Valuing Florida's Clean Waters

Elizabeth A. Stanton
Matthew Taylor
Stockholm Environment Institute – U.S. Center

November 13, 2012

Table of Contents

Executive Summary

In 1998 the EPA adopted the Clean Water Action Plan, which stated that excessive nutrient pollution results in greater than expected growth of macrophytes or phytoplankton, and potentially harmful algae blooms or outbreaks leading to declining oxygen levels, an imbalance among aquatic species, public health risks, and a general degradation of the aquatic resource. The “Key Action” for addressing nutrient over-enrichment was a requirement that states develop and implement numeric limits on the amount of so-called “nutrients” – phosphorus and nitrogen – allowed in waterbodies by the year 2004. If a state failed to do so, the EPA would establish criteria for them. As of 2008 the state of Florida had implemented just one such standard.

The EPA and the state of Florida’s failure to set numeric nutrient standards resulted in the filing of a lawsuit in 2008 with the intention of forcing their development and implementation. The plaintiffs, a coalition of environmental organizations represented by Earthjustice, claimed that the EPA was taking too long to establish the numeric nutrient criteria that the agency had already deemed necessary. The environmental groups argued that the EPA had an obligation to readily move forward with establishing and implementing such criteria in Florida. The EPA settled the litigation in August 2009, entering a consent decree with the plaintiffs, committing to have numeric nutrient criteria in place for Florida’s waterbodies by November 2010.

Water pollution from phosphorus and nitrogen is rapidly accelerated by human activity: population growth, together with agricultural and urban development, have led to large-scale wastewater discharges into aquatic environments. Nutrient pollution causes the gradual degradation, or eutrophication, of waterbodies. Ecological changes which otherwise might have occurred naturally over millennia instead have taken place in decades.

Nutrient pollution fuels the proliferation of harmful algae outbreaks. Excessive nitrogen and phosphorus in the water can make algae grow so quickly that ecosystems are overwhelmed by it. These high concentrations of algae have the potential to harm water quality, food resources and habitats, and reduce oxygen levels, making it more difficult for fish and other aquatic life to survive. Large growths of algae, called algae blooms, can result in illness or death of large numbers of fish by severely reducing or eliminating oxygen in the water. Some algae outbreaks produce toxins and bacterial growth that can make people ill from contact with polluted water, consumption of contaminated water, or tainted fish or shellfish.

The prevalence of harmful algae outbreaks throughout Florida was the central impetus for the Earthjustice lawsuit. The impacts of these events vary by species and intensity; some species, such as cyanobacteria and *K. brevis*, are toxic to humans and pets, and to other aquatic species, leading to respiratory difficulties, neurological issues, or food poisoning. Regardless of toxicity, harmful algae outbreaks have the potential to harm ecosystems by shading submerged vegetation and destroying aquatic habitats. Dense algae outbreaks often result in massive fish-kills by depleting the water’s oxygen levels. The evidence is now strong that many harmful algae blooms worldwide, in estuaries and coastal marine environments as well as freshwaters, are stimulated or supported by anthropogenic nutrient over-enrichment.

Rising levels of nutrients, in conjunction with increased water withdrawals, have been widely associated with human-induced pollution. As phosphorus and nitrogen are frequently the limiting factors in the growth of freshwater and saltwater algal species, nitrogen and phosphorus pollution tends to increase the potential for and severity of harmful algae outbreaks. Visitors and residents are deprived of their opportunity to fish, boat, and swim in public waters. The algae can produce dangerous toxins, emit noxious odors, adversely impact aquatic species, and degrade a water-body's aesthetic qualities. Harmful algae outbreaks have real costs to society and reduce the value of ecosystem services provided by Florida's waters.

The valuation of Florida's clean water presented in this report led to a range from $1.3 to $10.5 billion dollars annually (see Table ES1). The methodology used to provide this estimation, however, was based on a willingness-to-pay for non-use values that – while generated from a well-accepted method frequently used by the EPA – are not built from Florida-specific economic analysis, and a generic imputation of use values drawn from relationships presented in the literature.

Table ES1: Summary of Economic Valuation of Florida's Clean Waters

	In millions (2010 dollars)	
	at EPA (2010) willingness-to-pay	**at $23 per household per year willingness-to-pay**
EPA (2010) estimate of non-use ecosystem values related to Florida's water-quality improvements	$28	
Additional value from full assessment of part-time residents' willingness to pay for Florida's water quality improvements	$1	
Non-Florida U.S. residents' willingness to pay for Florida's water quality improvements	$419	$3,500
Imputed use values related to Florida's water-quality improvements	$838	$7,000
Total use and non-use values related to Florida's water-quality improvements	**$1,286**	**$10,500**

A better, more complete, and context-specific method would apply Florida-based economic analysis to physical data describing the extent and degree of human-induced threats to Florida's water quality. In our opinion, the main obstacle to completing a comprehensive, rigorous assessment of the value of clean water in Florida is the absence of high-quality, time-series data documenting changes to water quality as a result of human actions at a localized scale. Without a sound empirical basis for water quality changes and their causes, more detailed economic analysis would be unfounded. The scientific community is now clear that pollution is a primary cause of harmful algae outbreaks. What remains is for federal and state agencies to set, and fund, an agenda for gathering the underlying data needed to comprehensively assess the value of Florida's clean waters.

1. Florida's Harmful Algae Outbreaks

The Clean Water Act was enacted by Congress in 1972 to "restore and maintain the chemical, physical, and biological integrity of the nation's waters" (33 U.S.C § 1251(a)) declaring that "it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985" (33 U.S.C. § 1251(a)(1)). In order to meet this goal, the Clean Water Act (33 U.S.C. § 1313) requires U.S. States to establish water quality standards and provides a schedule for this process. It directs that the standards "shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of the [the Clean Water Act]" (33 U.S.C § 1313(c)(2)).

The Clean Water Act, as one means of maintaining or achieving those standards, mandates that the U.S. Environmental Protection Agency (EPA) "promptly prepare and publish" revised or new water quality standards for navigable waters "in any case where the Administrator determines that a revised or new standard is necessary to meet the requirements of [the Clean Water Act]" (33 U.S.C §1313(c)(4)(B)). The vast majority of water quality standards are expressed in numeric terms. Florida, however, has a "narrative" water quality standard for nutrients that reads, "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora and fauna." (Rule 62-302.530(47)(b), Fla. Admin. Code) The result of having a narrative rather than a numeric standard is that Florida has no measurable, objective water-quality baseline against which to measure progress in curbing nutrient pollution, nor is there any measurable, objective means of determining whether a water-quality violation has occurred.

In 1998 the EPA adopted the Clean Water Action Plan, which stated that excessive nutrient pollution results in greater than expected growth of macrophytes or phytoplankton, and potentially harmful algae blooms or outbreaks leading to declining oxygen levels, an imbalance among aquatic species, public health risks, and a general degradation of the aquatic resource. The "Key Action" for addressing nutrient over-enrichment was a requirement that states develop and implement numeric limits on the amount of so-called "nutrients" – phosphorus and nitrogen – allowed in waterbodies by the year 2004. (See Box 1 for a description of key measurements or indicators of nutrient pollution). If a state failed to do so, the EPA would establish criteria for them. As of 2008 the state of Florida had implemented just one such standard, a numeric total phosphorus criterion for the Everglades Protection Area that it was required to establish as part of the settlement of a lawsuit brought by the federal government against the South Florida Water Management District and the Florida Department of Environmental Protection.

Box 1: Key Measurements or Indicators of Nutrient Pollution

TN – total nitrogen, the sum of nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, and organic nitrogen.

TKN – total Kjeldahl nitrogen, the sum of ammonia-nitrogen and organic nitrogen.

TP – total phosphorus, the sum of orthophosphate and naturally occurring phosphorus.

Chlorophyll *a* – a photosynthetic pigment commonly used as a measure of algal biomass and algal production.

Secchi disc depth – the clarity, or turbidity, of a body of water, used as an indicator of the level of biological production.

TSI – Trophic State Index, an index for the biological productivity of a waterbody that can be calculated using TP, Chlorophyll *a*, and/or a Secchi depth measurements.

Water pollution from phosphorus and nitrogen is rapidly accelerated by human activity: population growth, together with agricultural and urban development, have led to large-scale wastewater discharges into aquatic environments. Nutrient pollution causes the gradual degradation, or eutrophication, of waterbodies. Ecological changes which otherwise might have occurred naturally over millennia instead have taken place in decades (Havens et al. 1996). Such human-induced nutrient pollution is a leading cause of degradation of water-bodies in the United States, including in Florida (National Research Council 2000). Of the water-bodies assessed in 2008 – the benchmark year for the EPA ruling – the state's Integrated Water Quality Assessment listed nutrients as the cause of impairment for 5-6 percent of rivers and streams, 23-24 percent of lakes, 24 percent of estuaries, and 2 percent of coastal waters.[1] Where possible, the Florida Department of Environmental Protection (FDEP) assessment reviewed trends in nutrient pollution over the period 1997-2007, concluding that 22 percent of the river and stream miles, 33 percent of the lake acres, and 7 percent of the estuary miles with sufficient data displayed conditions that were worsening over time (Florida Department of Environmental Protection 2008).

The EPA and the state of Florida's failure to set numeric nutrient standards resulted in the filing of a lawsuit in 2008 with the intention of forcing their development and implementation. The plaintiffs, a coalition of environmental organizations represented by Earthjustice, [2] claimed that the EPA was taking too long to establish the numeric nutrient criteria that the agency had

[1] Ranges represent the minimum-maximum nutrient impairment rates; some waterbody types were impaired by multiple nutrient indicators, and it is unclear as to whether they represent different bodies of water. The minimum value assumes that secondary impairment indicators were taken from the same bodies of water, whereas the maximum value assumes that they are all taken from different bodies of water and are additive.

[2] http://earthjustice.org/

already deemed necessary. The environmental groups argued that the EPA had an obligation to readily move forward with establishing and implementing such criteria in Florida. The EPA settled the litigation in August 2009, entering a consent decree with the plaintiffs, committing to have numeric nutrient criteria in place for Florida's waterbodies by November 2010 (with the exception of South Florida's estuaries and coastal waters, where an extra year was given for criteria to be implemented) (Obreza et al. 2010).

Nutrient pollution is potentially disastrous for aquatic ecosystems. Increased nitrogen and phosphorus levels can make water unsafe for consumption by humans and wildlife, decrease habitats' ability to support diverse biota, and, perhaps most importantly, stimulate the growth of algae. Increased algal growth can alter the species composition of the habitat, shift the relative dominance of species, and create the conditions for harmful algae outbreaks. According to the EPA, nutrient pollution is one of the most "widespread, costly and challenging" environmental problems in the United States today. High levels of nitrogen and phosphorus in water and from the air can cause serious health problems in both humans and animals, and can negatively impact the environmental quality of forests, lakes, rivers, streams and oceans. The economic effects of nutrient pollution may include losses in such sectors as tourism, commercial fishing, recreation, hunting, real estate, and water treatment, all of which depend on access to clean water. The costs to federal, state and local governments of preventing nutrient pollution and its effects are in the billions of dollars each year (U.S. EPA 2012a).

Many of these impacts are due to the nutrient-fueled proliferation of harmful algae outbreaks. Excessive nitrogen and phosphorus in the water can make algae grow so quickly that ecosystems are overwhelmed by it. These high concentrations of algae have the potential to harm water quality, food resources and habitats, and reduce oxygen levels, making it more difficult for fish and other aquatic life to survive. Large growths of algae, called algae blooms, can result in illness or death of large numbers of fish by severely reducing or eliminating oxygen in the water. Some algae outbreaks produce toxins and bacterial growth that can make people ill from contact with polluted water, consumption of contaminated water, or tainted fish or shellfish (U.S. EPA 2012b).

The prevalence of harmful algae outbreaks throughout Florida was the central impetus for the Earthjustice lawsuit. These outbreaks include a variety of species, including the high-profile cyanobacteria (blue-green algae) in Florida's fresh waterbodies, as well as more 50 different algal species – notably *Karenia brevis*, the infamous red tide – in marine waters (Florida Department of Environmental Protection 2012). The most commonly occurring toxigenic blue-green algae in Florida's freshwaters are *Microcystis* aeruginosa, *Cylindrospermopsis* raciborskii, *Lyngbya* wollei, *Anabaena* circinalis, and *Aphanizomenon* (Burkholder 2009). These outbreaks occur when the limits to algal growth – including light, micronutrients, competition from other species, and, oftentimes, nitrogen or phosphorus – are removed from the water. This allows high concentrations of harmful algae to form. While not true for all species of algae, the blooming of cyanobacteria and other species of concern in Florida result in a thick layer of algae on the water's surface, emitting noxious odors and, in many cases, toxins.

Harmful algae outbreaks are a serious threat to public health and safety. According to the Florida Department of Health:

Contact with blue green algae can make you sick. When blue-green algae (cyanobacteria) for "blooms" in lakes, ponds, or rivers, these organisms can release toxins which can make people and animals sick. Swimming in water with a toxic blue-green algae bloom can cause: skin rash, runny nose, irritated eyes. Swallowing such water can: cause vomiting or diarrhea, affect your liver, poison pets. . . . If you think you have symptoms that may be related to contact with blue-green algae contact your doctor or the Poison Information Hotline.[3]

The impacts of these events vary by species and intensity; some species, such as cyanobacteria and *K. brevis*, are toxic to humans and pets, and to other aquatic species, leading to respiratory difficulties, neurological issues, or food poisoning. Regardless of toxicity, harmful algae outbreaks have the potential to harm ecosystems by shading submerged vegetation and destroying aquatic habitats. Dense algae outbreaks often result in massive fish-kills by depleting the water's oxygen levels.

Human-induced nutrient pollution, however, is not the only cause of harmful algae outbreaks. While algae outbreaks are phenomena that naturally occur in Florida's waters, it is widely thought that there has been a rise in their incidence in recent decades, in Florida as well as many other parts of the world. Although it has long been accepted that freshwater harmful algae such as cyanobacteria are strongly stimulated by nutrient pollution (Burkholder 2009), until recently the issue in estuaries and marine waters was more contentious. The evidence is now strong enough that in the frequently cited journal, *Harmful Algae*, scientists reached an accord that many harmful algae blooms worldwide, in estuaries and coastal marine environments as well as freshwaters, are stimulated or supported by anthropogenic nutrient over-enrichment (Heisler et al. 2008).

A good example of the shift in scientific thought can be seen in research regarding the most prevalent Florida red tide organism, *K. brevis.*[4] Historically there has been skepticism about a causal relationship between *Karenia* red tides and nutrient pollution (e.g., Anderson 1989; Alcock 2007) because red tides are naturally occurring and first begin to develop out in the open, nutrient-poor waters of the Gulf of Mexico. Yet, it is well known that many naturally occurring harmful algae are strongly stimulated by nutrient pollution (GEOHAB 2006), and it is also well established that stimulation by nutrient enrichment can be both direct and indirect (Burkholder et al. 2008). Some nearshore *Karenia* blooms were shown to contain a stable isotope "signature" of nitrogen from sewage (Yentsch et al. 2008). *Karenia* also has been found to eat other organisms to augment its nutrition from photosynthesis in low-light conditions (Glibert et al. 2009). The small cyanobacteria that it consumes are themselves stimulated by nutrient enrichment (Abbott et al. 2008).

[3] See http://www.doh.state.fl.us/environment/community/aquatic/pdfs/BlueGreen_SlimePoster.pdf

[4] Florida red tides are now known to be caused by a group of *Karenia* species (see Brand et al. 2012).

In other words, *Karenia* is now known to be both directly stimulated by nutrient pollution to support its photosynthesis, and indirectly stimulated, mediated through cyanobacteria prey: More nutrients translate into more cyanobacteria prey for *Karenia* to eat. It is becoming widely accepted that nutrient pollution can strongly stimulate *Karenia* red tides close to shore. Thus, the University of Florida's Institute of Food and Agricultural Sciences now states that nutrients from bays, harbors, and rivers along the west coast of Florida can provide significant amounts of nutrients (both nitrogen and phosphorus) to support high-biomass blooms of *Karenia* (Hochmuth et al. 2011; Vargo et al. 2008), and that large red tides off Sanibel Island likely have been related to sewage effluent (Yentsch et al. 2008). Nutrient pollution has also been linked to an increase in the frequency and magnitude of *Karenia* red tides along the coast of Texas (Anderson et al. 2008).

Rising levels of nutrients, in conjunction with increased water withdrawals, have been widely associated with human-induced pollution (Anderson et al. 2002; U.S. Environmental Protection Agency 2010; Heisler et al. 2008). As phosphorus and nitrogen are frequently the limiting factors in the growth of freshwater and saltwater algal species, nitrogen and phosphorus pollution tends to increase the potential for and severity of harmful algae outbreaks (Havens and Frazer 2012). Visitors and residents are deprived of their opportunity to fish, boat, and swim in public waters. The algae can produce dangerous toxins, emit noxious odors, adversely impact aquatic species, and degrade a water-body's aesthetic qualities. Harmful algae outbreaks have real costs to society and reduce the value of ecosystem services provided by Florida's waters.

In this report, we provide a quantitative valuation of the benefits of restoring Florida's impaired fresh waterbodies to full health – a critical component of the value of clean water to Florida. We also provide a detailed assessment of the essential components of the full value of Florida's clean waters, both fresh and estuarine/marine. Section 2 describes the problems of nutrient pollution and harmful algae outbreaks. Section 3 is a literature review of potential values placed on clean water in Florida. Section 4 estimates the full use and non-use values associated with aquatic ecosystem restoration in Florida. Finally, Section 5 concludes with a research agenda for building up the underlying data needed to comprehensively assess the value of Florida's clean waters.

2. Nutrient Pollution and Harmful Algae Outbreaks

Healthily functioning freshwater habitats are utilized – both directly and indirectly – by Floridians and visitors in numerous capacities, providing real economic value. They provide water that is directly consumed by humans and wildlife, and used in the production of livestock and other agricultural operations, generating over $7 billion in 2008.[5] Furthermore, freshwater and marine ecosystems alike provide unique habitats for wildlife, offering a variety of recreational opportunities that helped to attract over $67 billion of tourism and recreation spending in 2011.[6] Nutrient pollution directly impairs the quality of the affected water, creating an environment increasingly susceptible to harmful algae outbreaks and their far-reaching ecosystem effects. (Also called anthropogenic eutrophication, nutrient pollution refers to excess nutrients, especially nitrogen and phosphorus, in water systems as a result of human activities.) When these bodies of water are impaired, their value to society declines.

Florida's lakes, rivers, and spring systems – differing across ecosystem types, geographic locations, and local human communities – have three common functions: they provide water for direct human consumption, they supply an important input directly used in human production processes (such as agriculture and manufactures), and they provide a habitat for a range of species that is indirectly enjoyed by Floridians. Marine and coastal waters provide recreational opportunities and a habitat that supports a significant commercial fishing industry, adding $4.3 billion to Florida's gross state product in 2009.[7]

The most immediate impact of increased phosphorus and nitrogen levels in water systems is the reduced potability of the water. Increased nitrogen levels render water unsafe for the consumption of human infants and young wildlife, diminishing the direct utility of the resource and its value in providing healthy wildlife habitat. Similarly, high levels of phosphorus can potentially interfere with treatment at water facilities, imposing further costs in the production of drinking water. [8]

More consequential, or at least further reaching, are the secondary effects that result when nutrient pollution increases the growth of plankton and algae outbreaks. By altering the composition of the water, excess nitrogen and phosphorus create conditions in aquatic habitats where the mix and dominance of species can change, altering the ecosystem and its functions (Anderson et al. 2002). Planktonic species, including algae, respond to increased nutrient levels more quickly than the benthic species of aquatic vegetation that live on the bottom of waterbodies. The relative abundance of algae may itself reduce the use and value of the

---

[5] Value of sales; see Florida Department of Agriculture and Consumer Services website, http://www.florida-agriculture.com/consumers/crops/agoverview/.
[6] Tourism spending; see VisitFlorida.com website, http://media.visitflorida.org/research.php.
[7] Value added; see NOAA Fisheries website; http://www.st.nmfs.noaa.gov/st5/publication/fisheries_economics_2009.html.
[8] See USGU website; http://ga.water.usgs.gov/edu/nitrogen.html.

waterbody (for example, by reducing the prevalence of particular species that create recreational opportunities at a given location), however, it is the potential for increasing and intensifying harmful algae outbreaks that has been of the most concern to Florida's residents and visitors.

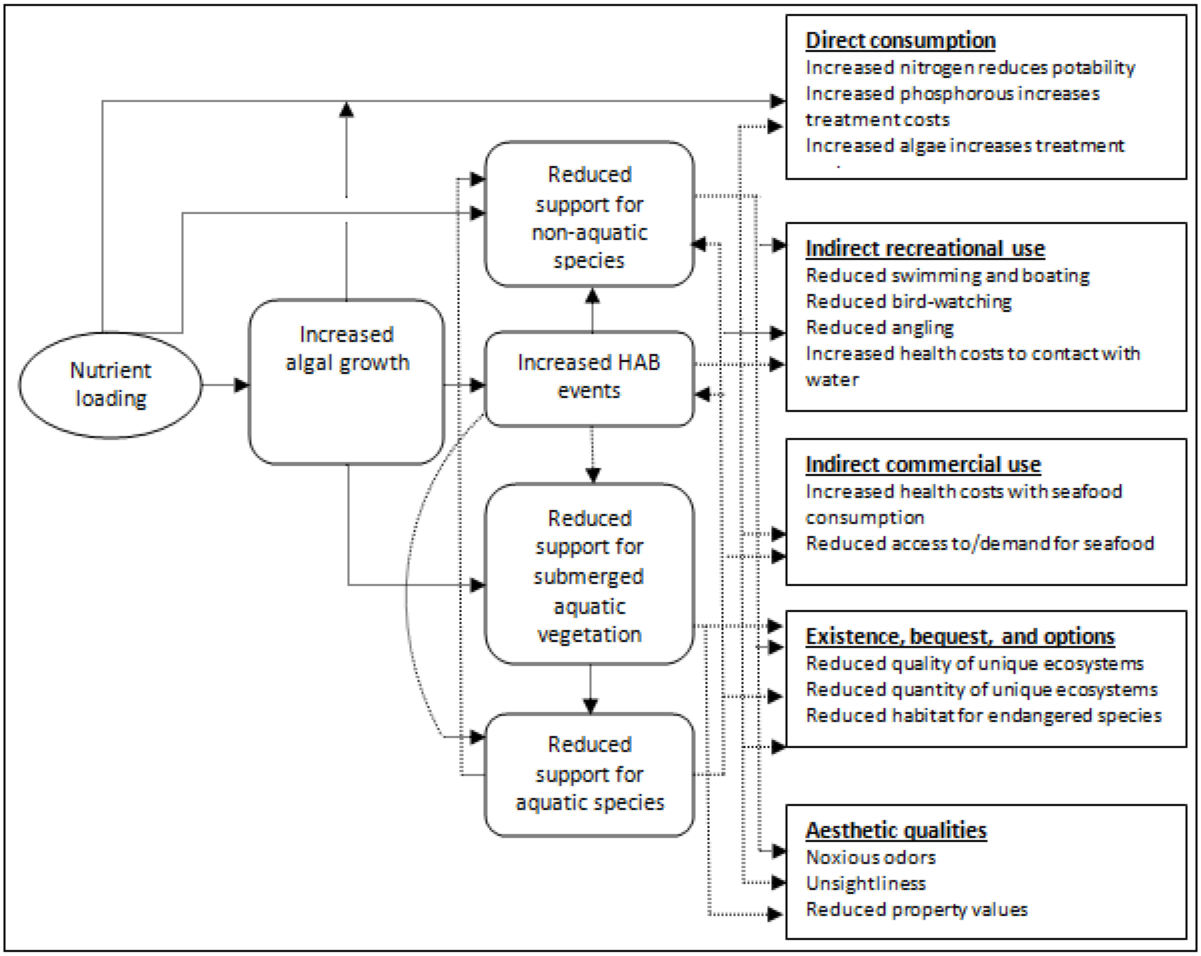
Freshwater harmful algae outbreaks events include a wide range of species, some producing toxins that are harmful to both humans and wildlife. Notable species include the genera of toxin-producing cyanobacteria most common in Florida – *Microcystis*, *Cylindrospermopsis*, and *Anabaena* – and the genus *Lyngbya* (recently changed to *Plectonema*, especially the organism called *P. wollei*) that can be found in Florida's freshwater springs as well as coastal waters (Burns 2008).

Reactions to excess nutrients will differ across algal species, ecosystems, conditions and geography; nutrient levels are just one of the factors that influence the frequency and severity of outbreaks. Other factors include the ratio of nutrients available; different algal species respond to nutrient pollution differently depending upon these ratios (Glibert et al. 2011). Similarly, the turbidity levels – or the cloudiness of the water – will have an impact on growth because, in addition to nutrients, light is a necessary component to algal production. Furthermore, the mixing and flushing dynamics of the waterbody will play a role in determining how stationary and how concentrated algae populations can become (Anderson et al. 2002).

Toxic or otherwise, harmful algae outbreaks can have severe impacts on the ecosystem services that bodies of water provide. The increased growth of algae, and outbreak conditions in particular, increases turbidity and effectively blocks sunlight from reaching submerged aquatic vegetation (Burkholder et al. 2007). This limits the growth of underwater flora, which provides habitat and resources to aquatic fauna – these species are often critical components to freshwater ecosystems and food webs. Damaging this aspect of the ecosystem, whether through sudden outbreaks or a long-term shift towards the dominance of algal species, limits the provision of wildlife habitat and alters aesthetic and other physical qualities of Florida's waters.

Furthermore, algae outbreaks can have a more direct impact on other aquatic species. As the algae eventually die off, their decay consumes the water's oxygen, frequently resulting in hypoxic or anoxic conditions (water having low oxygen levels or no oxygen, respectively). Low-oxygen stress leads to respiratory difficulties for other aquatic species, creating the potential for fish kills and the death of other beneficial aquatic life. The figure below, adapted from the EPA's analysis of its numeric nutrient criteria for Florida (U.S. Environmental Protection Agency 2010), summarizes the impacts of nutrient pollution on ecosystem functioning, relating these changes to impacts on the human use and valuation of the goods and services provided.

Figure 1: Impacts of Nutrient Pollution



Source: Adapted by authors from EPA (2010) Exhibit 12-1

Figure 1 maps the ways in which society's use of Florida's waterbodies is affected when aquatic ecosystems are degraded by human-induced nutrient pollution. Each of these uses, discussed in more detail below, provides value to segments of society and contributes to human well-being. The various uses have the potential to provide a range of use and non-use values (see Box 2 below) that require consideration and, where possible, valuation. A comprehensive valuation of Florida's bodies of freshwater, as well as any incremental change in their quality, would consider all of these values.

Florida's Ecosystem Services

The Millennium Ecosystem Assessment (2005) defines ecosystem services as "the benefits people obtain from ecosystems," whether directly or indirectly. Distinct from ecological functions – the physical processes that produce the ecosystem services that contribute to well-being – the Millennium Ecosystem Assessment's (2005) synthesis on wetlands, water, and human well-being identifies the following services provided by wetlands and waterbodies:

- *Provisioning services*, including food (i.e. aquatic species), freshwater, and a unique gene pool;
- *Regulatory services*, including carbon sequestration and other climate regulating processes, water and waste treatment and purification, and the regulation of erosion;
- *Cultural services*, including recreational and educational opportunities, aesthetics, and spiritual inspiration;
- *Supporting services*, including the formation of soil and cycling of nutrients.

Ecosystem services are utilized and valued by humans because they contribute to individuals' security, material well-being, physical and mental health, interpersonal relationships, and feeling of community cohesion.

A critical service provided by both marine and freshwater ecosystems is the provision of recreational opportunities. Past efforts to estimate the value provided by Florida's freshwater have focused on the contribution of springs' recreational opportunities to the local economy (Bonn and Bell 2003; Foster 2008). Similarly, evaluations of the impacts of marine harmful algae outbreaks have focused on the impacts on recreational opportunities and tourism (Hoagland et al. 2002; Anderson et al. 2000).

Using a similar set of definitions to the Millennium Ecosystem Assessment, Nuttle (2011) identifies a suite of ecosystem services provided by Florida's marine and coastal waters, including aesthetics, recreational opportunities, climate regulation, and the provisioning of food sources and biodiversity.

The services provided by Florida's marine ecosystems are distinct from those of freshwater in several ways: the relative size of Florida's maritime fishing industry indicates that the provisioning of food plays a large role in the valuation of Florida's saltwater ecosystem services when compared to the valuation of freshwater services; and, similarly, the importance of the ocean as a food source means that regulating seafood safety will be a relatively large component of valuing the benefits of clean marine and coastal waters. Past assessments of the costs of marine harmful algae outbreaks have emphasized impacts on the commercial fishing industry and the health-related issues surrounding the consumption of contaminated seafood (Hoagland and Scatasta 2006; Hoagland et al. 2002).

The Impairment of Florida's Waters

As of 2010, FDEP reports showed that Florida had assessed 10,476 river miles (20 percent of the river miles in the state) and that 53 percent or 5,587 miles had a nutrient-related impairment – meaning that they are no longer clean enough for a specified use.[9] Florida had also assessed 54

[9] See University of Florida IFAS Extension website, http://edis.ifas.ufl.edu/ss528.

percent of lake and reservoir acres (1,124,399 acres) and of those lake acres assessed, 82 percent or 919,000 acres had a nutrient-related impairments. Florida had assessed 5,317 square miles of estuaries constituting, 100 percent of the state's estuaries, of which 32 percent or 1,795 square miles had a nutrient-related impairments.[10]

Florida's famed springs, including the iconic Silver Springs, are impaired by nitrate pollution (nitrate is a form of nitrogen). The result is that the springs' rich and complex ecosystem of aquatic plants, fish and wildlife is being replaced with toxigenic blue-green algae *Lyngbya majescula*. Under natural conditions, nitrate levels in Florida springs were below .05 parts per million. The nitrate level at Silver Springs has reached 1,000 times the normal level and is still rising.[11] Increased nitrogen levels in Florida's springs and groundwaters have been human induced, caused by animal waste, inorganic fertilizers, and wastewater. FDEP has reported that almost 75 percent of Florida's springs have nitrate levels high enough to cause shifts in the ecosystems (FDEP 2012).

Nitrates are also polluting groundwater wells used in many rural areas for drinking water. Nitrate in groundwater drinking water systems is of concern because private self-supplied drinking water systems, which primarily draw from groundwater, are not federally regulated. A level of nitrates above 1 mg/L indicates that human activity is polluting the aquifer. EPA has estimated that 4,975 square miles in Florida (9 percent of the state) have groundwater nitrate concentrations in excess of 5 mg/L, which is half of EPA's maximum contaminant level for nitrates (set to protect against blue-baby syndrome). Ten percent of Florida's population has self-supplied drinking water.[12]

Sources of water pollution are classified into two categories, point and nonpoint. Nonpoint sources fail to meet the criteria of being a point source, defined by the EPA as "… any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged."[13] Nonpoint sources include runoff, drainage, precipitation, and other atmospheric deposition; they are diffuse in nature, often rendering them relatively more difficult to regulate and monitor than point sources.

In Florida, the most common point sources for nitrogen pollution are wastewater treatment facilities, whereas the most common nonpoint sources are fertilizer runoff – from both agricultural and residential applications – and rain and wind (Hauxwell et al. 2008). Foster's

---

[10] "Nutrient-related" impairment includes waters impaired for nutrients, algal growth, ammonia, noxious aquatic plants, and organic enrichment/oxygen depletion; see EPA "Waters Assessed as Impaired Due to Nutrient-Related Causes", http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/dataset_impaired.cfm.s

[11] http://articles.orlandosentinel.com/2010-04-11/news/os-floridas-dying-springs-20100411_1_nitrate-alexander-springs-native

[12] See EPA "Estimate Nitrate Concentrations in Groundwater Used for Drinking", http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/dataset_groundwater.cfm.

[13] Clean Water Act, Section 502(14), see http://water.epa.gov/polwaste/nps/whatis.cfm.

(2008) inventory of nitrogen sources in the Ichetucknee Springshed in Columbia County, Florida, found that 35 percent of nitrate loads were attributable to improved pasture land-use, 32 percent to wind and rain, 10 percent to urban land use, 9 percent to agricultural row-crop land use, 8 percent to septic tank discharge, and 6 percent to wastewater treatment, revealing a relatively large contribution from nonpoint sources (the combination of land-use, septic leakage, and wind and rain contributions).

3. The Potential for Economic Valuation

This section summarizes a review of the literature placing values on Florida's clean water. Box 2 provides brief definitions for the categories of use and non-use values surveyed below. The section concludes with an overview of valuations of damages from harmful algae outbreaks to the nation as a whole.

Box 2: Use and Non-use Economic Values

The values provided by Florida's waters fall into one of two broad categories: use values, both direct and indirect; and non-use values that do not involve the direct or indirect use of aquatic ecosystems.

Use Values:

> *Direct use value* – the value obtained when water is directly consumed or utilized (direct use value includes both drinking water and irrigation);
>
> *Indirect use value* – the value obtained when the ecosystem services (such as recreational opportunities, the provisioning of food and shelter, etc.) provided by clean water are consumed or utilized.

Non-Use Values:

> *Bequest value* – the value we may place in preserving these amenities for the enjoyment of future generations;
>
> *Existence value* – the value we may place on knowing that elements of Florida's unique ecosystem exist in a healthy state, even though we never plan to use them.

Straddling use and non-use value is the concept of *option value* – the non-use value provided by the option of future use. This concept is analogous to an option in financial markets, and arguably can be valued in a similar manner.

Direct Use

Human-induced nutrient pollution has the potential to impact the direct use of, and value provided by, Florida's bodies of freshwater. The direct use of freshwater for human consumption and various production processes, notably agriculture, is hampered by nutrient pollution. This use is further inhibited by harmful algae outbreaks. For example, the Olga Water

Treatment Plant in Lee County, providing water to some 30,000 residents, has repeatedly been shut down due to cyanobacteria levels in Florida's Caloosahatchee River.[14]

Cyanobacteria pose notable costs in this regard; water treatment facilities must not only remove cyanobacteria from the supply of drinking water, but they also may need to take additional measures to reduce extracellular toxins that have been produced by the algae, keeping toxin levels below the appropriate threshold. Many water treatment technologies that effectively remove cyanobacteria from drinking water do not effectively remove these extracellular toxin, and high levels of cyanobacteria may necessitate incremental water treatment (Westbrick 2008). If necessary, incremental treatments impose real costs on society; these avoided costs are a benefit to maintaining clean, toxin-free sources of freshwater. Assuming that the treatment of drinking water is cost-effective, a lower-bound valuation of this service would be the minimum of (1) the incremental costs associated with installing advanced treatment technologies in the necessary facilities, or (2) the costs of providing outside water sources, such as tanked or bottled water.

Indirect Recreational Use

Increased nutrient levels may have broad impacts on the indirect use of waterbodies when harmful algae outbreaks occur; impairment of freshwater ecosystem's provisioning of aquatic habitat affects the availability of recreational opportunities. Immediate effects of an algae outbreak include reduced utility of waterbodies for recreational activities, such as fishing, swimming, and boating, during the presence of unsightly, noxious, and/or harmful outbreaks. As a top U.S. destination for tourists interested in aquatic activities, it is apparent that the impacts of harmful algae outbreaks on the recreational use value of Florida's waterbodies are potentially large (Alcock 2007). The potential reduction in recreation value include the costs of any dermatological, respiratory, or neurological health problems that result from contact with algae outbreaks, lost benefits that residents and tourists forego when they decide not to utilize Florida's waters because of a harmful algae outbreak, and any lost benefits to local businesses in areas affected by harmful algae outbreaks.

Anecdotal evidence clearly demonstrates the devastation that harmful algae outbreaks can cause in a water-centric community. The character and magnitude of regional and statewide effects, however, are unclear – potential visitors to an algae-affected waterbody often have substitutes available in other parts of the state (Alcock 2007). These alternatives will minimize the value lost by consumers, although it is expected that both residents and tourists would experience some net loss. Several studies, however, suggest the existence of a "halo effect" where localized impacts cause collateral effects (Anderson et al. 2000; Hoagland and Scatasta 2006; Hoagland et al. 2002). A harmful algae outbreak in one area may very well cause visitors to avoid a much larger region, even the state of Florida as a whole.

[14] See http://www.sierraclubfloridanews.org/2012_01_01_archive.html

In theory, Florida businesses potentially could experience no net loss, or even a net benefit, from such events as consumers shift their activities from one location to another. Even so, individual businesses will lose out: Morgan et al. (2009) assess the impacts of harmful algae outbreaks on three coastal restaurants, finding that the presence of red tide reduced daily revenues by 13-15 percent, and Larkin and Adams (2007) looked at the effects of harmful algae outbreaks on the restaurant and lodging sectors in coastal Florida communities, estimating that the presence of red tide reduced daily restaurant and lodging revenues by 29 and 35 percent, respectively. It is evident that harmful algae outbreaks produce some losers, and the distributional effects of costs related to harmful algae outbreaks are important to consider. The regional impacts on recreational use values are not well understood and, given the size of the value potentially at risk, they are a topic in need of further research.

Closely related to any lost recreational value are the impacts on the health of those individuals who use contaminated waters recreationally, despite the presence of a harmful algae outbreak. Depending upon the type of algae, recreating in waters contaminated with a toxic outbreak can lead to dermatological, respiratory, and neurological health problems. Similarly, foregoing the consumption of fish acquired through recreational angling results in a lost benefit, although likely not as great in value as that of potential illnesses that may arise from consuming contaminated fish.

The aesthetic value provided by Florida's waterbodies is an additional important and potentially large indirect use value – Floridians may gain value from living by, or having access to vistas of, fresh and ocean waterbodies. This value may be reflected in the residential property market, as households may be willing to pay more for a home if it is on or near the water. Hedonic analysis can be used to identify homeowners' willingness to pay for waterbody proximity, estimating the value placed on the aesthetics of waterfront property. While no such study has yet been attempted in Florida, the potential value is enormous; almost 60 percent of Florida's residents live within 10 miles of the ocean (Hauxwell et al. 2008).

Indirect Commercial Use

Nutrient pollution and harmful algae outbreaks have two kinds of indirect commercial effects: health costs associated with eating toxic fish, and losses sustained by commercial fisheries. Previous assessments of the economic impacts of harmful algae outbreaks have placed significant emphasis on the public health costs of seafood poisoning. For example, Anderson et al. (2000) assess the economic impacts of harmful algae outbreaks in the United States, finding that public health costs make up 31-55 percent of the nation's total costs related to harmful algae outbreaks.

These health issues, however, are primarily a problem associated with harmful algae outbreaks in saltwater, red tide in particular. Cyanobacteria and other algal species can affect freshwater, estuarial, and coastal fisheries as well, but the consumption of cyanobacteria-exposed fish has not historically been associated with human illness (Codd et al. 1999). Furthermore, the monitoring of the commercial catch for toxins has greatly reduced the incidence of shellfish poisoning in the United States. Although the costs of this monitoring, along with programs that monitor and track algae outbreaks themselves, impose real economic costs on Florida and should be included in a comprehensive valuation of reduced nutrient pollution, it is not likely that the health costs associated with consuming contaminated fish will be as important as in the past.

A closely related impact of harmful algae outbreaks is the periodic closure and destruction of fisheries. Based upon a hypothesized link between cyanobacteria outbreaks and sea-grass die-off, Gorte (1994) estimated the potential loss to Florida Bay's pink shrimp harvests at $16.1 million per year. Sea grass provides critical habitat in Florida's coastal waters, sheltering a range of aquatic species, from oysters and clams to redfish and grouper, at some point in their life cycle. These species make up over 80 percent of Florida's commercially and recreationally caught fish. Although there are many natural and human-induced causes of damage to Florida's sea grass, human-induced nutrient pollution has been singled out as being among the most important. Globally, pollution from excess nutrients has been identified as the cause of 50 percent of the decline in sea grass populations (Hauxwell et al. 2008). The threat from harmful algae outbreaks to Florida's coastal commercial fisheries is real, and its avoided loss, to consumers and businesses alike, is a key benefit of improvements to Florida's water quality.

Non-Use Values: Existence, Bequest, and Option

To date, there has been no study that has explicitly explored the existence and bequest values associated with maintaining the health of Florida's lakes, rivers and estuaries. (The EPA study discussed in Section 4 below applies direct analysis of these values from studies conducted elsewhere.) Such a study would require the use of non-market valuation, specifically contingent valuation, to solicit the population's willingness-to-pay for clean waterbodies. Past studies of waterbodies have found existence value to be a relatively important component of the total value provided by healthy aquatic ecosystems: Greenley et al. (1982) indicate that household willingness-to-pay for reduced pollution of the South Platte River in Colorado was half recreation value and half existence and bequest value. Walsh, Loomis and Gillman (1984) use contingent valuation to elicit preferences of Colorado's residents for preserving wilderness areas. They too find that recreational value is roughly equal to the aggregated existence, bequest, and option values of increasing the size of protected areas. Brouwer et al (1999) conduct a meta-analysis of studies estimating willingness-to-pay for wetlands, finding that, among the studies reviewed, the average non-use value is roughly half that of average use value.

Furthermore, these values are likely to differ across specific bodies of water, with unique, high-profile, or otherwise irreplaceable locations providing the highest non-use values. Foster (2008) conducts a contingent valuation assessing Columbia County residents' willingness-to-pay for an improvement in the water quality of the Ichetucknee Springs system, finding that county residents were willing to pay a mean $16.90 per household per month for 10 years – a total willingness-to-pay of $42.4 million – for a 20 percent increase in quality of the spring system. In comparison, Brouwer et al. (1999) find that mean annual willingness-to-pay for maintaining water quality and for biodiversity were $52.50 and $76.10 per household, respectively.

A Comprehensive Valuation of Florida’s Clean Water

Comprehensive valuation of the benefits of an improvement in water quality to Florida would consider all of the uses and values discussed above. It is clear that the values provided by fresh and marine waterbodies differ, and that recreational use value and the suite of non-use values are important, necessary components to a complete valuation of both types of ecosystems. Although no comprehensive assessment of the impacts of nutrient pollution and harmful algae outbreaks on Florida’s economy exists in the literature, national surveys of the economic impacts of harmful algae outbreaks can provide some sense of the relative magnitudes.

Anderson et al. (2000) assess the impacts of harmful algae outbreaks, mostly for marine events, classifying the effects into the categories: public health, commercial fishery, recreation/tourism, and monitoring/management. Roughly 31-55 percent of the impacts were due to public health issues, resulting from the consumption of contaminated seafood. Economic losses to the commercial fishing industry were estimated to be 31-40 percent of the total, including losses from reduced aquaculture as well as wild harvests. Up to 36 percent of the economic effect was attributed to impacts on recreation and tourism, and just 3-6 percent to the costs of monitoring and managing harmful algae outbreaks. Dodds et al. (2009) perform a similar exercise for freshwater harmful algae outbreaks, estimating that 21-46 percent of economic impacts are due to lost recreational opportunities, 14-60 percent from declining property values, up to 2 percent from lost wildlife habitat for threatened or endangered species, and 17-38 percent from the degradation of drinking water.

Note that the distribution of these economic impacts, and thus the benefits and costs associated with harmful algae outbreaks, vary greatly. While most studies seek to estimate average annual costs, benefits, or impacts associated with harmful algae outbreaks, the duration and severity of these outbreaks have wide ranges, and especially large and severe events can result in much higher costs and prolonged loss of value.

Similarly, the distribution of costs and benefits are borne unequally across geographies and generations. Nutrient pollution does not necessarily lead instantaneously to harmful algae outbreaks, but, rather, increasing prevalence of harmful algae outbreaks have been known to lag human-induced nutrient pollution by 10 years or more (Anderson et al. 2002).

4. Estimating the Value of Florida's Clean Water

Economic assessment of Florida's clean water is hampered by a lack of physical data documenting the extent and severity of harmful algae outbreaks and other related environmental threats. This section expands on the EPA's 2010 quantification of the value of improved water quality in Florida to offer a tentative estimate of potential values.

EPA's 2010 Economic Analysis

The EPA's "Economic Analysis of Final Water Quality Standards for Nutrients for Lakes and Flowing Waters in Florida" (U.S. Environmental Protection Agency 2010, Sec. 13) includes a quantitative assessment of the potential incremental benefits of imposing numeric nutrient criteria in Florida. The EPA's 2010 valuation methodology is taken verbatim from an EPA assessment of national effluent standards (U.S. Environmental Protection Agency 2009), which in turn borrows heavily from a 2004 EPA ruling on power plant cooling water intake structures (U.S. Environmental Protection Agency 2004, Ch. A1). Presented in its simplest form:

EPA measures the current water quality of each of several thousand numbered segments of Florida rivers, lakes, and estuaries using its Water Quality Index (WQI). The Water Quality Index combines scores on six parameters (dissolved oxygen, biochemical oxygen demand, fecal coliform, total nitrogen, total phosphorus, and total suspended solids); on a 0 to 100 scale, higher values indicate better water quality. Waterbodies with values above 25 are suitable for boating; above 50, game fishing; above 70, swimming; and above 95, drinking without treatment.

EPA estimates the potential improvement in the WQI that its numeric nutrient criteria would affect in each waterbody identification district.

EPA borrows values for households' willingness-to-pay for water quality improvements from the EPA's (U.S. Environmental Protection Agency 2009) national effluent standard assessment. The actual annual dollar value per Florida household (in contrast to any standardized values for the United States as a whole) depends on four factors: (1) Florida's 2006 median household income – $52,406;[15] (2) current Water Quality Index levels in Florida's waterbody identification districts; (3) potential for Water Quality Index change in Florida's waterbody identification districts as a result of imposing numeric nutrient criteria; and (4) the EPA's chosen method of averaging Water Quality Index values across waterbody identification districts to arrive at a single willingness-to-pay value for all Florida residents. Factors (1) and (2) have little effect on willingness-to-pay; factors (3) and (4) strongly impact the bottom line.

[15] Converted into 2010 dollars (U.S. Census Bureau 2006; U.S. Department of Labor 2012).

EPA differentiates four classes of willingness-to-pay values: rivers and streams, for full- ($2.94 per household per year) and part-time residents ($0.78); and lakes, for full- ($0.89) and part-time residents ($0.24). Florida's lakes have a lower average potential for Water Quality Index improvement than do its rivers and streams. Part-time residents are assumed to live in-state for approximately one-fourth of the year and, therefore, to have one-fourth of a full-time resident's willingness-to-pay for water quality.

Total willingness-to-pay is estimated as the sum of average household willingness-to-pay multiplied by the number of full- and part-time households, respectively. The total potential annual benefits for water quality improvement to rivers, streams, and lakes in Florida are estimated by the EPA at $28 million (in 2010 dollars).

Critique of EPA Methodology

The EPA follows a standard 'benefits transfer' methodology for assessing non-use ecosystem values. The agency's specific approach, however, raises a few questions. First, EPA's choice of assigning part-time residents one quarter of the willingness-to-pay for Florida's water quality improvements – which it makes without any justification or citation – seems arbitrary at best. Simply replacing this assumption with the notion that part-time resident's willingness-to-pay is equal to that of full-time resident's raises total potential annual benefits from $28 million to $29 million.

The academic literature regarding the contingent valuation technique used by EPA (U.S. Environmental Protection Agency 2004; U.S. Environmental Protection Agency 2009; U.S. Environmental Protection Agency 2010) suggests that even this more balanced treatment of the value that residents place on clean water may be a gross underestimate. A strong willingness-to-pay for a clean and healthy environment extends far beyond state boundaries. Loomis (2000) finds that one-half or more of household willingness-to-pay for ecosystem improvements remains at a distance of 2,500 miles from most of the habitats included in the study. Conservatively applying this estimate to the EPA (2010) analysis by attributing one-half of Floridian's willingness-to-pay for in-state water improvements to every household in the United States outside of Florida raises total potential annual benefits from $29 million to $448 million.

A second key concern is EPA's choice to base Floridian's willingness-to-pay for water quality improvements on the average Water Quality Index and potential Water Quality Index improvement across all waterbody identification districts, weighted by river and stream miles or lake acreage. Again, this assumption is made without justification or citation and, unlike EPA's method of assessing part-time resident's willingness-to-pay, this choice has a profound effect on bottom-line results. Given the minimum and maximum potential values for Florida waterbody identification districts Water Quality Index and Water Quality Index improvements, the possible annual household willingness-to-pay for water improvements by waterbody identification districts range from \$0.61 to \$22.94. Far from basing their willingness-to-pay on state average Water Quality Index and Water Quality Index improvements, residents may:

- Exclusively place value on improvements to local waterbodies;
- Place greater weight on waterbodies that they use or otherwise observe;
- Have separate, additive, values for multiple waterbodies within Florida; or
- Have a willingness-to-pay for the maximum potential Water Quality Index improvement across all waterbody identification districts.

In the original EPA assessment using this methodology, the average household annual willingness-to-pay in the underlying contingent valuation studies of particular habitat improvements was \$111 for users of the ecosystem and \$87 for non-users (U.S. Environmental Protection Agency 2004). The high-end of the range of possible values suggested by EPA (2010), \$23 per household per year, is entirely within the realm of plausible values. Assuming that Floridians – and households around the United States at half the value – base their willing-to-pay for ecosystem improvements on the waterbody identification districts with the greatest potential improvement in Water Quality Index, not on the average waterbody identification districts, raises total potential annual benefits from \$448 million to \$3.5 billion.

A third set of limitations concerns the lack of appropriate data, both physical and economic, for Florida's waterbodies. EPA's methodology includes only the very limited number of waterbody identification districts for which existing data is sufficient to estimate a Water Quality Index: 67 percent of lake waterbody identification districts and just 4 percent of river and stream waterbody identification districts (by waterbody identification districts count, not acreage or miles) (U.S. Environmental Protection Agency 2010). Similarly, in the 45 contingent valuation analyses used in the EPA (2009; 2010) assessments, one was specific to a group of Florida waterways, two were national, and the 42 remaining studies focused on aquatic ecosystems in other U.S. states. There is a clear need for additional research regarding both the quality of and the value placed on Florida's ecosystems.

Finally, while EPA (2010, Ch. 12) presents a detailed assessment of the potential use and non-use values for improvements to Florida's water quality, its quantitative analysis exclusively estimates non-use values. Several studies (Greenley et al. 1982; Walsh et al. 1984; Brouwer et al. 1999) have suggested that the total – use plus non-use – value of ecosystem improvement can be valued at three times the non-use value. Applying this method raises total potential annual benefits of water quality improvements in Florida – a critical component of the value of clean water in Florida – from \$448 million (using the average willingness-to-pay) to \$3.5 billion (using the maximum willingness-to-pay) up to \$1.3 to \$10.5 billion.

Valuation Results in Context

The range of values for Florida's potential annual benefits of water quality improvements presented above – \$1.3 to \$10.5 billion – amounts to 2 to 16 percent of the state's total recreation revenues, \$67 billion; the use-value portion of these benefits amounts to just 1 to 10 percent. The benefits transfer methodology that underpins these results relies on the assumption that, after taking account of important characteristics such as income levels and the potential for water quality improvements, willingness-to-pay for ecosystem restoration is strikingly similar from state to state, and habitat to habitat. The possibility that the value that state residents, and the nation as a whole, place on Florida's aquatic ecosystems is in some way extraordinary should not be dismissed. Florida-specific field studies and surveys – using contingent valuation as well as other reputable methodologies – are essential to an accurate, comprehensive valuation of Florida's clean water. These essential, context-appropriate studies are all but absent from EPA's assessment and the adjustments to the EPA analysis presented here.

5. Conclusion

The valuation of Florida's clean water presented here led to a range from $1.3 to $10.5 billion dollars annually (see Table 1). The methodology used to provide this estimation, however, was based on a willingness-to-pay for non-use values that – while generated from a well-accepted method frequently used by the EPA – are not built from Florida-specific economic analysis, and a generic imputation of use values drawn from relationships presented in the literature.

Table 1: Summary of Economic Valuation of Florida's Clean Waters

	In millions (2010 dollars)	
	at EPA (2010) willingness-to-pay	**at $23 per household per year willingness-to-pay**
EPA (2010) estimate of non-use ecosystem values related to Florida's water-quality improvements	$28	
Additional value from full assessment of part-time residents' willingness to pay for Florida's water quality improvements	$1	
Non-Florida U.S. residents' willingness to pay for Florida's water quality improvements	$419	$3,500
Imputed use values related to Florida's water-quality improvements	$838	$7,000
Total use and non-use values related to Florida's water-quality improvements	**$1,286**	**$10,500**

A better, more complete, and context-specific method would apply Florida-based economic analysis to physical data describing the extent and degree of human-induced threats to Florida's water quality. In our opinion, the main obstacle to completing a comprehensive, rigorous assessment of the value of clean water in Florida is the absence of high-quality, time-series data documenting changes to water quality as a result of human actions at a localized scale. Without a sound empirical basis for water quality changes and their causes, more detailed economic analysis would be unfounded. The scientific community is now clear that pollution is a primary cause of harmful algae outbreaks. What remains is for federal and state agencies to set, and fund, an agenda for gathering the underlying data needed to comprehensively assess the value of Florida's clean waters.

References

Abbott, L., Barnes, T., Bennett, R., et al. (2008). "Chapter 12: Management and Restoration of Coastal Ecosystems." In *2008 South Florida Environmental Report*. West Palm Beach, FL: South Florida Water Management District.

Alcock, F. (2007). *An Assessment of Florida Red Tide: Causes, Consequences and Management Strategies*. 1190. Sarasota, FL: Mote Marine Laboratory.

Anderson, D.M. (1989). "Toxic algal blooms and red tides: A global perspective." In *Red Tides: Biology, Environmental Science and Toxicology*. New York: Elsevier, pp. 11–16.

Anderson, D.M., Burkholder, J.M., Cochlan, W.P., et al. (2008). "Harmful algal blooms and eutrophication: Examining linkages from selected coastal regions of the United States." *Harmful Algae* 8(1), 39–53. DOI: 10.1016/j.hal.2008.08.017.

Anderson, D.M., Glibert, P.M. and Burkholder, J.M. (2002). "Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition, and Consequences." *Estuaries* 25(4), 704–26.

Anderson, D.M., Hoagland, P., Kaoru, Y. and White, A.W. (2000). *Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States*. Available at http://stinet.dtic.mil/oai/oai?&verb=getRecord&metadataPrefix=html&identifier=ADA386861.

Bonn, M.A. and Bell, F.W. (2003). *Economic Impact of Selected Florida Springs on Surrounding Local Areas*. Tallahassee, FL: Florida Departmen of Environmental Protection. Available at www.dep.state.fl.us/springs/reports/files/EconomicImpactStudy.doc.

Brand, L.E., Campbell, L. and Bresnan, E. (2012). "Karenia: The biology and ecology of a toxic genus." *Harmful Algae* 14, 156–78. DOI: 10.1016/j.hal.2011.10.020.

Brouwer, R., Langford, I.H., Bateman, I.J., Crowards, T.C. and Turner, R.K. (1999). *A Meta-analysis of Wetland Contingent Valuation Studies*. GEC 97-20. The Centre for Social and Economic Research on the Global Environment.

Burkholder, J.M. (2009). "Harmful Algal Blooms." In *Encyclopedia of Inland Waters, Volume 1*. Oxford, UK: Elsevier, pp. 264–85.

Burkholder, J.M., Glibert, P.M. and Skelton, H.M. (2008). "Mixotrophy, a major mode of nutrition for harmful algal species in eutrophic waters." *Harmful Algae* 8(1), 77–93. DOI: 10.1016/j.hal.2008.08.010.

Burkholder, J.M., Tomasko, D.A. and Touchette, B.W. (2007). "Seagrasses and eutrophication." *Journal of Experimental Marine Biology and Ecology* 350(1–2), 46–72. DOI: 10.1016/j.jembe.2007.06.024.

Burns, J. (2008). "Toxic cyanobacteria in Florida waters." *Advances in experimental medicine and biology* 619, 127–37. DOI: 10.1007/978-0-387-75865-7_5.

Codd, G., Bell, S., Kaya, K., Ward, C., Beattie, K. and Metcalf, J. (1999). "Cyanobacterial toxins, exposure routes and human health." *European Journal of Phycology* 34(4), 405–15. DOI: 10.1080/09670269910001736462.

Dodds, W.K., Bouska, W.W., Eitzmann, J.L., et al. (2009). "Eutrophication of U.S. Freshwaters: Analysis of Potential Economic Damages." *Environmental Science and Technology* 43(1), 12–19. DOI: 10.1021/es801217q.

Florida Department of Environmental Protection (2012). *Integrated Water Quality Assessment for Florida: 2012 305(b) Report and 303(d) List Update*. Tallahassee, FL.

Florida Department of Environmental Protection (2008). *Integrated Water Quality Assessment for Florida: 2008 305(b) Report and 303(d) List Update*. Tallahassee, FL.

Foster, C. (2008). *Valuing Preferences for Water Quality Improvement in the Ichetucknee Springs System: A Case Study from Columbia County, FL*. Master of Science. University of Florida.

GEOHAB (2006). *HABs in Eutrophic Systems*. Paris and Baltimore: IOC and SCOR.

Glibert, P.M., Burkholder, J.M., Kana, T., Alexander, J., Skelton, H. and Shilling, C. (2009). "Grazing by Karenia brevis on Synechococcus enhances its growth rate and may help to sustain blooms." *Aquatic Microbial Ecology* 55, 17–30. DOI: 10.3354/ame01279.

Glibert, P.M., Fullerton, D., Burkholder, J.M., Cornwell, J.C. and Kana, T.M. (2011). "Ecological Stoichiometry, Biogeochemical Cycling, Invasive Species, and Aquatic Food Webs: San Francisco Estuary and Comparative Systems." *Reviews in Fisheries Science* 19(4), 358–417. DOI: 10.1080/10641262.2011.611916.

Gorte, R.W. (1994). *The Florida Bay Economy and Changing Environmental Conditions*. 94-435 ENR. Congressional Research Service.

Greenley, D., Walsh, R. and Young, R. (1982). *Economic Benefits of Improved Water Quality: Public Perceptions and Preservation Values*. Boulder, CO: Westview Press.

Hauxwell, J., Jacoby, C., Frazer, T.K. and Stevely, J. (2008). *Nutrients and Florida's Coastal Waters*. SGEB - 55. Gainesville, FL: Florida Sea Grant.

Havens, K. and Frazer, T. (2012). "Urban Water Quality and Fertilizer Ordinances: Avoiding Unintended Consequences: A Review of the Scientific Literature."

Havens, K.E., Aumen, N.G., James, R.T. and Smith, V.H. (1996). "Rapid Ecological Changes in a Large Subtropical Lake Undergoing Cultural Eutrophication." *Ambio* 25(3), 150–55.

Heisler, J., Glibert, P.M., Burkholder, J.M., et al. (2008). “Eutrophication and harmful algal blooms: A scientific consensus.” *Harmful Algae* 8(1), 3–13. DOI: 10.1016/j.hal.2008.08.006.

Hoagland, P., Anderson, D.M., Kaoru, Y. and White, A.W. (2002). “The Economic Effects of Harmful Algal Blooms in the United States: Estimates, Assessment Issues, and Information Needs.” *Estuaries* 25, 819–37.

Hoagland, P. and Scatasta, S. (2006). “The Economic Effects of Harmful Algal Blooms.” In *Ecology of Harmful Algae*. Berlin: Springer-Verlag, pp. 391–401.

Hochmuth, G., Nell, T., Sartain, J., Unruh, J.B., Martinez, C., Trenholm, L. and Cisar, J. (2011). “Urban Water Quality and Fertilizer Ordinances: Avoiding Unintended Consequences: A Review of the Scientific Literature.”

Larkin, S.L. and Adams, C.M. (2007). “Harmful Algal Blooms and Coastal Business: Economic Consequences in Florida.” *Society and Natural Resources* 20, 849–59. DOI: 10.1080/08941920601171683.

Loomis, J.B. (2000). “Vertically Summing Public Good Demand Curves: An Empirical Comparison of Economic versus Political Jurisdictions.” *Land Economics* 76(2), 312–21. DOI: 10.2307/3147231.

Millenium Ecosystem Assessment (2005). *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*. Washington, D.C.: World Resources Institute.

Morgan, K.L., Larkin, S.L. and Adams, C.M. (2009). “Firm-level economic effects of HABS: A tool for business lost assessment.” *Harmful Algae* 8, 212–18.

National Research Council (2000). *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*. National Academy Press. Available at http://www.nap.edu/openbook.php?isbn=0309069483.

Nuttle, W. (2011). *Ecosystem Services Definied for the South Florida Coastal Marine Ecosystem*. 7. MARES. Available at http://sofla-mares.org/docs/MARES_White%20Paper%207_20110412.pdf.

Obreza, T., Clark, M., Boman, B., et al. (2010). *A Guide to EPA’s Numeric Nutrient Water Quality Criteria for Florida*. SL316. Gainesville, FL: Institute of Food and Agricultural Sciences. Available at http://edis.ifas.ufl.edu/pdffiles/SS/SS52800.pdf.

Stanton, E.A. (2010). “Negishi welfare weights in integrated assessment models: the mathematics of global inequality.” *Climatic Change* 107, 417–32. DOI: 10.1007/s10584-010-9967-6.

U.S. Census Bureau (2006). “ACS 2006 Data Release.” Available at http://www.census.gov/acs/www/.

U.S. Department of Labor (2012). “Consumer Price Index: All Urban Consumers.” Available at ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt.

U.S. Environmental Protection Agency (2010). *Economic Analysis of Final Water Quality Standards for Nutrients for Lakes and Flowing Waters in Florida*. Washington, D.C.

U.S. Environmental Protection Agency (2009). *Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category*. EPA-821-R-09-012. Washington, DC: United States Environmental Protection Agency.

U.S. Environmental Protection Agency (2004). “National Pollutant Discharge Elimination System (NPDES) Glossary.”

U.S. EPA, O. of W. (2012a). “Nutrient Pollution: The Effects.” Available at http://www.epa.gov/nutrientpollution/effects/index.html.

U.S. EPA, O. of W. (2012b). “Nutrient Pollution: The Problem.” Available at http://www.epa.gov/nutrientpollution/problem/index.html.

Vargo, G.A., Heil, C.A., Fanning, K.A., et al. (2008). “Nutrient availability in support of Karenia brevis blooms on the central West Florida Shelf: What keeps Karenia blooming?” *Continental Shelf Research* 28(1), 73–98. DOI: 10.1016/j.csr.2007.04.008.

Walsh, R.G., Loomis, J.B. and Gillman, R.A. (1984). “Valuing Option, Existence, and Bequest Demands for Wilderness.” *Land Economics* 60(1), 14–29. DOI: 10.2307/3146089.

Westbrick, J.A. (2008). “Cyanobacterial toxin removal in drinking water treatment processes and recreational waters.” In *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs*. Advances in Experimental Medicine and Biology. Springer Press, pp. 275–90.

Yentsch, C.S., Lapointe, B.E., Poulton, N. and Phinney, D.A. (2008). “Anatomy of a red tide bloom off the southwest coast of Florida.” *Harmful Algae* 7(6), 817–26. DOI: 10.1016/j.hal.2008.04.008.