ERDC/TN EMRRP-ER-26
September 2023

Review of Riparian Models for Assessing Ecological Impacts and Benefits

by Samantha Wiest[1], Darixa Hernandez-Abrams[2], and S. Kyle McKay[3]

BACKGROUND: Riparian zones are key transitional ecosystems between upland and aquatic zones, and these systems are often degraded due to both land use change and stream processes (e.g., deforestation and water impoundments and/or diversions). These important ecosystems require restoration because of the many benefits they provide ranging from providing habitat for diverse species to promoting water quality. Restoration practitioners, regulators, and researchers require riparian assessment methods and models to efficiently guide mitigation and restoration planning. This technical note (TN) compiles a subset of existing riparian tools and evaluates them relative to model objectives, modeling approach, and input variables. Findings are synthesized into a gap analysis of these models to inform future riparian model development and improve riparian assessment.

INTRODUCTION: Riparian zones are the transitional areas between terrestrial and aquatic ecosystems located adjacent to freshwater systems (e.g., rivers, lakes, streams, reservoirs, wetlands; Fischer and Fischenich 2000; Lind et al. 2019). Riparian areas are important hotspots for biodiversity and ecological processes (Gene et al. 2019) as well as many other benefits such as filtering pollutants to prevent them from entering aquatic systems, attenuating floods, stabilizing streambanks to prevent erosion, and providing shade and temperature regulation for adjacent water bodies (National Research Council 2002). Land use conversion for agriculture, livestock, forestry, and (sub)urban development can have significant impact on riparian zones, negatively affecting ecological functions. Anthropogenic disturbances can trigger effects such as sediment accumulation, streambank erosion, altered water quality, changes to streamflow, and habitat degradation (National Research Council 2002). In some cases, riparian impacts can be minor enough for the area to recover naturally, while other times the degradation can be more severe and long lasting (NRCS 1996) requiring restoration.

A variety of tools and models have been developed to assist regulators, managers, and researchers with impact assessment, mitigation planning, restoration, and conservation. In general, ecological models seek to translate a complex system into a simplified representation, although the scope, assumptions, and other factors can limit the breadth of their utility. Identifying and understanding

---

[1] US Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, MS, Email: samantha.r.wiest@erdc.dren.mil
[2] ERDC-EL, Vicksburg, MS, Email: Darixa.D.HernandezAbrams@usace.army.mil
[3] ERDC-EL, New York, NY, Email: kyle.mckay@usace.army.mil

these gaps is helpful for improving the utility of models to inform environmental decision-making. The goals of this TN are to (1) review existing riparian models commonly applied within the US Army Corps of Engineers (USACE), (2) examine the use of these models in management and restoration contexts, and (3) identify gaps in existing models. Accomplishing these goals will highlight frequent trends and patterns among the tools and chart a path forward for future riparian model development.

METHODS AND RESULTS: A structured approach was applied to systematically review riparian models following methods in Gurevitch et al. (2018). Riparian assessment procedures, models, and tools were compiled through four primary techniques: (1) direct search of the USACE ecosystem restoration model library,[4] (2) informal requests for models through USACE District practitioners and the National Ecosystem Restoration Planning Center of Expertise (ECO-PCX), (3) exploration of tools developed by other government organizations (e.g., US Department of Agriculture and US Forest Service), and (4) search of peer-reviewed literature via Google Scholar.

Three criteria were used to screen riparian tools for this analysis. First, models had to be focused on assessment of riverine riparian zones. This excludes models with a primary purpose of performing stream or wetland assessment (e.g., the Qualitative Habitat Evaluation Index, Rankin 2006) and those focused on lentic systems (e.g., lakes, reservoirs). Second, all models had to highlight multiple hydrologic, ecological, and/or environmental components of riparian zones and their communities, which excludes models only including one variable such as buffer width or cover type. Third, models had to inform riparian conservation, rehabilitation, or other management applications. Fourteen models met the search criteria (Table 1). Notably, the terms model and tool are used interchangeably to refer to quantitative methods for ecological assessment.

Qualitative data were then collected on each riparian tool relative to the six topics listed below. Two topics focus on ecological processes (1–2) typically assessed in riparian tools, and the others (3-6) focus more generally on common scoping issues in ecological model development.

1. **Ecological Functions of Instream Processes:** The processes by which riparian zones influence streams, such as hydrologic attenuation, streambank erosion, thermal regulation, sediment trapping, nutrient uptake, and sequestration of contaminants (e.g., metals)
2. **Ecological Functions of Riparian Processes:** The processes that occur in the terrestrial zone, commonly characterized relative to vegetation communities (e.g., cover, patch size, species richness) and faunal habitat (e.g., bats, birds, herpetofauna, mammals)
3. **Model Type:** The framework and ideology the model is constructed around to obtain results. Common model types include habitat, statistical, and mechanistic models
4. **Geographic Scope:** The geography where the model is most suitable or has been studied previously. This area can range from a specific site to a general landscape or ecosystem
5. **Degree of model review:** The level to which the model has been reviewed. Applicable information includes publishing format, peer-review, and USACE model certification status (EC 1105-2-412, PB 2013-02)

---

[4] https://ecolibrary.planusace.us/#/home

6. **Numerical Structure:** The numerical environment or coding language in which the model is executed (e.g., spreadsheet vs. coding vs. executable software)

Table 1. Riparian modeling tools meeting the three criteria for riparian models.

Model	General Description
1. Resaca Reference Condition Model	This model uses a Habitat Suitability Index (HSI) framework[5] to assess restoration sites for resaca ecosystems (a dry channel or former marshy course of a stream) based on three vegetation communities: Texas Ebony Resaca Forest, Subtropical Texas Palmetto Woodland, and Texas Ebony/Snake-eyes Shrubland (USACE 2016).
2. Upper Mississippi River System	This HSI-based tool is designed to capture habitat changes from common management actions in floodplain forests (also known as "bottomland forests and "wooded swamps and floodplains"). The model assesses "silvicultural prescriptions" at a scale of "management areas," which are typically 5-100 acres (USACE 2021).
3. Modified Riverine HSI Model for Mink	This HSI model evaluates riverine cover types and their potential for providing year-round habitat for the mink species. A modification now includes an additional variable to compare natural versus channelized streams (Devendorf and Yager 2013).
4. Simple Model for Urban Riparian Function	This HSI-style model assesses multiple aspects of stream processes for constrained urban riparian zones in the Midwest (specifically Louisville, McKay et al. In Press).
5. Community-Based Model for Cottonwood Riparian Forests of Missouri River	The Missouri River model's purpose is to assess ecosystem benefits, specifically for Cottonwood riparian forests, through a community-based ecosystem response model. The model utilizes community- or ecosystem-scale indices (as opposed to taxa-specific models) to assess ecosystem functions on a broader and more complex, landscape scale (Burkes-Copes 2016).
6. Middle Rio Grande Bosque Riparian Community Index Model	The Middle Rio Grande model quantifies the effects of changes in 'bosque' (riparian) ecosystems of central New Mexico. The HSI-style model focuses the unique and culturally significant 'bosque' communities in New Mexico due to its diminishing habitat and ecosystem functions (Burkes-Copes and Webb 2012).
7. Ecological Functions Approach at Chatfield Reservoir	This model utilizes the application of the Colorado-specific model for wetland habitats, FACwet, to account for terrestrial habitats at Chatfield Reservoir. The model quantifies species/habitat and habitat/function relationships to aid in decision-making and mitigation planning within Chatfield (ERO Resources Corporation 2009).
8. Lower Willamette River Ecosystem Restoration Project	This model assesses riverine, riparian, and floodplain habitats and their connections to fish and wildlife species. The model adapts existing HSI models for a selection of individual species and addresses the concept of how habitat restoration benefits multiple key fish and wildlife species (Tetra Tech, Inc. 2014).
9. Skokomish River Environmental Benefits Analysis	This model was developed for restoration planning and aims to incorporate positive aspects of multiple existing frameworks, including Habitat Evaluation Procedures (HEP), HSI, and the Biodiversity Security Index (Cole 2010). The approach also compares sets of alternatives to identify key spatial gaps in restoration planning (Klimas and Yuill 2013).

---

[5] Habitat suitability index models provide an assessment of ecosystem condition relative to the quantity and quality of a given patch of habitat (i.e., the area and a 0-1 index of "suitability", respectively). Habitat quality or suitability is typically assessed relative to multiple environment metrics, each of which has an independent "suitability curve". These models follow a general approach called the Habitat Evaluation Procedures (HEP).

10. The Riparian Ecosystem Management Model	This US Department of Agriculture (USDA) tool quantifies water quality benefits of riparian buffers and management zones. The model uses analytical methods to estimate nonpoint source pollution control in various site conditions. It simulates processes including (sub)surface hydrology; sediment transport and deposition; carbon, nitrogen, and phosphorus transport, removal, and cycling; and vegetation growth. It also can simulate management options such as vegetation type, buffer zone size, and biomass harvesting (Lowrence et al. 2000).
11. Riparian Aquatic Interaction Simulator	This model quantifies forest growth and connects it to large wood dynamics, riparian recruitment, and shade. The tool is directly applicable to Pacific Northwest forest types and allows managers to forecast functions over a range of critical variables for up to 300 years (Welty et al. 2001).
12. Wetland and Riparian Forests in Ouachita Mountains and Crowley's Ridge Regions of Arkansas	This model is a Regional Guidebook following a Hydrogeomorphic (HGM) approach to assesses wetland functions. This approach applies functional indices and their protocols in the assessment of various wetland subclasses. is guidebook is intended for the most common types of wetlands and riparian forests that occur in the Ouachita Mountains and Crowley's Ridge Regions of Arkansas (Klimas 2006)
13. Wetland Functions of Riverine Floodplains in the Northern Rocky Mountains	The development and application of This HGM Regional Guidebook is intended for the most common types of wetlands and riparian forests that occur in the floodplains in the Northern Rocky Mountains (Hauer 2002).
14. High-Gradient Headwater Streams and Low-Gradient Perennial Streams in Appalachia	This HGM Regional Guidebook is intended for the most common types of wetlands and riparian forests that occur in the headwater and perennial streams in the Appalachia region (Summers 2017).

The fourteen riparian models were evaluated independently, and data were compiled for each of the six criteria shown above. Input variables related to instream and riparian functions were compiled and categorized, which ultimately provide the primary mechanism for the modeling gap analysis. These processes were sub-divided into groups of variables to identify trends across models. Notably, some variables overlap into both instream and riparian processes. Specifically, variables were grouped as follows:

- **Instream Processes**
    - **Physical Characteristics:** Geomorphological components of the stream and streambank (e.g., slope of bank, soil characteristics)
    - **Stream Condition:** Degree of disturbance within the stream (e.g., temperature, chemical concentrations)
    - **Hydrologic Processes:** Processes that occur in a stream in response to precipitation or flooding events (e.g., flood attenuation, interflow processes)
    - **Adjacent Land Use:** Land uses adjacent to the stream and riparian zone
    - **Climate and Weather:** Precipitation events and temperature patterns

- **Riparian Zone Processes**
    - **Bank Characteristics:** Physical components of the bank in relation to the riparian zone (e.g., depth to groundwater)
    - **Habitat Connectivity:** Organismal movement occurring within riparian habitats (e.g., migration/dispersal, neighboring habitat loss)
    - **Stream Habitat:** Vegetation and organism functions relative to the adjacent stream (e.g., aquatic vegetation)
    - **Canopy/Ground Cover:** Tree and ground vegetation within the riparian zone
    - **Native/Invasive Species:** Degree of invasive species dominance
    - **Vegetation Composition:** Diversity, size, and characteristics of vegetation.
    - **Species Richness:** The number of plant and animal species
    - **Riparian Functions:** Ecological processes occurring within the riparian zone that impact the riparian zone itself or the adjacent stream (e.g., large woody debris)
    - **Floodplain Functions:** Processes that occur within the floodplain in relation to the riparian zone (e.g., frequency of flooding, duration of flooding events)
    - **Landscape Connectivity:** Movements and processes occurring along the longitudinal dimension of the stream corridor (e.g., local confinement)
    - **Buffer Functionality:** Properties and functions of a buffer that impact adjacent streams and riparian areas (e.g., buffer capacity, buffer physical description)

Qualitative data were collected and summarized for each model. Table 2 presents input variables found in each model document summarized by the number of variables from each model relevant to each category. Notably, the Lower Willamette model data is the overall number of variables collected from three individual species habitat suitability models (beaver, wood duck, and yellow warbler), compared to the other models that do not have individual species indices. Additional data on model scope and structure are presented in Table 3.

Table 2. Summary of the number of input variables associated with a particular ecological process in each riparian model.

	Instream Processes					Riparian Zones Processes											
Existing Riparian Modeling Tools	Physical Characteristics	Stream Condition	Stream Hydrologic Processes	Adjacent Land Use	Climate and Weather	Bank Characteristics	Habitat Connectivity	Stream Habitat	Canopy/Groud Cover	Native/Invasive species	Vegetation Composition	Species Richness	Riparian Functions	Floodplain Functions	Landscape Connectivity	Buffer Functionality	Region of Application
1. Resaca Reference Condition Model	1	1				1		1	2	1	1	1					Southwest
2. Upper Mississippi River System									1	1	3						Southeast
3. Modified Riverine HSI Model for Mink		1						1	3		1						Varying
4. Simple Model for Urban Riparian Function	1	1	2				3								2	1	Northeast
5. Community-Based Ecosystem Response Model for the Cottonwood Riparian Forests of Missouri River	2			1					2	1	2	1		1	3		West/Midwest/ Southeast
6. Middle Rio Grande Bosque Riparian Community Index Model	1			1	3	1			5	1				3	3		Southwest
7. Ecological Functions Approach at Chatfield Reservoir	2	1	4				2				1					1	Varying
8. Lower Willamette River Ecosystem Restoration Project Model									8		3						Northwest
9. Skokomish River Ecosystem Restoration Project Environmental Benefits Analysis			1					2	1				1	1			Northwest
10. The Riparian Ecosystem Management Model		2		2	1						1					1	Varying
11. Riparian Aquatic Interaction Simulator											1		1				Northwest
12. Wetland and Riparian Forests in Ouachita Mountains and Crowley's Ridge Regions of Arkansas	3		2				1	1	3		6		2	1		2	South Central
13. Wetland Functions of Riverine Floodplains in the Northern Rocky Mountains	1			1			1		4	1	1		1	2	1		Southwest
14. High-Gradient Headwater Streams and Low-Gradient Perennial Streams in Appalachia	2			1		3			3	1	1	4	1				Southeast/Mid-Atlantic

Table 3. Gap analysis of riparian modeling tools.

Model	Model Type	Geographic Scope	Degree of model review	Numerical Structure
1. Resaca Reference Condition Model	Conceptual Index	Cameron County, TX. Resacas with three vegetation types (Table 1).	USACE certification	Spreadsheet calculator
2. Upper Mississippi River System	Conceptual Index	Wetland forest system dominated by hardwoods in eastern US. Upland forest systems.	Informal review via model development workshop	Spreadsheet calculator
3. Riverine HSI Model for Mink	Index	Inland wetland habitats of North America. Stream/riverine corridors (modified model).	USACE certification	Spreadsheet calculator
4. Simple Model for Urban Riparian Function	Conceptual Index	Urban areas with emphasis on Midwestern streams. Riparian zones to maximum width of 100m.	USACE certification (regional)	Function in the R statistical language
5. Community Model for Cottonwood Riparian Forests of Missouri River	Conceptual Index Analytical Spatial	Cottonwood-forested communities along the Missouri River.	Informal review via development; panel review; USACE certification	Access database format and spreadsheet file
6. Middle Rio Grande Bosque Riparian Community Index	Conceptual Index Analytical Spatial	Riparian habitat between levees along Middle Rio Grande, NM. Arid riparian forests, wetlands, or bosques.	USACE certification (one-time use)	Access database format and spreadsheet file
7. Chatfield Ecological Functions Approach	Conceptual Index Spatial	Great plains riparian vegetation with adjacent undisturbed grassland communities. Ephemeral streams, in-stream ponds, and canals / ditches.	Adapted from prior models	Spreadsheet calculator
8. Lower Willamette River Ecosystem Restoration Project	Index	Aquatic, riparian, & floodplain habitats in the Lower Willamette River between Columbia River and Willamette Falls and Columbia Slough and Tyron Creek.	USACE certification (one-time use)	Spreadsheet calculator
9. Skokomish River Environmental Benefits Analysis	Conceptual Index Spatial	Skokomish river basin. Pacific Northwest native river valley communities.	Adapted from prior models; USACE certification (one-time use)	Spreadsheet calculator
10. The Riparian Ecosystem Management Model	Conceptual Analytical	Built with data from mature riparian forest in south GA but applicable to various sites. Tested on buffer zones averaging 65m width.	Developed cooperatively by multiple agencies	C++ language
11. Riparian Aquatic Interaction Simulator	Conceptual Analytical	Pacific Northwest streams. Riparian stands of Douglas-fir, hemlock, alder, & big leaf maple. Bank full widths from 5 to 25m and gradients less than 6%.	Formally reviewed by universities, government, and industry	Metamodel that uses ORGANON forest simulator
12. HGM for Central Arkansas	Conceptual Spatial	Ouachita Mountains and Crowley's Ridge Regions of Arkansas. Common types of wetlands and riparian forests.	USACE certification (regional)	Spreadsheet calculator
13. HGM for the Northern Rocky Mountains	Conceptual Spatial	Northern Rocky Mountains throughout MT, WY, ID, and northeastern WA. Riverine floodplains on alluvial gravel-bed rivers and low riparian terraces.	USACE certification (regional)	Spreadsheet calculator
14. HGM for Streams in Appalachia	Conceptual Spatial	Appalachia Plateau in KY, VA, TN, OH, and PA. High-gradient headwater and low-gradient perennial streams.	USACE certification (regional)	Spreadsheet calculator

RIPARIAN MODELING GAP ANALYSIS: This analysis evaluated riparian models to highlight frequent trends and patterns among the tools. The gap analysis summarized these trends to understand the state-of-practice in riparian modeling and identify key opportunities to improve future riparian tools. The following major themes emerge from this analysis.

Heavy emphasis on habitat suitability-style approaches. Most of the reviewed tools have adopted an index-based approach, specifically quantifying numerical data with HSI variables. HSI models are a simple, yet efficient way to assess ecosystems with varying conditions, particularly when models have been locally validated against empirical outcomes. Index-based models allow users to connect ecological processes with changes in physical processes, evaluate changes in ecosystem quality and quantity, and communicate the model outcomes in a simple way. The HGM approach has also been used to assess ecosystem-scale outcomes for regulatory wetland decision making. While some wetlands are riparian, these models may not emphasize non-wetland functions of the riparian zone. Three HGM models were included in this analysis that emphasize riparian functions.

Division between ecological versus instream functions. In general, the models analyzed focus more directly on the habitat and corridor functions of a riparian zone itself rather than the riparian zone in relation to the processes that are occurring within the stream and habitat adjacent to it. Conversely, stream models tend to include few variables associated with riparian habitat, even though the two ecosystems are functionally connected. Because riparian zones have a significant impact on the instream processes as well as the ecological functions, it is beneficial to consider both systems as a connected ecosystem when completing assessment procedures.

Geographical influence on model prioritization. The gap analysis chart has been organized to display geographic trends among the regional areas where the tools are applicable. From this, it seems that, in general, model variables closer to Pacific Northwest regions of the US are species-oriented and reliant on the habitat aspects (aquatic and terrestrial) of the riparian zone for assessment. The Lower Willamette document, for example, incorporated HSI models where every variable was developed for individual species. This pattern could be a result of the other regions prioritizing the instream processes where pollution is of greater concern. Evidence of this includes both the Missouri River and Rio Grande models incorporating ‘adjacent land use’ as index variables. Assessing a larger number of riparian models would be beneficial to support this analysis.

Missing components of lateral/longitudinal connectivity. Lateral and longitudinal connectivity are important concepts to consider in riparian assessment. The idea of connectivity addresses the perception that an entire riparian ecosystem is interconnected through dimensional relationships rather than occurrences of separate individual processes. Some tools included in this review touched on the concept of lateral and longitudinal connectivity in their reports, but most failed to reflect the information in their model variables.

Few models include soil metrics. Soil is important because it is the source of many natural processes within an ecosystem. Riparian soil influences condition of vegetation, resiliency to droughts, floods, and fires, temperature regulation, carbon storage, and resistance to erosion. Very few models currently include metrics of soil condition, texture, or health. The lack of inclusion may stem from challenges of capabilities to assess soil condition in a rapid assessment process inherent in the index-based approach. While some tools include aspects of soil assessment (i.e. Cottonwood Riparian Forests of Missouri River, Middle Rio Grande Bosque Community, and most HGM models), determining an efficient method for assessing soil metrics within a riparian zone would be beneficial for understanding overall ecosystem condition.

Lack of urban representation as surrounding land use. The landscape surrounding a riparian zone can have a significant impact on the processes that occur within the ecosystem itself. Riparian buffer zones are frequently utilized as management practices in certain areas depending on the type (urban versus suburban versus rural) and the adjacent land use. The type of riparian model is going to be influenced by these factors and the purpose for which the tool will be developed. The gap analysis revealed that many of the tools were developed for rural and/or suburban settings. There is a different range of land-use activities that vary from rural to suburban to urban areas and their impact on riparian zones and streams. For example, runoff from agricultural areas could contain large amounts of sediment and chemicals from fertilizers (i.e., pesticides and herbicides), whereas runoff from a highly urbanized region with large areas of impervious surface may contain larger amounts of a different set of pollutants such as, hydrocarbons, PCBs, and heavy metals. Because of this, urban-oriented assessment tools are needed for larger densely populated cities and areas.

Minimal forecasting capability. The models reviewed here largely focus on static assessment of ecological condition with notable exceptions (Welty et al. 2001). However, many riparian management applications require the ability to predict condition through time in response to changing climate, forest succession, environmental variability, and other changes. Future models should seek to more explicitly and mechanistically incorporate dynamic change through time.

SUMMARY: The purpose of this review was to identify gaps in model components and model types critical to understanding riparian and instream processes. This systematic review has revealed existing limitations in current riparian models that would improve model performance if corrected in future development of riparian tools. Interpreting the gap analysis and understanding what trends have been observed from previously developed models will help guide the evolution of various prospective models. Concepts including riparian function, geographic scope, ecosystem connectivity, and land use will be important considerations for researchers, regulators, and managers when making management/planning decisions for riparian restoration and mitigation. This project aims to develop a riparian model that assesses the impacts and benefits of riparian management actions. Following a tiered approach, several steps will be implemented to reach the model objectives. This review will be utilized as a valuable tool when considering input variables and ecological factors for the future riparian model.

Beyond this analysis, there are broader gaps to acknowledge. Due to their complexity, riparian ecosystems are a regulatory gap. Identified as the transitional area between aquatic and terrestrial land, riparian zones are not considered to be regulatory streams nor wetlands. This gap has impacted the riparian model development process. Model frameworks tend to only focus on parts of riparian function (e.g., floodplain wetlands, wetlands in riparian zones, adjacent streams, buffer vegetation) instead of including processes in all necessary components of the ecosystem. As a result, many current riparian models lack important variables (e.g., soil, connectivity, land use) essential when assessing a riparian zone. There remains more to understand about riparian zones to effectively model and manage them, and this review has provided a brief state-of-the-practice of the current approaches to riparian assessment.

ADDITIONAL INFORMATION: The authors are grateful for thoughtful input from the ERDC integrated ecological modeling and wildlife ecology teams. Specifically, reviews by Drs. Jacob

Jung and Michael Guilfoyle significantly improved this TN. The use of products does not represent an endorsement of these products by either the author or the Department of the Army. The study was conducted with support from the Ecosystem Management and Restoration Research Program (EMRRP). For information on EMRRP, please contact the program manager, Dr. Brook Herman (Brook.D.Herman@erdc.usace.army.mil), or consult https://emrrp.el.erdc.dren.mil/. This TN should be cited as follows:

> Wiest, S., D. Hernandez-Abrams, and S. K. McKay. 2023. *Review of Riparian Models for Assessing Ecological Impacts and Benefits*. ERDC/TN EMRRP-ER-26. Vicksburg, MS: US Army Engineer Research and Development Center. http://el.erdc.usace.army.mil/emrrp/emrrp.html

REFERENCES

Burkes-Copes, K. A. 2016. *A Community-based Ecosystem Response Model for the Cottonwood Riparian Forests of the Missouri River*. ERDC-EL-TR-12-31. Vicksburg, MS: US Army Engineer Research and Development Center. ERDC Knowledge Core: A community-based ecosystem response model for the resacas (oxbow lakes) of the lower Rio Grande (dren.mil)

Burkes-Copes, K. A., and A. C. Webb. 2012. *A Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico*. ERDC/EL TR-12-26. Vicksburg, MS: US Army Engineer Research and Development Center. ERDC Knowledge Core: A bosque riparian community index model for the Middle Rio Grande, Albuquerque, New Mexico (dren.mil)

Cole, R. A. 2010. *A New Nonmonetary Metric for Indicating Environmental Benefits from Ecosystem Restoration Projects Of The U.S. Army Corps Of Engineers*. ERDC/EL TR-10-12. Vicksburg, MS: US Army Engineer Research and Development Center. A new nonmonetary metric for indicating environmental benefits from ecosystem restoration projects of the U.S. Army Corps of Engineers (dren.mil)

Devendorf, R., and T. Yager. 2013. *Modification of the Riverine Cover Type Component of the Habitat Suitability Index Model for Mink*. US Army Corps of Engineers St. Paul District.

ERO Resources Corporation. 2009. Ecological functions approach for terrestrial habitats at Chatfield Reservoir. ERO Project #4048. Denver, CO: ERO Resources Corporation.

Fischer, R. A., and J. C. Fischenich. 2000. Design recommendations for riparian corridors and vegetated buffer strips. ERDC TN-EMRRP-SR-24. Army engineer waterways experiment station Vicksburg MS: US Army Engineer Research and Development Center. Design recommendations for riparian corridors and vegetated buffer strips (dren.mil)

Gene, S. M., P. F. Hoekstra, C. Hannam, M. White, C. Truman, M. L. Hanson, and R. S. Prosser. 2019. "The Role of Vegetated Buffers in Agriculture and Their Regulation across Canada and the United States." *Journal of Environmental Management* 243: 12–21. https://doi.org/10.1016/j.jenvman.2019.05.003.

Gurevitch, Jessica, Julia Koricheva, Shinichi Nakagawa, and Gavin Stewart. 2018. "Meta-Analysis and the Science of Research Synthesis." *Nature* 555(7695): 175–82. https://doi.org/10.1038/nature25753.

Hauer, F. R., B. J. Cook, M. C. Gilbert, E. J. Clairain, and R. D. Smith. 2002. *A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Riverine Floodplains in the Northern Rocky Mountains*. ERDC/EL TR-02-21. Vicksburg, MS: US Army Engineer Research and Development Center.

Johnson, R. R., S. W. Carothers, D. M. Finch, K. J. Kingsley, and J. T. Stanley. 2018. "Riparian research and management: Past, present, future: Volume 1." Gen. Tech. Rep. RMRS-GTR-377. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Klimas, C. V., E. O. Murray, H. Langston, T. Witsell, T. Foti, and R. Holbrook. 2006. *A Regional Guidebook for Conducting Functional Assessments of Wetland and Riparian Forests in the Ouachita Mountains and Crowley's Ridge Regions of Arkansas*. ERDC/EL TR-06-14. Vicksburg, MS: US Army Engineer Research and Development Center.

Klimas, C. V., and B. Yuill. 2013. *Skokomish river ecosystem restoration project environmental benefits analysis*. Vicksburg, MS: US Army Engineer Research and Development Center. ERDC Knowledge Core: Skokomish river ecosystem restoration project environmental benefits analysis (dren.mil)

Lind, Lovisa, Eliza Maher Hasselquist, and Hjalmar Laudon. 2019. "Towards Ecologically Functional Riparian Zones: A Meta-Analysis to Develop Guidelines for Protecting Ecosystem Functions and Biodiversity in Agricultural Landscapes." *Journal of Environmental Management* 249(109391): 109391. https://doi.org/10.1016/j.jenvman.2019.109391.

Lowrance, R., L. S. Altier, R. G. Williams, S. P. Inamdar, J. M. Sheridan, D. D. Bosch, R. K. Hubbard, and D. L. Thomas. 2000. "REMM: The Riparian Ecosystem Management Model." *Journal of Soil and Water Conservation* 55(1): 27–34.

McKay, S. K., M. Goss, F. Veraldi, and L. Mattingly. In press. *Simple Model for Urban Riparian Function (SMURF), Version 1.0*. ERDC TR-EMRRP. Vicksburg, MS: US Army Engineer Research and Development Center.

National Research Council. 2002. Riparian Areas: Functions and Strategies for Management. Washington, DC: The National Academies Press. https://doi.org/10.17226/10327.

NRCS (Natural Resources Conservation Service). 1996. Riparian areas environmental uniqueness, functions, and values. United State Department of Agriculture (USDA). https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/?cid=nrcs143_014199

Rankin, E. T. 2006. "Methods for Assessing Habitat in Flow Waters: Using the Qualitative Habitat Evaluation Index (QHEI)." *Technical Bulletin EAS/2006-06-1*.

Summers, E. A., C. V. Noble, J. F. Berkowitz, and F. J. Spiker. 2017. *Operational Draft Regional Guidebook for the Functional Assessment of High-Gradient Headwater Streams and Low-Gradient Perennial Streams in Appalachia*. ERDC/EL TR-17-1. Vicksburg, MS: US Army Engineer Research and Development Center.

Swannack, T. M., J. C. Fischenich, and D. J. Tazik. 2012. *Ecological Modeling Guide for Ecosystem Restoration and Management*. ERDC/EL TR-12-18. Vicksburg, MS: US Army Engineer Research and Development Center.

Tetra Tech, Inc. 2014. "Lower Willamette River ecosystem restoration project." *Appendix F: habitat evaluation model planning models documentation*. Portland, OR.

USACE (US Army Corps of Engineers). 2021. *Upper Mississippi River System Floodplain Forest Habitat Model*. Vicksburg, MS: US Army Engineer Research and Development Center.

USACE (US Army Corps of Engineers) Galveston District. 2016. *Model approval plan resaca reference condition for Brownsville Resaca Ecosystem Restoration Study*. ERDC Knowledge Core: Model approval plan resaca reference condition for Brownsville Resaca Ecosystem Restoration Study (dren.mil)

Welty, Jeffrey J., Timothy Beechie, Kathleen Sullivan, David M. Hyink, Robert E. Bilby, Chip Andrus, and George Pess. 2002 "Riparian Aquatic Interaction Simulator (RAIS): A Model of Riparian Forest Dynamics for the Generation of Large Woody Debris and Shade." *Forest Ecology and Management* 162(2–3): 299–318. https://doi.org/10.1016/s0378-1127(01)00524-2.