Life-Cycle Cost of Urban Stream Restoration Alternatives

Liya Abera, Ph.D.[1]; and S. Kyle McKay, Ph.D., P.E.[2]

[1]Environmental Laboratory, US Army Engineering Research and Development Center, Vicksburg, MS. Email: liya.eshetu.abera@gmail.com
[2]Environmental Laboratory, US Army Engineering Research and Development Center, New York. Email: Kyle.McKay@usace.army.mil

ABSTRACT

In this study, cost drivers of urban stream restoration practices are evaluated by performing life-cycle cost analyses on common restoration actions. The study's objective is to examine the relative contributions of capital and operations and maintenance (O&M) costs to life-cycle costs over a range of restoration actions and sizes. Ultimately, this study will inform restoration practitioners of the importance of accounting for O&M expenses and help weigh the relative merits of different management actions. Capital and O&M costs were compiled from literature for typical urban stream restoration actions, such as bank stabilization, channel rehabilitation, and riparian restoration. Both costs were normalized by project extent to estimate typical ranges of unit costs and the frequency of actions. Representative costs were then estimated for a hypothetical project size range, life span, and other factors. Although capital costs are often a primary decision factor to select restoration actions, O&M costs are often underemphasized. This study showed that O&M expenses could rival capital costs in some contexts and that complete life-cycle cost analysis is crucial to decision-making about the long-term efficacy of urban stream management actions.

1. INTRODUCTION

The natural state of streams changes over time due to natural and human interaction. This change results in stream degradation, increased erosion, and reduced water quality. Stream restoration is an established practice to reverse streams to a more natural state. Urban stream restorations improve the ecological state of rivers, improve biodiversity, and prevent future losses; therefore, they are perceived as nature-based solutions (NbS) (Psenner, 2018). These interventions require regular maintenance to maintain the performance and meet the restoration action goals. Maintenance is most crucial in the first three to five years after construction (Moore, H. E., & Rutherfurd, I. D. 2017; Knutson 2015). Some common maintenance activities include mowing, hand clearing, debris and sediment cleanouts, and shoreline rebuilding (U.S. Burea of Reclamation 2020). Some interventions need regular maintenance over their lifetime while others reach a self-sustain point. For instance, riparian restoration needs weed management, site protection, and ongoing revegetation for the first five years. Once the vegetation is established, it will sustain for years without additional maintenance (Allen and Niering 2008).

Urban stream restoration and other NbS provide potential ecosystem benefits with expenses. However, little has been done on urban stream restoration's cost analysis (Kenney et al. 2012). The costs of urban stream restoration vary widely due to different factors, some of which include the type, extent, and density of restoration actions, the stream condition, and the accessibility of the restoration site (Guimarães et al. 2021; Kenney et al. 2012)

In this study, we evaluate the cost drivers of urban stream restoration practices and the role of long-term operations and maintenance (O&M) costs by performing life-cycle cost analysis (LCCA). Our primary objective is to examine the relative contributions of capital and operational costs on overall life cycle costs as well as identify key factors influencing cost estimates. We first compile cost data from representative studies to estimate typical unit cost ranges. We then estimate costs for a hypothetical stream restoration project case study with three common types of restoration interventions: bank stabilization, channel rehabilitation, and riparian restoration.

2 COST DATA

Representative restoration costs were compiled from prior urban restoration actions (Table 1). Reported cost data were inflation adjusted to $2023. Both capital and O&M costs were normalized by project extent to estimate typical ranges of unit costs per Area (m^2) as well as the frequency of maintenance actions. Capital costs include labor, material, and installation but not pre-construction costs, such as design costs. O&M costs were commonly defined as a percentage of the capital investment rather than a unit cost or annual rate (Knutson 2015).

Table 1. Stream restoration cost data based on literature review.

Source of Capital Cost	**Description**	**Unit Cost ($)**	
North Carolina (Templeton, Dumas, and Sessions 2008)	191,374 ft stream (45 projects)	$242 per ft	
Virginia (City of Charlottesville 2011)	72 acres	$50 to $280 per ft	
	Tree Cleaning	$5000 per acre	
Maryland (Kenney et al. 2012)	for a stream bank - 5 ft high	$105 per ft^2	
	(only one side)	$58 per ft^2	
Washington (Bair 2004)	Bank stabilization (5 ft height of bank)	$46,000-$220,000 per mile	
	Channel Rehabilitation	$41,000 -$137,000 per mile	
	Riparian Reforestation	$4,000-$8,000 per mile	
Oregan (Follstad Shah et al. 2007)	Riparian vegetation	$30,000 - $60,000 per acre	
	Improvement of channel	$16,000 - $29,000 per mile	
(Bishaw, Emmingham, and Rogers 2002)	Bank reshaping	$10 - $45 per foot	
Source of O&M Costs	**Description**	**Frequency**	**Cost**
Florida (WOIS 2019)	River canal retrofit	Yearly	$51,000 per mile
Washington (Knutson 2015)	Riparian restoration	Yearly in the 1st 3 to 5 years	20 to 40% of capital cost
General guidance (U.S. Bureau of Reclamation)	Bank stabilization	Every 2-3 years	
Washington (Knutson 2015)	Bank stabilization		5 to 20% of capital cost

Based on Table 1, unit costs were synthesized for channel rehabilitation (C.R.), bank stabilization (B.S.), and riparian planting (R.P.). Table 2 shows general ranges of inflation-adjusted unit costs derived from this small subset of studies. Cost varies significantly across studies and locations based on site accessibility, type of restoration action, and many other factors. To reflect this variability, unit costs were averaged across sources, and we report unit costs -20% and +30% from the average value as per the Association for the Advancement of Cost Engineering Class 5 guidelines (AACE 2020). These unit costs should be considered rough order of magnitude ranges, not site-specific estimates.

Table 2. Approximate unit cost ranges for typical stream restoration interventions.

Restoration Method	Unit	Capital Cost ($2023/m^2)	O&M Cost (%Capital)	Maintenance Frequency
Channel rehabilitation (C.R.)	Channel Area in m^2	13-22	5-10	Yearly up to 5 yrs post-construction
Bank Stabilization (B.S.)	Bank Area in m^2	67-109	5-20	Every 2-3 yrs
Riparian Planting (R.P.)	Riparian Area in m^2	12-24	3-5	Yearly for the first 3-5 yrs

3 ANALYSIS OF A HYPOTHETICAL STREAM RESTORATION PROJECT

In this section, we estimate costs for a hypothetical stream restoration project with three common types of restoration interventions: channel rehabilitation, bank stabilization, and riparian restoration. Many urban stream restoration projects apply these general families of actions, and this analysis is intended to look broadly at the relative cost-effectiveness of these actions under a representative range of options. For the purpose of this exercise, we use the following hypothetical reach of the river.

- Project Extent:
  - Channel width = 5 m
  - Bank Height = 1.5 m
  - Bank Slope = 1:2 H:V
  - Riparian width = 15 m
- Unit Cost Assumptions:
  - Channel Rehabilitation: Capital cost = $20 / m^2, O&M = $1.60 / m^2 (8%)
  - Bank Stabilization: Capital cost = $80 / m^2, O&M = $8.00 / m^2 (10%)
  - Riparian Planting: Capital cost = $18 / m^2, O&M = $0.72 / m^2 (4%)
  - O&M Frequency: CR = every 20 yrs, BS = every 10 yrs, RP = every 10 yrs
- Economic Assumptions:
  - Interest rate = 3%
  - Life span = 50 yrs

This hypothetical project's life cycle cost (L.C.C.) was then computed for a range of reach lengths from 0 to 10,000 m in 200 m intervals. L.C.C. was compared using a present value (P.V.) analysis. The capital and O&M costs were converted to a present value of cost (P.V.C.) using Equation 1. The P.V was calculated using a discount rate to account for the value of money over time. P.V analysis is a common approach used in life-cycle cost or benefit analysis (CNT 2009; WERF 2009). The proportion of cost components was estimated based on the P.V.C. All analyses were conducted using the R Statistical Software language. Specifically, we developed an R-package containing standard engineering economic methods that facilitate life cycle cost analysis[1]. The model is presently being reviewed for publication through the Comprehensive R Archive Network[2].

$$\mathrm{PVC} = \mathrm{C}_0 + \sum_{\mathrm{y}=1}^{\mathrm{n}} \mathrm{C}_{\mathrm{y}} \frac{1}{(1+\mathrm{i})^{y}} \tag{1}$$

where:

$\frac{1}{(1+i)^{y}}$ = discount factor

C_o = initial cost (capital cost)

C_y = O&M cost in year y

i = discount rate

n = life-cycle period

y = years 1 to n

This hypothetical project was used to examine three research questions that commonly arise in stream restoration planning: (1) Which restoration actions are most cost-effective? (2) How are costs distributed across the project life? and (3) How do economic assumptions affect cost-effectiveness? Six scenarios were identified to address these questions (Table 3). For each scenario, inputs were varied based on logical changes in cost engineering assumptions. For instance, a unit cost range was varied as -20% and +30% from the base scenario to examine sensitivity to uncertainties in these values. A number of assumptions were required to bracket this simplified analysis, specifically:

- Channel geometry is adequately characterized on a reach average basis from the parameters defined above (i.e., channel width, bank height, bank slope, riparian width). Riparian area was doubled to reflect actions on both sides of the river. Bank area was computed only for a single side, assuming that erosion primarily occurs on outer banks.
- Mobilization and demobilization costs are incorporated in unit costs. However, it is well acknowledged that these factors would represent a smaller portion of the cost as the project extent increases.
- Real estate costs for land acquisition or easements are included in the unit cost. Real estate costs would likely escalate the costs of riparian actions disproportionately to channel or bank alternatives, limiting the utility of the cost comparison here.
- Disposal cost was assumed to be $0 for each action, although disposal may be required for some types of channel rehabilitation or bank stabilization.
- Outcomes are compared relative to a cost-effectiveness analysis comparing monetary costs with ecological benefits. Restoration area is used as a surrogate for the ecological "benefits" of an action. Area may not be reflective of the problems associated with a given river or the value of a given action (e.g., bank stabilization may be disproportionately important relative to a sediment loading problem in a watershed). Many ecological or geomorphic models exist that would more accurately reflect these outcomes, but Area provides a coarse proxy for these metrics.

[1]Code available at: https://github.com/USACE-WRISES/EngrEcon-package
Model description available at: https://usace-wrises.github.io/EngrEcon-report/
[2]https://cran.r-project.org/

Table 3. Experimental design used to assess research questions.

Research Question	Unit Cost ($)	Interest Rate	Life Span (yr)	O&M Frequency (yr)
Which restoration actions are most cost effective?	Base scenario: CR = $20/m^2, OM=8% BS = $80/m^2, OM=10% RP = $18/m^2, OM=4%	3%	50	CR=20 BS=10 RP=10
How are costs distributed?	Base	3%	50	CR=20 BS=10 RP=10
How do economic assumptions affect cost effectiveness?				
(a) Interest rate	Base	1%, 3%, 5%	50	CR=20 BS=10 RP=10
(b) Life span	Base	3%	25, 50, 75	CR=20 BS=10 RP=10
(c) Unit cost	Base Base + 30% Base - 20%	3%	50	CR=20 BS=10 RP=10
(d) Maintenance Frequency	Base	3%	50	CR=20/10/25 BS=10/3/20 RP=10/3/25

3.1 Which restoration actions are most cost-effective?

A common issue arising in stream restoration is the relative cost-effectiveness of actions. For instance, is bank stabilization more or less cost-effective than riparian restoration at a given site? Here, we examine cost-effectiveness relative to the non-monetary metric of Area of channel, bank, or riparian zone, which can be thought of as a surrogate for the total amount of "habitat" provided by these actions. Figure 1A presents a cost-effectiveness diagram, where more efficient actions are to the lower right and less efficient actions to the upper left. Based on this scenario, bank stabilization actions are significantly less effective on a cost basis than channel rehabilitation actions. However, bank stabilization could address root causes of degradation (e.g., sediment loading from bank erosion), and riparian actions could have larger real estate costs not accounted for here. These results should be interpreted based not only on cost efficacy but also responsiveness to watershed problems (e.g., habitat loss vs. erosion).

Notably, riparian areas are generally much larger than channel or bank areas. These less constrained zones allow for significant expansion of habitat areas, and some quantities of habitat may only be obtained with riparian actions. For instance, a mitigation project could have a restoration target of 20 ha (200,000 m^2), a target that can only be achieved through riparian actions in this hypothetical scenario.

3.2 How are costs distributed across the project life?

Another common criticism or assumption about stream restoration is the perception that the O&M costs for riparian restoration actions are high. The relative contribution of the capital and O&M costs is presented in Figure 1B. Typically, the capital cost contributes a significant portion to the L.C.C. Relatively; the O&M cost contributes a much smaller portion of the cost, particularly for channel rehabilitation and riparian planting. Based on the P.V. analysis, the O&M cost proportion is higher for bank stabilization than channel restoration and riparian restoration. This difference is due to the variation in maintenance costs and frequencies for each restoration action.

In addition to the costs, capital and O&M expenses may be incurred by different parties. For instance, capital expenses could be covered by a one-time grant, whereas O&M may be required as an addition to an annual operating budget of a city, federal agency, or other entity. Understanding the proportion of costs can inform trade-offs in the total cost and the actor paying for a given expense.

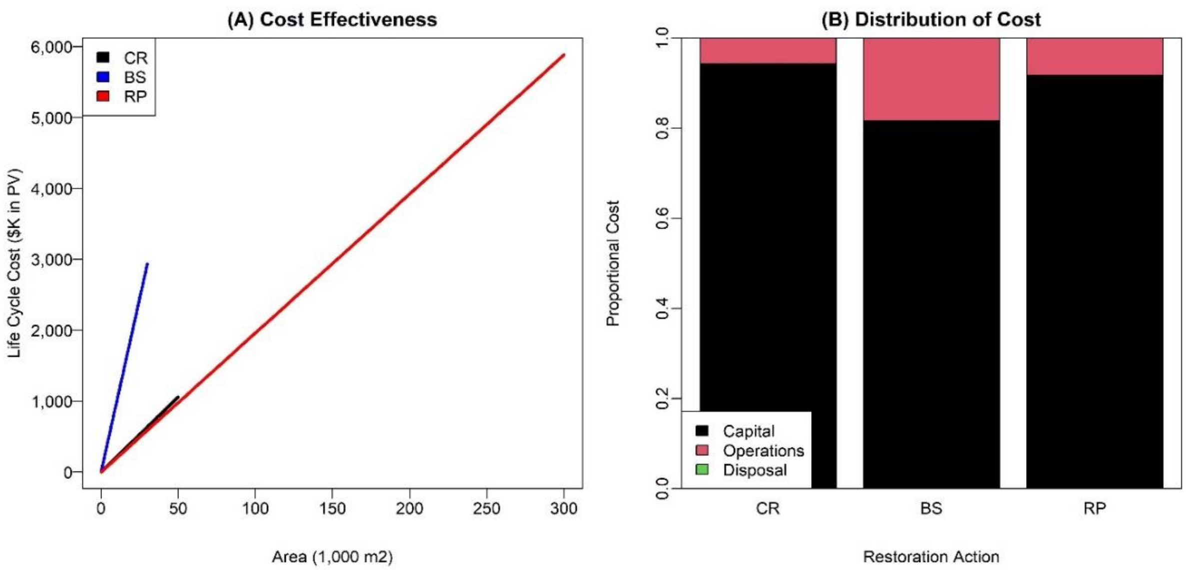

Figure 1. Cost-effectiveness and proportional cost of alternative restoration actions for the baseline restoration scenario.

3.3 How do economic assumptions affect cost-effectiveness?

Other design factors, such as interest rate, life span, unit costs, and maintenance frequency, can also affect the understanding of the relative cost-effectiveness of restoration actions. Figure 2 presents a diagram showing the effect of these factors on the P.V of life-cycle costs. Figure 2A presents the effect of interest rate on the cost; the higher the interest rate, the more the restoration actions are cost-effective because future O&M expenses have been discounted. For the analysis based on life span, all actions are more cost-efficient with a shorter life span than the longer ones, as presented in Figure 2B. Based on the scenario of varying unit costs (Figure 2C), the life cycle costs are significantly high with the increase in unit cost. Since the capital cost portion of the restoration actions is high, that effect is also shown in the result. Figure 2D presents the effect of maintenance frequency on cost-effectiveness; life cycle cost increases as the maintenance frequency increases. However, in most cases, executing more frequent maintenance improves the performance of the restoration action. Therefore, results should be interpreted based on design and performance requirements of an action, not only on cost efficiency.

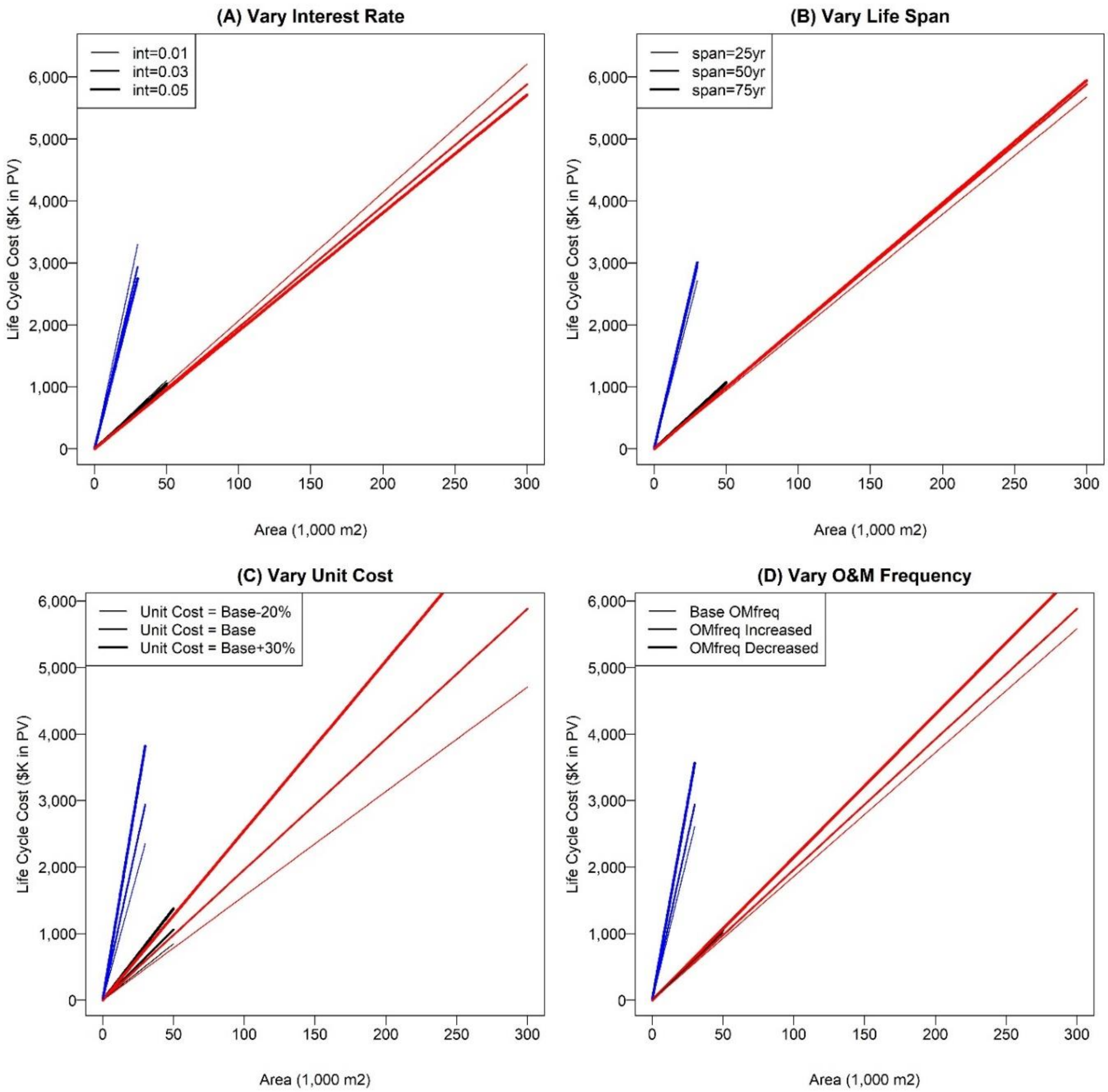

Figure 2. Cost-effectiveness and proportional cost of alternative restoration actions for the baseline restoration scenario.

4 DISCUSSION

Here, we presented a life-cycle cost analysis of a hypothetical stream restoration project along with scenarios varying common cost drivers such as interest rate, life span, unit cost, and O&M frequency. The analysis assessed the cost-effectiveness and proportional costs of restoration actions relative to capital and O&M expenses.

In general, capital cost contributes a more significant portion to the life-cycle cost of restoration actions than O&M expenses, and life-cycle costs show a strong dependency on the assumed unit cost estimates. As cost varies based on location, consideration should be taken for local material availability and cost, and the best restoration alternative should be selected based on these considerations. Even though capital costs are often the main consideration in selecting restoration actions, the importance of O&M costs should not be overlooked, specifically for bank stabilization, which typically has higher rates of O&M.

There is less variation in the cost due to life span compared with the other factors because there are only maintenance costs in the late life of the restoration actions. When the life span is extended, the related P.V. of costs for the O&M gets smaller and becomes negligible compared to previous years. However, by the point restoration actions reach their design life, they need to be removed, or rehabilitation work needs to be done, which has its own cost. Disposal cost is not included in this analysis, and we recommend this cost should be included in future analysis for a complete LCCA. Disposal costs could alter the understanding of the relative benefits of a given action. For instance, riparian planting may require no disposal, whereas some channel rehabilitation and bank stabilization forms could have significant disposal costs.

Our simplified life-cycle cost analysis considered only the capital and O&M costs. However, other cost factors, such as real estate, pre-construction design and permitting, and disposal, could also affect the L.C.C. in some interventions. This analysis indicates that life cycle cost analysis should play a larger role in understanding, designing, and selecting stream restoration actions, particularly in urban areas with diverse funding sources and partners.

REFERENCES

Allen, E. B., and W. A. Niering. 2008. "Riparian Restoration." *Restoration Ecology* 5: 1–1.

Bair, B. 2004. "Stream Restoration Cost Estimates." In *Salmon Habitat Restoration Cost Workshop*, 1–10. Portland, OR: Pacific State Marine Fisheries Commission.

Bishaw, B., W. Emmingham, and W. Rogers. 2002. "Riparian Forest Buffers on Agricultural Lands in the Oregon Coast Range: Beaver Creek Riparian Project as a Case Study." Research Contribution - Forest Research Laboratory, Oregon State University, no. No.38: 28 pp.

City of Charlottesville. 2011. "A Cost-Benefit Analysis of the Meadow Creek Stream Restoration Project." https://www.ptonline.com/articles/how-to-get-better-mfi-results.

CNT (Center for Neighborhood Technology). 2009. National Green Values Calculator Methodology. Center for Neighborhood Technology, Sustainable, 1–32. http://greenvalues.cnt.org/national/calculator.php.

Follstad Shah, J. J., C. N. Dahm, S. P. Gloss, and E. S. Bernhardt. 2007. "River and Riparian Restoration in the Southwest: Results of the National River Restoration Science Synthesis Project." *Restoration Ecology* 15 (3): 550–62.

Guimarães, L. F., F. C. Teixeira, J. N. Pereira, B. R. Becker, A. K. B. Oliveira, A. F. Lima, A. P. Veról, and M. G. Miguez. 2021. "The Challenges of Urban River Restoration and the Proposition of a Framework towards River Restoration Goals." *Journal of Cleaner Production* 316 (August 2020).

Kenney, M. A., P. R. Wilcock, B. F. Hobbs, N. E. Flores, and D. C. Martínez. 2012. "Is Urban Stream Restoration Worth It?" *Journal of the American Water Resources Association* 48 (3): 603–15.

Knutson, C. 2015. *Cost Estimates for Basin Restoration Planning*.

Moore, H. E., and I. D. Rutherfurd. 2017. Lack of maintenance is a major challenge for stream restoration projects. *River Research and Applications*, 33(9), 1387-1399.

Psenner, R. 2018. Buchbesprechung: River Ecosystem Management: Science for Governing Towards a Sustainable Future. *Die Bodenkultur: Journal of Land Management, Food and Environment*. Vol. 69.

Templeton, S. R., C. F. Dumas, and W. T. Sessions. 2008. "Estimation and Analysis of Expenses of Design-Bid-Build Projects for Stream Mitigation in North Carolina (Research Report RR 08-01)."

US Burea of Reclamaton. 2020. "Trinity River Channel Rehabilitation Site Chapman Ranch Phase B (River Mile 83. 5–83. 8) Draft Environmental Assessment/Initial Study DOI-BLM-CA-NO60-2020-0015-EA and CGB-EA-2020-025 State Clearinghouse # 2020050360 October 2020." Weaverville, California. https://www.trrp.net/library/document/?id=2466.

WERF (Water Environment Research Foundation). 2009. *SW2R08_Users Guide to the BMP and LID Whole Life Cost Models*. Water Environment Research Foundation.

Wood Environment & Infrastructure Solutions. 2019. *Estimate Unit Costs and Develop Total Life-Cycle Cost Model*. Wood Environment & Infrastructure Solutions, Inc. Vol. 2019.