Three Forks of Beargrass Creek Ecosystem Restoration
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Abstract

Beargrass Creek in Louisville, Kentucky is an urban stream draining a small watershed (~59 mi^2) through three main branches, the South Fork, Middle Fork, and Muddy Fork. More than 50 potential restoration sites were identified across the watershed and screened down to a final array of 21 sites for project planning. At each site, riverine and riparian restoration actions were combined into site-scale alternatives. Monetary costs were estimated using standard cost engineering and real estate techniques. Ecological benefits were calculated for the riverine and riparian areas using the Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS) and the Simple Model for Urban Riparian Function (SMURF), respectively. This technical report summarizes calculation of ecological benefits and monetary costs, and then conducts Cost-Effectiveness and Incremental Cost Analyses (CEICA) to inform restoration decision-making at the site and watershed scales. Secondary decision-making techniques were also applied to incorporate social outcomes and other qualitative factors. Ultimately, this report demonstrates a suite of methods for making transparent urban watershed restoration decisions in a complex socio-ecological system.

1. Introduction

Urban watersheds are complex ecological, physical, and social landscapes with nuanced (and sometimes conflicting) sets of management objectives and jurisdictions (Deason et al. 2010). These socio-ecological-technical systems provide the backdrop for the rapidly growing field of urban ecology (McPhearson et al. 2016) and the associated professional practice of stream and riparian restoration (Bernhardt et al. 2005). A large community of scientists and practitioners have developed a strong conceptual basis for this topic (e.g., Wenger et al. 2009) along with accompanying tools (e.g., Barbour et al. 1999, Bledsoe et al. 2007, Bledsoe et al. 2012) and design guidance (e.,g., FISRWG 1998, Copeland et al. 2001, Shields et al. 2003, Bernard et al. 2008). However, urban watershed restoration decisions remain challenging due to inherent trade-offs in monetary costs, ecological benefits, social benefits, and other outcomes.

The U.S. Army Corps of Engineers (USACE) ecosystem restoration mission was first authorized in the Water Resources Development Act of 1986 with the overarching purpose "…to restore significant structure, function and dynamic processes that have been degraded" (ER 1165-2-501). Over 200 restoration projects have been carried out nationwide in all eight USACE Divisions (Gardner et al. 2014). Urban watershed restoration plans have been developed in a variety of metropolitan areas like the Anacostia River near Washington, D.C. (USACE 2018), Proctor Creek in Atlanta, Georgia (McKay et al. 2018), and the Bronx River in New York City, New York (McKay et al. *In review*), among others. These projects demonstrate common challenges arising in urban restoration associated with multi-objective decision making, quantification of complex social and ecological outcomes, and the need for critical thinking when interpreting outcomes (Deason et al. 2010).

The overarching USACE restoration purpose (stated above) emphasizes the importance of ecological outcomes in decision making (as opposed to social or economic outcomes). Generally speaking, ecological resources may be quantified in a variety of ways ranging from habitat suitability for a focal taxa (e.g., an endangered species) to changes in physical processes (e.g., sediment delivery from geomorphic instability) to changes in biological processes (e.g., carbon uptake and storage). In other USACE decision contexts (e.g., navigation), costs and benefits of actions are compared in monetary terms, and the benefit-cost ratio serves as a crucial decision metric. However, outputs of restoration are typically not monetized, and a different set of methods are required to inform restoration decision-making and address the issue of "Is ecosystem restoration worth the Federal investment?"

Cost-effectiveness and incremental cost analyses (CEICA) provide reliable techniques for comparing non-monetary ecological benefits relative to the monetary costs of restoration actions (Robinson et al. 1995). CEICA are analytical tools for assessing the relative benefits and costs of ecosystem restoration actions and informing decisions. Cost-effectiveness provides a mechanism for examining the efficiency of alternative actions for a given level of investment or environmental benefit target. Incremental cost analysis is conducted on the set of cost-effective plans to sequentially reveal changes in unit cost as output levels increase. Benefits and costs are assessed prior to these analyses using ecological models and cost engineering methods, respectively. CEICA may be conducted at the site scale to compare alternatives at a single location (e.g., no action vs. in-channel improvement vs. riparian planting) or at the system scale to compare relative merits of multiple sites (e.g., no sites vs. Site-A only vs. Site-B only vs. Site-A and Site-B). Within the US Army Corps of Engineers, the Institute of Water Resources has provided a toolkit for conducting CEICA, the IWR Planning Suite, currently in Version 2.0.9.

USACE policy instructs teams to recommend a restoration plan that cost-effectively delivers ecological benefits. In particular, the Planning Guidance Notebook (ER 1105-2-100) directs teams to select a plan that "meets planning objectives and constraints and reasonably maximizes environmental benefits while passing tests of cost effectiveness and incremental cost analysis, significance of outputs, acceptability, completeness, efficiency, and effectiveness" (ER 1105-2-100, Page E-163). Five issues are highlighted to help interpret CEICA: inflection points in the analytical outcomes, ecological output targets, ecological output thresholds, cost affordability, and unintended effects (ER 1105-2-100, Page E-158). Policy provides further elaboration on unintended effects. "Decisions to recommend a particular cost effective or best buy plan are not made in isolation. Other factors that matter in terms of selecting one alternative over another could include, for example, land ownership, effects on other outputs, and effects on nearby stakeholders. It is possible that the unintended consequences could be just as important as the primary project purpose of ecosystem restoration. The importance and magnitude of these unintended effects will of course vary from study to study."

Secondary social outcomes may be particularly important decision factors in urban watersheds, given population density and visibility of restoration projects. USACE has long had policies and methods to consider social outcomes (Dunning and Durden 2007, Durden and Wegner-Johnson 2013), but recent USACE policy directives have emphasized the need to balance primary project purposes such as ecological restoration with secondary socio-economic outcomes (James 2020ab). Multiple authors have provided methods for integrating other objectives into CEICA (Deason et al. 2010, McKay et al. *In review*), but these techniques are only some of many alternative decision-making approaches for multi-objective management problems.

Given this context, this technical report has three main objectives. First, CEICA techniques and associated decision logic are demonstrated at the scale of a single restoration site (e.g., What actions are preferrable at each site?). Second, CEICA techniques are applied to inform decision-making at the system scale (e.g., What combination of sites within the watershed is most appropriate?). Third, alternative decision-making approaches are examined that provide a comparative view of methods and recommendations. All of these methods are applied and discussed for an urban watershed restoration project in Beargrass Creek, Louisville, Kentucky. As such, this report begins with a description of the decision context for Beargrass Creek project planning and ends with a presentation of the recommended restoration decision for the Beargrass Creek study. The report concludes by discussing urban restoration decision making more broadly and highlighting future research opportunities.

2. Three Forks of Beargrass Creek Ecosystem Restoration Feasibility Study

Beargrass Creek in Louisville, Kentucky is a representative example of common urban stream management challenges. Three main branches, the South Fork, Middle Fork, and Muddy Fork, drain this small watershed (~59 mi^2, Figure 1). Wetlands and forests were historically drained to support residential, commercial, and industrial land uses as the Louisville region grew. Some reaches were channelized to increase conveyance (e.g., Clay 1953), and further geomorphic change occurred as a result of increased runoff from urban development. The U.S. Army Corps of Engineers (USACE) Louisville District (LRL) and Louisville Metropolitan Sewer District (MSD) are partnering to confront these challenges and identify actions to restore aquatic ecosystems in the watershed. The two primary objectives of the projects are: (1) To reestablish quality and connectivity of *riverine* habitats and (2) To reestablish quality and connectivity of *riparian* habitats.

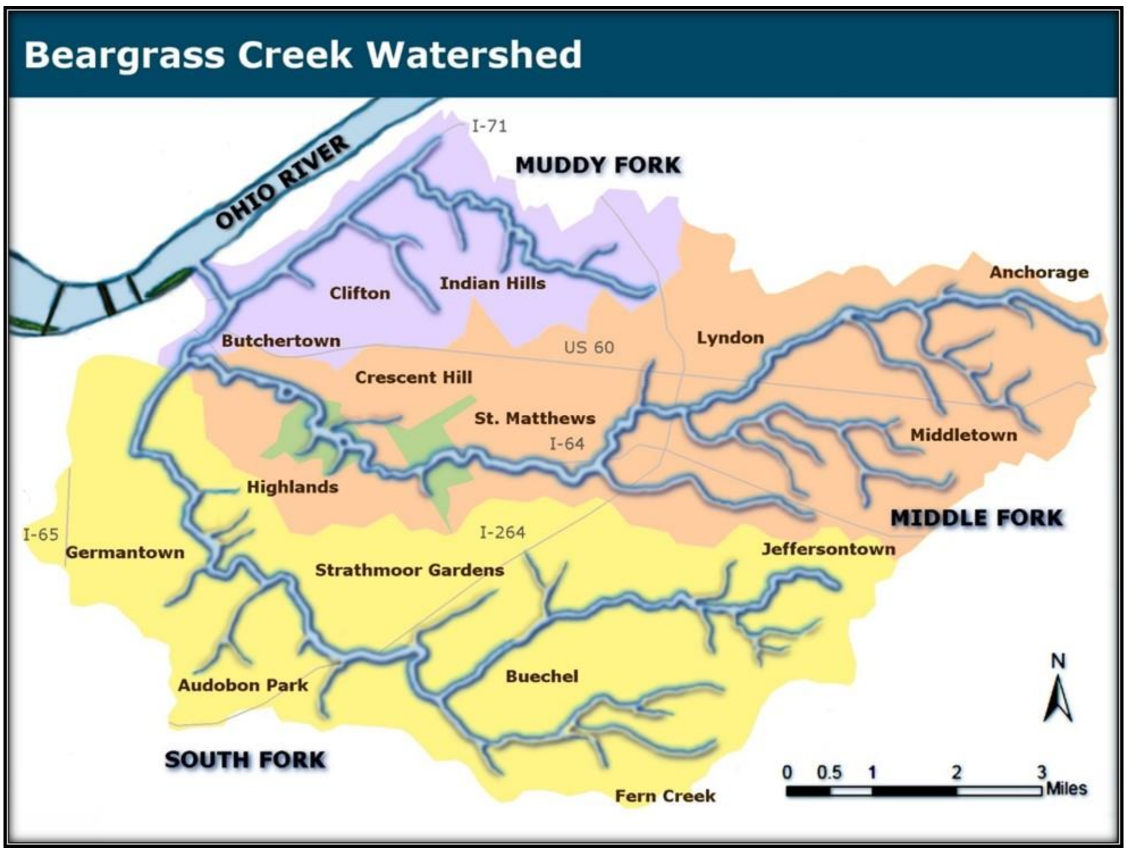


Figure 1. Beargrass Creek watershed.

Here, we describe the context of ecosystem restoration planning for the Beargrass Creek study. First, the general approach to developing and formulating restoration alternatives is considered. Second, cost estimates are summarized. Third, ecological outcomes are quantified, forecasted, and "annualized" (i.e., time-averaged) relative to two ecological models for riverine and riparian objectives.

2.1. Plan Formulation

This section describes the approach to development and formulation of alternatives. The watershed-scale of the project required a nested analytical framework spanning multiple scales of analysis. In this document, terms will be used as follows:

- *Site*: Refers to discrete locations where restoration actions were considered (e.g., X2, X10).

- *Action*: Refers to a proposed restoration activity at a given site (e.g., R1, H2, P).

- *Alternative*: Refers to a combination of proposed restoration actions at a site (e.g., Alt2=R1+H2, Alt3=R1+P).

- *Plan*: Refers to a watershed-scale combination of sites.

An initial array of 50+ potential restoration sites was identified based on prior watershed assessments, local knowledge, preliminary field scouting, and desktop geospatial analyses. These sites were screened relative to seven technical criteria addressing the extent of the site, proximity to other aquatic ecosystems, presence of hydric soils, existing soil coverage, impervious area, the potential for restored connectivity, and proximity to natural areas. Secondary screening involved logistical, administrative, and policy factors. These two forms of screening resulted in 21 sites carried through for feasibility-level analysis.

A generalized set of nine restoration actions was considered at each site and combined into restoration alternatives. The actions each have a different philosophy for guiding restoration of the degraded ecosystem. Some of the actions can be combined together at the site scale to create an alternative. Some actions are dependent upon the execution of others. The restoration actions and associated combinability and dependency are summarized below. Table 1 summarizes the restoration sites along with the actions and number of alternatives considered.

- *Riverine Connectivity* (C): These actions eliminate fragmentation points inhibiting movement of aquatic organisms. Connectivity actions are combinable with any other actions, and the Riverine actions are dependent on this action. Connectivity actions cannot be implemented in isolation of Riverine actions.

- *Riverine Habitat* (R1-R4): These actions emphasize in-channel actions taken to restore aquatic habitat and geomorphic processes. The four types of actions address instream habitat creation only (R1), instream habitat creation along with bank grading and floodplain reconnection (R2), initiation of natural stream migration (R3), and extensive channel realignment with accompanying changes in floodplain connectivity and instream habitat (R4). Riverine actions are not combinable with each other, but they are combinable with Connectivity, Hydrologic, and Planting alternatives. These actions are dependent on the Connectivity alternative, if Connectivity actions are recommended at the site. Dependency is based on the logic that if aquatic organisms cannot gain access to a restored habitat, then the plan is woefully incomplete and inefficient. Connectivity actions generally have lower cost than Riverine actions (and disproportionately high qualitative ecological benefit), and creating dependency between these actions assumes that connectivity actions could be removed from the alternative during plan optimization (i.e., after plan selection).

- *Hydrologic Restoration* (H): Hydrologic actions are applied in riparian zones to attenuate "peaky" urban hydrology and restore the natural flow regime. The three types of hydrologic actions address removal of existing drainage systems (H1), construction of features such as swales and wetlands (H2), and construction of small-scale water control features (H3). Hydrologic actions are combinable with each other, Connectivity, and Riverine actions. However, they often require the same project footprint at Planting actions, so they cannot be combined with Planting actions at this phase of planning.

- *Native Plant Community* (P): These actions emphasize the removal of dominant invasive plants and restoration of native riparian plant communities. Planting actions are fully combinable with all actions except hydrologic actions as noted above. Importantly, planting actions have been initially scoped at the maximum amount of plantable space at a site. The assumption is that the planting schemes would be reduced during plan optimization. This was deemed appropriate from a decision perspective because the benefits and costs of planting were largely linear relationships, and thus, a reduction in planting extent would be unlikely to alter the overarching conceptual recommendation at a site.

Table 1. Summary of Beargrass Creek restoration sites included in the final array.

Site Number	Site Name	Restoration Actions	Number of Alternatives
X2	Confluence	FWOP, R1, R2, R3, R4, H2, P	15
X4	Shelby Campus	FWOP, C, R1, R3, R4, H2, P	12
X5	Oxmoor Farm	FWOP, C, R3, H1, P	6
X8	Houston Acre's Farm	FWOP, C, R2, R4, P	6
X9	Clark Park	FWOP, C, R2, P	4
X10	Alpaca Farm / Zoo	FWOP, C, R1, R2, R4, H2, H3, P	20
X11	Collegiate	FWOP, R1, R2, H2, P	9
X15	Buechel Park	FWOP, C, R3, R4, H3, P	9
X19	South Fork / Newburg Rd	FWOP, R1, R4, H2, H3, P	15
X20	Brown Park	FWOP, R1, R2, H2, H3, P	15
X21	Arthur Draut Park	FWOP, R1, R2, R3, R4, H2, H3, P	25
X22	Concrete Channel	FWOP, R1, R2, H2, P	9
X24	Oxmoor Country Club	FWOP, C, R3, H2, P	6
X28	Hurstbourne Country Club	FWOP, C, R2, P	4
X29	Eastern / Creason Connector	FWOP, C, R1, R2, R3, R4, P	10
X30	Joe Creason Park	FWOP, C, R1, R2, R4, H2, H3, P	20
X31	Champions Trace	FWOP, C, R1, H3, P	6
X33	MSD Basin	FWOP, R2, H2, H3, P	10
X34	Cherokee / Seneca Parks	FWOP, C, R1, R2, R3, R4, H2, P	15
X35	Muddy Fork and Tribs	FWOP, C, R1, R2, H2, P	9
X38	Cave Hill Corridor	FWOP, R2, H2, H3, P	10

The most appropriate actions at each site were identified based on professional judgment relative to local conditions and constraints, sources of degradation, and other factors. The maximum number of potential alternatives was therefore 2^n for each site, where n is the number of actions. However, the combinability of actions dramatically reduced the number of potential alternatives. Table 2 presents an example of combinations of restoration actions into alternatives for the Alpaca Farm / Zoo site (X10). In this example, 8 restoration actions could have potentially been combined 256 ways (i.e., $2^8=256$), but in light of dependencies of actions only 20 alternatives remain.

Table 2. Example of combinations of actions at Alpaca Farm / Zoo (X10) with dependencies removed. One indicates action and zero indicates no action.

Alternative	C	R1	R2	R4	H2	H3	P
X10.Alt.1	0	0	0	0	0	0	0
X10.Alt.2	0	0	0	0	0	0	1
X10.Alt.3	0	0	0	0	0	1	0
X10.Alt.4	0	0	0	0	1	0	0
X10.Alt.5	0	0	0	0	1	1	0
X10.Alt.6	1	0	0	1	0	0	0
X10.Alt.7	1	0	0	1	0	0	1
X10.Alt.8	1	0	0	1	0	1	0
X10.Alt.9	1	0	0	1	1	0	0
X10.Alt.10	1	0	0	1	1	1	0
X10.Alt.11	1	0	1	0	0	0	0
X10.Alt.12	1	0	1	0	0	0	1
X10.Alt.13	1	0	1	0	0	1	0
X10.Alt.14	1	0	1	0	1	0	0
X10.Alt.15	1	0	1	0	1	1	0
X10.Alt.16	1	1	0	0	0	0	0
X10.Alt.17	1	1	0	0	0	0	1
X10.Alt.18	1	1	0	0	0	1	0
X10.Alt.19	1	1	0	0	1	0	0
X10.Alt.20	1	1	0	0	1	1	0

2.2. Cost Summary

Cost estimates were compiled for each site-scale restoration action following standard cost engineering and real estate methods. Project first cost currently represents a rough-order-of-magnitude estimate inclusive of real estate, restoration actions, pre-construction engineering and design, construction management, monitoring, and adaptive management. Monitoring and adaptive management are currently assumed to comprise 5% of total project first cost and spread over a ten-year window. Interest during construction was computed based on project first costs minus the 5% for monitoring and adaptive management with an assumed construction duration of 12-months for all actions. The FY21 Federal discount rate (2.50%) was used to annualize project first cost, interest during construction, and monitoring and adaptive management expenses over a 50-year planning horizon. Table 3 provides an example of cost estimates for Site-X10.

Table 3. Example cost summary for the Alpaca Farm / Zoo site (X10). A full summary of costs data for all sites and alternatives can be found in Attachment C.

Site	Action	Project First Cost ($)	Average Annual Cost ($)
X10	FWOP	0	0
X10	C	1,022,000	36,000
X10	R1	291,000	10,000
X10	R2	3,472,000	123,000
X10	R4	7,470,000	265,000
X10	H2	768,000	27,000
X10	H3	688,000	24,000
X10	P	9,187,000	325,000

2.3. Ecological Benefits

Here, we describe the tools and techniques for quantifying ecological outcomes relative to the riverine and riparian objectives. First, two different ecological models are briefly described, which were used to assess riverine and riparian outcomes. Second, these models are applied to assess existing conditions at each restoration site. Third, the models are applied to forecast the effects of multiple alternatives through time. Fourth, ecological outcomes are "annualized" (i.e., time-averaged) for consistent comparison with restoration costs.

2.3.1. Ecological Models

The riverine and riparian project objectives are assessed separately using two different ecological models, the Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS, pronounced "quails", McKay et al. 2021a) and the Simple Model for Urban Riparian Function (SMURF, McKay et al. 2021b). These models are applied to separate project areas (i.e., nonoverlapping channel and riparian polygons), and thus are treated separately throughout the analysis. This section briefly describes each tool to provide readers with context on how ecological benefits are assessed. Further details can be found in the model documentation referenced.

QHEILS is a simple tool for assessing stream outcomes relative to macrohabitat, geomorphology, and longitudinal connectivity. The macrohabitat module is adopted from the Qualitative Habitat Evaluation Index (QHEI), which is a rapid stream assessment protocol originally developed for applications in Ohio (Rankin 2006). The model has been approved for use on multiple USACE ecosystem restoration studies and evaluates stream ecosystem integrity relative to six primary dimensions: substrate (20 points), instream cover (20 points), channel morphology (20 points), bank erosion and riparian zone (10 points), relative distribution of habitat types (20 points), and channel gradient (10 points). Each factor is assessed independently through a series of field observations, visual assessments, desktop analyses, and scoring procedures. The second module of QHEILS assesses geomorphic condition of urban stream relative to channel incision and the degree of floodplain connectivity. The third module of QHEILS quantifies connectivity of the system relative to aquatic organism passage (20 points) and material transport (20 points). Overall ecosystem quality is assessed as the average of the 0 to 1 indices derived from each module. This habitat quality metric is combined with an assessment of channel area (in acres) to compute "habitat units."

Instream assessments such as QHEILS and QHEI often include riparian variables (such as the riparian zone metric above); however, these assessments are inherently focused on in-channel processes and outcomes. As such, we apply a separate rapid assessment technique to assess the integrity of riparian ecosystems. The SMURF (McKay et al. 2021) was designed for application in the Beargrass Creek study (USACE model certification pending). The SMURF addresses three major categories of outputs: (1) indirect effects of riparian zones on instream processes, (2) riparian areas as important providers of native faunal habitat, and (3) riparian zones as ecological corridors and sources of resilience in highly disturbed areas. The model uses data collected through a combination of rapid field assessment protocols and desktop geospatial assessments, which are applied independently to left and right bank riparian zones.

2.3.2. Existing Condition

QHEILS and SMURF were applied to each restoration site to assess the existing conditions at that location. A large-scale field campaign was executed in summer 2020 to assess over 50 locations in the Beargrass Creek watershed. Some of these assessment points were screened out of additional analyses, and some assessment points were combined into larger areas based on logical mobilization actions for restoration. When multiple sites were combined, the inputs to the QHEILS and SMURF were averaged across the number of locations. Table 4 summarizes the existing conditions associated with each restoration site in terms of "habitat units" for the channel, left bank riparian zone, and right bank riparian zone.

Table 4. Habitat units associated with the existing condition at each restoration site.

Site Number	QHEILS Channel (HU)	SMURF Left Bank (HU)	SMURF Right Bank (HU)	Total (HU)
X2	9.1	6.8	18.4	34.4
X4	0.9	10.2	17.5	28.7
X5	3.9	20.4	8.4	32.7
X8	2.6	30.5	33.0	66.1
X9	0.2	5.5	1.5	7.1
X10	1.2	1.7	8.7	11.6
X11	1.5	17.5	16.6	35.6
X15	0.6	0.6	0.5	1.7
X19	0.9	3.8	1.2	5.9
X20	0.8	1.7	0.7	3.3
X21	2.9	2.3	5.8	11.0
X22	1.6	1.5	1.0	4.2
X24	2.5	0.8	7.1	10.4
X28	1.2	0.7	0.1	2.0
X29	4.3	23.3	16.3	43.9
X30	1.4	35.3	1.0	37.8
X31	1.8	0.9	0.4	3.1
X33	0.4	2.6	0.5	3.5
X34	5.0	25.6	32.4	62.9
X35	1.9	17.6	23.1	42.6
X38	2.2	1.1	4.1	7.4

2.3.3. Alternative Forecasting

Restoration alternatives typically have differential effects on ecosystems through time. For instance, an alternative installing rock features within a stream may begin providing benefits relatively quickly compared to riparian forest restoration. For Beargrass Creek, five assessment points through time were deemed appropriate for adequately capturing the trajectories of these systems in response to restoration.

- *Year-0*: Captures the state of the ecosystem prior to any action. Assumed to be equivalent to the existing condition assessment.

- *Year-2*: Addresses the initial response of the stream following construction and the initial accrual of benefits. Only the QHEILS is assessed at this time period, given longer time scales for riparian response.

- *Year-10*: Assumes the initial riparian canopy response has occurred with growth to the mid-story size. This time period also corresponds with the end of the USACE adaptive management horizon.

- *Year-20*: Captures the growth of the riparian zone to a young forest with maturing of forest structure and arrival of overstory. Only the SMURF is applied at this time period, given the assumed consistency in performance of in-channel features from years 10-50.

- *Year-50*: Assesses the state of the system at the end of the design life. This time period assumes riparian forests have matured with fully functioning dynamics (e.g., gap processes are included).

The future without project condition (FWOP) is a dynamic state, particularly in a world of rapid change associated with land use, invasive species, climate, and other factors. Three main factors were considered in forecasting how the FWOP could deviate from the existing condition. Notably, all three factors have considerable uncertainty, and rather than introducing additional uncertainty, the FWOP mirrored the existing condition, unless there were compelling reasons to deviate.

- *Land use change*: Urban systems often undergo rapid land use development. This factor includes site-specific changes based on known development plans (e.g., Oxmoor Farms) and mirrors assumptions made by the engineering teams regarding long-term developmental trajectories in the basin.

- *Project completion*: A variety of actors are currently undertaking water management actions that could influence restoration sites. However, projects are at varying states of planning and significant uncertainty exists in implementation. Ongoing projects from the cost-share sponsor (MSD) were included, but none of these actions include proposed restoration sites.

- *Climate change*: Over the life of the project, temperature in the region is expected to increase, and precipitation is anticipated to increase in the winter/spring and decrease in the summer/fall. These changes were used to adjust variables in the riparian assessment based on a few qualitative factors. Detrital processes were assumed to accelerate under increased temperature. Organic matter retention, embeddedness, and bank erosion are all anticipated to be negatively impacted by increasingly flashy stream hydrology as a result of precipitation changes. Effects of climate on all other variables were deemed too uncertain to justify altered forecasts.

Existing condition values served as the basis for all assessments of temporal trajectories and alternatives. The existing condition was modified through a set of agreed upon guidelines to be applied uniformly across sites (Appendix B). The scoring "rubric" differed for each model input (e.g., deadfall vs. buffer flowpaths), each type of action (e.g., R1 vs. P), and each point in time (e.g., Year-10 vs. Year-50). For each action, both riparian and riverine variables may be altered, but no variables are altered by both actions to avoid "double counting" of benefits.

The rubric specifies a percent improvement in the *remaining* ecological degradation at a site. The metric value for a given action and time is then computed based on the following equation and examples. Table 5 shows the overall effects of this forecasting rubric on riverine and riparian outputs for proposed restoration actions at Site-X10.

$$X_{act} = X_{existing} + \Delta_{rubric}(X_{max} - X_{existing})$$

Where X_{act} is the value of metric X for a given action and time, $X_{existing}$ is the existing condition value for the metric X, Δ_{rubric} is the percent improvement in the remaining ecological condition at a site, and X_{max} is the maximum value for the metric X.

Example 1: $X_{existing} = 13$, $\Delta_{rubric} = 0.5$, and $X_{max} = 20$

$$X_{act} = 13 + 0.5(20 - 13) = 16.5$$

Example 2: $X_{existing} = 2$, $\Delta_{rubric} = 0.5$, and $X_{max} = 20$

$$X_{act} = 2 + 0.5(20 - 2) = 11$$

Example 3: $X_{existing} = 18$, $\Delta_{rubric} = 0.5$, and $X_{max} = 20$

$$X_{act} = 18 + 0.5(20 - 18) = 19$$

Example 4: $X_{existing} = 13$, $\Delta_{rubric} = 0.8$, and $X_{max} = 20$

$$X_{act} = 13 + 0.8(20 - 13) = 18.6$$

Table 5. Example of habitat units for the Alpaca Farm / Zoo site (X10). A full summary of habitat units for all sites can be found in Appendix B.

Site	Alternative	Year	QHEILS	SMURF.Left	SMURF.Right
X10	FWOP	0	1.2	1.7	8.7
X10	FWOP	2	1.2	NA	NA
X10	FWOP	10	1.2	1.7	8.7
X10	FWOP	20	NA	1.7	8.6
X10	FWOP	50	1.2	1.7	8.5
X10	C	0	1.2	1.7	8.7
X10	C	2	1.6	NA	NA
X10	C	10	1.6	1.7	8.7
X10	C	20	NA	1.7	8.6
X10	C	50	1.6	1.7	8.5
X10	R1	0	1.2	1.7	8.7
X10	R1	2	1.2	NA	NA
X10	R1	10	1.2	1.7	8.9
X10	R1	20	NA	1.8	9.1
X10	R1	50	1.2	1.8	9.2
X10	R2	0	1.2	1.7	8.7
X10	R2	2	2.2	NA	NA
X10	R2	10	2.3	2.0	9.9
X10	R2	20	NA	2.0	10.0
X10	R2	50	2.3	2.0	10.0
X10	R4	0	1.2	1.7	8.7
X10	R4	2	2.5	NA	NA
X10	R4	10	2.5	2.1	10.2
X10	R4	20	NA	2.1	10.2
X10	R4	50	2.5	2.0	10.1
X10	H2	0	1.2	1.8	8.7
X10	H2	2	1.2	NA	NA
X10	H2	10	1.2	2.4	9.6
X10	H2	20	NA	2.5	9.7
X10	H2	50	1.2	2.6	10.0

Table 5 (cont). Example of habitat units for the Alpaca Farm / Zoo site (X10). A full summary of habitat units for all sites can be found in Appendix B.

Site	Alternative	Year	QHEILS	SMURF.Left	SMURF.Right
X10	H3	0	1.2	1.7	8.7
X10	H3	2	1.2	NA	NA
X10	H3	10	1.2	1.7	9.6
X10	H3	20	NA	1.8	9.7
X10	H3	50	1.2	1.8	10.0
X10	P	0	1.2	2.4	9.3
X10	P	2	1.2	NA	NA
X10	P	10	1.2	30.0	21.6
X10	P	20	NA	30.7	22.0
X10	P	50	1.2	31.8	22.7

2.3.4. Benefit Annualization

Restoration benefits and costs are often distributed across the planning horizon. For instance, the ecological benefits of a riparian planting scheme may not be realized until the trees reach a certain size or height threshold. Annualization provides a mechanism for consistent comparison of benefits and costs. Ecological outputs are assessed at multiple time periods as described above, and benefits are computed as the time-averaged quantity over the planning horizon. Benefits are annualized by computing the area under the benefits curve and dividing by the duration of the planning horizon. A linear trajectory is assumed between all time periods.

Benefits are annualized separately for the channel (QHEILS), left riparian zone (SMURF), and right riparian zone (SMURF). For this project the total habitat at a site is computed as the sum of these three habitat outputs, which used non-overlapping assessment areas. For each alternative, net benefits were computed over the future without project (FWOP) condition to reflect the change in ecological condition associated with the restoration expenditure. This "lift" in benefits provides a consistent baseline for comparison. Table 6 provides an example of annualized benefits associated with Site-X10, which is derived from the temporally distributed data in Table 5.

Table 6. Example of average annual habitat units for the Alpaca Farm / Zoo site (X10). A full summary of average annual habitat units for all sites can be found in Appendix B.

Site	Action	QHEILS Channel (HU)	SMURF Left Bank (HU)	SMURF Right Bank (HU)	Total Benefits (AAHU)	Ecological Lift (AAHU)
X10	FWOP	1.2	1.7	8.6	11.5	0.0
X10	C	1.5	1.7	8.6	11.8	0.3
X10	R1	1.2	1.8	9.0	12.1	0.5
X10	R2	2.3	2.0	9.9	14.1	2.6
X10	R4	2.5	2.0	10.0	14.5	3.0
X10	H2	1.2	2.4	9.7	13.3	1.8
X10	H3	1.2	1.8	9.7	12.7	1.1
X10	P	1.2	28.1	20.9	50.2	38.7

3. Cost-Effectiveness and Incremental Cost Analysis (CEICA)

Cost-effectiveness analysis provides a mechanism for examining the efficiency of alternative actions. For any given level of investment, the agency wants to identify the plan with the most return-on-investment (i.e., the most environmental benefits for a given level of cost or the least cost for a given level of environmental benefit). An "efficiency frontier" identifies all plans that efficiently provide benefits on a *per cost basis*.

Incremental cost analysis is conducted on the set of cost-effective plans. This technique sequentially compares each plan to all higher cost plans to reveal changes in unit cost as output levels increase and eliminates plans that do not efficiently provide benefits on an *incremental unit cost basis*. Specifically, this analysis examines the slope of the cost-effectiveness frontier to isolate how the unit cost ($/unit) increases as the magnitude of environmental benefit increases. Incremental cost analysis is ultimately intended to inform decision-makers about the consequences of increasing unit cost when increasing benefits (i.e., each unit becomes more expensive). Plans emerging from incremental cost analysis efficiently accomplish the objective relative to unit costs and are typically referred to as "best buys." Importantly, all "best buys" are cost-effective, but all cost-effective plans are not best buys.

CEICA can be applied multiple ways when examining a multi-site restoration project such as Beargrass Creek. First, recommendations can be made at the site-scale (e.g., Alt-A at Site-1). Second, site-scale recommendations can be combined logically with other recommended actions to develop different "portfolios" of projects (e.g., Alt-A at Site-1 and Alt-C at Site-2). Third, all permutations of sites and alternatives can be assessed to develop project portfolios. Here, we applied CEICA using all three approaches with the logic that greater confidence may be placed in a recommendation arrived at through competing methods.

Overall, restoration recommendations were made to "reasonably maximize environmental benefits" (USACE 2000). In general, CEICA was interpreted through five guiding questions to identify a recommended alternative:

- Does this alternative/plan meet the planning objectives? Specifically, actions would ideally incorporate both riverine and riparian benefits.
- Which alternative/plan provides a "good" investment relative to increasing incremental unit cost? Specifically, increases in marginal cost could encourage (or discourage) a recommendation.
- Which alternative/plan has the lowest overall unit cost (i.e., $/AAHU)? Overall unit cost is an important metric for agencywide budgeting decisions and "roll-up" of restoration outcomes. This metric also strongly drives watershed-scale site prioritization, so efforts were made to avoid site-scale recommendations with high overall unit cost.
- Which is cost affordable relative to other sites and overall project limitations?

- What other qualitative decision factors are important? The Planning Guidance Notebook (USACE 2000) suggests that recommendations be made in light of non-linearities in the cost-benefit data, incremental cost associated with additional investment, and qualitative benefits not captured by ecological models. Additionally, alternatives (or sites) may provide disproportionate benefits relative to economic outcomes, other social effects, or other USACE or MSD mission areas.

Cost and ecological benefits provide the primary inputs to CEICA. Table 7 summarizes these data for all sites and action in the Beargrass Creek project.

Table 7. Summary of cost and benefit data for all sites and alternatives.

Site	Alt	Project First Cost ($)	Average Annual Cost ($)	QHEILS Channel (HU)	SMURF Left Bank (HU)	SMURF Right Bank (HU)	Total Benefits (AAHU)	Ecological Lift (AAHU)
X2	FWOP	0	0	9.1	6.7	18.4	34.2	0.0
X2	R1	1,891,000	67,000	9.5	7.2	19.5	36.1	1.9
X2	R2	1,170,000	41,400	9.3	7.4	20.0	36.6	2.4
X2	R3	642,000	22,700	9.2	7.0	19.0	35.2	0.9
X2	R4	1,648,000	58,400	9.7	7.5	20.3	37.5	3.3
X2	H2	8,564,000	303,300	9.1	11.2	30.0	50.3	16.1
X2	P	14,865,000	526,500	9.1	12.4	42.6	64.1	29.8
X4	FWOP	0	0	0.9	10.0	17.2	28.2	0.0
X4	C	557,000	19,700	1.1	10.0	17.2	28.4	0.2
X4	R1	1,318,000	46,700	0.9	10.8	18.5	30.2	2.0
X4	R3	2,376,000	84,200	0.9	10.4	17.9	29.2	1.1
X4	R4	3,690,000	130,700	1.6	11.4	19.7	32.7	4.5
X4	H2	3,530,000	125,000	0.9	11.9	21.3	34.1	5.9
X4	P	11,246,000	398,300	0.9	18.4	28.7	48.0	19.8
X5	FWOP	0	0	3.9	20.6	8.3	32.8	0.0
X5	C	1,246,000	44,100	5.1	20.6	8.3	34.0	1.1
X5	R3	2,468,000	87,400	4.1	21.0	8.7	33.8	1.0
X5	H1	42,135,000	1,492,400	3.9	22.4	9.6	36.0	3.1
X5	P	50,853,000	1,801,200	3.9	34.5	23.1	61.5	28.7
X8	FWOP	0	0	2.6	30.2	32.7	65.6	0.0
X8	C	762,000	27,000	3.4	30.2	32.7	66.3	0.8
X8	R2	7,110,000	251,800	2.7	31.5	34.2	68.4	2.8
X8	R4	3,556,000	126,000	2.7	31.7	34.5	68.9	3.3
X8	P	18,920,000	670,200	2.6	39.5	47.2	89.4	23.8

Site	Alt	Project First Cost ($)	Average Annual Cost ($)	QHEILS Channel (HU)	SMURF Left Bank (HU)	SMURF Right Bank (HU)	Total Benefits (AAHU)	Ecological Lift (AAHU)
X9	FWOP	0	0	0.2	5.5	1.5	7.1	0.0
X9	C	291,000	10,300	0.2	5.5	1.5	7.1	0.0
X9	R2	1,997,000	70,700	0.3	5.9	1.6	7.7	0.6
X9	P	3,209,000	113,600	0.2	10.0	12.3	22.4	15.3
X10	FWOP	0	0	1.2	1.7	8.6	11.5	0.0
X10	C	1,022,000	36,200	1.5	1.7	8.6	11.8	0.3
X10	R1	291,000	10,300	1.2	1.8	9.0	12.1	0.5
X10	R2	3,472,000	123,000	2.3	2.0	9.9	14.1	2.6
X10	R4	7,470,000	264,600	2.5	2.0	10.0	14.5	3.0
X10	H2	768,000	27,200	1.2	2.4	9.7	13.3	1.8
X10	H3	688,000	24,400	1.2	1.8	9.7	12.7	1.1
X10	P	9,187,000	325,400	1.2	28.1	20.9	50.2	38.7
X11	FWOP	0	0	1.5	17.4	16.4	35.4	0.0
X11	R1	4,754,000	168,400	1.7	18.4	17.3	37.4	2.0
X11	R2	6,459,000	228,800	2.4	18.8	18.0	39.2	3.9
X11	H2	1,112,000	39,400	1.5	18.3	18.1	37.9	2.5
X11	P	15,924,000	564,000	1.5	38.9	29.1	69.5	34.1
X15	FWOP	0	0	0.6	0.6	0.5	1.7	0.0
X15	C	598,000	21,200	0.6	0.6	0.5	1.7	0.0
X15	R3	739,000	26,200	0.6	0.6	0.6	1.8	0.1
X15	R4	2,778,000	98,400	0.6	0.7	0.6	2.0	0.3
X15	H3	712,000	25,200	0.6	0.7	3.6	4.8	3.1
X15	P	1,759,000	62,300	0.6	5.5	10.6	16.6	15.0
X19	FWOP	0	0	0.9	3.7	1.1	5.8	0.0
X19	R1	1,586,000	56,200	2.2	4.0	1.2	7.4	1.6
X19	R4	2,592,000	91,800	1.2	4.5	1.4	7.1	1.4
X19	H2	1,680,000	59,500	0.9	6.6	4.5	12.0	6.3
X19	H3	1,893,000	67,000	0.9	4.0	3.4	8.4	2.6
X19	P	5,748,000	203,600	0.9	9.7	9.3	19.9	14.1
X20	FWOP	0	0	0.8	1.7	0.7	3.3	0.0
X20	R1	822,000	29,100	1.8	1.8	0.8	4.3	1.1
X20	R2	1,142,000	40,400	1.0	1.9	0.8	3.7	0.4

Site	Alt	Project First Cost ($)	Average Annual Cost ($)	QHEILS Channel (HU)	SMURF Left Bank (HU)	SMURF Right Bank (HU)	Total Benefits (AAHU)	Ecological Lift (AAHU)
X20	H2	283,000	10,000	0.8	2.8	1.0	4.7	1.4
X20	H3	336,000	11,900	0.8	2.7	1.0	4.5	1.3
X20	P	2,882,000	102,100	0.8	8.5	10.8	20.1	16.9
X21	FWOP	0	0	2.9	2.3	5.7	10.9	0.0
X21	R1	463,000	16,400	3.0	2.4	6.0	11.4	0.5
X21	R2	479,000	17,000	3.0	2.5	6.2	11.6	0.7
X21	R3	579,000	20,500	3.0	2.3	5.9	11.2	0.2
X21	R4	1,631,000	57,800	3.1	2.5	6.2	11.8	0.9
X21	H2	601,000	21,300	2.9	2.5	6.1	11.5	0.6
X21	H3	562,000	19,900	2.9	3.9	5.9	12.8	1.9
X21	P	3,495,000	123,800	2.9	9.2	15.5	27.6	16.7
X22	FWOP	0	0	1.6	1.5	1.0	4.1	0.0
X22	R1	21,551,000	763,300	2.2	1.8	1.2	5.1	1.0
X22	R2	9,372,000	332,000	6.4	2.1	1.4	9.8	5.7
X22	H2	2,361,000	83,600	1.6	5.0	1.8	8.4	4.3
X22	P	4,141,000	146,700	1.6	7.7	2.8	12.2	8.1
X24	FWOP	0	0	2.5	0.8	7.5	10.8	0.0
X24	C	656,000	23,200	3.0	0.8	7.5	11.3	0.6
X24	R3	2,406,000	85,200	2.8	0.9	8.1	11.8	1.1
X24	H2	1,561,000	55,300	2.5	2.3	9.2	13.9	3.2
X24	P	7,404,000	262,200	2.5	5.6	26.8	34.8	24.1
X28	FWOP	0	0	1.2	0.7	0.1	2.0	0.0
X28	C	608,000	21,500	1.3	0.7	0.1	2.2	0.1
X28	R2	4,618,000	163,600	1.9	0.9	0.2	3.0	0.9
X28	P	2,089,000	74,000	1.2	4.4	1.7	7.3	5.3
X29	FWOP	0	0	4.3	22.9	16.0	43.3	0.0
X29	C	467,000	16,500	4.8	22.9	16.0	43.7	0.5
X29	R1	689,000	24,400	4.3	23.8	16.6	44.8	1.5
X29	R2	3,099,000	109,800	4.3	24.5	17.0	45.9	2.6
X29	R3	360,000	12,700	4.3	23.7	16.5	44.4	1.2
X29	R4	5,740,000	203,300	4.4	24.9	17.2	46.6	3.3
X29	P	14,721,000	521,400	4.3	37.0	32.8	74.1	30.8

Site	Alt	Project First Cost ($)	Average Annual Cost ($)	QHEILS Channel (HU)	SMURF Left Bank (HU)	SMURF Right Bank (HU)	Total Benefits (AAHU)	Ecological Lift (AAHU)
X30	FWOP	0	0	1.4	35.1	1.0	37.5	0.0
X30	C	873,000	30,900	1.6	35.1	1.0	37.6	0.1
X30	R1	409,000	14,500	1.5	36.5	1.1	39.0	1.5
X30	R2	16,775,000	594,200	2.0	40.2	1.2	43.5	6.0
X30	R4	4,762,000	168,700	2.3	41.1	1.2	44.7	7.2
X30	H2	741,000	26,200	1.4	36.8	1.6	39.8	2.2
X30	H3	641,000	22,700	1.4	37.1	1.7	40.2	2.7
X30	P	11,676,000	413,600	1.4	77.3	8.6	87.3	49.8
X31	FWOP	0	0	1.8	0.9	0.4	3.0	0.0
X31	C	225,000	8,000	2.1	0.9	0.4	3.4	0.3
X31	R1	1,374,000	48,700	1.9	1.0	0.4	3.4	0.3
X31	H3	1,222,000	43,300	1.8	8.2	4.9	14.9	11.8
X31	P	5,277,000	186,900	1.8	13.3	9.0	24.1	21.0
X33	FWOP	0	0	0.4	2.6	0.5	3.4	0.0
X33	R2	1,584,000	56,100	0.6	2.7	0.5	3.9	0.5
X33	H2	1,009,000	35,700	0.4	2.8	2.7	5.8	2.4
X33	H3	1,181,000	41,800	0.4	2.7	2.6	5.7	2.3
X33	P	1,942,000	68,800	0.4	3.7	0.9	5.0	1.5
X34	FWOP	0	0	5.0	25.3	32.0	62.3	0.0
X34	C	673,000	23,800	6.5	25.3	32.0	63.8	1.6
X34	R1	2,563,000	90,800	5.2	26.7	33.8	65.6	3.4
X34	R2	2,628,000	93,100	8.4	27.9	35.6	71.9	9.6
X34	R3	1,091,000	38,600	5.0	26.1	33.3	64.3	2.1
X34	R4	2,411,000	85,400	5.7	28.3	36.2	70.2	7.9
X34	H2	163,000	5,800	5.0	27.4	34.5	66.9	4.7
X34	P	16,961,000	600,800	5.0	57.7	71.6	134.2	72.0
X35	FWOP	0	0	1.9	17.3	22.9	42.1	0.0
X35	C	798,000	28,300	2.1	17.3	22.9	42.3	0.2
X35	R1	3,227,000	114,300	1.9	18.3	23.9	44.1	2.0
X35	R2	3,888,000	137,700	2.8	19.5	25.1	47.4	5.3
X35	H2	3,199,000	113,300	1.9	20.6	24.5	47.0	4.9
X35	P	15,117,000	535,400	1.9	41.6	36.6	80.1	38.0

Site	Alt	Project First Cost ($)	Average Annual Cost ($)	QHEILS Channel (HU)	SMURF Left Bank (HU)	SMURF Right Bank (HU)	Total Benefits (AAHU)	Ecological Lift (AAHU)
X38	FWOP	0	0	2.2	1.1	4.0	7.3	0.0
X38	R2	1,210,000	42,800	3.0	1.3	4.9	9.2	1.9
X38	H2	7,567,000	268,000	2.2	7.8	4.5	14.5	7.2
X38	H3	7,945,000	281,400	2.2	7.4	4.3	13.9	6.6
X38	P	8,155,000	288,800	2.2	17.0	7.5	26.8	19.5

3.1. Site-Scale CEICA

At each site, multiple alternatives were developed varying in their conceptual basis, costs, and benefits. Here, cost-effectiveness and incremental cost analysis are applied to compare alternatives at each site to identify both cost-effective (CE) and best buy (BB) alternatives. For each site, the logic of decision-making was to visually examine CEICA results side-by-side, default to a decision array of best buy plans from incremental cost analysis, and then explore other cost-effective plans if appropriate. For each site, the project development team met multiple times to discuss site-scale recommendations, including diverse perspectives from planning, engineering, environmental, real estate, cultural resources, project management, and the cost-share sponsor. CEICA data were synthesized with other information to arrive at a preliminary recommended action. Each recommendation is accompanied by the supporting decision logic at the site. Notably, incremental cost values use unrounded habitat units and costs, which may lead to minor rounding errors relative to manual calculations. Detailed model inputs and outputs are included in Attachments B and C, respectively.

X2: Confluence

Site X2 is a 171-acre river corridor near the confluence of Beargrass Creek with the Ohio River. This site has approximately 1.9-miles of river channel, and the area is surrounded by public spaces at Eva Bandman Park, the Waterfront Botanical Gardens, and Louisville Champions Park. The area near the confluence is a strategic focus of multiple organizations, and plans may complement left bank restoration actions by the Botanical Garden. The site is a key point for paddling access, and actions here have the potential for NED benefits associated with marina dredging and debris management. Six restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- R1: Creates instream habitat through the addition of rock structures, primarily focused on the main branch of Beargrass Creek.

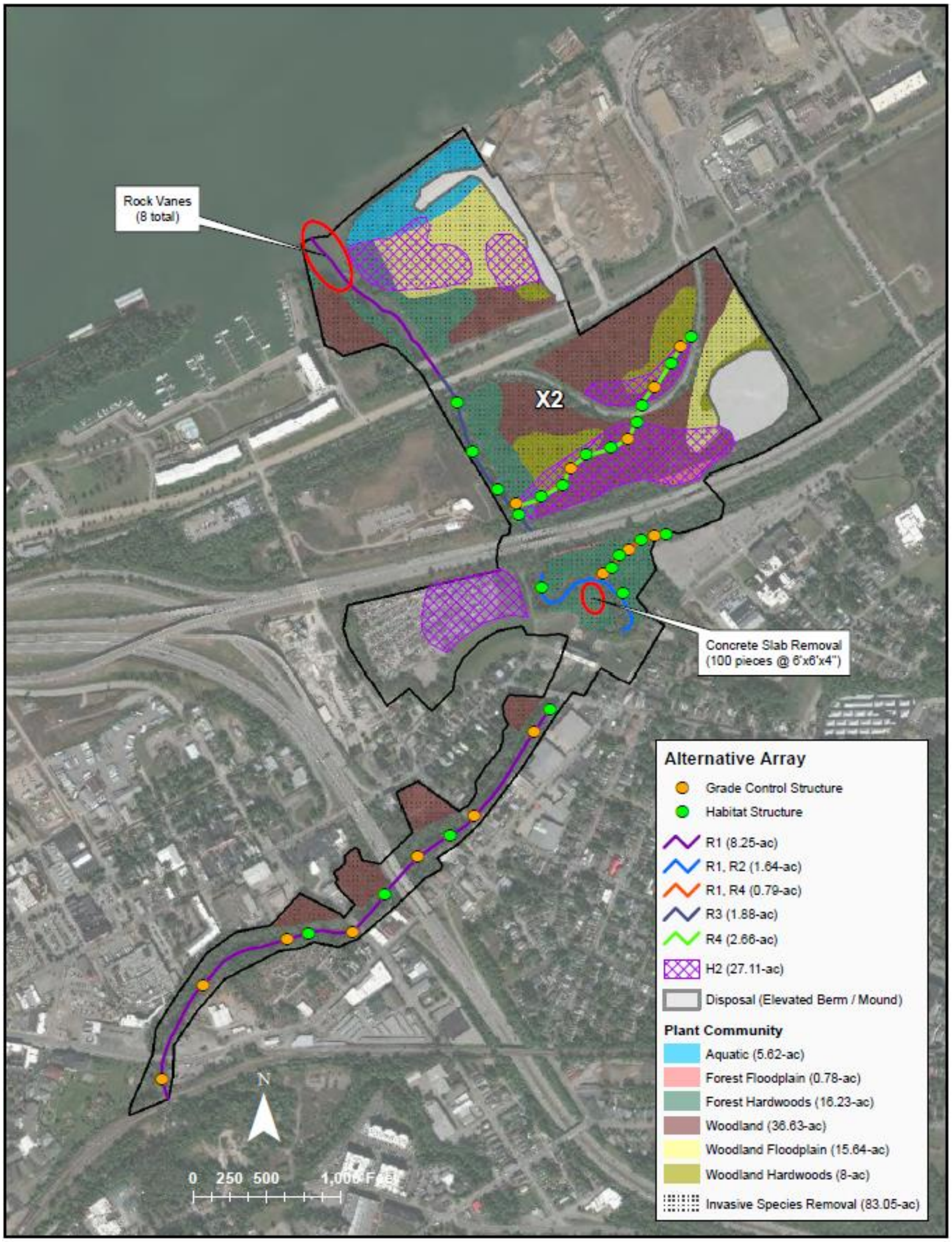
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves in a small segment of river.

- R3: Initiation of natural geomorphic processes in a small segment of river adjacent to the Botanical Garden.

- R4: Realigns the channel and significantly improves the overall geomorphic condition in tributaries on the site.

- H2: Addition of five large wetland features.

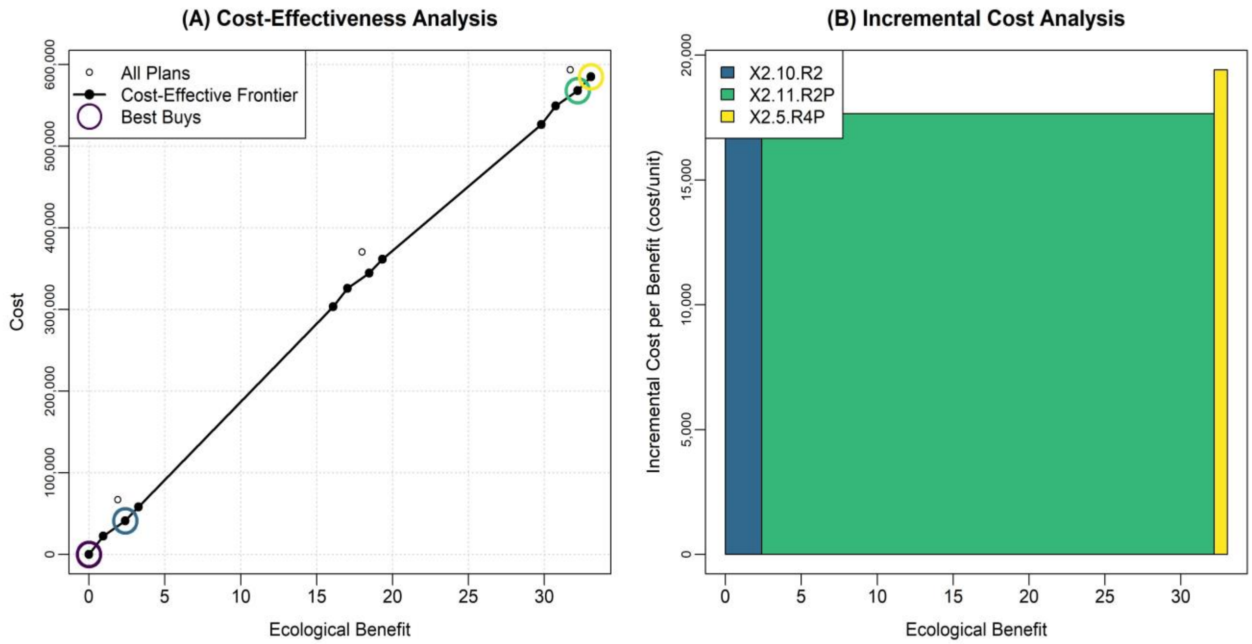
- P: Extensive planting of hardwood, floodplain, and woodland forests.



X2 Proposed Actions.

These 6 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 15 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 15 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X2 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X2.1.	0	0	NaN	0	0
X2.10.R2	2.4	41,400	17,400	17,400	1,170,000
X2.11.R2P	32.2	568,000	17,600	17,700	16,035,000
X2.5.R4P	33.1	584,900	17,700	19,400	16,513,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X2.1.	0	0	NaN	0	1	1
X2.2.P	29.8	526,500	17,700	14,865,000	1	0
X2.3.H2	16.1	303,300	18,900	8,564,000	1	0
X2.4.R4	3.3	58,400	17,900	1,648,000	1	0
X2.5.R4P	33.1	584,900	17,700	16,513,000	1	1
X2.6.R4H2	19.3	361,700	18,700	10,211,000	1	0
X2.7.R3	0.9	22,700	24,100	642,000	1	0
X2.8.R3P	30.8	549,300	17,900	15,507,000	1	0
X2.9.R3H2	17	326,100	19,100	9,206,000	1	0
X2.10.R2	2.4	41,400	17,400	1,170,000	1	1
X2.11.R2P	32.2	568,000	17,600	16,035,000	1	1
X2.12.R2H2	18.5	344,800	18,700	9,733,000	1	0
X2.13.R1	1.9	67,000	35,300	1,891,000	0	0
X2.14.R1P	31.7	593,500	18,700	16,756,000	0	0
X2.15.R1H2	18	370,300	20,600	10,455,000	0	0

Based on these data and team input, the **recommended action at this site is X2.12.R2H2**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the two largest best buys meet the planning objectives (i.e., X2.11.R2P and X2.5.R4P), both of which represent a large jump in total project cost over the next lowest cost best buy (X2.10.R2).

- Four cost-effective alternatives were identified with intermediate cost (i.e., X2.3.H2, X2.6.R4H2, X2.9.R3H2, and X2.12.R2H2). Three of these offer both riverine and riparian benefits and meet the planning objectives.

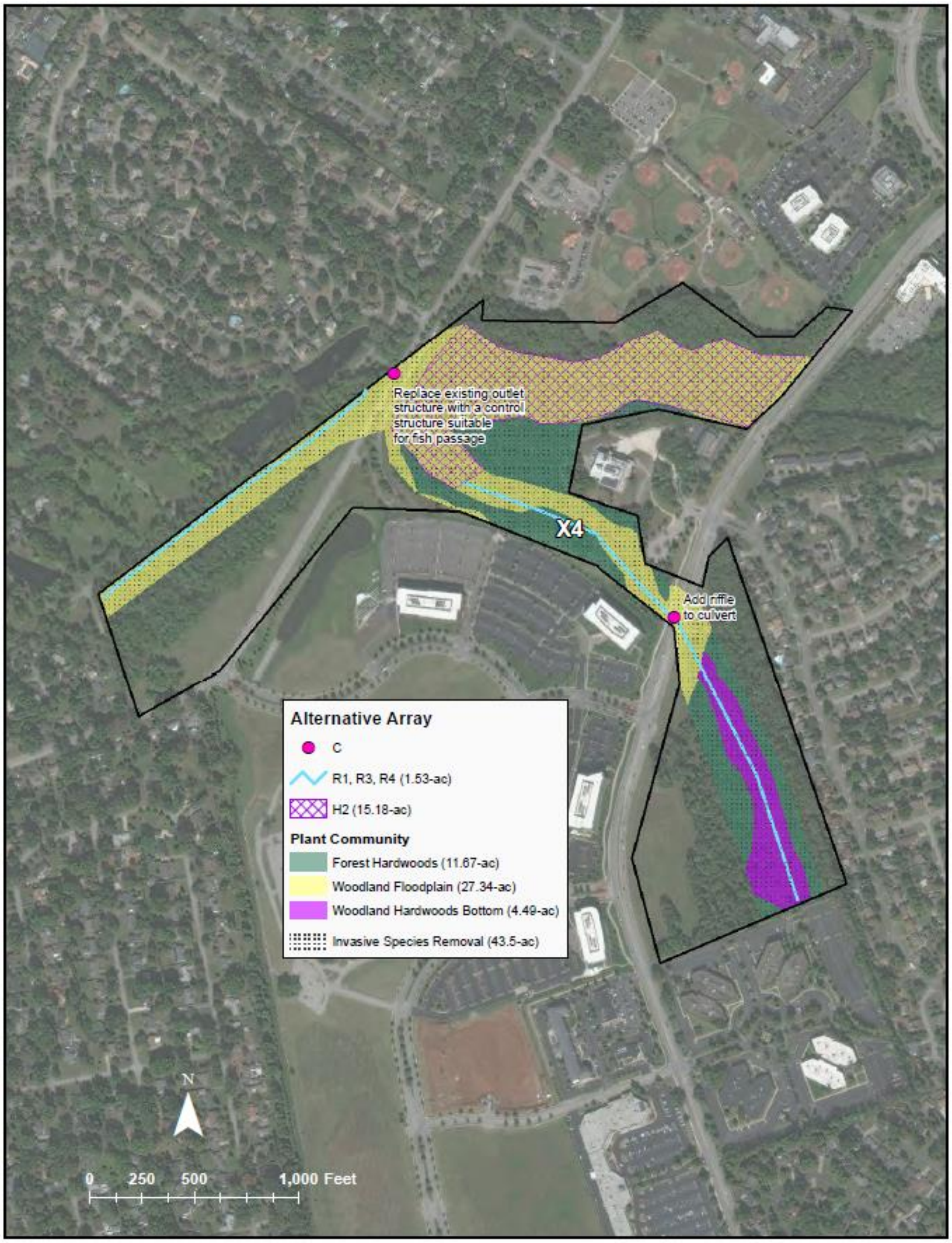
- Of these three plans, X2.12.R2H2 is recommended due to qualitative benefits associated with floodplain reconnection, known geomorphic issues in the reach, and the potential for complementing actions by other entities at the Botanical Garden (i.e., near the footprint of X2.9.R3H2). The X2.12.R2H2 alternative is also conceptually consistent with both riparian and channel actions in overlapping areas, thus protecting both investments. The X2.12.R2H2 alternative also avoids potential real estate challenges, which are concentrated around the areas containing the R4 actions.

- During optimization, the extent of the recommended plan should be reconsidered relative to incorporating downstream actions. Notably, debris management may be a challenge and an opportunity for reducing an ongoing problem. The north portion of this site is a known location for environmentally sensitive areas, and additional cultural mitigation may be required.

X4: Shelby Campus

Site X4 is an 82-acre river corridor along the north edge of the Shelby Campus of the University of Louisville on the Middle Fork. This site has approximately 1.3-miles of river channel and an existing retention basin. Six restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

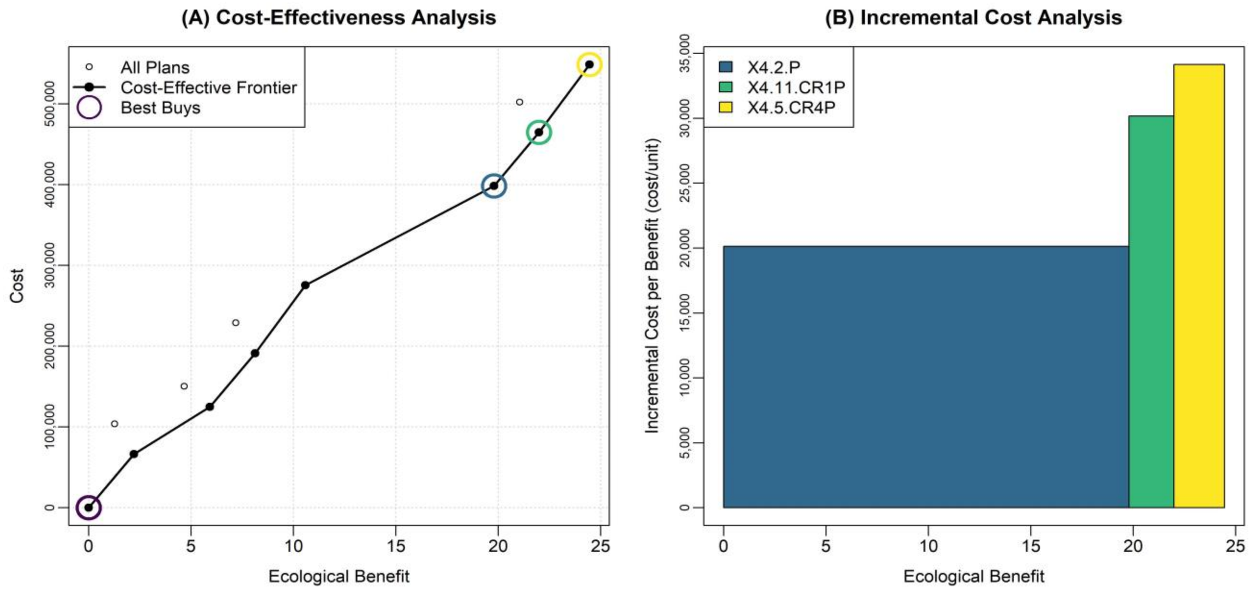
- C: Repair of one major connectivity barrier in the reach.
- R1: Creates instream habitat through the addition of rock structures.
- R3: Initiation of natural geomorphic processes.
- R4: Realigns the channel and significantly improves the overall geomorphic condition.
- H2: Addition of one large wetland feature.
- P: Extensive planting of hardwood and floodplain forests.



X4 Proposed Actions.

These 6 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 12 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 12 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X4 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X4.1.	0	0	NaN	0	0
X4.2.P	19.8	398,300	20,100	20,100	11,246,000
X4.11.CR1P	22	464,700	21,100	30,200	13,121,000
X4.5.CR4P	24.5	548,800	22,400	34,100	15,493,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X4.1.	0	0	NaN	0	1	1
X4.2.P	19.8	398,300	20,100	11,246,000	1	1
X4.3.H2	5.9	125,000	21,100	3,530,000	1	0
X4.4.CR4	4.7	150,400	32,300	4,247,000	0	0
X4.5.CR4P	24.5	548,800	22,400	15,493,000	1	1
X4.6.CR4H2	10.6	275,400	26,000	7,776,000	1	0
X4.7.CR3	1.3	103,900	82,600	2,933,000	0	0
X4.8.CR3P	21	502,200	23,900	14,179,000	0	0
X4.9.CR3H2	7.2	228,900	31,900	6,462,000	0	0
X4.10.CR1	2.2	66,400	30,200	1,875,000	1	0
X4.11.CR1P	22	464,700	21,100	13,121,000	1	1
X4.12.CR1H2	8.1	191,400	23,600	5,405,000	1	0

Based on these data and team input, the **recommended action at this site is X4.5.CR4P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the two largest best buys meet the planning objectives (i.e., X4.11.CR1P and X4.5.CR4P).

- The X4.11.CR1P alternative would add some habitat features, but the overall ecological effect may be relatively small. The X4.5.CR4P alternative would, however, allow for larger-scale ecological benefits to be pursued.

- The educational benefits of the larger alternative may also be significant given the proximity to educational institutions.

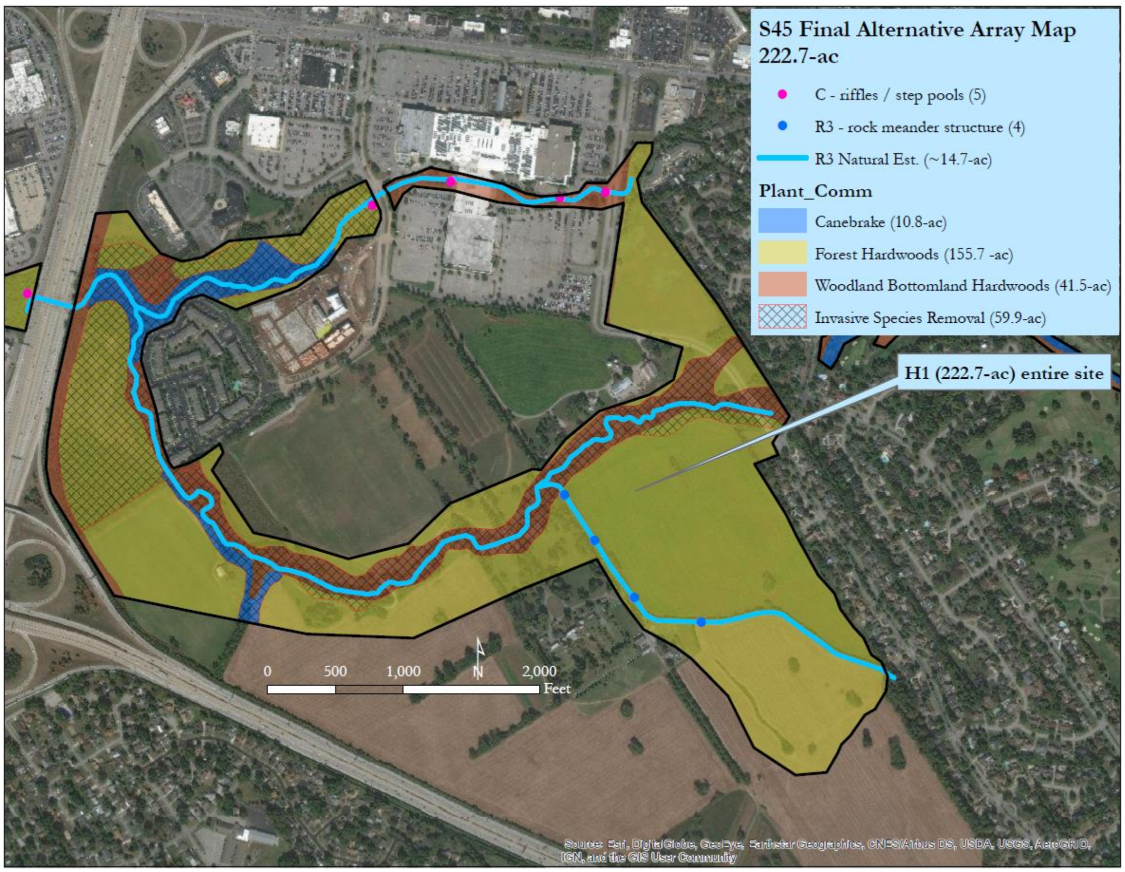
- The larger best buy (X4.5.CR4P) is deemed “worth it”, given the small increase in incremental unit cost.

- Notably, channel incision is not extreme at this site, so even large-scale riverine actions may ultimately be reduced in cost.

X5: Oxmoor Farm

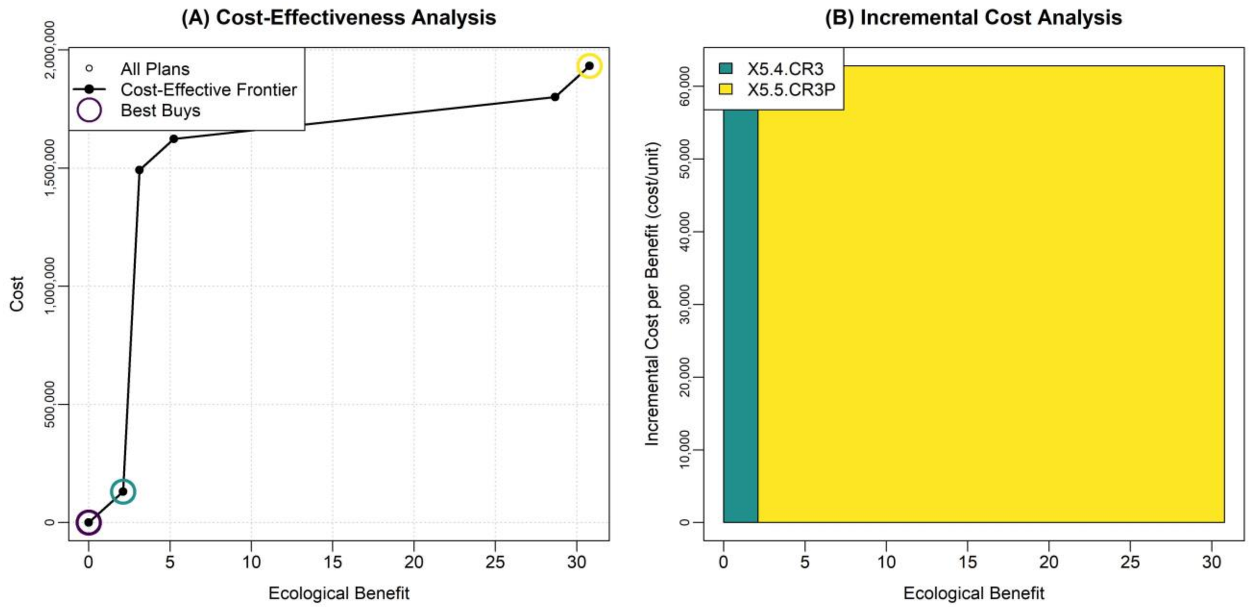
Site X5 is a 223-acre river corridor near an old farming site that is planned for development on the Middle Fork. This site has approximately 2.8-miles of river channel. Four restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- C: Repair of five connectivity barriers in the reach.
- R3: Initiation of natural geomorphic processes throughout the site.
- H1: Use of the entire site as a large scale infiltration zone.
- P: Extensive planting of canebrake, hardwood, and woodland forests.



X5 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 6 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for the 3 best buy alternatives as well as the results for all 6 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X5 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X5.1.	0	0	NaN	0	0
X5.4.CR3	2.1	131,600	62,500	62,500	3,714,000
X5.5.CR3P	30.8	1,932,800	62,800	62,800	54,567,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X5.1.	0	0	NaN	0	1	1
X5.2.P	28.7	1,801,200	62,800	50,853,000	1	0
X5.3.H1	3.1	1,492,400	478,000	42,135,000	1	0
X5.4.CR3	2.1	131,600	62,500	3,714,000	1	1
X5.5.CR3P	30.8	1,932,800	62,800	54,567,000	1	1
X5.6.CR3H1	5.2	1,624,000	310,600	45,849,000	1	0

Based on these data and team input, the **recommended action at this site is X5.1 (no action)**. The decision logic for this alternative is as follows:

- There is a potential affordability concern based on both unit cost and project first cost for even the least cost alternatives.

- Real estate cost is greater than 25% of project first cost (>40% for all best buys), which is discouraged by USACE policy.

- Site is part of a network of actions at sites X20 and X21, and the large footprint provides opportunity for significant ecological benefits. However, private ownership and real estate challenges could lead to a reduced footprint that ultimately makes the site less desirable. The real estate risk to project execution was deemed unacceptable.

X8: Houston Acre's Farm

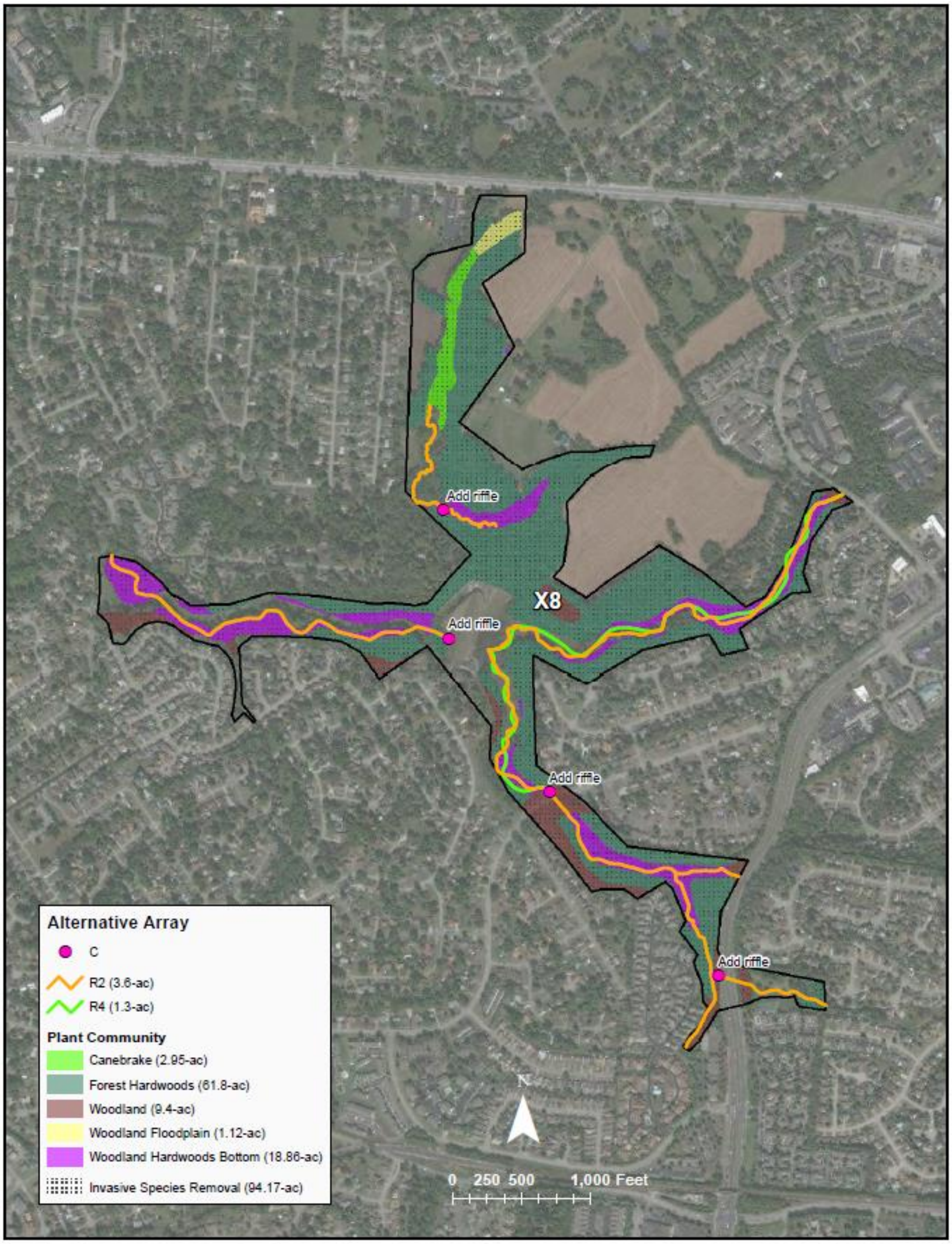
Site X8 is a 130-acre river corridor in a highly residential area on the South Fork of Beargrass Creek. This site has approximately 2.8-miles of river channel and is fragmented by a large retention structure. Four potential restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- C: Repairs one major and one minor connectivity barriers in the reach.

- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves throughout the site.

- R4: Realigns the channel and significantly improves the overall geomorphic condition at select portions of the site.

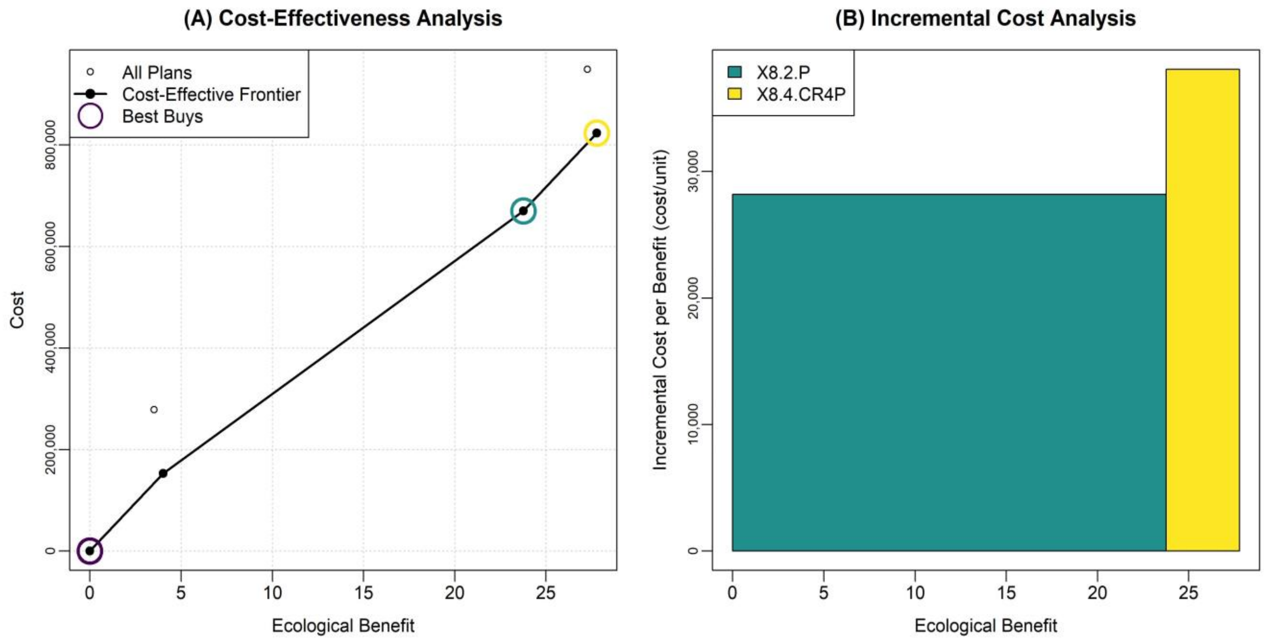
- P: Extensive planting of canebreak, hardwood, floodplain, and woodland forests.



X8 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 6 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 6 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X8 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X8.1.	0	0	NaN	0	0
X8.2.P	23.8	670,200	28,200	28,200	18,920,000
X8.4.CR4P	27.8	823,100	29,600	38,100	23,239,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X8.1.	0	0	NaN	0	1	1
X8.2.P	23.8	670,200	28,200	18,920,000	1	1
X8.3.CR4	4	153,000	38,100	4,319,000	1	0
X8.4.CR4P	27.8	823,100	29,600	23,239,000	1	1
X8.5.CR2	3.5	278,800	79,400	7,872,000	0	0
X8.6.CR2P	27.3	949,000	34,800	26,793,000	0	0

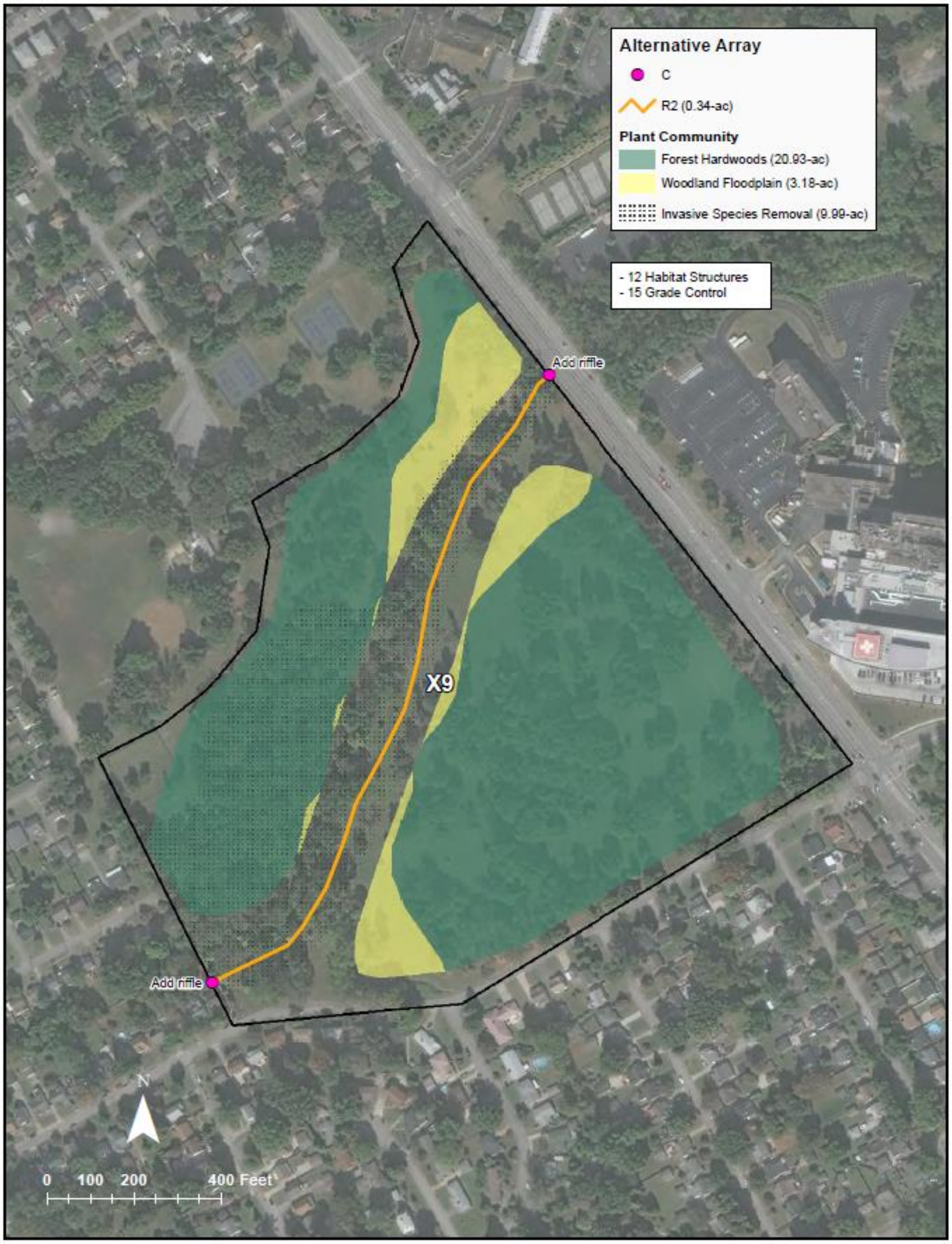
Based on these data and team input, the **recommended action at this site is X8.2.P**. The decision logic for this alternative is as follows:

- This alternative is the lowest cost best buy action.
- Although planning objectives include riparian and riverine outcomes, this alternative only includes riparian restoration. Site visits indicated high instream quality with significant observations of wildlife. Thus, a riparian only action would avoid disturbing the functioning instream community.
- The large footprint of the planting action preserves opportunities to potentially incorporate small-scale connectivity or riverine features during optimization. In particular, R1 and R3 actions could be effective additions to the alternative.
- The team noted potential affordability concerns based on project first cost. Invasive plant removal could comprise a larger component of the cost, and fewer plantings may be required. Ultimately, these factors could reduce project cost.
- The site possesses a few potential challenges during optimization. There is a dam onsite, which could provide an important design constraint at this location. Private ownership is extensive, and real estate challenges may occur. However, these discussions could lead to a reduced footprint and accompanying reduction in costs. Notably, the site is isolated relative to social outcomes, and the primary outcomes would need to be ecological to justify inclusion.

X9: Clark Park

Site X9 is a 37-acre river corridor in George Rogers Clark Park on the South Fork of Beargrass Creek. This site has approximately 0.3-miles of river channel and is surrounded by a high use recreational area. Three restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

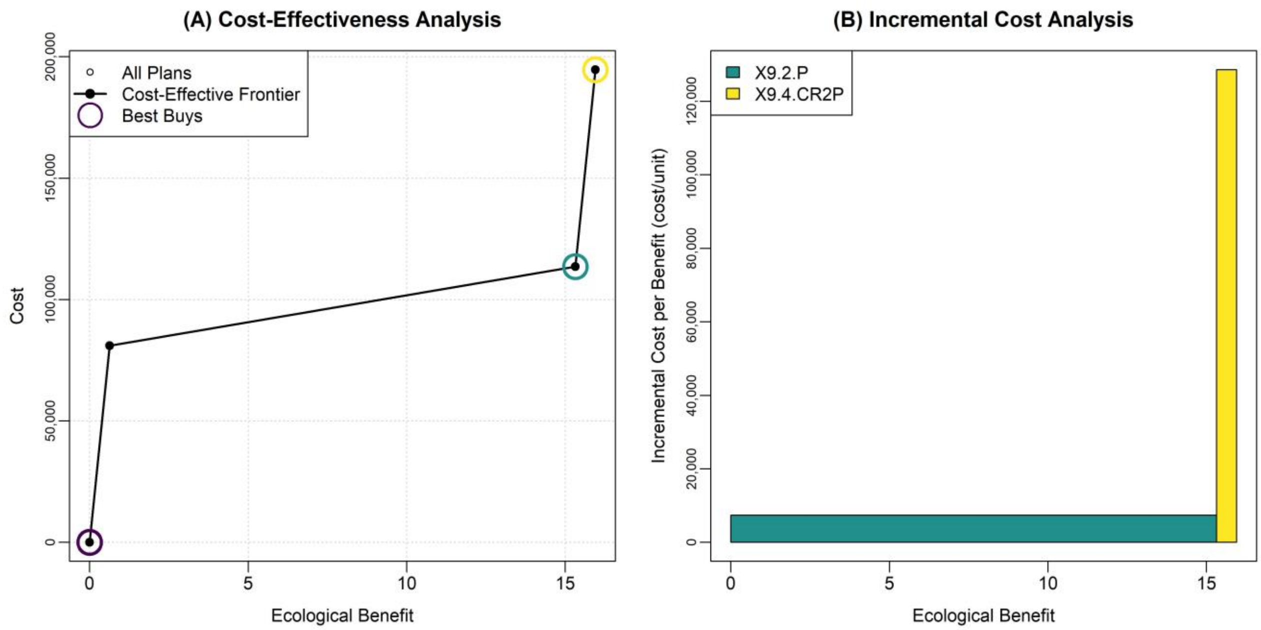
- C: Repair of two connectivity barriers at the upstream and downstream extent of the reach.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- P: Planting of hardwood and woodland forests.



X9 Proposed Actions.

These 3 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 4 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 4 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X9 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X9.1.	0	0	NaN	0	0
X9.2.P	15.3	113,600	7,400	7,400	3,209,000
X9.4.CR2P	16	194,700	12,200	128,600	5,496,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X9.1.	0	0	NaN	0	1	1
X9.2.P	15.3	113,600	7,400	3,209,000	1	1
X9.3.CR2	0.6	81,000	128,600	2,288,000	1	0
X9.4.CR2P	16	194,700	12,200	5,496,000	1	1

Based on these data and team input, the **recommended action at this site is X9.1 (no action)**. The decision logic for this alternative is as follows:

- Site visit indicated moderate quality stream with a potential for riparian improvement, which is consistent with CEICA outcomes.

- Planting could improve the riparian zone but would require additional land, which is in high recreational use at a Metro Park.

- Planting or riverine actions could both be compelling alternatives, depending on the city and the community's vision for park usage. However, the site produces relatively localized investment that may be more appropriate for other partners.

X10: Alpaca Farm / Zoo

Site X10 is a 79-acre river corridor near the Louisville Zoo and a small-scale alpaca farm on the South Fork of Beargrass Creek. This site has approximately 1-mile of river channel, and a recreational path runs adjacent to the stream. Seven potential restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- C: Removes three connectivity barriers in the reach.

- R1: Creates instream habitat through the addition of rock structures, primarily in a small footprint in upstream segments.

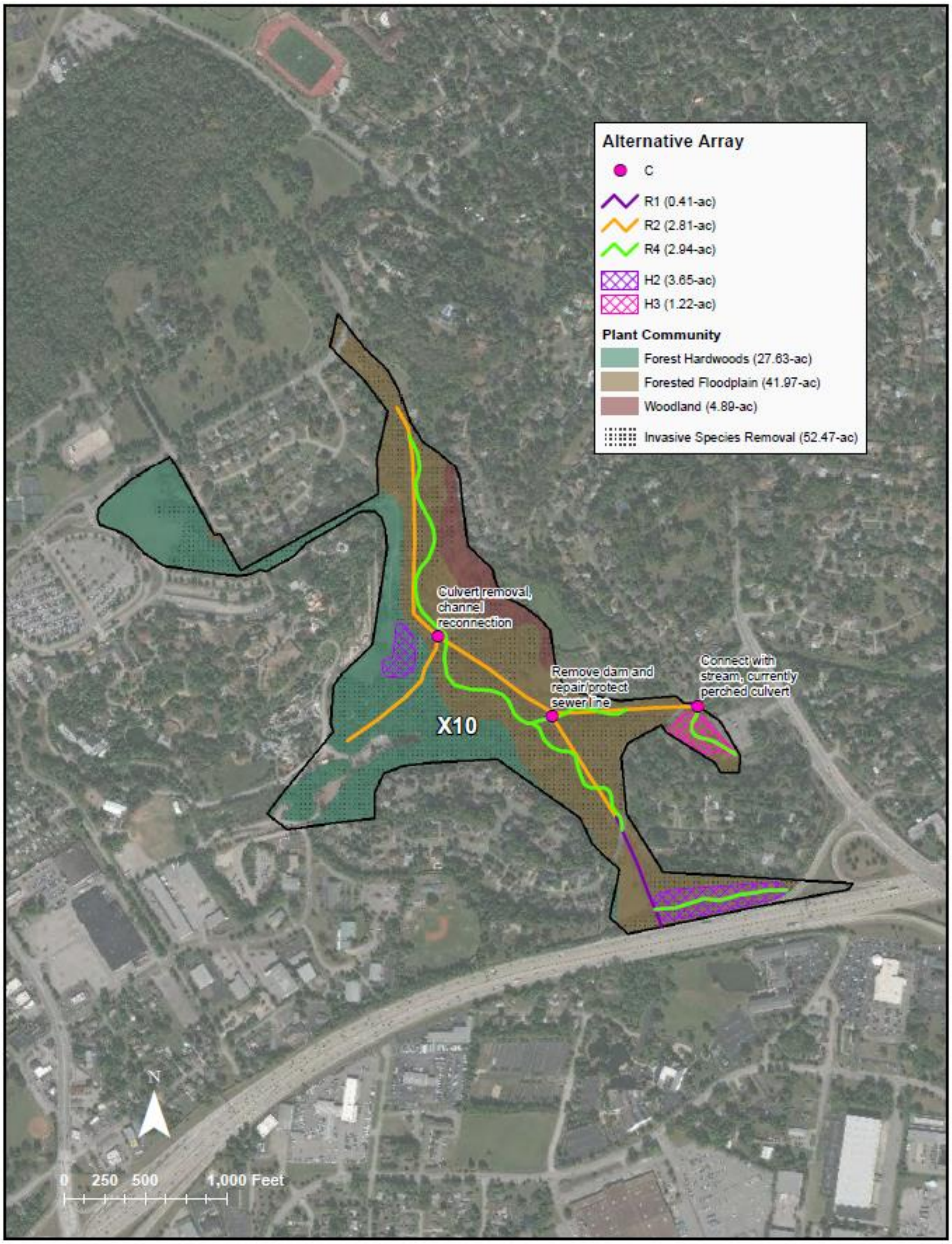
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.

- R4: Realigns the channel and significantly improves the overall geomorphic condition.

- H2: Addition of two small wetland features.

- H3: Construction of a small water control feature.

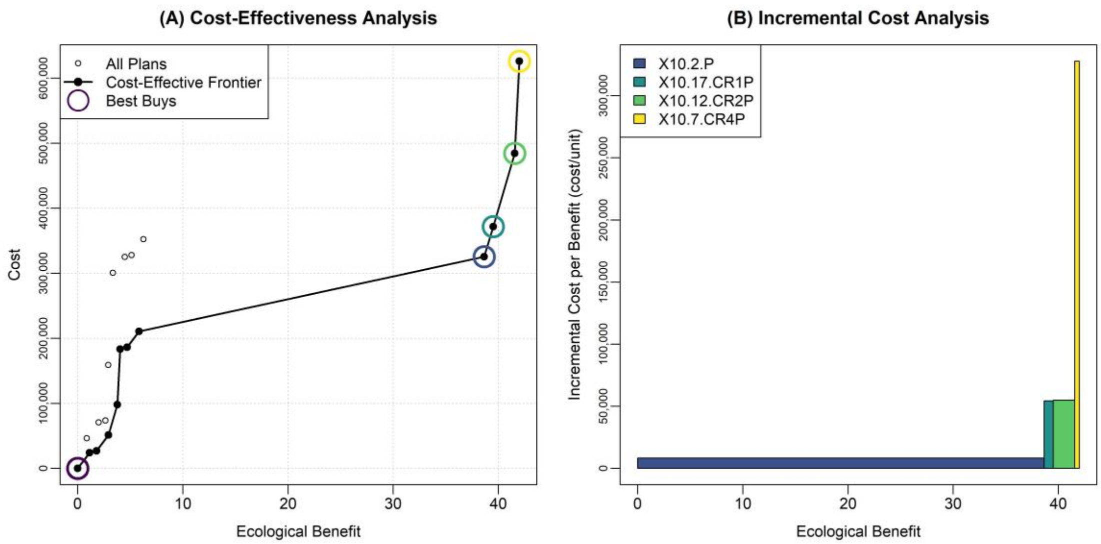
- P: Extensive planting of hardwood, floodplain, and woodland forests.



X10 Proposed Actions.

These 7 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 20 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 5 best buy alternatives as well as the results for all 20 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X10 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X10.1.	0	0	NaN	0	0
X10.2.P	38.7	325,400	8,400	8,400	9,187,000
X10.17.CR1P	39.5	371,900	9,400	54,400	10,500,000
X10.12.CR2P	41.6	484,600	11,700	54,900	13,682,000
X10.7.CR4P	42	626,200	14,900	327,800	17,680,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X10.1.	0	0	NaN	0	1	1
X10.2.P	38.7	325,400	8,400	9,187,000	1	1
X10.3.H3	1.1	24,400	21,500	688,000	1	0
X10.4.H2	1.8	27,200	15,200	768,000	1	0
X10.5.H2H3	2.9	51,600	17,700	1,455,000	1	0
X10.6.CR4	3.3	300,800	90,100	8,492,000	0	0
X10.7.CR4P	42	626,200	14,900	17,680,000	1	1
X10.8.CR4H3	4.5	325,200	72,700	9,180,000	0	0
X10.9.CR4H2	5.1	328,000	64,000	9,260,000	0	0
X10.10.CR4H2H3	6.3	352,300	56,300	9,948,000	0	0
X10.11.CR2	2.9	159,200	54,700	4,494,000	0	0
X10.12.CR2P	41.6	484,600	11,700	13,682,000	1	1
X10.13.CR2H3	4	183,600	45,500	5,182,000	1	0
X10.14.CR2H2	4.7	186,400	39,700	5,262,000	1	0
X10.15.CR2H2H3	5.8	210,700	36,200	5,950,000	1	0
X10.16.CR1	0.9	46,500	54,400	1,312,000	0	0
X10.17.CR1P	39.5	371,900	9,400	10,500,000	1	1
X10.18.CR1H3	2	70,800	35,700	2e+06	0	0
X10.19.CR1H2	2.6	73,700	27,900	2,080,000	0	0
X10.20.CR1H2H3	3.8	98,000	26,000	2,768,000	1	0

Based on these data and team input, the **recommended action at this site is X10.12.CR2P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the three largest best buys meet the planning objectives (i.e., X10.17.CR1P, X10.12.CR2P, and X10.7.CR4P).

- The next lowest cost best buy (X10.17.CR1P) also provides riverine benefits. However, the incremental unit cost is similar between the plans, and the R2 actions offer important qualitative benefits associated with floodplain reconnection.

- The larger best buy (X10.7.CR4P) is not deemed “worth it” given the large increase in incremental unit cost.

- The recommended plan (X10.12.CR2P) also includes a large increase in footprint over the next smaller best buy (X10.17.CR1P). This large footprint preserves options during plan optimization and may provide opportunities for incorporating small-scale R4 actions, if needed.

- In general, this site has high potential for complementary actions by the zoo as well as strong intangible benefits associated with the neighboring community. These benefits help support the slightly more expensive X10.12.CR2P alternative.

X11: Collegiate

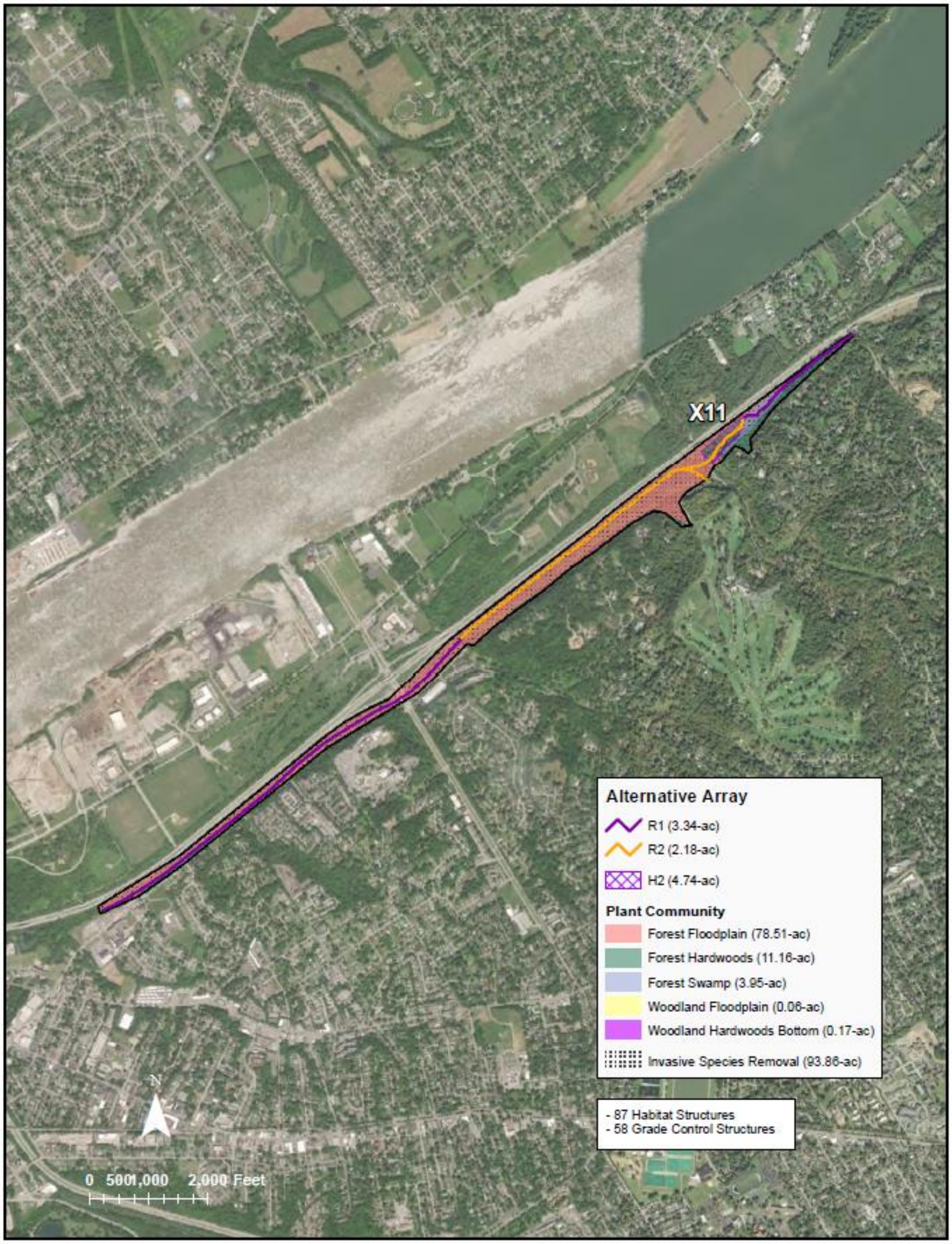
Site X11 is a 99-acre river corridor adjacent to I-71 on the Muddy Fork of Beargrass Creek. This site has approximately 3.1-miles of river channel, and a recreational path runs adjacent to the stream. Four restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- R1: Creates instream habitat through the addition of rock structures throughout the reach.

- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves with an emphasis on a middle segment of the site.

- H2: Addition of one large wetland feature spanning the site.

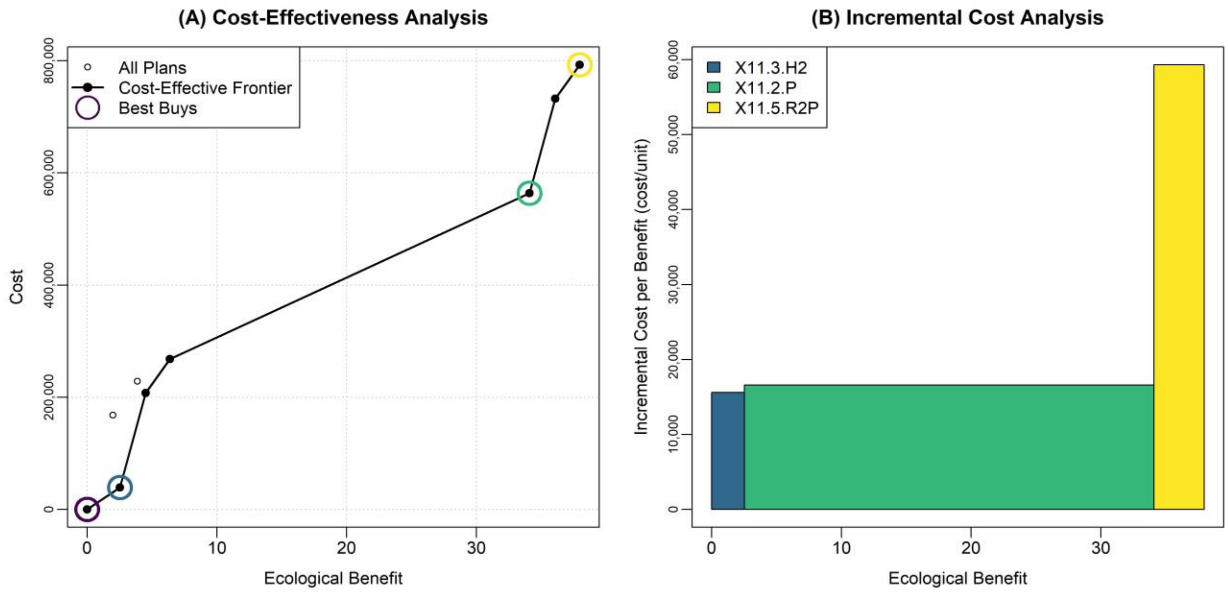
- P: Extensive planting of hardwood, floodplain, swamp, and woodland forests.



X11 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 9 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 9 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X11 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X11.1.	0	0	NaN	0	0
X11.3.H2	2.5	39,400	15,600	15,600	1,112,000
X11.2.P	34.1	564,000	16,500	16,600	15,924,000
X11.5.R2P	38	792,800	20,900	59,300	22,383,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X11.1.	0	0	NaN	0	1	1
X11.2.P	34.1	564,000	16,500	15,924,000	1	1
X11.3.H2	2.5	39,400	15,600	1,112,000	1	1
X11.4.R2	3.9	228,800	59,300	6,459,000	0	0
X11.5.R2P	38	792,800	20,900	22,383,000	1	1
X11.6.R2H2	6.4	268,100	42,000	7,571,000	1	0
X11.7.R1	2	168,400	85,200	4,754,000	0	0
X11.8.R1P	36.1	732,400	20,300	20,677,000	1	0
X11.9.R1H2	4.5	207,700	46,200	5,865,000	1	0

Based on these data and team input, the **recommended action at this site is X11.1 (no action)**. The decision logic for this alternative is as follows:

- The existing channel is severely degraded, and site constraints and risks lead to concerns about project efficacy. Specifically, planting actions along a freeway could be affected by continual invasive species introduction. Furthermore, riverine actions may be affected by freeway runoff.

- Given these risks, there also is potential for increased adaptive management cost during plan optimization.

- Utility easements from power lines could further limit project extent, particularly for riparian actions. Conversely, partnership with power company could lead to altered management practices regarding vegetation management.

- There are small scale educational opportunities, given proximity to a school, but river access may be challenging and therefore limited.

X15: Buechel Park

Site X15 is a 28-acre river corridor through a residential neighborhood on the South Fork of Beargrass Creek. This site has approximately 0.6-miles of river channel, and rail infrastructure brackets the northern boundary. Four restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- R3: Initiation of natural geomorphic processes, primarily in the downstream segment.

- R4: Realigns the channel and significantly improves the overall geomorphic condition, primarily in the upstream segment.

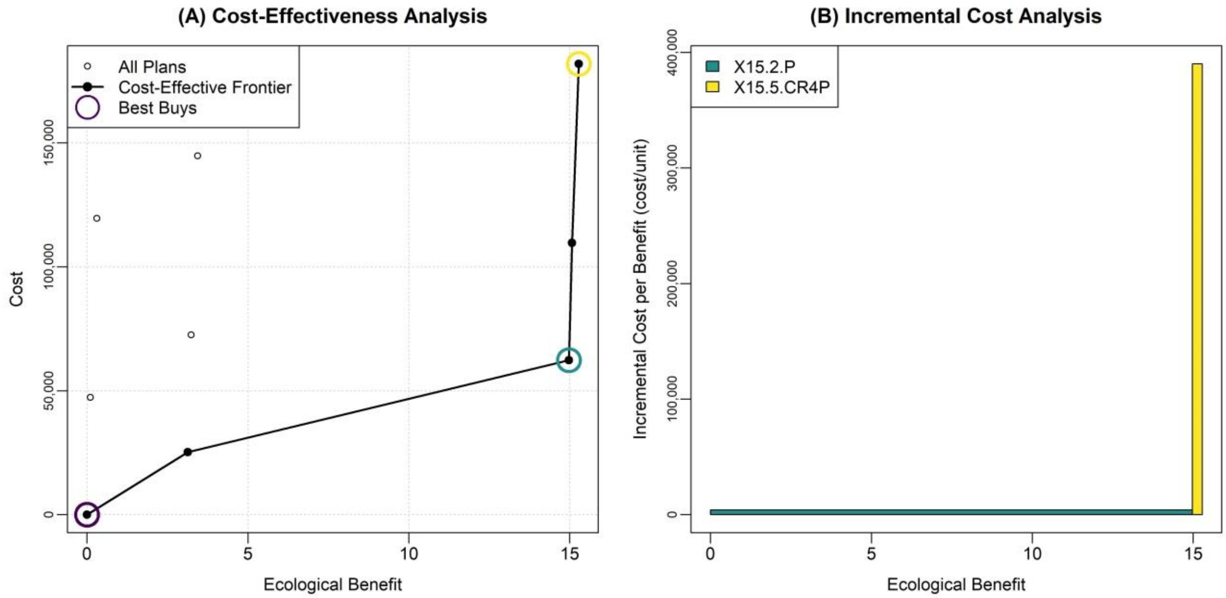
- H3: Construction of a small water control feature on the right floodplain.

- P: Planting of canebreak, floodplain, and hardwood forests.

X15 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 9 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 9 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X15 CEICA summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X15.1.	0	0	NaN	0	0
X15.2.P	15	62,300	4,200	4,200	1,759,000
X15.5.CR4P	15.3	181,900	11,900	390,200	5,135,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X15.1.	0	0	NaN	0	1	1
X15.2.P	15	62,300	4,200	1,759,000	1	1
X15.3.H3	3.1	25,200	8,100	712,000	1	0
X15.4.CR4	0.3	119,600	390,200	3,376,000	0	0
X15.5.CR4P	15.3	181,900	11,900	5,135,000	1	1
X15.6.CR4H3	3.4	144,800	42,100	4,088,000	0	0
X15.7.CR3	0.1	47,400	459,100	1,337,000	0	0
X15.8.CR3P	15.1	109,700	7,300	3,096,000	1	0
X15.9.CR3H3	3.2	72,600	22,400	2,049,000	0	0

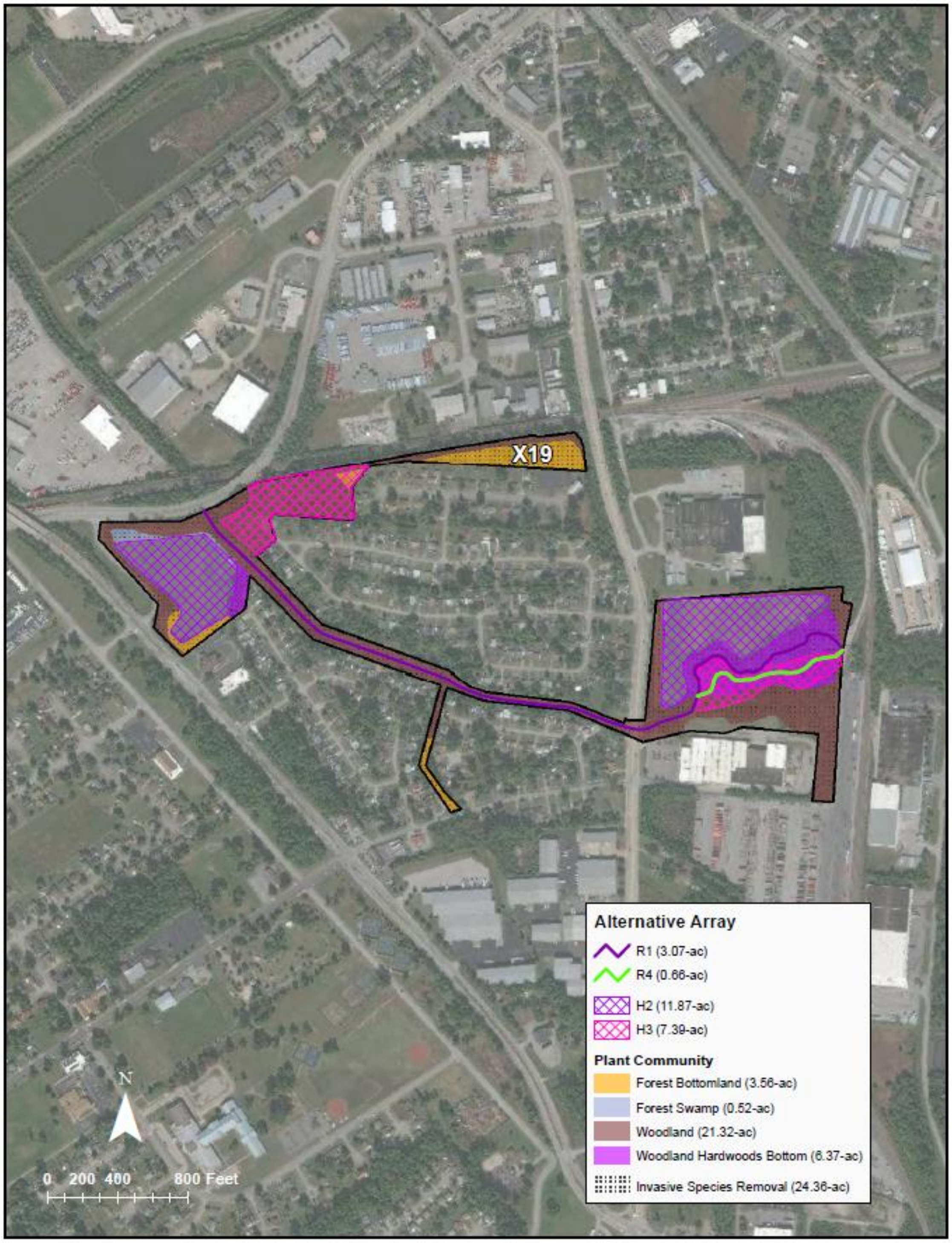
Based on these data and team input, the **recommended action at this site is X15.1 (no action)**. The decision logic for this alternative is as follows:

- The site benefits were deemed too small to warrant USACE actions, particularly along an intermittent stream.
- X15 is relatively isolated from other sites at a watershed scale.
- There are potential conflicts with usage as a park, which would reduce the footprint further.
- Planting or riverine actions could both be compelling alternatives, depending on the city and the community's vision for park usage. However, the site produces relatively localized investment that may be more appropriate for other partners.

X19: South Fork / Newburg Rd

Site X19 is a 44-acre river corridor on the South Fork of Beargrass Creek. This site has approximately 0.7-miles of river channel and flows through a confined residential corridor with industrial land uses upstream. Five restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

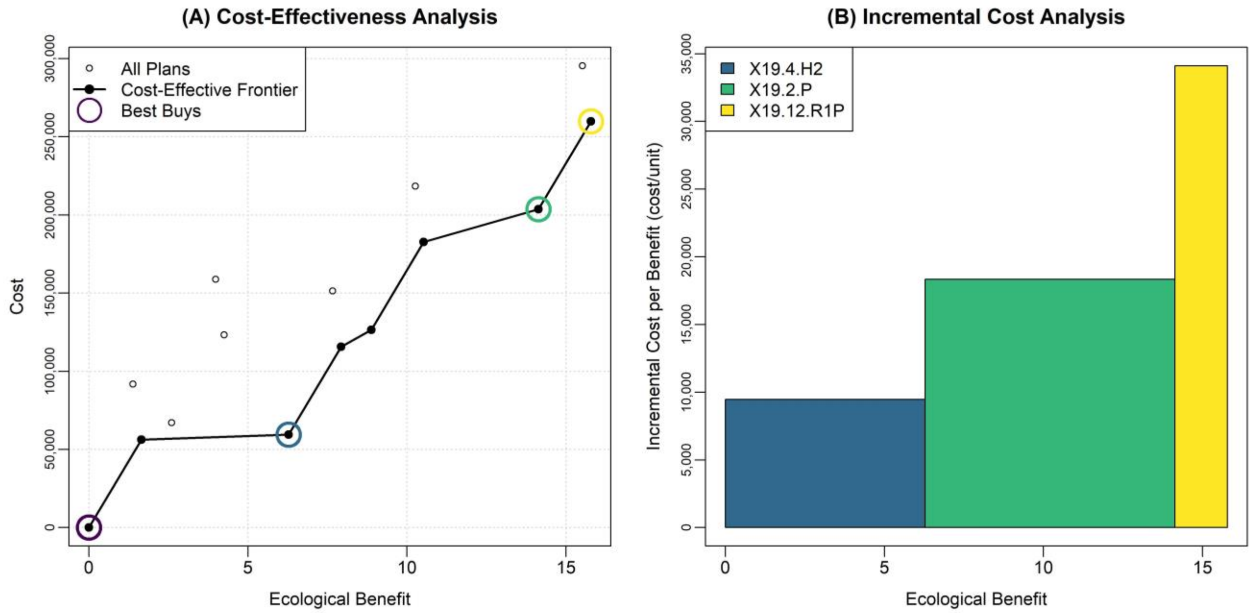
- R1: Creates instream habitat through the addition of rock structures.
- R4: Realigns the channel and significantly improves the overall geomorphic condition, primarily in a small footprint in upstream segments.
- H2: Addition of two small wetland features.
- H3: Construction of two small water control features.
- P: Extensive planting of hardwood, floodplain, and woodland forests.



X19 Proposed Actions.

These 5 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 15 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 15 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X19 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X19.1.	0	0	NaN	0	0
X19.4.H2	6.3	59,500	9,500	9,500	1,680,000
X19.2.P	14.1	203,600	14,400	18,300	5,748,000
X19.12.R1P	15.8	259,800	16,500	34,100	7,334,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X19.1.	0	0	NaN	0	1	1
X19.2.P	14.1	203,600	14,400	5,748,000	1	1
X19.3.H3	2.6	67,000	25,800	1,893,000	0	0
X19.4.H2	6.3	59,500	9,500	1,680,000	1	1
X19.5.H2H3	8.9	126,500	14,300	3,573,000	1	0
X19.6.R4	1.4	91,800	66,400	2,592,000	0	0
X19.7.R4P	15.5	295,400	19,000	8,340,000	0	0
X19.8.R4H3	4	158,900	39,900	4,485,000	0	0
X19.9.R4H2	7.7	151,300	19,700	4,272,000	0	0
X19.10.R4H2H3	10.3	218,400	21,300	6,165,000	0	0
X19.11.R1	1.6	56,200	34,100	1,586,000	1	0
X19.12.R1P	15.8	259,800	16,500	7,334,000	1	1
X19.13.R1H3	4.2	123,200	29,000	3,479,000	0	0
X19.14.R1H2	7.9	115,700	14,600	3,266,000	1	0
X19.15.R1H2H3	10.5	182,700	17,400	5,159,000	1	0

Based on these data and team input, the **recommended action at this site is X19.14.R1H2**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the largest best buy meets the planning objectives (i.e., X19.12.R1P). The large increase in cost raised potential affordability concerns relative to the magnitude of ecological benefits.

- Cost-effective plans were investigated at intermediate cost levels (i.e., X19.5.H2H3, X19.11.R1, and X19.14.R1H2). Of these actions, only X19.14.R1H2 included both riparian and riverine outcomes.

- Unit cost for X19.14.R1H2 was very similar to the next largest best buy (i.e., $14,600 / AAHU vs. $14,400 /AAHU). Furthermore, the incremental unit cost increase over the H2-only action was deemed satisfactory, given the large riverine footprint and potential for adding features and benefits during optimization.

- Overall, the recommended alternative has low unit cost and is very affordable.

- Importantly, the site contains multiple MSD basins, which could influence the efficacy of actions and/or conflict with existing basin uses. Plan optimization would need to proceed with basin uses as a key design issue. Notably, these restoration actions plans are generally aligned with other MSD basin management strategies at this location.

X20: Brown Park

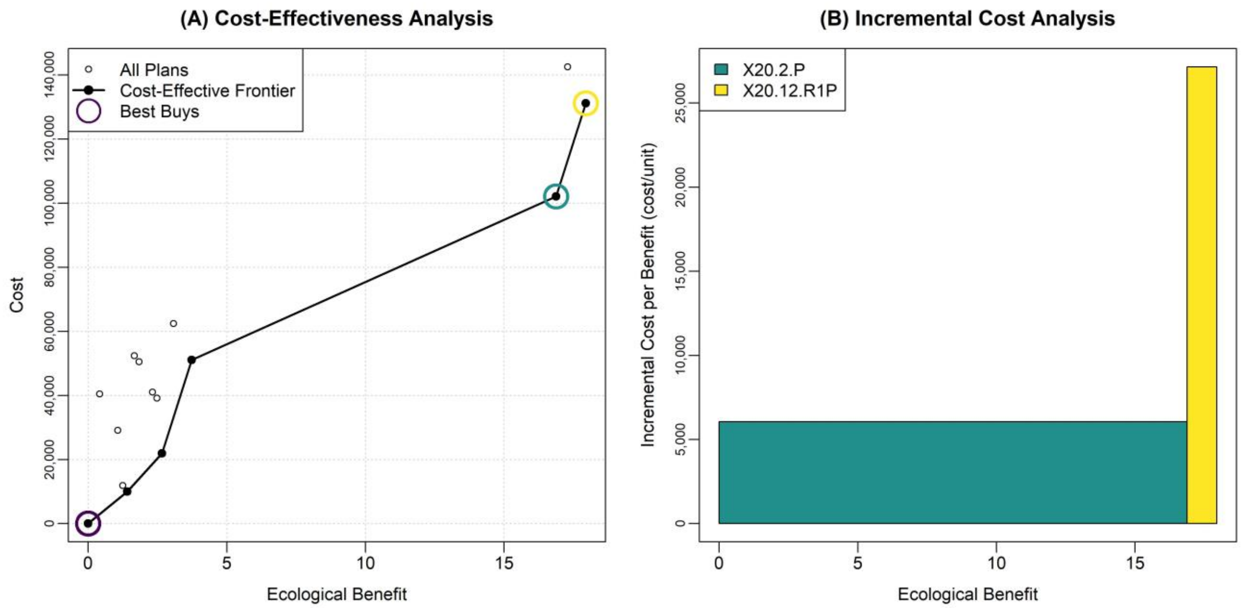
Site X20 is a 30-acre river corridor on the Middle Fork of Beargrass Creek. This site has approximately 0.6-miles of river channel and is in a public park. Five restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- R1: Creates instream habitat through the addition of rock structures, primarily in a small footprint in upstream segments.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- H2: Addition of two small wetland features.
- H3: Construction of a small water control feature.
- P: Extensive planting of hardwood, floodplain, and woodland forests.

X20 Proposed Actions.

These 5 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 15 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 15 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X20 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X20.1.	0	0	NaN	0	0
X20.2.P	16.9	102,100	6,100	6,100	2,882,000
X20.12.R1P	17.9	131,200	7,300	27,200	3,704,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X20.1.	0	0	NaN	0	1	1
X20.2.P	16.9	102,100	6,100	2,882,000	1	1
X20.3.H3	1.3	11,900	9,500	336,000	0	0
X20.4.H2	1.4	10,000	7,100	283,000	1	0
X20.5.H2H3	2.7	22,000	8,200	620,000	1	0
X20.6.R2	0.4	40,400	96,700	1,142,000	0	0
X20.7.R2P	17.3	142,500	8,200	4,024,000	0	0
X20.8.R2H3	1.7	52,400	31,400	1,478,000	0	0
X20.9.R2H2	1.8	50,500	27,600	1,425,000	0	0
X20.10.R2H2H3	3.1	62,400	20,200	1,761,000	0	0
X20.11.R1	1.1	29,100	27,200	822,000	0	0
X20.12.R1P	17.9	131,200	7,300	3,704,000	1	1
X20.13.R1H3	2.3	41,000	17,700	1,158,000	0	0
X20.14.R1H2	2.5	39,100	15,800	1,105,000	0	0
X20.15.R1H2H3	3.7	51,100	13,700	1,442,000	1	0

Based on these data and team input, the **recommended action at this site is X20.7.R2P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the largest best buy meets the planning objectives (i.e., X20.12.R1P). The recommended alternative is, however, a more costly non-cost-effective action (X20.7.R2P).

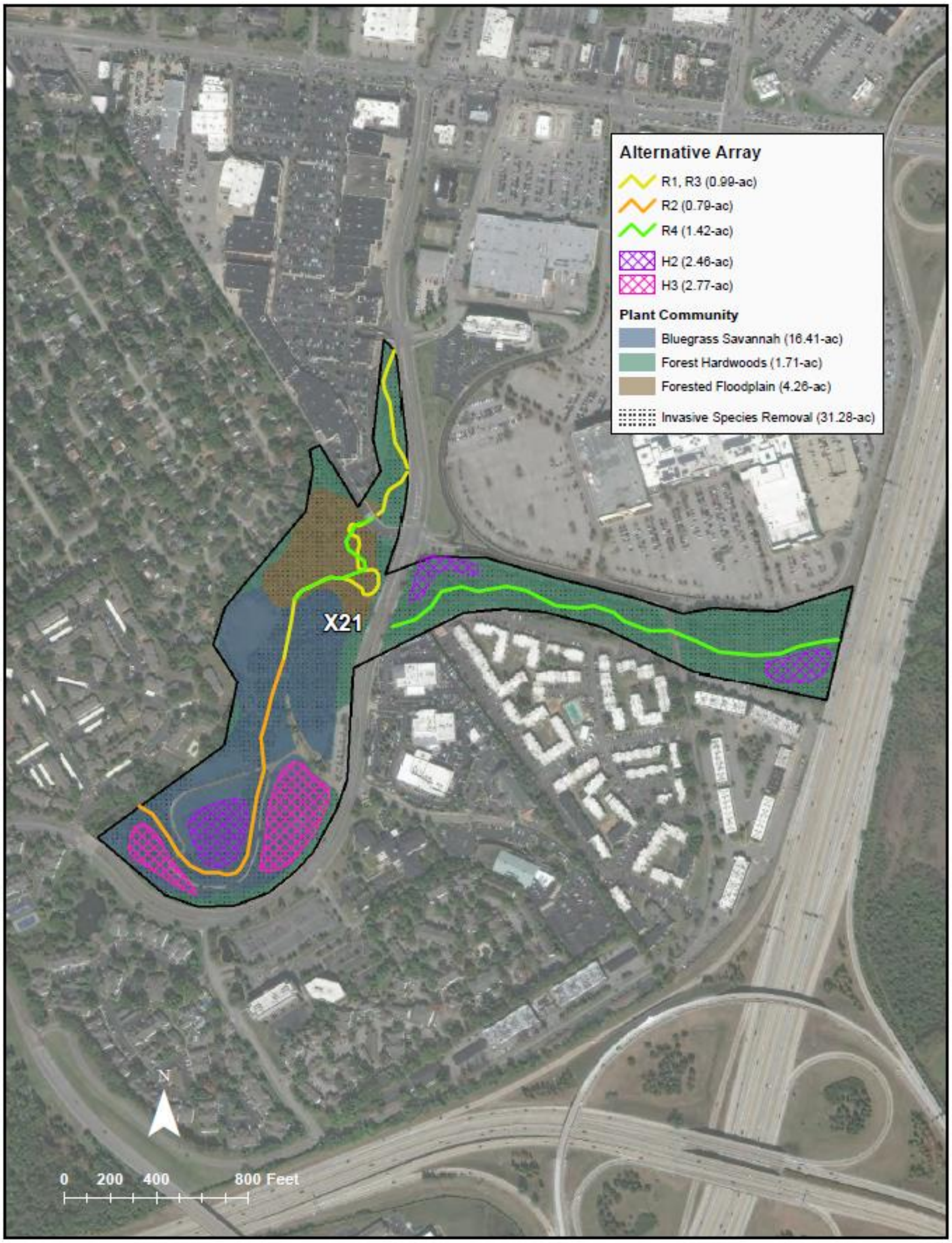
- Prior stream restoration work at the park requires repair and alteration. Additional riparian actions would be an important ecological benefit. However, channel incision is relatively high (bank height / bankfull depth ~ 2), which indicates a need for floodplain reconnection via R2 actions. Thus, there are important qualitative differences for recommending X20.7.R2P over X20.12.R1P. Furthermore, the cost difference between the two alternatives is relatively small ($320,000 or 8% of total project cost) and well-within the contingency for this site. Thus, the qualitative benefits of the R2 actions and small increase in cost are deemed "worth it."
- The site is also part of a network of actions with upstream site-X21, which collectively offer high potential ecological lift. These sites will be combined for future design purposes.

- The park location may require a revised planting scheme based on social uses of the site, and costs could also be reduced through plan optimization accounting for these adjustments.

X21: Arthur Draut Park

Site X21 is a 40-acre river corridor including but not limited to Arthur Draut Park on the Middle Fork of Beargrass Creek. This site has approximately 1.5-miles of river channel, and the neighboring land uses are largely commercial. Seven restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

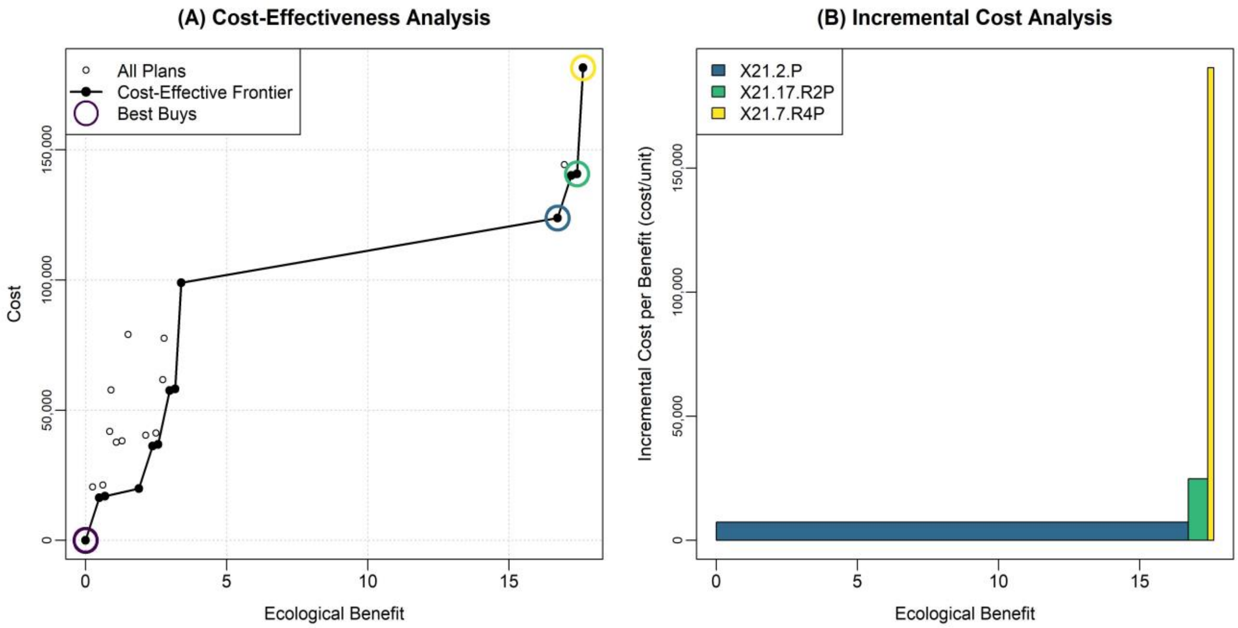
- R1: Creates instream habitat through the addition of rock structures.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves in the downstream segment near X20.
- R3: Initiation of natural geomorphic processes.
- R4: Realigns the channel and significantly improves the overall geomorphic condition in only the eastern portion of the site.
- H2: Addition of three small wetland features.
- H3: Construction of two large water control feature.
- P: Extensive planting of bluegrass savannah as well as hardwood and floodplain forests.



X21 Proposed Actions.

These 7 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 25 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 25 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X21 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X21.1.	0	0	NaN	0	0
X21.2.P	16.7	123,800	7,400	7,400	3,495,000
X21.17.R2P	17.4	140,800	8,100	24,800	3,974,000
X21.7.R4P	17.6	181,600	10,300	190,500	5,126,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X21.1.	0	0	NaN	0	1	1
X21.2.P	16.7	123,800	7,400	3,495,000	1	1
X21.3.H3	1.9	19,900	10,600	562,000	1	0
X21.4.H2	0.6	21,300	35,100	601,000	0	0
X21.5.H2H3	2.5	41,200	16,500	1,163,000	0	0
X21.6.R4	0.9	57,800	64,300	1,631,000	0	0
X21.7.R4P	17.6	181,600	10,300	5,126,000	1	1
X21.8.R4H3	2.8	77,700	27,900	2,193,000	0	0
X21.9.R4H2	1.5	79,100	52,500	2,232,000	0	0
X21.10.R4H2H3	3.4	99,000	29,200	2,794,000	1	0
X21.11.R3	0.2	20,500	84,400	579,000	0	0
X21.12.R3P	17	144,300	8,500	4,074,000	0	0
X21.13.R3H3	2.1	40,400	19,000	1,141,000	0	0
X21.14.R3H2	0.9	41,800	49,200	1,181,000	0	0
X21.15.R3H2H3	2.7	61,700	22,600	1,743,000	0	0
X21.16.R2	0.7	17,000	24,800	479,000	1	0
X21.17.R2P	17.4	140,800	8,100	3,974,000	1	1
X21.18.R2H3	2.6	36,900	14,400	1,041,000	1	0
X21.19.R2H2	1.3	38,300	29,600	1,080,000	0	0
X21.20.R2H2H3	3.2	58,200	18,300	1,642,000	1	0
X21.21.R1	0.5	16,400	34,000	463,000	1	0
X21.22.R1P	17.2	140,200	8,100	3,957,000	1	0
X21.23.R1H3	2.4	36,300	15,300	1,025,000	1	0
X21.24.R1H2	1.1	37,700	34,600	1,064,000	0	0
X21.25.R1H2H3	3	57,600	19,400	1,626,000	1	0

Based on these data and team input, the **recommended action at this site is X21.17.R2P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, X21.17.R2P is the lowest cost best buy plan meeting the planning objectives.

- This alternative (X21.17.R2P) occurs at a significant threshold in incremental unit cost. The larger best buy (X21.7.R4P) is not deemed "worth it" given the large increase in incremental unit cost.

- The R2 actions offer important qualitative benefits associated with floodplain reconnection, and plan optimization should consider expanding R2 options along the eastern portion of the site. Potential challenges may also emerge in design related to large urban developments and flashy runoff, which could encourage consideration of small-scale hydrologic actions.

- The site is part of a network of actions at site X20, which collectively offer high potential ecological lift. However, an isolated action at this site may not provide a level of lift to warrant USACE mobilization.

X22: Concrete Channel

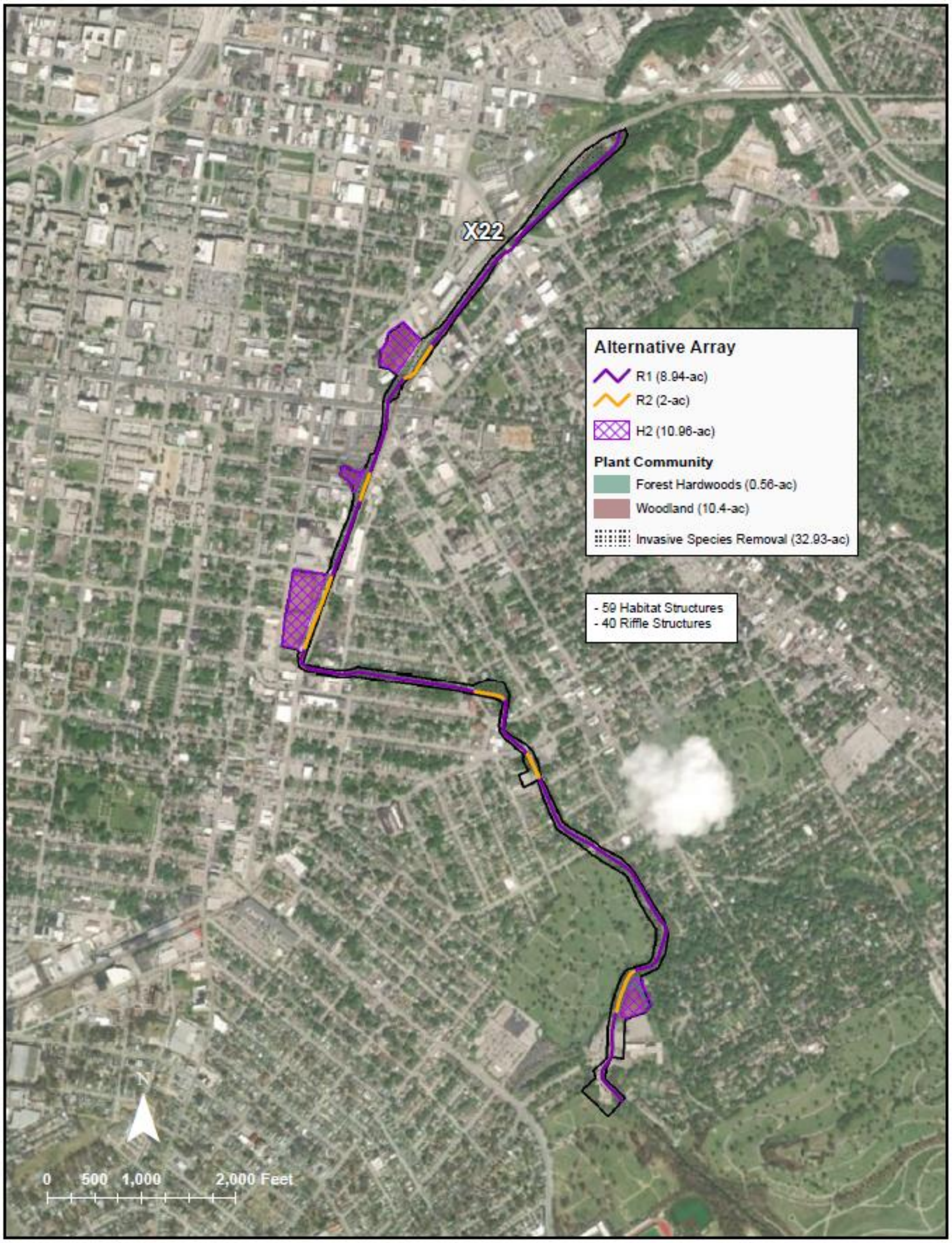
Site X22 is a 47-acre concrete-lined segment of river corridor near downtown on the South Fork of Beargrass Creek. This site has approximately 2.7-mile of river channel, and the site is highly constrained. Four restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- R1: Creates instream habitat through the addition of rock structures throughout the reach.

- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves at selection segments of river.

- H2: Addition of three wetland features.

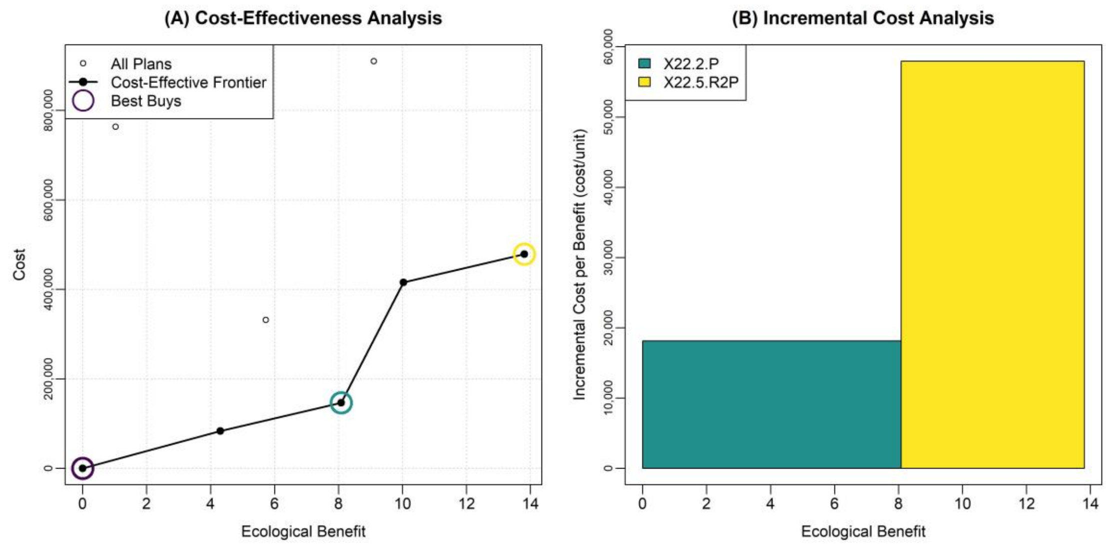
- P: Small scale plantings and invasive species management.



X22 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 9 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 9 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X22 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X22.1.	0	0	NaN	0	0
X22.2.P	8.1	146,700	18,200	18,200	4,141,000
X22.5.R2P	13.8	478,600	34,700	58,000	13,513,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X22.1.	0	0	NaN	0	1	1
X22.2.P	8.1	146,700	18,200	4,141,000	1	1
X22.3.H2	4.3	83,600	19,400	2,361,000	1	0
X22.4.R2	5.7	332,000	58,000	9,372,000	0	0
X22.5.R2P	13.8	478,600	34,700	13,513,000	1	1
X22.6.R2H2	10	415,600	41,400	11,733,000	1	0
X22.7.R1	1	763,300	745,400	21,551,000	0	0
X22.8.R1P	9.1	910,000	1e+05	25,692,000	0	0
X22.9.R1H2	5.3	847,000	158,900	23,912,000	0	0

Based on these data and team input, the **recommended action at this site is X22.3.H2**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the largest best buy meets the planning objectives (i.e., X22.5.R2P). However, the confined and constrained nature of the site presents logistical concerns about feasibility. The next lowest cost best buy (X22.2.P) presents similar concerns given its large footprint and only provides riparian benefits.

- The recommended alternative (X22.3.H2) is the lowest cost, cost-effective plan, and it has a similar (incremental) unit cost to the lowest cost best buy.

- The site has very high social benefits related to visibility and proximity to downtown and the dense neighborhood areas with scarce greenspace. The reach has been the focus of prior urban restoration studies from the Congress on New Urbanism, which highlighted redevelopment of a river corridor. As such, the site has high utility as a "proof-of-concept" action at a highly altered site.

- Presently, the site is very constrained including MSD use for access and challenges associated with hydrologic functions of the existing flood control challenge, all of which would need to be investigated in optimization. There are also potential cultural resource issues associated with channel infrastructure and neighborhood actions, and associated cultural mitigation costs may increase.

- The clear ecological benefit of improving a concrete channel may be under-quantified by both QHEILS and SMURF. The connectivity benefits of providing islands / pockets of habitat would be high, even in a confined urban area. Likewise, the forecasting rubric may under-account for the dramatic change from a concrete channel bottom to natural substrate.

- Presently, there are no known repetitive loss flood structures, but plans could incorporate select, localized flooding challenges and/or vacancy issues.

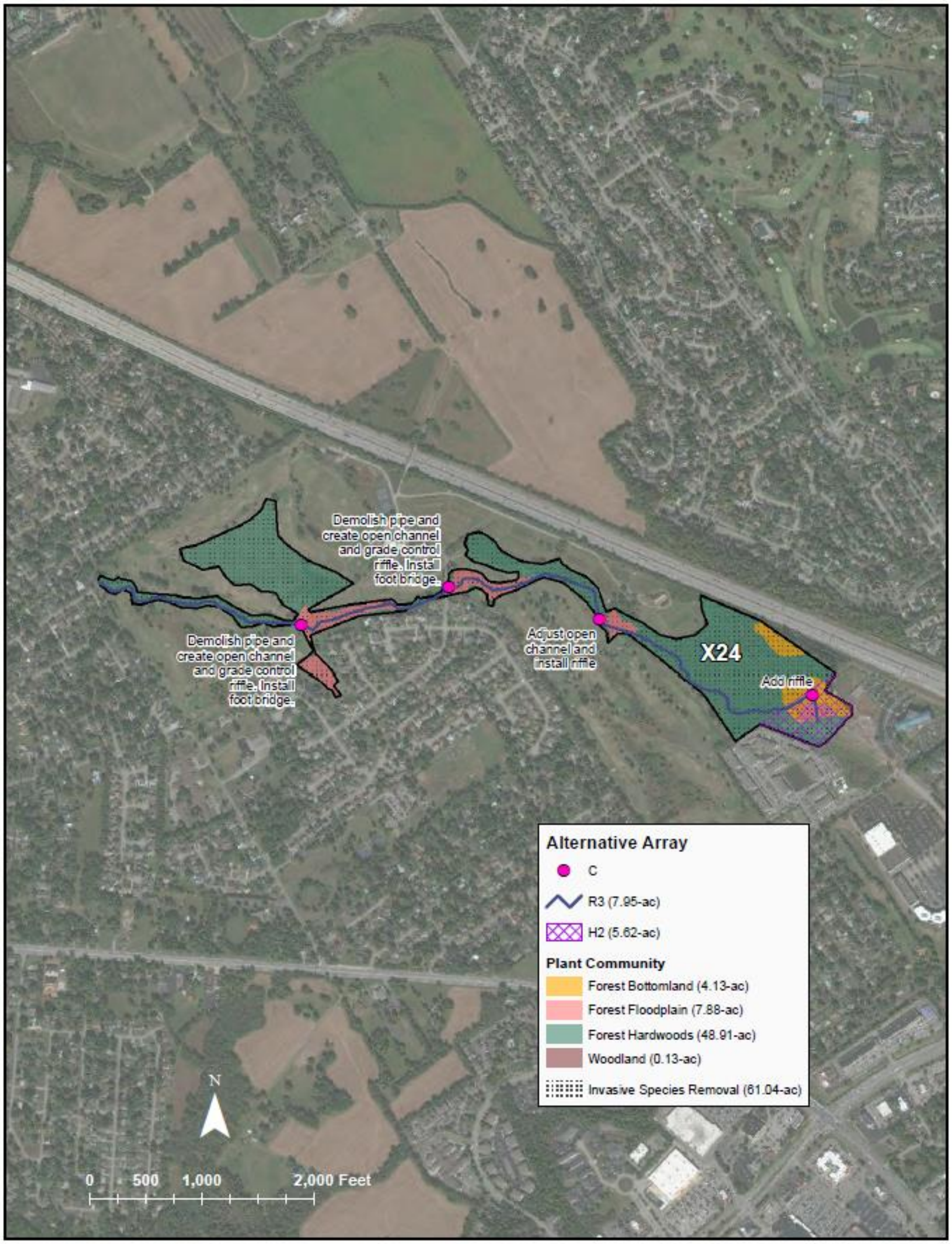
- In general, this site has high potential for complementary actions by other partners as well as strong intangible benefits associated with its visibility.

X24: Oxmoor Country Club

Site X24 is a 61-acre river corridor on a golf course on the Middle Fork of Beargrass Creek. This site has approximately 1.4-miles of river channel, and significant potential for riparian improvement. Four restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

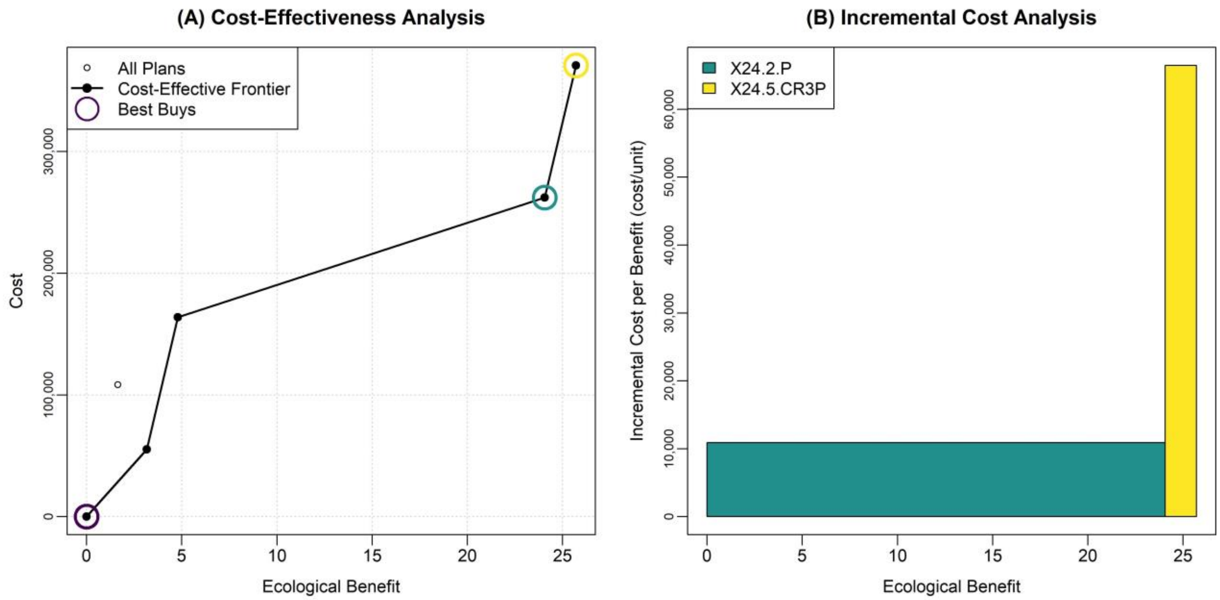
- C: Restoration of four connectivity barriers in the reach.

- R3: Initiation of natural geomorphic processes throughout the site.
- H2: Addition of one small wetland features.
- P: Extensive planting of hardwood, floodplain, and woodland forests.



X24 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 6 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for the 3 best buy alternatives as well as the results for all 6 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X24 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X24.1.	0	0	NaN	0	0
X24.2.P	24.1	262,200	10,900	10,900	7,404,000
X24.5.CR3P	25.7	370,700	14,400	66,500	10,466,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X24.1.	0	0	NaN	0	1	1
X24.2.P	24.1	262,200	10,900	7,404,000	1	1
X24.3.H2	3.2	55,300	17,500	1,561,000	1	0
X24.4.CR3	1.6	108,500	66,500	3,062,000	0	0
X24.5.CR3P	25.7	370,700	14,400	10,466,000	1	1
X24.6.CR3H2	4.8	163,800	34,200	4,623,000	1	0

Based on these data and team input, the **recommended action at this site is X24.1 (no action)**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Only the largest best buy meets the planning objectives, and this action (X24.5.CR3P) presents significant incremental unit cost concerns.
- The site is in the upper reaches of the watershed and disconnected from other sites.
- The private golf course presents a high potential for real estate issues.
- The site presents a good opportunity for MSD outreach to land owner for small scale planting efforts along the creek.

X28: Hurstbourne Country Club

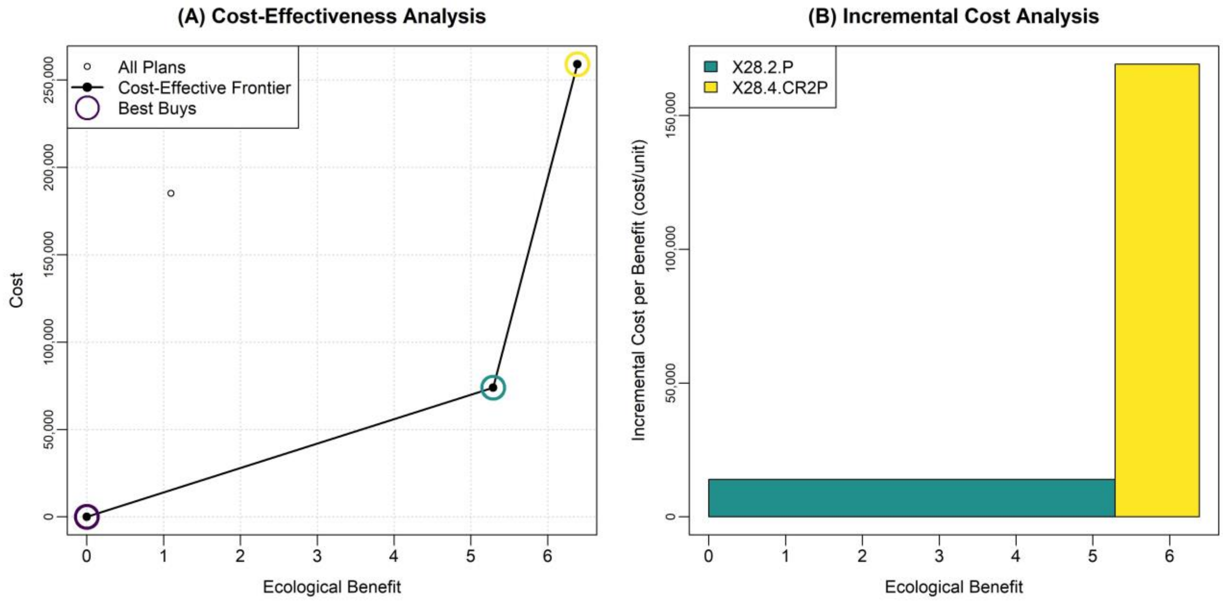
Site X28 is a 15-acre river corridor through a golf course on the Middle Fork of Beargrass Creek. This site has approximately 1.2-miles of river channel. Three restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- C: Restoration of three connectivity barriers in the reach.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- P: Extensive planting of canebreak and woodland forests.

X28 Proposed Actions.

These 3 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 4 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 4 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X28 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X28.1.	0	0	NaN	0	0
X28.2.P	5.3	74,000	14,000	14,000	2,089,000
X28.4.CR2P	6.4	259,100	40,600	169,200	7,315,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X28.1.	0	0	NaN	0	1	1
X28.2.P	5.3	74,000	14,000	2,089,000	1	1
X28.3.CR2	1.1	185,100	169,200	5,226,000	0	0
X28.4.CR2P	6.4	259,100	40,600	7,315,000	1	1

Based on these data and team input, the **recommended action at this site is X28.1 (no action)**. The decision logic for this alternative is as follows:

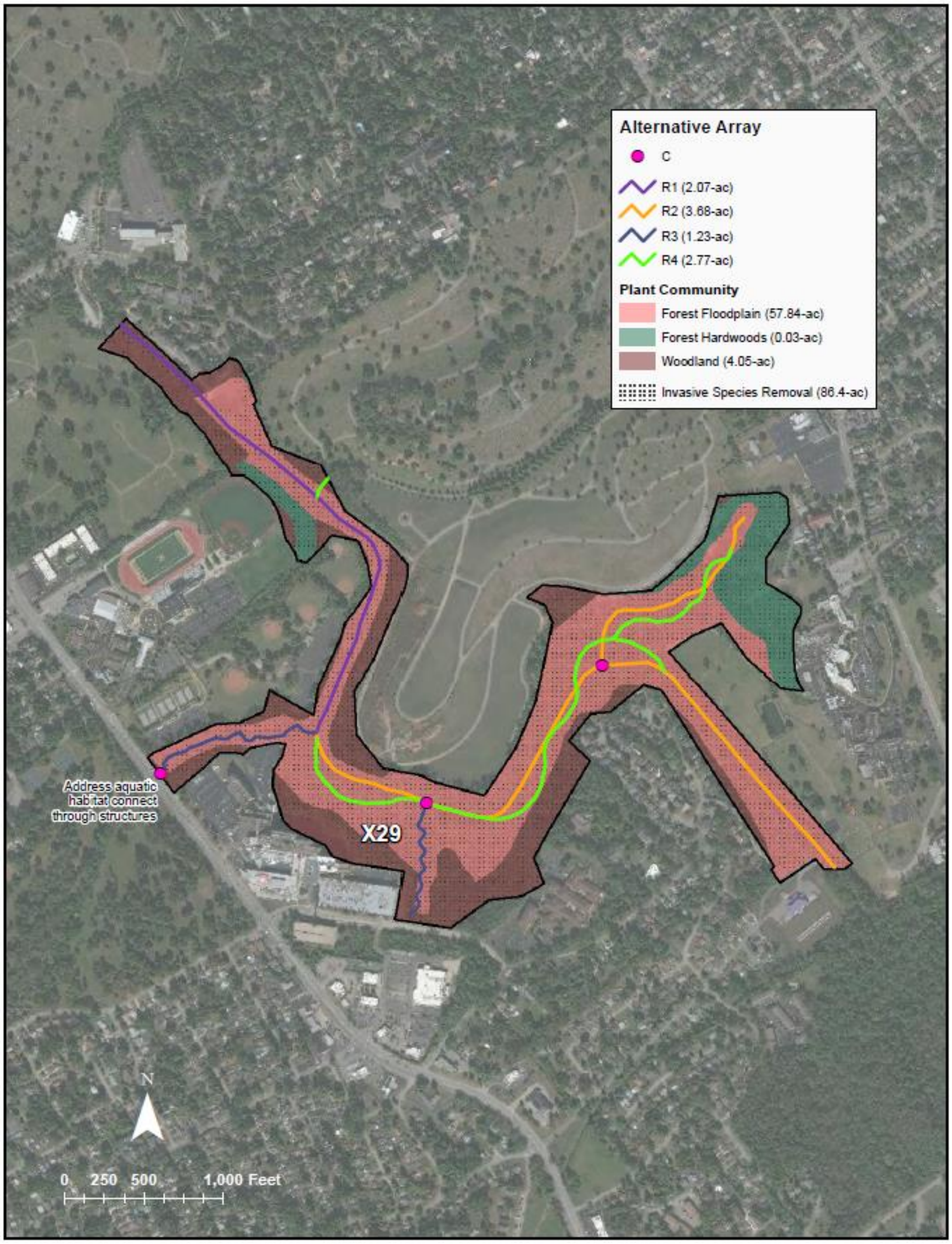
- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Only the largest best buy meets the planning objectives, and this action (X28.4.CR2P) presents significant incremental unit cost concerns.

- The site is small with relatively small ecological lift.
- The remote tributary site is not well connected to other potential actions.
- The site represents a good opportunity for MSD outreach to land owner for small scale planting efforts along the creek.

X29: Eastern / Creason Connector

Site X29 is a 97-acre river corridor near Bellarmine University and Calvary Cemetery on the South Fork of Beargrass Creek. This site has approximately 1.7-miles of river channel. Six potential restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

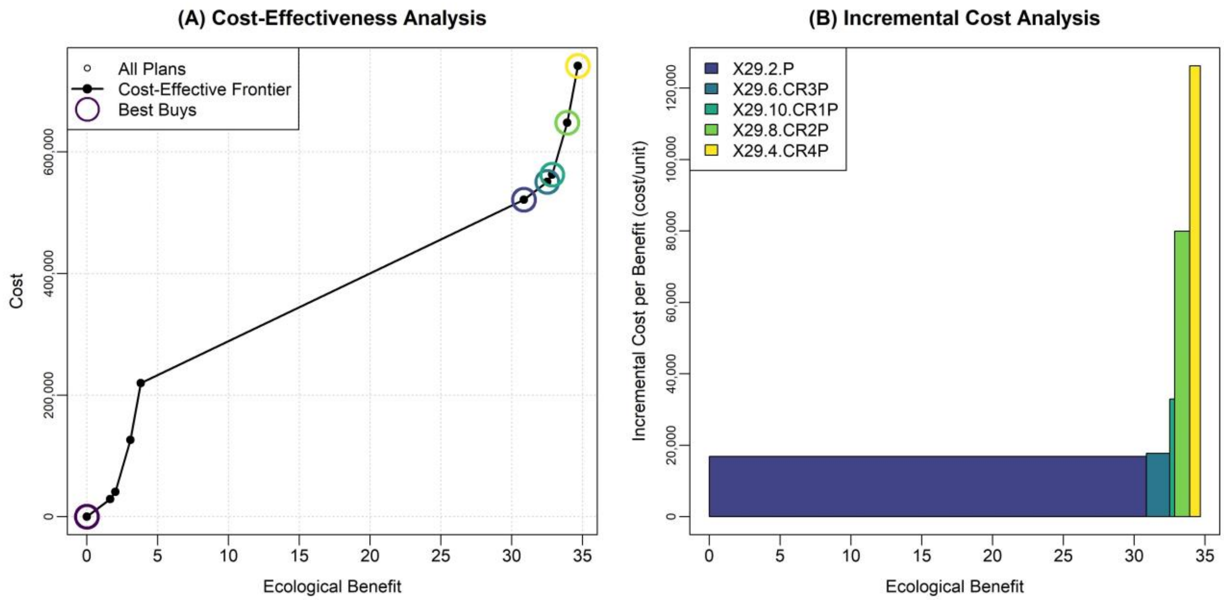
- C: Removes or repairs three connectivity barriers in the reach.
- R1: Creates instream habitat through the addition of rock structures, primarily in downstream segments.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- R3: Initiation of natural geomorphic processes, primarily in tributaries.
- R4: Realigns the channel and significantly improves the overall geomorphic condition.
- P: Extensive planting of hardwood, floodplain, and woodland forests.



X29 Proposed Actions.

These 6 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 10 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 6 best buy alternatives as well as the results for all 10 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X29 CEICA summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X29.1.	0	0	NaN	0	0
X29.2.P	30.8	521,400	16,900	16,900	14,721,000
X29.6.CR3P	32.5	550,700	16,900	17,800	15,547,000
X29.10.CR1P	32.8	562,400	17,100	32,900	15,877,000
X29.8.CR2P	33.9	647,700	19,100	80,000	18,287,000
X29.4.CR4P	34.7	741,300	21,400	126,300	20,927,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X29.1.	0	0	NaN	0	1	1
X29.2.P	30.8	521,400	16,900	14,721,000	1	1
X29.3.CR4	3.8	219,800	57,700	6,206,000	1	0
X29.4.CR4P	34.7	741,300	21,400	20,927,000	1	1
X29.5.CR3	1.6	29,300	17,800	826,000	1	0
X29.6.CR3P	32.5	550,700	16,900	15,547,000	1	1
X29.7.CR2	3.1	126,300	41,100	3,566,000	1	0
X29.8.CR2P	33.9	647,700	19,100	18,287,000	1	1
X29.9.CR1	2	40,900	20,400	1,156,000	1	0
X29.10.CR1P	32.8	562,400	17,100	15,877,000	1	1

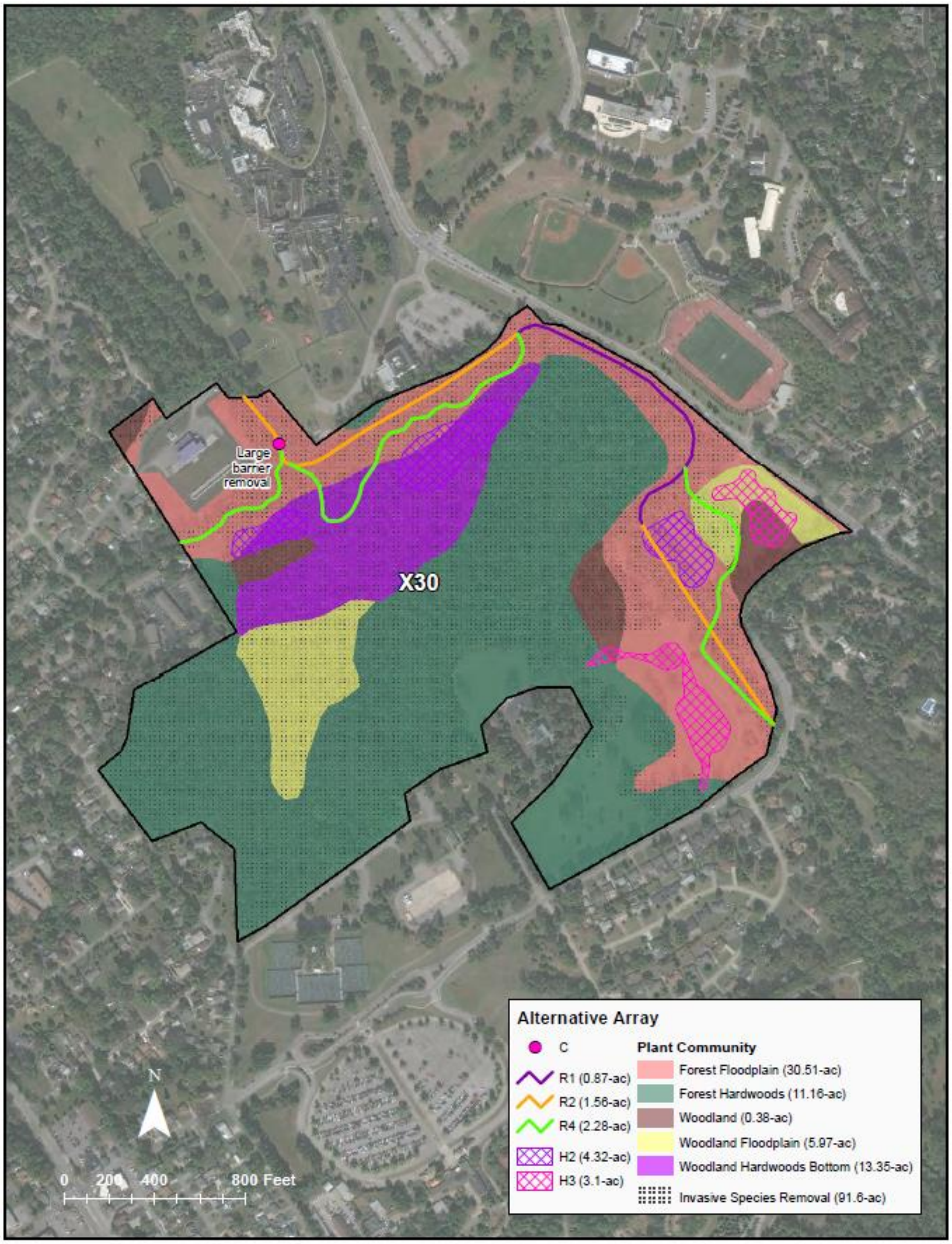
Based on these data and team input, the **recommended action at this site is X29.4.CR4P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the four largest best buys meet the planning objectives (i.e., X29.6.CR3P, X29.10.CR1P, X29.8.CR2P, X29.4.CR4P).
- The lowest cost best buy (X29.6.CR3P) only addresses tributary degradation in this highly degraded reach.
- This site has strong stakeholder interest with existing conservation easements, willing land owners, and important connection to complementary recreational plans.
- Historical channelization provides a great opportunity for addressing ecological degradation as well as education about the potential for stream restoration.
- The site is an important ecological corridor in close proximity to Joe Creason Park (X30) and the Alpaca Farm and Louisville Zoo sites (X10).
- There are potential real estate challenges in terms of the number of parcels and real estate costs, which could lead to reduced planting extent.
- Plan optimization should consider expanding the extent of R4-actions to include the downstream segment and R2 actions upstream.
- The bordering cemetery does not include active grave sites near the proposed actions, but a construction buffer of 100-feet is required.

X30: Joe Creason Park

Site X30 is a 121-acre river corridor in a large municipally owned park system on the South Fork of Beargrass Creek. This site has approximately 0.9-miles of river channel, and the site is bracketed by high use public areas. Seven restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

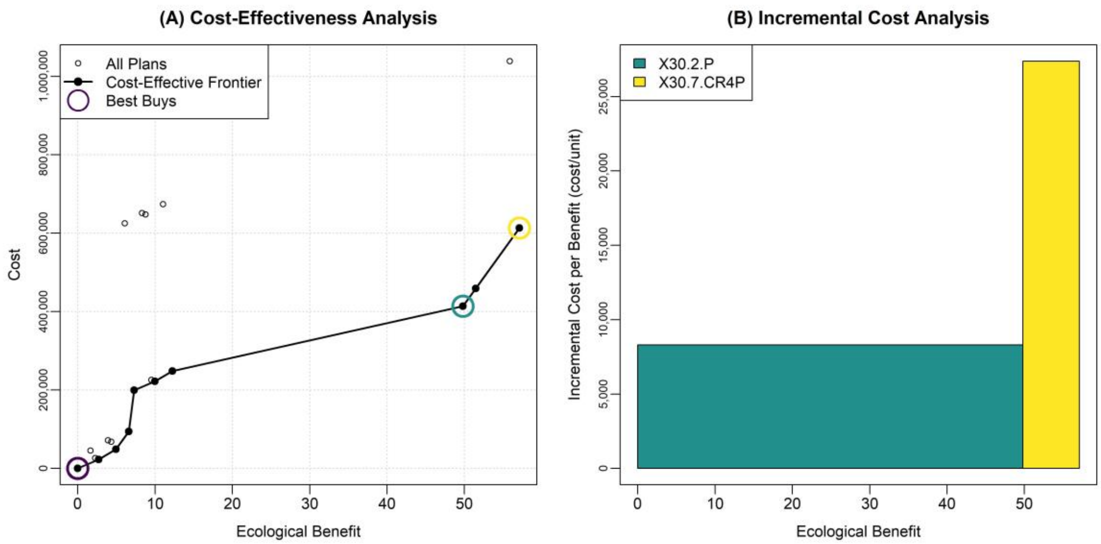
- C: One large barrier removal in the reach.
- R1: Creates instream habitat through the addition of rock structures, restricted to a small footprint.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- R4: Realigns the channel and significantly improves the overall geomorphic condition.
- H2: Addition of three wetland features.
- H3: Construction of two small water control features.
- P: Extensive planting of hardwood, floodplain, and woodland forests.



X30 Proposed Actions.

These 7 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 20 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 20 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X30 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X30.1.	0	0	NaN	0	0
X30.2.P	49.8	413,600	8,300	8,300	11,676,000
X30.7.CR4P	57.1	613,200	10,700	27,400	17,312,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X30.1.	0	0	NaN	0	1	1
X30.2.P	49.8	413,600	8,300	11,676,000	1	1
X30.3.H3	2.7	22,700	8,400	641,000	1	0
X30.4.H2	2.2	26,200	11,700	741,000	0	0
X30.5.H2H3	4.9	48,900	9,900	1,382,000	1	0
X30.6.CR4	7.3	199,600	27,400	5,636,000	1	0
X30.7.CR4P	57.1	613,200	10,700	17,312,000	1	1
X30.8.CR4H3	10	222,300	22,300	6,276,000	1	0
X30.9.CR4H2	9.5	225,800	23,700	6,376,000	0	0
X30.10.CR4H2H3	12.2	248,500	20,300	7,017,000	1	0
X30.11.CR2	6.1	625,100	102,800	17,648,000	0	0
X30.12.CR2P	55.9	1,038,700	18,600	29,324,000	0	0
X30.13.CR2H3	8.8	647,800	73,800	18,289,000	0	0
X30.14.CR2H2	8.3	651,300	78,300	18,389,000	0	0
X30.15.CR2H2H3	11	674,000	61,200	19,030,000	0	0
X30.16.CR1	1.7	45,400	27,500	1,282,000	0	0
X30.17.CR1P	51.5	459,000	8,900	12,958,000	1	0
X30.18.CR1H3	4.3	68,100	15,700	1,923,000	0	0
X30.19.CR1H2	3.9	71,600	18,400	2,023,000	0	0
X30.20.CR1H2H3	6.6	94,300	14,300	2,664,000	1	0

Based on these data and team input, the **recommended action at this site is X30.7.CR4P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the largest best buy meets the planning objectives (i.e., X30.7.CR4P). The overall unit cost is also quite low ($10,700/AAHU).

- The R4 actions offer important qualitative benefits associated with floodplain reconnection.

- The site is highly connected upstream to X10 and downstream to X29.

- This is a high visibility site on public lands (Metro Parks Headquarters and State Preserve), which provides important educational opportunities regarding local ecosystems and USACE's role in restoration.

- The site has significant archeological findings, which could lead to potential cultural mitigation. Owing to this factor, there are potential reductions in the project footprint during optimization. However, the site is large and will still provide substantial benefits and serve as an important corridor between sites.

X31: Champions Trace

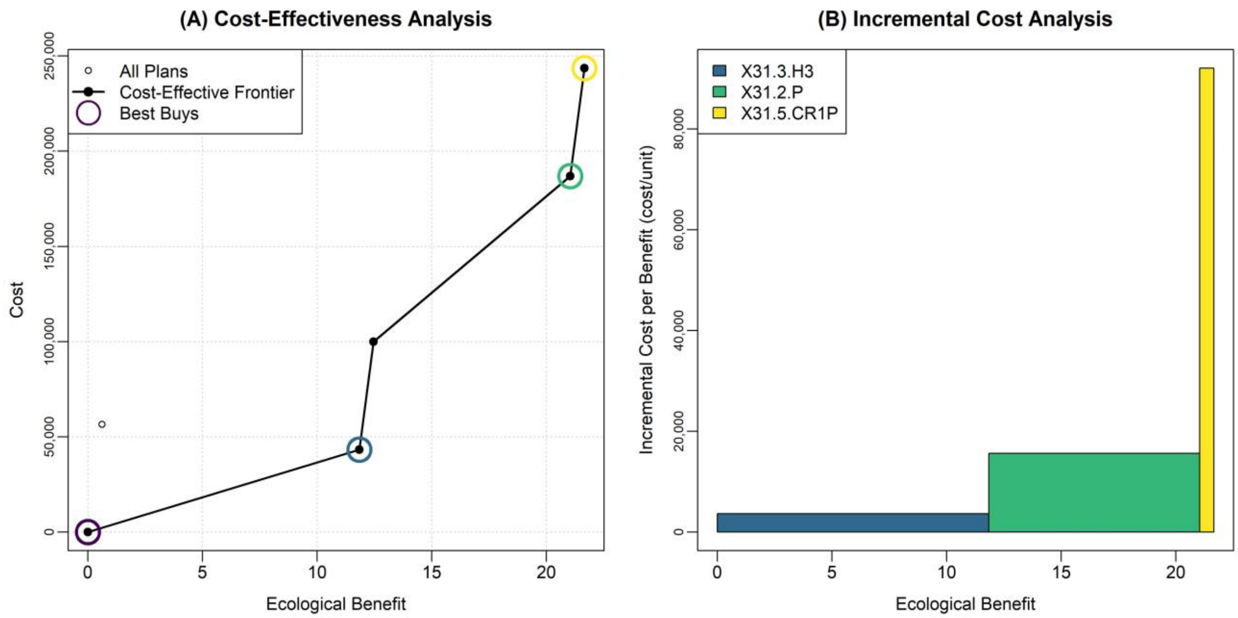
Site X31 is a 48-acre river corridor on the South Fork of Beargrass Creek. This site has approximately 1.0-mile of river channel and is extensively used for local recreation. Four restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- C: Repair one connectivity barrier in the reach.
- R1: Creates instream habitat through the addition of rock structures.
- H3: Construction of one large water control feature.
- P: Planting of woodland forests.

X31 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 6 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 6 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X31 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X31.1.	0	0	NaN	0	0
X31.3.H3	11.8	43,300	3,700	3,700	1,222,000
X31.2.P	21	186,900	8,900	15,600	5,277,000
X31.5.CR1P	21.7	243,600	11,200	92,100	6,877,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X31.1.	0	0	NaN	0	1	1
X31.2.P	21	186,900	8,900	5,277,000	1	1
X31.3.H3	11.8	43,300	3,700	1,222,000	1	1
X31.4.CR1	0.6	56,600	92,100	1,599,000	0	0
X31.5.CR1P	21.7	243,600	11,200	6,877,000	1	1
X31.6.CR1H3	12.5	99,900	8,000	2,821,000	1	0

Based on these data and team input, the **recommended action at this site is X31.1 (no action)**. The decision logic for this alternative is as follows:

- The site is within an existing stormwater basin, which compromises the degree of flexibility and refinement possible.
- There are potential conflicting uses of the project footprints, which are currently used for recreation by neighboring communities.

- There is good potential for small-scale actions by other partners (e.g., planting along drainage routes) which could preserve existing uses.

X33: MSD Basin

Site X33 is a 12-acre river corridor within an existing MSD basin on the South Fork of Beargrass Creek. This site has approximately 0.3-miles of river channel, and a recreational path runs adjacent to the stream. Four potential restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.

- H2: Addition of one large wetland features in the existing basin.

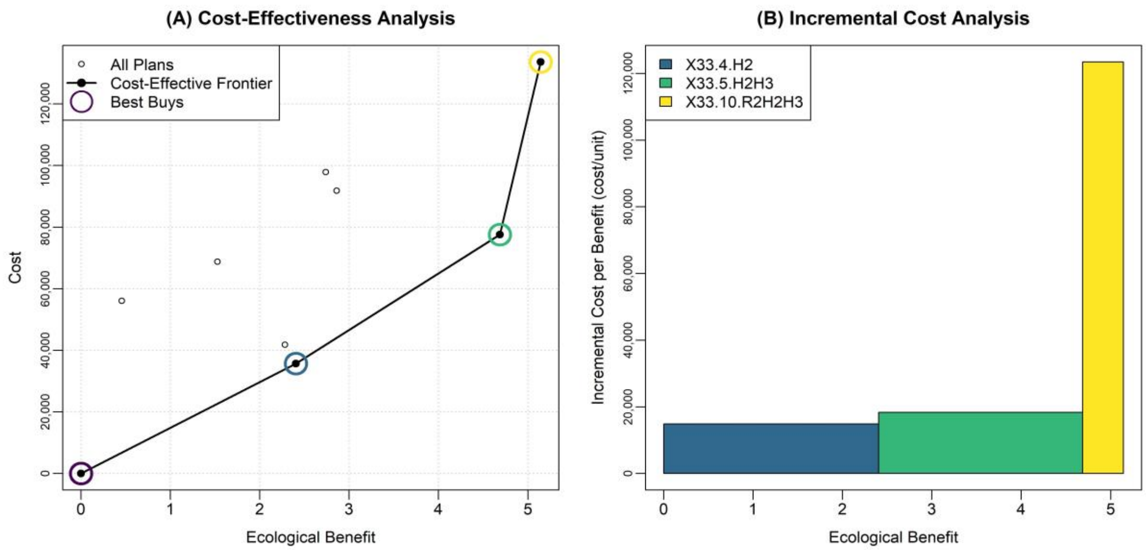
- H3: Modification of the existing basins as a water control feature.

- P: Local planting of hardwood and floodplain forests.

X33 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 10 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 10 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X33 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X33.1.	0	0	NaN	0	0
X33.4.H2	2.4	35,700	14,900	14,900	1,009,000
X33.5.H2H3	4.7	77,600	16,500	18,300	2,190,000
X33.10.R2H2H3	5.1	133,700	26,000	123,500	3,773,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X33.1.	0	0	NaN	0	1	1
X33.2.P	1.5	68,800	45,000	1,942,000	0	0
X33.3.H3	2.3	41,800	18,300	1,181,000	0	0
X33.4.H2	2.4	35,700	14,900	1,009,000	1	1
X33.5.H2H3	4.7	77,600	16,500	2,190,000	1	1
X33.6.R2	0.5	56,100	123,500	1,584,000	0	0
X33.7.R2P	2	124,900	63,000	3,525,000	0	0
X33.8.R2H3	2.7	97,900	35,800	2,764,000	0	0
X33.9.R2H2	2.9	91,800	32,100	2,593,000	0	0
X33.10.R2H2H3	5.1	133,700	26,000	3,773,000	1	1

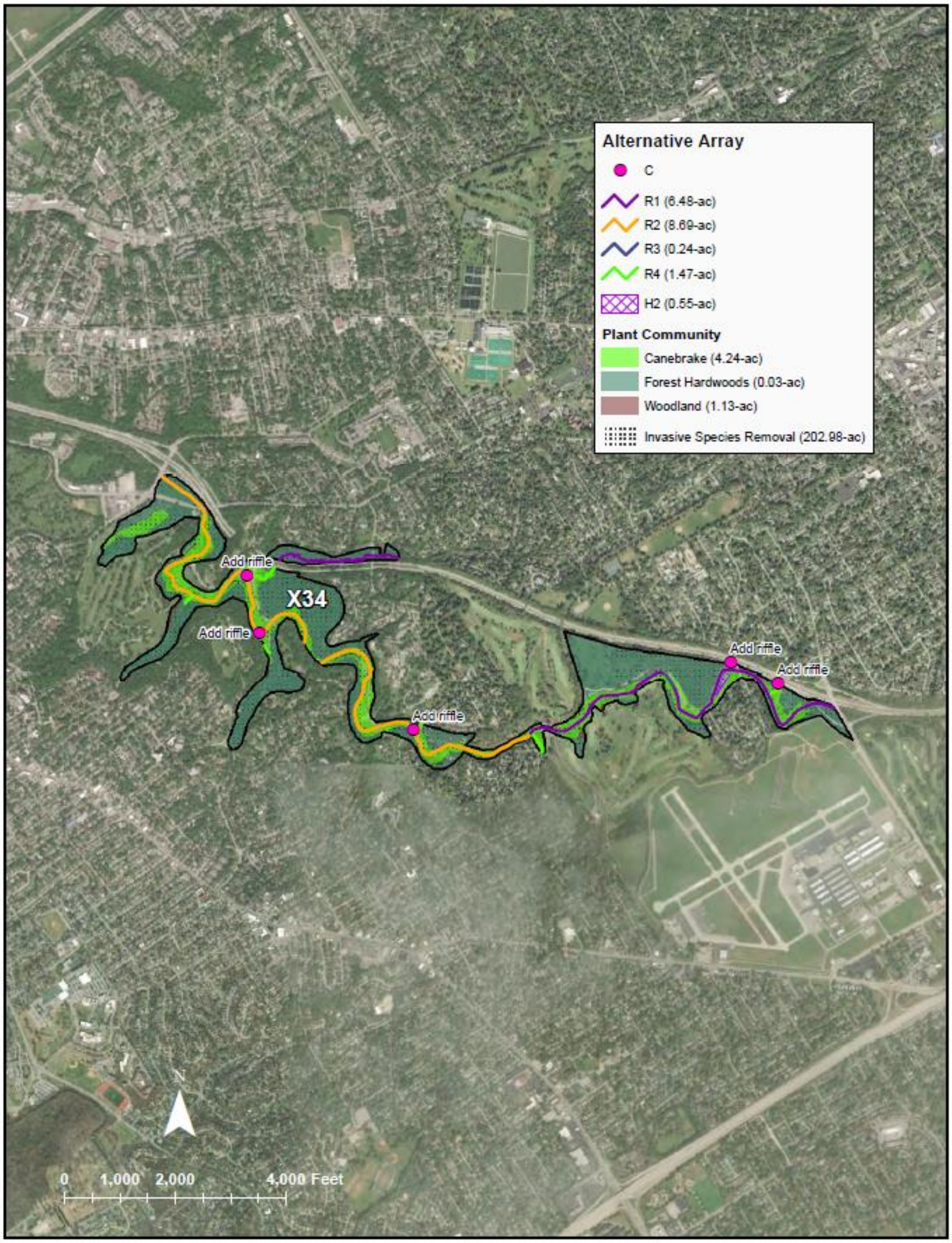
Based on these data and team input, the **recommended action at this site is X33.4.H2**. The decision logic for this alternative is as follows:

- This alternative is the lowest cost, best buy plan.
- Although it does not provide riverine benefits, the total amount of riverine habitat at this site is small.
- The site has a small project footprint, but there are potential synergies with ongoing MSD activities at the site.
- The site is somewhat disconnected from other potential USACE actions, but provide important hydrologic benefits to downstream locations on the South Fork.

X34: Cherokee and Seneca

Site X34 is a 267-acre river corridor through Cherokee and Seneca Parks on the Middle Fork of Beargrass Creek. This site has approximately 5.4-miles of river channel, and a recreational and historical values are exceptionally high. Seven restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

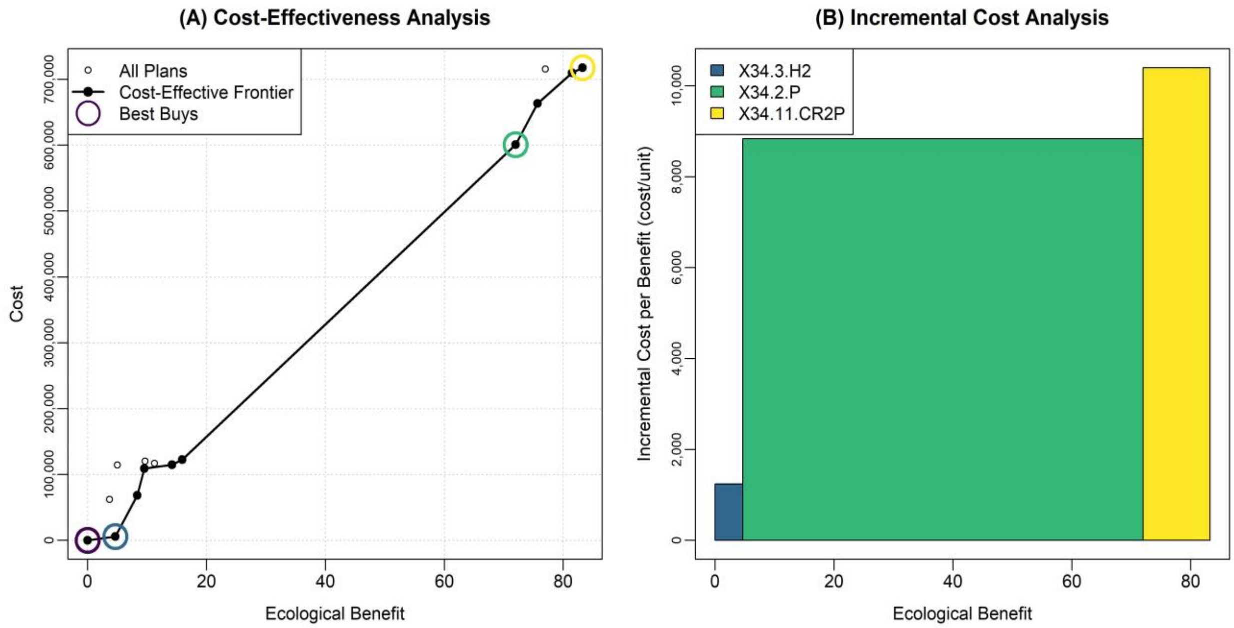
- C: Repair of four connectivity barriers.
- R1: Creates instream habitat through the addition of rock structures, primarily in the upstream reaches.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- R3: Initiation of natural geomorphic processes, primarily in small-scale areas.
- R4: Realigns the channel and significantly improves the overall geomorphic condition, in small areas largely confined to tributaries.
- H2: Addition of one small wetland features.
- P: Extensive planting of canebreak as well as hardwood and woodland forests.



X34 Proposed Actions.

These 7 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 15 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 4 best buy alternatives as well as the results for all 15 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X34 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X34.1.	0	0	NaN	0	0
X34.3.H2	4.7	5,800	1,200	1,200	163,000
X34.2.P	72	600,800	8,300	8,800	16,961,000
X34.11.CR2P	83.2	717,700	8,600	10,400	20,262,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X34.1.	0	0	NaN	0	1	1
X34.2.P	72	600,800	8,300	16,961,000	1	1
X34.3.H2	4.7	5,800	1,200	163,000	1	1
X34.4.CR4	9.5	109,200	11,500	3,084,000	1	0
X34.5.CR4P	81.5	710,000	8,700	20,045,000	1	0
X34.6.CR4H2	14.2	115,000	8,100	3,247,000	1	0
X34.7.CR3	3.7	62,500	16,900	1,764,000	0	0
X34.8.CR3P	75.7	663,200	8,800	18,724,000	1	0
X34.9.CR3H2	8.3	68,200	8,200	1,927,000	1	0
X34.10.CR2	11.2	116,900	10,400	3,301,000	0	0
X34.11.CR2P	83.2	717,700	8,600	20,262,000	1	1
X34.12.CR2H2	15.9	122,700	7,700	3,464,000	1	0
X34.13.CR1	5	114,600	23,000	3,236,000	0	0
X34.14.CR1P	77	715,400	9,300	20,197,000	0	0
X34.15.CR1H2	9.6	120,400	12,500	3,399,000	0	0

Based on these data and team input, the **recommended action at this site is X34.11.CR2P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the largest best buy meets the planning objectives (i.e., X34.11.CR2P). Riparian and riverine actions are recognized problems and sources of degradation (e.g., erosion "hot spots") at the site.

- The overall unit cost is very low ($8,600/AAHU) for an extremely large amount of restoration (83.2 AAHUs).

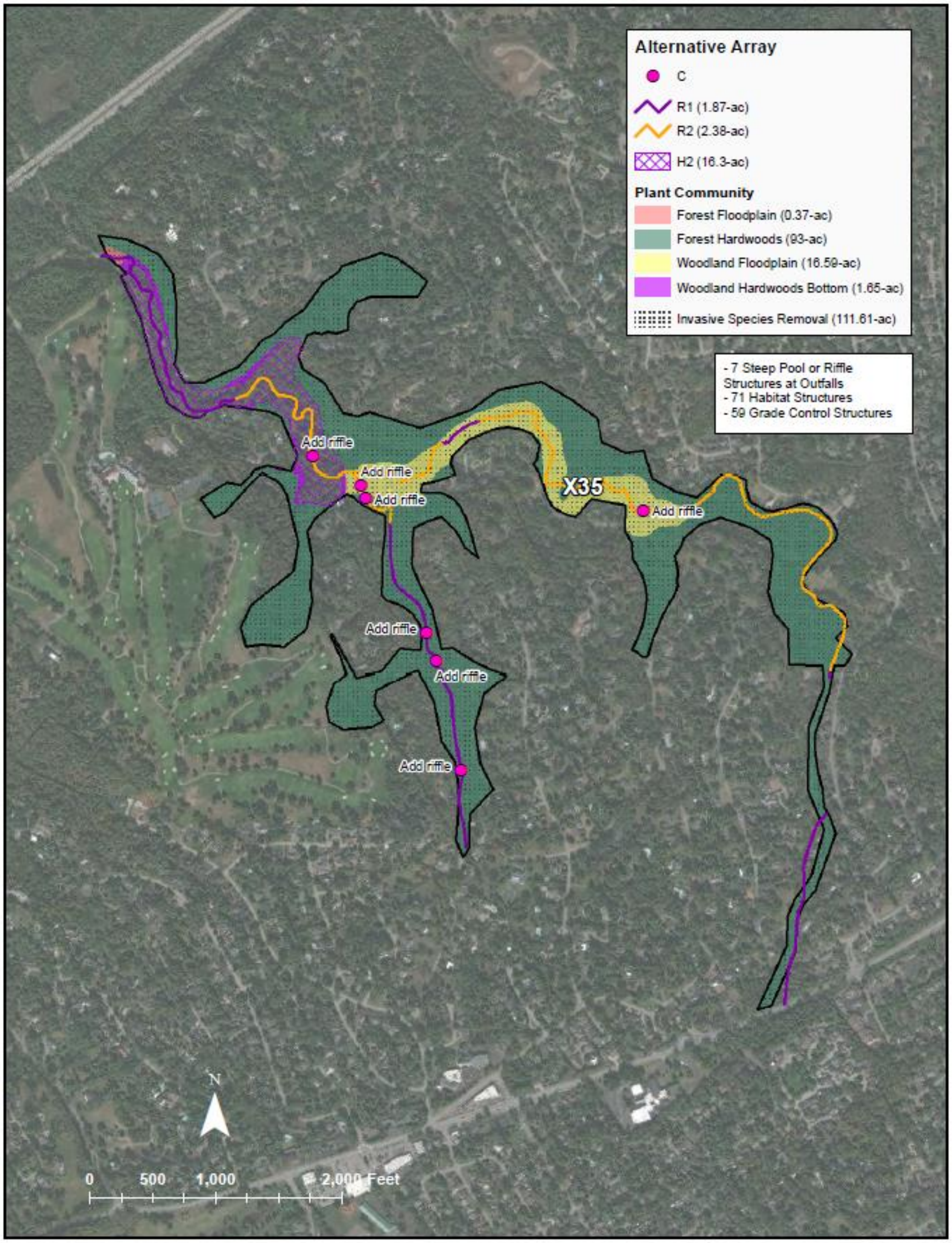
- The large R2 footprint provides opportunities for expanding riverine actions to include minor tributary work (potentially with small-scale R4 features).

- This is an extremely large site with very high visibility as a historic park with significant recreational uses (e.g., park visitors, golfing, river wading, mountain biking, etc.). However, challenges may arise due to the park's status on the National Register of Historic Places.

X35: Muddy Fork and Tribs

Site X35 is a 128-acre river corridor in a largely residential neighborhood on the Muddy Fork of Beargrass Creek. This site has approximately 3.2-miles of river channel. Five potential restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

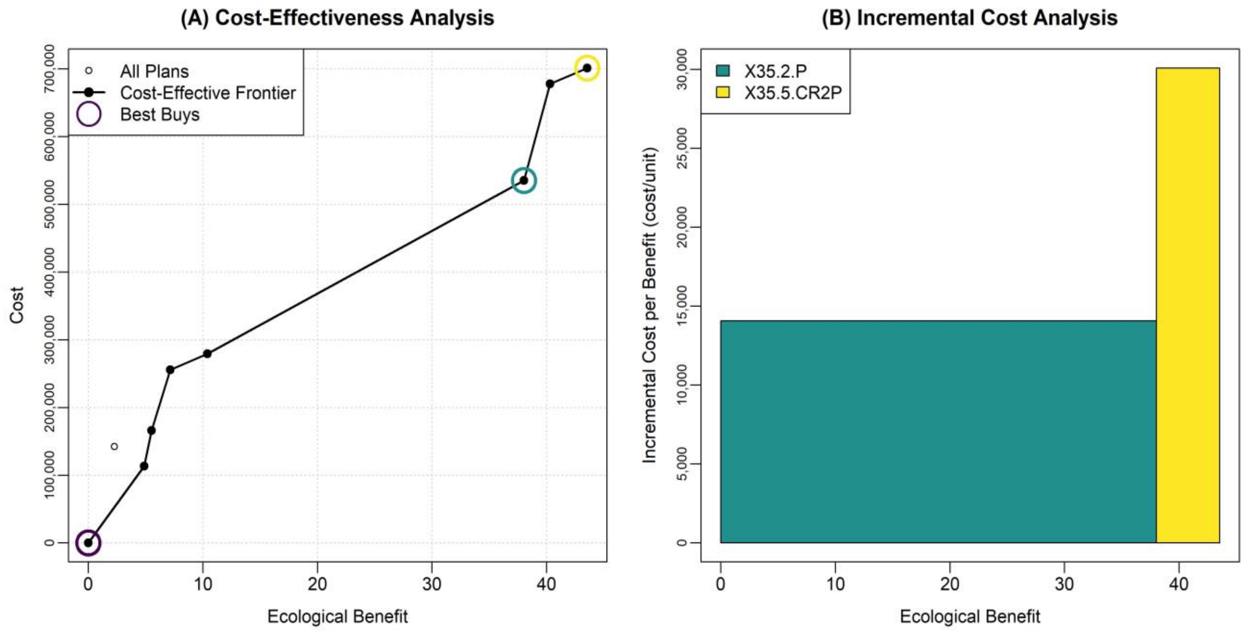
- C: Removes or repairs seven connectivity barriers in the reach.
- R1: Creates instream habitat through the addition of rock structures, primarily in tributary segments.
- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- H2: Addition of one large wetland feature.
- P: Extensive planting of hardwood, floodplain, and woodland forests.



X35 Proposed Actions.

These 5 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 9 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 9 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X35 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X35.1.	0	0	NaN	0	0
X35.2.P	38	535,400	14,100	14,100	15,117,000
X35.5.CR2P	43.5	701,400	16,100	30,100	19,802,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X35.1.	0	0	NaN	0	1	1
X35.2.P	38	535,400	14,100	15,117,000	1	1
X35.3.H2	4.9	113,300	23,200	3,199,000	1	0
X35.4.CR2	5.5	166,000	30,100	4,686,000	1	0
X35.5.CR2P	43.5	701,400	16,100	19,802,000	1	1
X35.6.CR2H2	10.4	279,300	26,900	7,885,000	1	0
X35.7.CR1	2.3	142,600	62,700	4,025,000	0	0
X35.8.CR1P	40.3	678,000	16,800	19,141,000	1	0
X35.9.CR1H2	7.1	255,900	35,800	7,224,000	1	0

Based on these data and team input, the **recommended action at this site is X35.6.CR2H2**. The decision logic for this alternative is as follows:

- The two best buy alternatives are high cost actions requiring a large increment of project first cost (i.e., The first best buy, X35.2.P, costs $15M).
- Two cost-effective alternatives (X35.9.CR1H2 and X35.6.CR2H2) provide an intermediate range of costs and benefits, including both riverine and riparian benefits.
- The recommended alternative (X35.6.CR2H2) provides 46% more AAHUs at 9% more cost than the lowest cost, cost-effective alternative (X35.9.CR1H2).
- Site is largely forested, so hydrologic actions likely provide important offsite benefits to downstream reaches.
- The large number of parcels could provide a real estate constraint, which encourages the reduced footprint action of CR2H2.
- Plan optimization should consider incorporating planting actions along with R2 mobilization.
- The PDT identify good potential for phasing implementation from upstream-to-downstream sections.

X38: Cave Hill Corridor

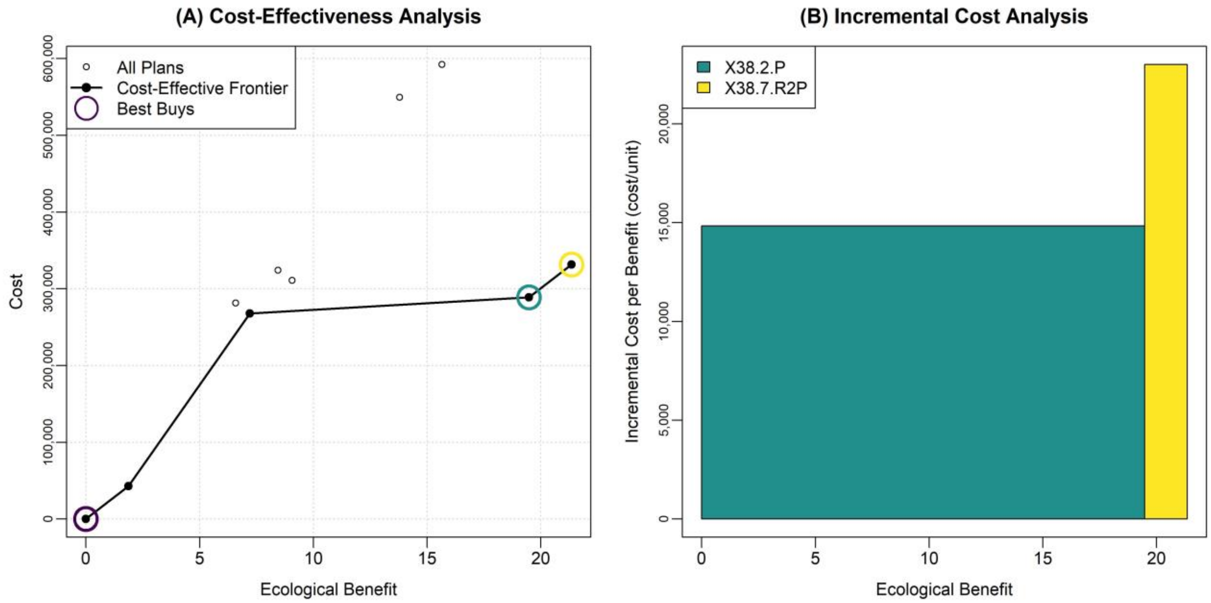
Site X38 is a 52-acre river corridor on the Middle Fork of Beargrass Creek. This site has approximately 1.8-miles of river channel with high public visibility due to recreational uses. Four restoration actions were identified as potentially appropriate at this location, which correspond to actions described in Section 2.1, specifically:

- R2: Reduces channel incision by grading streambanks to bank heights at the bankfull depth based on regional curves.
- H2: Addition of three wetland features.
- H3: Construction of a three water control features.
- P: Extensive planting of hardwood and woodland forests.

X38 Proposed Actions.

These 4 actions were combined based on a set of specified relationships regarding dependency between alternatives (Section 2.1), which resulted in 10 site-scale alternatives. Benefits and costs were computed additively for each alternative, and CEICA were applied to these data. The following figure and tables summarize the incremental cost analysis for

the 3 best buy alternatives as well as the results for all 10 alternatives, which also indicates whether or not the alternatives are cost-effective or best buys.



X38 CEICA Summary.

Incremental cost summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Overall Unit Cost ($/AAHU)	Inc Unit Cost ($/AAHU)	Project First Cost ($)
X38.1.	0	0	NaN	0	0
X38.2.P	19.5	288,800	14,800	14,800	8,155,000
X38.7.R2P	21.3	331,700	15,500	23,000	9,364,000

Cost-effectiveness summary.

Alt	Lift (AAHU)	Avg Ann Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	CE?	BB?
X38.1.	0	0	NaN	0	1	1
X38.2.P	19.5	288,800	14,800	8,155,000	1	1
X38.3.H3	6.6	281,400	42,800	7,945,000	0	0
X38.4.H2	7.2	268,000	37,200	7,567,000	1	0
X38.5.H2H3	13.8	549,500	39,900	15,512,000	0	0
X38.6.R2	1.9	42,800	23,000	1,210,000	1	0
X38.7.R2P	21.3	331,700	15,500	9,364,000	1	1
X38.8.R2H3	8.4	324,300	38,400	9,155,000	0	0
X38.9.R2H2	9.1	310,900	34,300	8,777,000	0	0
X38.10.R2H2H3	15.6	592,300	37,800	16,722,000	0	0

Based on these data and team input, the **recommended action at this site is X38.7.R2P**. The decision logic for this alternative is as follows:

- The planning objectives for the Beargrass Creek study emphasize the importance of both riverine and riparian outcomes. Thus, only the largest best buy meets the planning objectives (i.e., X38.7.R2P).

- Neither the next lowest cost best buy (X38.2.P) nor next lowest cost cost-effective plan (X38.4.H2) include riverine actions at this degraded sites.

- The smallest cost-effective plan (X38.6.R2) includes riverine, but not riparian actions.

- The site has high visibility with the community and is complementary to ongoing management actions by other partners (evidenced by inclusion in multiple existing plans and recommendations). Specifically, hydrologic management actions are a key activity identified by these prior plans.

- This is an important site for connectivity to upstream sites on the Middle Fork (e.g., the large-scale investment at X34).

- Ultimately, the team proposes that a hybrid alternative be developed during optimization that draws from the riparian benefits derived by the planting, the need for hydrologic management identified in other planning documents, and the need for restoration of a highly degraded riverine environment. The recommended action (X38.7.R2P) is identified as the best template from which the alternative may be optimized.

Site-Scale Summary

The prior analyses describe the logic of decision-making relative to 21 potential restoration sites. The "no action" alternative is recommended at 7 of these sites. Table 14 summarizes the remaining 14 sites with recommended restoration alternatives. The recommended alternatives vary widely in costs ($1.0M-$20.3M project first) and benefits (2.4-83.2 AAHUs). This range of outcomes provides an opportunity to examine effective combinations of alternatives at the watershed-scale.

Table 14. Summary of sites remaining in the system-scale analysis.

Site	Recommended Alternative	Lift	Average Annual Cost ($)	Project First Cost ($)
X2	X2.12.R2H2	18.5	344,800	9,733,000
X4	X4.5.CR4P	24.5	548,800	15,493,000
X8	X8.2.P	23.8	670,200	18,920,000
X10	X10.12.CR2P	41.6	484,600	13,682,000
X19	X19.14.R1H2	7.9	115,700	3,266,000
X20	X20.7.R2P	17.3	142,500	4,024,000
X21	X21.17.R2P	17.4	140,800	3,974,000
X22	X22.3.H2	4.3	83,600	2,361,000
X29	X29.4.CR4P	34.7	741,300	20,927,000
X30	X30.7.CR4P	57.1	613,200	17,312,000
X33	X33.4.H2	2.4	35,700	1,009,000
X34	X34.11.CR2P	83.2	717,700	20,262,000
X35	X35.6.CR2H2	10.4	279,300	7,885,000
X38	X38.7.R2P	21.3	331,700	9,364,000

3.2. System-Scale CEICA

The Beargrass Creek feasibility study will ultimately recommend a suite of restoration actions at the watershed scale to address both riverine and riparian ecological degradation. Portfolio planning presents a technical challenge to restoration teams faced with examining thousands, millions, or billions of potential combinations of actions. For instance, all combinations of restoration actions at the 14 remaining sites produces 2.9510^{15} combinations of actions. Even a reduced analysis examining only best buy actions produces 89,579,520 combinations. These logistical and computational realities often lead to simplifying assumptions associated with portfolio analysis at a watershed-scale.

For this study, a "winners compete" approach to CEICA was used, which examines all combinations of site-scale recommendations. The benefit of this method is that it preserves the nuanced thinking about alternatives at the site-scale, which may be obscured at the watershed-scale. This technique also provides a numerically feasible set of plans. The drawback of this approach is that is does not comprehensively search the solution space.

However, the qualitative factors involved in site-scale decision making were deemed more important than searching a larger number of watershed plans.

The recommendations at the 14 remaining sites were combined into 16,384 watershed plans. Ecological outcomes and monetary costs were computed for each plan as the sum of site-scale benefits. Plans range widely in investment cost and ecological benefit (i.e., $0-147.6M and 0-352 AAHUs). These plans were subjected to CEICA to identify efficient and effective portfolios of actions (Figure 8). This analysis identified 133 cost-effective plans and 15 best buy plans at the watershed-scale. Incremental unit cost increases from $0-34,300 / AAHU with increasing investment (Table 15).

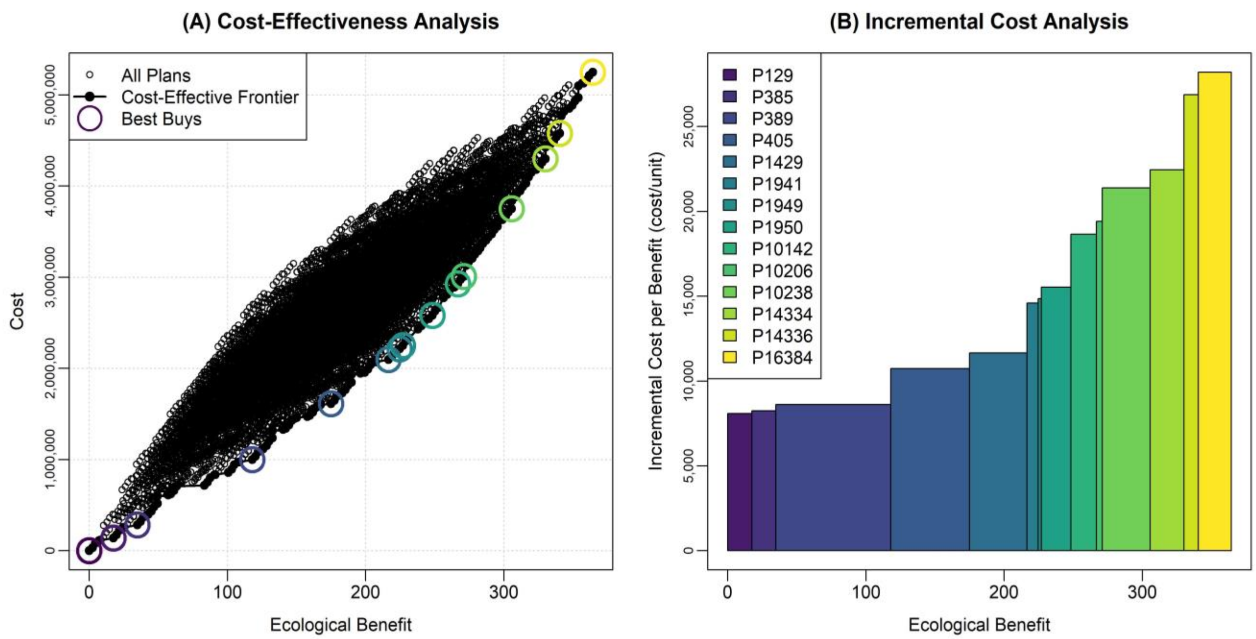


Figure 8. Watershed-scale CEICA summary for the "winners compete" method.

Table 15. Incremental cost analysis summary for the 'winners compete' analysis. For each site, '1' indicates action at the site and '0' indicates no action.

Plan	X2	X4	X8	X10	X19	X20	X21	X22	X29	X30	X33	X34	X35	X38	Lift	Avg Ann Cost ($)	Project First Cost ($)	Unit Cost ($/AAHU)	Incremental Unit Cost ($/AAHU)
P1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0	0	NaN	0
P129	0	0	0	0	0	0	1	0	0	0	0	0	0	0	17.4	140,800	3,974,000	8,100	8,100
P385	0	0	0	0	0	1	1	0	0	0	0	0	0	0	34.7	283,300	7,998,000	8,200	8,200
P389	0	0	0	0	0	1	1	0	0	0	0	1	0	0	117.9	1,001,000	28,259,000	8,500	8,600
P405	0	0	0	0	0	1	1	0	0	1	0	1	0	0	175.0	1,614,100	45,571,000	9,200	10,700
P1429	0	0	0	1	0	1	1	0	0	1	0	1	0	0	216.6	2,098,700	59,253,000	9,700	11,700
P1941	0	0	0	1	1	1	1	0	0	1	0	1	0	0	224.5	2,214,400	62,519,000	9,900	14,600
P1949	0	0	0	1	1	1	1	0	0	1	1	1	0	0	226.9	2,250,200	63,528,000	9,900	14,900
P1950	0	0	0	1	1	1	1	0	0	1	1	1	0	1	248.3	2,581,900	72,892,000	10,400	15,500
P10142	1	0	0	1	1	1	1	0	0	1	1	1	0	1	266.7	2,926,600	82,626,000	11,000	18,700
P10206	1	0	0	1	1	1	1	1	0	1	1	1	0	1	271.0	3,010,200	84,986,000	11,100	19,400
P10238	1	0	0	1	1	1	1	1	1	1	1	1	0	1	305.7	3,751,500	105,914,000	12,300	21,400
P14334	1	1	0	1	1	1	1	1	1	1	1	1	0	1	330.2	4,300,200	121,407,000	13,000	22,400
P14336	1	1	0	1	1	1	1	1	1	1	1	1	1	1	340.5	4,579,500	129,291,000	13,400	26,900
P16384	1	1	1	1	1	1	1	1	1	1	1	1	1	1	364.3	5,249,700	148,212,000	14,400	28,200

USACE policy specifies that restoration plan selection should seek to "reasonably maximize environmental benefits" (USACE 2000). As described at the beginning of Section 3, CEICA results were interpreted through five main lenses: the degree to which a plan has met planning objectives, increasing marginal cost, overall unit cost, affordability, and qualitative decision factors not captured in cost and benefit estimates. For Beargrass Creek, six "best buy" watershed-scale plans were identified as an initial decision array (See Table 15 for data).

- *Plan 10142 (X2 + X10 + X19 + X20 + X21 + X30 + X33 + X34 + X38)*: This plan includes actions at nine restoration sites in the Middle and South Fork. The plan has low overall unit cost ($11,000/AAHU). This plan incorporates actions at X2 at the confluence of the Three Forks, which is an extremely high visibility location with important ecological connectivity to the South, Middle, and Muddy forks. **This plan is the smallest plan that is ecologically and socially acceptable.**

- *Plan 10206 (X2 + X10 + X19 + X20 + X21 + X22 + X30 + X33 + X34 + X38)*: This plan incorporates small-scale actions along X22, which is a centrally located concrete channel near downtown Louisville. Ecological models are likely to be undervaluing the benefit of restoration actions in this extremely degraded system. The overall unit cost remains very low ($11,100/AAHU), and the incremental unit cost is very similar to the prior plan ($19,400/AAHU). This plan provides 74% of the potential ecological benefits in the watershed at 57% of the investment cost, indicating an efficient investment. The site is of high social importance, and the site has been a focal point for river revitalization plans associated with the Congress on New Urbanism.

- *Plan 10238 (X2 + X10 + X19 + X20 + X21 + X22 + X29 + X30 + X33 + X34 + X38)*: This plan adds X29 to the recommendation. Ecological benefits increase significantly from this action (34 AAHUs). The increase in overall and incremental unit cost is deemed "worth the investment" at this location, particularly in light of significant ecological benefits. X29 is near X30, so the inclusion of this site is likely to have synergistic ecological effects not accounted for in analyses. This site also has known stakeholder interest, willing landowners, and the potential for complementary actions by other entities. The plan also crosses thresholds in ecological benefits and project first cost (i.e., it is the first plan greater than 300 AAHUs and $100M).

- *Plan 14334 (X2 + X4 + X10 + X19 + X20 + X21 + X22 + X29 + X30 + X33 + X34 + X38)*: This plan adds restoration actions at site X4, which increases the total ecological benefit above 330 AAHUs. This site is at an educational institution and likely provides opportunities relative to education and site maintenance. The site occurs in a portion of the watershed not reached by other sites, and thus, this site reaches a different segment of the community.

- *Plan 14336 (X2 + X4 + X10 + X19 + X20 + X21 + X22 + X29 + X30 + X33 + X34 + X35 + X38)*: This plan incorporates actions at X35, which represents the only site on the Muddy Fork. This plan occurs at a threshold in incremental unit cost (i.e., Plan 14334 was $22,400/AAHU and Plan 14335 is $26,900/AAHU). **This plan is the largest plan that is worth the investment cost.**

- *Plan 16384 (X2 + X4 + X8 + X10 + X19 + X20 + X21 + X22 + X29 + X30 + X33 + X34 + X35 + X38)*: This plan includes all sites with recommended actions by incorporating X8. Only minor riverine actions were considered at this site because of the quality of existing instream conditions and the constraint of an onsite dam. This action is not deemed "worth the investment" in light of these constraints relative to increased incremental unit cost.

This initial decision array was narrowed to a range of watershed plans bracketed by Plan 10142 and Plan 14336. Table 16 and Figure 9 present a detailed presentation of all cost-effective plans in this range of ecological benefits and costs. The addition of X22 (Plan 10206) was identified as an important USACE-MSD contribution to a high visibility restoration priority for the region. Adding X29 (Plan 10238) provides significant ecological benefits both in quantitative and qualitative terms via 34 AAHUs and connectivity to Site-X30, respectively. This set of 11 sites represents a large amount of ecological lift (305 AAHUs) that is incrementally justified, but these sites do not include actions on all three branches of Beargrass Creek (i.e., Muddy Fork is absent). X4 is somewhat distantly located on the Middle Fork and does not represent a known priority for local partners. X35 incorporates actions on the Muddy Fork and provides hydrologic benefits anticipated to benefit other sections of the creek. Furthermore, X35 is the only site on the Muddy Fork, and the overall planning goal of restoring the Three Forks of Beargrass Creek could not be achieved without this site.

Given this context, a cost-effective plan was identified that includes all actions in Plan 10238 along with site-X35. Plan 10240 addresses major sources of ecological degradation throughout the watershed and efficiently obtains ecological benefits at a low unit cost ($12,800/AAHU). The incremental unit cost from P10238 to P14334 (the next best buy) would have been $22,400, and the incremental unit cost from P10238 to P10240 (the recommended plan) is $26,900. The added value of incorporating all three forks of Beargrass Creek is deemed worth this increase in incremental unit cost.

Table 16. Summary of the final decision array. For each site, '1' indicates action at the site and '0' indicates no action. For each plan, CE and BB of '1' denotes yes and '0' denotes no.

Plan	X2	X4	X8	X10	X19	X20	X21	X22	X29	X30	X33	X34	X35	X38	Lift	Average Annual Cost ($)	Project First Cost ($)	Unit Cost ($/AAHU)	CE?	BB?
P10142	1	0	0	1	1	1	1	0	0	1	1	1	0	1	266.7	2,926,600	82,626,000	11,000	1	1
P10198	1	0	0	1	1	1	1	1	0	1	0	1	0	1	268.6	2,974,500	83,977,000	11,100	1	0
P10206	1	0	0	1	1	1	1	1	0	1	1	1	0	1	271.0	3,010,200	84,986,000	11,100	1	1
P6046	0	1	0	1	1	1	1	0	0	1	1	1	0	1	272.7	3,130,600	88,385,000	11,500	1	0
P10136	1	0	0	1	1	1	1	0	0	1	0	1	1	1	274.7	3,170,100	89,501,000	11,500	1	0
P10144	1	0	0	1	1	1	1	0	0	1	1	1	1	1	277.1	3,205,900	90,510,000	11,600	1	0
P10200	1	0	0	1	1	1	1	1	0	1	0	1	1	1	279.0	3,253,800	91,862,000	11,700	1	0
P1974	0	0	0	1	1	1	1	0	1	1	0	1	0	1	280.5	3,287,400	92,811,000	11,700	1	0
P10208	1	0	0	1	1	1	1	1	0	1	1	1	1	1	281.4	3,289,500	92,871,000	11,700	1	0
P1982	0	0	0	1	1	1	1	0	1	1	1	1	0	1	282.9	3,323,100	93,820,000	11,700	1	0
P13726	1	1	0	1	0	1	1	0	0	1	1	1	0	1	283.3	3,359,700	94,852,000	11,900	1	0
P2038	0	0	0	1	1	1	1	1	1	1	0	1	0	1	284.8	3,371,000	95,172,000	11,800	1	0
P2046	0	0	0	1	1	1	1	1	1	1	1	1	0	1	287.2	3,406,700	96,181,000	11,900	1	0
P14230	1	1	0	1	1	1	1	0	0	1	0	1	0	1	288.8	3,439,600	97,109,000	11,900	1	0
P14238	1	1	0	1	1	1	1	0	0	1	1	1	0	1	291.2	3,475,400	98,118,000	11,900	1	0
P14294	1	1	0	1	1	1	1	1	0	1	0	1	0	1	293.1	3,523,200	99,470,000	12,000	1	0
P9662	1	0	0	1	0	1	1	0	1	1	1	1	0	1	293.5	3,552,200	100,287,000	12,100	1	0
P14302	1	1	0	1	1	1	1	1	0	1	1	1	0	1	295.5	3,559,000	100,479,000	12,000	1	0
P10166	1	0	0	1	1	1	1	0	1	1	0	1	0	1	299.0	3,632,100	102,544,000	12,100	1	0
P10174	1	0	0	1	1	1	1	0	1	1	1	1	0	1	301.4	3,667,900	103,553,000	12,200	1	0

Table 16 (cont). Summary of the final decision array. For each site, '1' indicates action at the site and '0' indicates no action. For each plan, CE and BB of '1' denotes yes and '0' denotes no.

Plan	X2	X4	X8	X10	X19	X20	X21	X22	X29	X30	X33	X34	X35	X38	Lift	Average Annual Cost ($)	Project First Cost ($)	Unit Cost ($/AAHU)	CE?	BB?
P10230	1	0	0	1	1	1	1	1	1	1	0	1	0	1	303.3	3,715,700	104,905,000	12,300	1	0
P10238	1	0	0	1	1	1	1	1	1	1	1	1	0	1	305.7	3,751,500	105,914,000	12,300	1	1
P14304	1	1	0	1	1	1	1	1	0	1	1	1	1	1	305.9	3,838,300	108,364,000	12,500	1	0
P6078	0	1	0	1	1	1	1	0	1	1	1	1	0	1	307.4	3,871,900	109,313,000	12,600	1	0
P10168	1	0	0	1	1	1	1	0	1	1	0	1	1	1	309.4	3,911,400	110,429,000	12,600	1	0
P10176	1	0	0	1	1	1	1	0	1	1	1	1	1	1	311.8	3,947,100	111,438,000	12,700	1	0
P10232	1	0	0	1	1	1	1	1	1	1	0	1	1	1	313.7	3,995,000	112,789,000	12,700	1	0
P10240	1	0	0	1	1	1	1	1	1	1	1	1	1	1	316.1	4,030,800	113,799,000	12,800	1	0
P13758	1	1	0	1	0	1	1	0	1	1	1	1	0	1	317.9	4,100,900	115,780,000	12,900	1	0
P13814	1	1	0	1	0	1	1	1	1	1	0	1	0	1	319.8	4,148,800	117,132,000	13,000	1	0
P14262	1	1	0	1	1	1	1	0	1	1	0	1	0	1	323.4	4,180,900	118,037,000	12,900	1	0
P14270	1	1	0	1	1	1	1	0	1	1	1	1	0	1	325.8	4,216,600	119,046,000	12,900	1	0
P14326	1	1	0	1	1	1	1	1	1	1	0	1	0	1	327.7	4,264,500	120,398,000	13,000	1	0
P14334	1	1	0	1	1	1	1	1	1	1	1	1	0	1	330.2	4,300,200	121,407,000	13,000	1	1
P13816	1	1	0	1	0	1	1	1	1	1	0	1	1	1	330.2	4,428,100	125,016,000	13,400	1	0
P14264	1	1	0	1	1	1	1	0	1	1	0	1	1	1	333.8	4,460,200	125,921,000	13,400	1	0
P14272	1	1	0	1	1	1	1	0	1	1	1	1	1	1	336.2	4,495,900	126,930,000	13,400	1	0
P14328	1	1	0	1	1	1	1	1	1	1	0	1	1	1	338.1	4,543,800	128,282,000	13,400	1	0
P14336	1	1	0	1	1	1	1	1	1	1	1	1	1	1	340.5	4,579,500	129,291,000	13,400	1	1

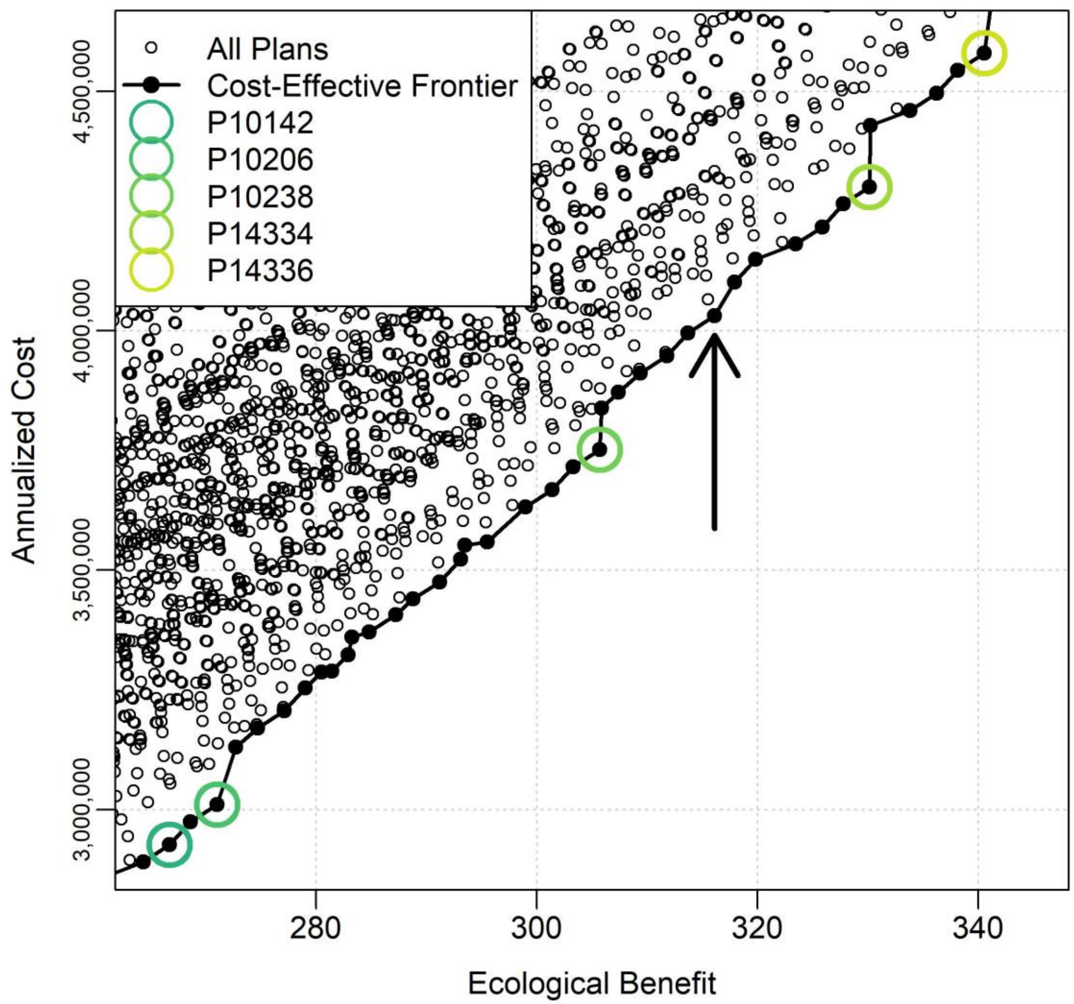


Figure 9. Cost-effectiveness diagram for final decision array. Arrow indicates recommended plan (P10240).

The Tentatively Selected Plan (TSP) identified through CEICA at the site- and system-scales is P10240. This watershed-scale plan includes 12 restoration sites at the confluence of the three forks (X2), Alpaca Farm and Louisville Zoo (X10), Newburg Road (X19), Brown Park (X20), Arthur Draut Park (X21), a concrete channel near downtown Louisville (X22), the Eastern-Creason Connector (X29), Joe Creason Park (X30), a small MSD Basin (X33), Cherokee and Seneca Parks (X34), a neighborhood along the Muddy Fork (X35), and the Cave Hill Corridor (X38). Collectively these actions provide 316 AAHUs at an average annual cost of $4,030,800 and a project first cost of $113,799,000.

4. Secondary Decision-Making Techniques

The overarching purpose of the USACE ecosystem restoration mission is "…to restore significant structure, function and dynamic processes that have been degraded" (ER 1165-2-501). This goal statement emphasizes that restoration plan formulation, evaluation, and selection should emphasize environmental outcomes. The Planning Guidance Notebook reinforces this issue by stating that plans should be selected to "reasonably maximize environmental benefits" (USACE 2000).

However, water resources projects often influence outcomes beyond their intended purpose. The 1983 Principles and Guidelines outlines four "accounts" related to National Economic Development, Regional Economic Development, Environmental Quality, and Other Social Effects (WRC 1983). USACE projects have often focused narrowly on one of these accounts as dictated by the Congressionally authorized purposes (e.g., a narrow focus on economic development for flood risk management or a narrow focus on environmental quality for restoration, James 2020). Recent USACE policies have directed teams "to ensure the USACE decision framework considers, in a comprehensive manner, the total benefits of project alternatives, including equal consideration of economic, environmental and social categories" (James 2021).

Sections 1-3 of this report have emphasized the Congressionally authorized purposes of the Beargrass Creek ecosystem restoration feasibility study. Proposed restoration actions have been justified through the lens of ecological benefits and costs. This chapter explores alternative approaches to decision-making that place greater emphasis on social outcomes and qualitative factors. Specifically, two methods are applied. First, a decision analysis is presented based on conducting CEICA relative to social factors alone. Second, a qualitative decision method is presented that compares sites to each other based on professional opinion (i.e., pairwise comparison). For both analyses, only the 14 restoration sites with proposed actions are included (Table 14) with the assumption that the sites must first meet ecological objectives before addressing secondary outcomes.

4.1. Other Social Effects (OSE)

Water resource management inherently affects a variety of economic, environmental, and social factors. Social outcomes are often particularly important in urban environments with higher population density. Regardless of location, OSEs are playing an increasingly prominent role in USACE decisions nationwide with diverse examples such as ecosystem restoration in the Hudson-Raritan Estuary, New York / New Jersey, flood risk management in Princeville, North Carolina, and coastal erosion in Barrow, Alaska. This analysis explores decision-making in Beargrass Creek assuming that social factors are the primary decision criteria. This extreme approach gives primacy to social factors over environmental outcomes and ignores the USACE restoration mission goals, but it also provides an avenue for examining the reliability of decisions. For instance, are the same sites recommended based on both environmental and social outcomes? Are some sites "worth the investment" socially but not environmentally or vice versa?

Social concepts and processes can be examined through a wide variety of indicators (Dunning and Durden 2007, Durden and Wegner-Johnson 2013, Hicks et al. 2016). In this study, OSEs were utilized during decision making qualitatively and then secondarily assessed using semi-quantitative metrics relative to four categories of outcomes related to logistics, economics, social factors, and technical issues used in agency budgeting. The logic of each factor is described below in more detail and summarized in Figure 10. Each category was assessed using a consistent constructed scale of 0 to 20, where 0 is undesirable and 20 is desirable. While a more empirical approach would be preferred (e.g., a stakeholder survey indicating community support), these simple scoring metrics have been used effectively to distinguish outcomes in other USACE projects (McKay et al. *in review*). Each metric was scored for the recommended alternative at the 14 remaining sites (data in Appendix B). The raw data (found in Appendix H) were summed for each category and normalized from 0 to 1 for consistent comparison across categories (Table 17). Normalized values were used to calculate the social units utilizing the total site area similar to habitat units as described in Section 2.3.3 in this report. Social units were used to verify and support the selection of the Recommended Plan by assigning a clear, holistic value on each site alternative.

- *Logistics*: Social factors often inhibit the execution of restoration projects. This category addresses logistical factors that can slow down (or eliminate) restoration plans at a given location such as real estate constraints, construction access, and Hazardous, Toxic and Radioactive Waste (HTRW) issues. While not strictly social "benefits", the absence of these social factors is crucial to restoration success.

- *Economic Effects*: This category addresses potential economic benefits associated with restoration such as a site's proximity to economic development corridors and employment opportunities. The effect of actions on flood levels were also incorporated into this category due to the potential for floods to inhibit economic development.

- *Social Outcomes*: This category assessed benefits of sites relative to community-oriented outcomes like visibility, equity, recreation and education, and stakeholder support.

- *Technical Significance for Budgeting*: USACE defines the significance of an ecosystem relative to institutional, public, and technical dimensions. Technical significance is also a crucial factor in determining the competitiveness of a USACE project in the budgeting process. Two criteria for budget prioritization were adapted as a qualitative metric of site significance (EC-11-2-206, USACE 2014).

Category	Sub-Category	Optimal 20 19 18 17 16	Suboptimal 15 14 13 12 11	Marginal 10 9 8 7 6	Poor 5 4 3 2 1
Logistical	Real Estate	All parcels owned by NFS	All parcels owned by NFS and public entity	Most parcels owned by public entity	Most parcels owned by private entity
	Access (constuctability)	Nearby public roadways and lands available to utilize for construction, no issues with topography	Topography is conducive to access but private properties surrounding	Topography is not ideal but access can be found in other ways, such as creating access roads that circumavigate steep terrain	Topography not conducive to good access, private property and obstructions
	HTRW issues	No known historical uses that may have contributed to contamination, very little uncertainty	No known historical uses that may have contributed to contamination, high levels of uncertainty	Known historical uses but resources for mitigation are present	Known historical uses that would have contributed to contamination
Economic	Employment	Ten or more businesses directly adjacent to stream	5-9 businesses directly adjacent to stream	1-4 businesses directly adjacent to stream	0 businesses directly adjacent to stream
	Potential	Located in accessible area with good visibility, nearby neighborhoods and businesses, restoration action will provide good potential for outdoor and paddlesport activities	Restoration action will provide good potential for outdoor and paddlesport activities but not accessible or visible	Accessible and visible but not a lot of opportuntiy for outdoor or paddlesport	Restoration action will not provide an opoortunity for paddlesport or outdoor activities, poor visibility and access
	Impact to local flooding	Vast improvement in flooding conditions based on H&H modeling	Slight improvement in flooding conditions based on H&H modeling	Flooding conditions stay the same based on H&H modeling	Flooding induction present based on H&H modeling
Social	Visibility	Good connecivity and accessibility to surrounding neighborhoods, included in other current plans with opportunity for aesthetic improvements	Some connections to surrounding neighborhoods but potential to improve, possibly included in current plans, aesethic improvement possible	Little accessibility to surrounding neighborhoods, little potential for improvement, not included in plans, aesthetic improvement unlikely	No accessibility from surrounding neighborhoods, little or no connection ro current plans, no aesthetic opportunity
	Environmental Justice	Located near low income or minority populations with little to no green infrastructure within 5 min walk	Located near low income or minority populations, very little green infrastrucutre within 5 min walk	No low income or minority populations present, some green infrastructure within 5 min walk	No low income or minority populations present, good network green infrastructure already within 5 min walk
	Recreation & Education	Predicted water quality improvements and points of access, adjacent to schools, churches, etc	Predicted some water qualilty improvements, some opportunity for points of access, schools, churches, etc nearby but not adjacent	Predicted minimal water qualilty improvements, very little opportunity for points of acces, schools, churches, etc nearby but not adjacent	No water quality improvements or potential to provide access points
	Community Support	Site specifically targeted at stakeholder and public meetings, broad interest across city	Some interest at public/ stakeholder meetings, surrounding neighborhood thinks project is important	Little interest a stakeholder/public meetings, some interest at neighborhood level	No interest at public/stakeholder meetings, no interest from local neighborhood
Technical	Scarcity	Habitat is extremely scarce, and restoration substantially reduces local scarcity (e.g., >50% over current reach condition).	Habitat is extremely scarce, and restoration reduces local scarcity (e.g., 25-50% over current reach condition).	Habitat is somewhat scarce, and project reduces local scarcity (e.g., 0-25% over current condition).	Habitat is common and/or project does not measurably reduce local scarcity.
	Connectivity	Makes critical direct physical connection between existing habitat areas or establishes a network of interconnected habitat.	Creates a nodal connection between existing habitat areas.	Restores suitability of existing connection. Expands area within corridor or home range.	Provides minor expansion to existing habitat.

Figure 10. Scoring criteria for the other social effects analysis.

Table 17. Overall other social effects outcomes summed across categories and normalized from 0 to 1. These scores represent the sites at the time of the analysis and have been updated for the final report to reflect optimization.*

Rest Num	Rest Name	Fork	Recommended Alternative	Total Site Area (ac)	Logistic (Norm)	Economic (Norm)	Social (Norm)	Technical (Norm)	Total	Units
X2	Confluence	South	CR2H2	170.6	0.583	0.667	0.775	0.850	0.719	122.7
X4	Shelby Campus	Middle	CR4P	81.7	0.833	0.500	0.462	0.750	0.636	52.0
X8	Houston Acre's Farm	South	P	130.4	0.667	0.317	0.525	0.325	0.458	59.7

X10	Alpaca Farm	South	CR2P	79.3	0.717	0.700	0.662	0.750	0.707	56.1
X19	South Fork / Newburg Rd	South	CR1H2	44.5	0.683	0.550	0.600	0.475	0.577	25.7
X20	Brown Park	Middle	CR2P	30.4	0.650	0.533	0.612	0.600	0.599	18.2
X21	Arthur Draut Park	Middle	CR2P	40.0	0.550	0.700	0.562	0.600	0.603	24.1
X22	Concrete Channel	South	H2	47.1	0.617	0.900	0.950	0.525	0.748	35.2
X29	Eastern / Creason Connector	South	CR4P	97.8	0.517	0.667	0.738	0.775	0.674	65.9
X30	Joe Creason Park	South	CR4P	121.3	0.900	0.733	0.712	0.775	0.780	94.6
X33	MSD Basin	South	H2	11.8	0.933	0.417	0.488	0.550	0.597	7.0
X34	Cherokee / Seneca Parks	Middle	CR2P	267.1	0.767	0.833	0.662	0.750	0.753	201.1
X35	Muddy Fork and Tribs	Muddy	CR2H2	127.9	0.550	0.383	0.538	0.575	0.512	65.5
X38	Cave Hill Corridor	Middle	R2P	52.1	0.617	0.700	0.712	0.625	0.664	34.6

While simple, these metrics clearly distinguish sites across each category. Logistical factors are generally challenging at sites with many land owners (e.g., X21, X29, X35). Economic development and social outcomes are generally highest at high profile sites in major parks and downtown (e.g., X22, X30, X34). Technical significance was highest at sites with large footprints and large-scale restoration actions. Overall, these analyses indicate that some sites are consistently important relative to social outcomes (e.g., X2, X10, X22, X30, and X34), whereas others consistently provide lower social benefits (e.g., X8, X19, X20, X21, X33).

As stated above, OSE metrics are typically used within USACE as qualitative decision factors. A recent coastal erosion study in Barrow, Alaska, however, used CEICA to assess non-monetary social effects related to community resilience. CEICA is applied in this study to examine the OSE metrics described above relative to investment cost. Drawing from the example of ecological habitat analyses, a quantity-quality metric of social outcomes was computed as a secondary decision criteria. The "quality" of a site relative to social issues was assessed as the overarching metric. The total site area was used as a proxy for the "quantity" of social outcomes. All things being equal, this assumes that a site with a larger area is socially more beneficial than a smaller site. The overall metric is referred to here as a "social unit" (SU).

While imperfect, this crude social indicator may provide a general assessment of the *relative* social benefits at a given restoration site. Average annual cost and social units were input to CEICA, and model outcomes are shown in Table 18 for system-scale combinations of actions.

Table 18. Incremental cost analysis summary for the other social effects outputs.

Plan	X2	X4	X8	X10	X19	X20	X21	X22	X29	X30	X33	X34	X35	X38	Soc Ben	Avg Ann Cost ($)	Project First Cost ($)	Unit Cost ($/SU)	Incremental Unit Cost ($/SU)
P1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0	0	NaN	0
P65	0	0	0	0	0	0	0	1	0	0	0	0	0	0	35.2	83,600	2,361,000	2,400	2,400
P8257	1	0	0	0	0	0	0	1	0	0	0	0	0	0	157.9	428,400	12,094,000	2,700	2,800
P8261	1	0	0	0	0	0	0	1	0	0	0	1	0	0	359.0	1,146,000	32,356,000	3,200	3,600
P8263	1	0	0	0	0	0	0	1	0	0	0	1	1	0	424.5	1,425,300	40,240,000	3,400	4,300
P8775	1	0	0	0	1	0	0	1	0	0	0	1	1	0	450.2	1,541,000	43,506,000	3,400	4,500
P8783	1	0	0	0	1	0	0	1	0	0	1	1	1	0	457.2	1,576,700	44,515,000	3,400	5,100
P8911	1	0	0	0	1	0	1	1	0	0	1	1	1	0	481.3	1,717,500	48,489,000	3,600	5,800
P8927	1	0	0	0	1	0	1	1	0	1	1	1	1	0	575.9	2,330,700	65,801,000	4,000	6,500
P9183	1	0	0	0	1	1	1	1	0	1	1	1	1	0	594.1	2,473,200	69,825,000	4,200	7,800
P10207	1	0	0	1	1	1	1	1	0	1	1	1	1	0	650.2	2,957,800	83,507,000	4,500	8,600
P10208	1	0	0	1	1	1	1	1	0	1	1	1	1	1	684.8	3,289,500	92,871,000	4,800	9,600
P14304	1	1	0	1	1	1	1	1	0	1	1	1	1	1	736.8	3,838,300	108,364,000	5,200	10,600
P16352	1	1	1	1	1	1	1	1	0	1	1	1	1	1	796.5	4,508,400	127,284,000	5,700	11,200
P16384	1	1	1	1	1	1	1	1	1	1	1	1	1	1	862.4	5,249,700	148,212,000	6,100	11,200

This analysis provides a few important observations about social outcomes in Beargrass Creek.

- The priority order of sites relative to CEICA of social outcomes is (Table 18): X22, X2, X34, X35, X19, X33, X21, X30, X20, X10, X38, X4, X8, and X29.

- The incremental unit cost of social outcomes increases rapidly beyond Plan 8927, which includes X2, X19, X21, X22, X30, X33, X34, and X35. Collectively, these sites provide 67% of social benefits at 46% of the project first cost. The efficiency of these actions could indicate that these are the most effective restoration investments from a social standpoint.

- The results generally align with the analyses presented in Table 16 with a few exceptions. High social benefits are consistent at sites X2, X22, X30, and X34, and low social benefits are consistent at sites X8 and X20. Mixed results at sites X10, X19, X33, and X35 could be an effect of low project costs or large total project areas rather than social processes.

4.2. Pairwise Comparison of Sites

Intangible benefits and costs are well-acknowledged challenges in decision-making (Saaty 2008), and recent USACE guidance explicitly acknowledges the potential importance of qualitative factors in agency choices (James 2020, James 2021). A spectrum of decision-making methods exists for comparing, combining, and synthesizing diverse information (Linkov et al. 2009), but USACE decisions tend to emphasize quantitative criteria and qualitative methods are infrequently applied. This section presents a qualitative decision making technique, pairwise comparison, as a means to verifying and supporting more rigorous quantitative approaches shown in Section 3.

At the simplest level, pairwise comparison is a dichotomous choice. Would you rather sit or stand? Is coffee or tea better? A sophisticated suite of methods exists for using pairwise choice to develop weights for multiple criteria (Saaty 2008). However, for this application, we use the simplest notion of directly comparing alternative restoration sites. Four project team members were presented with a pairwise choice experiment for each of the 14 sites with recommended action (Figure 11). Team members represented different organization perspectives (e.g., project management, planning, and engineering) and different disciplinary backgrounds (biology, landscape architecture, engineering, economics). For each combination of sites, an analyst had to choose their preferred action in light of assessed ecological benefits and costs as well as qualitative factors such as watershed position, known stakeholders support, and professional judgments of the efficacy of restoration actions. The number of pairwise "wins" provides a simple metric of the relative importance of a site. For instance, a site with 13 "wins" would indicate that the site is consistently preferred over all other sites. The average number of pairwise "wins" across the four team members was computed for each site.

Site	Name	Fork	X2	X4	X8	X10	X19	X20	X21	X22	X29	X30	X33	X34	X35	X38
X2	Confluence	South														
X4	Shelby Campus	Middle	X2													
X8	Houston Acre's Farm	South	X2	X8												
X10	Alpaca Farm / Zoo	South	X10	X10	X10											
X19	South Fork / Newburg Rd	South	X2	X19	X8	X10										
X20	Brown Park	Middle	X2	X20	X8	X10	X19									
X21	Arthur Draut Park	Middle	X2	X21	X8	X10	X21	X21								
X22	Concrete Channel	South	X22	X22	X22	X22	X22	X22	X22							
X29	Eastern / Creason Connector	South	X2	X29	X29	X29	X29	X29	X29	X22						
X30	Joe Creason Park	South	X30	X30	X30	X30	X30	X30	X30	X30	X30					
X33	MSD Basin	South	X2	X33	X33	X10	X19	X33	X33	X22	X29	X30				
X34	Cherokee / Seneca Parks	Middle	X34	X34	X34	X34	X34	X34	X34	X34	X34	X34	X34			
X35	Muddy Fork and Tribs	Muddy	X2	X35	X35	X10	X35	X35	X35	X22	X29	X30	X35	X34		
X38	Cave Hill Corridor	Middle	X2	X38	X38	X10	X38	X38	X38	X22	X38	X30	X38	X34	X38	
	Number of Pairwise "Wins"		9	0	4	9	3	1	3	11	8	12	4	13	6	8

Figure 11. Example of the pairwise comparison process.

The results of the pairwise comparisons clearly distinguish between sites (Figure 12). Five sites were consistently preferred (X2, X22, X29, X30, and X34). Conversely, four sites were consistently not represented in preferences (X4, X8, X20, and X33).

These results largely confirm prior analyses from CEICA with ecological and social inputs. The rank order of sites from the three methods were used as a consistent scale for comparing the analyses. Some sites effectively meet ecological objectives but underperform in social and intangible factors (e.g., X20). Whereas other sites may not provide ecological benefits as efficiently but they are enormously important socially (e.g., X2). The average rank across these three diverse assessments provides a simple assessment of the general level of expected outcomes. For instance, X34 is a large-scale restoration project in the high-profile location of Cherokee and Seneca Parks, and this site is identified by all three analyses as crucial. Conversely, sites X4 and X8 are ranked low in all three analyses.

Site	Avg Number of Pairwise "Wins" (max 13)	Pairwise Rank	Ecological Rank	Social Rank	Average Rank
X2	10.3	3	9	2	4.7
X4	2.0	14	12	12	12.7
X8	3.0	11	14	13	12.7
X10	7.0	7	5	10	7.3
X19	4.0	10	6	5	7.0
X20	2.3	12	2	9	7.7
X21	4.8	9	1	7	5.7
X22	9.8	4	10	1	5.0
X29	8.8	5	11	14	10.0
X30	10.8	2	4	8	4.7
X33	2.3	12	7	6	8.3
X34	12.3	1	3	3	2.3
X35	5.3	8	13	4	8.3
X38	8.8	5	8	11	8.0

Figure 12. Results of the pairwise comparison process relative to the site rankings provided by other methods.

5. Tentatively Selected Plan (TSP) Summary

In Chapter 3, Plan 10240 was identified as the Tentatively Selected Plan (TSP) based on CEICA of ecological outputs at the site- and system-scales. Chapter 4 subsequently supported this recommendation through assessment of social outputs and qualitative factors not captured in purely ecological approaches. The TSP is a cost-effective alternative from an ecological perspective, but it is not a best buy. The choice to recommend a cost-effective plan was bolstered by the OSE and pairwise analysis, which identified a larger suite of benefits associated with site X35 over sites X4 and X8. The cost-effective recommendation also allowed restoration actions to be executed in all three forks of the Beargrass Creek watershed.

Ultimately, Plan 10240 restores 12 ecologically degraded sites in the Beargrass Creek watershed (Table 19). Collectively these actions provide 316 AAHUs at an average annual cost of $4,030,800 and a project first cost of $113,799,000. Recommended restoration actions are clustered along the Middle and South forks of the creek to create synergies between sites with respect to both ecological and social outcomes (Figure 13). These 12 sites provide 87% of the ecological benefits and 87% of the social benefits of all 14 sites at 77% of the cost.

The TSP reflects a general conceptual direction for alternatives at each site and quantifies the relative magnitude of benefits and costs associated with actions. Feasibility-level design will refine these conceptual plans based on future analyses and investigations. Specifically, the following actions are anticipated, which will alter the existing designs and associated quantification of outcomes.

- Restoration actions at a site were combined based on a simple logic of separate riparian and riverine actions. As site plans develop, alternatives will be refined to reflect a more nuanced combination of actions (e.g., minor amounts of riverine actions along with planting alternatives).

- Restoration areas are currently based on professional judgments and have not actively incorporated willingness of land-owners.

- At present, the SMURF and QHEILS assessments were designed to avoid "double-counting" of benefits by only allowing model parameters to respond to one type of restoration action. However, riparian and riverine benefits are synergistic, and reciprocal benefits should be examined, where appropriate.

- Benefits of restoring watershed connectivity were only assessed with simple scoring at the site scale. However, these processes function at larger, watershed scales, and additional analyses could be explored to more accurately quantify these benefits.

- Restoration costs are anticipated to change as additional site detail becomes available. For instance, some sites may incorporate recreational features as appropriate and within policy constraints.

Table 19. Summary of the Tentatively Selected Plan (TSP).

Site	Site Name	Fork	Recommended Alternative	Lift	Average Annual Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	Site Area (ac)	Restored Channel (ft)	Social Units
X2	Confluence	South	R2H2	18	345,000	18,700	9,733,000	171	1,068	123
X10	Alpaca Farm / Zoo	South	CR2P	42	485,000	11,700	13,682,000	79	4,913	56
X19	South Fork / Newburg Rd	South	R1H2	8	116,000	14,600	3,266,000	44	4,489	26
X20	Brown Park	Middle	R2P	17	143,000	8,200	4,024,000	30	628	18
X21	Arthur Draut Park	Middle	R2P	17	141,000	8,100	3,974,000	40	1,527	24
X22	Concrete Channel	South	H2	4	84,000	19,400	2,361,000	47	0	35
X29	Eastern / Creason Connector	South	CR4P	35	741,000	21,400	20,927,000	98	4,549	66
X30	Joe Creason Park	South	CR4P	57	613,000	10,700	17,312,000	121	3,830	95
X33	MSD Basin	South	H2	2	36,000	14,900	1,009,000	12	0	7
X34	Cherokee / Seneca Parks	Middle	CR2P	83	718,000	8,600	20,262,000	267	12,951	201
X35	Muddy Fork and Tribs	Muddy	CR2H2	10	279,000	26,900	7,885,000	128	8,717	66
X38	Cave Hill Corridor	Middle	R2P	21	332,000	15,500	9,364,000	52	3,335	35
All Sites				316	4,031,000	12,800	113,799,000	1,090	46,007	751

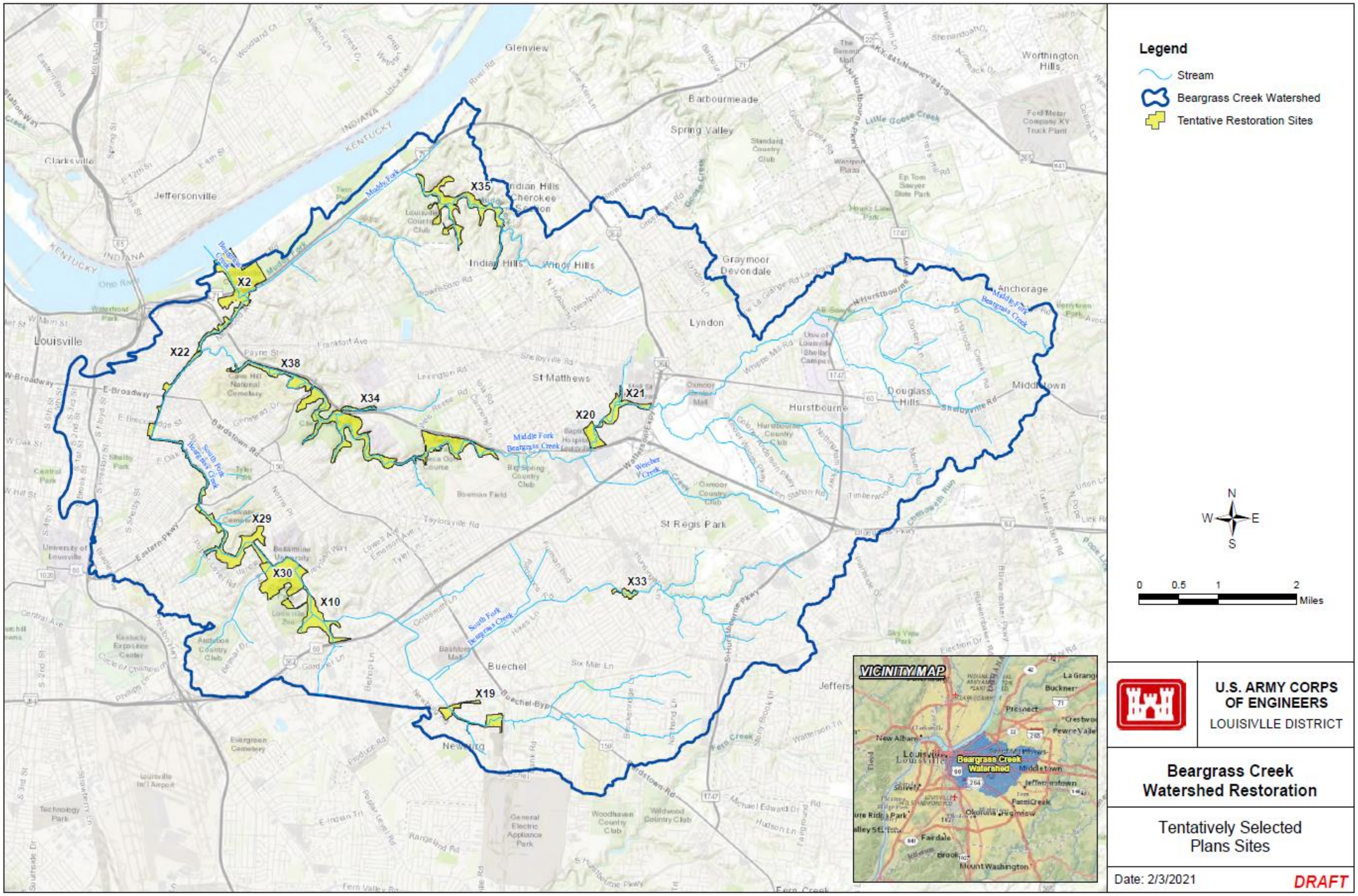


Figure 13. Tentatively Selected Plan (TSP) for the Three Forks of Beargrass Creek feasibility study.

6. Confirmation of the Recommended Plan

Designs were optimized at each restoration site following the release of the draft feasibility report. Optimization generally sought to improve designs to increase ecological benefits and decrease monetary costs in light of site constraints (e.g., utility areas, real estate boundaries). Site X38 provides a notable exception. The recommended alternative from the TSP included riverine and planting actions (R2P) with the intent to hybridize these actions with hydrologic features to complement other management in this part of the watershed. After optimization, the X38 alternative included larger hydrologic actions and smaller plantings, so the alternative was relabeled (R2H2) to better reflect these changes.

Ecological benefits and costs were recomputed based on optimized designs. Two analyses are presented here to ensure that changes in benefits and costs did not alter the recommended agency action described in Section 5. First, ecological benefits and costs were recomputed and annualized for the final restoration designs. Second, changes in unit cost were examined on a site-by-site basis. Together, these assessments confirm the National Ecosystem Restoration Plan, which is summarized at the end of this section.

6.1. Optimized Benefits and Costs

Restoration designs were optimized at the 12 remaining sites with accompanying reassessment of ecological benefits and costs. Following methods from Section 2.1, benefits were recomputed and annualized for the adjusted site boundaries. Table 20 presents optimized values associated with the recommended alternatives.

Table 20. Summary of ecological benefits for the optimized restoration designs.

Site	Site Name	Fork	Recommended Alternative	Lift
X2	Confluence	South	R2H2	19.6
X10	Alpaca Farm / Zoo	South	CR2P	23.0
X19	South Fork / Newburg Rd	South	CR1H2	6.8
X20	Brown Park	Middle	CR2P	14.8
X21	Arthur Draut Park	Middle	CR2P	12.8
X22	Concrete Channel	South	H2	1.9
X29	Eastern / Creason Connector	South	CR4P	38.0
X30	Joe Creason Park	South	CR4P	46.7
X33	MSD Basin	South	H2	1.6
X34	Cherokee / Seneca Parks	Middle	CR2P	121.1
X35	Muddy Fork and Tribs	Muddy	CR2H2	4.2
X38	Cave Hill Corridor	Middle	R2H2	6.4

Cost estimates were also revised for the optimized designs. Project first costs were estimated using standard cost engineering and real estate methods. Average annual economic costs were computed based on project first cost, interest during construction, and operations and maintenance. The fiscal year 2022 project evaluation and formulation rate (discount rate) of 2.25% was used in accordance with EGM 22-01. Monitoring and adaptive management costs were amortized over a five-year period. Annual operations and maintenance costs were assessed over a 50-year period. Table 21 presents optimized costs for the recommended alternatives.

6.2. Confirmation of the Recommended Plan

Table 22 summarizes changes in the ecological lift, average annual costs, and unit costs of each site relative to the TSP presented in Chapter 5. This table also shows percent change in unit cost and notes any sites where unit costs increased. Unit cost decreased at 5 of 12 sites, where either benefit increased, cost declined, or changes occurred in both. Declines in unit cost increased the competitiveness of these sites, which were previously justified in Sections 3 and 4. As such, these sites are assumed to be even more competitive and are easily confirmed as part of the recommended plan. Conversely, unit costs increased at seven sites, but these increases were deemed acceptable because of the following:

- Site X10: The Alpaca Farm / Zoo site is an important component of restoration actions in the South Fork tributary with adjacent actions at X29 and X30. Site constraints led to scaled-back riparian plantings on the right bank, which reduced ecological benefits and increased unit cost (+16.8%). The overall unit cost of this site ($13,600 / AAHU) is less than the unit cost of all watershed actions ($14,500 / AAHU), indicating it is an efficient investment. Furthermore, X10's connectivity to X29 and X30 provides a major restoration corridor in the South Fork.

- Site X19: The Newburg Road site is in a constrained corridor, and logistic factors reduced the extent of restoration and associated ecological benefits. The small change in unit cost (+5.2%) was deemed an acceptable increase well within the range of project contingency costs.

- Site X22: The concrete channel site is in the most constrained portion of the basin, and site boundaries were reduced to accommodate other infrastructure needs. However, the increased unit cost (+106%) was deemed acceptable given the low overall project first cost ($2.8M) and the extremely high visibility and social value of this location.

- Site X30: The Joe Creason Park site restoration was scaled back to accommodate park uses and avoid logistic constraints. The increased unit cost (+24.4%) was deemed acceptable given the high ecological value of this site in the X29-X30-X10 corridor. The overall unit cost of this site ($13,400 / AAHU) is also less than the unit cost of all watershed actions ($14,500 / AAHU), indicating it is an efficient investment.

- Site X34: Cherokee and Seneca Parks represent the largest contribution to restoration benefits at the watershed scale, and the decision was made to seize on these benefits by expanding planting areas. The increase in unit cost (+32%) is accompanied by a large increase in ecological benefits (38 AAHUs or +45%). Furthermore, the overall unit cost of this site ($11,400 / AAHU) is much less than the unit cost of all watershed actions ($14,500 / AAHU), indicating a very efficient investment.

- Site X35: This Muddy Fork site is highly constrained by real estate in this residential area. Ecological benefits declined substantially during optimization (-6.2 AAHUs) and unit cost increased significantly (+190%). Although this is a large increase in unit cost, the site is the only action in the Muddy Fork tributary. Thus, the increased cost is deemed worth the investment to meet the planning objectives of restoring all three forks of Beargrass Creek.

- Site X38: The ecological benefits declined significantly at this site with the significant reduction in riparian restoration areas. This reduction led to a large increase in unit cost of over 200%. This higher unit cost is deemed acceptable due to the watershed context of this site. X38 is a key corridor to three major upstream sites (X34, X20, and X21). Collectively, these three sites represent 50% of the total ecological benefits of the entire project. Connectivity between sites in the watershed is an important feature for maintaining resilience in an urban watershed as well as a stated planning objective of the study. Therefore, the increased unit cost at X38 is acceptable in light of the connectivity benefits to the project as a whole. Furthermore, this site has extremely high visibility and has been included in prior watershed restoration plans due to its social and ecological value.

Site optimization required scaling back actions to accommodate restoration in constrained urban environments, which led to increased average annual and unit costs at the watershed scale. The watershed unit cost increased from $12,800 / AAHU for the TSP to $14,500 / AAHU for the final plan (+13.4%). Although costs increased, ecological benefits were maintained relatively close to the TSP (a loss of 19 AAHUs or -6%).

6.3. Summary of the National Ecosystem Restoration Plan

Per the Planning Guidance Notebook (ER 1105-2-100, Appendix E, Page E-163), the National Ecosystem Restoration Plan "meets planning objectives and constraints and reasonably maximizes environmental benefits while passing tests of cost effectiveness and incremental cost analyses, significance of outputs, acceptability, completeness, efficiency, and effectiveness" with additional factors related to partnership context and reasonableness of costs. This appendix has sequentially presented the development of the National Ecosystem Restoration Plan for the Beargrass Creek watershed. This recommendation was developed based on multiple planning steps and analyses, specifically:

- An initial array of 50+ restoration sites were identified based on prior watershed assessments, local knowledge, preliminary field scouting, and desktop geospatial analyses. These sites were screened relative to seven technical criteria addressing the extent of the site, proximity to other aquatic ecosystems, presence of hydric soils, existing soil coverage, impervious area, the potential for restored connectivity, and proximity to natural areas. Secondary screening involved logistical, administrative, and policy factors. These two forms of screening resulted in 21 sites carried through for feasibility-level analysis.

- Preliminary designs were developed at these 21 sites, and ecological benefits and monetary costs were estimated. Cost-effectiveness and incremental costs analyses (CEICA) were conducted at the site-scale with annualized benefits and costs, and a recommended alternative was identified for 14 of the restoration sites (Section 3.1).
- Site-scale recommendations were combined into 16,384 watershed-scale plans (Section 3.2), and CEICA was applied to these plans to identify a Tentatively Selected Plan (TSP) with 12 sites.
- Additionally, secondary decision-making methods were used to examine the robustness of the TSP. First, other social effects were assessed for each site, and CEICA was conducted on an aggregated social metric. Second, a more qualitative method of pairwise comparison of sites was conducted. Ultimately, these two methods reinforced the importance of the 12 sites included in the TSP (Section 4).
- Designs were then optimized for the remaining twelve sites. Finalized benefits and costs were recomputed and annualized for consistent comparison, and analyses were conducted to confirm the recommendation of twelve restoration sites (Sections 6.1 and 6.2).

These analyses ultimately led to the National Ecosystem Restoration Plan, which is summarized in Table 23. The plan recommends twelve nationally significant sites with a project first cost of $121.1M, an ecological benefit of 297 habitat units, and a unit cost is $14,500 per habitat unit. Additionally, the plan provides important social benefits reflected by the qualitative “social units” metric. Ultimately, the plan “reasonably maximizes” ecological benefits in a cost-effective and cost-efficient manner and provides a substantial contribution to the overall ecological integrity of the Beargrass Creek watershed.

Table 21. Summary of costs for the optimized restoration designs.

Site	Recommended Alternative	Monitoring and Adaptive Management Cost ($)	Project First Cost ($)	Construction Duration (mo)	Total Interest During Construction ($)	O&M Cost ($)	Average Annual Cost ($)
X2	CR2H2	81,354	7,097,000	13	78,658	3,023	243,364
X10	CR2P	102,199	8,915,000	9	65,708	12,169	312,968
X19	CR1H2	34,696	3,027,000	11	27,923	2,300	104,621
X20	CR2P	32,061	2,797,000	5	10,282	5,603	99,630
X21	CR2P	22,576	1,969,000	7	10,871	4,909	71,223
X22	H2	26,198	2,285,000	3	4,195	901	77,575
X29	CR4P	235,670	20,558,000	41	772,865	21,295	735,764
X30	CR4P	200,652	17,504,000	31	490,465	21,411	624,125
X33	H2	5,627	491,000	3	901	216	16,692
X34	CR2P	439,530	38,342,000	40	1,404,528	49,750	1,381,044
X35	CR2H2	108,074	9,428,000	41	354,440	1,917	329,576
X38	R2H2	99,987	8,722,000	15	112,919	2,803	298,720

Table 22. Summary of ecological benefits for the optimized restoration designs.

Site	Recommended Alternative	Initial Lift (AAHU)	Final Lift (AAHU)	Initial Avg Ann Cost- ($)	Final Avg Ann Cost ($)	Initial Unit Cost ($/AAHU)	Final Unit Cost ($/AAHU)	Unit Cost (%change)
X2	CR2H2	18.5	19.6	345,000	243,000	18,660	12,403	-33.5
X10	CR2P	41.6	23	485,000	313,000	11,660	13,618	+16.8
X19	CR1H2	7.9	6.8	116,000	105,000	14,596	15,361	+5.2
X20	CR2P	17.3	14.8	143,000	100,000	8,245	6,754	-18.1
X21	CR2P	17.4	12.8	141,000	71,000	8,083	5,557	-31.3
X22	H2	4.3	1.9	84,000	78,000	19,420	40,107	+106.5
X29	CR4P	34.7	38	741,000	736,000	21,388	19,384	-9.4
X30	CR4P	57.1	46.7	613,000	624,000	10,739	13,355	+24.4
X33	H2	2.4	1.6	36,000	17,000	14,863	10,738	-27.8
X34	CR2P	83.2	121.1	718,000	1,381,000	8,623	11,403	+32.2
X35	CR2H2	10.4	4.2	279,000	330,000	26,880	78,032	+190.3
X38	R2H2	21.3	6.4	332,000	299,000	15,540	46,733	+200.7
All		316.1	296.9	4,033,000	4,295,000	12,759	14,467	+13.4

Table 23. Summary of the National Ecosystem Restoration Plan.

Site	Site Name	Fork	Recommended Alternative	Site Area (ac)	Lift (AAHU)	Average Annual Cost ($)	Unit Cost ($/AAHU)	Project First Cost ($)	Social Units
X2	Confluence	South	CR2H2	65.3	19.6	243,000	12,400	7,097,000	47.0
X10	Alpaca Farm / Zoo	South	CR2P	64.7	23.0	313,000	13,600	8,915,000	45.7
X19	South Fork / Newburg Rd	South	CR1H2	22.6	6.8	105,000	15,400	3,027,000	13.1
X20	Brown Park	Middle	CR2P	27.6	14.8	100,000	6,800	2,797,000	16.5
X21	Arthur Draut Park	Middle	CR2P	25.1	12.8	71,000	5,600	1,969,000	15.1
X22	Concrete Channel	South	H2	15.1	1.9	78,000	40,100	2,285,000	11.3
X29	Eastern / Creason Connector	South	CR4P	111.5	38.0	736,000	19,400	20,558,000	75.2
X30	Joe Creason Park	South	CR4P	103.9	46.7	624,000	13,400	17,504,000	81.0
X33	MSD Basin	South	H2	5.4	1.6	17,000	10,700	491,000	3.2
X34	Cherokee / Seneca Parks	Middle	CR2P	278.4	121.1	1,381,000	11,400	38,342,000	209.6
X35	Muddy Fork and Tribs	Muddy	CR2H2	37.6	4.2	330,000	78,000	9,428,000	19.3
X38	Cave Hill Corridor	Middle	R2H2	29.0	6.4	299,000	46,700	8,722,000	19.3
All Sites				786.3	296.9	4,295,000	14,500	121,135,000	556.3

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Attachment A: Glossary and Acronyms

- *AAHU*: Average annual habitat unit.
- *CEICA*: Cost-Effectiveness and Incremental Cost Analysis.
- *ERDC*: U.S. Army Engineer Research and Development Center.
- *FWOP*: Future WithOut Project Conditions.
- *HSI*: Habitat suitability index.
- *HU*: Habitat unit.
- *LRL*: USACE Louisville District.
- *MSD*: Louisville / Jefferson County Metropolitan Sewer District.
- *QHEI*: Qualitative Habitat Evaluation Index.
- *QHEILS*: Qualitative Habitat Evaluation Index for Louisville Streams.
- *SMURF*: Simple Model for Urban Riparian Function.
- *TSP*: Tentatively Selected Plan.
- *USACE*: U.S. Army Corps of Engineers.

Attachment B: Ecological Model Inputs

Table B1. Beargrass Creek restoration site metadata.

Rest_Num	Rest_Name	Fork	Assessment_Points	Latitude	Longitude	Drainage Area (km2)
X2	Confluence	South	SF.13/SF.17	38.26153	-85.71690	158.15
X4	Shelby Campus	Middle	MF.29	38.25986	-85.58524	14.76
X5	Oxmoor Farm	Middle	MF.11	38.24065	-85.61851	NA
X8	Houston Acre's Farm	South	SF.38/SF.41	38.21009	-85.61202	NA
X9	Clark Park	South	SF.20	38.21545	-85.72654	NA
X10	Alpaca Farm / Zoo	South	SF.22	38.20838	-85.70068	43.53
X11	Collegiate	Muddy	MU.14	38.27748	-85.69217	20.06
X15	Buechel Park	South	SF.43	38.19595	-85.62192	NA
X19	South Fork / Newburg Rd	South	SF.26/SF.42	38.18709	-85.65851	11.80
X20	Brown Park	Middle	MF.08US/MF.08DS	38.23940	-85.63495	36.46
X21	Arthur Draut Park	Middle	MF.09US/MF.09DS	38.24402	-85.62870	35.85
X22	Concrete Channel	South	SF.18/SF.19A/SF.35	38.23444	-85.73027	67.63
X24	Oxmoor Country Club	Middle	MF.34	38.22907	-85.61478	NA
X28	Hurstbourne Country Club	Middle	MF.12	38.24098	-85.58708	NA
X29	Eastern / Creason Connector	South	SF.19B	38.21872	-85.72135	54.23
X30	Joe Creason Park	South	SF.21	38.21452	-85.71016	50.86
X31	Champions Trace	South	SF.24	38.20330	-85.67659	NA
X33	MSD Basin	South	SF.39	38.21115	-85.62910	NA
X34	Cherokee / Seneca Parks	Middle	MF.04US/MF.04DS/MF.05/ MF.06US/MF.06DS	38.24164	-85.69549	60.09
X35	Muddy Fork and Tribs	Muddy	MU.15	38.27966	-85.66859	11.09
X38	Cave Hill Corridor	Middle	MF.02/MF.03	38.25018	-85.71695	64.60

Table B2. Beargrass Creek restoration site existing condition data.

Rest Num	Bankfull Depth (ft)	Bankfull Width (ft)	Bank Height Left (ft)	Bank Height Right (ft)	Incision Left	Incision Right	Incision Average	Canopy Height 25_Left (ft)	Canopy Height 25_Right (ft)
X2	4.70	60.00	3.500	2.500	0.7446809	0.5319149	0.6382979	60.00000	52.50000
X4	1.95	30.50	3.000	3.000	1.8987342	1.8987342	1.8987342	50.00000	50.00000
X5	1.80	34.00	2.200	2.200	1.2222222	1.2222222	1.2222222	20.00000	30.00000
X8	1.60	20.50	2.750	2.750	0.9166667	0.9166667	0.9166667	75.00000	72.50000
X9	3.50	13.00	6.000	6.000	1.7142857	1.7142857	1.7142857	60.00000	60.00000
X10	2.92	39.00	10.000	15.000	3.4482759	5.1724138	4.3103448	100.00000	100.00000
X11	2.19	22.00	5.500	5.500	1.5714286	1.5714286	1.5714286	40.00000	40.00000
X15	2.20	6.00	2.200	2.200	1.0000000	1.0000000	1.0000000	60.00000	60.00000
X19	1.80	23.00	9.000	6.000	3.0000000	2.0000000	2.5000000	45.00000	30.00000
X20	2.73	41.05	4.000	3.750	1.9184652	1.7985612	1.8585132	40.00000	45.00000
X21	2.71	32.25	3.085	3.085	1.1017857	1.1017857	1.1017857	45.00000	45.00000
X22	3.43	30.00	15.000	15.000	3.4090909	3.4090909	3.4090909	46.66667	51.66667
X24	2.00	34.00	6.000	5.000	3.0000000	2.5000000	2.7500000	10.00000	10.00000
X28	1.83	35.00	2.750	2.330	1.5027322	1.2732240	1.3879781	0.00000	0.00000
X29	3.16	20.00	4.000	4.000	1.0000000	1.0000000	1.0000000	50.00000	80.00000
X30	3.09	37.00	20.000	20.000	6.4516129	6.4516129	6.4516129	80.00000	80.00000
X31	2.60	55.00	10.000	10.000	3.8461538	3.8461538	3.8461538	50.00000	40.00000
X33	3.00	29.00	3.000	6.000	1.0000000	2.0000000	1.5000000	35.00000	45.00000
X34	3.29	34.60	4.360	4.560	1.9639640	2.0540541	2.0090090	44.00000	52.00000
X35	1.76	23.00	5.300	7.300	1.8928571	2.6071429	2.2500000	40.00000	40.00000
X38	3.37	39.90	6.615	12.750	2.5200000	4.8571429	3.6885714	35.00000	40.00000

Table B3. Beargrass Creek restoration site existing condition data for QHEILS inputs.

Rest Num	Substrate	Instream Cover	Channel Morphology	Bank Erosion Riparian Total	Pool Current	Riffle Run	Gradient	Aquatic Organism Passage	Material Transport
X2	5.5	9.0	7.00	7.500000	7.0	0.0000000	8.0	8	6
X4	13.0	10.0	11.00	6.250000	6.0	4.0000000	10.0	10	12
X5	15.0	14.0	9.00	6.500000	7.0	3.0000000	10.0	6	7
X8	20.0	14.0	12.25	9.000000	6.0	5.0000000	10.0	5	4
X9	14.0	11.0	11.00	6.000000	4.0	3.0000000	8.0	15	15
X10	13.0	9.0	9.00	9.000000	10.0	5.5000000	4.0	10	14
X11	5.5	4.0	4.00	5.500000	2.0	0.0000000	6.0	12	11
X15	8.5	9.0	7.00	3.000000	5.0	0.0000000	4.0	18	18
X19	10.0	9.0	8.00	5.250000	5.0	2.5000000	9.0	15	12
X20	13.5	12.0	13.00	3.750000	8.0	4.0000000	8.0	13	13
X21	15.5	11.0	11.00	6.750000	6.0	4.0000000	10.0	11	8
X22	0.0	1.0	6.00	5.166667	4.0	0.6666667	8.0	2	6
X24	3.0	2.0	6.00	5.000000	1.0	3.0000000	4.0	15	14
X28	3.0	2.0	8.00	4.000000	7.0	3.0000000	4.0	16	15
X29	19.0	16.0	12.00	9.500000	11.0	8.0000000	6.0	10	11
X30	19.0	8.0	14.50	8.500000	9.5	5.0000000	10.0	16	16
X31	12.0	9.0	6.00	3.500000	5.0	0.0000000	6.0	15	15
X33	18.0	14.0	11.00	4.000000	7.0	6.0000000	8.0	16	15
X34	12.0	3.0	10.00	6.450000	4.4	2.6000000	7.2	5	8
X35	10.0	15.0	10.00	5.500000	7.0	2.0000000	10.0	13	13
X38	11.0	12.5	9.50	7.750000	10.0	4.0000000	5.0	11	11

Table B4. Beargrass Creek restoration site existing condition data for SMURF inputs (1 of 2).

Rest Num	Buffer Development Left	Buffer Development Right	Buffer Flowpaths Left	Buffer Flowpaths Right	Overstory Left	Midstory Left	Woody Shrubs Left	Overstory Right	Midstory Right	Woody Shrubs Right	Snags Left	Snags Right
X2	9.5	10.5	11.5	12.5	1	1	1	1	1	1	13.0	13.0
X4	12.0	12.0	14.0	14.0	1	0	0	1	0	0	12.0	12.0
X5	8.0	5.0	16.0	4.0	1	0	0	0	0	0	6.0	6.0
X8	15.5	13.0	16.500000	15.5	2	1	1	2	1	1	16.5	14.5
X9	11.0	11.0	13.0	13.0	2	1	1	2	1	1	11.0	11.0
X10	11.0	15.0	5.0	11.0	1	1	1	1	1	1	18.0	18.0
X11	13.0	9.0	15.0	7.0	1	0	0	1	1	1	11.0	11.0
X15	6.0	6.0	11.0	11.0	0	0	0	0	0	0	6.0	6.0
X19	10.5	10.5	7.0	1.5	1	0	0	1	0	0	9.5	7.0
X20	9.5	11.0	11.0	11.0	1	1	0	1	1	0	8.0	13.0
X21	13.0	13.0	15.5	16.0	1	0	0	1	0	0	11.5	11.5
X22	3.3	2.7	2.7	2.7	1	0	0	1	0	0	8.3	9.3
X24	3.0	3.0	5.0	5.0	0	0	0	0	0	0	4.0	4.0
X28	4.0	4.0	4.0	3.0	0	0	0	0	0	0	6.0	3.0
X29	11.0	11.0	8.0	12.0	2	1	0	2	1	0	13.0	13.0
X30	13.0	8.0	3. 0	11.0	2	2	1	0	0	0	12.0	15.0
X31	4.0	2.0	4.0	2.	0	0	0	0	0	0	8.0	8.0
X33	12.0	12.0	8.0	8.0	0	0	0	1	0	0	13.0	8.0
X34	11.8	10.6	13.0	9.0	1	1	1	1	1	1	10.4	12.2
X35	11.0	13.0	12.0	14.0	0	0	0	1	1	1	11.0	13.0
X38	8.0	7.0	9.5	6.50	1	1	0	1	0	0	12.0	10.5

Table B5. Beargrass Creek restoration site existing condition data for SMURF inputs (2 of 2).

Rest_Num	Deadfall_Left	Deadfall_Right	Detritus_Left	Detritus_Right	Herbaceous_Left	Herbaceous_Right	Invasive_Dominance_Left	Invasive_Dominance_Right	Stream_Canopy_Cover	OM_Retention	Embeddedness
X2	11.500000	11.500000	12.0	12.0	11.000000	11.000000	10.000000	10.000000	7.500000	7.500000	4.0000000
X4	8.000000	9.000000	11.0	10.0	11.000000	9.000000	6.000000	5.000000	7.000000	4.000000	7.0000000
X5	6.000000	3.000000	10.0	5.0	13.000000	11.000000	8.000000	6.000000	16.000000	4.000000	16.0000000
X8	14.000000	11.500000	12.0	12.0	9.500000	9.500000	11.000000	11.000000	14.500000	12.000000	11.5000000
X9	7.000000	7.000000	13.0	13.0	18.000000	18.000000	15.000000	15.000000	18.000000	13.000000	5.0000000
X10	13.000000	13.000000	10.0	10.0	10.000000	10.000000	8.000000	9.000000	14.000000	11.000000	6.0000000
X11	15.000000	15.000000	16.0	16.0	14.000000	12.000000	13.000000	13.000000	10.000000	13.000000	1.0000000
X15	0.000000	0.000000	3.0	3.0	13.000000	13.000000	3.000000	3.000000	2.000000	6.000000	5.0000000
X19	8.000000	8.000000	5.0	5.0	8.000000	8.000000	7.000000	7.000000	5.000000	8.000000	6.5000000
X20	2.500000	4.000000	5.0	6.5	11.000000	11.500000	8.500000	8.500000	7.000000	7.000000	11.0000000
X21	9.500000	9.500000	12.0	12.0	10.500000	10.500000	12.000000	12.000000	10.500000	6.500000	7.5000000
X22	4.333333	4.333333	2.0	2.0	3.666667	5.333333	4.333333	4.333333	7.333333	1.333333	0.6666667
X24	4.000000	4.000000	4.0	4.0	11.000000	11.000000	7.000000	7.000000	4.000000	5.000000	6.0000000

Rest_Num	Deadfall_Left	Deadfall_Right	Detritus_Left	Detritus_Right	Herbaceous_Left	Herbaceous_Right	Invasive_Dominance_Left	Invasive_Dominance_Right	Stream_Canopy_Cover	OM_Retention	Embeddedness
X28	0.000000	0.000000	3.0	3.0	11.000000	11.000000	3.000000	3.000000	2.000000	5.000000	3.000000
X29	13.000000	13.000000	3.0	3.0	3.000000	8.000000	8.000000	8.000000	14.000000	13.000000	10.000000
X30	6.000000	3.000000	13.0	3.0	13.000000	3.000000	13.000000	8.000000	10.000000	13.000000	8.000000
X31	5.000000	5.000000	5.0	5.0	8.000000	8.000000	8.000000	8.000000	11.000000	8.000000	2.000000
X33	8.000000	8.000000	11.0	11.0	8.000000	8.000000	8.000000	8.000000	16.000000	13.000000	13.000000
X34	9.000000	9.200000	10.2	7.6	11.200000	10.000000	10.000000	9.800000	11.400000	8.200000	7.200000
X35	8.000000	8.000000	5.0	11.0	8.000000	13.000000	11.000000	11.000000	8.000000	12.000000	8.000000
X38	6.000000	9.000000	9.0	9.5	9.000000	9.500000	6.500000	6.500000	6.000000	9.000000	7.000000

Table B6. Scoring rubric for QHEILS forecasting. Values represent percentage increases over the existing condition, except Incision_Ratio which indicates the forecasted value for this parameter.

Alternative	Year	Substrate	Instream_Cover	Channel_Morphology	Bank_Erosion_Riparian	Pool_Current	Riffle_Run	Gradient	Incision_Ratio	Aquatic_Organism_Passage	Material_Transport
FWOP	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
FWOP	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
FWOP	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
FWOP	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
FWOP	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
C	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
C	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.9	0.75
C	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.9	0.75
C	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
C	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.9	0.75
R1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
R1	2	0.25	0.25	0.00	0.00	0.00	0.25	0.00	0	0.0	0.00
R1	10	0.25	0.50	0.00	0.00	0.00	0.25	0.00	0	0.0	0.00
R1	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
R1	50	0.25	0.50	0.00	0.00	0.00	0.25	0.00	0	0.0	0.00
R2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
R2	2	0.35	0.40	0.00	0.25	0.25	0.35	0.00	1	0.0	0.00
R2	10	0.50	0.80	0.00	0.25	0.25	0.50	0.00	1	0.0	0.00
R2	20	NA	NA	NA	NA	NA	NA	NA	1	NA	NA
R2	50	0.50	0.80	0.00	0.50	0.25	0.50	0.00	1	0.0	0.00
R3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
R3	2	0.05	0.00	0.05	0.05	0.05	0.05	0.05	0	0.0	0.00
R3	10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0	0.0	0.00

R3	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
R3	50	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0	0.0	0.00
R4	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
R4	2	0.80	0.80	0.90	0.70	0.90	0.90	0.50	1	0.0	0.00
R4	10	0.80	0.80	0.90	0.90	0.90	0.90	0.70	1	0.0	0.00
R4	20	NA	NA	NA	NA	NA	NA	NA	1	NA	NA
R4	50	0.80	0.80	0.90	0.90	0.90	0.90	0.70	1	0.0	0.00
H1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H1	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H1	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H1	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
H1	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H2	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H2	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H2	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
H2	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H3	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H3	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
H3	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
H3	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
P	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
P	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
P	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00
P	20	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
P	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.0	0.00

Table B7. Scoring rubric for SMURF forecasting. All values represent percentage increases over the existing condition, except canopy height and structure. Canopy_Height is an increase in height in feet over the existing condition. Overstory, Midstory, and WoodyShrubs are quality metrics (high, medium, low = 2,1,0) used unless the existing condition is higher.

Alternative	Year	Canopy Height	Buffer Develop-ment	Buffer Flowpaths	Overstory	Midstory	WoodyShrubs	Snags	Deadfall	Detritus	Herbaceous	Invasive Dominance	Stream Canopy Cover	OM Retention	Embedded-ness
FWOP	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
FWOP	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
FWOP	10	15	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.1	0.0	0.00	0.00
FWOP	20	30	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.2	0.0	0.00	0.00
FWOP	50	50	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.5	0.0	0.00	0.00
C	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
C	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
C	10	15	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.1	0.0	0.00	0.00
C	20	30	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.2	0.0	0.00	0.00
C	50	50	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.5	0.0	0.00	0.00
R1	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
R1	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R1	10	15	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.1	0.0	0.25	0.25
R1	20	30	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.2	0.0	0.60	0.60
R1	50	50	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	-0.5	0.0	0.80	0.80
R2	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
R2	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R2	10	15	0.0	0.25	0	0	0	0.00	0.00	0.0	0.0	-0.1	0.0	0.60	0.60
R2	20	30	0.0	0.50	0	0	0	0.00	0.00	0.0	0.0	-0.2	0.0	0.80	0.80
R2	50	50	0.0	0.80	0	0	0	0.00	0.00	0.0	0.0	-0.5	0.0	0.80	0.80

Table B7 (cont). Scoring rubric for SMURF forecasting. All values represent percentage increases over the existing condition, except canopy height and structure. Canopy_Height is an increase in height in feet over the existing condition. Overstory, Midstory, and WoodyShrubs are quality metrics (high, medium, low = 2,1,0) used unless the existing condition is higher.

Alternative	Year	Canopy Height	Buffer Develop-ment	Buffer Flowpaths	Overstory	Midstory	WoodyShrubs	Snags	Deadfall	Detritus	Herbaceous	Invasive Dominance	Stream Canopy Cover	OM Retention	Embedded-ness
R3	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
R3	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R3	10	15	0.0	0.25	0	0	0	0.00	0.00	0.0	0.0	-0.1	0.0	0.10	0.10
R3	20	30	0.0	0.50	0	0	0	0.00	0.00	0.0	0.0	-0.2	0.0	0.20	0.20
R3	50	50	0.0	0.80	0	0	0	0.00	0.00	0.0	0.0	-0.5	0.0	0.30	0.30
R4	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
R4	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
R4	10	15	0.0	0.80	0	0	0	0.00	0.00	0.0	0.0	-0.1	0.0	0.60	0.90
R4	20	30	0.0	0.90	0	0	0	0.00	0.00	0.0	0.0	-0.2	0.0	0.80	0.90
R4	50	50	0.0	0.90	0	0	0	0.00	0.00	0.0	0.0	-0.5	0.0	0.90	0.90
H1	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
H1	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
H1	10	15	0.5	0.00	0	0	0	0.00	0.00	0.1	0.1	0.1	0.0	0.00	0.00
H1	20	30	0.5	0.00	0	0	0	0.00	0.00	0.2	0.2	0.2	0.0	0.00	0.00
H1	50	70	0.5	0.00	0	0	0	0.00	0.00	0.5	0.5	0.5	0.0	0.00	0.00
H2	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
H2	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
H2	10	15	0.5	0.00	0	0	0	0.00	0.00	0.1	0.1	0.1	0.0	0.00	0.00
H2	20	30	0.5	0.00	0	0	0	0.00	0.00	0.2	0.2	0.2	0.0	0.00	0.00
H2	50	70	0.5	0.00	0	0	0	0.00	0.00	0.5	0.5	0.5	0.0	0.00	0.00

Table B7 (cont). Scoring rubric for SMURF forecasting. All values represent percentage increases over the existing condition, except canopy height and structure. Canopy_Height is an increase in height in feet over the existing condition. Overstory, Midstory, and WoodyShrubs are quality metrics (high, medium, low = 2,1,0) used unless the existing condition is higher.

Alternative	Year	Canopy Height	Buffer Develop-ment	Buffer Flowpaths	Overstory	Midstory	WoodyShrubs	Snags	Deadfall	Detritus	Herbaceous	Invasive Dominance	Stream Canopy Cover	OM Retention	Embedded-ness
H3	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
H3	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
H3	10	0	0.0	0.00	0	0	0	0.00	0.00	0.1	0.1	0.1	0.0	0.00	0.00
H3	20	0	0.0	0.00	0	0	0	0.00	0.00	0.2	0.2	0.2	0.0	0.00	0.00
H3	50	0	0.0	0.00	0	0	0	0.00	0.00	0.5	0.5	0.5	0.0	0.00	0.00
P	0	0	0.0	0.00	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.00
P	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
P	10	15	0.7	0.00	0	1	2	0.25	0.25	0.5	0.9	0.9	0.5	0.00	0.00
P	20	30	0.8	0.00	1	2	2	0.90	0.50	0.5	0.9	0.9	0.9	0.00	0.00
P	50	70	0.9	0.00	2	2	2	0.90	0.90	0.5	0.9	0.9	0.9	0.00	0.00

Table B8. Other social effects outcomes. All categories are semi-quantitative with a range of 0 to 20.

Rest Num	Rest Name	Fork	Recommended Alternative	Total Site Area (ac)	Logistic Real Estate	Logistic Access	Logistic HTRW	Economic Employment	Economic Potential	Economic Flooding	Social Visibility	Social Env Justice	Social Recreation	Social Community	Technical Scarcity	Technical Connectivity
X2	Confluence	South	CR2H2	170.6	12	18	5	11	18	11	16	9	18	19	18	16
X4	Shelby Campus	Middle	CR4P	81.7	15	18	17	5	12	13	11	1	15	10	16	14
X8	Houston Acre's Farm	South	P	130.4	15	13	12	7	2	10	8	14	11	9	11	2
X10	Alpaca Farm / Zoo	South	CR2P	79.3	12	13	18	10	18	14	13	5	20	15	12	18
X19	South Fork / Newburg Rd	South	CR1H2	44.5	19	16	6	16	8	9	15	19	10	4	13	6
X20	Brown Park	Middle	CR2P	30.4	10	16	13	5	15	12	15	15	13	6	15	9
X21	Arthur Draut Park	Middle	CR2P	40.0	8	14	11	14	16	12	14	13	12	6	15	9
X22	Concrete Channel	South	H2	47.1	10	14	13	20	20	14	20	20	18	18	13	8
X29	Eastern / Creason Connector	South	CR4P	97.8	8	5	18	10	15	15	16	10	18	15	16	15
X30	Joe Creason Park	South	CR4P	121.3	14	20	20	5	20	19	18	2	20	17	16	15
X33	MSD Basin	South	H2	11.8	18	20	18	5	5	15	11	11	11	6	14	8
X34	Cherokee / Seneca Parks	Middle	CR2P	267.1	10	17	19	16	20	14	20	0	15	18	14	16
X35	Muddy Fork and Tribs	Muddy	CR2H2	127.9	5	12	16	0	7	16	14	9	8	12	14	9
X38	Cave Hill Corridor	Middle	R2H2	52.1	10	16	11	12	16	14	18	7	16	16	16	9

Attachment C: CEICA Inputs

Table C1. All ecological model outputs.

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X2	FWOP	0	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.51	6.81	31.78	0.58	18.43
X2	FWOP	2	15.32	0.6	9.14	0	0.6	0	9.14	NA	NA	NA	NA	NA	NA
X2	FWOP	10	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.51	6.78	31.78	0.58	18.51
X2	FWOP	20	NA	NA	NA	NA	NA	NA	NA	13.27	0.51	6.75	31.78	0.58	18.43
X2	FWOP	50	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.5	6.66	31.78	0.57	18.18
X2	R1	0	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.51	6.81	31.78	0.58	18.43
X2	R1	2	4.63	0.6	2.76	10.69	0.62	6.67	9.44	NA	NA	NA	NA	NA	NA
X2	R1	10	4.63	0.6	2.76	10.69	0.63	6.77	9.53	13.27	0.53	6.98	31.78	0.6	19.03
X2	R1	20	NA	NA	NA	NA	NA	NA	NA	13.27	0.54	7.22	31.78	0.62	19.67
X2	R1	50	4.63	0.6	2.76	10.69	0.63	6.77	9.53	13.27	0.55	7.29	31.78	0.62	19.85
X2	R2	0	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.51	6.81	31.78	0.58	18.43
X2	R2	2	13.67	0.6	8.16	1.64	0.64	1.06	9.22	NA	NA	NA	NA	NA	NA
X2	R2	10	13.67	0.6	8.16	1.64	0.67	1.1	9.26	13.27	0.55	7.3	31.78	0.63	19.87
X2	R2	20	NA	NA	NA	NA	NA	NA	NA	13.27	0.56	7.48	31.78	0.64	20.31
X2	R2	50	13.67	0.6	8.16	1.64	0.67	1.11	9.26	13.27	0.56	7.45	31.78	0.64	20.22
X2	R3	0	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.51	6.81	31.78	0.58	18.43
X2	R3	2	13.43	0.6	8.01	1.89	0.6	1.14	9.15	NA	NA	NA	NA	NA	NA
X2	R3	10	13.43	0.6	8.01	1.89	0.62	1.16	9.17	13.27	0.52	6.91	31.78	0.59	18.84
X2	R3	20	NA	NA	NA	NA	NA	NA	NA	13.27	0.53	7.01	31.78	0.6	19.08
X2	R3	50	13.43	0.6	8.01	1.89	0.65	1.23	9.24	13.27	0.53	7.06	31.78	0.6	19.18
X2	R4	0	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.51	6.81	31.78	0.58	18.43

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X2	R4	2	11.86	0.6	7.08	3.46	0.75	2.6	9.68	NA	NA	NA	NA	NA	NA
X2	R4	10	11.86	0.6	7.08	3.46	0.75	2.61	9.69	13.27	0.57	7.55	31.78	0.64	20.5
X2	R4	20	NA	NA	NA	NA	NA	NA	NA	13.27	0.57	7.6	31.78	0.65	20.62
X2	R4	50	11.86	0.6	7.08	3.46	0.75	2.61	9.69	13.27	0.57	7.54	31.78	0.64	20.46
X2	H2	0	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.58	7.64	31.78	0.6	19.05
X2	H2	2	15.32	0.6	9.14	0	0.6	0	9.14	NA	NA	NA	NA	NA	NA
X2	H2	10	15.32	0.6	9.14	0	0.6	0	9.14	18.81	0.6	11.34	48.69	0.63	30.65
X2	H2	20	NA	NA	NA	NA	NA	NA	NA	18.81	0.61	11.46	48.69	0.64	30.99
X2	H2	50	15.32	0.6	9.14	0	0.6	0	9.14	18.81	0.63	11.83	48.69	0.66	31.98
X2	P	0	15.32	0.6	9.14	0	0.6	0	9.14	13.27	0.57	7.58	31.78	0.6	19.14
X2	P	2	15.32	0.6	9.14	0	0.6	0	9.14	NA	NA	NA	NA	NA	NA
X2	P	10	15.32	0.6	9.14	0	0.6	0	9.14	17.8	0.69	12.35	59.39	0.73	43.32
X2	P	20	NA	NA	NA	NA	NA	NA	NA	17.8	0.72	12.85	59.39	0.76	45
X2	P	50	15.32	0.6	9.14	0	0.6	0	9.14	17.8	0.75	13.33	59.39	0.78	46.58
X4	FWOP	0	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.54	10.21	32.82	0.53	17.54
X4	FWOP	2	2.34	0.38	0.9	0	0.38	0	0.9	NA	NA	NA	NA	NA	NA
X4	FWOP	10	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.53	10.14	32.82	0.53	17.39
X4	FWOP	20	NA	NA	NA	NA	NA	NA	NA	18.98	0.53	10.06	32.82	0.53	17.24
X4	FWOP	50	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.52	9.88	32.82	0.52	17.04
X4	C	0	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.54	10.21	32.82	0.53	17.54
X4	C	2	0.82	0.38	0.31	1.53	0.51	0.78	1.09	NA	NA	NA	NA	NA	NA
X4	C	10	0.82	0.38	0.31	1.53	0.51	0.78	1.09	18.98	0.53	10.14	32.82	0.53	17.39
X4	C	20	NA	NA	NA	NA	NA	NA	NA	18.98	0.53	10.06	32.82	0.53	17.24
X4	C	50	0.82	0.38	0.31	1.53	0.51	0.78	1.09	18.98	0.52	9.88	32.82	0.52	17.04

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X4	R1	0	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.54	10.21	32.82	0.53	17.54
X4	R1	2	0.82	0.38	0.31	1.53	0.4	0.61	0.93	NA	NA	NA	NA	NA	NA
X4	R1	10	0.82	0.38	0.31	1.53	0.41	0.63	0.94	18.98	0.55	10.48	32.82	0.55	17.99
X4	R1	20	NA	NA	NA	NA	NA	NA	NA	18.98	0.57	10.87	32.82	0.57	18.67
X4	R1	50	0.82	0.38	0.31	1.53	0.41	0.63	0.94	18.98	0.58	10.97	32.82	0.58	18.94
X4	R3	0	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.54	10.21	32.82	0.53	17.54
X4	R3	2	0.82	0.38	0.31	1.53	0.39	0.59	0.91	NA	NA	NA	NA	NA	NA
X4	R3	10	0.82	0.38	0.31	1.53	0.4	0.61	0.92	18.98	0.54	10.34	32.82	0.54	17.74
X4	R3	20	NA	NA	NA	NA	NA	NA	NA	18.98	0.55	10.45	32.82	0.55	17.93
X4	R3	50	0.82	0.38	0.31	1.53	0.42	0.65	0.96	18.98	0.55	10.48	32.82	0.55	18.09
X4	R4	0	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.54	10.21	32.82	0.53	17.54
X4	R4	2	0.82	0.38	0.31	1.53	0.83	1.27	1.58	NA	NA	NA	NA	NA	NA
X4	R4	10	0.82	0.38	0.31	1.53	0.83	1.27	1.58	18.98	0.61	11.54	32.82	0.6	19.85
X4	R4	20	NA	NA	NA	NA	NA	NA	NA	18.98	0.61	11.61	32.82	0.61	19.95
X4	R4	50	0.82	0.38	0.31	1.53	0.83	1.27	1.58	18.98	0.61	11.5	32.82	0.6	19.86
X4	H2	0	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.54	10.23	32.82	0.58	19.11
X4	H2	2	2.34	0.38	0.9	0	0.38	0	0.9	NA	NA	NA	NA	NA	NA
X4	H2	10	2.34	0.38	0.9	0	0.38	0	0.9	21.04	0.56	11.8	34.47	0.6	20.84
X4	H2	20	NA	NA	NA	NA	NA	NA	NA	21.04	0.57	11.99	34.47	0.62	21.23
X4	H2	50	2.34	0.38	0.9	0	0.38	0	0.9	21.04	0.59	12.52	34.47	0.65	22.3
X4	P	0	2.34	0.38	0.9	0	0.38	0	0.9	18.98	0.59	11.16	32.82	0.58	19.14
X4	P	2	2.34	0.38	0.9	0	0.38	0	0.9	NA	NA	NA	NA	NA	NA
X4	P	10	2.34	0.38	0.9	0	0.38	0	0.9	24	0.76	18.28	37.08	0.77	28.44
X4	P	20	NA	NA	NA	NA	NA	NA	NA	24	0.8	19.1	37.08	0.8	29.68

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X4	P	50	2.34	0.38	0.9	0	0.38	0	0.9	24	0.83	19.83	37.08	0.83	30.78
X5	FWOP	0	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.54	20.36	20.98	0.4	8.45
X5	FWOP	2	6.21	0.63	3.93	0	0.63	0	3.93	NA	NA	NA	NA	NA	NA
X5	FWOP	10	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.56	20.84	20.98	0.4	8.45
X5	FWOP	20	NA	NA	NA	NA	NA	NA	NA	37.41	0.55	20.71	20.98	0.4	8.36
X5	FWOP	50	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.54	20.32	20.98	0.39	8.15
X5	C	0	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.54	20.36	20.98	0.4	8.45
X5	C	2	0	0.63	0	6.21	0.82	5.08	5.08	NA	NA	NA	NA	NA	NA
X5	C	10	0	0.63	0	6.21	0.82	5.08	5.08	37.41	0.56	20.84	20.98	0.4	8.45
X5	C	20	NA	NA	NA	NA	NA	NA	NA	37.41	0.55	20.71	20.98	0.4	8.36
X5	C	50	0	0.63	0	6.21	0.82	5.08	5.08	37.41	0.54	20.32	20.98	0.39	8.15
X5	R3	0	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.54	20.36	20.98	0.4	8.45
X5	R3	2	0	0.63	0	6.21	0.64	3.96	3.96	NA	NA	NA	NA	NA	NA
X5	R3	10	0	0.63	0	6.21	0.64	4	4	37.41	0.56	21.06	20.98	0.41	8.67
X5	R3	20	NA	NA	NA	NA	NA	NA	NA	37.41	0.57	21.16	20.98	0.42	8.8
X5	R3	50	0	0.63	0	6.21	0.67	4.15	4.15	37.41	0.56	21	20.98	0.42	8.81
X5	H1	0	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.54	20.36	20.98	0.4	8.45
X5	H1	2	6.21	0.63	3.93	0	0.63	0	3.93	NA	NA	NA	NA	NA	NA
X5	H1	10	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.59	22.11	20.98	0.45	9.38
X5	H1	20	NA	NA	NA	NA	NA	NA	NA	37.41	0.6	22.41	20.98	0.46	9.6
X5	H1	50	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.62	23.27	20.98	0.49	10.23
X5	P	0	6.21	0.63	3.93	0	0.63	0	3.93	37.41	0.57	21.22	20.98	0.47	9.78
X5	P	2	6.21	0.63	3.93	0	0.63	0	3.93	NA	NA	NA	NA	NA	NA
X5	P	10	6.21	0.63	3.93	0	0.63	0	3.93	45.83	0.75	34.27	33.64	0.67	22.59

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X5	P	20	NA	NA	NA	NA	NA	NA	NA	45.83	0.78	35.88	33.64	0.73	24.57
X5	P	50	6.21	0.63	3.93	0	0.63	0	3.93	45.83	0.82	37.35	33.64	0.77	25.77
X8	FWOP	0	3.95	0.66	2.61	0	0.66	0	2.61	43.17	0.71	30.48	48.3	0.68	33.02
X8	FWOP	2	3.95	0.66	2.61	0	0.66	0	2.61	NA	NA	NA	NA	NA	NA
X8	FWOP	10	3.95	0.66	2.61	0	0.66	0	2.61	43.17	0.7	30.39	48.3	0.68	32.91
X8	FWOP	20	NA	NA	NA	NA	NA	NA	NA	43.17	0.7	30.29	48.3	0.68	32.8
X8	FWOP	50	3.95	0.66	2.61	0	0.66	0	2.61	43.17	0.69	30	48.3	0.67	32.46
X8	C	0	3.95	0.66	2.61	0	0.66	0	2.61	43.17	0.71	30.48	48.3	0.68	33.02
X8	C	2	0.34	0.66	0.23	3.6	0.88	3.15	3.38	NA	NA	NA	NA	NA	NA
X8	C	10	0.34	0.66	0.23	3.6	0.88	3.15	3.38	43.17	0.7	30.39	48.3	0.68	32.91
X8	C	20	NA	NA	NA	NA	NA	NA	NA	43.17	0.7	30.29	48.3	0.68	32.8
X8	C	50	0.34	0.66	0.23	3.6	0.88	3.15	3.38	43.17	0.69	30	48.3	0.67	32.46
X8	R2	0	3.95	0.66	2.61	0	0.66	0	2.61	43.17	0.71	30.48	48.3	0.68	33.02
X8	R2	2	0.34	0.66	0.23	3.6	0.68	2.45	2.68	NA	NA	NA	NA	NA	NA
X8	R2	10	0.34	0.66	0.23	3.6	0.69	2.48	2.71	43.17	0.73	31.43	48.3	0.71	34.09
X8	R2	20	NA	NA	NA	NA	NA	NA	NA	43.17	0.73	31.73	48.3	0.71	34.45
X8	R2	50	0.34	0.66	0.23	3.6	0.69	2.49	2.71	43.17	0.73	31.53	48.3	0.71	34.24
X8	R4	0	3.95	0.66	2.61	0	0.66	0	2.61	43.17	0.71	30.48	48.3	0.68	33.02
X8	R4	2	2.64	0.66	1.75	1.3	0.73	0.95	2.7	NA	NA	NA	NA	NA	NA
X8	R4	10	2.64	0.66	1.75	1.3	0.73	0.95	2.71	43.17	0.74	31.86	48.3	0.72	34.63
X8	R4	20	NA	NA	NA	NA	NA	NA	NA	43.17	0.74	31.94	48.3	0.72	34.72
X8	R4	50	2.64	0.66	1.75	1.3	0.73	0.95	2.71	43.17	0.73	31.72	48.3	0.71	34.46
X8	P	0	3.95	0.66	2.61	0	0.66	0	2.61	43.17	0.73	31.54	48.3	0.71	34.26
X8	P	2	3.95	0.66	2.61	0	0.66	0	2.61	NA	NA	NA	NA	NA	NA

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X8	P	10	3.95	0.66	2.61	0	0.66	0	2.61	48.35	0.83	39.99	58.67	0.82	47.88
X8	P	20	NA	NA	NA	NA	NA	NA	NA	48.35	0.83	40.36	58.67	0.83	48.64
X8	P	50	3.95	0.66	2.61	0	0.66	0	2.61	48.35	0.84	40.72	58.67	0.84	49.26
X9	FWOP	0	0.34	0.44	0.15	0	0.44	0	0.15	7.87	0.7	5.51	2.3	0.64	1.46
X9	FWOP	2	0.34	0.44	0.15	0	0.44	0	0.15	NA	NA	NA	NA	NA	NA
X9	FWOP	10	0.34	0.44	0.15	0	0.44	0	0.15	7.87	0.7	5.5	2.3	0.63	1.46
X9	FWOP	20	NA	NA	NA	NA	NA	NA	NA	7.87	0.7	5.49	2.3	0.63	1.45
X9	FWOP	50	0.34	0.44	0.15	0	0.44	0	0.15	7.87	0.69	5.45	2.3	0.63	1.45
X9	C	0	0.34	0.44	0.15	0	0.44	0	0.15	7.87	0.7	5.51	2.3	0.64	1.46
X9	C	2	0	0.44	0	0.34	0.51	0.17	0.17	NA	NA	NA	NA	NA	NA
X9	C	10	0	0.44	0	0.34	0.51	0.17	0.17	7.87	0.7	5.5	2.3	0.63	1.46
X9	C	20	NA	NA	NA	NA	NA	NA	NA	7.87	0.7	5.49	2.3	0.63	1.45
X9	C	50	0	0.44	0	0.34	0.51	0.17	0.17	7.87	0.69	5.45	2.3	0.63	1.45
X9	R2	0	0.34	0.44	0.15	0	0.44	0	0.15	7.87	0.7	5.51	2.3	0.64	1.46
X9	R2	2	0	0.44	0	0.34	0.81	0.28	0.28	NA	NA	NA	NA	NA	NA
X9	R2	10	0	0.44	0	0.34	0.83	0.28	0.28	7.87	0.74	5.82	2.3	0.67	1.54
X9	R2	20	NA	NA	NA	NA	NA	NA	NA	7.87	0.75	5.92	2.3	0.68	1.57
X9	R2	50	0	0.44	0	0.34	0.83	0.28	0.28	7.87	0.75	5.92	2.3	0.68	1.57
X9	P	0	0.34	0.44	0.15	0	0.44	0	0.15	7.87	0.74	5.84	2.3	0.72	1.65
X9	P	2	0.34	0.44	0.15	0	0.44	0	0.15	NA	NA	NA	NA	NA	NA
X9	P	10	0.34	0.44	0.15	0	0.44	0	0.15	12.29	0.83	10.18	16.3	0.81	13.15
X9	P	20	NA	NA	NA	NA	NA	NA	NA	12.29	0.85	10.41	16.3	0.83	13.45
X9	P	50	0.34	0.44	0.15	0	0.44	0	0.15	12.29	0.86	10.61	16.3	0.84	13.71

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X10	FWOP	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.42	1.71	14.58	0.6	8.72
X10	FWOP	2	3.06	0.4	1.22	0	0.4	0	1.22	NA	NA	NA	NA	NA	NA
X10	FWOP	10	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.42	1.7	14.58	0.6	8.68
X10	FWOP	20	NA	NA	NA	NA	NA	NA	NA	4.06	0.42	1.69	14.58	0.59	8.64
X10	FWOP	50	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.41	1.66	14.58	0.58	8.52
X10	C	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.42	1.71	14.58	0.6	8.72
X10	C	2	0.12	0.4	0.05	2.94	0.51	1.5	1.55	NA	NA	NA	NA	NA	NA
X10	C	10	0.12	0.4	0.05	2.94	0.51	1.5	1.55	4.06	0.42	1.7	14.58	0.6	8.68
X10	C	20	NA	NA	NA	NA	NA	NA	NA	4.06	0.42	1.69	14.58	0.59	8.64
X10	C	50	0.12	0.4	0.05	2.94	0.51	1.5	1.55	4.06	0.41	1.66	14.58	0.58	8.52
X10	R1	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.42	1.71	14.58	0.6	8.72
X10	R1	2	2.65	0.4	1.06	0.41	0.42	0.17	1.23	NA	NA	NA	NA	NA	NA
X10	R1	10	2.65	0.4	1.06	0.41	0.42	0.18	1.23	4.06	0.43	1.74	14.58	0.61	8.88
X10	R1	20	NA	NA	NA	NA	NA	NA	NA	4.06	0.44	1.79	14.58	0.63	9.12
X10	R1	50	2.65	0.4	1.06	0.41	0.42	0.18	1.23	4.06	0.44	1.8	14.58	0.63	9.17
X10	R2	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.42	1.71	14.58	0.6	8.72
X10	R2	2	0.25	0.4	0.1	2.81	0.76	2.14	2.24	NA	NA	NA	NA	NA	NA
X10	R2	10	0.25	0.4	0.1	2.81	0.78	2.19	2.29	4.06	0.49	1.97	14.58	0.68	9.86
X10	R2	20	NA	NA	NA	NA	NA	NA	NA	4.06	0.5	2.02	14.58	0.69	10.04
X10	R2	50	0.25	0.4	0.1	2.81	0.78	2.19	2.29	4.06	0.5	2.02	14.58	0.69	10
X10	R4	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.42	1.71	14.58	0.6	8.72
X10	R4	2	0.12	0.4	0.05	2.94	0.84	2.47	2.51	NA	NA	NA	NA	NA	NA
X10	R4	10	0.12	0.4	0.05	2.94	0.84	2.48	2.53	4.06	0.51	2.06	14.58	0.7	10.16

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X10	R4	20	NA	NA	NA	NA	NA	NA	NA	4.06	0.51	2.07	14.58	0.7	10.2
X10	R4	50	0.12	0.4	0.05	2.94	0.84	2.48	2.53	4.06	0.5	2.05	14.58	0.69	10.1
X10	H2	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.45	1.84	14.58	0.6	8.72
X10	H2	2	3.06	0.4	1.22	0	0.4	0	1.22	NA	NA	NA	NA	NA	NA
X10	H2	10	3.06	0.4	1.22	0	0.4	0	1.22	5.06	0.48	2.44	15.56	0.61	9.56
X10	H2	20	NA	NA	NA	NA	NA	NA	NA	5.06	0.49	2.47	15.56	0.62	9.68
X10	H2	50	3.06	0.4	1.22	0	0.4	0	1.22	5.06	0.51	2.56	15.56	0.64	10.01
X10	H3	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.42	1.71	14.58	0.6	8.73
X10	H3	2	3.06	0.4	1.22	0	0.4	0	1.22	NA	NA	NA	NA	NA	NA
X10	H3	10	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.43	1.73	15.8	0.61	9.58
X10	H3	20	NA	NA	NA	NA	NA	NA	NA	4.06	0.43	1.75	15.8	0.61	9.69
X10	H3	50	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.45	1.81	15.8	0.63	10.03
X10	P	0	3.06	0.4	1.22	0	0.4	0	1.22	4.06	0.6	2.41	14.58	0.64	9.26
X10	P	2	3.06	0.4	1.22	0	0.4	0	1.22	NA	NA	NA	NA	NA	NA
X10	P	10	3.06	0.4	1.22	0	0.4	0	1.22	42.41	0.71	30.03	29.23	0.74	21.61
X10	P	20	NA	NA	NA	NA	NA	NA	NA	42.41	0.72	30.72	29.23	0.75	22.03
X10	P	50	3.06	0.4	1.22	0	0.4	0	1.22	42.41	0.75	31.79	29.23	0.78	22.73
X11	FWOP	0	5.39	0.28	1.52	0	0.28	0	1.52	30.01	0.58	17.54	28.53	0.58	16.57
X11	FWOP	2	5.39	0.28	1.52	0	0.28	0	1.52	NA	NA	NA	NA	NA	NA
X11	FWOP	10	5.39	0.28	1.52	0	0.28	0	1.52	30.01	0.58	17.49	28.53	0.58	16.52
X11	FWOP	20	NA	NA	NA	NA	NA	NA	NA	30.01	0.58	17.44	28.53	0.58	16.47
X11	FWOP	50	5.39	0.28	1.52	0	0.28	0	1.52	30.01	0.58	17.28	28.53	0.57	16.33
X11	R1	0	5.39	0.28	1.52	0	0.28	0	1.52	30.01	0.58	17.54	28.53	0.58	16.57

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X11	R1	2	2.04	0.28	0.58	3.34	0.31	1.05	1.62	NA	NA	NA	NA	NA	NA
X11	R1	10	2.04	0.28	0.58	3.34	0.33	1.09	1.67	30.01	0.6	17.95	28.53	0.59	16.93
X11	R1	20	NA	NA	NA	NA	NA	NA	NA	30.01	0.62	18.52	28.53	0.61	17.46
X11	R1	50	2.04	0.28	0.58	3.34	0.33	1.09	1.67	30.01	0.62	18.72	28.53	0.62	17.65
X11	R2	0	5.39	0.28	1.52	0	0.28	0	1.52	30.01	0.58	17.54	28.53	0.58	16.57
X11	R2	2	3.21	0.28	0.9	2.18	0.67	1.47	2.37	NA	NA	NA	NA	NA	NA
X11	R2	10	3.21	0.28	0.9	2.18	0.71	1.54	2.44	30.01	0.62	18.7	28.53	0.62	17.75
X11	R2	20	NA	NA	NA	NA	NA	NA	NA	30.01	0.64	19.08	28.53	0.64	18.21
X11	R2	50	3.21	0.28	0.9	2.18	0.71	1.55	2.45	30.01	0.63	19.02	28.53	0.64	18.29
X11	H2	0	5.39	0.28	1.52	0	0.28	0	1.52	30.01	0.58	17.54	28.53	0.58	16.65
X11	H2	2	5.39	0.28	1.52	0	0.28	0	1.52	NA	NA	NA	NA	NA	NA
X11	H2	10	5.39	0.28	1.52	0	0.28	0	1.52	30.05	0.6	18.12	29.55	0.61	18.05
X11	H2	20	NA	NA	NA	NA	NA	NA	NA	30.05	0.61	18.25	29.55	0.62	18.18
X11	H2	50	5.39	0.28	1.52	0	0.28	0	1.52	30.05	0.62	18.62	29.55	0.63	18.57
X11	P	0	5.39	0.28	1.52	0	0.28	0	1.52	30.01	0.62	18.63	28.53	0.64	18.33
X11	P	2	5.39	0.28	1.52	0	0.28	0	1.52	NA	NA	NA	NA	NA	NA
X11	P	10	5.39	0.28	1.52	0	0.28	0	1.52	53.21	0.75	39.65	38.81	0.75	29.14
X11	P	20	NA	NA	NA	NA	NA	NA	NA	53.21	0.77	41.01	38.81	0.78	30.23
X11	P	50	5.39	0.28	1.52	0	0.28	0	1.52	53.21	0.79	42.19	38.81	0.8	31.18
X15	FWOP	0	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.25	0.61	2.26	0.24	0.54
X15	FWOP	2	0.74	0.76	0.56	0	0.76	0	0.56	NA	NA	NA	NA	NA	NA
X15	FWOP	10	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.24	0.6	2.26	0.23	0.53
X15	FWOP	20	NA	NA	NA	NA	NA	NA	NA	2.45	0.24	0.59	2.26	0.23	0.52

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X15	FWOP	50	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.24	0.59	2.26	0.23	0.52
X15	C	0	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.25	0.61	2.26	0.24	0.54
X15	C	2	0.29	0.76	0.22	0.44	0.78	0.35	0.57	NA	NA	NA	NA	NA	NA
X15	C	10	0.29	0.76	0.22	0.44	0.78	0.35	0.57	2.45	0.24	0.6	2.26	0.23	0.53
X15	C	20	NA	NA	NA	NA	NA	NA	NA	2.45	0.24	0.59	2.26	0.23	0.52
X15	C	50	0.29	0.76	0.22	0.44	0.78	0.35	0.57	2.45	0.24	0.59	2.26	0.23	0.52
X15	R3	0	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.25	0.61	2.26	0.24	0.54
X15	R3	2	0.29	0.76	0.22	0.44	0.76	0.34	0.56	NA	NA	NA	NA	NA	NA
X15	R3	10	0.29	0.76	0.22	0.44	0.78	0.34	0.57	2.45	0.25	0.62	2.26	0.24	0.54
X15	R3	20	NA	NA	NA	NA	NA	NA	NA	2.45	0.26	0.63	2.26	0.25	0.56
X15	R3	50	0.29	0.76	0.22	0.44	0.82	0.36	0.58	2.45	0.27	0.65	2.26	0.25	0.57
X15	R4	0	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.25	0.61	2.26	0.24	0.54
X15	R4	2	0.42	0.76	0.32	0.32	0.93	0.29	0.61	NA	NA	NA	NA	NA	NA
X15	R4	10	0.42	0.76	0.32	0.32	0.93	0.3	0.61	2.45	0.3	0.73	2.26	0.28	0.64
X15	R4	20	NA	NA	NA	NA	NA	NA	NA	2.45	0.3	0.73	2.26	0.29	0.64
X15	R4	50	0.42	0.76	0.32	0.32	0.93	0.3	0.61	2.45	0.3	0.74	2.26	0.29	0.65
X15	H3	0	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.25	0.61	2.26	0.39	0.87
X15	H3	2	0.74	0.76	0.56	0	0.76	0	0.56	NA	NA	NA	NA	NA	NA
X15	H3	10	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.26	0.64	9.06	0.4	3.64
X15	H3	20	NA	NA	NA	NA	NA	NA	NA	2.45	0.27	0.66	9.06	0.42	3.78
X15	H3	50	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.3	0.73	9.06	0.46	4.15
X15	P	0	0.74	0.76	0.56	0	0.76	0	0.56	2.45	0.4	0.98	2.26	0.41	0.92
X15	P	2	0.74	0.76	0.56	0	0.76	0	0.56	NA	NA	NA	NA	NA	NA

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X15	P	10	0.74	0.76	0.56	0	0.76	0	0.56	8.38	0.64	5.38	16.15	0.65	10.52
X15	P	20	NA	NA	NA	NA	NA	NA	NA	8.38	0.72	6.01	16.15	0.73	11.74
X15	P	50	0.74	0.76	0.56	0	0.76	0	0.56	8.38	0.76	6.34	16.15	0.77	12.38
X19	FWOP	0	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.46	3.8	3.63	0.32	1.17
X19	FWOP	2	2.35	0.39	0.91	0	0.39	0	0.91	NA	NA	NA	NA	NA	NA
X19	FWOP	10	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.45	3.76	3.63	0.32	1.16
X19	FWOP	20	NA	NA	NA	NA	NA	NA	NA	8.28	0.45	3.73	3.63	0.32	1.15
X19	FWOP	50	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.44	3.63	3.63	0.31	1.11
X19	R1	0	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.46	3.8	3.63	0.32	1.17
X19	R1	2	2.35	0.39	0.91	3.07	0.41	1.26	2.17	NA	NA	NA	NA	NA	NA
X19	R1	10	2.35	0.39	0.91	3.07	0.42	1.29	2.2	8.28	0.47	3.9	3.63	0.33	1.2
X19	R1	20	NA	NA	NA	NA	NA	NA	NA	8.28	0.49	4.06	3.63	0.35	1.26
X19	R1	50	2.35	0.39	0.91	3.07	0.42	1.29	2.2	8.28	0.49	4.07	3.63	0.35	1.26
X19	R4	0	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.46	3.8	3.63	0.32	1.17
X19	R4	2	1.69	0.39	0.66	0.66	0.86	0.57	1.22	NA	NA	NA	NA	NA	NA
X19	R4	10	1.69	0.39	0.66	0.66	0.87	0.57	1.23	8.28	0.55	4.58	3.63	0.4	1.46
X19	R4	20	NA	NA	NA	NA	NA	NA	NA	8.28	0.56	4.6	3.63	0.41	1.48
X19	R4	50	1.69	0.39	0.66	0.66	0.87	0.57	1.23	8.28	0.55	4.52	3.63	0.4	1.45
X19	H2	0	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.46	3.83	3.63	0.44	1.59
X19	H2	2	2.35	0.39	0.91	0	0.39	0	0.91	NA	NA	NA	NA	NA	NA
X19	H2	10	2.35	0.39	0.91	0	0.39	0	0.91	13.63	0.49	6.66	10.01	0.47	4.66
X19	H2	20	NA	NA	NA	NA	NA	NA	NA	13.63	0.5	6.81	10.01	0.48	4.77
X19	H2	50	2.35	0.39	0.91	0	0.39	0	0.91	13.63	0.53	7.24	10.01	0.51	5.08
X19	H3	0	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.46	3.8	3.63	0.44	1.59

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X19	H3	2	2.35	0.39	0.91	0	0.39	0	0.91	NA	NA	NA	NA	NA	NA
X19	H3	10	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.47	3.89	7.79	0.45	3.5
X19	H3	20	NA	NA	NA	NA	NA	NA	NA	8.28	0.48	3.98	7.79	0.46	3.58
X19	H3	50	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.51	4.23	7.79	0.49	3.82
X19	P	0	2.35	0.39	0.91	0	0.39	0	0.91	8.28	0.47	3.92	3.63	0.45	1.65
X19	P	2	2.35	0.39	0.91	0	0.39	0	0.91	NA	NA	NA	NA	NA	NA
X19	P	10	2.35	0.39	0.91	0	0.39	0	0.91	14.7	0.66	9.7	14.83	0.64	9.54
X19	P	20	NA	NA	NA	NA	NA	NA	NA	14.7	0.7	10.28	14.83	0.69	10.19
X19	P	50	2.35	0.39	0.91	0	0.39	0	0.91	14.7	0.73	10.71	14.83	0.72	10.62
X20	FWOP	0	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.44	1.74	2.01	0.37	0.74
X20	FWOP	2	1.94	0.42	0.82	0	0.42	0	0.82	NA	NA	NA	NA	NA	NA
X20	FWOP	10	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.44	1.73	2.01	0.37	0.74
X20	FWOP	20	NA	NA	NA	NA	NA	NA	NA	3.97	0.43	1.72	2.01	0.36	0.73
X20	FWOP	50	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.42	1.68	2.01	0.36	0.72
X20	R1	0	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.44	1.74	2.01	0.37	0.74
X20	R1	2	1.94	0.42	0.82	2.13	0.44	0.94	1.76	NA	NA	NA	NA	NA	NA
X20	R1	10	1.94	0.42	0.82	2.13	0.45	0.95	1.78	3.97	0.45	1.78	2.01	0.38	0.76
X20	R1	20	NA	NA	NA	NA	NA	NA	NA	3.97	0.46	1.83	2.01	0.39	0.78
X20	R1	50	1.94	0.42	0.82	2.13	0.45	0.95	1.78	3.97	0.46	1.83	2.01	0.39	0.78
X20	R2	0	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.44	1.74	2.01	0.37	0.74
X20	R2	2	1.52	0.42	0.65	0.42	0.79	0.33	0.98	NA	NA	NA	NA	NA	NA
X20	R2	10	1.52	0.42	0.65	0.42	0.8	0.34	0.98	3.97	0.48	1.89	2.01	0.4	0.8
X20	R2	20	NA	NA	NA	NA	NA	NA	NA	3.97	0.49	1.93	2.01	0.41	0.82
X20	R2	50	1.52	0.42	0.65	0.42	0.81	0.34	0.99	3.97	0.48	1.91	2.01	0.4	0.81

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X20	H2	0	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.49	1.94	2.01	0.38	0.76
X20	H2	2	1.94	0.42	0.82	0	0.42	0	0.82	NA	NA	NA	NA	NA	NA
X20	H2	10	1.94	0.42	0.82	0	0.42	0	0.82	5.43	0.52	2.82	2.53	0.41	1.04
X20	H2	20	NA	NA	NA	NA	NA	NA	NA	5.43	0.53	2.87	2.53	0.42	1.06
X20	H2	50	1.94	0.42	0.82	0	0.42	0	0.82	5.43	0.56	3.03	2.53	0.44	1.11
X20	H3	0	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.49	1.94	2.01	0.38	0.76
X20	H3	2	1.94	0.42	0.82	0	0.42	0	0.82	NA	NA	NA	NA	NA	NA
X20	H3	10	1.94	0.42	0.82	0	0.42	0	0.82	5.43	0.5	2.71	2.53	0.39	0.98
X20	H3	20	NA	NA	NA	NA	NA	NA	NA	5.43	0.51	2.76	2.53	0.39	0.99
X20	H3	50	1.94	0.42	0.82	0	0.42	0	0.82	5.43	0.54	2.91	2.53	0.41	1.04
X20	P	0	1.94	0.42	0.82	0	0.42	0	0.82	3.97	0.52	2.05	2.01	0.55	1.11
X20	P	2	1.94	0.42	0.82	0	0.42	0	0.82	NA	NA	NA	NA	NA	NA
X20	P	10	1.94	0.42	0.82	0	0.42	0	0.82	12.58	0.69	8.7	15.9	0.71	11.27
X20	P	20	NA	NA	NA	NA	NA	NA	NA	12.58	0.73	9.23	15.9	0.74	11.8
X20	P	50	1.94	0.42	0.82	0	0.42	0	0.82	12.58	0.77	9.66	15.9	0.77	12.32
X21	FWOP	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.41	2.3	10.5	0.55	5.75
X21	FWOP	2	4.17	0.71	2.95	0	0.71	0	2.95	NA	NA	NA	NA	NA	NA
X21	FWOP	10	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.41	2.29	10.5	0.55	5.73
X21	FWOP	20	NA	NA	NA	NA	NA	NA	NA	5.58	0.41	2.28	10.5	0.54	5.71
X21	FWOP	50	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.4	2.25	10.5	0.54	5.64
X21	R1	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.41	2.3	10.5	0.55	5.75
X21	R1	2	3.19	0.71	2.25	0.99	0.72	0.71	2.96	NA	NA	NA	NA	NA	NA
X21	R1	10	3.19	0.71	2.25	0.99	0.73	0.72	2.97	5.58	0.42	2.35	10.5	0.56	5.88
X21	R1	20	NA	NA	NA	NA	NA	NA	NA	5.58	0.44	2.43	10.5	0.58	6.08

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X21	R1	50	3.19	0.71	2.25	0.99	0.73	0.72	2.97	5.58	0.44	2.45	10.5	0.58	6.14
X21	R2	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.41	2.3	10.5	0.55	5.75
X21	R2	2	3.39	0.71	2.39	0.79	0.74	0.58	2.97	NA	NA	NA	NA	NA	NA
X21	R2	10	3.39	0.71	2.39	0.79	0.75	0.59	2.98	5.58	0.44	2.45	10.5	0.58	6.12
X21	R2	20	NA	NA	NA	NA	NA	NA	NA	5.58	0.45	2.5	10.5	0.59	6.24
X21	R2	50	3.39	0.71	2.39	0.79	0.75	0.59	2.98	5.58	0.45	2.48	10.5	0.59	6.2
X21	R3	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.41	2.3	10.5	0.55	5.75
X21	R3	2	3.39	0.71	2.39	0.79	0.71	0.56	2.95	NA	NA	NA	NA	NA	NA
X21	R3	10	3.39	0.71	2.39	0.79	0.72	0.56	2.95	5.58	0.42	2.32	10.5	0.55	5.81
X21	R3	20	NA	NA	NA	NA	NA	NA	NA	5.58	0.42	2.35	10.5	0.56	5.87
X21	R3	50	3.39	0.71	2.39	0.79	0.74	0.58	2.97	5.58	0.42	2.36	10.5	0.56	5.89
X21	R4	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.41	2.3	10.5	0.55	5.75
X21	R4	2	2.75	0.71	1.94	1.42	0.81	1.14	3.09	NA	NA	NA	NA	NA	NA
X21	R4	10	2.75	0.71	1.94	1.42	0.81	1.15	3.09	5.58	0.45	2.51	10.5	0.6	6.26
X21	R4	20	NA	NA	NA	NA	NA	NA	NA	5.58	0.45	2.53	10.5	0.6	6.31
X21	R4	50	2.75	0.71	1.94	1.42	0.81	1.15	3.09	5.58	0.45	2.51	10.5	0.6	6.27
X21	H2	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.41	2.3	10.5	0.55	5.75
X21	H2	2	4.17	0.71	2.95	0	0.71	0	2.95	NA	NA	NA	NA	NA	NA
X21	H2	10	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.44	2.45	10.61	0.57	6.02
X21	H2	20	NA	NA	NA	NA	NA	NA	NA	5.58	0.44	2.48	10.61	0.57	6.09
X21	H2	50	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.46	2.56	10.61	0.59	6.29
X21	H3	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.47	2.65	10.5	0.55	5.75
X21	H3	2	4.17	0.71	2.95	0	0.71	0	2.95	NA	NA	NA	NA	NA	NA

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X21	H3	10	4.17	0.71	2.95	0	0.71	0	2.95	8.34	0.48	4.01	10.5	0.55	5.82
X21	H3	20	NA	NA	NA	NA	NA	NA	NA	8.34	0.49	4.05	10.5	0.56	5.88
X21	H3	50	4.17	0.71	2.95	0	0.71	0	2.95	8.34	0.5	4.18	10.5	0.58	6.07
X21	P	0	4.17	0.71	2.95	0	0.71	0	2.95	5.58	0.56	3.14	10.5	0.63	6.57
X21	P	2	4.17	0.71	2.95	0	0.71	0	2.95	NA	NA	NA	NA	NA	NA
X21	P	10	4.17	0.71	2.95	0	0.71	0	2.95	13.52	0.7	9.5	20.46	0.77	15.81
X21	P	20	NA	NA	NA	NA	NA	NA	NA	13.52	0.73	9.87	20.46	0.8	16.4
X21	P	50	4.17	0.71	2.95	0	0.71	0	2.95	13.52	0.76	10.22	20.46	0.83	16.98
X22	FWOP	0	11.02	0.15	1.65	0	0.15	0	1.65	8.13	0.19	1.53	5.85	0.17	1.02
X22	FWOP	2	11.02	0.15	1.65	0	0.15	0	1.65	NA	NA	NA	NA	NA	NA
X22	FWOP	10	11.02	0.15	1.65	0	0.15	0	1.65	8.13	0.18	1.5	5.85	0.17	1.01
X22	FWOP	20	NA	NA	NA	NA	NA	NA	NA	8.13	0.18	1.48	5.85	0.17	0.99
X22	FWOP	50	11.02	0.15	1.65	0	0.15	0	1.65	8.13	0.18	1.46	5.85	0.17	0.98
X22	R1	0	11.02	0.15	1.65	0	0.15	0	1.65	8.13	0.19	1.53	5.85	0.17	1.02
X22	R1	2	0	0.15	0	11.02	0.19	2.07	2.07	NA	NA	NA	NA	NA	NA
X22	R1	10	0	0.15	0	11.02	0.2	2.25	2.25	8.13	0.2	1.63	5.85	0.19	1.09
X22	R1	20	NA	NA	NA	NA	NA	NA	NA	8.13	0.22	1.79	5.85	0.2	1.19
X22	R1	50	0	0.15	0	11.02	0.2	2.25	2.25	8.13	0.23	1.87	5.85	0.21	1.25
X22	R2	0	11.02	0.15	1.65	0	0.15	0	1.65	8.13	0.19	1.53	5.85	0.17	1.02
X22	R2	2	0	0.15	0	11.02	0.55	6.07	6.07	NA	NA	NA	NA	NA	NA
X22	R2	10	0	0.15	0	11.02	0.59	6.5	6.5	8.13	0.25	2.05	5.85	0.23	1.37
X22	R2	20	NA	NA	NA	NA	NA	NA	NA	8.13	0.27	2.15	5.85	0.25	1.44
X22	R2	50	0	0.15	0	11.02	0.59	6.54	6.54	8.13	0.27	2.18	5.85	0.25	1.46

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X22	H2	0	11.02	0.15	1.65	0	0.15	0	1.65	8.13	0.26	2.11	5.85	0.18	1.06
X22	H2	2	11.02	0.15	1.65	0	0.15	0	1.65	NA	NA	NA	NA	NA	NA
X22	H2	10	11.02	0.15	1.65	0	0.15	0	1.65	16.39	0.3	4.99	7.04	0.25	1.73
X22	H2	20	NA	NA	NA	NA	NA	NA	NA	16.39	0.32	5.2	7.04	0.26	1.79
X22	H2	50	11.02	0.15	1.65	0	0.15	0	1.65	16.39	0.35	5.76	7.04	0.28	1.97
X22	P	0	11.02	0.15	1.65	0	0.15	0	1.65	8.13	0.26	2.11	5.85	0.18	1.06
X22	P	2	11.02	0.15	1.65	0	0.15	0	1.65	NA	NA	NA	NA	NA	NA
X22	P	10	11.02	0.15	1.65	0	0.15	0	1.65	16.39	0.47	7.67	7.04	0.39	2.71
X22	P	20	NA	NA	NA	NA	NA	NA	NA	16.39	0.51	8.34	7.04	0.42	2.99
X22	P	50	11.02	0.15	1.65	0	0.15	0	1.65	16.39	0.54	8.88	7.04	0.46	3.22
X24	FWOP	0	7.67	0.32	2.47	0	0.32	0	2.47	3.53	0.22	0.77	20.92	0.34	7.11
X24	FWOP	2	7.67	0.32	2.47	0	0.32	0	2.47	NA	NA	NA	NA	NA	NA
X24	FWOP	10	7.67	0.32	2.47	0	0.32	0	2.47	3.53	0.24	0.83	20.92	0.36	7.49
X24	FWOP	20	NA	NA	NA	NA	NA	NA	NA	3.53	0.24	0.86	20.92	0.37	7.65
X24	FWOP	50	7.67	0.32	2.47	0	0.32	0	2.47	3.53	0.23	0.82	20.92	0.35	7.34
X24	C	0	7.67	0.32	2.47	0	0.32	0	2.47	3.53	0.22	0.77	20.92	0.34	7.11
X24	C	2	0	0.32	0	7.67	0.4	3.04	3.04	NA	NA	NA	NA	NA	NA
X24	C	10	0	0.32	0	7.67	0.4	3.04	3.04	3.53	0.24	0.83	20.92	0.36	7.49
X24	C	20	NA	NA	NA	NA	NA	NA	NA	3.53	0.24	0.86	20.92	0.37	7.65
X24	C	50	0	0.32	0	7.67	0.4	3.04	3.04	3.53	0.23	0.82	20.92	0.35	7.34
X24	R3	0	7.67	0.32	2.47	0	0.32	0	2.47	3.53	0.22	0.77	20.92	0.34	7.11
X24	R3	2	0	0.32	0	7.67	0.33	2.54	2.54	NA	NA	NA	NA	NA	NA
X24	R3	10	0	0.32	0	7.67	0.35	2.66	2.66	3.53	0.25	0.88	20.92	0.38	7.85

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X24	R3	20	NA	NA	NA	NA	NA	NA	NA	3.53	0.27	0.94	20.92	0.4	8.32
X24	R3	50	0	0.32	0	7.67	0.4	3.05	3.05	3.53	0.27	0.95	20.92	0.4	8.37
X24	H2	0	7.67	0.32	2.47	0	0.32	0	2.47	3.53	0.28	0.99	20.92	0.34	7.12
X24	H2	2	7.67	0.32	2.47	0	0.32	0	2.47	NA	NA	NA	NA	NA	NA
X24	H2	10	7.67	0.32	2.47	0	0.32	0	2.47	6.59	0.34	2.23	21.99	0.4	8.72
X24	H2	20	NA	NA	NA	NA	NA	NA	NA	6.59	0.36	2.39	21.99	0.42	9.3
X24	H2	50	7.67	0.32	2.47	0	0.32	0	2.47	6.59	0.39	2.58	21.99	0.46	10.04
X24	P	0	7.67	0.32	2.47	0	0.32	0	2.47	3.53	0.29	1.02	20.92	0.35	7.25
X24	P	2	7.67	0.32	2.47	0	0.32	0	2.47	NA	NA	NA	NA	NA	NA
X24	P	10	7.67	0.32	2.47	0	0.32	0	2.47	10.27	0.52	5.3	43.13	0.59	25.37
X24	P	20	NA	NA	NA	NA	NA	NA	NA	10.27	0.6	6.18	43.13	0.68	29.3
X24	P	50	7.67	0.32	2.47	0	0.32	0	2.47	10.27	0.64	6.54	43.13	0.72	30.85
X28	FWOP	0	2.46	0.49	1.19	0	0.49	0	1.19	3.92	0.17	0.68	0.88	0.13	0.11
X28	FWOP	2	2.46	0.49	1.19	0	0.49	0	1.19	NA	NA	NA	NA	NA	NA
X28	FWOP	10	2.46	0.49	1.19	0	0.49	0	1.19	3.92	0.18	0.71	0.88	0.13	0.12
X28	FWOP	20	NA	NA	NA	NA	NA	NA	NA	3.92	0.19	0.74	0.88	0.14	0.12
X28	FWOP	50	2.46	0.49	1.19	0	0.49	0	1.19	3.92	0.19	0.75	0.88	0.14	0.13
X28	C	0	2.46	0.49	1.19	0	0.49	0	1.19	3.92	0.17	0.68	0.88	0.13	0.11
X28	C	2	0	0.49	0	2.46	0.55	1.34	1.34	NA	NA	NA	NA	NA	NA
X28	C	10	0	0.49	0	2.46	0.55	1.34	1.34	3.92	0.18	0.71	0.88	0.13	0.12
X28	C	20	NA	NA	NA	NA	NA	NA	NA	3.92	0.19	0.74	0.88	0.14	0.12
X28	C	50	0	0.49	0	2.46	0.55	1.34	1.34	3.92	0.19	0.75	0.88	0.14	0.13
X28	R2	0	2.46	0.49	1.19	0	0.49	0	1.19	3.92	0.17	0.68	0.88	0.13	0.11

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X28	R2	2	0	0.49	0	2.46	0.75	1.85	1.85	NA	NA	NA	NA	NA	NA
X28	R2	10	0	0.49	0	2.46	0.79	1.94	1.94	3.92	0.22	0.86	0.88	0.17	0.15
X28	R2	20	NA	NA	NA	NA	NA	NA	NA	3.92	0.24	0.95	0.88	0.19	0.16
X28	R2	50	0	0.49	0	2.46	0.79	1.95	1.95	3.92	0.25	0.98	0.88	0.19	0.17
X28	P	0	2.46	0.49	1.19	0	0.49	0	1.19	3.92	0.26	1.01	0.88	0.18	0.16
X28	P	2	2.46	0.49	1.19	0	0.49	0	1.19	NA	NA	NA	NA	NA	NA
X28	P	10	2.46	0.49	1.19	0	0.49	0	1.19	8.28	0.5	4.12	3.84	0.41	1.58
X28	P	20	NA	NA	NA	NA	NA	NA	NA	8.28	0.59	4.85	3.84	0.5	1.91
X28	P	50	2.46	0.49	1.19	0	0.49	0	1.19	8.28	0.63	5.21	3.84	0.54	2.06
X29	FWOP	0	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.59	23.29	26.51	0.61	16.28
X29	FWOP	2	5.51	0.78	4.3	0	0.78	0	4.3	NA	NA	NA	NA	NA	NA
X29	FWOP	10	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.59	23.15	26.51	0.61	16.19
X29	FWOP	20	NA	NA	NA	NA	NA	NA	NA	39.15	0.59	23	26.51	0.61	16.09
X29	FWOP	50	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.58	22.55	26.51	0.6	15.8
X29	C	0	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.59	23.29	26.51	0.61	16.28
X29	C	2	1.84	0.78	1.43	3.68	0.91	3.35	4.78	NA	NA	NA	NA	NA	NA
X29	C	10	1.84	0.78	1.43	3.68	0.91	3.35	4.78	39.15	0.59	23.15	26.51	0.61	16.19
X29	C	20	NA	NA	NA	NA	NA	NA	NA	39.15	0.59	23	26.51	0.61	16.09
X29	C	50	1.84	0.78	1.43	3.68	0.91	3.35	4.78	39.15	0.58	22.55	26.51	0.6	15.8
X29	R1	0	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.59	23.29	26.51	0.61	16.28
X29	R1	2	3.45	0.78	2.69	2.07	0.78	1.62	4.31	NA	NA	NA	NA	NA	NA
X29	R1	10	3.45	0.78	2.69	2.07	0.79	1.63	4.32	39.15	0.6	23.58	26.51	0.62	16.47
X29	R1	20	NA	NA	NA	NA	NA	NA	NA	39.15	0.61	24.03	26.51	0.63	16.77

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X29	R1	50	3.45	0.78	2.69	2.07	0.79	1.63	4.32	39.15	0.61	23.95	26.51	0.63	16.71
X29	R2	0	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.59	23.29	26.51	0.61	16.28
X29	R2	2	1.84	0.78	1.43	3.68	0.79	2.9	4.33	NA	NA	NA	NA	NA	NA
X29	R2	10	1.84	0.78	1.43	3.68	0.79	2.92	4.35	39.15	0.62	24.39	26.51	0.64	16.96
X29	R2	20	NA	NA	NA	NA	NA	NA	NA	39.15	0.63	24.8	26.51	0.65	17.19
X29	R2	50	1.84	0.78	1.43	3.68	0.79	2.92	4.35	39.15	0.63	24.63	26.51	0.64	17.02
X29	R3	0	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.59	23.29	26.51	0.61	16.28
X29	R3	2	4.29	0.78	3.34	1.23	0.78	0.96	4.3	NA	NA	NA	NA	NA	NA
X29	R3	10	4.29	0.78	3.34	1.23	0.79	0.96	4.31	39.15	0.6	23.54	26.51	0.62	16.4
X29	R3	20	NA	NA	NA	NA	NA	NA	NA	39.15	0.61	23.78	26.51	0.62	16.52
X29	R3	50	4.29	0.78	3.34	1.23	0.8	0.98	4.32	39.15	0.61	23.76	26.51	0.62	16.46
X29	R4	0	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.59	23.29	26.51	0.61	16.28
X29	R4	2	2.74	0.78	2.14	2.77	0.83	2.3	4.43	NA	NA	NA	NA	NA	NA
X29	R4	10	2.74	0.78	2.14	2.77	0.83	2.31	4.44	39.15	0.64	25.22	26.51	0.66	17.4
X29	R4	20	NA	NA	NA	NA	NA	NA	NA	39.15	0.65	25.26	26.51	0.66	17.42
X29	R4	50	2.74	0.78	2.14	2.77	0.83	2.31	4.44	39.15	0.64	24.88	26.51	0.65	17.17
X29	P	0	5.51	0.78	4.3	0	0.78	0	4.3	39.15	0.6	23.66	26.51	0.62	16.5
X29	P	2	5.51	0.78	4.3	0	0.78	0	4.3	NA	NA	NA	NA	NA	NA
X29	P	10	5.51	0.78	4.3	0	0.78	0	4.3	48.43	0.78	37.7	43.4	0.78	33.99
X29	P	20	NA	NA	NA	NA	NA	NA	NA	48.43	0.79	38.46	43.4	0.8	34.66
X29	P	50	5.51	0.78	4.3	0	0.78	0	4.3	48.43	0.8	38.95	43.4	0.81	35.1
X30	FWOP	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.32	3.31	0.31	1.03
X30	FWOP	2	2.8	0.52	1.44	0	0.52	0	1.44	NA	NA	NA	NA	NA	NA

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X30	FWOP	10	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.22	3.31	0.31	1.02
X30	FWOP	20	NA	NA	NA	NA	NA	NA	NA	58.64	0.6	35.12	3.31	0.3	1.01
X30	FWOP	50	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.59	34.81	3.31	0.29	0.97
X30	C	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.32	3.31	0.31	1.03
X30	C	2	0.52	0.52	0.27	2.28	0.57	1.3	1.57	NA	NA	NA	NA	NA	NA
X30	C	10	0.52	0.52	0.27	2.28	0.57	1.3	1.57	58.64	0.6	35.22	3.31	0.31	1.02
X30	C	20	NA	NA	NA	NA	NA	NA	NA	58.64	0.6	35.12	3.31	0.3	1.01
X30	C	50	0.52	0.52	0.27	2.28	0.57	1.3	1.57	58.64	0.59	34.81	3.31	0.29	0.97
X30	R1	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.32	3.31	0.31	1.03
X30	R1	2	1.93	0.52	0.99	0.87	0.53	0.46	1.45	NA	NA	NA	NA	NA	NA
X30	R1	10	1.93	0.52	0.99	0.87	0.54	0.47	1.46	58.64	0.61	35.9	3.31	0.32	1.05
X30	R1	20	NA	NA	NA	NA	NA	NA	NA	58.64	0.63	36.74	3.31	0.33	1.09
X30	R1	50	1.93	0.52	0.99	0.87	0.54	0.47	1.46	58.64	0.63	36.98	3.31	0.33	1.09
X30	R2	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.32	3.31	0.31	1.03
X30	R2	2	1.25	0.52	0.64	1.56	0.87	1.36	2	NA	NA	NA	NA	NA	NA
X30	R2	10	1.25	0.52	0.64	1.56	0.89	1.39	2.03	58.64	0.68	39.99	3.31	0.37	1.21
X30	R2	20	NA	NA	NA	NA	NA	NA	NA	58.64	0.7	40.92	3.31	0.37	1.24
X30	R2	50	1.25	0.52	0.64	1.56	0.89	1.39	2.03	58.64	0.7	41.18	3.31	0.37	1.22
X30	R4	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.32	3.31	0.31	1.03
X30	R4	2	0.52	0.52	0.27	2.28	0.92	2.1	2.37	NA	NA	NA	NA	NA	NA
X30	R4	10	0.52	0.52	0.27	2.28	0.92	2.1	2.37	58.64	0.71	41.63	3.31	0.38	1.26
X30	R4	20	NA	NA	NA	NA	NA	NA	NA	58.64	0.71	41.88	3.31	0.38	1.26
X30	R4	50	0.52	0.52	0.27	2.28	0.92	2.1	2.37	58.64	0.71	41.63	3.31	0.37	1.23

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X30	H2	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.32	3.31	0.35	1.15
X30	H2	2	2.8	0.52	1.44	0	0.52	0	1.44	NA	NA	NA	NA	NA	NA
X30	H2	10	2.8	0.52	1.44	0	0.52	0	1.44	58.74	0.62	36.38	3.99	0.38	1.53
X30	H2	20	NA	NA	NA	NA	NA	NA	NA	58.74	0.62	36.68	3.99	0.39	1.58
X30	H2	50	2.8	0.52	1.44	0	0.52	0	1.44	58.74	0.64	37.56	3.99	0.43	1.71
X30	H3	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.6	35.32	3.31	0.35	1.16
X30	H3	2	2.8	0.52	1.44	0	0.52	0	1.44	NA	NA	NA	NA	NA	NA
X30	H3	10	2.8	0.52	1.44	0	0.52	0	1.44	60.49	0.61	36.74	4.57	0.36	1.65
X30	H3	20	NA	NA	NA	NA	NA	NA	NA	60.49	0.61	37.05	4.57	0.37	1.71
X30	H3	50	2.8	0.52	1.44	0	0.52	0	1.44	60.49	0.63	37.93	4.57	0.41	1.85
X30	P	0	2.8	0.52	1.44	0	0.52	0	1.44	58.64	0.65	38.14	3.31	0.47	1.55
X30	P	2	2.8	0.52	1.44	0	0.52	0	1.44	NA	NA	NA	NA	NA	NA
X30	P	10	2.8	0.52	1.44	0	0.52	0	1.44	104.58	0.75	78.42	12.49	0.69	8.68
X30	P	20	NA	NA	NA	NA	NA	NA	NA	104.58	0.78	81.91	12.49	0.75	9.36
X30	P	50	2.8	0.52	1.44	0	0.52	0	1.44	104.58	0.8	83.46	12.49	0.79	9.81
X31	FWOP	0	4.6	0.39	1.79	0	0.39	0	1.79	3.66	0.24	0.89	2.13	0.18	0.38
X31	FWOP	2	4.6	0.39	1.79	0	0.39	0	1.79	NA	NA	NA	NA	NA	NA
X31	FWOP	10	4.6	0.39	1.79	0	0.39	0	1.79	3.66	0.24	0.89	2.13	0.19	0.4
X31	FWOP	20	NA	NA	NA	NA	NA	NA	NA	3.66	0.24	0.88	2.13	0.18	0.39
X31	FWOP	50	4.6	0.39	1.79	0	0.39	0	1.79	3.66	0.23	0.85	2.13	0.18	0.38
X31	C	0	4.6	0.39	1.79	0	0.39	0	1.79	3.66	0.24	0.89	2.13	0.18	0.38
X31	C	2	0	0.39	0	4.6	0.46	2.1	2.1	NA	NA	NA	NA	NA	NA
X31	C	10	0	0.39	0	4.6	0.46	2.1	2.1	3.66	0.24	0.89	2.13	0.19	0.4

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X31	C	20	NA	NA	NA	NA	NA	NA	NA	3.66	0.24	0.88	2.13	0.18	0.39
X31	C	50	0	0.39	0	4.6	0.46	2.1	2.1	3.66	0.23	0.85	2.13	0.18	0.38
X31	R1	0	4.6	0.39	1.79	0	0.39	0	1.79	3.66	0.24	0.89	2.13	0.18	0.38
X31	R1	2	0	0.39	0	4.6	0.41	1.89	1.89	NA	NA	NA	NA	NA	NA
X31	R1	10	0	0.39	0	4.6	0.42	1.93	1.93	3.66	0.26	0.95	2.13	0.2	0.42
X31	R1	20	NA	NA	NA	NA	NA	NA	NA	3.66	0.28	1.01	2.13	0.21	0.45
X31	R1	50	0	0.39	0	4.6	0.42	1.93	1.93	3.66	0.28	1.02	2.13	0.21	0.46
X31	H3	0	4.6	0.39	1.79	0	0.39	0	1.79	3.66	0.39	1.41	2.13	0.36	0.77
X31	H3	2	4.6	0.39	1.79	0	0.39	0	1.79	NA	NA	NA	NA	NA	NA
X31	H3	10	4.6	0.39	1.79	0	0.39	0	1.79	21.4	0.4	8.54	13.62	0.37	5.06
X31	H3	20	NA	NA	NA	NA	NA	NA	NA	21.4	0.41	8.81	13.62	0.38	5.22
X31	H3	50	4.6	0.39	1.79	0	0.39	0	1.79	21.4	0.45	9.53	13.62	0.42	5.65
X31	P	0	4.6	0.39	1.79	0	0.39	0	1.79	3.66	0.39	1.41	2.13	0.36	0.77
X31	P	2	4.6	0.39	1.79	0	0.39	0	1.79	NA	NA	NA	NA	NA	NA
X31	P	10	4.6	0.39	1.79	0	0.39	0	1.79	22.03	0.6	13.25	15.47	0.58	9.04
X31	P	20	NA	NA	NA	NA	NA	NA	NA	22.03	0.66	14.62	15.47	0.65	10
X31	P	50	4.6	0.39	1.79	0	0.39	0	1.79	22.03	0.7	15.38	15.47	0.68	10.54
X33	FWOP	0	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.56	2.62	1.25	0.41	0.52
X33	FWOP	2	0.73	0.49	0.35	0	0.49	0	0.35	NA	NA	NA	NA	NA	NA
X33	FWOP	10	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.55	2.6	1.25	0.41	0.51
X33	FWOP	20	NA	NA	NA	NA	NA	NA	NA	4.71	0.55	2.59	1.25	0.41	0.51
X33	FWOP	50	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.54	2.53	1.25	0.4	0.5
X33	R2	0	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.56	2.62	1.25	0.41	0.52

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X33	R2	2	0.01	0.49	0	0.72	0.84	0.61	0.61	NA	NA	NA	NA	NA	NA
X33	R2	10	0.01	0.49	0	0.72	0.85	0.61	0.62	4.71	0.58	2.73	1.25	0.43	0.54
X33	R2	20	NA	NA	NA	NA	NA	NA	NA	4.71	0.59	2.77	1.25	0.44	0.55
X33	R2	50	0.01	0.49	0	0.72	0.86	0.62	0.62	4.71	0.58	2.75	1.25	0.43	0.54
X33	H2	0	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.56	2.62	1.25	0.58	0.72
X33	H2	2	0.73	0.49	0.35	0	0.49	0	0.35	NA	NA	NA	NA	NA	NA
X33	H2	10	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.58	2.73	4.73	0.6	2.84
X33	H2	20	NA	NA	NA	NA	NA	NA	NA	4.71	0.59	2.78	4.73	0.61	2.88
X33	H2	50	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.62	2.91	4.73	0.64	3.01
X33	H3	0	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.56	2.62	1.25	0.58	0.72
X33	H3	2	0.73	0.49	0.35	0	0.49	0	0.35	NA	NA	NA	NA	NA	NA
X33	H3	10	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.57	2.67	4.73	0.59	2.77
X33	H3	20	NA	NA	NA	NA	NA	NA	NA	4.71	0.58	2.71	4.73	0.6	2.82
X33	H3	50	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.6	2.84	4.73	0.62	2.94
X33	P	0	0.73	0.49	0.35	0	0.49	0	0.35	4.71	0.56	2.65	1.25	0.44	0.55
X33	P	2	0.73	0.49	0.35	0	0.49	0	0.35	NA	NA	NA	NA	NA	NA
X33	P	10	0.73	0.49	0.35	0	0.49	0	0.35	4.93	0.73	3.6	1.57	0.58	0.91
X33	P	20	NA	NA	NA	NA	NA	NA	NA	4.93	0.77	3.81	1.57	0.61	0.95
X33	P	50	0.73	0.49	0.35	0	0.49	0	0.35	4.93	0.8	3.95	1.57	0.63	0.99
X34	FWOP	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.59	58.7	0.55	32.4
X34	FWOP	2	19.01	0.26	4.95	0	0.26	0	4.95	NA	NA	NA	NA	NA	NA
X34	FWOP	10	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.48	58.7	0.55	32.24
X34	FWOP	20	NA	NA	NA	NA	NA	NA	NA	47.18	0.54	25.36	58.7	0.55	32.09

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X34	FWOP	50	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.53	25	58.7	0.54	31.6
X34	C	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.59	58.7	0.55	32.4
X34	C	2	10.32	0.26	2.69	8.69	0.45	3.89	6.58	NA	NA	NA	NA	NA	NA
X34	C	10	10.32	0.26	2.69	8.69	0.45	3.89	6.58	47.18	0.54	25.48	58.7	0.55	32.24
X34	C	20	NA	NA	NA	NA	NA	NA	NA	47.18	0.54	25.36	58.7	0.55	32.09
X34	C	50	10.32	0.26	2.69	8.69	0.45	3.89	6.58	47.18	0.53	25	58.7	0.54	31.6
X34	R1	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.59	58.7	0.55	32.4
X34	R1	2	12.53	0.26	3.26	6.48	0.29	1.85	5.12	NA	NA	NA	NA	NA	NA
X34	R1	10	12.53	0.26	3.26	6.48	0.3	1.94	5.21	47.18	0.55	26.13	58.7	0.56	33.09
X34	R1	20	NA	NA	NA	NA	NA	NA	NA	47.18	0.57	26.91	58.7	0.58	34.1
X34	R1	50	12.53	0.26	3.26	6.48	0.3	1.94	5.21	47.18	0.57	27.07	58.7	0.58	34.3
X34	R2	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.59	58.7	0.55	32.4
X34	R2	2	10.32	0.26	2.69	8.69	0.64	5.58	8.26	NA	NA	NA	NA	NA	NA
X34	R2	10	10.32	0.26	2.69	8.69	0.67	5.83	8.52	47.18	0.59	27.79	58.7	0.6	35.35
X34	R2	20	NA	NA	NA	NA	NA	NA	NA	47.18	0.6	28.32	58.7	0.62	36.15
X34	R2	50	10.32	0.26	2.69	8.69	0.67	5.86	8.54	47.18	0.6	28.14	58.7	0.61	36.03
X34	R3	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.59	58.7	0.55	32.4
X34	R3	2	18.77	0.26	4.89	0.24	0.27	0.06	4.95	NA	NA	NA	NA	NA	NA
X34	R3	10	18.77	0.26	4.89	0.24	0.28	0.07	4.96	47.18	0.55	25.9	58.7	0.56	32.91
X34	R3	20	NA	NA	NA	NA	NA	NA	NA	47.18	0.56	26.2	58.7	0.57	33.41
X34	R3	50	18.77	0.26	4.89	0.24	0.31	0.08	4.97	47.18	0.56	26.29	58.7	0.57	33.63
X34	R4	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.59	58.7	0.55	32.4
X34	R4	2	17.54	0.26	4.57	1.47	0.74	1.09	5.66	NA	NA	NA	NA	NA	NA

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X34	R4	10	17.54	0.26	4.57	1.47	0.75	1.1	5.67	47.18	0.61	28.56	58.7	0.62	36.6
X34	R4	20	NA	NA	NA	NA	NA	NA	NA	47.18	0.61	28.71	58.7	0.63	36.82
X34	R4	50	17.54	0.26	4.57	1.47	0.75	1.1	5.67	47.18	0.6	28.45	58.7	0.62	36.47
X34	H2	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.54	25.64	58.7	0.55	32.4
X34	H2	2	19.01	0.26	4.95	0	0.26	0	4.95	NA	NA	NA	NA	NA	NA
X34	H2	10	19.01	0.26	4.95	0	0.26	0	4.95	47.66	0.57	27.03	58.7	0.58	33.93
X34	H2	20	NA	NA	NA	NA	NA	NA	NA	47.66	0.57	27.37	58.7	0.59	34.42
X34	H2	50	19.01	0.26	4.95	0	0.26	0	4.95	47.66	0.59	28.33	58.7	0.61	35.81
X34	P	0	19.01	0.26	4.95	0	0.26	0	4.95	47.18	0.6	28.42	58.7	0.59	34.39
X34	P	2	19.01	0.26	4.95	0	0.26	0	4.95	NA	NA	NA	NA	NA	NA
X34	P	10	19.01	0.26	4.95	0	0.26	0	4.95	80.74	0.72	58.32	101.65	0.71	72.53
X34	P	20	NA	NA	NA	NA	NA	NA	NA	80.74	0.75	60.74	101.65	0.74	75.37
X34	P	50	19.01	0.26	4.95	0	0.26	0	4.95	80.74	0.78	63.02	101.65	0.77	78.28
X35	FWOP	0	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.48	17.55	38.62	0.6	23.14
X35	FWOP	2	4.57	0.42	1.9	0	0.42	0	1.9	NA	NA	NA	NA	NA	NA
X35	FWOP	10	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.48	17.45	38.62	0.6	23.05
X35	FWOP	20	NA	NA	NA	NA	NA	NA	NA	36.31	0.48	17.34	38.62	0.59	22.96
X35	FWOP	50	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.47	17.02	38.62	0.59	22.69
X35	C	0	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.48	17.55	38.62	0.6	23.14
X35	C	2	2.19	0.42	0.91	2.38	0.51	1.22	2.13	NA	NA	NA	NA	NA	NA
X35	C	10	2.19	0.42	0.91	2.38	0.51	1.22	2.13	36.31	0.48	17.45	38.62	0.6	23.05
X35	C	20	NA	NA	NA	NA	NA	NA	NA	36.31	0.48	17.34	38.62	0.59	22.96
X35	C	50	2.19	0.42	0.91	2.38	0.51	1.22	2.13	36.31	0.47	17.02	38.62	0.59	22.69

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X35	R1	0	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.48	17.55	38.62	0.6	23.14
X35	R1	2	2.7	0.42	1.12	1.87	0.43	0.81	1.93	NA	NA	NA	NA	NA	NA
X35	R1	10	2.7	0.42	1.12	1.87	0.44	0.82	1.94	36.31	0.49	17.94	38.62	0.61	23.51
X35	R1	20	NA	NA	NA	NA	NA	NA	NA	36.31	0.51	18.51	38.62	0.62	24.06
X35	R1	50	2.7	0.42	1.12	1.87	0.44	0.82	1.94	36.31	0.51	18.59	38.62	0.63	24.16
X35	R2	0	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.48	17.55	38.62	0.6	23.14
X35	R2	2	2.19	0.42	0.91	2.38	0.78	1.86	2.77	NA	NA	NA	NA	NA	NA
X35	R2	10	2.19	0.42	0.91	2.38	0.8	1.9	2.8	36.31	0.54	19.45	38.62	0.65	25.06
X35	R2	20	NA	NA	NA	NA	NA	NA	NA	36.31	0.55	19.86	38.62	0.66	25.45
X35	R2	50	2.19	0.42	0.91	2.38	0.8	1.9	2.81	36.31	0.54	19.71	38.62	0.66	25.31
X35	H2	0	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.49	17.72	38.62	0.6	23.14
X35	H2	2	4.57	0.42	1.9	0	0.42	0	1.9	NA	NA	NA	NA	NA	NA
X35	H2	10	4.57	0.42	1.9	0	0.42	0	1.9	39.23	0.51	20.14	39.19	0.62	24.24
X35	H2	20	NA	NA	NA	NA	NA	NA	NA	39.23	0.52	20.58	39.19	0.62	24.48
X35	H2	50	4.57	0.42	1.9	0	0.42	0	1.9	39.23	0.56	21.78	39.19	0.64	25.19
X35	P	0	4.57	0.42	1.9	0	0.42	0	1.9	36.31	0.5	18.27	38.62	0.62	23.77
X35	P	2	4.57	0.42	1.9	0	0.42	0	1.9	NA	NA	NA	NA	NA	NA
X35	P	10	4.57	0.42	1.9	0	0.42	0	1.9	59.74	0.69	41.09	50.15	0.73	36.41
X35	P	20	NA	NA	NA	NA	NA	NA	NA	59.74	0.74	44.35	50.15	0.76	37.88
X35	P	50	4.57	0.42	1.9	0	0.42	0	1.9	59.74	0.77	46.12	50.15	0.78	39.31
X38	FWOP	0	5.82	0.38	2.23	0	0.38	0	2.23	3.4	0.32	1.1	9.89	0.41	4.07
X38	FWOP	2	5.82	0.38	2.23	0	0.38	0	2.23	NA	NA	NA	NA	NA	NA
X38	FWOP	10	5.82	0.38	2.23	0	0.38	0	2.23	3.4	0.32	1.1	9.89	0.41	4.04

Site	Action	Time	QHEILS Unrest Area	QHEILS Unrest HSI	QHEILS Unrest HU	QHEILS Rest Area	QHEILS Rest HSI	QHEILS RestHU	QHEILS HU	SMURF Left Area	SMURF Left HSI	SMURF Left HU	SMURF Right Area	SMURF Right HSI	SMURF Right HU
X38	FWOP	20	NA	NA	NA	NA	NA	NA	NA	3.4	0.32	1.09	9.89	0.41	4.01
X38	FWOP	50	5.82	0.38	2.23	0	0.38	0	2.23	3.4	0.31	1.07	9.89	0.4	3.92
X38	R2	0	5.82	0.38	2.23	0	0.38	0	2.23	3.4	0.32	1.1	9.89	0.41	4.07
X38	R2	2	3.75	0.38	1.43	2.07	0.74	1.54	2.98	NA	NA	NA	NA	NA	NA
X38	R2	10	3.75	0.38	1.43	2.07	0.76	1.58	3.01	3.4	0.39	1.32	9.89	0.49	4.85
X38	R2	20	NA	NA	NA	NA	NA	NA	NA	3.4	0.4	1.36	9.89	0.5	4.98
X38	R2	50	3.75	0.38	1.43	2.07	0.76	1.58	3.02	3.4	0.4	1.34	9.89	0.5	4.96
X38	H2	0	5.82	0.38	2.23	0	0.38	0	2.23	3.4	0.45	1.54	9.89	0.41	4.07
X38	H2	2	5.82	0.38	2.23	0	0.38	0	2.23	NA	NA	NA	NA	NA	NA
X38	H2	10	5.82	0.38	2.23	0	0.38	0	2.23	16.92	0.49	8.25	9.89	0.44	4.38
X38	H2	20	NA	NA	NA	NA	NA	NA	NA	16.92	0.5	8.41	9.89	0.45	4.46
X38	H2	50	5.82	0.38	2.23	0	0.38	0	2.23	16.92	0.52	8.84	9.89	0.47	4.67
X38	H3	0	5.82	0.38	2.23	0	0.38	0	2.23	3.4	0.45	1.54	9.89	0.41	4.07
X38	H3	2	5.82	0.38	2.23	0	0.38	0	2.23	NA	NA	NA	NA	NA	NA
X38	H3	10	5.82	0.38	2.23	0	0.38	0	2.23	16.92	0.46	7.81	9.89	0.42	4.15
X38	H3	20	NA	NA	NA	NA	NA	NA	NA	16.92	0.47	7.96	9.89	0.43	4.22
X38	H3	50	5.82	0.38	2.23	0	0.38	0	2.23	16.92	0.49	8.37	9.89	0.45	4.43
X38	P	0	5.82	0.38	2.23	0	0.38	0	2.23	3.4	0.49	1.66	9.89	0.45	4.42
X38	P	2	5.82	0.38	2.23	0	0.38	0	2.23	NA	NA	NA	NA	NA	NA
X38	P	10	5.82	0.38	2.23	0	0.38	0	2.23	26.53	0.67	17.67	11.92	0.62	7.41
X38	P	20	NA	NA	NA	NA	NA	NA	NA	26.53	0.7	18.67	11.92	0.66	7.87
X38	P	50	5.82	0.38	2.23	0	0.38	0	2.23	26.53	0.74	19.52	11.92	0.69	8.22

Table C2. Comprehensive summary of cost data for all sites and actions.

Site	Action	Project First Cost ($)	Average Annual Cost ($)
X2	FWOP	0	0
X2	R1	1,891,000	67,000
X2	R2	1,170,000	41,000
X2	R3	642,000	23,000
X2	R4	1,648,000	58,000
X2	H2	8,564,000	303,000
X2	P	14,865,000	527,000
X4	FWOP	0	0
X4	C	557,000	20,000
X4	R1	1,318,000	47,000
X4	R3	2,376,000	84,000
X4	R4	3,690,000	131,000
X4	H2	3,530,000	125,000
X4	P	11,246,000	398,000
X5	FWOP	0	0
X5	C	1,246,000	44,000
X5	R3	2,468,000	87,000
X5	H1	42,135,000	1,492,000
X5	P	50,853,000	1,801,000
X8	FWOP	0	0
X8	C	762,000	27,000
X8	R2	7,110,000	252,000
X8	R4	3,556,000	126,000
X8	P	18,920,000	670,000
X9	FWOP	0	0

X9	C	291,000	10,000
X9	R2	1,997,000	71,000
X9	P	3,209,000	114,000
X10	FWOP	0	0
X10	C	1,022,000	36,000
X10	R1	291,000	10,000
X10	R2	3,472,000	123,000
X10	R4	7,470,000	265,000
X10	H2	768,000	27,000
X10	H3	688,000	24,000
X10	P	9,187,000	325,000
X11	FWOP	0	0
X11	R1	4,754,000	168,000
X11	R2	6,459,000	229,000
X11	H2	1,112,000	39,000
X11	P	15,924,000	564,000
X15	FWOP	0	0
X15	C	598,000	21,000
X15	R3	739,000	26,000
X15	R4	2,778,000	98,000
X15	H3	712,000	25,000
X15	P	1,759,000	62,000
X19	FWOP	0	0
X19	R1	1,586,000	56,000
X19	R4	2,592,000	92,000
X19	H2	1,680,000	59,000
X19	H3	1,893,000	67,000

X19	P	5,748,000	204,000
X20	FWOP	0	0
X20	R1	822,000	29,000
X20	R2	1,142,000	40,000
X20	H2	283,000	10,000
X20	H3	336,000	12,000
X20	P	2,882,000	102,000
X21	FWOP	0	0
X21	R1	463,000	16,000
X21	R2	479,000	17,000
X21	R3	579,000	21,000
X21	R4	1,631,000	58,000
X21	H2	601,000	21,000
X21	H3	562,000	20,000
X21	P	3,495,000	124,000
X22	FWOP	0	0
X22	R1	21,551,000	763,000
X22	R2	9,372,000	332,000
X22	H2	2,361,000	84,000
X22	P	4,141,000	147,000
X24	FWOP	0	0
X24	C	656,000	23,000
X24	R3	2,406,000	85,000
X24	H2	1,561,000	55,000
X24	P	7,404,000	262,000
X28	FWOP	0	0
X28	C	608,000	22,000

X28	R2	4,618,000	164,000
X28	P	2,089,000	74,000
X29	FWOP	0	0
X29	C	467,000	17,000
X29	R1	689,000	24,000
X29	R2	3,099,000	110,000
X29	R3	360,000	13,000
X29	R4	5,740,000	203,000
X29	P	14,721,000	521,000
X30	FWOP	0	0
X30	C	873,000	31,000
X30	R1	409,000	14,000
X30	R2	16,775,000	594,000
X30	R4	4,762,000	169,000
X30	H2	741,000	26,000
X30	H3	641,000	23,000
X30	P	11,676,000	414,000
X31	FWOP	0	0
X31	C	225,000	8,000
X31	R1	1,374,000	49,000
X31	H3	1,222,000	43,000
X31	P	5,277,000	187,000
X33	FWOP	0	0
X33	R2	1,584,000	56,000
X33	H2	1,009,000	36,000
X33	H3	1,181,000	42,000
X33	P	1,942,000	69,000

X34	FWOP	0	0
X34	C	673,000	24,000
X34	R1	2,563,000	91,000
X34	R2	2,628,000	93,000
X34	R3	1,091,000	39,000
X34	R4	2,411,000	85,000
X34	H2	163,000	6,000
X34	P	16,961,000	601,000
X35	FWOP	0	0
X35	C	798,000	28,000
X35	R1	3,227,000	114,000
X35	R2	3,888,000	138,000
X35	H2	3,199,000	113,000
X35	P	15,117,000	535,000
X38	FWOP	0	0
X38	R2	1,210,000	43,000
X38	H2	7,567,000	268,000
X38	H3	7,945,000	281,000
X38	P	8,155,000	289,000

Attachment D: Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS)

Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS)

by S. Kyle McKay[1], George Athanasakes[2], Sarah Taylor[3], Wolffie Miller[4], Erin Wagoner[5], and Laura Mattingly[6]

Abstract

Urban stream restoration typically involves multiple objectives addressing different aspects of ecosystem integrity such as habitat provision, geomorphic condition, watershed connectivity, water quality, and land use change, among others. Multiple stream assessment tools and models have been developed and applied to inform restoration prioritization, planning, and design. Here, we present the Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS, pronounced "quails"), which is designed as an interdisciplinary assessment method for urban streams in the Louisville, Kentucky metropolitan region. The model adapts a regional habitat assessment procedure called the Qualitative Habitat Evaluation Index by incorporating additional processes related to geomorphic change and watershed connectivity. The model was developed in the context of the Beargrass Creek Ecosystem Restoration Feasibility Study, and QHEILS provides a rapid procedure for assessing multi-objective benefits associated with proposed restoration actions. This technical note summarizes the model and provides example applications within the Beargrass Creek watershed.

1. Beargrass Creek Ecosystem Restoration Feasibility Study

Urban streams present well-described ecosystem management and restoration challenges due to myriad drivers of ecological change like watershed land use, increased runoff, channel erosion, modified water quality, and other stressors (Wenger et al. 2009). The phrase "urban stream syndrome" often is used to describe the accompanying effects of these changes on hydrologic regimes, geomorphic condition, ecosystem processes, and aquatic biota (Walsh et al. 2005). Urban stream management and restoration have become key points of emphasis for water managers nationwide, and interdisciplinary and inter-institutional partnerships are often used to find routes to more effective urban water management (Muir 2014).

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Beargrass Creek in Louisville, Kentucky is a representative example of these common urban stream management challenges. Three main branches, the South Fork, Middle Fork, and Muddy Fork, drain this small watershed (~59 mi^2, Figure 1). Wetlands and forests were historically drained to support residential, commercial, and industrial land uses as the Louisville region grew. Some reaches were channelized to increase conveyance, and further geomorphic change occurred as a result of increased runoff from urban development. To confront these challenges, the U.S. Army Corps of Engineers (USACE) Louisville District (LRL) and Louisville Metropolitan Sewer District (MSD) are partnering to identify actions restoring aquatic ecosystems at multiple sites throughout the watershed. The two primary objectives of the project are: (1) To reestablish quality and connectivity of *riverine* habitats and (2) To reestablish quality and connectivity of *riparian* habitats.

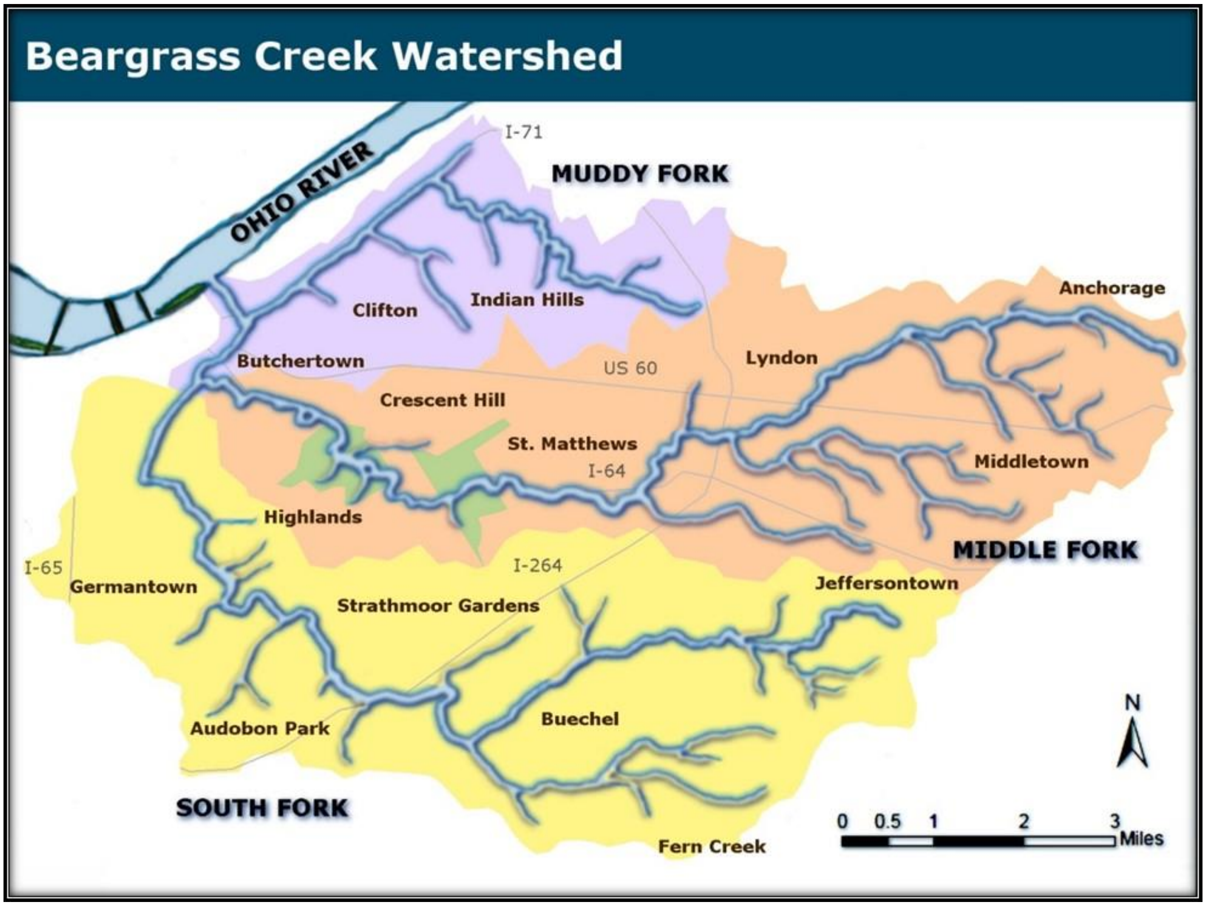

Figure 1. Beargrass Creek watershed.

Many assessment methods and tools have been developed to support and inform urban watershed restoration projects nationwide. These tools are often centered on specific project outcomes such as hydrologic or geomorphic change (e.g., Bledsoe et al. 2007 and Bledsoe et al. 2012, respectively), taxa-specific metrics (e.g., Guilfoyle et al. 2008), or wetland processes (e.g., Ainslie et al. 1999). Rapid assessment techniques have also been developed to assess multiple aspects of stream processes, such as the Rapid Bioassessment Protocol (Barbour et al. 1999), the Stream Visual Assessment Protocol (Newton et al. 1998, Bjorkland et al. 2001), the Qualitative Habitat Evaluation Index (Rankin 2006), and many site-specific adaptations (e.g., Rowe et al. 2009, McKay et al. 2018, Pruitt et al. 2020).

This technical note describes a model for urban stream evaluation in the context of the Beargrass Creek project. Specifically, the Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS) combines common environmental metrics to evaluate urban stream outcomes. Riparian outcomes for the Beargrass Creek project are addressed using the Simple Model for Urban Riparian Function (SMURF), which is described elsewhere (McKay et al. 2021). The QHEILS draws heavily from prior frameworks and merely presents a context-specific use of these models for the urban streams of Louisville. This technical note presents the theoretical underpinning of the model, the numerical code used to execute the model, evaluation of the model to date, and an example application in Beargrass Creek.

2. Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS)

This section presents development of the Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS, pronounced "quails"). The tool was developed following a common ecological modeling process of conceptualization, quantification, evaluation, application, and communication (Grant and Swannack 2008). The model was developed iteratively with the model development team (i.e., authors of this document) and the larger Beargrass Creek project development team. Ultimately, the model is executed in the R statistical software language, and this report provides documentation of the technical details, use, and relevant information for USACE model approval and certification (USACE 2011, EC 1105-2-412).

In general, QHEILS seeks to capture the general condition of riverine ecosystems and predict their response to restoration alternatives. An index-based, habitat-suitability modeling framework is applied to assess reach-scale effects. Index models combine assessments of habitat quantity (typically an area-metric like acres) with a multi-variate assessment of habitat quality (a 0 to 1 "suitability" score). Three major functional categorical outcomes are included in this model: (1) instream macrohabitat, (2) geomorphic condition of the channel, and (3) longitudinal connectivity within the riverine environment. In general, the scale of model application should be applied consistently a given use. For instance, a "reach" should be defined similarly across sites to create a consistent frame of comparison. QHEILS leaves this definition of reach and assessment area open to the analysts judgment on appropriate size or definition. Table 1 describes a variety model scoping issues associated with the QHEILS.

Table 1. Overview of model scoping for QHEILS.

Scoping Issue	QHEILS
Model Objective	To quantify the general ecological condition of urban streams in the Louisville metropolitan region for informing watershed management and restoration actions
General approach	Index-based, habitat-style model
Spatial processes	Spatially lumped, reach-scale model where user decides on the unit of analysis
Temporal processes	None. The model applies at a single moment in time.
Input data type	Combination of rapid, field assessment and desktop, geospatial analyses
Forecasting methods	Initial field and desktop data are adjusted based on other modeling or professional judgment
Intended application	Preliminary assessment of urban streams in the context of management actions (e.g., restoration)
Major assumptions	(1) Reach-scale models adequately capture the complexity of complex, connected stream ecosystems, (2) Assessments are a snapshot in time not dependent upon prior time periods, (3) Forecasts of ecosystem response can be reliably obtained from adjustment of parameters based on professional judgment, data from other sites, and other forms of inference, (4) Models are being applied for relative comparison rather than absolute prediction, and (5) QHEILS omits variables that may be important in other ecosystems because it was developed in the context of the Beargrass Creek restoration project and regional context.

2.1. Conceptualization

Conceptual models are "descriptions of the general functional relationships among essential components of an ecosystem" (Fischenich 2008). Here, we focus on conceptual modeling as a means to numerical model development (Grant and Swannack 2008), but these models also provide a mechanism for communicating links between restoration actions and focal outcomes of the Beargrass Creek project. Figure 2 shows how restoration actions directly influence key intermediate process and model variables, and how those variables are subsequently combined into overarching categorical outcomes related to effects on instream macrohabitat, geomorphic condition, and longitudinal connectivity of aquatic systems.

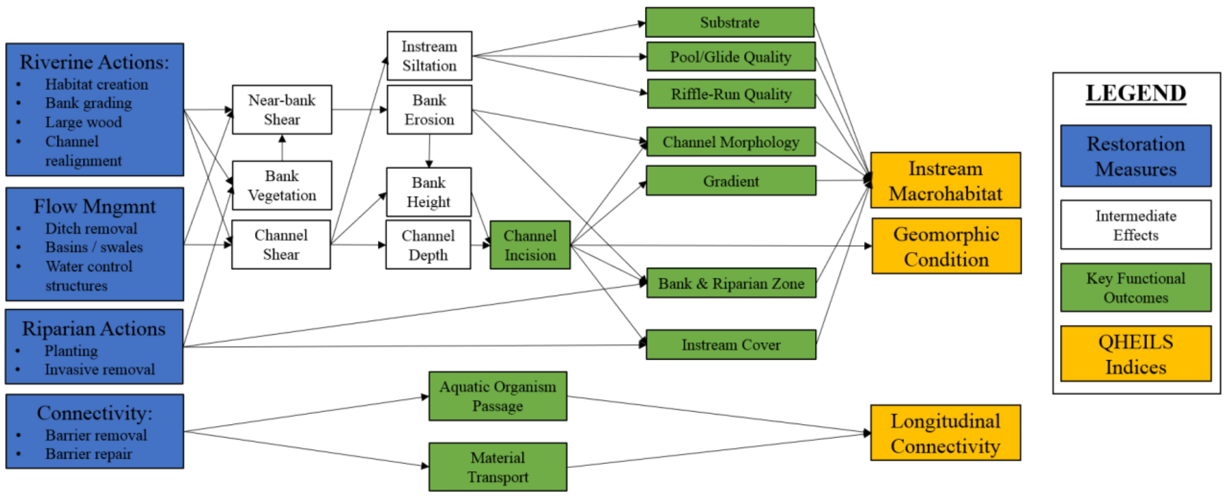

Figure 2. QHEILS Conceptual Model.

2.2. Quantification

The quantification phase of ecological model development formalizes the conceptual model in terms of mathematical relationships, model parameters, and a numerical algorithm (Grant and Swannack 2008). This section describes the QHEILS model structure and provides background on the theoretical underpinnings of the model, protocols for compiling inputs, and the associated numerical toolkit. The model is divided into three "modules" addressing each of the main outcomes of instream habitat, geomorphic condition, and longitudinal connectivity.

Each of the three modules is assessed independently as a 0 to 1 index of ecosystem quality. Table 2 summarizes modules and the variables composing the assessment of that process. Overall ecosystem quality is computed as the average of the quality scores for each module, which assumes that each function can occur without the others. The modules are each viewed as equally important contributions to overall stream function, and no "weighting" of outcomes is applied.

$$HSI = (I_{qhei} + I_{geomorph} + I_{longcon})/3$$

Where HSI is an overarching index of ecosystem quality, I_{qhei} is an index of a stream's habitat quality, $I_{geomorph}$ is an index of geomorphic integrity of the channel, and $I_{longcon}$ is an index of relative to the system's role in the flux of organisms, matter, and energy. All indices are quality metrics scaled from 0 to 1, where 0 is unsuitable and 1 is ideal. The overall quality index can be combined with the area of a given reach (typically in acres) to derive a quality-weight area metric, a so-called "habitat unit."

Table 2. Overview of the quality sub-models in the QHEILS.

Module	Variables	Assessment Metric
Macrohabitat (*strhab*)	Substrate	Qualitative 0-20 score
	Instream cover	Qualitative 0-20 score
	Channel morphology	Qualitative 0-20 score
	Bank erosion and riparian zone	Qualitative 0-10 score
	Pool and glide quality	Qualitative 0-12 score
	Riffle and run quality	Qualitative 0-8 score
	Channel gradient	Qualitative 0-10 score
Geomorphic Condition (*geomorph*)	Channel incision	Bank Height Ratio = bank height / bankfull depth
Longitudinal Connectivity (*longcon*)	Aquatic organism passage	Qualitative 0-20 score
	Material transport	Qualitative 0-20 score

2.2.1 Macrohabitat ($strhab$)

Physical structure of stream ecosystems strongly influences the composition of biotic communities, and stream habitat assessment is a long-standing topic of investigation with many proposed methods (e.g., Barbour et al. 1999, Newton et al. 1998, Rowe et al. 2009, McKay et al. 2018, Pruitt et al. 2020). In the Midwestern United States, the Qualitative Habitat Evaluation Index (QHEI) is a commonly applied set of field protocols with an associated habitat index. QHEI was developed by the Ohio Environmental Protection Agency to provide an empirical, quantified evaluation of the general lotic macrohabitat characteristics that are important to fish communities. The model has undergone multiple revisions from 1989 to present (Rankin 2006), and USACE certified these models for use in ecosystem restoration and impact assessment in December 2014.

The QHEI is composed of the seven principle scoring metrics summarized below, which are scored individually based on professional judgment (and guidance in the field protocols) and summed for a total score with a maximum of 100. For the purpose of QHEILS, this total score is normalized on a scale from 0 to 1 for comparison with other modules. Notably, QHEI incorporates some gemorphic variables, but this protocol was not intended for use as a geomorphic assessment tool but rather to capture the influence of geomorphology on fish communities. Appendix A presents the field data sheets for QHEI assessment, and additional field protocols can be found in Rankin (2006).

- *Substrate* (sub, 0-20 score): Channel boundaries exert a strong influence on aquatic communities, and the substrate variable addresses the material type (e.g., grain size classes like gravel and sand), the geological origin of materials (e.g., limestone vs. sandstone), and the quality of the substrates relative to embeddedness from fine sediments.
- *Instream cover* (ins, 0-20 score): Fish communities often thrive under high diversity of habitat features. The instream cover metrics incorporates the presence and extent of

multiple habitat types such as undercut banks, boulders, macrophyte beds, and large wood.

- *Channel morphology* (mor, 0-20 score): The geomorphic template for fish habitat is assessed relative to channel sinuosity, development of bedform complexes, history of channelization, and stability.
- *Bank erosion and riparian zone* ($bank$, 0-10 score): Streambank and riparian ecosystems provide the transitional ecotone between aquatic and upland ecosystems. This score reflects the degreee of bank erosion along with the width and general quality of the riparian zone. Notably, this is an assessment of how the riparian zone influences instream habitat, not the quality of the riparian zone itself.
- *Pool and glide quality* ($pool$, 0-12 score): Bedforms such as pools provide important thermal refugia for fishes and other aquatic organisms. This metric assesses the quality of pool and glide environments relative to depth, width, and velocity criteria.
- *Riffle and run quality* (rif, 0-8 score): Similarly to the pool metric, bedforms such as riffles and runs are important fast flowing areas that often serve as habitat for unique fishes rarely found in pools. The riffle quality score addresses the depth, substrate, and embeddedness of these features.
- *Channel gradient* ($grad$, 0-10 score): Stream slope varies predictably with watershed area, and this metric translates the degree of change in channel gradient into a quality metric for a given slope and drainage area.

$$I_{strhab} = (sub + ins + mor + bank + pool + rif + grad)/100$$

Where I_{strhab} is a suitability index for instream macrohabitat defined by the QHEI protocol (Rankin 2006) and all inputs are defined as summarized above.

2.2.2 Geomorphology ($geomorph$)

Fluvial systems evolve in response to how driving variables like water and sediment inflow interact with boundary characteristics such as topography and bed/bank materials. These process influence the form and shape of a channel observed through cross-sectional geometry, longitudinal profile, and meander planform. Urban land use change often alters many conditions simultaneously such as increasing runoff and sediment load, channelizing reaches, and altering riparian boundary conditions. Although processes vary, urban streams often follow a predictable channel evolution as a stream downcuts, widens, aggrades, and ultimately arrives at a new stable equilibrium at a lower elevation (Schumm et al. 1984, Simon 1989, Watson et al. 2002).

Geomorphologists and engineers have developed a variety of metrics for assessing geomorphic condition and change. The QHEILS utilizes a relatively simple (but crucial) metric of channel change to provide a general snapshot of a stream's geomorphic status. The incision ratio (also known as bank height ratio, sensu Harman and Jones 2016) is the ratio of bank height to the bankfull depth. As channels undertake the evolutionary process above, channel bottoms incise leaving bank heights much greater than those typically observed in unmodified systems. In an unmodified stream, the "bankfull" condition can be defined as the depth at which a channel overflows onto the floodplain (Shields et al. 2003), but the bankfull depth is often significantly less than bank height in altered streams (Harman and Jones 2016). Regional regressions have been developed throughout western Kentucky for estimating bankfull channel dimensions and discharge in relatively unmodified conditions (Ainslie et al. 1999, Pruitt et al. 1999, Parola et al. 2007, Agouridis et al. 2011, Brockman et al. 2012). Here, the following regression equation from Brockman et al. (2012) is used to estimate bankfull conditions for the Outer Bluegrass region.

$$H_{bankfull} = 0.22 * A_{drainage}^{0.37}$$

Where $H_{bankfull}$ is bankfull depth in m, and $A_{drainage}$ is watershed drainage area in km^2.

This bankfull depth may be coupled with a field assessment of bank height (i.e., vertical distance from the channel thalweg to the top of bank for incipient flooding) to derive an incision ratio. This metric has been used widely in other stream restoration projects to quantify the relative condition of the channel and inform design targets. For instance, Harman and Jones (2016) identify thresholds in geomorphic performance relative to incision as: less than 1.3 is highly functioning, between 1.3 and 1.5 is functioning at risk, and greater than 1.5 is not functioning. Regional evidence indicates that thresholds in performance occur closer to 1.2 rather than 1.3 (Athanasakes and Taylor, personal communication), which is consistent with modifications in other systems (IA DNR 2018). In QHEILS, these thresholds were used to articulates how channel incision is translated into a 0 to 1 metric of geomorphic quality. Notably, incision is calculated independently for each bank and averaged for use in QHEILS.

$$I_{geomorph} = \begin{pmatrix} 1.0 & inc < 1.2 \\ 5.0 - 3.333 * inc & inc = 1.2 - 1.5 \\ 0.0 & inc >= 1.5 \end{pmatrix}$$

Where $I_{geomorph}$ is a suitability index for geomorphic integrity, $inc = \frac{H_{bank}}{H_{bankfull}}$ is the incision ratio, H_{bank} is bank height, and $H_{bankfull}$ is bankfull depth defined by the regional curves of Brockman et al. (2012).

2.2.3 Longitudinal Connectivity ($longcon$)

Watersheds and streams are important conduits and pathways for many biotic and abiotic processes. Hydrologic connectivity refers to the "water-mediated transfer of matter, energy, and/or organisms within or between elements of the hydrologic cycle" (Pringle 2003). In urban systems, connectivity is not only important for natural processes, but also as a source of resilience and buffer against disturbances like unexpected spills. Many methods exist for quantifying connectivity relative to movement of organisms and transport processes, some of which incorporate complex spatial dynamics at the watershed scale (e.g., McKay et al. 2017 and Czuba and Foufoula-Georgiou 2014, respectively). For QHEILS, a simpler reach-scale approach to connectivity was developed to qualitatively assess effects relative to aquatic organism passage and material transport (Table 3). These qualitative methods are aligned with the relative level of effort associated with other

QHEILS modules. These two qualitative scores are then translated into a 0 to 1 metric of reach quality relative to longitudinal connectivity.

$$I_{longcon} = (aop + trans)/40$$

Where $I_{longcon}$ is a suitability index for geomorphic integrity, aop is a qualitative score assessing aquatic organism passage, $trans$ is a qualitative score assessing connectivity relative to material transport processes, and the denominator (40) is the sum of the maximum potential scores.

Table 3. Overview of the longitudinal connectivity sub-model in the QHEILS.

Process	Optimal (20-16)	Suboptimal (15-11)	Marginal (10-6)	Poor (5-0)
Aquatic organism passage	No barrier exist within the reach or in neighboring reaches.	Minor barriers exist, but allow for movement of most species during portions of the flow regime.	One or more barriers disrupt animal movement a majority of the time.	Multiple barriers disconnect the system.
Material transport	Sediment, wood, and other transported materials move freely.	Minor barriers exist but only minimally disrupt long-term transport mechanisms.	Major barriers fragment the flux of one or more constituents.	Sediment, wood, and other transported materials are unable to move downstream.

2.2.4 QHEILS Numerical Code

As described in Sections 2.2.1-2.2.3, QHEILS is a tool for evaluating general riparian quality based on many separate lines of evidence. A single function was developed to combine inputs into suitability indices for each module as well as an overaching habitat suitability index and habitat units. The `QHEILScalc` function was programmed in the open-source, USACE-approved, R statistical software language. `QHEILScalc` has two inputs. First, a vector of ten values addressing the seven qualitative scores associated with the QHEI, a channel incision ratio, and two qualitative scores associated with connectivity assessment. Second, reach area (i.e., acres from feasibility study alternatives) is input for the extent of the stream associated with the prior inputs. `QHEILScalc` subsequently outputs a simple data frame with six fields corresponding to the quality index for each module, an overarching habitat quality index, the site area (in acres), and the number of habitat units.

```
#Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS)

#Vector of site-specific inputs for the QHEILS
  #site.qheils <- c("sub", "ins", "mor", "bank", "pool", "rif", "grad",
"inc", "aop", "trans")
  #sub, ins, mor, bank, pool, rif, and grad = qualitative inputs from QHEI
assessment
  #inc = bank height / bankfull depth (average of left and right bank)
  #aop and trans = qualitative inputs from connectivity assessment
#Single number indicating reach area for this assessment
  #site.area = total channel area

###########################################################################
###
#Import the ecorest package containing the SIcalc function used in the
geomorph module
library(ecorest)

#Specify function for executing the QHEI model
QHEILScalc <- function(site.qheils, site.area){

  #Create empty data frame to store outputs
  QHEILS.out <- as.data.frame(matrix(NA, nrow = 1, ncol = 6))
  colnames(QHEILS.out) <- c("strhab", "geomorph", "longcon", "HSI", "Area",
"HU")

  #If any input is NA, return NA
  if (sum(is.na(site.qheils)) > 0){
    QHEILS.out$strhab <- NA;    QHEILS.out$geomorph <- NA
    QHEILS.out$longcon <- NA;   QHEILS.out$HSI <- NA
    QHEILS.out$Area <- NA;      QHEILS.out$HU <- NA
  }

  #Else compute overarching habitat suitability index and habitat units
  else{
    QHEILS.out$strhab <- sum(site.qheils[1:7]) / 100
    QHEILS.out$geomorph <-
SIcalc(data.frame(matrix(c(0,1.0,1.2,1.0,1.5,0.0,10,0.0),
nrow=4,ncol=2,byrow=TRUE)), site.qheils[8])
    QHEILS.out$longcon <- sum(site.qheils[9:10]) / 40
    QHEILS.out$HSI <- (QHEILS.out$strhab + QHEILS.out$geomorph +
QHEILS.out$longcon) / 3
    QHEILS.out$Area <- site.area
    QHEILS.out$HU <- QHEILS.out$HSI * QHEILS.out$Area
  }

  #Send output from function
  QHEILS.out
}
```

2.3. Evaluation

Ecological models typically rely on multiple variables, ecological processes, and in many cases present a variety of ecological outcomes. As such, models can quickly become complex system representations with many components, inputs, assumptions, and modules. Model evaluation is the process for ensuring that numerical tools are scientifically defensible and transparently developed. Evaluation is often referred to as verification or validation, but it in fact includes a family of methods ranging from peer review to model testing to error checking. The USACE has established an ecological model certification process to ensure that planning models are sound and functional. These generally consist of evaluating tools relative to the three following categories: system quality, technical quality, and usability (EC 1105-2-412).

2.3.1 System Quality

System quality refers to the computational integrity of a tool and involves assessing the numerical accuracy of a model. System quality has three primary phases for avoiding errors (quality assurance), detecting errors through formal testing (quality control), and updating models based on review and use (model update) (McKay et al. 2020).

Multiple quality assurance practices were followed throughout the development of QHEILS. First, the simple workflow of a single function minimizes potential locations for errors. Second, code was written following a standard style used by the first author in more than a dozen prior models. Third, models were programmed by the lead author (SKM) and code was subsequently interrogated by authors and independent reviewers during certification. Finally, models were developed with the "reproducible research" tool R Markdown, which allows developers to integrate technical documentation and numerical code. These processes cannot guarantee error-free analyses; however, best practices were sought to minimize the occurrence of errors.

Additionally, quality control procedures were applied to find and correct any errors. The first author used interim line-level checks of code to verify functionality. A test plan was also devised to examine the overaching function as well as the computation of the `strhab`, `geomorph`, and `longcon` indices. Table 4 presents the input tests and associated results, all of which matched a spreadsheet version of the QHEILS.

Model errors are often uncovered during peer review and/or applications (i.e., "bugs"), which can be particularly important for complex models. QHEILS is a relatively simple tool and has been developed in the context of a single application in Beargrass Creek. This technical note and accompanying model were reviewed through USACE certification procedures, and review comments are archived here for future reference (Appendix B). This report will be published via the ERDC Knowledge Core, which also provides a means for archival of associated code.

Table 4. Summary of QHEILS model testing.

Test	sub	ins	mor	bank	pool	rif	grad	inc	aop	trans	strhab	geomorph	longcon	HSI
1	20	20	20	10	12	8	10	1.00	20	20	1.00	1.00	1.00	1.00
2	0	20	20	10	12	8	10	1.00	20	20	0.80	1.00	1.00	0.93
3	0	0	0	10	12	8	10	1.00	20	20	0.40	1.00	1.00	0.80
4	0	0	0	0	0	8	10	1.00	20	20	0.18	1.00	1.00	0.73
5	0	0	0	0	0	0	0	1.00	20	20	0.00	1.00	1.00	0.67
6	20	20	20	10	12	8	10	1.20	20	20	1.00	1.00	1.00	1.00
7	20	20	20	10	12	8	10	1.35	20	20	1.00	0.50	1.00	0.83
8	20	20	20	10	12	8	10	1.50	20	20	1.00	0.00	1.00	0.67
9	20	20	20	10	12	8	10	2.50	20	20	1.00	0.00	1.00	0.67
10	20	20	20	10	12	8	10	1.00	0	20	1.00	1.00	0.50	0.83
11	20	20	20	10	12	8	10	1.00	20	0	1.00	1.00	0.50	0.83
12	20	20	20	10	12	8	10	1.00	0	0	1.00	1.00	0.00	0.67
13	10	13	12	15	6	2	4	1.00	20	20	0.62	1.00	1.00	0.87
14	10	13	12	15	6	2	4	1.25	20	20	0.62	0.83	1.00	0.82
15	10	13	12	15	6	2	4	1.25	8	11	0.62	0.83	0.48	0.64
16	10	13	12	15	6	2	4	1.49	8	11	0.62	0.03	0.48	0.38
17	10	13	12	15	6	2	4	1.50	8	11	0.62	0.00	0.48	0.36
18	10	13	12	15	6	2	4	2.00	8	11	0.62	0.00	0.48	0.36
19	0	0	0	0	0	0	0	2.00	0	0	0.00	0.00	0.00	0.00
20	0	0	0	0	0	0	0	1.00	0	0	0.00	1.00	0.00	0.33

2.3.2 Technical Quality

The technical quality of a model is assessed relative to its reliance on contemporary theory, consistency with design objectives, and degree of verification and validation against independent field data. As described in Section 2.2, QHEILS draws from methods used in other peer-reviewed and grey literature resources. However, much of the model currently relies on qualitative scoring based on professional judgments. Although qualitative, this general family of methods have been shown to provide significant utility and predictive power, and remain highly applied in stream assessment (Hughes et al. 2010).

2.3.3 Usability

The usability of a model can influence the repeatable and transparent application of a tool. This type of evaluation typically examines the ease of use, availability of inputs, transparency, error potential, and education of the user. As such, defining the intended user(s) is a crucial component of assessing usability. QHEILS was developed for application by the USACE technical team of the Beargrass Creek ecosystem restoration study. In its current form, the tool is not intended for broader application, and there is no associated graphical user interface beyond the script itself (shown above). However, the model is programmed in the widely available R Statistical Software language, and users familiar with R could likely apply the model easily, given its single functional form.

3. Beargrass Creek Model Application

The Beargrass Creek ecosystem restoration feasibility study is examining potential restoration actions at dozens of sites through the watershed. Here, the QHEILS is demonstrated for a single restoration site and a limited number of actions. Site-X10 is a 1-mile reach including 3.06 acres of stream channel surrounded by 79 acres of riparian areas near the Louisville Zoo. The following alternatives were examined for the purpose of this analysis:

- FWOP: The "future without project" condition is the no action alternative, which is considered here to be the same as the existing condition observed during field surveys in May 2020.
- Alt1: Removes three connectivity bariers in the reach (i.e., C-alt).
- Alt2: Creates instream habitat through the addition of rock structures (i.e., R1-alt).
- Alt3: Reduces channel incision by grading streambanks to bank heights at the bankfull depth from regional curves (i.e., R2-alt).
- Alt4: Realigns the channel and significantly improves the overall geomorphic condition (i.e., R4-alt).
- Alt5: Combines actions of the C-alt and R1-alt.
- Alt6: Combines actions of the C-alt and R2-alt.
- Alt7: Combines actions of the C-alt and R4-alt.

A simple rubric was developed to adjust QHEILS FWOP scores based on these different alternatives (Appendix C). Table 5 shows the input values for this application. Table 6 presents the associated indices for each module, the total HSI, the habitat units produced, and the "lift" above the FWOP condition (i.e., the outputs). This analysis shows the ability of the QHEILS to distinguish the effects of different types of urban stream restoration actions. For the broader Beargrass project, these data would be combined with costs, riparian benefits, and other factors to inform decision-making.

Table 5. Model inputs for an example restoration application for site X10 in the Beargrass Creek ecosystem restoration study.

	Calt	Ralt	sub	ins	mor	bank	pool	rif	grad	inc	aop	trans
FWOP	0	0	13.00	9.0	9.0	9.0	10.0	5.500	4	4.370629	2.00	8.000
Alt1	1	0	13.00	9.0	9.0	9.0	10.0	5.500	4	4.370629	19.00	17.500
Alt2	0	1	14.75	14.5	9.0	9.0	10.0	6.125	4	4.370629	2.00	8.000
Alt3	0	2	16.50	16.7	9.0	9.5	10.5	6.750	4	1.350000	2.00	8.000
Alt4	0	4	18.60	17.8	18.9	9.9	11.8	7.750	4	1.000000	2.00	8.000
Alt5	1	1	14.75	14.5	9.0	9.0	10.0	6.125	4	4.370629	19.00	17.500
Alt6	1	2	16.50	16.7	9.0	9.5	10.5	6.750	4	1.350000	19.05	17.625
Alt7	1	4	18.60	17.8	18.9	9.9	11.8	7.750	4	1.000000	19.18	17.950

Table 6. Model outputs for an example restoration application for site X10 in the Beargrass Creek ecosystem restoration study.

	strhab	geomorph	longcon	HSI	Area	HU	Lift
FWOP	0.60	0.0	0.25	0.28	3.06	0.86	0.00
Alt1	0.60	0.0	0.91	0.50	3.06	1.54	0.68
Alt2	0.67	0.0	0.25	0.31	3.06	0.94	0.08
Alt3	0.73	0.5	0.25	0.49	3.06	1.51	0.65
Alt4	0.89	1.0	0.25	0.71	3.06	2.18	1.32
Alt5	0.67	0.0	0.91	0.53	3.06	1.62	0.76
Alt6	0.73	0.5	0.92	0.72	3.06	2.19	1.33
Alt7	0.89	1.0	0.93	0.94	3.06	2.87	2.01

4. Summary

This technical note has presented a simple stream assessment model, the Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS). This tool is augments the broadly used QHEI scoring protocol with additional information regarding geomorphic condition and watershed connectivity. This model represents one of many similar tools that have been applied in stream assessment and restoration (e.g., Barbour et al. 1999, Newton et al. 1998, Rowe et al. 2009, Harman and Jones 2016, McKay et al. 2018, Pruitt et al. 2020). An important distinguishing factor of this tool is that it has been designed specifically to examine instream quality only, and the Beargrass Creek project is applying a separate model for assessing riparian function (i.e., the SMURF, McKay et al. 2021). This coupled set of tools is designed to more fully describe the separate benefits of stream and riparian restoration in an integrated fashion. Both models were designed for rapid application in the context of a USACE feasibility study, and future analyses could adapt these tools by replacing judgment-based metrics with empirical inputs, incorporating additional variables, and examining processes not considered here (e.g., hydrologic regimes).

5. Acknowledgements

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McKay, S.K., Athanasakes G., Taylor S., Miller W., Wagoner E., and Mattingly L. 2021. Qualitative Habitat Evaluation Index for Louisville Streams (QHEILS). ERDC TN-EMRRP-xx. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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Appendix A: Field Data Sheets

Ohio EPA — Qualitative Habitat Evaluation Index and Use Assessment Field Sheet — *QHEI Score:* ____

Stream & Location: ______ *RM:* _ _ _._ *Date:* _ _ / _ _ / 06

Scorers Full Name & Affiliation: ______

River Code: _ _ - _ _ _ - _ _ _ *STORET #:* ______ *Lat./ Long.:* (NAD 83 - decimal °) _ _ . _ _ _ _ /8 _ . _ _ _ _ Office verified location ☐

1] SUBSTRATE Check ONLY Two substrate TYPE BOXES; estimate % or note every type present

BEST TYPES (POOL RIFFLE):
- ☐ ☐ BLDR /SLABS [10] ____ ____
- ☐ ☐ BOULDER [9] ____ ____
- ☐ ☐ COBBLE [8] ____ ____
- ☐ ☐ GRAVEL [7] ____ ____
- ☐ ☐ SAND [6] ____ ____
- ☐ ☐ BEDROCK [5] ____ ____

OTHER TYPES (POOL RIFFLE):
- ☐ ☐ HARDPAN [4] ____ ____
- ☐ ☐ DETRITUS [3] ____ ____
- ☐ ☐ MUCK [2] ____ ____
- ☐ ☐ SILT [2] ____ ____
- ☐ ☐ ARTIFICIAL [0] ____ ____

(Score natural substrates; ignore sludge from point-sources)

NUMBER OF BEST TYPES: ☐ 4 or more [2] ☐ 3 or less [0]

Comments

Check ONE (Or 2 & average)

ORIGIN: ☐ LIMESTONE [1] ☐ TILLS [1] ☐ WETLANDS [0] ☐ HARDPAN [0] ☐ SANDSTONE [0] ☐ RIP/RAP [0] ☐ LACUSTURINE [0] ☐ SHALE [-1] ☐ COAL FINES [-2]

QUALITY:
- SILT: ☐ HEAVY [-2] ☐ MODERATE [-1] ☐ NORMAL [0] ☐ FREE [1]
- EMBEDDEDNESS: ☐ EXTENSIVE [-2] ☐ MODERATE [-1] ☐ NORMAL [0] ☐ NONE [1]

Substrate ____ *Maximum 20*

2] INSTREAM COVER Indicate presence 0 to 3: 0-Absent; 1-Very small amounts or if more common of marginal quality; 2-Moderate amounts, but not of highest quality or in small amounts of highest quality; 3-Highest quality in moderate or greater amounts (e.g., very large boulders in deep or fast water, large diameter log that is stable, well developed rootwad in deep / fast water, or deep, well-defined, functional pools.

- ____ UNDERCUT BANKS [1]
- ____ OVERHANGING VEGETATION [1]
- ____ SHALLOWS (IN SLOW WATER) [1]
- ____ ROOTMATS [1]
- ____ POOLS > 2.3ft [2]
- ____ ROOTWADS [1]
- ____ BOULDERS [1]
- ____ OXBOWS, BACKWATERS [1]
- ____ AQUATIC MACROPHYTES [1]
- ____ LOGS OR WOODY DEBRIS [1]

AMOUNT — Check ONE (Or 2 & average): ☐ EXTENSIVE >75% [11] ☐ MODERATE 25-75% [7] ☐ SPARSE 5-<25% [3] ☐ NEARLY ABSENT <5% [1]

Comments

Cover ____ *Maximum 20*

3] CHANNEL MORPHOLOGY Check ONE in each category (Or 2 & average)

SINUOSITY	DEVELOPMENT	CHANNELIZATION	STABILITY
☐ HIGH [4]	☐ EXCELLENT [7]	☐ NONE [6]	☐ HIGH [3]
☐ MODERATE [3]	☐ GOOD [5]	☐ RECOVERED [4]	☐ MODERATE [2]
☐ LOW [2]	☐ FAIR [3]	☐ RECOVERING [3]	☐ LOW [1]
☐ NONE [1]	☐ POOR [1]	☐ RECENT OR NO RECOVERY [1]	

Comments

Channel ____ *Maximum 20*

4] BANK EROSION AND RIPARIAN ZONE Check ONE in each category for EACH BANK (Or 2 per bank & average)

River right looking downstream

EROSION (L R)	RIPARIAN WIDTH (L R)	FLOOD PLAIN QUALITY (L R)	
☐ ☐ NONE / LITTLE [3]	☐ ☐ WIDE > 164ft [4]	☐ ☐ FOREST, SWAMP [3]	☐ ☐ CONSERVATION TILLAGE [1]
☐ ☐ MODERATE [2]	☐ ☐ MODERATE 33-164ft [3]	☐ ☐ SHRUB OR OLD FIELD [2]	☐ ☐ URBAN OR INDUSTRIAL [0]
☐ ☐ HEAVY / SEVERE [1]	☐ ☐ NARROW 16-33ft [2]	☐ ☐ RESIDENTIAL, PARK, NEW FIELD [1]	☐ ☐ MINING / CONSTRUCTION [0]
	☐ ☐ VERY NARROW < 16ft	☐ ☐ FENCED PASTURE [1]	Indicate predominant land use(s) past 100m riparian.
	☐ ☐ [1] NONE [0]	☐ ☐ OPEN PASTURE, ROWCROP [0]	

Comments

Riparian ____ *Maximum 10*

5] POOL / GLIDE AND RIFFLE / RUN QUALITY

MAXIMUM DEPTH — Check ONE (ONLY!): ☐ > 3.3ft [6] ☐ 2.3-3.3ft [4] ☐ 1.3-2.3ft [2] ☐ 0.7-1.3ft [1] ☐ < 0.7ft [0]

CHANNEL WIDTH — Check ONE (Or 2 & average): ☐ POOL WIDTH > RIFFLE WIDTH [2] ☐ POOL WIDTH = RIFFLE WIDTH [1] ☐ POOL WIDTH > RIFFLE WIDTH [0]

CURRENT VELOCITY — Check ALL that apply: ☐ TORRENTIAL [-1] ☐ VERY FAST [1] ☐ FAST [1] ☐ MODERATE [1] ☐ SLOW [1] ☐ INTERSTITIAL [-1] ☐ INTERMITTENT [-2] ☐ EDDIES [1]

Indicate for reach - pools and riffles.

Recreation Potential: *Primary Contact* / *Secondary Contact* (circle one and comment on back)

Comments

Pool / Current ____ *Maximum 12*

Indicate for functional riffles; Best areas must be large enough to support a population of riffle-obligate species: Check ONE (Or 2 & average). ☐ NO RIFFLE [metric=0]

RIFFLE DEPTH	RUN DEPTH	RIFFLE / RUN SUBSTRATE	RIFFLE / RUN EMBEDDEDNESS
☐ BESTAREAS > 0.3ft [2]	☐ MAXIMUM > 1.6ft [2]	☐ STABLE (e.g., Cobble, Boulder) [2]	☐ NONE [2]
☐ BESTAREAS 0.2-0.3ft [1]	☐ MAXIMUM < 1.6ft [1]	☐ MOD. STABLE (e.g., Large Gravel) [1]	☐ LOW [1]
☐ BESTAREAS < 0.2ft		☐ UNSTABLE (e.g., Fine Gravel, Sand) [0]	☐ MODERATE [0]
			☐ EXTENSIVE [-1]

Comments

Riffle / Run ____ *Maximum 8*

6] GRADIENT (ft/mi) ☐ VERY LOW - LOW [2-4] ☐ MODERATE [6-10] ☐ HIGH - VERY HIGH [10-6]

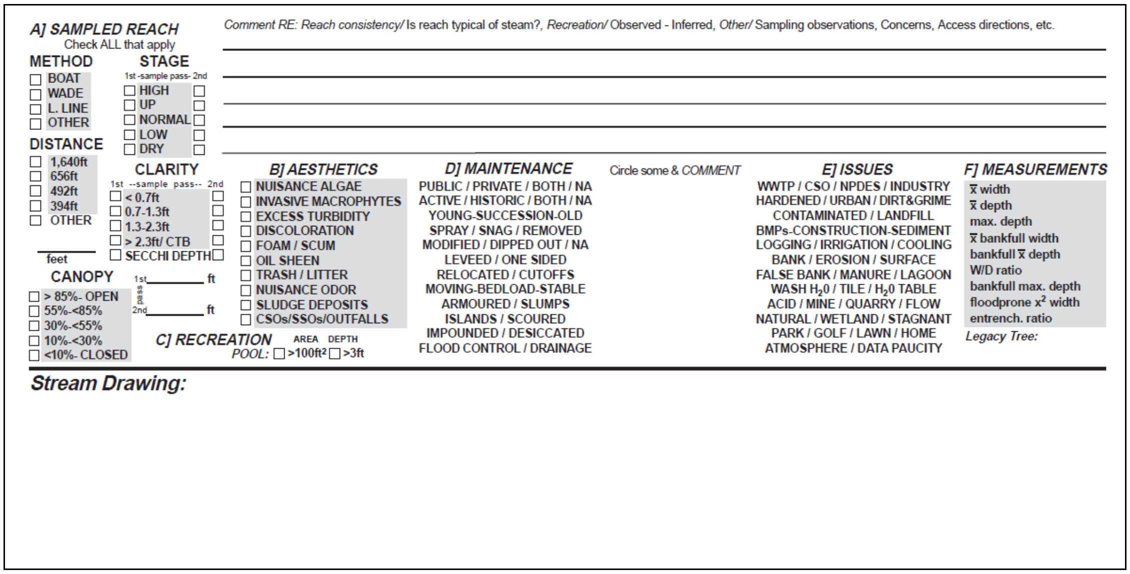
DRAINAGE AREA (mi²)

%POOL: ____ %GLIDE: ____ %RUN: ____ %RIFFLE: ____

Gradient ____ *Maximum 10*

EPA 4520 06/16/06

QHEI Field Data Sheet (front).



A] SAMPLED REACH
Check ALL that apply

Comment RE: Reach consistency/ Is reach typical of steam?, Recreation/ Observed - Inferred, Other/ Sampling observations, Concerns, Access directions, etc.

METHOD
☐ BOAT
☐ WADE
☐ L. LINE
☐ OTHER

STAGE
1st -sample pass- 2nd
☐ HIGH ☐
☐ UP ☐
☐ NORMAL ☐
☐ LOW ☐
☐ DRY ☐

DISTANCE
☐ 1,640ft
☐ 656ft
☐ 492ft
☐ 394ft
☐ OTHER
____ feet

CLARITY
1st --sample pass-- 2nd
☐ < 0.7ft ☐
☐ 0.7-1.3ft ☐
☐ 1.3-2.3ft ☐
☐ > 2.3ft/ CTB ☐
☐ SECCHI DEPTH ☐
1st pass ____ ft
2nd pass ____ ft

CANOPY
☐ > 85%- OPEN
☐ 55%-<85%
☐ 30%-<55%
☐ 10%-<30%
☐ <10%- CLOSED

B] AESTHETICS
☐ NUISANCE ALGAE
☐ INVASIVE MACROPHYTES
☐ EXCESS TURBIDITY
☐ DISCOLORATION
☐ FOAM / SCUM
☐ OIL SHEEN
☐ TRASH / LITTER
☐ NUISANCE ODOR
☐ SLUDGE DEPOSITS
☐ CSOs/SSOs/OUTFALLS

C] RECREATION
AREA DEPTH
POOL: ☐ >100ft² ☐ >3ft

D] MAINTENANCE
PUBLIC / PRIVATE / BOTH / NA
ACTIVE / HISTORIC / BOTH / NA
YOUNG-SUCCESSION-OLD
SPRAY / SNAG / REMOVED
MODIFIED / DIPPED OUT / NA
LEVEED / ONE SIDED
RELOCATED / CUTOFFS
MOVING-BEDLOAD-STABLE
ARMOURED / SLUMPS
ISLANDS / SCOURED
IMPOUNDED / DESICCATED
FLOOD CONTROL / DRAINAGE

Circle some & COMMENT

E] ISSUES
WWTP / CSO / NPDES / INDUSTRY
HARDENED / URBAN / DIRT&GRIME
CONTAMINATED / LANDFILL
BMPs-CONSTRUCTION-SEDIMENT
LOGGING / IRRIGATION / COOLING
BANK / EROSION / SURFACE
FALSE BANK / MANURE / LAGOON
WASH H_20 / TILE / H_20 TABLE
ACID / MINE / QUARRY / FLOW
NATURAL / WETLAND / STAGNANT
PARK / GOLF / LAWN / HOME
ATMOSPHERE / DATA PAUCITY

F] MEASUREMENTS
$\bar{x}$ width
$\bar{x}$ depth
max. depth
$\bar{x}$ bankfull width
bankfull $\bar{x}$ depth
W/D ratio
bankfull max. depth
floodprone x^2 width
entrench. ratio
Legacy Tree:

Stream Drawing:

QHEI Field Data Sheet (back).

Appendix B: USACE Model Certification Review

USACE model certification review was provided by Dr. Chuck Theiling (ERDC Environmental Laboratory) and Mr. Nate Richards (USACE Ecosystem Restoration Planning Center of expertise). All comments follow the four-part comment structure of: (1) identify the problem, (2) describe the technical basis for the comment, (3) rate the significance or impact of the problem, and (4) recommend a mechanism for resolution. Comments and author responses are provided for long-term archival purposes.

Comment 1: Inappropriate use of "trajectory" to describe model output.

- Basis: I'm having trouble with the use of trajectory for a "snapshot" in time evaluation. The term is used in the model report and is inappropriate for the QHEI and geomorphology metrics. Trajectory implies multiple measurements taken over time, but in this case planners are estimating the outcomes of restoration measures, a deterministic future.
- Significance: Low.
- Resolution: Consider deleting trajectory and stick with the general condition discussion.
- Author Response: Concur. All references to trajectories were removed.

Comment 2: Inconsistent use of terminology with regard to scale.

- Basis: Terms used to express scale are not consistent and include: patch scale, reach scale, and assessment area. The size of a reach is a factor in QHEI protocols and is defined for each site in the main report. QHEI reaches and planning reaches may not be the same. Boundaries should be placed on a reach (e.g., the stretch between bends, riffle-pools, bridges, or 10X the width) for consistency of application. For instance, a 1-mile reach is used for the example site, which seems too large.
- Significance: Medium.

- Resolution: Definition of the scale of model application should be specified.
- Author Response: Concur. We have clarified the definition of the "reach" in section two and removed reference to other terminology.

Comment 3: Clarify model assumption regarding forecasting.

- Basis: Table 1 articulate a model assumption that professional judgement can be used to estimate response to projects (#3). Can forecasts also be obtained from monitoring results from similar completed projects?
- Significance: Low.
- Resolution: Clarify language about model usage.
- Author Response: Concur. Observed ecological response at other projects provides important insight into model application. However, this inference would be interpreted through the lens of professional judgment. The text in the table has been clarified to reflect this point.

Comment 4: Inappropriate use of terminology in conceptual model.

- Basis: Some of the conceptual model processes are outcomes and vise-versa. Bank Vegetation is not a process, but "native riparian succession" is. Bank Height and Depth are not processes but are outcomes from Channel Incision. Channel Incision is a process, incised channels are a Channel Morphology outcome. With Channel Incision changed to a process, it drives Substrate, Channel Morphology, Gradient, Bank & Riparian Zone, and Instream Cover. Bank & Riparian Zone outcome is vague, maybe Bank & Riparian Vegetation or Habitat?
- Significance: Low.
- Resolution: Edit conceptual model and accompanying language.
- Author Response: Concur. Language was edited to identify intermediate "effects" rather than processes or outcomes, which we view as a broader notion of ecological response. The terminology for "bank and riparian zone" are a direct adoption of the QHEI, and as such, are not edited.

Comment 5: Thresholds in habitat suitability associated with channel incision model.

- Basis: Incision ratios are ranked to indicate degradation, and the ranks may vary by region. Iowa is provided as an example, but Iowa is a much different hydrologic region than Kentucky. Ranks may need to be explained differently.
- Significance: Medium.
- Resolution: Alter suitability thresholds or provide additional support and clarification in the text.
- Author Response: Concur. Thresholds in geomorphic performance relative to incision were identified from an assessment method developed in North Carolina (Harman and Jones 2016). Personal observations of the authors (Athanasakes and Taylor) indicate 1.2 to be a more appropriate threshold in the Louisville area, which is consistent with other regional adjustments of the Harman and Jones threshold (e.g., IA DNR 2018).

Comment 6: Units of habitat quantity are not specified.

- Basis: Assessment area units are never defined in text. The code implies acres which needs to be stated.
- Significance: Medium.
- Resolution: Specify appropriate units for habitat quantity.
- Author Response: Concur. Technically the model is agnostic to units, and stream length or area could be used depending on the user's application. However, units of acres were noted throughout the report to increase consistency in USACE applications.

Comment 7: Inadequate describe of the parameterization of Alternative-3 in example application.

- Basis: Alt3 recommends restoration to bankfull dimensions. Confusion over the term is noted in text, perhaps the 1.5-yr or 2-yr return interval stage perhaps? Is this where regional curve matters, right?
- Significance: Medium.
- Resolution: Clarify language to reflect intent.
- Author Response: Concur. The description of the alternatives was clarified to reflect that bank heights were lowered to bankfull depth from regional curves.

Appendix C: Beargrass Creek scoring rubric

	QHEILS Inputs									
Alternative	**Substrate**	**Instream_Cover**	**Channel_Morphology**	**Bank_Erosion_Riparian**	**Pool_Current**	**Riffle_Run**	**Gradient**	**Incision_Ratio**	**Aquatic_Organism_Passage**	**Material_Transport**
Future Without Project	E	E	E	E	E	E	E	E	E	E
Restore Connectivity Barriers (C-alt)	E	E	E	E	E	E	E	E	E+90%	E+75%
Habitat Creation (R1-alt)	E+25%	E+50%	E	E	E	E+25%	E	E	E	E
Bank Grading (R2-alt)	E+50%	E+80%	E	E+50%	E+25%	E+50%	E	1.35	E	E
Channel Realignment (R4-alt)	E+80%	E+80%	E+90%	E+90%	E+90%	E+90%	E+70%	1	E	E

Scoring rubric for application of QHEILS to site-X10 of the Beargrass Creek study. "E" denotes the existing condition, and "E+%" denotes the percent increase in performance as a result of the alternative

Attachment E: Simple Model for Urban Riparian Function (SMURF), Version 1.0

ERDC TR-XX-DRAFT

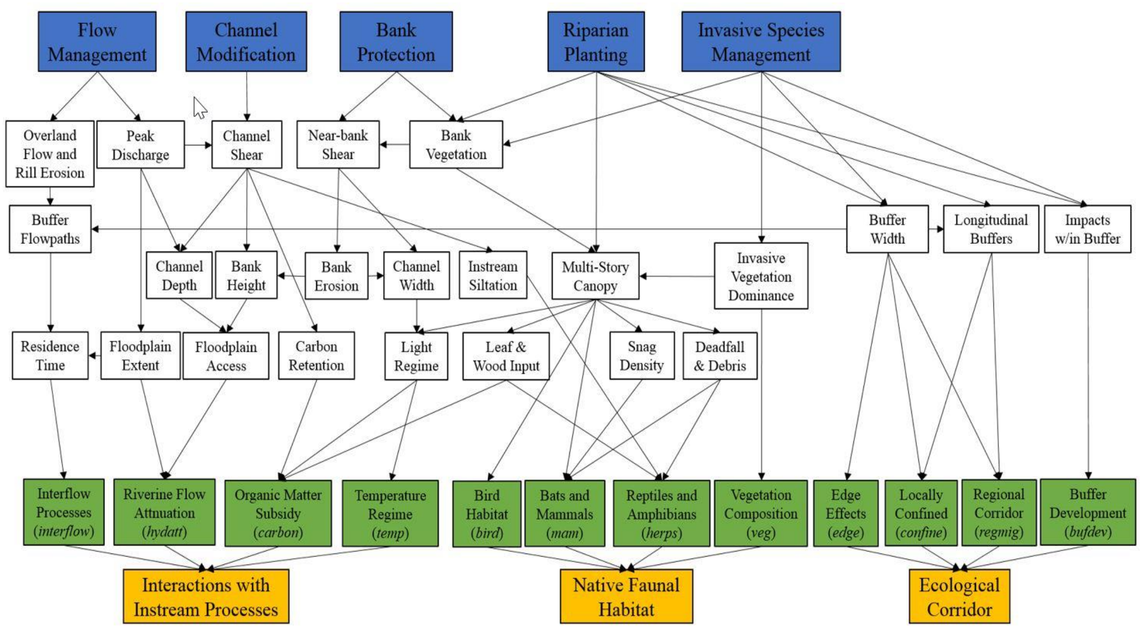
US Army Corps of Engineers®
Engineer Research and Development Center

Ecosystem Management and Restoration Research Program

Simple Model for Urban Riparian Function (SMURF), Version 1.0

S. Kyle McKay, Miranda K. Goss, Frank M. Veraldi, and Laura L. Mattingly

September 2021



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Ecosystem Management and Restoration
Research Program

ERDC TR-XX-DRAFT
September 2021

Simple Model for Urban Riparian Function (SMURF), Version 1.0

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Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under "Three Forks of Beargrass Creek Ecosystem Restoration Feasibility Study"

Monitored by USACE Louisville District
600 Dr. Martin Luther King Jr. Place
Louisville, KY 40202

Abstract

Aquatic ecosystem degradation is often an indirect by-product of high societal demand on urban waters. Urban stream and riparian restoration are challenging endeavors constrained by available lands, legacy effects of historic land use, multiple objectives, and finite resources. Stream assessment tools have been developed for rapid application and restoration prioritization in this context. While these models typically include riparian variables, they are often inherently focused on in-channel outcomes. Here, we develop a Simple Model for Urban Riparian Function (SMURF), which is designed as a rapid assessment technique for highly urbanized environments. The SMURF was developed following a common modeling process of conceptualization, quantification, evaluation, application, and communication. Three major categories of outputs are addressed: (1) indirect effects of riparian zones on instream processes, (2) riparian areas as important providers of native faunal habitat, and (3) riparian zones as ecological corridors and sources of resilience in highly disturbed areas. The model uses a combination of rapid field assessment protocols and desktop geospatial assessments applied independently to left and right banks. The SMURF was developed and applied in the context of the Beargrass Creek ecosystem restoration study in Louisville, Kentucky; however, the modeling approach is adaptable to other urban riparian zones.

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Figures

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Preface

This study was conducted for the USACE Louisville District under the "Three Forks of Beargrass Creek Ecosystem Restoration Feasibility Study." This study was also conducted in partnership with the Ecosystem Management and Restoration Research program under the direction of Dr. Brook Herman, Acting Program Manager. Dr. Jennifer Seiter-Moser, CEERD-EZT, was the Acting Technical Director for Civil Works Environmental Engineering and Sciences.

The work was performed by the ERDC Environmental Laboratory, USACE Louisville District (LRL), and USACE Chicago District. At the time of publication, Ms. Lynn Escalon was Acting Chief, Ecological Resources Branch (CEERD-EEE), and Mr. Mark Farr was Chief, CEERD-EE. The Deputy Director of ERDC-EL was Dr. Jack Davis and the Director was Dr. Edmond Russo.

COL Teresa A. Schlosser was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters

1 Introduction

1.1 *Background*

Cities contain more than half of the global population, and urban residency is more than 80% in the United States (World Bank 2020). Growing urban centers often lead to degraded streams and riparian zones with stressors resulting from change in land use, increased runoff, altered water quality from sanitary and storm sewer inputs, reduced extent of ecosystems, and other factors (Wenger et al. 2009). Subsequent changes in geomorphology, lost biodiversity, and reduced ecosystem function are well-documented, and collectively, these stressors and effects are often described as the "urban stream syndrome" (Walsh et al. 2005, Paul and Meyer 2006, Booth and Bledsoe 2009). In response, stream and riparian restoration have grown into large areas of professional practice (Bernhardt et al. 2005), requiring integrated solutions spanning organizations and disciplines (Deason et al. 2010).

1.2 *Three Forks of Beargrass Creek Feasibility Study*

Beargrass Creek in Louisville, Kentucky is a representative example of common urban stream management challenges. Three main branches, the South Fork, Middle Fork, and Muddy Fork, drain this small watershed (~59 mi^2, Figure 1). Wetlands and forests were historically drained to support residential, commercial, and industrial land uses as the Louisville region grew. Some reaches were channelized to increase conveyance, and further geomorphic change occurred as a result of increased runoff from urban development. To confront these challenges, the U.S. Army Corps of Engineers (USACE) Louisville District (LRL) and Louisville Metropolitan Sewer District (MSD) are partnering to identify actions that could restore aquatic ecosystems in the watershed. The two primary objectives of the projects are: (1) To reestablish quality and connectivity of *riverine* habitats and (2) To reestablish quality and connectivity of *riparian* habitats.

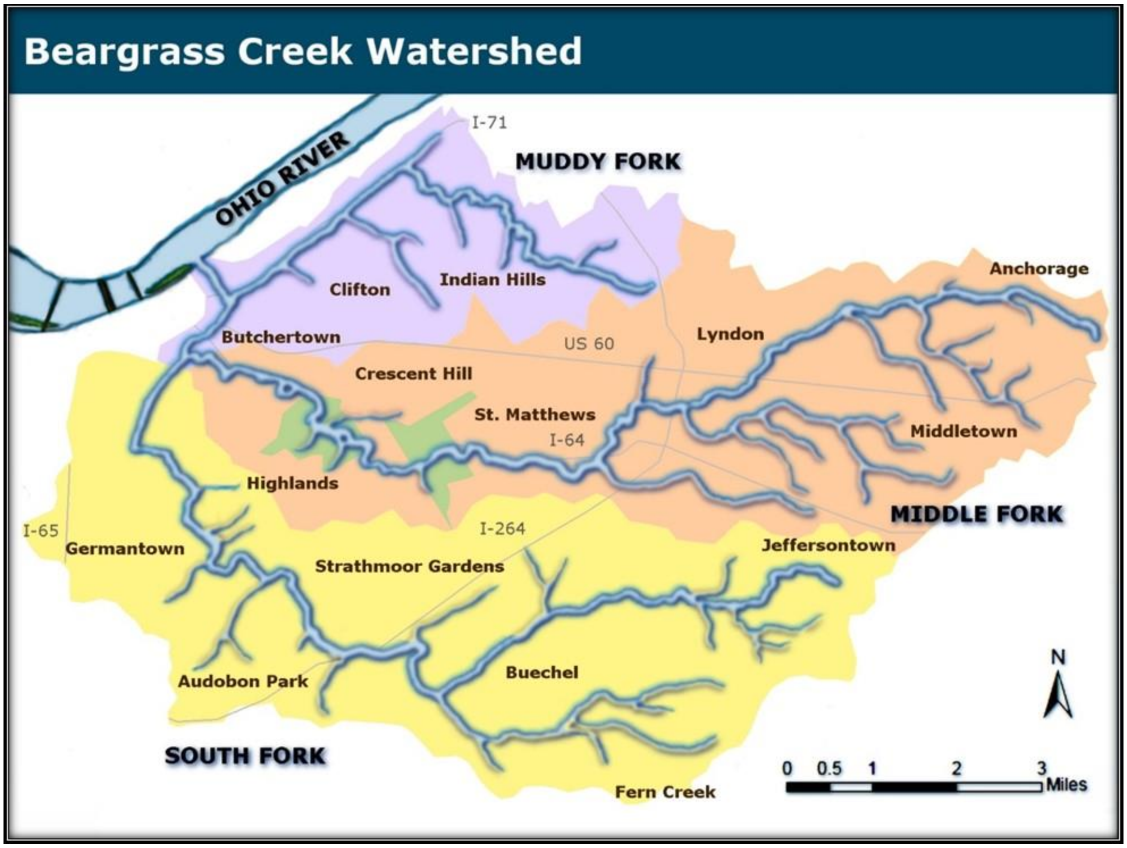

Figure 1. Beargrass Creek watershed.

1.3 *Problem Statement*

Many assessment methods and tools have been developed to support and inform urban watershed restoration projects. These tools are often centered on specific project outcomes such as hydrologic or geomorphic change (e.g., Bledsoe et al. 2007 and Bledsoe et al. 2012, respectively), taxa-specific metrics (e.g., Guilfoyle et al. 2008), or wetland processes (e.g., Ainslie et al. 1999). Rapid assessment techniques have also been developed to assess multiple aspects of stream processes, such as the Rapid Bioassessment Protocol (Barbour et al. 1999), the Stream Visual Assessment Protocol (Newton et al. 1998, Bjorkland et al. 2001), the Qualitative Habitat Evaluation Index (Rankin 2006), and many site-specific adaptations (e.g., Rowe et al. 2009, McKay et al. 2018ab). However, these methods largely focus on instream processes with an indirect emphasis on riparian outcomes.

The conceptual and numerical models presented here seek to articulate and quantify the general ecological condition of urban riparian zones for informing watershed management and restoration actions. The following goals guided model development:

- Models should focus on key aspects of riparian condition and function.

- Models should be capable of distinguishing the relative effects of different magnitudes and types of stream and riparian restoration actions.

- Models should be applicable within typical USACE project planning timelines, which means they should rely on common sources of existing data, be informed through desktop analyses, or may be parameterized by rapidly collected field surveys.

- Models should be adaptable to new information and data as project planning proceeds.

- Models should be developed within the context of the Beargrass Creek project, but seek to maintain flexibility for other systems where possible.

1.4 *Report Overview*

This report presents development and application of the Simple Model for Urban Riparian Function (SMURF). An index-based modeling framework (i.e., a habitat-suitability-style, quantity-quality approach) is applied to assess patch-scale effects. Index models combine assessments of habitat quantity (typically an area-metric like acres) with a multi-variate assessment of habitat quality (a 0 to 1 "suitability" score). Three major functional categorical outcomes are included in this model: (1) indirect effects on in-stream processes, (2) habitat provision for native fauna, and (3) the role of riparian zones as ecological corridors. The model is executed in the R statistical software language, and this report provides documentation of the technical details, use, and relevant information for USACE model approval and certification (EC 1105-2-412, PB 2013-02). The following sections summarize the major elements of model development:

- *Model Development Process*: Summarizes how the model was developed through a combination of literature review and engagement with the Beargrass Creek project development team.

- *Conceptualization*: Describes the overarching view of the structure and function of riparian ecosystems captured by the model.

- *Quantification*: Reviews the technical details of the models (i.e., suitability index curves and numerical structure).

- *Evaluation*: Assesses the models relative to underlying scientific theory, numerical accuracy, and usability.

- *Application*: Describes application of models for the Beargrass Creek ecosystem restoration study led by USACE Louisville District, specifically assessment of the existing watershed conditions.

- *Communication*: Describes the communication strategy for presenting model outcomes to USACE team members, non-federal sponsors, and other interested parties.

2 Model Development Process

SMURF development followed a common ecological modeling process of conceptualization, quantification, evaluation, application, and communication (Grant and Swannack 2008; Swannack et al. 2012). The model was developed iteratively with the model development team (i.e., authors of this document) and the larger Beargrass Creek project development team. An outline of model structure was presented prior to field data collection, and the field team made recommendations on the structure and assessment of variables. The model development team subsequently programmed, tested, and evaluated the numerical algorithms. Finally, models were documented with accompanying peer-reviewed literature support, where available.

Quality assurance procedures were followed throughout the modeling process and detailed throughout this report. Overall, the SMURF was developed using principles of "open science," which embrace transparency in all phases of technical analyses including scoping, data sharing, analytical code, and published products (Hampton et al. 2015). For instance, conceptual models were iteratively developed with input from the modeling and project development teams. Numerical code was extensively documented, and input data are provided for future use (Appendix C). Models were programmed by the lead author (SKM) and code was subsequently interrogated by three reviewers. Finally, models were developed with the "reproducible research" tool R Markdown, which allows developers to integrate documentation and numerical code. These processes cannot guarantee error-free analyses; however, best practices were sought to minimize the occurrence of errors.

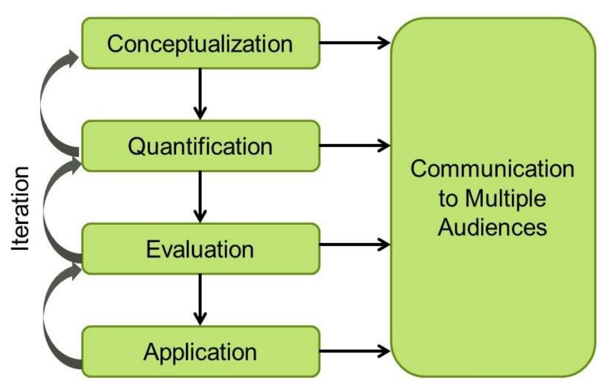

Figure 2. Ecological model development process (modified from Grant and Swannack 2008).

3 Conceptualization

Conceptual models are "descriptions of the general functional relationships among essential components of an ecosystem," and ecosystems can be conceptualized in a variety of media including narrative descriptions, tables, schematics, flow charts, and others (Fischenich 2008). Conceptual models have particular utility in interdisciplinary undertakings like ecosystem restoration, where they have proven useful for tasks ranging from objective setting (McKay et al. 2012) and stakeholder buy-in (McKay et al. 2020a) to numerical model development (Swannack et al. 2012) and design of restoration alternatives (Fischenich 2008). Here, we focus on conceptual models as a means to numerical model development, but these models also provide a mechanism for communicating links between restoration actions and focal outcomes of the Beargrass Creek project.

We followed a generalized, seven-step process for developing an urban riparian zone conceptual model (Fischenich 2008; Table 1). In doing so, we drew heavily from a long history of stream and riparian conceptual models (e.g., the Channel Evolution Model, Simon 1989; the River Continuum Concept, Vannote et al. 1980; urban stream impact models, Wenger et al. 2009). Specifically, we developed a simple box-and-arrow style model linking potential restoration actions with key categories of ecological outcomes (Figure 3). The model shows how restoration actions directly influence key intermediate process and model variables, and how those variables are subsequently combined into overarching categorical outcomes related to effects on instream processes, faunal habitats, and the role of riparian zones as ecological corridors.

Table 1. Stepwise development of the SMURF conceptual model (following steps in Fischenich 2008).

Step	**Simple Model for Urban Riparian Function (SMURF)**
1. State the model objectives.	To inform development of a rapid numerical modeling approach for assessing the overarching aspects of riparian condition and function in urban environments.
2. Bound the system of interest.	Riparian zones in urban areas with a preliminary emphasis on Midwestern streams. Riparian zones are defined outward from the top of streambanks to a maximum extent of 100m. Models are intended for independent application to riparian areas on river-left and river-right (looking downstream).
3. Identify critical model components within the system.	Model variables were identified through review of existing stream assessment models as well as peer-reviewed literature.
4. Articulate relationships among model components.	Given the emphasis on management applications, common families of stream and riparian restoration actions were identified (blue boxes) and linked to intermediate processes (white boxes). These intermediate outcomes were then linked to primary model variables (green boxes) and ultimately the three major functional categories (yellow boxes).
5. Represent the conceptual model.	A box-and-arrow style graphic was used to communicate linkages between model components (Figure 3).
6. Describe the expected pattern of behavior.	The processes linking restoration actions and model outcomes are described more mechanistically in the model quantification section of this report.
7. Test, review, and revise.	All conceptual (and numerical) models were developed iteratively among the authorship team, the Beargrass Creek project planning team, technical staff collecting field data, and independent colleagues not actively engaged in development.

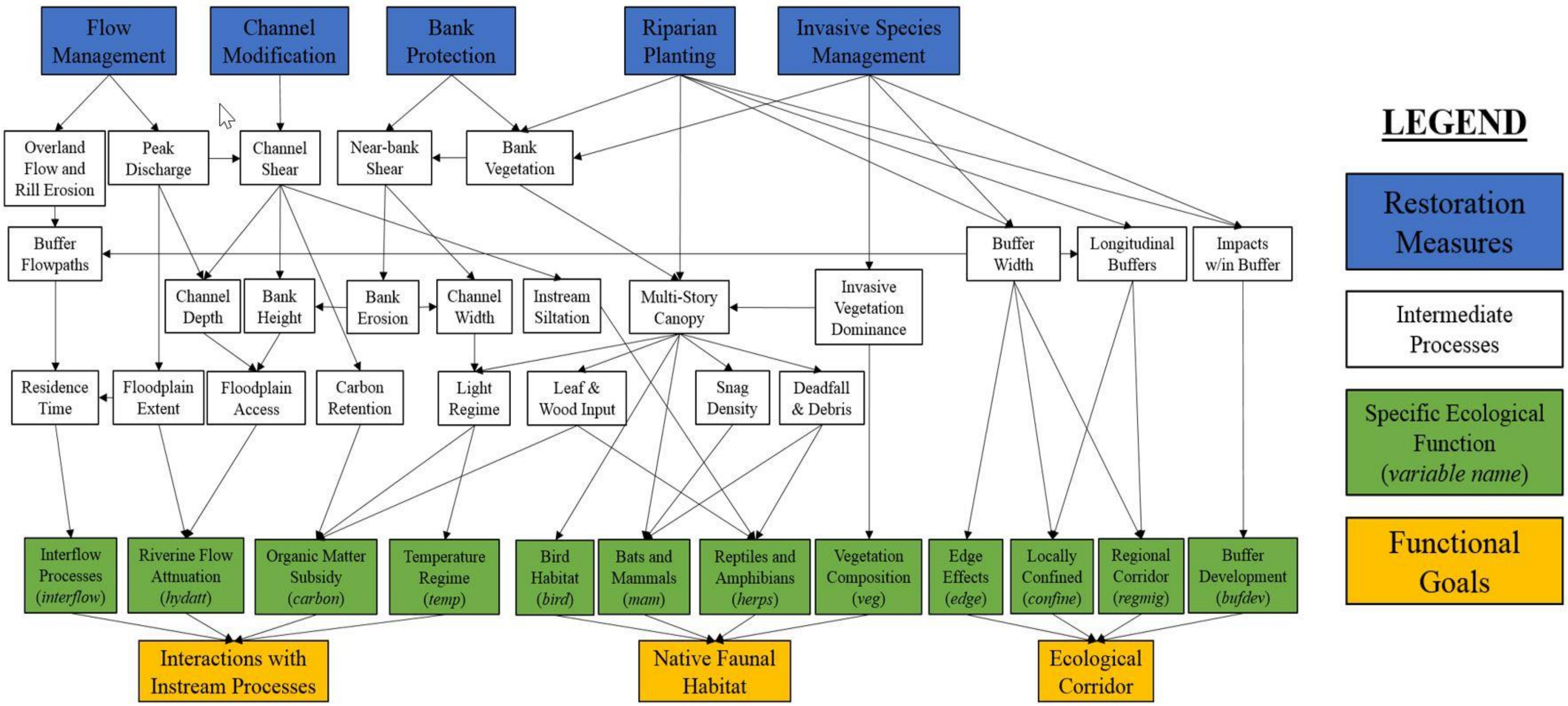

Figure 3. SMURF Conceptual Model.

4 Quantification

The quantification phase of ecological model development formalizes the conceptual model in terms of mathematical relationships, model parameters, and a numerical algorithm (Grant and Swannack 2008). This section describes the SMURF model structure and provides background on the theoretical underpinnings of the model, protocols for compiling inputs, and the associated numerical toolkit.

SMURF uses an index-based modeling framework (i.e., a habitat-suitability-style, quantity-quality approach) to assess patch-scale effects. Index models combine metrics of habitat quantity with a multi-variate assessment of habitat quality. Quality is typically assessed as a 0 to 1 score of the "suitability" of a site (i.e., 0=unsuitable, 1=ideal). The model is intended to be applied to a relatively homogenous patch of riparian ecosystem (e.g., the left bank riparian area as delineated from aerial photography) to provide a "snapshot" in time of the system condition. Table 2 summarizes key issues of SMURF scoping relative to model quantification.

Three major functional categorical outcomes are included in SMURF: (1) indirect effects on instream processes, (2) habitat provision for native fauna, and (3) the role of riparian zones as ecological corridors. These basic riparian functions are well-described in the broader literature on riparian function (e.g., Wenger 1999, Medina et al. 2016), and categories are generally derived from Fischer and Fischenich's (2000) review of the subject. For SMURF, the three modules provide independent assessments of habitat quality, which are then combined into an overarching index of riparian quality. The modules and assessment protocols are described in detail in subsequent sections, and each index is composed of multiple model variables (Table 3).

Table 2. Summary of model scoping for SMURF.

Aspect of Model Scoping	**Simple Model for Urban Riparian Function (SMURF)**
General approach	Index-based, habitat-style model
Treatment of spatial processes	Spatially lumped, patch-scale model where user decides on the unit of analysis (left and right bank riparian zones are assessed separately)
Treatment of time	Single moment in time
Input data type	Combination of rapid, field assessment and desktop, geo-spatial analyses
How are fore-casts conducted	Initial field and desktop data are adjusted based on other modeling or professional judgment
Intended application	Preliminary assessment of urban riparian zones in the context of management actions (e.g., restoration)
Major assumptions	(1) Patch-scale models adequately capture the complexity of a connected, interdependent riparian mosaic, (2) Assessments are a snapshot in time not dependent upon prior time periods, (3) Forecasts can be reliably obtained from adjustment of parameters based on professional judgment, (4) Models are being applied for relative comparison rather than absolute prediction, and (5) SMURF omits variables that may be important in other ecosystems because it was developed in the context of the Beargrass Creek restoration project and regional context.

Table 3. Overview of the quality sub-models in the SMURF. The modules are explained in more detail in Sections 4.1 (instream), 4.2 (fauna), and 4.3 (corridor) of this report.

General Outcome	Specific Outcome	Proxy Metric(s) used in SMURF
Indirect effects on instream function (instream)	Flow attenuation (hydatt)	(1) Incision Ratio = bank height / bankfull depth
	Interflow processes (interflow)	(1) Average buffer width, (2) Qualitative flowpath score
	Temperature and light regulation (temp)	(1) Shading = canopy height / bankfull width, (2) Percent of stream with canopy cover
	Organic matter dynamics (carbon)	(1) Qualitative canopy structure score, (2) Qualitative instream retention score
Native faunal habitat (fauna)	Avian taxa (birds)	(1) Qualitative canopy structure metric
	Small mammals and bats (mammals)	(1) Qualitative canopy structure metric, (2) Snag density, (3) Deadfall density
	Reptiles and amphibians (herps)	(1) Deadfall density, (2) Leaf litter, (3) Instream embeddedness
	Vegetation composition (veg)	(1) Invasive species dominance of plant community
Role as an ecological corridor (corridor)	Buffer development (bufdev)	(1) Qualitative development score
	Edge effects (edge)	(1) Edge density = edge length / buffer area
	Local confinement (confine)	(1) Percent of reach with buffer less than 25 feet wide

Each model variable is translated into a 0 to 1 "suitability curve" to provide a consistent scale across diverse processes. Equations for suitability curves are derived from the Toolkit for interActive Modeling (TAM, Carrillo et al. 2020). Each suitability curve was derived from a combination of literature review and professional judgment of the Beargrass Creek project development team. Specific resources are highlighted as each suitability curve is presented, but four types of resources were generally consulted in constructing suitability curves:

- General descriptions of riparian processes (Wenger 1999, Fischer and Fischenich 2000, Medina et al. 2016, Johnson et al. 2018, Carothers et al. 2020) and existing assessment approaches (Smith et al. 2005, Lin et al. 2008, Guilfoyle et al. 2009).

- Stream rapid assessment protocols like the Rapid Bioassessment Protocol (Barbour et al. 1999), the Stream Visual Assessment Protocol (Newton et al. 1998, Bjorkland et al. 2001), the Qualitative Habitat Evaluation Index (Rankin 2006), and similar site-specific adaptations (e.g., Rowe et al. 2009, McKay et al. 2018ab).

- Hydrogeomorphic method (HGM) manuals for wetland assessment in western Kentucky (Ainslie et al. 1999), eastern KY streams (Noble et al. 2010), and associated model validation reports (Sweeten and Ford 2016).

- Regional studies of stream and riparian ecosystems as they relate to existing assessment methods (KDOW 2011), geomorphic outcomes (Parola et al. 2007, Agouridis et al. 2011), and habitat of key taxa such as birds (Kelly 2018), bats (Hammond et al. 2016, Richardson 2017), and others (Larson et al. 2003).

Each of the three main modules is assessed independently as a 0 to 1 index of ecosystem quality. Overall ecosystem quality is computed as the combination of the quality scores for each module. The modules are combined using a geometric mean, which assumes that deficiency in any modules can limit overall system quality. For instance, unsuitable habitat (i.e., $I_{fauna} = 0$) can drive even ideal assessments of the instream and corridor modules (i.e., $I_{instream} = 1$ and $I_{corridor} = 1$) to a low overarching index ($I_{SMURF} = 0$). The modules are each viewed as equally important contributions to overall riparian function, and no "weighting" of outcomes is applied.

$$I_{SMURF} = (I_{instream} I_{fauna} I_{corridor})^{1/3}$$

Where I_{SMURF} is an overarching index of ecosystem quality, $I_{instream}$ is an index of a riparian zone's contribution to instream processes, I_{fauna} is an index of patch habitat quality for native fauna, and $I_{corridor}$ is an index relative to the system's role as an ecological corridor. All indices are quality metrics scaled from 0 to 1, where 0 is unsuitable and 1 is ideal.

The overall quality index can be combined with the area of a given patch to derive a quality-weight area metric, a so-called "habitat unit." Habitat units should be assessed separately for left and right bank riparian areas.

4.1 Indirect Effects on Instream Function ($I_{instream}$)

USACE restoration programs explicitly target, "restoration opportunities that are associated with wetlands, riparian and other floodplain and aquatic systems" (USACE 2000, ER 1105-2-100, Page 3-24). The instream module addresses the mechanisms by which a riparian zone alters ongoing processes in the neighboring stream. In particular, four main outcomes are assessed: (1) Longitudinal connectivity associated with riverine flow attenuation, (2) Lateral connectivity associated with interflow processes, (3) Temperature and light regulation, and (4) Organic matter subsidy from riparian zones to stream ecosystems. The variables associated with each of these processes are presented below along with any proxy metrics used to assess effects on instream condition. The instream index ($I_{instream}$), was assessed as the arithmetic mean of the four metrics.

$$I_{instream} = \frac{hydatt + interflow + temp + carbon}{4}$$

Where $I_{instream}$ is an index of a riparian zone's contribution to instream processes, $hydatt$ is a suitability index for longitudinal connectivity associated with flow attenuation, $interflow$ is a suitability index for lateral river-floodplain connectivity associated with interflow processes, $temp$ is a suitability index associated with temperature and light regulation, and $carbon$ is a suitability index for organic matter dynamics. All variables are quality metrics scaled from 0 to 1, where 0 is unsuitable and 1 is ideal. Figure 4 summarizes all suitability curves associated with instream function.

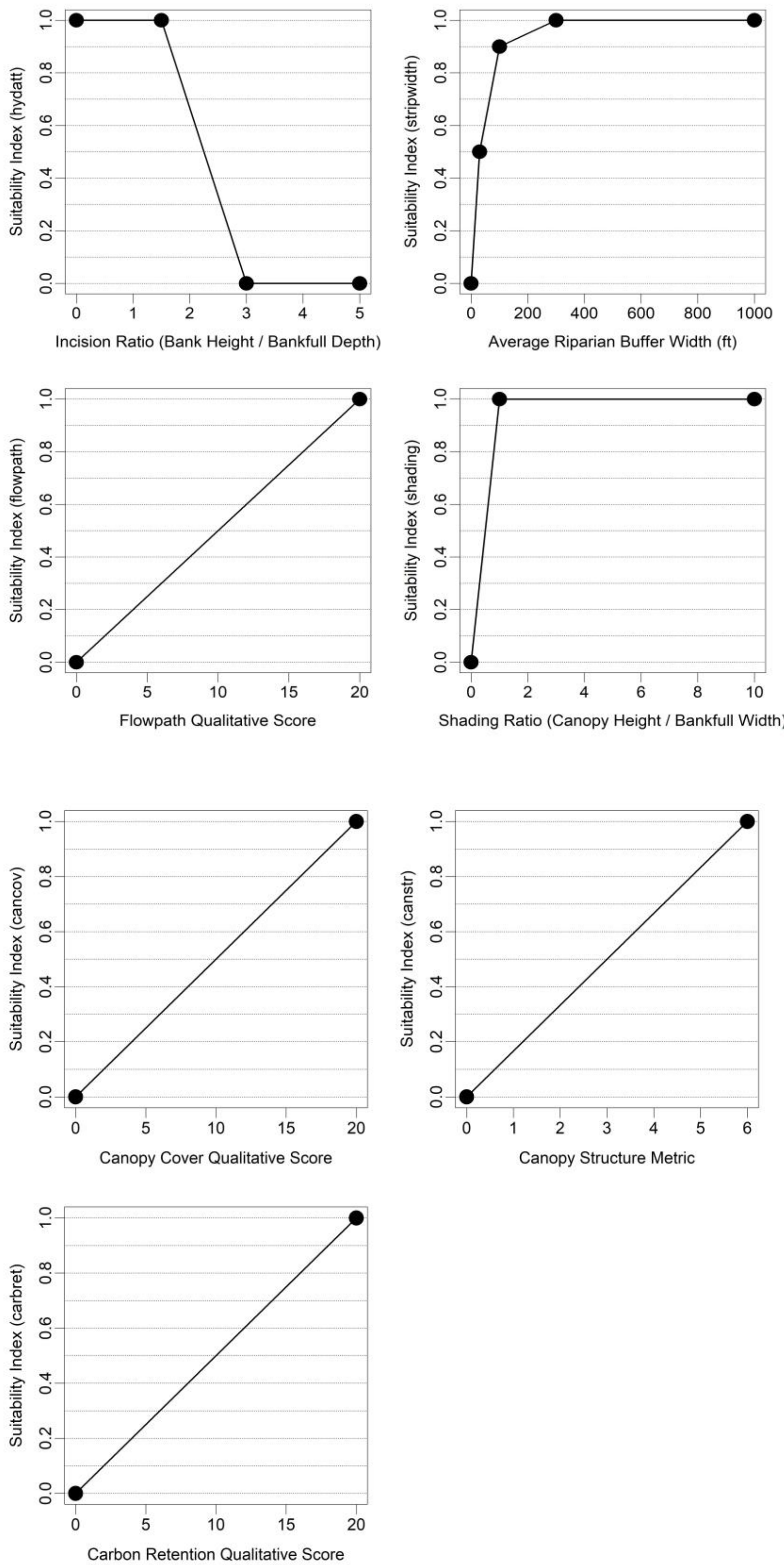

Figure 4. Suitability curves for the instream module.

Hydrologic Attenuation (*hydatt*)

River-floodplain connectivity is an important bi-directional process influencing the ecological health of both systems. This metric assesses the role of riparian areas in slowing down and attenuating river flows, which is particularly important in urban streams with "flashy" hydrologic response. In an unaltered stream, the bankfull condition generally refers to the incipient point of flooding, which indicates the long-term channel shape in response to a watershed's hydrologic regime and geology. Owing to hydrologic change, many urban streams are incised, and rivers are often disconnected from floodplains.

Geomorphologists and engineers have developed a variety of metrics for assessing geomorphic condition and change. The SMURF uses a relatively simple (but crucial) metric of channel change to provide a general snapshot of a stream's geomorphic status. The incision ratio (also known as bank height ratio, sensu Harman and Jones 2016) is the ratio of bank height to the bankfull depth. As channels undertake the evolutionary process above, channel bottoms incise leaving bank heights much greater than those typically observed in unmodified systems. In an unmodified stream, the "bankfull" condition can be defined as the depth at which a channel overflows onto the floodplain (Shields et al. 2003), but the bankfull depth is often significantly less than bank height in altered streams (Harman and Jones 2016). Bankfull depth was identified and measured based on field indicators such as wrested vegetation and tops of sediment depositional features (e.g., point bars). Bank height was identified and measured based on the perceived elevation of historic floodplains. A simple schematic field guide was constructed as a reference for observers (Appendix B).

Here, the incision ratio (i.e., bank height / bankfull depth), is used as a proxy for the degree of river-floodplain connectivity and the associated attenuation of flows. An incision ratio near 1 would indicate ideal conditions with little evidence of geomorphic incision and frequent connectivity between the river and floodplain. Conversely, an incision ratio above 3 would indicate highly disturbed conditions with a high degree of downcutting. This metric has been used widely in other stream restoration projects to quantify the relative condition of the channel and inform design targets. For instance, Harman and Jones (2016) identify thresholds in geomorphic performance relative to incision as: less than 1.3 is highly functioning, between 1.3 and 1.5 is functioning at risk, and greater than 1.5 is not functioning. Similar thresholds have been used in other regions (IA DNR 2018). For SMURF, an incision ratio of 1.5 is used as a threshold for the decline in floodplain function, although many functions may decline at lower thresholds as described above. The following equation presents the SMURF suitability curve associated with hydrologic attenuation.

$$hydatt = \begin{pmatrix} 1.0 & incision < 1.5 \\ 2.0 - 0.667 * incision & incision = 1.5 - 3.0 \\ 0.0 & incision >= 3.0 \end{pmatrix}$$

Where $hydatt$ is a suitability index for longitudinal connectivity associated with flow attenuation, $incision = \frac{H_{bank}}{H_{bankfull}}$ is the incision ratio, H_{bank} is bank height, and $H_{bankfull}$ is bankfull depth.

Future analyses could include alternative metrics such as a direct assessment of floodplain extent such as the hydraulic top width for a 5-year flood divided by the hydraulic top width for a 1-year flood or the entrenchment ratio (i.e., ratio of the width of the flood-prone area to the surface width of the bankfull channel).

Interflow Processes ($interflow$)

Riparian zones serve as important ecotones between upland systems and streams, and hillslope scale effects are important benefits of riparian zones on stream processes. Riparian zones often directly affect both overland flow and shallow subsurface processes like interflow. Fischer and Fischenich (2000) distinguish these types of benefits as those related to riparian areas as vegetated buffer strips, which play important roles in moderating nonpoint source pollution and the associated impacts on stream ecosystems. The SMURF uses two metrics for assessing interflow mechanics, buffer width and a qualitative flowpath metric.

Dozens of studies have examined the roles of riparian buffer width and slope on sediment and water quality processes (See reviews by Wenger 1999 and Fischer and Fischenich 2000). Slope plays an important role in these processes as well, particularly in steep sloped systems; however, this factor was eliminated to minimize analytical burden. Based on a meta-analysis of buffer efficacy, Wenger (1999) identified 25% slope as a generalized cutoff for riparian zones capable of providing these functions, and

SMURF should not be applied in areas with slopes greater than 25%. More generally, slopes greater than 15% could affect riparian function (and model performance), and caution should be taken in model application.

Studies show that wider riparian zones provide enhanced benefits to interflow processes and associated storage and processing of sediment, nutrients, and other constituents. Notably, there appear to be diminishing returns after the first 30 ft (10 m) providing a substantial amount of benefit. As such, the reachwide average buffer width (W_{buffer}) was computed in a Geographic Information System (GIS) and used to compute a metric of benefits relative to a riparian zone's role as a vegetated buffer stip. Appendix B presents additional details on measurement protocols.

$$stripwidth = \begin{pmatrix} 0.0167 * W_{buffer} & W_{buffer} = 0 - 30 \\ 0.33 + 0.0057 * W_{buffer} & W_{buffer} = 30 - 100 \\ 0.85 + 0.0005 * W_{buffer} & W_{buffer} = 100 - 300 \\ 1.0 & W_{buffer} >= 300 \end{pmatrix}$$

Where $stripwidth$ is a suitability index for the hydrologic and water quality benefits associated with a wide buffer strip and W_{buffer} is the average width of the riparian buffer in a reach as delineated in GIS (in ft).

Wenger (1999) highlights the importance of flow paths through buffers versus those flowing around a system. A simple qualitative scoring system and associated schematic guide (Appendix B) were developed to assess hydrologic flows through riparian areas. Specifically, the metric emphasized the importance of urban development and drainage networks in "short circuiting" flow paths and reducing residence time of interflow processes.

$$flowpaths = 0.05 * S_{flowpaths}$$

Where $flowpaths$ is a suitability index for preferential flowpaths through the riparian buffer strip and $S_{flowpaths}$ is a 0-20 qualitative scale defined in Appendix B.

The buffer strip and flowpath metrics were combined to provide an index of the relative contribution of a riparian area to interflow processes.

$$interflow = \frac{stripwidth + flowpaths}{2}$$

Where $interflow$ is a suitability index for lateral river-floodplain connectivity associated with interflow processes.

Temperature and Light Regulation ($temp$)

Urban areas often exhibit higher stream temperatures due to increased runoff from hot impervious areas (e.g., parking lots, roofs), reduced stream shading, and delivery of warm inputs from point sources (Kaushal et al. 2010). USACE restoration actions are unlikely to alter the delivery of hot water from impervious zones upstream or point sources. However, some restoration actions have a direct impact on temperature regimes relative to stream shading. Stream temperatures have been shown to increase dramatically in forest gaps, but also reduce quickly in response to forested cover.

Two simple proxies of canopy shading are combined as an overall assessment of the role of the riparian area in temperature and light regulation. First, the ratio of the canopy height within 25 feet of the top of bank to the bankfull width is used as a surrogate for canopy shading (i.e., shading = canopy height / bankfull width). This metric provides an objective basis for assessing the relative influence of riparian forests on stream temperatures. This ratio is assessed for each bank independently based on field estimates. The metric is assumed to be ideal for any ratio greater than 1 and decline linearly to 0.

$$shading = \begin{pmatrix} \frac{H_{canopy}}{W_{bankfull}} & \frac{H_{canopy}}{W_{bankfull}} = 0 - 1 \\ 1.0 & \frac{H_{canopy}}{W_{bankfull}} >= 1.0 \end{pmatrix}$$

Where $shading$ is a suitability index for channel shading and W_{buffer} is average width of the riparian buffer in a reach as delineated in GIS (in ft).

Second, canopy cover of the channel was assessed visually from within the stream based on a qualitative scale (Appendix B, Figure B1, "Stream Canopy Cover"). Thresholds in this process are adopted from the QHEI stream assessment protocol (Rankin 2006). In addition to visual estimates, field teams are encouraged to explore other more empirical approaches such as use of a densiometer.

$$cancov = 0.05 * S_{cancov}$$

Where $cancov$ is a suitability index for canopy coverage of the stream and S_{cancov} is a 0-20 qualitative scale defined in Appendix B.

These two simple metrics were combined to provide an overall index of the relative contribution of a riparian area to temperature and light regulation.

$$temp = \frac{shading + cancov}{2}$$

Where $temp$ is a suitability index for temperature and light regulation.

Organic Matter Subsidy (*$carbon$*)

Stream food webs obtain energy from inside of the stream (i.e., "autochthonous" sources such as algal growth) and outside of the stream (i.e., "allochthonous" sources such as leaf litter and coarse woody debris input). The relative ratio of internally and externally derived carbon varies with size of the stream, land use conditions upstream, and level of disturbance in the riparian zone. This metric assesses the contribution of different carbon sources as a proxy for energy input and its role in driving food web structure.

First, riparian forest structure was used as a surrogate for the diversity of available carbon sources. The quality of the overstory, midstory, and understory were each assessed visually as high, medium, or low. A "high quality" assessment is assumed to be a diverse native assemblage of trees for this particular vertical layer of the forest. Diversity should be considered relative to high functioning ecosystems in the region. These qualitative assessments were translated into quantitative scores of 2, 1, and 0 for high, medium, and low, respectively. The overall canopy structure is computed as the sum of the three layers. For instance, a high quality score for each layer gives a maximum score of 6.

$$canstr = 0.1667 * (S_{overstory} + S_{midstory} + S_{understory})$$

Where $canstr$ is a suitability index for canopy structure of the riparian forest, $S_{overstory}$ is a 0, 1, or 2 score for overstory, $S_{midstory}$ is a 0, 1, or 2 score for midstory, and $S_{understory}$ is a 0, 1, or 2 score for understory.

Second, carbon sources must not only be diverse in nature, but also retained in the stream long enough to be consumed. The second metric focuses on carbon retention within the stream. A qualitative scoring system was developed to assess the potential for washout or storage of leaf matter and wood within the stream (Appendix B).

$$carbret = 0.05 * S_{carbret}$$

Where $carbret$ is a suitability index for canopy coverage of the stream and $S_{carbret}$ is a 0-20 qualitative scale defined in Appendix B.

These two simple metrics were combined to provide an overall index of the relative contribution of a riparian area to temperature and light regulation.

$$carbon = \frac{canstr + carbret}{2}$$

Where $carbon$ is a suitability index for organic matter subsidy of the riparian zone to the stream.

4.2 *Native Faunal Habitat* (I_{fauna})

Riparian zones are important ecosystems in their own right, and the fauna module addresses the role of riparian zones in providing habitat for diverse native fauna. Three main habitat quality outcomes are included in the SMURF assessment: (1) avian taxa, (2) select small mammals and bats, (3) reptiles and amphibians (i.e., herpetofauna). Additionally, a fourth category is included, which addresses the prevalence of invasive flora and its role in habitat quality for native fauna. The variables associated with each of these processes are presented below along with any proxy metrics used in the assessment. The native faunal habitat index (I_{fauna}), was assessed as the arithmetic mean of the four metrics.

$$I_{fauna} = \frac{birds + mammals + herps + veg}{4}$$

Where I_{fauna} is an index of a riparian zone's contribution to habitat processes, $birds$ is a suitability index for generalized avian taxa, $mammals$ is a suitability index for small mammals and bats, $herps$ is a suitability index for generalized reptile and amphibian habitat, and veg is a suitability index for vegetation community composition. All variables are quality metrics scaled from 0 to 1, where 0 is unsuitable and 1 is ideal. Figure 5 summarizes all suitability curves associated with faunal function.

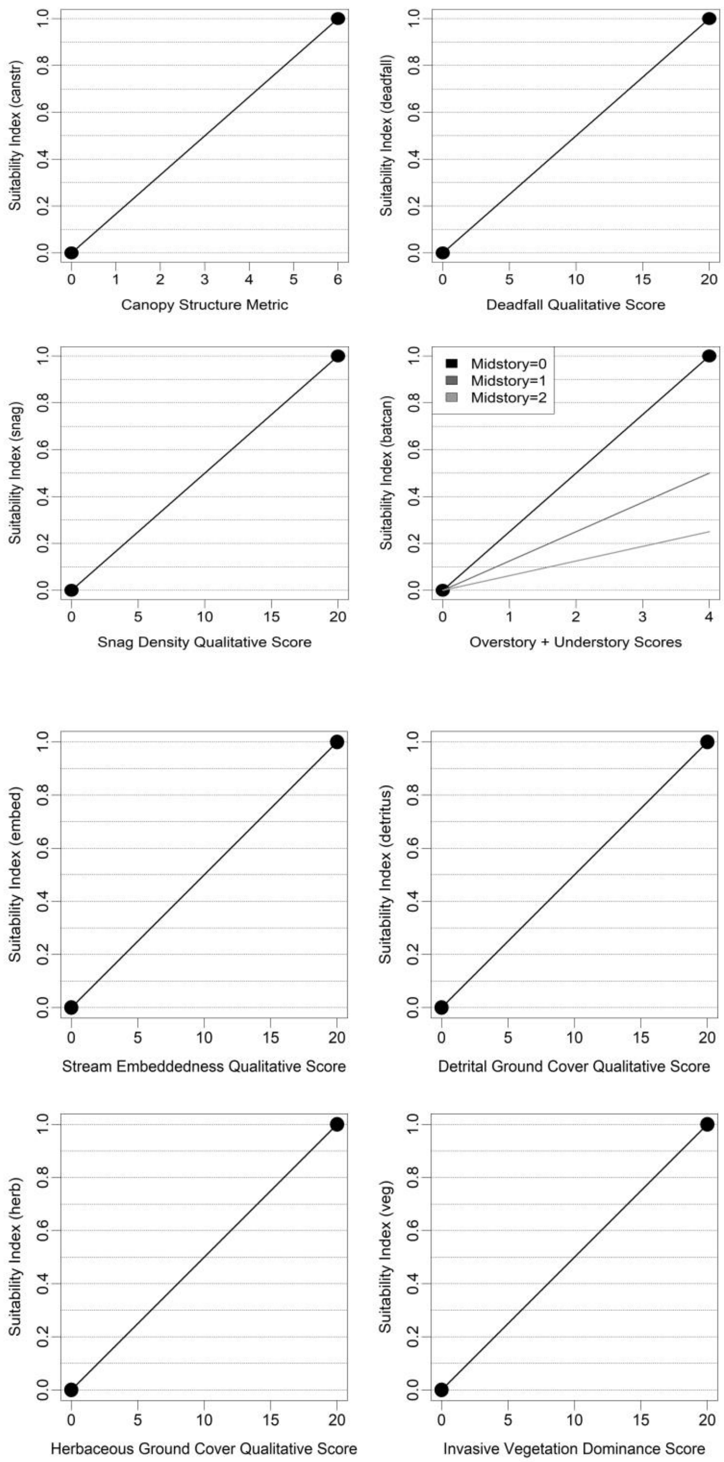

Figure 5. Suitability curves for the fauna module.

Avian Habitat (*birds*)

Avian species frequently utilize urban riparian forests as corridors throughout the year for foraging and nesting (Rottenborn 1999). Several factors affect how many species of bird can utilize a riparian forest for nesting, but canopy complexity can be rapidly assessed and is likely to have the greatest impact on biodiversity.

Forest canopy structure has been widely acknowledged as an important indicator of forest health and, generally, the more complex a canopy structure is, the greater the biodiversity found within the forest (MacArthur and MacArthur 1961, Kelly 2018, Storch et al. 2018). This is especially true concerning bird species, many of which rely on the presence of a relatively narrow niche to thrive (e.g. a certain food source or a certain layer of canopy required for nesting). The greater layering and species diversity a riparian forest exhibits, the more likely it is to possess habitat suitable to a given species.

Canopy structure was assessed using the basic quality and structure metrics described in the *carbon* metric above.The quality of the overstory, midstory, and understory were each assessed visually as high, medium, or low. A "high quality" assessment is assumed to be a diverse native assemblage of trees for this particular vertical layer of the forest. These qualitative assessments were translated into quantitative scores of 2, 1, and 0 for high, medium, and low, respectively. The overall canopy structure is computed as the sum of the three layers. For instance, a high quality score for each layer gives as maximum score of 6. This canopy structure metric provides the overall metric for avian habitat (i.e., $birds = canstr$).

$$canstr = 0.1667 * (S_{overstory} + S_{midstory} + S_{understory})$$

Where $canstr$ is a suitability index for canopy structure of the riparian forest, $S_{overstory}$ is a 0, 1, or 2 score for overstory, $S_{midstory}$ is a 0, 1, or 2 score for midstory, and $S_{understory}$ is a 0, 1, or 2 score for understory.

Small Mammal and Bat Habitat (*mammals*)

Two focal groups of mammals are assessed within SMURF: small mammals and bats. In urban and agricultural areas, it is thought that riparian forest corridors are an important refuge for small mammal species generally considered pests (e.g. mice, shrews, voles, etc.). Small mammal presence has been shown to be positively associated with the abundance of fallen logs (Miklos and Ziak 2002) and many species use deadwood as forest runways, for shelter, and for nesting (Bowman et al. 1999).

$$deadfall = 0.05 * S_{deadfall}$$

Where $deadfall$ is a suitability index for fallen logs in the riparian zone and $S_{deadfall}$ is a 0-20 qualitative scale defined in Appendix B.

Riparian corridors also provide essential habit to Kentucky's 14 resident bat species, 3 of which are federally endangered. Bat species are of special concern as white-nose syndrome moves across the U.S., resulting in the wide-scale decline of many bat species. In urbanized landscapes, natural maternity roosting habitat may be limited and maternity colonies are often unwelcome on man-made structures (Brittingham and Williams 2000). Snags in riparian corridors can provide this roosting habitat as well as a safe place for juveniles to learn to hunt and fly (Gardner et al. 1991, Britzke et al. 2003). The availability of standing deadwood (i.e., snags) was assessed on a 0-20 qualitative scale (Appendix B)

$$snags = 0.05 * S_{snags}$$

Where $snags$ is a suitability index for standing deadwood suitable for roosting habitat and S_{snags} is a 0-20 qualitative scale defined in App B.

Small forest openings or gaps in canopy layers increase the thermal suitability of snags and allow for flight. Ideally, bats have room to move between overstory and woody shrub layers, and the absence of a midstory facilitates flight. The canopy metrics described above were adapted to reflect a preference for the absence of a well-developed midstory as follows.

$$batcan = 0.25 * \frac{2 - S_{midstory}}{2} * (S_{overstory} + S_{understory})$$

Where $batcan$ is a suitability index for canopy structure of the riparian forest relative to bat flight needs, $S_{overstory}$ is a 0, 1, or 2 score for overstory, $S_{midstory}$ is a 0, 1, or 2 score for midstory, and $S_{understory}$ is a 0, 1, or 2 score for understory.

These three simple metrics were combined to provide an overall index of the relative contribution of a riparian area to mammal habitat provision.

$$mammals = \frac{deadfall + snags + batcan}{3}$$

Where $mammals$ is a suitability index for small mammal and bat habitat.

Reptile and Amphibian Habitat (*herps*)

Herpetofaunal species diversity is often used itself as a metric of habitat health. As ectothermic species, both reptiles and amphibians are sensitive to the thermal conditions of streams and riparian forests. Amphibians are, in addition, susceptible to urban contaminants and must utilize both aquatic and terrestrial habitats within the riparian zone to complete their life cycle.

As aquatic larvae, amphibians in streams are susceptible to habitat reduction when potential cover objects (e.g. boulders, driftwood) are heavily embedded in silt or sand. Larvae use these sites to shelter from predators as well as to avoid fast-flowing stream waters. Lowe and Bolger (2002) found stream embeddedness to be negatively correlated with larval salamander abundance along with several other factors that increase fine particulate availability near streams. A qualitative embeddedness scale was adapted from the EPA's Rapid Bioassessment Protocol (Barbour et al. 1999) and the Qualitative Habitat Evaluation Index (QHEI, Rankin 2006), which is presented in Appendix B.

$$embed = 0.05 * S_{embed}$$

Where $embed$ is a suitability index for stream embeddedness and S_{embed} is a 0-20 qualitative scale defined in Appendix B.

In their terrestrial life stage, woody debris and leaf litter density provide moist, protected habitat to many species of salamanders and frogs (Whiles and Grubaugh 1996). Several salamander species even exhibit territorial defense of fallen logs, potentially making deadfall a limiting resource for these species (Mathis 1989, Chivers et al. 1994, Lang and Jaeger 2000). Herpetofauna also use leaf litter to move over the forest floor avoiding desiccation, actively foraging, or sheltering from predators (O'Donnell et al. 2014). Herbaceous vegetation also provides additional shelter and cover. All three metrics were assessed qualitatively with a simple scoring system and translated into a suitability index as follows:

$$deadfall = 0.05 * S_{deadfall}$$

$$detritus = 0.05 * S_{detritus}$$

$$herb = 0.05 * S_{herb}$$

Where $deadfall$ is a suitability index for fallen logs in the riparian zone, $S_{deadfall}$ is a 0-20 qualitative scale, $detritus$ is a suitability index for detrital leaf fall, $S_{detritus}$ is a 0-20 qualitative scale, $herb$ is a suitability index for herbaceous vegetation cover, and S_{herb} is a 0-20 qualitative scale. All qualitative scales are defined in Appendix B.

These four simple metrics were combined to provide an overall index of the relative contribution of a riparian area to reptile and amphibian habitat provision.

$$herps = \frac{embed + deadfall + detritus + herb}{4}$$

Where $herps$ is a suitability index for herpetofauna habitat.

Vegetation Community Composition (veg)

Invasive species such as kudzu, privet hedge, multiflora rose, Russian olive, and English ivy can rapidly homogenize riparian habitats if left unchecked (Cheng 2007, Fischer et al. 2012). This homogenization is of particular conservation concern, as it reduces the biodiversity of both flora and fauna. Because invasive species out-compete native plants, forests colonized by them typically become tightly packed and exhibit low canopy complexity and limited species diversity. The invasive species dominance of a plant community should therefore be taken into account when considering the health and potential of a riparian forest. A qualitative score was developed and translated into a suitability index as follows.

$$veg = 0.05 * S_{inv}$$

Where veg is a suitability index for vegetation community composition within the riparian zone and S_{inv} is a 0-20 qualitative scale defined in Appendix B.

4.3 *Ecological Corridor* ($I_{corridor}$)

Riparian zones serve as movement corridors for a variety of taxa, and their role as corridors is distinct from effects on instream processes or as habitat. Said differently, Wenger (1999) states, "Because there is general agreement that riparian buffers offer important high-quality habitat, there is little need to debate their merits as movement corridors at this time." Three categories of corridor impacts and functions are used within SMURF, namely: (1) the extent of development within the corridor, (2) the degree of "edge" habitat, and (3) the degree of confinement associated with the width of the riparian area. The variables associated with each of these processes are presented below along with proxy metrics used in the assessment. The corridor index ($I_{corridor}$), was assessed as the arithmetic mean of the three categories metrics.

$$I_{corridor} = \frac{bufdev + edge + confine}{3}$$

Where $I_{corridor}$ is an index of a riparian zone's function as an ecological corridor, $bufdev$ is a suitability index for buffer development, $edge$ is a suitability index for edge effects, and $confine$ is a suitability index describing the confinement of the zone relative to width. All variables are quality metrics scaled from 0 to 1, where 0 is unsuitable and 1 is ideal. Figure 6 summarizes all suitability curves associated with faunal function.

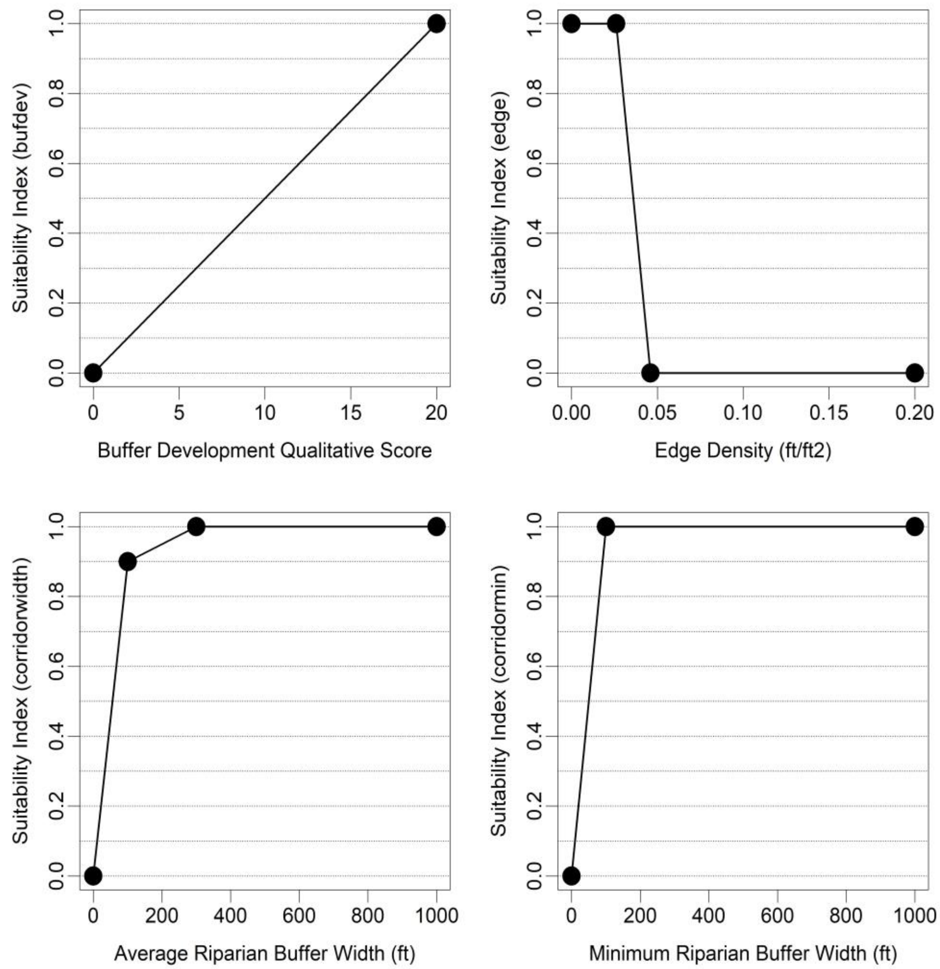

Figure 6. Suitability curves for the corridor module.

Buffer Development ($bufdev$)

Riparian zones are important ecotones between upland and aquatic systems, and their societal value is often high for uses ranging from recreational greenways to infrastructure rights-of-way to aesthetic benefits of viewing streams. Development and human use can disturb riparian zones and disrupt their functions as animal movement corridors. A qualitative scoring scale was used to assess the general level of development effects on buffer function (Appendix B).

$$bufdev = 0.05 * S_{bufdev}$$

Where $bufdev$ is a suitability index for buffer development and S_{bufdev} is a 0-20 qualitative scale defined in Appendix B.

Edge Effects ($edge$)

Animal movement and behavior can be impacted by development outside of the riparian zone. For instance, many bird species are sensitive to edge effect. Kelly (2018) found that both the overall Shannon Wiener Diversity Index for birds and percent presence of insectivores decreased in Kentucky wetlands as disturbance increased. By assessing the spatial structure of the edge of the riparian zone, bird species' sensitivity to disturbance can be taken into account. Edge density accounts for the relative proportion of edge length to interior habitat area. Rohde et al. (2005) report edge densities for regulated, restored, and "near-natural" rivers in Switzerland. We adopted this methodology and assume that the average edge density for their "near-natural" sites (~850 m/ha or 0.026 ft/ft^2) is a lower limit for the best possible habitat quality, and that suitability declines linearly as edge density increases. We then use their maximum observed edge density (~1,500 m/ha or 0.046 ft/ft^2) as an upper limit for the lowest habitat suitability.

$$edge = \begin{pmatrix} 1.0 & \frac{L_{buffer}}{A_{edge}} < 0.026 \\ 2.3 - 50 * \frac{L_{buffer}}{A_{edge}} & \frac{L_{buffer}}{A_{edge}} = 0.026 - 0.046 \\ 0.0 & \frac{L_{buffer}}{A_{edge}} > 0.046 \end{pmatrix}$$

Where $edge$ is a suitability index for the hydrologic and water quality benefits associated with a wide buffer strip, A_{buffer} is the area of the riparian buffer in a reach as delineated in GIS (in ft^2), and L_{edge} is the exterior length of the polygon defining the area (in ft).

Buffer Confinement ($confine$)

Corridor functions may be limited by the width of a riparian zone. Here, average and minimum width of a riparian zone are used as proxies for how animal movement may be limited along a corridor. Reach-averaged buffer width provides a general metric, and suitability thresholds are set based on meta-analyses by Fischer and Fischenich (2000) and Wenger (1999), who identify 100 ft (~30m) and 300 ft (~100m) as common recommendations from other studies.

$$corridorwidth = \begin{pmatrix} 0.009 * W_{buffer} & W_{buffer} = 0 - 100 \\ 0.85 + 0.0005 * W_{buffer} & W_{buffer} = 100 - 300 \\ 1.0 & W_{buffer} >= 300 \end{pmatrix}$$

Where $corridorwidth$ is a suitability index for the hydrologic and water quality benefits associated with a wide buffer strip and W_{buffer} is the average width of the riparian buffer in a reach as delineated in GIS (in ft).

Additionally, the most narrow riparian width of a given reach could provide a "pinch point" for movement. Impacts are conceptualized as width decreases below 100 ft (~30m), which is a common threshold as described above.

$$corridormin = \begin{pmatrix} 0.01 * W_{bufmin} & W_{bufmin} = 0 - 100 \\ 1.0 & W_{bufmin} >= 100 \end{pmatrix}$$

Where $corridormin$ is a suitability index representing local confinement of the riparian zone relative to movement corridors and W_{bufmin} is the minimum width of the riparian buffer in a sample reach as delineated in GIS (in ft).

These two metrics were combined to provide an overall index of the relative confinement of a riparian area.

$$confine = \frac{corridorwidth + corridormin}{2}$$

Where $confine$ is a suitability index for riparian corridor confinement.

4.4 *Numerical Model*

As described in Sections 4.1-4.3, SMURF is a tool for evaluating general riparian quality based on many separate lines of evidence. Input data to SMURF include a variety of field observations (e.g., bankfull channel dimensions) and desktop analyses (e.g., buffer width), which are assessed separately outside of the model. A single function was developed to combine inputs into suitability indices for each module as well as an overarching habitat suitability index and habitat units.

The `SMURF` function was programmed in the open-source, USACE-approved, R statistical software language. The model utilizes the ecorest package for conducting habitat suitability analyses. **`ecorest`** provides a suite of functions for computing suitability indices and habitat units, given a set of suitability index curves defined by breakpoints as shown in Figures 4-6. The package then allows for computation of an overarching habitat suitability index based on multiple suitability curves. Effectively, **`SMURF`** is an application-specific wrapper for **`ecorest`**. The **`ecorest`** package is being reviewed and certified for USACE use separately from **`SMURF`** (McKay et al. *draft*).

As presented below, **`SMURF`** has seven inputs: three sets of suitability curves corresponding to the modules (**`instream`**, **`fauna`**, **`corridor`**), three sets of application-specific inputs to the modules (**`site.instream`**, **`site.fauna`**, **`site.corridor`**), and an area associated with the assessed riparian zone (**`site.area`**). The application-specific inputs are vectors of input variables as described in Sections 4.1-4.3 and Appendix B. The **`SMURF`** subsequently outputs a simple data frame with six fields corresponding to the quality index for each module, an overarching habitat quality index, the site area, and the number of habitat units.

```r
#Import and return suitability index curves for instream module
instream <- read.csv("SMURF_Parameters_2020-09-10_instream.csv", header=TRUE, dec=".")
instream

##   hydatt hydatt.SI stripwidth.ft stripwidth.SI flowpath.score flowpath.SI
## 1    0.0         1             0           0.0              0           0
## 2    1.5         1            30           0.5             20           1
## 3    3.0         0           100           0.9             NA          NA
## 4    5.0         0           300           1.0             NA          NA
## 5     NA        NA          1000           1.0             NA          NA
##   shading.ratio shading.SI cancov.score cancov.SI canstr.score canstr.SI
## 1             0          0            0         0            0         0
## 2             1          1           20         1            6         1
## 3            10          1           NA        NA           NA        NA
## 4            NA         NA           NA        NA           NA        NA
## 5            NA         NA           NA        NA           NA        NA
##   carbret.score carbret.SI
## 1             0          0
## 2            20          1
## 3            NA         NA
## 4            NA         NA
## 5            NA         NA

#Import and return suitability index curves for fauna module
fauna <- read.csv("SMURF_Parameters_2020-09-10_fauna.csv", header=TRUE, dec=".")
fauna

##   canstr.score canstr.SI deadfall.score deadfall.SI snag.score snag.SI
## 1            0         0              0           0          0       0
## 2            6         1             20           1         20       1
##   batcan.score batcan.SI embed.score embed.SI detritus.score detritus.SI
## 1            0         0           0        0              0           0
## 2            4         1          20        1             20           1
##   herb.score herb.SI inv.veg.score inv.veg.SI
## 1          0       0             0          0
## 2         20       1            20          1

#Import and return suitability index curves for corridor module
corridor <- read.csv("SMURF_Parameters_2020-09-10_corridor.csv", header=TRUE, dec=".")
corridor

##   buffer.dev.Score buffer.dev.SI edge.density.perft edge.density.SI
## 1                0             0              0.000               1
## 2               20             1              0.026               1
## 3               NA            NA              0.046               0
## 4               NA            NA              0.200               0
##   corridorwidth.ft corridorwidth.SI corridormin.ft corridormin.SI
## 1                0              0.0              0              0
## 2              100              0.9            100              1
## 3              300              1.0           1000              1
## 4             1000              1.0             NA             NA
```

```
#Describe inputs to SMURF

#ecorest suitability format is parameter columns followed by SI value columns. The paired
"breakpoints" define a suitability index curve.

#instream = data frame of suitability curves defining instream module (in ecorest format)
#site.instream = vector of site-specific inputs for the instream module
  #variables are: hyd.att, stripwidth.ft, flowpath.score, shading.ratio,
  #               cancov.score, canstr.score, and carbret.score

#fauna = data frame of suitability curves defining the fauna module (in ecorest format)
#site.fauna = vector of site-specific inputs for the fauna module
  #variables are: canstr.score, deadfall.score, snag.score, batcan.score,
  #               embed.score, detritus.score, herb.score, and inv.veg.score

#corridor = data frame of suitability curves defining the corridor module (in ecorest form
at)
#site.corridor = vector of site-specific inputs for the corridor module
  #variables are: buffer.dev.Score, edge.density.perft, corridorwidth.ft, & corridormin.ft

#site.area = area of riparian zone being assessed (typically acres)
##########
#Specify function for executing the SMURF model

SMURF <- function(instream, site.instream, fauna, site.fauna, corridor, site.corridor, sit
e.area){
  #Create empty matrices to store suitability outputs
  SI.instream <- c(); SI.fauna <- c(); SI.corridor <- c()

  #Calculate suitability indices for each input variable and module using SIcalc( ) from t
he ecorest package
  SI.instream <- SIcalc(instream, site.instream)
  SI.fauna <- SIcalc(fauna, site.fauna)
  SI.corridor <- SIcalc(corridor, site.corridor)

  #Create empty data frame to store outputs (Instream SI, Habitat SI, Corridor SI, HSI, Ar
ea, Habitat Units)
  SMURF.out <- as.data.frame(matrix(NA, nrow = 1, ncol = 6))
  colnames(SMURF.out) <- c("Instream.SI", "Fauna.SI", "Corridor.SI", "HSI", "Area", "HU")

  #If any input is NA, return NA
  if (sum(is.na(c(site.instream,site.fauna,site.corridor))) > 0){
    SMURF.out$Instream.SI <- NA
    SMURF.out$Fauna.SI <- NA
    SMURF.out$Corridor.SI <- NA
    SMURF.out$HSI <- NA
    SMURF.out$Area <- NA
    SMURF.out$HU <- NA
  }

  #Else compute all other outputs
  else{
    #Compute module-specific habitat suitability indices using HSIarimean( ) from the ecor
est package - ARITHMETIC MEAN
    SMURF.out$Instream.SI <- HSIarimean(SI.instream)
    SMURF.out$Fauna.SI <- HSIarimean(SI.fauna)
    SMURF.out$Corridor.SI <- HSIarimean(SI.corridor)

    #Compute overarching habitat suitability index and habitat units
    SMURF.out$HSI <- (SMURF.out$Instream.SI * SMURF.out$Fauna.SI * SMURF.out$Corridor.SI)
^ (1/3)
    SMURF.out$Area <- site.area
    SMURF.out$HU <- SMURF.out$HSI * SMURF.out$Area
  }
  #Send output from function
  SMURF.out
}
```

5 Evaluation

Ecological models typically rely on multiple variables, ecological processes, and in many cases present a variety of ecological outcomes. As such, models can quickly become complex system representations with many components, inputs, assumptions, and modules. Model evaluation is the process for ensuring that numerical tools are scientifically defensible and transparently developed. Evaluation is often referred to as verification or validation, but it in fact includes a family of methods ranging from peer review to model testing to error checking (Schmolke et al. 2010). The USACE has established an ecological model certification process to ensure that planning models are sound and functional. These generally consist of evaluating tools relative to the three following categories: system quality, technical quality, and usability (EC 1105-2-412).

5.1 *System Quality*

System quality refers to the computational integrity of a tool and involves assessing the numerical accuracy of a model. System quality has three primary phases for avoiding errors (quality assurance), detecting errors through formal testing (quality control), and updating models based on review and use (model update) (McKay et al. 2020b).

Multiple quality assurance practices were followed throughout the development of SMURF. First, the simple workflow of a single function minimizes potential locations for errors. Second, code was written following a standard style used by the first author in more than a dozen prior models. Third, all code was documented extensively with in-line comments during development to articulate model logic, clarify naming conventions, and avoid editing errors. Fourth, model documentation was developed as functions were constructed using R Markdown. Fifth, model versions were controlled by date-stamping all input and model files.

Additionally, quality control procedures were applied to find and correct any errors. The first author used interim line-level checks of code to verify functionality. A colleague with R expertise subsequently inspected and verified the model. Finally, a test plan was devised to examine the overarching function as well as the computation of the instream, fauna, and corridor indices. Specifically, the test approach and results are as follows:

- Boundary conditions: A set of site-specific model inputs were derived, which represent the lowest and highest possible suitability values for SMURF. These "worst" and "best" case scenarios were then used to test the limits of the **SMURF**. For instance, a set of "worst" case inputs should result in 0 habitat suitability at both the module and overarching stages of computation. All combinations of worst and best case inputs were examined for each module. Table 4 summarizes these tests, all of which produce the expected outcome. **TEST RESULT = PASS**.

- Instream Suitability: Five input sets were developed for the instream module, to verify the computation of each suitability index. The data sets were pseudo random and intended to provide values that could be easily verified through manual calculations. Table 5 summarizes these tests, all of which produce the expected outcome. **TEST RESULT = PASS**.

- Fauna Suitability: Five input sets were developed for the fauna module, to verify the computation of each suitability index. The data sets were pseudo random and intended to provide values that could be easily verified through manual calculations. Table 6 summarizes these tests, all of which produce the expected outcome. **TEST RESULT = PASS**.

- Corridor Suitability: Five input sets were developed for the corridor module, to verify the computation of each suitability index. The data sets were pseudo random and intended to provide values that could be easily verified through manual calculations. Table 7 summarizes these tests, all of which produce the expected outcome. **TEST RESULT = PASS**.

Table 4. Model testing with extreme inputs for each module. Worst and Best indicate the worst and best possible input values, which should correspond to suitability indices of 0 and 1, respectively. Area is also varied to test sensitivity to input area values.

Instream Input	Fauna Input	Corridor Input	Instream SI	Fauna SI	Corridor SI	HSI	Area	HU
Worst	Worst	Worst	0	0	0	0	100	0
Best	Worst	Worst	1	0	0	0	100	0
Worst	Best	Worst	0	1	0	0	100	0
Worst	Worst	Best	0	0	1	0	100	0
Best	Best	Worst	1	1	0	0	100	0
Best	Worst	Best	1	0	1	0	100	0
Worst	Best	Best	0	1	1	0	100	0
Best	Best	Best	1	1	1	1	100	100
Best	Best	Best	1	1	1	1	0	0
Best	Best	Best	1	1	1	1	50	50

Table 5. Model testing for instream module.

hyd.att	stripwidth.ft	flowpath.score	shading.ratio	cancov.score	canstr.score	carbret.score	Instream.SI
1.5	120	12	5	20	1	10	0.74
0.5	25	6	2	5	6	4	0.60
2.0	250	18	4	15	3	20	0.83
6.0	250	14	3	10	2	16	0.62
3.0	75	2	1	10	4	12	0.52

Table 6. Model testing for fauna module.

canstr.score	deadfall.score	snag.score	batcan.score	embed.score	detritus.score	herb.score	inv.veg.score	Fauna.SI
6	20	2	0	2	15	17	8	0.52
0	11	5	1	12	18	1	9	0.38
1	3	10	2	20	10	15	5	0.48
4	6	15	3	5	8	11	14	0.55
2	17	20	4	15	17	18	19	0.83

Table 7. Model testing for corridor module.

buffer.dev.Score	edge.density.perft	corridorwidth.ft	corridormin.ft	Corridor.SI
0	0.005	25	20	0.36
20	0.040	750	100	0.82
5	0.010	85	60	0.65
10	0.020	125	100	0.85
15	0.030	245	200	0.88

Model errors are often uncovered during peer review and/or applications (i.e., "bugs"), which can be particularly important for large-scale or complex models. SMURF is a relatively simple tool and has been developed in the context of a single application in Beargrass Creek. However, the general framework may be easily adapted to other riparian zones and regions. As such, this report explicitly identifies the accompanying model as SMURF Version 1.0. The model and report were reviewed through USACE certification procedures, and review comments are archived here for future reference (Appendix C). This report will be published by ERDC, and the ERDC Knowledge Core will provide a means for archival of documents and associated code.

5.2 *Technical Quality*

The technical quality of a model is assessed relative to its reliance on contemporary theory, consistency with design objectives, and degree of verification and validation against independent field data. As described in Chapter 4, SMURF combines a variety of processes well-acknowledged as important to riparian ecosystem integrity. Where possible, model assessments were adopted or adapted from peer-reviewed resources. However, suitability curves and associated inputs are heavily based on professional judgment and hypothesized riparian function. Although qualitative, field-based judgments are used, these methods have been shown to provide significant utility and predictive power and remain highly applied in stream assessment (Hughes et al. 2010). In addition to qualitative evidence of technical quality, two quantitative evaluation methods were applied: pseudo-verification with field judgments and sensitivity analysis.

Ideally, a riparian assessment procedure would be rigorously validated against empirical data for multiple ecological processes. However, validation data were not available in the Beargrass Creek system. Alternatively, field assessors were asked to provide an overall judgment of each site relative to their impression of the general riparian condition. These data provide a crude means of pseudo-verification of the SMURF framework, which is presented in Appendix D. The SMURF generally aligns with the overall professional judgment of field personnel. Interestingly, the fauna index and the overall habitat suitability index show the most agreement with the field teams, and the instream and corridor indices show the least. Faunal habitat provision could be easier to observe as a field scale than more complex off-site effects on instream processes or corridor functions. These data indicate that SMURF indices generally agree with professional judgment associated with the 104 samples in Beargrass Creek (i.e., independent left and right bank assessments at 52 access points). The general approach of pseudo-verification could provide a useful means of rapid model evaluation in future studies.

Sensitivity analysis "investigates how the variation in the output of a numerical model can be attributed to variations of its input factors" (Pianosi et al. 2016). Here, a global sensitivity analysis is undertaken using two approaches following the approaches described in Pianosi et al. (2016). First, a 'one-[factor]-at-a-time' method was applied by systematically inducing variation in each model input, while holding all other values constant at the "best case" scenario described in Section 5.1. Figure 7-9 show the effects of each parameter on the suitability index for a given module as well as the overall habitat suitability index. These analyses show that SMURF is more sensitive to inputs in the corridor module due to the lower number of suitability curves. Although the overall habitat suitability index is not dramatically altered relative to any one input, each variable can have noticeable effects on the overall index even when holding all other values at the "best case" scenario.

The second form of global sensitivity analysis used an all-[factors]-at-a-time method. The entire solution space for SMURF modules was explored comprehensively by examining inputs associated with every "breakpoint" in the model suitability curves. These combinations of inputs led to 960 input vectors for the instream module, 256 input vectors for the fauna module, and 96 input vectors for the corridor module. It was not numerically feasible to simulate the complete combination of all input vectors for SMURF as a whole (23,592,960 input data sets). Figures 10-12 present the results of the all-at-a-time analysis by showing the distribution of module indices relative to a given input. These analyses confirm the results from the one-at-a-time method and indicate that SMURF outputs are sensitive to inputs but any one input does not disproportionately dominate the analysis.

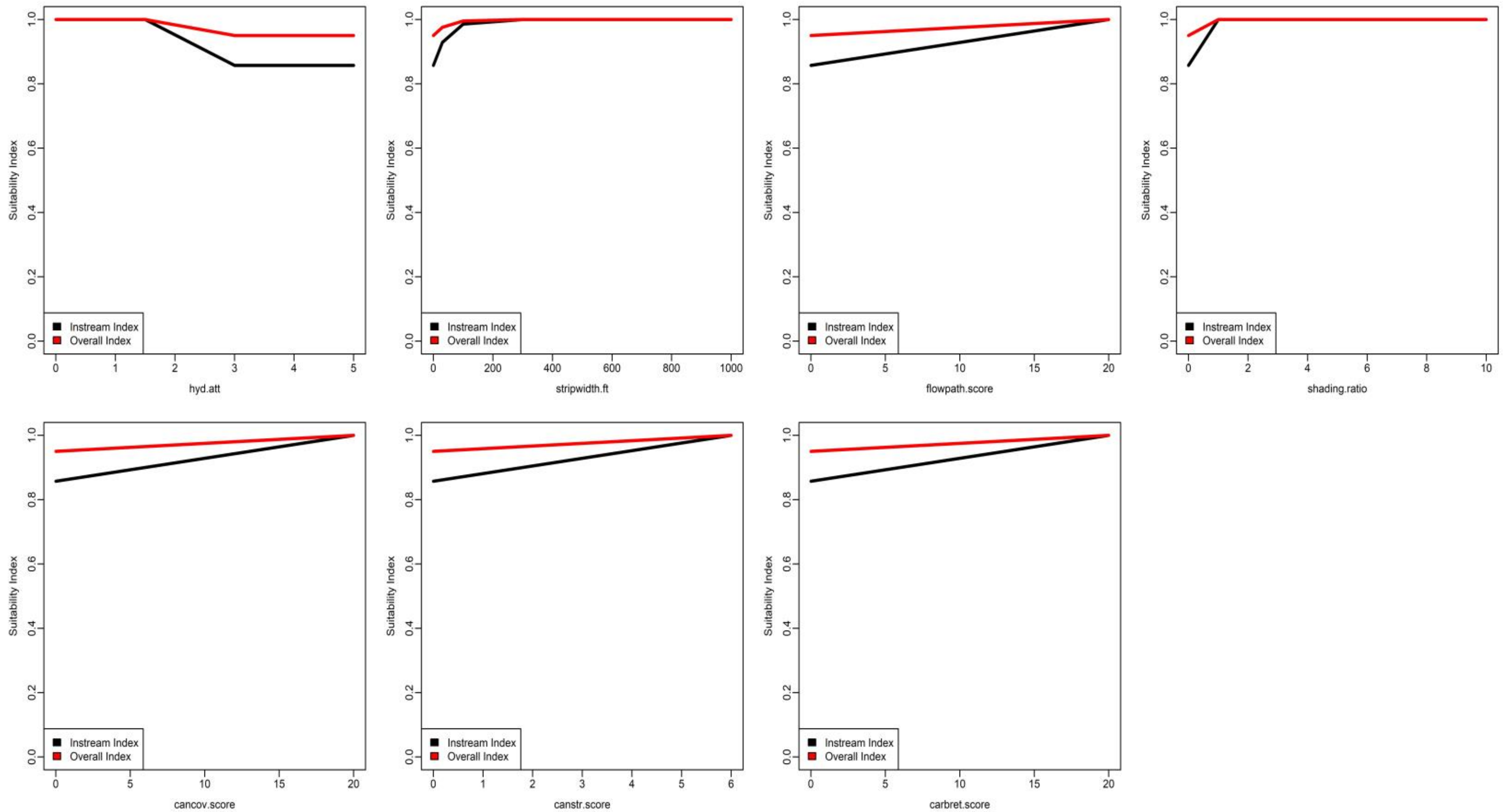

Figure 7. Local sensitivity analysis for the instream module.

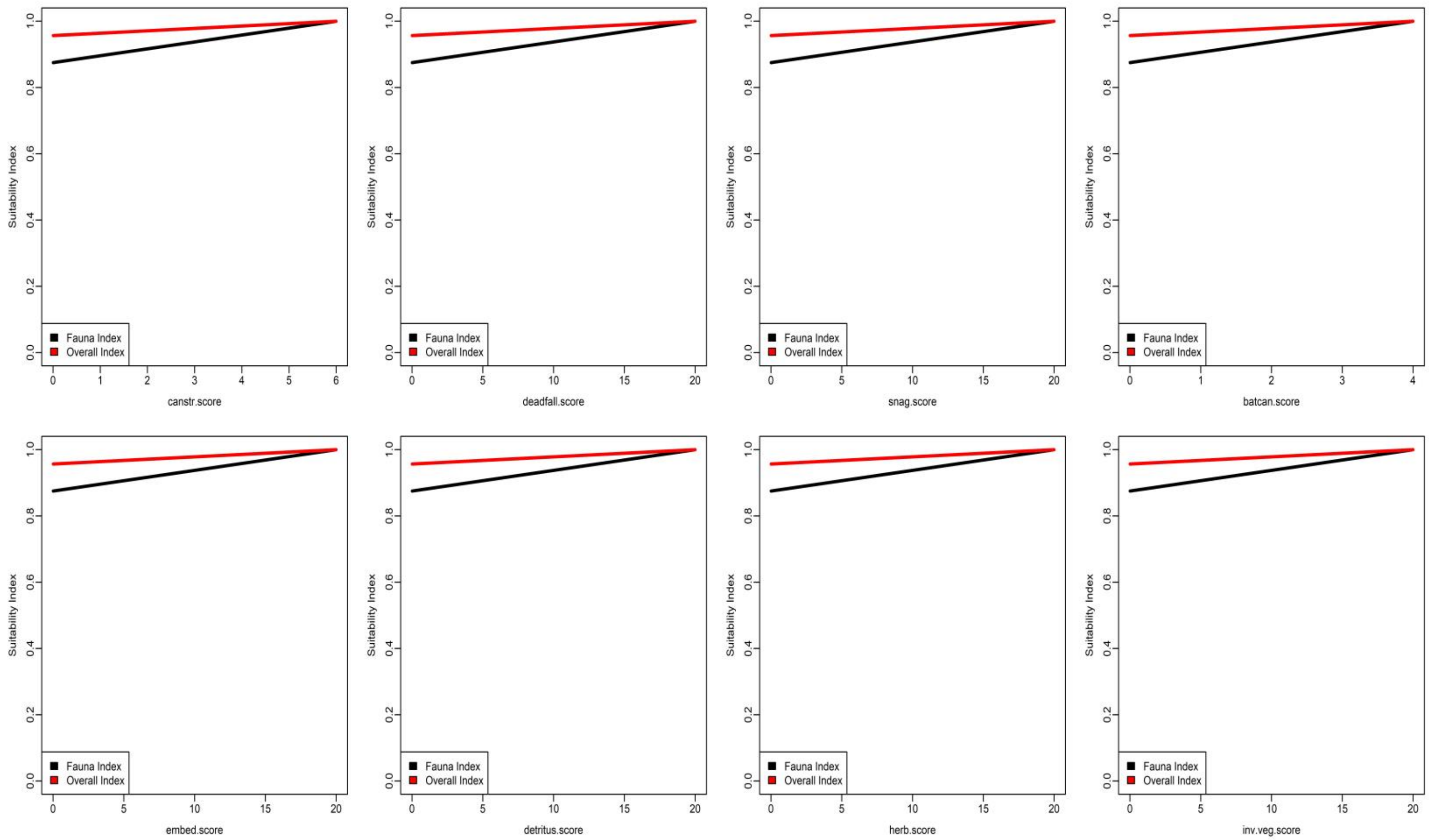

Figure 8. Local sensitivity analysis for the fauna module.

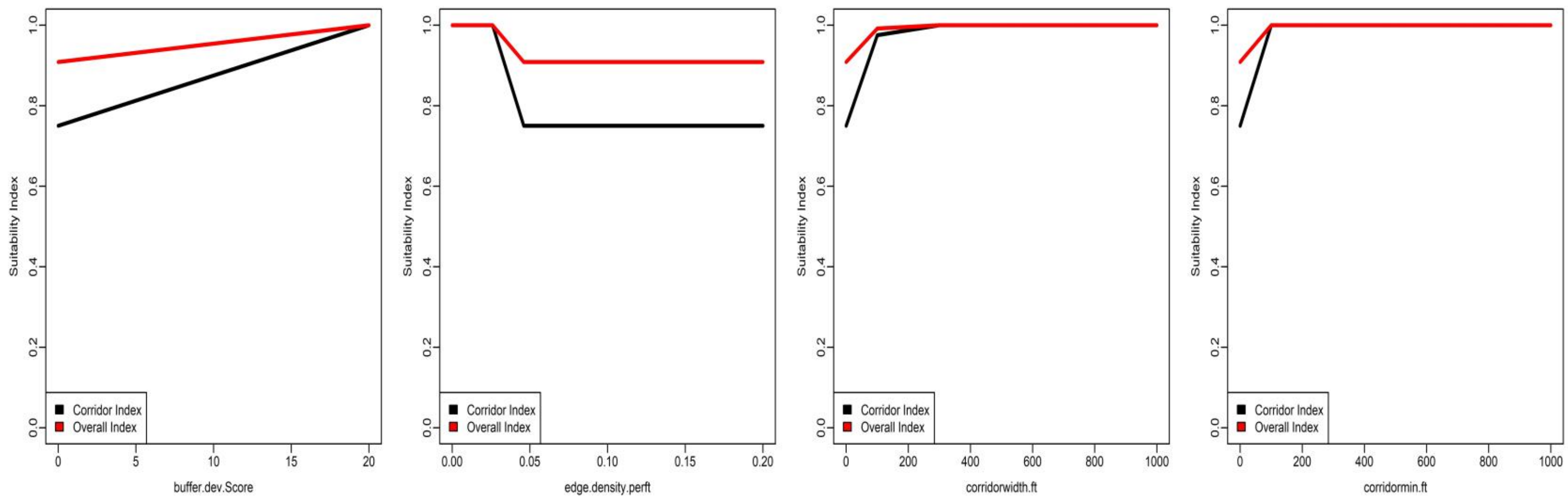

Figure 9. Local sensitivity analysis for the corridor module.

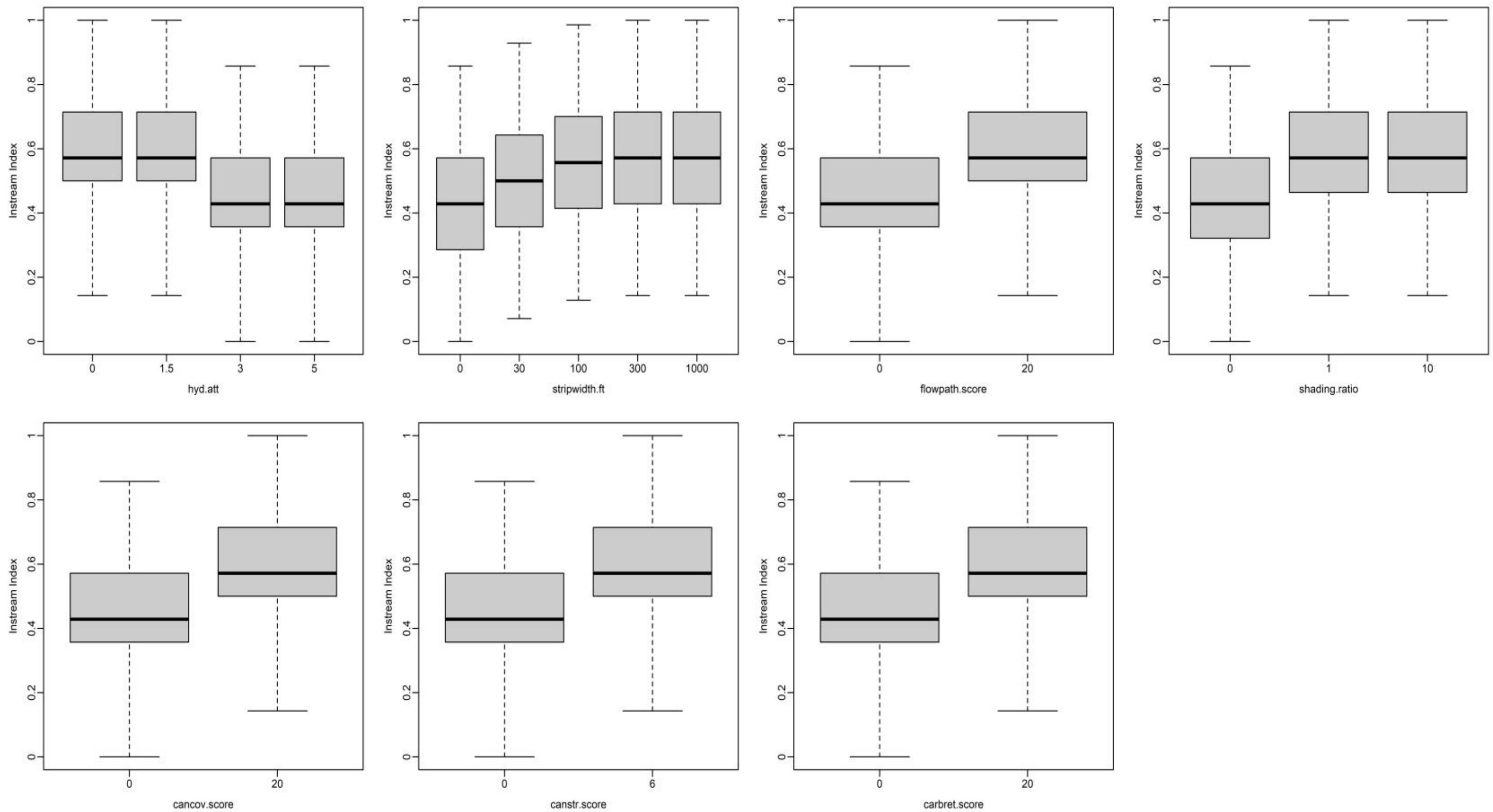

Figure 10. Global sensitivity analysis for the instream module.

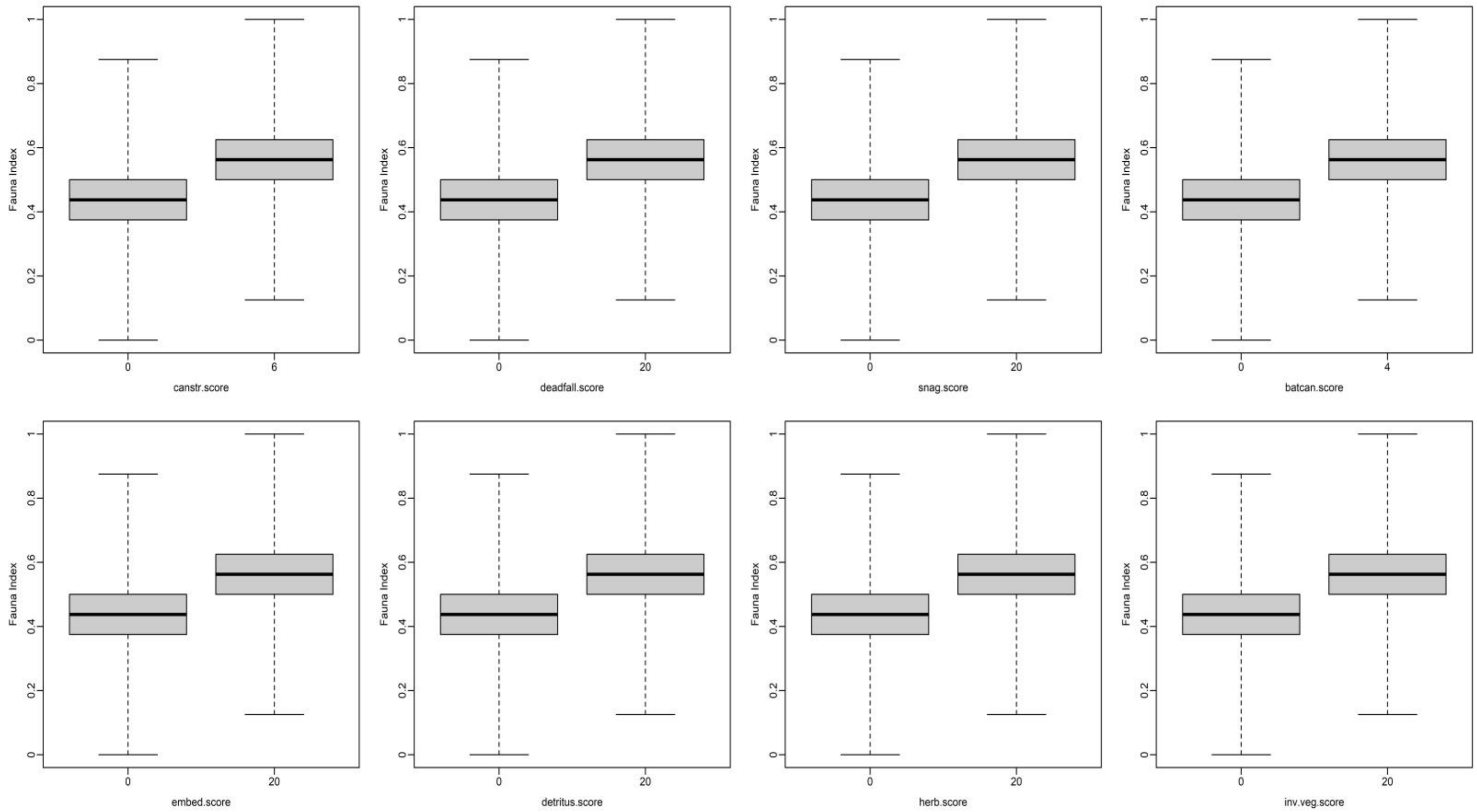

Figure 11. Global sensitivity analysis for the fauna module.

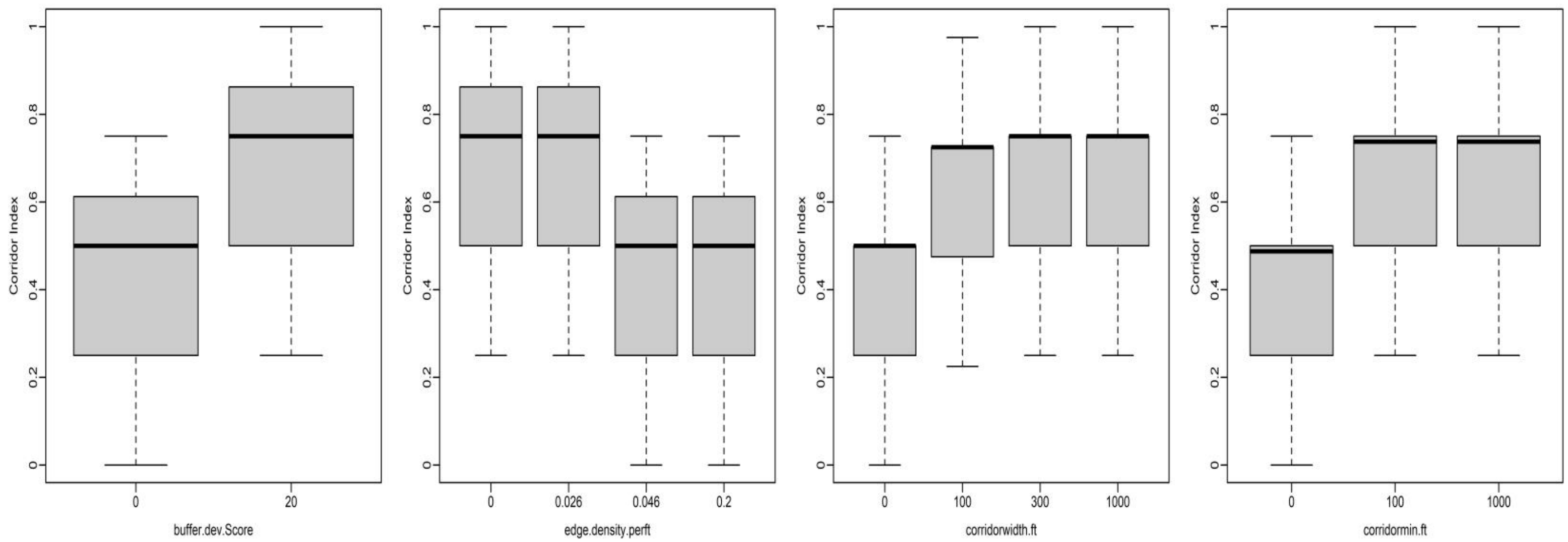

Figure 12. Global sensitivity analysis for the corridor module.

5.3 *Usability*

The usability of a model can influence the repeatable and transparent application of a tool. This type of evaluation typically examines the ease of use, availability of inputs, transparency, error potential, and education of the user. As such, defining the intended user(s) is a crucial component of assessing usability. SMURF was developed for application by the USACE technical team of the Beargrass Creek ecosystem restoration study. In its current form, the tool is not intended for broader application, and there is no associated graphical user interface beyond the script itself. However, the model is programmed in the widely available R Statistical Software language, and users familiar with R could likely apply the model easily, given its single functional form.

6 Application and Communication

SMURF could be used to assess riparian condition in a variety of applied restoration decision-making contexts (e.g., site screening, alternatives analysis, scenario planning). Here, a simple demonstration of SMURF is presented to assess existing conditions in the Beargrass Creek watershed. As described in Section 1.2, Beargrass Creek is a small urban watershed in Louisville, Kentucky. The USACE Louisville District (LRL) and Louisville Metropolitan Sewer District (MSD) are partnering to identify actions that could restore aquatic ecosystems in the watershed. The two primary objectives of the project are: (1) To reestablish quality and connectivity of *riverine* habitats and (2) To reestablish quality and connectivity of *riparian* habitats. An initial array of 50+ potential restoration sites was identified based on prior watershed assessments, local knowledge, preliminary field scouting, and desktop geospatial analyses. These sites were screened relative to technical, logistical, administrative, and policy factors, ultimately identifying 21 sites for detailed analysis.

SMURF is used here to assess existing conditions at these 21 potential restoration locations. SMURF assessments were conducted separately for left and right bank areas. Field data were collected through a coordinate campaign involving personnel from LRL and MSD from June-July 2020. Desktop geospatial analyses were conducted separately in December 2020. All data were compiled in a single Microsoft Excel spreadsheet for easy use and transfer. The assessments represent 42 independent applications of SMURF throughout the Beargrass Creek watershed (i.e., left and right bank assessments for 21 sites). The following code imports all data, compiles data into the input structure for the `SMURF` function, and executes the model. Data are archived in Appendix D (Tables D1-D8), and SMURF results are summarized in Tables 8 and 9 for the left and right bank riparian zones.

```r
#Import Beargrass Data
Beargrass <- read.csv("Beargrass_Data_2021-02-11_SMURFonly_existing.csv", header=TRUE, dec=".")

#Compute the number of Beargrass Creek access point sites
nBG <- length(Beargrass$Rest_Name)

##########
#Compute derived variables and add as columns to data frame

#Shading ratio (shading)
Beargrass$Shading_Left <- Beargrass$Canopy_Height_25_Left_ft / Beargrass$Bankfull_Width_ft
Beargrass$Shading_Right <- Beargrass$Canopy_Height_25_Right_ft / Beargrass$Bankfull_Width_ft

#Canopy Structure (canstr)
Beargrass$Canstr_Left <- Beargrass$Overstory_Left + Beargrass$Midstory_Left + Beargrass$WoodyShrubs_Left
Beargrass$Canstr_Right <- Beargrass$Overstory_Right + Beargrass$Midstory_Right + Beargrass$WoodyShrubs_Right

#Bat Canopy Structure (batcan)
Beargrass$Batcan_Left <- ((2 - Beargrass$Midstory_Left) / 2) * (Beargrass$Overstory_Left + Beargrass$WoodyShrubs_Left)
Beargrass$Batcan_Right <- ((2 - Beargrass$Midstory_Right) / 2) * (Beargrass$Overstory_Right + Beargrass$WoodyShrubs_Righ
t)

##########
#Create an empty data frame to store LEFT bank inputs
BG.left <- data.frame(matrix(NA, nrow=nBG, ncol=19))
colnames(BG.left) <- c(instream.names, fauna.names, corridor.names)
rownames(BG.left) <- Beargrass$Rest_Num

#Specify inputs for instream module
BG.left[,1:7] <- cbind(Beargrass$Incision_Left, Beargrass$Buffer_Width_Mean_Left_ft,
                       Beargrass$Buffer_Flowpaths_Left, Beargrass$Shading_Left,
                       Beargrass$Stream_Canopy_Cover, Beargrass$Canstr_Left, Beargrass$OM_Retention)

#Specify inputs for fauna module
BG.left[,8:15] <- cbind(Beargrass$Canstr_Left, Beargrass$Deadfall_Left,
                        Beargrass$Snags_Left, Beargrass$Batcan_Left,
                        Beargrass$Embeddedness, Beargrass$Detritus_Left,
                        Beargrass$Herbaceous_Left, Beargrass$Invasive_Dominance_Left)

#Specify inputs for corridor module
BG.left[,16:19] <- cbind(Beargrass$Buffer_Development_Left, Beargrass$Edge_Density_Left_perft,
                         Beargrass$Buffer_Width_Mean_Left_ft, Beargrass$Buffer_Width_Min_Left_ft)

##########
#Create an empty data frame to store LEFT bank inputs
BG.right <- data.frame(matrix(NA, nrow=nBG, ncol=19))
colnames(BG.right) <- c(instream.names, fauna.names, corridor.names)
rownames(BG.right) <- Beargrass$Rest_Num

#Specify inputs for instream module
BG.right[,1:7] <- cbind(Beargrass$Incision_Right, Beargrass$Buffer_Width_Mean_Right_ft,
                        Beargrass$Buffer_Flowpaths_Right, Beargrass$Shading_Right,
                        Beargrass$Stream_Canopy_Cover, Beargrass$Canstr_Right, Beargrass$OM_Retention)

#Specify inputs for fauna module
BG.right[,8:15] <- cbind(Beargrass$Canstr_Right, Beargrass$Deadfall_Right,
                         Beargrass$Snags_Right, Beargrass$Batcan_Right,
                         Beargrass$Embeddedness, Beargrass$Detritus_Right,
                         Beargrass$Herbaceous_Right, Beargrass$Invasive_Dominance_Right)

#Specify inputs for corridor module
BG.right[,16:19] <- cbind(Beargrass$Buffer_Development_Right, Beargrass$Edge_Density_Right_perft,
                         Beargrass$Buffer_Width_Mean_Right_ft, Beargrass$Buffer_Width_Min_Right_ft)

##########
#Create empty matrix to store LEFT BANK outputs
BG.left.out <- as.data.frame(matrix(NA, nrow = nBG, ncol = 6))
colnames(BG.left.out) <- c("Instream.SI", "Fauna.SI", "Corridor.SI", "HSI", "Area", "HU")
rownames(BG.left.out) <- Beargrass$Rest_Num

#Create empty matrix to store RIGHT BANK outputs
BG.right.out <- as.data.frame(matrix(NA, nrow = nBG, ncol = 6))
colnames(BG.right.out) <- c("Instream.SI", "Fauna.SI", "Corridor.SI", "HSI", "Area", "HU")
rownames(BG.right.out) <- Beargrass$Rest_Num

#Execute SMURF for all sites
for(i in 1:nBG){
 BG.left.out[i,] <- SMURF(instream, BG.left[i,1:7], fauna, BG.left[i,8:15], corridor, BG.left[i,16:19], Beargrass$Ripari
an_Area_Left_ft2[i]/43560)
 BG.right.out[i,] <- SMURF(instream, BG.right[i,1:7], fauna, BG.right[i,8:15], corridor, BG.right[i,16:19], Beargrass$Ri
parian_Area_Right_ft2[i]/43560)
}
```

Table 8. Summary of SMURF riparian assessment at Beargrass Creek restoration site (LEFT BANK ONLY).

	Instream.SI	**Fauna.SI**	**Corridor.SI**	**HSI**	**Area**	**HU**
X2	0.64	0.48	0.44	0.51	13.3	6.8
X4	0.58	0.40	0.68	0.54	19.0	10.2
X5	0.64	0.42	0.60	0.54	37.4	20.4
X8	0.82	0.60	0.72	0.71	43.2	30.5
X9	0.81	0.56	0.75	0.70	7.9	5.5
X10	0.50	0.50	0.30	0.42	4.1	1.7
X11	0.69	0.49	0.59	0.58	30.0	17.5
X15	0.50	0.19	0.17	0.25	2.4	0.6
X19	0.44	0.33	0.61	0.44	8.3	3.7
X20	0.56	0.34	0.43	0.44	4.0	1.7
X21	0.61	0.45	0.25	0.41	5.6	2.3
X22	0.31	0.20	0.11	0.19	8.1	1.5
X24	0.19	0.22	0.22	0.21	3.5	0.7
X28	0.28	0.16	0.11	0.17	3.9	0.7
X29	0.74	0.41	0.70	0.59	39.2	23.3
X30	0.59	0.51	0.72	0.60	58.6	35.3
X31	0.36	0.22	0.18	0.24	3.7	0.9
X33	0.68	0.38	0.66	0.56	4.7	2.6
X34	0.65	0.46	0.54	0.54	47.2	25.7
X35	0.60	0.32	0.63	0.49	36.3	17.9
X38	0.43	0.37	0.24	0.33	3.4	1.1

Table 9. Summary of SMURF riparian assessment at Beargrass Creek restoration site (Right BANK ONLY).

	Instream.SI	Fauna.SI	Corridor.SI	HSI	Area	HU
X2	0.67	0.48	0.61	0.58	31.8	18.4
X4	0.59	0.38	0.69	0.53	32.8	17.5
X5	0.54	0.29	0.41	0.40	21.0	8.4
X8	0.81	0.57	0.69	0.68	48.3	33.0
X9	0.77	0.56	0.59	0.64	2.3	1.5
X10	0.60	0.51	0.70	0.60	14.6	8.7
X11	0.67	0.52	0.56	0.58	28.5	16.6
X15	0.49	0.19	0.14	0.24	2.3	0.5
X19	0.45	0.31	0.27	0.33	3.6	1.2
X20	0.55	0.40	0.23	0.37	2.0	0.7
X21	0.64	0.45	0.58	0.55	10.5	5.8
X22	0.29	0.21	0.09	0.17	5.9	1.0
X24	0.32	0.22	0.59	0.35	20.9	7.3
X28	0.23	0.14	0.06	0.13	0.9	0.1
X29	0.77	0.44	0.69	0.61	26.5	16.3
X30	0.46	0.25	0.26	0.31	3.3	1.0
X31	0.29	0.22	0.09	0.18	2.1	0.4
X33	0.60	0.40	0.27	0.40	1.3	0.5
X34	0.63	0.44	0.60	0.55	58.7	32.3
X35	0.62	0.49	0.66	0.59	38.6	22.7
X38	0.40	0.38	0.46	0.41	9.9	4.1

These results demonstrate how SMURF effectively distinguishes ecological outcomes in urban riparian zones. For instance, Site-X28 is a golf course with very little riparian forest, and the suitability indices and overall suitability are low (less than 0.28 for all indices). Conversely, Site-X8 is a reach with functioning riparian forests and significant wildlife observations during the site visits (all indices greater than 0.57). This analysis also shows the importance of distinguishing left and right riparian areas as unique ecosystems. For instance, Site-X2 is a location with significantly larger site area on the right bank, and thus, there are three-fold as many habitat units even though the quality assessments are similar.

SMURF may be used to forecast management and restoration outcomes through multiple mechanisms. Ideally, each parameter would be linked to a process-oriented model, such as basing channel incision on geomorphic change tools. A second approach would be to develop a "rubric" for how inputs should be consistently varied across time and management alternatives. For instance, in Beargrass Creek project planning, a set of rules were used to modify each model input (e.g., a percent change in the deadfall parameter) in response to a specific alternative (e.g., riparian planting) at a specific point in time (e.g., Year-50); these guidelines facilitates consistent model application across many sites. A third approach would be to adjust model inputs based on professional judgment and knowledge.

7 Summary

This report has documented the development of a Simple Model for Urban Riparian Function (SMURF). The SMURF has been developed in the context of ongoing restoration planning in the Beargrass Creek watershed in Louisville, Kentucky. The model has been constructed and parameterized around local details, although the framework and approach may be applicable elsewhere. This report intended to document the technical details of this model and demonstrate its application in Beargrass Creek. Future improvements to this tool may include:

- Verification of model predictions relative to empirical observations of riparian function (e.g., bird occupancy, herpetofaunal density, vegetation community surveys, etc.),
- Incorporation of geospatial analyses and data processing algorithms within the model,
- Refinement of model parameters based on sites where additional data may be available,
- Modification of the model structure or parameterization based on additional research or literature support, or
- Refinement of suitability curves based on input from technical stakeholders.

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Appendix A: Acronyms

- *ERDC*: U.S. Army Engineer Research and Development Center.
- *FWOP*: Future WithOut Project Conditions.
- *LRL*: USACE Louisville District.
- *MSD*: Louisville / Jefferson County Metropolitan Sewer District.
- *QHEI*: Qualitative Habitat Evaluation Index.
- *SMURF*: Simple Model for Urban Riparian Function.
- *USACE*: U.S. Army Corps of Engineers.
- *USFWS*: U.S. Fish and Wildlife Service.

Appendix B: Field Data Sheets

Simple Model for Urban Riparian Function (SMURF)

Reach ____________________
Date ____________________
Assessor ____________________
Lat/Long ____________________
Bankfull Depth (ft) __________
Bankfull Width (ft) __________

Dimensions (ft)	Left	Right
Bank Height		
Canopy Height (within 25 feet of bank)		

Parameter	Optimal 20 19 18 17 16	Suboptimal 15 14 13 12 11	Marginal 10 9 8 7 6	Poor 5 4 3 2 1 0	Left	Right
Buffer properties						
Buffer Development	Very minor evidence of human disturbance and no impact to corridor function.	Notable impacts within footprint (e.g., paths, lawns) but minor effect on animal movement.	Large scale impacts to buffer reducing migratory corridor function.	Significant major impacts inhibiting corridor functions.		
Buffer Flowpaths	Runoff flows through buffer evenly, in natural channels, or through wetlands.	Minor rills / channels are visible but mostly used during large events.	Major rills, flow paths, and channels used during small events.	Obvious short-circuiting of buffer by pipes and drainage at most events.		
Riparian habitat properties						
Multi-story Canopy Structure	Check all that are present and associated habitat quality in the LEFT riparian zone: Quality: High / Medium / Low Canopy / Overstory Midstory Woody Shrubs		Check all that are present and associated habitat quality in the RIGHT riparian zone: Quality: High / Medium / Low Canopy / Overstory Midstory Woody Shrubs			
Snag Density	Greater than 3 pieces of large, *standing* deadwood (4+in diameter, 36+in length) in 25'x100' area.	1-3 pieces of large, *standing* deadwood (4+in diameter, 36+in length) in 25'x100' area.	No large, *standing* deadwood, but large live trees for future snags.	No large, *standing* deadwood or large *live* trees.		
Deadfall Density	Greater than 10 pieces of large, down woody stems (4+in diameter, 36+in length) in 25'x100' area.	5-10 pieces of large, down woody stems (4+in diameter, 36+in length) in 25'x100' area.	0-5 pieces of large, down woody stems (4+in diameter, 36+in length) in 25'x100' area.	No large, down woody stems (4+in diameter, 36+in length).		
Detrital Ground Cover	Organic ground cover >70%. Mostly covered by thick detritus / woody debris layer.	Organic ground cover (detritus/woody debris) is 40-70%.	Organic ground cover (detritus/woody debris) is 20-40%.	Organic ground cover is <20%. Ground is mostly bare, lawn, or impervious.		
Herbaceous Vegetation Cover	Extensive and layered throughout reach.	Extensive, but lacks complexity and layering/	Patchy and lacks complexity or layers.	Minimal or absent throughout reach.		
Invasive Vegetation Dominance	Primarily native taxa. Little, if any, ecological effect of invasives.	Invasives notably present, but playing a minor ecological role.	Invasive species are dominant, but natives remain.	Invasive dominance in both composition and function.		
From the perspective of the stream						
Stream Canopy Cover	>85% cover with clear channel shading.	55-85% cover with stippled or time-dependent shading.	30-55% canopy cover. Temperature notably altered.	< 30% canopy cover. Temperature dramatically altered.		
Organic Matter Retention	Significant leaf matter introduction from riparian zone. Instream retention is evident (e.g., leaf packs).	Some leaf matter introduction. Retention affected by high flows.	Minor leaf matter introduction to stream. Little retention in reach.	Little evidence of organic matter loading and / or retention.		
Embeddedness	None. Less than 25% of the site has fine sediment surrounding and/or covering rocks.	Normal. Fine sediment fills 25-50% of the living spaces around gravel, cobble, and boulders.	Moderate. Fine sediment and silt fills 50-75% of living spaces around gravel, cobble, and boulders.	Extensive. Fine sediment and silt fills > 75% of living spaces around gravel, cobble, and boulders.		
Overall judgment of riparian condition						
Professional Opinion	**Highest quality habitat. Best attainable in watershed.**	**Good habitat. Minimal impact with significant levels of remaining ecological function.**	**Significantly impacted. Complete loss of some ecological functions.**	**Highly impacted. Little ecological value.**		

Figure B1. SMURF Field Data Sheet.

Simple Model for Urban Riparian Function (SMURF) Geospatial Analyses

Reach ______________________________
Date ______________________________
Assessor ______________________________
Lat/Long ______________________________
GIS Directory ______________________________

Parameter	Description	Units	Left	Right
Watershed Area	(*Recommended*) Watershed area is not required for SMURF. However, this parameter may be used in estimating bankfull dimensions from regional hydraulic geometry curves, and it may provide crucial contextual data (e.g., hydrologic metrics from regional streamflow regressions). Area calculations can be derived from manual delineation, the National Hydrography Dataset, ArcHydro, or online tools (e.g., Colorado State's eRAMS).			
Total Site Area	(*Recommended*) This field captures the total extent of riparian management actions including intact and degraded patches. This is generally a manually delineated polygon based on the assessor's professional judgment.			
Riparian Area	This is the area of functioning riparian zone associated with the SMURF assessment. This factor should be aligned with the quality assessment. Consistency can be found by intersecting the total site area (above) with locally available datasets for vegetation or riparian zones (often available through city planning). SMURF is agnostic to area units (e.g., km^2, ac, ft^2), but acres are the most common metric.			
Riparian Perimeter	This factor is the edge length of the entire riparian area on one bank. This is generally assessed as the polygon length associated with the riparian area described above.			
Channel Length	(*Recommended*) Channel length is not an explicit SMURF input, but it provides the simplest method for calculating mean buffer width (as well as important context on relative size of a site).			
Mean Buffer Width	Reach-averaged buffer width is most easily calculated as the riparian area divided by channel length. However, this may also be estimated from the average of multiple measurements of width along a riparian corridor. *SMURF requires this measurement in feet.*	ft		
Minimum Buffer Width	This factor is the lowest buffer width in a reach. This may be estimated from manual measurements and visual inspection of aerial photographs. *SMURF requires this measurement in feet.*	ft		
Edge Density	Edge density is calculated as riparian perimeter divided by riparian area. *SMURF requires this measurement in ft/ ft^2.*	ft/ft^2		

Figure B2. SMURF Desktop Geospatial Analysis Data Sheet.

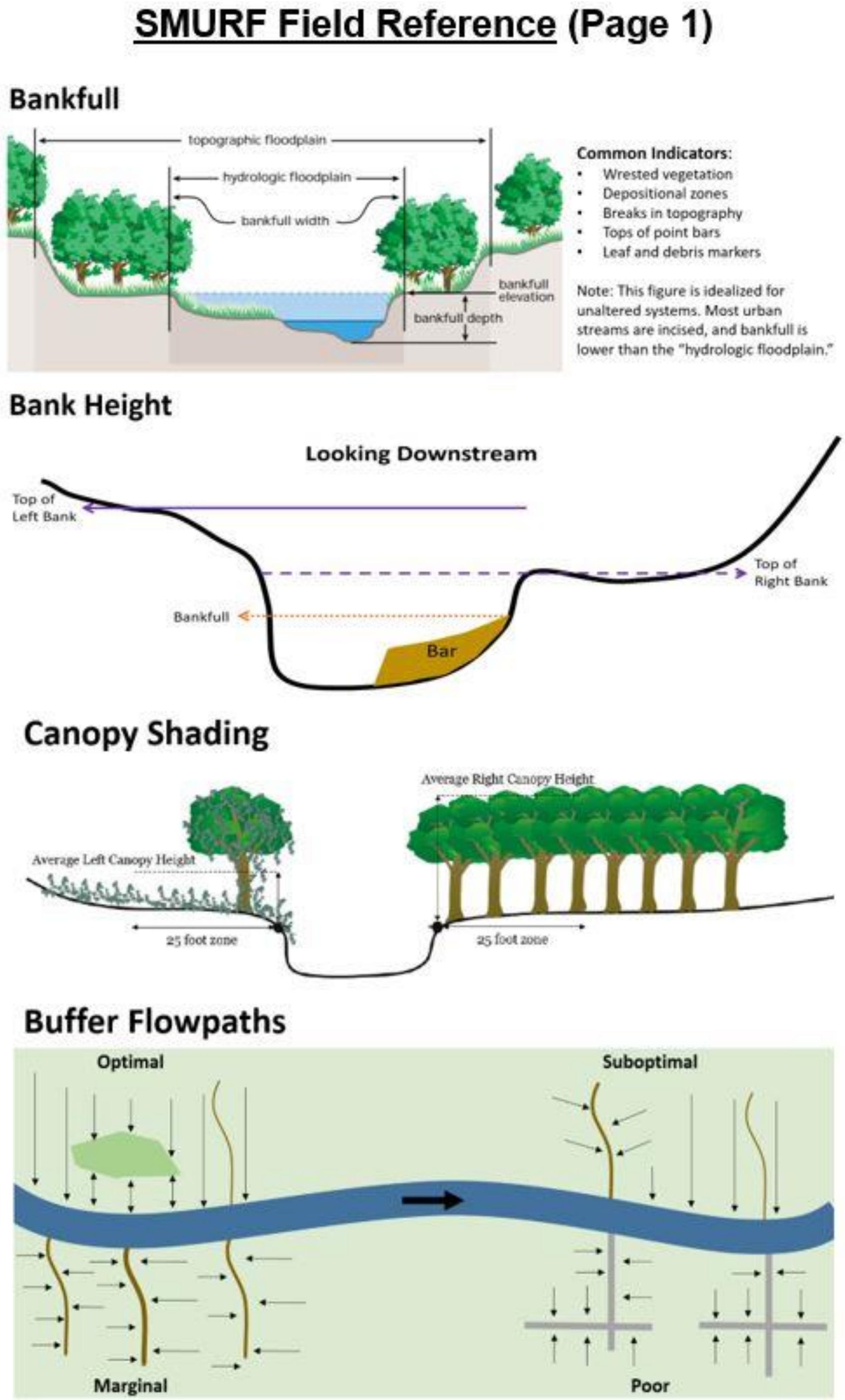
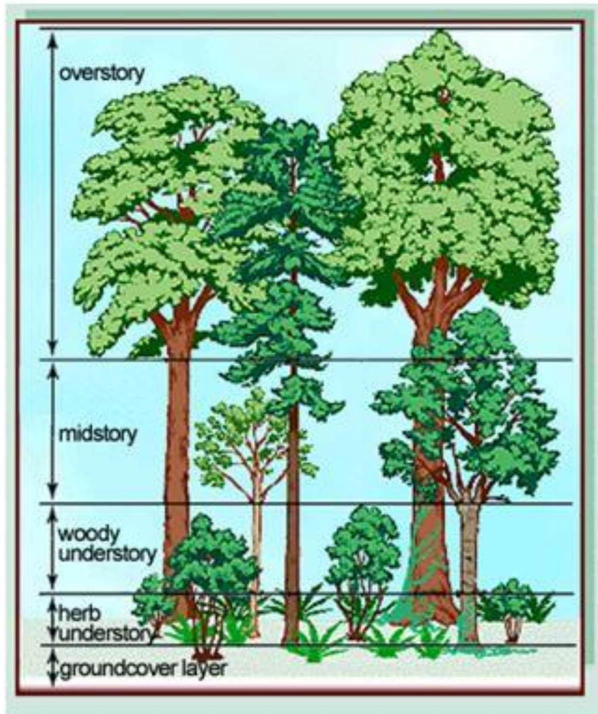


Figure B3. SMURF Field Reference (Page 1).

SMURF Field Reference (Page 2)

Canopy Structure



Organic Matter Retention

Figure B4. SMURF Field Reference (Page 2).

Appendix C: USACE Model Certification Review

USACE model certification review was provided by Dr. Michael Porter (USACE Albuquerque District, "Reviewer-1") and Mr. Mark Shafer (USACE Southwestern Division, "Reviewer-2"). All comments follow the four-part comment structure of: (1) identify the problem, (2) describe the technical basis for the comment, (3) rate the significance or impact of the problem, and (4) recommend a mechanism for resolution. Comments and author responses are provided for long-term archival purposes.

C.1. Reviewer-1

Comment 1.1: Application is missing inputs.

- Basis: I don't see the calculation for the edge metrics in this module. The code imports the arrays for buffer development, buffer average width, and buffer min width. Column 2 is populated with NA, and assigned the name edge.density.perft. Also see note at the end of line 1131.
- Significance: Low as it only affects this application.
- Resolution: Repair application.
- Author Response: Concur. The application was significantly revised to amend errors and clarify model application.

Comment 1.2: Automate edge calculations.

- Basis: In Section 4.3, the formula for the edge metric uses polygon area and perimeter length. The Beargrass dataset has unpopulated fields for the riparian buffer area or perimeter. The data has length and width for the buffer areas which can be used to estimate area and perimeter.
- Significance: Low as it only affects this application.
- Resolution: I suggest the following. Add code to read GIS file and extract perimeter and area values for polygons. Add a default option when data is unavailable from GIS. Add code to verify type of riparian buffer spatial data to support options below. Add calculation for edge using perimeter & area. Add alternate calculation for edge using buffer length and width.
- Author Response: Reject. The authors appreciate the goals of this comment, but geospatial analyses are beyond the current scope of SMURF. The protocol for the calculations has been clarified in the main body, but the calculations remain separate from this version of the model. Future versions of the model will consider adding geospatial assessment.

Comment 1.3: Improve description of organic matter scoring in field protocol.

- Basis: Descriptions for Organic Matter Retention categories in the Data Sheet would be better with example figure(s) in the Field Reference section (in Appendix B).
- Significance: Low.
- Resolution: Refine description.
- Author Response: Concur. Amended as suggested by adding example figures to the field reference.

Comment 1.4: Data compilation protocols do not adequately describe geospatial data.

- Basis: The Beargrass dataset includes many fields derived from GIS and other sources that are not on the field datasheets.
- Significance: Medium.
- Resolution: Suggest adding a GIS Data page describing the fields, other data sources, and metadata equivalent to the field data sheet. Include GIS filename and location.
- Author Response: Concur. A data form has been added for geospatial inputs.

Comment 1.5: Minor editorial issues in Section 4.2.

- Basis: Citation should be "Rankin 2006" not "Ranking 2006". Also the 4th parameter in the herps formula should be "herb" not "her". Note the hyperlink for Barbour et al. 1999 leads to broken links for acquiring the chapters. Suggest identifying a supported source or deleting the link.
- Significance: Low.
- Resolution: Edit accordingly.
- Author Response: Concur.

C.2. Reviewer-2

Comment 2.1: The index relationship for hydatt that relates incision ratio (bank height/ bankfull depth) is not sufficiently documented by either team discussions or by literature references.

- Basis: The scientific basis of each response curve should be provided in model documentation to assist model users in first determining if the curve is appropriate for their setting and second how to score their site.
- Significance: Low for one-time use authorization of model. Medium for regional/national use of model.
- Resolution: Provide either the logic used by the modeling team in setting the hydatt response cure and/or the literature that supports the curve.
- Author Response: Concur. The text was clarified and references added to provide the supporting logic (Harman and Jones 2016, IA DNR 2018).

Comment 2.2: Incision ration (bank height/bankfull depth) as a proxy does not appear to be the best available metric to utility for hydrologic connectivity.

- Basis: Where possible, the best available metrics should be used instead of a proxy particularly when attempting to predict with and without project conditions.
- Significance: Medium.
- Resolution: Recommend replacing this version of hydatt with one that relies on hydrologic model output (state/storm-event modeling) as mentioned in documentation since there will be better information to parameterize a hydatt function using predicted with and without project conditions for flood width divided by top width. (These type of projects will all require hydrologic modeling.).
- Author Response: Reject. The authors agree with that an assessment of top width may be preferrable in many circumstances. However, these analyses would have required both hydrologic models for rainfall-runoff processes (e.g., HEC-HMS) and hydraulic models to integrate streamflow with bathymetry (e.g., HEC-RAS). These tools are rarely available in early phases of project planning, and it was deemed infeasible to construct SMURF around these metrics. Similarly, SMURF is generally designed as a rapid assessment framework for restoration practitioners from multiple disciplines, so discipline-specific tools were not included. Future versions of SMURF may differentiate between rapid, coarse tools for relative comparison (like the present model) and fine-grained tools for detailed assessment (which could incorporate these types of analyses).

Comment 2.3: With respect to buffer width, there is insufficient documentation regarding how this function should be consistently scored by users who are not part of the model development team (once generally certified).

- Basis: Consistency in scoring across multiple users on a single team is important to the reliability of the model output.
- Significance: Medium. Consistency in model application is key to reliable output.
- Resolution: Provide a more robust description of the details considered when scoring this metric. Provide justification for 1 to 20 scoring system. Describe best practices for the scorers to use when potentially averaging flow path conditions across distinct sub-reach areas.
- Author Response: Concur. A data sheet and associated protocols were added for all geospatial inputs.

Comment 2.4: Buffer strip effectiveness is influenced by the slope of the buffer in addition to factors considered in the existing Buffer Width sub-factor. Slope may not be an important factor for Beargrass but if model is generally certified slope should be added to model parameters.

- Basis: Slope is a factor in the effectiveness of buffers in removing pollutants from overland flow.
- Significance: Medium.
- Resolution: Consider adding a slope factor to the buffer width sub-metric calculation to adjust effectiveness for steep slopes. If not added, then provide justification in the model documentation and/or discussion of limits of the buffer width calculation in terms of suitability for steep sloped terrain.
- Author Response: Concur. Slope is a crucial consideration. However, this factor was eliminated to minimize analytical burden. A discussion was added in section 4.1 (interflow) relative to the importance of slope in buffer performance and potential model limitations accompanying this omission.

Comment 2.5: In the temperature and light parameters, the documentation provides limited information on how this sub-matrix should be scored. This may lead to inconsistent scoring results when using multiple assessors.

- Basis: Uniform scoring assumptions are necessary for teams to consistently score model inputs.
- Significance: Low for one-time use. Medium for general certification use.
- Resolution: Provide additional discussion of scoring of the temperature and light regulation sub-indices.
- Author Response: Concur. Text in Section 4.1 was clarified to more adequately describe these metrics.

Comment 2.6: In the organic matter parameters, the scoring field sheet does not provide enough explanation of how these sub-indices should be rated. For instance, while a "diverse" assemblage of canopy species should be rated "high", no explanation of whether diversity in this case means, "more than one species", "50% of the number of species found at a reference site" or something else. Medium and low diversity scores are similarly not adequately described. The carbon retention scoring also could be better described using photo examples, for instance.

- Basis: Model should include sufficient documentation for use by users other than the developers.
- Significance: Low for one-time use. Medium for general certification of model.
- Resolution: Provide more information for scoring these sub indices.
- Author Response: Concur. Diversity is intended to be assessed based on regionally appropriate standards by the assessor. Additional language was added to clarify this reference based approach in Section 4.1, when the metric is first introduced. Carbon retention was clarified by adding figures to the field reference sheets.

Comment 2.7: With respect to overall system scoring, it appears that the model is designed to help estimate the habitat index score for individual reaches within a project study area. Several of the sub-indices, in particular "Ecological Corridor" appear to measure the connectivity between one reach and another. There does not seem to be any measurement of the continuity of the inter-connections between reaches within the study area. Presumably, the model allows users to estimate project related lift for each reach independently instead of interdependent units with scoring that reflects the habitat conditions of adjacent, and other upstream/downstream reaches. For example, one project alternative could provide great lift in the farthest upstream and downstream reaches but no lift in the middle reaches. A second alternative could provide similar overall average lift but geographically consistent lift across the entire stream corridor within the study areas. The model might predict equal lift, but ecologically it may actually be more preferable to select the more-uniform restoration alternative.

- Basis: It is unclear that in its current setup the model can provide a result that reflects upstream/downstream connectivity.
- Significance: Medium. The degree to which this issue is important may be stream and habitat/fauna specific.
- Resolution: Consider if it is important to provide a mechanism to address the interdependence of reaches with regards to acting independently/interdependently for ecological corridor function. Modify model if appropriate. Add section to model documentation to discuss interdependence/independence between reaches.

- Author Response: Reject. The authors agree that the importance of a riparian zone as a corridor is best measured through an approach addressing network dependencies. We have included proxy metrics for broader network connectivity, but a more comprehsnive approach (e.g., using network modeling) was considered beyond the scope of the present tool. This deficiency will be noted for future model improvements.

Comment 2.8: Methods to secure index curve inputs used to define ecorest function curves are not apparent since R package models don't have locked data inputs. For instance, accurate use of SMURF index functions require inputting the proper curve breakpoints into ecorest to define the curves. An incorrect dataset for these breakpoints may be used inadvertently or intentionally when a certified model is applied to a project application. This would be hard to detect unless reviewers use a prescribed process to test certified input files for curve breakpoints and compare that output to the output provided with the model application under review.

- Basis: Certified models should be either protected against incorrect input datasets or a verification system should be specified for reviewers to use certify that the model was properly used.
- Significance: High.
- Resolution: The Ecosystem Restoration Planning Center of Expertise and the developers of SMURF and ecorest should develop a "best practices" document for District Quality Control and Agency Technical Review reviewers that require them to check and test themselves whether the R package models they review are using the correct ecorest function curve datasets.
- Author Response: Concur. Incorrect user-specified suitability curves could impact the model significantly. To mitigate this issue, the suitability curves as explicitly displayed in the model document to avoid the issue and increase transparency.

Appendix D: Beargrass Creek Existing Condition Data

SMURF assessments were conducted for left and right bank areas at 52 sites in the Beargrass Creek watershed (24 South Fork, 22 Middle Fork, 6 Muddy Fork). Field data were collected through a coordinate campaign involving personnel from the USACE Louisville District and Louisville Metropolitan Sewer District from June-July 2020. Some sites were screened out and others grouped into logical sets for restoration planning. Desktop geospatial analyses were conducted for the remaining 21 sites in December 2020. Tables D1-D8 provide all data used in the SMURF analysis.

Table D1. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Rest_Name	Fork	Assessment_Points	Latitude	Longitude
X2	Confluence	South	SF.13 / SF.17	38.26153	-85.71690
X4	Shelby Campus	Middle	MF.29	38.25986	-85.58524
X5	Oxmoor Farm	Middle	MF.11	38.24065	-85.61851
X8	Houston Acre's Farm	South	SF.38 / SF.41	38.21009	-85.61202
X9	Clark Park	South	SF.20	38.21545	-85.72654
X10	Alpaca Farm / Zoo	South	SF.22	38.20838	-85.70068
X11	Collegiate	Muddy	MU.14	38.27748	-85.69217
X15	Buechel Park	South	SF.43	38.19595	-85.62192
X19	South Fork / New-burg Rd	South	SF.26 / SF.42	38.18709	-85.65851
X20	Brown Park	Middle	MF.08US / MF.08DS	38.23940	-85.63495
X21	Arthur Draut Park	Middle	MF.09US / MF.09DS	38.24402	-85.62870
X22	Concrete Channel	South	SF.18 / SF.19A / SF.35	38.23444	-85.73027
X24	Oxmoor Country Club	Middle	MF.34	38.22907	-85.61478
X28	Hurstbourne Country Club	Middle	MF.12	38.24098	-85.58708
X29	Eastern / Creason Connector	South	SF.19B	38.21872	-85.72135
X30	Joe Creason Park	South	SF.21	38.21452	-85.71016
X31	Champions Trace	South	SF.24	38.20330	-85.67659
X33	MSD Basin	South	SF.39	38.21115	-85.62910
X34	Cherokee / Seneca Parks	Middle	MF.04US / MF.04DS / MF.05 / MF.06US / MF.06DS	38.24164	-85.69549
X35	Muddy Fork and Tribs	Muddy	MU.15	38.27966	-85.66859
X38	Cave Hill Corridor	Middle	MF.02 / MF.03	38.25018	-85.71695

Table D2. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Bankfull_Depth_ft	Bankfull_Width_ft	Bank_Height_Left_ft	Bank_Height_Right_ft
X2	4.7	60.0	3.5	2.5
X4	2.0	30.5	3.0	3.0
X5	1.8	34.0	2.2	2.2
X8	1.6	20.5	2.8	2.8
X9	3.5	13.0	6.0	6.0
X10	2.9	39.0	10.0	15.0
X11	2.2	22.0	5.5	5.5
X15	2.2	6.0	2.2	2.2
X19	1.8	23.0	9.0	6.0
X20	2.7	41.0	4.0	3.8
X21	2.7	32.2	3.1	3.1
X22	3.4	30.0	15.0	15.0
X24	2.0	34.0	6.0	5.0
X28	1.8	35.0	2.8	2.3
X29	3.2	20.0	4.0	4.0
X30	3.1	37.0	20.0	20.0
X31	2.6	55.0	10.0	10.0
X33	3.0	29.0	3.0	6.0
X34	3.3	34.6	4.4	4.6
X35	1.8	23.0	5.3	7.3
X38	3.4	39.9	6.6	12.8

Table D3. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Canopy Height w/in 25 ft Left_ft	Canopy Height w/in 25 ft Right_ft	Buffer Dev Left	Buffer Dev Right	Buffer Flowpaths Left	Buffer Flowpaths Right
X2	60	52	10	10	12	12
X4	50	50	12	12	14	14
X5	20	30	8	5	16	4
X8	75	72	16	13	16	16
X9	60	60	11	11	13	13
X10	100	100	11	15	5	11
X11	40	40	13	9	15	7
X15	60	60	6	6	11	11
X19	45	30	10	10	7	2
X20	40	45	10	11	11	11
X21	45	45	13	13	16	16
X22	47	52	3	3	3	3
X24	10	10	3	3	5	5
X28	0	0	4	4	4	3
X29	50	80	11	11	8	12
X30	80	80	13	8	3	11
X31	50	40	4	2	4	2
X33	35	45	12	12	8	8
X34	44	52	12	11	13	9
X35	40	40	11	13	12	14
X38	35	40	8	7	10	6

Table D4. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Overstory Left	Midstory Left	WoodyShrubs Left	Overstory Right	Midstory Right	WoodyShrubs Right
X2	1	1	1	1	1	1
X4	1	0	0	1	0	0
X5	1	0	0	0	0	0
X8	2	1	1	2	1	1
X9	2	1	1	2	1	1
X10	1	1	1	1	1	1
X11	1	0	0	1	1	1
X15	0	0	0	0	0	0
X19	1	0	0	1	0	0
X20	1	1	0	1	1	0
X21	1	0	0	1	0	0
X22	1	0	0	1	0	0
X24	0	0	0	0	0	0
X28	0	0	0	0	0	0
X29	2	1	0	2	1	0
X30	2	2	1	0	0	0
X31	0	0	0	0	0	0
X33	0	0	0	1	0	0
X34	1	1	1	1	1	1
X35	0	0	0	1	1	1
X38	1	1	0	1	0	0

Table D5. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Snags Left	Snags Right	Deadfall Left	Deadfall Right	Detritus Left	Detritus Right	Herb Left	Herb Right
X2	13	13	12	12	12	12	11	11
X4	12	12	8	9	11	10	11	9
X5	6	6	6	3	10	5	13	11
X8	16	14	14	12	12	12	10	10
X9	11	11	7	7	13	13	18	18
X10	18	18	13	13	10	10	10	10
X11	11	11	15	15	16	16	14	12
X15	6	6	0	0	3	3	13	13
X19	10	7	8	8	5	5	8	8
X20	8	13	2	4	5	6	11	12
X21	12	12	10	10	12	12	10	10
X22	8	9	4	4	2	2	4	5
X24	4	4	4	4	4	4	11	11
X28	6	3	0	0	3	3	11	11
X29	13	13	13	13	3	3	3	8
X30	12	15	6	3	13	3	13	3
X31	8	8	5	5	5	5	8	8
X33	13	8	8	8	11	11	8	8
X34	10	12	9	9	10	8	11	10
X35	11	13	8	8	5	11	8	13
X38	12	10	6	9	9	10	9	10

Table D6. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Invasive Dominance Left	Invasive Dominance Right	Stream Can-opy Cover	OM Re-tention	Embed-dedness	Overall Left	Overall Right
X2	10.0	10.0	7.5	7.5	4.0	10.0	10.0
X4	6.0	5.0	7.0	4.0	7.0	7.0	7.0
X5	8.0	6.0	16.0	4.0	16.0	10.0	10.0
X8	11.0	11.0	14.5	12.0	11.5	14.0	12.0
X9	15.0	15.0	18.0	13.0	5.0	13.0	13.0
X10	8.0	9.0	14.0	11.0	6.0	13.0	13.0
X11	13.0	13.0	10.0	13.0	1.0	10.0	9.0
X15	3.0	3.0	2.0	6.0	5.0	8.0	8.0
X19	7.0	7.0	5.0	8.0	6.5	8.5	8.0
X20	8.5	8.5	7.0	7.0	11.0	10.5	10.5
X21	12.0	12.0	10.5	6.5	7.5	9.5	10.0
X22	4.3	4.3	7.3	1.3	0.7	3.0	2.0
X24	7.0	7.0	4.0	5.0	6.0	5.0	5.0
X28	3.0	3.0	2.0	5.0	3.0	4.0	5.0
X29	8.0	8.0	14.0	13.0	10.0	11.0	14.0
X30	13.0	8.0	10.0	13.0	8.0	16.0	10.0
X31	8.0	8.0	11.0	8.0	2.0	3.0	3.0
X33	8.0	8.0	16.0	13.0	13.0	8.0	8.0
X34	10.0	9.8	11.4	8.2	7.2	11.2	9.4
X35	11.0	11.0	8.0	12.0	8.0	11.0	12.0
X38	6.5	6.5	6.0	9.0	7.0	8.5	7.5

Table D7. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Total Site Area_ft2	Riparian Area Left_ft2	Riparian Area Right_ft2	Riparian Perimeter Left_ft	Riparian Perimeter Right_ft
X2	7432938	578031	1384409	17726	23471
X4	3560369	826663	1429638	11963	16985
X5	9694538	1629401	913972	27403	28240
X8	5680621	1880479	2103996	32871	33815
X9	1598978	342979	100039	4349	2641
X10	3452381	176658	635077	7455	15395
X11	4295026	1307096	1242605	32503	32257
X15	1213163	106692	98428	4778	5719
X19	1936982	360573	157926	6144	6874
X20	1325175	173059	87629	5872	5752
X21	1741770	243083	457463	12028	11853
X22	2051402	354190	254979	23841	20629
X24	2658974	153803	911084	5761	7958
X28	637414	170930	38210	7821	2017
X29	4258276	1705439	1154652	22562	20829
X30	5285708	2554496	144338	11695	6292
X31	2102471	159317	92999	10774	10349
X33	514820	205213	54635	3981	3369
X34	11632832	2055032	2556929	58840	53987
X35	5571659	1581578	1682320	37162	25152
X38	2271040	148176	430825	5923	12388

Table D8. Existing condition data for Beargrass Creek restoration sites.

Rest_Num	Buffer Width Mean Left_ft	Buffer Width Mean Right_ft	Buffer Width Min Left_ft	Buffer Width Min Right_ft
X2	58	139	0	0
X4	125	217	20	20
X5	109	61	10	10
X8	126	141	20	20
X9	207	60	50	30
X10	33	119	15	15
X11	81	77	0	10
X15	34	31	0	0
X19	105	46	0	0
X20	59	30	10	10
X21	30	56	10	15
X22	25	18	5	5
X24	21	122	10	30
X28	27	6	0	0
X29	189	128	30	30
X30	543	31	25	25
X31	29	17	25	10
X33	114	30	15	20
X34	73	90	5	5
X35	95	101	10	10
X38	16	46	10	20

Ideally, a riparian assessment procedure would be rigorously validated against empirical data for multiple ecological processes. However, validation data were not available in the Beargrass Creek system. Alternatively, field assessors were asked to provide an overall judgment of each site relative to their impression of the general riparian condition. These data provide a crude means of pseudo-verification of the SMURF framework. The SMURF generally aligns with the overall professional judgment of field personnel. Interestingly, the fauna index and the overall habitat suitability index show the most agreement with the field teams, and the instream and corridor indices show the least (i.e., greater variability in assessments). Faunal habitat provision could be easier to observe at a field scale than more complex off-site effects on instream processes or corridor functions. These data indicate that SMURF indices generally agree with professional judgment associated with the 42 samples in Beargrass Creek (i.e., independent left and right bank assessments at 21 restoration sites).

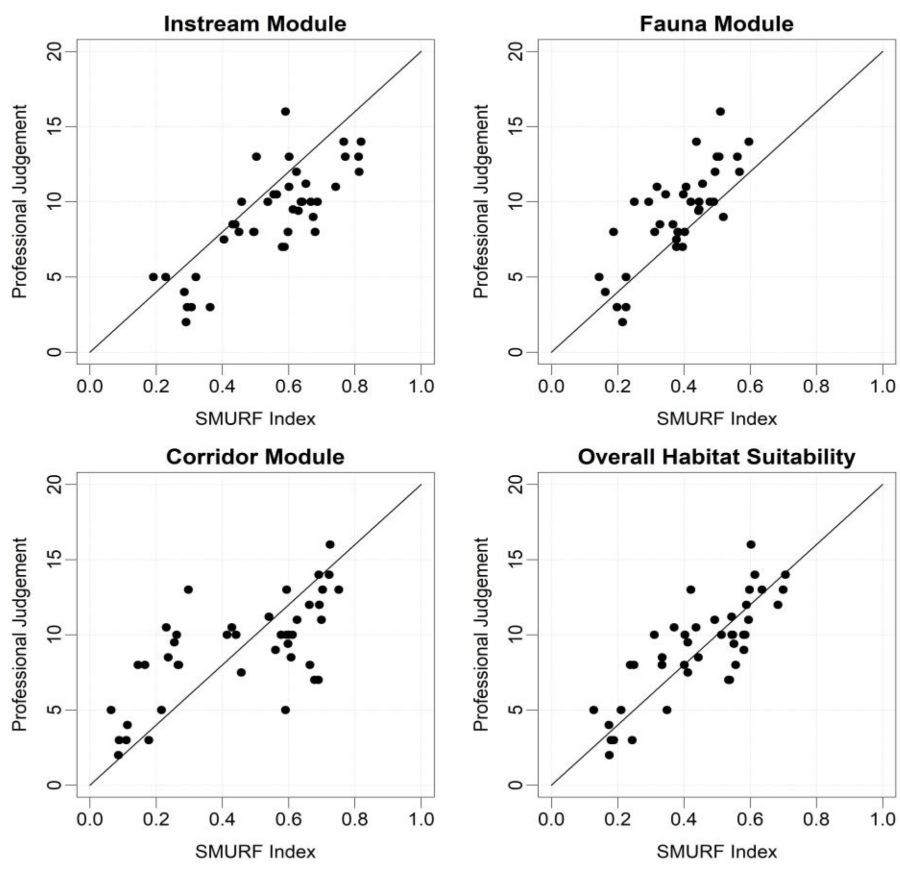


Figure D1. Pseudo-verification of SMURF relative to professional judgment of field assessors.