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A Comprehensive Review of the Evidence of the Impact of Surface Water Quality on Property Values

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Abstract: The desirability of living on or close to water is reflected in sometimes substantial property price premiums. Water quality has an important influence on property prices, since it impacts a water body's appearance, capacity to support wildlife, and recreational potential. As water quality continues to be altered by human use and activity, and in light of new threats posed by projected climate and associated environmental change, understanding the impact of changing quality on property prices, and the associated property tax base, is paramount. This paper reviews the body of evidence on this topic to date. Of the 43 distinct studies represented in the 48 publications reviewed, the expected, statistically significant relationship between water quality and property price was demonstrated in at least one of the models developed in all but two studies. As a whole, they provide convincing evidence that clean water has a positive effect on property values.

Keywords: hedonic pricing; property value; water quality; water pollution

1. A Comprehensive Review of the Evidence of the Impact of Surface Water Quality on Property Values

"We are inspired by water—hearing it, smelling it in the air, playing in it, walking next to it, painting it, surfing, swimming, or fishing in it, writing about it, photographing it, and creating lasting memories along its edge ... We know instinctively that being by water makes us healthier, happier, reduces stress and brings us peace" [1] (p. 10). Water's appeal is consistent with the "biophilia" explanation that Wilson adopted to describe his hypothesis that the deep affiliation humans have with nature stems from their evolutionary biology [2].

There is increasing recognition of a societal trend towards preferring the acquisition of experiences over products. This is manifested in the importance of lifestyle amenities in the decision-making of both individuals and businesses. Places that offer access to natural resource-based amenities such as clean water, and to all the activities and associated benefits that such resources provide, are rapidly proving to have more success in attracting and retaining talented employees and footloose businesses [3,4]. Much nature-based tourism also is based on, in, or near bodies of water; for example, in the US paddle sports such as stand-up paddle boarding and kayaking are among the fastest growing outdoor recreation activities [5].

Water is also a central component of "nature's capital". Pollution adversely impacts the value of water's ecosystem services. This is often underappreciated because residents do not pay for these services, so their valuable role is not part of the collective consciousness. However, they provide a stream of economic benefits such as local habitat preservation, detoxification, increased biodiversity, migratory habitat enhancement, enhanced aesthetics, and increased cultural and scientific opportunities. If these assets are degraded, communities often have to pay for expensive mechanical or remedial systems to perform the services they currently receive at no cost. Alternatively, if pollution in water bodies is improved, then communities will enjoy increased benefits at lower cost.

The attraction of water results in the desire to reside proximate to it. Since the supply of waterfront and water view property is limited and demand is high, there is invariably a premium associated with such parcels. Multiple studies have demonstrated that views of and/or access to oceans, lakes, rivers, streams, and wetlands generate substantial property price premiums. However, those premiums sometimes are modified or removed as a result of less than pristine water quality.

The most thorough and comprehensive analysis of water pollution changes between 1962 and 2004 concluded: "Most types of water pollution in the US have declined." However, the Intergovernmental Panel on Climate Change (IPCC) has noted, "Climate change is projected to reduce raw water quality" [6] (p. 14). This is attributable to a set of interacting factors that include: increasing air and water temperatures; increasing sediment, nutrient, and pollutant loadings from heavy rainfalls; increasing concentrations of pollutants during droughts; and disruption of treatment facilities during floods. According to the Third National Climate Assessment [7], increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts in the US are likely (with a medium level of confidence) to decrease river and lake water quality due to: decreased levels of dissolved oxygen; increased levels of sediment, nitrogen, phosphorus, toxic metals, and other pollutants; and rising numbers of algal blooms. Further, climate change is projected (with high confidence) to reduce the ability of natural ecosystems to improve water quality [8], exacerbating these negative effects.

Given the importance of clean water, the relatively small number of studies addressing this topic is surprising. In 2000 Leggett and Bockstael lamented the "paucity of hedonic water quality studies", describing it as "startling" [9] (p. 142), while more recently, Walsh et al. characterized the hedonic price water quality literature as "somewhat thin, particularly compared to air quality" [10] (p. 7).

This paper reviews empirical studies that have evaluated the influence of water quality on property values. Some studies have been framed to evaluate the negative influence of water pollution, while others have explored the positive influence of alleviating it. Water quality is a multidimensional concept that can be evaluated by a variety of measures. The studies reviewed here are considered in the context of the three dimensions of water quality identified in an early study as being of most concern to proximate property owners and thus most likely to be capitalized into real estate prices: (i) aesthetics, e.g., water clarity, which declines with increasing eutrophication; (ii) capacity to support wildlife, which can vary with levels of dissolved oxygen, temperature and acidity; and (iii) recreational potential for, e.g., fishing, boating and swimming, which might vary with the appearance or smell of a water body, and plant growth within it [11].

The search for materials was extensive, embracing all empirical English-language contributions from all nations, from both the economic and resource/amenities domains, and from both academic and professional sources. Keywords "hedonic", "property price", or "property value", and "water quality" were searched in Scopus, CAB Abstracts, and Google Scholar. Additional citations were sought in the reference lists of this preliminary selection of items. Professional sources that the authors judged to be methodologically sound were included, even though they had not been through a formal review process. The review is divided into four sections: (i) early US studies (published prior to 1984); (ii) US studies conducted between 1984 and 2003; (iii) the most recent US studies (2003–2017); and, (iv) international analyses. For the most part, findings are presented in chronological order, which allows for improvements in the methodological approach to be highlighted. An overview of each study is provided and the methods and key findings across the set of studies is synopsized. A summary table is provided for each section, containing additional information relating to the methods and results associated with each contribution. The paper focuses only on studies that have incorporated one or more measures of water quality. There is a much larger literature on the influence of proximity and access to, and views of, water that is beyond the scope of this review.

2. Early US Studies: 1968–1983

The first reported study of the relationship between property values and water quality was conducted in Wisconsin [12]. Water quality was captured by three dummy variables (poor, moderate, and good) as rated by two local experts. As expected, regression analysis showed that lakefront tract values were higher on lakes with better water quality. Tracts on poor quality lakes saw no premium; tracts on moderate quality lakes saw a statistically significant premium in three of five models; and tracts on good quality lakes saw a significant premium in four of five models.

The first assessments of changes in property values attributable to improvements in water quality as a result of pollution abatement came from the same research team [11,13]. Their studies focused on four sites—San Diego Bay, California; Kanawha River, West Virginia; Willamette River, Oregon; and Ohio River, Pennsylvania—all of which had experienced substantial water quality improvements during the 1960s. The Willamette, for example, was popularly described prior to 1960 as "an open sewer" [13] (p. 761), but between 1960 and 1970 quality was improved as a result of the enhancement of municipal and industrial waste treatment, new discharge regulations, low flow augmentation, and restrictions on withdrawals by agriculture and industry during critical low flow periods. By 1970, the Willamette "met all applicable water standards throughout the year over its entire length" [13] (p. 761). Based on the differential between property values in 1960 and 1970, conclusive regression findings were generated at four of six study sites (two housing areas were considered on the Willamette and Kanawha Rivers). At those four sites, property value increases associated with improving water quality during the study period were calculated for houses 100, 500, 1000, and 2000 feet from the river bank. Though pioneering at the time, the study exhibited several methodological weaknesses, the most serious of which was that water quality per se was not in fact measured and that any/all increases in property value over the time period assessed were assumed to result exclusively from improved water quality [14].

In the only study in this review that did not use some form of regression analysis, the authors attempted to quantify the loss in shoreline property value associated with lack of pollution control in the period from 1950 to 1973 by developing a property value index [15]. They applied it to 1437 waterfront, lakeside (near to but not on the lake), and upland (not near the lake) parcels along Lake Erie (686 properties), and Chautauqua Lake (751 properties). The latter was described as having "experienced far less obvious pollution in the past 25 years" [15] (p. 79) and thus was used as a benchmark against which to estimate the price improvements that might have occurred along Lake Erie had pollution been curtailed. The values of upland parcels increased by similar amounts over the study period (by 256% on Lake Erie and 248% on Lake Chautauqua). The differential was more marked, but not in the expected direction, for lakeside properties (326% on Lake Erie and 255% on Lake Chautauqua). The most substantial differential was for waterfront price increases, which were 188% on Lake Erie but 406% on Lake Chautauqua. The authors argued that the low price gains on Lake Erie were attributable to its high pollution and shoreline erosion, and pointed out that it resulted in a considerably reduced tax base on that lake.

In Pennsylvania, Epp and Al-Ani analyzed 25 small rivers and streams (12 clean, 13 polluted) [16]. The sample comprised 212 owner-occupied residences within 700 feet of one of the streams, sold between 1969 and 1976. They ran a series of regressions on a pooled and then a paired set of samples. Water quality was assessed in two ways: dummy variables representing pH (recognizing that water under pH 5.5 severely limits recreational use) and property owners' perceptions (whether or not owners perceived a quality issue that prevented their use of a stream). In the pooled sample, it was found that increasing water quality had a significant positive impact on adjacent property prices and the signs were in the expected direction when measured by both pH and perception. In the case of pH, a one-point increase (or 17.5% increase from the mean) resulted in a 6.0% increase in the mean sales price. Further, the water quality variable interacted with the variable representing population growth, showing that improving quality was positively related to population growth along good quality streams. As expected, the paired sample demonstrated that in locations near poor quality streams, influences on sales price other than water quality assumed greater importance. Separate analyses of clear and polluted streams revealed that variation in pH had a large and significant effect on property values adjacent to clean streams, but no effect on property values adjacent to polluted streams. The authors explained this finding by suggesting that increases in pH within the normal range (6.5–8.5) had increased value to property owners because it permitted additional recreational activities, such as trout fishing. Increases in pH below the normal range (3.7–5.5 in this study), however, permitted no additional recreational activities and therefore had no value.

Analysis of the sales of 42 residential parcels within one-eighth of a mile of the Housatonic River in western Massachusetts before and after a water pollution abatement program showed an increased value of $37 per acre (1975 dollars). (The parentheses indicate the year in which the dollar amounts were reported. An inflation index has to be used to translate them into current 2018 dollars) [17]. A year later, another study on the same river was used to illustrate the potential limitations of these early hedonic studies [14]. It used multiple models that revealed counter intuitive results. After the water quality of the Housatonic River had been upgraded, a hedonic analysis was conducted to assess the upgrade's impact on property values. Perceptions of a sample of 81 single family home (SFH) sales transactions within 1500 feet of the river revealed that water quality had no significant effect on property values. The authors offered three possible explanations for this result. First, surveys indicated that few of the proximate homeowners were aware of improvements in water quality. Second, there were substitute water bodies nearby with superior water quality. Third, given the limited information processing ability of the human brain and "the multiplicity of objectives that bear on the choice of a home to purchase, it stretches the imagination to believe that preferences for water quality characteristics are accurately reflected in the decision alongside all other arguments of the utility function" [14] (p. 56). Elsewhere in Massachusetts, one of only two studies in this review that focused on coastal beaches reported that the concentration of oil and level of turbidity both had significant negative impacts on median home values across 506 census tracts in Boston [18].

Results of early studies of the impacts of surface water quality on property prices are summarized in Table 1. The positive influence of clean(er) water was indicated in all or a majority of models in six of the seven studies. However, methodological rigor was low relative to later studies that employed more sophisticated modeling techniques. Six of the seven used multiple regression analysis (what is now referred to as hedonic pricing methods). Five used sales price as the dependent variable, the benefits of which relative to assessed or census values have subsequently been documented in the hedonic literature [19,20].

Table 1. Summary of US studies conducted in the period of 1968–1983.

Author (Year) * Refereed	Study Site/Location	Year(s) of Data	Method, Sample Size, (Adjusted) R^2 (as Applicable and Listed)	Dependent Variable(s)	Water Quality Variable(s)
David (1968) *	60 artificial lakes in Wisconsin	1952, 1957, and 1962	Series of linear regressions, 2131 lakefront tracts, 0.20–0.69	Per acre value of land, per acre value of improvements, and number of improvements (all assessed)	Dummy variables to represent poor, moderate, and good quality
Dornbusch and Barrager (1973) Barrager (1974) *	San Diego Bay, CA; Kanawha River, WV; Willamette River, OR; Ohio River, PA	1960 and 1970	Six sets of multiple regressions (one for San Diego Bay, two for Kanawha River, two for Willamette River, one for Ohio River), 0.10–0.72	Change in value of single family residences during study period (based on sales prices and assessed values)	Distance from water front (two forms: linear and inverse proportion)
Fisher, Starler, and Fisher (1976) *	Lake Erie and Chautauqua Lake, NY	1950 to 1973	Property value index based on actual and interpolated sales prices with visual comparison of index values for waterfront, lakeside, and upland parcels across the time period and two study sites, 686 parcels along Erie and 751 on Chautauqua	N/A	N/A
Epp and Al-Ani (1979) *	Small rivers and streams (12 clean, 13 polluted) in PA	1969 to 1976	Four hedonic models, 212 properties within 700 feet of river or stream (93 near a clean stream, 119 near a polluted stream), 0.65–0.74	Log of sales prices of non-farm rural single family houses	Perceived quality (PQ), pH, interaction of PQ/pH with % population change
Feenberg and Mills (1980)	29 beaches (mix of fresh and salt water) in Boston, MA	1970	Hedonic model, 506 census tracts	Log of median values of owner-occupied houses	Concentration of oil and turbidity at nearest beach (both squared over distance)
Rich and Moffit (1982)	Housatonic River in MA	1957–1975	Hedonic model, 42 residential parcels, sales price within 1/8 of a mile of the river	Log of sales price per acre	Pre (n = 31) and post (n = 11) cleanup of pollution
Willis and Foster (1983)	Housatonic River, MA and Winoski River, Montpelier, VT	1962–1980	Multiple hedonic model, 81 or 40 properties within 1500 feet of the river, 0.68–0.78	Sales prices of single family homes	Purchase date relative to improvement in water quality (pre or post)

3. Middle Era US Studies: 1984–2003

In this section, 13 studies are reviewed, 12 of which were conducted in the Northeast or Midwest. Rising pollution levels at St. Albans Bay on Lake Champlain, Vermont, relative to other locations on the lake, were attributed to an inadequate municipal wastewater plant and nonpoint agricultural sources [21]. The result was extensive macrophyte growth and a drop in annual day use from more than 25,000 visits in 1960 to fewer than 5000 by the late 1970s. The effect of the degraded water quality on the values of seasonal homes adjacent to the Bay was incorporated into hedonic models in two ways. First, location on St. Albans Bay was entered as a dummy variable to test the assumption that homebuyers were conscious of the inferior level of water quality and would discount that location accordingly (i.e., any difference in price was assumed to result from decreased water quality). Second, a panel of local experts (planning and conservation professionals, as well as longtime residents) was asked to rate water quality at various points along the bay.

The average property located on St. Albans Bay sold for $4500 (20%) less than a similar property on a different, cleaner stretch of lakefront according to the first measure, generating a total loss of value for the 430 bayside dwellings of $2 million (1981 dollars). The loss according to the subjective measure was only slightly smaller ($4200, or 19%). These figures were then incorporated into a cost-benefit analysis of bay cleanup which was being undertaken under at the time.

Brashares (1985) evaluated the utility of an array of different water quality measures on property prices [22]. From a starting list of 40 variables, he identified just two—turbidity and fecal coliform levels—that were consistently correlated with property prices around 78 southeast Michigan lakes. For lakefront houses, a one standard deviation (SD) change in turbidity from the mean (±4.9 TU) caused prices to vary from about −$82 to −$771 (1977 dollars), while the marginal price of a one SD increase in fecal coliform concentration (20.2 per 100 mL) was −$96 (mean marginal prices were −$426 for turbidity and −$22 for fecal coliform). When canal-front houses were considered, the magnitudes of these prices per one SD change were −$86 for turbidity and −$71 for fecal coliform (mean marginal prices were −$222 for turbidity and −$23 for fecal coliform). The finding with respect to turbidity was considered to be more obvious because turbidity is visible, but Brashares noted that although fecal coliform levels were not visually perceptible, they were readily available to homeowners from local officials.

In California's San Francisco Bay, Kirshner and Moore (1989) compared water proximity premiums at two communities with markedly different water quality: Tiburon, on the North Bay, had relatively clean water, while Foster City on the South Bay had low water quality caused primarily by nutrient, circulation, and pollution problems such as excessively high coliform bacteria counts and high concentrations of multiple heavy metals [23]. A series of four hedonic pricing models showed that the implicit marginal price of water proximity (a location within 100 feet of the waterfront) was $65,000 (1986 dollars) or 20% of the property value in Tiburon and $24,000 or 9% in Foster City. The difference between the two sets of prices was statistically significant, thus supporting the authors' hypothesis that the premium associated with water proximity varied according to the quality of water. This finding differed from other studies that reported decreases in value due to poor water quality, because in this case poor quality only reduced the level of the premium relative to cleaner water. However, the study did not incorporate any direct measures of quality; instead, it used direct proximity (and by definition unobstructed view) as a proxy. An additional limitation may have been a lack of direct comparability between the two communities, which the authors acknowledged but did not perceive to compromise their findings.

The work of Mendelsohn et al. (1992) is somewhat anomalous, both in its focus on a hazardous waste site (the polychlorinated biphenyl [PCB]-impacted harbor in New Bedford, Massachusetts) and the data and techniques employed (residential panel data) [24]. Affected properties were identified according to their location in one of two PCB zones, based on the hazard level of the closest water: zone 1, the inner harbor, where regulations prohibited swimming, fishing, and lobstering, and zone 2, the proximate outer harbor, where there were restrictions on bottom fishing and lobstering.

Findings suggested that properties subject to PCB contamination sold for $7000–$10,000 less than non-contaminated properties, relative to the average sales price of $71,630 (1989 dollars). Use of the panel data approach indicated that the negative effect of PCB pollution on property prices did not emerge until a large proportion of residents became aware of the problem. The authors estimated that the total lost value on all single family properties within the study zone was almost $40 million.

Based on the premise that water quality impacts accrue to land rather than improvements, Steinnes (1992) used a variety of appraisal measures of land value to establish the effect of water clarity (measured using Secchi disk readings) on seasonal use lots across 53 northern Minnesota lakes [25]. His analyses showed that increasing water clarity by one foot added $3384 to the total price of all lakefront lots, $206 to the average price per lot, or $1.99 to the average price per front foot. Steinnes noted the potential drawback of using water clarity as a measure of quality in areas prone to acid rain, which makes lakes appear extremely clear by killing off algal growth.

A series of five studies were conducted at locations in Maine over a five-year period by members of the same research team. In the first, the effect of water clarity (based on Secchi disk readings) was assessed across 22 different lakes in four distinct housing markets, using a sample of 543 lakefront properties sold between 1990 and 1994 [26]. This was the first study to relate clarity to lake area (in markets where area correlated positively with price, clarity was multiplied by area; when the correlation was negative, clarity was divided by area). Based on implicit price equations, the effect of a one-meter improvement in water clarity on average sales price ranged from $11 to $200 per front foot (1984 dollars) across the 22 lakes. The potential effects of one-meter improvements or declines in clarity (relative to the average) on total property prices on three sample lakes were estimated to be $6.5, $9.2, and $49.4 million. When scaled up to the 260 lakes and pond in Maine that did not meet federal water standards at that time, the implications for homeowners and local authorities in terms of lost value were immense.

The second study of 25 Maine lakes in four housing markets (two of which it appears were considered in the previous sample) found that water clarity was statistically significant in all four markets according to two of three specifications (semi-log and Cobb-Douglas) [27]. Again, water quality was related to lake area and it was found that clarity was more important to homebuyers on larger lakes. The study was especially notable because it implemented a second-stage analysis. Average prices of visibility in the four housing markets as estimated by the first-stage functions (measured per meter and computed at the average visibility and average lake size) were: Bangor, $2337; Waterville, $2695; Lewiston/Auburn, $4235; and, Camden, $12,938 (1995 dollars). Graphing of the demand functions for each specification indicated that while the linear and semi-log demand curves intersected the two axes (visibility and the price of visibility) at approximately the same points, the Cobb-Douglas curve increased dramatically below three meters. This was especially relevant because the Maine Department of Environmental Protection (MDEP) had identified three meters as the threshold below which lakes experience significant and typically irreversible quality decline. Results showed that surplus loss associated with reductions in clarity exceeded gain from an equal improvement, i.e., the benefits of protection exceeded those of improvement. The surplus associated with raising visibility from 3.78 m (the average visibility for all Maine lakes) to 5.15 m (the average visibility for Maine lakes without compromised water clarity) was $3765 (semi-log model) and $3677 (Cobb-Douglas model). In contrast, the welfare loss associated with reducing visibility from 3.78 m to 2.41 m (the average visibility for Maine lakes that had compromised water clarity) was $25,388 (semi-log) or $46,750 (Cobb-Douglas).

In their third study, Michael et al. (2000) identified the variables that most appropriately reflected buyers' and sellers' perceptions of environmental quality (rather than simply using the one most readily available to a researcher) [28]. Using the same 22 lakes investigated in their first study, but this time assigned to only three housing markets, the authors incorporated a telephone survey of property owners to identify the measures of water clarity they considered during purchase. Results of the survey were then used to construct nine different clarity variables, related to historical and current clarity levels as well as seasonal changes, each of which was then entered into a series of three hedonic regression models (one for each market).

Five of the nine clarity variables tested were significant and of the expected sign across all three markets; another two variables were significant in two of the three markets. Implicit clarity prices did vary across markets. Though the confidence intervals did sometimes overlap, the proportion of average house price accounted for by water clarity ranged from 5% to 23%, which indicated there was value in dividing large spatial areas into submarkets. Within each market area, differences between implicit prices on the various water clarity measures tested were not significantly different, but they were nevertheless substantial. For example, in one of the submarkets implicit prices using different measures of water clarity ranged from $5246 to $10,430 (1994 dollars). This makes it likely that policymakers may reach a different conclusion with different policy outcomes if any one individual variable is selected for use as a single point estimate in a cost-benefit analysis without consideration of others. The authors concluded that variable selection "should be based on conceptually and theoretically sound logic" [28] (p. 296), as well as reflective of public perception, and "not be based solely on the convenience of available environmental data" [28] (p. 296).

The fourth Maine study addressed the potential disconnect between objective measures and subjective perceptions of water quality, in particular for those variables that are not immediately apparent to the human senses [29]. Objective lake water clarity was measured using traditional Secchi disk readings and was interacted with lake size, while subjective clarity was assessed via 348 mail surveys which asked respondents to estimate the minimum water clarity in the summer their property was purchased; 47% of respondents estimated clarity within one meter of the objective measure, though respondents were more likely to under- rather than overestimate clarity. The authors suggested that this was likely attributable to the property owners not being trained to take into account weather conditions and the refractive and reflective effects of sunlight when viewing water clarity at an angle.

Coefficients on both water clarity variables were significant in two of the four housing markets from which respondents were drawn. In Augusta, the implicit price of water clarity (based on average size lake and average clarity) according to the homebuyers was $2756 (1995 dollars), 6% more than that accorded to the objective measure ($2600); this differential was not significant. In Lewiston, the subjective coefficient ($8985) was 43% higher than the objective one ($6279), a difference significant at the 1% level. The direction of the difference was as expected, i.e., the larger implicit subjective prices seemed likely given homebuyers' tendency to underestimate clarity. Based on the application of the Davidson and MacKinnon non-nested J-test, the authors concluded the equations incorporating objective measures of clarity were better predictors of sales price than the subjective measures. This supported the use of existing data readings over the need to collect primary data. The authors also noted that though homebuyers may not be able to accurately identify water quality on any given lake, they could nevertheless gauge relative differences in water clarity when evaluating lakes on which to purchase a property.

For their final study, the Maine research team used a subset of the properties referenced in the previous study to investigate the influence of the source of property data on the magnitude and significance of the objective water clarity variable [30]. Assessor information on the characteristics of sold properties was obtained from local authorities, while descriptions of the characteristics of those property owners' estimates were elicited from the aforementioned survey. The coefficients on the water clarity variable (interacted with lake area) were significant in all four markets, with implicit prices of water clarity ranging from $2000 to $8000 per meter (1995 dollars). There was convergent validity and no statistically significant differences between coefficients on the clarity variable within each market, i.e., the use of assessor and owner property data produced essentially the same results.

Some dimensions of the Maine studies were replicated by Gibbs et al. (2002) in New Hampshire [31]. The authors noted that "cultural eutrophication [in New Hampshire] due to nonpoint source pollution from humans, has increased the rate of eutrophication, with the change in some of New Hampshire's lakes in the last 50 years equivalent to what took place in the previous 10,000 years" [31] (p. 39). Using a sample of 447 lakefront properties, water clarity (measured using Secchi disk readings and interacted with lake area) was found to have a statistically significant positive impact in all four housing markets tested. The absolute and percentage increases in property prices associated with a one-meter increase in clarity were: $1268 (0.91%) in the Conway/Milton market; $6122 (3.50%) in Winnipesaukee; $4411 (3.39%) in Derry/Amherst; and $11,094 (6.64%) in Spofford/Greenfield (1995 dollars). Differences among the four markets were attributed primarily to variations in average clarity and lake size. The variable designed to capture the interaction between lake size and water clarity was significant and positive in all four models, i.e., the implicit price of water clarity increased with lake size.

The authors noted substantial variation in market and physical characteristics between New Hampshire and Maine in access to large metropolitan areas (better in New Hampshire), size of the lakes (larger in Maine), lake shorelines (more developed in New Hampshire), and average lakefront sales prices (much higher in New Hampshire—in some cases double). Magnitudes of the hedonic coefficients on the water clarity variable (defined as lake area*the natural log of water clarity in meters based on Secchi measurements) also varied, from 2.05 to 40.92 in Maine and from 4.48 to 149.60 in New Hampshire. In summary, the authors noted the substantially different values between these two adjacent states, suggesting that generalizations are likely to be tenuous, especially since other states were likely to exhibit even more variation in housing market, physical characteristics, water quality, and/or human preferences.

A similar approach was taken in Minnesota where findings showed that water clarity (interacted with lake size) was significant and positive in all 12 hedonic models developed [32]. The implicit increase (decrease) in lakeshore property price per front foot for a one-meter increase (decrease) in clarity ranged from $1.08 to $423.58 ($1.43 to $594.16) (2001 dollars) across the 37 lakes analyzed. The authors scaled their findings by aggregating the feet of lake frontage at each lake to estimate the total change in property values for each lake. The total increase (decrease) in the combined price of all lakeshore property at each lake with a one-meter increase (decrease) in clarity ranged from $30,467 to $93 million ($36,264 to $151 million). The authors observed that homebuyers appeared to prefer and to be willing to pay more for what they described as "more developed and urbanized" properties, which were the type of residential development most likely to contribute to declining water quality and, thus, be antithetical to the preference for lakes with higher water quality.

Using a sample of 1183 properties on Maryland's Chesapeake Bay, it was found that the effect of a rising fecal coliform count (FCC) on property prices was negative in all eight models the analysts developed (significant at 5% in seven instances and 10% in the other) [9]. High FCCs are not only hazardous to human health, but also lead to unpleasant odors and unsightly water. A change of 100 FCC per 100 mL was associated with a 1.5% change in price, with the mean absolute effect ranging from $5114 to $9824 (1997 dollars) across the eight specifications (the mean reading was 103 counts per 100 mL, with a range from 4 to 2300, and state regulations mandated a beach closing at a count of 200 counts/mL). Spatial autocorrelation was tested for, but it accounted for no consistent bias. Hypothetical improvement of FCC levels to the state standard of 200 counts per 100 mL at all 6704 waterfront residences in the study area (494 of which exceeded that standard at the time) was associated with an upper bound property price increase of $12.1 million (with a 95% confidence interval of $3.8 million to $20.5 million).

One of the methodological contributions of this piece was its attempt to address omitted variable bias, specifically the likelihood that pollution sources are considered undesirable neighbors by buyers (in addition to any impact on objective measures of water quality that they have). A series of separate variables was incorporated to capture the emitter effects of various pollution sources (inverse distances to the nearest industrial National Pollutant Discharge Elimination Service (NPDES) site, marina, and sewage treatment plant). The coefficient on the NPDES variable was negative and significant in all eight cases, whereas those on marina and sewage treatment variables were significant in only one and two cases, respectively. The authors concluded that the omission of these variables would have resulted in larger negative coefficients and higher t-values on the main variable of interest. The inclusion of these variables, therefore, allowed for greater confidence in the final results.

Results of the middle era of studies are summarized in Table 2. Studies reported in this time period invariably used multiple regression-based hedonic pricing techniques [33]. All but one of the 13 studies utilized sales prices as their dependent variable, and a majority of the analyses included experimentation with a variety of functional forms. Ten of the studies employed objective measures of water quality (clarity in eight of those cases), two compared subjective and objective measures, and one used the implicit price of proximity on two different water bodies as a proxy for quality differences. The level of variance explained by the model(s) consistently exceeded 65% in three cases, and ranged from 27% to 81% in the eight other studies for which R-squared values were reported. Increasing (decreasing) water quality had the expected and statistically significant positive (negative) effect in at least one model in all of the studies.

Table 2. Summary of US studies conducted in the period of 1984–2003.

Author (Year) * Refereed	Study Site/Location	Year(s) of Data	Method, Sample Size, (Adjusted) R^2 (as Applicable and Listed)	Dependent Variable(s)	Water Quality Variable(s)	Key
Young and Teti (1984)	St. Albans Bay, Lake Champlain, VT	1976 to 1981	Two hedonic models, 93 seasonal homes adjacent to lake, 0.67–0.76	Sales prices of residential property	Objective measure: dummy to represent location on bay; subjective measure: rating by panel of local experts	Objec $4500 total $2 mi Avera simil
Brashares (1985)	78 lakes in southeast Michigan	1977	Multiple hedonic models, up to 2370 properties (178 on lake), 0.66–0.73.	Log of sales prices of houses	Of a starting list of 40, only two were employed in final models: squared values of turbidity and fecal coliform level	Turbi impa signi Neith acces via a
Kirshner and Moore (1989) *	Tiburon (T) and Foster City (FC), San Francisco Bay, CA	1984 to 1986	Four hedonic models (linear and log-log forms), 117 properties in town on clean part of bay (T) and 159 in town with much lower water quality (FC), 0.70–0.76	Sales prices of single family houses	Dummy variable to represent location immediately proximate to water	Linea proxi Log r prope Diffe at 95
Mendelsohn, Hellerstein, Huguenin, Unsworth, and Brazee (1992) *	Harbor in New Bedford, MA	1969 to 1988	Multiple panel data (repeat sale) regressions (linear and semi-log forms), 1916 sales of 780 properties within two miles of the harbor, 0.27–0.49	Sales prices of single family houses	PCB zone (based on hazard level of harbor water closest to property)	Prope $7000 (relat dolla singl
Steinnes (1992) *	53 lakes in northern Minnesota	Not stated	Three hedonic models, seasonal use leased lots on 53 lakes (only land values considered, unit of analysis = lakes not lots), 0.31–0.74	Total price, average price, and average price per front foot of lots (all appraised)	Water clarity (per Secchi disk readings)	Wate three the to or $1
Michael, Boyle, and Bouchard (1996)	22 lakes in Maine	1990 to 1994	Four hedonic models, 543 lakefront properties in four markets (90, 84, 214, 155), 0.37–0.65	Sales prices per front foot of single family houses and unimproved land	Water clarity (per Secchi disk), interacted with lake area	Effec mode clarit range $200
Boyle, Poor, and Taylor (1999) *	25 lakes in Maine	1990 to 1995	12 hedonic models (linear, semi-log and Cobb-Douglas forms; first and second stage analysis), 249 lakefront properties in four markets (48, 112, 68, 21)	Sales prices of houses	Natural log of minimum water clarity during summer months of purchase year (Secchi disk), interacted with lake area	Wate Cobb visibi Bang $4235

Table 2. *Cont.*

Leggett and Bockstael (2000) *	Anne Arundel County, Chesapeake Bay, MD	1993 to 1997	Eight hedonic models (linear, semi-log, double-log, inverse semi-log forms), 1183 waterfront properties, 0.39–0.76	Sales prices and residual land prices of properties	Median fecal coliform count in year of sale (inverse distance-weighted average of counts at three nearest monitoring stations)	Effec signi 100 c in pri $5114 with
Michael, Boyle, and Bouchard (2000) *	22 lakes in Maine	1990 to 1994	27 hedonic models, 531 lakefront properties in three markets (89, 295, 147)	Sales prices of single family houses and unimproved land (tract max 20 acres)	Semi-log of nine variations on current, historical, and seasonal change water clarity measures (per Secchi disk)	Most signi of cla differ differ policy estim
Boyle and Taylor (2001) *	34 freshwater lakes and ponds in Maine	1990 to 1995	Eight hedonic models, 318 lakefront properties in four markets (55, 158, 74, 31), 0.38–0.81	Sales prices of properties	Natural log of water clarity (per Secchi disk) interacted with lake size	Coeff eight betw mark $2000
Poor, Boyle, Taylor, and Bouchard (2001) *	Freshwater lakes and ponds in Maine	1990 to 1995	Eight hedonic models, 348 lakefront properties in four markets (56, 174, 52, 66), 0.49–0.75	Sales prices of properties	Natural log of water clarity (measured both objectively and subjectively) interacted with lake size	Coeff subje Augu $2756 signi objec 1% le were
Gibbs, Halstead, Boyle, and Huang (2002) *	69 public access lakes in 59 towns in New Hampshire	1990 to 1995	Four hedonic models, 447 lakefront properties in four markets (115, 178, 80, 74), 0.43–0.67	Sales prices of properties	Natural log of water clarity (per Secchi disk) interacted with lake area	Wate mode from Milto $3923 (6.64
Krysel, Boyer, Parson, and Welle (2003)	37 lakes in the headwaters of the Mississippi River, MN	1996 to 2001	12 hedonic models, 1205 lakeshore properties in six markets, 0.29–0.53	Sales prices of single family properties and assessed values of land	Natural log of water clarity in year property sold (per Secchi disk) interacted with lake area	Wate 12 mo per fr range total a 1-m $30,4

4. Recent US Studies: 2003–2017

Analysis of properties in Walworth County, Wisconsin, revealed that a one-foot increase in clarity was associated with a $5207 increase in the price of the average property (2003 dollars). For a typical property on Lake Delavan, which had experienced "an expansive, intensive, and historically unique $7 million lake rehabilitation program between 1989 and 1993" [34] (p. 222), this translated into a $49,000 increase in assessed value between 1987 and 1995.

The first study to look beyond the primarily aesthetic and recreational values associated with a single (set of) lakes or rivers to the influence of ambient water quality on both waterfront and non-waterfront properties throughout an entire local watershed focused on St. Mary's River, Maryland, an area subject to increasing development and associated runoff from impervious surfaces [35]. Marginal implicit prices for a one milligram per liter increase in levels of total suspended solids and dissolved inorganic nitrogen (DIN) were −$1086 and −$17,642 (2003 dollars), respectively, based on the average house price of just over $200,000. Current mean levels of these pollutants were 13.3 mg/L and 0.6 mg/L, i.e., a 1 mg/L increase would be substantial, particularly in the case of DIN.

Another first was Carey and Leftwich's (2007) analysis of the impact of a specific algal bloom on property prices, in this case in Lake Greenwood, South Carolina [36]. The authors also incorporated a parallel study of the influence of chlorophyll-a levels on property sales prices and included a dummy variable to denote location within one-half mile of an NPDES site in both models. None of these water quality variables were statistically significant in either model. The authors attributed the lack of significance of chlorophyll-a levels to their invisible nature and, hence, to lack of awareness on the part of the public. They speculated that buyers viewed the algal bloom as an isolated event which would not impact their future enjoyment of the lake.

A study in Augusta County, Virginia, compared the price effect of proximity to two rivers (one known to be polluted and one not) [37]. Coefficients on the variables measuring distance to the river were negative and significant in all models. As anticipated, marginal willingness-to-pay [WTP] to locate one foot closer to the clean river ($5.41 based on total property value and $2.67 for land value only) was larger than those to locate one foot closer to the polluted waterway ($3.77 and $1.41). Noting the natural experiment afforded by the geographic setting, the authors attributed the differences in WTP to variation in water quality. Spatial-lag models were employed, thereby accounting for spatial dependence in the data.

A sample of home sales within 1000 m of 146 lakes in Orange County, Florida, was comprised of 1496 lakefront and 53,216 non-lakefront properties. It was used to consider the effects of edge (location directly on the waterbody) and proximity (distance to the waterbody) on water quality coefficients, as well as the more commonly employed measure of lake size [38–40]. Using Secchi depth as their measure of water quality, the authors reported significant edge, proximity, and size effects. The mean marginal value of water quality was significantly higher for waterfront properties. A one-foot increase in Secchi depth generated a $5500 (1.2%) (2004 dollars) increase in the price of the mean lakefront property, compared to a $700 (0.3%) increase for houses not on the lakefront. The impact of water quality declined steeply with distance from the waterfront. The mean implicit price of water quality decreased by about one-fourth between 100 m and 200 m from the waterfront, by more than one half at 600 m, and by five-sixths at 1000 m. The effect of size was significant, i.e., water quality was valued more highly on larger lakes than smaller ones, reflecting the greater attractive power of larger water bodies. Size effects were relatively larger for non-lakefront properties. Thus, a tenfold increase in lake size from 100 to 1000 acres generated a $1000 (20%) increase in the marginal implicit price of water quality for properties on a lake, but a $700 (300%) increase for properties not directly on a lake. The authors recognized that this finding could have substantial implications for densely developed urban watersheds, where the number and proportion of non-lakefront homes is high compared to the relatively small number and proportion of properties located on a waterfront. Controlling for individual lake- and time-specific effects was important across all model specifications. In the six models highlighted in the findings, coefficients on between 91 and 113 of the 145 lake dummy variables, and all eight of the time dummy variables, were significant at the 1% level.

In a first of its kind analysis, Cho et al. (2011) compared the willingness to bear the negative externality of impaired water quality between those who do and do not benefit economically from the impairment source (a North Carolina paper mill) [41]. Specifically, they conducted hedonic analyses of two housing markets in the Pigeon River watershed, one in North Carolina and the other in Tennessee, using a series of 10 dummy and continuous variables to capture the effect of view of and proximity to impaired and unimpaired rivers and streams. Results overall were inconclusive, indicating no differences in the willingness to bear negative externalities based on the variables measuring the view of or proximity to impaired rivers or streams. Those coefficients for which significance was indicated suggested that the North Carolina residents who received economic benefits from the paper mill exhibited a greater willingness to bear the harmful effects of water pollution, while internalization of the negative externality was weaker for residents in Tennessee. This was also the first study of its kind to incorporate an assessment of the impact of different spatial weighting matrices on findings.

A study that compared technical and non-technical water quality measures in a hedonic analysis found that technical measures of quality (pH, dissolved oxygen (DO), visibility, and salinity) better predicted prices than those based on a less technical grading system [42]. The non-technical measure was a “location grade” of A, B, C, D, or F which the Florida Oceanographic Society, a volunteer organization that monitors water quality, assigned to provide lay-people a simple means of evaluation. The grade was constructed directly from other technical measures of water quality publicized in local media and online. This led the researchers to conclude that homebuyers in their Martin County, Florida, study area were “relatively sophisticated” in their understanding of water quality issues. Although the nominal WTP estimates (shown in Table 4) were relatively large, the authors pointed out that the mean housing values in their study (close to $950,000 in 2004 dollars) were unusually high. When considered in percentage terms (e.g., about 3.8% of mean house price for visibility), the mean WTP estimates aligned quite well with prior findings.

A Rhode Island study of properties alongside Narragansett Bay used sales data from 1992–2013, along with chlorophyll measurements taken at 13 monitoring points along the bay [43]. In 2004, the state passed a law requiring wastewater treatment plants, the major source of pollution in the bay, to reduce nitrogen loads by 50% of 1995–96 levels by 2008. Analysis found that housing values decreased as chlorophyll levels increased, though decreases were marginal—a one-unit increase in chlorophyll concentration led to price declines of 0.06–0.1% within 100 m of the bay and 0.05–0.08% in the surrounding 100–750-m band. Nevertheless, when aggregated across the entire study region, the present value of benefits associated with a chlorophyll concentration reduction goal of 25% (if achieved in 2017) was substantial, over $45.5 million. The authors noted that prices were more likely to be impacted by extreme environmental events than typical water quality conditions.

A similar analysis in the same state that also employed chlorophyll concentration as the single measure of water quality reported stronger effects on house values [44]. Good quality water (defined by a chlorophyll concentration of 7.2 ppm or less and interacted with variables representing lakefront location, log of distance to the nearest lake, and lake size) had a significant impact on sales prices. Properties with frontage on a good quality lake saw a 2.3% price increase above the 4.7% main lakefront effect. Sales prices decreased as the distance between a property and its nearest lake increased for good quality lakes, but increased with lake size. The total lakefront property sales price increase associated with the improvement of all state-managed lakes from poor or extremely poor quality to good quality was estimated to exceed $11 million (2012 dollars). Contrary to expectations, the amenity value (in percentage terms) of water quality was found to be constant for lakefront properties over the study period (1988–2012), suggesting that appreciation of good quality water is insensitive to fluctuations in economic conditions.

Bin et al. (2015, 2016) [45,46] confirmed Gorelick’s (2014) [44] finding that homebuyer value associated with water quality is resistant to economic downturn. The study was one of the most advanced of its kind, commencing with a segmented regression to identify breakpoints in the data (based on median prices and number of sales) to allow these turning points to be accounted for in the spatial error hedonic modeling that followed. A spatial fixed effects model was then used to examine the impact of the temporal breakpoints on the implicit price of water quality. The authors observed that their results suggested "there may be significant economic returns associated with water quality protection in an economic contraction" (p. 18). WTP for a one-percentage point improvement in water quality (over the entire study period and at the mean house price) was $1754 (with 90% lower and upper bounds of $86 and $3276) in their 2015 working paper, and $2614 ($1026 and $3964) in their subsequent 2016 article (the latter piece entered water quality in log form) (2010 dollars).

Netusil et al. (2014) simultaneously considered the effect of five water quality variables (fecal coliform, pH, dissolved oxygen (DO), stream temperature, and total suspended solids (TSS)) at four distances (within $\frac{1}{4}$ miles, within $\frac{1}{2}$ mile, within one mile, or more than one mile) on two creeks (Johnson Creek, Portland, Oregon, and Burnt Bridge Creek, Vancouver, Washington) [47]. In addition, the authors compared effects using annual averages for each quality measure with those for the wet (November–April) and dry (May–October) seasons. They employed both traditional ordinary least squares [OLS] and spatial autoregressive (SAR) models. Given the large number of combinations possible, only selected results were presented in the article. Coefficients on the water quality variables for Johnson Creek in the dry season are summarized in Table 4. The largest estimated DO resulted in increases of 13.7–14.5% in price for each 1 mg/L increase for properties within $\frac{1}{4}$ mile of the creek, declining to increases of 3.1–3.75% in price for each 1 mg/L increase for properties beyond 1 mile. Other statistically significant estimated effects on sales prices included decreases of 2.8–2.9% per 100 count per mL increase in fecal coliform for properties within $\frac{1}{4}$ mile, declining to decreases of 0.7–0.9% beyond 1 mile. The effects of pH and temperature were only consistently significant beyond 1 mile, with a 0.5-unit increase in pH generating price increases of 6.2–8.4%, and a 1° increase in temperature generating price increases of 4.5–4.9%, beyond that distance.

Results were robust across OLS and SAR models. Johnson Creek results were consistently (in)significant across annual and both seasonal measures at all distances for DO (all significant); for properties within $\frac{1}{2}$ mile (insignificant) and beyond 1 mile (significant) for fecal coliform; for properties within $\frac{1}{4}$ mile (insignificant) and beyond 1 mile (significant) for pH; and for properties within $\frac{1}{4}$ mile for temperature and TSS (insignificant). The authors also demonstrated differences in WTP for quality improvements based on the measurement of change in units compared to standard deviations between the two study areas, noting that such variations illustrate the need to consider differences between watersheds when using results to inform policy.

After the release of waters from Lake Okeechobee into the St. Lucie and Caloosahatchee Rivers in 2013, a report was commissioned by Florida Realtors® to examine the impact of water quality and clarity on sales prices in Martin and Lee Counties between 2010 and 2013. Water quality was represented by DO levels and Secchi disk readings in both counties, while the Lee County analysis incorporated two additional measures, chlorophyll level and turbidity. Two sets of models were run for each location, measuring the average value of each quality metric for the month and for the entire year prior to a property's contract date.

Statistical significance was found for all of the water metrics except for dissolved oxygen, which was not significant in either the Lee or Martin County models. This is likely because dissolved oxygen is the only one of the four quality measures that was not visible to a potential homebuyer and because the relationship between oxygen levels and algal blooms not necessarily direct. Coefficients were much larger in the year model, indicating that homebuyers more heavily considered long-term quality indicators in their purchasing decisions. That is, while a single algal bloom may not have been considered problematic by a potential buyer, their regular occurrence did negatively impact sales price. The continuing recurrence and increasing frequency of negative water quality events was therefore identified as a key challenge for the area's housing market.

In the Lee County month model, the marginal price effects of changes in clarity (Secchi disk depth) were more pronounced than that of chlorophyll or turbidity levels among waterfront properties, e.g., a one-unit decrease in chlorophyll (−1 μg/L) and turbidity (−1 NTU) produced a 0.46% and 1.07%, respectively, increase in property value, whereas a one-foot increase in clarity produced a 2.47% increase. These findings held true when percentage rather than unit changes in quality measures were calculated. As shown in Table 3, the impact of quality decayed rapidly with distance from the waterfront in both counties and for both timeframes. Improved water clarity (a one-foot increase in average Secchi disk depth) could result in an aggregate increase in property values of $541 million in Lee County and $428 million in Martin County (2013 dollars), while a one-foot decrease in clarity could cause property value losses of an equal magnitude.

Table 3. Marginal price effects of a one-foot increase in Secchi disk depth by distance from waterfront (% change in value).

Location of Property	One Month Model		One Year Model	
	Lee	Martin	Lee	Martin
On waterfront	2.47	5.41	14.66	10.32
1/8 mile from waterfront	1.93	4.21	11.42	8.03
1/4 mile from waterfront	1.50	3.28	8.89	6.26
1/2 mile from waterfront	0.91	1.99	5.39	3.80
1 mile from waterfront	0.34	0.73	1.98	1.40
2 miles from waterfront	0.05	0.10	0.27	0.19
4 miles from waterfront	0.00	0.00	0.00	0.00

Source: Florida Realtors®, 2015 [48].

On Cape Cod, nitrogen pollution from septic systems and lawn fertilizer is of special concern given the tourism industry's reliance on clear and attractive beaches and coastal waters. Analysis conducted by the Cape Cod Commission (Ramachandran, 2015) showed that prices fell an average of 0.61% for every 1% increase in nitrogen concentration [49]. This was especially meaningful because the nitrogen concentration in the area increased by 15.84% over the study period (2005–2013).

Adirondack Park, the largest protected area in the mainland US, was the focus of a study in which the hedonic analysis incorporated both a scientific measure (pH) and two ecological endpoints (the presence or absence of loons, an indicator species for methylmercury contamination, and of the aquatic invasive Eurasian water milfoil) [50]. A fixed effects approach (at the level of the census block) was employed to help address omitted variables bias and spatial dependence. Water quality variables were entered individually and then simultaneously, and models were developed for all parcels as well as just those parcels within 0.05 miles of water (considered waterfront). Marginal values for the water quality variables with significant coefficients (listed in Table 4) were as follows: presence of loons in year of sale, $21,803 (2009 dollars) for all parcels and $46,158 for waterfront parcels (an 11% increase in both cases); number of loons in year of sale, $1819 per loon for all parcels and $3308 for waterfront parcels (1% in both cases); presence of milfoil, −$10,459 (−6%, all parcels); and, poor (<6.5) pH, −$30,144 (−18%, all parcels) and −$69,734 (−24%, waterfront). The mean sales prices were $179,190 for all parcels and $362,557 for waterfront parcels.

Table 4. Summary of US studies conducted in the period of 2003–2017.

Author (Year) * Refereed	Study Site/Location	Year(s) of Data	Method, Sample Size, (Adjusted) R^2 (as Applicable and Listed)	Dependent Variable(s)	Water Quality Variable(s)	Ke
Kashian, Eiswerth, and Skidmore (2006) *	Three lakes in Walworth County, WI	1987, 1995, and 2003	Hedonic model, 314 homes assessed at three time points = 942 observations, 0.60	Assessed values of residential properties	Water clarity (per Secchi disk)	Effe A or a $5
Carey and Leftwich (2007)	Lake Greenwood, Greenwood County, SC	1980 to 2006	Two hedonic models, 548 and 295 properties within 1000 feet of western shore of lake, 0.76–0.79	Sales prices of properties (including both houses and lots)	Sale during 1999 algal bloom; chlorophyll-a level at time of sale; location within $\frac{1}{2}$ mile of a National Pollutant Discharge Elimination Service (NPDES) site	Non sign
Poor, Pessagno, and Paul (2007) *	St. Mary's River watershed, MD	1999 to 2003	Two hedonic models, 1231 and 1377 properties, 0.34–0.35	Log of sales prices of single family houses	Yearly averages of dissolved inorganic nitrogen (DIN) and total suspended solids (TSS) at 26 monitoring stations (two separate regressions)	Both Mar incr was
Morgan, Hamilton, and Chung (2010)	Two rivers (Middle, not polluted, and South, polluted) in Augusta County, VA	Not stated	Four spatial-lag hedonic models, 2069 and 1252 properties on Middle and South Rivers, respectively	Log of assessed total value (house + land) and of assessed land value	Natural log of distance to Middle or South River	Coe sign pay (tota willi $3.7 impr betw
Walsh (2009) Walsh, Milon, and Scrogin (2010) (2011) *	146 lakes in Orange County, FL	1996 to 2004	Multiple hedonic models (including spatial lag), 54,712 properties within 1000 m of a lake (1496 lakefront), 0.893–0.894	Log of sales prices of single family properties	Log of mean annual water quality (Secchi depth) in nearest lake at time of sale, interacted with (i) dummy variable to represent lakefront properties, (ii) distance to waterfront, and (iii) lake area	Wate of si with all n clari Imp dista Bene accr
Cho, Roberts, and Kim (2011) *	10 of 18 sub-watersheds of the Pigeon River watershed, North Carolina and Tennessee	2001 to 2004	Six spatial hedonic models (four for NC, two for TN), 595 properties in NC and 497 in TN	Sales prices of detached single family houses	Impairment status of subwatershed (two dummy variables, one each for rivers and streams); water view (four dummy variables, view of (un)impaired river or stream); water proximity (four variables, natural log of euclidean distance to nearest (un)impaired portion of river or stream)	Rive five TN) four mod all s six r and unir

Table 4. *Cont.*

Bin and Czajkowski (2013) *	St. Lucie River and Estuary and Indian River Lagoon, Martin County, southeastern Atlantic coast of Florida	2000 to 2004	Eight spatial hedonic models, 510 waterfront properties	Log of sales prices of single family residences	Non-technical: water quality location letter grade (weighted average of pH, visibility, salinity, and dissolved oxygen (DO) (entered as grade, grade squared, and dummy)). Technical: pH and DO (linear and squared), visibility and salinity (level, level squared, and dummy for fair or good).	Non tech Mar bour loca $13, $164 $353 (mg
Gorelick (2014)	99 lakes in Rhode Island	1988 to 2012	Hedonic model, up to 97,352 properties within 5 miles of a lake (3315 lakefront), 0.69	Log of sales prices of single family houses	Good water quality (lake with chlorophyll concentration $\leq$ 7.2 ppm) interacted with dummy variable for lakefront, log of distance to nearest lake, and lake size	Wat pric with (extr (tota over
Netusil, Kincaid, and Chang (2014) *	Two urbanized watersheds in Portland, Oregon (Johnson Creek) and Vancouver, Washington (Burnt Bridge Creek)	Not stated	Multiple OLS and spatial autoregressive (SAR) hedonic models, 5093 (WA) and 10,479 (OR) properties, 0.57–0.72	Log of sales prices of single family houses	Fecal coliform (FC), pH, dissolved oxygen (DO), stream temperature (temp), total suspended solids (TSS); annual averages as well as wet (November–April) and dry (May–October) seasons; properties within $\frac{1}{4}$, $\frac{1}{2}$, 1 mile, or more than 1 mile from creek	Not John dista sign sign sign 1-mi TSS $\frac{1}{4}$ m
Bin, Czajkow-ski, Li, and Villarini (2015) (2016) *	St. Lucie River and Estuary and Indian River Lagoon, northeast Martin County, southeastern Atlantic coast of Florida	2001 to 2010	Multiple spatial hedonic models, with and without spatial fixed effects and temporal breakpoints, 1526 waterfront properties	Log of sales prices of single family residences	Water quality location grade (annual mean percentage score at nearest monitoring station in year of sale, grade incorporates temperature, pH, visibility, salinity, and dissolved oxygen) (linear in 2015, log in 2016)	Wat hom cont not wate $261
Florida Realtors® (2015)	St. Lucie River, Martin County, and Caloosahatchee River, Lee County, FL	2010 to 2013	12 hedonic models, 7975 (Martin) and 48,572 (Lee) properties, 0.86–0.88	Log of sales prices of single family properties	Both counties: water clarity (per Secchi disk) and levels of dissolved oxygen. Lee County only: levels of chlorophyll-a and turbidity.	Lee sign mea influ qual A or in ar mill

Table 4. *Cont.*

Ramach-Andran (2015)	Three Bays, Barnstable, Cape Cod, MA	2005 to 2013	Four hedonic models, n not stated, 0.68–0.72	Sales prices of single family homes	Concentration of nitrogen	Coe sign 0.61
Tuttle and Heintzelman (2015) *	52 lakes in Adirondack Park, New York	2001 to 2009	10 fixed effects hedonic models, five for all 12,001 parcels and five for 2624 parcels within 0.05 miles of water, 0.44–0.55	Log of sales prices of residential parcels	Presence/absence of loons present (dummy), number of loons present, presence/absence of Eurasian water milfoil (dummy), annual average pH (<6.5 (poor), 6.5–8.5, or unknown) (measured at (or at closest time to) time of sale)	Pres unk indi pres Nur of m for a pH Pres whil pres
Walsh, Griffiths, Guignet, and Klemick (2015)	14 counties on Chesapeake Bay, Maryland	1996 to 2008	Multiple general spatial hedonic models using four different spatial weight matrices (each county modeled separately), 229,513 properties, "approximately 0.7 to 0.9"	Log of sales prices of single family houses and townhouses	Linear and log of K_D, the water-column light attenuation coefficient (average one-year and three-year spring-summer values at/prior to time of sale), interacted with distance from bay (dummy variables to represent bayfront, or 0–500, 500–1000, 1000–1500, or 1500–2000 m from bay)	Not usin nega posi five usin (all 0–50 m. F coef nega for 0 500– Seve six r nega for 5
Walsh and Milon (2016) *	76 lakes in Orange County, Florida	1996 to 2004	Multiple general spatial hedonic models, 33,670 properties up to 1000 m from a lake, 0.93 for all six models reported	Log of sales prices of residential single family properties	Log of: water quality (WQ), WQ interacted with waterfront location, distance to and area of nearest lake, dummy for clear, low alkalinity lake. Six measures of water quality: total nitrogen (TN), total phosphorus (TP), chlorophyll-a (CHLA), TN + TP + CHLA, trophic state index, one-out all-out indicator based on TN, TP, and CHLA.	Sign Inco ente indi indi expe and indi calc mag

Table 4. *Cont.*

Liu, Opaluch, and Uchide (2017) *	Narragansett Bay, Rhode Island	1992 to 2013	Multiple semilog linear OLS and spatial hedonic models, 40,433 transactions of 27,040 properties, 0.78–0.88 for OLS	Log of sales prices of single-family residential properties	Concentration of chlorophyll (in micrograms per liter) (i) for all years up to and including transaction year ("informed model" and (ii) in the five most recent summer months prior to purchase ("myopic model")	Wate nega moc case (insi poor with close of be decr mill
Kung, Guignet, and Walsh (2017)	Long Island Sound, New York	2003 to 2015	Six spatial (SAC) hedonic models, up to 16,926 properties within five kilometers of the sound, 0.79	Natural log of transaction prices of single family and town homes	Natural log of enterococcus level (in colony-forming units per 100 mL at waters closest to each home (controlling for beach closures in five of six cases)	Neg to or near and clos
Wolf and Klaiber (2017) *	Six counties surrounding four inland lakes in Ohio	2009 to 2015	Two hedonic models (semi-log and spatially heterogeneous), 15,866 properties, 0.74	Log of sales prices of single family homes	Microcystin concentration levels (two to six months prior to sale)	Ove of al alga the 1 the v 20 ar four
Klemick, Griffiths, Gaigaet, and Walsh (forthcoming) *	Meta-analysis: 14 counties on Chesapeake Bay, Maryland; benefit transfer: DC, Delaware, Virginia, four additional Maryland counties	1996 to 2008	Meta-analysis of 70 estimates of water clarity, used to estimate property value impacts of pollution reduction policies using benefit transfer techniques	Log of sales prices of homes	Log of water-column light attenuation coefficient (K_D)	Imp the b atten valu 0.1% Agg proj to w

Table 5. Summary of international studies.

Author (Year) * Refereed	**Study Site/Location**	**Year(s) of Data**	**Method, Sample Size, (Adjusted) R^2 (as Applicable and Listed)**	**Dependent Variable(s)**	**Water Quality Variable(s)**	**K**
No author (no date)	Rivers, canals, and lakes, the Dommel, Netherlands	2005	12 hedonic models (six OLS, six spatial error), 5358 properties, 0.76–0.84	Log of sales prices of properties	Water turbidity (per Secchi disk), nitrogen (N) concentration (three forms: continuous linear, continuous quadratic, and set of categories)	Se 12 co fo m in in 4.
Artell (2010) (2014) *	Large number of lakes and rivers, and Baltic coastline, in Finland	2004	OLS and SAR hedonic models, 1844 (2010) or 1806 (2014) waterfront lots, 0.31–0.39	Log of sales prices of unbuilt summer house lots (2014 version excluded upper and lower 1% of sales)	Five-class water usability index (poor-passable-satisfactory-good-excellent) based on 15 ecological and chemical criteria that influence recreation use	In to – – (9 ev
Clapper and Caudill (2014) *	74 lakes in North Ontario, Canada	2010	Six OLS hedonic models (linear, log-linear and log-log forms), 253 lakefront cottages, 0.14–0.57	Linear and log of sales prices and sales prices per square foot (psq)	Water clarity (per Secchi disk) or log of water clarity	C A p (l $9 1° (b
Chen (2017) *	Pearl River and its tributaries, Guangzhou, southern China	2013	Three OLShedonic models, 968 apartments, 0.61–0.62	Log of sales prices of apartments		M w in q lo (c D (p si

An insightful comparison of the effects of different measures of water quality on the implicit price of water quality emerged when six singular and composite quality measures were tested: total nitrogen (TN), total phosphorus (TP), chlorophyll-a (CHLA), each entered individually into a spatial hedonic regression; TN, TP, and CHLA entered simultaneously; trophic state index (TSI), a non-continuous combination of TN, TP, and CHLA levels based on the TN/TP ratio; and a one-out all-out (OOAO) indicator that equaled 1 if all criteria for TN, TP, and CHLA were achieved, and 0 otherwise [51]. Water quality was also interacted with waterfront location, distance to and area of the nearest lake, and a dummy variable representing clear, low alkalinity lakes. The only model to produce a significant result of the unexpected sign for the uninteracted quality measures was the OOAO indicator.

To illustrate the practical ramifications of these findings, the authors quantified the benefits of improving nutrient levels to minimum standards for five representative lakes (the model with TN, TP, and CHLA was not considered due to the inconsistency of coefficients). Comparison of the three models containing single measures with the TSI model indicated order of magnitude (and greater) differences between benefits; two of the most extreme examples were for TP, which was estimated to provide benefits of more than $22 million on two of the five lakes in the singular models, but of only $5000 in the composite TSI model (2004 dollars). Similarly large differences were seen when the benefits of achieving all three criteria were calculated according to the TSI and OOAO composite measures. Based on their findings, the authors concluded "the composite indicator TSI provides the most direct linkage between waterbody health and property prices and it is a more reliable measure of the economic benefits of water quality improvements that would result from nutrient reductions" (p. 658).

Using a dataset of 229,513 residential property transactions and water quality measured by the water-column light attenuation coefficient (K_D), hedonic price functions were estimated for each of 14 Maryland counties bordering the Chesapeake Bay [52]. K_D is essentially the inverse of water clarity i.e., higher light attenuation is equivalent to cloudier water. The authors matched each home sale to the average reading of the nearest monitoring site. Details of the results are given in Table 4. Using the log of water clarity averaged over the spring and summer of the sale year, which best represented the most common functional form used in the literature, the authors found a positive impact of water clarity on waterfront property prices in 10 of the 14 counties, seven of which were statistically significant. In the four other counties, the waterfront impact was insignificant. Although the results were more mixed in the non-waterfront areas, there was still evidence that the impact of water quality stretched past the waterfront. While the one-year average of spring-summer water quality is most prevalent in the literature, the authors repeated their analyses using a three-year average. These analyses yielded larger, but much more variable, estimates.

The same research team subsequently undertook a meta-analysis [53]. They used the estimates of the impact of water clarity on properties at five different distance bands from the bay in each of the 14 counties, which provided 70 estimates. The analysis showed, for the most part, that effects were not significant beyond the waterfront and 0–500 m bands; the value of water clarity was greater in areas with shallower water and higher property values; and the three-year average produced a significantly larger effect on home values than the one-year average—almost doubling the elasticity of K_D for waterfront homes. This latter finding suggested that homebuyers were more concerned with the long-term trends in water clarity than with short-term impacts.

Kung et al. (2017) complemented the conventional approach of measuring property value effects at increasing distances from a polluted source by considering effects at the closest recreational access point [54]. Their goal was to more accurately capture the value to residents who live proximate to a water body, but do not have direct access to it.

Water quality was measured by levels of enterococcus, which is a bacterial indicator of fecal pollution. The study used 16,926 property sales from 2003 to 2015 in Westchester County within five miles of Long Island Sound, where sewage overflows were a long-standing problem. Five thousand two hundred and ten samples of enterococcus were collected from 35 different measuring sites in the sound. Results from the conventional analyses were consistent with most others, showing negative price effects extended to one kilometer. Homes within 500 m of the sound were affected the most, experiencing an average decrease in sales price of 0.14% for every 10% increase in enterococci, i.e., an average decrease in home value of $1543. However, the effect became insignificant when controlling for levels at the nearest beach. When enterococcus counts were measured at the nearest beach, the negative effect of 0.03–0.02 elasticity extended to 2.5 km.

Harmful algal blooms are likely to increase in frequency and intensity due to rising temperatures associated with climate change and higher nutrient enrichment from increased urbanization. Wolf and Klaiber (2017) reported the negative impact of these blooms on house values for six counties surrounding four Ohio lakes [55]. The data comprised property sales of single family homes between July 2009 and April 2015. The number of samples of algae density at the four lakes varied widely: 792, 334, 41, and 16. Since house prices are typically determined two months before a sale date, the closest sample taken two months before a sale was used to measure the algal conditions at each lake site. The analyses showed that capitalization losses associated with proximate lake homes located between 20 and 300 m are negatively impacted by 11–17%. This rose to 17–22% for lake adjacent homes.

Results of the most recent studies of the impacts of surface water quality on property prices are summarized in Table 4. They are the most sophisticated studies with all but two presenting multiple models using a variety of linear and more complex forms, and 11 of the 19 including spatially explicit specifications. Seventeen of the 19 studies employed sales price as their dependent variable. In 14 cases the number of observations exceeded 1000, while it exceeded 5000 in 11 of those examples. Models for which R^2 was reported generally performed well, consistently exceeding 60% in 12 cases and exceeding 85% in three instances (other metrics such as the Aikaike information criterion are more typically reported for spatial models).

5. International Studies

Possibly the first non-US study of water quality effects on property prices was conducted in the Dommel region of the Netherlands using 2005 data [56]. Two indicators of water quality were employed, nitrogen concentration and Secchi depth (which the authors label as a measure of turbidity or cloudiness, but what US studies would consider clarity). Coefficients on Secchi depth were significant and positive in 11 of 12 OLS and spatial error models, while nitrogen levels were significant in all models when entered as continuous measures (positive in the linear form, negative when quadratic) and in one-half of the models when entered in categorical form. In the best model, a 1-decimeter increase in visibility was associated with a 3.6% increase in property price. The relationship between house price and nitrogen level was non-linear, reaching a maximum premium of 4.3% at a concentration of 4.2 mg/L.

In Finland, Artell (2010, 2014) used OLS and spatial autoregressive (SAR) models to capture the effect of a five-class water usability index (poor-passable-satisfactory-good-excellent) on prices of unbuilt summer house lots on an unspecified number of lakes and rivers and along the Baltic coast [57,58]. Implicit price estimates for water quality relative to the satisfactory class are reported for the 2014 dataset in Table 5. The 2014 dataset excluded the upper and lower 1% of sales, i.e., extremely high and low sales prices, and resulted in less extreme implicit price estimates, particular for the poor class. The non-linear nature of WTP for water quality suggested a diminishing rate of return for quality improvements, i.e., losses in value may be disproportionate to benefits for equal step changes in quality as measured by the index. Artell therefore noted that owners at poor quality sites have the most to gain from improvements to passable or better conditions. Artell's study included several variables that have not appeared in previous publications, including whether or not the lot was located on an island, and the direction its water view faced (aspect). Six different types of planning/zoning rules were also included in the models.

In the only known Canadian example, Clapper and Caudill (2014) reported that water clarity had a significant, positive effect on the prices of lakefront cottage in North Ontario in all of their six models [59]. A one-foot increase in water clarity led to price premiums of $13,390 (linear model) or 2% (log-linear), and price per square foot premiums of $9.50 (linear) and 2% (log-linear). A 1% increase in clarity increased price (total and per square foot) by 0.3% in the log-log form.

The first analysis focused on a rapidly developing country (China) and on apartments rather than homes, was consequently the first to incorporate a measure of the influence of the vertical dimension (height/story) [60]. The measure of water quality in this study was on a six-grade (I through V+) classification administered by the Ministry of Environmental Protection. Grades of IV or better were contrasted with V or V+ (indicating water usable only for agriculture or landscaping). This water quality dummy was also interacted with apartment floor (floors of 10 or lower were considered less desirable due to odor pollution) and whether or not the nearest river section had been restored. Spatial autocorrelation and heteroscedasticity were tested but were not found to be present. The coefficient on the water quality variable was significant and positive when entered by itself, with the floor level interaction variable (also significant and positive), and with the restoration interaction term (also significant and positive). The marginal implicit price of improving water quality from grade V or worse to grade VI represented a 0.9% increase, while restoring the nearest river section added 4.6%; the interaction between these two terms added an additional 0.1% to an apartment's value.

Results of the four identified international studies of water quality impact on property prices are summarized in Table 5. All four employed hedonic methods (two included spatially explicit versions in addition to OLS) and all four used objective measures of water quality (measures of individual criteria in two cases, and an index or classification scheme based on multiple criteria in the others). All demonstrated the statistically significant, positive influence of quality on price.

6. Discussion

The studies reviewed consistently demonstrate that property price premiums are associated with surface water quality. Of the 43 distinct studies represented in the 48 publications reviewed, the expected, statistically significant relationship between water quality and property price was demonstrated in at least one of the models developed in all but two studies.

It is unfortunate that while many of the studies mention the relationship between changes in property prices and magnitude of the local property tax base, none translated those observations into concrete calculations of the impacts of water quality changes on the inflow of tax revenues. This contrasts with studies of the impact of other amenities such as parks and brownfields which have quantified the revenue gains to public agencies associated with their presence [61,62].

The studies illustrate the evolution of advances in measurement and analytical techniques. The few early (1960s and 1970s) studies for the most part either compared price indices at different times or locations, or employed linear regression, and the entirety of any price change was typically attributed to differences in water quality over time or space. Water quality per se was not explicitly measured. Since the emergence of hedonic pricing methods (HPM) in the 1980s, analysts have consistently employed this technique. Like all applications of HPM, they demonstrate the variety of outcomes possible using the many functional forms available, the best choice of which remains an unresolved issue. The most recent analyses (since 2007) have increasingly incorporated consideration of spatial autocorrelation (dependence) using spatially-explicit econometric techniques. Use of these techniques serves to emphasize the unique characteristics of every location, in terms of its housing market and the quantity and quality of its water resources. Thus, while generalization is often seen as desirable from a research perspective, site-specific studies continue to be necessary to provide findings which can inform local policy decisions.

Almost all (39 of 43) of the studies identified pertain to the US. Their emergence in the 1970s reflects the passage of a series of laws designed to decrease pollution and increase water quality, e.g., the 1972 Federal Water Pollution Control Act and the Clean Water Act of 1977. In December 2015, the United States (US) Environmental Protection Agency (2015), using state-level data from 2006 to 2014, reported 43,209 impaired waters in the US [63]. These are water bodies that either do not, or are not expected to, meet applicable water quality standards with current pollution control technologies.

States are required to identify these waters under Section 303(d) of the Clean Water Act. Yet water quality is a pervasive issue across the globe, and is likely to become more prominent in the future; additional research in other nations is therefore desirable.

The small number of European studies in the past decade is puzzling given the passing of the European Union Water Framework Directive in 2000, which commits member nations to improving ground and surface water quality to 'good status' via integrated river basin management approaches by set deadlines [64]. The dearth of Canadian and Scandinavian studies is similarly surprising given the dominance of the cottage/second home phenomenon in those two regions [65].

Most studies focused on lakes (23 of 43, 53%), while 10 (23%) analyzed rivers/streams, 10 (23%) assessed bays or harbors, and three (7%) focused on entire watersheds (some focused on more than one type, hence the sum of percentages exceeds 100). Most (31, 72%) employed objective measures of quality, usually water clarity. Although a handful did incorporate subjective measures (by asking either experts or homebuyers to categorize or rate the quality of nearby features), or compared the results of an objective and subjective approach, only two studies directly asked homebuyers to identify the elements of quality they were (i) able to perceive, and/or (ii) considered important and influential on property sales prices. These include the second oldest study identified, based on just 160 participants [11] and one of the Maine studies that had only 52 respondents [28]. Thus, while the use of Secchi disk readings to measure water clarity appears to have become the accepted norm in studies that employ a single measure, additional perceptions-based research could affirm the validity of the assumptions inherent in the use of this measure.

Several of the more recent studies have taken a more comprehensive approach, employing usability indices or government classification schemes based on combinations of multiple ecological and chemical criteria that allow simultaneous consideration of numerous visible and invisible influences on quality. Most studies (35, 81%) considered influences on parcels with structures (in all but one case including single family houses or cottages); two (5%) focused only on unbuilt lots, while six (14%) included both. Early studies tended to concentrate solely on waterfront properties, other than in those cases where distance was used as the direct proxy for quality. In contrast, some of the more recent studies considered entire watersheds including properties both on and off the water, acknowledging that value can accrue to non-frontage residents.

Although the studies consistently reported positive impacts on proximate property values, evaluating their utility for policy decisions requires that three broader contextual issues be considered. First is the issue of publication bias. That is, "the tendency on the part of investigators to submit, or the reviewers and editors to accept, manuscripts based on the direction or strength of the study findings" [66] (p. 235). The preponderance of findings in this review are significant and social science research projects with significant results are substantially more likely to be written up and published than those with null results [67,68]. The extent of this bias with respect to this review is indeterminable, but its potential existence should nevertheless be acknowledged. Hopefully, the inclusion of 14 methodologically sound professional studies that have not been through the journal review process (or been developed into an article at a later date, as was the case for six included reports) contributes to mitigating this potential bias.

A second qualifying issue is that most of the studies report only the benefits side of a cost-benefit analysis. Since the 1972 US Clean Air Act, over $1 trillion has been invested by government and industry to abate water pollution in the US, or $100 per person year. An analysis of grants awarded to municipal wastewater treatment plants which were a major source of river pollution concluded: "A grant's estimated effects on home values are about 25% of the grant's costs. Put another way, while the average grant project cost is around $35 million, the estimated effect on the value of housing within 25 miles of the affected river is around $9 million" [69] (p. 3).

Similarly, the US Environmental Protection Agency (2000a, 2000b) concluded that the cost-benefit ratio of the Clean Water Act was below 1 [70,71].

A third contextual issue is that although the hedonic approach captures the price that proximate homeowners are willing to pay for improved water quality, for at least five reasons this price should be regarded as only a partial measure of total benefits. First, most homeowners are likely to have incomplete information about levels of, and changes in, water pollution. The correlation between subjective perceptions of water quality and objective measures is imperfect [16,21,29,69,72–75]. Many pollution impacts are imperceptible to homebuyers. Levels of dissolved oxygen, nitrogen, and phosphorus are all commonly employed as measures of water quality by scientists. Although fish kills or algae growth sometimes draw attention to pollution, for the most part, it is invisible to the human eye. Hence, its full impact is frequently not capitalized into home sale prices.

A second reason is that incomplete information is likely to extend to the enhanced health benefits that may emerge from investments in pollution abatement. Several epidemiological studies have established relationships between water pollution and selected geographical areas, and documented the negative impacts it has on health [76–79]. Nevertheless, it is likely that many impacted residents remain unaware of these potential negative health effects.

Third, as Walsh et al. (2010, 2011) point out, hedonic analyses fail to include the aesthetic and/or recreational value placed on water clarity by people who do not reside on lake frontage [39,40]. Fourth, related to recreational access is the economic impact that accrues to a community from the direct spending of visitors attracted by clean water. A final source of limitations of hedonic pricing is option and existence values, i.e., the values placed on high quality surface water resources by non-proximate residents who might never visit or use them, but nevertheless place value on their presence.

The findings of this review have substantial implications for environmental policy. They indicate that in areas of declining water quality or infrastructure, the value of maintaining a higher quality of water as capitalized into property prices and ultimately the property tax base should be incorporated into any cost-benefit analysis of potential pollution control measures or investment in the enhancement or replacement of aging water adduction and sewer systems. As noted by Gibbs et al. (2002), the process of eutrophication is virtually impossible to reverse, suggesting that losses in property prices and tax bases become irretrievable at some point [31]. In cases where restoration is possible, results of hedonic pricing studies could be used to confirm that proactively maintaining water quality through the use of judicious policy decisions and active enforcement is more cost effective than a more reactive response. Moreover, the findings suggest that if surrounding land owners are made aware of the quantitative impact of enhanced water quality on the value of their property, they are more likely to be supportive of protective measures and to engage in behavior that supports the maintenance or improvement of quality. This linkage reinforces the value of efforts to provide educational messaging to those owners and to encourage collective action to benefit not only the environment but also personal, local, and regional economies.

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