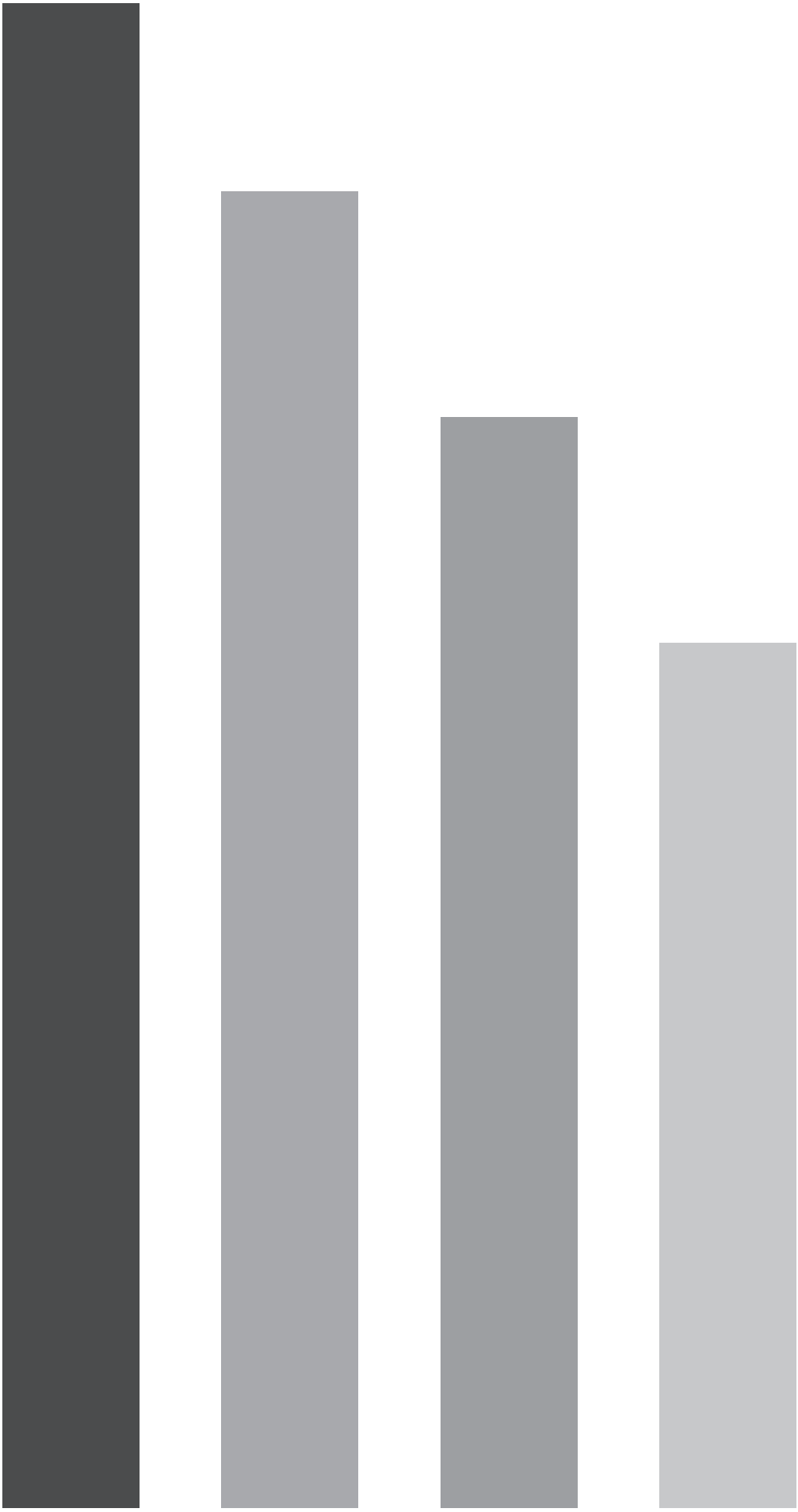

VERTICAL LAND MOTION in the CHESAPEAKE BAY

WORKSHOP SUMMARY

Sea Grant Maryland

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This report summarizes presentations, discussions, and results from the Vertical Land Motion in the Chesapeake Bay Workshop, held February 28, 2020, in Hampton, Virginia. The workshop, sponsored by Maryland Sea Grant and the National Science Foundation, was to discuss processes contributing to vertical land motion in the Chesapeake Bay, the current measurement techniques used to estimate vertical land motion rates, and how those estimates may affect predictions of relative sea level rise around the Chesapeake Bay.

This publication was made possible by a grant to Maryland Sea Grant from the National Science Foundation through the Coastlines and People program, Grant number ICER–1940218 and funding from the National Oceanic and Atmospheric Administration, Department of Commerce, through the National Sea Grant College Program, Grant number NA18OAR4170070, and funding from the state of Maryland through the University of Maryland Center for Environmental Science.

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WORKSHOP SUMMARY

OVERVIEW

Vertical land motion (VLM) refers to the long-term rate of elevation change of the land surface compared to the Earth's center. VLM can be a significant contributor to relative sea level rise (RSLR) in parts of the Mid-Atlantic region. Rates of VLM occur at the millimeter-per-year scale and local VLM rates vary widely along the Atlantic coast with the Chesapeake Bay (CB) having an estimated range between 1- 4 mm yr^{-} of subsidence.[1] Accurately determining VLM rates across the region could contribute to better predictions of local variation in RSLR and identify human-caused subsidence hotspots. Vertical land motion in the CB region is measured using a variety of data collection techniques. The methods–e.g. Global Navigation Satellite Systems (GNSS), Interferometric Synthetic Aperture Radar (InSAR), extensometers, and tidal stations–differ in their extent of spatial coverage, temporal detail, and cost. In 2019, a consortium of federal and state agencies and university partners[2] took a novel approach to obtain consistent and reproducible Global Positioning System-based VLM measurements across the region in a "VLM Monitoring Campaign." Because of the interest in VLM in the CB region, a workshop was held to explore current VLM research and connect VLM scientists with coastal managers to discuss how VLM and RSLR data may contribute to coastal resilience planning.

The workshop hosted by Maryland Sea Grant (MDSG) on February 28, 2020, gathered eighty-three participants at the Virginia Air and Space Center library in Hampton, Virginia, to discuss processes contributing to VLM in the CB region, the current measurement techniques used to estimate VLM rates, and how those estimates may affect predictions of RSLR around the CB region. Participants came mostly from Virginia and Maryland representing a range of expertise and organizations (e.g. federal, state, and local government, academia, land managers, and graduate and undergraduate students from Morgan State University, Hampton University, and Virginia Tech).

This report is informed by pre- and post-workshop participant surveys and the in-person workshop. We share findings on research needs, communication strategies, policy considerations, and next steps for the future.

METHODS

A steering committee used information gleaned from a participant pre-workshop survey (Appendix A) and steering committee member discussions, to design this workshop, which brought together VLM experts and attendees interested in VLM and RSLR.

The workshop goals were:

1. Improve understanding of mechanisms causing land subsidence in the CB region and its impacts on coastal resiliency planning and management.
2. Determine data gaps and research needs to advance VLM science and management response.
3. Identify communities' information needs and information delivery methods regarding VLM and coastal resiliency.
4. Strengthen collaborations among VLM experts and stakeholders.

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1 Boon, J., J. Brubaker, and D. Forrest. (2010). Chesapeake Bay Land Subsidence and Sea Level Change: An Evaluation of Past and Present Trends and Future Outlook

2 At the time (June 2019) members included National Oceanic and Atmospheric Administration's National Geodetic Survey, U.S. Geological Survey, Old Dominion University, Virginia Polytechnic Institute and State University, Maryland Geological Survey, National Aeronautics and Space Administration, and Hampton University.

The workshop was organized into three sessions: (1) the state of the science on processes that contribute to VLM in the CB Region; (2) the current measurement techniques to estimate VLM rates; and (3) the implications of VLM on managing coastal ecosystems (Appendix B). Dr. Timothy Dixon's (University of South Florida) keynote address provided a critical overview of the challenges of measuring VLM and the link between subsidence and flood hazards. Discussion sessions (nine groups of ten or less) explored effective communication strategies for sharing VLM impacts with different audiences, identified research needs, and highlighted potential new collaborations (Appendix C). The workshop ended with a discussion among a panel of experts and the participants about outstanding VLM issues.

MDSG used the notes from the discussion sessions to compile a list of needs and communication ideas. This list was used in the post-workshop survey to ask participants how useful each need/idea would be if further developed (using a Likert Scale of 1 being not useful – 5 being extremely useful) and their willingness to collaborate toward its development (Appendix D). Interested parties were connected via email to collaborate on topics of mutual interest.

WORKSHOP FINDINGS

Survey results and discussion group comments are organized under the four workshop goals. The bullets describe overall themes or priority actions that were emphasized or repeated by multiple discussion groups. While not all the bullets were included in the post-workshop survey, asterisks next to bullets indicate it was among the top 10 suggestions in the post-workshop survey (Appendix D).

Goal 1: *Improving understanding of mechanisms causing land subsidence in the CB and its impacts on coastal resiliency planning and management*

- Pre-workshop, participants indicated support for goal one (learning about VLM's contribution to RSLR in the Chesapeake Bay), as well as a high level of interest in multiple related topics (Appendix A).
- Post-workshop, participants reported ~20% increase in understanding VLM's relationship to RSLR. The percentage ranged significantly between participants (possibly reflecting the mix of newcomers and experts) (Appendix D).
- Participants indicated their top two sources for VLM information were the United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) (Appendix D).
- Participants noted a need for additional information and education about VLM effects on ecosystem function and on land subsidence in Maryland (Appendix D).

Overall, the participants found the workshop valuable and plan to incorporate the information learned into their research and/or outreach (Appendix D). The surveys indicated the workshop addressed topics of high interest to the participants and they gained knowledge about VLM and RSLR from the workshop.

Goal 2: *Determine data gaps and research needs to advance VLM science and management responses*

Participants and speakers identified numerous gaps in understanding in the Chesapeake Bay region. These gaps include:

- Identifying and separating anthropogenic and natural VLM processes.*
- Including more types of monitoring (e.g. hydrologic monitoring, aquifer salinity, sediment supply) in the region.*
- Increasing VLM monitoring infrastructure and VLM measurement frequency and/or density to improve understanding of VLM rates at smaller spatial scales across the region, which is necessary to help implement local policy.
- Determining if drivers of subsidence differ to help target management strategies (i.e. if shallow aquifer injection would affect subsidence rates).

Participants felt it necessary to further research causes of VLM to advance mitigation efforts. As there are still places throughout the region that do not have VLM monitoring infrastructure in place, the groups expressed a need to fill spatial and temporal monitoring gaps to provide a more accurate, continuous record. Furthermore, groups shared concern that existing data sets differ in accuracy and comparability, which could be resolved if regional standards were in place. In particular, participants noted data gaps made it difficult to know where it might be important to optimize groundwater withdrawal to minimize subsidence in areas where this was the primary VLM driver.

Goal 3: *Identify communities' information needs and information delivery methods regarding VLM and coastal resiliency.*

Discussion within the groups was wide-ranging yet yielded several communication themes on challenges and possible solutions:

- *Challenge:* It is difficult to communicate the complexity of VLM given local variability in drivers, rates, measurements, and unknowns.
    - *Potential solution:* Scientists continue to confer to reach agreement on numbers or rates, where possible, or specifics about data uncertainty, which might improve understanding and management efforts with municipalities and other stakeholders.
- *Challenge:* Some audiences do not perceive that the annual millimeter rates of change in land subsidence can have significant impacts to their livelihoods or the environment.
    - *Potential solutions:*
        - Show how vertical rates of VLM/RSLR relates to horizontal flooding on the landscape.*
        - Compare VLM and sea level rise (SLR) rates over time.*
        - Show the cumulative effects of millimeter change on RSLR over different time scales.
        - Link VLM rates to the current nuisances and costs resulting from RSLR (i.e. inundation, costs to infrastructure, costs to personal/private investments, ecological transformations). For example, using extensometer data to show rapid response in ground height to aquifer pumping.
- *Challenge:* Some audiences may think their actions will have no impact.
    - *Potential solution:* Convey there are ways to manage VLM—especially groundwater management—that can slow RSLR.

A few participants noted in the post-survey that greater scientific consensus is required before embarking on a communication campaign. During the discussion sessions, multiple groups stated the need for consistent data on VLM rates and measurements to effectively communicate and inform management across various geographies. Several best practices were discussed including the use of clear graphics and stories as well as recruiting trusted messengers—e.g. military, National Aeronautics and Space Administration (NASA), news meteorologists, and community members—to deliver information.

Goal 4: *Strengthen collaborations across VLM experts and stakeholders.*

To advance research, management, and communication needs, participants stressed greater collaboration among stakeholders at multiple scales.

- Facilitate collaboration via regional commissions, meeting fora, and/or clearinghouses.*
- Increase collaboration at multi-jurisdiction, interagency, and interstate levels.
- Include social scientists, legal perspectives, and trusted community messengers such as church leaders and civic league members to further VLM and sea-level rise discussions.
- Improve VLM data access so municipalities can access data beyond their jurisdiction.
- Combine different data sets to yield the best results (e.g. satellite, field surveys, ecological, geological, long-term monitoring campaign, short-term data collection).

The groups stressed that multi-sector collaboration could help standardize VLM data sets, form consistent regulations for VLM mitigation, increase the extent of data collected, and improve access to existing data. Increasing interdisciplinary stakeholder engagement would help better understand end-user priorities and increase communication between scientists and end-users to inform mitigation or adaptation actions. The groups suggested that focused workshops or dedicated entities with a coordinating role could build these interdisciplinary or collaborative relationships.

CONCLUSIONS AND NEXT STEPS

When asked for additional feedback about the workshop in the post-workshop survey, a majority (71%) of respondents (n=21) described the workshop as successful, specifically in terms of identifying VLM experts, promoting connections, networking with workshop participants, learning methods to identify VLM and existing data gaps, and identifying shortcomings and possible improvements in communication to the public, managers, and policymakers. For the survey question which asked about turning information into action, 25 respondents shared they have used or plan to use the workshop knowledge gained to distribute information to their stakeholders, incorporate this knowledge into their current research, and collaborate with new partners.

The VLM workshop proved to be a valuable opportunity for scientists to share knowledge about, and identify uncertainties associated with, assessing VLM in the CB region to a diverse audience. Shortly after the workshop, the COVID-19 pandemic forced a national lockdown. In a continuing effort to advance topics of interest, MDSG sent out post-workshop emails connecting survey respondents who indicated that they were willing to collaborate on a particular communication topic (e.g. communicating how SLR rates and VLM rates will compare over time) or make progress on identified needs (e.g. cost-benefit analysis of VLM's effect on land use in the long and short term [Appendix D]). While MDSG has not found evidence that the participants developed these ideas post workshop and under COVID-19 constraints, monitoring VLM impacts continue and the workshop results have informed MDSG outreach efforts. For instance, the VLM Monitoring Campaign participants, many of whom attended the workshop, did collaborate to collect simultaneously measured land elevation data throughout the CB region in October 2020. This October campaign was year 2 of a 5-year study to produce new VLM estimates for the CB region and is on-going. In addition, information from this workshop guided a second MDSG workshop, conducted virtually, on Evaluating Land Use Tradeoffs. This workshop explored the implications of RSLR to farmers' and woodlot managers' land management decisions. Within the constraints of the ongoing COVID-19 pandemic, MDSG anticipates using this report to share workshop results and catalyze key stakeholders and collaborators to discuss and potentially develop VLM outreach priorities.

ACKNOWLEDGEMENTS

This was the first of two workshops supported through a National Science Foundation's Coastlines and People program to grant #ICER–1940218 to Maryland Sea Grant College. Maryland Sea Grant would like to thank the National Science Foundation for their support as well as the following steering committee members:

- David Andreason, *Maryland Geological Survey*
- Linda Blum, *University of Virginia*
- Philippe Hensel, *NOAA, National Geodetic Survey*
- Scott Knoche, *Morgan State University*
- Kate McClure, *Maryland Sea Grant Extension*
- Cindy Palinkas, *University of Maryland Center for Environmental Science*
- Heather Quinn, *Maryland Geologic Survey*
- Andrew Staley, *Maryland Geologic Survey*
- Sarah Stamps, *Virginia Polytechnic Institute and State University*

APPENDIX A
PRE-SURVEY

MDSG conducted a pre-workshop survey to inform the workshop's agenda and to ensure diverse perspectives and geographies. Seventy participants completed the pre-workshop survey. The first eight questions assessed their interest in workshop topics. The next six questions asked about demographics.

Survey results are discussed below.

Question 1 asked why they wanted to attend the workshop:

- Participants wanted to attend the workshop based on the following:
  - Sought knowledge on VLM and its relation to RSLR (n=21)
  - Relevance to their work or concern about ecosystem resilience to VLM/RSLR (n=15)
  - VLM science is part of their current research or profession (n=14)
  - Relevance to their climate change planning work (n=11)
  - Using VLM science to inform management strategies (n=7)
  - Intent to communicate VLM to stakeholders (n=6)
  - Specific interests include:
    - How InSAR work on VLM relates to other VLM projects (n=1).
    - Interest in quantifying subsidence (n=1).
    - VLM's effect on marsh resiliency or marsh migration (n=2).
    - Correlation between groundwater pumping and VLM (n=2).
    - How the workshop could inform infrastructure design products (n=1).

Questions 2-5 asked about level of interest in potential RSLR topics, using a Likert scale: Not at all interested (1), A little interested (2), Neutral (3), Somewhat Interested (4), Very Interested (5). The majority of responses were "somewhat" to "very interested". The highest "very interested" (80%, n=70) topic was "how VLM contributes to RSLR in the Chesapeake Bay." The lowest "very interested" (42%, n =70) topic was regarding "extensometers" when asked "How interested are you to learn about the following vertical land motion measuring techniques?" Table A1 is the list of topics organized by category.

Table A1. Pre-survey responses list of topics organized by topics. The percentage is the combination of "somewhat" and "very interested" answers.

SUMMARIZED RESPONSES	
Relative sea level rise topics	
	Why relative sea level rise varies around the Chesapeake Bay (97%)
	How vertical land motion contributes to relative sea level rise in the Chesapeake Bay (96%)
	How future rates of relative sea level rise are predicted (90%)
	How relative sea level rise rates are measured (89%)
Vertical land motion	
	What geologic processes are responsible for vertical land motion in the Chesapeake Bay (94%)
	What anthropogenic processes are responsible for vertical land motion in the Chesapeake Bay (93%)
	How an understanding of vertical land motion informs coastal ecosystem processes (91%)

SUMMARIZED RESPONSES	
Vertical land motion measuring techniques	
	Global Position System (GPS)/Global Navigation Satellite System (GNSS) monitoring (91%)
	Interferometric synthetic aperture radar (InSAR) satellites (86%)
	Extensometers (75%)
Vertical land motion management options	
	Sediment management for marsh accretion (87%)
	Erosion prevention (86%)
	Groundwater withdrawal optimization (84%)
	Groundwater injection (84%)
	Water Conservation (75%)

Question 6 asked about additional topics that they were interested in; Table 2 has a summary of responses.

Table A2. Pre-survey summary of responses regarding additional topics that respondents were interested in. *Below is a summary of responses of the 32 responses.*

SUMMARIZED RESPONSES	
Marshes	
	Anticipated impacts of VLM on coastal ecosystems (marshes, forests, communities)
	Marshes response to relative sea level rise
	Late Pleistocene and Holocene changes in land motions on the Atlantic coast and its effects on marshes
Groundwater	
	Groundwater recharge and natural formation
	Future anticipated risks of sea water intrusion into groundwater
	Surface and subsurface hydrological processes in this region
	Virginia Department of Environmental Quality groundwater permitting process
VLM extent	
	Geographic extent and severity of land motion distribution
	How the vertical land movement differs for MD's counties
	Compare VLM along other coastlines to understand the complexities of what is occurring in the Chesapeake Bay
	How to better predict hotspots for VLM
VLM history	
	History of tracking VLM
Monitoring and data analysis	
	Real-Time Kinematic (RTK) Monitoring
	Surface Elevation Tables (SETs)
	GNSS reflectometry
	Priority data needs (both types of data and geospatial)
	Ways to improve data
	VLM monitoring along spatial gradients
	Slope surveys to assess upland vegetative migration
	Data analysis requirements along with confidence intervals of vertical motion analysis
	Relevance of tidal datums in small tidal regimes considering high sea level rise rates
	Larger scale modeling
Mitigation	
	How land use has changed/affected VLM in the CB region
	Land conservation and future building practices

SUMMARIZED RESPONSES	
	Levees, shoreline armoring, living shorelines
	How governments can help reduce erosion and other impacts resulting from land use changes such as dams, barriers, channeling, etc.
	Policy influence on scientists and land managers dealing with land subsidence and sea level rise
Other	
	"What other science is contributing to land motion"
	"What other resources are available on this topic?"
	"What future work to better understand these issues is being developed and how we can be a part of this effort."
	"Mapping of fill and land creation along with predictions of land subsidence associated with these areas."
	"Analysis of crater rim geology"
	"Ties to mapping and charting, as well as completed and ongoing LIDAR projects"
	"Macro engineering projects around the world that could positively effect sea levels, such as the Dead Sea water infusion project, the Quatara Depression flooding potential in the Libyan Sahara Dessert, etc."
	"Regional variations in sea level due to changes to the Meridional Overturning Circulation in the North Atlantic Gyre."

Question 7 was open-ended and asked where respondents get information on vertical land motion (Figure A1).

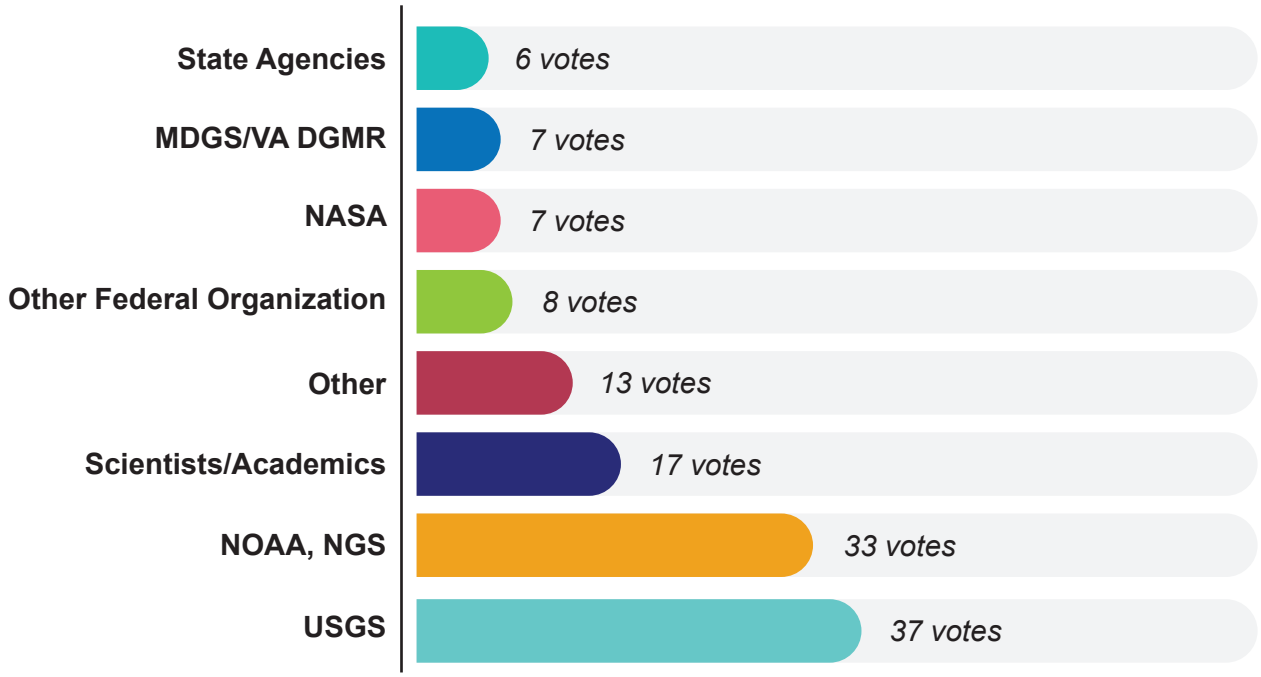

Figure A1. Pre-workshop results on where respondents go for information on VLM (n=70). *Note: respondents were allowed to choose more than one option. Maryland Geological Survey (MDGS)/ Virginia Division of Geology and Mineral Resources (VA DGMR), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey (NGS), U.S. Geological Survey (USGS). Scientists/Academics section also includes scientific journal articles and universities. The "Other" category includes: American Geophysical Union, American Society of Civil Engineers, Chesapeake Bay National Estuarine Research Reserve, Environmental and Water Resources Institute, European Space Agency, international agencies, Maryland Port Authority, National Science Foundation, Sustainable Water Initiative for Tomorrow (SWIFT), United Nations Educational Scientific and Cultural Organization's Land subsidence international initiative, University NAVSTAR Consortium, and Wetlands Board. Not depicted are the nine respondents who did not identify an agency.*

Question 8 (Figure A2) asked participants to rank their top two preferred methods of information delivery on VLM. In-person presentations (70%) ranked first, followed by webinars (39%), websites (37%), and scientific journals (34%). The lowest ranked were videos (6%) and blog/magazine articles (6%) (n=70).

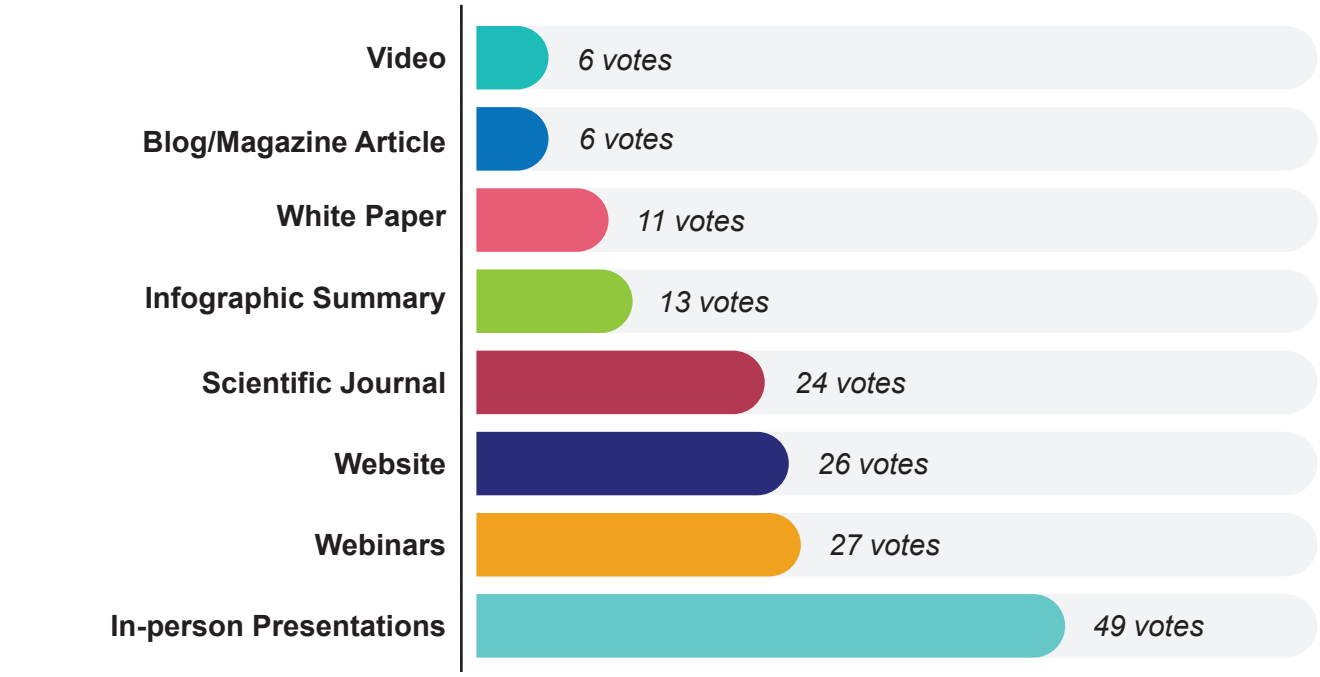

Figure A2. Pre-workshop results on the respondents' preferred methods of information delivery on VLM topics (n=70). *Respondents were encouraged to pick their top two options.Depicted are the number of votes for each information delivery method.*

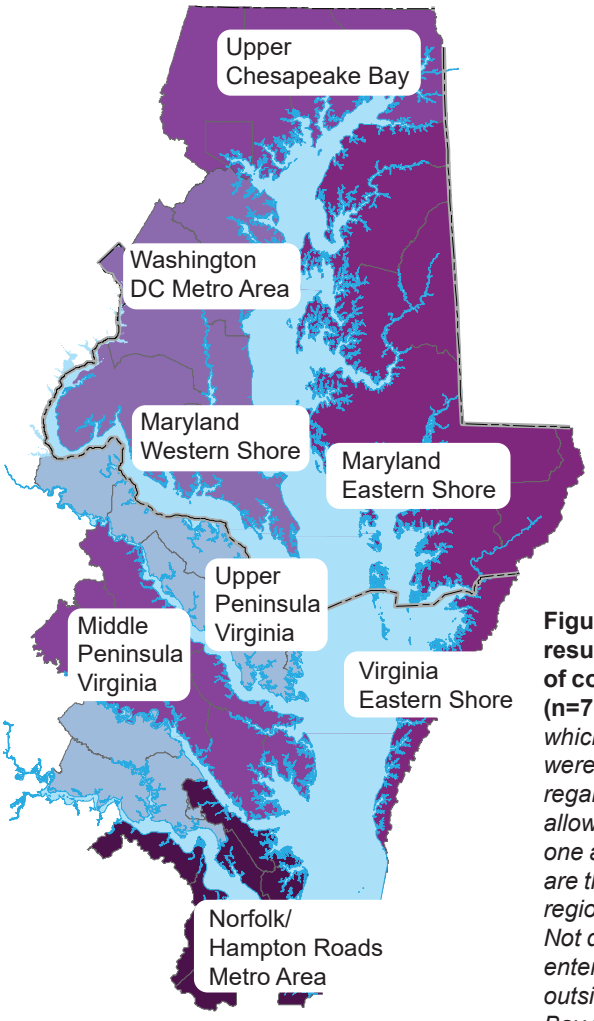

Figure D3. Pre-workshop results on geographic area of concern regarding VLM (n=70). *Respondents indicated which geographies they were most concerned about regarding VLM and they were allowed to choose more than one area. The depicted values are the votes indicated for each region in the Chesapeake Bay. Not depicted are six answers entered as "Other" that are outside the Chesapeake Bay region.*

The final six questions (Figures A3-A6) asked about: geographic area of concern regarding VLM (e.g. Eastern Shore, Upper Chesapeake Bay, Norfolk/Hampton Roads); participant's sector (e.g. federal, state or local government, nonprofit, industry); type of work (e.g. research, planning, outreach); and career length (e.g. early, mid, long). Participants were most concerned about the Eastern Shore and Norfolk/ Hampton Roads. Representation was high among academia, followed by federal and state government, with lowest representation of county government and policy development. Most participants' indicated their work was in scientific research. There was a nearly even distribution between early, mid, and long career.

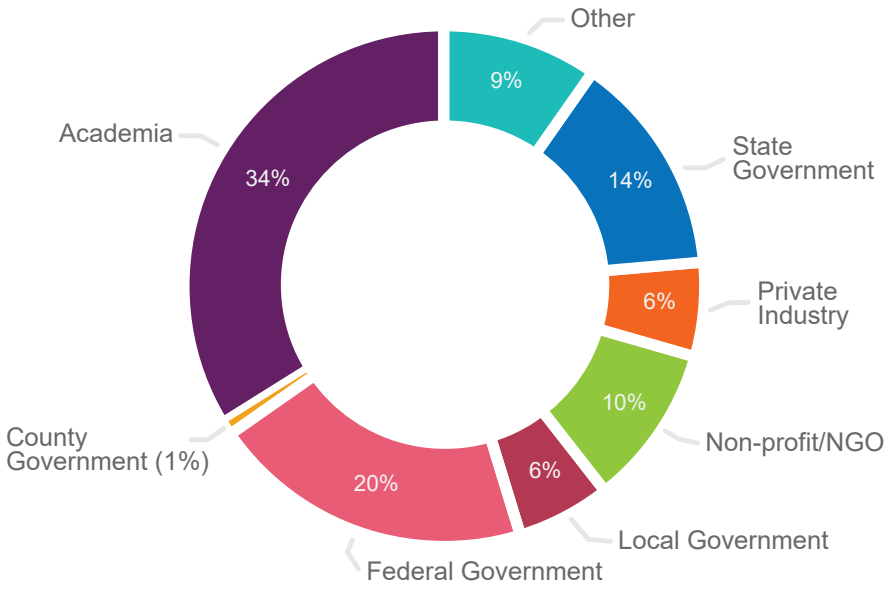

Figure A4. Pre-workshop results on respondents' sector (n=70). *Respondents indicated the sector which best represented their work.*

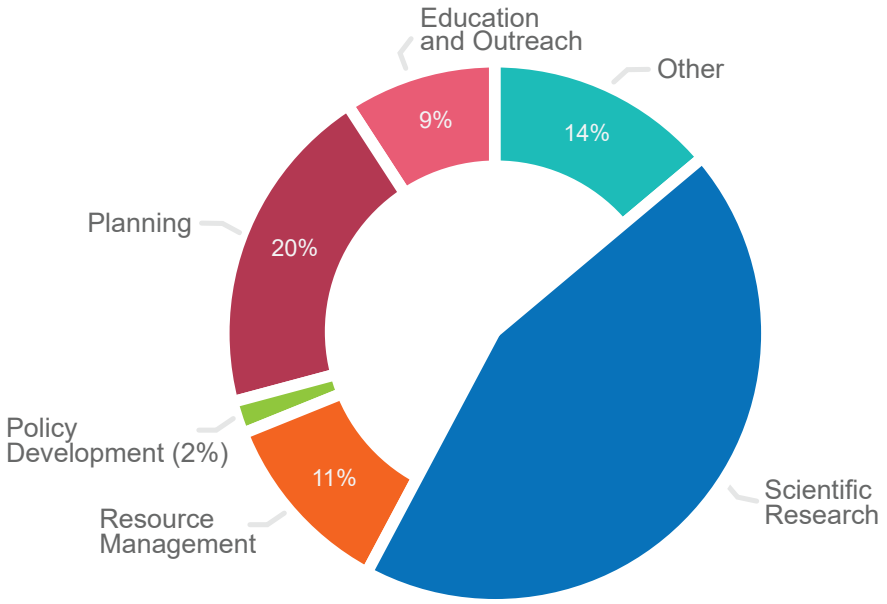

Figure A5. Pre-workshop results on respondents' type of work (n=70). *Respondents indicated work they are primarily involved in.*

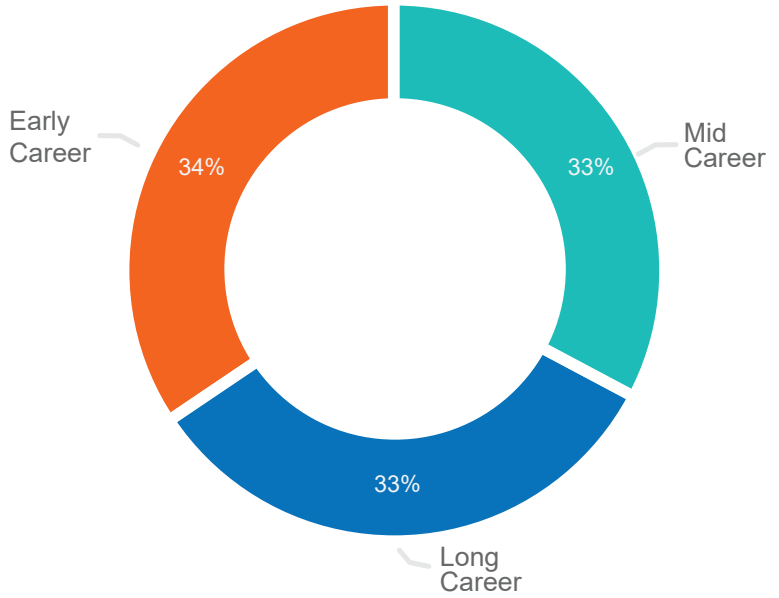

Figure A6. Pre-workshop results on respondents' career stage (n=70). *Respondents (n=70) indicated how long they have been in their profession.*

VERTICAL LAND MOTION in the CHESAPEAKE BAY

APPENDIX B
WORKSHOP AGENDA

8:00 a.m. – 8:30 a.m.	*Registration Opens*
8:30 a.m. – 8:45 a.m.	**Welcome** Fredrika Moser, *Maryland Sea Grant*
8:45 a.m. – 11:00 a.m.	**PART I: STATE of the SCIENCE**
8:45 a.m.	KEYNOTE PRESENTATION **The first few meters: How compaction of uppermost Holocene sections can lead to elevated rates of land loss in certain deltaic regions** Timothy Dixon, *University of South Florida*
9:20 a.m.	**Relative sea level rise at Galveston Pier 21, Texas, USA: Contributions from land subsidence** Yi Liu, *Morgan State University*
9:40 a.m.	**Co-evolution of wetland landscapes, flooding and human settlement in the Mississippi River Deltaic Plain: An update** Robert Twilley, *Louisiana Sea Grant College Program and University of Louisiana*
9:55 a.m.	**What geologic processes could influence vertical land motions** D. Sarah Stamps, *Virginia Tech*
10:10 a.m.	**A review of vertical land motion caused by fluid withdrawals in the eastern US and beyond** Kurt McCoy, *Virginia-West Virginia U.S. Geological Survey Water Science Center* Andrew Staley, *Maryland Geological Survey*
10:30 a.m.	**Vertical land motion considerations in environmental monitoring** Linda Blum, *University of Virginia*
10:45 a.m.	*Break*
11:00 a.m.	**Get it out there—how to communicate your work through traditional methods and digital platforms** Lisa Tossey, *Maryland Sea Grant*
11:15 a.m.	**Discussion session I**

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11:45 a.m. – 12:30 p.m.	**PART II: MEASUREMENT TECHNIQUES**
11:45 a.m.	**Vertical land motion monitoring methods and October 2019 Chesapeake Bay subsidence surveys** Russ Lotspeich, *Virginia-West Virginia USGS Water Science*
12:15 p.m.	**NISAR and applications of SAR interferometry** Batuhan Osmanoglu, *NASA Goddard Space Flight Center*
12:30 p.m. – 1:15 p.m.	*Networking lunch*
1:15 p.m. – 2:40 p.m.	**PART III: MANAGEMENT IMPLICATIONS for COASTAL ECOSYSTEMS**
1:15 p.m.	**Vertical land movement estimated in the Harris-Galveston, Texas, region: A case study of using GNSS-derived ellipsoid heights to measure crustal movement** David B. Zilkoski, *Geospatial Solutions by DBZ*
1:35 p.m.	**Groundwater management and regulation in coastal Virginia** Scott Kudlas, *Office of Water Supply, Virginia Department of Environmental Quality*
1:50 p.m.	**Salt marsh restoration for coastal resilience in an era of accelerated SLR** Carolyn Currin, *NOAA NOS National Centers for Coastal Ocean Science*
2:05 p.m.	**Discussion session II**
2:40 p.m. – 3:30 p.m.	**PART IV: SUSTAINING WHILE SUBSIDING: A PANEL on FUTURE INVESTMENTS**
	Timothy Dixon, *University of South Florida* Debbie Herr Cornwell, *Maryland Department of Planning* Whitney Katchmark, *Hampton Roads Planning District Commission* Robert Twilley, *Louisiana Sea Grant College Program and University of Louisiana*
3:30 p.m.	**Closing Remarks**

APPENDIX C
DISCUSSION SESSIONS

Each discussion group had an assigned facilitator and notetaker, who were given instructions and the discussion questions beforehand. The groups had approximately ten randomly assigned participants to allow for different perspectives and new networking opportunities. This appendix provides summaries on the two discussion sessions. The notes from each group were summarized, combined, and organized by similar themes. These paraphrased points reflect the candor of the conversations but cannot be attributed to any one person nor are they a reflection of MDSG's position on the posed questions.

SESSION 1

The first discussion session addressed Goal 3 of the workshop to create a communication strategy on how variability in local VLM rates could affect RSLR planning. The session began with an overview of effective communication strategies presented by Lisa Tossey, MDSG Assistant Director for Communications. The intent was to learn what participants found most important to communicate, who the message must be communicated to, and how that message could be delivered most effectively.

Discussion Question 1. *What do you think is most important for your stakeholders to know about VLM based on what you have heard so far?*

- Consistency in messaging
  - Consistency helps gain stakeholder trust
  - Consistency can be improved if municipalities use the same SLR scenarios
  - Communicating multiple factors is difficult, especially with local variability in drivers, rates, measurements and unknowns
  - Mixed messages or conflicting strategies are challenging, i.e. inland groundwater pumping may alleviate aquifer compaction but surface pumping could damage fisheries
  - Reach agreement on numbers or rates, where possible, or be very specific about qualifying data
  - Show that physical data is being collected in addition to model predictions
- Importance of planning for the long term
  - Deleterious SLR impacts are occurring due to inaction or reacting to the short-term rather than the long term impacts
  - Communicate how seemingly insignificant millimeter change per year will add up over time and lead to significant changes
  - Include how an increase in RSLR affects horizontal water movement
  - Make the distinction that subsidence is important now but SLR will be the larger driver in the future
- Talk about daily impacts
  - Groups showed concern that numerous SLR/VLM impacts go unseen (e.g. water table, septic tanks) and this possible "out of sight, out of mind" mentality may contribute to inaction
  - Demonstrate that VLM causes visible impacts, such as nuisance flooding
  - Use extensometers to display the ground's rapid response to changes in groundwater pumping
- Convey economics of VLM
  - Relate VLM impacts to current costs, such as impacts to real estate and insurability
  - While large-scale data gathering (e.g. NASA satellite missions) may have a high initial price tag, communicate that this data could be used for many years and inform sound planning

- Think about solutions and how communities can take action:
  - Some audiences are hopeful that they can do something while others think there's no point or their actions will have no impact
  - Convey that there are ways to manage VLM, especially groundwater management, which can slow RSLR

Question 2. How can this information, given limited resources, be effectively communicated to your stakeholders?

- Venues
  - Newspaper, TV news, paid Facebook advertisements, presentations at town council meetings, civic leagues, and/or faith-based meetings
- Who
  - Trusted messengers (military, NASA, weathermen, community members) need to share VLM information with stakeholders
  - Recommend that trusted messengers state they believe in SLR, that SLR is accelerating, and that they're investing resources to adapt
  - Scientists need stronger connections with communicators to help guide their message delivery, i.e. universities share message with high schools
- How
  - Multiple groups suggested that visuals are the best way to communicate
  - Be specific! Use clear graphics and clear stories
  - Message may vary by locale so what works in one place may not necessarily work in another
  - Address the reality of the situation and include a positive aspect
- Content ideas
  - Focus on local issues and RSLR. Resilience Adaptation Feasibility Tool (RAFT) is a good example of evaluating local sea level rise impacts with a community
  - Relate VLM to human health impacts (e.g. morbidity, mortality, disease, food scarcity) or environmental justice (e.g. where do flood protection strategies currently exist?)
  - Highlight economic trade-offs
  - Use interactive maps (e.g. FloodIQ.com now called Floodfactor.com) to learn about impacts
  - Share a personal story on how landscapes have changed with stakeholders/scientists (e.g. this is where I played as a kid on Tangier, but this is what it looks like now)
- Best practices
  - Keep it simple and un-politicized
  - Utilize terms that stakeholders would comprehend (e.g. imperial measurements vs. metric)
  - Have ready examples to point to such as New Orleans or Blackwater National Wildlife Refuge
  - Go to where the stakeholders are
  - Form rapport with stakeholders via constant communication
- Other challenges
  - It's tough to reach audiences who are not actively seeking out information on RSLR, VLM, and climate change
  - How to combat social media posts that try to debunk the science
  - The publishing world should renew interest in topics for each generation, who may not consult articles from decades ago

Question 3. *What information delivery method is most appropriate?*

- The groups shared a range of ideas to share information such as: paid Facebook advertisements, hosting a happy hour, and creating time lapse visuals.
- Another suggestion was a white paper for communicators to show how data is collected and used to calculate the results, but were uncertain how transferable the data is between regions.

SESSION 2

The second discussion session addressed Goals 1 & 3 to identify data gaps, research needs, and potential collaborations or projects that may improve VLM rate estimates and/or improve management response to RSLR.

Question 1. *Where do you see current data gaps or areas that require further research in VLM measurement relative to coastal management efforts?*

- Monitoring gaps
  - There are still places throughout the region which do not have the infrastructure in place to monitor VLM or marsh resilience
  - Accuracy and comparability are questionable among data sets without regional standards for data collection (e.g. elevation data)
  - VLM measurements tend to be site-specific leading to spatial and temporal gaps. Municipalities still do not have the frequency or density of measurements that are usable at the planning/policy level. Groups saw potential in the approach described by Dave Zilkoski in Harris-Galveston to fill-in spatial and temporal gaps around long-term VLM sites to provide a better and more continuous record
  - There is a mismatch between the time required to get high-quality data (5 years for the VLM measurements) and the need for communities to respond before the data is ready
  - One other monitoring gap a group asked about was “how is the saline profile changing in aquifers?”
  - Another group discussed the need for monitoring living shorelines, including the rate of compaction of sediments for those shorelines or thin layer restorations
- Drivers of VLM
  - Determine what is causing VLM and separate out what the anthropogenic causes are so that mitigation could occur
  - If possible, separate different subsidence drivers by depth
  - Groundwater withdrawal: How can one optimize groundwater withdrawal to mitigate the intense cones of depression? Could more optimization modeling help to understand how stresses can be distributed? Is it worth injecting water into shallow aquifers? Do we need more monitoring or enforcement to make sure withdrawal permits are not violated?
- Communication gaps
  - Some groups stated that data need to be more widely available (e.g. there is no national coverage of coastal models), though the high cost of research puts a limitation on the availability of data that can be obtained
  - More data could demonstrate the need for action by government
  - Other groups pointed out the need to better understand (and then address) the policy makers and managers’ questions
- Other comments and suggestions made by groups:
  - How will VLM and SLR interact in the future to cause landward movement of the coastline and impact the built environment?
  - How does managed retreat influence the housing market? Will houses further inland increase in value?

- What is the effectiveness of oyster sills for marsh protection?
- What are some projects and ideas to show changes in flooding? King Tides project, Blue Line project, using traffic cameras for monitoring flooding are a few examples
- Link InSAR data with the rest of VLM data and compare this to different SLR scenarios (Virginia Institute of Marine Science SLR Report Card as a resource).

Question 2. *What research and/or resources could improve management decisions or actions?*

- Improve communication and stakeholder engagement
  - Consider factors that can paralyze stakeholders from action, e.g. politics, permits, government compliance, and economics
  - Incorporate more social science/humanities in research, which could also address environmental justice issues
  - One group also suggested more science activism
  - Share lessons learned from past project failures
- Increase on-the-ground monitoring including
  - Water level monitoring to be able to apply water levels to SAR images
  - Hydrology data, through the installation of more groundwater wells, to also help determine the storage capacity for different watersheds
  - Information on the spatial trend in subsidence rates and marsh migration rates
  - Information on sediment supply (e.g. is there a sediment deficit?)
  - Types of data at VLM and SLR sample stations (e.g. weather, water quality, flooding, information on the built system such as hardened shorelines)
  - Timely data sharing across different groups, possibly through Memorandums of Understanding
  - Data standardization/protocols to ensure data compatibility
- Other research needs mentioned
  - Risk assessment and analysis of septic issues related to VLM
  - Improvement of river and coastal flooding forecasts

Question 3. *What types of collaboration and/or projects can meet current research, management, or communication needs?*

- Interdisciplinary and increased stakeholder engagement
  - Increase engagement with scientists, groundwater managers, lawmakers, city engineers, planners, and watermen. Churches and civic leagues could also be potential trusted messengers
  - Use social scientists and communicators to help train local community stakeholders, including citizen scientists
  - Use citizen scientists, such as those in the education system (i.e. grade school, middle school) as a low-cost method for monitoring to back up the high-cost monitoring methods. The Blue Line Project was noted as a good example
- Improve data access
  - One group said that cities do not have easy data access to areas beyond their cities, so a collaboration with planners in neighboring areas could help
  - A data clearinghouse, run by a government entity, could be helpful; it should include data on subsidence and SLR from different studies
  - Combine different data sets for best results (e.g. satellite, field surveys, ecological, geological, long-term campaign, short-term data collection)
  - The Chesapeake VLM monitoring campaign could also extend to aquifer research

- Stress interagency and interstate collaboration
  - Groups emphasized the need for greater collaboration between states, agencies, and departments which could help standardize the data and form consistent regulations, which would aid the uniformity of resilience efforts
  - Collaboration could also increase the extent of data collected (e.g. more states could join the Chesapeake VLM monitoring project) and access to existing data (e.g. USGS has a lot of data and processing procedures that other partners could benefit from)
  - A regional commission that is federal-state-local which has a long-term interest could function well. The United States Army Corps of Engineers' Silver Jackets is a good example
- Facilitating collaboration
  - Uncertainty remains about how to effectively communicate science to managers.
  - Meetings help build relationships. For example, Sea Grant and the Hampton Roads Forum are entities that help do that
  - It is important to have entities dedicated to facilitating interactions among research, management, and communication
  - Specialized workshops can offer a focus that larger conferences do not have
  - Finally one group stated, "We need to try to facilitate more collaboration and data access with everyone, everywhere!"

APPENDIX D
POST SURVEY

Of the 83 participants in the workshop, 33 responded to the post-workshop survey. Participants were given a week to respond and were notified three times.

KEY SURVEY FINDINGS

The post-workshop survey assessed four primary objectives: (1) How did the workshop benefit participants? (2) Did they improve their understanding of VLM and its impacts on management (Goal 1)? (3) What are the best communication strategies to pursue and collaborate on (Goal 3)? and (4) What future research is necessary (Goal 2)?

1. The majority (91%) of respondents indicated that the workshop helped them convey VLM information to stakeholders a "moderate amount" to a "great deal." Their comments stressed the value in networking and the importance of having a space where scientists and communicators can discuss and share information. They have/plan to distribute information gained to their stakeholders (though some had reservations that the state of the science is not ready to be communicated), incorporate information gained into their current research, and collaborate with new partners.

2. We assessed for knowledge gain but recognize that having both experts and non-experts would cause knowledge gain to vary significantly. Overall, we saw, on average, a mid-level (54-63 on a scale of 0 – 100) incoming knowledge, based retrospectively on the post-workshop survey and a high-level (74-84) of outgoing knowledge, meaning that our participants are more confident in their understanding of the VLM topics presented. The highest level of knowledge gain after the workshop was for "how uncertainty in VLM affects RSLR rate estimates" and " how groundwater withdrawal and management influence on VLM rates." The lowest level was for "how the accurate estimate of VLM rates may affect ecological monitoring and coastal ecosystem management."

3. We compiled the communication ideas raised during the discussion session and asked survey respondents to indicate their importance on a Likert scale and their willingness to collaborate to help achieve that idea. These results will help MDSG and a group of relevant partners determine recommendations to pursue and collaborators willing to develop the idea. Respondents felt most strongly that we must communicate where flooding is happening horizontally on the landscape rather than the vertical change in RSLR and how SLR rates compare with VLM rates over time.

4. We also compiled and identified needs and collaborations for respondents to rate in terms of importance. Respondents indicated strongly that we must differentiate between naturally occurring VLM rates and those that have anthropologic causes. They expressed the need for a common space or clearinghouse to share VLM information. They also felt that more monitoring is required. Developing a consistent message on VLM rates, creating a concept paper for VLM for communicators, and using time lapse photos were also in the top half of scores.

KNOWLEDGE GAIN

The post-workshop survey asked respondents to rate their level of knowledge before and after the workshop on a scale from 0 to 100, with 0 being no knowledge and 100 being expert-level understanding (Figure D1). For example, "Indicate your level of knowledge on how uncertainty in VLM affects relative sea level rise rate estimates BEFORE the workshop" (slider scale 0 to 100) and "Indicate your level of knowledge on how uncertainty in VLM affects relative sea level rise rates estimates AFTER the workshop" (slider scale 0 to 100). The post-survey asked participants to assess the following topics:

- “How uncertainty in VLM affects RSLR rate estimates”
- “VLM measurement techniques”
- “How the accurate estimate of VLM rates may affect ecological monitoring and coastal ecosystem management”
- “How groundwater withdrawal and management influence VLM rates”
- “Geological processes affecting VLM”

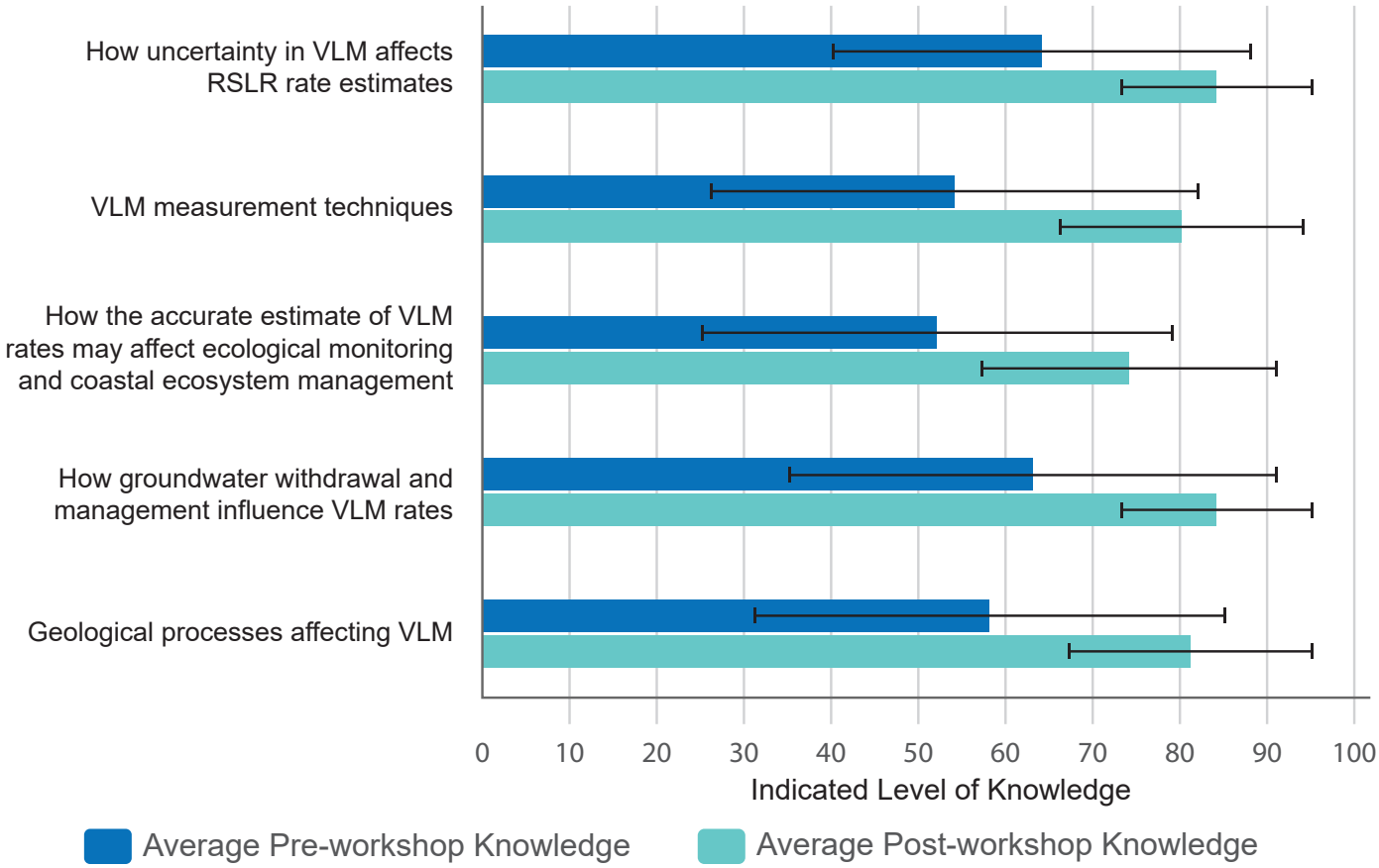

Figure D1. Post-workshop results knowledge on topics pre and post-workshop (n=33). *The post-workshop survey asked respondents to rate their level of knowledge before and after the workshop on a scale from 0 to 100, with 0 being no knowledge and 100 being expert-level understanding.*

Question 11 asked how much this workshop helped participants explain VLM to stakeholders on a scale of “none at all” to “a great deal.” 50% of participants indicated it helped “a great deal,” 41% “a moderate amount” and 9% “a little.”

Question 12 asked which agencies or informational groups participants access for VLM information (open-ended). The figures (Figure D2 and D3) below compare the pre-survey (n=70) and post-survey (n=33) results.

In both situations the leading agencies were USGS, NOAA (specifically the National Geodetic Survey), universities (VA Tech, VIMS, University of Maryland), and NASA. After the workshop, MDSG and the Chesapeake Bay Sentinel Site Cooperative (CBSSC) were listed as information sources.

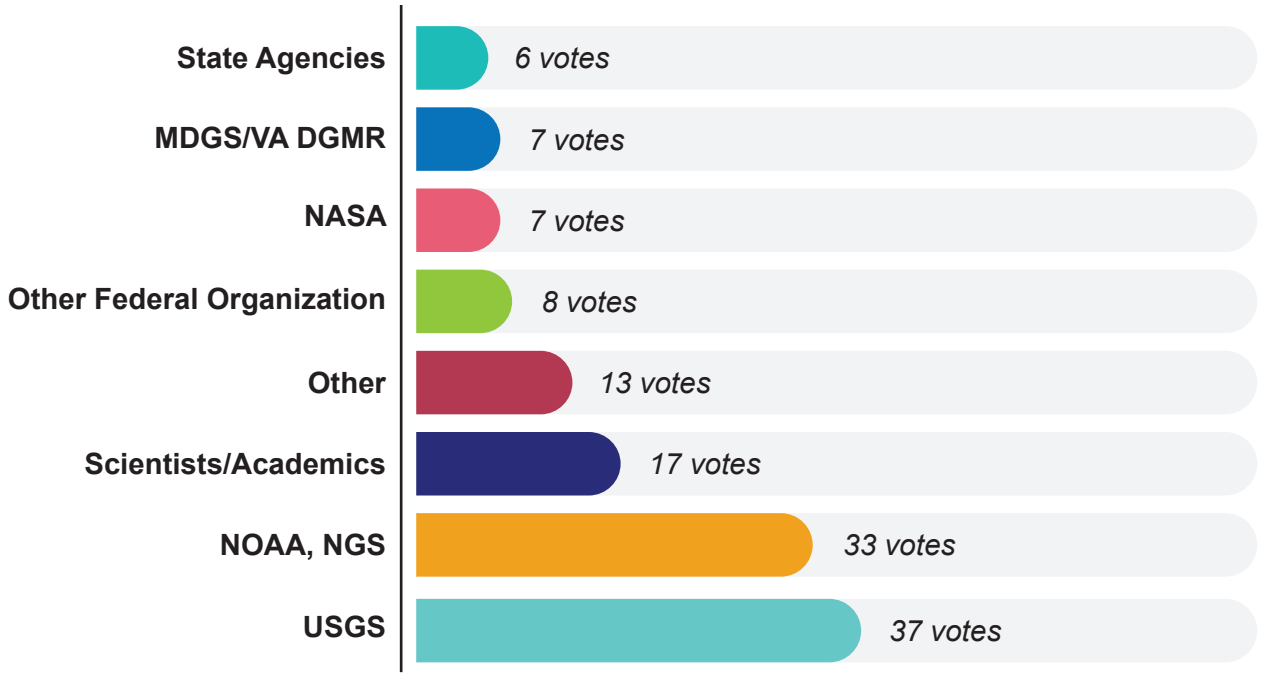

Figure D2. Pre-workshop results on where respondents go for information on VLM (n=70). *Note: respondents were allowed to choose more than one option. Maryland Geological Survey (MDGS)/ Virginia Division of Geology and Mineral Resources (VA DGMR), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey (NGS), U.S. Geological Survey (USGS). Scientists/Academics section also includes scientific journal articles and universities. The "Other" category includes: American Geophysical Union, American Society of Civil Engineers, Chesapeake Bay National Estuarine Research Reserve, Environmental and Water Resources Institute, European Space Agency, international agencies, Maryland Port Authority, National Science Foundation, Sustainable Water Initiative for Tomorrow (SWIFT), United Nations Educational Scientific and Cultural Organization's Land subsidence international initiative, University NAVSTAR Consortium, and Wetlands Board. Not depicted are the nine respondents who did not identify an agency.*

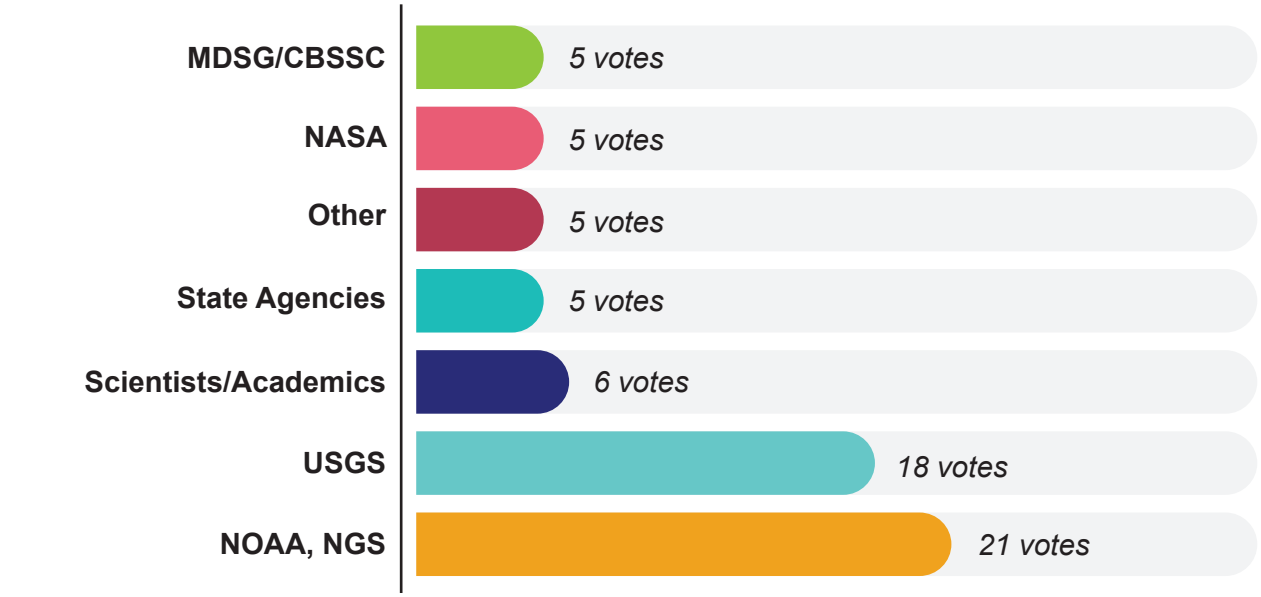

Figure D3. Post-workshop results on where respondents go for information on VLM (n=33). *Note: respondents were allowed to choose more than one option. Maryland Sea Grant (MDSG), Cheasapeake Bay Sentinel Site Cooperative (CBSSC), National Aeronautics and Space Administration (NASA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey (NGS). Scientists/Academics section also includes scientific journal articles and universities.The "Other" category includes: Chesapeake Bay National Estuarine Research Reserve, Intergovernmental Panel on Climate Change, Virginia Planning District Commission.*

COMMUNICATION STRATEGY AND COLLABORATION

A second goal of this workshop was to develop a communication strategy to explain VLM, RSLR, and their potential effects on land-use management and community resilience based on the workshop participants' feedback. We compiled a list of (1) outreach ideas, (2) outreach messages, (3) possible collaborative projects, and (4) needs which were conceived and discussed during the workshop's discussion sessions. In the post-workshop survey, we asked participants to indicate idea usefulness (scale of 1 to 5 with 1 being least useful and 5 being extremely useful) and interest in further developing the idea. It is not in the capacity of MDSG/CBSSC to lead or contribute to all these projects; the expectation was for those potential work groups to self-organize and find their own resources. Tables D1-D4 are the results of those questions.

Table D1. Post-survey response to participant generated outreach ideas. *The weighted average is derived from the Likert scale used, which had a scale of 1 to 5 with 1 being least useful and 5 being extremely useful.*

ANSWER CHOICES	NUMBER OF RESPONSES	WEIGHTED AVERAGE	NUMBER OF PARTICIPANTS WILLING TO COLLABORATE
More targeted workshops	32	3.93	7
Collect photographs that show time lapses of land change	33	3.84	2
A concept paper on VLM for communicators	33	3.84	5
Including VLM into school curriculums	33	3.48	6
The military becoming better spokespersons	33	3.21	3
Training for interested citizens to become quasi-spokespersons	33	3.12	6
Lectures on VLM spatial variability	33	3.12	2
Communicating via a happy hour	33	3.00	6
Facebook ads to communicate messages	32	2.16	2

Table D2. Post-survey response to participant generated outreach messages. *The weighted average is derived from the Likert scale used, which had a scale of 1 to 5 with 1 being least useful and 5 being extremely useful.*

ANSWER CHOICES	NUMBER OF RESPONSES	WEIGHTED AVERAGE	NUMBER OF PARTICIPANTS WILLING TO COLLABORATE
Show where flooding is happening horizontally on the landscape (not only vertical change in RSLR)	33	4.33	8
Differentiate between VLM rates that are natural and human-induced	33	4.24	7
Communicate how SLR rates and VLM rates will compare over time	33	4.21	9
The significance of millimeter change per year	33	3.64	8
Show how responsive the VLM signal is (i.e. extensometer readings)	32	3.44	5

Table D3. Post-survey response to participant generated possible collaborative projects. *The weighted average is derived from the Likert scale used, which had a scale of 1 to 5 with 1 being least useful and 5 being extremely useful.*

ANSWER CHOICES	NUMBER OF RESPONSES	WEIGHTED AVERAGE	NUMBER OF PARTICIPANTS WILLING TO COLLABORATE
Create a clearinghouse to convey VLM information	31	4.19	4
More Mid-Atlantic states participate in the Chesapeake Bay Vertical Land Motion monitoring campaign	31	3.90	7
Create a regional commission dedicated to VLM	32	3.64	4

Table D4. Post-survey response to participant generated identi ied needs. *The weighted average is derived from the Likert scale used, which had a scale of 1 to 5 with 1 being least useful and 5 being extremely useful.*

ANSWER CHOICES	NUMBER OF RESPONSES	WEIGHTED AVERAGE	NUMBER OF PARTICIPANTS WILLING TO COLLABORATE
More monitoring: groundwater wells, tide gauges, SETs	32	4.16	7
More hydrology data	29	4.10	4
Develop a consistent story on VLM rates in the Bay, agree on the numbers	32	4.00	6
Saline profile in aquifers	32	3.87	5
Cost-benefit analysis of VLM effect on land use, long-term versus short-term	32	3.81	5
Need better FEMA maps	32	3.81	6
Watershed storage capacity	31	3.81	4
Calculate the cost per person per millimeter of relative sea level rise	32	3.59	5
Septic tank management	31	3.40	3

Question 18 asked participants to describe their post-workshop action plans; Table D5 has the summarized list of responses from this question.

Table D5. Summary of post-survey responses to describing to turn the presented information into action. *Note: Two respondents believe scientists should first reach a consensus on the scale of the problem and the impact of human action before communicating about VLM. They voiced the need to better understand how local subsidence and VLM are impacting the accuracy of our SET measurements*

SUMMARIZED RESPONSES
Distribute information to stakeholders via public lectures, professional presentations, individual consultations, web-based information (e.g. StoryMaps), citizen science projects, sharing with colleagues)
Collaborate with partners for research or additional monitoring (e.g. SWIFT technical team, NASA, USGS, ODU)
Reach out to new contacts on grant and publication opportunities
Incorporate information into current or future research projects
Prompt additional monitoring (e.g. GPS benchmarks, Tripodapalooza)
Re-evaluating how they are using elevation data

The final post-survey question asked for any additional feedback; Table 6 has the summarized list of responses.

Table D6. Summary of post-survey responses for additional feedback regarding the workshop (n=21).

SUMMARIZED RESPONSES	
Workshop outcome	
	15 of the 21 responses generally commented that the workshop was successful.
	“The workshop was very helpful in identifying who is/has been studying what types of VLM, how they are studying it, where some data gaps are, and promoting connections between some of these people; identify shortcomings in communication (to public, managers, policymakers) about this and related topics; provide some suggestions on how to improve communication.”
Importance of networking	
	“More time to have networked would have been helpful”
	“It’s important to have a constructive time built in for folks to talk about their fields of interest and study to expand our knowledge base.”
	“These workshops are very valuable not only in sharing the science, but in strengthening partnerships, collaboration, creating synergies and leveraging assets.”

SUMMARIZED RESPONSES

Future communications	
	"My takeaway from the workshop is that VLM and RSLR are complicated and many aspects of the science are still being decided. I think the focus should be on convening scientists and figuring out the science before tackling education/outreach of the topic. If we don't know what is happening yet, how can we communicate it? Or, if there are some things that we do know about VLM in the Chesapeake Bay, it would be helpful to have that information compiled (with the help of VLM experts) as a first step."
Further topics to be discussed	
	"More information in terms of recent projects in the Chesapeake Region (covering with examples drawn from research in Gulf of Mexico, as well as mention of others in N. America should be considered). A follow up workshop should also cover more info from the MD portion of the Bay and its watershed. This unfortunately this appeared to be largely 'terra Incognita', despite classic work of MD Geol Survey, NOAA & other group"
	"Any information on a world view of global engineering projects that can reduce SLR, increase desalination cost effectively, or mass calculations re atmospheric water vapor (more vapor equals less insolation?)"

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