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Optimization and reflexivity in interdisciplinary agri-environmental scholarship

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Introduction: The Chesapeake Bay and Upper Bann watersheds in the United States and Northern Ireland, respectively, exemplify how agricultural systems contribute to groundwater and surface water pollution, which leads in turn to water quality issues in downstream water bodies. Interdisciplinary research, public outreach, and stakeholder engagement have received increased attention and consideration as pragmatic approaches for addressing these types of complex agri-environmental dilemmas. However, such approaches are far from guaranteed to improve water quality, as political-economic constraints, power asymmetries, cultural differences, divergent incentives, research gaps, and personality differences all complicate the process, and this can ultimately impact water quality efforts.

Methods: We present a holistic approach to addressing these challenges in the Chesapeake Bay and Upper Bann watershed management efforts by integrating the methodological strategies of optimization and reflexivity. Our use of these approaches, widely recognized as respective successful practices in quantitative and qualitative research, is novel in that it focuses directly on the researchers themselves as they discuss, evaluate, and develop potential solutions for complex agri-environmental water quality dilemmas. More specifically, our quantitative optimization is explored via a Functional Land Management (FLM) approach to land and natural resources management, while our qualitative reflexivity is explored through the process of participant observation.

Results: This paper provides a behind-the-scenes perspective on how interdisciplinary teams can improve their cooperation efficiency when addressing complex agri-environmental issues. In being reflexive, we sought to "optimize" on the methodological, ethical, social, and environmental possibilities of our scholarship. We found that our reflexive work on this project furthered our interest in FLM, a tool that embraced complexity and creativity over rigidity and oversimplification - the very same principles that guided our reflexive work.

Discussion: Throughout our collaborative investigation of FLM as a potential solution to soil and water quality issues, we came to appreciate that in order to better understand agri-environmental challenges issues, we also needed to better understand ourselves—our own disciplinary, cultural, and ethical standpoints. Reflexive approaches to research can provide practical guidance in this process by encouraging us to critique and analyze our assumptions, our methodologies, and the socio-historical context of our research.

KEYWORDS

agricultural sustainability, rural sociology, environmental science, water quality, interdisciplinary research

1. Introduction

Water impaired by nitrogen, phosphorus, and sediment, predominantly due to agricultural soil management, is a costly problem worldwide that negatively effects waterways, their organisms, and the economies of many nations. Sustainable Development Goal 15 ("Life on Land") accordingly calls on governments and stakeholders to "protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (Nations, 2012)." Improving soil health is also vital to attaining other Sustainable Development Goals, including "1 (End Poverty), 2 (Zero Hunger), 3 (Good Health and Wellbeing), 5 (Gender Equality), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 9 (Industry Innovation and Infrastructure), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), and 13 (Climate Action; Lal et al., 2021)."

Governing agencies in the United States (US) and across the European Union (EU) have tried to reduce agricultural runoff pollution to water bodies by developing specific policies through EU Directives, the EU Common Agricultural Policy, EU member nation legislation, US national policies, and US state-level environmental legislation. For example, in the US Chesapeake Bay Watershed, policymakers have established fixed-time limits on the restoration of impacted surface water bodies. The US Environmental Protection Agency has mandated water quality improvement goals issued through the Chesapeake Bay Total Maximum Daily Load (TMDL), thereby setting limits on the maximum amount of nitrogen, phosphorus and sediment loads to the Chesapeake Bay that must be met by 2025 (USEPA, 2010). Similarly, the EU Water Framework Directive uses five classifications to evaluate water quality status (high, good, moderate, poor and bad) among all water bodies (surface and groundwater) in EU Member States, and requires all Member States to reach "good" ecological, quantitative, and chemical status and protected area objectives by 2027 (Carvalho et al., 2019). Besides mandatory requirements under the EU Nitrates Directive (an agriculture-focused section of the Water Framework Directive), voluntary agri-environmental measures have been increasingly integrated into the EU Common Agricultural Policy since the late 1980's (Hart et al., 1994; Angileri et al., 2011; Meyer et al., 2014), while the more recent integration of compulsory environmental cross-compliance regulations reflects the EU's efforts to pursue its environmental targets (Solazzo and Pierangeli, 2016; Bertoni et al., 2018). Soil scientists have made significant contributions to policymakers' understanding of these problems in recent decades (Keesstra et al., 2016; Lal et al., 2021; Bouma et al., 2022). Nonetheless, while progress has been made, research and policy measures have been inadequate in light of the sheer scale of the problem. Part of the problem could be due to how we (as agri-environmental researchers more broadly) collectively work together.

Interdisciplinary research and outreach efforts are receiving increased attention and consideration as a solution to inform policy making by addressing complex agri-environmental challenges like the reduction of waterway pollution from agriculture (Andersen, 2016; Keesstra et al., 2016; Annan-Diab and Molinari, 2017; McBean and Martinelli, 2017; Szell et al., 2018). Indeed, "all this is only possible if researchers look over the hedge toward other disciplines, to the world at large and to the policy arena, reaching over to listen first, as a basis for genuine collaboration (Keesstra et al., 2016, p. 124)." Yet few accounts exist of researchers' interpersonal experiences in interdisciplinary research efforts (Datta, 2018) and little empirical evidence exists that interdisciplinarity works as intended (Lyle, 2017). Oftentimes, there is a failure to support—or allow for—the risks involved and time frame needed to overcome unequal/undistributed disciplinary contributions (Anonymous, 2017). In Datta's (2018) experience on an interdisciplinary project, he found that respect, trust, vulnerability, attentiveness to others' feelings, professional flexibility, timely leadership, and courage were essential to a successful outcome. Adequately addressing these issues can be particularly challenging for many researchers, given the power asymmetries between different disciplines (Morris et al., 2019) and between academic ranks.

To further invigorate collaborative and holistic research on agri-environmental challenges, we present a critical examination of an international-interdisciplinary collaboration between biophysical scientists, engineers, and one social scientist (the lead author). In contrast to Lyle's (2017) solo-authored participant-observation paper, which emerged from her feelings of marginalization and solitude on an interdisciplinary medical device team, our group sought to co-author a paper that integrated our respective disciplinary backgrounds through conscientious and deliberate reflection (Leavy, 2015).

In what follows, we first discuss our methodological approach: a collaborative workshop on the social and methodological potential of Functional Land Management (FLM). Our quantitative approach was complemented by the lead author's participant-observation role, whereby he encouraged the team to be more reflexive about our a priori assumptions and disciplinary lenses. In the subsequent section of the paper, we situate this methodological discussion in agri-environmental context by looking at two case studies where we do our respective work: the Susquehanna River Basin within the Chesapeake Bay watershed (United States) and the Upper Bann watershed (Northern Ireland; Figure 1). This section is followed by a more in-depth discussion of the discursive themes and tensions that permeated throughout our collaborative process. Throughout the paper, in the spirit of interdisciplinary synthesis, we use the technical concepts of "modeling" and "optimizing" as metaphors for our group's collective aspiration to be exemplary scholars—always striving to be more rigorous and more reflexive. We conclude our discussion with a set of key questions and considerations that can help to inform future international-interdisciplinary collaborations in agri-environmental scholarship.

2. Methods

The overarching purpose of our collaborative scholarship was to re-envision both the environmental possibilities and the ethical implications of different rural land use strategies. We laid the foundation for this work by assembling an international-interdisciplinary workshop for select researchers from Ireland, Northern Ireland, the Netherlands, and the United States. The explicit purpose of the workshop (held in June 2018, in Wageningen) was to explore different methods for optimizing soil-based ecosystem services by agricultural land, or "soil functions" (Schulte et al., 2014, 2015), according to societal demands for production and environmental preservation. Throughout the process, we found that the strength of our collaborative network was grounded in our ability to engage in an iterative, dialectic, and non-sequential conversation across two key dimensions: optimization and reflexivity.

2.1. Optimization

The application of quantitative methods toward addressing large-scale social, economic, military, and environmental questions exploded with the postwar advancement of computing technologies. Indeed, in highly developed societies with large populations, optimization is a valuable tool for addressing complex, macro-level problems. Optimization, or mathematical optimization, is a process whereby (A) the choice of the optimal component (with regard to some criterion) is made from a collection of potential alternatives or (B) the optimal choice is derived from a combination of components, where the result of the combination is greater than the sum of its parts and effects of antagonist trade-offs are minimized. Multi-objective mathematical optimization, heuristic problem-solving, targeting, and other techniques for operations research and numerical problem solving are quite widely used in the study of natural systems (Craig et al., 2001; Moles et al., 2003; Veith et al., 2003, 2004; Williams et al., 2004).

To this end, the specific optimization approach that we investigated at the workshop was FLM—a policy support framework that seeks to optimize the agronomic and environmental returns from diverse soil and landscape settings (Schulte et al., 2014, 2015; O'Sullivan et al., 2015; Coyle et al., 2016). While people generally understand that soil delivers multiple functions to society and associated ecosystems, it is much less appreciated that soils vary in their ability to deliver these services (Blum, 2005; Bouma, 2015). FLM can potentially remedy agri-environmental misalignments by matching the supply of soil functions to societal demands (Schulte et al., 2014, 2015; O'Sullivan et al., 2018). FLM focuses on five soil functions (services) as outlined by Bouma (2014): (A) primary productivity; (B) water purification and regulation; (C) carbon cycling and storage; (D) habitat for biodiversity; and (E) recycling of (excess) nutrients/agro-chemicals. FLM thus provided us with an ideal conceptual and methodological framework with which to compare and contrast soil and water quality practices across different landscapes.

2.2. Reflexivity

Despite their many advantages and obvious necessity, there are also many limitations that come with implementing the solutions identified through optimization and quantitative methods as a whole. Accordingly, a parallel objective throughout our collaborative process involved reflexivity, i.e., researcher self-awareness with respect to their standpoint, disciplinary training, values, emotions, and social position throughout all stages of data collection and analysis (Guillemin and Gillam, 2004; Walsh, 2009; Emerson et al., 2011). While all professionals use tacit knowledge to address "complexity, uncertainty, instability, uniqueness, and value conflicts," they often find it difficult to publicly embrace and explain their use of experiential and improvisational skills (Schön, 2017, p. 18; see also Ramage, 2020). For Burawoy (1998), reflexive approaches to science are grounded in the assumption that researchers will always disturb the local setting when they come into contact with others, and that such disturbances should therefore be embraced, reflected upon, and used as a springboard for further analysis and inquiry. Here, a researcher's interaction with and interpretation of the social world is seen as a phenomenon to be recognized (or considered), critiqued, and analyzed, rather than a "bias" or "confounding variable" that must be eliminated.

The core mechanism for the reflexive component of our investigation was the method of participant observation, a qualitative data collection technique through which the researcher immerses in the studied "socio-cultural space" by "taking part and continually reflecting on what is happening," as opposed to "pure observation," where the researcher excludes themselves from the observed environment (Walsh, 2009). This approach is particularly valuable when working in interdisciplinary contexts, particularly with respect to open communication, microethics, insider/outsider relations, differing professional priorities, transparency, and the need for shared goals (Pardee et al., 2018). The participant-observation contribution to this project was primarily made by the lead author, who took detailed field notes while encouraging overall team reflexivity through writing activities, discussions, and co-authoring this manuscript.

In the following section, we consider two paradigmatic case studies in agri-environmental management where our team members have long sought to affect change: the Chesapeake Bay and the Upper Bann watersheds. Indeed, it was our shared frustrations with the soil and water quality governance in these regions that brought us together at the workshop.

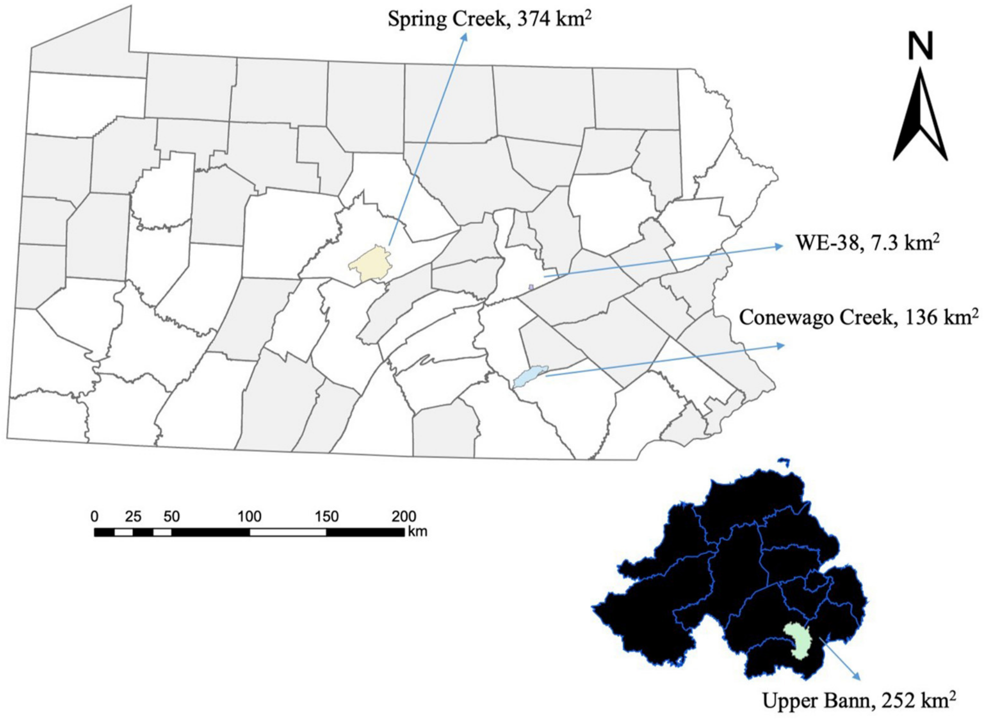

FIGURE 1
Respective land area for Spring Creek and Conewago Creek (part of the Chesapeake Bay watershed) as compared to the Upper Bann.

3. Case studies

3.1. Chesapeake Bay

The 165,759 km^2 mile Chesapeake Bay watershed is the largest estuary in the United States. It spans six U.S. states and the District of Columbia (Washington, D.C.) and provides drainage for over 100,000 tributaries, including the Spring Creek and Conewago Creek (Figure 2) regions (where we do much of our empirical work). To improve water quality throughout the Chesapeake Bay, policymakers have established fixed-time limits on water quality improvement. The federal US Environmental Protection Agency has mandated water quality improvement goals issued through Chesapeake Bay Total Maximum Daily Load (TMDL) targets (USEPA, 2010), thereby striving to decrease nitrogen, phosphorous and sediment loads to Chesapeake Bay. The Chesapeake Bay Program partnership has set restoration goals under the Chesapeake Bay TMDL to reduce these forms of pollution by 2025 (USEPA, 2018). To meet water quality improvement requirements under the TMDL, the US Environmental Protection Agency incentivizes farmers to implement best practices, for example, riparian buffers on their land. All farms in Pennsylvania, for example, are required to write and comply with a nutrient management plan, which includes determining appropriate land-application plans for their manure. These management plans are focused on nitrogen rather than phosphorous. Much (if not most) phosphorous over-application comes from year-round land application of livestock manure in excess of crop needs due to the higher nitrogen:phosphorous ratio in manure vs. crop needs. Since nutrient management plans and manure application rates are determined based on crop nitrogen requirements, over-application of phosphorous becomes inevitable. However, switching the plans to be based on crop phosphorous requirements leaves farmers with excess manure that they are unable to land-apply. The Chesapeake Bay watershed thus provides an exemplary case of how global production and consumption systems contribute to acute nutrient management crises that are both distributed across regional settings and concentrated in local watersheds. Action must soon produce results. A 2017 federal evaluation of Pennsylvania's progress toward meeting TMDL goals resulted in federal enforcement actions being implemented on agricultural and urban/suburban land uses, as the state fell short of meeting its TMDL requirements in these sectors (USEPA, 2022). Reducing excess agricultural nutrient pollution to meet water quality standards is similarly challenging for many European nations. Thus, our second area of interest was the Upper Bann study catchment (<300 km^2) in Northern Ireland (Barry and Foy, 2016).

3.2. Upper Bann

The Upper Bann was chosen as a complementary case study *via* exploratory collaborations between researchers from the United States, Northern Ireland, the Republic of Ireland, and the Netherlands (these partnerships evolved from Pennsylvania's development of the Fertilizer Forecaster tool—see Easton et al.,

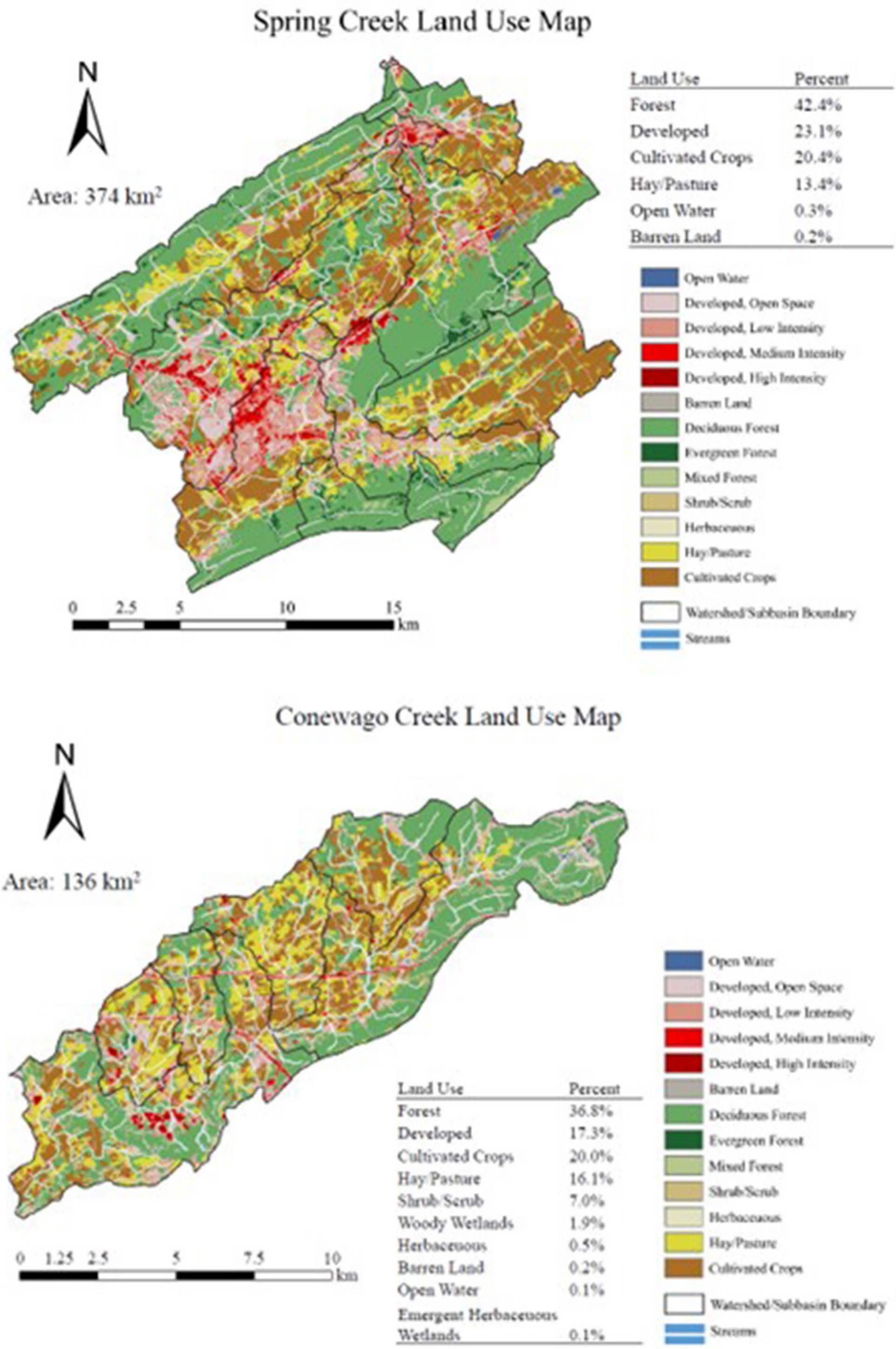

FIGURE 2
Spring Creek land use map and Conewago Creek land use map. Both regions are part of the Susquehanna River Basin and have been a key focus area for the Chesapeake Bay scholars on the team.

2017; Drohan et al., 2019). The Upper Bann is comprised of moorland, with some forest at higher elevations transitioning to intensive grassland pastures for dairy cattle, beef and sheep in the lower watershed areas (Figure 3). The overwhelming majority of the Upper Bann's surface water bodies do not have a "good" status per the EU Water Framework Directive, and many rivers fail to achieve good status due to elevated phosphorus and impacted macroinvertebrate communities. This is a widespread problem across Northern Ireland, where only 31.3% of 450 river water bodies and 23.8% of 21 lake water bodies have reached good or

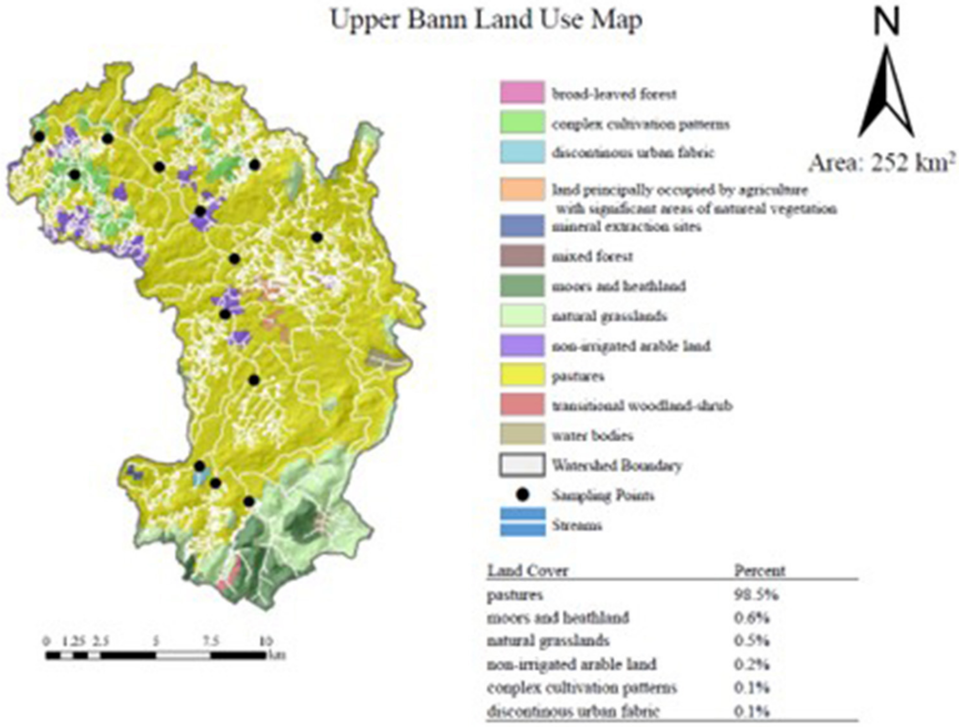

FIGURE 3
Upper Bann land use map.

higher status as of 2018 (DAERA, 2018). In the Upper Bann, there has been a decades-long deterioration in water quality, associated with increased inorganic nitrogen and phosphorus fertilizers, resulting in increased nutrients and sediments transported to water and reduced ecological status. In order to address these water quality issues, EU policymakers developed an overarching Water Framework Directive—a framework for the community action in the field of water policy (Directive, 2000/60/EC)—focused on the ecological quality of water. The EU Nitrates Directive (2000/60/EC) more specifically addresses water quality in relation to agriculture, monitors nitrate concentrations in water bodies, with a total territory approach taken to its implementation in Northern Ireland. Under this directive, which does not consider local soil quality, polluted waters (or those considered to be at risk of pollution) include (A) surface waters with a concentration of $> 50\,\text{mg l}^{-1}$ of nitrates and (B) Groundwater containing/could contain $> 50\,\text{mg l}^{-1}$ of nitrates. In addition, the Phosphorus (use in agriculture) 2006 Regulations were implemented in Northern Ireland to mitigate the impact of agricultural phosphorous on aquatic ecosystems in Northern Ireland. These measures have shown limited effectiveness.

In short, legislative and land management efforts to reduce water quality pollution from agriculture vary considerably between the EU and US. A comparative analysis of these two governing frameworks provided our group with a promising approach toward developing more comprehensive research and policy tools at the workshop.

4. Results

Our results section proceeds as follows: first, we actively reflect upon our own a priori assumptions and perspectives regarding the social and environmental challenges that confront agri-environmental researchers in the Chesapeake Bay and the Upper Bann. The purpose of being transparent and reflexive about our own preconceptions in this section is not to treat them as "expert opinions" to be disseminated as "truth." Rather, we sought to better understand the lenses and sociotechnical frames that shaped the ways in which we interpreted and approached these issues in the first instance. Second, as based upon our collective experiences at the workshop, we reflexively consider both the potentials and limitations of FLM and participant-observation to address these agri-environmental challenges as we understood them.

4.1. Team perspectives on case study I: Chesapeake Bay

Our project group engaged in extensive discussion and writing activities about our different assumptions and perspectives regarding the role of farmers, policymakers, and scientists in the Chesapeake Bay. From our collective standpoint, many farmers are willing to use less nutrients due to cost savings, but only if and when this practice can ensure continued yields. We also recognize that Chesapeake Bay farmers' approach toward agri-environmental issues has been shaped to a large extent by family farming traditions, the type of information that the government shares with farmers, and the reality of dealing with daily on-farm nutrient challenges (i.e., full manure storage facilities).

Consumer waste and dietary choices also have a tremendous impact on agricultural practices, albeit less directly. We further noted that extension and outreach activities by scientific organizations have helped in a great way to change the way farmers think and connect farmers with science and policy. Nonetheless, we remained concerned that farming practices and/or technological solutions proposed by scientists and researchers fail to convince the farmers for multiple reasons: practical factors such as socioeconomic constraints, access to quality information, implementation challenges (Baumgart-Getz et al., 2012; Liu et al., 2018; O'Sullivan et al., 2018), a lack of connection to empowering networks, countervailing belief systems, (dis)trust in science and mainstream institutions (Baumgart-Getz et al., 2012; Schall et al., 2018; Eanes et al., 2019), and/or concerns about policy "lock-in" from long-term engagement in conservation programs (O'Sullivan et al., 2015).

Our group also discussed the different social factors that have encouraged conservation practices and what the overall effectiveness of these practices has been. On the one hand, we agreed that conservation practices have long been used by farmers in Chesapeake Bay watershed to minimize impacts to ecosystems, and many farmers have shown a willingness to work toward consensus on these issues with extension agents and policymakers (USDA, 2013). Nonetheless, numerous hindrances, as mentioned above, have limited and constrained these farmers' avenues of potential options. Our group also considered the possibility that the voluntary contributions of individual landowners to agricultural land use change simply may not be a sufficient way to address the aggregate problem. We nonetheless recognized the importance of respecting and acknowledging the unique and locally-situated knowledge of rural landowners.

We arrived at a loose consensus that farmers had the most influential voice in the water quality debate, policymakers largely played second fiddle, and existing policies on non-point source pollution were largely dependent on voluntary action. During the workshop, EU participants discussed a lack of certified staff who could conduct on-farm inspections to ensure compliance with nutrient management plans, resulting in farms only being inspected an average of once every 8 years instead of annually. Here, one of the Americans in the group commented that in the US, there's a lot of pressure on the government to not overregulate. At the federal level, despite the fact that Pennsylvania fell behind in its 2025 TMDL goals for the Chesapeake Bay, the previous US administration's "The Waters of the US" policy had been rescinded by the US administration in office at the time of workshop (held in 2018). Moreover, the USDA Natural Resources Conservation Service and state environmental protection staff used to help with management planning, for free. Now—with essentially all farmers being required to create a nutrient management plan—there are substantial shortages of staff and farmer-paid contractors to fill this role.

Where policymakers have taken action, many of us agreed that legislation was oftentimes aimed at a quick and easy fix through "one-size-fits-all" approaches as opposed to customized guidelines that considered local soil, hydrological and environmental conditions (these concerns were also raised with respect to the current situation in the Upper Bann). Additionally, the continued shift from local agricultural production *via* small farms to widely-transported products from large-scaled concentrated animal feeding operations places increased strain on the effort to balance soil nutrients and reduce nutrient exports from farms. Many rural communities appear to be deeply divided in their support of these types of facilities, and their long-term political viability—particularly in an era of persistent rural depopulation, farm loss, and rural/urban economic disparities—remains an open question.

In terms of the impact that scientists had on the US water quality debate, our group felt that scientists were more likely to be influential when they worked within (rather than against) the current political-economic system. In practice, this has meant more grant funding for individual and local-level approaches (e.g., P-index and best management practices) as opposed to "paradigm shifting" proposals, although there are a handful of major grant programs for large and ambitious programs. Even still, several among us commented that many scientists were not effectively communicating and collaborating with farmers and policymakers, and that—despite many ongoing and fruitful efforts to build bridges—a "large disconnect" remained between these groups. While extension educators can minimize this gap, it is often unidirectional, with knowledge flowing from universities to farmers but not back in the other direction. In this way, the knowledge created at universities may not fill all farmer needs because those needs are unbeknownst to scientists. Mismatches in needs and solutions can therefore be significant.

4.2. Team perspectives on case study II: Upper Bann

When compared to the Chesapeake Bay, communities on the Upper Bann face comparable yet quite distinctive ecological problems—particularly with respect to water quality—that have been met with very different socio-institutional approaches. Strengthening the ongoing partnerships within and between our respective US and EU teams provided us with a unique window of opportunity in which to examine these challenges.

In reflecting upon the socioeconomic context of the Upper Bann, our group agreed that farmers' actions were strongly shaped by both increases in fertilizer prices and EU policy changes (e.g., the Nitrates Directive). Here, there was a sense that stronger regulatory action was being taken in response to decades of deteriorating water quality. Moreover, despite the social and political influence of farmer organizations in Northern Ireland, our group agreed that EU policymakers had more flexibility in designing policy solutions as compared to their American contemporaries. At the same time, we remained concerned that there was inadequate support, training, and incentives being provided to farmers (due in part to budget cuts, among other factors). When farmers did act, water quality could still be compromised due to scientific knowledge gaps (e.g., in relation to soil types or weather changes) and misaligned regulatory controls. To the latter point, the European scientists in our group shared the concern of American scientists' with "one size fits all" and "blanket target" regulatory policies that disregarded local soil and landscape diversity.

Moreover, in addition to the agri-environmental challenges that Northern Ireland is already facing, our group noted that the situation could well be further compromised by policies that continue to intensify agricultural production. Indeed, Northern Ireland's Water Framework directive might struggle to maintain water quality given the large numbers of livestock on the land, the low carrying capacity of many of the soils, and the lack of an economic incentive to build large manure processing facilities that are required to address the phosphorus surplus that exists in many catchments. Moreover, there are high temporal and spatial risks with slurry spreading, as there are huge difficulties in finding times when farmers can spread slurry sustainably. The poultry sector in Northern Ireland has nonetheless continued to expand, increasing competition for (and intensification on) what little land is still available. Optimism was nonetheless shown as the neighboring Republic of Ireland was shifting toward a more inclusive, multi-stakeholder approach to water quality challenges.

Our group also agreed that Irish scientists faced similar constraints as compared to American scientists, namely, a considerable difficulty in impacting policy discussions and short-term funding cycles that led to reductionist/one-dimensional methodological approaches.

4.3. "Optimizing" on land use: Using Functional Land Management to address socio-technical knowledge gaps and political-economic imperatives

At the workshop, we discussed how FLM land and soil function optimization could be used to identify key drivers (e.g., land use, policy, and economic indicators) that could help Chesapeake Bay and Upper Bann farmers better manage nutrients and reduce agricultural runoff. In theory, this would enable us to: (A) build the base water quality and land use data sets for our FLM scenarios; (B) identify the US (federal and state), Northern Ireland and EU policies that can facilitate farm to watershed scale water quality improvements; (C) generate FLM land use scenarios and assess how watersheds in the Chesapeake Bay and the Upper Bann respond to alternate water quality policies; and (D) initiate the development of a new framework from which to critically evaluate and compare watershed decision-making.

Workshop participants who were new to the concept sought to learn how FLM could be adapted, applied, and scaled to different political and geographic contexts, while also helping to identify knowledge gaps and the need for additional expertise. Accordingly, during the workshop, we reviewed US, UK and EU policies impacting key soil functions, discussed modeling approaches that could be used to evaluate policy effects on water quality outcomes and inform decision-making, and set goals for next steps, project publications, grant development, and public outreach.

During our preparatory meetings in advance of the workshop, members of our group were particularly interested in learning more about what was particularly new about the FLM approach, and how it might improve on existing farm conservation planning, various modeling techniques, best management practices, and stakeholder analysis tools that had already been in use for decades. The implication of these concerns was that good quantitative modeling of different environmental scenarios doesn't necessarily lead to social change. The upside of FLM is that it can help construct different types of scenarios which encompass the baseline, intensification of agricultural production, resource efficiency (Schulte et al., 2014), and water quality improvement potential of different agri-environmental practices by cropping/land use shifts. Additionally, FLM can be used to assess how watersheds respond (shifts in soil function, commodity kind and value) to water quality improvement policies. By quantifying nutrient export for each FLM scenario using the Soil & Water Assessment Tool (SWAT), further information can be obtained regarding how each nation's water policies differ, can offer improvement over the status quo, or could be adjusted to achieve water quality improvements.

An approach like FLM has a great deal of appeal in a political-economic environment in which farmers are asked to take voluntary action, policymakers' efforts have been limited and ineffectual, and scientists have struggled to make their voices heard. In a nutshell, beyond its utility in supporting policy design and land use planning, FLM provides farmers with accessible data on the possible consequences of different land use scenarios, thus enabling them to make their own decisions about which types of economic and/or ecosystem benefits they want to prioritize. While an FLM-oriented approach may not offer the type of regulatory enforcement that many stakeholders in the water quality debate might prefer, it does help to democratize scientific decision making and empower farmers who want to improve their environmental performance. Identifying and clarifying these values provided a useful context for the more technical goals that we set out to accomplish over the course of the workshop.

Throughout our collaborative process, we were keenly focused on what the incentive structure would be for farmers to use FLM. One of our many concerns, for example, was that EU agri-environment incentive schemes for farmers in Northern Ireland would end or be modified with Brexit. Potentially, FLM might be used to identify other win-win land use opportunities that might go unnoticed, for example, by helping to convert marginal landscapes to hemp or biofuel production. Our group also talked about the different ways in which to quantify the social dimension of water quality controversies by using network analysis to study decision-making processes among farmers.

During the workshop, FLM presenters also spoke extensively about how they incorporated farmer outreach into their projects. Here, they discussed their work in setting up lighthouse farms—"global outdoor laboratories" that showed local residents how alternative land uses could be both sustainable as well as profitable. While each lighthouse farm scored highly on one category of sustainability, none were perfect in every indicator, which further helped to illustrate the different range of options that landowners might consider. FLM presenters also showcased "FarmDESIGN," a bio-economic whole-farm modeling software that displays the flows of resources (cash, labor, and food) between a farm enterprise, the farm household and the farm's direct local environment, allowing for identification of optimization scenarios in terms of economic and environmental performances (Ditzler et al., 2019). The presenters emphasized that while there's always a tradeoff between habitat protection and economic production, there was still lots of room to expand on both, and that the idea was to leave it to the stakeholders and the farmers to decide.

Among the most dynamic sessions at the workshop was a hypothetical map activity where the presenters issued the following challenge to group members: "How can we establish a financially productive 'healthy beef' farm that preserves biodiversity and minimizes greenhouse gas emissions?" Interestingly, the conversation shifted into a lively and engaged discussion about the policy incentive structure for EU member states, farmers, and rural communities. Actual environmental remediation, system options, and technical solutions were scarcely even mentioned. One of the presenters made a comment during the workshop that put all of these complexities, concerns, and hypotheticals into a much broader context:

> "Sometimes people want a very clear, defined answer... I'm hoping that people see that there are different ways. FLM offers a lot of possibilities... it's developed in-action... [and] we're adding more components to the toolbox [as we go along]."

4.4. "Optimizing" on humility: Acknowledging the limitations of Functional Land Management and participant observation

Despite the clear upsides to using quantitative modeling tools like FLM, group members maintained a sense of humility regarding the ability of these tools to resolve the complex social dimensions of agri-environmental problems. Some of the methodological limitations that our group identified were as follows: that scientists didn't always understand the limits of particular data sources, that lots of data on rural land management was private and thus unavailable, that mathematical models could oversimplify problems and overpromise on solutions, and that spatial data layers couldn't capture the nuances of complex agriculture fields or micro topography. Optimization methodologies also require computational power, so they may not always be a practical solution in underdeveloped regions. Moreover, people who don't rely on computational solutions can often solve the agri-environmental problems by contributing their own expertise and local knowledge.

Throughout the process, group members also noted a mixture of confidence and skepticism about the future of FLM and our collective ability to overcome agri-environmental challenges as a whole. FLM might have a more immediate impact on scientists and policymakers than farmers, and any type of change to agri-environmental policy faces numerous obstacles and hurdles. FLM is also emerging at a time when climate change poses an increasing threat to agricultural production, many high-use landscapes have already been severely degraded, the global demand for animal protein and ultra-processed foods is accelerating, and local policy environments face strong pressures to embrace sustainable intensification. Overall, however, participants came away from the workshop very impressed with the diverse set of practical applications that FLM could provide for farmers.

Lastly, it is important to acknowledge our group's concerns and skepticism toward the participant-observation work that informed this paper. Many members of our group expressed concerns about the narrative in the first draft of the paper, specifically, that it highlighted individual statements without providing sufficient context or speaking more broadly to the collective experience of the group. Indeed, what the lead author expected to be a short turn-around time from the workshop to submission for publication ended up being a far lengthier process of iterative revision, negotiation, and (re)submission, highlighting the steep learning curve that those conducting new interdisciplinary research projects must overcome.

Par for the course, all participant-observation researchers must confront the limitations of their ambitious project ideas, their potential lack of acceptance in the field, mistakes, ambiguities, missed opportunities, gaps in their data, and their status as outsiders (Lareau and Shultz, 2018). The solution to these problems, ironically, lies in being reflexive, honest, and transparent about them.

5. Four years on: Post-workshop deliverables

In the aftermath of the workshop, Author 2 presented on the importance of global perspectives in addressing water quality issues at Teagasc's Catchment Science 2019 in Wexford, Ireland; Author 2 and Author 5 published a paper that compared P management in the US, Ireland, UK, New Zealand, Norway, Finland, and Sweden (Author 2, et al.); and Author 2 is also working on a paper examining how elements of the EU's Nitrate's Directive might improve Chesapeake Bay water quality. Above all, however, we agreed that the most significant outcomes were the training of our graduate students from Penn State (Author 8) and Wageningen (Author 10). After the workshop, (Author 8) (Penn State) would go on to lead the US team's application of FLM principles in sub-watersheds of the Chesapeake Bay (Author 8 et al.). She also led this team's effort to expand the framework to Susquehanna River Basin, which examined scaling issues with the FLM framework (Author 8 et al.). Author 8 et al.'s third manuscript, in progress, explores the use target phosphorus management and riparian buffer installation in Northern Ireland.

Author 10, a Wageningen student, was hosted at Penn State by Author 7 in Spring 2019. Together, they applied a mixed-method approach, combining Social Network Analysis, signals analysis (i.e., analysis of information flow and their influences), and a qualitative content analysis of stakeholders' interviews to assess information flows around best management practices in dairy farming in central Pennsylvania. Their results reveal both governance opportunities and gaps, which they use to provide insights for better tailored policy interventions (Author 10 et al., in progress). Author 10 is now completing a PhD in collaboration with Teagasc (Ireland), Wageningen, and Penn State. One member of our group noted that

TABLE 1 Agri-environmental challenges in the Chesapeake Bay and Upper Bann: governance contexts, team perspectives, and post-workshop outcomes.

	Chesapeake Bay	Upper Bann
Governing bodies	United States (US) national laws (e.g., Clean Water Act) and policies (Chesapeake Bay Total Maximum Daily Load targets), and US state-level environmental legislation	European Union (EU) Directives (e.g., EU Water Framework Directive and EU Nitrates Directive), the EU Common Agricultural Policy, EU member state legislation
Team perspectives on key social and agri-environmental challenges	Farmer concern for yields; family farming traditions; access to quality information; implementation challenges; (dis)trust in science and mainstream institutions; dependence on voluntary action; lack of support staff; anti-regulatory culture; "one-size-fits-all" policies; concentrated animal feeding operations; ineffective science communication; consumer waste; dietary choices	Inadequate support, training, and incentives being provided to farmers; scientific knowledge gaps; misaligned regulatory controls; "one size fits all" policies; agricultural intensification policies; lack of economic incentive for manure storage; competitiveness in agriculture; ineffective science communication; short-term grant funding cycles; Brexit disruptions
Team perspectives on what's currently working	Conservation-oriented farmers; Extension and outreach	EU policymakers' flexibility in designing policy solutions; recent shifts toward a more inclusive, multi-stakeholder approach
Post-workshop: Using *optimization* to improve agri-environmental management	Adapting Functional Land Management (FLM) principles in sub-watersheds of Chesapeake Bay watershed; expanding the FLM framework to the Susquehanna River Basin and exploring its use at different levels of scale	Exploring the use of target phosphorus management and riparian buffer installation in Northern Ireland
Post-workshop: Using *reflexivity* to improve agri-environmental management	Using active listening skills when engaging with stakeholders; doing qualitative content analysis of stakeholders' interviews to assess information flows around best management practices in dairy farming in central Pennsylvania	Improving our understanding re: the impact of different governance contexts, which can help to expand the possible solution spaces for stakeholders

> "Author 10's scholarship has been a key outcome, along with the potential for future collaborations between our organizations. Such a tangible outcome as has happened with Author 10 hasn't happened previously... That's provided a formative experience for her. She also had direct engagement with farmers immediately after the workshop."

6. Discussion

FLM continues to serve as a useful tool for agri-environmental research and stakeholder engagement (O'Sullivan et al., 2022; Valujeva et al., 2023). It also provides a complementary framework for digital soil mapping (Smith, 2020), i.e., "the creation, and population of spatial soil information systems by the use of field and laboratory observational methods coupled with spatial and non-spatial soil inference systems (Lagacherie and McBratney, 2006)." Active training and use of these tools is of increasing importance, as they take advantage of recent advances in machine learning, satellite imagery, precision agriculture, and other adjacent fields to improve analytical accuracy (see Smith, 2020; Kaya et al., 2022; Keshavarzi et al., 2022). Technical skills alone, however, are not enough to address global socioeconomic and environmental challenges.

Throughout our own investigation of FLM as a potential solution to soil and water quality issues, we came to appreciate that in order to better understand complex agri-environmental problems, we also needed to better understand ourselves—our own disciplinary, cultural, and ethical standpoints. In speaking to the socioeconomic blindspots of our respective scientific fields, for example, group members commented that their respective discipline was too focused on production as opposed to environmental consequences, that scientists didn't have an adequate understanding of socioeconomic challenges (and thus had difficulty making their work relevant to policy), that there was not enough focus on farmer adaptive capacity (financial, social, human, and physical capital), and that some scientists had an overall naivety about the complex motivational factors that guided citizens' choices. Rather than gloss over these complexities, we chose to embrace and actively confront them, and we found that our collective scholarship became more dynamic for having aspired to do so (see Table 1).

One of the key challenges of interdisciplinary research was brought into focus by the process of writing this paper. The lead author occupied something of a hybrid role, as he was a full Co-PI on the research team but also a "stranger (Simmel, 1950)" in that he was the only qualitative researcher on the project. Throughout the collaborative process, the lead author experienced a continual tug of war between his desire to be a "team player" and his need to keep a critical gaze from a healthy distance. Indeed, after reading the lead author's first draft of the paper, some of the natural scientists struggled with the terminology, and found it difficult to identify their own voices within the paper. However, ultimately it was acknowledged that this was a result of their lack of relevant experience. The co-authorship process helped us to close this gap, make clarifications, and work in unison toward achieving true synergy.

While many FLM workshops include growers, policymakers, and other stakeholders, all the attendees at our 2018 workshop were academics, and this allowed us to speak more freely and openly. To be sure, for researchers to be transparent about what occurs during these types of "backstage" moments can be intimidating. One of us noted that they felt so close to their research that it was hard to step back and communicate at an appropriate level of definition and engagement. The second author of the paper noted post-workshop that

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> "A manuscript such as this one is a type of mirror for a scientist. The image is not of the individual in this case but the collective thought process. While it is comforting to find similarities in thinking, and not surprising that there are also contrasting opinions, it is discomforting that we as scientists feel severely limited in affecting change."

The post-workshop process of writing, revising, and (re)submitting this manuscript admittedly took much longer than anticipated, and this did result in opportunity costs vis a vis our respective disciplinary work. Nonetheless, waiting several years until we completed the manuscript also provided us with additional opportunities to reflect on what had been accomplished, not just in terms of the scholarship and graduate student training, but our own personal and professional growth. One co-author commented that he didn't understand the purpose of the paper at first, but he later appreciated the value of doing the reflection. Another co-author noted that doing the workshop had helped her feel more comfortable doing outreach. Now, she explained, she felt more engaged when listening to local stakeholders rather than "going there and explaining."

While we agreed that the workshop had been a positive experience, we also wanted to be careful not to oversell it. Here, one of the co-authors noted that we were all predisposed to do interdisciplinary work on day 1, we self-selected into the group, one workshop alone doesn't shatter paradigms and change the world overnight, and we still face institutional barriers and challenges. She further wondered if the workshop had effectively served to validate our thinking, while also fulfilling funding agencies' expectations for interdisciplinarity and broader impacts work. In response, another co-author noted that the workshop wasn't a randomized clinical trial, and we weren't making the argument that the post-workshop outcomes couldn't possibly have happened without doing the workshop. We later came to an agreement that while the concept of hosting a workshop was not new, what was different about our approach was that we were talking about the research process itself: what went on behind the scenes, the failures, and the mundane practice of doing science, so that we could all do better.

7. Conclusion

Reflexive approaches to research facilitate creativity, innovation, and ethical practice by encouraging us to critique and analyze our assumptions, our methodologies, and the socio-historical context of our research. With more and more research and development programs being developed as multi-agent, project-based cooperative efforts, involving a variety of actors across disciplines and professions, soft skills in flexibility, adaptation, empathy, attentiveness, and humility are indispensable. Best practices in participant-observation research can thus help to improve communication and provide improved clarity on transdisciplinary research goals and objectives. By the same token, when top-down agri-environmental governance appears to be ineffectual and/or unlikely, toolkits that empower scientist-stakeholder collaboration may provide an alternative path forward. Education and training programs can play a crucial role in enhancing these capacities and formally recognizing them as professional competencies as opposed to personality traits.

In being reflexive, we sought to "optimize" on the methodological, ethical, social, and environmental possibilities of our scholarship. We found that our reflexive work on this project furthered our interest in FLM, a tool that embraced complexity and creativity over rigidity and oversimplification—the very same principles that guided our reflexive work. We have moreover argued in this paper that researchers can benefit from embracing, exploring, and acknowledging their fears. In doing so, we can model for others a new and exciting path for international and interdisciplinary agri-environmental scholarship.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

RoC: conceptualization, methodology, investigation, writing—original draft, review, editing, project administration, and funding acquisition. PD, RaC, DD, HP, and TV: conceptualization, methodology, writing—original draft, review, editing, visualization, supervision, project administration, and funding acquisition. LO'S and RS: conceptualization, methodology, resources, writing—original draft, review, editing, visualization, supervision, project administration, and funding acquisition. CG: conceptualization, methodology, investigation, writing—original draft, review, editing, visualization, supervision, project administration, and funding acquisition. FJ and ED: writing—original draft, review, editing, and visualization. AA: writing—original draft, review, and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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