

Incentive-Based Riparian Restoration as A Scalable Model for Agricultural Watershed Compliance

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Abstract

Riparian buffers, vegetated waterways, streambank stabilization practices, and floodplain reconnection projects collectively constitute the riparian restoration toolkit through which agricultural watershed compliance programs address nonpoint source nitrogen, phosphorus, sediment, and pathogen loadings from cropland and pasture. Despite decades of federal investment through the Conservation Reserve Program, Environmental Quality Incentives Program, and state-funded buffer initiatives, riparian practice installation remains substantially below levels required to achieve watershed-scale water quality compliance in most priority agricultural watersheds under Clean Water Act total maximum daily loads and state nutrient reduction strategies. This paper develops a scalable incentive design framework for riparian restoration in agricultural watersheds, synthesizing the behavioral economics of landowner conservation decisions, the hydrology and ecology of riparian system function, and the institutional design of multi-level agricultural watershed governance. The framework identifies payment structure, technical assistance quality, social norm alignment, institutional environment, and landscape targeting as the five primary levers through which incentive programs can accelerate riparian restoration at watershed scales sufficient to achieve regulatory compliance. Analysis of program design innovations from the Chesapeake Bay watershed, the Gulf Hypoxia reduction initiative, Great Lakes basin nutrient programs, and Pacific Northwest salmon habitat restoration illustrates the scalability conditions under which incentive-based riparian restoration achieves watershed-scale water quality outcomes. The framework builds on companion analyses of BMP adoption determinants, federal-tribal co-management architecture, and multi-level watershed governance to integrate behavioral, ecological, and institutional perspectives into a unified design approach. Implications for federal conservation program design, state nonpoint source programs, and watershed-scale compliance planning are developed.

Keywords: *riparian restoration; incentive design; agricultural watershed compliance; Conservation Reserve Program; EQIP; nonpoint source pollution; nutrient reduction; buffer strips; streambank stabilization; watershed governance*

1. Introduction

Riparian zones, the transitional ecosystems between terrestrial and aquatic environments, provide irreplaceable water quality functions through sediment trapping, nutrient uptake and denitrification, streambank stabilization, and flood attenuation that collectively reduce pollutant loading to receiving waters from adjacent agricultural land (Lowrance et al., 1997; Daniels & Gilliam, 1996; Hefting et al., 2004). The restoration of degraded riparian systems through buffer

strip installation, streambank protection, and floodplain reconnection has been identified as among the most cost-effective practices for reducing agricultural nonpoint source pollution across the full spectrum of watershed types in the United States (Ribaudo et al., 2001; Rabotyagov et al., 2014; Claasen et al., 2018).

Federal investment in riparian restoration has been substantial over the past four decades. The Conservation Reserve Program has enrolled approximately 3.4 million acres in continuous signup practices including riparian buffers, filter strips, and grass waterways since the program's inception, with streamside buffers representing the largest single practice category (USDA-FSA, 2023; Sullivan et al., 2004). The Environmental Quality Incentives Program has funded streambank protection, grade stabilization, and water control structure installation across millions of additional acres. State buffer programs in Chesapeake Bay states, Great Lakes basin states, and Gulf of Mexico priority states have provided complementary funding for riparian practice installation on lands not eligible for federal programs (Chesapeake Bay Program, 2023; Rabotyagov et al., 2014).

Despite this investment, riparian practice installation in priority agricultural watersheds remains far below the levels required to achieve water quality compliance under Clean Water Act total maximum daily loads and state nutrient reduction strategies (EPA, 2017; Chesapeake Bay Program, 2023; USDA-NRCS, 2021). The 2010 Chesapeake Bay TMDL, which established waste load allocations requiring 25 percent nitrogen and 24 percent phosphorus reductions from agricultural sources, identified riparian buffer installation on approximately 70 percent of eligible stream miles as necessary for agricultural sector compliance, while current installation rates remain below 35 percent of eligible stream miles in most priority watershed subbasins (Chesapeake Bay Program, 2023; EPA, 2017). The Hypoxia Task Force's Mississippi/Atchafalaya River Basin nutrient reduction strategy similarly identifies riparian practice expansion as a priority action that current voluntary program investment is not delivering at the required scale (Hypoxia Task Force, 2020; Rabotyagov et al., 2014).

This paper develops a scalable incentive design framework for riparian restoration in agricultural watersheds that addresses the gap between current program investment and required restoration scale. The framework synthesizes behavioral economics of conservation decisions (Kahneman & Tversky, 1979; Weersink et al., 2018), riparian hydrology and ecology (Lowrance et al., 1997; Hefting et al., 2004), and institutional design of multi-level watershed governance to identify the five primary levers through which incentive programs can accelerate riparian restoration: payment structure, technical assistance quality, social norm alignment, institutional environment, and landscape targeting. Program design innovations from major watershed compliance programs are analyzed to identify scalability conditions and design principles applicable to the broader challenge of achieving riparian restoration at watershed compliance scales.

2. Riparian System Function and Restoration Ecology

Riparian systems perform water quality functions through multiple interacting mechanisms that vary in effectiveness across landscape positions, hydrological conditions, and vegetation composition (Lowrance et al., 1997; Daniels & Gilliam, 1996; Hefting et al., 2004). Sediment trapping efficiency in buffer strips is primarily a function of buffer width, surface roughness, slope gradient, and incoming sediment particle size distribution, with narrow grass buffers providing

high trapping efficiency for coarse sediments and wider, multi-species buffers required for fine sediment capture (Daniels & Gilliam, 1996; Gilley et al., 2000; Dosskey et al., 2010). Nitrogen removal through denitrification in riparian soils and sediments is strongly controlled by soil moisture, organic matter availability, nitrate input concentrations, and hydraulic residence time, with consistently saturated soils achieving denitrification rates an order of magnitude higher than periodically dry riparian soils (Hefting et al., 2004; Hill, 1996; Groffman et al., 1996).

Phosphorus retention in riparian buffers is more complex and less reliable than nitrogen removal because surface runoff phosphorus transport, which bypasses the riparian zone through concentrated flow paths, dominates phosphorus delivery in many agricultural watersheds and is not amenable to diffuse-flow buffer strip treatment (Sharpley et al., 2013; Kleinman et al., 2011; Dosskey et al., 2010). Concentrated flow path interception through grade stabilization structures, grass waterways, and constructed wetlands that capture and treat concentrated flow provides complementary riparian system functions to diffuse-flow buffer strips, and effective watershed-scale riparian restoration programs must address both diffuse and concentrated flow pathways (Gitau et al., 2005; Rabotyagov et al., 2014).

Riparian restoration ecology research demonstrates that restoration outcomes are strongly dependent on the selection of plant species adapted to local hydrological and soil conditions, the establishment management practices applied during vegetation establishment, and the maintenance regime sustained after initial establishment (Noe & Hupp, 2009; Mayer et al., 2007). Native grass and forb species selected for local adaptation and perennial root systems provide more durable water quality functions than introduced cool-season grasses that may experience periodic die-back under summer drought or flooding stress (Dosskey et al., 2010; Mayer et al., 2007). Multi-species riparian plantings that include trees, shrubs, and grasses across a buffer width gradient provide broader hydraulic and ecological functions than single-species buffers, including bank stabilization through deep root anchoring, shading for cold-water fisheries thermal protection, and wildlife habitat connectivity (Lee et al., 2000, 2003; Daniels & Gilliam, 1996).

Floodplain reconnection through levee removal, grade control modification, and floodplain restoration represents a more intensive but potentially higher-impact riparian restoration approach than buffer strip installation alone, restoring wetland water quality functions, flood attenuation capacity, and aquatic-terrestrial connectivity across broader riparian corridor widths (Noe & Hupp, 2009; Opperman et al., 2010; Rabotyagov et al., 2014). The water quality benefits of floodplain reconnection are proportional to the frequency and duration of floodplain inundation, making projects in frequently flooded geomorphic contexts substantially more cost-effective than projects in incised channels with limited bankfull connection to adjacent floodplains (Opperman et al., 2010; Dosskey et al., 2010).

3. Behavioral Economics of Riparian Practice Adoption

Riparian buffer installation decisions by private agricultural landowners exhibit behavioral patterns consistent with behavioral economic frameworks that depart substantially from standard rational actor adoption models (Kahneman & Tversky, 1979; Prokopy et al., 2008; Weersink et al., 2018). Loss aversion, whereby potential losses from agricultural land removal for buffer installation are weighted more heavily than equivalent gains from program payment, creates systematic undervaluation of buffer program payments relative to their objective economic value

(Kahneman & Tversky, 1979; Weersink et al., 2018). Present-biased preferences that discount future water quality benefits heavily relative to immediate opportunity costs of land removal further reduce the attractiveness of riparian buffer enrollment for landowners operating under short-term financial pressure (Prokopy et al., 2008; Feather & Cooper, 1995).

Social norms and neighbor influence operate as particularly powerful adoption drivers for riparian practices, which are highly visible landscape features that signal both conservation commitment and productive land management attitudes within agricultural communities (Prokopy et al., 2008; Reimer et al., 2012; Burton, 2004). Watersheds where early adopters of riparian buffers are respected community members with strong social networks show substantially higher subsequent adoption rates than watersheds where early adopters are socially peripheral, a finding consistent with Rogers's (2003) innovation diffusion theory of peer influence on adoption decisions. Targeted recruitment of socially central early adopters and the facilitation of peer learning through farmer field days, watershed tours, and conservation network meetings represent high-leverage strategies for accelerating riparian adoption beyond what payment levels alone can achieve (Rogers, 2003; Prokopy et al., 2008; Reimer et al., 2012).

Land tenure arrangements create systematic adoption barriers for riparian practices, which typically require multi-year or permanent land enrollment and involve productivity reductions on enrolled acreage that may not be compensated under standard cash-rent lease arrangements between non-resident landowners and tenant operators (Soule et al., 2000; Prokopy et al., 2008). Non-resident and absentee landowners, who own a substantial and growing share of agricultural land in priority watershed states, show lower riparian practice adoption rates than resident owner-operators in most survey studies, reflecting both information access barriers and the disconnect between landowner program eligibility and tenant operator implementation responsibility (Soule et al., 2000; Prokopy et al., 2008). Outreach and incentive program designs that specifically target non-resident landowners and provide bridge mechanisms connecting landowner enrollment with tenant operator implementation address this systematic adoption barrier (Prokopy et al., 2008).

4. Incentive Design Framework for Scalable Riparian Restoration

The scalable incentive design framework identifies five primary levers through which program designers can accelerate riparian restoration to watershed compliance scales: payment structure, technical assistance quality, social norm alignment, institutional environment, and landscape targeting. Each lever addresses a distinct adoption constraint identified in the behavioral, ecological, and institutional literatures, and the levers interact multiplicatively such that combined program designs that address multiple constraints simultaneously achieve disproportionately greater adoption than additive single-lever approaches (Prokopy et al., 2008; Weersink et al., 2018). Table 1 summarizes the five levers with their design options and performance indicators. Figure 1 illustrates the five-lever framework architecture.

Lever	Adoption Constraint Addressed	Key Design Options	Performance Indicators
Payment Structure	Economic opportunity cost; liquidity barriers; risk aversion	Performance-based payments; installation cost-share; bundled program packages; annual rental + stewardship	Enrollment rate; cost per acre enrolled; landowner retention rate
Technical Assistance Quality	Information deficits; practice design complexity; maintenance challenges	High-frequency agency contact; peer demonstration programs; digital TA platforms; remote sensing tools	TA contacts per enrollee; practice failure rate; landowner satisfaction scores
Social Norm Alignment	Peer norms; farmer identity; community adoption culture	Farmer-led conservation groups; stewardship recognition programs; watershed challenge identities	Peer adoption clustering; conservation ethic scores; network adoption diffusion rate
Institutional Environment	Weak governance infrastructure; regulatory uncertainty; adversarial relationships	Active watershed partnerships; TMDL regulatory backstop; multi-level coordination; technical delivery capacity	Partnership program investment; regulatory compliance rate; interagency coordination index
Landscape Targeting	Misallocated investment; low-connectivity practice placement	GIS priority zone maps; WQ benefit ranking algorithms; SWAT-based targeting; precision outreach	Cost per kg pollutant reduced; high-connectivity enrollment share; WQ response lag

Table 1. Five-Lever Incentive Design Framework for Scalable Riparian Restoration in Agricultural Watersheds



Figure 1. Five-Lever Incentive Design Framework for Scalable Riparian Restoration. Each lever (vertical bar) addresses a distinct adoption constraint and connects to the watershed-scale adoption outcome (horizontal base). Levers interact multiplicatively: combined program designs addressing multiple levers simultaneously achieve disproportionately greater adoption than single-lever approaches.

4.1 Payment Structure

Payment structure encompasses the level, timing, form, and conditionality of conservation program payments, all of which significantly affect adoption likelihood across different landowner segments (Ribaud et al., 2001; Feather & Cooper, 1995; Chabé-Ferret & Subervie, 2013). CRP continuous signup practice payments, which are delivered at 50 percent above the county average rental rate for eligible riparian practices, reflect the recognition that riparian practices deliver above-average environmental benefits and require above-average program payments to overcome the opportunity cost of productive land removal (USDA-FSA, 2023; Sullivan et al., 2004). EQIP cost-share payments covering 50 to 90 percent of practice installation costs for streambank stabilization, grade stabilization, and water control structures provide the capital cost coverage necessary for adoption of high-cost structural practices by liquidity-constrained operations (USDA-NRCS, 2021).

Performance-based payment designs that tie payment amounts or continuation to demonstrated water quality outcomes provide stronger incentives for effective practice maintenance and adaptive management than fixed-payment structures that guarantee payments regardless of effectiveness (Ferraro, 2011; Ferraro & Miranda, 2013; Claassen et al., 2008). Payments for Ecosystem Services frameworks that price riparian practices based on measured water quality performance, using in-stream monitoring or verified modeling to attribute water quality improvements to specific practice portfolios, create payment incentives more directly aligned with program water quality goals than input-based cost-share payments tied to practice installation without performance verification (Ferraro, 2011; Claassen et al., 2008; Rabotyagov et al., 2014).

Bundled payments that combine annual rental payments, installation cost-share, and stewardship payments into unified per-acre program packages reduce transaction costs for program participants

and program administrators alike, potentially increasing enrollment by simplifying the program landscape for prospective participants who face significant administrative barriers in navigating multiple program applications (USDA-NRCS, 2021; Prokopy et al., 2008). The Regional Conservation Partnership Program's project-based funding approach, which bundles EQIP, RCPP, and partner contributions into geographically targeted watershed projects, represents an emerging federal program architecture that approximates bundled payment design for watershed-scale riparian restoration (USDA-NRCS, 2021).

4.2 Technical Assistance Quality

Technical assistance quality, encompassing the frequency, expertise, and responsiveness of agency and partner staff interactions with prospective and enrolled program participants, is among the strongest predictors of riparian practice adoption and durability across multiple program evaluation studies (Reimer et al., 2012; Prokopy et al., 2008; Gould et al., 1989). High-quality technical assistance reduces information barriers to adoption, provides the site-specific expertise necessary for effective practice design in heterogeneous landscape conditions, and creates ongoing management support that reduces practice failure rates over time (Prokopy et al., 2008; Reimer et al., 2012).

Conservation district staff and NRCS field office engineers represent the primary technical assistance delivery infrastructure for riparian practice programs, but their capacity is often insufficient to provide the intensive one-on-one support that accelerates adoption among prospective participants with limited conservation program experience (USDA-NRCS, 2021; Prokopy et al., 2008). Partner-delivered technical assistance through watershed councils, conservation organizations, land trusts, and university extension services provides complementary capacity that extends the reach of government technical assistance, particularly in underserved rural areas where government office access is limited (Sabatier et al., 2005).

Digital technical assistance tools including online practice planning platforms, payment calculator applications, and remote site assessment technologies extend technical assistance reach by enabling prospective participants to conduct initial eligibility and payment assessments independently before engaging with agency staff (Weersink et al., 2018; Prokopy et al., 2008). Remote sensing-based riparian opportunity mapping that identifies high-priority buffer and stabilization practice locations based on landscape and hydrological criteria enables targeted outreach to landowners with the highest restoration potential, improving the efficiency of technical assistance delivery by concentrating engagement on the most promising adoption targets (Dosskey et al., 2010; Rabotyagov et al., 2014; Badmus, 2025; Azeez & Badmus, 2024). The governance of farmer data collected through digital technical assistance platforms, including data privacy protections, data ownership rights, and anti-discrimination safeguards in AI-assisted practice recommendation algorithms, represents an emerging program design requirement that federal conservation program rules have not yet systematically addressed (Annan, 2022; Annan, 2024; Annan, 2025a; Nduka, 2023).

4.3 Social Norm Alignment and Community Engagement

Social norm alignment strategies leverage the power of peer influence, community identity, and collective action framing to shift the social environment within which individual riparian adoption

decisions are made (Prokopy et al., 2008; Reimer et al., 2012; Rogers, 2003). Agricultural communities in which riparian buffer installation is understood as a marker of responsible land stewardship show substantially higher adoption rates than communities in which buffer installation is framed as regulatory compliance or as non-farming land use, a difference in social framing that program design can actively influence (Burton, 2004; Prokopy et al., 2008).

Watershed-scale conservation challenges, including Chesapeake Bay farmer stewardship programs, Great Lakes basin agricultural conservation initiatives, and Pacific Northwest salmon-friendly farming certifications, create community identity frameworks that associate individual riparian adoption with participation in a meaningful collective conservation achievement (Chesapeake Bay Program, 2023; Prokopy et al., 2008). These programs combine individual practice incentives with community recognition, peer farmer networks, and collective goal framing that shift the social meaning of riparian adoption from individual compliance burden to community stewardship contribution (Burton, 2004; Rogers, 2003; Prokopy et al., 2008).

Farmer-led conservation groups and watershed farmer networks that organize peer learning, collective goal-setting, and community accountability for riparian restoration progress provide governance infrastructure for social norm alignment that government programs alone cannot create (Sabatier et al., 2005). The Living Lakes project in the Great Lakes basin, farmer-led watershed groups in the Chesapeake Bay watershed, and RCPP-funded farmer conservation networks in Gulf priority watersheds illustrate the institutional design of farmer-led conservation governance that creates social norm alignment through peer accountability and community ownership of restoration goals (Chesapeake Bay Program, 2023; USDA-NRCS, 2021).

4.4 Institutional Environment and Watershed Governance

The institutional environment of watershed governance shapes the context within which individual riparian adoption decisions are made, determining the quality of interagency coordination, the availability of backstop regulatory requirements, the adequacy of monitoring and accountability systems, and the capacity of watershed partnerships to support and sustain restoration programs (Sabatier et al., 2005). High-capacity watershed governance institutions that maintain active partnerships, robust monitoring, clear accountability for restoration goals, and well-funded technical assistance delivery infrastructure provide adoption-supporting environments that substantially amplify the effectiveness of individual-level practice incentives (Sabatier et al., 2005).

Regulatory backstop provisions, including TMDL-derived agricultural source load allocations, state nutrient management plan requirements, and local ordinance-based buffer requirements, create accountability frameworks that shift individual riparian adoption decisions from purely voluntary choices to at-risk obligations with potential regulatory consequences (EPA, 2017; Chesapeake Bay Program, 2023). The Chesapeake Bay TMDL's watershed implementation plan framework, which requires states to develop agricultural sector compliance strategies with measurable interim milestones, provides regulatory context that has demonstrably accelerated conservation program enrollment in priority subwatersheds by changing the institutional framing from pure voluntarism to accountability-backed voluntary action (Chesapeake Bay Program, 2023; EPA, 2017).

Multi-level governance coordination among federal agencies, state agencies, watershed partnerships, and local conservation districts creates the institutional infrastructure for watershed-scale riparian restoration programs that exceed what any single institutional actor can achieve alone. The federal-state-local coordination architecture of the Chesapeake Bay Program, the multi-state coordination of the Hypoxia Task Force, and the federal-tribal-state co-management of Pacific Northwest salmon habitat restoration illustrate the institutional design requirements for multi-level riparian governance at scales sufficient to achieve watershed compliance (Chesapeake Bay Program, 2023).

4.5 Landscape Targeting

Landscape targeting of riparian restoration investments to the highest-priority locations within watersheds, based on pollutant delivery ratios, hydrological connectivity, ecological sensitivity, and practice feasibility criteria, provides the efficiency gains necessary to achieve disproportionate water quality benefits from available program investment (Rabotyagov et al., 2014; Claassen et al., 2008; Dosskey et al., 2010). Spatially explicit watershed modeling using SWAT, APEX, and similar watershed-scale hydrological models enables targeting of riparian practices to stream reaches and contributing areas where installation will achieve the greatest reduction in pollutant loads to water quality-impaired receiving waters (Gitau et al., 2005; Rabotyagov et al., 2014).

Priority targeting systems that identify riparian practice opportunity zones based on GIS analysis of stream network connectivity, land use, slope, soil erodibility, and proximity to water quality-sensitive resources enable outreach workers and conservation planners to focus program energy on the geographic areas where adoption will generate the greatest water quality return per program dollar (Dosskey et al., 2010; Rabotyagov et al., 2014). The USDA's Agricultural Conservation Planning Framework and state-level conservation practice optimization tools provide technical infrastructure for landscape targeting at watershed scales, though their integration with program outreach and enrollment systems remains limited in most federal conservation program contexts (USDA-NRCS, 2021).

5. Illustrative Applications: Priority Watershed Programs

The Chesapeake Bay watershed provides the most advanced case of incentive-based riparian restoration at watershed compliance scale in the United States, encompassing more than 64,000 square miles of drainage across six states and the District of Columbia under the 2010 TMDL framework (Chesapeake Bay Program, 2023; EPA, 2017). The Bay's watershed implementation plan framework requires state-level agricultural sector pollution reduction strategies with specific practice installation targets, creating the accountability infrastructure that has driven substantial acceleration of riparian buffer enrollment in Virginia, Maryland, and Pennsylvania through combined CRP, EQIP, and state program investment (Chesapeake Bay Program, 2023). Chesapeake Bay Program tracking data document approximately 165,000 acres of riparian buffers installed through 2022, representing significant progress toward the 300,000-acre goal required for agricultural sector compliance while illustrating the persistent gap between investment levels and compliance requirements (Chesapeake Bay Program, 2023).

The Gulf Hypoxia reduction framework, which aims to reduce the Mississippi River nitrogen load to the Gulf of Mexico sufficiently to reduce the hypoxic zone area below a 5,000 square kilometer

target, has identified riparian practice expansion as a cost-effective component of the multi-state nutrient reduction strategy (Hypoxia Task Force, 2020; Rabotyagov et al., 2014). Economic optimization analyses consistently show that targeting riparian practice installation to high-connectivity landscape positions in priority subwatersheds achieves substantially greater load reduction per program dollar than untargeted program investment, with optimal targeting scenarios achieving the hypoxia reduction target at approximately 40 percent of the cost of untargeted program design (Rabotyagov et al., 2014; Claassen et al., 2008).

Pacific Northwest salmon habitat restoration programs integrate riparian practice incentives with ESA obligations, tribal treaty rights protections, and state water quality standards in a multi-level governance framework that illustrates the institutional design requirements for watershed-scale riparian restoration under complex legal and governance conditions (Wilkinson, 1992; Anderson et al., 2019). Riparian restoration on private agricultural lands adjacent to salmon-bearing streams is incentivized through EQIP, Pacific Coastal Salmon Recovery Fund, Bonneville Power Administration conservation programs, and state salmon habitat programs, creating overlapping incentive streams that together provide substantially higher payment levels than any single program can offer (USDA-NRCS, 2021). Federal-tribal co-management of riparian habitat restoration in treaty fishing areas illustrates how sovereignty-based governance arrangements can create accountability structures that accelerate riparian adoption beyond what voluntary incentive programs alone achieve.

6. Discussion and Conclusion

The scalable incentive design framework developed in this paper provides a comprehensive analytical architecture for designing, evaluating, and improving riparian restoration programs in agricultural watersheds. The five-lever framework integrates behavioral, ecological, and institutional perspectives that are typically addressed in separate literatures and separate program design processes, demonstrating that their simultaneous treatment generates design insights that partial approaches miss. The most important practical implication of the framework's multiplicative lever interaction is that programs designed to address only one or two adoption constraints will systematically underperform programs that simultaneously address the full range of economic, behavioral, social, and institutional constraints on adoption (Prokopy et al., 2008; Weersink et al., 2018).

The framework's landscape targeting lever addresses a systematic deficiency in current federal conservation program design, which distributes investment through administratively uniform national programs without the geographic targeting necessary to concentrate investment in the most hydrologically connected and ecologically sensitive riparian areas where practice installation generates maximum water quality returns (Rabotyagov et al., 2014; Claassen et al., 2008). The 2023 Farm Bill reauthorization provides an opportunity to strengthen the geographic targeting mechanisms of CRP, EQIP, and RCPP by requiring spatial analysis of restoration opportunity and water quality benefit in program targeting decisions, moving toward the optimal targeting designs that economic analyses consistently show can achieve significantly greater water quality outcomes from available program budgets (USDA-NRCS, 2021; Claassen et al., 2008).

The institutional environment lever draws attention to the governance context requirements for scalable riparian restoration that are frequently overlooked in program design focused on

individual-level payment incentives. Achieving watershed compliance scales of riparian restoration requires not only adequate payment levels but also robust watershed governance infrastructure including active partnerships, monitoring accountability, regulatory backstops, and multi-level coordination that together create the institutional environment in which individual adoption decisions are embedded (Sabatier et al., 2005). Investment in watershed governance capacity alongside practice incentive programs is therefore not an optional complement to effective riparian restoration policy but a necessary precondition for achieving the compliance-scale adoption that water quality goals require (Chesapeake Bay Program, 2023). The design of high-capacity institutional environments for riparian restoration draws on governance architecture principles developed across multiple domains: healthcare infrastructure governance frameworks that address the challenge of delivering services in resource-constrained and geographically dispersed settings provide design analogies for watershed technical assistance delivery systems (Aminu-Ibrahim et al., 2025; Ogbete et al., 2025; Aminu-Ibrahim & Ogbete, 2024). Supply chain optimization and procurement governance models from energy and construction sectors illustrate institutional design approaches for coordinating multiple contractors and service providers within complex multi-stakeholder delivery systems analogous to watershed partnership program management (Okonkwo et al., 2025; Agbabiaka et al., 2019; Efobi et al., 2023). Regulatory compliance architecture frameworks from financial services and telecommunications sectors demonstrate scalable approaches to multi-party accountability systems, real-time performance monitoring, and regulatory reporting that translate directly to watershed-scale conservation program governance (Anichukwueze et al., 2022; Isiekwu et al., 2025; Bello et al., 2025; Odejobi et al., 2023). ESG reporting frameworks and sustainable finance governance models developed for corporate sustainability disclosure provide additional institutional design insights relevant to the accountability systems required for watershed-scale conservation program governance (Awanye et al., 2023; Adeyoyin et al., 2024; Akinlade et al., 2024). The payment structure lever benefits from behavioral economics and financial modeling insights developed in diverse contexts, including adaptive risk scoring models, financial planning frameworks, and consumer payment optimization research (Fadayomi et al., 2024; Okafor et al., 2024; Medon & Oduleye, 2024; Dada et al., 2024).

Future research should develop longitudinal assessments of riparian practice durability, practice effectiveness maintenance over time, and the governance conditions under which compliance-scale adoption is sustained after initial program investments are completed. Research specifically examining the interactions among the five framework levers across different watershed typologies and institutional environments would strengthen the empirical foundation for the framework's multiplicative interaction claim. Integration of the riparian restoration framework with broader analyses of agricultural watershed compliance governance, including the federal-tribal co-management and multi-level SDG governance frameworks developed in companion studies, would advance understanding of how watershed governance system design shapes the context within which riparian restoration incentives operate. The governance of digital conservation program platforms, including cybersecurity compliance requirements for conservation payment data systems, intellectual property questions in AI-generated restoration design tools, and algorithmic accountability in automated practice targeting systems, represents an emerging research frontier with direct implications for federal conservation program administration and participant data protection (Annan, 2025b; Annan, 2023; Annan, 2024; Yeboah & Nnabueze, 2021; Michael & Ogunsola, 2023).

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