JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

AMERICAN WATER RESOURCES ASSOCIATION

IS URBAN STREAM RESTORATION WORTH IT?[1]

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ABSTRACT: Public investment in urban stream restoration is growing, yet little has been done to quantify whether its benefits outweigh its cost. The most common drivers of urban stream projects are water quality improvement and infrastructure protection, although recreational and aesthetic benefits are often important community goals. We use standard economic methods to show that these contributions of restoration can be quantified and compared to costs. The approach is demonstrated with a case study in Baltimore, Maryland, a city with a legal mandate to reduce its pollutant load. Typical urban stream restoration costs of US$500-1,200 per foot are larger than the cost of the least expensive alternatives for management of nitrogen loads from stormwater (here, detention ponds, equivalent to $30-120 per foot of restored stream) and for protecting infrastructure (rip-rap armoring of streambanks, at $0-120 per foot). However, the higher costs of stream restoration can in some cases be justified by its aesthetic and recreational benefits, valued using a contingent valuation survey at $560-1,100 per foot. We do not intend to provide a definitive answer regarding the worth of stream restoration, but demonstrate that questions of worth can be asked and answered. Broader application of economic analysis would provide a defensible basis for understanding restoration benefits and for making restoration decisions.

(KEY TERMS: natural resource economics; rivers/streams; urban areas; nonpoint source pollution; best management practices (BMPs); restoration; watershed management; stormwater management.)

Kenney, Melissa A., Peter R. Wilcock, Benjamin F. Hobbs, Nicholas E. Flores, and Daniela C. Martínez, 2012. Is Urban Stream Restoration Worth It? *Journal of the American Water Resources Association* (JAWRA) 1-13. DOI: 10.1111/j.1752-1688.2011.00635.x

INTRODUCTION

Stream restoration projects are a common and growing public investment. In 2005, the national annual expenditure was conservatively estimated to exceed US$1B (Bernhardt *et al.*, 2005). Today's total costs are not known but likely much larger. Yet little has been done to quantify the benefits of stream restoration or its cost-effectiveness relative to other means of achieving the goals of restoration. It is unclear whether this investment is worthwhile.

Our goal in this paper is not to develop a single definitive answer regarding the value of stream restoration, but to emphasize that questions of worth can (and should) be asked and answered. We demonstrate

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[1] Paper No. JAWRA-10-0159-P of the *Journal of the American Water Resources Association* (JAWRA). Received September 21, 2010; accepted December 12, 2011. © 2012 American Water Resources Association. **Discussions are open until six months from print publication.**

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that the benefits of restoration can be evaluated in light of the costs and seek to encourage broader application of such analyses. Too often, stream restoration success is defined in terms of limited and vague metrics purporting to represent success (Bernhardt *et al.*, 2005). There is a pressing need for benefits to be explicitly stated and quantified to the extent possible to evaluate whether the public investment is worthwhile. We do not attempt to address all possible benefits and costs of stream restoration, but demonstrate that rigorous decision making can be supported by a quantitative assessment of economic impacts. We consider a typical suite of economic impacts for urban streams that represent part or all of the value provided many individual urban projects. There is considerable uncertainty in the economic valuation of these effects, but we are able to define the problem such that a useful assessment is possible. We note that the type and amounts of economic benefits will depend strongly on the context and design of individual projects.

We choose urban streams for this study because they are often impaired and because such stream projects are numerous and typically expensive due to permitting, land value, and construction costs. Although a variety of benefits can be claimed, water quality improvement and infrastructure protection are typically the dominant drivers (Corsair *et al.*, 2009) of urban stream projects. For instance, of 14 project goals enumerated in the National River Restoration Science Synthesis Project (NRRSS) (Bernhardt *et al.*, 2005; http://nrrss.nbii.gov), those that can be clearly attributed to water quality and infrastructure protection account for approximately 40% of the projects and 50% of the project costs. This study did not distinguish between urban and rural projects, and the actual percentages are likely larger for urban settings where water quality and infrastructure concerns often dominate. Also, the NRRSS study reports only a single goal for each project. Water quality and infrastructure goals often motivate urban projects, even if a different objective was reported as primary. In the case of projects focused on water quality improvement, restoration investments are often made to improve an essential element of aquatic life habitat in response to total maximum daily load (TMDL) requirements under the Clean Water Act and national pollutant discharge elimination system (NPDES) permits for municipal separate storm sewer systems. Particularly in older, built-out urban environments, stream restoration is perceived as a promising management practice for meeting TMDL and NPDES requirements.

To provide context and specificity, we estimate the economic effects of stream restoration in Baltimore, Maryland, a city with aging infrastructure as well as legal obligations to reduce pollutant loadings from stormwater (Maryland Department of the Environment, 2005). In addition to restoration's cost-effectiveness for water quality and infrastructure protection, we evaluate the social benefits of aesthetic and recreation enhancements because these benefits are a frequent justification of stream restoration in urban areas (Bernhardt *et al.*, 2005; Corsair *et al.*, 2009). We consider a generic 0.25-mile stream length in need of restoration, a size not atypical of such restoration projects. The water quality, infrastructure, and aesthetic and recreation values are expressed in present worth 2008 dollars over a 50-year restoration project life (Center for Watershed Protection & Maryland Department of the Environment, 2000).

There are other potentially important benefits of stream restoration in urban areas. These include educational, ethical, and community benefits that arise from restoring a naturalized environment within an urban setting, as well as from enhancing aquatic and riparian ecosystems along streams with improved water quality. These additional benefits can be difficult to quantify. Our goal is not to provide a single, definitive judgment, and we do not attempt to evaluate all possible benefits. By considering three dominant categories of benefits—water quality improvement, infrastructure protection, and aesthetic and recreational enhancement—we are able to demonstrate the application of standard economic evaluation methods to a realistic situation.

The analytical paradigm we use is cost-effectiveness analysis in which the cost of an urban stream restoration is compared to the cost of other alternatives for promoting the water quality and infrastructure goals of restoration. We find that the stream restoration we analyze is unlikely to be cost-effective for these purposes. However, there are additional social benefits that may offset the extra cost of restoration in the form of willingness-to-pay (WTP) for recreational and aesthetic enhancements, which we quantify by a contingent valuation survey of Baltimore City residents, in which they express their willingness-to-pay for the stream restoration. The resulting net cost of restoration is then compared to the cost of the alternatives. (Alternatively, and equivalently, the net benefit of stream restoration could be expressed as the aesthetic and recreational benefits plus the avoided costs of the next best alternatives for achieving water quality and infrastructure goals, minus the cost of restoration. This would assume that the goals would be achieved by the least costly alternative means if restoration is not implemented.) In the subsequent three sections, we describe the methods used to quantify cost-effectiveness for water quality improvements and infrastructure protection, and public WTP for recreational and aesthetic enhancements, and conclude by summarizing the resulting estimates of benefits and costs.

COST-EFFECTIVENESS FOR WATER QUALITY IMPROVEMENTS

Water quality benefits claimed for stream restoration projects include reduction of sediment and phosphorus (P) loadings by reducing streambank erosion as well as enhancing nitrogen (N) removal by increasing water retention time for denitrification (Craig *et al.*, 2008). Water quality improvements, particularly N reduction, are the primary driver of stream projects in Baltimore City, which operates under legal mandates to attain NPDES targets for diffuse pollution (Maryland Department of the Environment, 2005). We quantified water quality in economic terms by considering stream restoration's cost-effectiveness compared to the least expensive alternative for providing the same pollution load reduction for N as the restoration project. We focus on N for two reasons. First, based on the methodology described below, our calculation of the avoided cost benefit of pollutant reductions is larger for N than for P or sediment; because we are interested in whether stream restoration might be justified on the basis of cost-effectiveness for water quality improvement alone, we use the larger value. Second, N is the most important nutrient influencing eutrophication of the Chesapeake Bay, although P may play a seasonal role (Howarth and Marino, 2006).

As alternatives to restoration, we consider a range of best management practices (BMPs) for nonpoint pollution reduction that are feasible in Baltimore City; each is sized so that it provides the same N reduction as the stream restoration. The least expensive such BMP is then the basis for assessing the cost-effectiveness of restoration for N reduction.

The reduction of N loads provided by stream restoration is uncertain. We use standard regional values adopted by the Chesapeake Bay Program (Urban Storm Water Workgroup, 2003) of 0.02 lb/ft/year to calculate the mass of N (26.4 lb/year) reductions associated with a 0.25-mile stream project. (In the case of sediment and P, the values are respectively 2,640 and 3.3 lb/year). These values are used by regulators to determine the pollution control credit for stream restoration projects (Urban Storm Water Workgroup, 2003). This is therefore the relevant N value for sizing and costing alternative BMPs using the procedure outlined in Figure 1, described in this section. Data assumptions are documented in the supplementary Appendix S1 available as part of the on-line paper.

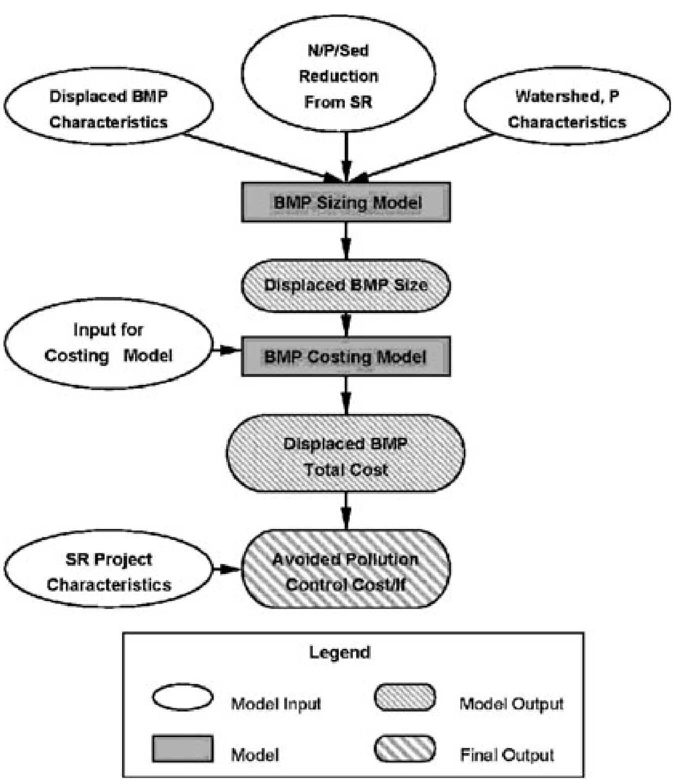

FIGURE 1. Procedure for Quantifying the Nitrogen Benefits of Stream Restoration. BMP, best management practice.

Pollutant reductions used in the regulatory process will, of course, differ from the actual values realized in any particular case. Actual reductions would vary strongly from site to site, and are highly uncertain (Craig *et al.*, 2008). For example, Craig (2009) detected no NO_3 uptake in both urban and forested second order streams in the Maryland Piedmont, whereas Klocker *et al.* (2009) observed measurable NO_3 uptake in four Baltimore County streams, but could not detect different uptake rates between two that were restored and two that were not. In the LINX II study (Mulholland *et al.*, 2008), half of the urban stream sites had denitrification rates smaller than 0.02 lb/ft/year, and 16 of 18 urban sites were below 0.03 lb/ft/year. The Chesapeake Bay Program's values consider denitrification, but additional N reductions could also occur via, for instance, plant and algal uptake (although remineralization of this N can result in its return to the stream when the organism has died) and hyporheic processes (e.g., Hester and Gooseff, 2010), so actual N reductions could be higher. Yet Klocker *et al.* (2009) observed that uptake rates for denitrification were essentially equal to total NO_3 uptake rates in a restored Baltimore County stream.

In general, there is a growing set of observations of N uptake in urban streams with and without restoration (e.g., Kaushal *et al.*, 2008), yet "(q)uantification of the benefits of restoration aimed at N reduction is just beginning … and data are sorely needed to support the idea that stream restoration leads to substantial N reductions" (Mulholland *et al.*, 2008, p. 536). We adopt the reduction value that regulators credit to stream restoration because this value falls within the range observed and is the value that will drive the cost savings to the city of Baltimore.

Best Management Practice Sizing Model

The first model used in the procedure of Figure 1 is the BMP sizing model, which utilizes the Simple Method (Schueler, 1987). This method calculates the annual pollution loading in stormwater runoff from an urban watershed area given average annual precipitation, percent imperviousness, and a flow-weighted event mean concentration of pollution. We invert this model to determine, for each candidate BMP b, the area A_{bN} of the watershed whose loading of N (in mass/year) would be reduced by the BMP by an amount equal to the N reduction (again, mass/year) due to our proposed 0.25-mile stream restoration. This equivalent area is then used in the BMP sizing model, in which the capacity of BMP type b is expressed as a function of the size of the treated area draining into it. This capacity is then converted into cost using the BMP costing model, described later in this section. The least expensive feasible BMP that can mitigate N pollution equivalent to stream restoration is the most cost-effective alternative to restoration for water quality improvement.

The relations used to determine the basin area for which a designated BMP would provide pollutant reduction equivalent to stream restoration are (Schueler, 1987):

$$A_{bN} = \frac{LT_{bN}}{U_1 * R * C_N}, \tag{1}$$

where:

$$R = P * P_j * (0.05 + (0.9 * I_a)), \tag{2}$$

$$LT_{bN} = \frac{L_N}{E_{bN}}. \tag{3}$$

The notation is:

A_{bN} is the area of the watershed [acres] for BMP b for pollutant z,

b is the index for urban BMPs that are alternatives to stream restoration,

C_N is the flow-weighted annual mean concentration of N [mg/liter],

E_{bN} is the removal efficiency [] for BMP b for N,

I_a is the imperviousness of the area [],

L_N is the N reduction equivalent to reduction resulting from stream restoration [lb/year],

LT_{bN} is the total annual N load [lb/year] for BMP b in the runoff from the equivalent watershed area, as calculated by Equation (3),

P is the average annual rainfall depth [inches/year],

P_j is a factor to correct for P when the event produces no rainfall [],

R is the runoff depth for the site [inches/year] as calculated by Equation (2), and

U_1 is a unit conversion factor equal to 0.226 [liters * lb/acre * mg * inches].

The Simple Method relationship is rearranged as Equation (1) to calculate the equivalent treated area of the watershed A_{bN} given the N load and the watershed characteristics for each BMP b. Equation (2) calculates the annual runoff depth as a function of rainfall depth, a correction factor for events that produce no runoff, and the runoff coefficient. Finally, the total pollution load, Equation (3), is calculated using the pollution load equivalent to stream restoration and the pollution removal efficiency of the BMP.

Next, given the size of the watershed/treatment area (A_{bN}), we calculate the size of the BMP, expressed as a volume of storage WQ_{bN}, that gives the same N reduction as the restoration. The treatment area is needed to calculate the cost of the BMP; this value is calculated using water quality sizing guidelines for a 90% rainfall event, which is the BMP size required to store and treat a 24-h storm event that is less than or equal to 90% of annual 24-h precipitation events. The equation to make this calculation is (Schueler, 1987):

$$WQ_{bN} = \frac{P_1 * R_v * A_{bN}}{U_2} * U_3, \tag{4}$$

where WQ_{bN} is the water storage volume of the BMP [ft^3], P_1 is the annual 90% rain event [inches], U_2 is a unit conversion factor equal to 12 [inches/feet], U_3 is a unit conversion factor equal to 43,560 [ft^3/acre-foot] and the other variables are as previously defined. For those BMPs that do not have detention, namely the retention BMPs (vegetated swales and riparian buffers), the WQ_{bN} is instead calculated as the area (i.e., depth is assumed to be 1 foot).

The drainage area of the equivalent BMP is compared to the average size of treated areas in Baltimore City to determine if it is realistic. The watershed areas for each BMP are, with one exception, between the maximum and minimum area treated by actual BMPs of that type in the city. The sole exception is the infiltration basins BMP, for which real projects have a maximum treated area of 5 acres (Center for Watershed Protection & Maryland Department of the Environment, 2000). Given that the area that would need to be treated under that BMP (from Equation 1) is 11 acres, we assumed that the equivalent BMP in this case would be three such basins, with two projects sized for 5 acres and one project sized for 1 acre.

Best Management Practice Costing Method

The second model in the water quality benefits procedure (Figure 1) estimates the cost of each type of equivalent BMP based on the size WQ_{bN}, determined above. To explain how the costs are quantified, we first present the BMP cost model and then describe the input values and calculations (Figure 1).

The BMP cost model quantifies the cost (Steiner, 1992) as the present worth of a BMP that provides the same N reductions as stream restoration. We convert this to an annualized cost (in 2008 US$) using an appropriate capital recovery factor and escalation rates based on the Engineering News-Record (ENR) construction cost index (Grogan, 2009). Then calculating the present worth of those annual costs for the same assumed lifetime (50 years) as the restoration allows for cost-effectiveness comparison with restoration itself. (This requires the "infinite replacement" assumption for any alternative.)

The resulting equivalent BMP costs include construction, design, and engineering expenses. The lowest value of this cost across candidate BMPs *b* is then used to assess the cost-effectiveness of stream restoration for N reduction assessed. Dividing the present worth of that cost by the stream restoration length allows us to obtain the equivalent cost per foot of stream restoration.

Best Management Practice Cost Results

Costs, in 2008 US$ per foot, were estimated for seven common urban BMPs addressing N (Table 1). BMP options involving ponds or wetlands tend to be less expensive but also require an appropriate site, which may not be available in built-out urban areas. If such low-cost BMPs are infeasible, a manager would then consider higher cost BMPs (e.g., infiltration basins and riparian buffers) that can be dispersed throughout the watershed, either solely or in combination with other BMPs. Hence, we distinguish between less expensive (ponds and wetlands) and more costly (infiltration basins and riparian buffers) BMP options. There may be some urban watersheds where it is not possible to install these BMPs. In such cases, a municipality will need to consider other BMPs such as widespread vegetated swales, rain barrels, and street sweeping, whose costs per pound of N can be considerably higher and whose water quality benefits are not yet widely accepted.

TABLE 1. Water Quality Benefits of Stream Restoration (avoided pollution control costs in 2008 US$/equivalent restored foot of stream), Based on N Reductions as Calculated Using the Water Quality Benefit Model, Which Combines a BMP Sizing Model and BMP Costing Model.

BMP *b*	**Stream Restoration Without Land Costs [$/ft]**	**Stream Restoration With Land Costs [$/ft]**
Dry extended detention pond	40	99
Wet extended detention pond	30	90
Wetland	40	94
Infiltration basin	73	279
Riparian buffer	45	67

Table 1 shows that the least expensive BMPs are ponds or wetlands, whose N reduction cost would be equivalent to $30-40 per foot of restored stream. (At our assumed reduction of 0.02 lb N/ft/year for stream restoration, this is equivalent to a cost of approximately $100/lb N.) More expensive, dispersed, water quality improvements include infiltration basins and buffers at $45-73 per foot.

The water quality benefit values calculated here do not include the cost of acquiring land because BMPs in Baltimore are generally sited on donated or public land (David Framm, Baltimore City General Services, July 8, 2011, personal communication). For completeness, we include an approximate analysis incorporating land value. If vacant land were purchased at $200,000/acre (http://www.loopnet.com/Maryland/Baltimore_Land-For-Sale/), BMP costs increase by an equivalent of $22-206 per foot of restored stream (Table 1), with the least expensive BMPs more than doubling in cost to approximately $100/ft.

In contrast, the costs of stream restoration in Baltimore City, derived from the expenditures of recently implemented stream projects, are $500-1,200 July 8, 2011, per foot, or at least $600,000 for a quarter-mile project. (These costs appear to be higher than those reported in Hassett *et al.*, 2005; however, their cost data have a highly skewed distribution, and it is not possible from their data to derive a $ per length cost.) It is likely that these costs depend in part on project scale. For example, the fixed cost of bringing equipment to the site can be spread over a larger project. However, in the absence of evidence of strong economies of scale (which was not present in the Baltimore

City data), we assume that they can be disregarded and that cost per foot is constant for different project sizes. Thus, for N reductions, stream restoration is considerably more costly per unit (and thus much less cost-effective) than the best alternative BMPs, so water quality cannot by itself justify restoration.

Uncertainty in Water Quality Benefits

The uncertainty in estimating water quality benefits, together with the fact that the water quality benefits we calculated are small relative to typical costs for urban stream projects, led us to consider conditions that could provide a larger water quality benefit. That is, if stream restoration is found to be considerably more expensive than alternative actions to reduce nutrient and sediment loadings, we wanted to make sure we did not underestimate the benefits. To start, we used N as the water quality target and assigned small BMP efficiencies in order to yield a higher cost for restoration alternatives than other possible choices. We did this so that the resulting BMP costs represent an upper range, which increases the water quality benefit of stream restoration.

Among all inputs to the cost model, we consider stream restoration pollution reduction and BMP pollution removal efficiency (E_N) to be the most uncertain. Because of the multiplicative nature of the BMP sizing and costing models, any two input variables that are varied by the same percentage will have the same percentage effect on the output. Thus, a ± 50% change in pollution removal resulting from restoration or BMP efficiency will change the water quality benefit by as much as −25% to +100%. (Such a range of uncertainty for efficiencies is broadly consistent with ranges of estimates provided by Simpson and Weammert, 2009.) This relation can be used to evaluate possible larger values of water quality benefit. We used a removal rate of 0.02 lb N/ft/year to determine the quantity of N removed by a stream restoration project. This value is close to the median reported for urban streams in the LINX II study (Mulholland *et al.*, 2008). If the largest urban denitrification value from that study, 0.03 lb N/ft/year, is used to determine the target N removal, the water quality benefit reported in Table 1 would increase by 50%. The largest denitrification rate observed in 48 LINX II studies (0.11 lb/ft/year) would increase the water quality benefit by a factor of more than 5. That an extreme value of denitrification rate from a national survey is needed to increase water quality benefits to values comparable to project costs suggests that stream restoration is generally more expensive than the alternative for reducing nutrient and sediment loadings. Appendix S1 (online supplementary material) documents additional sensitivity analyses.

COST-EFFECTIVENESS FOR INFRASTRUCTURE PROTECTION

Urban stream projects are often undertaken to stabilize streambanks to protect sewer lines, stormwater outfalls, bridges, roads, and property boundaries. Even when other objectives are stated, the immediate need to protect infrastructure frequently determines the location and design of stream projects. We estimate the cost-effectiveness of restoration for infrastructure protection by comparing it to the avoided cost of riprap bank protection. Riprap is chosen as the displaced alternative because riprap is typically the least costly form of bank stabilization and provides negligible aesthetic or water quality benefits.

The cost of riprap per foot can be estimated using a standard cost per installed area and a specified height and length of bank to be treated. Current cost for appropriately sized riprap in Baltimore is approximately $105 per square yard (materials, labor, equipment, overhead, and profit) (RS Means, 2008). This corresponds to a cost of $58 per foot for a streambank 5 feet high; to armor both sides of the 0.25-mile streambank doubles the cost to about $120 per foot. This cost may apply to only a portion of the stream length restored, depending on infrastructure location and stream configuration, so the cost of infrastructure protection by riprap can vary between $0 and $120 per foot. This is approximately an order of magnitude less expensive than stream restoration.

AESTHETIC AND RECREATION ENHANCEMENT BENEFITS

Approach

Although alternatives to urban restoration for water quality improvement and infrastructure protection are considerably less expensive than restoration, when expressed on a $/ft basis, stream restoration provides other benefits that may justify its greater cost. For example, anecdotal evidence suggests that aesthetic and recreation enhancements such as instream riffles and falls, walking paths, stream access, debris removal, signage, and desirable streamside vegetation may have public appeal. An estimate of the aesthetic and recreation benefit of our stream project was sought using methods to determine WTP for public goods.

One such approach is hedonic pricing, in which the effect of stream restoration on property prices is assessed by statistically comparing property values near and far from restored streams (Loomis, 2006). This approach has the advantage of being based on revealed preferences, as opposed to a stated preference approach. However, it can only be applied where a stream restoration has already taken place and sufficient property value data can be collected; this is not possible in Baltimore, where stream restorations have been undertaken only very recently.

Instead, we use the stated preference technique of contingent valuation to quantify the dollar value of aesthetic and recreation benefit. Contingent valuation is a standard approach for eliciting stated WTP for public goods (Carson and Hanemann, 2005). In particular, we conducted a mail survey of Baltimore City residents to assess design preference and to value different features of urban stream restoration projects. Specifically, we asked a random sample of Baltimore City residents to assess (i) the importance of stream projects relative to other city services, (ii) their preferences for appearance and recreational access, (iii) the importance that stream projects provide water quality benefits, (iv) the monetary value of stream projects, and (v) basic demographic information (see Appendix S2 for survey).

We did not directly ask for a WTP for aesthetic and recreational benefits of stream restoration because stream projects can serve multiple purposes and it was not clear that respondents would be able to consistently factor out other benefits. Instead, we asked survey respondents to compare two stream restoration designs that are stated to provide identical infrastructure and water quality benefits. Based on stated preferences for one design, differences in WTP can be viewed as a premium that the respondents would be willing-to-pay for a design that they view as having more desirable aesthetic and recreational opportunities. As explained below, this approach provides a lower bound for the aesthetic and recreational benefits of restoration.

Instrument Development and Response

The survey was tested prior to deployment. First, we conducted a scoping study consisting of semi-structured interviews at a high profile stream restoration location in Baltimore City, Stony Run, to understand the design features that the users stated were desirable or undesirable in a restoration project. The contingent valuation survey was then designed given this input and vetted by experts in stream restoration and contingent valuation. Finally, the survey was tested using a focus group; small changes in the wording and the layout were then modified given the focus group's comments.

The voluntary public survey used a random sample of 1,800 residents throughout Baltimore City and 200 residents within a 1-mile radius of a high-profile Baltimore City restoration project on Stony Run. Since the latter area encloses a small proportion of Baltimore residents, this implies that the latter subpopulation was sampled more intensively. Within the Baltimore subsample, we used a split sample where 90% of the households received a letter and invitation to participate in an online survey or to send back a card that prompted us to mail them a paper survey. The remaining 10% of households received the paper survey, and they were given the option of completing the paper survey or completing the survey online. We originally planned to test the response rate difference between the two samples, but there were too few paper surveys returned to adequately compare response rates. We mailed follow-up reminders two more times if there was no response. The response rate, adjusted for incorrect addresses, was 9.9% for Baltimore City and 24.5% for those living near the restoration project.

These response rates are lower than experienced in most contingent valuation studies (for instance, Loomis *et al.*, 2000), and less than ideal for questionnaires for non-salient environmental issues. This raises concerns over the representativeness of respondents' opinions relative to the population as a whole. Therefore, as we describe below, we make the most conservative assumptions possible (i.e., non-respondents have zero value) to ensure that the value that we are presenting can be reasonably thought of as a lower bound.

It is interesting to note that there are differences in the income and educational level of the survey respondents and Baltimore City residents. The median household income category for all survey respondents was $50,000-74,999 compared to the median income of Baltimore City households of $39,000 (U.S. Census Bureau, 2006). Similarly the median education category for the survey participants was college graduate (e.g., B.A., B.S.), whereas only 24% of Baltimore City residents greater than 25 years old have a college degree (U.S. Census Bureau, 2006). This distinct difference in education and income of respondents and the population at large indicates that extrapolation of sample responses to the population would potentially be subject to large selection bias. Therefore, we choose to be conservative and assume that non-respondents assign zero aesthetic and recreation value to restoration.

Results: Design Preferences

We focus on two results from the survey, the participant's design preferences and their WTP for two different stream projects located approximately 5 miles from their residence. Because only a small portion of residents would have such access, we chose to place the stream restoration 5 miles from the respondent to exclude experiential use. As a result we are capturing a relatively small use value (Carson *et al.*, 1999). Thus, it can be argued that the value is a lower bound because we are potentially underestimating the aesthetic and recreation benefit of the stream restoration, as nearby residents would presumably have a much higher value because of greater opportunity to use the resource.

Survey participants were asked to express their preference for restoration design choices by comparing combinations of streambank type, high and dry *vs*. low and wet, and surrounding vegetation cover, tree cover *vs*. meadow. The most preferred design was the high and dry streambank with tree cover (HT) and the least preferred design was the low and wet streambank with meadow (LM) (83% preferred HT, 12% preferred LM, and the remainder indicated no preference) (Figure 2). The preference difference between the most preferred and least preferred was significant at $p < 0.001$ using a two-sided binomial test. We then used this preference result in the subsequent analysis to assess WTP for aesthetic and recreation benefits.

Results: Willingness-to-Pay for Two Designs

We used contingent valuation to quantify the aesthetic and recreation dollar benefit because it is a widely used tool in environmental economics to value non-market goods, such as aesthetics and recreation (Carson and Hanemann, 2005). Specifically, we designed a multiple response payment card (Carson and Hanemann, 2005) that asked whether the respondent would accept a one-time tax of six different specified values ($5, $15, $25, $50, $100, $250). We asked respondents their WTP for a 0.25-mile HT stream project and for a 0.25-mile LM stream project. The two projects were described using photographs, and the respondents were told that the project would protect infrastructure near the stream but would provide negligible water quality benefits.

To quantify WTP given the survey information, we analyzed the survey responses using two methods: ordered probit (Hanemann, 1984) and stepwise integration under the demand curve (Haab and McConnell, 1997). In both models, if the respondents indicated that "I would not vote," we conservatively treated such responses as the same as "I would vote no." The survey participants were not required to respond to the payment card question, so 10% of participants chose not to respond to this question. Thus, these missing data were excluded from the WTP analysis.

Using the first method, the ordered probit model, we estimate the WTP distribution using the mean (μ) and standard deviation (σ) for HT and LM. This model posits that WTP is a normally distributed random variable. The interval-censored data that result from the payment card responses for the two different programs is used in maximum likelihood estimation of the mean and standard deviation (Hanemann, 1984). The seven intervals defined by the payment card are less than $5; between $5 and $15; between

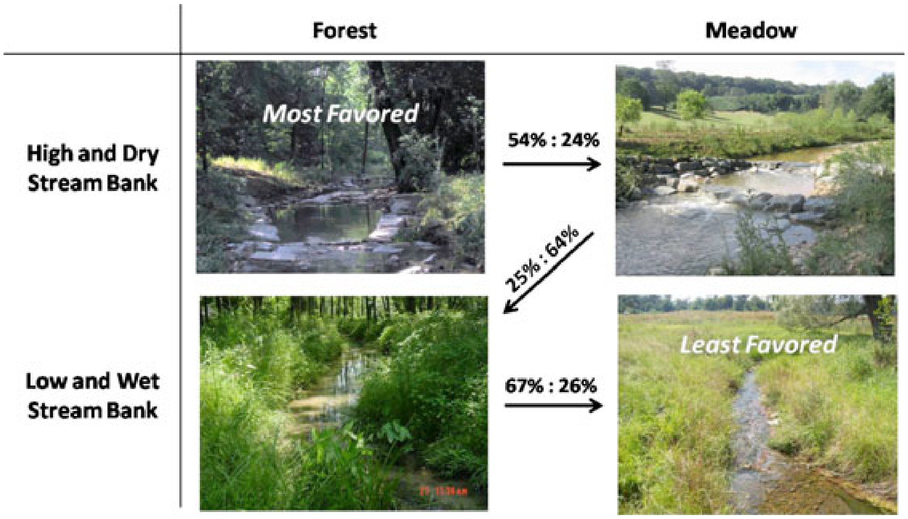

FIGURE 2. Design Preferences for Baltimore City, Showing the Percentage Preferring the More Favored Design: Percentage Preferring the Less Favored Design with the Arrow Pointing from the More Favored Design to the Less Favored Design. The rankings of designs for the Stony Run sample were identical to these and had similar percentages.

\$15 and \$25; between \$25 and \$50; between \$50 and \$100; between \$100 and \$250; and greater than \$250. Letting n_k denote the number of people whose responses indicate their value falls in the k^{th} interval, the likelihood function takes the following form:

$$L(\mu, \sigma|y) = \prod_{k=1}^{7} P(WTP \in I_k)^{n_k}. \tag{5}$$

$P(WTP \in I_k)$ is the probability that the random variable WTP falls in the k^{th} interval. Letting $\Phi(\bullet)$ denote the standard normal probability distribution function, the probability of falling in the first interval is given by $\Phi(\frac{5-\mu}{\sigma})$. The probability of falling in the last interval is $1 - \Phi(\frac{250-\mu}{\sigma})$. For the other intervals, the probability is $\Phi\left(\frac{b_k^h-\mu}{\sigma}\right) - \Phi\left(\frac{b_k^l-\mu}{\sigma}\right)$ where b_k^h is the upper end of the interval and b_k^l the lower end of the interval. We used Stata statistical software's maximum likelihood estimation routine to find the values for μ and σ that maximize the likelihood function.

The mean WTP differs significantly depending on whether or not the respondent is located in the Stony Run watershed. The model estimates of the mean μ (standard error) for LM are \$17 (\$6.8) per respondent for Baltimore City and \$28 (\$22) for the Stony Run subsample. For the HT, the estimated means μ (standard error) are \$74 (\$7.3) for Baltimore City and \$140 (\$21) for Stony Run. Calculating weighted averages of these estimated means, adjusting for numbers of households in the two subsample locations (i.e., approximately 250,000 total Baltimore City households of which 2,000 of those households are within 1 mile of Stony Run), the mean household WTP was \$75 (95% confidence interval: \$60-89) for the HT design and \$17 (\$3-31) for LM.

These results were compared to the Baltimore City WTP to determine whether or not there was a difference in the WTP given the survey mode (mail *vs*. Internet). The mean WTP response for HT was almost exactly the same for the Internet and mail responses; meanwhile, the LM mean was lower for the mail responses, but was still within one standard error of the mean for the Internet responses. Thus, our benefit analyses use pooled results, rather than distinguishing values by survey mode.

In addition, we considered the WTP of Baltimore City residents given their income level; there was not enough diversity in the Stony Run sample to conduct a similar analysis. We split the city participants into a low household income level (<\$75,000) and a high household income level (≥\$75,000), which is the middle of the income scale (see Appendix S2). There was a small difference in WTP given income, but it was in the expected direction: those with low income were willing-to-pay \$62 (\$9.1) for HT and \$15 (\$7.9) for LM and those with high income were willing-to-pay \$90 (\$12) for HT and \$21 (\$12) for LM. It is useful to note that these values are still lower than the values assigned by the Stony Run participants. The statistics for all the models are documented in the supplementary Appendix S3 available in the on-line version of this paper.

Results: Lower Bound to Willingness-to-Pay for Restoration Aesthetic and Recreation Benefits

The difference between the WTP for the most preferred design (high and dry) and the least preferred (low and wet), weighted by the relative proportion of households in Baltimore City, is \$58 (57*0.99 + 108*0.01) per household, where 1% is the proportion of Baltimore households within 1 mile of Stony Run. This value is highly significant by a difference of means test. As mentioned above, we use the difference in WTP between the two project designs as the amount respondents are willing-to-spend for a more aesthetically desirable design. It is important to note that because the income and education levels of the residents near Stony Run are significantly higher than the general Baltimore City population, it is impossible to disaggregate the additional WTP that was assigned by this subpopulation due to direct experience with stream projects *vs*. their socioeconomic status. In addition, this result can be interpreted conservatively as a lower bound estimate based on three assumptions: (1) that, as asked, the respondents considered only the aesthetic and recreational differences of the designs, (2) the value expressed is a passive use value (excluding experiential use), and (3) that the aesthetic and recreational value of the less preferred design exceeds that of no stream restoration at all.

We also quantified the difference in WTP between locations using a stepwise integration under the WTP demand curve (Figure 3). This curve is derived by noting the fraction of respondents that accept each payment level; the declining fraction as a function of payment defines a demand curve for an average respondent. This is the standard procedure for translating payment card responses into WTP (Carson and Hanemann, 2005). For Baltimore City residents, the resulting HT value is \$57 and for LM is \$24. For Stony Run respondents, the HT value is \$110 and for LM is \$49. Thus the weighted average of the difference is \$33 per household.

To calculate the equivalent aesthetic and recreation benefit in 2008 US\$ per foot, we calculate a weighted total aesthetic and recreation value for the project and normalize given the number of linear feet in the project.

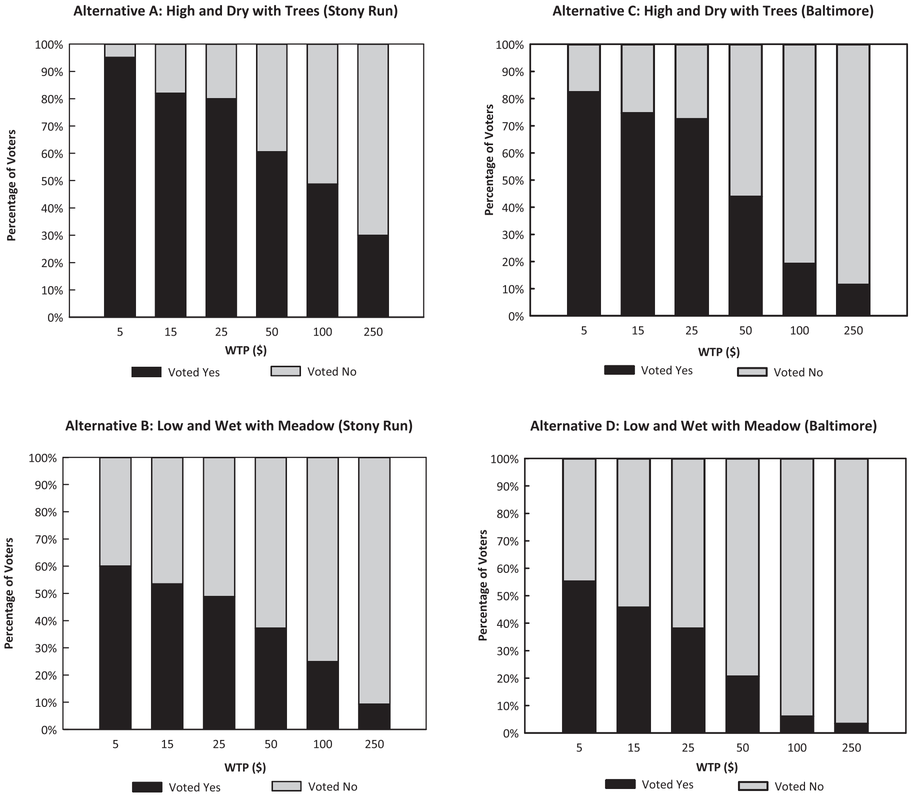

FIGURE 3. WTP Survey Responses for High and Dry with Trees and Low and Wet with Meadow for Both Stony Run and Baltimore City. Stony Run respondents had a higher WTP, however, these respondents represented only 1% of Baltimore City households.

$$AR = \sum \frac{v_d * h_d * s_d}{f}, \qquad (6)$$

where AR is aesthetic and recreation enhancement value [\$/ft], f is the number of feet in the project, which is 1,320 feet for a 0.25-mile stream, h_d is the approximate number of households from which subsample d is drawn, which is 248,000 for Baltimore City and 2,000 for Stony Run, s_d is the response rate of subsample d, and v_d is the unweighted esthetic premium value for subsample d (i.e., Baltimore City or Stony Run).

The range produced by the two methods, $33-58 per household, is attributed to the same proportion of Baltimore City households as responded to our survey under the very conservative assumption in Equation (6) that non-respondents have zero WTP. (In fact, it is likely that some or even a large proportion of non-respondents have a positive WTP, but we disregard that possibility in order to avoid the possibility of overstating this category of benefits.) The aesthetic and recreation value of an urban stream project to the city of Baltimore population is approximately $560-1,100 per foot. These values are of the same order of magnitude as the cost of stream restoration itself, and are well in excess of the water quality benefits.

Others have obtained estimates of WTP for stream restoration using similar contingent valuation methods. Loomis *et al.* (2000) and Collins *et al.* (2005) also asked for binary responses (yes/no) to a stated level of payment for restoration, analyzing the data using a logit-based approach. In the former study, the mean WTP for restoration of a 45-mile rural stretch of the Platte River was $21/household/month, while in the latter, the average WTP for restoring a 24-mile rural creek in West Virginia was in the range of $12-16/household/month. In both studies, the benefits considered included not only aesthetic and recreational benefits, but also ecological and water quality benefits, which we exclude. Their values per foot of stream restoration are of the same order of magnitude as ours. In particular, assuming an interest rate of 7% and a 50-year lifetime, our $33/household (total) benefit for a 0.25 mile restoration results in a monthly benefit of approximately $0.8/household/month per mile of restored stream, compared to the roughly $0.5/household/month per mile of restored stream in the above studies. However, their settings are very different from ours, so too much should not be made of the similarity of our results.

OTHER BENEFITS

Other potential benefits of urban stream projects can be identified, such as improved aquatic and riparian habitat, flood control, and educational, ethical, and community benefits associated with a closer connection between residents and a naturalized stream corridor (Bernhardt *et al.*, 2005). These benefits may in some cases be more important than the ones quantified in this paper. Thus, we wish to emphasize that our analysis cannot be used to draw conclusions about the value of urban stream restoration in general. In cases where additional benefits are important, an analysis of the type presented here can be used as a starting point by providing an assessment of infrastructure, water quality, and amenity benefits. In some cases, additional benefits can be quantified using standard benefit-cost analysis tools, although possibly with large uncertainty. When additional benefits are not monetized, managers can judge whether the incremental non-monetized benefits justify the project costs. Alternatively, multiobjective decision analysis also can be useful for quantifying manager and stakeholder willingness to make such tradeoffs (Reichert *et al.*, 2007; Corsair *et al.*, 2009).

IS URBAN STREAM RESTORATION WORTH IT?

It is not our intention in this paper to provide a universal judgment regarding the benefits and costs of urban stream restoration projects. Indeed, the wide range of water quality conditions and possible aesthetic, community, or recreational objectives suggests that many urban restoration projects can offer favorable benefit/cost ratios. By asking "is it worth it?", we hope to encourage explicit and quantitative evaluation of project benefits and costs such that the most effective projects are carried forward. Our aim is to demonstrate that such analyses are feasible and should become standard practice.

The costs of urban stream restoration projects can vary widely, depending not only on project design but also on a range of local considerations such as site access, property value, stream condition, and permitting and contracting requirements. Though there is little published data on the cost of stream restoration, in general, urban stream projects are more expensive than rural projects. Based on city records (Baltimore City, unpublished data) and discussions with local regulators, designers, and construction firms, the expense of Baltimore projects typically range from $500 to $1,200 per foot.

We find that for the immediate purposes many urban stream projects—infrastructure protection and water quality improvement—stream restoration is unlikely to be cost-effective compared to other approaches for accomplishing those purposes, considering typical costs for urban stream projects (Figure 4). However, when aesthetic and recreational benefits are considered, stream restoration can be socially beneficial, because those benefits may more than offset the additional costs of restoration. Figure 4 indicates that the value that would be provided our urban stream restoration (bars) is dominated by aesthetic and recreational benefits, with cost savings resulting from not taking other measures to protect infrastructure and enhance water quality being appreciably lower. These observations indicate that a broader range of factors needs to be considered in developing and judging the value of stream restoration projects. Where public access to the stream is likely or desired, greater focus should be placed on those project elements that improve aesthetic and recreational benefits. Where public access is restricted, a broad palette of management options should be considered for infrastructure protection and water quality improvement, including inexpensive bank protection or off-site water quality measures. A standard treatment for all streams or an expensive stream restoration for water

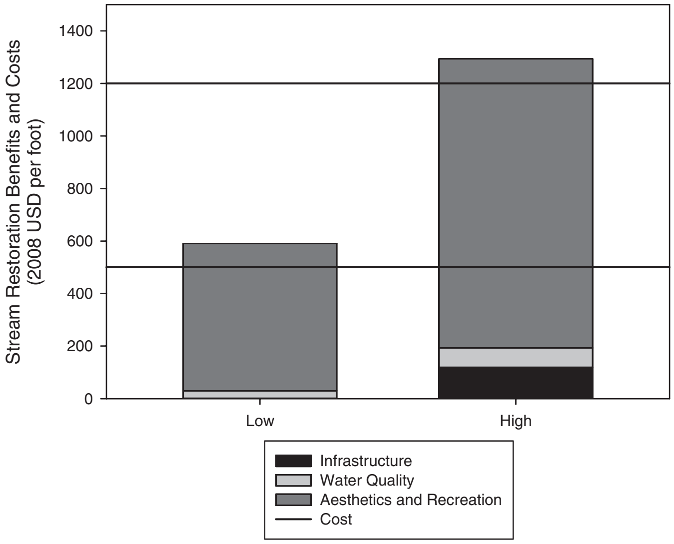

FIGURE 4. Comparison of Value (bars) and Cost (horizontal lines) of Urban Stream Restoration Projects. Low indicates the lower bounds for cost and the three contributors to value (water quality, infrastructure, and aesthetic and recreation); high indicates their upper bounds.

quality enhancement alone may be a poor investment. Other objectives not considered here—educational, ethical, and ecological (Palmer *et al.*, 2005)—might also provide sufficient benefits to balance typical urban stream project costs. Further work is needed to better quantify the full suite of likely benefits.

Multiple objectives for urban stream restoration projects are often stated, although the associated benefits may be vaguely defined and the monitoring and evaluation of appropriate metrics to determine project success are rare (Bernhardt *et al.*, 2005). The objectives for stream restoration projects can be stated in a way that supports valuation of benefits in the context of project costs. By evaluating the benefits for a specific but typical set of objectives for urban stream restoration, we hope to encourage a more common application of such methods to support better focused assessment of the question of whether stream restoration provides benefits that exceed costs. Although there is uncertainty in the value of any specific benefit, we have demonstrated that useful information can be made available to guide decision making regarding stream restoration.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Water Quality Input Assumptions and Sensitivity Analysis.

Appendix S2. Contingent Valuation Survey for Esthetic and Recreation Benefits.

Appendix S3. Statistics for Willingness-to-Pay Model.

ACKNOWLEDGMENTS

W. Stack, T. Schueler, S. Weammart, E. Sudduth, E. McClure, D. Framm, and S. Lowe provided data, supporting studies, and background information; B. DeTemple edited photos for the survey; C.S. Norman provided guidance on the missing data methods for the contingent valuation data; and P. Wu, V. Prava, and L. Zhou provided research assistance. The anonymous reviewers provided helpful comments that improved the manuscript. This work was supported by the STC program of the National Science Foundation via the National Center for Earth-surface Dynamics under the agreement Number EAR-0120914.

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