



## Integrating scientific and local knowledge to inform risk-based management approaches for climate adaptation



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### ABSTRACT

Risk-based management approaches to climate adaptation depend on the assessment of potential threats, and their causes, vulnerabilities, and impacts. The refinement of these approaches relies heavily on detailed local knowledge of places and priorities, such as infrastructure, governance structures, and socio-economic conditions, as well as scientific understanding of climate projections and trends. Developing processes that integrate local and scientific knowledge will enhance the value of risk-based management approaches, facilitate group learning and planning processes, and support the capacity of communities to prepare for change. This study uses the Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) process, a form of analytic-deliberative dialogue, and the conceptual frameworks of hazard management and climate vulnerability, to integrate scientific and local knowledge. We worked with local government staff in an urbanized barrier island community (Sullivan's Island, South Carolina) to consider climate risks, impacts, and adaptation challenges associated with sea level rise and wastewater and stormwater management. The findings discuss how the process increases understanding of town officials' views of risks and climate change impacts to barrier islands, the management actions being considered to address the multiple impacts of concern, and the local tradeoffs and challenges in adaptation planning. We also comment on group learning and specific adaptation tasks, strategies, and needs identified.

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### Introduction

Recommended approaches to climate change adaptation are converging on risk-based management approaches (NRC, 2010b; IPCC, 2012). At their foundation, the ability of these approaches to provide detailed assessment of the potential threats, and their causes, vulnerabilities, and impacts requires understanding of broad processes and the detail of local settings. The integration of both sources of knowledge is important because scientific understanding of local risks and potential impacts is often quite generalized when contrasted to the complex details of community characteristics, such as infrastructure

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design and performance, values, governance structures, and vulnerable populations. At the same time, local managers generally do not have expertise in climate science and impacts or the trends and projections for their regions, although they often have detailed knowledge of local factors that bear on impacts, vulnerability, and requirements for implementation of adaptation strategies (Amundsen et al., 2010; Picketts et al., 2012; Kettle, 2012). Integration of scientific and local knowledge is expected to enhance risk-based management approaches and adaptation by providing insight into the adaptation process, facilitating community-based learning and the co-production of knowledge, and increasing the usability of climate science information (Moser and Dilling, 2007).

This paper illustrates the value of deeper engagement with local knowledge for understanding adaptation goals, planning, and challenges. Using lessons gained through the VCAPS process (Webler et al., 2014) with officials from an urbanized barrier island community, Sullivan's Island, South Carolina, we illustrate significant insights into local climate change impacts and adaptation challenges. The paper begins by discussing the significance and limitations of both scientific and local knowledge and the value of integrating these knowledge classes. In this paper, scientific knowledge is understood as knowledge generated systematically from formalized processes and principles, such as the scientific method. Local knowledge refers to knowledge situated in specific locales that reflects expertise and understanding of local phenomena (Raymond et al., 2010). Our results are presented in two sections. The first section reports on results of the VCAPS process, focusing specifically on the management challenges associated with stormwater and wastewater management. We also discuss local sensitivities, management actions, and the multiple impacts of concern, as revealed through the VCAPS process. Following these results, we discuss how the VCAPS process facilitated deliberative group learning, which led to the identification of specific adaptation tasks and strategies responsive to local tradeoffs. These findings illustrate how deliberative mediated modeling, informed by local engagement and scientific knowledge, support risk based management approaches to adaptation.

## Literature review

The need to integrate local and scientific knowledge to inform adaptation is well illustrated by the particular challenges facing barrier island communities. Some research has investigated the vulnerability of barrier island communities to existing hazards and risks because of their high level of exposure and coastal dynamics (Esnard et al., 2001; Stockdon et al., 2007). These studies generally focus on understanding physical processes such as erosion, overwash, breaching, or inlet formation (Ceia and Patrício, 2010; Cañizares and Irish, 2008). Other research has addressed how changes in sea level, coupled with changes in wave climates, hurricanes and Nor'easters, and other climate-related stressors may exacerbate existing and create new management challenges (McNamara and Werner, 2008; McNamara and Keeler, 2013). These studies identify many significant interactions among climatic, geomorphologic, hydrologic, and human factors shaping the management of barrier islands (Stutz and Pilkey, 2005; Oost et al., 2012). For instance, both tidal stage and precipitation influence the height of the water table beneath barrier islands (Corbetta et al., 2000), which has direct implications for the management of septic fields and wastewater treatment systems (Cogger et al., 1988). Stormwater management is also a challenge due to the low land elevations, high water tables, and lack of elevation gradients to drive drainage. These local threats, which are associated with tidal events, complicate planning and risk management efforts on barrier islands. However, comprehensive data inventories and analyses of these factors and their interactions with local infrastructure systems are rarely available on a site-specific basis or as generalized input to broad scale management for adaptation studies.

### *Scientific knowledge*

Climate science is continuing to advance our understanding of system processes, functions, and dynamics, including both climate variability and change. Climate impacts are an essential element of adaptation planning, although the temporal and spatial scale of analysis does not match the scales typically requested by decision-makers (NRC, 2010b; IPCC, 2012). The most recent models included in the IPCC analysis refine the detail of regional projections and the treatment of major climate processes and feedbacks, such as the release of greenhouse gasses from permafrost melt, the role of the stratosphere, and atmospheric fertilization of carbon dioxide on vegetation (IPCC, 2013), rather than locally significant features such as sea breezes which play a major role in the distribution of rainfall along the coast.

Scientific knowledge of climate is critical to understanding of potential impacts, feedbacks, and thresholds associated with climate change and ultimately, to the development of decision support tools. Climate science information may be used to develop seasonal forecasts to address challenges related to food security, water resource management, fire, and public health and safety (Dilling and Lemos, 2011). Outputs from climate scenarios are often used to simulate potential impacts and vulnerabilities to various sectors and regions; however, top down impact assessments are often quite generalized compared to site-specific conditions and less frequently engage the higher order impacts on communities (Stern, 2007; Nicholls et al., 2011). There also remains a limited understanding of processes and interactions in some systems (e.g., barrier islands), which require local knowledge to develop a more detailed understanding of impacts. For example, elevation mapping is too coarse a resolution to anticipate local patterns of flooding and it does not account for the influences of infrastructure nor the combination sea level rise and rainfall that lead to flooding. Such findings suggest that although climate science plays a key role in understanding systems processes and potential changes, local knowledge is needed to develop a more detailed understanding of potential impacts and inform the selection of adaptation strategies.

### *Local knowledge*

Local community managers and planning officials play an important role in the management and protection of community resources through regulation of land use development, building codes, transportation, and environmental quality issues (Cullingworth and Caves, 2009). Their situated knowledge, experiences, and awareness of local sensitivities, including the interactions between biophysical and social contexts, are important in understanding local phenomena, balancing competing priorities and values, policy making, and managing socio ecological systems (Picketts et al., 2012; Berkes and Folke, 2002). Understanding the potential for adaptation strategies to conflict with other locally significant social goals and preferences is one example (Adger et al., 2009). For instance, awnings can reduce temperatures in buildings, but they may also distract from the historical character of a town and conflict with heritage policies (Björnberg and Svenfelt, 2009). These local goals and preferences may favor some adaptation strategies and pose constraints to others; thus nuanced understandings of the subjective and qualitative dimensions of decisions are important factors in consideration of not only what strategies might work but also which are likely to be acceptable. There are also cross scale differences in adaptation priorities, which shape adaptation choices at local levels (Amundsen et al., 2010; Kettle, 2012; Urwin and Jordan, 2008). Potentially conflicting priorities highlight the importance of bringing local or situated knowledge into adaptation planning across scales and recognizing potential social limits to adaptation (Adger et al., 2009). They also emphasize the importance of incorporating subjective and qualitative dimensions of decisions extend beyond economics to include worldviews and culture, into analytic-deliberative processes (Dietz, 2013; O'Brien and Wolf, 2010).

### *Integrating local and general scientific knowledge*

Efforts to integrate local and scientific understanding, such as “bottom-up/top down” approaches, are increasingly recognized as valuable in climate adaptation, environmental management, and risk and vulnerability assessment (Raymond et al., 2010; Grêt-Regamey et al., 2013; Armitage et al., 2011; Mastrandrea et al., 2010). Knowledge integration is important because much of the scientific understanding of local risks and potential impacts provides generalized insight while the management of communities requires engaging with the very specific details of the physical environment, the infrastructure systems, livelihoods, lifestyles, governance arrangements, and other attributes. Knowledge about these types of local issues and resources are sufficiently specialized and demanding that they are frequently distributed among a number of local managers and augmented with support from other levels of government. Knowledge integration provides opportunities to generate new knowledge for both scientists and stakeholders, enhance decision making, and facilitate climate adaptation (Grêt-Regamey et al., 2013).

There is an emerging consensus on processes useful for integrating local and scientific knowledge. These approaches often share the use of participatory methods, employment of iterative strategies to support learning and feedback, attention to temporal and spatial scales, and incorporation of values into decision processes (Raymond et al., 2010; Dietz, 2013; Klopogge and Van Der Suljjs, 2006). They also share an increasing focus on active engagement, deliberation, and process (rather than product alone) to enhance individual and social learning experiences (Moser and Dilling, 2007; NRC, 1996, 2009a, 2010a; Jones et al., 2009; Berkhout et al., 2002). NRC (2009a) suggests that decision support tools, which focus on the active engagement of stakeholders and creative methods to translate climate information into risk information, are essential in shared learning experiences. Others highlight the importance of sustained dialogues between climate scientists and decision makers and among peers (Dow and Carbone, 2007). These processes are more likely to be effective when they engage in active communication, foster translation and sharing of information across actors and organizations, mediate tradeoffs and potential conflicts, and maintain high levels of trust (Cash et al., 2003).

Mediated modeling has emerged as a valuable method for integrating scientific and local knowledge together in order to enhance group understandings. This approach structures group understanding around building models (or boundary objects), where scientists serve as both facilitators and sources of scientific information, which is incorporated into the modeling process (van den Belt, 2004). Such processes can be powerful tools for individual and group learning, promotion of systems thinking, and consensus building (Jones et al., 2009; van den Belt, 2004). This research evaluated the VCAPS mediated modeling process with planning officials and professional staff of the Town of Sullivan's Island, South Carolina. The goals of VCAPS are to: (1) integrate local knowledge and scientific data into understandings of climate impacts on the local system; (2) improve understandings of potential impacts, sensitivities, and management options among local decision makers; and (3) help identify options for action.

### **The VCAPS process**

The VCAPS process is a facilitated dialogue among diverse decision makers oriented around co-creating scenario diagrams of how climate stressors may act on a community to create harm. VCAPS builds on a mediated modeling approach by engaging decision makers to build shared understandings of how climate change stressors may influence management challenges, such as stormwater management and waste water management, and how these impacts and vulnerabilities can be mitigated (Webler et al., 2014). The VCAPS methodology is based on participatory, analytic, and deliberative processes (Understan, 1996; NRC, 1999b, 2008) and other experiences with social learning (Webler et al., 1995). This type of collaborative group

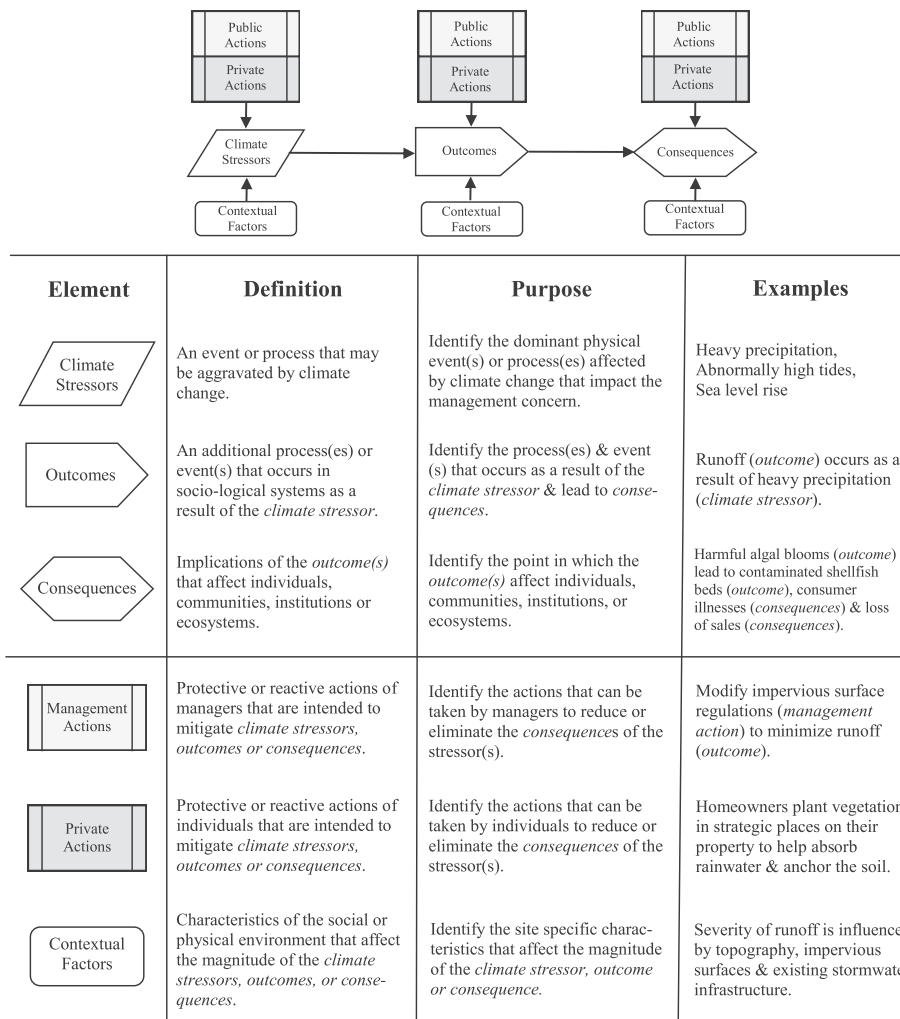
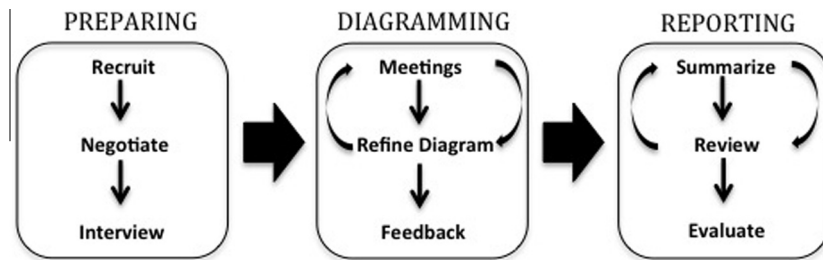


Fig. 1. Key elements in VCAPS diagramming process.

approach is widely applied in watershed management, risk management, and impact assessments (Kinney and Leschine, 2002; Renn, 1999; Webler and Tuler, 1999). Central to VCAPS is the diagramming and visualization of causal pathways that link climate stressors with impacts. VCAPS diagrams are created in real-time using a laptop and a projector. This approach allows users to visualize the diagrams and revise key points as the discussion evolves.<sup>1</sup>

The conceptual basis of VCAPS is grounded in hazards analysis (Kates et al., 1985), vulnerability of coupled human-environmental systems (Burton et al., 1978; Turner et al., 2003), and the analytic-deliberative model (NRC, 1996; Renn, 1999; Burgess et al., 2007). From the hazard analysis perspective, events are structured as a succession of human choices, system responses, and consequences (Kates et al., 1985). Eliciting local information about consequences is particularly important as scientists and local communities have a high potential to disagree about what are the critical impacts and priorities (Whipple, 1992). Diagramming hazard chains allows managers to visualize how individual or regulatory actions could mitigate responses or consequences. The basic elements used to diagram a hazard chain with VCAPS consist of seven building blocks – each block representing a concept that is linked together through a sequence of events that generally flows from left to right (Fig. 1) and local diagrams are included with the discussion of findings. From a vulnerability perspective, the differential susceptibility to harm is based on the magnitude of the exposure, sensitivity to the perturbation, and ability to resist or cope. This concept clarifies how separate entities can be affected differently by similar exposures and includes the concept of coping. For the diagramming process in VCAPS, the academic debates around dimensions of vulnerability seemed unnecessary and we substituted the term “contextual factors” to capture characteristics that differentiate impacts across places or groups.

<sup>1</sup> Many software packages are available for dynamic diagramming. For this project, we developed our own diagramming tool, but there are many other tools available. Most recently we have been using VUE (Visual Understanding Environment) developed at Tufts University.



**Fig. 2.** Summary of VCAPS process. Figure used with permission from Taylor & Francis ([www.tandfonline.com](http://www.tandfonline.com)), as published in Webler et al. (2014). (<http://www.tandfonline.com/doi/full/10.1080/13549839.2014.930425>).

During a VCAPS process participants focus on short and long term mitigation efforts, which is important as short term responses can shape future vulnerability. The process also allows communities to focus their efforts on issues that are important to them, although expert scientists are involved to ensure that important science issues are not ignored. Scientists were involved both at the VCAPS meetings and through follow-up consultation.

### Phases of VCAPS

VCAPS is implemented in three basic phases: preparing, diagramming, and reporting (see Fig. 2). In the preparing phase we identify and recruit participants, plan the details of the process including meeting schedule, and collect background information relevant to understanding past planning, hazard events, and ongoing concerns within the community. Findings from the preparing phase are important for understanding local priorities and values and guiding science communication strategies throughout the VCAPS process. The diagramming phase involves holding meetings to develop scenarios. At the start of the first meeting we arrange for a local climate expert to discuss regional climate trends, projections, and potential impacts. The purpose is to help participants think about how climate variability and change may influence possible futures. In the final reporting phase the team summarizes, reviews, and evaluates results from the meetings. The information is presented in ways that facilitate its integration into local planning, including hazard mitigation planning, comprehensive planning, and adaptation planning. This may include discussions about how to prioritize and schedule implementation (e.g., short term vs. long term) of management actions. Member checking is used to validate results. Webler et al. (2014) provides a detailed review of the VCAPS process.

### Sullivan's Island, South Carolina

We implemented the VCAPS process in Town of Sullivan's Island, South Carolina – a small, primarily residential, barrier island community located just north of the Charleston Harbor entrance. The preparation phase involved review of published material about Sullivan's Island (including web-based material on the town site), existing emergency planning documents, natural and cultural resource inventories, economic profiles, newspaper coverage, and scientific research on potential regional climate changes. Eight semi-structured interviews, targeting key elected officials and staff in Sullivan's Island and Charleston County, South Carolina, were then conducted to better understand current and anticipated (5–20 years) local management concerns, priorities, sensitivities, and values and to identify other possible participants in the VCAPS process.

In the second phase, four two-hour meetings were held with participants (town staff) from the Sullivan's Island and project staff from the Carolinas Integrated Sciences and Assessments, North and South Carolina Sea Grant Extension, and the Social and Environmental Research Institute (Table 1). Nine people from the Town of Sullivan's Island participated in the

**Table 1**  
Participant interview and meeting schedule.

Event	Date(s)	Participants	Objective
Interviews	Nov. 3, 2009	1	Scope project feasibility with town administrator
	Dec. 16–18, 2009	8	Gather background information and develop preliminary scenario diagrams
Meeting 1	May 6, 2010	7	Provide participants site-specific climate change information and examples of how these changes affect current management challenges; introduce diagramming tool
Meeting 2	May 11, 2010	9	Co-develop stormwater vulnerability diagram with participants
Meeting 3	May 17, 2010	6	Revise stormwater diagrams and begin developing building code and zoning diagram
Meeting 4	May 20, 2010	7	Revise both diagrams; conclusions and feedback
Interviews	Aug. 16–20, 2010	8	Evaluate participant learning; feedback

meetings, including staff from the town's Administration, Building, Finance, and Water and Sewer Departments, members of the Planning Commission, and Town Council Members. Participation varied between six to nine people for each of the meetings.

The first meeting focused on linking climate to existing coastal management challenges, introducing participants to the mediated modeling process, and sharing sample diagrams. Following a brief overview of the meeting, a one hour presentation on climate change science and impacts, specific to the southeast (and Sullivan's Island when possible) was given by the Regional Climate Extension Specialist of the South Carolina Sea Grant Consortium and North Carolina Sea Grant to provide the basis for linking climate concerns to existing management challenges (Tribbia and Moser, 2008). The content of this presentation was tailored to address key community concerns, priorities, and vulnerabilities by linking climate concerns to stormwater management, as this issue was frequently identified in the initial interviews. After this presentation, the research team introduced participants to the diagramming process. The modeling began by asking the participants to choose a topic of interest, and the topic of "stormwater management" was selected. While one researcher facilitated a discussion, another used the diagramming software to map the content of the dialogue, using the structure of the hazard chain. Others took supplemental notes to augment the review process. Once the preliminary stormwater management diagram was created, the research team elicited feedback from VCAPS participants, through informal conversations, on the structured dialogue and diagramming process, including information that should be revised in the diagrams. Differences were flagged and discussed at the next meeting.

During the second meeting, the research team facilitated the creation of a more detailed stormwater management diagram. Participants witnessed the scenario emerge out of their discussion, which afforded an opportunity for the group to discuss changes or feedback, which was captured immediately (van den Belt, 2004). Following the second meeting, the research team organized the elements in the diagram (which gets messy in the attempt to keep up with the discussion) and presented it back to the participants at the start of the third meeting. In the third meeting, the group confirmed the revised stormwater diagram and began developing a diagram focused on zoning and building decisions. For the fourth and final meeting, participants finished the zoning and building diagram and discussed the major lessons learned from the process.

Following the meetings, we completed the reporting phase. Participants were provided a short discussion summary and copies of the final diagrams. Eight semi-structured interviews were conducted following the final meeting to elicit further feedback from VCAPS participants on topics related to what participants learned during the process, how the diagramming helped or hindered discussion, and how the process may enable the town do to things differently in the future. Four individuals participated in both sets of interviews during the preparing and reporting phases.

The Town of Sullivan's Island (Fig. 3) was selected for participation because it has been actively engaged in coastal planning, it faces numerous climate-related hazards, and staff and planning officials were willing to participate in the process. The island encompasses approximately 8 sq.km. and is inhabited by approximately 1800 residents (Census Data, 2010). The town is extremely vulnerable to coastal storms because the entire island lies within the 100-year floodplain. Significant portions of the oceanfront are subject to wave action and flooding during exceptionally high tides. These conditions contribute to frequent flooding events, thereby affecting surface drainage and stormwater management issues. The development of Charleston Harbor has also altered coastal processes along Sullivan's Island, which has caused much of the island to remain relatively stable or accrete, though the northeast end of the island is one of the most critically eroded beaches in Charleston County (Levine and Kaufman, 2006). Looking ahead, relative sea level rise ( $3.15 \pm 0.25$  mm/yr), as indicated by long-term tidal gauge measurements in Charleston, SC (NOAA CO-O, 2013), will likely increase flooding and the height of storm surge events throughout most of the island.

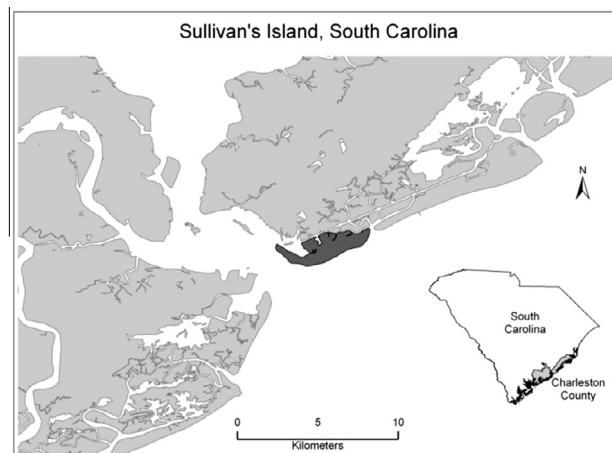


Fig. 3. Sullivan's Island, South Carolina.

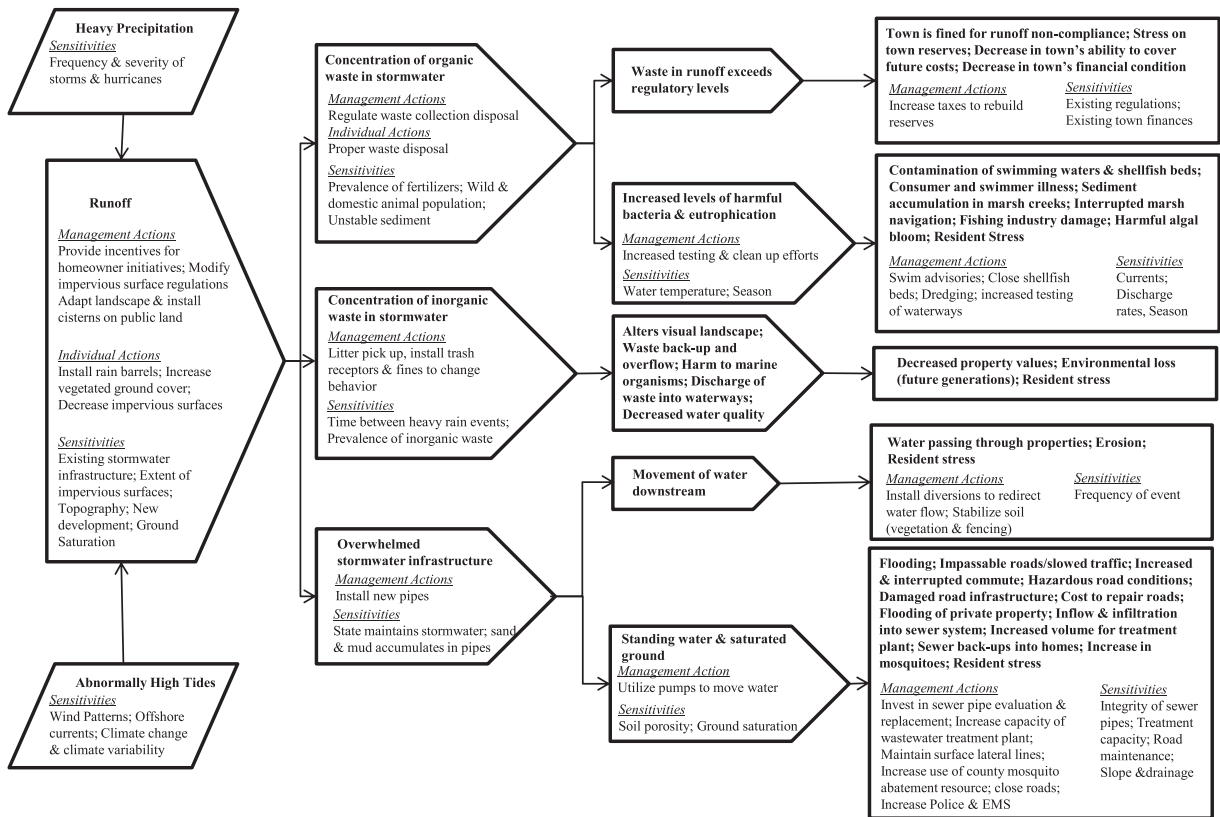


Fig. 4. Summary of stormwater vulnerability diagram.

**VCAPS results**

The VCAPS process on Sullivan’s Island provided a platform for participants to explore, identify, and document relevant management challenges, sensitivities, and impacts of concern. This section briefly discusses the range of existing weather and climate- related challenges, local contextual factors (sensitivities), and management actions identified by town staff through the VCAPS process. It centers on the challenges associated with stormwater and wastewater management because these were topics identified by the participants and they are more broadly relevant to planning on barrier islands. A summary of the VCAPS process related to stormwater management, as created by the participants, is provided in Fig. 4.<sup>2</sup> Fig. 5 provides a more detailed view of a single linear chain or pathway created during the VCAPS process. We then discuss the range of impacts of concern that emerge from the diversity of management challenges. Our examples illustrate the building of understanding among the participants and the role of local knowledge in assessing the complexity of near- and long-term decision making processes that must be negotiated on barrier islands.

*Management challenges*

The meetings with the Sullivan’s Island officials revealed how weather and climate-related stressors are contributing to several management challenges for the community. Many of these challenges begin with stormwater management and connect to other concerns, including flooding, wastewater management, salt-water intrusion, zoning and building codes, and coastal erosion. For example, stormwater issues are exacerbating wastewater treatment concerns for the town. Although water consumption is declining on Sullivan’s Island, the volume of water receiving wastewater treatment is increasing because of inflow and infiltration into aging, cracked infrastructure and a high water table that places pressure on the lines. The town is aware that EPA sets treatment capacity requirements for wastewater treatment plants and significant expenses and challenges would be involved if they were required to expand capacity. Although this is less of an issue during drier periods, most of the sewer lines are often submerged due to the high water table. The management challenges associated with

<sup>2</sup> It is not possible to include the original and complete VCAPS diagram for stormwater management because the diagram is too large to fit on a single page. A summary diagram (Fig. 4) was used to illustrate the broad range of responses.

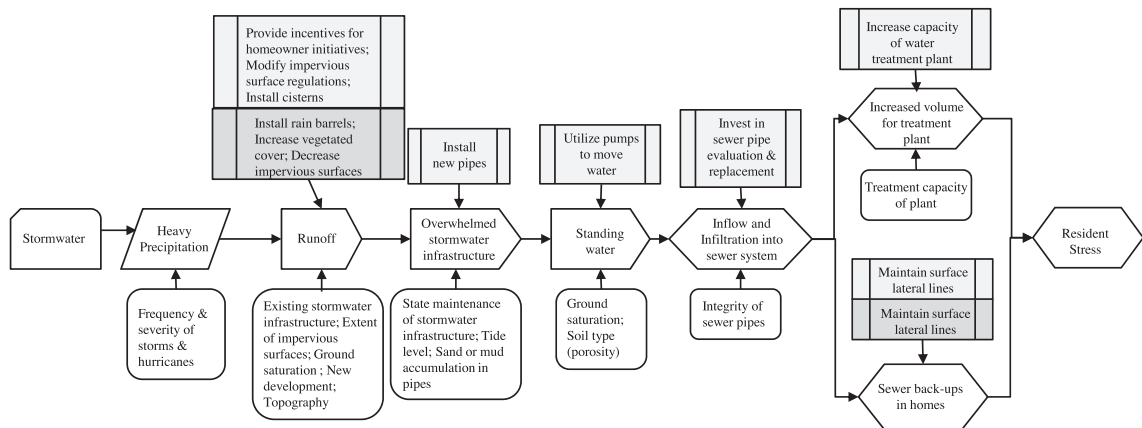


Fig. 5. Sample of a single linear chain from the stormwater vulnerability diagram.

storm and wastewater management were articulated by several participants. As one participant stated, “It’s a challenge to keep a gravity system running, especially an old one, during a heavy rain event. What will compound that is if you have a high tide event during that same time period.” To address these concerns, the Town has installed meters on sewer subsections to calculate the difference between the metered water use of private residents and the total volume of wastewater being pumped through the sewer system. Sewer lines that have the greatest difference between metered use and total pumpage are targeted for replacement and improvements to reduce inflow and infiltration. The height above sea level for this barrier island community is simply too low to elevate manholes above the 50-year flood level, as required by the South Carolina Department of Health and Environmental Control (SC DHEC), however, the town is working to seal the inter-chambers of manholes with gaskets to reduce inflow. The Town is also trying to raise manholes as high as possible without getting complaints from residents.

The VCAPS process also revealed challenges associated with stormwater management. Specifically, backflow of sea water into stormwater discharge pipes can occur during high tides. This reduces the outflow rate of stormwater, but it had not reversed the direction of flow to discharge saltwater on to land, although this has occurred in other communities. Stormwater management is further compounded by backfilling around stormwater pipes, which restricts the movement of stormwater. Of concern to town staff is that the restricted movement of stormwater off the island contributes to localized flooding, which undercuts roads leading to potholes in roads and unsafe driving conditions. The physical characteristics and the patterns of use and development on this barrier island pose a relatively unique set of challenges to adaptation.

### Contextual factors

The structured dialogue process, as graphically represented by the diagrammatic representation of scenarios (e.g., Fig. 4), supported the identification and exploration of a range of contextual factors (sensitivities) among the participants, including specific characteristics of being a barrier island. For example, participants discussed how climate-related contextual factors, such as intensity of rainfall, the interval between rainfall events, wind patterns and ocean currents and tides, and the rate of sea level rise, affected the magnitude of surface runoff on the barrier island. Participants also identified several non-climate related contextual factors specific to Sullivan’s Island, including the political climate, environmental conditions, regulations, and town finances, and explored their significance in influencing the magnitude of specific outcomes and consequences in conjunction with being a barrier island. For example, the regulations which set fines for runoff exceeding water quality regulatory levels were becoming more stringent. Participants also identified cross-scale contextual factors relating to local control versus state ownership of stormwater infrastructure that complicated potential management actions. In speaking on the challenges of wastewater management, one participant stated:

Water, wastewater, gravity, and stormwater are so important to each other in that if the stormwater system is working and functioning properly, it minimizes the infiltration that you may get with the sanitary. And the town does not own any of the storm collection system, the state owns it all, as well as the roads. That is a challenge to wastewater in that some of the stormwater collection systems just don’t function properly and it leaves water setting, which is going to seep into the ground and get into the sewer system.

Identification and discussion of localized climate and non-climate contextual factors enabled participants to develop a collective understanding of the diversity of conditions that may potentially affect the magnitude of the management challenge and the suite of public and private management actions available to the community. These contextual factors also highlight the importance of local place-based knowledge in the development of adaptation strategies.



**Table 2**

Categories of impacts that emerged from the VCAPS process.

Impacts of concern	Example(s)
Aesthetics	Preserving historic character of town, scenic views of ocean and beach
Private property loss	Localized erosion, condemning of property, flooding of property, “takings cases”, decreased property value
Public health and safety	Hazardous road conditions, nuisances (mosquitoes, rats, snakes), sewer back-up into homes, contamination of swimming waters and shellfish beds, salt-water intrusion into drinking water supplies, water quality, evacuation routes, residential stress, increase in mosquitoes
Public infrastructure and operations	Replacement/upgrade of wastewater treatment plan, damage and repairs to roads, salinity disrupting biological processes of wastewater treatment, erosion, increased inflow and infiltration into sewer systems
Regulatory requirements	Non-compliance for stormwater quality or treatment capacity of wastewater
Recreation	Beach and marsh access, fishery (including oysterbed) closures, interrupted marsh navigation
Social conflict	Management of accreted land (90 acres), individual rights vs. community welfare

### Management actions

Town staff identified several potential actions related to stormwater management challenges on this barrier island through the VCAPS process. Some actions are related broadly to how managers address threats, and others are more specific to the conditions created by being on a barrier island and in the specific historical and cultural attributes of the community. These actions included both public and private actions. They also included upstream and downstream actions (left and right side of the diagram, respectively). For example, town staff noted that they could encourage private residents to install rain barrels or increase vegetated ground cover (decrease impervious surface) to reduce the volume of runoff (private actions). The town could also provide incentives for homeowner initiatives, modify impervious surface regulations, or install cisterns on public land (public actions). In addition to these upstream actions, participants identified several downstream actions to address consequences stemming from stormwater runoff, including the closure of beaches or shellfish beds because of contaminated waters. Throughout the structured dialogue process, town staff discussed the tradeoffs among public and private actions as well as upstream versus downstream actions, including the social and cultural reasons that some actions would be more or less acceptable in the community.

### Multiple impacts of concern

The broad range consequences identified by town staff during the VCAPS discussion highlights the multiple impacts of concern for hazard management (Table 2). Some concerns are common to low-lying barrier island coastal communities, while others may be more specific to Sullivan’s Island. As shown in Table 3, participants identified concerns specific to their

**Table 3**

Management challenges identified in VCAPS include those common to barrier island communities and specific to Sullivan’s Island.\*

#### General concerns – barrier island communities

- Sea level rise, storms, and coastal erosion increase the risk of salt water intrusion into the surface lateral lines (sewer lines running from property line to the privately owned structures) of coastal properties
- Increased inflow and infiltration of salt-water and groundwater into the wastewater system, due to sea level rise and an elevated groundwater table, may lead to sewer back-ups in homes, disrupt biological processes at the wastewater treatment plant, and lead to exceeding permit levels for wastewater discharge
- Increased backflow of seawater into storm water pipes during high tides reduces drainage and may reverse the direction of flow (saltwater onto land), contributing to localized flooding
- More frequent flooding leads to more frequent undercut roads, pothole formation, and unsafe driving conditions
- Loss of recreational opportunities (beaches, marshes, shellfish bed closures) due to erosion or sea level rise.
- Legal challenges of “takings cases.” Elevated tides and water table may necessitate shutting off wastewater services to low lying properties, causing the homes to be condemned
- FEMA requirement to elevate manholes above the 50-year flood elevation
- Salt-water penetration may expand the range of salt marshes and move state-determined development boundaries inland, affecting property values and the ways that land can be used

#### Specific concerns – Sullivan’s Island (as a low-lying barrier island community)

- Social conflict regarding the management of 90 acres of accreted land
- Local ordinances that preserve the historical character of town may restrict the ability to reduce future flood losses through increased building elevation
- Local ordinances allow landowners to place fill under their structures, which may displace water onto other roads and homes in heavy rain events, exacerbating the flooding of lower elevations
- Hurricane vulnerability due to single evacuation route via a narrow causeway
- The high water table means that most sewer lines are already submerged
- Management of aging storm water infrastructure at the island-scale is complicated because of county ownership
- The low-lying elevation of this barrier island community precludes the placement of manholes above the 50-year flood level, as required by the SC DHEC

\* We do not know the extent that these concerns are shared by other barrier islands and low lying communities.

community, beyond what could be learned from “general principles.” This section provides examples of the different types of concerns generated during the workshops to illustrate the diversity of risks and goals to be considered in adaptation planning on barrier islands.

Regulatory requirement concerns surfaced throughout the meetings. Some concerns regarding non-compliance with regulatory requirements were perceived as having limited consequences and others were viewed as more serious. For example, town staff expressed a low level of concern about meeting the Federal Emergency Management Agency’s (FEMA) requirement to locate manholes above the 50-year flood elevation on the island because the island’s low elevation is a physical limit to regulatory compliance which is given consideration in enforcement. The town has planned to reduce the threat to the extent possible by tagging the low lying manholes, developing planning to elevate them above the road crest, and installing water tight lids to reduce inflow. Non-regulatory compliance for other issues pose greater concern. For example, the Town of Sullivan’s Island is allowed to discharge 0.57 million gallons of wastewater a day under their National Pollutant Discharge Elimination System permit; however, wastewater treatment may exceed this amount during future extreme storm events. There are concerns that total volume of wastewater treatment will increase regardless of water demand because increasing pressure on lines due to sea level rise and an elevated water table may increase in inflow and infiltration. If the volume of treated wastewater exceeds regulatory requirements, the town will need to expand current treatment capacity – an expensive endeavor.<sup>3</sup>

Public health and safety concerns also emerged during the VCAPS process. For example, inflow and infiltration of saltwater into manholes and surface lateral lines, arising in part from sea level rise and aging infrastructure, may lead to sewer back-ups in homes. Additional public health and safety concerns included hazardous road conditions for transportation, contaminated swimming waters and shellfish beds, and the loss of a maritime forest that provides storm surge and erosion protection. Town staff was also concerned about the loss of recreational opportunities, and thus identified management options to protect town lands in order to preserve both visual and physical access to the marshscape.

In some cases, possible approaches to address one concern raised additional management challenges or conflicted with other recommendations; some adaptation strategies did not have positive synergies with other each other or with other goals. For example, in addition to the infiltration issues, rising sea level and potentially more intense storms reinforced concerns about the vulnerability of the public wastewater operations and infrastructure. Although coastal erosion does not endanger the majority of infrastructure on the island, some surface lateral lines (those sewer lines running from property line to the privately owned structures) connecting to private homes immediately adjacent to the coast are at risk to salt water intrusion from sea level rise, storms, and coastal erosion. If these surface lateral lines are compromised or damaged, there is a risk that a significant amount of saltwater could enter the wastewater processing plant and kill the biological processes involved, and disable wastewater treatment for the entire community. However, it is unclear how this risk should be managed. Decisions to no longer offer wastewater services to households or condemn homes may result in a “takings case” (private property loss) and lead to a social and political quagmire. VCAPS participants discussed the difficulties of when to take action, weighing the risk of collapse of the public wastewater treatment system against the potential to be taken to court by affected individuals. The situation is further complicated by the politics of a small community, where people know each other and are highly connected and where today’s decisions represent precedents for others.<sup>4</sup>

The complexity of management challenges and impacts of concern are particularly well-illustrated through one of most contentious issues on Sullivan’s Island, which deals with the management of roughly 90 acres of accreted land. Coastal processes have created “new” land, which is held under a community land conservation easement. Over the past 20 years this accreted land has developed into a successional maritime forest, and local citizens have expressed diverse and divergent priorities on how this land should be managed. Town council meetings have exceeded four hours due to long discussions about the issue. Nearly all members of the town staff voiced their concern about the social conflicts arising from management of the accreted land. This issue is well summarized by one town staffperson:

There is a terrible battle going on on the island to influence the town council about what to do with the accreted land. Many of us think that we should maintain as much as reasonable in its current state. Others are convinced it harbors criminals and deadly animals. . . [Some people] see it as a protection and enhancement of the value of our property. Other people see it as something that diminishes their view, and therefore diminishes their property value.

For some public residents, cutting the forest down is perceived to enhance public health and safety by removing nuisances that live in the forest, maintain aesthetics by removing the trees that block the view, and mitigate private property loss that would occur by the loss of beach and ocean views. For others, the maritime forest enhances public health and safety by serving as a form of hazard mitigation by buffering the impact of coastal storms. Social conflict may be a significant factor in decision making involving private versus public tradeoffs and what are acceptable solutions.

Several additional tradeoffs were identified by town staff. For example, a few years prior to this study, the town revised zoning ordinances and placed limits on height of first floors above FEMA flood elevation requirements. This revision was made to preserve the streetscape from being flanked by walls of tall ground-level foundations. Although this management action

<sup>3</sup> Since implementing the VCAPS process, the Town has acquired a low interest loan from the South Carolina Revolving fund for a chemical grouting of the wastewater collection system. The project is expected to greatly reduce inflow and infiltration to the collection system and reduce the burden on the treatment plant and ultimately reduce treated effluent discharge into the creek.

<sup>4</sup> Since implementing the VCAPS process, the Town has developed a plan to install valves at the main/lateral connection. In the event a property is compromised, the lateral can be closed and isolated from the main and plant.

preserves the visual appeal from the streets, it may compromise the potential to reduce future flood losses (creating an aesthetic vs public health and safety tradeoff). There are also tradeoffs that balance private property loss versus public infrastructure and operations. Private land owners may place fill to elevate the land under structures in order to decrease the frequency of flooding events. While raising the elevation beneath a structure reduces its flood vulnerability, this practice is likely to displace water onto other infrastructure, roads, and homes that are relatively lower and thus more vulnerable to flooding. As such, an individual effort to reduce personal flood risk could increase risks to other private and public property, such as roads. The VCAPS discussion identified differences in adaptation goals and the associated tradeoffs which indicate that not all objectives can be met and that the way to resolve differences and determine a path forward is not well established.

## Discussion

The VCAPS process brought out a diversity of management challenges, local contextual factors, possible public and private actions, and impacts of concern associated with climate change. In this section we discuss the ways that VCAPS facilitated knowledge exchange and adaptation planning through the documentation and synthesis of existing issues, prioritization of management actions, connection of environmental- and climate-related changes to consequences, and identification of adaptation tasks, communication strategies, and information needs among town staff.

### *Document and synthesize existing knowledge*

The documentation and sharing of existing knowledge through the VCAPS process facilitated a deeper understanding of the diversity of management challenges involved in adaptation, leading to both individual and group learning; outcomes which have been documented elsewhere in the literature on participatory modeling (Jones et al., 2009; Berkhout et al., 2002; Muro and Jeffrey, 2012). In some cases, the VCAPS dialogue documented information already known by the entire town staff. In other cases, VCAPS provided a platform for participants to synthesize what was known by individuals or small groups, but not by everyone, thus addressing issues of stove-piping among departments and staff. In speaking on the importance of learning from town staff specialists, such as the stormwater manager and zoning administrator, a member of the planning commission stated “We rarely get a chance to sit down and talk and pick their brains” and learn about specific wastewater treatment issues on the island.

Several participants commented on the value of documenting and synthesizing existing knowledge from the entire town staff in developing more comprehensive decisions. As one participant explained, “[VCAPS] requires group thinking so many outside views are heard. Input from several individuals enriches the decision-making process as well as making the participants part of the solution for whatever decisions are made. Consequences we never would have thought of surfaced.” Participants went on to explain that the process of sharing existing knowledge and diagramming causal connections enabled them to see how actions designed to address a single issue may cause problems elsewhere. This is a particularly important feature of VCAPS as it helps to work against the selective use of scientific or local knowledge to advance particular priorities or decisions, which may have support in advance of the VCAPS process. As such, the VCAPS process helped participants synthesize information and help understand tradeoffs in management actions in a more transparent manner.

### *Link climate- and environment-related change to impacts*

The process of integrating local and scientific knowledge also helped participants connect environmental and climate-related changes to impacts and consequences for their town. This result is consistent with prior applications of analytic-deliberative processes in risk and environmental decision making (Burgess et al., 2007; Failing et al., 2007). Participants discussed how increased salinity levels may alter the distribution of marsh grasses used as indicators in the delineation of coastal management critical lines in South Carolina. The placement of these critical lines determines how lands can be developed (e.g., permanent structures or alternative uses). The VCAPS dialogue also facilitated deeper consideration of what changes in climate mean for community planning. In describing how increased wastewater treatment resulting from more frequent storms may contribute to higher use and depreciation of infrastructure, one participant stated: “Climate change could really change our thoughts about the lifetime of the system.” However, VCAPS could also inadvertently contribute to a narrow focus on specific climate related impacts. On Sullivan’s Island, the participants identified stormwater management as a priority issue and we followed their lead. Although this process enabled participants to take the lead in designating the focal issue, this may not always lead to the most beneficial learning within a community. For example, a more independent assessment of potential impacts and adaptation challenges might identify other issues, which a community may either not understand or seek to avoid because of potential conflict. On Sullivan’s Island the role of accreted land in climate adaptation was initially “off the table” because of the conflict surrounding the issue.

### *Prioritize management strategies*

Documenting existing challenges through the structured dialogue also enabled town staff and representatives to consider the priority of management strategies based on level of control. In the case of stormwater management, the town’s

adaptation choices are limited because infrastructure is owned by the state and maintained by the county. Participants expressed concern that if the town assumed responsibilities and costs, even for a short period of time, it would be difficult return those back to the county and state. During the group sessions, participants reiterated these concerns and were also able to identify strategies within their control that would not assume responsibility for stormwater infrastructure expenses. For example, participants considered the option that they could change pervious surface requirements to increase infiltration of runoff.

#### *Identify adaptation tasks*

Significantly, the causal connections identified through discussing climate changes and local issues led to the identification of specific climate-related adaptation tasks for the town; further supporting the role of scenario building and participatory modeling in management of complex systems (Jones et al., 2009). For example, to address challenges associated with saltwater intrusion, participants identified the possibility of creating water recharge ponds to be filled with treated wastewater, rather than pumping the treated water into the ocean. The goal would be for the water pressure created by these ponds to help push back the saltwater wedge while also providing homeowners a source of irrigation water.

#### *Refine communication strategies*

Exchanging different types of knowledge helped town staff and representatives think about ways to communicate the challenges, issues, and needs of the town to the residents. For example, the group noted that sealing manhole covers and replacing old wastewater pipes is already a management priority for the town staff because periodic flooding and hurricanes often lead to inflow and infiltration, which increases operating costs. Participants commented that this *no regret* management action will be important as mean high tides reach further inland as a result of sea level rise, leading to even higher operating costs for the wastewater treatment system. Identification of this no-regret strategy was illuminating to participants because they realized that this strategy enabled them to make a stronger case regarding what actions the community could take to make them more resilient, regardless of whether climate change was occurring or not. Other participants stated that the process of developing the diagrams needed to be continued with other influential people on the island to identify or change management priorities.

#### *Identify information needs*

Discussion identified specific information needed to help assess local vulnerabilities. Some information needs were easy to resolve. For example, the main evacuation route for the island is a narrow swing bridge approached by narrow causeways, and the elevation of that road, which can be found in construction records, is important to understanding the risks of flooding. Elevation data were also deemed important for identifying the vulnerability of individual manholes to inundation and determining how much they needed to be raised. Other identified information needs pointed to research needs, such as specific information on the saline concentration that would kill biological processes within wastewater treatment. More difficult information needs included how tides affect groundwater table elevations in the unconfined aquifer beneath the island.

Together, the specific adaptation tasks, strategies, and information needs generated through the knowledge exchange revealed the value of deliberative and integrated processes for climate change adaptation. Benefits of the process were particularly well-illustrated during a post-workshop interview:

The entire process provided an extremely important benefit for the Town. Decisions by political organizations tend to be based on short-term thinking that respond to immediate concerns; very little long term pro-active decision making is usually done. To examine potential issues with a long-term perspective is fraught with controversy so not normally a part of the political decision process. The thought process with your tool requires the users to understand all consequences of the action, takes most of the emotionalism out, and provides fact-based documentation. This not only forces us to address the many consequences associated with the examination, but also creates a richer experience for all involved. These results provide us with fact-based defense when questioned by interested residents, especially those with self-interest in the outcome. Subjectivity is lessened and objectivity becomes the driving factor.

## **Conclusion**

Developing adaptation strategies will require approaches to integrate scientific and local knowledge in order to develop solutions that take into account the multiple, and inter-related values, risks, and goals of significance in communities, each with unique characteristics. Analysis of key issues and concerns emerging from a VCAPS analytical-deliberative dialogue with the staff of the Town of Sullivan's Island, South Carolina, illustrate this complexity with respect to stormwater management issues. This process supported the exchange and integration of various forms of knowledge and led to the documentation of specific management challenges for a barrier island community, site-specific sensitivities, multiple impacts of concern, and tradeoffs involved among specific adaptation strategies. It also led to the identification of data and information

needs, communication strategies for dialogues with the community, and specific adaptation tasks and strategies. Although specific coastal management challenges vary from place to place, the existence of multiple impacts of concern and tradeoffs that must be negotiated among management actions are likely common conditions within all communities (Adger et al., 2009; Antunes et al., 2006). We situate the insights obtained from Sullivan's Island into the broader context of how mediated modeling processes, informed by local engagement and deliberation, support risk-based management approaches for climate adaptation.

The learning environment facilitated by the VCAPS process advances practice-relevant adaptation science by identifying vulnerabilities, developing local adaptation options and tasks, and connecting research and applications in ways that provide concrete benefits for society (Moss et al., 2013). In many cases, the vulnerabilities identified through this 'bottom up-top down' process extended beyond the generalized impacts to engage with indirect and location specific impacts – a key component in increasing the usability of scientific information (Dilling and Lemos, 2011; Cash et al., 2003). In addition to these insights, this case details how the process of synthesizing scientific and local knowledge supports adaptation as it builds context specific understandings of what is being managed; promotes systems-based thinking; stimulates thinking and learning; facilitates governance; and establishes deliberative mechanisms to foster consensus building. These outcomes are consistent with other theoretical and empirical studies (Webler et al., 2014; Berkhout et al., 2002; Muro and Jeffrey, 2012; Antunes et al., 2006).

Our experiences implementing VCAPS on Sullivan's Island also highlight important considerations in the design and facilitation of processes developed to support climate adaptation. A key observation is that the combination of facilitated discussions and structured diagramming can be a valuable approach to learning, identifying the diversity of risk issues associated with potential climate change, and identifying adaptation strategies. Specifically, the facilitated discussions enabled information sharing among participants and the diagram provided a structure for documenting discussions, fostering deliberation, and integrating different types of knowledge held by participants. As such, the VCAPS process illustrates how boundary objects can be used to develop credible processes for integrating multiple types of expertise, foster arenas for transparent access to information, provide a common language and focus for important discussions, and create processes for the production of relevant and salient information (Cash et al., 2003). As one participant stated in a post meeting interview, "Diagramming is a vehicle, a focal point to help thinking. It helps focus on the problem and elaborate thinking."

At the same time, there are challenges and limitations in implementing the VCAPS process. Some of these challenges are common to boundary work, such as obtaining time commitments from the town and identifying local champions. Although local champions are important for compelling participation and enhancing credibility, local champions may push personal agendas and actively exclude individuals with alternative priorities and values, thus compromising the legitimacy of the planning processes because individuals may have disparate values and assess hazard impacts differently (Spies et al., 1998). Furthermore, the process does not start with a blank slate; participants seek to develop information and justifications for their own priorities. Rather than simply help participants justify priorities by the selective integration of local and scientific knowledge, the research team must be careful to encourage reflective exploration of the issues and knowledge brought forth in the discussions. Other challenges are more specific to mediated modeling processes. In terms of facilitation, keeping the diagramming focused on one particular line of thinking when the discussion split into multiple conversations and multiple contributions were given simultaneously is a challenge. Finally, the steps of VCAPS do not include formal and systematic validation of the scenarios developed, as represented by diagrams (Webler et al., 2014).

The Sullivan's Island discussions illustrated the range of concerns and knowledge that can emerge from a relatively homogeneous group of town staff, who shared many expectations and goals and brought out the potential for greater controversy among residents on some topics, such as managing risks to the wastewater treatment plant from breaking residential line. It also identified some topics where further dialogue could be valuable in advancing adaptation. Future applications may also be used to identify important thresholds and tipping points, which represent significant breaks in the nature of risks. This process may also provide several benefits for generating understanding among groups with disparate priorities, values, and needs or who are engaged in management objectives across different scales of governance.

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