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Valuing the Potential Benefits of Water Quality Improvements in Watersheds Affected by Non-Point Source Pollution

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Academic Editor: Kelly T. Morgan
Received: 21 January 2016; Accepted: 11 March 2016; Published: 23 March 2016

Abstract: Nonpoint source (NPS) pollution has been identified by the US Environmental Protection Agency (EPA) as "the nation's largest water quality problem". Urban development, septic systems, and agricultural operations have been identified as the major sources of diffuse pollution in surface and ground water bodies. In recent decades, urban and agricultural Best Management Practices (BMP) have been developed in several states to address agricultural water quality and water use impacts, including the reduction of nutrient loads to help meet water quality standards. Compliance with BMPs is associated with some costs to local governments, homeowners, and agricultural operations, but the improvements in water quality associated with BMP adoption are expected to yield significant benefits to society in the form of improved recreational opportunities, navigation, flood control, and ecosystem health. The development of sound policies and decision making processes require balancing the costs of BMP adoption to the agricultural operations with the social benefits to be derived from the improved water quality. In this paper we develop a benefits transfer model to provide estimates of the economic benefits of properly implemented and effective Best Management Practices (BMP) throughout the state of Florida. These benefit estimates can be used in a cost-benefit framework to determine the optimal level of BMP adoption throughout the state of Florida and provide a framework for other regions to estimate the potential benefits of BMP-mediated water quality improvements.

Keywords: water quality; benefit transfer; meta-analysis; best management practices

1. Introduction

1.1. Nonpoint Source Pollution and BMP Adoption

Nonpoint source (NPS) pollution has been identified by the US Environmental Protection Agency (EPA) as "the nation's largest water quality problem" [1]. Urban development and agricultural operations have been identified as the major sources of diffuse pollution in surface and ground water bodies [1]. While the Clean Water Act (CWA) is the primary law for addressing water quality in the United States, only industrial point sources of pollution are directly regulated at the Federal level. The goal of the CWA is to protect and restore water quality to the nation's water bodies so as to attain goal of the "fishable and swimmable" status in all surface waters of the United States. To accomplish this, individual states are charged with designating uses for their waterways and with establishing water quality criteria based on those uses. Similarly, Section 303 of the CWA established the Total Maximum Daily Load (TMDL) program that requires states, territories, and authorized tribes to monitor water quality and develop measures to curb the problem of NPS pollution [2]. Urban and agricultural Best Management Practices (BMP) have been developed in several states to address water quality and water use impacts, including the reduction of nutrient loads to help meet TMDLs [3]. However, compliance with BMPs may result in significant costs for local governments, homeowners, and agricultural operations.

Sound policy development and decision making require balancing the costs of BMP adoption to agricultural operations with the economic and environmental benefits for society as a result of improved water quality. In this paper, we conduct a meta-analysis of the non-market valuation literature focused on water quality improvements in the United States, and use this meta-analysis to estimate benefits transfer functions for the economic benefits associated with water quality improvements. We use these benefit transfer functions to estimate the potential economic benefits of water quality improvements that would result from the adoption and successful implementation of effective BMPs throughout the state of Florida. The estimated benefits vary across counties due to differences in incomes, population density, urbanization, and the presence of coastline. We also control for various methodological differences of the original non-market valuation studies.

Reduction in NPS pollution can be expected to yield significant benefits for society in the form of improved water quality in the nation's surface and ground water bodies. For example, improvements in surface water quality are likely to result in improved recreational opportunities, navigation, and flood control and ecosystem health [4]. In Florida, reductions in NPS pollution will likely improve water quality in springs, creeks, rivers, lakes, estuaries, bays and throughout the coastline in all regions of the state. In addition to improvements in ecosystem health, these improvements will benefit a wide range of constituents of water bodies, including recreational users, owners of adjacent property, and individuals who hold passive or non-use value for the water bodies themselves.

A cost-benefit analysis of agricultural BMPs, TMDLs, and other programs designed to curb NPS pollution requires the valuation of the benefits resulting from these programs [5]. Traditionally, these benefits are estimated through the use of non-market valuation techniques such as contingent valuation [6,7], travel cost models [8], and hedonic pricing [9]. While these techniques can provide reliable estimates for the economic benefits of improvements in environmental quality, the estimates they provide are specific to the local site characteristics and quality improvement defined in the study. Extrapolation of benefit estimates to other locations or consideration of different types of quality improvements is possible through the use of the benefits transfer method [10].

Simply put, benefits transfer is the use of existing non-market valuation studies to estimate the benefits of changes in environmental quality at a location that bears some resemblance to that in which the original studies were conducted. In this framework, the locations in which the original studies were conducted are known as "study sites", while the location under consideration for the transfer of benefit estimates is known as the "policy site".

Benefit transfer is commonly used in legal proceedings and government policy analyses in cases with insufficient time or funding to conduct a primary valuation study. Early studies using the benefits transfer methodology focused on a few original research studies dealing with quality changes and initial resource conditions that were very similar to those of the policy site [11]. While the benefits transfer methodology was commonly used during the 1980s, procedures and protocols for its use were not formalized until the early 1990s [10]. Three main types of benefit transfer studies include unit or fixed value transfer [12], transfers adjusted using expert judgment [13], and function transfer [14].

One of the biggest criticisms of the benefits transfer approach is that it lacks a micro-level theoretical foundation. Study site estimates of the benefits from changes in environmental quality depend on the estimated demand functions, which in turn depend on the specific site attributes as well as preferences and demographic characteristics of the population. However, site attributes, individuals' preferences, and demographic characteristics are likely to differ substantively between the study and the policy sites [15]. Similarly, while demographic and other characteristics may be similar between the study and policy sites, the change in environmental quality considered in the study sites may differ dramatically from that considered in the policy site, a problem known as commodity inconsistency. A third problem with benefits transfer is that the transfer process itself may introduce a measurement error, thereby aggravating any existing measurement error in the original studies [10].

Several of the shortcomings of the benefits transfer methodology are addressed by the use of meta-analysis, where benefit estimates and other characteristics of the study site and population are combined across many studies. Specifically, a database of studies that includes environmental quality changes, estimated benefits, study type, physical characteristics of the study site, among other attributes, is constructed. This database is then used to estimate a valuation function that relates willingness to pay across studies to attributes such as extent of environmental quality changes, the type of study, physical characteristics of the site, and demographics of the surveyed population. By doing so, meta-analysis takes into account systematic variations in willingness to pay caused by differences in site attributes, preferences, and demographic characteristics, as well as differences in the extent of environmental quality changes considered or methodological characteristics of individual studies. Accounting for these systematic variations represents a major improvement over the single study benefits transfer approach. In this study, we refer to this meta-analysis database as meta-dataset.

The estimated function is used to transfer benefits to policy sites by plugging in the policy site characteristics to the function and using the predicted values of benefits—or willingness to pay—as an indicator of the value of the environmental quality change at the policy site. In addition, Smith *et al.* [16] proposed a preference calibration or structural benefits transfer method in which the researcher specifies a preference or utility function to describe an individual's choices over a set of market and non-market goods. Although meta-analysis and the use of the transfer functions might alleviate the similarity requirement across policy and study sites, similarities over populations, resources, markets and other site attributes are still important determinants for the validity and reliability of the benefits transfer studies [17]. In addition, while various classical and Bayesian statistical approaches have been used to develop benefits transfer functions using meta-analysis, the reliability of the approach still remains somewhat of an open question [18]. Lastly, it is important to note that the quality of any meta-analysis function transfer study depends directly on the quality of the primary studies used for the analysis.

Meta-analyses of the non-market valuation literature have been previously used to develop benefits transfer functions for several types of environmental services, including outdoor recreation, wetlands restoration, and water quality improvements. For instance, Smith and Kaoru [19] conducted a meta-analysis of the travel cost recreation demand studies and estimated several benefits transfer functions for recreation-related economic benefits and found that benefits estimates vary systematically due to the variation in site and study attributes. Walsh, Johnson, and McKean [20] also developed a benefits transfer meta-analysis of outdoor recreation demand in the United States, and provided guidance to improve future efforts in information or benefits transfer. Similarly, Rosenberger and Loomis [18] conducted a meta-analysis of outdoor recreation demand studies and estimated benefits transfer functions, which were tested for in-sample convergent validity. Ghermandi *et al.* [21] developed a meta-analysis and estimated benefits transfer functions for the benefits of man-made wetlands across several countries, and standardize measures of willingness-to-pay using purchasing power parity (PPP). Similarly, Adusumilli [22] conducted a meta-analysis of wetlands mitigation studies in the United States and estimated the benefits of wetlands mitigation across the contiguous United States. Johnston and Thomassin [10] conducted an international meta-analysis to estimate the benefits of water quality changes affecting aquatic life habitats in Canada, based mostly on primary studies from the United States.

The rest of this paper is organized as follows. Next subsection summarizes the legal and policy framework for agricultural best management practices in Florida and provides information about water quality in Florida's water bodies. The meta-analysis database and some important insights from the covered articles are provided in Section 2. The definition of changes in environmental quality and the use of a water quality ladder as the basis for this measure are described in the following subsections, and we introduce the estimation method and describe the important variables. Our results are reported in Section 3, and the paper concludes with the discussion of the implications of our results for stakeholders, policy makers and the future improvement prospects for BMP development.

1.2. Water Quality and Agricultural Best Management Practices in Florida

With over 100,000 miles of rivers, streams, canals, and ditches, more than 1000 springs, over 1.8 million acres of lakes, reservoirs, and ponds, and 1197 miles of coastline Florida is a state rich in surface waters [23]. However, a large proportion of the state's surface waters are impaired due to water quality concerns (Figure 1), and non-point source pollution is responsible for more than half of the total pollution load entering surface waters [23]. The Florida Department of Environmental Protection (FDEP) is the state counterpart to the US EPA and is the lead state agency implementing the provisions of the CWA. As such, the FDEP plays a major role in the permitting process for point sources of water pollution and in the restoration of water bodies impaired by non-point source pollution.

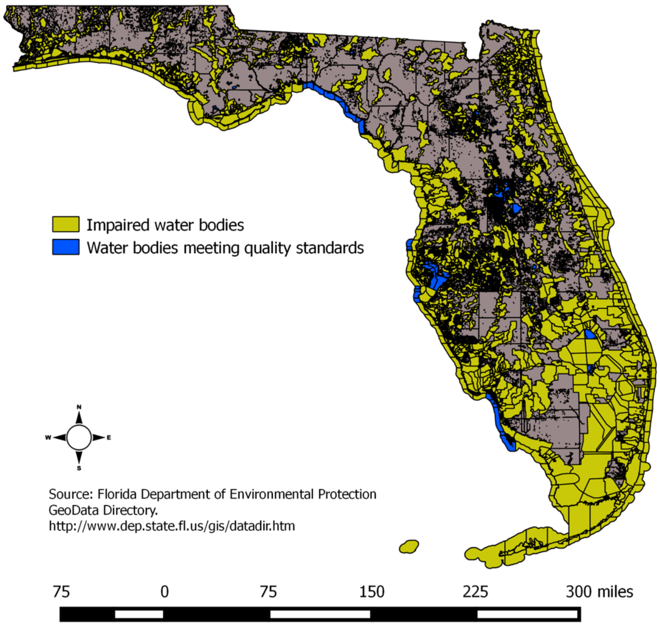

Figure 1. Impaired surface water bodies of Florida.

In Florida, management of NPS pollution is achieved through a water-basin specific planning and implementation process that begins with the assessment of the water bodies for water quality impairment. Impaired water bodies are then prioritized for development of TMDL's, and specific TMDL's for a variety of pollutants—particularly nutrient and bacterial pollutants—are consequently developed for water bodies according to this priority ranking. In essence, a TMDL specifies the amount of a particular pollutant that a water body can assimilate while maintaining the quality necessary to support its intended use. Once this process is complete, water bodies with established TMDL's are prioritized once again for development of watershed management plans, also known as Basin Management Action Plans (BMAP's). Up to this point, the process is of a technical nature and is carried out exclusively by FDEP staff, but public input is sought out and incorporated on the prioritization scheme [23].

The development and implementation of BMAP's involves a gamut of state and regional agencies and private entities such as the Water Management Districts, the Florida Department of Agriculture and Consumer Services (FDACS), local Soil and Water Conservation Districts, environmental groups, regulated entities, and affected pollution sources. The BMAP is a watershed's "blueprint for watershed restoration" and may include permit limits of wastewater facilities, urban and agricultural BMP's, conservation programs, and financial assistance for the private entities or local governments, among other strategies to reduce pollution loads. Once a BMAP is adopted it becomes a legally binding plan, and implementation of this plan includes water quality monitoring to track progress toward the achievement of the TMDL's.

Urban and agricultural BMP's are a major component of most BMAP's. Construction activities, impervious surfaces, residential yards, golf courses, and septic systems are major contributors to pollution in urban stormwater. Similarly, a variety of agricultural activities contribute to NPS pollution, including pesticides and fertilizers used to grow crops, sediment from timber harvesting and transportation, manure from livestock operations and effluent from aquaculture ponds and tanks. Broadly speaking, the two main types of BMP's used to reduce diffuse pollution are structural and management BMP's [24].

Structural BMP's generally involve the installation or construction of structures or changes to the landscape, and, as such, their implementation is easily verified and monitored. These BMP's may be as simple as the installation of fences to keep livestock away from water bodies or the planting of vegetated buffers around waterways, or as intricate as the construction of artificial wetlands or retention ponds. Similarly, structural BMP's may include the upgrade of septic systems, changing the contour of the landscape, or the installation of water control structures. To foster the adoption of structural BMP's, state agencies, such as the FDEP and FDACS, offer cost-share, grants, and similar financial incentives to private entities and local governments required to adopt or install these types of structural changes [24].

Management BMP's generally involve subtle changes in agricultural or landscaping practices. Since these types of BMP's are associated with predominantly behavioral changes on the part of agricultural producers or homeowners, they are difficult to verify and to monitor. Improved nutrient management, where farmers adjust fertilizer type, amount, placement, and timing as a result of soil and tissue testing is one example of a management BMP. Other examples of management BMP's include conservation tillage, planting cover crops, use of rotational grazing, and use of drip irrigation [24].

FDACS publishes a series of BMP manuals that identify the best practices for agricultural, silvicultural, and aquacultural operations. Producers who voluntarily adopt BMPs undergo an on-site assessment to identify the particular BMP's applicable to each operation and sign a notice of intent to implement these structural or management changes [24]. Producers who complete this process may be eligible to receive financial assistance for BMP adoption, but most importantly they are granted presumption of compliance with the requirements of the CWA.

2. Materials and Methods

2.1. Data

We conducted a literature review of the peer-reviewed and other high quality studies that estimate the non-market benefits of water quality improvements in the United States. Thus far, we have identified 39 related studies that use the contingent valuation method or choice experiments, six that use the hedonic pricing method, and nine that use the travel cost method. Our meta-analysis dataset includes 19 studies, all of which use contingent valuation or travel cost to value water quality improvements (Table 1). The methodologies, respondent demographics, study area characteristics, type of water quality improvement, and estimated willingness to pay associated with the water quality improvements were recorded and a dataset of studies was created (Table 1). Each individual estimate of willingness to pay or related welfare measure found in these studies constitutes one observation in the meta-dataset. To ensure that all estimates of willingness to pay are commensurate, they were converted to 2014 dollars using the Consumer Price Index (CPI). The database contains 89 observations, as the number of estimates from studies range from 1 to 20 (Table 1).

Table 1. Studies on water valuation used in meta-analysis.

Study	Survey Year	State	Number of Estimates	Water-Body Type	Methodology	WTP Range (2014 Dollars)
Azevedo *et al.* [25]	2000	IA	2	Freshwater lake	CVM	113.34–566.69
Berrens *et al.* [26]	1995	NM	3	Stream	CVM	43.28–135.11
Bhat [27]	1996	FL	4	Florida keys	Travel Cost	295.09–424.47
Boyle *et al.* [28]	1990	AZ	12	River	CVM	195.05–1560.38
Carson and Mitchell [7]	1990	N/A	20	Freshwater	CVM	123.00–643.13
Carson *et al.* [29]	1994	SC	1	Saltwater coastal system	CVM	86.14
Cordell and Bergstrom [30]	1989	NC	4	Freshwater reservoirs	CVM	77.24–139.02
Duffield *et al.* [31]	1988	MT	8	Freshwater river	CVM	93.18–1584.01
Eiswerth *et al.* [32]	2004	WI	1	Freshwater lake	Travel Cost	55.06
Farber and Griner [33]	1996	PA	6	Freshwater stream	Choice Experiments	5.5–161.51
Herriges and Shogren [34]	1993	IA	6	Lake	CVM	66.60–223.56
Huang *et al.* [35]	1995	NC	8	Sounds	CVM	120.05–127.97
Lipton [36]	2001	MD	4	Bay	CVM	17.08–52.66
McKean *et al.* [37]	1998	ID	2	Freshwater river	Travel Cost	18.53–21.44
Murray *et al.* [38]	1998	OH	3	Freshwater lake	Travel Cost	17.18–23.31
Park *et al.* [39]	1996	FL	1	Keys	CVM	468.45
Shrestaha *et al.* [40]	2001	FL	1	Freshwater river	Travel Cost	41.89
Stumborg *et al.* [41]	2001	WI	1	Freshwater lake	CVM	458.42
Whitehead *et al.* [42]	1995	NC	2	Sounds	Travel Cost	79.09–101.40

During the data collection process we have realized that a large majority of the peer reviewed non-market valuation literature on water focuses not only on providing valid estimates of willingness to pay for water quality improvements, but also on the methodological issues associated with valuing changes in environmental quality. Therefore, it is not uncommon to find studies that present a dozen or more estimates for the same site under slightly different quality scenarios, or even for the same site and scenarios but different estimation techniques. For instance, our dataset includes results from journal articles focused on the methodological problems in contingent valuation, such as question ordering and respondent experience [28], estimation with ordinary least squares *versus* maximum likelihood [7], and starting point bias [34].

2.2. Ensuring Commodity Consistency: A Variation of the RFF Water Quality Ladder

Another challenge in the creation of the meta-analysis database is the variety of water quality scenarios encountered across the reviewed studies. While several authors used the water quality ladder developed by Resources for the Future—also known as the RFF water quality ladder—other authors use other pollution indices or simply focus on recreational fishing catch rates [43]. To deal with this problem of commodity inconsistency, it was imperative that a common currency of water quality states of the world and changes be established.

We use a variation of the RFF water quality ladder (Figure 2) to develop a common currency of water quality states and changes across studies. Several of the reviewed studies already used the RFF ladder's water quality states and numeric indicators (*i.e.*, 0 = not safe for human use; 2 = boatable; 5 = fishable; 7 = swimmable; 9 = drinkable), hence no adaptation was required and the water quality states were coded using the RFF ladder as a guide. However, a number of other studies used different water quality criteria based on severity of pollution [33], and quality of recreational fishing [31,34]. We therefore created the mapping guide illustrated in Figure 2 to include these variations in water quality scenarios, and coded the different water quality states in the meta-database accordingly.

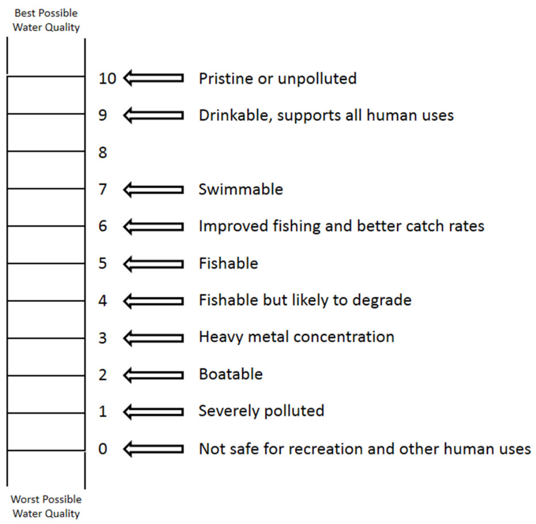

Figure 2. Water Quality Ladder.

To characterize a change in water quality, both the baseline state and the end or goal state must be specified. However, another perhaps more informative way to characterize a water quality change is by its magnitude. Therefore, after developing the water quality ladder shown in Figure 2 and mapping the water quality baseline and end states specified in the varied studies, we also created a variable that characterizes the size of the water quality change. We do so by subtracting the baseline state from the end or goal state. This allows us to characterize a water quality change by its magnitude and its location in the ladder.

2.3. Model Specification

The basic premise of benefits transfer using meta-analysis is that there is an underlying distribution of willingness to pay for changes in environmental quality that varies systematically due to factors such as the magnitude of the change, the baseline level of environmental quality, and the uses supported by the environmental commodity in question, as well as preferences and demographic characteristics of the population. In this framework, individual estimates of the value of changes in water quality represent points in that distribution. A sample of these points can then be obtained through the careful review of water quality valuation studies, and a valuation function for improvements in water quality across all ranges of quality changes can be estimated using this sample.

It can be expected that various characteristics might be associated with the non-market value for water quality improvements [44–46], and that these characteristics can be identified through estimation of a valuation function. The independent variables in such a function should include the characteristics of the resource, site, study type and affected population in the regression that are hypothesized to explain observed variation in the dependent variable [47]. We define this valuation function as follows:

$$\mathrm{WTP} = \mathrm{f}(q^{\circ}, q^{\Delta}, d, l, m) \tag{1}$$

where q° is a vector that represents the baseline level of water quality, q^{Δ} is a vector representing the change in water quality, d represents demographic characteristics of the population including income, l represent characteristics of the study site and resource such as the source of pollution that is impairing water quality, and m represents the methodological characteristics of the primary studies. This function provides the basic conceptual foundation for constructing a benefit transfer function to predict values for defined changes in water quality (Non-market valuation is based on the utility maximization theory that is central to the economics of consumption. However, utility is unobservable and very difficult—if not impossible—to quantify. Therefore, non-market valuation methods attempt to measure willingness to pay as an observable variable that results from the maximization of utility by individual consumers of natural assets such as water bodies).

The variables included in our estimated valuation function are listed in Table 2. Both the baseline level of water quality and the change in water quality are included. The demographic characteristics included are average income of the respondents or the population in the study area, and population density in the affected area. As site or resource characteristics we include a variable that indicates if the pollution that impairs water quality in the site is from point and non-point sources. We also control for a variety of methodological characteristics of the study such as estimation technique (OLS, logit or others), sampling method (in person, mail or phone), elicitation format (single bounded dichotomous choice or other), type of payment vehicle (taxes *vs.* others), dimension of the payment vehicle (one time individual payment or multiple annual payments), and statistic used to report willingness to pay (mean *vs.* median), as well as the proportion of survey respondents from each study who reported being users of the water body whose water quality was being valued.

We opt for the semi-log functional form proposed by Johnston, *et al.* [45] since its statistical performance and ability to capture curvature in the valuation function are recommended elsewhere in the meta-analysis literature [10]. A special characteristic of this form is that it allows the independent variables to influence willingness to pay in a multiplicative rather than an additive manner. Therefore, the dependent variable used is the natural log of the willingness to pay estimates for changes in water quality, while all independent variables are included in linear form.

Table 2. Meta analysis variables and descriptive statistics.

Variable	Description	Units and Measurement	Mean	Standard Deviation
Ln WTP	Natural log of willingness to pay for 2014 dollars.	Natural log of WTP values in dollars	4.56	0.98
Water quality difference	The target change in the water quality defined by Resources of Future.	Water quality ladder units (Range: 0 to 10)	1.85	2.06
Water quality base	The base water quality defined by Resources of Future.	Water quality ladder units (Range: 0 to 10)	4.30	2.19
Income	Per capita income for 2014 dollars; collected from the studies if mentioned or from U.S. Bureau of Economic Analysis.	US dollars (Range: 18,825 to 76,422)	41,761.17	12,839.44
Population density	Population density of study area; collected from the studies if mentioned or from U.S. Census Bureau.	Population per square km (Range: 0.6 to 1000.7)	189.36	239.48
Urban areas	Indicator for accessibility of the water body through urban areas.	Binary (Range: 0 to 1)	0.63	0.49
Water body type (freshwater)	Indicator for water body type as a freshwater.	Binary (Range: 0 to 1)	0.75	0.43
Pollution source	Indicator for non-point and point source pollution present.	Binary (Range: 0 to 1)	0.39	0.49
Estimation method	Indicator of estimation of WTP function using CVM.	Binary (Range: 0 to 1)	0.79	0.41
Elicitation format	Indicator of single bounded dichotomous choice.	Binary (Range: 0 to 1)	0.62	0.49
WTP dimension	Indicator of payment as a single time event by each individual.	Binary (Range: 0 to 1)	0.74	0.44
Payment vehicle	Indicator of tax increase as payment vehicle.	Binary (Range: 0 to 1)	0.45	0.50
Users	Indicator for users of water body in the sample.	Percentage (Range: 0 to 100)	89.91	25.20

3. Results

The model is estimated with ordinary least squares regression, and our preliminary results show a well-behaved valuation function. Regression results are shown in Table 3. The R-square shows that the variables explain 71% of the variation in willingness to pay estimates, which is higher than the median R-square value of 0.44 reported by Nelson and Kennedy [47] in their assessment of meta-analyses in the literature. Collinearity and multicollinearity would be problematic in meta-analysis; therefore, we check correlation of the variables to address this issue (Table S1). Although none of the correlations are over the critical value of 0.80, we use Tolerance test for some key variables for multicollinearity. We do not detect collinearity or multicollinearity in the estimation. Eleven of the 13 estimated coefficients are statistically different from zero at the 10% level or higher. Furthermore, the coefficients associated with water quality difference, population density, urban areas, payment vehicle, and users' percentage in surveys are statistically significant at the 1% level. Similarly, the coefficient associated with the baseline water quality, water body type, and estimation method (CVM) are statistically significant at the 5% level, while income and pollution source are statistically significant at the 10% level.

Table 3. Estimated Coefficients.

Variable	Semi-Log Estimation	Standard Errors
Intercept	4.615 ***	1.014
Water quality difference	0.201 ***	0.045
Water quality base	−0.249 **	0.104
Income	0.000021 *	0.000012
Population density	−0.003 ***	0.000
Urban areas	1.621 ***	0.362
Water body type (freshwater)	−0.984 **	0.407
Pollution source (non-point)	−0.900 *	0.475
Estimation method (CVM)	0.725 **	0.286
Elicitation format (multi DC)	0.139	0.252
WTP dimension (individual one-time)	0.014	0.341
Payment vehicle (tax)	−1.582 ***	0.365
Users	0.024 ***	0.003
R^2	0.71	
Log likelihood value	−60.68	

***: 1% significance level; **: 5% significance level; *: 10% significance level.

All the signs of the significant coefficients are as expected. For instance, the coefficient associated with baseline water quality is negative and the water quality difference is positive. These coefficients show that as water quality improves, willingness to pay for further improvements also increases. In other words, improvements in water quality near the top of the ladder have a higher value than those at the bottom of the ladder. Our results show that elicitation format and WTP dimension (individual one-time) do not affect the WTP level since the coefficients of these variables are not statistically different from zero.

Our results also show a unique effect that urbanization and population density have on estimated willingness to pay for water quality improvements. The relatively large, positive coefficient for urban areas implies that individuals and households in urban areas are on average willing to pay higher amounts for improvements in water quality. However, the small, negative coefficient on population density implies that more heavily populated areas are on average less willing to pay for improvements in water quality. Taken together, these two coefficients imply that while residents of urban areas are willing to pay more for water quality improvements, their willingness to pay decreases as cities get more heavily populated. In other words, residents of small urban areas are on average willing to pay more for water quality improvements than their counterparts in large urban areas.

Another striking feature of our results is the strong relationship between the type of water body valued and willingness to pay for improvements in water quality. As shown by the relatively large, negative coefficient on the indicator for freshwater, people's willingness to pay for water quality improvements for freshwater is on average smaller than for saltwater. The implication is that people living in coastal areas are likely to have a higher willingness to pay for water quality improvements than their inland counterparts.

We use the estimated valuation function to forecast the willingness to pay for a water quality improvement from level 5 (fishable) to level 7 (swimmable) for residents of each of Florida's 67 counties (Table S2; Figure 3). This 2 point magnitude improvement is representative of the types of improvements needed to restore water quality in surface water bodies impaired by fecal coliforms or heavy nutrient pollution where fish are able to survive, but the water is not safe for other recreational uses such as swimming. To forecast willingness to pay, we assume that water pollution in all counties comes from point and non-point sources (pollution source = 1), that the estimates would be obtained through contingent valuation (CVM = 1), and the elicited payment vehicle would be taxes (tax = 1). In addition, we assume that 90% of individuals in the county are direct users of the waterways, which is in line with recent surveys that have found outdoor recreation participation rates in Florida as high as 96% and 63% of Floridians participating in beach activities [48]. Median income, population density, and indicators for urban areas and inland areas (freshwater) are allowed to vary for each county.

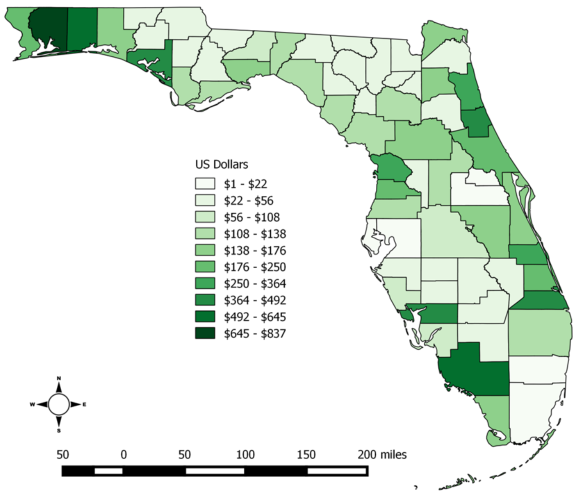

Figure 3. Individual WTP by counties for an improvement from level 5 (fishable) to level 7 (swimmable) in the state of Florida.

The map showing willingness to pay for the specified water quality improvement shows predominantly higher values in coastal areas of the state, with the notable exception of southeast Florida (Miami-Dade and Broward counties), the Tampa Bay area, and the Jacksonville area. While these are all coastal areas, they are also the most heavily populated areas of the state—along with the Orlando area in Central Florida. In these regions, the negative effect of population density overtakes the positive effects of urban areas and saltwater. In contrast, the largest values are found in the coastal counties of the Western Florida panhandle, where a combination of small urban areas with low population density and presence of saltwater result in high forecasted values of willingness to pay for water quality improvements. Relatively high values of willingness to pay are also found in coastal Southwest Florida and coastal East Florida (with the exceptions mentioned), where small coastal cities are predominant.

The forecasted individual estimates of willingness to pay can also be combined with the number of households in each county to construct an estimate of total willingness to pay for the specified water quality improvement per county (Table S2). The largest overall values are found in areas where high forecasted individual willingness to pay combine with large number of households. This is the case of Palm Beach County, where a relatively large individual estimate of $127.69 combined with more than half a million households results in a forecasted total willingness to pay for improvements in water quality of $67.6 million. Statewide, the forecasted total willingness to pay for the specified improvement in water quality is close to $803 million. While our forecasted willingness to pay refers to the willingness to pay for each individual, we use the number of households to obtain a conservative estimate of the statewide willingness to pay for water quality improvements.

4. Discussion

Our results suggest that benefits transfer using meta-analysis is a useful tool for developing estimates of the value of water quality improvements. Specifically for our policy site—the 67 Florida counties—we developed estimates that can be taken as "ballpark" estimates of willingness to pay for the water quality improvements ranging between 4 cents and $837 per person per year, for an improvement in water quality from level 5 (fishable) to level 7 (swimmable). This range represents the variation in expected willingness to pay across different counties in Florida and is not a confidence interval for the expected willingness to pay for the average resident of Florida. The large range is due to differences in population density, proximity to saltwater, designation as an urban area, and median household incomes. When multiplied by the number of households in each county, these estimates imply a statewide willingness to pay of $803 million for such an improvement in water quality. In essence, this represents a conservative estimate of the maximum cost of statewide BMP implementation that would still pass the cost-benefit test; statewide BMP implementation beyond this cost threshold would result in net losses to Floridians.

Our estimated model also allows the development of alternative estimates under different proportions of users of water bodies in the population and different payment vehicle scenarios. For instance, changing the assumed proportions of users of water bodies in Florida's population will have a major impact on the expected willingness to pay for improvements in water quality across all counties. The individual willingness to pay, when extrapolated across the number of households in Florida, ranges from $391 million when the assumed proportion of users is 60%, to $1.02 billion when the assumed proportion of users is 100% (Table S3). Similarly, holding the assumed proportion of users of water bodies at 90% but allowing for a payment vehicle other than taxes raises the expected willingness to pay across all Florida households to $3.9 billion.

Implementation of water quality standards and achievement of restoration goals is likely to be an expensive undertaking. Having at least a ballpark estimate of the expected benefits of implementing these standards and achieving these goals can give policymakers an indication of how stringent the standards or how lofty the goals need to be in order to yield overall gains to social well-being. The estimates presented in this study can give policymakers a starting point in this discussion.

However, it is important to note that even the $1.6 billion total willingness to pay estimate is likely to be an underestimate of the overall willingness to pay of Floridians for meeting the water quality goals set by the FDEP. In the first place, we are calculating the total willingness to pay using the number of households, when the number of individuals in the workforce is a more appropriate number to use for this extrapolation. In addition, our estimates are based on studies that sought to value improvements in water quality at the local level, and the possibility that individuals can hold values for water quality improvements in other regions of the state is not accounted for. Similarly, our estimate does not take into account Floridians' willingness to pay for restoration of unique wetlands such as the Everglades.

Most of the studies we have included in the dataset were published in the 1990s, in addition to a few from the late 1990s and the 2000s. The latest article we have included thus far was published in 2007. While we have included work from a variety of authors, some that appear in multiple publications include Richard Carson, Robert Mitchell, Kevin Boyle, and John Bergstrom. While these are some of the preeminent names in non-market valuation, we take the exclusion of other notable authors as an indication of further opportunities to expand our meta-dataset. Additionally, a majority of the articles in the database were published in the Journal of Environmental Economics and Management, Marine Resource Economics, and Water Resources Research, all of which are very selective and probably take methodological improvements as a requirement for publication. This study only focuses on the non-market valuation for U.S. surface waters, therefore, we do not include recent publications which use similar methodologies but focus on different countries [49,50].

Perhaps the most challenging aspect of a meta-analysis of water quality is the difficulty in finding a common currency of water quality improvements. For example, during the data collection process we have encountered significant differences between the Western and Eastern United States. Specifically, most of the studies from the Western United States (particularly the mountain states) seem to focus on water quantity, while those from the Eastern United States and the Midwestern region focus on water quality. Both water quality and water quantity represent "environmental quality" dimensions of hydrological resources, as both can affect recreational fishing catch rates, for instance. Similarly, high levels of flow can aid in the dilution of pollutants, and the same amount of pollution can create significant problems under low flow conditions but be imperceptible under high flow conditions. This is a problem that adds to the commodity inconsistency issue we discuss in Section 4. It is likely that similar problems are to be encountered when conducting meta-analyses of non-market values in other types of natural resources and environmental amenities. While the obvious way to get around this problem is to filter out the studies in the meta-analysis to exclude those that represent incommensurable commodities, this filtering exercise is made difficult by certain nuanced differences between problems that focus uniquely on water quality and those that focus on water quantity, which is inherently, but indirectly tied to water quality.

It is also clear that the studies that use RFF's water quality ladder seem to be the most amenable to benefit transfer because they use a common currency that we can take advantage of. In contrast, it would be very difficult to do a benefit transfer study using the articles with an emphasis on water quantity. Water quantity is generally measured very specifically using physical quantities of flow such as cubic feet per second (cfs). However, the same value of cfs may be related to very different conditions depending on the size of the river. Similarly, it is also difficult to relate physical measures of water quality, such as milligrams per liter or parts per million of a particular pollutant, to an easily understandable level of water quality, such as fishable or swimmable.

While a common currency that is easily understandable and transferrable appears to be a pre-requisite of water quality valuation, it may prove to be the bane of efforts to integrate non-market valuation with the physical sciences. The water quality policy debate, for instance, is now more than ever brimming with benchmarks and goals developed using physical measures of water quality. In Florida, for instance, the debate on water quality improvements centers around numeric nutrient criteria and TMDL's, both of which are physical improvement benchmarks measured in units of nutrient load reductions and total maximum daily loads of specific nutrients. It is difficult for economic analysts and the public at large to relate measures of water quality such as milligrams per liter or parts per million to the straightforward "fishable" or "swimmable' measures, which are likely to be the way most people think of surface water quality.

In addition, it is important to note that willingness to pay is a function of people's preferences, and preferences are shaped through education, the media, and social discourse. It is entirely possible that campaigns designed to raise awareness about the importance of water quality or the benefits of BMPs and other interventions designed to improve water quality can increase the public's willingness to pay for water quality improvements and related interventions. Similarly, greater understanding among the general population about the links between environmental quality, human well-being, and economic growth, can also result in increased willingness to pay for environmental quality in general as well as specific interventions to improve the quality of the environment. Conversely, the relatively low willingness to pay estimates found in this study could be a direct result of a lack of understanding among the public of the importance of environmental quality for human well-being and economic growth, or a lack of understanding of the effectiveness of interventions designed to improve environmental quality.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/8/4/112/s1, Table S1: Correlation Matrix of the dependent and the independent variables. Table S2: Forecasted individual and total willingness to pay for an improvement in water quality from level 5 (fishable) to level 7 (swimmable), by county. Table S3: Sensitivity Analysis for Different Proportion of Water Body Users and for payment vehicle other than an increase in taxes in the Population of Florida.

Acknowledgments: We would like to thank two anonymous reviewers, Tatiana Borisova from the Food and Resource Economics Department at the University of Florida, and the participants of the 2014 SAEA and 2015 AAEA meetings for their useful comments and suggestions.

Author Contributions: Sergio Alvarez and Serhat Asci conceived and designed the experiments; Serhat Asci performed the experiments; Sergio Alvarez, Serhat Asci and Ekaterina Vorotnikova analyzed the data; Sergio Alvarez and Serhat Asci contributed reagents/materials/analysis tools; Sergio Alvarez and Ekaterina Vorotnikova wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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