associated with the Closing of the CSSC

Description of Prevention Activity	Time	Source	Cost ($US)
Transportation related costs of physical separation of Mississippi & Great Lakes basins	2010	Taylor & Roach, 2010	$64-69 M / yr.
	2010	Schwieterman, 2010	$95.2 M/yr.
External costs & additional highway wear	2010	Schwieterman, 2010	$29.8 M/yr.
Costs to Recreational Boating (incl. cruises & tours)	2010	Schwieterman, 2010	$24.8 M/yr.
Additional Flood Protection Infrastructure	2010	Schwieterman, 2010	$375.5 M/yr. (over 8 years)
Municipal Protection (Fire & Police Services)	2010	Schwieterman, 2010	$5.1 – 5.6 M/yr.
Property value loss	2010	Schwieterman, 2010	$51.0 M

3.4 Cost Assessment

The costs presented above in Exhibit 4 are gathered from several sources. In some cases, these costs are budgeted but not spent amounts. In other cases (highlighted), amounts are estimated or recommended levels of spending. Actual spending levels presented overlap one another to varying degrees, often because they have been reported by different sources, or because they report on different or overlapping portions of the same activity. This section attempts to fill gaps with reasonable assumptions and remove duplication and overlap in the four areas of spending identified: Physical Barriers, Control/Removal, Studies and Planning & Enforcement.

3.4.1 Physical Barriers

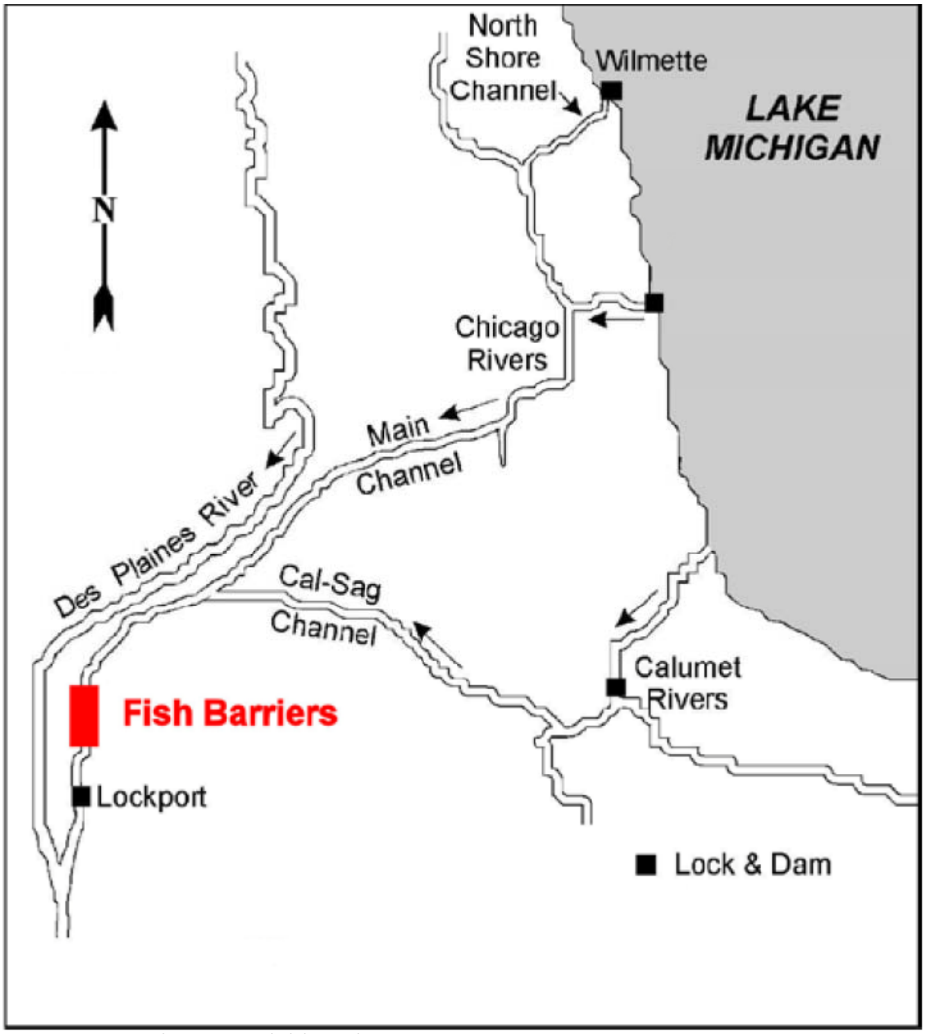
Exhibit 4 outlines costs associated with three separate physical barriers, which are illustrated in the following exhibits:

- As illustrated in Exhibit 6 fish barriers are located in the CSSC slightly upstream of the confluence of the Des Plaines River – part of the Mississippi watershed - and the CSSC which is fed from Lake Michigan. Shown in detail in Exhibit 7, Barriers I (labeled “Demonstration Barrier”), IIA and IIB create an electric field across the width of the CSSC that acts as a deterrent to fish.

- The Des Plaines River and Illinois & Michigan Canal Barriers include 13.5 miles of concrete and chain link fencing between the Des Plaines River and the CSSC and the blockage of connections between the CSSC and the Illinois and Michigan Canal (not shown in Exhibit 6 or Exhibit 7).

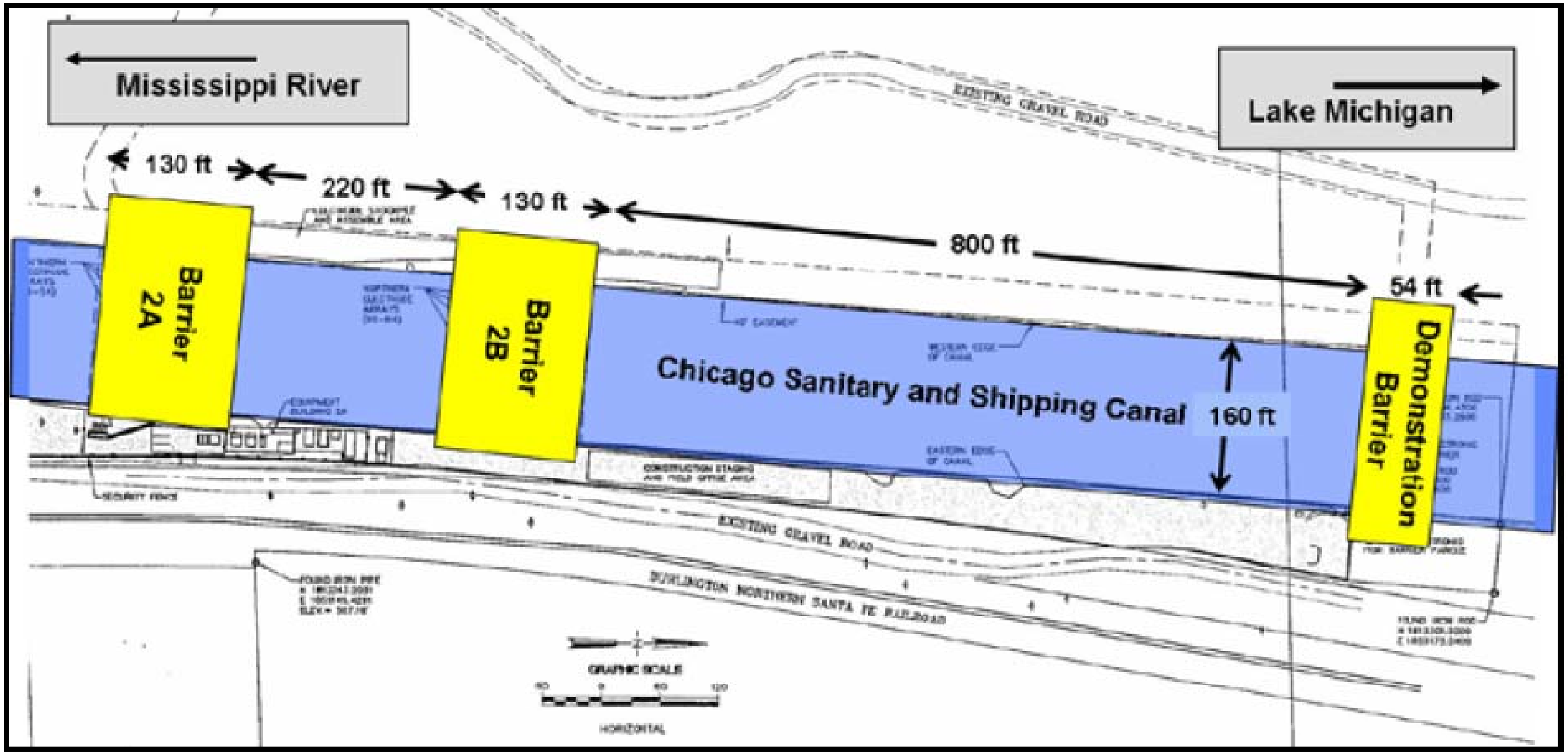
These undertakings are meant to prevent Asian carp from entering the CSSC above the current barriers during flood events.

Exhibit 6 Asian Carp: Physical Barrier Locations



Source: USACE Barriers Fact Sheet. Available online [http://www.lrc.usace.army.mil/projects/fish_barrier/file/2009-08-12-CSSC-FactSheet.pdf]

Exhibit 7 Asian Carp: Barrier I, IIA & IIB Diagram



Source: USACE Barriers Fact Sheet. Available online [http://www.lrc.usace.army.mil/projects/fish_barrier/file/2009-08-12-CSSC-FactSheet.pdf]

Accounting for wholly or partially overlapping costs in Exhibit 4, our best estimate of the total cost of physical barriers is provided in Exhibit 8 below.

Exhibit 8 Summary of Costs of Physical Barriers to Asian carp

Activity	Reported Cost ($US)	Cost (Annualized $C2009)	Rationale
Barrier I Construction (2002) and upgrade (2008)	$5 M	$1.1 M/yr	Most recent figure. 7 year service life.[17] Assume 50% costs incurred in 2002, 50% incurred in 2008.
Barrier IIA Construction (2007)	$8.5 M	$1.7 M/yr	7 year service life.
Barrier IIB Construction (2010)	$17.0 M	$3.3 M/yr	Contract amount. 7 year service life.
Construction of Des Plaines River and Illinois & Michigan Canal Barriers (2010)	$4.5 M	$380,000/yr	Contract amount. 20 year service life.
Barrier effectiveness testing (2010)	$400,000	$80,000/yr	One-time cost. Annualize over 7 year life of barriers.
Yearly Operations Maintenance (Barriers I, IIA & IIB)	$675,000/yr.	$800,000/yr	Conover et al. estimate $450,000/yr. for Barriers IIA and IIB. Barrier I assumed to have the same yearly operating costs.
SUM		**$7.4 M/yr**	

3.4.2 *Control/Removal*

Costs for control and removal include ongoing fishing upstream of barriers and monitoring activities downstream of barriers. One highly variable cost is expenditures associated with rotenone treatment. Rotenone is a fish toxin which has been applied in the CAWS in order to test for the presence of Asian carp in certain reaches of the waterway, or when electric barriers have been shut down for maintenance. USEPA et al. (2010) have identified funding of $US 2 million in 2010 for targeted removal within the CAWS, including rotenone treatment, however a single rotenone treatment event in December 2009 is reported to have cost approximately $US 3 million.

Although not explicitly stated, it is assumed that a consistent level of Asian carp fishing effort will continue into the future for both commercial fishing and fishing for monitoring purposes. Published expenditures for these activities are therefore considered yearly costs. Accounting for wholly or partially overlapping figures in Exhibit 4, best estimate total cost of control/removal is provided in Exhibit 9 following.

[17] Conover et al. (2007) report an expected service life of 3 to 5 years for Barrier I as it was originally constructed (as a demonstration project). USACE (2007) includes a statement indicating that Barriers IIA and IIB are will have a longer service life than Barrier I as originally constructed. A 7 year service life is assumed for Barriers I IIA and IIB for the purpose of annualizing their cost.

Exhibit 9 Summary of Control and Removal Costs for Asian Carp

Activity	Reported Cost ($US)	Cost (Annualized $C2009)	Rationale
Targeted Removal within Chicago Area Waterway System	$US 2 M / yr	$2.4 M/yr	Funded amount for 2010. Assume yearly spending at this level. Includes rotenone application, electrofishing, netting etc.
Downstream commercial fishing to reduce propagule pressure	$US 300,000/yr	$360,000/yr	Funded amount for 2010. Assume yearly spending at this level.
Monitoring, Testing and Contract Fishing (adjacent to and upstream of electrical barriers)	$US 2.6 M/yr	$3.1 M/yr	Funded amount for 2010. USEPA et al. (2010) notes "This action will continue for next several fiscal years"
Promotion of Commercial Fishing & Commercial Market Development (2010)	$US 3 M	$790,000/yr	USEPA et al (2010) indicates "long term" timeframe. 5 year funding cycle assumed.
SUM		**$6.6 M/yr**	

3.4.3 *Studies & Planning*

No areas of overlap have been identified under the heading *Studies & Planning* in Exhibit 4. In addition to those activities listed, many states include Asian carp as part of their individual AIS management plans and fund rapid response actions for AIS. We have not attempted to characterize expenditures related to these activities that are specific to Asian carp. The best estimate of total current cost for studies and planning is provided in Exhibit 10 following.

Exhibit 10 Summary of Costs for Studies and Planning to Prevent Asian Carp

Activity	Reported Cost ($US)	Cost (Annualized $C2009)	Rationale
Barrier Efficacy Study	$1.1 M	$1.3 M/yr	-
"Great Lakes and Mississippi River Inter-basin Study"	$1 M	$425,000/yr	3 year study
Inter-basin Transfer Feasibility Study exploring hydraulic pathways	$500,000	$600,000/yr	-
Barrier Effectiveness Study Using Tagged Fish	$400,000	$480,000/yr	-
Study to Evaluate Tow Boats & Barges as Vector for Asian carp	$500,000	$600,000/yr	-
Study to evaluate seismic technology to control Asian carp	$200,000	$240,000/yr	
Research re: Asian carp attraction pheromones	$300,000	$360,000/yr	-
Research re: Identification of Selective Toxicants	$300,000	$360,000/yr	-
Research re: Toxicant Delivery Mechanisms	$200,000	$240,000/yr	-

Activity	Reported Cost ($US)	Cost (Annualized $C2009)	Rationale
Development of Oral Toxicant Delivery Platforms	$1.6 M	$1.0M/yr	2 year study
Study re: reducing Asian Carp Food Sources *via* Nutrient Removal	$1.0 M	$425,000/yr	3 year study
SUM		**$6.0 M/yr**	

3.4.4 *Enforcement*

Additional enforcement costs of $400,000/yr have been spent to support increased law enforcement related to Asian carp, as well as to support legislative efforts to list bighead carp as an “injurious species” under US legislation. This equates to $480,000/yr in 2009 Canadian dollars. Similar State-level expenditure figures are not readily available. Our enforcement costs sum based on available information is $480,000/yr.

A summary of costs presented in this section for Asian Carp prevention is shown in Exhibit 11.

Exhibit 11 Summary of Total Annual Costs of Asian Carp Prevention

Prevention Activity	Total Annual Costs
Physical Barriers	$7,400,000
Control and Removal	$6,600,000
Studies and Planning	$6,000,000
Enforcement	$480,000
SUM	**$20,480,000**

3.5 Limitations and Uncertainties: Asian Carp

A primary limitation of the preceding analysis is that it addresses prevention costs only and does not attempt to discuss the benefits associated with these expenditures. This boundary has been drawn to avoid the analysis of hypothetical situations, as an attempt at characterizing the effects of an Asian carp invasion into the Great Lakes watershed (and the benefits foregone due to such an invasion) would be highly speculative.

A major uncertainty inherent in the above analysis is the relationship between prevention effort (*i.e.* expenditure levels) and the likelihood of invasion. It is assumed that more effort and resources spent on prevention lead to a lower likelihood of invasion. Recent events, including multiple discoveries of Asian Carp DNA and the June 2010 capture of a bighead carp upstream of electric barriers, indicate that current prevention strategies may not be 100% effective (although conclusive evidence is not available about the nature of these breaches[18]). In any case, current spending aimed at preventing Asian carp from entering the Great Lakes may not be sufficient to ultimately prevent an invasion.

[18] See for example, http://www.google.com/hostednews/ap/article/ALeqM5gPBBiKJKfp1MbkPXxJCnNjnZCCrQD9HDIBGG0: "Tests of chemical markers in the bighead carp suggest it was not a recent arrival to the waterway and probably did not get there by evading an electric barrier meant to prevent the species from infesting the Great Lakes, said Jim Garvey, a fisheries biologist at Southern Illinois University Carbondale."

An additional consideration of the costs of Asian carp prevention is that there are co-benefits associated with the measures in terms of preventing other AIS from migrating into the Great Lakes, or from the Great Lakes into the Mississippi River system. By not incorporating these co-benefits to reduce the costs of Asian carp prevention, the analysis of the costs of Asian carp prevention is very conservative. That is, the costs of prevention of Asian carp are higher in our analysis than they would be had we apportioned some of the costs to other AIS threats.

While speculation on the potential environmental impacts of a successful Asian carp invasion into the Great Lakes is not within scope of this report, Canada's Department of Fisheries and Oceans indicates it may be large (DFO, 2004). With the current state of scientific knowledge, it would be highly speculative to discuss the economic dis-benefits associated with an Asian carp invasion. However, the Government of Canada has recently pledged over $400,000 to study the impacts of Asian carp in the Great Lakes, with an emphasis on Lake Huron.[19] Consequently, the results of that study, once completed, could be used to help better understand the potential economic costs of an Asian carp invasion.

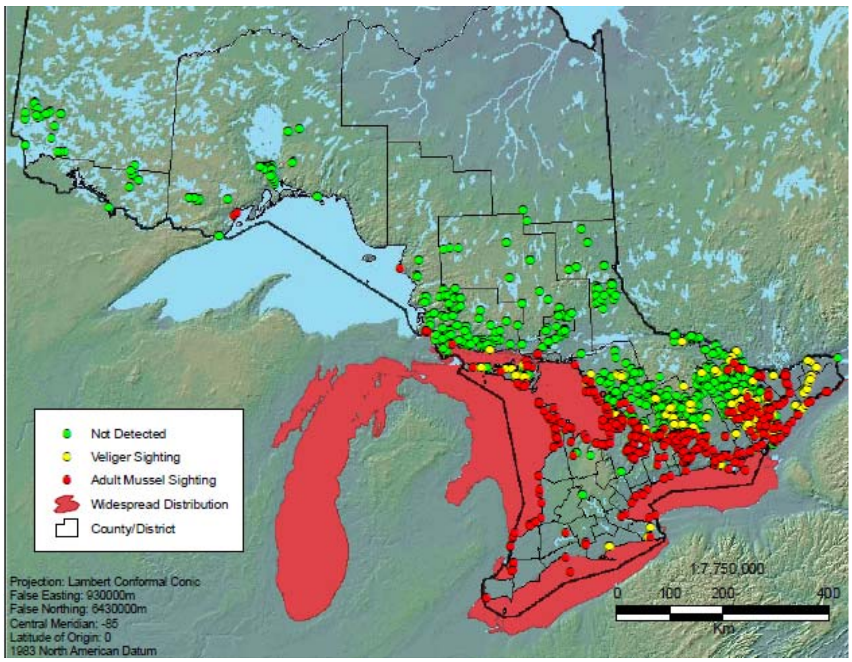
[19] The press release can be viewed at http://www.dfo-mpo.gc.ca/media/npress-communique/2010/ca03-eng.htm

4 Analysis: Zebra Mussel Mitigation Costs

4.1 Introduction

Zebra mussels were brought to the Great Lakes in the mid-1980s *via* ballast water from ships coming from Eastern Europe. They have spread through the watershed by several means, including trailered boats and bait buckets (Johnson et al., 2001). Zebra mussels have infested the Great Lakes in Ontario, except Lake Superior (where limited observations of zebra mussel presence have been made). They have also made their way to interconnected waterways and many river systems within the Great Lakes Basin. See Exhibit 12, below, for a map of current zebra mussel distribution.

Exhibit 12 Ontario Zebra Mussel Distribution



Data provided by the Ontario Ministry of Natural Resources and the Ontario Federation of Anglers and Hunters. Map created by John Zoltak, February 2010.

The key factors influencing zebra mussel distribution and abundance are: the availability of suitable substrata to which to adhere[20]; adequate dissolved calcium; and, suitably low salinity (Strayer, 1999). The low quantities of calcium in the waters of Lake Superior potentially explain why this Lake has not been extensively colonized by zebra mussels (USEPA, 2007). Female zebra mussels have extremely high fecundity rates, producing up to 1,000,000 eggs per year that are expelled into the water (Sprung, 1987). Fertilized eggs hatch into microscopic larvae called veligers. The veligers drift in water for 2 to 4 weeks, after which they attach onto suitable substrates, which include native clam and mussel species, and grow to adult size (~30mm). Because veligers cannot be seen by the naked eye, they are not apparent in ship ballast water.

[20] Zebra mussels only colonize hard substrates, while quagga mussels colonize both hard and soft substrates, allowing them to establish in deeper water. See URL:http://fl.biology.usgs.gov/Nonindigenous_Species/Zebra_mussel_FAQs/Dreissena_FAQs/dreissena_faqs.html for a discussion of the associated implications in the Great Lakes ecosystem.

4.2 Impacts

4.2.1 Ecological Impacts

Exhibit 13 Zebra Mussels

Source: Ontario Ministry of Natural Resources

Zebra mussels can have profound effects on physical, chemical and biological aspects of other aquatic communities. For example, zebra mussel filtration increases light penetration in shallow lakes which has subsequent effects on several factors, including enhanced aquatic plant and benthic algae growth, and changes in fish and invertebrate communities (MacIsaac, 1996). Zebra mussels can also affect nutrient concentrations and contaminant dynamics in lakes which, in turn, impacts plankton and benthic species populations (MacIsaac, 1996; Arnott and Vanni, 1996; Mazak et al., 1997; Nicholls et al., 2002). Experts have suggested that zebra mussels concentrate phosphorus in the benthos leading to filamentous green algae blooms. These blooms interfere with net fishing, leading to a 20 to 30% reduction in the gillnet fishery (Rothlisberger, 2009). In addition, bluegreen algae blooms have increased markedly in the Great Lakes since the invasion of *Dreissenid* mussels, as the mussels tend to avoid consuming bluegreen algae (Vanderploeg et al., 2001).

Zebra mussels can severely impact native mussel populations by outcompeting them in terms of feeding, growth, respiration and reproduction (Ricciardi et al., 1995). Adult zebra mussels feed primarily on free-floating algae (phytoplankton) and can filter approximately one liter of water per day. This process removes plankton and significantly increases water clarity (MacIsaac et al., 2002). The effect can be interpreted as a benefit for humans enjoying the aesthetic or recreational value of clear water (Limburg et al., 2010). However, it has a detrimental effect on fish populations (MacIsaac et al., 2002). For example, zebra mussels compete directly with zooplankton and small fish for phytoplankton resources (OFAH, 2010). Such shifts in species interaction can distort existing food webs and disrupt the ecosystem. A drop in the population of small fish results in less food for larger fish such as trout, and thus a drop in the population of the larger fish. Zebra mussels also suffocate native mussels by covering their shells, reducing their ability to move, feed, and breed, eventually leading to their death (OFAH, 2010; Ricciardi et al. 1995). Massive extirpations of native mollusks have occurred following the invasion of zebra mussels. For example, Lake St Clair lost 13 species of mollusks in the 8 years following invasion, while in the western basin of Lake Erie 10 mollusk species have been lost (Nalepa et al., 1996; Schloesser and Nalepa, 1994).

4.2.2 *Economic Costs*

In many cases, the ecological impacts of zebra mussels translate to economic costs. The impacts on food webs and fish populations, described above, contribute to economic losses to recreational and commercial fishing (Pimentel, 2005). Zebra mussels cause major impairment to industrial, municipal, hydro electric, and nuclear power plant water intakes, clogging pipes and causing decreased water flow and reduced plant efficiency (O'Neill, 1997; Colautti et al, 2006). The increase in water clarity produced by zebra mussel filtration increases the growth of plants attached to substrate (Heath, 1993). These plants can flourish to the point of clogging harbours and canals (Friends of the Rideau Canal, 2010; Miller et al, 1992). Iincreased plant and benthic algae growth can also result in several other negative impacts for human uses, such as impairment to recreational boating and swimming beaches, taste and odor problems in drinking water supplies, and blocked water-intake pipes during storm events (USGA, 2008).

Other users (e.g. irrigation farms, golf courses) that draw water directly from sources infested with zebra mussels may be adversely affected (O'Neill, 1997). The mussels also can damage water pipes of private homes, and cottages located along infected lakes, rivers, and streams, and they can also damage the body and engines of boats (O'Neill 1997; Colautti et al, 2006). The U.S. Fish and Wildlife Service estimate the potential economic cost at $5 billion from 2000 to 2010 to U.S. and Canadian water users within the Great Lakes region (USGS, 2000). A summary of the economic costs of the impacts of Zebra Mussels in Ontario are presented in Section 5.2.

The impacts of zebra mussels can be assessed in terms of their impacts within the TEV framework: direct uses; ecosystem services; option value; and, non-use value. (See Exhibit 2 above for an illustration of the TEV framework.) A summary of the impacts caused by zebra mussels in the TEV framework is shown in Exhibit 14 following.

Exhibit 14 TEV Categorization of Zebra Mussel Impacts

TEV Category	Description of Impacts
DIRECT USES	
Extractive Uses	
Residential water	Taste and odor problems attributed to zebra mussels consequent algae growth, intake pipes clogged
Industrial water	Intake pipes clogged, damage to water filters and facility infrastructure
Agricultural water	Intake pipes clogged
Recreational fishing	Improved by increased clarity from reduced floating algae, impeded from subsequent increase in aquatic plants, impeded by changes in fish populations, impeded by fouling of fishing boats
Commercial fishing	Improved when used as fishing bait or fish meal production, impeded by increased aquatic plants, impeded by changes in fish populations, impeded by fouling of fishing boats and equipment (i.e.: destruction of nets)
Heating and Cooling	Damage to pipes and systems, reduced heat transfer
Non-Extractive Uses	
Recreational boating	Damage to boat engine, body and engine
Beaches and lakefront	Nuisance caused by increased aquatic plants, mussel shells, and odor
Aesthetic and amenity values	Nuisance caused by increased aquatic plants, mussel shells, and odor

TEV Category	Description of Impacts
Wildlife watching	Bird populations are reduced because of loss of food (now consumed by mussels) or because of toxic contamination as a result of consuming mussels
Other recreational/ tourism	Nuisance caused by increased aquatic plants, mussels, mussel shells, and odor
Power generation	Damage to pipes, generators, systems, and facility infrastructure
ECOSYSTEM SERVICES	
Disease prevention	Accumulate mercury and lead (in fish eaten); contributes to avian botulism
Water purification	Efficient filter feeders; uptake contaminants;
Nutrient cycling	changes nutrient fluxes, resulting in reduced phytoplankton and increased cyanobacterial blooms
Habitat, Refugium and Nursery	outcompete and invade habitat of native mussels; water clarity due to filtration imparts changes on fish communities, changes in size structure and abundance of zooplankton and phytoplankton, and enhanced/prolonged visitations by waterfowl that consume mussels; May alter spawning habitats and disrupt availability of foods to fish
OPTION VALUE	
Possibility of using Lakes in the future	the permanence of zebra mussels in water systems that they have invaded, ultimately impacts the future uses derived from the water systems
NON-USE VALUES	
Existence Values	
Intrinsic value of the Great Lakes	Negatively impacted because the primary features of the natural system have been altered
Bequest Values	
Benefits others obtain from the Great Lakes in the future	the permanence of zebra mussels in water systems that they have invaded, ultimately impacts the benefits derived from future uses of the water systems

4.3 Mitigation Measures

To date, it has not been possible to eradicate established zebra mussel populations. Several chemicals can be used to kill zebra mussels but because the *Dreissenid* species are relatively tolerant, and because no species-specific deterrents are known, the high chemical application rate required to kill zebra mussels also harms other species (USGS, 2008). Most affected facilities rely on chemicals such as chlorine, filters or mechanical scraping, to remove mussels from intake pipes and systems (USGS, 2008). Zebra mussels can also be controlled by killing veligers in pipes or restricted water passages with chlorination, dewatering/desiccation, steam injection, acoustic vibration, electrical current, filters/screens, toxic coatings, CO2 injection, ultraviolet light, and induced anoxia (MacIsaac et al, 2002).

Given the enduring substantial costs needed to control and treat zebra mussels, simple efforts to prevent their invasions in unaffected areas are important. These measures include draining live wells, motors and bilge, cleaning vegetation off boat trailers, hulls, and anchors, cleaning boats when changing water-bodies and avoiding dumping bait into lakes or rivers (Miller et al., 1992; OFAH, 2010).

4.4 Mitigation Measure Costs

4.4.1 Literature Data Sources

Where available, we report economic cost values from Ontario. Where Ontario-specific values are not available, we rely primarily on cost values from other jurisdictions. Sources are primarily peer-reviewed studies. However, due to the paucity of empirical evidence regarding many of the impact categories, data from “grey sources” of literature are also cited.

The majority of data sources derived results from surveys on expenditures related to zebra mussel control and treatment sent to various stakeholders.

- Vilaplana and Hushak (1994) surveyed holders of Ohio driver’s licenses on their recreation activities and the effect of zebra mussels.
- The New York Sea Grant (O’Neil, 1997) conducted a study on reported expenditures incurred for zebra mussel monitoring, control, prevention, training, and planning. These figures were obtained from a survey (339 respondents) of industrial, drinking water treatment, electric power generation, and other facilities located mainly in New England, the Mid-West, and the South.
- Hushak and Deng (1997) also relied on survey data to assess the costs of zebra mussel control technologies employed by 141 facilities located on, or near, one of the Great Lakes.
- Reutter (1997) provides cost impact estimate for large surface water users, but does not does not provide a methodology.
- The Ohio Sea Grant Program (Park and Hushak, 1999) followed essentially the same methodology as O’Neil’s 1997 New York Sea Grant study. They reported expenditures on monitoring, research, and control by surveying water takers including power plants, water companies, golf courses, and other industries. A total of 420 facilities with costs incurred responded.
- MacIsaac et al. (2002) estimated all control and treatment costs related to zebra mussels, incurred by different stakeholders. These cost estimates were derived from published literature or from unpublished estimates obtained from interviews with workers in the affected sector.
- Pimentel (2005) reported on impacts to various industries affected by zebra mussel infestations. Pimentel used a literature review to inform most of his reported cost estimates, and left some estimates un-explained.
- Connelly (2007) estimated the economic impact of zebra mussels on drinking water treatment plants and electric power facilities, from 1989 to 2004. She used a mail survey which resulted in 402 respondents as well as 100 telephone interviews. Her questionnaire was designed so that results would be comparable with those of the 1995 New York Sea Grant survey (O’Neill 1997).
- Limburg et al. (2010) also used a mail survey which resulted in responses from 281 homeowners and 75 businesses. The study was conducted along the shores of Lake Ontario and its outflow at the western end of the St. Lawrence River in New York State. Four homeowner communities were selected, representing coastal and bay communities. Selected businesses included charter boat operations, marinas, diving businesses, tackle shops, restaurants, and campgrounds. The survey questioned homeowners on the changes in their properties’ values based on zebra mussels impacts and questioned businesses on their expenditures or loss of profit related to zebra mussel control, treatment, or other impacts.
- Van Oostrom (2010a) presented on *dreissena* mussel treatment programs for Ontario Power Generation facilities, at the Zebra Mussel Workshop that took place in Saskatchewan

in April 2010. He provides cost data for these treatment systems, for four hydroelectric facilities in the Niagara region.

4.4.2 Literature Results for Mitigation Measure Costs

The costs for mitigation measures from the various literature sources have been categorized within the TEV framework. A summary of the mitigation measure costs and associated data sources is presented in Exhibit 15 following. Note that costs summarized in this Exhibit are gathered from several sources which vary in timeframe and geographic scope.

Exhibit 15 Costs of Mitigation Measures for Zebra Mussels

TEV Category	Mitigation Measure Description	Cost of Measure (2009 $)	Author & Year
DIRECT USES			
Extractive Uses			
Residential water (Water filtration plants)	retrofitting pipelines for chlorination	$29,979-$59,958/facility*	Maclsaac et al., 2002
	removing Z.M. from wells	$3597-$4797/yr/facility	Maclsaac et al., 2002
	Installing carbon filtration	$539,623/yr/facility	Maclsaac et al., 2002
	average costs for control and treatment	$56,753/yr /facility	O'Neil, 1997
	average control and monitoring costs for small facilities	$36,537/yr/facility	Park and Hushak, 1999
	Average control and monitoring costs for large facilities	$126,821/yr/facility	Park and Hushak, 1999
	average costs for control	$40,509/yr/facility	Hushak and Deng, 1997
Residential water (Houses and cottages)	Filtration systems installed in coastal/bay homes	$275/house *	Colautti et al., 2006
	Value of drinking water taste and odor problem	$6.97/person	Brox et al., 2003
Industrial water	Average expenditures for industrial facilities	$44,223/facility	O'Neil, 1997
	Average control costs for utility and industrial facilities	$166,800/yr/facility	Hushak and Deng, 1997
	Control costs large users of surface water	$556,001-$635,430/yr	Ruetter, 1997
	Monitoring and control costs for surface water using facilities	$683,087/yr/facility	Park and Hushak, 1999
Agricultural water	----	---	---
Recreational fishing	Sports fishing industry impacts	0.25% impact on sports fishing industry	Pimentel, 2005
Commercial fishing	Impacts on aquaculture	$7,766/facility/yr	O'Neil, 1997
	Impacts on commerical fishing industry	0.3% impact on commercial fishing industry	Pimentel, 2005
Heating and Cooling	Damage to pipes and systems	---	---
Non-Extractive Uses			
Recreational boating	Recreational boat maintenance	$457-$1210/boat/yr	Pimentel, 2005
	Recreational boat maintenance	$433-$901/boat/yr	Vilaplana & Hushak, 1994
	Impacts on boating activity	4% reduction in boating trips	Pimentel, 2005
Navigational boating	Impact on navigational transport industry	0.04% impact on transport industry	Pimentel, 2005
Beaches and lakefront	Impacts on swimmers / beach visits	---	---
Aesthetic and amenity values	Average loss in household property values for cay and coastal houses from algae associated with Z.M.	$919*	Limburg et al., 2010
	Average business expenditures to remove algae caused by Z.M.	$1,039/yr	Limburg et al., 2010

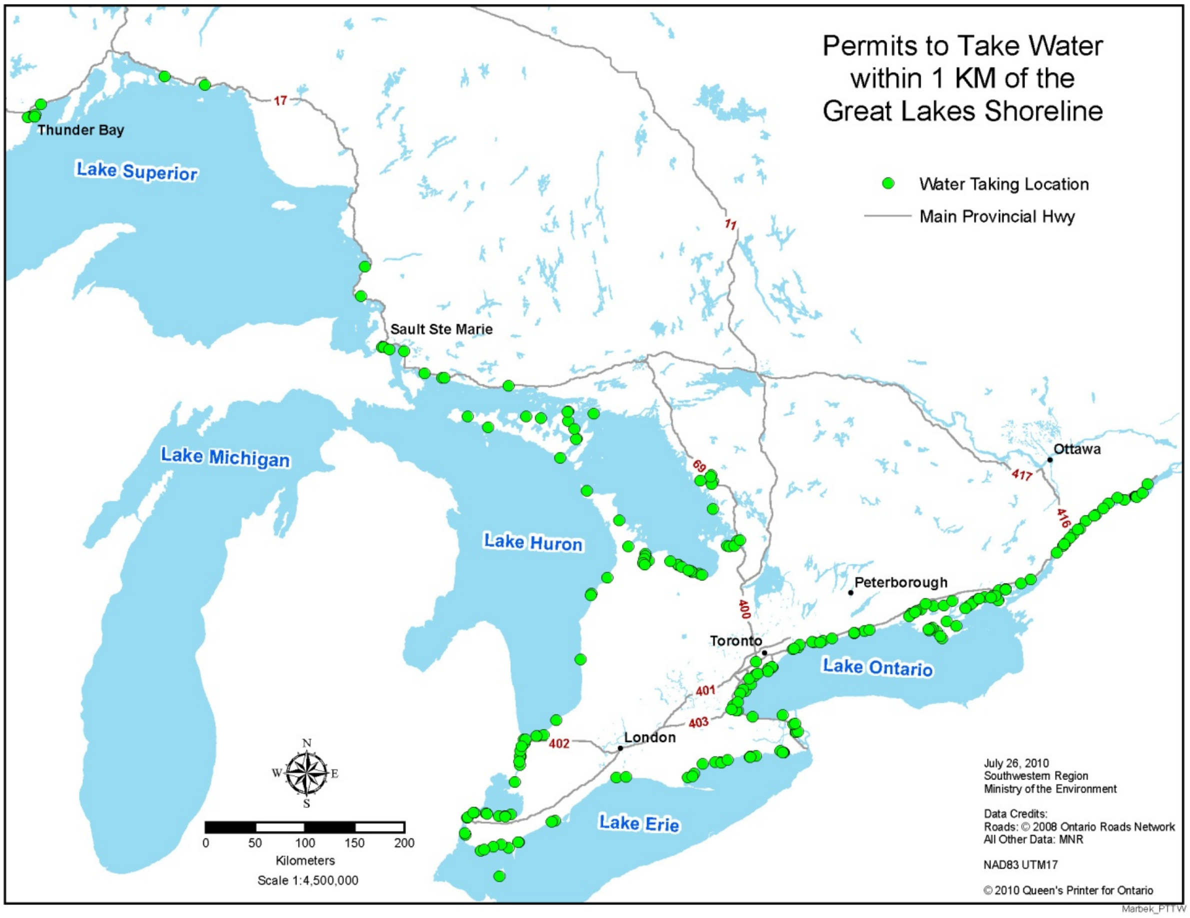
TEV Category	Mitigation Measure Description	Cost of Measure (2009 $)	Author & Year
Wildlife watching	Impact on bird watcing value	---	---
Other recreational/tourism	Impact on other recreational activities' value (hiking, kayaking, etc.)	---	---
Power generation	Ontario power plants control & operation costs	$959,329/station/yr	MacIsaac et al., 2002
	Ontario power plants research	$1,199,161/yr	MacIsaac et al., 2002
	Ontario hydroelectric plants treatment system installation cost	$132,868-$1,156,825/station*	Van Oostrom, 2010
	Average expenditures for nuclear power plants	$208,280/yr/facility	O'Neil, 1997
	Average costs for fossil fuel electric generation plants	$38,555/yr/facility	O'Neil, 1997
ECOSYSTEM SERVICES			
Disease prevention	Accumulate mercury and lead (in fish eaten); contributes to avian botulism	---	---
Water purification	Efficient filter feeders; uptake contaminants;		---
Nutrient cycling	changes nutrient fluxes, resulting in reduced phytoplankton and increased cyanobacterial blooms	---	---
Habitat, Refugium and Nursery	outcompete and invade habitat of native mussels; water clarity due to filtration imparts changes on fish communities, changes in size structure and abundance of zooplankton and phytoplankton, and enhanced/prolonged visitations by waterfowl that consume mussels; May alter spawning habitats and disrupt availability of foods to fish	---	---
OPTION VALUE			
Possibility of using Lakes in the future	the permanence of zebra mussels in water systems that they have invaded, ultimately impacts the future uses derived from the water systems	---	---
NON-USE VALUES			
Existence Values			---
Intrinsic value of the Great Lakes	Negatively impacted because the primary features of the natural system have been altered	---	---
Bequest Values			---
Benefits others obtain from the Great Lakes in the future	the permanence of zebra mussels in water systems that they have invaded, ultimately impacts the benefits derived from future uses of the water systems	---	---

* one time investment cost
--- no data

4.4.3 *Other Sources of Data*

As an input to this study, the Program Services Unit of MOE (MOE, 2010; Schraeder, pers. comm.) furnished data on the number of permits-to-take-water existing within 1 km of the Great Lakes Shoreline, categorized by water source and facility type. This database includes facilities by category: industrial; power generation; commercial (including golf courses and aquaculture); and, municipal. It also indicates source of water (i.e. by surface (lake or river) or groundwater) and water intake capacity. Locations of facilities with permits to take water are shown in Exhibit 16. We excluded from this dataset facilities bordering Lake Superior and facilities using only groundwater. We assume that all remaining facilities have incurred costs related to zebra mussel impacts. From this final dataset, we extract the number of affected golf courses, aquaculture facilities, independent power production facilities, as well as small and large industrial facilities.

Exhibit 16 Facilities with Permits to Take Water within 1 km of the Great Lakes Shoreline



Source: Southwestern Region, Ontario Ministry of Environment
Data Credits: ©2008 Ontario Roads Network; Ontario Ministry of Natural Resources

The Drinking Water Branch of the OMOE provided a dataset on the number of drinking water treatment plants in Ontario that use chemicals for zebra mussel control (Ahmed, 2010). There are 93 of these plants. This dataset does not indicate the water intake capacities of these plants.

We rely on data from Ontario Power Generation (OPG, 2010) to determine the number of power generation facilities within the Ontario Great Lakes (hydroelectric, nuclear, coal, and thermal), and their power generation capacity.

Data on the number of waterfront residences in the Ontario Great Lakes were obtained from the Federation of Ontario Cottagers' Association (Rees, 2010).

The cost of household anti-fouling water filters is available in MacIsaac et al, 2002. To validate this data, and to verify the average life-expectancy of these filters, the websites of two water filter producers were reviewed.[21]

4.5 Cost Calculations

Given the literature results and database information available from OMOE, we calculate the costs of mitigation measures for key TEV categories, where data are available. In deriving the mitigation costs, we have had to make numerous assumptions surrounding adoption rates, extent of impacts etc. In general, assumptions were made to err on the side of underestimating rather than overestimating costs of mitigation. However, in cases where there were no data available on implementation rates for measures, we assume all members in a sub-population are affected (for example, golf courses and private water supply systems in close proximity to infested lakes), since there is no justifiable rationale to assign any other number. As the scientific and economic knowledge surrounding these mitigation costs improves, these numbers can be further refined. However, with the current state of knowledge and data available, the results are meaningful for the purposes of the case study approach adopted for this analysis. The values in this section are presented as best estimates.

4.5.1 Residential Water

The impact on residential water affects drinking water treatment plants as well as homeowners. Annual costs to drinking water treatment plants are derived from Park and Hushak (1999). Park and Hushak present average monitoring and control costs to water treatment plants from 1989 to 1994. They separate costs by size of facility: small facilities having water intake capacities less than 38 million liters per day, and large facilities having water intake capacities between 38 and 1136 million liters per day. These costs include retrofits, planning, monitoring, all control measures, training, research, and other related expenditures. The average annual cost for small facilities amount to $36,537 per facility, and the average annual cost for large facilities amount to $126,821 per facility.

From the dataset provided by the Program Services Unit of the OMOE (Schraeder, 2010), 73% of drinking water treatment plants within 1 km of the Great Lakes are small (less than 38 million liters/day) and 27% are large (more than 37 million liters/day). To estimate total costs, the mean cost values are multiplied by the respective number of small and large drinking water treatment plants in Ontario that use chemicals for zebra mussel control, as shown in Exhibit 17.

Exhibit 17 Calculation of Drinking Water Treatment Costs

(93 facilities[22] * 0.73* $36,537) + (93 facilities * 0.27 * $126,821)

Mussel infestation also can damage water pipes of private homes, and cottages located along infected lakes, rivers, and streams. To prevent this damage, homeowners may invest in anti-fouling water filters. The least expensive filter costs approximately $275 (MacIsaac et al, 2002 and filter suppliers). The Federation of Ontario Cottagers' Association estimates 250,000 waterfront residences along the Great Lakes (Rees, 2010). We assume that all of these residences are affected and that the costs of impacts to homes that do not install anti-fouling water filters is the same as the costs to homes that do install the filters (with no installation cost). We assume homes that do not install filters will incur costs related to removing mussels

[21] http://www.zebramussel.com/zmfs.html, http://www.w-s-p-s.ca/zebraMussels.htm
[22] There are 93 water treatment plants in Ontario that use chemicals for zebra mussel control (Ahmed, 2010).

that clog pipes and other filters using, for instance, mechanical or chemical treatments. The total cost of mussel infestation to private homes amounts to $68,750,000. Since these costs are capital costs, the total cost is annualized assuming a 4-year filter life expectancy, for a total annual cost of $18,717,266.

Exhibit 18 Calculation of Total Capital Cost of Residential Water Filtration Systems

Number of residences (250,000) * Filter cost/or, clogged mussel removal ($275)

4.5.2 Industrial Water

The average annual costs for industrial facilities are derived from Park and Hushak (1999). Water treatment plants are divided into two groups according to their water intake capacity. Small plants have a capacity of 38 million liters per day or less and large plants have a capacity of 37 million liters per day or more. The average annual cost to small plants is $15,568 per facility and the average annual cost to large plants is $75,457 per facility. Using the dataset provided by Schraeder (2010), there are 42 small industrial facilities and 17 large facilities assumed to incur costs related to zebra mussel control.

Exhibit 19 Calculation of Costs to Industrial Facilities

(42 small facilities * $15,568) + (17 large facilities * $75,457)

4.5.3 Golf Courses

O'Neil (1997) reports costs to golf courses amounting to $199 per facility per year, which only consisted of monitoring costs. As 72 golf courses with permits to take water in Ontario are located within one kilometer of the Great Lakes (Schraeder, 2010), we assume that all of these facilities incur costs related to zebra mussels. We assume that all of these golf courses were affected and that the costs of impacts to golf courses that do not incur monitoring costs are the same as the costs to golf courses that undertake monitoring. Therefore the total cost to golf courses amounts to $14,328 per year.

Exhibit 20 Calculation of Costs to Golf Courses

72 golf courses * $199

4.5.4 Recreational Fishing

Several sources note that zebra mussels may cause decreases in fish populations (Heath, 1993; Madenjian, 1993; OFAH, 2010) Lower fish populations, in addition to foul odors and aesthetic deterioration caused by zebra mussel colonies, can reduce the magnitude of recreational fishing activities. The impact of zebra mussels on recreational fishing is derived from Vilaplana and Hushak (1993), which provides information on reduced angling days due to zebra mussels. The results of this survey of Ohio residents show that 4% of respondents indicate having reduced their time on Lake Erie due to zebra mussel impacts on the Lake. On average, these residents reduced their time spent on the lake by 38%. Based on this finding, we assume that 4% of anglers in the Ontario Great Lakes decrease their angling days by 38% due to zebra mussel impacts, resulting in a 1.5% decrease in overall angling days.

In 2005, anglers spent an aggregate 4.80 million days on Ontario's Great Lakes system (4.56 million excluding recreational fishing effort in Lake Superior) (DFO, 2008). A recent primary valuation study has estimated the average value of an angler day in the Credit Valley watershed using the travel cost approach (DSS Management Consultants Inc., 2008). This study finds that the average value of an angling day ranges from a low of $9 a trip in the fall to a high of $155 a trip in the spring, with an average value of $41 a trip.[23] Assuming that 2005 represents a typical impacted year in terms of angling effort, and taking the average value of $41 per angling day, a 1.5% decrease in angling days (as calculated above) represents negative impact of $2,847,122 per year. Exhibit 21 following lays out the calculation used to estimate costs of zebra mussels for recreational fishing.

Exhibit 21 Calculation of Costs to Recreational Fishing

[4,560,024 angling days / (1 - (0.04 * 0.38)) – 4,560,024 angling days] * $41

4.5.5 *Commercial Fishing and Aquaculture*

Changes in fish populations caused by zebra mussels also impact the commercial fishing industry. Since commercial fisheries of Ontario's Great Lakes contribute approximately $180 million to $215 million annually (OMNR, 2010), we assume an average value of $197 million. Pimentel (2005) estimates the cost of zebra mussel impacts on the commercial fishing industry in the U.S. Great Lakes Basin to be 0.3% of the industry's value. We apply the same assumption to the Ontario Great Lakes, resulting in a negative impact of approximately $590,000 per year.

Exhibit 22 Calculation of Costs to Commercial Fishing

$197,000,000 / (1 - 0.003) - $197,000,000

The economic costs of zebra mussels to aquaculture farms is derived from O'Neil (1997). The annual cost per facility is estimated to be $7,776. A report on the *Economic Impact of the Cage Culture Industry in Ontario* (HCA, 2007) states that there are 7-8 cage culture operators in Ontario, with most of these operations located in northern Lake Huron. Ontario Ministry of Natural Resources[24] has record of 10 cage aquaculture sites operating in Ontario – two in Georgian Bay and the rest in northern Lake Huron. We assume that these 10 facilities are affected by zebra mussels, resulting in total costs to aquaculture of $77,760 per year. Exhibit 23 following lays out the calculation for this total cost.

Exhibit 23 Calculation of Costs to Cage Aquaculture

10 facilities * $7,776

4.5.6 *Recreational Boating*

The annual expenditure incurred by recreational boat owners is derived from Vilaplana and Hushak (1994). The authors surveyed boat owners in Ohio's Lake Erie region regarding expenses incurred explicitly as a result of zebra mussels. Costs identified included expenses for protective paints (average cost of $154 per year) and additional maintenance costs (averaging $280 per year). In total, these additional costs amount to $434/boat/year.

There were 1.2 million recreational boats registered in Ontario in 2000 an estimated 65 % of these boats are used on the Great Lakes (Thorpe and Stone, 2000). Since 13% of boat owners reported expenses in Vilaplana and Hushak's (1994) survey, we assume that the same

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[23] This average value was found by taking the total value of the fishery, $1,224,247, and dividing by the number of angler trips, 30,154.

[24] Personal communication, Lisa Miller-Dodd, September 2010

proportion of Ontario Great Lakes boats incur these costs. Therefore, 101,400 boats used in the Great Lakes are estimated to incur an average cost of $434/year as a result of zebra mussel impacts, giving a total cost of $44,007,600 per year. Exhibit 24 following lays out the calculation for this total cost.

Exhibit 24 Calculation of Costs to Recreational Boating

(1,200,000 boats * 0.65 * 0.13) * $434

4.5.7 *Commercial Shipping and Boating*

As with recreational boating, zebra mussels interfere with some aspects of shipping. For example, buildup of mussels on the hull of the ships leads to increased drag (leading to increased fuel costs) and damage to boat parts. Pimentel (2005) estimates a 0.04% impact on the value of navigational transport industry due to zebra mussel impacts. In Ontario, this industry is valued at $2.6 billion per year (Marine Delivers, 2010), resulting in zebra mussel costs of approximately $1 million per year. Exhibit 25 following lays out the calculation for this total cost.

Exhibit 25 Calculation of Costs to Shipping Industry

$2,600,000,000 / (1 - 0.0004) - $2,600,000,000

4.5.8 *Power Generation*

Expenditures incurred by power generation facilities include capital costs of infrastructure retrofits as well as operating costs such as maintenance, planning, monitoring, materials, operators, and technician labour. In 1989, Ontario Power Generation (OPG) spent an average of $869,245 per facility to install piping infrastructure for chlorine (sodium hypochlorite) (Wiancko, 2000; in Maclsaac et al, 2002). Second generation retrofits have been lower, with costs on average of $598,163 per hydroelectric facility, ranging from $132,868 for a facility with low capacity (144 MW), to $1,156,825 for a facility with high capacity (1,499 MW) (Van Oostrom, 2010a). The second generation system has an expected lifetime of 20 years (Van Oostrom, 2010b). We use the more recent capital costs and expected lifetime for our analysis (i.e. the second generation costs). Based on OPG (2010), we estimate that there are 22 large facilities (≥150 MW) and 22 small facilities (≤150 MW) within 1 km of the Ontario Great Lakes (OPG website[25]). In addition, there are 8 thermal power plants (3 gas, 2 coal, and 3 nuclear) owned by OPG which border the Ontario Great Lakes, all with large power generating capacities. In the absence of cost data specific to nuclear, gas, and coal power plants, we assume that these facilities incur the same costs as hydroelectric plants (OPG website).

In addition to OPG plants, there are 11 independent power producers within 1 km of the Ontario Great Lakes (Schraeder, 2010). Available data does not permit categorization of these plants by size. However these plants have the largest permitted water intake capacity of all permit-holding facilities (Schraeder, 2010). As a conservative estimate, we apply the average capital ($598,163) and operating costs ($33,100) (incurred by OPG) to these independent facilities.

[25] See Section 4.4.3 for URL and other data source information

Exhibit 26 Calculation of Total Capital Costs to Power Plants

[22 small hydro plants * $132,868] + [(22 large hydro plants + 8 other large power plants) * $1,156,825] + [11 large independent power plants * $598,825]

In 2000, OPG estimated that total operating costs per facility ranged from $600,000 to $1.8 million per facility, with an average of $959,329 (Wiancko, 2000; in Maclsaac et al, 2002). These costs include maintenance, veliger sampling, diver/video inspections, external cleaning, chemicals, operators, chemical technician and engineering. In 2010, OPG's reported operating costs include only labour for treatment system installation, planning, and support, as well as materials and monitoring costs (Van Oostrom, 2010a). These costs amount to an average of $33,100 per facility ($8,865 for small facilities and $92,341 for large facilities (Van Oostrom, 2010a). We use the more recent operating costs for our analysis. following lays out the calculation for this total cost.

Exhibit 27 Calculation of Total Operating Costs to Power Plants

[22 small hydro plants * $8,865] + [(22 large hydro plants + 8 other large power plants) * $92,341] + [11 large independent power plants * $33,100]

In addition to capital costs and ongoing operating costs, OPG incurred annual zebra mussel control research costs of approximately $1,190,909 per year from 1990 to 2001 (Maclsaac et al., 2002). To calculate the total capital, operating, and research costs to power plants, we add $1,190,909 to the value obtained from the formulas in Exhibit 26 and Exhibit 27.

4.6 Cost Summary

This section summarizes the monetized annualized costs of zebra mussels. Exhibit 28 following presents the total annualized costs of zebra mussel impacts, with a low, mean, and high cost value. Where data sources identified low and high cost values, these are used in our analysis. In the absence of data on low and high costs per facility, we assume a 25% deviation from the mean, to derive low and high estimates.

Exhibit 28 Summary of Total Annual Costs of Zebra Mussel Impacts

	Total Annualized Costs (Inputs)		
Value Category	**Low**	**Mean**	**High**
Residential Water	$18,279,230	$24,372,307	$30,465,384
Industrial Water	$657,677	$1,936,625	$3,752,219
Golf Courses	$10,746	$14,328	$17,910
Recreational Fishing	$2,127,243	$2,847,122	$3,572,503
Commercial Fishing and Aquaculture	$485,021	$670,438	$809,483
Recreational Boating	$33,005,700	$44,007,600	$55,009,500
Commercila Shipping and Boating	$780,234	$1,040,416	$1,300,650
Power Generation	$5,723,075	$7,630,766	$9,538,458
TOTAL	**$61,068,925**	**$82,519,602**	**$104,466,107**

Exhibit 28 shows that the greatest share of costs (53%) is attributed to recreational boating, followed by residential water (30%) and power generation (9%). The total annual costs presented in Exhibit 28 are used as inputs for a Monte Carlo simulation to develop an uncertainty analysis as described in Section 2.4.

While representing an exhaustive literature review, the above costs include only a subset of value categories that are impacted. Non-monetized impacts are discussed in Section 5 following.

4.7 Limitations and Uncertainties: Zebra Mussels

Limitations

An important limitation with our study of the impacts of zebra mussels is the lack of up-to-date, site-specific data. We rely mostly on impact cost values for the U.S. Great Lakes dating back to the 1990s. We apply these costs to our analysis using the cost-transfer method. Because secondary data is used to transfer values to a different location, the appropriateness of these values is limited by: 1) variations in the objectives and parameters of the source and target study; and, 2) important differences in the characteristics of the source and target study locations. The magnitude of these effects will determine the overall accuracy and relevance of the transferred values (Rossi et al., 2004).

In this study, we undertake a static analysis of Asian carp prevention costs and zebra mussel impact costs by providing annualized values of these costs and impacts. Therefore, in using this approach, we do not analyze the dynamic aspects of impacts/benefits and how they may change over time, nor do we account for changing costs in mitigation measures. However, we do develop robust information that can be used to assess the magnitude of expenditures and costs for two case study AIS.

One of the greatest limitations identified for the zebra mussel impacts costs is that only a sub-set of costs can be captured. Other costs are not included either because data on impacts or on costs are inconclusive, incomplete, or unavailable. For example, a common way to value aesthetic and amenity values is through property values. However, aesthetic and amenity values cannot be accurately monetized because there is inconclusive data on the cause-and-effect relationship between zebra mussel impacts and changes in property values. One study reported decreases in property values due to the nuisance of mussel decay on lakefront property, but also reported increases in property values due to the increased clarity of lakes attributed to zebra mussel filtration (Limburg et al., 2010). Other value categories that are not (or incompletely) monetized are discussed below and presented in Exhibit 31 in Section 5.2.1 following.

Impacts on non-extractive use values (such as wildlife watching) and ecosystem service values (such as habitat provision) cannot be monetized because there are no data quantifying the link between zebra mussels and changes in these uses. These values may be very large; because the zebra mussel invasion is essentially irreversible and has ecosystem function impacts, the loss in economic welfare it represents is potentially enormous.

Almost all of the costs reported in this analysis refer to directly observable expenditures or loss of profit, with the exception of recreational fishing. In general, using costs of damage estimates will tend to underestimate the true welfare implications of impacts. The welfare impacts of the zebra mussel invasion are approximated by what individuals are willing to pay to avoid the impacts. However there is a paucity of empirical literature on the welfare implications of invasive species in general, even for high profile cases like the zebra mussels. Therefore, cost estimates are used as a proxy for the welfare impacts of zebra mussels, keeping in mind these costs are likely lower bound estimates.

Uncertainties

The uncertainties contained in this analysis are reflected in our assumptions. We use assumptions because of uncertainty of actual values. For example, we are uncertain about the number of facilities incurring costs associated with zebra mussel infestations, so we assume that all facilities with permits to take water within 1 km of the Great Lakes shoreline incur costs. However, we realize that not all owners of intake pipes have permits to take water and not all intake pipes will have been affected by zebra mussels to the same degree.

Another important area of uncertainty is potential correlations among zebra mussel costs. In Section 5, following, we present the model outputs of the Monte Carlo analysis of various variable values. Implicitly, we have assumed that these zebra mussel costs are independent of each other. However, there are likely correlations among these costs. For example, if zebra mussels impose a large cost to recreational fishers due to lost angling days, it is more likely that commercial fishers would also bear large, rather than small, zebra mussel related costs. This analysis did not consider the effects of these likely correlations.

5 Results

5.1 Results: Asian Carp Prevention

Exhibit 29 presents the current annualized costs ($2009 Canadian) being incurred in order to prevent Asian carp from becoming established in the Great Lakes, described previously in Section 3. As these costs are actual incurred and reported costs, no uncertainty analysis is performed.

Exhibit 29 Current Annual Costs of Preventing Asian Carp Invasion

Cost Category	Current Annual Cost
Physical Barriers	$7,400,000
Control/Removal	$6,600,000
Studies	$6,000,000
Enforcement	$480,000
TOTAL	**$20,500,000**

Note: Numbers do not add exactly due to rounding.

The results show that the total annual cost for prevention activities is approximately $20.5 million. Costs are distributed roughly evenly between physical barrier construction and maintenance (36%), control/removal (32%) and studies (29%). Two percent of reported costs are attributed to increased enforcement activities.

5.2 Results: Zebra Mussel Mitigation

This section presents the results of the uncertainty analysis on the cost data presented in Section 4 above. Zebra mussel costs are reported following as annualized values. As noted in Section 2, the uncertainty analysis software attaches the RiskTrigen triangular distribution function to all the modeled variables. In total, eight input variables are subject to 5000 iterations or samplings. These iterations produce a range of annualized cost estimates. Results are presented as low, mean and high values. The low columns report the values at the 20th percentile of all the model runs. Therefore, 80% of model runs reported values higher than the low column, and 20% lower. Similarly, the high column reports the 80th percentile. The mean represents the average value across all the model runs.

Exhibit 30 summarizes the results of the total annualized costs of zebra mussels.

Exhibit 30 Summary of the Total Annualized Costs with Uncertainty Analysis Results

	Low*	Mean*	High*
Residential Water	$21,103,930	$24,355,209	$27,571,510
Industrial Water	$1,488,706	$2,223,433	$2,941,593
Golf Courses	$11,943	$14,308	$16,735
Recreational Fishing	$2,363,521	$2,856,629	$3,344,868
Commercial Fishing and Aquaculture	$500,775	$599,894	$699,171
Recreational Boating	$37,112,280	$44,233,155	$51,388,449
Navigational Boating	$871,959	$1,044,882	$1,220,191
Power Generation	$6,884,591	$7,646,884	$8,378,534
TOTAL	**$75,198,160**	**$82,974,395**	**$90,879,145**

* Because these results show combinations of outcomes, the columns are not additive. That is, the low column may be a combination of a low costs and a high costs for different category and any number of combinations in between.

As noted in Section 4.6, the average total cost is assumed to be a low bound calculation since it excludes several other impacts that have economic significance but could not be monetized (see Section 5.2.1).

Furthermore, our cost estimates are much more conservative than cost estimates that have been published for the United States. For instance, it was estimated that zebra mussels cost the U.S. power industry alone an average of $517 million per year in the 1993-1999 period. When the impact on industries, businesses and communities is added to this cost, the total cost is over $833 million per year (New York Sea Grant 1994). The cost to the power industry in the United States therefore represents 62% of all zebra mussel impact costs. Other reports indicate a similar majority share of costs attributed to power generation. Pimentel (2005) finds that the power industry represents 80% of all zebra mussel impact costs to the New York State Canal and Hudson River systems, while the Idaho Aquatic Nuisance Species Taskforce (2009) finds that costs to hydropower generation plants in Idaho represent 50% of all zebra mussel impact costs. Had we used other data sources to derive our cost estimates, we would have had a significantly larger cost attributed to power generation. However, we chose to use the most recent primary data source available and make conservative average estimates.

A published report with the most similar results to our study is the Idaho Aquatic Nuisance Taskforce (2009) report. This report summarizes the potential costs of zebra mussels to hydro power, other dams, drinking water, golf courses, boat facilities, hatcheries/aquaculture, boat maintenance and recreational fishing in the state of Idaho. The results show that total costs amount to $144 million. While recreational boating contributed to 55% of our total annual costs, they made up 25% of Idaho's total costs due to the fact that there are fewer boats in Idaho.

There have also been other studies on the potential calculated costs of a zebra mussel invasion in States that have not been affected yet by zebra mussels. These studies include an analysis for Florida and another for Lake Tahoe. The estimated annualized cost of a major zebra mussel infestation in Florida is $20 million (Lee et al, 2007). An analysis of the potential economic costs of a mussel invasion in Lake Tahoe (USACE 2009) estimates that the annualized cost of a zebra mussel infestation would be $27 million. Both sets of authors (Lee et al, 2007 and USACE 2009) also estimate the cost of prevention and conclude that it is worthwhile to invest in prevention.

5.2.1 Non-Monetized Impacts

There are several other value categories that are impacted by zebra mussels but that cannot be accurately monetized. More than half of all value categories identified as impacted (see Exhibit 31) cannot be monetized due to lack of data or uncertain impacts. These other impacts and their possible economic significance are presented in Exhibit 31.

Exhibit 31 Non-Monetized Impacts

Value Category	Other Impacts	Reason not Quantified/Monetized	Possible Significance
Industrial Water	Shutting down operations in order to clean out mussels or implement control measures	Lack of data on number of facilities closed for this purpose	Lost profit from stopping operations
Power Generation	Shutting down operations in order to clean out mussels or implement control measures	Lack of data on number of facilities closed for this purpose	Lost profit from stopping operations
Heating and Cooling	Damage to pipes and systems; reduced heat transfer	Lack of data on costs incurred due to z.m. impacts	Cost of control measures, maintenance, and lost efficiency
Beaches and Lakefront	Nuisance caused by increased aquatic plants, mussel shells, and odor	Lack of data on impacts caused specifically by z.m. and economic value related to these impacts	Cost of decreased beach and lakefront visitors
Aesthetic and Amenity	Nuisance caused by increased aquatic plants, mussel shells, and odor	Lack of data on impacts caused specifically by z.m. and economic value related to these impacts	Lower lakefront property values
Other Recreation	Nuisance caused by increased aquatic plants, mussels, mussel shells, and odor	Lack of data on impact to other recreational activities	Loss of value other recreational activities (i.e.: wildlife watching, kayaking)
Disease Prevention	Accumulate mercury and lead (in fish eaten); contributes to avian botulism	Lack of data on disease causation; lack of data on the value of disease outbreaks	Loss of value of wildlife watching, biodiversity (WTP); Cost of increased human health impacts due to contaminated fish
Nutrient Cycling	changes nutrient fluxes, resulting in reduced phytoplankton and increased cyanobacterial blooms	Lack of consistent information on impact to nutrient cycling and algae blooms; impacts related to aesthetic and amenity values, beaches and lakefront, and recreation	Loss of value of aesthetic and amenity values, beaches and lakefront, and recreation
Habitat, Refugim and Nursery	Outcompete and invade habitat of native mussels; decrease habitat of certain fish species	Lack of clear indicator on habitat, refugium, and nurseries	Loss of value of aquatic habitat, refugium and nurseries (WTP)*
Option Values	Increased impacts on future uses	Uncertainty of future impacts on uses; uncertainty in the option values	Loss of value of maintaining the option of future uses from the Great Lakes
Non-Use values	Increased impacts on ecosystem integrity, and on future uses	Uncertainty of impacts on ecosystem integrity/health/resilience, and on the future impacts on uses; uncertainty in existence and bequest values	Loss of existence and bequest values

* WTP = Willingness-to-pay. This value is typically captured by estimating how much individuals are willing to pay for the existence/protection/improvement of a resource

These non-monetized impacts would increase the impact costs of zebra mussels if it were possible to assess them.

6 Discussion

This analysis has taken a purposely simplified approach by dealing with a limited number of species and examining relatively well-defined costs and (foregone) benefits in order to ensure very defensible cost estimates and to avoid speculation on hypothetical invasion situations. Nevertheless, there is significant uncertainty associated with costs of both prevention and mitigation. The uncertainties associated with prevention costs pertain to the effectiveness of the prevention measures. The June 2010 capture of a bighead carp in the CAWS illustrates that prevention measures may not buy immunity from invasion.

Uncertainties associated with the zebra mussel invasion costs pertain to numerous and varied factors including uncertainties and unknowns regarding ecosystem effects. There are three main reasons why this analysis underestimates the total welfare implications of zebra mussel impacts:

- This analysis purposely only estimates the costs of zebra mussel impacts in the Great Lakes to Ontario. Zebra mussels also have significant impacts in the American waters of the Great Lakes.
- This analysis underestimates the total welfare implications of zebra mussel impacts as only a sub set of the identified impacts could be quantified and monetized. These non-monetized impacts (summarized in Exhibit 31) could comprise a large part of the total welfare impacts of the zebra mussel invasion to Ontario, especially for impacts to option and non-use values.
- Finally, this analysis underestimates the welfare implications because it almost exclusively relies on cost of damage values to estimate the economic costs. As noted above, using cost of damage estimates provides a lower bound on the total welfare impacts of the zebra mussel invasions because individuals may have a higher WTP to avoid these impacts. The lack of empirical information on zebra mussel impacts on welfare measures such as WTP reflects the current state of knowledge.

Notwithstanding the uncertainties described above, the results clearly show that costs associated with preventing entry of Asian carp are a fraction of the mitigation costs associated with the current zebra mussel invasion. This finding comes despite the fact that many identified impacts of the zebra mussel invasion could not be quantified, resulting in an underestimation of the cost of the zebra mussel invasion to Ontario.

From a broader North American perspective, measures to prevent Asian carp from entering the Great Lakes are measures to prevent further impacts of an invasion already in progress. With the benefit of seeing the impacts of Asian carp in the Mississippi River system, it is clear that early action to prevent successful invasion is the most cost effective course. The relatively small cost of legislative support and enforcement of laws and the benefits of scientific and other research indicates that these tools also comprise important components of a prevention plan. Further study of the effectiveness of the research undertaken would be needed to assess cost-effectiveness of this group of activities.

Given the uncertainty surrounding the effects of Asian carp (and other potential invaders) on the Great Lakes system, the enormous impact associated with the zebra mussels (and other established AIS) in the Great Lakes, and the relative magnitude of prevention costs compared to mitigation costs, a focus on prevention of future invasions is warranted. Increased expenditures on the prevention of specific AIS could be justified where the risk of significant ecosystem alteration is high.

An economic impact assessment is not recommended for AIS because the results would not be useful in informing policy decisions. The greater the AIS impact, the more resources that need to be mobilized to mitigate impacts and, therefore, the greater the economic impact. It is not useful information to know that invasive species have more impact on the economy than prevention since a decision to prevent invasion is not contingent on the magnitude of the economic impacts (i.e. jobs created, resources purchased, etc.). The decision, instead, is contingent on the severity of the impacts on ecological goods and services and associated impacts on social welfare (i.e. the reduction in societal welfare associated with the invasion).

Future work could build on the results of this study and the TEV methodology used to estimate zebra mussel costs. An important area for future research is estimating the social welfare impacts of invasive species as opposed to cost of damage estimates (Shogren 2005). For specific AIS of concern, a series of scenarios could be created to estimate the potential ecological impacts of invasion, with reliance on the input of scientists or case studies of other regions experiencing successful invasion of that species. The scenarios chosen should reflect a credible range of low, medium and high invasion rates. The TEV framework could be used to monetize use impairments for the scenarios, where literature is sufficient to estimate these. The impact results could be compared with planned budget expenditures for prevention to develop a ratio of costs to potential impacts. The ratio could be used to adjust or establish budgets for prevention measures so that they are commensurate with the magnitude of potential impacts of a successful invasion. The social welfare costs of invasion could also be used to inform policy decisions on regulatory tools, research budgets, use of physical barriers, etc.

Future work would be assisted by studies on the public's willingness to pay for prevention of AIS impacts and/or studies of the impacts on property values of AIS (Shogren 2005).

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