Received: 10 November 2021 | Accepted: 7 October 2022

DOI: 10.1111/1752-1688.13079

AMERICAN WATER RESOURCES ASSOCIATION JAWRA JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

RESEARCH ARTICLE

Considerations for using alternative technologies in nutrient management on Cape Cod: Beyond cost and performance

Kate K. Mulvaney[1] | **Nathaniel H. Merrill**[1] | **Sarina F. Atkinson**[2]

[1]Atlantic Coastal Environmental Sciences Division, Center for Environmental Measurement and Modeling, Office of Research and Development, United States Environmental Protection Agency, Narragansett, Rhode Island, USA

[2]Student Contractor, Cooperative Institute for Marine & Atmospheric Studies, Rosentiel School of Marine & Atmospheric Science, University of Miami, Miami, Florida, USA

Correspondence
Kate K. Mulvaney, Atlantic Coastal Environmental Sciences Division, Center for Environmental Measurement and Modeling, Office of Research and Development, United States Environmental Protection Agency, Narragansett, RI, USA.
Email: mulvaney.kate@epa.gov

Abstract

Mitigating non-point source nitrogen in coastal estuaries is economically, environmentally, logistically, and socially challenging. On Cape Cod, Massachusetts, nitrogen management includes both traditional, centralized wastewater treatment and sewering as well as a number of alternative technologies. We conducted semi-structured interviews with 37 participants from governmental and non-governmental organizations as well as related industries to identify the barriers and opportunities for the use of alternative technologies to mitigate nitrogen pollution. The interviews were recorded, transcribed, and then analyzed using content analysis and rhetorical analysis. Cost and technical capacity to reduce nitrogen were the most discussed considerations. Beyond those, there were a slew of additional considerations that also impacted whether a technology would be installed, permitted, and socially accepted. These included: maintenance and monitoring logistics, comparisons to sewering, co-benefits, risk/uncertainty, community culture, extent of public engagement, permitting/regulatory challenges, and siting considerations. The insights about these additional considerations are valuable for transferring to other coastal areas managing nutrient impairments that may have not yet factored in these considerations when making decisions about how to meet water quality goals.

KEYWORDS
alternative technologies, best management practices, green infrastructure, social acceptance, nitrogen mitigation, nutrient pollution

1 | INTRODUCTION

Nutrient pollution is one of the biggest pollution problems in the United States (U.S.) inland and coastal waters (Bricker et al., 2003; Howarth et al., 2000; Woodward et al., 2012). In coastal waters, cultural eutrophication can lead to a suite of adverse outcomes including the degradation of seagrass beds and shellfish habitats, decreased water clarity, and more (Bricker et al., 1999; Driscoll et al., 2003). Similar to non-point source water quality management efforts elsewhere, Cape Cod, Massachusetts, USA ("the Cape") faces a number of challenges in dealing with nutrient pollution (Boesch, 2002). These challenges include the diffuse nature of the nitrogen inputs, a relatively low density (for the northeastern U.S.) of residential and commercial development which makes sewering more expensive, and a complex set of stakeholders and decision makers with sometimes conflicting interests and values (Perry et al., 2020).

Paper No. JAWR-22-0068-P of the *Journal of the American Water Resources Association* (JAWR).
Discussions are open until six months from issue publication.

Published 2022. This article is a U.S. Government work and is in the public domain in the USA.

Research Impact Statement

There are a number of barriers and opportunities in the use of alternative technologies to mitigate the nitrogen pollution affecting Cape Cod's estuaries beyond just costs and technical performance.

The Cape has more than 30 small embayments under extensive nitrogen management planning due primarily to the use of traditional septic systems which provide insufficient wastewater treatment. The traditional solution, centralized wastewater treatment and sewering (referred to by many stakeholders engaged in the process and throughout this paper as just "sewering"), is being considered alongside more than 50 possible alternatives for nitrogen mitigation, referred to collectively here as "alternative technologies" (although generally referred to elsewhere as "BMPs" or "best management practices"). The alternative technologies range from source control efforts such as innovative and alternative septic systems (I/A systems) that treat wastewater before it is released to the groundwater to others that remediate nitrogen in the ground or surface waters, including aquaculture, rain gardens, and permeable reactive barriers (PRBs). The technologies also include diverse environmental restoration projects such as culvert widening, constructed wetlands, salt marsh restorations like living shorelines, and more (Cape Cod Commission, 2021a, 2021c).

To best understand how nutrient mitigation practices can be advanced, it is critical to identify behavioral barriers of individuals and communities (Reddy et al., 2016). There is an increasing set of studies investigating the adoption of conservation practices for remediating nutrient pollution from agricultural and stormwater sources, which provide helpful insights into the adoption of non-point source pollution control practices in general. Barriers to the adoption of agricultural conservation practices include economic complications, information deficits, social/interpersonal conflicts or communication limitations, risk aversion, social norms, land ownership and tenure, and aesthetics (Petrzelka & Marquart-Pyatt, 2011; Ranjan et al., 2019; Ulrich-Schad et al., 2018). Kaplowitz and Lupi (2012) investigated stakeholder preferences for non-point source BMPs. They found that social science methods (choice experiments in this case) can be utilized to evaluate stakeholder preferences for BMPs and highlighted the importance of integrating stakeholder input and values into decision making. A large part of the discussion on the adoption of conservation practices for stormwater is based on the application of green infrastructure approaches, mainly in urban settings. Flynn and Davidson (2016) found operational-choice rules (ordinances, funding, management plans) were one of the most complex factors in green infrastructure implementation.

There has been less work conducted on the adoption of various alternative technologies for nutrient reduction in non-agriculture/stormwater settings. Heberling et al. (2018) explore the engagement of other types of nutrient pollution mitigation beyond agriculture for use in nutrient market trading, such as the repair/replacement of failing septic systems and various types of green infrastructure. In earlier work on Cape Cod, Valiela et al. (2000) defined end point measures such as phytoplankton and biomass that can be meaningful for stakeholders for use as modeling goals in various loading management efforts. However, this work does not incorporate social acceptance challenges to implementing the different management efforts.

In an analysis of alternative toilets for mitigating nitrogen on Cape Cod, Wood et al. (2016) noted that some research has been conducted the toilets' technical capacity to reduce nitrogen, there is little consideration of the decision-making processes for the homeowners who will ultimately need to install the technologies (Wood et al., 2016). This is also generally true for the towns, county, and watershed-level organizations who are actively developing plans that will include or reject these technologies for use on Cape Cod. As there is increasing information about nitrogen reduction capacity and costs (although both still have considerable uncertainty associated with them), a concurrent body of information about the other reasons why a technology will/will not be used has not been collected. This paper explores, through semi-structured interviews with a range of participants ($n = 37$) in the planning and implementation process, barriers to and opportunities for the use of these alternative technologies for nitrogen management. We sought to understand why different technologies are considered, implemented, or rejected. The lessons drawn from these interviews can be applied in many of the coastal communities considering the use of alternative technologies for nitrogen remediation.

2 | CASE STUDY DESCRIPTION

On Cape Cod, only 3% of wastewater is processed at centralized treatment plants. The remainder is handled by more than 120,000 septic systems designed to control pathogens that do little to remediate nitrogen (Cape Cod Commission, 2021b). Instead, the remaining nitrogen passes through those septic systems and is discharged to ground- and ultimately surface waters, accounting for more than half of the nitrogen loading to the Cape's estuaries (Howes et al., 2003). These waters are nutrient limited and are strongly affected by the influx of nitrogen pollution, especially the dozens of smaller, largely enclosed estuaries that line the Cape's southern shoreline. Because current efforts to address eutrophication are insufficient, total maximum daily loads (TMDLs) for nitrogen have been set for more than 30 watersheds on Cape Cod (see Figure 1).

FIGURE 1 Embayment watersheds for sub-embayments with nutrient total maximum daily loads (in red) on Cape Cod, Massachusetts, USA. Inset shows the eastern United States and the box within it highlights the location of Cape Cod. GIS data from the Cape Cod Commission's Open Data Hub and basemap courtesy of OpenStreetMap.

Current efforts to meet water quality goals on Cape Cod stem from actions to implement Section 208 of the Clean Water Act. Implementation of Section 208 of the Clean Water Act is placed with the states, in this case, the Massachusetts Department of Environmental Protection (DEP). In 2013, the state designated the Cape Cod Commission (the regional planning agency) as the agency responsible for updating the 208 Plan, originally written in 1978, to address nutrient pollution in Cape Cod waterbodies. The 208 Update adopted a watershed approach to planning, with the towns within a watershed ultimately responsible for the decision making and implementation of nitrogen management efforts (Perry et al., 2020). This is complicated, as implementation of nitrogen-reduction efforts requires agreement by neighboring towns to site, permit, fund, install, maintain, and monitor remediation efforts (Cape Cod Commission, 2015; Milz, 2018; Perry et al., 2020).

Early decision-making efforts and community engagement has largely centered on discussions about the costs of implementation and analysis of the nitrogen-reduction capacities of various technologies (Cape Cod Commission, 2021a; Perry et al., 2020). Initial estimates for sewering all of the watersheds on Cape Cod totaled $4.2 to 6.8 billion USD for capital expenditures only (Cape Cod Commission, 2013). This was considered to be a high cost to be borne by the approximately 200,000 year-round residents, and also by seasonal homeowners and tourists, who are present during the summer (June–September) peak season for which wastewater system capacity must be sized. Because of the cost, the Cape Cod Commission and the individual communities began exploring other ways to remediate nitrogen pollution beyond sewering. Communities have explored various alternative nitrogen mitigation technologies ranging from the use of shellfish within the estuaries to source control through I/A systems (Cape Cod Commission, 2021a), seeking to defray costs, hasten remediation, and enjoy co-benefits. Some technologies serve as source control to reduce the nitrogen loading into the groundwater (sewering and I/A systems), while others intercept nitrogen pollution in the groundwater or before it reaches the estuaries (e.g., constructed wetlands, PRBs) or can be removed from the estuaries (e.g., shellfish aquaculture). A number of pilot projects for different types of technologies have been installed across Cape Cod (Cape Cod Commission, 2021c), with additional pilot efforts in process.

The state, Cape Cod Commission, and towns have worked to develop the Watershed Permit system to meet the TMDLs, a first-of-its-kind permit that outlines the individual steps each of the towns within a watershed will take to mitigate nitrogen. The first Watershed Permit was issued in 2018 for Pleasant Bay. To receive approval for the Watershed Permit, four towns developed a Targeted Watershed Management Plan and Inter-Municipal Agreement that establishes each town's reduction responsibility, performance standards, authorizes certain activities, and lays out timeframes for implementation and monitoring. Watershed permits, issued by Massachusetts DEP, allow for the inclusion of alternative technologies in addition to traditional sewering to meet the TMDLs (Pleasant Bay Alliance, 2018). Several of the Cape Cod towns are considering the implementation of Watershed Permits in some other watersheds but are also looking into other policy instruments that are more focused on traditional wastewater treatment plans at an individual municipality level.

3 | RESEARCH METHODS

For this qualitative case study, we conducted 26 semi-structured interviews with 37 decision makers and technical experts responsible for implementing nitrogen mitigation efforts on Cape Cod in the spring and fall of 2017 (see Figure 2). Semi-structured interviews, and other qualitative methods, are often employed as an exploratory method to develop rich, in-depth insights about a specific situation (Hammarberg et al., 2016; Prokopy, 2011), in this case, the use of alternative technologies for nutrient management on Cape Cod. The use of semi-structured questions allows for open-ended investigation of considerations in nutrient management beyond what could have been investigated for known phenomenon through a survey or other quantitative methodologies (Burnham et al., 2016; Hammarberg et al., 2016; Prokopy, 2011). Qualitative data are generally not appropriate in use for counting or quantifying (Hammarberg et al., 2016). Past work employing semi-structured interviews has been used to investigate a number of water research topics. These include a range of topics from drinking water provisioning from forests (Huizenga et al., 2022), the urban use and exploitation of groundwater (Akpabio & Udom, 2018), approaches for protecting isolated wetlands (Floress et al., 2017), through the major challenges from climate change and social change related to water management (Burnham et al., 2016).

Participants represented (1) town, county, state, and federal agencies and departments, (2) regional and non-governmental organizations and (3) related consulting companies and industries. The participants included both those ultimately responsible for meeting TMDLs and setting policies as well as the technical experts and consultants and non-government organizations engaged to provide insights on the potential use of the various technologies. TMDL implementation crosses governance boundaries and includes efforts from municipal, county, state, and federal agencies. Most of the participants from government agencies were career civil servants, but two of the interviewees were municipal-level elected officials. Interview participants (hereafter "participants") were identified through their participation in regional meetings and in local media presentations, with additional participants identified through snowball sampling (Lindlof & Taylor, 2011). Except for two phone interviews, all were face-to-face interviews. Participants were contacted via email. All contacts except one contact who did not respond to our emails agreed to be interviewed. The number of interview participants, $n = 37$, is above the threshold generally applied for grounded theory analysis ($n = 30$, Thomson, 2010). The interviews averaged 72 min in length. Five of the interviews had multiple participants leading to a higher number of interview participants ($n = 37$) than interviews ($n = 26$). Qualitative sampling is not designed to be generalizable, but rather to capture a richness in perspective among decision makers and technical experts that can highlight important dimensions in water decision making and that are comprehensive in scope to explicate the scope of the topic (Morse, 2010; similar to Huizenga et al., 2022; Popovici et al., 2021; Floress et al., 2017). In the interviews, data saturation was reached, meaning no additional novel information was generated in the final interviews of the process (Corbin & Strauss, 2014).

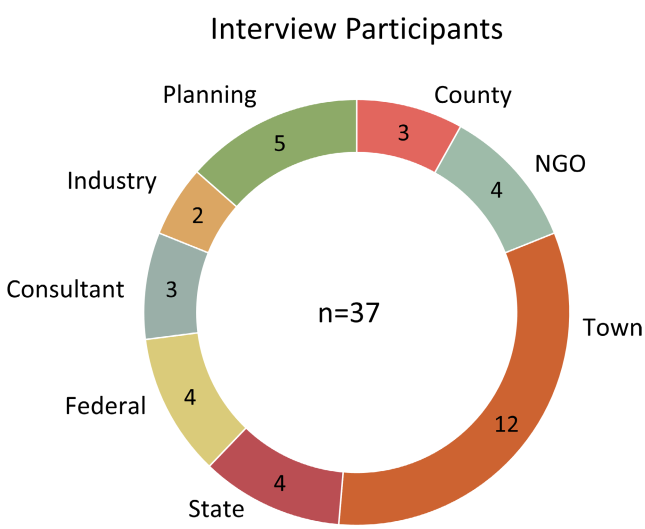

FIGURE 2 The number of interview participants by type of organization (non-governmental [NGOs] and planning organizations, town, state, and federal agencies, consulting companies, and industry). There were 37 total participants.

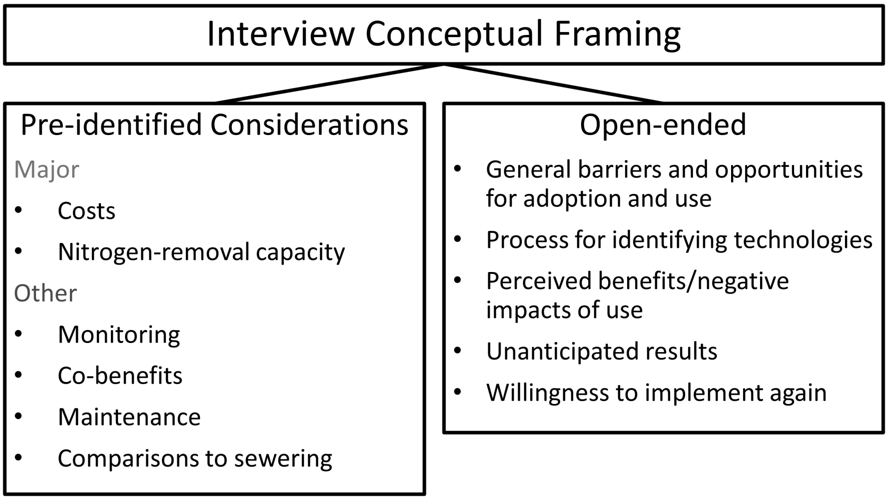

FIGURE 3 Basic framing for the semi-structured interviews. Full interview questionnaire is available in the Appendix.

Prior to starting the questions, a consent form was read to all participants and participation in the interviews was voluntary. Once the interviews were started, no participants ended the interviews nor declined to participate. This research was determined to be exempt from further review by the University of North Carolina at Chapel Hill Office of Human Research Ethics (Study #: 16-2245). The primary discussion of the interviews was based on the consideration of alternative technologies relative to traditional sewering for reducing nitrogen input into the bays. The specific technologies targeted in the interviews included: constructed wetlands, I/A septic systems, living shorelines, PRBs, rain gardens, and shellfish aquaculture.

The central framing of the interviews focused on identifying the reasons why or why not a technology or technologies was/were investigated or adopted (Figure 3 the full set of semi-structured interview questions can be found in the Appendix). Based on prior experience working on nutrient management in the area, we specifically asked about the known major considerations of cost and nitrogen-reduction capacity, as well as some other known considerations: monitoring, maintenance, co-benefits, and comparisons to traditional sewering. We included multiple open-ended questions to allow for the identification of lesser-known considerations in the adoption of alternative technologies. The use of a semi-structured interview format allowed for follow-up questions for clarification or additional probing into the topic.

The interviews were recorded and professionally transcribed. Colloquial use of "you know," "um," and "hmm" was removed from the quotations for clarity. The transcriptions were open coded and axially coded using QSR NVivo 10 to identify and categorize relevant themes and arguments. Open coding assigns initial codes to data (quotations in this work) based on its properties and axial coding then draws connections among the initial codes to identify more general themes or categories (Corbin & Strauss, 2014). All the interviews were coded by one author and a subset of the interviews ($n = 7$) were also coded by another author to test for intercoder reliability. Coding agreement was higher than 97% for each of the seven tested interviews.

4 | RESULTS AND DISCUSSION

The interviews revealed the complexity of both the nitrogen problems and the adoption of potential solutions. The watershed-scale impacts of individual household and community nitrogen inputs coupled with the high costs of mitigation make decisions difficult for local, regional, and state governments. The major anticipated themes, costs, and nitrogen-reduction capacity were elicited in all of the interviews and presented multifaceted considerations. The other anticipated themes of considerations (maintenance, monitoring, co-benefits, and comparisons to sewering) were also important themes across the interviews. Additional themes of considerations for the use of alternative technologies emerged from coding the more interview data, including risk/uncertainty, community culture, local participation and outreach, siting, and permitting/regulations. Many of these themes are strongly connected to the other themes. The themes should not be considered as tidy silos, but rather interconnected considerations for the use of alternative technologies in nutrient management.

4.1 | General considerations

All the participants acknowledged that nitrogen pollution is a serious challenge to Cape Cod's waters and that impacts are already being realized in their communities and have been a challenge for several decades. For example, one participant noted,

> When we started our, our planning process in the mid-90s, we recognized that there was a nutrient problem that was becoming more and more obvious. I was getting phone calls from residents saying, “You know, I've lived here 50 years, I grew up and there's no [sea]grass where it used to be and there's no shellfish where it used to be.” And, fishermen would come and say kind of the same thing, and shellfishermen would come in and say the same thing. And so, people were recognizing that the local environment was changing, but they didn't necessarily know why.

The surge in population during the summer months (estimates range from doubling to tripling of the population) by many visitors who contribute nitrogen to the system, but who are not taxpayers, complicates the enforcement of the “polluter pays principle.” This is similar to other non-point source management efforts (Tobey & Smets, 1996) and a considerable management challenge. Because of the seasonal nature of the Cape, it also means that infrastructure needs to be built to handle peak summer nutrient input, which is markedly greater than what is needed for the rest of the year.

Ultimate implementation of water quality improvements lands largely on the shoulders of local governments (Perry et al., 2020). On Cape Cod, 14 of 15 of the towns have a Town Meeting form of government that heavily incorporates community participation into governance and decision making. Participants found both value and challenges for local decision making within this type of governance. For example, one participant said,

> Now putting this together, I would say, is really complicated, because you've got citizens involved, you've got committees involved, and you're getting involved in something that nobody, well, very few people have any experience with … So, the people process is really complicated.

Most of the participants did not discuss the use of alternatives versus sewering as either/or, but rather as coupled use to meet policy targets. As one participant noted, “We believe that we can significantly reduce the sewer footprint and approach the rest of our obligations with non-traditional technologies. And we have moved in that direction ever since.” Participants revealed a depth of complexity and uncertainty in deciding about how much traditional wastewater infrastructure to install. For example, one participant said,

> The alternatives open up much more questions than the traditional sewering in so that, my opinion, traditional sewering is easy, understandable, containable, and we trust it. So … you have the unknown of the alternatives and then you have the huge opportunities to achieve a result that may produce the same results in the estuary but open up a whole new myriad of other considerations.

Others were concerned that the consideration of alternative technologies was being used as a delay tactic. For example, one participant noted:

> …potentially on the Cape, people see it [alternative technologies] as an easy fix or we'll do this instead of controlling nitrogen because it's easier to get people to go along with this and we don't have to make people build sewers or do source control … I think that it has a potential to be a dangerous distracting away from what we're trying to do.

Another participant noted,

> …it's a combination of cost cutting, fervor whipped up by proponents who may or may not have the best interest of the communities at heart, and people who are untrained in, in these kinds of things or just simply uninformed and just don't want to spend the money, that they'll just jump and latch onto anything and, and try to push it.

4.2 | Costs and nitrogen-reduction capacity

In early decision-making and research efforts on the Cape and in nitrogen mitigation efforts and analysis elsewhere, the primary focus has been on two factors: the identified costs and nitrogen-reduction capacity of the various technologies (e.g., Cape Cod Commission, 2021a; Hasler et al., 2019; Merrill et al., 2021). All participants noted considerable concerns about both components. In addition to costs and nitrogen-reduction capacity, a number of other barriers and opportunities were voiced related to the social acceptance in the use of alternative technologies. Below, we will first discuss the two primary factors (costs and nitrogen-reduction capacity), and then also highlight other critical factors affecting community acceptance of the technologies. These other factors have been largely ignored in technical discussions of the technologies but are pressing concerns for many of those tasked with decision making related to the exploration, implementation, and regulation of the alternative technologies.

4.2.1 | Costs

The cost of nitrogen pollution mitigation through sewering or alternative technologies to meet the TMDLs was a concern for every participant. For example, when asked about paying for mitigation efforts, one participant stated, "So we haven't had any impediments other than getting money. We've had to hustle money to, to do everything … money will always be a barrier."

When participants talked about "costs" as a major barrier, they meant any number of different related topics ranging from the large price tag for sewering to a lack of understanding related to the true cost of the alternative technologies to concerns about how the costs will be distributed among the community. Many of the technologies are still being piloted, so long-term costs can be difficult to estimate, and it is also challenging to estimate how much it would cost to scale up implementation. Many communities have not determined how they will pay for the nitrogen mitigation, and participants believed the distribution of costs was going to be a significant barrier in moving forward. As one participant stated, "…the issue will ultimately be … how does a town cover these costs over the long term? … how do you do that in a way that's fair?"

Alternative technologies are often discussed as being potentially cheaper than traditional sewering and wastewater treatment (Wood et al., 2015) for meeting the reduced nitrogen loading goals in the 208 Plan Update. Cost is the primary reason for consideration of the different alternative technologies in watershed planning. One participant noted: "It is seen as potentially being more cost effective. I think that's probably one of the major drivers." Another participant said, "The increased cost efficiency [cost per kilogram of nitrogen removed]. That it's expected to cost a lot less."

Many of the participants noted that costs remain unclear, and that it is likely that source reduction could be a more cost-effective approach in some areas. As one participant noted, "There may indeed be times when reduction at the source is infeasible or really cost prohibitive. But, there's going to be other times where it is going to be probably the best way forward in, in terms of future growth and in terms of reducing some of the impacts on freshwater bodies and whatnot that … attenuate load."

While the costs of sewering was perceived to be more expensive, many participants felt more confident in the investment in the traditional infrastructure. There were concerns about the difficulty in calculating that actual costs of the technologies. One participant explained, "That's my own personal thing of getting those maintenance and replacement times … and to get that in a uniform way where we're collecting across these projects where, some is grant money, some is town money, some is all over the place, it's hard to collect that in a usable format." Another participant noted, "…I would start to see if you can address source reduction at the home and whether the cost over the long term would be less than sewering that home. Because my guess is some of these technologies can be quite expensive and would require operation and maintenance costs, plus the cost of an operator to keep it working effectively."

Participants were also concerned about who would bear the costs of the mitigation. One participant noted, "…they'll be some decisions made on what, which portions of the town should be sewered and which ones not, and as a result, some homeowners won't be charged for putting in the pipe, and there's that question of, 'How do you make this fair so that everyone's responsible?'" One town, Chatham, has decided to sewer the entire community instead of using any of the alternative technologies to meet their nitrogen load reductions. By sewering every property a participant noted that "it spreads the cost out among the entire community … So everybody will get the advantage of having sewers … [and everyone will pay because] everybody benefits from the improved water quality."

Other participants were concerned that those who benefit most from improvements and co-benefits of the technologies may not be paying proportionally for the implementation of technologies or sewering. Those seen as having disproportionate benefits included tourists as well as waterfront homeowners (which are often second homes on Cape Cod). For example, in a discussion of wetland restoration efforts, a participant noted:

> …So, by the government paying for this restoration, this was an externality. It was a gift that is being absorbed by the abutters who don't have to pay for it … it's a market imperfection, and, and I think if you could, I think there has to be a way to get people to understand, for developers to understand they can do this [restoration], and, and then the people who benefited would be paying for it.

Another participant described the perception that the impact of nitrogen pollution from tourism and seasonal residents falls on the local, year-round residents.

> And that infrastructure cost is born on the residents that live on the Cape year-round … there's a backlash by those on the Cape saying, 'Wait a minute. Year-round, where are these people? They're gone. They're not contributing. Yet when they come, they're impacting with their nitrogen loads and everything else at a time of year when we see turbidity impacts in our coastal embayments.' Those loads are huge, and it should not be a cost that's borne by the residents that live there year-round, many of whom fall below poverty level.

Most of the communities are still working out how they will distribute the costs for nitrogen management, but in many areas, there is an emphasis on charging second-home owners. As one participant described, "So, we're not at all bashful about talking about charging our seasonal homeowners more than our year-round homeowners who can least afford these. If somebody's got a second home here, it's more likely that they're going to be able to pay a lot more. So, I don't think there's been any qualms about having that conversation."

4.2.2 | Nitrogen-reduction capacity of the technologies

Many of the technologies that are being considered for nitrogen mitigation are still in their piloting phases, and their abilities to remove nitrogen from the watersheds at all or over the long term remain uncertain. There is a range of nitrogen reduction for the cost and uncertainty associated with the different technologies, similar to other nitrogen BMPs (e.g. Hasler et al., 2019), but all remain less certain than the reduction rates of wastewater treatment plants. One participant said, "There's no definite data. There's no official recognition that they're better. Like, we're still learning." Another participant noted, "There are some that are more proven, that we have more faith in … as opposed to ones that are not very well proven … we're going to keep it [alternative technologies] on a very short leash in terms of how much credit we give until the data either proves or disproves the, the efficacy of any given technology."

In addition to uncertainty related to the nitrogen-reduction capacity of the various technologies, there were also concerns that many of the alternative technologies (other than I/A systems) did not prevent nitrogen from entering the system. As one participant described related to the use of shellfish to remove nitrogen from within the estuaries: "I think it's just, it's the equivalent of sending the fire department out after your house is already burned down, because … shellfish are harvesting phytoplankton, the nitrogen has already expressed itself, already done whatever damage its gonna do …" Another participant said,

> I felt strongly on the need for reducing the loads at the source. And for that purpose alone, sewering made the most sense to me, professionally and scientifically … My concern is that any of these technologies … they don't really address the source at its source. They allow loads to pass through the watershed, in the aquifer, doing damage in a way that we haven't taken into account.

4.3 | Other considerations beyond costs and nitrogen-reduction capacity

While almost all participants identified the costs and capacity to remove nitrogen from the system as the key considerations for both alternative technologies and sewering, a number of other themes of considerations were identified as critical barriers and opportunities for their use. The major considerations included both the anticipated considerations of maintenance, monitoring, co-benefits, and comparisons to sewering, as well as a number of additional considerations elicited through the more general questions such as risk/uncertainty, community culture, local participation, siting, and permitting/regulations (see Figure 4).

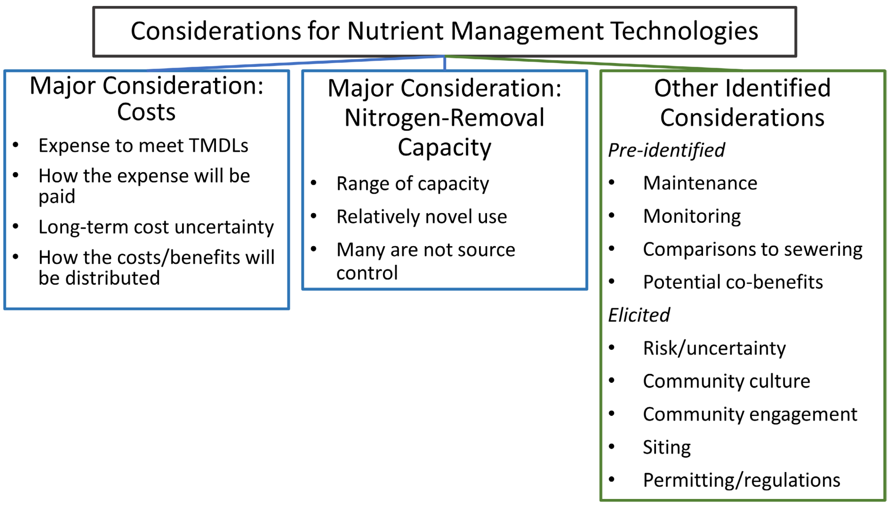

FIGURE 4 The identified considerations for the use of alternative technologies in nitrogen management. Costs and nitrogen-reduction were the most discussed topics, but a number of additional considerations were identified across the interviews as well.

4.3.1 | Pre-identified consideration: Maintenance

Consistent concerns among participants about the use of alternative technologies are who will be responsible and what is needed for the long-term operations and maintenance of those technologies? How will these technologies be kept functional to meet the ecological targets? While a considerable amount of maintenance is required for traditional wastewater treatment, participants felt more confident in predicting future maintenance needs and the responsible parties for it relative to the alternative technologies. For example, "Water treatment plants, wastewater treatment plants, we know those. We know how to deal with them." was a response from a participant when asked about maintenance challenges. Thus far, most of the alternative technologies have been installed as pilot projects or for primary reasons other than nitrogen mitigation such as stormwater management to prevent flooding or for ecological restoration, so most do not have clear guidance for long-term efforts. One participant noted,

> So far, maintenance is a huge thing. And it's just this glaring thing that we have realized that in order for them to work they have to be checked on, they have to be maintained. And, the towns are just, they have so many things they already need to do. They're already overworked and understaffed. And, so it's not, it's not for lack of will. They just don't have the time and it doesn't get highly prioritized.

Other participants spoke more generally about the aversion to maintenance. For example, one participant said, "I think people have a natural negative response to a lot of maintenance because they link it to their own lives, right? Like, I don't paint my house every four years, right? … if you look at the lifecycle cost, and something is less expensive, but it requires a lot of maintenance, I think there's still a negativity to that …".

Traditional wastewater treatment requires significant investment in ongoing, long-term maintenance through its wastewater treatment plants operation and upkeep of sewer lines. One of the more desirable characteristics of some of the alternative technologies is the ability to implement more "passive upkeep." As one participant said, "I mean, yeah. If you, if you have the technology that's effective and … and it doesn't require a lot of maintenance, you've got a win-win there." For example, one participant described restoration as,

> …we, my office, myself, we are very stubborn about our view about what makes the restoration. So, it's going to try to repair fundamental physical processes on the one hand that drive habitat formation and maintenance. It's going to not involve human maintenance in the long term as possible … So that is our culture of ecological restoration.

Another participant described the motivation as: "Some communities also want to pursue alternative methods because they just think that they're more in keeping with the environment. More environmentally sustainable. They like the idea of working more with nature, letting nature kind of do its thing to help reduce the nitrogen on its own."

Concerns about long-term maintenance at the household level were also voiced, particularly in discussions about I/A septic systems which are primarily installed at the household level. Concerns included both the need for long-term upkeep and also for paying for that upkeep. One example of this is:

> You got technology that's simple, easy, throw it in your backyard and you get an extra bedroom. Oh, that's great. Wait a minute, it's gonna cost me $28 a month to run? And then I'm gonna have somebody coming in here four times a year, taking samples? And what else is gonna happen here? Oh, I'm gonna have to pump it more frequently? Well, wait a minute …

That participant also voiced concerns about what the maintenance requirements would be to meet regulatory standards for the TMDLs. He stated,

> Yeah, the watershed permit, this worries me a little bit because theoretically, and I've talked to regulators about this too … I hope they don't approve watershed plans without that (maintenance plans). Because, boy, I see disaster coming. Because if you are not monitoring and maintaining they are not working.

How passively the technologies perform in the long run remains largely unknown. For example, some of our participants described rain gardens as a relatively easy, passive technology. One participant said, "the beauty of the rain garden is that it's so simple. Every homeowner can get it, and yet the magnitude of the effect of having every homeowner get it can have a significant impact …" While some described rain gardens as one of the easiest-to-maintain technologies, even they had a number of concerns about long-term maintenance. A participant recounted the following story about the challenges of maintaining rain gardens: "A rain garden, you would think we would know how to deal with them … They kept on mowing down some of the plants … I finally ended up going down and taking plastic knives and write "no cut" and stuck them around so they knew …" Other rain garden projects from years ago were no longer maintained leaving one participant wondering: "…I'm like, what am I missing, and like, am I in the right spot? I did lots of wandering around. And I was like, I don't think these things are working the way that they, you need them to."

4.3.2 | Pre-identified consideration: Monitoring

"So, there's lots of things that need to be looked at." This short response to the question "What about monitoring?" is representative of all of the participants' responses regarding monitoring needs. When discussing "monitoring" for the use of alternative technologies, there are several monitoring considerations on Cape Cod. As another participant noted, "Part of the problem is getting down to the nuts and bolts of what is the problem and how comfortable can we be knowing it works, or doesn't work, right?" Monitoring of the technologies includes evaluating whether they are reducing nitrogen to the intended extent and conducting general monitoring to identify how well ecological targets within the watersheds are being met. Monitoring protocols to measure progress in meeting the ecological targets, the TMDLs for the estuaries, were outlined through the Massachusetts Estuary Program and in the 208 Plan Update (Cape Cod Commission, 2016), but it is less clear what monitoring efforts for each of the alternative technologies is appropriate for their use in meeting the ecological targets. The Cape Cod Commission, along with an ad hoc monitoring committee, developed several skeleton monitoring plans for some of the technologies being most considered on the Cape for use in watershed permits. Included as an Appendix to the 208 Plan update (Cape Cod Commission, 2016), general monitoring requirements for non-traditional technologies to be used to meet watershed TMDLs are outlined as well as more specific protocols for eight technologies.

This Technology Monitoring Guidance from the 208 Plan Update specifically calls for an adaptive management approach to incorporate monitoring efforts for the alternative technologies into watershed permits or for otherwise meeting TMDL limits (Cape Cod Commission, 2016). This is particularly important with the implementation of new watershed permits and credit system. There was a lot of discussion among almost all of the participants about determining monitoring efforts, both for an individual technology's capacities as well as for meeting the ecological target TMDLs, as many of these alternative technologies have not been used for receiving credit for nitrogen load reduction before. As one participant noted, "…we don't know what the state is going to require us to do, or the EPA, or for any of these projects and that's when we don't know … how much money is its gonna cost? Are they going to require us to do testing that we have to take to a certified lab …?"

There are a number of different organizations conducting baseline nutrient and nutrient-related monitoring efforts for various waterbodies on Cape Cod that include data collection for ecological targets. Efforts include citizen science monitoring groups and professional scientific research efforts (e.g., Barnstable Clean Water Coalition, 2021; Cape Cod Cooperative Extension, 2021; Center for Coastal Studies, 2021). Despite these monitoring efforts, a number of participants noted that measurable impacts for nitrogen reduction have not been documented for many of the technologies. For example, when discussing shellfish aquaculture, one shellfish farmer participant said,

> I challenge people who have, who are promoting this, especially the people around town who have done some pilot work. Can you demonstrate a change, a measurable change, in water quality? I don't care what the prior is, you can measure chlorophyll A, you can measure light transparency, you can measure nitrogen, anything. If you can demo, you can show me a measurable change in water quality, then I'll get excited about this.

Despite the calls for monitoring of both the individual technologies as well as ecological targets, participants also discussed how there is often no or insufficient funding associated with many monitoring efforts. As one participant noted, "So the first thing to make clear is that there's no money … for all of the amount of money that the federal government spends on restoration, there's no money for monitoring." Another participant noted some interest across the towns on a regional monitoring effort as a cost-saving measure: "There is some talk on the Cape of whether or not that [monitoring] can be taken up as a regional program that would be administered by Barnstable County and alleviate some of the financial burden from the towns to do that …".

4.3.3 | Pre-identified consideration: Comparisons to sewering

Although a majority of the towns' efforts and plans to meet the nitrogen TMDLs are through sewering, there are still a number of limitations to just using the traditional infrastructure. One limitation identified by a number of participants is the time delay to meet the TMDLs due to the nitrogen load already in the groundwater. Because of the non-point source nature of the pollution and the up-to-100-year time delay in the groundwater reaching the estuaries, source control will take decades to change nitrogen loads to the bays (Balogh et al., 2022). One participant noted the following about an area that had already been sewered, "And because there is such a slug of nitrogen from the poorly treated effluent … it is taking a long time for that to flush through … that's a constant problem." Additionally, plans for sewering will take decades to be installed.

Beyond time delays, siting wastewater treatment plants is often even more challenging than it is for the smaller, site-scale technologies and can lead to time delays and other complications. Collectively, the time delay for meeting TMDLs and restoring the nitrogen impacts in the estuaries on Cape Cod will take multiple decades, leaving more time for ecological and social impacts from the nitrogen pollution to continue or increase. As one participant noted,

> So, what we're also looking at is to help us with we're having issues in the waters now? What can we do that's quick that we can get in to help us so that we're not going over to that point where the whole system collapses and it's very hard to get it back up and running again? The idea is, some of this is, you put in now to help us through what's coming in the water now and what might be coming in the near future also. 'Cuz even if we go and, say I, go and sewer all of [local bay]. We still have a lot of nitrogen in that water and we're not gonna see that much of an improvement at first. It's gonna take some time … You're looking at these alternatives sometimes in short-term or mid-term to help us with issues that we're having right now. That sewering wouldn't help immediately.

An additional potential limitation of sewering discussed by participants was the loss of "community character" as the use of septic systems was perceived to limit growth in development. As one participant noted,

> And then a decision to step back and recognize that there were people in town who did not want to sewer the whole town. And part of that was cost, but other parts of that was a perception about what that would do to the character of the community if sewers came in. So, I think it really depends on the community and what kind of conversation they're having, and what the values are of the folks who live there, and how much you're willing to speak out about that.

4.3.4 | Pre-identified consideration: Co-benefits

An advantage identified in many of the interviews for the alternative technologies relative to sewering is the potential suite of co-benefits. Some co-benefits were identified as general motivations for the use of alternative technologies relative to traditional wastewater treatment. Other co-benefits were identified more specifically such as the possible flooding reduction benefits of rain gardens or wetland restorations. As one participant noted, "as you get that added benefit of whatever BMP install you're taking out of the physical component. So, for an urban environment, you, you want to really think about flooding in the physical stormwater problem, as well as the, the pollutant problem."

A number of participants noted the relative visibility of many of the alternative technologies provided valuable educational opportunities for their communities. One participant noted, "Yeah, I mean we get a lot of flow of traffic through there. People going to and from the islands. So, it's a lot of, even off Cape, people that get to learn a little bit." One community, Cotuit in the town of Barnstable, has a walking tour of its stormwater projects, many of which are intended to mitigate nitrogen (APCC, 2019).

Living shorelines are a relatively recent advancement in saltmarsh restoration to reduce erosion and are also being explored for nitrogen mitigation. In describing a pilot project, one participant noted the value of living shorelines, not just for ecological benefits, but for educational purposes as well. She said,

> Our intent wasn't like, "Oh, we're going to stop this erosion." That's kind of a positive biproduct, but it's about, I think, it's more about positive action. It's really, really important right now, especially with the state of climate education. That's one of our things, do climate education. People don't want to come and hear about they're going to be flooded and we're going to lose half our shorelines. But, they do want to hear, like, here's an example of something we can do and this is transferable …

Nitrogen reduction was seen as a co-benefit, not the primary driver for several of the technologies being considered on Cape Cod, including the use of living shorelines and the restoration of farmed cranberry bogs to wetlands. Cape Cod has a long history of cranberry farming, but many of these farms are less economically viable than in the past primarily due to external market forces (new farming approaches and higher-yielding cranberry varieties in other U.S. states and Canada; MDAR, 2016). Wetland restoration is a heavily considered use for these retired agriculture lands to provide public open space, wildlife and fish habitat, greenhouse gas and nutrients mitigation, floodplain restoration, and other ecological co-benefits. Restoration of cranberry bogs provides denitrification through changes in soil moisture, organic matter, and microbial biomass and restoration provides much greater nitrogen mitigation than just retirement of the cranberry farms (Ballantine et al., 2017). Some participants saw the nitrogen mitigation potential as a mechanism for gaining support for wetland restoration from cranberry bogs. As one participant stated, "So, the fact that the nitrogen issue is rising … is good for overall positioning of regaining wetlands …".

Many participants noted the possibility of job creation through the implementation of alternative technologies via the need for installation, monitoring, maintenance, and more of the technologies. Instead of seeing these as just barriers for use on the Cape, one participant noted the "job creation opportunities around those maintenance requirements … if you look at the lifecycle cost, and something is less expensive, but it requires a lot of maintenance, I think there's still a negativity to that, but it might be a good thing. Those might be local jobs, so … the higher maintenance might be a really good thing."

Job creation was particularly highlighted for the expansion of commercial aquaculture. As one participant noted,

> Like my pitch has always been like … it's a sustainable job. It's good, healthy seafood. It takes away from the seafood deficit in our country. It's employment … year-round employment in rural areas that's typically depending on tourism. And if it also helps clean up the water a little bit, that's good, but like aren't those other four things … isn't that enough?

4.3.5 | Elicited consideration: Risk/uncertainty

"They're in a town meeting saying 'We're gonna solve the problem here.' There better not be a town meeting 2 years later saying, 'Well, we thought we had it.'" As described in this quote, a barrier to use of alternative technologies that was consistently discussed in the interviews was their relative uncertainty and risk relative to sewering. As one participant noted: "Everybody knows wastewater technology is going to reduce the amount of nitrogen going into the waterbodies. But it's really, really expensive to implement. So, people want to avoid it. So, money is going into all sorts of alternatives, but I think there's a fear from a lot of people that if it doesn't work out all that money and time will have been wasted."

Contained within many of the participants' framing of risk, was a concern that many of the technologies would tackle the nitrogen pollution but would not be able to tackle additional types of pollution. Past research has revealed contaminants of emerging concern such as hormones and pharmaceuticals in the wastewater effluent from septic systems on Cape Cod (e.g., Standley et al., 2009). A number of participants expressed concern that they would spend considerable effort and money on technologies that would address nitrogen pollution, but then would need to implement more, different technologies to address contaminants of emerging concerns of other issues in the future. For example, one participant said, "Obviously contaminants are an emergent concern, are a big concern. I would much rather have to retrofit one wastewater treatment plant than 5000 septic systems. If at some point in the future the regulations change, which they invariably will, [it's] much easier to deal with it at that scale than backyard scale [for I/A systems]."

A common insight across participants was that local pilots were one mechanism for reducing uncertainty about the effectiveness and acceptance of alternative technologies. There are many ongoing water quality improvement projects on Cape Cod, many of which are pilots of alternative technologies to meet the TMDLs (Cape Cod Commission, 2021c). The participants heavily emphasized the need for more pilots of the alternative technologies to reduce risks of failure. As one participant noted, "But it's really important to actually have the data that shows if they work or not. We can't just put them in and hope." Another participant noted:

> We also are doing pilot projects, better understanding of where things are working and not working, to inform the decision making. The pilot projects are an important part of the step, because we really don't want towns just rushing out and using a lot of these alternative technologies before we really understand … what kind of conditions are best, how do you ideally want to design them? We're trying to collect that information right now to help the process.

4.3.6 | Elicited consideration: Community culture

While on a national or global scale the communities on Cape Cod may appear relatively homogenous, the individual communities identify as unique from one another. Almost every participant noted the unique attributes of the different Cape towns. Each community's individual social, political, and ecological conditions influenced the consideration of sewering as well as the implementation and piloting of various alternatives. As one town selectman said, "I, personally, having spent my life in town meetings … It's very difficult to say, 'X [meaning a different town] did it. We want to try it here.'" Another participant noted, "[nitrogen management efforts] that seems to really shake out town by town and a really sort of a philosophy of the community and how they, how they value their community. It's really different on the Cape, I think, from town to town."

Many of the local participants emphasized their unique community characteristics and how they were adapting the nitrogen mitigation efforts around those values. For example, as one participant noted, "Town culture makes a big difference … from a planning perspective, you have to be really sensitive. Some towns are absolutely concerned about everything. And it's just what they are. It's who they are. Towns have different personalities … A town full of lawyers is going to have a really different level of comfort than a town full of scientists." While nitrogen loading needs to be reduced in many of the watersheds, the strategies for doing so do not need to be the same. Because the decisions ultimately fall to the towns, individualized plans that meet community cultural goals are being developed, and may ultimately be easier to implement to meet those goals. Some communities, like Chatham, are implementing full traditional wastewater treatment while others, like Falmouth, are heavily piloting various alternative technologies to test usability within their watersheds. If and how quickly these various strategies are able to meet TMDLs will help to inform similar decisions that other communities off Cape Cod are working on as they grapple with how to meet TMDLs.

A unique consideration for many of the Cape towns relative to the rest of the country is the high rate of second-home ownership (UMass Donahue Institute, 2017). The second-home ownership influences the culture of the communities as well as the nitrogen management efforts. One participant noted, "…we hear that all the time on things like schools and fire stations and all. 'Well, I'm just a second homeowner. I'm only here for 3 months and I don't use the schools. Why should I have to pay for them?' Frankly, we never heard that with the wastewater plan. I think because people understood." Many of the second-home owners are pro-sewering, and they are also sometimes less aware of local conditions. As one participant noted,

> The other thing that factored into it … a very high second-home owner population. A lot of those folks come from places where they have sewers. They're used to sewers. They know how efficient and effective sewers are. A lot of them came to town and frankly used to go to meetings that I was presenting at and say, 'Well, wait a minute. We already have sewer. I flush my toilet; it's in a sewer.' And I'm like, 'No. It's going to your backyard where you have a septic system.' And they're like, 'My realtor never told me that.' And I'm like, 'Well, that's not my problem, but you don't have a sewer.'

4.3.7 | Elicited consideration: Community engagement

"So really, it's all gonna be familiarity which normally breeds contempt … but in this case, it would be comfort. They'd look at it and say, 'Oh, it's not too bad.'" This statement from one of the participants demonstrated the need to increase the visibility and familiarity of the alternative technologies. The 208 Plan Update included an extensive stakeholder engagement process (Perry et al., 2020), in which a number of different engagement efforts were implemented to understand the range of perspectives about nitrogen impacts and the possible solutions, build trust, and improve communication (Milz, 2018, 2019). Many of the participants noted the adoption of traditional or non-traditional nitrogen mitigation technologies comes down to the support of the communities who will benefit from improved water quality as well as bear the burden of impacts and costs. As one participant put it, "…it's not only a technology game, but it's an information game. And it is. Because it has a lot to do with messaging and having people understand exactly what's at risk because [nitrogen] pollution, as you know, is very difficult to measure and see …".

Engagement of the local communities ranged from one-way communication at public meetings to active collaboration in technical committees. One participant described the engagement in his community as, "It's a collaboration throughout the whole town. We even have people on our committee who are in charge of land or appropriating land, development. We have people from [NGOs and communities], but they're actually expanding their outlook for the whole town now, so that's actually something that's, I hope will be a big improvement."

While most of the participants identified community engagement as important for nitrogen management, many also noted that good engagement is difficult. For example, one participant noted the need for those who support nitrogen management to also participate in the process: "…So, they'll get you anyway they can. It's their right to do that, but it would be nice to have the other people that are supporting it be so vocal. That's an issue, you might have 10 people that want something positive, and you might have one person who's against it. If they're vocal they can overwhelm all the other people."

4.3.8 | Elicited consideration: Siting

Siting of both traditional wastewater treatment plants and the alternative technologies is a significant challenge for implementing nitrogen management on Cape Cod. Siting can be logistically challenging to implement because of the need for specific placement of a technology. For example, PRBs need to be sited in areas with concentrated groundwater flow, usually on public lands with enough space for the large, heavy construction equipment. This is not easy to find. One participant said, "So there is a lot of interest in PRBs, and, as a hydrologist, it's a little bit surprising because I think of PRB as, like, oh, it's got to really work to make it work right. You know? …. You gotta really nail it, or it's not gonna work." In an effort to characterize possible sites for PRBs conducted by the U.S. EPA, U.S. Geographical Survey, and the Cape Cod Commission, the Cape towns were asked to identify the sites where they thought PRBs would be most appropriate. From those sites, they selected five sites for extensive hydrogeologic and geochemical characterization to determine suitability for PRB placement. All the five sites had some challenges related to placement of PRBs (low or uncertain nitrate flux, depth to treatment zone, etc.), although several of the sites were deemed possible (WaterVision LLC, 2016). Similar to PRBs, rain gardens are also very dependent on siting to be effective. One participant noted,

> So I found one site and it was, basically a big sand pile with some beach grass planted in it … But the rain actually was just going down the road and then into the parking lot and then eroding the edge of the parking lot and then going straight into [a river]. So we had a rain garden but it was very clear from watching rain storms that the water wasn't getting in there.

In addition to the logistical challenges of siting the technologies, there is often resistance by the community to absorb the impacts of a technology at a site. For example, this resistance was discussed in the context of the shellfish farms disrupting water views or recreational use of an area by one participant,

> …the initial opposition of those folks who didn't want to see aquaculture in their front yard … and then you bump into the people who don't want to sacrifice any square inch of their water skiing and jet skiing and sailing opportunities, so, they don't want to look at dirty, muddy people growing shellfish in their viewscapes … So, if you can overcome the sociological challenges of placing oyster farms in these highly utilized estuaries, then it, I believe, can-- it's certainly going to be a net positive.

In addition to the challenges of siting technologies with impacts at a community or neighborhood level, household-level siting for technologies is also challenging. The best example of this is the urine-diverting toilet effort that was piloted in Woods Hole (Falmouth) on Cape Cod. Wood et al. (2015) found that urine-diverting toilets coupled with traditional septics for greywater waste had the lowest life cycle cost and highest cost-effectiveness. However, the installation of urine-diverting toilets has faced real limitations of social acceptance, as described by one participant:

> So we sent a flyer out to every single person with a water account in Falmouth saying we will install an eco, eco-toilet in your house, and we will give you a bonus … And, we will have somebody come and evaluate what changes have to be made to your house. Okay, so that flyer went out to everybody … So, the answer was zero [willing participants]. So, we have concluded from, from an acceptance point of view eco-toilets is not an avenue that's going to produce any real results.

While the alternative technologies introduce some new challenges in siting, the siting of wastewater treatment plants has a long history of challenges. For example, Makropoulos et al. (2007) identified 16 different attributes to consider in the implementation of centralized wastewater treatment plants. These attributes range from geochemical properties of the site to logistical limitations (e.g., distance to service area, utilities, or receiving waterbody) to social concerns (e.g., distance to residential areas) and more. Often because of their size and need to release effluent, they are very difficult to site on Cape Cod (and in other areas). For example, one participant described their difficulties in siting a wastewater treatment plant, "…because our wastewater treatment plant is in [another community], anything that you collect in the sewer goes into a whole 'nother watershed, and a whole 'nother waterbody … So that's a political issue …".

4.3.9 | Elicited consideration: Permitting/regulations

A consistent barrier identified for the use of alternative technologies in nitrogen mitigation is permitting and regulatory challenges. Because the alternatives that are being considered are so diverse, the permitting challenges for installation alone range from getting the Board of Health approval for the installation of a new type of septic system to Army Corps of Engineers approval for large-scale restoration projects. Many of the efforts have only been implemented in a few places, sometimes not even on Cape Cod or even Massachusetts. This makes determining the appropriate path forward for permitting a challenge for the towns or organizations who are attempting to pilot or install projects as both those who apply for and issue permits. One participant noted, "There's a whole lot of rigamarole that goes on." Another stated,

> The second obstacle or challenge I would say is the permitting burden. I am a strong believer in environmental permitting. I am not saying I don't want to do it, but it's important to recognize that these [restoration] projects are still treated like the construction of a shopping mall. I still have to get the exact same permits … for a project that has a benefit ecologically, culturally, and that has very minimal impacts. I would be very pleased if we could figure out a way to streamline it.

In addition to the challenges of permitting the technologies for installation, the towns are also considering the capacity of the technology to get credit toward their nitrogen TMDL reductions. Credit toward the TMDL-reduction goals is being assigned by the state through the Watershed Permit process, as discussed earlier. As of August 2021, only one watershed permit has been approved (for Pleasant Bay; Pleasant Bay Alliance, 2018), and it was the result of an extensive decision-making process involving the four towns in the watershed; multiple stakeholders; representatives from the EPA, state, and Cape Cod Commission; and more. Towns remain uncertain about the pursuit of the permits and are closely watching the implementation of the first Watershed Permit for Pleasant Bay. As one participant described his impression about the implementation of I/A systems in watershed permits as, "Yeah, the watershed permit, this worries me a little bit because theoretically, and I've talked to regulators about this too, theoretically if a town … decides 250 homes are gonna do all I/A systems, then that becomes part of their watershed permit. Then whose jurisdictional responsibility is it now to make sure those 250 work?"

5 | CONCLUSION

"It's tricky. But it's also not impossible." One participant provided this statement when describing the incorporation of alternative technologies into the overall plans for mitigating nitrogen in the Cape's impaired estuaries. In addition to the attention given to costs and capacity to mitigate nitrogen pollution with the use of alternative technologies, a number of other considerations were identified as important for realizing the opportunity of non-traditional nutrient control technologies. Some of these considerations, maintenance, monitoring, comparisons to sewering, and co-benefits were anticipated, but better clarified, through this work. Additional considerations for decision makers were also elicited, including risk and uncertainty, community culture, public engagement, permitting/regulations, and siting. These considerations are heavily interconnected and provide insights into the complexity of nutrient management. For example, a technology that is not maintained might have reduced nitrogen-reduction capabilities or siting often presents permitting challenges.

As the Cape's communities continue to work toward water quality improvements, considering the use of a number of alternative technologies will remain alongside the work of addressing the primary sources of nitrogen, the use of septic systems, through implementation of more comprehensive wastewater treatment systems. Several communities have already moved forward on expansion of sewering which will reduce excess nutrients. However, building wastewater treatment plants and getting every house hooked up to sewer lines is a multi-decadal effort, which means the existing legacy nitrogen will continue to pollute coastal waters (Merrill et al., 2021). Some of the technologies provide an opportunity to intercept nitrogen that has already been released into the groundwater or estuaries on the Cape, while potentially achieving other environmental improvements. As we learn more about alternative technologies cost, efficacy and acceptance, some may provide the flexibility, within their niches, to complement the region's wastewater management goals. Intensive piloting has already begun for many of the technologies, with important steps being taken to identify monitoring protocols for individual technologies as well as ecological targets.

There remain both qualitative and quantitative research gaps about the use of different technologies relative to sewering and relative to one another to meet nitrogen goals. Better quantifying the costs per kilogram of nitrogen removed for each of the technologies requires costing information not just for installation, but also to cover monitoring and maintenance over time. Alongside the investigations of cost and nitrogen-reduction efficacy of the various technologies, there needs to be consideration of the human actions needed to implement a technology and a community's willingness to do so. No technology is removing nitrogen if it is never installed. Future research needs to investigate the adoption, permitting, and installation processes to better identify specific barriers that prevent installation beyond cost and technical capacity.

Cape Cod is not unique in its coastal nutrient issues, with similar non-point pollution control planning processes moving along regionally, such as on Long Island, New York, and nationally related to stormwater, urban, and agricultural runoff. The lessons learned through Cape Cod's 208 Update process have the ability to inform these efforts and vice-versa. Unlike traditional point-source pollution management, non-point source issues involve more decision makers, overlapping property rights and interests, and multitudes of technologies to address the issues depending on the natural and social context. What was traditionally a problem suited to an engineering solution is now as much a socio-economic process. Understanding the social aspects of the Cape's pollution control efforts is crucial for learning between communities and transferring knowledge to other settings facing similar challenges. Better anticipating considerations beyond just cost and nitrogen-reduction will enable more informed decisions for individual communities and could increase the confidence in the use of alternative technologies. Over the next decades, the communities on Cape Cod will decide what type of coastal environment they choose to support with their development and nutrient management choices.

AUTHOR CONTRIBUTIONS

Kate K. Mulvaney: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; supervision; validation; visualization; writing – original draft; writing – review and editing. **Nathaniel H. Merrill:** Conceptualization; data curation; formal analysis; investigation; methodology; project administration; validation; writing – review and editing. **Sarina F. Atkinson:** Conceptualization; data curation; formal analysis; investigation; methodology; validation; writing – review and editing.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the interview participants who provided their valuable insights for this research. Sarina Atkinson was a student contractor at the U.S. Environmental Protection Agency at the time of the majority of the work for this paper, but is now employed by the University of Miami as a senior research associate contractor for the National Oceanic and Atmospheric Administration. This research was determined to be exempt from further review by the University of North Carolina at Chapel Hill Office of Human Research Ethics (Study #: 16-2245). This is ORD STICS tracking number ORD-033765. The views expressed in this paper are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency. Any mention of trade names, products, or services does not imply an endorsement by the U.S. government or the U.S. Environmental Protection Agency. The EPA does not endorse any commercial products, services, or enterprises.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Kate K. Mulvaney https://orcid.org/0000-0003-2581-7677
Nathaniel H. Merrill https://orcid.org/0000-0003-3891-2833

REFERENCES

Akpabio, E.M., and E.S. Udom. 2018. "'Borehole Race' and the Dilemma of Governing the 'Ungoverned': Understanding the Urban Political Ecology of Groundwater Exploitation in Nigeria." *Society & Natural Resources* 31(9): 1030–44.

APCC (Association to Protect Cape Cod). 2019. "Cotuit Village Stormwater Walking Tour." https://www.apcc.org/threebays/cotuit_stormwater_walking_tour.pdf.

Ballantine, K.A., T.R. Anderson, E.A. Pierce, and P.M. Groffman. 2017. "Restoration of Denitrification in Agricultural Wetlands." *Ecological Engineering* 106: 570–77. https://doi.org/10.1016/j.ecoleng.2017.06.033.

Balogh, S., K. Mulvaney, N. Merrill, and A. Piscopo. 2022. "A Dynamic Modeling Approach to Estimate Nitrogen Loading in Coastal Bays on Cape Cod, Massachusetts, USA." *Water* 14: 1529. https://doi.org/10.3390/w14101529.

Barnstable Clean Water Coalition. 2021. "Monitor." https://bcleanwater.org/what-we-do/monitor/.

Boesch, D.F. 2002. "Challenges and Opportunities for Science in Reducing Nutrient Over-Enrichment of Coastal Ecosystems." *Estuaries* 25(4b): 886–900.

Bricker, S.B., C.G. Clement, D.E. Pirhall, S.P. Orlando, and D.R.G. Farrow. 1999. "National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries." https://repository.library.noaa.gov/view/noaa/1693/noaa_1693_DS1.pdf.

Bricker, S.B., J.G. Ferreira, and T. Simas. 2003. "An Integrated Methodology for Assessment of Estuarine Trophic Status." *Ecological Modelling* 169: 39–60. https://doi.org/10.1016/S0304-3800(03)00199-6.

Burnham, M., Z. Ma, J. Endter-Wada, and T. Bardsley. 2016. "Water Management Decision Making in the Face of Multiple Forms of Uncertainty and Risk." *Journal of the American Water Resources Association* 52(6): 1366–84. https://doi.org/10.1111/1752-1688.12459.

Cape Cod Commission. 2013. "Cape Cod Regional Wastewater Management Plan: Estimating Cape-Wide Costs of Wastewater Infrastructure." http://www.capecodcommission.org/resources/RWMP/RWMP_costs_capewide.pdf.

Cape Cod Commission. 2015. "208 Plan: Cape Cod Area Wide Water Quality Management Plan Update." https://sp.barnstablecounty.org/ccc/public/Documents/208%20Final/Cape_Cod_Area_Wide_Water_Quality_Management_Plan_Update_June_15_2015-Printable.pdf.

Cape Cod Commission. 2016. "Preliminary Guidance for Piloting, Monitoring, and Evaluating Non-Traditional Water Quality Improvement Technologies on Cape Cod." http://www.capecodcommission.org/resources/208/appendices/Appendix%20D%20-%20Technology%20Monitoring%20Guidance%20and%20Protocols.pdf.

Cape Cod Commission. 2021a. "2020 Technology Matrix Update." http://www.capecodcommission.org/index.php?id=656.

Cape Cod Commission. 2021b. "Wastewater." https://www.capecodcommission.org/our-work/wastewater/.

Cape Cod Commission. 2021c."Cape Cod Water Quality Improvement Projects." http://www.capecodcommission.org/index.php?id=562.

Cape Cod Cooperative Extension. 2021. "Marine & Aquaculture Water Quality Monitoring." https://www.capecodextension.org/marine/waterquality/.

Center for Coastal Studies. 2021. "Water Quality Monitoring Program." https://coastalstudies.org/cape-cod-bay-monitoring-program/.

Corbin, J., and A. Strauss. 2014. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, CA: Sage Publications.

Driscoll, C.T., D. Whitall, J. Aber, E. Boyer, M. Castro, C. Cronan, C.L. Goodale, et al. 2003. "Nitrogen Pollution in the Northeastern United States: Sources, Effects, and Management Options." *BioScience* 53: 357–74. https://doi.org/10.1641/0006-3568.

Floress, K., M.B. Kolozsvary, and J. Mangun. 2017. "Expert Perceptions of Approaches to Protecting Isolated Wetlands in the Northeastern United States." *Journal of the American Water Resources Association* 53(5): 1048–61.

Flynn, C.D., and C.I. Davidson. 2016. "Adapting the Social-Ecological System Framework for Urban Stormwater Management: The Case of Green Infrastructure Adoption." *Ecology & Society* 21(4): 19. https://doi.org/10.5751/ES-08756-210419.

Hammarberg, K., M. de Kirkman, and S. Lacey. 2016. "Qualitative Research Methods: When to Use Them and How to Judge Them." *Human Reproduction* 31(3): 498–501. https://doi.org/10.1093/humrep/dev334.

Hasler, B., L.B. Hansen, H.E. Andersen, and M. Termansen. 2019. "Cost-Effective Abatement of Non-Point Source Nitrogen Emissions–The Effects of Uncertainty in Retention." *Journal of Environmental Management* 246: 909–19.

Heberling, M.T., H.W. Thurston, and C.T. Nietch. 2018. "Exploring Nontraditional Participation as an Approach to Make Water Quality Trading Markets More Effective." *Journal of the American Water Resources Association* 54(3): 586–93. https://doi.org/10.1111/1752-1688.12648.

Howarth, R., D. Anderson, J. Cloern, C. Elfrin, C. Hopkinson, B. Lapointe, T. Malone, et al. 2000. "Nutrient Pollution of Coastal Rivers, Bays, and Seas." *Issues in Ecology* 7: 1–14. https://www.esa.org/esa/wp-content/uploads/2013/03/issue7.pdf.

Howes, B.L., R.I. Samimy, and B. Dudley. 2003. *Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators Interim Report*. Massachusetts Estuaries Project. https://www.mass.gov/doc/massachusetts-estuaries-project-interim-report-on-site-specific-nitrogen-thresholds-for/download

Huizenga, E., E.S. Huff, A.L. Dowtin, and J.A. Latimore. 2022. "Untapped Potential: Do Stakeholders Value Forests for Providing Clean Drinking Water?" *Journal of the American Water Resources Association* 58: 420–34. https://doi.org/10.1111/1752-1688.13002.

Kaplowitz, M.D., and F. Lupi. 2012. "Stakeholder Preferences for Best Management Practices for Non-Point Source Pollution and Stormwater Control." *Landscape and Urban Planning* 104: 364–72. https://doi.org/10.1016/j.landurbplan.2011.11.013.

Lindlof, T.R., and B.C. Taylor. 2011. *Qualitative Communication Research Methods* (Third Edition). Thousand Oaks, CA: Sage.

Makropoulos, C.K., E. Argyrou, F.A. Memon, and D. Butler. 2007. "A Suitability Evaluation Tool for Siting Wastewater Treatment Facilities in New Urban Developments." *Urban Water Journal* 4(2): 61–78. https://doi.org/10.1080/15730620701336729.

MDAR (Massachusetts Department of Agricultural Resources). 2016. "The Massachusetts Cranberry Revitalization Task Force Final Report." https://www.mass.gov/files/documents/2016/08/tx/cran-rtfinal-5-24-16.pdf.

Merrill, N.H., A.N. Piscopo, S. Balogh, R.P. Furey, and K.K. Mulvaney. 2021. "When, Where, and How to Intervene? Tradeoffs Between Time and Costs in Coastal Nutrient Management." *Journal of the American Water Resources Association* 57: 328–43.

Milz, D. 2018. "The Hidden Benefits of Facilitated Dialogue." *Journal of Planning Education and Research*. 42: 19–35. https://doi.org/10.1177/0739456X18798903.

Milz, D. 2019. "Spatial Planning Judgments and Computer Supported Collaborative Planning." *Planning Theory & Practice*. 20(1): 70–96. https://doi.org/10.1080/14649357.2019.1575460.

Morse, J.M. 2010. "Sampling in Grounded Theory." In *Chapter 10 in The Sage Handbook of Grounded Theory*, 229–44. Thousand Oaks, CA: Sage.

Perry, E., S.N. Smith, and K.K. Mulvaney. 2020. "Designing Solutions for Clean Water on Cape Cod: Engaging Communities to Improve Decision Making." *Ocean & Coastal Management* 183: 104998.

Petrzelka, P., and S. Marquart-Pyatt. 2011. "Land Tenure in the U.S.: Power, Gender, and Consequences for Conservation Decision Making." *Agriculture Human Values* 28: 549–60. https://doi.org/10.1007/s10460-011-9307-0.

Pleasant Bay Alliance. 2018. "Pleasant Bay Watershed Permit. Permit No.: 001-0." Date of Issuance: August 3, 2018. Date of Expiration: August 31, 2038.

Popovici, R., A. Erwin, Z. Ma, L.S. Prokopy, L. Zanotti, E.F.B. Delgado, J.P.P. Cáceres, et al. 2021. "Outsourcing Governance in Peru's Integrated Water Resources Management." *Land Use Policy* 101: 105105. https://doi.org/10.1016/j.landusepol.2020.105105.

Prokopy, L.S. 2011. "Agricultural Human Dimensions Research: The Role of Qualitative Research Methods." *Journal of Soil and Water Conservation* 66(1): 9A–12A.

Ranjan, P., C.B. Wardropper, F.R. Eanes, S.M.W. Reddy, S.C. Harden, Y.J. Masuda, and L.S. Prokopy. 2019. "Understanding Barriers and Opportunities for Adoption of Conservation Practices on Rented Farmland in the US." *Land Use Policy* 80: 214–23. https://doi.org/10.1016/j.landusepol.2018.09.039.

Reddy, S.M.W.J., Y.T. Montambault, E. Masuda, W. Keenan, J.R.B. Butler, S.T. Fisher, S.T. Asah, and A. Gneezy. 2016. "Advancing Conservation by Understanding and Influencing Human Behavior." *Conservation Letters* 10(2): 248–56. https://doi.org/10.1111/conl.12252.

Standley, L.J., R.A. Rudel, C.H. Swartz, K.R. Attfield, J. Christian, M. Erickson, and J.G. Brody. 2009. "Wastewater-Contaminated Groundwater as a Source of Endogenous Hormones and Pharmaceuticals to Surface Water Ecosystems." *Environmental Toxicology and Chemistry* 27(12): 2457–68. https://doi.org/10.1897/07-604.1.

Thomson, S.B. 2010. "Sample Size and Grounded Theory." *Journal of Administration and Governance* 5(1): 42–52.

Tobey, J.A., and H. Smets. 1996. "The Polluter-Pays Principle in the Context of Agriculture and the Environment." *The World Economy* 19: 63–87. https://doi.org/10.1111/j.1467-9701.1996.tb00664.x.

Ulrich-Schad, J.D., N. Babin, Z. Ma, and L.S. Prokopy. 2018. "Out-of-State, Out of mind? Non-Operating Farmland Operators and Conservation Decision Making." *Land Policy* 54: 602–13.

UMass (University of Massachusetts) Donahue Institute. 2017. "Cape Cod Second Homeowners, Technical Report of 2017 Survey Findings." http://www.capecodcommission.org/resources/economicdevelopment/Report_Cape_Cod_Second_Homeowners_2017_FINAL.pdf.

Valiela, I., G. Tomasky, J. Hauxwell, M.L. Cole, J. Cebrián, and K.D. Kroeger. 2000. "Operationalizing Sustainability: Management and Risk Assessment of Land-Derived Nitrogen Loads to Estuaries." *Ecological Applications* 10(4): 1006–23. https://doi.org/10.1890/1051-0761(2000)010[1006:OSMARA]2.0.CO;2.

WaterVision, LLC. 2016. "Cape Cod Permeable Reactive Barrier Initial Hydrogeologic Site Characterization Results and Evaluation of Site Suitability for Permeable Reactive Barriers Installation." https://www.epa.gov/sites/production/files/2016-08/documents/cape-prb-isc-report.pdf.

Wood, A., M. Blackhurst, J.L. Garland, and D.F. Lawler. 2016. "Incentivizing Decentralized Sanitation: The Role of Discount Rates." *Environmental Science & Technology* 50: 6146–53. https://doi.org/10.1021/acs.est.6b00385.

Wood, A., M. Blackhurst, T. Hawkins, X. Xue, N. Ashbolt, and J. Garland. 2015. "Cost-Effectiveness of Nitrogen Mitigation by Alternative Household Wastewater Management Technologies." *Journal of Environmental Management* 150: 344–54. https://doi.org/10.1016/j.jenvman.2014.10.002.

Woodward, G., M.O. Gessner, P.S. Giller, V. Gulis, S. Hladyz, A. Lecerf, B. Malmqvist, et al. 2012. "Continental-Scale Effects of Nutrient Pollution on Stream Ecosystem Functioning." *Science* 336: 1438–40.

How to cite this article: Mulvaney, Kate K., Nathaniel H. Merrill, and Sarina F. Atkinson. 2023. "Considerations For Using Alternative Technologies In Nutrient Management On Cape Cod: Beyond Cost And Performance." *Journal of the American Water Resources Association* 59(2): 226–243. https://doi.org/10.1111/1752-1688.13079.

Appendix

INTERVIEW GUIDE: BARRIERS AND OPPORTUNITIES FOR ALTERNATIVE WASTEWATER TECHNOLOGIES AND INTERVENTIONS

1. What was your role in installing/implementing the [technology or intervention]?
2. Could you tell us about your process identifying the use of [technology; an intervention], to choosing it, to installing it and whatever has come after?
    a. When was the location of [technology; intervention] selected in the process?
    b. Were there other technologies or interventions being considered at the time?
    c. Are there any monitoring efforts to measure its efficacy in nutrient removal?
    d. Were the costs for installation/monitoring tracked and what is the plan for moving forward?
3. For each one: How was that technology or intervention chosen?
    a. If nitrogen management was not mentioned, was nitrogen reduction an additional reason or co-benefit for choosing the technology or intervention?
    b. If it was mentioned, was nitrogen reduction the main motivation, or was it more of a co-benefit?
    c. Why was it considered instead of a traditional gray infrastructure solution?
    d. Can you run us through the time frame from when you initially started considering the technology?
    e. What were the goals and targets that you were interested in when the technology/intervention was chosen?
4. Does this technology need to be maintained?
    a. Who is responsible?
    b. What is needed?
    c. What is the estimated timeframe for replacement?
    d. How will it be tracked?
    e. How will costs for maintenance be kept?
5. What are the perceived benefits of the [technology; intervention] for your community?
    a. Who benefits from it in particular?
    b. How well do you think it reduces nitrogen?
6. What are the perceived negative impacts of the technology or intervention for your community?
7. What made the use of that [technology; intervention] possible for use in the community?
8. What are some of the opportunities that you identify in your community for using other alternative technologies or interventions such as [technology]?
9. What were some of the barriers for identifying and using the appropriate technology/installing/intervention/monitoring the technology?
10. What are some of the barriers that you identify in your community for using other alternative technologies or interventions such as [technology]?
11. Were there any unanticipated results from the use of the [technology; intervention]?
    a. What have you learned from implementing the [technology; intervention]?
12. Would you install an [technology; intervention] again?
    a. If yes, why and would you change anything?
    b. If no, why not?
13. Have you considered/worked with other technologies or interventions? Which ones and why?
14. Who else do you think we should be meeting with/talking to about the use of alternative nitrogen management technologies or interventions?