Lake Erie's Ecosystem goods and Services

A Review of Concepts, Data Sources and Methods

Prepared for:

Brad Bass, PhD
Great Lakes Issue Management and Reporting Section
Environment Canada

By:

Robert Smith
Midsummer Analytics

March 2014

Table of contents

1

Executive Summary

In recent years, considerable effort has been devoted to classifying the goods and services provided by ecosystems. Based on these efforts, there is now general agreement that ecosystem goods and services generally fall into three broad categories:

- Provisioning goods and services
- Regulating and maintenance services
- Cultural services

Each of these is broken down into several sub-categories as shown in the table below, which defines the ecosystem goods and services provided by Lake Erie.

Summary of Ecosystem Goods and Services Provided by Lake Erie

Ecosystem Good or Service Category		Ecosystem Goods or Services provided by Lake Erie
1. Provisioning goods and services		
	Nutritional goods	• Freshwater fish • Waterfowl • Water for drinking
	Raw material goods	• Water for non-drinking purposes • Genetic material for fish rearing
	Energy services	• Wind power
2. Regulating and maintenance services		
	Regulation of air, water and soil quantity and quality	• Assimilation of sewage water, urban runoff, agricultural runoff, atmospheric wastes • Cycling of air and water though the regional climate system and hydrological cycle
	Climate regulation	• Regulation of the regional temperature, precipitation and air currents
	Regulation of energy flows	• Regulation of waste heat from industrial activities (cooling water)
	Regulation of mass surface flows	• Regulation of mass surface water flows (flood control)
		• Regulation of mass surface soil flows

		(shoreline erosion)
	Pest and disease control	• Regulation of human disease vectors (*e.g.*, toxins, microbes) • Regulation of pest migration from south to north
	Space	• Lake Erie provides space for a wide variety of human and ecosystem activities
3. Cultural services		
	Religious and spiritual interactions	• Spiritual retreat centres • Spiritual reflection
	Knowledge of existence	• Existence of, for example, clean water in the future
	Inspiration for artistic creations	• Works of art depicting the lake among many others
	Recreation opportunities	• Bird watching, recreational hunting and fishing, boating, beach activities and hiking.
	Scientific exploration	• Discovery of link between phosphorus and eutrophication, among many others
	Cognitive and educational development	• Public and private education programs based on the lake, among others
	Aesthetic enjoyment	• Enjoyment of the lake's beauty by the millions of people living and vacationing in the region

Lake Erie's ecosystem goods and services provide benefits to a wide range of socio-economic sectors. Individuals (or the "household sector" in formal statistical terms) are obvious beneficiaries. Many cultural service benefits flow directly to individuals as they engage in activities, both experiential and spiritual, that involve use or knowledge of the environment. Households also benefit from provisioning and regulating flows (in particular waste assimilation).

Many other sectors of the economy also benefit.

- The farmers who use water from the lake to irrigate fields and benefit from the lake's waste assimilation service when they permit fertilizers and manure to runoff into it and its tributaries.
- The public agencies responsible for the provision of drinking water and the treatment of sewage use the lake in the first instance as the source of a provisioning good (raw water) and in the second instance as the source of regulating service (waste assimilation).

- The mining, manufacturing and construction companies that withdraw water from the lake for various purposes (or use its waste assimilation service).
- The various companies (operating in several different industries) that make up the "tourism sector" are important beneficiaries of the recreational opportunities afforded by Lake Erie.[1]
- Organizations that are engaged at the community level (churches, environmental groups, educational organizations, recreation associations, etc.) are another important group of beneficiaries.

At the moment, the benefits all these sectors derive from Lake Erie are under threat. The algal bloom situation has deteriorated significantly in the last two decades and, it is safe to say, many previously enjoyed benefits – notably recreation – have been diminished as a result. The evolution of the algal bloom situation is impossible to predict. Its severity in the future will depend on the extent and success of control and remediation efforts and on a number of factors (such as climate change) that cannot be effectively managed in the short term. This said, three plausible future scenarios are 1) that control efforts will be insufficient, algal blooms will get worse and Lake Erie will, once again, be lamented as a "dead lake"; 2) that blooms will stabilize as are result of moderately successful control/remediation efforts ("stable lake"); or that 3) blooms will be reduced in severity as a result of significantly successful control/remediation efforts ("recovered lake").

Under both the "dead lake" and "stable lake" scenarios, major reductions in some flows of ecosystem goods and services from Lake Erie should be expected. In particular, cultural services are likely to be significantly impacted in both scenarios, as even the current situation is likely to reduce cultural service flows substantially. If the lake stabilizes to a steady state resembling today's state (more or less permanent annual recurrence of algal blooms in parts of the lake), the current reductions in cultural services will become permanent. Only scenario 3 ("recovered lake") is likely to see improvements in cultural services. For the other flows provided by the lake (provisioning goods/services and regulating services), the scenario outcomes are more varied.

It is worth noting that cultural services are often found to be among the most important benefits associated with ecosystems. People give quite a lot of significance in particular to the existence value of ecosystems. Recreational opportunities are, of course, also usually highly valued. This is all the more true for an ecosystem like Lake Erie with such a substantial human population nearby.

[1] Recreation services offer a good example to use in illustrating a potential problem in measuring ecosystem goods and services. This is the risk of double counting benefits and thereby overstating the true value of the ecosystem to society. In measuring recreation services it is important not to measure the benefit both for the individual engaged in the recreation and for the companies engaged in supporting them (*e.g.*, outfitters providing lodging services to duck hunters).

Understanding how Lake Erie's ecosystem goods and services are, and will be, affected by algal blooms requires tacking a complex measurement challenge. Two basic approaches are available: measurement using physical units and measurement in value (monetary) terms. Both have advantages and disadvantages. Physical measures are, in principle applicable to all ecosystem goods and services (though direct physical measurement of ecosystem *services* is not possible, so proxy physical measures must be used[2]). Their drawback is that measures based on different physical units cannot be summed; there is no meaningful way to add tonnes of fish to hectares of wetland.

Monetary measures overcome the problem of incommensurability through use of a single unit – dollars – to track flows of all ecosystem goods and services. While attractive in theory, in practice it can be very difficult to arrive at suitable dollar valuations for many ecosystem goods and services. One obstacle is that not all people accept the notion that we can (or should) apply monetary measures to the environment. Valuation, by definition, gives precedence to human preferences; a choice that conflicts with the view held by some that the environment has value independent of human preferences. Another objection of some is that existing prices for *all* market goods and services may be badly distorted because of pervasive and significant environmental externalities and other market failures. If this is true, values for ecosystem goods and services derived using current market prices as the point of reference are likely to badly misrepresent their true worth to society.

Aside from these fundamental objections[3], significant practical challenges sit in the way of full monetary measurement of ecosystem goods and services. While the market allows us to observe values for some of them (those that are sold in the market, like commercial fish and timber), it is impossible to directly observe values for most. To fill this void, economists have developed a number of methods for indirectly valuing ecosystem goods and services.

The methods developed to date broadly fall into two groups: *revealed preference methods* and *stated preference methods*. The former use the fact that ecosystem goods and services are often tied in analyzable ways to goods and services that *are* sold in the market. So, for example, the value of a beautiful view might be derived by comparing the prices of two houses similar in all respects except for the good fortune of one to have an enviable view (*hedonic pricing method*). Similar methods use expenditures made to travel to recreation sites (*travel cost method*) or avoid the loss of benefits associated with degraded ecosystem good and services (*damage-cost*

[2] For example, the flood control service of a forest might be proxied by the area of the forest measured in hectares.

[3] These objections are, obviously, serious and if upheld would certainly be sufficient reason to thoroughly question the suitability of monetary valuation. The economists who advocate valuation do not dismiss them out of hand but, instead, offer various arguments as counterpoints, often noting that valuation does nothing more than use empirical analysis to reveal what people do every day: make tradeoffs regarding competing sources of value. There is active and thoughtful debate in the literature on these points.

avoided method) as ways of elucidating their values. These methods have appeal because they rest fundamentally on economic behaviour that can be observed in the market, even if teasing the ecosystem value out of this observed behaviour requires large amounts of data and sophisticated statistical methods. Their main drawback is that they are applicable only to the sub-set of ecosystem goods and services for which a relationship to a market good of service can be identified (mainly regulating and maintenance services).

Stated preference methods, on the other hand, can be used to value any ecological good or service, including highly esoteric services like existence value. This makes them, in principle, powerful measurement tools. Their drawbacks are numerous however. They require direct, costly and time-consuming questioning of large numbers of individuals about their preferences in the face of various scenarios for the protection of ecosystems. Based on what respondents say during these interviews, economists are able to construct demand curves for the good or service in question. Long experience with the methods has shown, however, that many people either 1) have trouble stating their true preferences in the context of artificial (or "contingent") markets or 2) intentionally mislead interviewers for various strategic reasons. For this reason, the results of stated preference valuations are often met with a degree of skepticism.[4]

For the moment, the measurement of ecosystem goods and services will remain an imperfect science. Researchers wishing to comprehensively measure the goods and services associated with a given ecosystem will likely be forced to use a combination of physical and monetary measures.

[4] A third "method" of valuation is known as benefits transfer. In this approach, values derived for a given ecosystem good or service in a published study (using any of the observed, revealed or stated preference methods) are applied to the same good or service in another location. The approach is commonly used in spite of the inaccuracies introduced in applying values from one context to another.

1 Introduction

This review was prepared at the request of the Great Lakes Issue Management and Reporting Section of Environment Canada as an input into the Great Lakes Nutrient Initiative. It is intended to serve background material for an eventual larger effort at measuring the ecosystem goods and services associated with Lake Erie. The background, purpose, goals and objective of the review are laid out below.

1.1 Background

Since 1994, there has been a general widespread deterioration of Great Lakes nearshore water quality and aquatic ecosystem health. New and re-emerging threats to water quality caused by population growth and urbanization, agriculture intensification, aquatic invasive species and the impacts of climate change, working in combination, are responsible for this deterioration. This impaired condition also contributes to the resurgence of large-scale toxic and nuisance algal blooms, culminating in some of the worst algal blooms recorded in 40 years during the summers of 2010 and 2011. The cause of this increase in not fully understood, but is believed to be the result of a number of factors.

The primary nutrient causing excess algae growth is phosphorus. Common sources of phosphorus include urban and agricultural runoff (fertilizers and manure); municipal wastewater discharges; private septic systems and industrial discharges.

There is a growing body of evidence that suggests the return of the toxic and nuisance algae problem is being exacerbated by changes in the Great Lakes ecosystem. A significantly larger portion of the phosphorus entering the lake is in a more bioavailable form, causing greater algae production. The presence of dreissenid (zebra and quagga) mussels that filter phosphorus and excrete it, leading to higher nearshore phosphorus concentrations, is believed to be exacerbating the problem. Addressing this situation requires new management strategies.

Of all the Great Lakes, Lake Erie is the most susceptible to nearshore water quality issues and is the most heavily impacted by algal blooms. Lake Erie is the smallest, shallowest and most biologically productive of the Great Lakes, making it highly sensitive to changes in phosphorus levels.

1.2 Purpose

The Great Lakes Nutrient Initiative will contribute to the development of a bi-national assessment and management framework to address the multiple stresses to water quality. Developing a management framework will utilize a socio-economic impact assessment of algal blooms for the Lake Erie Basin. This socio-economic impact assessment will provide insight on the costs of algal blooms and the net benefits of managing phosphorus loads into Lake Erie.

There are various approaches for evaluating the costs and benefits of improved management practices in a lake ecosystem. One approach is to value changes in the relevant ecosystem goods and services that may be affected by algal blooms in the ecosystem under study.

1.3 Goal and objectives

The goal of this review was to provide insight into important factors and methodologies for evaluating the socio-economic impact of algal blooms in the Lake Erie basin with an emphasis on the impacts on the ecosystem goods and services delivered by the lake.

The specific objectives of the review were to:

- Scope the ecosystem goods and services delivered by the lake that may be affected by the presence of algal blooms
- Identify the sectors affected by algal blooms in terms of economy, location and social impacts
- Identify the methodological considerations in conducting socio-economic impact assessment of algal blooms on Lake Erie and management actions for bloom control, with an emphasis on valuing outcomes in terms of ecosystem goods and services

1.4 Structure of this report

The report is divided into six sections. Following this introduction, Section 2 presents the concept of ecosystem goods and services in general terms.

Section 3 discusses the specific ecosystem goods and services offered by Lake Erie and how they might be affected under different scenarios for the evolution of the algal blooms currently affecting the lake.

Section 4 is a summary of existing scientific databases and studies that are relevant to measuring Lake Erie's ecosystem goods and services.

Section 5 discusses the socio-economic sectors that are likely to be impacted by the degradation of the lake's quality and the resulting reductions in its flows of ecosystem goods and services. A brief overview of Statistics Canada data sources relevant to their measurement is given.

Section 6 presents general concepts related to the measurement of ecosystem goods and services in physical and, in particular, monetary terms. A summary of the major methodologies used for their valuation is given.

A bibliography provides information on a number of studies relevant to measuring ecosystem goods and services in general and to Lake Erie specifically.

2 Classifying Ecosystem goods and Services

In recent years, considerable effort has been devoted to classifying the goods and services provided by ecosystems.[5] Three of the most notable efforts are:

- The well-known *Millennium Ecosystem Assessment* (MEA) (Millennium Ecosystem Assessment, 2005)
- The series of reports produced by the UN Environment Program under the heading of *The Economics of Ecosystems and Biodiversity*, better known as the TEEB reports (TEEB, 2010), and
- The Common International Classification of Ecosystem Services (CICES) produced by the European Environment Agency

In these classifications, ecosystem goods and services are generally broken into three broad categories:

- Provisioning
- Regulating and maintenance
- Cultural

Each of these is defined more fully below.[6]

2.1 Provisioning goods and services

Provisioning goods and services include the materials goods and energy services that are extracted from the environment by humans through business, government and household activities. They are broken into three categories.

- *Nutritional goods*
  - Non-cultivated[7] plants and animals used as food
  - Water used for drinking

[5] It should be noted that the term "ecosystem services" is often used in the literature to refer to both the tangible goods and the intangible services that are provided by ecosystems. It is recommended here that the more descriptive term "ecosystem goods and services" be used. This term more accurately reflects the benefits that humans realize from ecosystems, which rely on flows from the environment that are both material and non-material in nature. Use of this term also avoids the need for awkward concepts like "abiotic provisioning services", the term used in CICES to cover ecosystem goods that are not biological in nature. The tension this creates is acknowledged by the authors of CICES. They note that ecosystems are composed of biotic and abiotic elements that interact with geophysical processes that, in turn, provide a number of abiotic outputs that benefit people (Haines-Young and Potschin, 2013). Other authors also argue that abiotic outputs must be included in classifications of ecosystem goods and services (Armstrong et al., 2012; Kandziora et al., 2012).

[6] The definitions here are those of the author and are based on an amalgam of the approaches taken in the MEA, TEEB and CICES.

[7] Cultivated plants and animals are not considered ecosystem goods here. Rather, they are considered the output of human activities (farming, aquaculture) that, themselves, rely on inputs of ecosystem goods and services (space, pollination, precipitation, etc).

- *Raw material goods*
    - Non-cultivated trees and other plant and animal biomass (other than that used as food)
    - Soil[8]
    - Metallic and non-metallic minerals[3]
    - Fossil fuels[3]
    - Water (other than that used for drinking)
    - Genetic material
- *Energy services*
    - Energy provided by animals (draught horses, for example)
    - Energy provided by wind, water, sunlight and the earth's heat

2.2 Regulating and maintenance services

Regulating and maintenance services are those related to ecosystem functions that regulate flows of materials and energy and maintain the stability of ecosystems. They can be broken into several categories.

- *Regulation of air, water and soil quantity and quality*
    - Assimilation of solid, liquid and gaseous wastes introduced by human activity and by ecosystem processes
    - Cycling of air, water and soil
- *Climate regulation*
    - Regulation of temperature
    - Regulation of precipitation
    - Regulation of air currents
- *Regulation of energy flows*
    - Assimilation of waste energy (heat, noise, light) introduced by human activity
- *Regulation of surface mass flows*
    - Regulation of surface water flows (including ice and snow)
    - Regulation of soil flows
- *Pest and disease control*
    - Control of pest and disease vectors directly affecting humans
    - Control of pest and disease vectors affecting other animal and plant species

[8] There is debate in the literature regarding the treatment of soil, minerals and fossil fuels as ecosystem goods. CICES, for example, explicitly restricts itself to ecosystems goods that are biological in nature – with the exception of water, which the authors include in part because "water bodies of all scales host communities of species that provide ecosystem services" (Haines-Young and Potschin, 2013; p. ii) and in part because most scientists queried in the creation of the classification believe it simply makes sense that water be included. The view taken here is that soil, minerals and fossil fuels are no different in this regard. They are all important raw materials derived, like water, from the environment. And, like water, their extraction has important consequences for other ecosystem goods and services. Indeed, the CICES authors note that the ultimate goal of a classification of ecosystem goods and services should be "a combined classification that integrates outputs across ecosystems and from other natural resources" (Haines-Young and Potschin, 2013; p. 11).

- *Space*
    - Space suitable for human activities (agriculture, aquaculture, housing, etc.)
    - Space suitable for ecosystem processes (habitat)
- *Pollination of cultivated crops*

2.3 Cultural services

Cultural services include all the non-material, and normally non-consumptive, interactions with ecosystems that affect mental states of humans. They may involve direct enjoyment of natural areas during recreational or other visits, indirect enjoyment through film or other artificial media or simple satisfaction from the knowledge that a given ecosystem exists. Cultural services are broken into the following categories.

- *Religious and other spiritual interactions*
- *Knowledge of existence (benefits associated with knowledge that a given ecosystem exists, either out of belief in its intrinsic value or out of hope it will one day be of instrumental value)*
- *Inspiration for artistic creations*
- *Recreation opportunities*
- *Scientific exploration*
- *Cognitive and educational development*
- *Aesthetic enjoyment*

3 Ecosystem Goods and Services Provided by Lake Erie

This section takes the general classification of ecosystem goods and services that was proposed in Section 2 and applies it to the specific case of Lake Erie. It then discusses the possible impacts on the lakes EGS flows under three possible scenarios for the evolution of algal blooms:

1. Hazardous and nuisance algal blooms get worse due to exacerbated effects of climate change and increasing nutrient loadings ("dead lake" scenario).
2. Nutrient and other control efforts are moderately successful and hazardous and nuisance algal blooms stabilized at their current levels ("stable lake" scenario).
3. Nutrient and other control efforts are substantially successful and significant reductions in both hazardous and nuisance algal blooms are witnessed ("recovered lake" scenario).

3.1 Lake Erie - Provisioning good and services

Based on the classification of ecosystem goods and services presented in the Section 2, the ecosystem goods and services associated with Lake Erie may be identified.[9]

- *Nutritional goods provided by Lake Erie*
    - Non-cultivated[10] plants and animals used as food
        - Various species of freshwater fish (perch, walleye, lake trout, etc.)[11]
        - Various species of waterfowl (ducks, geese)[12]
    - Water used for drinking
        - Water is extracted from Lake Erie for drinking purposes by the following communities: Amherstburg Water Treatment System (Detroit River); Windsor Utilities Commission (Detroit River); Regional Municipality of Niagara, Municipality of Chatham-Kent, Corporation of Norfolk County, Town of Essex, Township of Pelee, the Corporation of Haldimand County, The Town of Niagara-on-the-Lake, Elgin Area Primary Water

[9] A good summary of these services that is largely consistent with those presented here is found in Northeast-Midwest Institute and National Oceanic and Atmospheric Administration (2001). Venema and Voora (2008, p. 7) present a summary of the ecosystem services in Lake Winnipeg that is also largely consistent.

[10] Cultivated plants and animals are not considered ecosystem goods here. Rather, they are considered the output of human activities (farming, aquaculture) that, themselves, rely on inputs of ecosystem goods and services (space, pollination, precipitation, etc).

[11] The following species were harvested commercially from Lake Erie in 2012 (in order of landed weight): Rainbow Smelt, Yellow Perch, Walleye, White Bass, White Perch, Lake Whitefish, Freshwater Drum, Channel Catfish, Bullhead, Sunfish, Northern Pike, Common Carp, Crappie (Department of Fisheries and Oceans, 2014).

[12] See, for example, this report.

Supply System, City of London, various individual and small communal water systems[13]

- *Raw material goods*
  - Non-cultivated trees and other plant and animal biomass (other than that used as food)
    - Unknown – no significant use is likely
  - Soil[14]
    - N/A
  - Metallic and non-metallic minerals
    - N/A
  - Fossil fuels
    - N/A
  - Water (other than that used for drinking)
    - Water is extracted from Lake Erie, the Detroit River and the Niagara River and for non-drinking purposes for use in electric power generation, agricultural irrigation, construction, golf course irrigation, food and beverage processing, manufacturing, aquaculture and miscellaneous uses[15]
  - Genetic material
    - Genetic material related to commercial and recreation freshwater fish breeding
- *Energy services*
  - Energy provided by animals (draught horses, for example)
    - N/A
  - Energy provided by wind, water, sunlight and the earth's heat
    - Wind farms are located on Lake Erie's north shore, benefiting from the steady winds that blow in that direction over the lake[16]

3.2 Lake Erie – Regulating and maintenance services

- *Regulation of air, water and soil quantity and quality*

---

[13] Government of Ontario, Open Data Portal, *Permits to Take Water*.
[14] There is debate in the literature regarding the treatment of soil, minerals and fossil fuels as ecosystem goods. CICES, for example, explicitly restricts itself to ecosystems goods that are biological in nature – with the exception of water, which the authors include in part because "water bodies of all scales host communities of species that provide ecosystem services" (Haines-Young and Potschin, 2013; p. ii) and in part because most scientists queried in the creation of the classification believe it simply makes sense that water be included. The view taken here is that soil, minerals and fossil fuels are no different in this regard. They are all important raw materials derived, like water, from the environment. And, like water, their extraction has important consequences for other ecosystem goods and services. Indeed, the CICES authors note that the ultimate goal of a classification of ecosystem goods and services should be "a combined classification that integrates outputs across ecosystems and from other natural resources" (Haines-Young and Potschin, 2013; p. 11).
[15] Government of Ontario, Open Data Portal, *Permits to Take Water*.
[16] See, for example, this project.

- Assimilation of solid, liquid and gaseous wastes introduced by human activity and by ecosystem processes
    - Lake Erie receives pollutants, including phosphorus, from storm- and melt-water runoff from cropland and livestock operations. It similarly receives phosphorus and other pollutants from runoff from urban areas. About three-quarters of the lake's phosphorus loadings are thought to come from runoff from Canadian and US sources.[17,18]
    - Lake Erie receives raw and treated wastewater containing phosphorus and many other pollutants from sewage treatment plants and from combined sewer overflows in at least the following Canadian municipalities: Windsor (Detroit and Little Rivers), London (*via* the Thames River and Lake St. Clair), Sarnia (*via* Lake St. Clair).[19] In addition to these larger sources, many private household septic systems adjacent to the lake contribute to pollutant loadings.[20] About 16% of the lake's phosphorus loadings are thought to come from these and other point sources (e.g., industrial outfalls) in Canadian and US territory.
    - Lake Erie receives atmospheric deposition of a wide range of pollutants, including phosphorus. Approximately 6% of the lake's phosphorus loading is thought to come from the atmosphere.[21]
  - Cycling of air, water and soil
    - Lake Erie plays a role in the cycling of air and water through the regional hydrological cycle and climate in the Great Lakes region of North America[22]
- *Climate regulation*[23]
  - Regulation of temperature, precipitation and air currents
    - Along with the other Great Lakes, Lake Erie plays a major role in determining the climate of the region.
- *Regulation of energy flows*
  - Assimilation of waste energy (heat, noise, light) introduced by human activity
    - Lake Erie provides cooling water for use in manufacturing and electric power production[24]
- *Regulation of mass surface flows*

---

[17] International Joint Commission, 2013 and 2014.
[18] It is worth noting that the single largest source of phosphorus in the western basin of Lake Erie is the Maumee River where the city of Toledo, Ohio is situated.
[19] Ecojustice, 2013, *The Great Lakes Sewage Report Card.*
[20] IJC, 2014, p. 72
[21] Great Lakes Commission, 2006 and International Joint Commission, 2014.
[22] http://www.epa.gov/greatlakes/atlas/glat-ch2.html
[23] http://www.epa.gov/greatlakes/atlas/glat-ch2.html
[24] Government of Ontario, Open Data Portal, *Permits to Take Water*.

    - Regulation of mass surface water flows (including ice and snow)
        - Through its important role in the regional hydrological cycle, Lake Erie plays a major role in the regulation of surface water flows.
    - Regulation of mass soil flows
        - Through its role in regulating the regional climate, Lake Erie plays a role in regulating mass soil flows associated with shoreline erosion.
- *Pest and disease control*
    - Control of pest and disease vectors directly affecting humans and other plant and animal species
        - Through its role in the maintenance of the quality of the water source used for drinking water by millions of residents in Canada and the US, Lake Erie plays a major role in regulating microbial disease vectors.[25]
        - Lake Erie and the other great lakes provide a natural barrier to the movement of certain pests from south to north.
- *Space*
    - Space suitable for human and ecosystem activities
        - Lake Erie and its shoreline provides space that is used by humans for commercial activity (fishing), recreation and dwellings (cottages and permanent homes). Many species of plants and animals make use of the lake for habitat.
- *Pollination of cultivated crops*
    - N/A

3.3 Lake Erie – Cultural services

- *Religious and other spiritual interactions*
    - An interesting discussion of the spiritual value of ecosystems in general is in Cooper (2009). Evidence that Lake Erie is valued by people for its spiritual value is provided at the links here and here.
- *Knowledge of existence*
    - Many studies of ecosystem services in the Great Lakes note that people place a value on the simple existence of the lakes, whether or not they ever visit the lakes or make any direct or indirect use of them. Notable among these studies is a report by Telhelm (1988) for the Great Lakes Fisheries Commission. Others include Austin et al.(2007); Krantzberg and de Boer (2006) and Marbek (2010). Brox et

[25] Public concerns about the impact of harmful algal blooms on drinking water in Lake Erie were heightened in the summer of 2013 when residents in Carroll Township, Ohio, were advised not to drink water from their local treatment plant due to high levels of microcystin produced by cyanobacteria - the first time a toxin associated with algae led to a plant shutdown in the state (International Joint Commission, 2014; p. 6)

al. (1996) estimate the value of existence of habitat services in the Grand River (a tributary of Lake Erie).

- *Inspiration for artistic creations*
  - Ample evidence is available on-line for the artistic inspiration that Lake Erie provides.
- *Recreation opportunities*
  - Lake Erie is heavily used for the following recreational pursuits: bird watching, recreational hunting and fishing, boating (motorized and non-motorized), beach activities and hiking.[26]
- *Scientific exploration*
  - Perhaps the clearest example of the value of Lake Erie as a source of scientific exploration is the opportunity it provided to scientists in the 1960s to understand the effects of excess nutrient loadings on freshwater lake eutrophication. These studies, of course, played an important in the regulations that were ultimately put in place to control nutrient loadings to water bodies. The resulting improvement in water quality around the world is of enormous value. Beeton (1961 and 1963) and International Joint Commission (1970) are two early examples of scientific research related to the causes of eutrophication in Lake Erie.
- *Cognitive and educational development*
  - Direct evidence that Lake Erie contributes to human cognitive development is not available, though there is no reason to believe that the general notion that ecosystems make such a contribution should not apply to Lake Erie. As for educational development, one concrete example of this is the US National Oceanic and Atmospheric Administration's education and outreach program for Lake Erie. In Canada, the Carolinian Canada Coalition is a charitable organization devoted to educating citizens about the importance of the Lake Erie/Lake Ontario region, noting that 25% of our population lives in this area that covers only 0.25% of our land mass.
- *Aesthetic enjoyment*
  - As with cognitive development, there is little direct evidence that Lake Erie provides aesthetic enjoyment services though there is every reason to believe that the millions of people of live and play in the region, or see images of it in the media, derive considerable enjoyment from its natural beauty.

Table 1 summarizes the ecosystem goods and services provided by Lake Erie.

Table 1 - Summary of Ecosystem Goods and Services Provided by Lake Erie

Ecosystem Good or Service	Ecosystem Goods or Services provided by

[26] See, for example, International Joint Commission, 2013; Yeh et al., 2006; Northeast-Midwest Institute and National Oceanic and Atmospheric Administration, 2001; Austin et al., 2007.

Category		Lake Erie
1. Provisioning goods and services		
	Nutritional goods	• Freshwater fish • Waterfowl • Water for drinking
	Raw material goods	• Water for non-drinking purposes • Genetic material for fish rearing
	Energy services	• Wind power
2. Regulating and maintenance services		
	Regulation of air, water and soil quantity and quality	• Assimilation of sewage water, urban runoff, agricultural runoff, atmospheric wastes • Cycling of air and water through the regional climate system and hydrological cycle
	Climate regulation	• Regulation of the regional temperature, precipitation and air currents
	Regulation of energy flows	• Regulation of waste heat from industrial activities (cooling water)
	Regulation of mass surface flows	• Regulation of mass surface water flows (flood control)
		• Regulation of mass surface soil flows (shoreline erosion)
	Pest and disease control	• Regulation of human disease vectors (*e.g.*, toxins, microbes) • Regulation of pest migration from south to north
	Space	• Lake Erie provides space for a wide variety of human and ecosystem activities
3. Cultural services		
	Religious and spiritual interactions	• Spiritual retreat centres • Spiritual reflection
	Knowledge of existence	• Existence of, for example, clean water in the future
	Inspiration for artistic creations	• Works of art depicting the lake among many others
	Recreation opportunities	• Bird watching, recreational hunting and fishing, boating, beach activities

		and hiking
	Scientific exploration	• Discovery of link between phosphorus and eutrophication, among many others
	Cognitive and educational development	• Public and private education programs based on the lake, among others
	Aesthetic enjoyment	• Enjoyment of the lake's beauty by the millions of people living and vacationing in the region

3.4 Lake Erie's Ecological Good and Services Under Different Scenarios for the Evolution of Algal Blooms

The concern over algal blooms on Lake Erie has two dimensions. First, and most seriously, is the concern over algae capable of producing toxins that can be hazardous (to the point of lethality) to humans, fish and other wildlife. Less serious, though still a major preoccupation, is the presence over so-called "nuisance" algae that foul the lake's shoreline. Related to these concerns is the issue of hypoxia, or oxygen deficiency, that affects parts of the lake. Each of these concerns is discussed in turn below.[27]

3.4.1 Hazardous algal blooms

Since the mid-1990s, a resurgence of planktonic cyanobacterial harmful algae blooms has been noted in Lake Erie. Increased loadings of phosphorus in a highly reactive form (dissolved reactive phosphorus) are thought to be in large part responsible for the return of these blooms, not seen since the 1970s. Increased summertime temperatures are also a factor.

Free-floating blooms of *Microcystis aeruginosa* and other toxin-producing cyanobacteria[28] now form annually in the water column of the lake's shallow, warm western basin and along the shorelines of the deeper, cooler central and western basins. Blooms are developing earlier and remaining present later in the year as time goes by. The 2011 bloom was the worst on record as a result of substantial spring rains followed by high summertime temperatures.

If people drink water contaminated by microcystins (the toxin produced by *microcystis*), symptoms of exposure include nausea, vomiting and, in rare cases, acute liver failure. Minor skin irritation can also occur with contact. Reported health effects from cyanobacteria in humans are uncommon in the United States and Canada. The effects of toxic algae on fish are mostly due to the hypoxia induced by decaying algae rather than from the algae itself (see below).

[27] The material in this discussion is drawn from International Joint Commission (2013) and Michigan Sea Grant (no date).
[28] Cyanobacteria, or "blue-green algae" are not, strictly speaking, algae but, in fact, large masses of bacteria.

3.4.2 Nuisance algal blooms

Some areas of the lake's western basin are also affected by dense bottom-resting mats of *Lyngbya*, which is a non-toxic but odourous cyanobacteria. In the eastern basin, large shoreline blooms of the bottom-attached filamentous green algae *Cladophora*[29] are common. These blooms foul recreational beaches with dense covers of dead algal "muck", clog municipal and industrial water intakes, impair water quality and can also pose microbial health risks[30] to wildlife and humans.

As with hazardous blooms, increased loadings of dissolved reactive phosphorus are a major cause of the growth of nearshore nuisance blooms. Other factors are increased summertime temperatures and, in the case of *Cladophora*, the presence of dreissenid (zebra and quagga) mussels, which filter water (allowing more light to penetrate to depths where the algae form) and provide a substrate for algal growth.

3.4.3 Hypoxia

Hypoxia refers to the condition where the dissolved oxygen content of water is reduced to zero or very low levels. It occurs during summer months in the deeper central basin of Lake Erie when the water column stratifies and warmer, oxygenated waters near the surface are separated from the colder bottom water. The production of excessive organic material (algae and other organisms) in the sunlit surface layers followed by the death and subsequent decomposition of this material in the bottom layers rapidly depletes the supply of oxygen in the bottom layers, creating so-called "dead zones," where dissolved oxygen levels are so low that fish and other aquatic life cannot survive. Cold-water fish species such as perch, walleye and lake trout would be expected to decline if such conditions persist over time, while species more tolerant to warm water likely will thrive.

3.4.4 Scenarios for the evolution of algal blooms and their impacts on Lake Erie's ecosystem goods and services

As noted in the discussion above, several factors influence the growth of algal blooms: loadings of dissolved reactive phosphorus and other nutrients; climate change-related changes to temperature and precipitation regimes; presence of invasive species such as dreissenid mussels. Other factors (e.g., water circulation patterns) are also involved. Scientists' understanding of the processes is still evolving.

Based on the evolution the above factors, there are various scenarios for the evolution of algal blooms on Lake Erie. Three plausible pathways[31] are given below followed by a discussion of the impacts on Lake Erie's EGS flows under each scenario.

---

[29] *Cladophora* is a true form of algae.

[30] Though nuisance algae do not produce toxins, they can harbour harmful bacteria (such as *e-coli*).

[31] Carpenter et al., 1999 refer to three states for eutrophic lakes: irreversible, hysteretic and reversible. These correspond roughly to the "dead", "stable" and "recovered" scenarios proposed here.

Three scenarios for the evolution of algal blooms

1. Hazardous and nuisance algal blooms get worse due to exacerbated effects of climate change and increasing nutrient loadings. The deep waters of Lake Erie move toward persistent "dead" (hypoxic) status again (as in the 1960s and 70s) and most of the lake's shoreline is permanently degraded from algal "muck".
2. Nutrient and other control efforts are moderately successful and hazardous and nuisance algal blooms stabilized at their current levels; that is, they are present to varying degrees in most years, with hazardous blooms restricted mainly to the western basin and nuisance blooms mainly to the eastern basin. The lake is degraded but not "dead".
3. Nutrient and other control efforts are substantially successful and significant reductions in both hazardous and nuisance algal blooms are witnessed. The lake "recovers" as in the 1980s.

The possible impacts of these scenarios on Lake Erie's EGS flows are summarized in Table 2 below. Text colour is used to indicate the degree of possible impact: severe, moderate or low.

Under both scenario 1 ("dead lake") and scenario 2 ("stable lake"), there are major reductions in some flows of EGS. In particular, cultural services are likely to be significantly impacted in both scenarios, as even the current situation with respect to algal blooms is likely to reduce cultural service flows substantially. If the lake stabilizes to today's state (more or less permanent annual recurrence of algal blooms in parts of the lake), the current reductions in cultural services will become permanent. Only scenario 3 ("recovered lake") is likely to see improvements in cultural services. For the other flows provided by the lake (provisioning goods/services and regulating services), the scenario outcomes are more varied.

It is worth noting that cultural services are often found to be among the most important benefits associated with ecosystems. People give quite a lot of significance in particular to the existence value of ecosystems. Recreational opportunities are, of course, also usually highly valued. This is all the more true for an ecosystem like Lake Erie with such a substantial human population nearby.

Table 2 - Lake Erie's ecosystem goods and services under different scenarios for the evolution of algal blooms

Ecosystem Good or Service Category	Ecosystem Goods or Services provided by Lake Erie	Impact under scenario 1 ("dead lake")	Impact under scenario 2 ("stable lake")	Impact under scenario 1 ("recovered lake")
1. Provisioning goods and services				
Nutritional	• Freshwater fish	• Freshwater fish	• Impact on	• Freshwater fish

	goods	• Waterfowl • Water for drinking	will change from the current species distribution towards one more tolerant of warm, turbid, low-oxygen water; significantly reduced value for the commercial fishery and likely also for the sport fishery • Waterfowl of interest to hunters not likely to be significantly affected, though hunters likely to be less attracted to the lake because of reduced aesthetic values • Significantly increased costs to treat drinking water; colour, smell and turbidity concerns leading to lower consumer satisfaction	freshwater fish uncertain but likely gradual shift away from current species distribution to one tolerant of warm, turbid, low-oxygen water; significantly reduced value for the commercial fishery and likely also for the sport fishery in the longer term • Waterfowl of interest to hunters not likely to be significantly affected, though hunters likely to be less attracted to the lake because of reduced aesthetic values • Increased costs to treat drinking water; localized colour, smell and turbidity concerns leading to lower consumer satisfaction	species distribution remains much as today, supporting on-going commercial and sport fishing • Waterfowl remain as today and hunting remains an aesthetically pleasurable experience • Water for drinking improves in quality vis à vis today and treatment costs stabilize or decline
	Raw material goods	• Water for non-drinking purposes • Genetic material for fish rearing	• Significantly increased costs to treat water used for non-drinking purposes for industries with high water quality requirements • Reduced effort to stock the lake with sport and commercial fish species leading to reduction in the value of genetic material	• Somewhat increased costs to treat water used for non-drinking purposes for industries with high water quality requirements • Supply of and demand for genetic material unchanged	• Stabilized or reduced costs to treat water used for non-drinking purposes, especially for industries with high water quality requirements • Supply of and demand for genetic material unchanged

	Energy services	• Wind power	• No impact	• No impact	• No impact
2. Regulating and maintenance services					
	Regulation of air, water and soil quantity and quality	• Assimilation of sewage water, urban runoff, agricultural runoff, atmospheric wastes • Cycling of air and water though the regional climate system and hydrological cycle	• Waste assimilation service is used beyond its maximum level leading to very high external costs (i.e., permanent hypoxicity and algal blooms); however, those using the service do not see a direct reduction in its value • Value of the water cycling service greatly dimished • Air cycling not impacted	• Waste assimilation service is used beyond its maximum level leading to high external costs (i.e., semi-permanent hypoxicity and algal blooms); however, those using the service do not see a direct reduction in its value • Value of the water cycling service gradually diminishes over time • Air cycling not impacted	• Waste assimilation service is used mainly within its maximum level leading to acceptable external costs (i.e., occasional hypoxicity and algal blooms) • Value of the water cycling service stabilizes or increases over time • Air cycling not impacted
	Climate regulation	• Regulation of the regional temperature, precipitation and air currents	• Contribution to regional climate system not impacted	• Contribution to regional climate system not impacted	• Contribution to regional climate system not impacted
	Regulation of energy flows	• Regulation of waste heat from industrial activities (cooling water)	• Other than increased costs to treat intake water for cooling purposes, no major impact	• Other than increased costs to treat intake water for cooling purposes, no major impact	• Decreased costs to treat intake water for cooling
	Regulation of mass surface flows	• Regulation of mass surface water flows (flood control)	• No impact	• No impact	• No impact
		• Regulation of mass surface soil flows (shoreline erosion)	• No impact	• No impact	• No impact
	Pest and disease control	• Regulation of human disease vectors (*e.g.*, toxins, microbes) • Regulation of pest migration	• Possibly great impact if cyanobacteria toxins and/or microbial contamination	• Possible great in parts of the lake in parts if cyanobacteria toxins and/or microbial	• Increased pest and disease control service as algae-related toxins are significantly

		from south to north	becomes widespread and permanent; significantly increased costs required to protect drinking water (as noted above)	contamination becomes locally permanent; significantly increased costs required to protect drinking water for some cities (as noted above)	reduced	
	Space	• Lake Erie provides space for a wide variety of human and ecosystem activities	• Lake Erie will be much less desirable as a location for human activities such as recreation and dwelling	• Much of Lake Erie will continue to be desirable as a location for human activities such as recreation and dwelling, though certain areas will be significantly degraded	• Most of Lake Erie will be desirable as a location for human activities such as recreation and dwelling	
3. Cultural services						
	Religious and spiritual interactions	• Spiritual retreat centres • Spiritual reflection	• Major loss in value; cultural services are predicated on the lake prospering	• Major loss in value in those parts of the lake subject to recurring blooms	• Increased value due to the improvement of the lake's condition	
	Knowledge of existence	• Existence of, for example, clean water in the future	• Major loss in value; cultural services are predicated on the lake prospering	• Major loss in value in those parts of the lake subject to recurring blooms	• Increased value due to the improvement of the lake's condition	
	Inspiration for artistic creations	• Works of art depicting the lake among many others	• Major loss in value; cultural services are predicated on the lake prospering	• Major loss in value in those parts of the lake subject to recurring blooms	• Increased value due to the improvement of the lake's condition	
	Recreation opportunity	• Bird watching, recreational hunting and fishing, boating, beach activities and hiking	• Major loss in value; cultural services are predicated on the lake prospering	• Major loss in value in those parts of the lake subject to recurring blooms	• Increased value due to the improvement of the lake's condition	
	Scientific exploration	• Discovery of link between phosphorus and eutrophication, among many others	• Major loss in value though offset somewhat by the opportunity to study an extreme example of freshwater lake "death"	• Major loss in value in those parts of the lake subject to recurring blooms, though offset somewhat by the opportunity to study an extreme,	• Increased value due to the improvement of the lake's condition	

				if partial, example of freshwater lake "death"	
	Cognitive and educational development	• Public and private education programs based on the lake, among others	• Major loss in value though offset somewhat by the opportunity to educate people about the significance of ecological harm; cognitive value greatly reduced, as positive human interaction with the lake ecosystem will likely diminish significantly	• Major loss in value in those parts of the lake subject to recurring blooms, though offset somewhat by the opportunity to educate people about the significance of ecological harm; cognitive value greatly reduced, as positive human interaction with the lake ecosystem will likely diminish significantly	• Increased value due to the improvement of the lake's condition
	Aesthetic enjoyment	• Enjoyment of the lake's beauty by the millions of people living and vacationing in the region	• Major loss in value; cultural services are predicated on the lake prospering	• Major loss in value in those parts of the lake subject to recurring blooms	• Increased value due to the improvement of the lake's condition

4 Summary of existing databases and studies

This section summarizes the existing scientific databases and studies relevant to the ecosystem services provided by Lake Erie.[32] The information is structured according to the ecosystem goods and services delivered by the lake identified in the preceding section`.

Wherever possible, the studies identified come from the scientific literature (both published and "grey"). In cases where no scientific studies are available, studies providing qualitative information have been included.

In cases where electronic copies of the databases and studies cited were collected for the purposes of this study, copies have been furnished to Environment Canada. In all cases, effort has been made to indicate the name of an individual or website where the database or study in question can be obtained.

Some databases and/or studies may be repeated in the tables below in cases where they are relevant to more than one ecosystem service category.

Where no database or study is listed, it means that none was found during the research undertaken for this study. More extensive study may reveal additional databases and/or studies.

[32] A discussion of socio-economic data relevant to measuring Lake Erie's EGS flows is given in Section 5.

Table 3 - Existing Databases and Studies Relevant to *Provisioning Goods and Services*

Provisioning good or service category		Databases				Studies			
		Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
Nutritional goods									
	Commercial fish harvests	Lake Erie and Lake St. Clair Landed Weight and Value by Species	Rowena Orok, Director, Economic Analysis and Research, Fisheries and Oceans Canada, rowena.orok@dfo-mpo.gc.ca	Yes	Excel spreadsheet with landed value and catch (weight) of all commercial fish species caught in lakes St. Clair and Erie from 2008 to 2012				
	Commercial fish harvests					Ontario Ministry of Natural Resources (website)	Click here	No	Background information relevant to the importance of commercial fishing in the Great Lakes to the Ontario economy
	Commercial fish harvests					Krantzberg and de Boer, 2008	Click here	Yes	
	Commercial fish harvests					Lake Erie Committee, 2004	Click here	Yes	This is one of a series of annual press releases from the Lake Erie

Provisioning good or service category		Databases				Studies			
		Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
									Committee of the Fishery Management Agencies of Lake Erie and Lake St. Clair. News releases for other years from 1997 to 2013 are available here. The news releases provide information on the allowable catch of commercial fish species as well as the quantities landed. It covers both the US and Canadian sides of the lakes.
	Fish stocks					Tyson et al., 2009	Click here	Yes	Detailed scientific study of the state of fish stocks in Lake Erie in 2004
	Recreational waterfowl harvests					Badzinski et al., 2006	Click here	Yes	
	Water for drinking purposes	Ontario Permits to Take Water	Click here	Yes	Database of all organizations and individuals permitted to extract water in Ontario.				

Provisioning good or service category	Databases				Studies			
	Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
				Excel spreadsheet database				
Raw material goods								
Water, non-drinking purposes	Ontario Permits to Take Water	Click here	Yes	Database of all organizations and individuals permitted to extract water in Ontario. Excel spreadsheet database				
Genetic material	Provincial Fish Stocking Summary	Click here	No	Considerable information on fish hatching in Ontario, including total numbers of fish stocked annually in the Great Lakes (no breakdown for Lake Erie) is available from the Ontario Ministry of Natural Resources website. More information may be available by contacting the Ministry of Natural Resources directly. Databases of fish stocking are available annually back to 2000 online.				

Provisioning good or service category	Databases				Studies			
	Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
Energy services								
Wind energy					Erie Shores Wind Farm	Click here	No	Website of a company that provides wind power from turbines installed on the north shore of Lake Erie

Table 4 - Existing Databases and Studies Relevant to *Regulating and Maintenance* Services

Regulating and maintenance service category	Databases				Studies			
	Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
Regulation of air, water and soil quantity and quality								
Waste assimilation					International Joint Commission, 2013	Click here	Yes	
Waste assimilation					International Joint Commission, 2014	Click here	Yes	
Waste assimilation					Ecojustice, 2013	Click here	Yes	
Waste assimilation					Great Lakes Commission, 2006	Click here	Yes	
Waste Assimilation					Hofmann, 2009	Click here	Yes	Study on manure production by watershed basin in Canada
Waste Assimilation					Hartig et al., 2007	Click here	Yes	"State of the Strait" indicators focused on Lake Erie and the Detroit River. Covers a wide range of indicators on wastes and

Regulating and maintenance service category	Databases				Studies			
	Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
								other issues.
Regulation of water quality					Krantzberg and de Boer, 2008	Click here	Yes	Nutrient cycling in the Great Lakes
Regulation of water quality					Wilson, 2008	Click here	Yes	Focused on forest ecosystems in Ontario's Greenbelt
Regulation of water quality					Roy et al., 2010	Click here	Yes	Study of the relationship between invasive species, eutrophication and social systems
Waste assimilation and regulation of water quality					Phosphorus Reduction Task Force, 2012	Click here	Yes	Detailed study of phosphorus loadings and control measures
Climate regulation								
Climate regulation					Krantzberg and de Boer, 2008	Click here	Yes	Climate regulation services of Great Lakes
Regulation of energy flows								
Cooling water	Ontario Permits to	Governm ent of	Yes					

Regulating and maintenance service category	Databases				Studies			
	Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
	take water database	Ontario open data portal (https://www.ontario.ca/environment-and-energy/permit-take-water)						
Regulation of mass surface flows								
Flood control					Krantzberg and de Boer, 2008	Click here	Yes	Flood control value of the Great Lakes
Flood control					Wilson, 2008	Click here	Yes	Focused on forest ecosystems in Ontario's Greenbelt
Pest and disease control								
					Krantzberg and de Boer, 2008	Click here	Yes	Pest control value of the Great Lakes
Invasive species (dreissenid mussels)					Roy et al., 2010	Click here	Yes	Study of the relationship between invasive species,

Regulating and maintenance service category	Databases				Studies			
	Title	**Source**	**Copy provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copy provided to Environment Canada**	**Comment**
								eutrophication and social systems
Invasive species (dreissenid mussels)					Pejchar and Mooney, 2009	Click here	Yes	Study of the costs of dreissenid mussels to Lake Erie's ecosystem services
Space								

Table 5 - Existing Databases and Studies Relevant to *Cultural* Services

Cultural service category	Databases				Studies			
	Title	**Source**	**Copied provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copied provided to Environment Canada**	**Comment**
Religious and other spiritual interactions								
Existence value								
Existence value of Great Lakes fisheries					Talhelm, 1988	Click here	Yes	
Existence and option value of the Great Lakes					Talhelm and Johnson, 1984	Click here	Yes	
Existence value benefit of restoring Great Lakes quality					Austin et al., 2007	Click here	Yes	
Various aspects of existence value of the Great Lakes					Krantzberg and de Boer, 2006	Click here		
Existence value in the Rouge River watershed					Marbek, 2010	Click here	Yes	
Existence value in the Grand River watershed					Brox et al., 1996	Journal article	No	

Cultural service category	Databases				Studies			
	Title	**Source**	**Copied provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copied provided to Environment Canada**	**Comment**
Inspiration for artistic creations								
Recreation opportunities								
Recreational fishing in the Great Lakes					Ontario Ministry of Natural Resources, 2009	Click here	Yes	Results from the 2005 Survey of Recreation Fishing in Ontario.
Recreational fishing in the Great Lakes					Ontario Ministry of Natural Resources (website)	Click here	No	Background information relevant to the importance of recreational fishing in the Great Lakes to the Ontario economy
Recreational fishing in the Great Lakes					Fisheries and Oceans Canada, 2008	Click here		Results from the 2005 Survey of Recreation Fishing in Ontario.
Wildlife based recreation in Canada					Gray et al., 1993	Click here	Yes	A study comparing the results of the 1981, 1987 and 1991 editions of the *Survey of the Importance of Wildlife to Canadians*
Recreation in the Great Lakes					Krantzberg and de Boer, 2008	Click here	Yes	Recreational fishing; boating and beaches

Cultural service category	Databases				Studies			
	Title	**Source**	**Copied provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copied provided to Environment Canada**	**Comment**
Recreation in Ontario's Greenbelt					Wilson, 2008	Click here	Yes	Focused on forest ecosystems in Ontario's Greenbelt
Recreational hunting and fishing					U.S. Department of the Interior et al., 2006	Click here	Yes	2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation
Beach recreation					Sohngen et al. 1999	Click here	Yes	Value of day trips to Lake Erie beaches (focused on US beaches)
Fish stocks					Tyson et al., 2009	Click here	Yes	Detailed scientific study of the state of fish stocks in Lake Erie in 2004
Recreation					Allan et al. 2013	Click here	Yes	Spatial study of the Great Lakes using high-resolution satellite data to study spatial aspects of stress, including for recreation
Recreation and use of nature in general					DuWors et al., 1999	Click here	Yes	Results of the 1996 Survey of the Importance of Nature to Canadians
Recreational					Knoche and	availabl	Yes	Study of the value

Cultural service category		Databases				Studies			
		Title	**Source**	**Copied provided to Environment Canada**	**Comment**	**Author**	**Source**	**Copied provided to Environment Canada**	**Comment**
	hunting					Lupi, 2007	e here		of deer hunting ecosystem services from farm landscapes in Michigan

5 Sectors affected by algal blooms

In this section, the sectors of the economy that are potentially affected by Lake Erie's algal blooms are identified and discussed. Socio-economic data sources from Statistics Canada useful for measuring the affected sectors are briefly discussed. "Affected" means impacted either in terms of the quantity and/or quality of the inputs required by the sector to produce its output or in terms of the quantity and/or quality of the outputs themselves.

The term "sector" has both formal and informal usages. Informally, the term is used loosely to refer to any grouping of producers or consumers that is of interest in a particular discussion. Examples of this kind of use include references to:

- Specific industries (the "pulp and paper sector")
- Groupings of industries (the "private sector"; the "manufacturing sector" or the "finance sector")
- Groupings of governments (the "public sector" or the "municipal sector")
- Groupings of quasi-industries (the "charitable sector" or the "not-for-profit sector")
- Groupings of economic activities (the "tourism sector" or the "information technology sector")
- Consumers (the "household sector")

Such use is convenient in everyday language and usually does not lead to confusion because convention and the context of the discussion usually make clear what is included in these loosely defined "sectors".

Informal use of the term is not recommended in rigorous analytical contexts such as the measurement of EGS flows however. For this, the formal definition of the term as used in business statistics is the proper reference point.

For business statisticians, there are 20 formally defined sectors that cover all production and consumption activities in the Canadian economy.[33] The sectors are listed below.

[33] In the macroeconomic statistics of the *System of National Accounts* (*e.g.*, GDP) a higher-level definition is used in which there are only three principle sectors: the corporate sector, the government sector and the household sector. The corporate sector is actually divided into two: "non-financial corporations sector" and the "financial corporations sector". In addition to the households sector, there is a "non-profit institutions serving households sector" that comprises social, religious, cultural, sports, professional and other similar associations that provide services to their members. Finally, there is a "non-residents sector" represent producers and consumers outside of Canada, for a total of six sectors in macroeconomic statistics.

The Sectors of the North American Industrial Classification System

11	Agriculture, forestry, fishing and hunting
21	Mining, quarrying, and oil and gas extraction
22	Utilities
23	Construction
31-33	Manufacturing
41	Wholesale trade
44-45	Retail trade
48-49	Transportation and warehousing
51	Information and cultural industries
52	Finance and insurance
53	Real estate and rental and leasing
54	Professional, scientific and technical services
55	Management of companies and enterprises
56	Administrative and support, waste management and remediation services
61	Educational services
62	Health care and social assistance
71	Arts, entertainment and recreation
72	Accommodation and food services
81	Other services (except public administration)
91	Public administration

Each of these sectors is formally sub-divided into smaller units (sub-sectors and industries) that are used to compile, analyze and publish official business statistics. This partitioning of the economy is accomplished in the *North American Industrial Classification System* (NAICS; Statistics Canada, 2012b). Mutually agreed upon by the statistical offices of Canada, Mexico and the United States, NAICS is updated on a roughly five yearly schedule to ensure on-going relevance with the changing structure of the economy. The current version is NAICS 2012.

NAICS is a hierarchical system that starts with a 2-digit classification of the economy (there are 20 "sectors" at this level) and descends to a 6-digit classification (there are 922 "industries" at this level). To illustrate, the classification of the *Agriculture, forestry, fishing and hunting sector* is shown below. In NAICS terminology, ***Agriculture, forestry, fishing and hunting*** *(11)* is a **sector**, *Crop production (111)* is a **sub-sector**, *Oilseed and grain farming (1111)* is an **industry group**, *Soybean farming (11111)* is an **industry** and *Soybean farming (111110)* is a **"Canadian" industry.**[34]

[34] The framework is agreed upon in its entirety between the three participating countries only to the 5-digit level. Industries at the 6-digit level are in some cases also agreed upon by all three countries.

Example of the NAICS industrial classification

11 Agriculture, forestry, fishing and hunting

- 111 Crop production
  - 1111 Oilseed and grain farming
    - 11111 Soybean farming
      - 111110 Soybean farming
    - 11112 Oilseed (except soybean) farming
      - 111120 Oilseed (except soybean) farming[US]
    - 11113 Dry pea and bean farming
      - 111130 Dry pea and bean farming[US]
    - 11114 Wheat farming
      - 111140 Wheat farming
    - 11115 Corn farming
      - 111150 Corn farming[US]
    - 11116 Rice farming
      - 111160 Rice farming
    - 11119 Other grain farming
      - 111190 Other grain farming[CAN]

It should be noted that both households and governments are formally included in NAICS. Governments are classified in *91 Public administration*[35] while households are classified as a sub-sector (814) of *Other services (except public administration) (81).* While it may seem strange that households and governments would be included in an *industrial* classification, there are good reasons. Households actually employ significant numbers of people directly in the production of a variety of services: childcare, lawn care, house cleaning, meal preparation and other personal services. To an even greater extent, governments are engaged in the production of a wide range of services worth billions of dollars and employing thousands of people. Thus, it makes economic (if not intuitive) sense that households and governments should be part of an "industrial" classification.

Of course, households participate in the economy mainly as consumers, not producers. Business statistics are mainly concerned with measuring production, however, which is why NAICS focuses on households as producers. The consumption activity of households is paid much greater attention in macroeconomic statistics and the definition of the household sector in the *System of National Accounts* (see footnote 33) is focused mainly on households as consumers. The point is that households can be both producers and consumers and the decision

---

In others, they are common to just two of them or, in rare cases, specific to just one country. When common to just Canada, they are labeled CAN. When common to Canada and Mexico or Canada and the US they are labeled either MEX or US. When unlabeled, they are common to all three countries.

[35] The activities of governments are actually found in several places in the classification. Municipal government operation of water utilities and solid waste treatment facilities, for example, is found in sector 21 (*Utilities)*, while public education is classified to sector 61 (*Educational services).*

about which to emphasize depends on the analytical goal of the statistics in question.

One more concept must be introduced before turning to the question of identifying the sectors affected by algal blooms. This is the distinction between *intermediate* and *final* consumption. Economists and statisticians define *intermediate consumption* as current consumption undertaken in the process of producing another good or service. For example, when farmers purchase fertilizer they are undertaking intermediate consumption, as the fertilizer is used in the process of producing food and it is all used up in the course of one production cycle. *Final consumption*, in contrast, is that undertaken either for the purpose of satisfying final needs – for example, the need for nutrition on the part of the people who buy the farmer's food – or for the purpose of investing in capital assets that will provide inputs into production over a time. Thus, a tractor purchased by a farmer is final consumption because s/he uses it over many years.

Having discussed the formal definition of sectors and the distinction between intermediate and final consumption, these concepts can now be applied to the question of identifying the sectors affected by algal blooms on Lake Erie. To do so, we will identify the consumption (intermediate and final, market and non-market) and production (market and non-market) activities that are potentially affected by the blooms and who (that is, which sectors) undertakes these activities.

5.1 *Consumption* activities susceptible to impacts from algal blooms

Both *intermediate* and *final consumption* activities are potentially affected by algal blooms.

5.1.1 Final consumption

The relevant *final consumption* activities are those of the households that 1) purchase *market* ecosystem goods derived from Lake Erie and 2) consume Lake Erie's freely provided non-market ecosystem goods and services.[36]

Market EGS provided by Lake Erie that are consumed by households are commercial fish, water for drinking and wind power. Of these, both commercial fish and water are clearly susceptible to impacts from algal blooms (wind power should not be affected). Both the quantity and quality of commercial fish are potentially at risk. The quality of fish is at risk from toxins associated with the blooms and the quantity available is at risk from decreased biological productivity in hypoxic areas of lake.

Drinking water is susceptible to quality issues – taste, colour and toxic contaminants. The quantity of drinking water is not at risk from algal blooms.

[36] There are no *final* consumption activities of sectors other than households that are potentially affected by algal blooms.

The *non-market* EGS provided by Lake Erie that are "consumed" by households are listed below. Those marked with an asterisk are susceptible to impacts from algal blooms.

- Regulation of air, water and soil quantity and quality (waste assimilation, cycling of air and water)*
- Regional climate regulation
- Regulation of mass surface flows (flood control, erosion control)
- Pest and disease control*
- Space
- Religious and spiritual interactions*
- Knowledge of existence*
- Inspiration for artistic creations*
- Recreation opportunities*
- Scientific exploration*
- Cognitive and educational development*
- Aesthetic enjoyment*

Most of the non-market EGS flows affected by algal blooms will be *negatively* affected. The presence of algal blooms means that the lake's waste assimilation service, for example, is already being over-consumed and that consumption of this valuable service must, presumably, be reduced in the future (unless society makes the choice to live with the blooms). Similarly, it is hard to imagine how most of the others can be affected in any way but negatively by the presence of the blooms.

Two that could plausibly be argued to benefit are scientific exploration and educational development (to the extent that these services are consumed by households and/or non-profit institutions providing services to households). Because massive freshwater algal blooms do offer somewhat unique opportunities to study the impacts of human activity on ecological systems and to educate citizens about them, it is possible to conceive of the blooms increasing these particular flows. Of course, any such increase would have to be offset by the decline in opportunities for scientific exploration of and education about other aspects of the lake that are negatively affected by the blooms.

5.1.2 Intermediate consumption

The relevant *intermediate consumption* activities potentially affected by algal blooms are those undertaken by the industries[37] that engage in production processes that rely on inputs of market and non-market EGS flows from Lake Erie.

Market EGS flow provided by Lake Erie that are consumed by industries as intermediate inputs include water for drinking and non-drinking purposes and wind power. Of these, only water is susceptible to impacts from algal blooms. As noted

[37] Bear in mind here that "industries" include governments.

above, only the quality of water and not its quantity is likely to be affected by algal blooms.

Based on a preliminary review[38] of the information available from the *Ontario Permits to Take Water Database*, water from Lake Erie appears to be used as an intermediate input in the following industrial sectors:

- 11 Agriculture, forestry, fishing and hunting
- 21 Mining, quarrying, and oil and gas extraction
- 22 Utilities (specifically, 22131 *Water supply and irrigation systems)*
- 23 Construction
- 31-33 Manufacturing

The impact of the blooms on these industries would likely be in terms of increased costs to treat water from the lake to render it of sufficient quality for use in their processes. The degree to which these costs would increase would depend on the importance of water quality to the use in question. Water used for cooling purposes can be of lower quality than water withdrawn for the purposes of producing drinking water or irrigating fields.

The *Non-market* EGS flows provided by Lake Erie that are consumed by industries as intermediate inputs are listed below. Those with an asterisk are susceptible to impacts from algal blooms.

- Raw materials (genetic material for fish rearing)*
- Regulation of air, water and soil quantity and quality (waste assimilation, cycling of air and water)*
- Regional climate regulation
- Regulation of mass surface flows (flood control, erosion control)
- Pest and disease control*
- Space*
- Religious and spiritual interactions*
- Inspiration for artistic creations*
- Recreation opportunities*
- Scientific exploration*
- Cognitive and educational development*

5.1.2.1 Raw materials (genetic material for fish rearing)

Commercial and recreational fishing on Lake Erie both rely on fish stocking programs to ensure viable fish populations. The hatcheries that produce the fry used in these programs are classified to industry 11251 (*Aquaculture)* in NAICS. This industry is susceptible to impacts if the quality of fish resources from which to

[38] More detailed investigation of the database will be required to identify the specific industries that rely on the lake for intake water.

draw genetic material is degraded by algal blooms and/or if algal blooms reduce the demand for commercial or recreational fish and, therefore, the requirement for hatchery services.

5.1.2.2 Regulation of air, water and soil quantity and quality (waste assimilation, cycling of air and water)

Several industries rely directly on Lake Erie's waste assimilation and air/water cycling services. Based on preliminary investigations and on "common sense", those that do so would appear to include:

- 111 *Crop production* (field crop runoff)
- 114114 *Freshwater fishing* (regulation of water quality)
- 112 *Animal production and aquaculture* (assimilation of livestock wastes)
- 22132 *Sewage treatment facilities* (discharge of treated sewage)
- 3114 *Fruit and vegetable preserving and specialty food manufacturing* (assimilation of waste heat).[39]

If Lake Erie's waste assimilation service is already overburdened then use of this service may have to be reduced in the future. This may result in extra costs to the industries that currently rely on the service. Farmers, for example, may be forced to undertake modifications to their fields to reduce fertilizer runoff.

5.1.2.3 Pest and disease control[1] and space[2]

The role that Lake Erie plays in providing the above four services is, in some sense, a benefit to all industries in the region. However, it is primarily the commercial fishing, agriculture and tourism industries that benefit directly and substantially.

- Industry 111 (*Crop production)* – Service 1 contributes to crop production
- Industry 114114 (*Freshwater fishing)* - Services 1 and 2 contribute to the output of commercial fish
- The "tourism" industry - Service 2 permits tourist activity to occur on and around the lake)[40]. Note that the tourism industry is not a true industry in the NAICS sense, but an amalgam of businesses operating in the following industries:
    - 481 *(Air transportation)*
    - 482 *(Rail transportation)*
    - 483 *(Water transportation)*
    - 485 *(Transit and ground passenger transportation)*
    - 5321 *(Automotive equipment rental and leasing)*

[39] Based on evidence from the *Ontario Permits to Take Water Database* there are food processing plants that rely on Lake Erie for cooling water. Further analysis of this database is required to definitively list the manufacturing facilities that rely on Lake Erie for direct assimilation of heat and other industrial wastes.

[40] The "tourism" industry also benefits from the other services, but these benefits are reflected in the "recreation opportunities" service included under the cultural services heading. They are not included here to avoid double counting.

- 5615 *(Travel arrangement and reservation services)*
- 71 *(Arts, entertainment and recreation)*
- 721 *(Accommodation services)*
- 722 *(Food services and drinking places*)

Reductions in the flows of either of these services would negatively affect these industries. Crop farmers, for example, could be forced to incur additional costs to treat irrigation water from the lake (or find alternative sources) if the disease regulation function of the lake is damaged due to eutrophication and hypoxia.

5.1.2.4 Religious and spiritual interactions, Inspiration for artistic creations, Recreation opportunities

The "tourism" industry (see immediately above for a definition of this industry) is a major user of *religious and spiritual interactions, Inspiration for artistic creations and recreation opportunities* as intermediate inputs. In particular, the industry benefits substantially from the recreation opportunities afforded by the lake. The lake attracts large numbers of tourists who engage in activities from hunting and fishing to watersports, enjoyment of beaches, hiking, birdwatching and vacationing. Some of the visitors are drawn by the opportunities for religious and spiritual interactions and to find inspiration for artistic creations (care needs to be taken not to double count these flows).

The opportunities for religious and spiritual interactions offered by the lake are mainly enjoyed, however, by individuals privately and by the NAICS industry that provides religious services (8131 - *Religious organizations*).

As just noted, many of the benefits associated with inspiration for artistic creations are associated with the recreational opportunity benefit, since one of the things that normally attracts visitors to natural areas is the opportunity to view and purchases artworks that represent the area. Though disentangling these two benefits is likely to be difficult in practice, in theory there is a benefit independent of the tourism benefit to those in the arts industry (7115- *Independent artists, writers and performers*) whose works represent the lake and its surroundings. Of course, many private citizens also benefit from the artistic inspiration the lake offers.

5.1.2.5 Scientific exploration and Cognitive and educational development

The use of the scientific exploration and cognitive and educational development services is primarily by:

- The education industries (6111 *Elementary and secondary schools*, 6112 *Community colleges* and 6113 *Universities*)
- Non-profit organizations focused on environment-related issues (813310 *Social advocacy organizations*); and
- Government research organizations focused on the natural sciences (54171 *Research and development in the physical, engineering and life sciences)*

As was noted above with respect to the EGS flows consumed by households, most of Lake Erie's market and non-market flows consumed as intermediate inputs by industries are likely to be *negatively* affected by the presence of algal blooms. The two that could plausibly be argued to benefit (also as noted above) are scientific exploration and educational development. Any such increases would have to be offset by the decline in opportunities for scientific exploration and education about other aspects of the lake that are negatively affected by the blooms.

5.2 *Production* activities susceptible to impacts from algal blooms

Production is the flip side of consumption. Thus, all of the sectors noted above as *consuming* Lake Erie's EGS flows are also *producers* of their own goods and services. Because they consume the lake's services in producing their outputs, if the quantity and/or quality of these flows decline, the sectors' production will either decline or their costs will go up, or both.

In the case of households, the concept of output is an abstract one. For the most part, households are engaged in producing well-being for their members. At the societal level, this is usually referred to as welfare (Section 6 discusses the concepts of well-being and welfare and their relation to the measurement of EGS flows in much more detail).

As just said, well-being is an abstract concept. It is essentially the sense of satisfaction associated with having one's needs and wants met through the "consumption" of goods and services. The important idea to keep in mind here is that it is not just consumption in its traditional sense of consuming goods and services purchased in the market that counts for well-being. In the context of a study on EGS flows, consumption must be understood very broadly to include consumption of goods and services bought in the market but also goods and services freely provided by nature (Lake Erie in this case).

Thus, an important production measure we are looking for in the case of households is the well-being produced by consuming the market and non-market ecosystem goods and services provided by Lake Erie. Much of the Section 6 is devoted to a discussion of how this might be done by using monetary values to measure EGS flows. It is not discussed further here.

There are other, more tangible, aspects of household production that are important to note as well. Lake Erie is also the source of nutritional goods (waterfowl, fish and other wildlife, crops produced for own consumption and drinking water) and (likely) energy services produced by private windmills. The latter is not susceptible to impacts from algal blooms, but the production of nutritional goods certainly is. Algal blooms might impact the productivity of the lake ecosystem, reducing the quantities of waterfowl, fish and other wildlife available. Or it may simply make the harvesting of waterfowl/wildlife less attractive if there are concerns about toxic contamination. With respect to crops produced for own consumption, the concern is that lake water used for irrigation may be lowered in quality with negative

implications for its use on fields. The impacts on drinking water production by households are potentially serious for households with no other source of water than the lake (most likely vacation properties).

With respect to industries, production is measured in terms of the value of the goods and services they sell on the market. The same sectors that were noted in the preceding discussion of intermediate inputs of Lake Erie's EGS flows are relevant to the discussion of production activities susceptible to impacts from algal blooms. Essentially, the potential impacts on production amount to impacts on the output of:

- Crops and animals produced on farms and vineyards surrounding the lake (111 *Crop production* and 112 *Animal production and aquaculture*)
- Commercial fish products (114114 *Freshwater fishing*)
- Water supplied for drinking and non-drinking purposes (22131 *Water supply and irrigation systems*)
- Sewage treatment services (22132 *Sewage treatment facilities*)
- Good and services[41] produced by the following industries that rely on the lake as source of self-supplied water:
    - Mining, quarrying, and oil and gas extraction
    - 22 Utilities (specifically, 22131 *Water supply and irrigation systems)*
    - 23 Construction
    - 31-33 Manufacturing
- The "tourism" industry, which includes tourism-related outputs[42] of the following industries:
    - 481 *Air transportation*
    - 482 *Rail transportation*
    - 483 *Water transportation*
    - 485 *Transit and ground passenger transportation*
    - 5321 *Automotive equipment rental and leasing*
    - 5615 *Travel arrangement and reservation services*
    - 71 *Arts, entertainment & recreation*
    - 721 *Accommodation services*
    - 722 *Food services and drinking places*
- Scientific and educational outputs of the:
    - Education industries (6111 *Elementary and secondary schools*, 6112 *Community colleges* and 6113 *Universities*)
    - Non-profit organizations focused on environment-related issues (813310 *Social advocacy organizations*); and
    - Government research organizations focused on the natural sciences (54171 *Research and development in the physical, engineering and life sciences)*

[41] Further research will be need to determine precisely what industries withdraw water from the lake for self-supply and, therefore, what goods and services are potentially affected by algal blooms).
[42] Identifying "tourism-related" outputs is a non-trivial task, as all of these industries produce outputs that are serve multiple purposes, only some of which are related to tourism.

- Services of religious organizations that place important on the spiritual value of Lake Erie (8131 *Religious organizations*) also benefit
- Works of art that draw upon Lake Erie as a source of inspiration (7115 *Independent artists, writers and performers*)

5.3 Data required to measure potential impacts of algal blooms on consumption and production activities

Having discussed the potential consumption and production activities that might be impacted by algal blooms, the remainder of this section is devoted to a discussion of data sources relevant to measuring the scale of these impacts.

The first thing to note is that the measurement of the impacts of algal blooms on production and consumption is complex and the data requirements are therefore large. There is no intention to be comprehensive here. Rather, the sources that are noted and the issues that are raised are meant as useful starting points for what will necessarily be a much larger effort.

The second thing to note is that the discussion here is focused on the economic and social data needed, the primary source for which is Statistics Canada. Scientific data on EGS flows are covered in Section 4.

5.3.1 Constraints on economic and social data availability

Any effort to measure EGS flows and their relation to consumption and production activity will require significant inputs of basic economic and social data. Statistics Canada is, generally speaking, the most important source of these data in Canada. Though an important source, several factors that limit the applicability of Statistics Canada's data to the measure of EGS flows need to be noted.

First, a number of the consumption and production activities that are relevant to Lake Erie's EGS flows are simply not measured directly by Statistics Canada. In particular, the flows of non-market EGS are in all cases not measured directly. The best that can be hoped for is to find data that *are* measured and that are indirectly related to these flows; for example, the quantity of water withdrawn from the lake for cooling water purposes might be taken as a proxy for its waste heat assimilation service (the next section talks more about the use of proxies to measure EGS flows).

Second, Statistics Canada's economic data collection efforts are generally not devoted to producing estimates for small geographic areas but for provinces/territories and the country as a whole.[43] This can affect the quality of the data when they are compiled for smaller areas. Because most economic surveys conducted by the agency are based on samples rather than censuses of the target population, the accuracy of the results can be assured at a high level of geographic aggregation for not necessarily for small areas where there may not be sufficient

[43] This is less true of social and demographic (census) statistics, which are generally more available for small areas.

"sample" to make accurate statistical estimates. The relatively small size of the Canadian economy also contributes to this. Although there is an enormous amount of economic activity in the region surrounding Lake Erie (and therefore much pressure on the lake), the majority of this activity takes place on the US side of the border. Aside from Windsor (Canada's 23rd largest city) there is no large population centre within Lake Erie's direct drainage basins.[44] (In contrast, there are four major cities on the US shoreline of the lake.)[45] As a result, there is relatively little economic activity within Lake Erie's Canadian drainage basins, making it even harder to compile economic statistics.

A third constraint is that Statistics Canada is prevented by law from revealing information about individual companies or people, including revealing aggregate information that could be used to "back calculate" (or "residually disclose" in the agency's terminology) information about an individual company or person. Thus, even if Statistics Canada knew exactly how much water was withdrawn from Lake Erie by every manufacturing facility that relies on the lake (which, it does not because not every manufacturing facility in the drainage basin would ever be "sampled" for inclusion in Statistics Canada's survey of manufacturing water use), it may be legally prevented from revealing the information. This is because it is likely that there are too few establishments in the basin to satisfy the agency's confidentiality rules.

5.3.2 Statistics Canada data sources

With these caveats in mind, the following Statistics Canada data sources can be mentioned as relevant to understanding Lake Erie's EGS flows. Note that requests for special tabulations of Statistics Canada data may incur costs.

- **Census of Population** - Estimates every five years of the size of the population along with basic socio-economic information (age, sex, marital status, first language) living in Census Metropolitan Areas around Lake Erie (Windsor is the only one that is within Lake Erie's drainage area) are available directly from Statistics Canada's website. Estimates of the total population living in the Lake Erie drainage basins can also be compiled on special request.[46] Latest results are for 2011.
- **National Household Survey (NHS)[47] -** Similar to the Census of Population but includes additional data related to employment, education, ethnic origin, commuting habits, housing characteristics and income. As with the census,

[44] London (Canada's 15th largest city) drains through the Thames River into Lake St. Clair and, therefore, indirectly into Lake Erie.
[45] Detroit, Toledo, Cleveland and Buffalo. Buffalo, being at the far eastern end of the lake does not have a significant impact on surface pollutant loadings to the lake, though it does contribute pressures from human use and atmospheric loadings.
[46] Contact: Carolyn Cahill, Assistant Director, Environment Accounts and Statistics, Carolyn.cahill@statcan.gc.ca, 613-951-3790.
[47] The *National Household Survey* is the voluntary survey that took the place of the long-form census in 2011.

NHS results may be compiled on special request by drainage basin.[48] Latest results are for 2011.[49]

- **Census of Agriculture** – Estimates every five years of the number and size of farms, crops and animals grown, fertilizer and pesticide use (in dollar values) and a variety of other variables are available. As with the above two data sets, there is a possibility of special tabulations of agriculture census data by drainage basin.[50] Latest data are for 2011
- **Survey of Industrial Water Use** – Biennial estimates of the amount of water consumed for various purposes in the mining, manufacturing and thermal electric power industries. Data are available for Ontario as a whole and for major drainage basins (the Great Lakes together represent a single major drainage basin). It is unlikely that tabulations for small drainage basins could be compiled for the reasons given above (confidentiality, sampling, etc.), though an inquiry to this end would be warranted.[51] Latest data are for 2010.
- **Survey of Drinking Water Treatment Plants** – Biennial estimates of the quantities of water supplied by drinking water treatment plants. Data on the costs of providing water are also provided. Data are available for Ontario as a whole and for major drainage basins (the Great Lakes together represent a single major drainage basin). It is unlikely that tabulations for small drainage basins could be compiled for the reasons given above (confidentiality, sampling, etc.), though an inquiry to this end would be warranted.[52] Latest data are for 2011.
- **Agricultural Water Use Survey** – Biennial estimates of water use, irrigation methods and practices, and sources and quality of water used for agricultural purposes on Canadian farms. Data are available for Ontario as a whole and for major drainage basins (the Great Lakes together represent a single major drainage basin). It is unlikely that tabulations for small drainage basins could be compiled for the reasons given above (confidentiality, sampling, etc.), though an inquiry to this end would be warranted.[53] Latest data are for 2012.
- **Farm Environmental Management Survey** – Estimates every five years of a wide variety of variables related to management of environmental quality on Canadian farms. Data are available for Ontario as a whole but not at the drainage basin level. It is unlikely that tabulations for drainage basins could be compiled for the reasons given above (confidentiality, sampling, etc.), though an inquiry to this end would be warranted.[54] Latest data are for 2011.

---

[48] Contact: see footnote 46.
[49] The change from the long-form census to the National Household Survey means that the data for periods prior to 2011 are not necessarily comparable with those for 2011.
[50] Contact: see footnote 46.
[51] Contact: see footnote 46.
[52] Contact: see footnote 46.
[53] Contact: see footnote 46.
[54] Contact: see footnote 46.

- **Ecoregion profiles** – Ecoregion profiles are series of short reports produced periodically by Statistics Canada describing Canada's ecoregions in terms of population characteristics (size, employment), land cover and farm activity. An example of a profile for the Annapolis-Minas Lowlands ecoregion in Nova Scotia can be found here. No profile has been prepared for the Lake Erie North Shore ecoregion but one could be prepared relatively easily upon request.[55]
- **Households and the Environment Survey –** Biennial estimates of a variety of variables related to household activities (recycling, composting, water and energy conservation. Estimates are available at the Census Metropolitan Area (including for Windsor) and for non-urban areas. Tabulations for the Lake Erie drainage basins may be possible on special request, though would likely require considerable effort.[56] Latest data are for 2011.
- **Labour Force Survey** – Monthly estimates of employment including information on numbers of people employed by industry. Data are available for Ontario as a whole and for Census Metropolitan Areas (including Windsor) but not by drainage region. Tabulations for the Lake Erie drainage basins may be possible on special request, though would likely require considerable effort.[57] Latest data are for 2014.[58]
- **National Tourism Indicators** – Quarterly estimates of tourism and related activities in Canada. The indicators cover the domestic supply of tourism commodities (such as transportation, accommodation, food and beverages, recreation and entertainment), the demand for these commodities by Canadian and foreign visitors, and the employment and GDP generated as a result of this demand. Data are available at the Canada level only. A more detail Tourism Satellite Account is also available but only once every five years approximately. No data are available at sub-provincial levels and it is unlikely that any could be produced at that level.
- **GDP by industry –** Annual constant-dollar estimates of the dollar value of GDP (value added) by NAICS industry and province. Data are available for Ontario as a whole only. There is no possibility of data being produced at finer geographic scales. Latest data are for 2012.[59]
- **Consumer price index –** Monthly index of consumer prices for a wide variety of goods and services. Data are available for Ontario as a whole and for Ottawa, Toronto and Thunder Bay. Latest data are for 2014.

[55] Contact: see footnote 46.
[56] Contact: see footnote 46.
[57] Contact: see footnote 46.
[58] Contact: Vincent Ferrao, 613-951-4750 (vincent.ferrao@statcan.gc.ca) or Andrew Fields, 613-951-3551; (andrew.fields@statcan.gc.ca), Labour Statistics Division.
[59] Contact: Bruce Cooke, 613-951-9061, cookeb@statcan.gc.ca, Industry Accounts Division.

6 Methodological considerations

This section discusses various issues related to the measurement of the ecosystem goods and services provided by Lake Erie. It considers both physical and monetary approaches.

The objective of measurement in general is to determine the amount of some particular thing that exists in a given place at a given time. When the "thing" being measured is tangible (like an ecosystem good), the amount of it can be expressed using units of measure that describe its physical properties (mass, volume, length, area, energy content, etc.). However, when the thing being measured is intangible (like an ecosystem service), units designed to measure physical properties are not appropriate and another kind must be used. The most commonly used unit in this case is currency.

A currency unit is a standardized unit represent an agreed upon quantity of value within a given society.[60] One of the advantages of currency (or dollars) as a measurement unit is that it can be used to measure anything, tangible or intangible, to which people ascribe value and is traded in open markets. An automobile can be measured in dollars as easily as a haircut. Moreover, when both are measured in dollars, the total "amount" of them (their combined value) can be meaningfully measured. This is not true when the automobile is measured in tonnes and the haircut in dollars. Nor is it true when physical units are used to measure different tangible things. Cubic metres of standing timber cannot be meaningfully added together with cubic metres of natural gas.

Another option for measuring intangible flows is to use proxy measures. A proxy is a substitute measure used to provide insight into a flow when it is not possible to measure the flow directly (Layke 2009). To be valid, proxy measures must be known to track closely and predictably the direct measures they substitute for. Thus, the degree of security in a society might be proxied by the number of crimes committed and the degree of social cohesion by the number of people reporting attachment to a volunteer organization. Neither of these proxies measures security or social cohesion directly but both give meaningful indirect information about the "amount" of these intangibles present in society. Proxy measures can be based on physical or monetary units.

[60] Unlike physical units of measure that are standardized through international processes involving relatively small numbers of scientific experts, currency units are "standardized" through the millions of market transactions that take place every day using that currency. Currency units are "standardized" in the sense that there will be general agreement at a point in time between members of a society regarding the amount of value represented by one unit of currency. But this amount of value is certainly not fixed, unlike physical units that a unvarying over time.

Each of the two main types of measures – physical and monetary – is discussed in more detail next in relation to the measurement of EGS.

6.1 Physical measures of EGS

All ecosystem goods and services are, in principle, measurable in physical units, either directly in the case of ecosystem goods or *via* proxy physical measures in the case of ecosystem services. For this reason, physical measurement is the recommended starting point for any evaluation of EGS flows. Even in cases where the goal of measurement is ultimately to place a monetary value on EGS flows, physical measures are required as a starting point. Considerable effort should, therefore, be put into obtaining physical measures in any study of EGS.

6.1.1 Ecosystem goods

Direct measurement of ecosystem *goods* in physical units is straightforward in principle and, therefore, reliable physical measures are often available from agencies responsible for monitoring flows of these goods (e.g., provincial ministries of natural resources and Statistics Canada). In particular, flows related to market transactions – the sale of commercial timber or fish, for example – are generally tracked in detail because they are important to the economy and/or because their use is regulated. Such measurement is usually carried out through statistical or administrative surveys conducted either for the purpose of measuring economic output or for a regulatory purpose such as monitoring compliance with an allowable harvest or catch quota.[61] In cases where such surveys are not carried out by government agencies, they are sometimes carried out by individual researchers[62], by NGOs or by private consulting/research companies.[63] Mounting such surveys is generally costly and time consuming but may be the only means of obtaining useful data for some ecosystem flows.

Though straightforward to measure in most instances, the cost of doing so means there are times when direct physical measures of ecosystem goods are not available even though they might be of economic or regulatory interest. In particular, flows that are related to non-market activity – recreational harvests of wildlife or direct household withdrawal of water, for example – are often not tracked closely enough to yield direct physical measures. Wildlife harvests, if measured at all, are likely to be tracked only in terms of the number of animals harvested and not in terms of their mass. Similarly, available data on household well-water withdrawals may be limited to the number of wells drilled in a given area, which says nothing direct about the volume of water used.

There are several other ways in which the measurement of market and non-market ecosystem goods may differ.

---

[61] Sources of such data for Lake Erie are noted in Section 5 of this report.
[62] See, for example, this study being carried out at the University of Alberta.
[63] For example, in the United States, Southwick Associates is a data-analysis firm specializing in the measurement of hunting and angling. No equivalent firm exists in Canada.

- **Frequency** – While market ecosystem goods are usually tracked at set and frequent intervals, often annually, the non-market variety are often measured infrequently and at variable intervals.
- **Scope** – There are two aspects to scope that are relevant. First, there is the question of what goods are covered by measurement efforts. In the case of market ecosystem goods, it is likely that all goods of any economic important will be measured (*e.g.*, all commercial fish species). For non-market goods, it is much more likely that there will be gaps in coverage. For example, while harvests of some wildlife species hunted for recreation in Ontario are measured in all cases (e.g., moose), there are others (waterfowl) that are not at all and still others (deer) that are only measured in certain instances.[64]

  The second aspect of scope is the geographic coverage of the measurement effort. Whereas market ecosystem goods are likely to be measured no matter where their extraction occurs, non-market goods may be measured only in certain geographic areas. This may be because funds are not available to undertake comprehensive measurement or because no agency has assumed or been given responsibility for measurement in certain areas.
- **Methodology –** Measurement of market ecosystem goods is usually based on sound statistical methods (*e.g.*, mandatory surveys) that is applied consistently over time so that comparable time series data are created. Measurement of non-market ecosystem goods is more often based on weaker methods (*e.g.*, voluntary reporting) and less attention may be paid to ensuring consistency in measurement over time.
- **Accessibility –** Data on market ecosystem goods are usually readily accessible directly from government websites/on-line databanks given the economic and/or regulatory importance of the goods in question. Data on non-market goods may be less accessible, requiring direct communication with government officials to obtain them. This is particularly true if the data are collected for scientific rather than statistical purposes.

Thus, obtaining *comprehensive* data on flows of a given ecosystem good may require reliance upon estimation methods to deal with gaps and other shortcomings in data on non-market goods. Household well-water withdrawals, for example, might be estimated in volume terms by multiplying an average household water-use value, based on measured use in cities and towns, by the number of households with wells. Of course, there is a considerable degree of inaccuracy introduced in this, not least because urban households and rural households are likely for all sorts of reasons to use different amounts of water. Such inaccuracies are the price to be paid for comprehensiveness in measurement.

Between directly observed data and data based on simple estimation methods (inaccuracies notwithstanding), compiling comprehensive physical measures of flows of ecosystem *goods* should be largely possible for Lake Erie.

[64] See here for more information on wildlife harvest data in Ontario.

6.1.2 Ecosystem services

As already discussed, ecosystem *services* cannot be measured directly in physical units but can often be measured using proxy physical measures. For example, the flood protection service offered by a forest might be proxied by equating the "amount" of the service to the number of hectares of wetland found within the forest. The recreational service offered by the same forest might be proxied by the number of recreational hunters who frequent it (Layke, 2009).

Stocks of ecosystem assets can also be used as proxies for related ecosystem service flows. The stock of fish in a freshwater lake may, for example, provide a proxy for the recreational fishing service of the lake. So long as the service flow is proportionate to the stock, the stock is a valid proxy for the service (Boyd and Bahnzaf, 2007).

At the moment, there is no accepted list of proxy physical measures for different ecosystem services in the literature on ecosystem goods and services. Different authors choose different proxies for the same service and as long as the proxies can be plausibly seen to track the direct measures they substitute for, there seems to be willingness to accept a wide variety of proxy measures. Boyd and Bahnzaf (2007, p. 621) suggest, for example, "the stock of bees in a particular location may be a reasonable and desirable proxy for pollen delivered." In another study, Kremen et al. (2004, p. 1111) prefer to use "estimates of total pollen deposition per flower as a proxy for pollination services." While both of these approaches seem reasonable on the face of it, equating pollination services on the one hand to numbers of bees and on the other to pollen deposition could lead to very different, and incommensurable, conclusions regarding the "amount" of pollination services present. Until a standard list of proxy measures for ecosystem services is developed, studies of EGS flows will have to live with such inconsistencies and researchers will have to decide for themselves what proxy measures to use.

A number of data sources can be mentioned as important for proxy physical measures of ecosystem services. The potentially wide range of such measures makes anything more than a general assessment of data sources impossible.[65]

- **Land use/cover statistics** – Following the argument of Boyd and Banzhaf (2007) noted above, ecosystem services related to land-based ecosystem (e.g., flood control) can be proxied by the area (a stock measure) of the ecosystem in question. This points to the value of land cover/use statistics and spatial scales (Hein et al., 2006) in proxying ecosystem services flows. In the past, detailed and up-to-date land cover/use statistics were extremely costly and not widely available. Thanks to remotely sensed land information and geographic information systems technology, however, such statistics are now more available than before. Statistics Canada's (2012d) recent report on

[65] Miller and Lloyd-Smith (2012) offer a useful and thorough discuss of data sources and methods (including gaps) for the physical (and monetary) measurement of ecosystem services in Ontario.

measuring ecosystem goods and services in Canada provide a good example of what is possible with land use/cover statistics.

- **Survey data** – As with ecosystem *goods*, survey data from government agencies and other institutions can be a useful source of information for proxy physical measures of ecosystem *services.* For example, surveys of recreational hunting and fishing often provide information on numbers of days spent in these activities that might be used as proxy measures of the recreational service.
- **Scientific studies** – Many of the proxy physical measures for ecosystem services are based on scientific data about the ecosystem that delivers the service. Keeping with the examples cited above, ecological data on bees (their numbers or their success in delivering pollen to crops) are one way to proxy pollination services.

6.2 Monetary measures of EGS

Though physical measurement (directly or *via* a proxy physical measure) is possible for many, if not all, EGS, there are reasons why *monetary* measures may be chosen over physical measures.

Most obviously, monetary measures offer the attractive possibility of *direct* measurement of ecosystem *service,* including highly esoteric services such as aesthetic enjoyment. As discussed above, the most that can be hoped for with physical measures of ecosystem services is to use proxies to *indirectly* them.

Second, monetary measures may be preferred over physical measures for ecosystem *goods* even though the latter can be directly measured in physical terms. The reason for this is the problem of incommensurability of different physical measures that was noted earlier. This problem is a serious impediment if the goal of a study requires an estimate of the *total* EGS flow provided by a given ecosystem. Adding flows of commercial fish, wild ducks, water and wind energy together when they are all measured in disparate physical units is not possible.

Monetary measures offer a solution to the problem of incommensurability. When all EGS flows are measured in terms of their dollar value, they can be meaningfully added together to get an estimate of the total flow. This is true whether the flows in question are ecosystem goods, ecosystem services or both. This is a very attractive feature of valuation that physical measurement cannot offer.[66]

The main drawback of monetary measures of EGS is relatively few observed measures exist. Values exist only for EGS that are sold in competitive markets, which are effectively limited to provisioning goods like timber, fish and (in some cases)

[66] It is worth noting that there are theoretical approaches to measurement relying upon biophysical units that also offer solutions to the problem of incommensurability (Patterson, 1998). One such approach is to use energy units as the basis for measurement. While of theoretical interest, very few practical efforts to use energy or other commensurable biophysical units have been made.

water. For all others, observed values do not exist. This includes essentially all ecosystem *services* as well as ecosystem *goods* for which no market transactions occur (e.g., recreational harvests of wildlife). It also includes ecosystem goods, like water, for which market transactions occur but for which the markets are not truly competitive and the prices charged therefore do not reflect the true cost of provision of the good in question.[67]

If valuation is to be a viable alternative to physical measurement as a means of assessing EGS flows, means are needed to indirectly establish values for those flows for which the market does not already do so. This is the topic of great deal of research and empirical effort in the economic and ecological literature and a number of useful methods have been developed. These are discussed next.

6.2.1 The concept of value and the total economic value framework

The starting point in any discussion of monetary measurement should be a definition of the concept of value. According to Bockstael *et al.*, (2000), there are several aspects of this concept that must be borne in mind.

First, they note that in economics value relates to human welfare.[68] Thus, when applied to EGS, the concept "relates only to the contribution [the EGS flows] make to human welfare, where human welfare is measured in terms of each individual's own assessment of his or her well-being" (*op cit*., p. 1385). Whether something contributes to an individual's well-being is determined by whether or not it satisfies that individual's preferences, implying that individual preferences are what count in valuation of EGS. However, not all decisions need (or should) be made on the basis of what people want. Other factors, such as what is morally "right" now and for the future and what is administratively feasible, must be taken into account. Such issues are less amenable to empirical analysis, however, and this is part of what makes valuation attractive. Still, the economic value of EGS flows is just one element among many that should be considered in decision-making about the environment (Pearce and Özdemiroglu, 2002).

Second, Bockstael *et al*. note that the concept of value as applied to EGS is relevant only in the context of *limited* and *well-defined* changes in the ecosystems that deliver the goods and services. "It makes little sense to talk about the economic value of ecosystems as if the choice were between having them as they are or not having

[67] While there are often economic charges associated with water withdrawn from the environment (*e.g.,* water utility charges to homeowners or licence fees charged to industries that withdraw water for their own consumption), these charges normally do not reflect the true (or full marginal) cost of providing the flow. The charges, therefore, tend to undervalue the water.

[68] To be more precise, it is the concept of value in modern *neoclassical economics* that relates to human welfare. The 19th century *classical school* of economics had a different conception of value that focused on the value embodied in a good or service resulting from the labour used in its creation. Today, there are other theories of value that compete, at least theoretically, with the welfare-based conception. The most well developed of these is the energy theory of value (Hall 2008). However, no other conception of value, including the energy theory, competes seriously today with the welfare-based conception in either empirical or theoretical economic research and decision-making.

them at all, because *economic value is about tradeoffs* and as such requires defining the alternatives clearly" (*ibid.*; emphasis added).

Economists call the measurement of the value of limited and well-defined changes in the delivery of a good or service *valuation at the margin.* This is a key concept in all economic valuation, including valuation of EGS (see the text box for further discsussion).

One of the implications of marginal valuation is that values so derived cannot be used to value wholesale changes in the flow of a good or service; this is the point that Bockstael *et al*. are getting at in the quote above about the valuation of ecosystems. While it may be legitimate to estimate the value of a change in the flow of an EGS associated with an isolated policy initiative to modify the functioning of a given ecosystem, it would be wrong to use that value as the basis for assessing the value of that EGS in all ecosystems.[69] It should be noted that Lake Erie, though a large and complex ecosystem, is not so large that the limitations imposed by marginal valuation eliminate the possibility of using valuation as a legitimate means of measuring the EGS associated with the lake.

Economists talk of individuals' *willingness to pay* for good and services (products) as the means by which they reveal their relative preferences for different products and, therefore, the value they place on them.[70] The value individuals place on products is equivalent in economics to the benefit – what economists call *utility* – they derive from using them. An important point to realize about utility is that some people derive more utility from a given product than they are forced to pay for the product in the market. This is because market prices are not based on the utility of the consumer who *most* values a product, but the utility of the consumer who *least* values it – the marginal consumer.[71] For the marginal consumer, the utility derived from using a product is exactly measured by the price paid for it. For all other consumers, there is utility associated with the product above and beyond what is

[69] There are a number of reasons why this is so, but one of the most obvious is that for methods that rely on prevailing market prices to be used to value EGS flows that, in reality, are not priced, there has to be a presumption that the prevailing prices would not change substantially if the EGS flows were, in fact, priced. While such an assumption can be reasonably assumed to hold in the instance of limited policy action in a well-defined ecosystem, it could not be assumed to hold in the instance were all EGS flows in all ecosystems were to be priced. Such a dramatic change in economic conditions would have significant impacts on prices of *all* goods and services, reorienting them in large and unpredictable ways. Obviously, such a change would call seriously into question any valuation of EGS based on prevailing prices. See the discussion of Victor's (1991) criticisms of valuation later in this section for a concern even about marginal valuation of EGS flows.

[70] A related concept is willingness to accept, which reflects the fact that people are, in theory, indifferent to paying for a product as a means of gaining utility or being paid compensation as a means of avoiding the loss of utility when asked to give a product up. In practice, people are often less amenable to being compensated for giving products up than they are to gaining utility through acquiring new products, so willingness to accept usually exceeds willingness to pay for a given change in utility.

[71] The reason for this is the downward-sloping nature of demand curves, or the decreasing marginal utility of consumption.

paid. The term given to this additional, unpaid for, utility is *consumer surplus* and it is a central concept in the valuation of EGS.[72]

There is a fundamental distinction that must to be made before going further with this discussion. This is the distinction between valuation in a welfare economics context, the context in which the vast majority of the literature on economic valuation operates, and valuation in the context of measuring the scale of economic activity, what can be called valuation for accounting. Valuation for accounting, which is the basis for all economic statistics, including the widely used macroeconomic indicator, GDP, relies entirely on observed market prices. As just noted, market prices are based on the willingness to pay of the marginal consumer, meaning that they *exclude consumer surplus* and, therefore, do not fully reflect the utility that consumers derive from market consumption. Market measures of value are not, then, welfare measures of value. Economic statisticians, therefore, are studious in avoiding inclusion of measures that include consumer surplus in their work.

In evaluating the *ex ante* costs and benefits of proposed policy measures, economists are interested in revealing the *total* value of the change in economic well-being associated with the policy. For this reason, they, unlike economic statisticians, *are* very much interested in understanding the change in consumer surplus (and producer surplus) associated with a policy change. Only by evaluating the total economic value of the proposed change can economists be sure to be in a position to fully compare the costs and benefits of the policy change. For this reason, the methods that economists use to value EGS flows can and do result in valuations that include estimates of consumer surplus.[73] Two implications fall out of this. First, the values for EGS flows arising from welfare economics methods are often not comparable with accounting valuations. Second, and as has already been note, the methods used in welfare economics should not be used to value non-marginal changes in economic conditions. Their validity rests on their use in contexts where small changes in economic conditions (prices and quantities of goods and services) are made and people's reactions to them are either observed (in real markets) or measured otherwise (see further below for the methods used to do this).

There are robust literatures on the valuation of EGS flows in both the welfare economics context and, to a lesser extent, in the valuation for accounting context. The methods presented in this report come exclusively from the welfare economics literature, as that is the one most relevant to understanding value in the context of

[72] A related concept is producer surplus, which represents the benefit that entrepreneurs gain from engaging in market activity; it is very close in most instances to the common notion of profit. The difference between consumer and producer surplus is that the former is purely abstract while the other is, literally, money in the bank.

[73] It is worth repeating here that any empirical measure of consumer surplus is in a sense artificial. There is no basis on which the concept can be measured based on the directly observable behaviour of people. It can only be inferred by eliciting responses from people to questions about their preferences that can then be used in empirical methods to estimate what consumer surplus must be.

the kind of policy changes that will be required to deal with the algal bloom problem in Lake Erie.

Continuing now with the discussion of valuation in the welfare economics context, as noted above, willingness to pay for some ecosystem *goods* is directly observable in market transactions where individuals face an actual price for the goods. They must make explicit decisions whether the goods are worth enough to them in terms of well-being to justify allocating some of their limited budgets to their purchase. In these cases, the price paid for the good can be taken as a lower bound on the value (or utility) to the purchaser. For everyone except the marginal consumer, there will be consumer surplus on top of this.[74]

Willingness to pay for non-market ecosystem *goods* (wildlife harvested by recreational hunters, for example) and for all ecosystem *services* is never observable directly in market transactions, as there are no direct payments made in association with the flows of these products. To deal with the lack of market information, economists have developed indirect methods for measuring their value. The methods can be broadly grouped into two categories: *revealed preference methods* and *stated preference methods*.

Revealed preference methods rest on the premise that the value of EGS flows can be measured by observing choices that individuals make regarding the purchase of other products that are complementary to the EGS. For example, a price difference can normally be measured between two homes that are similar in all respects except for some environmental amenity; a beautiful ocean view, for example. The price premium for the home with the view is attributed to the view using a technique called *hedonic pricing*. This is just one of a number of revealed preference methods available for valuing EGS flows.

Stated preference methods rest on the premise that individuals can be asked directly what their preferences for different products are by constructing artificial markets in which they make choices that are intended to reflect those they would make if acting in an actual market. There are two main types of stated preference methods: *contingent valuation* and *choice modeling*.

A third type of approach, *benefits transfer*, involves the use of EGS values from an existing study using either a revealed or stated preference method and applying them in another study. Benefits transfer has the advantage of being inexpensive and

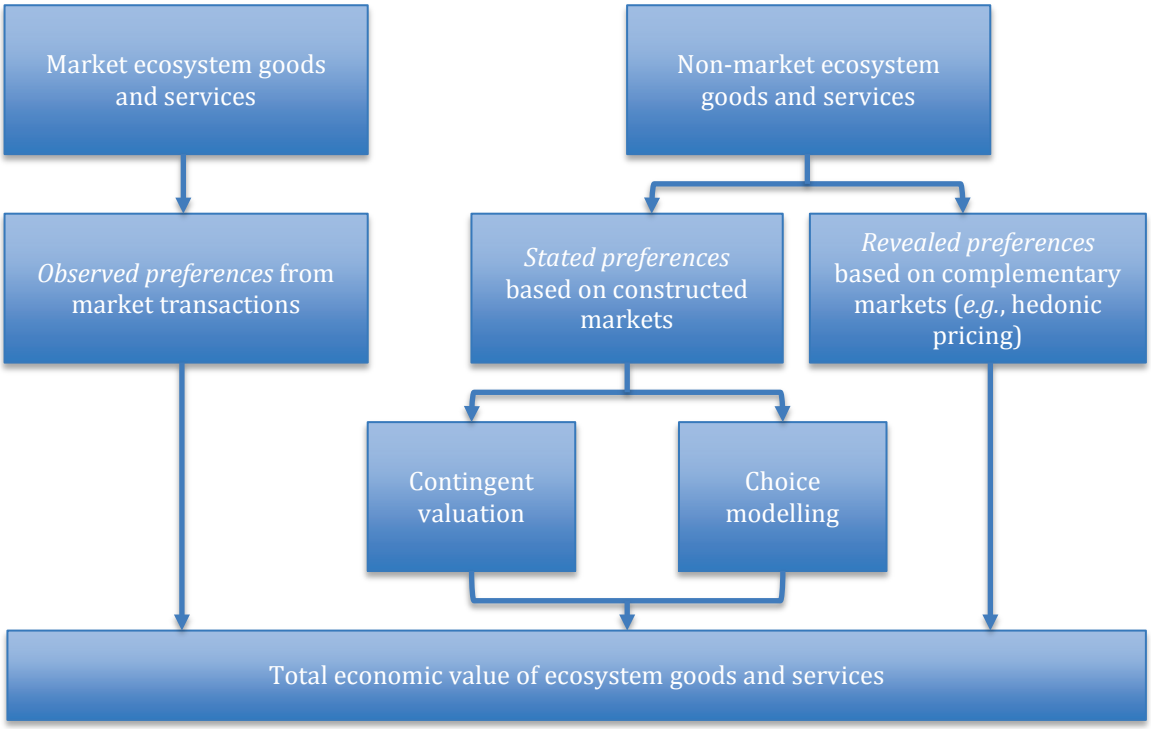
[74] An important point to bear in mind in this discussion is that the context for thinking about value and valuation is always around a small changes in the provision of some ecosystem good or service; that is, small changes in its price and the quantity of it consumed. In the case of such small changes, consumer surplus effects can generally be ignored and the change in utility for all consumers, not just the marginal consumer, can be taken as equal to the difference between the product of price times quantity of the good consumed at the old price and the produce of price times quantity consumed at the new price.

rapid but its validity rests on the "transferability" of values from one ecosystem to another. There are usually reasons why this is not perfect.

The various methods are summarized in Table 6 at the end of this section. An indication of which of Lake Erie's EGS flows they are relevant to and some of the issues that should be kept in mind when applying them is given. The methods are described in more detail in the annex.

Figure 1 below shows the relationship between TEV and the various approaches to valuing flows of market and non-market EGS flows.

Figure 1 - Approaches to Measuring the Total Economic Value of EGS



Source: After Pearce and Özdemiroglu, 2002.

The aim of the valuation techniques in Figure 1 is to uncover the total economic value (TEV) of a given EGS. TEV identifies all the ways in which human well-being benefits from EGS flows or, more precisely, from small and well-defined changes in their availability. In the context of goods like EGS that can have both public and private aspects,[75] these values are of two types: those associated with *use* of the

[75] Public goods are those whose use by one individual does not preclude use by another individual. Many EGS flows have the nature of public goods; my enjoyment of a beautiful sunset, for example, in no way diminishes the opportunities for other to enjoy it as well. Private goods, in contrast, are those for which benefits can be restricted to just the owner. The same banana cannot be bought and enjoyed by two people – it is indivisible (Kneese, 1984). Most EGS are public goods, with the

good/service and those that do not accrue from any use but simply from a willingness to pay for the continued existence of the good/service (*non-use values*). An example of the latter would be willingness to pay for the conservation of an endangered species, even though the individual making the payment may not have seen, nor expect to see, the species in question. Another example is willingness to pay for conservation for the purpose of preserving the option of using the EGS in the future, either for the current or a future generation.

The TEV framework, which is shown graphically in Figure 2,[76] is very commonly presented in the environmental valuation literature. It is used in studies on valuation of EGS flows and on the valuation of natural capital more broadly. The appeal of the framework is that it is rigorous and comprehensive (Marbek, 2010) and that it provides a checklist of impacts and effects that need, in principle, to be valued in any EGS study (Pearce and Özdemiroglu, 2002). Its overall logic comes from its foundations in welfare economics, in which any consumption activity that yields utility to an individual is recognized to have economic value (Marbek, 2010). Thus, the well-being that some people derive from "consumption" of the knowledge that ecosystems exist is sufficient for the existence value of EGS to be recognized in the framework. The various elements of the framework are defined in more detail below.

- *Use value* refers to the value that individuals derive from either *direct* or *indirect* use of ecosystems and their goods and services. *Direct* use involves, as the name suggests, value that derives from the indivdual's direct engagement with the ecosystem in a consumption activity. This could include engagement through the harvesting of resources (a *consumptive* use) or through experiential activities like recreation (a non-*consumptive* use).

  Indirect use, which is always non-consumptive, involves value that derives from an individual's consumption of ecosystem regulating services "at a distance"; for example, the benefits received from a forest's flood control function do not require an individual to be directly engaged in any way with the forest.

- *Non-use value* refers to the value that individuals derive from knowledge of the continued existence of ecosystems. This value could emanate from an individual's conviction that ecosystems have intrinsic value and, therefore, their existence fulfills a basic right (*existence value*). It could also emanate

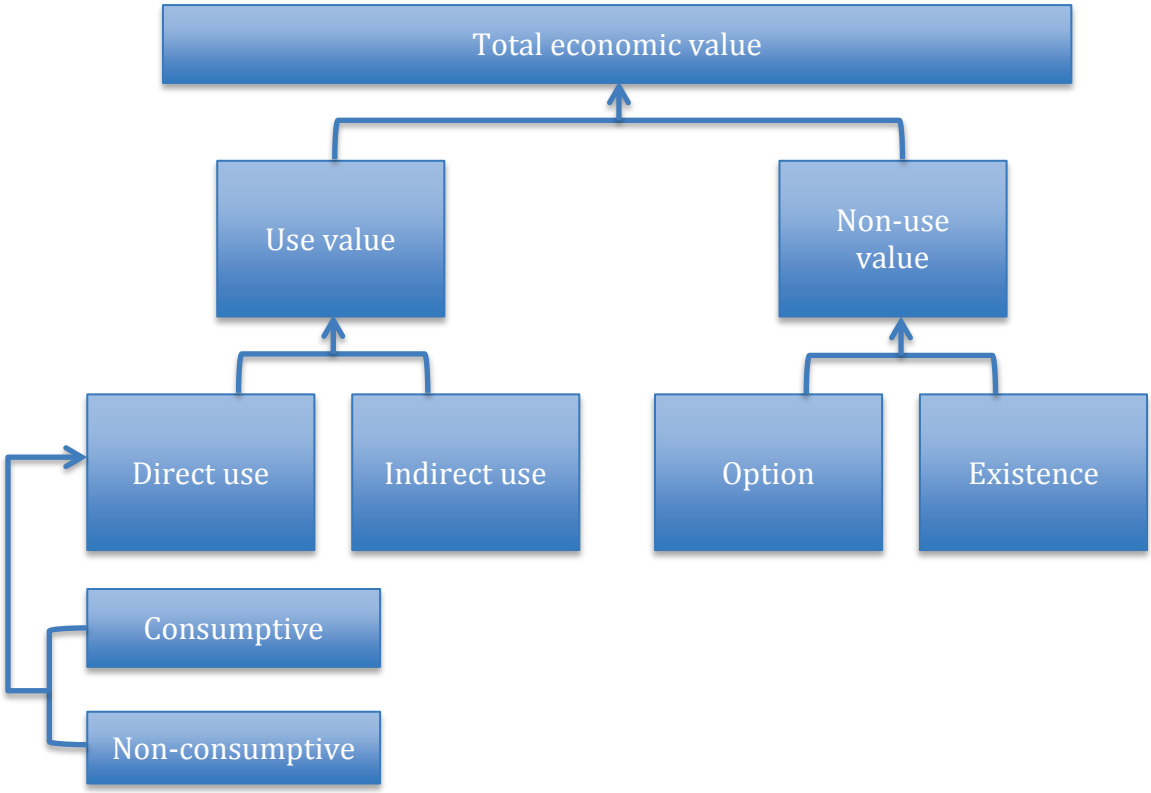
---

exception of provisioning goods like timber and fish; these are private because their use is not divisible.

[76] The TEV framework is not without its problems and, despite its usefulness as a valuation "checklist", its practical value has been questioned (Pearce and Moran, 1994). For one thing, Figure 2 is just one among many presentations of the framework. The considerable heterogeneity in this regard implies on-going uncertainty over the underlying concepts. In fact, other than direct-use value, no consensus exists in the academic community as to what set of categories to use in capturing the elements of the framework (Dziegielewska, 2013).

from an individual's desire to hedge against future risk by preserving the *option*[77] for future use of an EGS (whether direct or indirect).

Figure 2 - The Total Economic Value Framework



6.2.2 Concerns with valuation

In any discussion of valuation, it is important to note that there is not universal support for the use of monetary measures for EGS flows. An important category of objections comes from those who note that valuation rests on a utilitarian ethical view of the environment that does not cohere with the observation that many people ascribe intrinsic (rights-based) ethical standing to certain species or even to whole ecosystems (Spash, 2007). Placing human preferences at the centre when valuing EGS flows is illegitimate if the environment has intrinsic value, or value that exists independent of any human interest.

While it is certainly true that some people do consider the environment to have ethical standing in one way or another, it is equally true that other people do not. This debate, which is at least as old as the environmental movement itself, is important to note. But the mere fact of the debate, however, is not reason to set valuation aside. Nor has it been set aside. The valuation literature is already large and it continues to grow. The debate around the ethical acceptability of valuation is

[77] Because option value implies the possibility of use, it is sometimes included in the framework as a use value or as a third category of value between use and non-use.

alive and well within this literature (see, for example, Davidson, 2013) and may never be fully resolved because it is philosophical rather than empirical.

A more practical concern raised by Victor (1991) is that prevailing market prices for all products in the economy are badly distorted by environmental externalities and, therefore, inappropriate for use in the valuation of EGS flows. Since environmental externalities are pervasive and, in some cases, extremely serious (the possible effects of excess greenhouse gas emissions on climate stability being perhaps the most worrisome), Victor's reasoning goes, prevailing market prices are *very* far from where they would be if there were no externalities. In this situation, demand for products with significant externalities is relatively much higher than it would be without externalities. Using prevailing, badly distorted, prices as the basis for measuring the value of EGS flows, either the directly observed value of market ecosystem goods or the estimated value of non-market EGS, is sure to result in a distortion of their true value to society.

Victor's concern is legitimate if one believes, as he does, that externalities are *pervasive* and *large*. If they are not, then the use of prevailing prices to value EGS flows may be acceptable. Most economists seem to implicitly be of the view that externalities are not so pervasive and large as to render prevailing prices irrelevant for valuation of EGS flows (otherwise, they would presumably not pursue such valuation).[78] Which perspective is correct is not clear. It is, however, essentially an empirical question and therefore amenable to an analytical solution. Sophisticated and complex models would be required to establish a new set of equilibrium prices for the wide range of products in the economy.

Another practical concern is that the use of welfare economic valuation methods often precludes the establishment of "baseline" valuations against which future values might be compared. The values established using stated preference methods, in particular, are specific to the contexts in which the methods are applied and cannot be meaningfully used outside of those contexts. The demand curves that are constructed in these techniques are valid *only* in the context of the economic decision (tradeoff) that people are faced with when asked about their willingness to pay. For example, by asking a number of people how much they would be willing to pay to be able to catch 25 more fish per year on Lake Erie, it is possible to establish an aggregate willingness to pay for that improvement in the lake's recreational fishing service. It would be wrong, however, to take that number and use it to estimate a value for the total recreational fish harvest from the lake. This is because the initial valuation was made in a context that was specific to the small change in the lake's condition that would result in 25 extra fish being available to all fishers. The willingness to pay expressed by those interviewed is specific to this small change only and not to the value of each and every fish they or other harvest.

[78] This is not to say that other economists and a lot of non-economists do not share Victor's view (see Hinterberger et al. (1997) for similar concerns). But those who feel prevailing prices are too badly distorted to be legitimate for valuation of EGS flows do seem to be in the minority.

As a result, stated preference techniques are of no value in *ex post* analysis of policy success. They cannot be used to compare the total value that individuals place on a given EGS flow before and after a policy intervention to determine whether the policy was justified or not. For this, revealed preference methods (either direct market valuation – that is, accounting prices – or indirect methods that rely on market prices like hedonic pricing) must be used. The shortcoming of these methods is that, unlike stated preference methods, they are not applicable to all EGS flows. They work only in instances where market transactions are available that reveal, either directly or indirectly, individuals' valuations of EGS flows. (There is the additional difficulty that revealed preference methods exclude consumer surplus while those that are based on stated preferences include consumer surplus).

There are other, more technical, criticisms of the use of monetary measures for EGS flows but these are particular to the various stated and revealed preference methods used. They are noted in Table 6 below and discussed in more detail in the annex.

Table 6 - Summary of Ecosystem Valuation Methods and their Applicability to Lake Erie

Valuation method	Comments	Scope	Applicability to Lake Erie
1. Market price (observed preferences) Observed market prices for marketed EGS are used to estimate the change in economic value associated with a policy that affects the quantities or quality of these products supplied	Requires estimation of demand and supply curves for the EGS flows in question.	Applicable to any EGS traded in a competitive market. In practice, this is limited to certain provisioning goods (*e.g.*, commercial fish and timber) and renewable energy flows (*e.g.*, wind power). For the method to work well, the EGS must be a private good with no characteristics of public goods.	• Commercial fish • Wind power • Water (with the caveat that water markets are not usually competitive and, therefore, the method will likely undervalue water provisioning).
2. Production function (observed preferences) The value of EGS flows are estimated by determining their contribution to the economic value of related commercial products before and after a policy change. For example, the water	Requires a sound understanding of how the EGS flows contributes to the output of the commercial good and how the EGS flow will be affected by the policy change.	Applicable in cases where a direct link between an EGS flow and the output of a commercial product can be demonstrated.	• Water (for agricultural irrigation or industrial use • Genetic material for commercial fish (difficult) • Assimilation of industrial waste products (including heat)

Valuation method	Comments	Scope	Applicability to Lake Erie
quality regulating service of a wetland can be estimated as the contribution it makes to the supply of crops.			
3. Hedonic pricing (revealed preferences) The value of EGS flows are estimated by observing differences between market goods (houses, in particular) that can be attributed to the association between the EGS and the market good. For example, the value a beautiful view can be determined by observing differences in prices between houses with and without views.	Requires detailed housing market data and reasonably sophisticated statistical analyses. Separating the value of the EGS flow from the values of the other characteristics that determine house prices can be complex.	Applicable mainly to EGS flows that are associated with settled areas where housing market data are available.	• Assimilation of wastes • Regional climate regulation • Aesthetic enjoyment • Recreation opportunities • Space
4. Travel costs (revealed preferences) The value of EGS flows are estimated by observing the willingness to pay the travel costs associated with visiting sites with particular EGS flows.	Requires careful analysis of travel expenditures, including assessing the value of the time that people spend travelling. Deriving the value of specific EGS flows through travel cost analysis can be confounded by the presence of other EGS flows and by the fact that people travels for reasons other than benefiting from EGS flows.	Applicable mainly to the valuation of recreational sites.	• Recreation (hunting, fishing, watersports and beach activities, vacationing)
5. Damage-cost avoided and replacement cost (revealed preferences) The value of EGS flows are estimated by observing market expenditures individuals make to avoid losses in well-	Using costs as a means of measuring benefits is problematic and should be a last resort. The values so derived are likely to underestimate the full value of the EGS flow. The method works best when there is a relationship of perfect	Applicable only to regulating EGS flows for which market substitutes exist.	• Assimilation of wastes • Regulation of shoreline erosion • Regulation of disease vectors

Valuation method	Comments	Scope	Applicability to Lake Erie
being associated with the loss of an EGS flow (damage-cost avoided) or the willingness to pay for the replacement of an EGS flow (replacement cost). For example, household expenditures on water filters could be used to measure the value they place on the regulation of water quality. The cost of building a new water treatment facility to replace the water filtration service of wetlands could be taken as a minimal value of that service.	substitutability between expenditure on a market product and the EGS flow. For example, additional chlorination in water treatment plants is a near perfect substitute for the filtration service of a wetland.		
6. Contingent valuation (stated preferences) The value of EGS flows are estimated by asking individuals directly about their willingness to pay for increases in EGS flows (or willingness to accept compensation for decreases). The questioning takes place in the context of "contingent" markets – hypothetical markets in which individuals are asking through survey questionnaires to express their willingness to pay for (accept compensation for) changes EGS flows under specific conditions.	Widely practiced but controversial valuation method. The design of contingent markets is very complex and a number of sources of bias can influence the quality of the results. Well-designed contingent value surveys are costly and time consuming to implement.	Very broad applicability to EGS valuation. Can be used to estimate both use and non-use values.	• In principle, all non-market EGS associated with the lake • Particularly valuable as a means of estimating non-use values, which cannot be estimated with either observed preference or revealed preference methods.
7. Choice modelling (stated preferences) Similar to contingent valuation except that individuals are asked to rank preferences for	Does not reveal willingness to pay (or accept) directly. Some individuals find it easier to express relative rankings than	Very broad applicability to EGS valuation. Can be used to estimate both use and non-use values. Particularly useful for	• In principle, all non-market EGS associated with the lake • Particularly valuable as a

Valuation method	Comments	Scope	Applicability to Lake Erie
different scenarios regarding changes in EGS flows. So long as the scenarios include the cost of the proposed changes, the ranking of the scenarios can be used to infer individuals' valuations of the EGS flows.	absolute values in stated preference surveys, so non-response bias can be reduced. The method also eliminates other biases associated with the contingent valuation method.	valuing bundles of EGS flows.	means of estimating non-use values, which cannot be estimated with either observed preference or revealed preference methods.
8. Benefit transfer EGS values are estimated by transferring values estimated in another study. Willingness to pay can be transferred directly or as a "benefit function". In the latter case, the function accounts for characteristics of the population studied in the primary study so that the adjustments to account for the characteristics of the population in the target study can be accounted for.	Widely used method that can be cost and time effective. The quality of the resulting estimates can only be as good as those in the primary study and is usually lower because value estimates are rarely perfectly transferable. Can be used as a "quick and dirty" initial study to guide a decision regarding investment in a primary valuation study. Two significant examples of the use of benefits transfer to study EGS flows in Ontario are Troy and Bagstad (2009) and Marbek (2010).	Very broad applicability to EGS valuation. Can be used to estimate both use and non-use values. Particularly useful for valuing bundles of EGS flows.	• In principle, all non-market EGS associated with the lake

Annex – Summary of EGS Valuation Methods[79]

A1 Market price method (observed preferences)

The market price method estimates the economic value of EGS that are bought and sold in competitive markets, such as commercial fish and timber. The method can be used to value changes in either the quantity or quality of market EGS. It uses standard economic techniques for measuring the economic benefits of market products.

The method relies upon the estimation of *consumer surplus* and *producer surplus* using market price and quantity data. The total net economic benefit of the EGS, or economic surplus, is the sum of consumer surplus and producer surplus. Estimation of consumer and producer surplus requires knowledge of the demand and supply curves for the EGS in question. These curves must normally be derived from observed market data on the quantity people purchase at different prices and the quantity supplied at different prices. The graphs below illustrate the basic concepts.

Figure A 1 is a standard economic portrait of demand and supply for a given product. The market price for the product is established by the point of intersection of the demand and supply curves, marking the point at which the marginal cost of production is exactly equal to the marginal utility of consumption.

The blue triangle represents consumers' surplus in this situation; that is, the utility derived from the consumption of the EGS over and above what it costs consumers to buy the fish (this cost is represented by the sum of the green and white triangles delimited by points 0PBQ). The green triangle represents producers' surplus (effectively corporate profits) associated from supplying the EGS. The white triangle is the producers' costs of supply (labour, materials, produced capital).

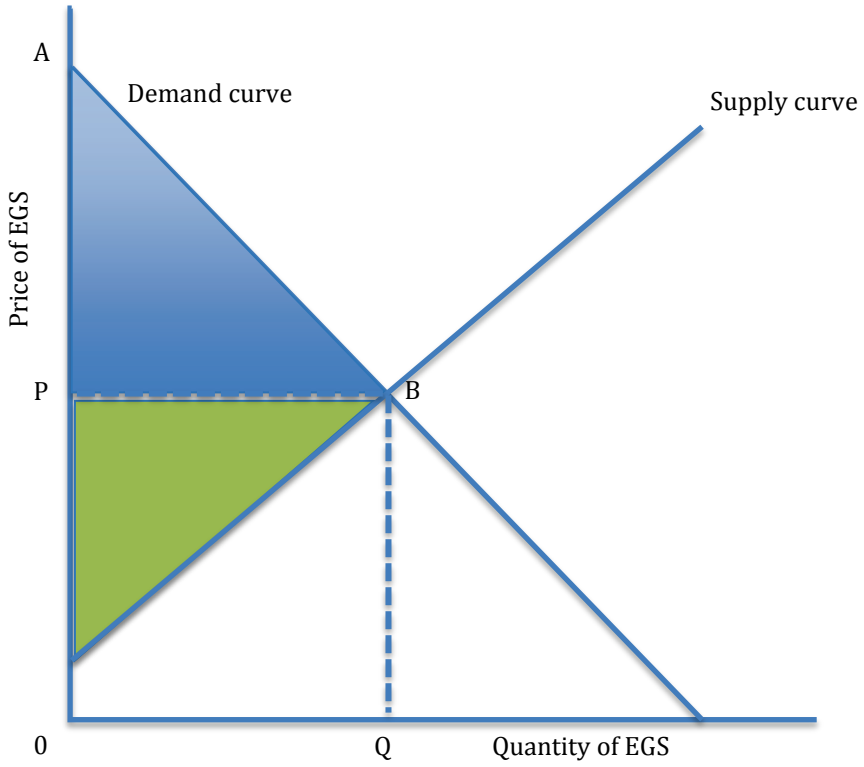
Assume the good in question is fish harvested commercially from a freshwater lake and that a policy proposal to improve the lake's quality is being considered. The policy imposes new costs on commercial fishing vessels (say to reduce pollution discharges from vessels to the lake) and that causes the supply curve for commercial fish to move upward (Figure A 2). As a result, a new, more expensive, equilibrium price is established for fish (it is assumed that the demand for curve for fish does not change as a result of this policy). As a result, the sum of consumer surplus (green triangle) plus producer surplus (blue triangle) is smaller than before the imposition of the policy (by an amount equal to the area of the quadrilateral CC'B'B). This reduction in the total societal surplus represents the change in the value of the EGS

[79] The descriptions of the valuation methods presented in this annex all draw heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).

flow, commercial fish catch in this case, associated with the pollution reduction policy.[80]

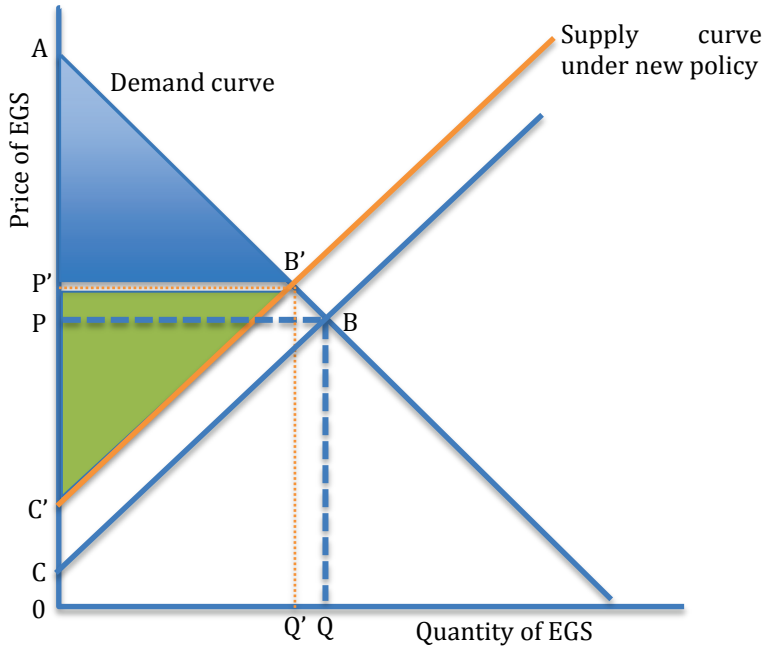
The principles of cost-benefit analysis would suggest that the benefits of the policy in terms of increases in other EGS flows and/or other economic benefits (net of costs in addition to the reduction of commercial fish harvests) must be greater than the loss in the value of commercial fish. Otherwise, the policy would not be worth adopting on the grounds of its net *economic* benefit.

Figure A 1 - Supply and Demand for an EGS



[80] As noted in footnote 74, there is a simplifying assumption that can be made of small shifts in the demand curve. This is that the change in societal surplus is simply equal to the difference between the market value of the EGS flow before and after the policy change. This is because the change in consumer surplus for small changes in price is likely negligible in comparison to the change in the market value of the EGS flows. The more elastic the demand for the EGS is, the smaller the change in consumer surplus will be. So, if the simplifying assumption is made that consumers will simply accept a small price change for an EGS and continue to demand the same amount of it after the policy change but at a new price, change in societal surplus can be estimated with information only on the impacts of the policy on producers' costs.

Figure A 2 - Supply and Demand Under a New Policy



Advantages of the Method

- Price, quantity and cost data are relatively easy to obtain for EGS sold in the market.
- The method uses standard, accepted economic techniques.

Limitations of the method

- Applies only to EGS that are sold in the market, effectively limiting its use to flows of provisioning goods and services.
- The true economic value of EGS flows may not be accurately reflected in existing market prices due to externalities and other market failures.

A2 Production function method (observed preferences)[81]

The *production function method*[82] (see, for example, Barbier, 2000; DSS Management Consultants, 2010; Opulach, 1999) is used to estimate the economic value of ecosystem products or services that contribute to the production of commercially marketed goods. It is applied in cases where the products or services of an ecosystem are used, along with other inputs, to produce a commercial good. For example, coastal mangroves that serve as fish spawning grounds affect the productivity of offshore fisheries. The economic benefits a policy to preserve mangrove forests can thus be measured by value of increased revenues from greater productivity of the commercial fishery.

Two types of benefits (or costs) must be considered. First, if the quality or price to consumers of the final good, commercial fish in the above example, there will be changes in consumer surplus that must be measured. Second, if productivity or production cost changes, there will be changes in producer surplus that must also be measured.

The method is as follows. The first step is to specify a production function for the commercial good in question. This could be, for example, a standard Cobb-Douglas production function (DSS Management Consultants, 2010). The production function establishes a theoretical relationship between the output of the commercial good and the various inputs that are required in its production, including the inputs of EGS. In the case of the offshore fishery, a "normal" production function would specify the output of commercial fish as a function of the input of labour, materials, fuel and produced capital (boats and fishing gear). In order to value the contribution of the mangrove forests to the fish output, a variable would be added to this production function representing the input of mangroves. Since the input of the mangrove is a service for which no price is paid, a physical proxy (such as area of mangroves) can be used in the production function.

The second step is to estimate how the cost of producing the commercial good (fish) changes when the input of the EGS (mangroves) changes. This requires estimating changes in the supply curve of the fishing industry as the EGS input changes, holding other inputs constant. Using the approach described above for the market price method, the difference between the total economic surplus (consumer and producer) for two different levels of EGS input (two different areas of mangrove forest) can be calculated. Dividing this difference by the change in the number of

[81] This description draws heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).

[82] This approach is also known as the "valuing the environment as input" approach and the "value of changes in productivity" approach (Barbier, 2000). It is similar to the approach that is used in environmental accounting of calculating resource rent (United Nations, no date).

hectares of mangrove yields a per hectare value of the mangrove forest as an EGS input (actually, as a proxy for the regulating service of fish habitat).

Advantages of the method:

- In general, the methodology is conceptually straightforward.
- In simple cases of a single EGS that provides an input into production process for which there is a perfect substitute (for example, the water filtration service of a wetland and chlorination in a water treatment facility), data requirements may be limited and the relevant data may be readily available. More complex situations will have greater data requirements.

Limitations of the method:

- The method is limited to valuing those EGS that can be used as inputs in production of commercially marketed goods. This means that it cannot be used to value non-use EGS flows.
- Information is needed on the scientific relationships between actions to improve quality or quantity of EGS and the actual outcomes of those actions. In some cases, these relationships may not be well known or understood and data to describe them may not be readily available.

A3 Hedonic Pricing (revealed preferences)[83]

The *hedonic pricing method* (see, for example, Poor *et al.*, 2007; Waltert and Schläpfer, 2010; and Opaluch et al., 1999) is used to estimate economic values for EGS that can be shown to directly affect market prices for commercial goods or services. It is most commonly applied to variations in housing prices that reflect the value of local ecosystem attributes.

The basic premise of the method is that the price of any commercial good is related to its characteristics. The price of a house reflects its comfort, size, luxury, location and many other factors, including the EGS associated with it. Houses with scenic views, lovely sunsets or good air quality generally command higher prices than similar houses without them. In theory, the individual characteristics of house can be valued – including associated EGS – by looking at the prices people are willing to pay for otherwise similar houses with and without specific characteristics.

The method requires data on residential properties that change hands in a given region over a specific time period (usually one year). The required data include:

- Location, selling price and physical characteristics of the house (number of rooms, etc.)
- Neighborhood characteristics (property tax rates, crime rates, and quality of schools)
- Accessibility characteristics (distances to work and shopping centers, availability of public transportation), and
- EGS associated with the house (scenic views, clean air, access to nature, etc.).

Once the necessary data are collected and compiled, a regression model relating property values to the property characteristics, including associated EGS, is constructed. The model may be used to measure the portion of the property price attributable to each characteristic, including the EGS.

The hedonic pricing method is relatively straightforward and uncontroversial to apply, because it is based on actual market prices and fairly easily measured data. If data are readily available, it can be relatively inexpensive to apply. However, if primary data collection is required, costs can increase substantially.

The regression modelling may be complicated by a number of factors. In particular, the relationship between price and the various characteristics of the property may not be linear. In addition, some variables are likely to be correlated, so that their values change in similar ways. This can lead to understating the significance of

[83] This description draws heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).

some variables in the analysis. To deal with this, different functional forms and model specifications can be considered.

Advantages of the method

- Property markets are relatively efficient in responding to information, so can be good indications of value.
- Property records are typically very reliable.
- Data on property sales and characteristics are readily available through many sources and can be related to other secondary data sources to obtain descriptive variables for the analysis.
- The method is versatile, and can be adapted to consider several possible interactions between market goods and environmental quality.

Limitations of the method

- The scope of EGS flows that can be valued is limited to those that are associated with housing. This effectively limits it to that sub-set of regulating services consumed by private citizens.
- The method will only capture people's willingness to pay for perceived differences in EGS flows. Thus, if people aren't aware of the linkages between EGS flows and their property, the value of the EGS will not be reflected in home prices.
- The method assumes that people have the opportunity to select the combination of features they prefer, but this is not always so.
- The method is relatively complex to implement and interpret, requiring a high degree of statistical expertise.
- arge amounts of data must be gathered and manipulated, making the method expense and slow to carry out.

A4 Travel Cost Method (revealed preferences)[84]

The *travel cost method* (see, for example, Knoche and Lupi, 2007 and Opaluch et al., 1999) is used to estimate the value of recreational benefits generated by ecosystems. It assumes that the value of a recreational site is reflected in how much people will spend to travel to it.

The basic premise of the method is that the time and travel expenses people incur to visit a site represent the "price" of access to the site. Thus, peoples' willingness to pay to visit the site can be estimated based on the number of trips that people make at different travel costs. This is analogous to estimating peoples' willingness to pay for a marketed good based on the quantity demanded at different prices.

The method can be used to estimate the economic value of:

- Changes in access costs for a recreational site
- Elimination of an existing recreational site
- Addition of a new recreational site
- Changes in environmental quality at a recreational site.

On average, people who live farther from a site will visit it less often, because it costs more in terms of actual travel costs and time to reach the site. The number of visits from points of origin at different distances from the site, and travel cost from each origin, are used to derive an aggregate demand curve for visits to the site, and thus for the recreational services of the site. This demand curve shows how many visits people would make at various travel costs and is used to estimate the willingness to pay for people who visit the site.

Data required to implement the travel cost method include:

- Number of visits from each point of origin (POI)
- Demographic information about citizens living in different POI
- Round-trip mileage from POI
- Travel costs per kilometer and other costs of trip
- The value of time spent traveling, or the opportunity cost of travel time
- Length of trip
- Amount of time spent at the recreational site

This information is typically collected through surveys—on-site, telephone, mail or electronic methods may be used. In addition, especially for simpler applications, much information may be available from government agencies responsible for parks and/or natural resource management.

[84] This description draws heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).

The most challenging aspects of the travel cost method include accounting for the opportunity cost of travel time, how to handle multi-purpose and multi-destination trips, and the fact that travel time might not be a cost to some people, but might be part of the recreational experience.

Advantages of the method

- The travel cost method is relatively uncontroversial, because it is modeled on standard economic techniques for measuring value and it uses information on actual behaviour. It is often relatively inexpensive to apply.
- The method is based on actual behavior
- The method is relatively inexpensive to apply.
- On-site surveys provide opportunities for large sample sizes, as visitors tend to be interested in participating.
- The results are relatively easy to interpret and explain.

Limitations of the method:

- The most simple models assume that individuals take a trip for a single purpose – to visit a specific recreational site. Thus, if a trip has more than one purpose, the value of the site may be overestimated. It can be difficult to apportion the travel costs among the various purposes.
- The opportunity cost of the time spent travelling should be added to the out-of-pocket travel expenses or the value of the site will be underestimated. However, defining and measuring the opportunity cost of time spent traveling can be problematic. This is particularly so if people enjoy the travel itself. Then travel time becomes a benefit, not a cost, and the value of the site could be overestimated.
- The availability of substitute sites will affect values and should be accounted for, though doing so is challenging. If two people travel the same distance to a given site, they are assumed to value it equally. However, if one person has several substitutes available but travels to the site because it is preferred, the value that person places on the site is actually higher.
- Those who value certain sites highly may choose to live nearby. If this is the case, they will have low travel costs that will not reflect the high value they place on the site.
- Interviewing visitors on-site can introduce sampling biases to the analysis.
- In order to estimate the demand function, there needs to be enough difference between distances traveled to affect travel costs and for differences in travel costs to affect the number of trips made. Thus, the approach is not well suited for sites near major population centers.

A5 Damage-cost Avoided and Replacement Cost Methods (revealed preferences)[85]

The *damage–cost avoided* and *replacement cost* methods estimate values of EGS based on either the costs of avoiding damages incurred by individuals due to losses of EGS flows or the cost of replacing EGS flows with flows from a produced asset.

The *damage-cost avoided* method uses either the value of property protected or the cost of actions taken to avoid damages as a measure of EGS benefits. For example, if a wetland protects adjacent property from flooding, the flood protection benefits may be estimated by the damages avoided if the flooding does not occur or by the expenditures property owners make to protect their property from flooding.

The replacement cost method uses the cost of replacing EGS with flows from produced capital as an estimate of their value. A famous example was the use of replacement costs to justify protection of the water provisioning function of the Catskills' watersheds in New York State. In the 1990s, the city of New York was faced with the prospect of a multi-billion dollar investment in a new drinking water treatment plant because of deteriorating water quality in the Hudson River. The cause of the loss in quality was increased human activity in the Catskill Mountains, which drained into the Hudson.

The cost of maintaining the water provisioning function was estimated to determine which was greater: the cost of maintaining the EGS flow or the cost of its replacement with produced capital. Maintaining the service, which required purchasing and protecting over 140 thousand hectares in addition to a series of land-use regulations, was estimated to cost $1 to $1.5 billion, much less than the $6-$8 the new water treatment plant was expected to cost. The case was compelling and the decision to protect the watersheds was made (Barbier and Heal, 2006)

Because these methods use costs to estimate benefits, it is important to note that they do not provide a technically correct measure of economic value. Value is properly measured by willingness to pay less the actual cost of the good. The presumption behind the methods is that if people incur costs to avoid damages due to or to replace lost EGS, then those EGS must be worth *at least* what people pay to replace them and that they would actually replace them if lost rather than simply live with the decline in utility. It is also necessary that the replacement for the EGS be the least-cost alternative and that it provides the same service.

The first step in applying either of these methods is to assess the EGS flows provided. This involves identifying the relevant flows and understanding how they are provided by ecosystems, to whom and at what levels.

[85] This description draws heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).

In the case of the damage-cost avoided method, the second step is to estimate the potential physical damage to property due to the loss of the EGS flow over some discrete time period. The final step for the damage-cost avoided method is to calculate either the dollar value of potential property damage or the amount that people spend to avoid such damage.

The second step for the replacement cost method is to estimate the cost of the *least costly* alternative means of providing the EGS flows and to demonstrate that there would be public demand for this alternative if it were to be pursued.

Advantages of the methods

- The methods provide surrogate measures of value that largely consistent the economic concept of value.
- Measures of damage-cost avoided or replacement cost are generally much easier to estimate than people's willingness to pay.

Limitations of the methods

- Expenditures to repair damages or to replace ecosystem services are not fully appropriate as measure of EGS value. They should be thought of as a last resort to value ecosystem services.
- The replacement cost method requires knowledge of the degree of substitutability between produced capital flows and EGS flows. Few EGS flows have direct produced capital substitutes.
- The EGS flows being replaced may represent only a portion of the range of services provided by the ecosystem. Thus, the full value of the ecosystem might be understated if only one of its flows can be valued using costs avoided or replacement costs.
- The methods should be used only if society has demonstrated its willingness-to-pay to pay to replace the EGS flow. Without evidence that the public would demand the alternative, these methods are not economically valid means of estimating EGS values.

A6 Contingent Valuation Method (stated preferences)[86]

The contingent valuation (CV) method (Pearce and Özdemiroglu, 2002; Loomis et al., 1999) is widely used to estimate economic values for EGS flows. The method has great flexibility, allowing valuation of a wider variety of flows than is possible with any other non-market valuation technique. It can be used to estimate both use and non-use values, and it is the most widely used method for estimating non-use values. It is also the most controversial of the non-market valuation methods.

The method is best used to estimate values for EGS flows that are easily identified and understood by people and that are consumed in discrete units (*e.g.*, days of recreation).

It involves directly asking people, in a survey or experimental setting, how much they would be willing to pay for changes in specific EGS flows, *contingent* on a hypothetical market scenario (public or private) and a description of the EGS. In some cases, people are asked the opposite question: how much they would be willing to accept in compensation to give up specific EGS flows. CV studies can be conducted through face-to-face, telephone, mail or electronic surveys, with face-to-face surveys being the best but also the most expensive approach. The results are used to build demand curves for the EGS flows in question.

The fact that CV is based on asking people questions as opposed to observing their actual behaviour is the source of controversy (Cummings et al., 1986). The conceptual, empirical, and practical problems associated with developing dollar estimates of economic value on the basis of how people respond to hypothetical questions about hypothetical market situations are debated widely in the economics literature. Many economists, psychologists, sociologists, judges[87] and policy makers do not believe the dollar estimates that result from CV are valid. Even the respondents themselves wonder about the validity of the results (Clark et al., 2000).

Conducting CV studies is generally complicated, lengthy, and expensive. The results of CV surveys are sensitive to what people believe they are being asked to value as well as the context that is described in the survey. Thus, CV surveys must be properly designed, pre-tested and implemented. Questions must focus on specific and clearly defined EGS flows in a specific and clearly defined context.

Survey questions can be asked in a variety of ways, using both open-ended and closed-ended formats. In the open-ended format, respondents are simply asked to state their maximum willingness to pay for the change in the EGS flow. In the closed-ended format, also referred to as discrete choice, respondents are asked whether or

[86] This description draws heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).
[87] Valuations of EGS flows are often used in court cases to argue for or against protection of ecosystems.

not they would be willing to pay a particular amount for the change, or whether they would vote yes or no for a specific policy at a given cost. The discrete choice format is generally accepted as the preferred approach.

Issues that need to be considered in designing CV surveys include the following.

- Respondents' familiarity with the EGS in question
- The appropriate population from which to draw the sample for the survey and the appropriate size of the sample.
- Careful and detailed description of the scenario defining the change in EGS flows associated with policy choice under consideration so that respondents express their willingness to pay only for that specific change and not related changes as well.
- Clarity about the mechanism by which payment to preserve the EGS flow would be made; for example, through increased taxes.
- Clear recognition on the part of respondents about their real-world budget constraints so that stated willingness to pay reflects actual ability to pay.
- Pre-testing of the surveys to eliminate potential biases.
- Means to achieve a high response rate and avoid any biases introduced if certain segments of the population choose not to respond (non-response bias).

Advantages of the method:

- CV can be used to estimate the economic value of both use and non-use EGS values.
- Though the technique requires competent survey analysts to achieve defensible estimates, the nature and results of CV studies and not difficult to describe and analyze. Values can be presented in terms of mean or median values per capita or per household or as aggregate values for the affected population.
- CV is widely used and a great deal of research is being conducted to improve the methodology, make results more valid and reliable, and better understand its strengths and limitations.

Limitations of the method:

- The method is expensive when implemented to high standards.
- The method remains controversial and many people do not believe the results of CV studies.
- People are unfamiliar with placing dollar values on EGS flows, as there are no markets for them in reality. Therefore, they may not have an adequate basis for stating their true value.
- Respondents may answer differently than the interview intends for a variety of reasons. For example, respondents may express a positive willingness to pay because they feel good about the act of contributing to a public good even if they believe that the good itself is unimportant. Or they may state a

positive willingness to pay in order to signal the importance they attach to improved environmental quality in general. Alternatively, some respondents may actually value the EGS in question, but state no willingness to pay for it out of protest about some aspect of the scenario, such as increased taxes.

- Respondents may make associations among environmental goods that the researcher does not intend. For example, if asked about willingness to pay for improved visibility, the respondent may actually answer based on the health risks that he or she associates with dirty air.
- Respondents may fail to take questions seriously because they will not actually be required to pay the stated amount. Willingness to pay may be unrealistically high if respondents believe they will not really have to pay, and *vice versa*.
- Strategic bias can arise when the respondent wishes to influence a particular outcome. If a decision to preserve a stretch of river for fishing, for example, depends on CV estimates of willingness to pay, respondents who enjoy fishing may be tempted to provide intentionally high values.
- Willingness to pay and willingness to accept, which should be equal in theory, rarely are in practice. Critics point to this as evidence of underlying problems in the practice of CV.
- If respondents are first asked their willingness to pay for part of an ecosystem asset (*e.g.* one lake in a region) and then asked to value the whole asset (*e.g.* all lakes in the region), the amounts stated may be similar. This is referred to as the "embedding effect."
- In some cases, people's willingness to pay has been found to depend on where an item is placed on a list of things to be valued. This is referred to as the "ordering problem."
- The choice of starting point can affect respondents' final willingness to pay response ("starting point" bias).

A7 Choice Modelling Method (stated preferences)[88]

The *choice modelling method* (also known as choice modelling) is similar to contingent valuation, in that it can be used to estimate values for virtually EGS flow (Pearce and Özdemiroglu, 2002).

Like CV, the method asks people to make choices based on hypothetical scenarios. However, it differs in that it does not ask respondents to directly state their willingness to pay. Instead, their willingness to pay is inferred from the choices make when faced with a range of options. For example, a study might ask respondents to state which of two hypothetical ecosystem states they prefer, with each state described in terms of its characteristics. Statistical techniques are then used to establish a relation between the characteristics and the individual's preferences. As long as one of the characteristics is price, it is possible to derive the willingness to pay for changes in the levels of the ecosystem's other characteristics. In addition, while choice modelling can be used to estimate willingness to pay, the results may also be used to simply rank options without focusing on dollar values.

Because it focuses on tradeoffs among scenarios with different characteristics, choice modelling is especially suited to policy decisions where a set of possible actions might result in different impacts on EGS flows. Thus, it is particularly useful in valuation of policies aiming at broad ecosystem improvements given that multiple service flows are likely to be simultaneously affected in such policy actions. For example, improved lake quality will improve the quality of several services provided by the lake: drinking water supply, recreation and commercial fishing, for example.

There are a variety of formats for applying choice modelling.

- *Contingent Ranking* – Contingent ranking surveys ask individuals to compare and rank alternate program outcomes with various characteristics, including costs. For instance, people might be asked to compare and rank several mutually exclusive improvement programs under consideration for a watershed, each of which has different outcomes and different costs. Respondents are asked to rank the alternatives in order of preference.
- *Discrete Choice*—In the discrete choice approach, respondents are simultaneously shown two or more different alternatives and their characteristics, and asked to identify the most preferred alternative in the choice.
- *Paired Rating*—This is a variation on the discrete choice format, where respondents are asked to compare two alternate situations and are asked to rate them in terms of strength of preference. For instance, people might be

[88] This description draws heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).

asked to compare two environmental improvement programs and their outcomes, and state which is preferred, and whether it is strongly, moderately, or slightly preferred to the other program.

Whatever format is selected, the choices that respondents make are statistically analyzed using discrete choice statistical techniques to determine the relative values for the different characteristics or attributes. If one of the characteristics is a monetary price, then it is possible to compute the respondent's willingness to pay for the other characteristics.

As with contingent valuation, in order to collect useful data and provide meaningful results, choice modelling surveys must be properly designed, pre-tested, and implemented. However, because responses are focused on tradeoffs, rather than direct expressions of dollar values, choice modelling may minimize some of the problems associated with contingent valuation. Often, relative values are easier and more natural for people to express than absolute values.

As with contingent valuation, a good choice modelling study will consider the following in its application:

- Respondents' familiarity with the EGS in question.
- The appropriate population from which to draw the sample for the survey and the appropriate size of the sample.
- Careful and detailed description of the scenario defining the change in EGS flows associated with policy choice under consideration so that respondents express their willingness to pay only for that specific change and not related changes as well.
- Clarity about the mechanism by which payment to preserve the EGS flow would be made; for example, through increased taxes.
- Clear recognition on the part of respondents about their real-world budget constraints so that stated willingness to pay reflects actual ability to pay.
- Pre-testing of the surveys to eliminate potential biases.
- Means to achieve a high response rate and avoid any biases introduced if certain segments of the population choose not to respond (non-response bias).

Advantages of the method

- Choice modelling can be used to value the outcomes of an action as a whole, as well as the various attributes or effects of the action.
- The method allows respondents to think in terms of tradeoffs, which may be easier than directly expressing dollar values. Respondents are generally more comfortable providing qualitative rankings of attribute bundles that include prices, which de-emphasizes price as simply another attribute.
- The method minimizes many of the biases that can arise in open-ended contingent valuation studies.

Issues and Limitations of the Choice modelling Method

- Respondents may find some tradeoffs difficult to evaluate, because they are unfamiliar.
- Respondents may resort to simplified decision rules if the choices are too complicated, which can bias the results of the statistical analysis.
- If the number of attributes or levels of attributes is increased, the sample size and/or number of comparisons each respondent makes must be increased.
- When presented with a large number of tradeoff questions, respondents may lose interest or become frustrated.

A8 Benefit Transfer Method[89]

Benefits transfer (BT) is the process of taking information about economic values from one context and applying it to another context. For example, values for recreational fishing in a particular lake may be estimated by applying measures of recreational fishing values from a study conducted in another, similar lake. The attraction of BT is that it may eliminate the need for a primary (expensive and time consuming) stated or revealed preference study. It is possible to transfer: 1) an average willingness to pay estimate from the primary study; 2) willingness to pay estimates from a meta-analysis of several primary studies; or 3) a willingness to pay (or benefit) function.

A large number of valuation studies proceed using BT (Pearce and Özdemiroglu, 2002). For example, Troy and Bagstad (2009) used BT in a study of the value of EGS in Southern Ontario. Marbek (2010) used the technique in a study of nutrient reduction and nearshore health protection associated with Ontario's Rouge River watershed. Obviously, the quality of estimates based on BT can only be as good as those in the primary study. For a variety of reasons, they are likely to be lower.

The simplest type of BT involves the direct transfer of a willingness to pay estimate from a primary study. A more rigorous approach involves transferring a benefit function from another study. The benefit function statistically relates peoples' willingness to pay to characteristics of the ecosystem with the characteristics of the people whose values were elicited. When a benefit function is transferred, adjustments can be made for differences in these characteristics, thus allowing for more precision in transferring benefit estimates between contexts.

The benefit transfer method is most reliable when the original site and the study site are very similar in terms of factors such as quality, location, and population characteristics; when the environmental change is very similar for the two sites; and when the original valuation study was carefully conducted and used sound valuation techniques. Environment Canada and several international partners maintain a database known as the Environment Valuation Resource Inventory (EVRI) that is widely used as a source of studies useful for primary valuations in BT studies.

In evaluating whether primary values may be appropriately transferred, if it is important to consider 1) whether the EGS to be valued is comparable to that valued in the primary study; and 2) whether the demographic, economic and other characteristics of the individuals living in the two regions are comparable.

[89] This description draws heavily upon the material found on the environmental valuation website maintained by King and Mazzotta (no date).

It may be necessary to adjust the primary values to better reflect the values for the site under consideration, using whatever information is available and relevant. Supplementary data may be required in order to do this.

Advantages of the methods

- BT is cost and time effective.
- BT can be used as a screening technique to determine if a primary valuation study should be considered.

Limitations of the method

- Benefit transfers can only be as accurate as the initial value estimate and, unless the site characteristics are identical between the primary study and target study, they are likely to be less accurate.
- It may be difficult to track down useful primary studies since many are not published.
- Reporting of primary studies may be inadequate to make the needed adjustments.
- Estimates from primary studies can quickly become dated; they have a "shelf-life".

Selected bibliography

Allan, J. David, Peter B. McIntyre, Sigrid D. P. Smith, Benjamin S. Halpern, Gregory L. Boyer, , Andy Buchsbaum, Linda M. Campbell, W. Lindsay Chadderton, Jan J. H. Ciborowski, Patrick J Doran, Lucinda B. Johnson, Christine A. Joseph, Adrienne L. Marino, Alexander Prusevich, Jennifer G. Read, Joan B. Rose, Edward S. Rutherford, Scott P. Sowa, and Alan D. Steinman, 2013, "Joint analysis of stressors and ecosystem services to enhance restoration effectiveness" in *Proceedings of the National Academy of Science of the United States,* Vol. 110, No. 1, pp. 372-377 (available here).

Anderson, S., J. Read and D. Scavia, 2009, *Restoring Great Lakes Ecosystems: Worth the Cost?,* Resources for the Future weekly policy commentary (available here).

Armstrong, W., N.S. Foley, R. Tinch, S. van den Hove, 2012, "Services from the deep: Steps towards valuation of deep-sea goods and services" in *Ecosystem Services,* Vol. 2: pp. 2-13 (available here).

Austin, J. C., Soren Anderson, Paul N. Courant and Robert E. Litan, 2007, *Healthy Waters, Strong Economy: The Benefits of Restoring the Great Lakes Ecosystem*, Washington: The Brookings Institution (available here).

Badzinski, S., S. Petre and S. Proracki, 2006, *Long-term Trends in Waterfowl Hunters, Harvest, Waterfowl Use, and Marsh Habitat in the Crown Marsh - Long Point, Ontario, A proposal for the Long-Point Waterfowlers' Association* (available here).

Barbier, Edward B., 2000, "Valuing the environment as input: review of applications to mangrove-fishery linkages", in *Ecological Economics*, Vol. 35, pp. 47–61 (available here).

Barbier, Edward B. and Geoffrey M. Heal, 2006, "Valuing Ecosystem Services" in the *Economist's Voice*, Vol. 3, Issue 3 (available here).

Beeton, A. M., 1963, *Limnological survey of Lake Erie in 1959 and 1960*. Great Lakes Fishery Commission Technical Report, 6, 1-32.

Beeton, Alfred M, 1961, "Environmental Changes in Lake Erie", in *Transactions of the American Fisheries Society*, Vol. 90, No. 2, pp. 153-159.

Bockstael, Nancy E., A. Myrick Freeman III, Raymond J. Kopp, Paul R. Portney and Kerry Smith, 2000, "On Measuring Economic Values for Nature" in *Environmental Science and Technology*, Vol. 34, pp. 1384-1389 (available here).

Boyd, J. and S. Banzhaf, 2007, "What are ecosystem services? The need for standardized environmental accounting units", in *Ecological Economics*, Vol. 63, pp. 616-626.

Brox, J. Ramesh Kumar, and Kenneth Stollery, "Willingness to Pay for Water Quality and Supply Enhancements in the Grand River Watershed," in *Canadian Water Resources Journal,* Vol. 21, no. 3: pp. 275–88.

Carpenter, S.R., D. Ludwig and W.A. Brock, 1999, "Management of Eutrophication for Lakes Subject to Potentially Irreversible Change," in *Ecological Applications*, Vol. 9, pp. 751-771 (available here).

Clark, Judy, Jacquelin Burgess and Carolyn M. Harrison, 2000, " 'I struggled with this money business': Respondents' perspectives on contingent valuation," in *Ecological Economics*, Vol. 33, pp. 45-62 (available here).

Cooper, N. 2009, *The spiritual value of ecosystem services: An initial Christian exploration,* Anglia Ruskin University, Paper published for the Cambridge Conservation Forum (available here).

Cummings, Ronald G., David S. Brookshire and William D. Schulze (eds.), 1986, *Valuing Environmental Goods: An Assessment of the Contingent Valuation Method*, Chapter 1, Totowa, NJ: Rowman and Allenheld.

Davidson, Marc, 2013, "On the relation between ecosystem services, intrinsic value, existence value and economic valuation", in *Ecological Economics*, Vol. 95, pp. 171-177 (available here).

Department of Fisheries and Oceans, 2014, *2008-2012 Landed Weight and Value of Commercial Fishery for Lake Erie & Lake St. Clair by Species*, Excel Database (provided by Rowena Orok, personal communication).

DSS Management Consultants, 2010, *Valuation of Ecological Goods & Services in Canada's Natural Resources Sectors,* unpublished study prepared for Ecosystems and Biodiversity Priorities Division, Environment Canada (provided by Susan Preston, personal communication).

DuWors, Elaine , Michel Villeneuve, Fern L. Filion, Roger Reid, Pierre Bouchard, Douglass Legg, Peter Boxall, Tim Williamson, Alistair Bath, Scott Meis, 1999, *The Importance of Nature to Canadians: Survey Highlights,* Catalogue No. En 47-311/1999E, Ottawa: Environment Canada (available here).

Dziegielewska, D., 2013, "Total Economic Value", in *Encyclopedia of the Earth* (available here)

Ecojustice, 2013, *The Great Lakes Sewage Report Card 2013* (available here).

EFTEC, 2005, *The Economic, Social and Ecological Value of Ecosystem Services: A Literature Review,* report prepared for the UK Department for Environment, Food and Rural Affairs (available here).

Fisheries and Oceans Canada, 2008, *Survey of Recreational Fishing in Canada: Selected Results for the Great Lakes Fishery, 2005*, Catalogue No. Fs23-522/2005-1E, Ottawa (available here).

Gray, P., P. Boxall, R. Reid, F. Filion, E DuWors, A. Jacquemot, Pierre Bouchard and A. Bath, 1993, "The Importance of Nature to Canadians: Results from Three Surveys", in *Proceedings of the International Union of Game Biologists XXI Conference*, Canadian Forest Service, Cat. No. Fo18-33/1193E. (available here)

Great Lakes Commission, 2006. *Clearing the Air: Reducing Air Toxic Deposition to the Great Lakes* (available here).

Hall, C., 2008, "Value Theory"*,* in *The Encyclopedia of the Earth,* (available here).

Haines-Young, R. and Potschin, M., 2013, *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4*, EEA Framework Contract No EEA/IEA/09/003 available here and here).

Hartig, J.H., M.A. Zarull, J.J.H. Ciborowski, J.E. Gannon, E. Wilke, G. Norwood, and A. Vincent, eds. 2007. *State of the Strait: Status and Trends of Key Indicators,* Great Lakes Institute for Environmental Research, Occasional Publication No. 5, University of Windsor, Ontario, Canada (available here).

Hannon, Bruce M., 1973, "An Energy Standard of Value", in *Annals of the American Academy of Political Science*, Vol. 410, pp. 139-15.

Hein, Lars, 2012, *Monetary Valuation in Ecosystem Accounts*, paper presented at the Expert Meeting on Ecosystem Accounts Melbourne, Australia, 16-18 May (available here).

Hein, Lars, Kris van Koppen, Rudolf S. de Groot, Ekko C. van Ierland, 2006, "Spatial scales, stakeholders and the valuation of ecosystem services" in *Ecological Economics*, Vol. 57, pp. 209–22 (available here).

Hinterberger, F., F. Luks, and F. Bleek-Schmidt, 1997, "Material Flows versus 'Natural Capital' – What Makes an Economy Sustainable?", in *Ecological Economics*, Vol. 23, pp. 1-14 (available here).

Hofmann, Nancy, 2009, "Production of nitrogen and phosphorus from livestock manure, 2006" in *EnviroStats*, Spring, Ottawa: Statistics Canada (available here).

International Joint Commission, 1970, *Pollution of Lake Erie Lake Ontario and the International Section of the St. Lawrence River*, Catalogue No. E95-1970, Ottawa: Information Canada. (available here).

International Joint Commission, 2013, *Lake Erie Ecosystem Priority: Scientific Findings and Recommendations to Reduce Nutrient Loadings and Harmful Algal Blooms* (available here).

International Joint Commission, 2014, *A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms*, Report of the Lake Erie Ecosystem Priority (available here).

Kandziora, M., B. Burkhard and F. Müller, 2013 "Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators — A theoretical matrix exercise.", in *Ecological Indicators*, Vol. 28, pp. 54-78 (available here).

Kennedy, M., and J. Wilson, 2009, *Natural Credit: Estimating the Value of Natural Capital in the Credit River Watershed*, Pembina Institute and Credit Valley Conservation Authority, Mississauga, ON (available here).

King, Dennis M. and Marisa J. Mazzotta, no date, *Ecosystem Valuation – www.ecosystemvaluation.org,* (available here).

Knights, Paul, Jeroen Admiraal, Ada Wossink, Prasenjit Banerjee, John O'Neill, Michael Scott, no date, *Economic Environmental Valuation: An Analysis of Limitations and Alternatives, European Union Seventh Framework Programme, BIOMOT Project Deliverable 1.1* (available here).

Knoche, Scott and Frank Lupi, 2007, "Valuing deer hunting ecosystem services from farm landscapes", in *Ecological Economics*, Vol. 64, pp. 313-320 (available here).

Krantzberg, G. and C. de Boer, 2006, *A Valuation Of Ecological Services in the Great Lakes Basin Ecosystem to Sustain Healthy Communities and a Dynamic Economy,* Prepared for the Ontario Ministry of Natural Resources (available here).

Krantzberg, G. and C. de Boer, 2008, "A Valuation Of Ecological Services in the Laurentian Great Lakes Basin with an Emphasis on Canada" in the *Journal of the American Water Works Association*, Vol. 100, No. 6, pp. 100-111 (available here).

Kremen, Claire, Neal M. Williams, and Robin W. Thorp, 2004, "The area requirements of an ecosystem service: crop pollination by native bee communities in California" in *Ecology Letters*, Vol. 7, pp. 1109–1119 (available here).

Lake Erie Committee, 2004, Catch Limits Set for Lake Erie Walleye and Yellow Perch in 2004, news release of the Fishery Management Agencies of Lake Erie and Lake St. Clair (available here).

Lake Erie LaMP, no date *Lake Erie LaMP Update 2005/06, report by the Lake Erie Lakewide Management Plan* (available here).

Layke, Christian, 2009, *Measuring Nature's Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators*, WRI Working Paper, World Resources Institute, Washington DC. (available here).

Loomis, John, Paula Kent, Liz Strange, Kurt Fausch, Alan Covich, 2000, "Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey", in *Ecological Economics*, Vol. 33, pp. 103-117 (available here).

Marbek, 2010, *Assessing the Economic Value of Protecting the Great Lakes: Rouge River Case Study for Nutrient Reduction and Nearshore Health Protection*, report prepared for the Ontario Ministry of the Environment (available here).

Michigan Sea Grant, no date, *Harmful Algal Blooms & Muck - What's the Difference?*, on-line information sheet (available here).

Millennium Ecosystem Assessment, 2005, *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC. (available here).

Miller, Eric and Patrick Lloyd-Smith, 2012, *The Economics of Ecosystem Services and Biodiversity in Ontario: Assessing the Knowledge and Gaps,* report prepared for the Ontario Ministry of Natural Resources (available here).

Northeast-Midwest Institute and National Oceanic and Atmospheric Administration, 2001, *Revealing the Economic Value of protecting the Great Lakes* (available here).

Opaluch, James J., Thomas Grigalunas, Jerry Diamantides, Marisa Mazzotta, and Robert Johnston, 1999, *Recreational and Resource Economic Values for the*

Peconic Estuary System, report prepared for Peconic Estuary Program, Suffolk County Department of Health Services, County Center, Riverhead, N.Y. (available here).

Parsons, G.R., 2003, "The travel cost model", in Champ, P.A., Boyle, K.J., Brown, T.C. (Eds.), *A Primer on Nonmarket Valuation*, Dordrecht: Kluwer Academic Publishers, pp. 427–440.

Patterson, Murray, 1998, "Commensuration and Theories of Value in Ecological Economics" in *Ecological Economics,* Vol. 25, pp. 105–125 (available here).

Pearce, David and Ece Özdemiroglu, 2002, *Economic Valuation with Stated Preference Techniques – Summary Guide,* London, UK: Department for Transport, Local Government and the Regions (available here).

Pearce, David and Dominic Moran, 1994, *The Economic Value Of Biodiversity,* London: Earthscan Publications (available here).

Pejchar, Liba and Harold A. Mooney, 2009 "Invasive species, ecosystem services and human well-being" in *Trends in Ecology and Evolution,* Vol.24, No.9, pp. 497-504 (available here).

Phosphorus Reduction Task Force, 2012, *Priorities for Reducing Phosphorus Loadings and Abating Algal Blooms in the Great Lakes – St. Lawrence River Basin: Opportunities and Challenges for Improving Great Lakes Ac Ecosystems,* Ann Arbor: Great Lakes Commission (available here).

Pittini, Michele, 2011, *Monetary valuation for ecosystem accounting,* Issue paper prepared for the UN/World Bank/EEA Expert Meeting on Ecosystem Accounts, London, 5 -7 December (available here).

Poor, P. Joan, Keri L. Pessagno, Robert W. Paul, 2007, "Exploring the hedonic value of ambient water quality: A local watershed-based study", in *Ecological Economics*, Vol. 60, pp. 797-806 (available here).

Roy, Eric D., Jay F. Martin, Elena G. Irwin, Joseph D. Conroy, and David A. Culver, 2010, "Transient Social–Ecological Stability: the Effects of Invasive Species and Ecosystem Restoration on Nutrient Management Compromise in Lake Erie" in *Ecology and Society, Vol.* 15, No. 1 (available here).

Sohngen, Brent, Frank Lichtkoppler and Mary Bielen, 1999, The Value of Day Trips to Lake Erie Beaches, Ohio Sea Grant College Program Technical Bulletin Series Publication OSHU-TB-039 (available here).

Spash, Clive L., 1997, "Ethics and Environmental Attitudes With Implications for Economic Valuation" in *Journal of Environmental Management,* Vol. 50, pp. 403–416 (available here).

Statistics Canada, 2012a, *Industrial Water Use, 2009*, Ottawa: Minister of Industry (available here).

Statistics Canada, 2012b, *North American Industry Classification System (NAICS) Canada, 2012*, Ottawa: Minister of Industry (available here).

Statistics Canada, 2013a, *Agricultural Water Use in Canada, 2012*, Ottawa: Minister of Industry (available here).

Statistics Canada, 2013b, *Farm Environmental Management Survey, 2012*, Ottawa: Minister of Industry (available here).

Statistics Canada, 2013c, *Households and the Environment, 2011*, Ottawa: Minister of Industry (available here).

Statistics Canada, 2013d, *Human Activity and the Environment: Measuring ecosystem goods and services in Canada, 2013*, Ottawa: Minister of Industry (available here).

Statistics Canada, 2013e, *Survey of Drinking Water Plants, 2011*, Ottawa: Minister of Industry (available here).

TEEB, 2010, *The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations*, Edited by Pushpam Kumar, Earthscan: London and Washington (available here).

Talhelm, D.R., and R.L. Johnson, 1984, Unrevealed Economic Values of Ecosystem Management, Great Lakes Fishery Commission Project Completion Report (available here).

Talhelm, D.R. R.C. Bishop, K.W. Cox, N.W. Smith, K.N. Stiennes, A.L.W. Tuomi, *Current Estimates of Great Lakes Fisheries Values: 1979 Status Report*, Great Lakes Fisheries Commission (available here).

Talhelm, D.R., 1988, *Economics of Great Lakes fisheries: A 1985 assessment*, Great Lakes Fisheries Commission, Technical Report No. 54 (available here).

Treasury Board Secretariat of Canada, 2007, *Canadian Cost-Benefit Analysis Guide for Regulatory Proposals,* Ottawa (available here).

Tyson, J.T., R.A. Stein, and J.M. Dettmers [eds.], 2009, *The state of Lake Erie in 2004*. Great Lakes Fisheries Commission, Special Publication 09-02 (available here).

United Nations, no date, *System of Environmental-Economic Accounting Experimental Ecosystem Accounting - Consultation Draft,* New York: United Nations *(available here).*

U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2006 *National Survey of Fishing, Hunting, and Wildlife-Associated Recreation* (available here).

Waltert, Fabian and Felix Schläpfer, 2010, "Landscape amenities and local development: A review of migration, regional economic and hedonic pricing studies", *Ecological Economics*, Vol. 70, pp. 141-152 (available here).

Wilson, Sara J., 2008, *Ontario's Wealth, Canada's Future: Appreciating the Value of the Greenbelt's Eco-Services,* report prepared for the David Suzuki Foundation (available here).

Venema, H. and V. Voora, 2008, An Ecosystem Services Assessment of the Lake Winnipeg Watershed: Phase 1 Report – Southern Manitoba Analysis, International Institute for Sustainable Development, Winnipeg (available here).

Victor, P., 1991, "Indicators of Sustainable Development: Some Lessons from Capital Theory," in *Economic, Ecological and Decision Theories: Indicators of Ecologically Sustainable Development*, Canadian Environmental Advisory Council, Minister of Supply and Services, Ottawa.

Yeh, Chia-Yu, T. Haab and B. Sohngen, 2006, "Modelling Multiple-Objective Recreation Trips with Choices over Trip Duration and Alternative Sites", in *Environmental & Resource Economics,* Vol. 34, pp.189–209 (available here).