An Hedonic Analysis of the Effects of Lake Water Clarity on New Hampshire Lakefront Properties

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Policy makers often face the problem of evaluating how water quality affects a region's economic well-being. Using water clarity as a measure of the degree of eutrophication levels (as a lake becomes inundated with nutrients, water clarity decreases markedly), analysis is performed on sales data collected over a six-year period. Our results indicate that water clarity has a significant effect on prices paid for residential properties. Effects of a one-meter change in clarity on property value are also estimated for an average lake in four real estate market areas in New Hampshire, with effects differing substantially by area. Our findings provide state and local policy makers a measure of the cost of water quality degradation as measured by changes in water clarity, and demonstrate that protecting water quality may have a positive effect on property tax revenues.

Key Words: eutrophication, hedonics, water clarity, water quality

Between 1986 and 1996, the number of eutrophic lakes (those with high nutrient levels) in New England doubled to 32% (U.S. Environmental Protection Agency, 1997). Fully 23% of New Hampshire's lakes have reached the eutrophic stage. It is estimated that cultural eutrophication, 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 over the previous 10,000 years (Schloss, 1999). Eutrophication leads to increased photosynthetic activity, causing algal growth, which can decrease the recreational and aesthetic benefits of the water body (Michael, Boyle, and Bouchard, 2000).

Benefit measures of reducing nonpoint-source pollution can serve two purposes: one is in benefit-cost analyses of lake protection programs, and the second is to demonstrate to owners of lakefront properties that it is in their own interest to take actions to protect lakes from eutrophication. Using the hedonic method, this study assesses how water clarity affects sale prices of lakefront properties—adopting procedures identical to those of similar studies examining properties in Maine (Michael, Boyle, and Bouchard, 2000; Boyle, Poor, and Taylor, 1999).

Despite the similarity in study methodologies, however, we do not expect similar results. New Hampshire lakes are closer to major metropolitan areas such as Boston and New York, and, in contrast to Maine, New Hampshire enjoys a more developed highway system. Further, the shorelines of Maine's lakes are substantially less developed than those of New Hampshire. Finally, Maine's lakes tend to be considerably larger on average than their New Hampshire counterparts.

The noticeable differences of the lakefront housing markets between the two adjacent states provide opportunities to test the basic hypothesis that water *quality* (as measured by the proxy of water *clarity*)

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is indirectly related to housing prices, and to examine if the effects of water quality on housing markets are affected by market conditions.

Previous Studies

Only a few studies have been conducted on water *quality* and its effects on property value. Due to the public-goods nature of water bodies, their (mis)use is difficult to monitor. Epp and Al-Ani (1979) estimated the relationship between the value of residential properties adjacent to streams and the quality of the water in the streams. The final model used pH as the environmental variable because it was the most commonly understood measure of quality to the homeowners. When the "clean" streams were estimated as a separate group, the results showed pH had a significant positive effect while the polluted streams were unaffected by pH changes.

Wilman (1984), in her work on coastal pollution, used market data on property rentals to discover the cost of beach pollution. The rental price equation included variables for distance from the beach and debris, and a proxy for pollution, along with structural and neighborhood characteristics. Wilman found beach debris to be a significant negative factor in rental prices for all housing markets studied.

Young and Teti (1984) studied residential properties on St. Alban's Bay on Lake Champlain in Vermont. Data were collected from surveys on the basis that consumers are able to perceive changes in water quality, and from market sales data. The water quality variable was entered as a dummy variable, indicating its location inside or outside the bay. The average property located in polluted areas of the bay lost 20% of its value as compared to similar properties located in nonpolluted areas.

More recently, Michael, Boyle, and Bouchard (2000) investigated the effects of eutrophication on property values. Changes in chlorophyll levels, dissolved oxygen, and water clarity are all ways to measure water quality in lakes where cultural eutrophication may be problematic. Since changes in water clarity are the measure most likely to be observed by the public, secchi disk measurements of clarity were chosen as the water quality variable to be used in the hedonic equation.[1] Using the same application, Boyle, Poor, and Taylor (1999) were the first to examine a number of separate markets in estimating the demand for water clarity in a State of Maine case study.

With regard to functional form, the literature does not readily suggest a correct form for the hedonic equation (Rosen, 1974; Freeman, 1979), although it does recommend several possible forms that can be examined for the best fit. The semi-log form used in two-stage least squares is the most popular alternative to the Box-Cox transformation (Mendelsohn, 1984; Michaels and Smith, 1990; Graves et al., 1988; Brown and Pollakowski, 1977; Bouwes and Schneider, 1979; Murdoch and Thayer, 1992; Young and Teti, 1984; Wilman, 1984; Milon, Gressel, and Mulkey, 1984; Halstead, Bouvier, and Hansen, 1997).

There are two possible semi-log forms. The log-lin form regresses the log of price on the attributes, which implies the marginal value of the attribute of interest increases monotonically with the price (Nelson, 1978; Garrod and Willis, 1992). In contrast, the lin-log form regresses price on the log of the attribute such that the effect of the attribute decreases monotonically with the level of the attribute.

Based on work by Smeltzer and Heiskary (1990), and the subsequent findings of Michael, Boyle, and Bouchard (2000, p. 287) that "a one-meter improvement in clarity in a murky lake is more noticeable and produces a greater change in price than a one-meter improvement in a clear lake," the lin-log functional form (regressing price on the log of water clarity) was chosen as the most appropriate form for our study.

Lakes and Market Areas

Sixty-nine public access lakes in 59 towns were selected for this study. In New Hampshire, water bodies with surface areas of more than 10 acres are considered available for public use. Lakes identified for this analysis were part of the New Hampshire Volunteer Lakes Assessment Program (VLAP).[2] In spring and fall, clarity is subject to fluctuations of water flows and silt disturbance, and in winter the ice prohibits measurement. Since summer months are the time when eutrophication levels are affected by long exposure to the warm sunlight which

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[1] The professional secchi disk is made of 1/4" acrylic with a diameter of 20 cm. It has a standard quadrant pattern of two white and two black quadrants. The disk is attached to an open-reel fiberglas measuring tape. The tape's markings are metric, in increments of meters, centimeters, down to 2 millimeters. The disk is lowered into the water until it disappears, and water clarity can no longer be measured. The top marking on the tape is read as the clarity of the water in meters and is the unit of measurement used for water clarity changes in this study.

[2] The New Hampshire Volunteer Lakes Assessment Program (VLAP) is a cooperative program between lake residents and the New Hampshire Department of Environmental Services. VLAP was initiated in 1985 in response to lake associations' desire to be involved in lake protection and watershed management.

stimulates algae growth, it was the most appropriate time to measure the water's trophic status.

In consultation with the New Hampshire Department of Environmental Services (DES) and others familiar with New Hampshire's lakes regions, the lakes were broken into four market areas in central and southern New Hampshire: area 1 = Conway/Milton, area 2 = Winnipesaukee,[3] area 3 = Derry/Amherst, and area 4 = Spofford/Greenfield.[4]

Lakes were grouped into markets due to close proximity to each other and the probability that they share common characteristics. Division of the lakes into distinct markets facilitates the estimation of separate coefficients for the water clarity variable. This approach also provides an instrumental variable which can be used later in the second-stage hedonic estimation for purging the correlation that exists between income and purchase of water clarity (James, 1995).

Model Specification

Following the structure of previous studies, the general form of the hedonic price equation used here is:

(1) $HP = f(S, L, E)$,[5]

where *HP* = home price,[6] *S* = structural characteristics, *L* = locational characteristics, and *E* = environmental characteristics.

Based on previous work by James (1995), several regressions were run testing different water clarity variables. *LWC* (the natural log of water clarity in meters as calculated by secchi measurements) was used as a proxy for the water clarity; lake area (*LKA*) was incorporated into the equation via an interaction variable {*Lake Area* × ln(*Water Clarity*)}, or *LKALWC*.

This specification follows the analysis of Michael, Boyle, and Bouchard (2000) for Maine, where *LKA* is the surface area of the lake and *LWC* is the natural logarithm of water clarity. The water clarity measure is the minimum clarity reading for the year the property sold. The minimum clarity reading represents the poorest water quality for the year, and the lower the clarity the higher the degree of eutrophication. The derivative of this interaction is the implicit price of water clarity:

(2) $\partial HP95/\partial WC = \beta \times LKA \times WC^{-1}$.

LKALWC was chosen because its use incorporates more of each lake's characteristics into the equation, making the estimated coefficients more robust. The combination variable *LKALWC* also removes the price bias resulting from using one regression coefficient for lakes of all sizes within a single market. This implies the implicit price of water clarity is larger for larger lakes.

Boyle, Poor, and Taylor (1999) found that individuals familiar with lakes and sales of lakefront properties believe water clarity is more important to people who purchase properties on lakes with larger surface areas—a finding consistent with the use of this interaction variable.

It is worth noting that using solely the interaction variable *LKALWC* could cause too much influence to be consolidated into one variable. By using *LKA* and *LWC* as separate variables, the equation might capture all reasons why consumers could choose them either jointly or separately. However, the results of those regressions were inconclusive; while signs and statistical significance of the individual variable coefficients were consistent with theoretical expectations, the effects of marginal changes in water clarity were difficult to interpret. In addition, using all three variables raises collinearity issues. Therefore, {*Lake Area* × ln(*Water Clarity*)}, or *LKALWC*, alone was selected as the most appropriate clarity variable.

Descriptions of the variables included in the model are provided in table 1, and summary statistics for each of these variables are presented in table 2. The structural and locational variables were selected based on a review of variables included in previous hedonic studies and the availability of a parsimonious set of variables consistently reported for all property sales.

By expanding the general equation (1) to include the described independent variables and incorporating the water clarity measure from (2), the resulting equation is:

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[3] Market area 2 includes the lakes around Winnipesaukee, but Lake Winnipesaukee itself was excluded from the study. The surface area of Lake Winnipesaukee is in excess of 44,000 acres; total shore frontage is approximately 182 miles. Thus, because of its size and because it is comprised of so many "mini-market areas," inclusion of Lake Winnipesaukee would have confounded any attempt to fit it into one of the individual market areas, particularly given the time and budget constraints of this study.

[4] Initially a fifth market (Sunapee/Enfield) was delineated, but subsequent statistical testing showed this probably was not a properly segmented market area.

[5] A similar model was run with identical independent variables but with a logged dependent variable. Results were not substantially different, and are available from the authors upon request.

[6] Actual selling price of the house was used, rather than asking price or assessed value.

Table 1. Names and Descriptions of Variables Used in Lake Water Clarity Model

Variable Name	Description	Anticipated Effect
Dependent Variable:		
HP95	Selling price of house, 1995 dollars	
Dwelling Structural Variables:		
AGE	Age of house, in years	Negative
AGESQ	Age of house, in years, squared	Positive
SQFT	Square footage of finished living area, excluding bathrooms and closets	Positive
PLUM	1 if full plumbing, 0 otherwise	Positive
FF	Property abutting the water (feet)	Positive
Locational Variables:		
DIST	Miles to nearest town with population > 9,000	Negative
DENS	Housing density (lots/1,000 feet of lake frontage)	Negative
TR	Tax rate in year of purchase	Negative
LKA	Surface area of lake (acres)	Indeterminate
Environmental Quality Variables:		
WC	Secchi disk measurement of water clarity (meters)	Positive
LKALWC	*Lake Area* (ln(*Water Clarity*)	Positive

Table 2. Descriptive Statistics for Variables Used in Lake Water Clarity Model

	MARKET AREA							
	[1] Conway/Milton (N = 115)		[2] Winnipesaukee (N = 178)		[3] Derry/Amherst (N = 80)		[4] Spofford/Greenfield (N = 74)	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
HP95	138,763.05	57,895.45	175,157.73	181,263.61	132,162.84	82,328.29	167,104.70	124,466.83
AGE	34.05	21.62	34.83	26.34	44.49	24.45	44.51	28.18
AGESQ	1,617.83	1,722.09	1,902.72	3,636.65	2,569.46	2,309.76	2,764.84	3,411.30
SQFT	987.50	489.97	1,099.47	734.77	1,203.50	858.05	1,215.82	724.74
PLUM	0.95	0.23	0.92	0.28	0.96	0.19	0.95	0.29
FF	172.06	349.37	144.11	126.19	107.29	104.45	151.67	125.02
DIST	15.52	6.96	12.75	7.84	16.67	36.08	16.08	7.02
DENS	7.70	3.09	8.08	2.88	11.02	3.09	7.57	3.33
TR	18.57	6.75	23.04	7.06	30.51	7.66	21.89	6.33
WC	4.88	1.64	5.88	2.12	4.18	0.86	4.35	2.94
LWC	1.53	0.36	1.70	0.38	1.41	0.24	1.22	0.76
LKA	1,235.77	1,269.99	1,879.10	1,879.03	213.58	148.47	283.69	248.10
LKALWC	2,073.10	2,258.37	3,345.28	3,299.80	304.75	226.09	477.76	605.04

$$(3)\quad HP95 = \text{"} + \$_1 AGE + \$_2 AGE^2 + \$_3 SQFT + \$_4 PLUM + \$_5 FF + \$_6 DIST + \$_7 DENS + \$_8 TR + \$_9 LKALWC + \text{g}.$$

Ordinary least squares (OLS) was chosen as the preferred estimation technique to determine the marginal value of the characteristics.

Data Collection

Following Freeman (1993), the study uses cross-sectional data for individual sales of lakefront properties. Cross-sectional data are necessary because eutrophication, and therefore clarity, changes slowly over long periods of time, and repeat sales of lakefront properties are infrequent. Lakefront housing sales data were collected for the period between 1990 and 1995, and converted to 1995 dollars for estimation.[7]

Information on the selected variables was taken from public assessment and transaction records available in the towns where the properties are located. However, the data available are not consistent across towns with lakefront properties in the study area. This inconsistency in the availability of data restricted the variables available for use in regression analyses.

The original number of usable observations collected was 742. After observations were removed due to inconsistent town records, unrecoverable gaps in the secchi disk readings, other missing data, and the Sunapee subset was deleted, the final number of observations for this analysis was 447.

Results

Results of OLS regressions are summarized in table 3. Breusch-Pagan tests indicated the presence of heteroskedasticity in the equations for all four market areas. Therefore, all *t*-statistics and confidence intervals were calculated using White's method for corrected standard errors. All statistically significant variables had correct signs.

Water clarity, through the interaction variable with lake area, has a significant, positive impact on property values in all four market areas. For example, using equation (2), the implicit price of water clarity for Sunset Lake in the Spofford/Greenfield market ($LKA = 31$, $WC = 3.2$, and $\$_9 = 149.6$) is:

$$\mathrm{M}HP95/\mathrm{M}WC = \$_9 \,(\, LKA \,(\, WC^{!1} =$$
$$149.6 \,(\, 31 \,(\, (1/3.2) = \$1{,}449.25.$$

The estimated marginal benefit (or loss) of water clarity from a base of the average water clarity at Sunset Lake is approximately $1,500. Because of the lin-log functional form, the marginal effect of water clarity increases as the base level of water clarity decreases.

For a better understanding of the policy relevance, the effects of a one-meter decrease in clarity from the average clarity are calculated for each market. The estimates are reported in table 4. Implicit prices at the mean values of *LKA* and *LWC* are also presented.

As observed in table 4, there is a wide variation in the effects of decreasing one-meter water clarity on property values across markets. These differences are due to variations in the average clarity and lake area in each market, but mostly are attributable to different hedonic price coefficients in the four markets. We focus on decreases in clarity here, as losses in value from a decrease in clarity exceed a comparable increase in clarity. More important is that once a lake becomes more eutrophic, it is very difficult to reverse this process. Thus, the benefit of protecting lakes from eutrophication and the consequent declines in water clarity is the policy-relevant information.

Data Problems and Limitations

Pairwise correlation tests were performed on all variables within each market area to test for a linear relationship between sets of variables. Only market area 1 (Conway/Milton) had any correlation coefficients above *0.5*, with none higher than *0.63*. In addition, variance inflation factors (VIFs) were calculated for all variables in each market. Based on these tests, degrading multicollinearity was not considered a problem.

The form of the equation may have been somewhat restricted by availability of some data. Assessment record information is often recorded sporadically from town to town. Most towns' records were incomplete or incompatible with other towns for many of the smaller structural characteristics. The lack of consistently available data limited the minor structural characteristics that could be included. Gaps related to some of the major data, which had been limited by inconsistent records, have been filled in from survey responses.

Secchi disk readings came from two sources: the University of New Hampshire and the New Hampshire Department of Environmental Services (DES). While both sources use the traditional secchi disk, they employ different methods of collecting secchi readings. One uses a view scope to minimize influences that hamper readings. Use of the view scope minimizes glare from the sun; it also eliminates surface disturbances caused by wind and other sources. These adjustments created by the view scope are suspected to cause a divergence from conventional secchi reading methods.

The percentage difference in readings from these two sources is unknown; consequently, the effect on

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[7] The specific time period (1990–95) was chosen for consistency with two studies previously conducted at the University of Maine, so that a pooled data set could be used later to generate second-stage hedonic estimates (Michael, Boyle, and Bouchard, 1996).

Table 3. OLS Regression Results (dependent variable = *HP*, adjusted to 1995 prices)

	MARKET AREA							
	[1] Conway/Milton (N = 115)		[2] Winnipesaukee (N = 178)		[3] Derry/Amherst (N = 80)		[4] Spofford/Greenfield (N = 74)	
Variable	Estimated Coefficient	*t*-Statistic	Estimated Coefficient	*t*-Statistic	Estimated Coefficient	*t*-Statistic	Estimated Coefficient	*t*-Statistic
Intercept	170,377.50***	4.703	202,288.57***	2.899	94,045.00**	2.172	111,048.57**	2.256
AGE	226.89	0.767	!3,139.29***	!4.823	!2,447.73***	!2.819	!1,889.36**	!2.303
AGESQ	!4.79	!0.567	32.44***	6.780	16.06**	1.980	12.11**	1.966
SQFT	44.65**	2.334	38.50**	1.967	42.18***	5.444	25.75*	1.348
PLUM	19,093.01	1.393	!5,260.00	!0.398	13,094.11	0.997	15,283.00	0.661
FF	19.01	0.865	384.98*	1.670	154.42**	2.382	217.49**	1.881
DIST	!2,350.92***	!3.208	2,984.94*	1.599	!166.21	!1.16	250.16	0.204
DENS	!1,530.00	!1.124	!7,555.19**	!2.024	!961.25	!0.490	!8,346.37**	!2.628
TR	!3,117.10***	!4.383	!4,668.16***	!2.929	516.95	0.603	711.97	0.610
LKALWC	4.4806***	2.575	17.34***	2.913	76.77**	2.234	149.60***	5.148
Adjusted R^2	0.430		0.576		0.666		0.666	
Breusch-Pagan P^2	30.7281 (9 d.f.)		727.2235 (9 d.f.)		24,4724 (9 d.f.)		37.6542 (9 d.f.)	
Mean of Dep. Var.	138,763.00		175,157.73		132,162.84		167,104.70	

Note: *, **, and *** denote significance at the 90%, 95%, and 99% confidence intervals, respectively, in a one-tailed *t*-test.

Table 4. Average Estimated Impacts of Water Clarity Variables by Market Area

Description	Implicit Prices[a]	Value of One-Meter Change in Secchi Reading,[b] (Standard Error)[c]		% Increase in Average *HP* Due to One-Meter Change
Conway/Milton Market:				
HP = \$125,915.00 + 4.4806*LKALWC*	\$1,134.63	\$1,268.24	(492.58)	0.91
Winnipesaukee Market:				
HP = \$172,225.30 + 17.338*LKALWC*	\$5,541.43	\$6,122.33	(2,101.60)	3.50
Derry/Amherst Market:				
HP = \$132,924.27 + 76.775*LKALWC*	\$3,922.62	\$4,411.39	(2,004.51)	3.39
Spofford/Greenfield Market:				
HP = \$171,028.81 + 149.6*LKALWC*	\$9,756.33	\$11,094.09	(2,154.99)	6.64

Note: The estimates are expressed using grand constants calculated from the individual regressions at the mean for each characteristic for the properties in that market area.

[a] Calculated via formula: $\$_9 \,(\, LKA \,(\, WC^{!1}$.

[b] Based on mean secchi readings for market area.

[c] Standard errors derive from the standard error of the estimated coefficient $\$_9$, since average lake area and average water clarity are exogenous.

regression results is unknown. Further work on identifying the differences between the two measurement methods needs to be done to determine if the effects change the regression results. The same method was used consistently for all observations taken from an individual lake; the variation of methods occurred only between lakes.

Comparison Across States: New Hampshire versus Maine

One of the stated objectives of this analysis was to compare the effects of changes in water clarity on property values in New Hampshire to those same effects on Maine properties. An initial overview shows that the basic descriptive statistics for Maine properties vary substantially from those of New Hampshire.

While the average sale price of lakefront properties in New Hampshire varied from about $132,000 to more than $175,000 (table 2), the average selling price for market areas in the Maine study ranged from about $70,000 to $107,000 (Boyle et al., 1998). The average for three of four market areas was less than $100,000.

Average water clarity showed much more variation across markets in Maine, ranging from 3.88 meters to 6.09 meters, while the averages for New Hampshire were all between 4.18 and 5.88 meters. The highest average lake area in New Hampshire was 1,879 acres; in contrast, only one market area in Maine had an average lake area of less than 2,000 acres, and the largest average was 4,756 acres. The smallest average for Maine was 679 acres, which is still more than two to three times larger than the two smallest averages for New Hampshire, 214 and 284 acres. These results strongly suggest there are basic market and physical differences between the New Hampshire and Maine data.

More important, perhaps, are the magnitudes of the estimated hedonic coefficients. The estimated coefficients for New Hampshire water clarity ranged from 4.48 to 149.60, while the comparable range for Maine was 2.05 to 40.92.

Collectively, these findings indicate there is very little comparability between the New Hampshire and Maine data, and the respective results from these studies. Specifically, the findings from Maine could not be easily transferred to New Hampshire, and an original study in New Hampshire was warranted. This conclusion likely extends to other regions of the country where real estate markets and baseline water clarity may differ, and people may have different preferences for water clarity.

However, when one considers simply the implicit prices rather than the effects of a one-meter change, the differences between Maine and New Hampshire lakes are not so marked. As table 4 illustrates, the implicit prices for the New Hampshire market areas range from about $1,100 to $9,800. Michael, Boyle, and Bouchard (2000) reported that average implicit prices in the three Maine market areas studied ranged from about $1,500 to $10,000, depending on the method of calculation used. Thus, by some measures, the demand functions between Maine and New Hampshire lakes may not vary by as much as first appears.

Conclusions and Implications

Our findings confirm that water clarity is a concern to consumers who own lakefront property on New Hampshire lakes. Based on study results, a one-meter decrease in water clarity can lead to decreases in property value ranging from 0.9% to over 6%, on average. Given the number of properties abutting New Hampshire's lakes, an overall decline in water clarity caused by eutrophication could have a major negative impact on local property tax revenues. Further, it is highly likely that non-lakefront properties located near these lakes would also be negatively affected by decreases in water clarity, as would visitors to the lakes. Thus the estimates provided in this study represent a conservative lower bound to the financial losses potentially caused by continued cultural eutrophication.

Mail survey results (a related effort of the overall study) confirmed the importance of water clarity as a factor in purchase decisions of waterfront property in New Hampshire; 76% of respondents made the effort to inquire about water clarity prior to purchasing their property. Also, of those who responded, 96.9% said clean water is a very important consideration, while 98.5% said clear water is very important. Clarity of the water influenced the purchasing decision of 45.5% of survey respondents.

Decreasing property values, due to continued cultural eutrophication, can affect both state and local tax revenues. Protection of water clarity is important for the fiscal health of both the State of New Hampshire and individual towns. Given that it is nearly impossible to reverse the eutrophication process, and the costs (foregone benefits) increase as clarity decreases, efforts to protect lakes from further reductions in water clarity appear to be warranted.

The results of our hedonic price equations can be used to educate property owners and local communities by convincing them it is in their economic interest to take collective action to protect lake clarity. The estimated implicit price estimates can be used as marginal values to identify protection programs where the benefits exceed the costs of the actions.

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