Stormwater Management Challenges in Rural Coastal Maine:

Identifying Place-Based Solutions by Studying Current Practices

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ABSTRACT

In December 2023 and January of 2024, three historically severe storms resulted in catastrophic flooding, overwhelming culverts and stormwater infrastructure in Maine's rural coastal communities. These storm events highlight the urgent need to accelerate climate resilience planning and investment. To better understand current stormwater management and maintenance practices and challenges, we conducted semistructured interviews with town officials of three rural Maine counties. Conversations with town officials revealed challenges such as delays in problem point identification due to lack of formal data collection, a dearth of mapping systems, and dependence on word-of-mouth knowledge. Stormwater management is deprioritized due to budget constraints and the common practice of delegating multiple responsibilities to a single person. Findings suggest voluntary education, collaboration among towns, culvert inventory, and stormwater system mapping could lead to community-engaged, prompt decision-making and sustainable stormwater management.

INTRODUCTION

Coastal regions of the United States are home to 40 percent of the country's total population (Wahl et al. 2015). Higher rates of coastal population growth and urbanization increase flood exposure in low-lying coastal areas, and the devastating impacts from floods in these vulnerable regions will continue to worsen with projected sea level rise. Rural communities, with a heavy reliance on natural resources, have more limited financial resources and capacities to respond to these challenges than urban counterparts facing similar flooding challenges (Bukvic and Harrald, 2019).

Coastal regions are vulnerable to flooding due to convergence of different flood drivers such as heavy rainfall, storm surge, high tides, and inland flooding known as compound flooding (Gold et al. 2022; Shen et al. 2019). More frequent and severe compound flooding overwhelms stormwater drainage systems, a challenge further worsened by improper management and aging infrastructure. Alongside these challenges, land cover and land use changes also significantly accelerate the stormwater accumulation (Quast 2024). As development replaces vegetated areas, the time of concentration—or the time it takes for the water to travel from the farthest point in an area to the drainage outlet—is reduced depending on factors such as rainfall intensity, land steepness, roughness of ground surface, and velocity of flow. Reduction in time of concentration leads to flashier and rapid flooding (USDA SCS 1986), which is exacerbated by sea level rise and tidal intrusion through gravity-based drainage systems (Bukvic and Harrald 2019).

Maine is experiencing more frequent and severe storm events (Johnson et al. 2019). Three severe storms in December 2023 and January 2024 resulted in catastrophic flooding, overwhelming the culverts and stormwater infrastructure in Maine's rural coastal communities. Stormwater flooding is a significant challenge in these communities due to aging and poorly maintained culverts (Colgan and Merril 2008) and is exacerbated by limited budget for maintenance and upgrades, staffing constraints, technical capacity limitations, record keeping, and complex permitting processes for repairs and upgrades (Maine IIRC 2025). Maine has a home-rule government structure, where local-level policy and decision making has a huge influence on resiliency to the coastal hazards (Sherwin 2017). The study by Johnson et al. (2019) highlights the urgent need to accelerate climate resilience planning and investment in Maine, and specifically on understanding how local governments manage, maintain, and operate culvert infrastructure.

Solutions to stormwater management are complicated by several factors. Traditionally, stormwater management challenges were tackled as a technical problem and addressed by enlarging stormwater systems to meet the increased frequency of flood events (Qiao et al. 2018), or by implementing other structural flood control approaches (Albuquerque et al. 2019). This approach was considered in response to the expected rise in volume of runoff and to enable design for higher return periods. However, according to Nayak et al. (2025), most of the flood losses occur from frequent and moderate rainfall events with lower return periods rather than the 100-year events. Additionally, rural and coastal regions show frequent flood losses due to lower return period events compared to the urban areas. Enlarging stormwater systems to handle increased volume often only shifts the problem downstream, rather than mitigating it by infiltrating water to recharge groundwater or retaining it temporarily to reduce peak discharge by construction of retention ponds, infiltration trenches, permeable pavements, and infiltration basins (Brown 2005). The recent drought events of 2025 (Enking 2025) further exacerbate conditions. Lack of rainfall causes topsoil to harden, become more concrete, and impede rainwater infiltration to the groundwater table, further contributing to an increase in surface runoff volume.

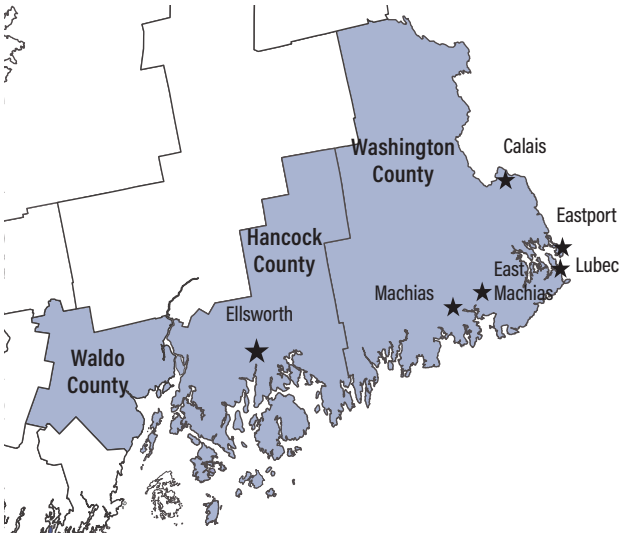
Budgetary constraints, limited knowledge and public awareness, as well as available training opportunities also significantly hamper stormwater management solutions. Funding for stormwater management is typically provided on a reactive rather than proactive basis. In the aftermath of storm events, state or federal funds may become available to address the losses and repair damage to roads, culverts, and stormwater infrastructure when budgets allow and losses meet minimum thresholds. Funding to proactively plan for stormwater infrastructure improvements is limited (Gray 2012) and variable, and sustainable stormwater management is constrained by governance factors such as varying support from state and federal level, decision-makers and the community (Qiao et al. 2018). Rural coastal communities often rely on informal decision-making and on-the-ground observation, highlighting the critical importance of local knowledge and experience for managing municipal stormwater management systems (Bukvic and Harrald, 2019).

Taken together, these constraining factors call attention to the importance of integrated stormwater management (Qiao et al. 2018). Increasingly, stormwater management approaches are moving away from reliance on flood control (structural approaches) towards a combination of both structural and nonstructural approaches (Saraswat et al. 2016) that emphasize the importance of economic, governance, social, and technological factors to enhance sustainability. Nonstructural approaches towards stormwater management focus on planning, policy, and behavioral measures rather than engineering constructions to reduce runoff volume. These include planning measures such as long-term coordination across different sectors and levels of government and community and inclusion of stormwater management as a key factor in planning and management decisions. Policy measures encompass wetland protection, preservation of natural drainage patterns, zoning ordinances, and regulation of development in flood-prone areas. Behavioral measures emphasize community engagement, encouraging communities to adopt low-impact development practices, and raising public awareness. These measures can help support more sustainable practices such as construction guidance to prevent improper land use and reduce flood risk, practices to prevent debris accumulation and blockages in drainage systems, and outreach to improve understanding of flood-prevention strategies (Albuquerque et al. 2019).

Nonstructural measures offer valuable strategies for sustainable management and planning. However, integration of place-based knowledge is critical to improving their applicability. For instance, the practical understanding, lived experience, and insights developed by residents and town officials strengthens the relevance and effectiveness of nonstructural measures by grounding them in local realities and experiences. Not only are these approaches practical, but they also help encourage local participation, prevention, and adaptation. Broad participation leverages place-based knowledge and bolsters the sense of responsibility and shared ownership within the community ensuring long-term sustainable practices (Albuquerque et al. 2019).

In rural coastal areas with limited capacity and resources and with unique conditions, nonstructural approaches may be more cost effective and sustainable (Albuquerque et al. 2019). A critical ingredient for nonstructural solutions is the place-based knowledge that municipalities accrue in the process of managing stormwater systems. There is little research focusing on nonstructural approaches. This study aims to fill this gap in knowledge, using stormwater management in Maine as an exemplary case. To document current stormwater

FIGURE 1: **Map of the Study Area: Waldo, Hancock and Washington Counties, Maine**



management and maintenance practices and challenges, we conducted semistructured interviews with town officials in three rural Maine counties. This research contributes to rural community resilience by highlighting context-specific approaches that help improve infrastructure sustainability, bolster local capacity, and promote collaborative adaptation and adaptive decision-making with changing conditions. The results from this study affirm the critical role of understanding persistent and emergent issues in stormwater management based on deep, place-based knowledge, revealing issues such as lack of systematic data and records, inadequate staffing, and recurrent issues related to ageing culverts. Such knowledge can guide actions at the citizen, municipal, county, and state levels to support community resilience, complement engineering work, and enhance weather and climate information systems to improve stormwater management.

METHODOLOGY

We conducted nine semistructured interviews with town officials responsible for planning, public works, and environmental management in Hancock, Waldo and Washington Counties. Semistructured interviews offered a flexible approach to data collection that allowed the participants to elaborate on their experiences, challenges, and perspectives without having to tightly adhere to predefined questions (Santoso et al. 2011). This approach was chosen to collect both formal (municipal stormwater plans, policies, and procedures) and informal (local expertise, experience-based understanding, and daily on-the-ground information) knowledge of stormwater management practices. Additionally, this approach allowed us to understand how they perceived barriers and opportunities to apply nonstructural approaches. Interviews centered on topics such as decision processes, maintenance, management, seasonal challenges, resource and funding constraints, and record keeping as they contributed to infrastructure performance, specifically culverts. We also asked participants about their experiences with recent extreme weather events to understand their infrastructure vulnerability and any recurrent issues facing their communities.

We followed criterion sampling to recruit town officials (town managers, select-people, road commissioners, and public works personnel). The officials were selected based on their involvement, experience, and decision-making responsibilities in stormwater management and, more specifically, culvert management and maintenance in their respective towns. The interviews were conducted using the videoconferencing platform Zoom from August 2024 to March 2025. Each session lasted for approximately 60 minutes. Cleaned transcripts were coded using Dedoose software to identify recurring themes and patterns in the ways participants described their day-to-day experiences with stormwater management in their towns.

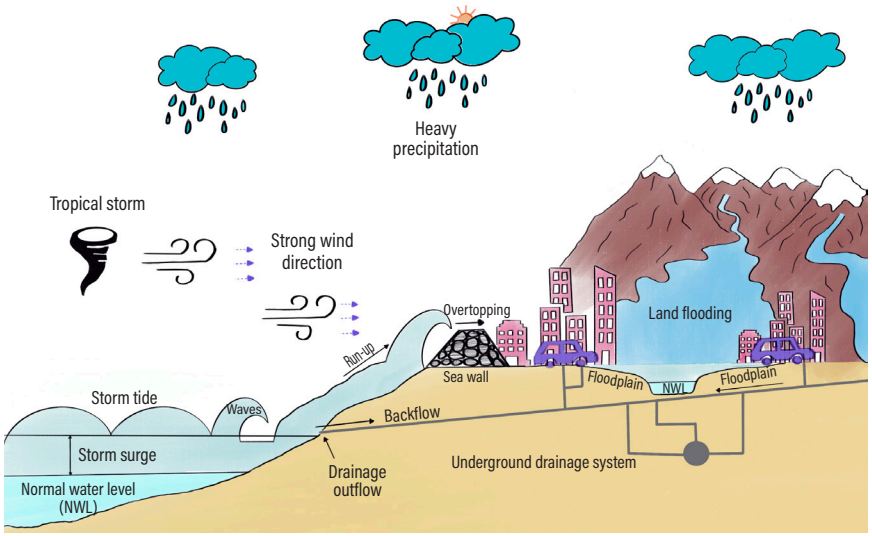
For data analysis, we used a combination of inductive and deductive coding methods. Inductive coding is a data analysis method that does not have predefined codes. Rather, the patterns, codes, themes, and categories emerged directly from the data, based on participants' own words and phrases. This is a flexible and exploratory method used to capture new and unexpected themes and insights. Deductive coding began with a predefined set of codes or categories based on research questions, literature, and existing theories. Deductive coding helped ensure consistency and focus of the analysis process (Bihu 2024).

RESULTS

Our interviews revealed important strengths as well as significant challenges in local stormwater management systems. They also highlighted important lessons learned from current experience

and management strategies. The selected towns had a range of coastal exposure and resources capacities, which helped identify patterns and show how difference in local context affects the application and effectiveness of stormwater management practices and strategies.

FIGURE 2: **Schematic Diagram of Compound Flooding in Coastal Regions**



Experience with Recent Storms

Most town officials shared that the storms of December 2023 and January 2024 were an eye-opener for the community. The storms showed erratic behavior with spatial variation of storm impacts with no specific pattern within a small area. They mentioned that recent storms and rainfall are not as they used to be, sharing that the region now commonly experiences back-to-back storms, resulting in cumulative impacts with saturated soils, flood risks, and prolonged recovery efforts.

> *We've had an increase in rain. Storms are getting heavier, and it overwhelms the system quicker....nothing you can do because the system is maxed out...very hard on the system because we're starting to have a blowout where the piping fails, and you don't know where.*

High tides, storm surges, and heavy precipitation are increasingly combining to create compound flooding, with their effects intensifying each other (Figure 2). Moreover, the officials have seen an increase in banding effects in storms, which occurs when two places within a short distance have storms with different duration and intensity. "Our storms are getting heavier, and most of the storms have banding now," said one official. "One side of the town can get super heavy rain while the other side is just getting a heavy storm, not as bad."

Similarly, town officials have noted the varying impacts from storm events that are geographically close but differ in severity. An official in one town noted, "I think it was a storm, December 18th..., that's the one that we really took the worst damage on." Whereas another official from a nearby town said, "The January storms were the most impactful that we've had. The December storms were nowhere as near as bad as the January ones were." These varying experiences highlight how storm intensity can differ significantly across neighboring areas, even within the same event.

Despite the growing scientific warnings about the extreme storm events, many local officials remained confident in their stormwater management and maintenance strategies. However, the storm of January 2024 was a critical juncture for town officials to accept the validity of the scientific findings. One official said they had been satisfied with their existing stormwater management and maintenance strategies until the storms of January 2024 that caused significant damage and prompted them to reconsider their approach towards stormwater management and climate change. "The biggest surprise: the storm surge, which all of the scientists keep telling us about, actually came very true."

Differing Perspectives Among Town Officials

Most officials in our survey firmly believe that infrastructure upgrades are the ultimate solution to the challenges of stormwater management. "I totally believe that you need to have upgrades. That is my belief. Regular inspection and maintenance only take you so far. We need to be thinking forward all the time." However, officials also said that upgrades in one area often led to problems elsewhere. "Are we taking care of the problem or just moving the problem?" one town manager asked. Even when town managers consider natural solutions, such as swales and rain gardens that would retain water for recharge rather than allowing it to move downslope, road commissioners often disagree. This mismatch of perspectives creates conflict in solving problems.

There is frequent turnover among town managers in Maine, while the road commissioners generally stay in position for longer periods, thereby gaining deep local knowledge and experience. This can create a conflict between the two roles, where a town manager's efforts to introduce innovative approaches might be discounted or disregarded by a longtime road commissioner. "That's a big piece. Management styles and philosophies differ and how people approach things differ."

Officials noted that the work is more efficient when there is a shared understanding between town officials. One town manager provided this example,

> *[A] came, and [A] has a much more comprehensive vision for the city and its infrastructure, in my mind. I replaced my previous person. Their priority was more on roads and highways. I am more in the realm of where [A] is at, in which I want to take a much more comprehensive look at all our infrastructure, including stormwater.*

Challenges in Stormwater Management

Our interviews with town officials also revealed several recurring challenges, including improper planning of stormwater systems, limited availability of human resources, dependence on reactive maintenance, delayed repairs due to budget constraints, uncertainty around funding and responsibility, lack of stormwater system inventories, lack of knowledge and skills for data management (access, visualization, and use), seasonal management and maintenance issues, frequent turnover of town officials, and lack of community awareness or support.

Several officials shared the perspective that stormwater maintenance is underfunded, deprioritized, and politically unattractive as the underground infrastructure is not visible as are roads, bridges, or buildings. One official commented, "[Visible infrastructure has] political value. Redoing a stormwater system is wildly more expensive, and its political value is not high. So, [we are] pushing every way to just do little, tiny patch repairs and let the larger system get worse and worse."

Most town officials identified time and budget constraints as major challenges affecting overall management and maintenance of stormwater systems. They are compelled to prioritize multiple important issues and determine which requires urgent attention and which can wait. In many cases, these rural towns have been operating on tight resource constraints, limiting their efforts to maintain even the status quo. Proactive and comprehensive solutions to the problem areas are beyond their capacity.

> *I could do it if I've got more men, equipment, dump trucks or something like that, but just don't have that. So we're just trying to maintain the status quo, and get the problem areas taken care of.*

Many officials noted that, even after finding problem areas, they are unable to address them as identifying the problem in itself takes up all their funding.

> *Well, I'd have to say that dealing with stormwater management is really costly. We have done some engineering studies. We know where some of the problem areas are, but it's the money to be able to deal with [the problems].*

Similarly, in other studies (e.g., Gray 2012), we found that constrained budgets in these small rural towns resulted in a lack of full-time municipal staff. Some interviewees noted that they do not have directors of public works. In particular, they highlighted the need to build capacity with local expertise and a full-scale public works department. "Having a public works department is paramount," said one official. Some of the smaller towns do not have their own public works department, which leads to problems related to contracting work, such as dealing with multiple contractors, an uncoordinated workflow, and reactive maintenance approaches.

In lieu of full-time public works staff, town managers and administrators are required to handle stormwater management along with their multiple other responsibilities, dividing their attention. One official said, "You know you're distracted, and you know you're not going to catch everything. So, you're looking for the glaring things." Having a public works department would enable towns to save money, coordinate efforts, and take advantage of training for more effective long-term planning. Because of the lack of full-time workers, most of the smaller towns must contract stormwater infrastructure jobs, which leaves the towns tethered to the contractor's schedule, delays the important work, and further exacerbates any problem. Contracting the work to different vendors causes disruption in workflow and can increase costs as contractors unfamiliar with local conditions require more time to figure out problem points and locate underground stormwater infrastructure.

> *Most small towns hire multiple contractors. Five different contractors do five different projects per year....and when you do that, three of the contractors don't even know what the other fellow did or how he fixed something.*

Beyond budgetary and logistical constraints, many officials said they lacked needed technical knowledge and stormwater expertise. In smaller towns, stormwater management is the responsibility of staff with multiple roles and limited skills and knowledge. A majority of town officials underscored their need for additional technical assistance, increased capacity, and ideas for new strategies, in addition to funding for upgrades and additional resources. Officials pointed out that training programs, data-sharing platforms, and seasonal maintenance guidelines could help them optimize budgets. Further, an official said that the people who are working on the ground (road commissioners) provide continuity with their long tenure. "Town select boards are elected, we come and go, but what doesn't change is that the road commissioner is always there." Therefore, they asserted, training and support programs should focus on the long-term personnel with deep understanding and knowledge of local infrastructure. "They're not going to change the way they do things until somebody trains them to do it differently." Also, they suggested that inter-town collaboration and sharing knowledge and experience of road commissioners can help strengthen stormwater practices.

> *[It's] better to support people that are there on the long term, that are doing the repairs. If we put these folks together to share information, there's a lot of different things that could be done better, but you really need to involve the people who are actually on the ground.*

In contrast, we found that larger, more urban towns face a different set of challenges. Many of the towns in our study area have culverts over 100 years old. Installed culverts are clay pipes, which are crumbling, and towns cannot update intensity-duration-frequency (IDF) curves and re-engineer and rebuild their infrastructure.[1] Rather than lack of expertise, municipal officials in these larger rural towns described challenges related to large areas of impervious surface and aging structures originally designed to serve smaller populations. These issues have caused old culverts to fail and catch basins to plug due to lack of regular cleaning and maintenance.

In all three study communities, these challenges were compounded by improper planning and design of existing stormwater infrastructure, which does not meet current requirements. Some of the stormwater systems are under residential areas "We have to do a lot of dye testing to try to find our pipes, where they go," said one public works director. Some areas have nonuniform-sized culverts along the same path, where larger culverts upstream discharge into smaller ones, creating a bottleneck and resulting in overland flow of excess water. These inconsistencies in the culvert design not only increase runoff but also limit the opportunities for water to infiltrate into the ground.

One town official expressed concern about groundwater recharge and highlighted the need for more sustainable solutions in stormwater management.

> *We're depleting our groundwater with impermeable surface and stormwater runoff going so quickly, we're not recharging the aquifer. I've been trying to shift the focus of development and permitting to processing stormwater on site, to diverting water into rain gardens or catch basins or something to try to hold the water on site longer and not just run it into the ocean as quickly as possible. That's very hard to do. In rural areas, people just want to have a ditch. They want to run the water off the land and be done. They don't want to create wetlands.*

Efforts to manage stormwater sustainably (by holding the water and reducing the peak discharge) have had limited impact due to different priorities among town staff. Without unified understanding, coordination, and shared vision within a town, steady progress is difficult to achieve.

A dedicated public works team with real-world understanding and direct management of local infrastructure leads to more practical and place-based solutions. According to the municipal officials interviewed, having such expertise on staff not only helps with infrastructure challenges, but it can also help when the town is developing ordinances, making land use decisions, and enforcing fines and penalties related to proper stormwater management practices. Their input could be helpful for incentive and subsidy programs to encourage residents and developers to adopt and implement sustainable practices such as rain gardens and permeable pavements. One official said, "A lot of the stormwater work is to reduce flooding, running water straight into the ocean. But we can also recharge aquifers. It takes a complete rethinking of how we manage stormwater, like rain gardens, absorption areas, and preserving wetlands." However, it is not an easy task to convince the community, he stated, "It's hard because it costs money, and there's no immediate economic benefit for the private property owners."

Officials also reported public awareness as one of their root challenges to progress towards sustainable stormwater management goals. For instance, catch

basins and culverts are commonly clogged due to improperly managed yard waste. One official revealed that,

> *Homeowners [need] to take some responsibility. When a homeowner's leaves and branches move down into the ditch, the side of the road and a storm comes, they should be a little more cognizant of their responsibility of keeping pathways clear... So the first step is always to educate the town and the public, to keep everybody informed."*

Current Practices and Strategies

As stormwater infrastructure faces increasing pressure, it is vital to understand strategies and practices municipal officials follow to balance resource constraints and leverage institutional knowledge for more adaptive management. During interviews, officials described how current stormwater management practices and strategies within their towns were more focused on reactive (issue-driven) and maintenance-based approaches. An official said,

> *Things happen during storms that you just don't anticipate. Overall, we've been pretty effective, we've addressed the worst of the worst locations with upgrades over time. We've learned some of our challenging spots. Those get attention well before the storm and we learn new spots as the storms develop, or things happen.*

In some communities, however, officials have succeeded in finding funding for proactive upgrades. For instance, one town official described their use of funds,

> *We've upsized everything. It's more keeping them cleaned out and the ditching going and keeping the litter and trash that gets caught up in it, fighting some beavers and stuff like that. So, that's kind of the drainage part of it that's like a maintenance thing and then paving the roads and usually if we're going to pave a road it always was before you changed out the culverts.*

One of the officials highlighted the tension between structural and nonstructural controls as noted by Saraswat et al. (2016). They pointed out that communities sometimes "upgrade just to upgrade," underscoring that infrastructure changes are not always strategic but often driven by available funding and a focus on quick fixes. Outsourcing is a major issue in resource-constrained communities, which tends to have a ripple effect in terms of cost and delays. Officials also repeatedly pointed out the significance of owning equipment, noting that frequently relying on contractors is more costly. They suggested ways to be more self-sufficient to respond effectively and efficiently to stormwater management needs such as co-owning equipment with multiple towns to make it cost effective and accessible.

> *Because if you contract [projects] out, it costs a lot, but you're also a slave to their schedule. If they can't come in the fall and spring, they come in winter and summer; you have to accommodate that. I think effective stormwater management is being as self-sufficient as possible. It's going to make you much more effective.*

Most of the town officials we spoke with also recognized the importance of consistent data keeping for improved planning, efficiency, and decision-making. Some towns have started formalized, systematic record keeping. "We are just beginning a mapping project hopefully this fall." Towns typically do not have comprehensive and accessible documentation of their stormwater assets. Most documentation is in paper form, and most record keeping is informal and generated by multiple staff members in different roles. Moreover, much of the stormwater management knowledge is simply stored in the memories of road commissioners or public works directors.

> *I think it's what we're doing now, first collecting the data in the correct way, with help from engineers of what it is like, taking pictures of the culverts, locating it, pinpointing it, the height of it and different things. It's beyond information that we generally have, right now.*

All officials interviewed identified reliable and effective documentation as a basic requirement. Easy and timely access to data in times of emergency helps them deal with the problem immediately and effectively.

> *The good thing about GIS is, whenever we do maintenance or work on any piece of infrastructure, everything is in GIS. We can attach videos and files so we can have a complete history of that piece of infrastructure going forward. But getting that inventory is time-consuming.*

Even though collecting and maintaining data is time-consuming and costly, most town officials said that they need inventories of their stormwater systems to help with budget decisions and best management practices. "The biggest thing to be effective would be if we had some resources that could help us do the inventory of culverts and stormwater systems, full, accurate GIS." Additionally, municipalities in Hancock and Waldo Counties are working together to share insights, strategies, and experiences and address similar challenges in stormwater management. "We can't be isolated," noted one official "If I have my act together, and the neighboring town doesn't. What I'm doing to protect my area

might hurt theirs, or what they don't do might be hurting mine."

Also, they noted that collaborating on bidding or grant writing processes could also increase the chances of obtaining grants and getting more work done for multiple towns with a single contractor. Some towns are strategically applying for combined grant funding,

> *Generally, when a contractor comes into an area and he has more work, you might get a better price. So we're working on a collaborative effort to make that easier. So you don't have to say, it's going to cost us too much, we'll put that work off next year. Well, next year it turns into three years. And then you have stormwater management that doesn't work.*

The town officials we interviewed stressed that sustainable stormwater management depends on effective allocation of resources, thorough documentation, equipment acquisition, and system planning. Further, they noted how important it is for people to be in the field to identify problems with stormwater infrastructure. Also, several officials said that having multiple perspectives on the same problem helps in generating a complete understanding of stormwater management problems and devising solutions.

DISCUSSION

Our findings underscore the role of local officials, particularly road commissioners and public works officials, in shaping effective and sustainable stormwater management practices in rural coastal Maine communities. Town officials provided firsthand insights on how such communities perceive, prioritize, and respond to stormwater challenges with limited capacity. The knowledge acquired through years of on-the-ground experience has provided local officials with a critical knowledge base to address ongoing operation and planning. Unlike the town managers who often have only a short-term tenure, road commissioners and public works officials bring a deep-rooted foundation and understanding of the local topography, weather patterns, and infrastructure.

Town officials with longer tenures were generally quite able to identify problems and effective solutions, guided by their previous experiences. In contrast, newer town officials struggled with problem-solving due to a lack of institutional knowledge and experience. Our findings demonstrate that both local knowledge and training in new technologies and approaches are important. Education and training for municipal staff should incorporate innovative adaptations to long-standing practices to improve stormwater management. The study also highlighted the positive effects of rapport between town managers and road commissioners or public works officials as they work to manage stormwater systems. Towns in which the perspectives of town managers and road commissioners regarding stormwater management were aligned had better working conditions, compared to towns with a lack of alignment. This observation highlights how unclear leadership roles and overlapping responsibilities among local officials can be obstacles for the decision-making process and delay stormwater initiatives.

The study also revealed that nearly all towns lacked formal and systematic data documentation. Most of the community's knowledge and information sharing remained informal, undocumented, and highly dependent on the individual in office. These rural coastal communities rely on informal decision-making with limited technical capacity and high dependence on local knowledge and experience. There are concerns about knowledge and information continuity when a person leaves a job or is unavailable at a crucial time; however, most officials have started to document their data, such as the culvert inventory as a way to address this issue.

As storms started intensifying, officials said they began to recognize the value of systematic data recording. All of the officials advocated for culvert inventories and mapping as an essential and basic factor for the improvement in stormwater management. Additionally, officials thought that having town-owned equipment was a significant factor in optimizing budgets because using contractors costs a lot and disrupts the schedule. Due to limited resources, constrained budget and lack of comprehensive data, however, most towns are focused on adopting reactive rather than proactive approaches. The findings in this study align with findings by Qiao et al. (2018), that unclear leadership and responsibilities, insufficient funding, lack of knowledge and lower stakeholder engagement are challenges to sustainable stormwater management.

CONCLUSION

Our study on stormwater management in rural coastal communities emphasizes that nonstructural approaches are as important as structural approaches. Town officials, specifically road commissioners and public works officials, play a pivotal role.

They often possess long-standing field experience and crucial local knowledge and understanding. They have a key role in policy development and infrastructure maintenance. The experience of town officials is a fundamental component for developing place-based strategies that reflect the everyday challenges and experience with rural infrastructure systems.

Our study suggests that sustainable stormwater management in small rural areas not only depends on infrastructure upgrades, but also on the abilities of local officials, staffing capacity and structure, cross-departmental coordination within and between towns, programs and policies, funding, local conditions, and technical assistance. As the intensity and frequency of storms rise, these rural communities must be better equipped with technical, financial and institutional support for resilience and adaptation.

Most towns lack consistent documentation or inventories of their infrastructure. They commonly lack maintenance schedules or flooding history, and coordination across towns is limited and informal. Determining the whereabouts and attributes of infrastructure is one of the basic requirements for better stormwater management. Lacking structured documentation can impede proactive planning, decrease the possibility of funding, and make tracking changes over time more difficult. When road commissioners or public works officials carry the system information in their heads, that information may be lost during staffing changes. Developing simple and easy-to-access platforms and tools for data collection through spreadsheets, GIS, and logs will help preserve and secure institutional knowledge, improve communication, and streamline contracting.

While budget constraints were one recurring theme throughout the interviews, available funds could be used more effectively via collaborative efforts within and between towns. As federal dollars become even more scarce, the need to be strategic and collaborative becomes even more crucial. Our findings suggest an urgent need for additional support to intensify the adaptive capacity of these rural municipalities. Place-based, targeted training, shared maintenance arrangements, and collaborative efforts could help increase capacity and interest in new strategies such as limiting impervious surfaces and using rain gardens and swales to slow water and increase recharge. Integrating local knowledge, insights and perspectives into planning, policymaking, and decision-making frameworks can also help communities move towards a more resilient and sustainable future.

These research findings highlight key barriers to stormwater management such as limited technical capacity, inconsistent documentation, and lack of coordinated approach to stormwater management between towns. This underscores the need for an integrated approach for stormwater management with coordinated efforts between towns and the state, instead of the currently applied fragmented approach. Exploring opportunities for state level policy may help in bridging the municipal or town-level implementation and state level coordination. Improving the state support structures (systems, programs, and resources) by providing technical guidance (training, manuals, and expert help for towns collectively), incentives for collaborative work between towns, and standardizing contractors' involvement to ensure quality control, efficiency and fairness. The state could help train town officials on proper documentation and reporting, so data are standardized and easier to compare, which would further support collaboration between towns. The state could also create a shared technical assistance center to provide on-demand expertise. This would significantly improve local capacity and regional resilience. Future policies should facilitate cross-town collaboration and partnership and streamline technical processes, to support more effective and sustainable stormwater management in rural communities.

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NOTES

1 IDF curves are used to determine the peak discharge for the design and sizing of culverts and stormwater systems (USDA SCS, 1986). The IDF curve estimates the rainfall intensity for a certain duration and frequency of rainfall (Schlef et al. 2023).

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