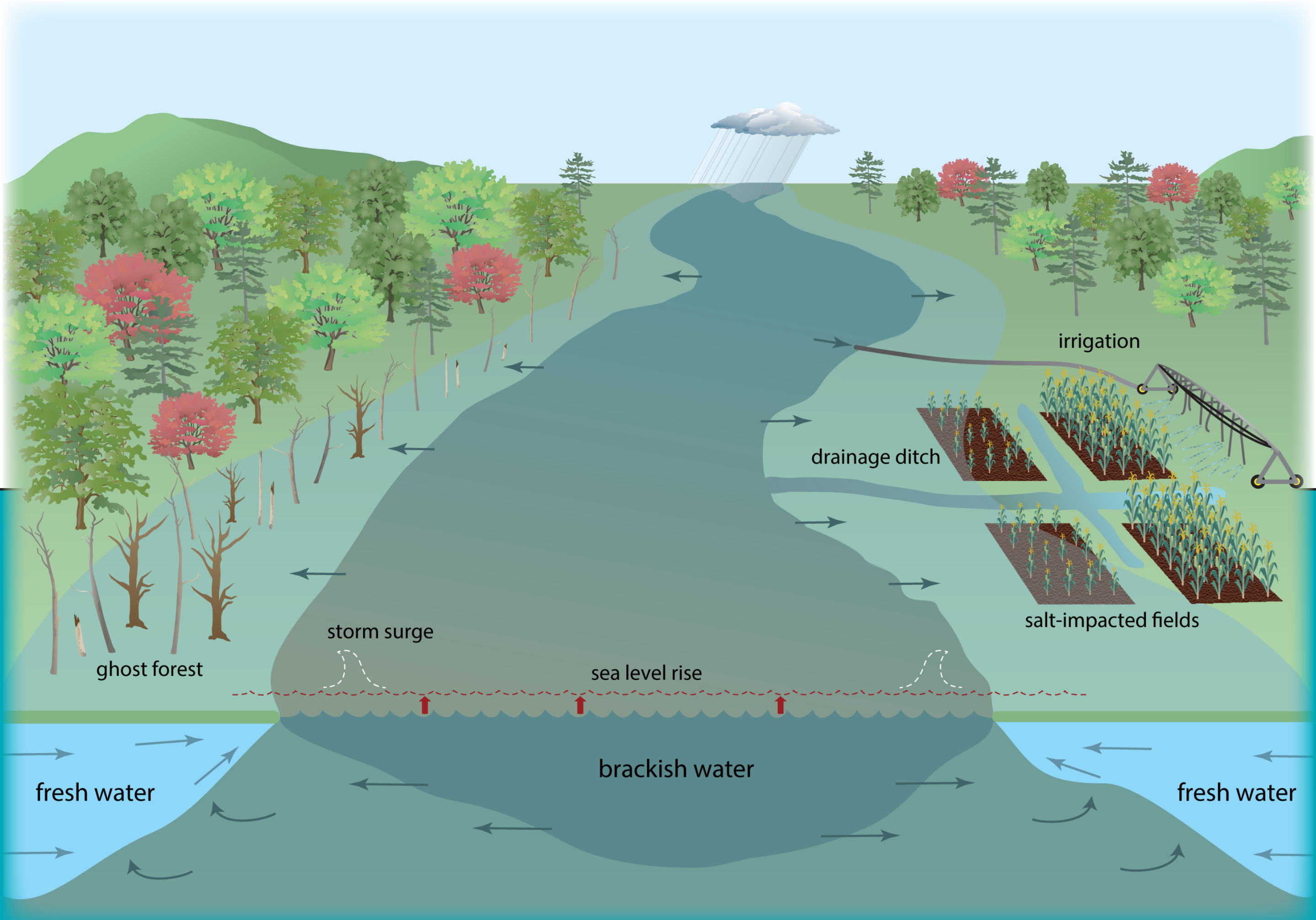
# Maryland's Plan to Adapt to Saltwater Intrusion and Salinization




Prepared by the Maryland Department of Planning

December 2024

## Acknowledgements

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**Citation**

Maryland Department of Planning, “State of Maryland Plan to Adapt to Saltwater Intrusion and Salinization: 2024 Update,” Dubow, J and D.H. Cornwell, primary authors, D. Andreasen, A. Staley, K. Tully, K. Gedan, and R. Epanchin-Niell, and E. Marcian, contributing authors, 2024.

# Contents

# Executive Summary

Under Chapter 628 of the 2018 Laws of Maryland, the Maryland General Assembly tasked the Maryland Department of Planning (MDP) with establishing "a plan to adapt to saltwater intrusion," in consultation with the Maryland Departments of Natural Resources, the Environment and Agriculture, by December 15, 2019, and to update the plan at least once every five years. **This 2024 plan update represents the first five-year update.**

Saltwater intrusion is a technical and complex issue that is steadily worsening due to climate change's influence on increased flooding and sea level rise. To varying degrees, saltwater intrusion and salinization already impact Maryland's groundwater, surface waters, wetlands, coastal forests, agriculture, and infrastructure. Although progress has been made in understanding current impacts and forecasting future salinization impacts to agriculture and wetlands, **there generally remains no comprehensive understanding of all of the areas currently at risk, and limited knowledge of which areas are at risk in the future**. Map 1 displays areas of Maryland at risk of inundation and possible saltwater intrusion as sea levels rise; however, researchers expect additional salt-impacted lands in the future beyond these areas. The full extent is not yet known.

Increased salinity has already made some of Maryland's coastal farmland unusable, required regulatory measures to protect drinking water aquifers, and altered the ecological landscape of Maryland's wetlands and coastal forests. Recent data illustrates the pace and scale of the issue:

1. Using conservative estimates, the extent of farmland salinization was recently quantified by scientists in nine Maryland Eastern Shore counties, where **the area of farmland affected has doubled from 18,988 acres in 2011-2013 to 40,120 acres in 2016-2017 in only about 5 years**.[1]
2. In July 2021, the Maryland Department of Agriculture completed its aerial Maryland Forest Health Survey across the lower Eastern Shore. This flight mirrored annual flights taken since 2017. The 2021 flight found 84,831 acres of salt-impacted forest in Dorchester, Somerset, Worcester, and Wicomico counties, equivalent to approximately 32% of the forested land in those four counties. **Assuming a conservative estimate of 200 trees per acre (a sparse forest), the number of affected trees is roughly 17 million, many of which will become new ghost forests**. The 2020 flight identified 50,365 salt-impacted forest acres, representing **an increase of approximately 68% acres in one year**.[2]
3. The Maryland Department of Natural Resources completed modeling and in 2024 published maps to display the expected transformation of uplands to wetlands. **The modeling forecasts a loss of up to 30,000 acres of dry land to wetlands in Maryland by 2050, more than half the size of Baltimore City**. In addition, Maryland's coastal biodiversity is significantly changing as freshwater and brackish wetlands transform into saltmarsh.

**The continued loss of farmland and coastal forests, especially on Maryland's Eastern Shore, and the transformation of coastland to saltmarsh threatens Maryland's economy, coastal communities, and ecological health**. Maryland's Chesapeake Bay restoration and climate pollution reduction goals could be impacted by increasing phosphorus and methane emissions from salinization of farmland and wetlands, as well as by the continued significant loss of coastal trees. Several Maryland aquifers already have been impacted by saltwater intrusion and the potential added threat to coastal infrastructure is of high concern.

1 Mondal, P., Walter, M., Miller, J. et al., The spread and cost of saltwater intrusion in the US Mid-Atlantic, Nat Sustain 6, 1352–1362, 2023, [Online], Available: doi.org/10.1038/s41893-023-01186-6 [Accessed: 29 October 2024]. USDA, 2022 Census of Agriculture, [Online], Available: nass.usda.gov/Publications/AgCensus/2022/Full_Report/Census_by_State/Maryland/index.php [Accessed: 29 October 2024].

2 Maryland Department of Agriculture, Forest Pest Management, Maryland 2022 Forest Health Highlights, [Online], https://fs.usda.gov/foresthealth/docs/fhh/MD_FHH_2022.pdf [Accessed: 29 October 2024]. Chesapeake Conservancy, 2017/2018 Chesapeake Bay Program Land Use/Land Cover, [Online], Available: chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/ [Accessed: 29 October 2024].

**More research is needed to better understand the repercussions and level of impact that would enhance measures for mitigation and adaptation to better prepare for these impacts**. While more data and research is available today than in 2019, the accelerated rate of salt impacts is outpacing our current adaptation efforts. We can see the visible signs of salinization on the landscape and **although we recognize the need for additional research, identification and prioritization of adaptation actions is needed now**.

Based on the data and trends of the last five years, MDP, in consultation with University of Maryland researchers, the Maryland Department of the Environment, Maryland Department of Natural Resources, Maryland Department of Agriculture, the Harry R. Hughes Center for Agro-Ecology, and others, has **identified the urgent need for ongoing research, modeling, and monitoring to strategically focus on priority adaptation areas identified through this plan. Maryland should establish a Salinity Resilience Network (SRN) within the university system or nonprofit sector, or within existing resiliency entities** to engage all sectors, nongovernmental organizations, grantmaking and academic organizations, and communities to identify priority research and adaptation needs, raise awareness, share information, encourage progress, and identify and pursue actions that should be taken now.

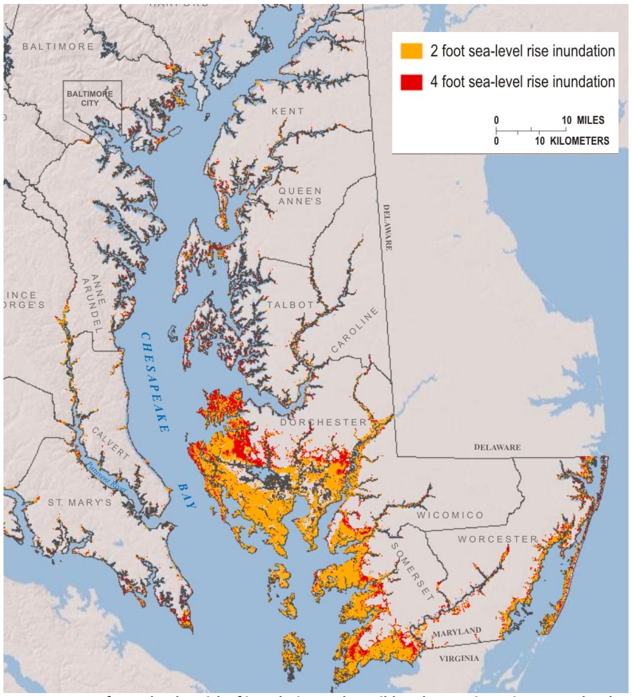
Setting priorities among the research and adaptation actions should be based on the following pillars of sustainability:

- **Social Impact**: Underserved and/or overburdened communities already being impacted based on aquifers.
- **Economic Impact**: Land types that most directly impact local economies based on loss of acres as a proportion of total.
- **Ecological Impact**: Areas that will directly influence Bay watershed goals.

Based on these priorities and the updated information in this plan, the following steps should be taken by the proposed SRN through each of its members:

1. Conduct a pilot study of surficial aquifers in Maryland to identify coastal infrastructure, including building foundations, most at risk of saltwater intrusion.
2. Support the variety of adaptation needs for Maryland farmers, including creating markets for salt-tolerant crops, and establishing coastal resilience easements when land can no longer support farming.
3. Research the net methane emissions from salinization of wetlands and uplands.
4. Research impact of salinization of wetlands and uplands on phosphorus storage and release, with a focus on farmlands.
5. Host an annual forum to share knowledge and support continued, collaborative progress.

**Implementation of this plan, including assessments of vulnerability, monitoring of environmental change, the development of forecasting tools, and adoption of effective adaptation measures, is essential to minimize the economic, social, and environmental disruption to Maryland's economy, coastal communities, and ecological health.**




*Map 1. Areas of Maryland at risk of inundation and possible saltwater intrusion as sea levels rise. Source: NOAA Office for Coastal Management, coast.noaa.gov/slrdata/; County Boundaries: MD iMAP, SHA; Base Map: Esri.*

# Introduction

### *Much of Maryland is surrounded by saltwater*

Maryland is divided into the western and eastern shores by the Chesapeake Bay, whose waters are a combination of freshwater and seawater with varying levels of salinity depending on location, season, and depth. These brackish waters are also found in the major rivers and streams, and smaller tributaries for much of their length. In addition, the easternmost border of Maryland-- Fenwick (Ocean City) and Assateague Islands -- are barrier islands surrounded by the Atlantic Ocean on one side and the brackish Coastal Bays fronting the eastern shore of Worcester County on the other.

### *Saltwater intrusion is already occurring in Maryland and is impacting portions of the state*

These salty waters already impact the natural and human-made resources that they move into, both aboveground and belowground. Aboveground, the plant species composition of wetlands, for example, differs depending on the salinity level of surrounding surface waters. Belowground, the portions of Maryland's shallow, unconfined aquifers adjacent to salty surface waters have a freshwater-saltwater transition zone within the groundwater that is a gradient from fresh to saline water.[1] In addition, small portions of Maryland's deeper, confined freshwater aquifers adjacent to salty surface waters occasionally are impacted by saltwater intrusion, usually due to human activities (e.g., overpumping) occurring near hydrological pathways that already exist through overlying geological formations (e.g., a break in a clay confining unit).

### *What is "saltwater intrusion"? What is saltwater?*

Under Section 3-1001 of the Natural Resources Article, "saltwater intrusion" means the movement of brackish water-- water with a total dissolved-solid (TDS) concentration[2] greater than or equal to 1,000 milligrams per liter (mg/L)-- into freshwater, including into surface waters, aquifers, and water within soils. Historically, saltwater intrusion has been used to describe the movement of saltwater into aquifers only. In this report, saltwater intrusion is used to describe the movement of saltwater into aquifers, while the term "salinization" is used to describe the process by which water-soluble salts accumulate in fresh surface waters or in soils within agricultural land, wetlands, and coastal forests.

Freshwaters typically contain less than 1,000 mg/L TDS. A TDS concentration of 1,000 to 3,000 mg/L is considered slightly saline, 3,000 to 10,000 mg/L is considered moderately saline, and 10,000 to 35,000 mg/L is considered very saline.[3] For comparison, seawater typically has a TDS concentration of 35,000 mg/L.[4]

1 USGS, Sustainability of Ground-Water Resources, U.S. Geological Survey Circular 1186, William M. Alley, Thomas E. Reilly, and O. Lehn Franke, pp. 64-66, 1999.

2 "The dissolved solids concentration in water is the sum of all the substances, organic and inorganic, dissolved in water. This also is referred to as 'total dissolved solids', or TDS. Calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and silica typically make up most of the dissolved solids in water. Combinations of these ions—sodium and chloride, for example—form salts, and salinity is another term commonly used to describe the dissolved solids content of water." USGS, "Chloride, Salinity, and Dissolved Solids," [Online]. Available: usgs.gov/mission-areas/water-resources/science/chloride-salinity-and-dissolved-solids. [Accessed 29 October 2024].

3 USGS, "National water summary 1986; Hydrologic events and ground-water quality," Water Supply Paper 2325, D. W. Moody, et al. 1988.

4 Drever, J.I., The Geochemistry of Natural Waters, Englewood Cliffs, NJ, 388 p., 1982.

Whether within groundwater or within surface waters, saltwater intrusion and salinization look similar. The freshwater-saltwater transition zone is gradational (anywhere from a few feet to thousands of feet in length), with freshwater atop the saltwater (since freshwater is less dense than saltwater) along a gradient, and with an increase in average salt concentration seaward from the land or towards downstream.[5]

### *How does the definition of saltwater intrusion affect the content of this plan? How does the title of the bill affect the content of this plan? What are the mechanisms for the movement of saltwater into the state's resources? Which resource impacts does the plan discuss?*

Since Maryland's statutory definition of saltwater intrusion includes the movement of saltwater into surface waters, aquifers and soils, this plan discusses the impact of saltwater to Maryland's: agricultural lands; coastal forests; freshwater and brackish wetlands; and water supply sources (rivers, streams and aquifers, whether for municipal, domestic, irrigation or commercial use). Although not required, this plan also discusses the impact of salinization or saltwater intrusion on infrastructure (e.g., building foundations, roads, wells, septic systems and electric systems) given additional research and growing concern about this issue in coastal areas.

Chapter 628 of the 2018 Laws of Maryland, which created the requirement for a Maryland plan to adapt to saltwater intrusion, is titled "Sea Level Rise Inundation and Coastal Flooding – Construction, Adaptation, and Mitigation;" therefore, this plan focuses not only on saltwater intrusion that already occurs, but also considers expected future impacts of worsening saltwater intrusion due to climate change. In addition, given the focus of Chapter 628 on sea level rise and flooding, anthropogenic sources of salt (e.g., road salts), although also a growing concern, are not the primary focus of this plan. On the other hand, since anthropogenic actions can worsen saltwater intrusion, they are considered as contributing factors in connection with saltwater intrusion due to climate change. Lastly, although the title of the law only references sea level rise and coastal flooding (whether from tides or storms), which will bring more salt from the ocean or estuaries directly onto the land as well as below ground further into aquifers, changing precipitation patterns also are considered in this plan, since these can push the freshwater-saltwater transition zone landward or seaward (for example, drought can limit freshwater flows, which moves the transition zone landward).

### *What are the projections for sea level rise in Maryland?*

In the U.S., the Chesapeake Bay region is the third most vulnerable area to sea level rise, with Louisiana and southern Florida ranked first and second, respectively.[6] Maryland's coastal plain, in addition to being relatively flat-lying, is subsiding due to long-term glacial adjustment effects. Over the past 100 years, due to the combination of global sea level rise and regional land subsidence, historic tidal records show that sea level has risen in Maryland by approximately one foot within the Chesapeake Bay.[7] Sea level rise associated with climate change will continue to add to the change associated with glacial adjustment. The most recent sea level rise projections for Maryland indicate the likely potential for sea level to rise between 1 ft and 1.6 ft by 2050 (from a 2005 starting point). Under a Current Commitments scenario, the best estimate of sea level rise in 2100 is 2.7 ft. These projections are for mean sea level and do not include the effects of high tides and storm surges which must be factored into flooding risk assessments.[8] Also, sea level rise is accelerating over time.[9] Lands and waters inundated by sea level rise will become impacted by salinity; in addition, lands further inland also will become impacted by salinity due to saltier groundwater being wicked toward the land surface and the episodic movement of coastal waters upstream, including into ditches and over land during tides and storms of differing intensities.

5 National water summary 1986; Hydrologic events and ground-water quality. Water Supply Paper 2325. Compiled by: David W. Moody, Jerry E. Carr, Edith B. Chase, and Richard W. Paulson. U.S. Geological Survey.

6 MDE Water Supply Program, "Climate Change Adaptation for Maryland Water Utilities," [Online]. Available: mde. state.md.us/programs/water/water_supply/Documents/120516_CCbrochure_Web.pdf. [Accessed 29 October 2024].

7 Ibid.

8 Boesch, D. F., et al. Sea-level Rise Projections for Maryland 2023. University of Maryland Center for Environmental Science, Cambridge, MD. 2023.

9 Ibid

*How quickly are climate change impacts causing saltwater intrusion and salinization? How reversible are the effects?*

Sea level rise is occurring and accelerating now and will continue to do so into the future. The salinity effects from sea level rise could potentially be mitigated to some extent but cannot be reversed. Coastal storms and associated flooding occur several times each year, but are increasing in intensity and frequency over time.[10] Depending on the intensity of coastal storms, salinity effects due to overwash of tidal waters onto land can last for several months.[11] The frequency of droughts occur every few years in Maryland and can sometimes last as long as a year[12]: causing worsened salinity impacts due to reduced freshwater flows during those times, but reverses once precipitation returns to normal. Conversely, periods of excessive precipitation mitigate salinity impacts.

***Photo credit: Will Parson/Chesapeake Bay Program***

10 NOAA National Centers for Environmental Information, State Climate Summaries, Maryland and District of Columbia. [Online] Available: statesummaries.ncics.org/chapter/md/. [Accessed 29 October 2024].

11 White E., and D. Kaplan, “Restore or retreat? Saltwater intrusion and water management in coastal wetlands,” Ecosystem Health and Sustainability, 3(1):e01258, 2017 (cites Flynn et al., 2015; McKee and Mendelssohn, 1989).

12 National Drought Resilience Partnership, “National Integrated Drought Information System, Drought in Maryland,” [Online]. Available: drought.gov/drought/states/maryland. [Accessed 29 October 2024].

# Background

Under Chapter 628 of the 2018 Laws of Maryland, the Maryland General Assembly tasked the Maryland Department of Planning (MDP) to "establish a plan to adapt to saltwater intrusion," in consultation with the Maryland Departments of Natural Resources, Environment and Agriculture, by Dec. 15, 2019, and to update the plan at least once every five years.

This 2024 plan update, represents the first five-year update of the 2019 plan. To complete the update, MDP obtained guidance from subject matter experts, completed research, and obtained progress updates from the state agency saltwater intrusion team.

When developing the 2019 plan, MDP established and led a state agency team, which included the Departments of Natural Resources (including the Maryland Geological Survey), Environment, and Agriculture, as well as the University of Maryland, (including the Center for Environmental Science), Maryland Sea Grant, and the Harry R. Hughes Center for Agro-Ecology.

For this update, MDP continued to research and conduct interviews with subject matter experts to better understand how saltwater intrusion and salinization[13] currently affects Maryland, how saltwater intrusion is expected to worsen over time due to climate change, which resources are at risk, which adaptation measures are currently used or could be explored in the future, and what additional research is recommended to better understand the issue, and to better inform needed adaptation measures.

Many universities and organizations within all levels of government were identified, both inside and outside of Maryland, that are initiating or already conducting monitoring, research, analysis, modeling and outreach regarding saltwater intrusion and salinization. One of the challenges and purposes of this plan is to capture the lessons learned and detailed knowledge generated by these organizations, as well as the needs they have identified as essential to make further progress in addressing this issue. Considerable efforts to study saltwater intrusion and salinization and to develop possible adaptation measures are underway. This plan, although not exhaustive, aims to document and consolidate the findings and recommendations of these initiatives As part of our ongoing efforts, we have highlighted progress (see Appendix B) made by the many partners working on this issue.

This plan update is a further step towards better understanding and addressing saltwater intrusion and salinization in Maryland.

As MDP conducted its 2019 research, the department quickly determined the extensive breadth, technical nature, and complexity of this issue. To varying degrees, saltwater intrusion and salinization already impacts Maryland's groundwater, surface waters, wetlands, coastal forests, agriculture and infrastructure; however, there is currently no comprehensive understanding of all of the areas currently at risk, and limited knowledge of which areas are at risk in the future. Five years later, although progress has been made in understanding current and forecasting future salinization impacts to agriculture and wetlands, this is still largely the case. To determine current and future areas at risk, additional extensive research, modeling and monitoring is recommended.

13 In this document, "saltwater intrusion" is used to describe the movement of saltwater into aquifers, while the term "salinization" is used to describe the process by which water-soluble salts accumulate in fresh surface waters or in soils within agricultural land, wetlands, and coastal forests.

## How Climate Change Increases Saltwater Intrusion And Salinization Impacts In Maryland

Climate change and land subsidence increases saltwater intrusion and salinization within Maryland's coastal areas through both long term and episodic events:

Sea level rise* steadily is bringing more brackish water from Maryland's estuaries, tidal tributaries, and the ocean:

- on to the land;
- farther upstream; and
- farther inland underground into surficial groundwater aquifers.

Tides and storms periodically bring brackish water from Maryland's estuaries, tidal tributaries, and the ocean onto the land and farther upstream. Climate change is increasing the frequency, and intensity of storms and flooding.

Also, as sea level rises, low-lying land becomes more difficult to drain due to higher groundwater levels in relation to coastal waters. The reduced drainage results in less removal of accumulated salt from the land over time.

These impacts are mitigated or worsened by heavier precipitation or drought, respectively, both of which are occurring more often due to climate change. Other factors, such as the use of groundwater, the application of road salt, and the use of engineering controls, also affect salinity in Maryland's waters.

Collectively, the increased salinity has already made some of Maryland's coastal farmland unusable, and is altering the ecological landscape of Maryland's wetlands and coastal forests. Those who depend upon Maryland's coastal groundwater and surface waters for agricultural irrigation or drinking water will need to remain vigilant of increased salinity. Planners focused on Chesapeake Bay restoration and greenhouse gas mitigation will need to track changes in phosphorus loads and methane emissions resulting from the changing landscape to ensure restoration plans are well-informed (see the Coastal Wetlands and Coastal Forests chapters).

Without updating and ensuring implementation of a plan of action, including assessments of vulnerability, monitoring of environmental change, the development of forecasting tools, and adoption of effective adaptation measures, Maryland could lose valuable resources and land types, leading to economic, social, and environmental challenges.

* The most recent sea level rise projections for Maryland indicate the likely potential for sea level to rise between 1 ft and 1.6 ft by 2050 (from a 2005 starting point). Under a Current Commitments scenario, the best estimate of sea level rise by 2100 is 2.7 ft. These projections are for mean sea level and do not include the effects of high tides and storm surges which must be factored into flooding risk assessments. See Boesch, D. F., et al. Sea-level Rise Projections for Maryland 2023. University of Maryland Center for Environmental Science, Cambridge, MD. 2023.

# Saltwater Intrusion and Salinization in Maryland's Coastal Plain

**Climate change increases saltwater intrusion and salinization within Maryland's coastal areas through both long-term and episodic events. Sea level rise is steadily bringing more brackish water from Maryland's estuaries, tidal tributaries, and the ocean onto the land, farther upstream, and farther inland underground into surficial groundwater aquifers. As sea level rises, low-lying land becomes more difficult to drain due to higher groundwater levels in relation to coastal waters. The reduced drainage results in less removal of accumulated salt from the land over time.**

**Tides and storms periodically bring brackish water from Maryland's estuaries, tidal tributaries, and the ocean onto the land and farther upstream. Climate change is increasing the intensity of storms and flooding. Collectively, the increased salinity has already made some of Maryland's coastal farmland unusable and is altering the ecological landscape of Maryland's wetlands and coastal forests. Without a plan of action, including assessments of vulnerability, monitoring of environmental change, the development of forecasting tools, and adoption of effective adaptation measures, Maryland could lose valuable resources and land types, leading to economic, social, and environmental challenges.**


agriculture fields

ghost forest

storm surge

salt-impacted field

water systems previously impacted by salt

Bay Bridge

## Adaptation

Adaptation measures are actions that individuals, government, businesses, and nongovernmental organizations can implement to reduce the vulnerability or impact of climate change, including from saltwater intrusion and salinization, on resources and land types.

Saltwater intrusion and salinization have varying impacts on different resources, with different abilities to overcome those impacts with adaptation measures. For example, most agricultural land heavily impacted by salt currently cannot be farmed. Until alternative salt-tolerant crops are found (which is a temporary remedy before future inundation occurs), one option is to allow the land to transition to tidal saltmarsh since this provides ecosystem services and the potential for some economic benefit (e.g., through the sale of conservation easements, rental for hunting, and/or carbon sequestration credits if a regional carbon market is established). Anecdotes from Eastern Shore farmers clearly show that salinization of Maryland farmland is happening. Furthermore, the extent of the issue was recently quantified by scientists as 16,236 ha in 2016/2017 in nine coastal counties of Maryland (all Eastern Shore), using conservative estimates. Notably, the area of farmland affected had doubled since the years of 2011-2013.[14]

On the other hand, groundwater impacted by saltwater intrusion has several adaptation measures available. The Maryland Geological Survey and the Maryland Department of Environment have provided several examples of public water systems in Maryland that have addressed saltwater intrusion within groundwater through adaptation measures. Although there is a cost, these adaptation measures for water systems are relatively easy to implement.

This plan identifies possible adaptation measures based on input from the state agency workgroup, subject matter experts, and stakeholders. Some adaptation measures are not yet available but are recommended now to address ongoing saltwater intrusion and salinization impacts, others are available now for implementation on an as-needed basis, while several could be explored further to determine their feasibility or utility in Maryland. A compilation of adaptation measures are provided in Appendix A.

Overall, Maryland should pursue a reasonable response rather than a rush to regulate. Feedback and guidance should be gathered from stakeholders regarding innovative approaches and strengths and weaknesses of possible adaptation technologies, policies, programs, projects and plans, as well as the identification of possible roles for stakeholders in implementing likely adaptation measures.

## Unanswered Questions

MDP identified many unanswered questions regarding current and future impacts of saltwater intrusion and salinization in Maryland. Some examples include:

- How will sea level rise affect the extent of brackish water currently in the Chesapeake Bay and Maryland's Coastal Bays?
- How will the salinization of surface waters affect the rate and extent of saltwater intrusion within Maryland's groundwater aquifers?
- How will the extensive ditch network within farmland and wetlands on Maryland's Eastern Shore affect the movement of saltwater over time?
- Which particular water users (public and individual drinking water users, agricultural irrigators, etc.) in Maryland are at risk?
- Where are the locations of agricultural land, wetlands, coastal forests, and infrastructure that are at risk and how will these lands and at-risk areas change over time?
- Do adjacent lands exist to allow for the migration of at-risk land cover types over time?
- How significant and/or extensive are the current and forecasted impacts (economic,

14 Mondal, P., et al. The spread and cost of saltwater intrusion in the US Mid-Atlantic. Nat Sustain, 6, 1352–1362, 2023. https://doi.org/10.1038/s41893-023-01186-6. [Accessed 29 October 2024].

- social, environmental) of saltwater intrusion and salinization for each resource?
- What is the cost to local communities, with or without adaptation?
- Are there land use practices that exacerbate saltwater intrusion impacts?

## Research Needs

Based on guidance from technical experts, stakeholders and the state agency workgroup, the following research process was identified to coordinate and organize an efficient framework for gathering data and knowledge, knowing that there is limited funding and time to understand the issues of saltwater intrusion and salinization. The research will increase the understanding of saltwater intrusion, and salinization impacts and processes in aquifers, surface waters, agricultural land, wetlands, coastal forests and infrastructure in Maryland, and will inform adaptation and management approaches.

Step 1: Reach consensus among data collectors from different levels of government, academia, nongovernmental organizations and others regarding methodology, including equipment used, and needed data categories.

Step 2: Create, and revise over time, an information repository by compiling available, geographically specific, and updated data on:

- Current and past status of resources and land types.
- Natural and anthropogenic processes influencing saltwater intrusion and salinization.
- Locations and extent of other factors (e.g., ditch network, abandoned wells, soils, topography, floodplains) that impact resources and land types.
- Available areas for (and barriers to) migration of coastal wetlands and forests.
- Adaptation measures or other actions (e.g., policies, regulations, resource management practices) being taken by landowners, government, etc., that impact the status of resources and land types.
- Effectiveness and outcomes (benefits and drawbacks) of particular adaptation measures.

Step 3: Take appropriate actions with the information repository.

Step 4a: When adequate information, including financial analyses of actions (and the cost of inaction), and other expected benefits and drawbacks, is available to initiate decision-making, implement adaptation/management technologies, policies, programs, projects and plans.

Step 4b: When additional information is needed before the next stage of decision-making, implement study plans to fill knowledge gaps.

Step 5: Improve/refine the information repository (Step 2) with additional knowledge (from Step 4b), and then continue to Step 3.

The above research steps are meant to incorporate the following concept of adaptive management:

"Adaptive management is a strategy that provides for making management decisions under uncertain conditions using the best available science rather than repeatedly delaying action until more information is available. Adaptive management allows for continuous learning resulting in management decisions based on what was learned, rather than adopting a management strategy and implementing it without regard for scientific feedback or monitoring. Adaptive management is an approach to resources management that increases the likelihood of success in obtaining goals in a manner that is both economical and effective because it provides flexibility and feedback to manage natural resources in the face of often considerable uncertainty."[15]

15 Delta Stewardship Council, The Delta Plan: Ensuring a reliable water supply for California, a healthy Delta ecosystem, and a place of enduring value, Appendix 1b, 2013.

Setting priorities among the research needs is difficult given that all of the resources and land types impacted by saltwater intrusion or salinization are valuable; however, the following criteria in combination can be used to achieve this goal:

- Assist people who already are being impacted, focusing first on underserved and/or overburdened communities
- Focus on resources and land types that are currently being impacted significantly
- Focus on resources and land types that are most at risk
- Focus on resources and land types that have the highest value (health, economic, social, environmental)
- Given these criteria, research in Maryland would initially be prioritized as follows:
- Agriculture
- Wetlands and coastal forests
- Infrastructure
- Surface waters (drinking water, irrigation, aquatic resources)
- Aquifers (drinking water, irrigation)

As research continues and new information is learned about impacts and risks, including the costs of inaction, priorities would be reassessed. Also, continued updates of sea level rise projections over time will be critical for informing management decisions, especially given that sea level rise is currently accelerating and is expected to continue to accelerate over time.[16]

## Technical and Financial Resources

Government agencies and some nongovernmental organizations have technical and/or financial resources to assist landowners, water suppliers, farmers, households and others in Maryland with responding to and planning for sea level rise and other hazards influenced by climate change. Some also have specialized knowledge and experience in dealing with saltwater intrusion and/or salinization. A list of these resources is included in Appendix A.

Financial resources are also essential for ensuring that the research recommendations of this plan are implemented, and the adaptation recommendations explored, by universities, nongovernmental organizations, and government agencies.

## Communications and Outreach

To ensure communities, farmers and landowners are aware of the threat of saltwater intrusion

and salinization, as well as the availability of technical and financial resources, the state could develop a communications and outreach plan that makes use of existing avenues and programs, including the University of Maryland Extension, Soil Conservation Districts, regional state agency staff (forestry, agriculture, environment, critical areas), local environmental health departments, University of Maryland Sea Grant, Maryland Climate Leadership Academy, and the Education, Communication and Outreach Working Group of the Maryland Commission on Climate Change.

16 Boesch, D. F., et al., Sea-level Rise Projections for Maryland 2023, University of Maryland Center for Environmental Science, Cambridge, MD, 2023.

## Establish a Permanent Salinity Resilience Network

Given that the plan must be updated at least once every 5 years, the fundamental role of academic institutions and grant-making organizations to the success of this plan, and the extent of research recommended and number of adaptation strategies to be explored, *this plan proposes a long term implementation approach that recommends the formation of a permanent **Salinity Resilience Network** of researchers, grantmaking organizations, policy-makers, and others centered on investigating and implementing the research and adaptation recommendations of this plan*. Network actions could include the development of annual workplans, annual conferences or workshops to bring stakeholders together, as well as overarching strategies to coordinate research efforts, implement an adaptive management approach, and identify innovative funding approaches (e.g., private and public funding). This approach is discussed further in the Long Term Implementation chapter. Also, since the timing for implementing the plan's recommendations is dependent on sufficient funding from grantmaking organizations and others for required research, the 2024 plan update removes the timeframe for completing the research recommendations, and instead categorizes these as first, second and third priorities. Appendix A lists possible funding and technical resources to support this work.

## Plan Organization

The 2024 plan update is organized by each resource understood to be impacted by saltwater intrusion or salinization in Maryland, including groundwater aquifers, surface waters, agriculture, wetlands, coastal forests, and infrastructure. Each chapter describes the following for each resource:

- The scientific context for how saltwater moves within the physical environment and how
- it impacts different resources;
- The current knowledge of impacts, threats, and concerns regarding saltwater intrusion and salinization, and how climate change is expected to worsen those threats and concerns over time;
- Additional research recommended, based on current understanding of knowledge gaps; and
- Possible adaptation strategies.

***Photo credit: ©Matt Kane/The Nature Conservancy***

# Aquifers

## Resource

Saltwater intrusion in aquifers is a long-standing issue that has been studied for many years; however, climate change is intensifying this threat. Over fifty years ago, the American Society of Civil Engineers established a Task Committee on Saltwater Intrusion, which published the results of its nationwide survey of saltwater intrusion within aquifers of the U.S.[17] That study indicated that saltwater intrusion, including within Maryland, is almost always due to human activities, such as groundwater pumping or construction projects that inadvertently remove a natural barrier between freshwater and saltwater.

Today, climate change presents an additional threat to Maryland's aquifers, although hydrogeologists in Maryland have been aware of this threat for many years: in 1958, the Maryland Geological Survey published data documenting sea level rise in the Chesapeake Bay and its likely impact of saltwater intrusion into Maryland's aquifers.[18] Those who depend upon Maryland's coastal groundwater for agricultural irrigation or drinking water will need to remain vigilant of possible increases in salinity over time.

The Atlantic Coastal Plain region (see Figure 3) is the only geographic and geological area in Maryland where saltwater intrusion of aquifers can occur. Underground, 16 aquifers and 14 confining units are recognized; 14 of these aquifers are confined artesian aquifers and two are water-table aquifers. Predominantly sandy and gravelly layers, capable of yielding water to wells, form the aquifers while fine-grained layers (silts and clays) impede the flow of water and form confining units (see Figure 1).

## Drivers of Saltwater Intrusion

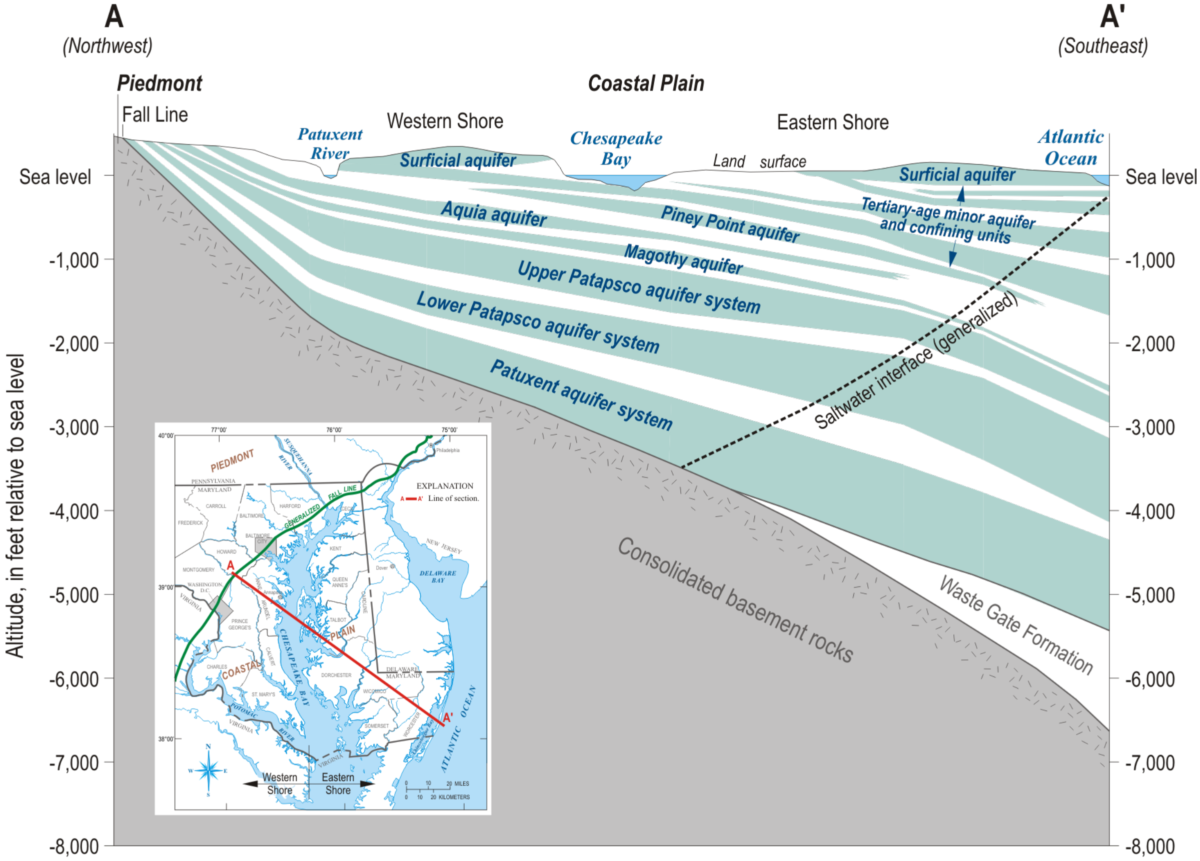
Saltwater naturally intrudes into Maryland's aquifers wherever the aquifers are in direct hydraulic connection with saline or brackish tidal waters and aquifer head gradients, which generally define the direction and slope of groundwater movement, trend below sea level landward. Hydraulic connections with salty tidal waters occur in shallow, unconfined (water table) aquifers and less frequently in deeper, confined aquifers. When saltwater intrusion occurs in confined aquifers, saltwater intrudes through natural erosional channels in the overlying clay layers or through "leaky" clay layers. This can occur within the outcrop or subcrop, where aquifer materials of confined aquifers are exposed at the surface or below the surface, respectively.[19]

17 Task Committee on Saltwater Intrusion of the Committee on Groundwater Hydrology of the Hydraulics Division, Saltwater Intrusion in the United States, Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 95, Issue 5, pp. 1651-1669, 1969

18 Overbeck, R.M., Slaughter, T.H., and Hulme, A.E., "The water resources of Cecil, Kent and Queen Anne's Counties," Maryland Geological Survey, Bulletin 21, p. 77, 1958. [Online] Available: mgs.md.gov/publications/report_pages/BULL_21.html. [Accessed 29 October 2024]..

19 Andreasen, D.C., Staley, A.W., and Achmad, G., Maryland Coastal Plain Aquifer Information System: Hydrogeologic framework, Maryland Geological Survey, Open-File Report 12-02-20, 121 p., 2013.

**Figure 1. Unconfined (surficial) and Confined Aquifers in Maryland's Coastal Plain.**[20]




Groundwater withdrawals also can lead to saltwater intrusion whenever pumping of water occurs in a portion of the aquifer that already has or is near saline water, and where a pathway exists connecting the saltwater to freshwater (see Figure 2 below). As groundwater pumping lowers aquifer heads (water levels) below sea level, the freshwater-saltwater transition zone can move close enough to the well to allow for saltwater intrusion into the water source.[21] How far this intrusion extends into the aquifers depends in part on the freshwater head in the aquifer, and the degree to which pumping has lowered the freshwater head relative to sea level.

Saltwater is also naturally present in Maryland's deeper aquifers, predominantly on the Eastern Shore, as a result of cyclic movement of saltwater responding to large-scale sea level fluctuations probably during the Neogene and Quaternary periods).[22] Repeated advance and retreat of the salty groundwater over geologic time caused the saltwater and freshwater to mix.

20 Modified from Staley, A.W., Andreasen, D.C., and Curtin, S.E., "Potentiometric surface and water-level difference maps of selected confined aquifers in Southern Maryland and Maryland's Eastern Shore, 1975-2015," Maryland Geological Survey, Open-File Report 16-02-02, 30 p., 2016.

21 USGS, Sustainability of Ground-Water Resources, U.S. Geological Survey Circular 1186, William M. Alley, Thomas E. Reilly, and O. Lehn Franke, pp. 64-66, 1999.

22 Meisler, Harold, "The occurrence and geochemistry of salty ground water in the Northern Atlantic Coastal Plain," USGS, Professional Paper, 1404–D, 51 p., 1989. [Online]. Available: pubs.usgs.gov/pp/1404d/report.pdf. [Accessed 29 October 2024].

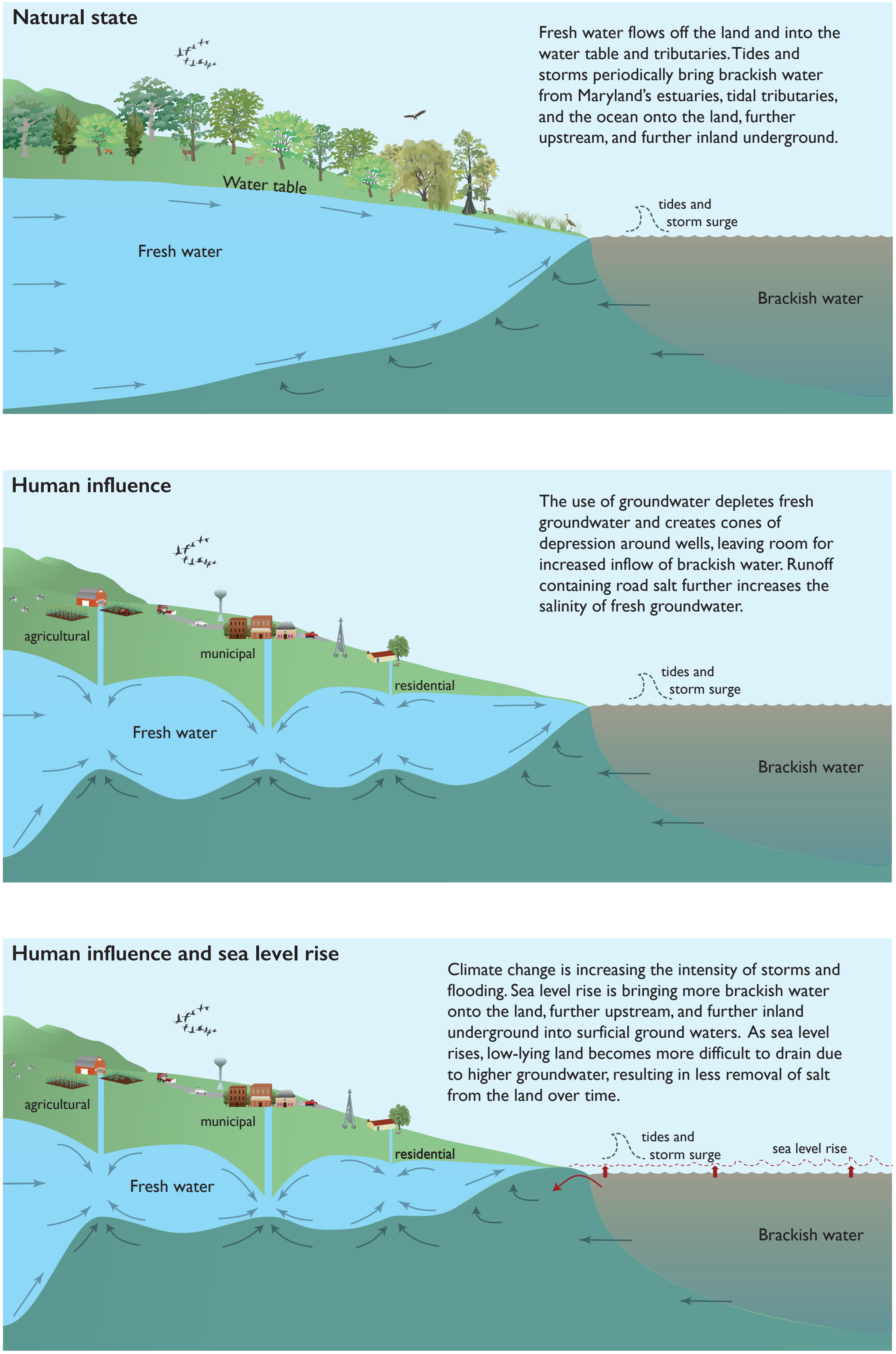



**Figure 2. Impact of Human Influence and Sea Level Rise on Saltwater Intrusion (UMCES-IAN)**

As sea level rises, the extent of tidal, brackish surface waters within the Chesapeake Bay, Coastal Bays, and Atlantic Ocean expands both upstream and landward above and below the ground, which in turn increases saltwater intrusion into aquifers. Low-elevation coastal areas will become more vulnerable to episodic coastal flooding events and vertical saltwater intrusion. Surficial aquifers (often used for agricultural purposes) are most susceptible to vertical saltwater intrusion; however, if pressure gradients and flow pathways are present, deeper aquifers used to supply drinking water could also be threatened.[23]

In addition, changes in precipitation due to climate change can affect the extent of saltwater intrusion into aquifers. During periods of drought, the decreased flow of precipitation into surface waters and groundwater allows the freshwater-saltwater transition zone to expand landward, while during periods of increased precipitation, the transition zone will recede.[24]

Lastly, as heat increases due to climate change, demand for water is likely to increase, placing more stress on the aquifer system and resulting in lower groundwater levels,[25] which creates a greater likelihood of saltwater intrusion.

## Threats, Concerns and Impacts

Maryland's unique rules governing the withdrawal of water prohibit MDE from granting a water appropriation and use permit that causes or contributes to saltwater intrusion into a freshwater aquifer (see COMAR 26.17.06.06.D.(8)). The MDE policy of incorporating climate change vulnerabilities into the Water Appropriation and Use Permit has significantly reduced the risk of saltwater intrusion due to overpumping. Water managers can prevent this type of saltwater intrusion into larger Maryland water supplies by implementing a comprehensive "One Water" approach. The ability to implement this depends on having better information and forecasts regarding saltwater intrusion and coastal aquifers.

The research recommendations in this chapter would facilitate state implementation of COMAR 26.17.06.06.D.(8), allowing for earlier detection of saltwater intrusion, and quicker pursuit and identification of alternative water sources.

Detection of saltwater intrusion is needed to inform decision-making by water regulators, users, and suppliers. Currently, salt (sodium chloride) is not a frequent water-quality test constituent when new or replacement private wells are constructed in Maryland's coastal plain; however, in some counties in Maryland's coastal plain, county environmental health departments do test wells, including domestic wells, in select areas for chloride. Public groundwater drinking systems in Maryland are required to test for chloride whenever a new source is constructed, although there is no ongoing chloride monitoring except in special cases. On the other hand, sodium is routinely tested for and also can be used as a surrogate for saltwater in most aquifers. TDS and specific conductance, which can be used to help identify the presence of brackish and salty water, are tested sporadically in both public water systems and domestic wells in Maryland. Ultimately, the presence of salt in wells used for drinking water can be detected by the taste of the water. In irrigation or industrial wells, salt may be detected by damaged crops or infrastructure, such as reduced crop yield or corroded pipes.[26]

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23 Cantelon, J. A., et al, Vertical saltwater intrusion in coastal aquifers driven by episodic flooding: A review, Water Resources Research, 58, e2022WR032614, 2022. [Online]. Available: https://doi.org/10.1029/2022WR032614 [Accessed 29 October 2024]..

24 Meisler, Harold, The occurrence and geochemistry of salty ground water in the Northern Atlantic Coastal Plain, USGS, Professional Paper, 1404–D, 51 p., 1989. [Online]. Available: pubs.usgs.gov/pp/1404d/report.pdf. [Accessed 29 October 2024].

25 MDE Water Supply Program, "Climate Change Adaptation for Maryland Water Utilities," [Online]. Available: mde.state.md.us/programs/water/water_supply/Documents/120516_CCbrochure_Web.pdf. [Accessed 29 October 2024].

26 Government of Western Australia, Department of Primary Industries and Regional Development, "Water salinity and plant irrigation," [Online]. Available: agric.wa.gov.au/fruit/water-salinity-and-plant-irrigation?page=0%2C0. [Accessed: 29 October 2024]; New South Wales, Office of Environment and Heritage, "Salinity," [Online]. Available: environment.nsw.gov.au/topics/land-and-soil/soil-degradation/salinity. [Accessed: 29 October 2024].

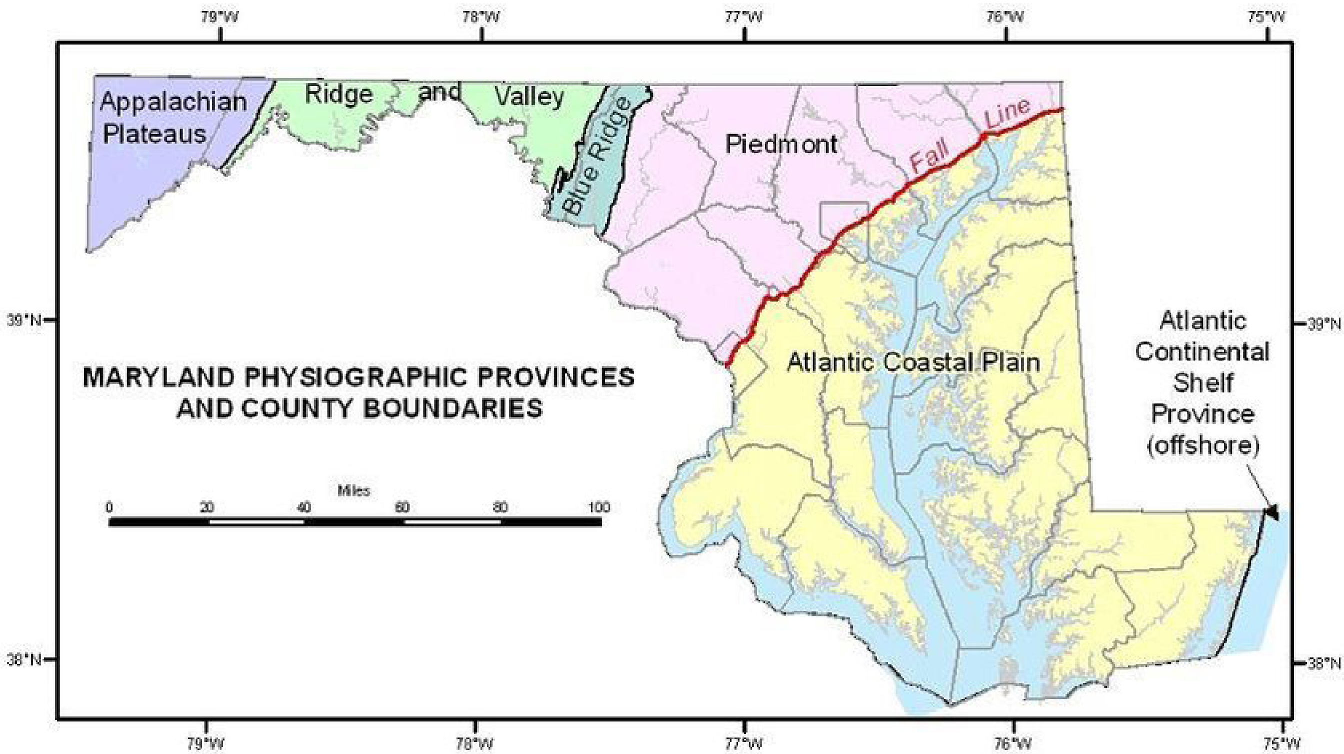



**Figure 3. Atlantic Coastal Plain (*MGS*)**

***Most of Maryland's groundwater users rely on aquifers that are not impacted by saltwater intrusion.***

These include aquifers that are either far from tidal waters (e.g., Piedmont aquifers) or are within deeper, confined aquifers in the coastal plain that for the most part are protected from saltwater intrusion by overlying, low permeability clay layers.

There are however, some Maryland groundwater users within the coastal plain who rely on aquifers that are at risk of saltwater intrusion.[27] Generally, Maryland's unconfined aquifer is at a low risk of saltwater intrusion now; however, the portion of the unconfined aquifer that will be inundated by sea level rise will be at greater risk of having saltwater intrusion in the future.[28]

Overall, within Maryland's coastal plain in areas closest to tidal waters, both the shallow unconfined aquifers (the surficial aquifer on the Eastern Shore and the Surficial Lowland aquifer in southern Maryland), and some portions of the deeper confined aquifers are at greater risk of saltwater intrusion; however, proximity to the coast within the surficial aquifer does not automatically mean that a use in that area is at risk of saltwater intrusion.

The two risk factors for users of Maryland's surficial aquifer are proximity to salty surface water and a hydraulic gradient toward the point of withdrawal. Also, since groundwater, and the saltwater-freshwater interface, moves slowly, the head gradient would have to persist over a relatively long period to create a risk. A high withdrawal rate relative to the rate of recharge (whether in the unconfined or confined aquifers) does not indicate by itself that an aquifer is at risk of saltwater intrusion. Maryland currently does not have hydraulic heads mapped for determining gradients for all aquifers.[29] Appendix C provides a sense of Marylanders' use of the surficial aquifer compared to other, less vulnerable water supplies. Those figures, however, do not provide any indication at this time of how many of these water users are at risk.

27 MGS, "Is Maryland's Groundwater in Jeopardy?" [Online]. Available: mgs.md.gov/groundwater/gw-status.html. [Accessed 29 October 2024].

28 David Andreasen, MGS, personal communication, 22 May 2019.

29 David Andreasen, MGS, personal communication, 22 May 2019.

***The exact number of Maryland groundwater users that are at risk due to increasing saltwater intrusion due to climate change is currently unknown.***

Map 1 shows the areas of Maryland at risk of inundation and potential saltwater intrusion as sea level rises. Inundation caused by sea level rise would advance brackish water in coastal aquifers landward, which could accelerate rates of saltwater intrusion into aquifers already experiencing saltwater intrusion or result in intrusion in areas currently containing fresh groundwater. Although sea level rise would increase the potential for saltwater intrusion, landward movement will depend in part on the degree to which groundwater withdrawals have lowered aquifer heads below sea level, as well as changes in precipitation, runoff, and recharge that may occur within coastal watersheds as a part of climate change. For example, increased freshwater runoff could counterbalance the landward movement of saltwater. On the other hand, rising sea levels might also cause upstream migration of saltwater in coastal tributaries, flooding of low-lying areas (beyond those indicated in Map 1), and submergence of coastal unconfined aquifers.

A limitation of Map 1 is that it does not account for the extensive ditch systems that exist in many areas of Maryland's coastal plain. Agricultural, roadside, mosquito[30], and residential ditches all can bring saltwater further inland. To account for saltwater intrusion vulnerability due to ditch systems, future modeling in Maryland could make use of a saltwater intrusion vulnerability index (SIVI).[31] The SIVI considers, for each small geographic unit (pixel), elevation above sea level, and the ability of expected freshwater flows within ditches and natural waterways to counteract the inland movement of brackish waters.

***Maryland's confined aquifers are at lower risk, even with the amount of sea level rise forecasted this century, because of overlying, low permeability clay layers that act as a hydraulic barrier to flow.***

The rate of flow through the confining layer is controlled by the permeability of the clay and the hydraulic gradient across the confining layer. If the permeability of the clay is very low, and therefore an effective confining layer, a slight increase in head gradient (e.g., as a result of a 4-foot rise in sea level) will increase velocity, but the rate will remain very low.[32] At this time, Maryland can only identify which water systems dependent on confined aquifers have already dealt with, and for the most part have so far successively adapted to, saltwater intrusion issues (see Appendix C), with an understanding that sea level rise likely will present a further challenge for these particular systems over time.

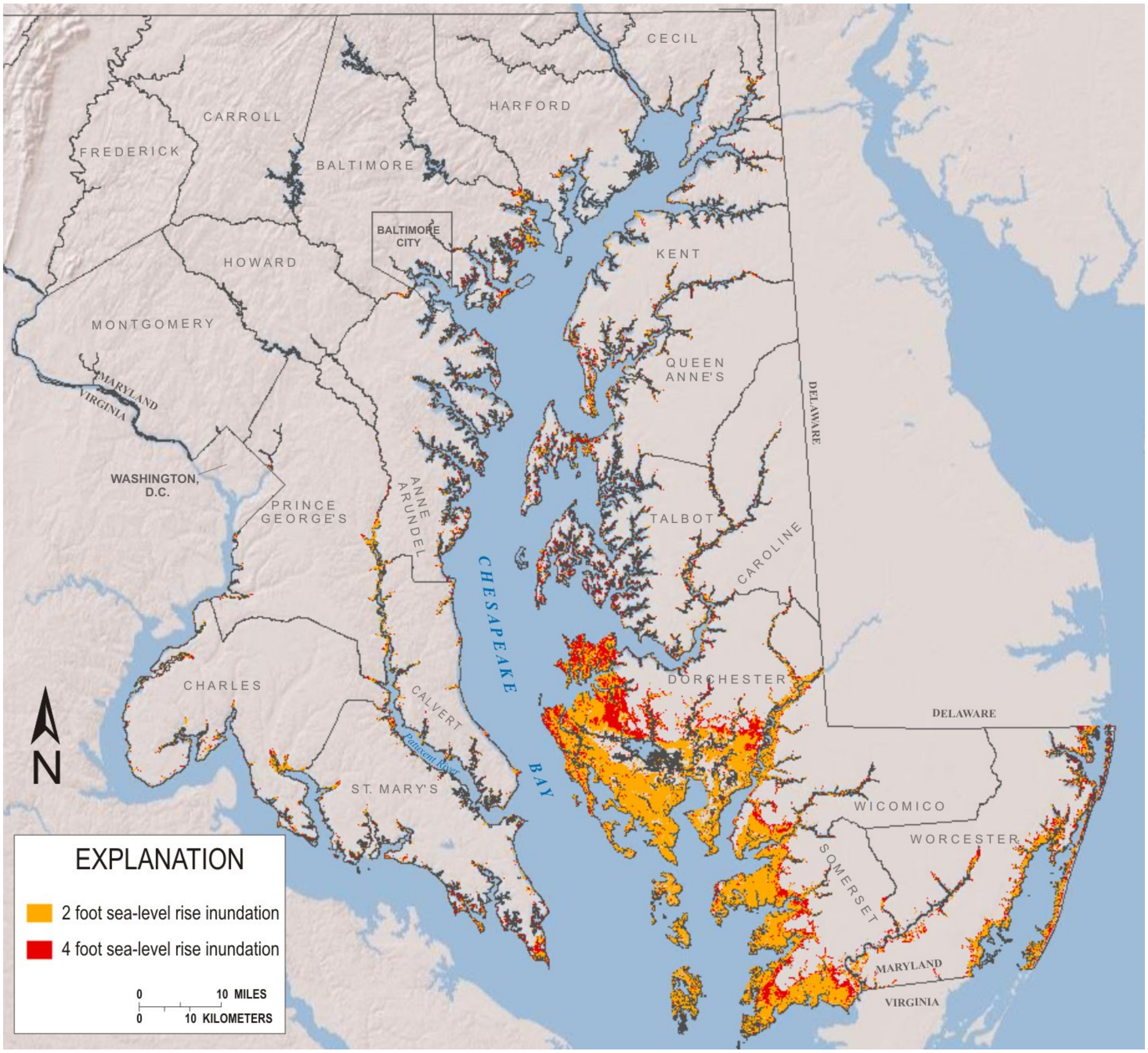
The last comprehensive study of Maryland's coastal plain aquifer system, both unconfined and confined, was completed in 2013 by MGS; however, that work did not include an investigation of saltwater intrusion.[33] More localized mapping of saltwater intrusion in specific aquifers within certain locations has also been conducted over the past decades by the Maryland Geological and U.S. Geological surveys.

30 Straight, narrow channels that were dug to drain the upper reaches of salt marshes in order to control the populations of mosquitoes that breed there. USGS. https://apps.usgs.gov/thesaurus/term-simple.php?thcode=62&code=GC-250 [Accessed: 29 October 2024].

31 Bhattachan, A, et al., "Evaluating the effects of land-use change and future climate change on vulnerability of coastal landscapes to saltwater intrusion," Elem Sci Anth, 6: 62, 2018. [Online]. Available: doi.org/10.1525/elementa.316 or elementascience.org/articles/10.1525/elementa.316/. [Accessed 29 October 2024].

32 David Andreasen, MGS, personal communication, 22 May 2019.

33 Andreasen, D.C., Staley, A.W., and Achmad, G., Maryland Coastal Plain Aquifer Information System: Hydrogeologic framework, Maryland Geological Survey, Open-File Report 12-02-20, 121 p., 2013.




**Map 1. Areas of Maryland at risk of inundation and possible saltwater intrusion as sea levels rise. Source: NOAA Office for Coastal Management, 2017, coast.noaa.gov/slrdata/; County Boundaries: MD iMAP, SHA; Base Map: Esri.**

***Aside from those few specific locations and aquifers of documented saltwater intrusion in Maryland, the extent of salty groundwater in Maryland's coastal plain aquifers remains largely unknown.***

Therefore, mapping the current occurrence of saltwater intrusion in Maryland's coastal plain aquifers is critically important for preparing for future saltwater intrusion problems by developing baseline data.[34]

Reports, studies or anecdotes of saltwater intrusion occurring in Maryland in other groundwater systems, whether household wells, agricultural irrigation wells, or other purposes, are still unknown. For example, the extent of complaints due to saltwater intrusion from households, farmers or businesses using wells within the coastal plain is unknown. Additional research, such as interviews with local health officials, soil conservation districts, well contractors, and local economic development officials, to identify the extent of complaints of saltwater intrusion could be helpful.

34 USGS, Bibliography on the Occurrence and Intrusion of Saltwater in Aquifers along the Atlantic Coast of the United States, Paul M. Barlow and Emily C. Wild, Open-File Report 02-235, 2002. [Online]. Available: pubs.usgs.gov/of/2002/ofr02235/pdfs/text03.pdf. [Accessed: 29 October 2024].

The economic impact of saltwater intrusion in aquifers is the added cost of adaptation measures to ensure an adequate and safe water supply, such as the construction of new or replacement wells in deeper or alternative aquifers, the removal of salt by reverse osmosis, or the use of cement grout and flood-proof caps to prevent saltwater infiltration. The continued use of groundwater with elevated salt content can result in costs associated with damaged cropland if used for irrigation, damaged plumbing and infrastructure if used for either domestic or municipal supply, and damage to some types of equipment if used for industrial supply.[35]

Although there is a health impact from drinking salty water associated with high sodium levels, generally people stop drinking water once it becomes too salty. The World Health Organization, for example, indicates that water becomes unpalatable at TDS levels greater than about 1,000 mg/L.[36] In extreme hypothetical cases, however, some households might drink salty water due to the economic expense of adaptation measures such as drilling a new well, or purchasing bottled water. Also, although the presence of high chlorides or TDS does not legally require the drilling of a new well, some households might not report an impacted well out of fear that other contaminants could be found that would require the closure of the well .

The EPA standard for chloride in drinking water is a Secondary Maximum Contaminant Level (SMCL) of 250 mg/L. An SMCL is a water quality standard for nuisance substances; neither sodium nor chloride have a health-based standard that must be achieved within drinking water.[37] On the other hand, EPA recommends no more than 20 mg/L of sodium for individuals on a 500 milligrams-per-day restricted sodium diet,[38] such as those with severe hypertension or diabetes, or renal dialysis patients.[39] For these individuals, testing well water on a more frequent basis and providing treatment technology to reduce salt will be an added expense to help limit salt intake.

35 Ameh, T. “The Use of Salt Water in Industry,” [Online]. Available: web.archive.org/web/20170714134500/ehow.com/about_5449483_use-salt-water-industry.html. [Accessed 29 October 2024].

36 Government of South Australia, “Salinity and Drinking Water,” [Online]. Available: www.sahealth.sa.gov.au/wps/wcm/connect/Public%20Content/SA%20Health%20Internet/Public%20health/Water%20quality/Salinity%20and%20drinking%20water. [Accessed 29 October 2024].

37 University of Rhode Island Water Quality Program, Rhode Island Department of Health., “Sodium and Chloride in Drinking Water Wells,” Safe Well Water RI. Tip Sheet 14. [Online]. Available: web.uri.edu/wp-content/uploads/sites/61/TipSheetC14-SodiumChloride.pdf. [Accessed: 29 October 2024.

38 U.S. Environmental Protection Agency, “2012 Edition of the Drinking Water Standards and Health Advisories,” EPA 822-S-12-001, 12 p., 2012. [Online]. Available: rais.ornl.gov/documents/2012_drinking_water.pdf. [Accessed 29 October 2024].

39 Government of South Australia, “Salinity and Drinking Water,” [Online]. Available: www.sahealth.sa.gov.au/wps/wcm/connect/Public%20Content/SA%20Health%20Internet/Public%20health/Water%20quality/Salinity%20and%20drinking%20water. [Accessed: 29 October 2024].

## Additional Research

Significant research has been conducted over the years such as developing numerical groundwater-flow and solute transport models to predict future changes to the saltwater-freshwater interface in select aquifers, and monitoring to detect changes in chloride concentrations in targeted areas/aquifers. While this research has provided valuable information to water managers, the extent of saltwater intrusion in many of Maryland's coastal plain aquifers remains unknown. Additionally, there is presently a lack of tools (flow and transport models) and monitoring networks to effectively track, forecast and manage saltwater intrusion as groundwater withdrawals continue or increase and sea level rises. A comprehensive assessment of the potential for saltwater intrusion is lacking because data is not available.[40]

Due to this lack of information about the current and forecasted extent of saltwater intrusion in Maryland's coastal plain aquifers, and the current and forecasted extent of salinization within Maryland's surface waters, the number of Maryland residents, farmers and businesses depending on water supplies at risk of saltwater intrusion is unknown. Certain areas of aquifers and surface waters may be at greater risk.

Several county and municipal water suppliers in Maryland rely on the surficial aquifer,[41] which generally is more vulnerable to saltwater intrusion than Maryland's confined aquifers; however, additional research (e.g., determining aquifer head gradients) is recommended to evaluate whether any of these supplies are at increased risk of saltwater intrusion due to climate change. See Appendix C.

The following research (mapping, forecasting, monitoring) tasks are recommended to adequately address the risk of saltwater intrusion to Maryland's coastal plain aquifers:

## First Priority

**Assess available data.** There are many data sets in existing governmental (federal, state, and local) and academic databases that can be obtained and analyzed. Obtaining and assessing the data would help identify knowledge gaps. Compiling the data (both groundwater and surface water) into a single database would be helpful. Also, additional research by government and nongovernmental partners, such as interviews with local health officials, soil conservation districts, well contractors, and local economic development officials, to identify the extent of complaints of saltwater intrusion could be helpful.

**Assess potential vulnerability.** To identify vulnerable aquifers, consider an assessment of withdrawal by sector, initial estimates of hydraulic gradients, and a study of recharge rates. Additional monitoring wells are needed to estimate hydraulic gradients (to date only available for 5 confined aquifers in Southern Maryland and the Eastern Shore). To identify vulnerable water users of the surficial aquifer, overlay groundwater appropriation permits and locations of domestic wells, which must be estimated using water service areas from county water/sewer plans and data on improved parcels, with sea level rise inundation areas. Problem areas such as improperly constructed or improperly abandoned wells and wells in low areas prone to flooding also could be identified. Conduct status and trends analyses.

**Identify areas where more research and data is needed.** Based on an assessment of the available data, areas and aquifers where more information is required could be targeted, as well as knowledge gaps in the aquifer framework, processes of saltwater intrusion, and forecasting. Aquifer Information System revision is in progress and local areas needing refinement need to be identified.

**Develop study plans.** Detailed study plans are suggested to effectively and efficiently design and target research and quantify required resources (funding, staffing, etc.).

40 USGS, "Sustainability of the Ground-Water Resources in the Atlantic Coastal Plain in Maryland," USGS Fact Sheet FS-2006-3009. [Online]. Available: pubs.usgs.gov/fs/2006/3009/. [Accessed 29 October 2024].

41 John Grace, MDE, personal communication, 2 January 2019.

**Strengthen the partnership with county health departments and offer technical assistance with existing local databases.** Local health department databases house volumes of information and local program managers have a working knowledge of water issues. Local health departments can use additional funding and support to export local information effectively. Disparate formats among county health department databases should be standardized to allow for more effective data export and compilation. Identify areas at risk and knowledge-gap areas and search local databases in those areas first.

## Second Priority

**Develop monitoring networks for saltwater intrusion.** A robust monitoring well network is suggested to detect changes in the freshwater-saltwater interface as sea level rises and changes occur in groundwater withdrawals. The monitoring network could also assist calibrating groundwater-flow and solute transport models, and in developing and evaluating future management strategies. Identify emerging technologies that could be deployed to better track salinities.

**Map freshwater-saltwater interface, develop aquifer head maps, refine aquifer framework.** To help assess future impacts of sea level rise, the present extent of saltwater intrusion in each of Maryland's coastal plain aquifers could be mapped. To assess the potential for groundwater withdrawals to induce saltwater intrusion, current aquifer potentiometric surfaces (groundwater levels) could be mapped as well. Lastly, additional information on the aquifer framework (structure) will also be helpful to better understand potential pathways for intrusion to the deeper, confined aquifers.

**Identify risks.** To plan for future adaptation, a full accounting of freshwater supplies (groundwater and surface water), farmland, coastal wetlands, and infrastructure "at risk" of saltwater intrusion is recommended. This analysis could estimate the extent of the risk (the product of the probability of occurrence and the magnitude of the consequence), and assess the level of effort and cost to reverse or prevent damage. The GALDIT method may be used to identify 'at risk' areas.[42]

## Third Priority

**Develop forecast models.** To help plan for and adapt to the effects of saltwater intrusion, detailed forecast models (groundwater-flow and solute transport models) could help predict the future extent of intrusion into groundwater and surface water. To identify vulnerable water users of confined aquifers, modeling can be used. This modeling may also include predicted change in irrigation with climate change, which could affect both the probability and consequence of saltwater intrusion.

**Inform adaptation and management plans.** This can include a study of reverse osmosis costs now and in the future, the improvement of business sector, and especially agricultural, awareness of the need for water conservation, and the value of investing in technology and adopting practices that reduce water use. Also, after assessing and creating an inventory of existing wells located in floodplains, owners of these wells could be encouraged to appropriately (see adaptation section below) abandon vulnerable wells or bring existing wellheads up to specified standards.

42 Chachadi, A.G. and Lobo-Ferreira, João-Paulo, Sea water intrusion vulnerability mapping of aquifers using the GALDIT method. Coastin—A Coastal Policy Res Newsl. 4, 7-9, 2001. Note: The most important factors controlling seawater intrusion were found to be the following: Groundwater occurrence (aquifer type; unconfined, confined and leaky confined); Aquifer hydraulic conductivity; Depth to groundwater Level above the sea; Distance from the shore (distance inland perpendicular from shoreline); Impact of existing status of sea water intrusion in the area; and Thickness of the aquifer. The acronym GALDIT is formed from the highlighted letters of the parameters for ease of reference.

## Adaptation

As noted earlier in this chapter, Maryland's unique regulations governing the withdrawal of water prohibit MDE from granting a water appropriation and use permit that causes or contributes to saltwater intrusion into a freshwater aquifer (see COMAR 26.17.06.06.D.(8)). The MDE policy of incorporating climate change vulnerabilities into the Water Appropriation and Use Permit has significantly reduced the risk of saltwater intrusion due to overpumping. Maryland can prevent this type of saltwater intrusion into larger Maryland water supplies by implementing a comprehensive "One Water" approach. Also, the ability to successfully implement this depends on having better information and forecasts regarding saltwater intrusion and coastal aquifers. This requires forward-looking supply models that consider forecasted climate change impacts (sea level rise, saltwater intrusion, etc.) and the identification of vulnerable areas.

Maryland rules already mandate some specific adaptation measures:

1) Wells must be constructed at least 2 feet above grade in flood-prone areas (COMAR 26.04.04.21.C).
2) Flood resistant caps, which include a gasket that forms a waterproof seal, on wells must be used in flood-prone areas (COMAR 26.04.04.21.G).
3) Bentonite grout (sodium bentonite derived from clay, commonly used to surround well casings to prevent contaminants from mixing with well water) is prohibited where groundwater is at 1,000 mg/l of TDS (COMAR 26.04.04.19.C(2)(b)), given that brackish water reduces the viscosity, and therefore, the effectiveness of the grout.

Together, these can limit saltwater contamination of freshwater supplies in coastal areas by ensuring that wells do not become a conduit for saltwater into aquifers. However, the ability to successfully apply these measures depends on understanding the location and depth of future water levels, both above and below ground.[43]

Adaptation measures are not only useful to prevent saltwater intrusion, such measures also can address existing problem areas. Existing problem areas include improperly abandoned or improperly constructed wells such as:

1) Within confined aquifers, abandoned or existing wells grouted with bentonite that have not been perforated and sealed with cement to the confining unit.
2) Within either unconfined or confined aquifers, wells that were never abandoned that are now, due to land subsidence/erosion, in the water.
3) Within confined aquifers, wells in known saltwater intrusion areas that are not currently being grouted with cement.44

Maryland water users, whether individual property owners, farmers, industry or local government, have several existing adaptation approaches to adjust to saltwater intrusion, including shifting water sources (e.g., to unaffected confined aquifers or surface waters) or adjusting water withdrawals from the existing water source. For water suppliers, increasing water treatment capabilities is another adaptation option to allow for the removal of salinity.[45]

Of the few documented cases of saltwater intrusion into water suppliers in Maryland, adaptation measures have been successfully used at Annapolis Neck/Mayo Peninsula, Kent Island, and Ocean City to ensure an adequate and safe water supply (please note: adaptation measures also have been used at Indian Head, but monitoring is needed to show whether those measures have succeeded). Adaptation measures used to address saltwater intrusion in those instances included modifying water withdrawals from the impacted aquifer and developing a balanced use of deeper aquifers.

43 John Grace, MDE, personal communication, 10 September 2018.

44 John Boris, MDE, personal communication, 14 November 2018.

45 MDE Water Supply Program, "Climate Change Adaptation for Maryland Water Utilities," [Online]. Available: mde.state.md.us/programs/water/water_supply/Documents/120516_CCbrochure_Web.pdf. [Accessed October 29 2024]

MDE has identified a few water management strategy areas[46] that are at risk from saltwater intrusion. The designation results in special groundwater management considerations, including limiting withdrawals in a certain aquifer, directing withdrawals to a different aquifer, or additional analysis and/or monitoring when permits are requested for these areas.[47]

Among Maryland's jurisdictions, Ocean City has completed the most planning concerning adaptation measures for adjusting to saltwater intrusion. Over the long term, the town is considering the potential for desalinization facilities to remove salt from the groundwater; estimates show these facilities would cost up to $25 million. Over the near term, the town intends to continue to install replacement pumping wells with spacing between wells that is large enough to spread pumping centers in an effort to minimize saltwater intrusion, and reduce usage of any wells (within its 22-well system) that indicate chloride levels of 250 parts per million.[48] The MDE appropriation permit issued to Ocean City requires monitoring of chloride levels, and tracking of water use from individual wells so that trends can be properly observed and usage can be focused on sources that reduce potential for higher chloride levels.[49] Also in the near term, the town will seek to encourage the use of water conservation measures to reduce the drawdown of its groundwater supplies, which also can help prevent saltwater intrusion.[50] This effort appears to be working; reported annual water usage by Ocean City during the period of 2019 through 2023 was about 12 percent lower than the period of 2014 through 2019, and the annual total usage for 2017 and 2018 was similar to withdrawals in 1985 and 1986.[51]

Other adaptation measures might not be applicable in Maryland due to the cost, the number of ratepayers available within the water service area to help pay for the measure, pollution prevention concerns (e.g., polychlorinated biphenyls introduction), and/or hydrogeography. Examples include injection of freshwater (treated wastewater) to create a hydraulic barrier against saltwater intrusion (Orange County, California) and the use of recharge basins to replenish the threatened unconfined surficial aquifer with freshwater (Long Island, New York).[52] On the other hand, if project benefits can be increased by providing additional services, such measures could potentially be worth the cost (e.g., recharge basins managed for shoreline protection, wildlife and/or recreational benefits).

46 The MDE water management strategy areas currently listed for saltwater intrusion in Maryland are: (1) Aquia aquifer on Kent Island in Queen Anne's County (groundwater in the Aquia along the western edge of Kent Island adjacent to the Bay has locations of elevated chloride); (2) Patapsco aquifer on Indian Head peninsula (Charles County) has had elevated chloride in the past; (3) Aquia aquifer (shallow surficial aquifer at this location) on Annapolis Neck and Mayo Peninsula (Anne Arundel County) has had areas of elevated chloride; (4) Surficial aquifer in West Ocean City (Worcester County)- St. Martins River- no documented elevated chloride- concern is for potential due to the connectivity of Columbia aquifer to the Atlantic Coastal Bays and the water level trend observed from 1994 through 2005 (John Grace, MDE, personal communication, 4 December 2018).

47 MDE Water Supply Program, "Groundwater Protection Program, Annual Report to the Maryland General Assembly 2012," July 2012. [Online]. Available: mde.state.md.us/programs/water/water_supply/source_water_assessment_program/documents/gwreport_2012_final.pdf.

48 Jeremy Cox and Rachael Pacella, "Delmarva fights salt in drinking water," Delmarva Now, 16 December 16 2015. [Online]. Available: delmarvanow.com/story/news/2015/12/16/officials-eye-saltwater-intrusion/76364998/. [Accessed 17 November 2019].

49 John Grace, MDE, personal communication, 3 May 2019.

50 Town of Ocean City, "2017 Update, Town of Ocean City Comprehensive Plan," Approved March 5, 2018. [Online]. Available: oceancitymd.gov/pdf/PZCapproved.pdf. [Accessed 17 November 2019].

51 John Grace, MDE, personal communication, 3 May 2019.

52 USGS, Sustainability of Ground-Water Resources, U.S. Geological Survey Circular 1186, William M. Alley, Thomas E. Reilly, and O. Lehn Franke, pp. 74-75, 1999.

For households using individual wells, potential adaptation measures include reverse osmosis, distillation and deionization; however, each method has its drawbacks, such as cost and environmental hazards.[53]

Lastly, the reuse of treated effluent and graywater in accordance with MDE's policies can reduce or minimize saltwater intrusion impacts by reducing groundwater drawdown within Maryland's aquifers.

***Photo credit Johns Hopkins University/ GETTY IMAGES***

53 New Hampshire Department of Environmental Services, "Environmental Fact Sheet, Sodium and Chloride in Drinking Water," WD-DWGB-3-17, 2010, [Online]. Available: http://maineenvironmentallaboratory.com/wp-content/uploads/NH-Sodium-and-Chloride-in-DW-2010.pdf. [Accessed 27 November 2019].

# Surface Waters

## Resource

As noted in the introduction, Maryland is divided into the western shore and the eastern shore by the estuarine Chesapeake Bay, and its tributaries are brackish for significant portions of their length.

Fenwick (Ocean City) and Assateague Islands, the easternmost border of Maryland, are barrier islands surrounded by the Atlantic Ocean and the brackish Coastal Bays, which front the eastern shore of Worcester County.

In addition to their significant economic, environmental, cultural and recreational value, tidal freshwater surface waters of the Chesapeake Bay also are used, to some extent, for water supply. Those who depend upon Maryland's coastal surface waters for agricultural irrigation, drinking water or natural resources will need to remain vigilant of impacts from possible increases in salinity over time.

## Drivers of Salinization

The primary climate change drivers of salinization of Maryland's surface waters include:

- Sea level rise, which is steadily moving the existing freshwater-saltwater transition zone further upstream.
- Changing precipitation patterns that periodically move the freshwater-saltwater transition zone further upstream (during periods of drought) or further downstream (during periods of higher than normal precipitation creating higher freshwater discharge).
- Changes to tides, winds, waves, storm surge, and estuary shape and topography. [54]

Also, human actions, such as dam construction, water diversions, and land use change, can increase the amount of freshwater that enters the state's tidal surface waters, which also can affect the freshwater-saltwater transition zone.

One tool currently under development is SaltCast. It uses a watershed-estuary model to simulate the transport and fate of major salt ions and the model output is combined with artificial intelligence algorithms to identify management strategies to increase the resilience of coastal infrastructure, water security and public health.[55]

## Threats

***The majority of Maryland's surface water users rely on water bodies that would not be impacted by salinization due to sea level rise.***

These include the water supplies in the Potomac River Basin, the Washington Suburban Sanitary Commission's reservoir on the Patuxent River, and the three Baltimore City reservoirs. On the other hand, public water suppliers on the tidal Susquehanna River and the nearby North East River may be vulnerable to salinization as the freshwater-saltwater transition zone moves upstream within the Chesapeake Bay.

This increased salinization may impact other surface water users, including farmers withdrawing from tidal streams and rivers (such as the Choptank and Tuckahoe rivers on the Eastern Shore), golf courses withdrawing from tidal streams, and power plants and industries using tidal water for non-contact cooling.

54 Richard Tian, "Factors controlling saltwater intrusion across multi-time scales in estuaries, Chester River, Chesapeake Bay," *Estuarine, Coastal and Shelf Science*, Volume 223, 31 July 2019, Pages 61-73.

55 SaltCast [Online], Available: https://saltcast.io/ [Accessed: 29 October 2024]

There will be an economic impact to some extent for surface water users to adapt to saltwater intrusion. At this time, the amount of impact is unknown.

In addition to impacts on water supply, salinization of surface waters may have pronounced impacts on aquatic habitat and attendant communities. Studies of increased salinity in freshwater habitats have documented declines in fish diversity,[56] indicated potential losses in benthic invertebrate species,[57] and raised concerns over indirect impacts to fish health and reproduction.[58] While salinization from sea level rise can be detrimental to freshwater habitats, it can extend habitat for estuarine species. Strong freshets like those of 2017 and 2018, extended freshwater beyond its typical range and lowered salinities in oyster habitat causing increased mortality.[59] The state could consider these types of extreme weather events (pro and con) when assessing resource management options in response to salinization.

## Additional Research

The following research (mapping, forecasting, monitoring) is recommended to adequately address the risk of salinization to water users of surface waters in Maryland:

### First Priority

**Identify currently vulnerable water users.** Map the locations of intake pipes (surface water appropriation permits) relative to the current salt freshwater-saltwater transition zone.

**Identify and catalog ditches.** Having high-resolution geographic data on the location, depth and extent of ditches (agricultural, wetland, etc.) could help researchers better estimate and understand the upstream movement of saltwater within Maryland surface waters.

**Review system-wide approach for monitoring surface water salinity to detect long term changes.** This could include a statistical review of the experimental design of any necessary supplemental monitoring, and will also allow for model calibration and validation. Conduct status and trends analyses using this information.

### Second Priority

**Conduct research to inform the development of a forecast model.** Given the complexity of the movement of surface waters in the Chesapeake Bay, the Coastal Bays, the tidal tributaries, and the Atlantic Ocean, additional research is needed to inform the development of a forecast model to predict how the freshwater-saltwater transition zone will change in the future due to climate change. This effort could be completed in conjunction with modeling ecological impacts of salinization of surface waters to wetlands and forests.

56 Love, J.W., Gill, J. and Newhard, J.J, “Saltwater intrusion impacts fish diversity and distribution in the Blackwater River drainage (Chesapeake Bay watershed),” *Wetlands*, 28: 967, 2008; Dasgupta, S., et al., “2016 Impact of Climate Change and Aquatic Salinization on Fish Habitats and Poor Communities in Southwest Coastal Bangladesh and Bangladesh Sundarbans,” World Bank, Policy Research Working Paper 7593; Hoagstrom, C. W., “Causes and Impacts of Salinization in the Lower Pecos River,” ***Great Plains Research: A Journal of Natural and Social Sciences***, 994, 2009.

57 Kefford B.J., et al., “Salinized rivers: degraded systems or new habitats for salt-tolerant faunas?” ***Biol. Lett***, 12: 20151072, 2016.

58 Whitney, J.E., et al., “Physiological Basis of Climate Change Impacts on North American Inland Fishes,” ***Fisheries***, 41:7, 332-34, 2016.

59 Tarnowski, M, “Maryland Oyster Population Status Report,” 2018 Fall Survey, Publ. No. 17-070819-154 Maryland Department of Natural Resources, 2019.

**Increase the state's understanding of the impact of surface water modification projects on the freshwater-saltwater interface.** Determining the impacts, in combination with sea level rise, of existing small scale (e.g., dam removals) and large-scale surface water modification projects, such as the Chesapeake-Delaware Canal and the shipping channels to Baltimore Harbor, could be a research priority. Surface water modification projects can increase saltwater intrusion by decreasing the distance for saltwater to reach fresher waters. [60]

## Third Priority

**Develop a forecast model.** Risks to tidal surface water users depend on modeling of the freshwater-saltwater transition zone. The state has not mapped the future freshwater-saltwater transition zone due to sea level rise; modeling, as well as field data to calibrate the models, is recommended to inform this type of mapping.

**Identify future vulnerable water users.** To identify vulnerable water users of the surface waters, overlay the future freshwater-saltwater transition zone (due to climate change) with existing and likely future surface water appropriation permits (intake pipes). Assess the extent within underserved and/or overburdened communities.

**Long term monitoring of economic, environmental, cultural and recreational resources.**

# Adaptation

Research needs and adaptation measures to assist these water users are unique to the individual settings as the factors influencing salinization are site-specific, and the challenge of dealing with increased salinity depends on the type of use.

The adaptation measures for surface water users impacted by saltwater intrusion are similar to those for aquifers (see Aquifer chapter): modify the use of the surface water, obtain other sources of water, or employ technologies to reduce the amount of salt or to tolerate the salt. Given the challenges of developing robust predictive models, including the significant amount of time and resources to devote to their development, moving forward with some adaptation measures could be helpful even before such models are complete.

***Photo courtesy of Shore Rivers - Sassafras Riverkeeper***

60 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," ***Ecosystem Health and Sustainability***, 3(1):e01258, 2017.

# Agriculture

## Resource

Agriculture, forestry, fishing and hunting together contribute over $1 billion in gross state product, with a total market value of $2.2 billion in products sold.[61] Farming on the Eastern Shore is largely devoted to the poultry industry, including operations that grow over 300 million birds annually. In 2017, over 300,000 acres of corn were planted on the Eastern Shore, with most of it being used for poultry feed.[62]

The Eastern Shore is one of the oldest farming communities in the nation, dating back to the mid-1600s, with some lands being farmed by the same family since that time. Over the years, agricultural lands along the edges of the Chesapeake Bay have cultivated table crops like tomatoes, peppers and green beans, but production has shifted to corn and soybeans for animal feed.

Due to a combination of land subsidence and sea level rise, the mid-Atlantic is experiencing some of the highest rates of relative elevation change in the world,[63] and particularly affected are the low-lying and shallow sloping lands of the Eastern Shore of Maryland. Indeed, climate change is easily observed on the shores of the Bay as the high tide lines have crept across the salt marshes, over the banks of tidal ditches, and onto upland areas.

## Drivers of Salinization

Periodic episodes of salinization can occur years in advance of permanent inundation from sea level rise, due to (1) the frequency and magnitude of storms and tides, such as from surges and “king tides” (perigean spring tides), (2) drought, (3) water use (e.g., surface and groundwater withdrawals), and (4) hydrologic connectivity of streams, creeks, and agricultural ditch networks.[64]

On the Eastern Shore, salinization is already occurring on large swaths of agricultural lands as ditches overflow and salty groundwater is wicked toward the land surface. In fact, while ditches were installed to remove water from fields, in the face of sea level rise, they may be serving the reverse purpose, serving as a conduit connecting the surface waters of the Chesapeake Bay to uplands. Saltwater floods the lands, and when it infiltrates and/or recedes, it often leaves a visible crust of salt on the soil surface and bare patches that ring fields where no crops or plants can grow.[65]

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61 Maryland Department of Commerce, “Agribusiness”, 2019, [Online]. Available: open.maryland.gov/industries/agribusiness/. [Accessed 29 October 2024].

62 USDA National Agricultural Statistics Service, State Agriculture Overview, Maryland.

63 Sallenger, Jr., A. H., K. S. Doran and P. A. Howd. 2012, “Hotspot of accelerated sea level rise on the Atlantic coast of North America,” Nature Climate Change, 2012; Ezer, T., L.P. Atkinson and W.B. Corlett, “Gulf Stream’s induced sea level rise and variability along the U.S. mid-Atlantic coast,” ***American Geophysical Union***, 2013; Goddard, P. B., et al., “An extreme event of sea level rise along the Northeast coast of North America in 2009-2010,” N*ature Communications*, 2015.

64 K. Tully, K. Gedan, R. Epanchin-Niell, et al., “The Invisible Flood: The Chemistry, Ecology, and Social Implications of Coastal Saltwater Intrusion,” ***BioScience***, Volume 69, Issue 5, pp. 368–378, 2019.

65 Mondal, Pinki, Matthew Walter, Jarrod Miller, Rebecca Epanchin-Niell, Keryn Gedan, Vishruta Yawatkar, Elizabeth Nguyen, and Katherine L. Tully. “The spread and cost of saltwater intrusion in the US Mid-Atlantic.” *Nature Sustainability*, 1-11, 2023.

## Threats, Concerns, and Impacts

The Eastern Shore of Maryland supports a major poultry industry, which along with other farmers in Delmarva, produces around 600 million broiler chickens per year.[66] Poultry litter is a valuable source of nitrogen and other nutrients applied to agricultural cropland as a fertilizer. Any phosphorus not utilized by the crops that remains in the soil is known as legacy phosphorus. For years, agronomists made nutrient management recommendations based on the understanding that phosphorus remains bound in the soil. However, current understanding is that inundated conditions, including saltwater inundation, can enable legacy phosphorus to be released into solution and transported out of agricultural fields to creeks and coastal wetlands. In areas at risk for saltwater inundation near coastlines, these nutrients may be released with the tide cycles. Ongoing research is evaluating the potential for increased phosphorus loading from areas impacted by saltwater intrusion and the effects of this on local waters.[67 68]

Higher saline levels in soils reduce the effectiveness of applied nitrogen and phosphorus, which may lead producers to apply higher quantities of fertilizer to achieve desired results for their crops. Saltwater inundation, as a result, may contribute to increased levels of runoff and nutrient pollution due to increased application rates.

Long-standing regulations in Maryland require farmers to follow nutrient management plans that specify how much fertilizer, manure or other nutrient sources may be safely applied to crops to achieve yields and prevent excess nutrients from impacting waterways. In addition, the Phosphorus Management Tool (PMT) adopted in 2015, and phased in through 2022 provides a methodology for assessing the risk of phosphorus loss from farm fields and determining whether to restrict phosphorus applications or the use of animal manure. For fields that exceed set thresholds for the PMT, future phosphorus application will be limited or not permitted, and techniques will be implemented to remove some of the excess phosphorus or draw it down slowly. As nutrient management plans and the PMT do not yet account for leaching of nutrients by saltwater, this could result in excess nutrient loss to the estuary. Techniques to enhance phosphorus recycling include changing crops, managing soil pH or expanding the use of nitrogen-fixing cover crops. The sensitivity of crops to salinity must be taken into account when considering these techniques within soils vulnerable to saltwater intrusion

Few crops can grow in sustained conditions of greater than 2 ppt salinity.[69] However, some crops can tolerate shorter duration pulses of salinity.[70] Salinity levels have been documented as high as 35 ppt on salt-affected fields in the Eastern Shore.[71] The typical rotation of corn-soy-wheat is intolerant of these salinity levels. The extent of salt patches and likely adjacent salinization on agricultural lands was recently quantified by scientists as 16,236 ha in 2016/2017 in nine coastal counties of Maryland (all Eastern Shore), using conservative estimates, with the area of farmland having doubled since 2011-2013.[72] Similarly, estimates of agricultural area at risk from salinization based on preliminary soil salinity analysis and land elevation relative to tidal extremes, shows 7,687 ha at current risk of salinization, with Dorchester and Somerset Counties having the greatest extents of land at risk. In addition, the extent of agricultural land at risk in these two counties is projected to double between now and 2070.[73]

66 Delmarva Chicken Association, “DCA Facts and Figures,” [Online]. Available: https://www.dcachicken.com/facts/facts-figures.cfm. [Accessed 29 October 2024]..

67 Weismann, Danielle, Ouyang, Tianyin and Tully, Katherine L., “Saltwater intrusion affects nitrogen, phosphorus and iron transformation under oxic and znoxic conditions: an incubation experiment” *Biogeochemistry*, 2021.

68 Weismann, D.S. and K.L. Tully, Saltwater intrusion affects nutrient concentrations in soil porewater and surface waters of coastal habitats, *Ecosphere* 11(2):e03041, 2020.

69 Millar, J. “Managing salt affected soil,” 2003. [Online]. Available: https://web.archive.org/web/20040524190335/sdnotill.com/Newsletters/2003_Salt_Soils.pdf. [Accessed: 29 October 2024].

70 DiCara, C. and Gedan, K., “Distinguishing the Effects of Stress Intensity and Stress Duration in Plant Responses to Salinity.” Plants, 12(13), 2522, 2023.

71 Cox, J. “Sea level rise: Saltwater intrusion laying waste to Delmarva farms,” 2019. [Online]. Available: delmarvanow. com/story/news/local/maryland/2019/03/29/sea-level-rise-saltwater-intrusion-laying-waste-delmarva- farms/3276897002/ [Accessed: 29 October 2024].

72 Mondal, P., Walter, M., Miller, J. et al. The spread and cost of saltwater intrusion in the US Mid-Atlantic. *Nat Sustain* 6, 1352–1362, 2023.

73 “Climate Vulnerability of Maryland Agriculture”, draft report. University of Maryland.

## Additional Research

Understanding and modeling the future impacts of saltwater intrusion is a complex process that involves the hydrology of groundwater, land elevation, sea level rise and other factors. The research addressing the agricultural resource will likely overlap and build upon research for other resource sectors.

The following research (mapping, forecasting, monitoring) is recommended to adequately address the risk of saltwater intrusion to farmers in Maryland:

### First Priority

**Continue to develop and improve maps of past, current, and future salinization.** Determining current and forecasting future salinization will help farmers better understand future risks of saltwater intrusion. For example, which lands are most likely to be susceptible to saltwater intrusion and how to manage them to maintain profitability. Assess the vulnerability of Maryland's farms and overall coastal ecosystems to saltwater intrusion via surficial drainage networks by developing a saltwater intrusion vulnerability index (SIVI).

### Second Priority

**Explore transitional crops and land uses, including the creation and restoration of tidal wetland habitat.** This effort would focus in areas greatly affected by saltwater intrusion and no longer suitable for farming.[74]

**Investigate alternative crops (including table crops), soil amendments, and management practices.** These alternatives would reduce the economic loss from saltwater intrusion for affected farmers by addressing the impacts on farm profitability, nutrient runoff and ecosystem benefits.[75] Develop tools for farmers to facilitate decisions on whether and when to plant certain crops, and when to pursue particular adaptation practices.

**Pursue revisions of federal agriculture policies to incentivize farmers to manage crop production conducive to increasingly saltier and wetter soils.**[76]

**Create an ability to track real-time sea level rise and identify areas of declining crop health and opportunities for inland migration of coastal wetlands.** In other words, determine where it is best to yield to sea level rise and to allow agricultural land to revert to beneficial wetlands.[77]

### Third Priority

**Complete a comprehensive analysis of adaptation strategies.** Obtain a better understanding of how adaptation strategies may help capture or prevent nutrient runoff in the Chesapeake Bay; examine trade- offs of different strategies, barriers and incentives for farmer adoption of those strategies; explore economic and environmental trade-offs of alternative adaptation strategies; consider how agricultural adaptation strategies and policies affect farmers and other ecosystem values in coastal Maryland.[78]

**Identify past Mid-Atlantic field trials of table crop salt-tolerance to inform the design of new field trials.** Especially with the shortage of table crops produced in Maryland, providing technical assistance to growers to introduce table crops or increased diversity of commodity crops into rotations may facilitate adaptation to changing soil conditions in the long term.

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74 Currently being studied by Keryn Gedan, GWU.

75 Currently being studied by Kate Tully, UMD; Keryn Gedan, GWU; Becky Epanchin-Neill, UMD.

76 Taryn A. Sudol, Christine D. Miller Hesed, Jenna M. Clark, Fredrika C. Moser. Resisting-accepting-directing sea level rise on the Chesapeake Bay: Agricultural producers' motivations and actions, *Journal of Environmental Management*, Volume 332, 2023, 117355, ISSN 0301-4797.

77 Currently being studied by Jeff Allenby, Chesapeake Conservancy, and by Kate Tully, UMD.

78 Currently being studied by Kate Tully, UMD; Keryn Gedan, GWU; Becky Epanchin-Neill, UMD..

## Adaptation

Adaptation can follow a range of strategies as lands face increasing salinization, from aiming to delay salinization (e.g., barriers, tide gates, ditch management), agricultural adaptation to maintain profitability in the face of increasing salinization, to eventual transition out of agriculture.

One of the effects of saltwater intrusion is a decline in crop productivity. Using an alternative crop that is more salt-tolerant may hold promise for cultivation on these lands. For example, sorghum may be useful as a transitional crop, due to its higher salt and inundation tolerance that other traditional crops grown on Maryland's eastern shore (e.g. corn and soy). In fact, sorghum is planted at a substantially higher rate on low elevation fields than higher elevation fields in coastal areas.[79] Sorghum has been observed to germinate[80] and grow[81] more robustly in saline conditions compared to other crops. Other potential crops that are under investigation or have been suggested as potential salt-tolerant alternatives include switchgrass, giant miscanthus, and asparagus.

In addition to alternative crops, transitional land uses are another pathway for retiring marginal farm lands. For example, saltwater-affected farmland may be set aside or planted for recreation and wildlife benefits. Given concern in the region for the drowning and habitat loss of tidal wetlands, which is another side effect of sea level rise (see Wetlands chapter), the gradual transition of marginal farmlands to tidal wetlands could be preferred to retain the ecosystem services that tidal wetlands provide the region.[82] Fallow, salt-damaged farmland is colonized by wetland plants, as well as agricultural weeds, within a single year. Within the following few years, the plant communities of these lands begin to resemble natural wetlands.[83] The invasive lineage of the common reed, ***Phragmites australis***, is a threat for salt-affected farmland, as it is for natural wetland migration corridors. This species outcompetes native plants and provides less valuable habitat for wildlife species that depend on the tidal wetlands. Therefore, some management (e.g. mowing, seed sowing) of abandoned fields is necessary to ensure that native marsh species are favored over invasive species.

Federal subsidized crop insurance may also play an important, but conflicting role, as agricultural communities adapt to climate change.[84] While subsidized insurance may reduce the uncertainty about potential income loss from the effects of saltwater intrusion that result in reduced crop yields, it may also delay the decision to shift to a salt-tolerant crop or alternative land use since it provides a financial safety net for crop failure of the predominant salt-sensitive crops. Additionally, farmers may be reluctant to share concerns about saltwater intrusion due to the effects on their property values.

79 Epanchin-Niell, Rebecca S., Thompson, A., Han, X., Post, J., Miller, J., Newburn, D., Gedan, K., Tully, K., 2023. "Coastal agricultural land use response to sea level rise and saltwater intrusion," 2023 Annual Meeting, July 23-25, Washington D.C. 335970, Agricultural and Applied Economics Association. [Online], Available: ageconsearch.umn.edu/record/335970?ln=en&v=pdf [Accessed: 29 October 2024].

80 de la Reguera et al. "The effects of saltwater intrusion on germination success of standard and alternative crops". *Environmental and Experimental Botany*, 2020.

81 DiCara, C.; Gedan, K. "Distinguishing the Effects of Stress Intensity and Stress Duration in Plant Responses to Salinity". Plants, 12, 2522, 2023.

82 K. Tully, K. Gedan, R. Epanchin-Niell, et al., "The Invisible Flood: The Chemistry, Ecology, and Social Implications of Coastal Saltwater Intrusion," ***BioScience***, Volume 69, Issue 5, pp. 368–378, 2019.

83 Gedan, K.B. and E. Fernández-Pascual. "Salt marsh migration into salinized agricultural fields: a novel assembly of plant communities." Journal of Vegetation Science 30, no. 5, pp. 1007-1016, 2019.

84 Epanchin-Niell, R., et al., "Saltwater Intrusion and Coastal Climate Adaptation: Building Community Resilience," ***Resources***, Resources for the Future, 2018. [Online]. Available: resourcesmag.org/archives/saltwater-intrusion-and-coastal-climate-adaptation-building-community-resilience/. [Accessed 29 October 2024].

Coastal resilience easements, in conjunction with coastal resilience management plans, are a mechanism to support land use transition in the coastal zone, and to support marsh migration onto unprofitable farmland. The first of these types of easements has been implemented by the DNR in Maryland, and more are likely to follow. Other federal and state programs and options (e.g., MDA Maryland Agricultural Water Quality Cost-Share, federal Environmental Quality Incentives Program and Wetland Reserve Program) can also be used to support marsh migration onto unprofitable farmland.

**Stunted corn struggles to grow in a section of a field damaged by saltwater intrusion.**
***Photo courtesy of Becky Epanchin-Niell***

# Coastal Wetlands

## Resource

Of Maryland's roughly 6 million acres, about 10% are wetlands: more than half are freshwater wetlands (including tidal and nontidal), while the remainder are coastal brackish and saltwater wetlands. In Maryland, coastal freshwater, brackish and saltwater wetlands occur within the coastal plain as part of the Chesapeake Bay and Coastal Bays ecosystems, including along associated tidal tributaries..[85]

Aside from providing water quality benefits through pollution filtration, wetlands provide a large number of other ecosystem services, such as flood protection, aquatic and terrestrial wildlife habitat, and shoreline stabilization, as well as human and cultural services, such as the provision of harvestable natural resources and recreational opportunities.[86] DNR estimates that coastal wetlands provide the highest per acre ecosystem values of any land type.[87]

## Drivers of Salinization

Saltwater intrusion and inundation have been identified as leading drivers of wetland losses in the mid-Atlantic region in recent decades.[88] Both coastal freshwater wetlands and coastal brackish wetlands are vulnerable to salinization. These wetlands exist either directly along Maryland's coastal or riverine shorelines or just landward of coastal salt marshes. When these types of wetlands experience sufficient saltwater stress (from sea level rise, coastal storms, etc.), wetland plants die, and they then may convert into open water, mudflat, or salt marsh. If the amount of saltwater stress is less, lower salinity wetland plants can recover, depending on physical and ecological factors, such as the likelihood of dispersal of seeds of freshwater or brackish wetland plants to repopulate the area, competition with more salt tolerant plants, and the period of recovery prior to another stressful inundation event or other site disturbances such as changes in runoff due to roads or levees.[89] Drought can be another source of saltwater intrusion, and can also result in rapid declines in the diversity of coastal wetland species and their ability to regenerate.[90]

Even in the absence of climate change, a variety of natural events, such as storm surge, hurricanes and drought, as well as human actions, such as dam construction, water diversions, and land use change, can bring saltwater into coastal freshwater and brackish wetlands, or reduce the amount of freshwater reaching these wetlands.[91] Aside from groundwater, input of water into wetlands can come from direct precipitation, stream flow, overbank flow from streams and rivers, surface runoff or tides.[92]

85 K. C. Haering and J. M. Galbraith, Department of Crop and Soil Environmental Sciences, Virginia Tech and D. Clearwater, Wetlands and Waterways Program, MDE, "Literature Review for Development of Maryland Wetland Monitoring Strategy: Background Information on Maryland's Wetland Types," Prepared for MDE, Wetland and Waterways Program, September 2009.

86 Ibid.

87 Elliot Campbell, Rachel Marks, and Christine Conn, Maryland Department of Natural Resources, "Accounting for Maryland's Ecosystem Services" Prepared for MD DNR, February 2017. [Online] Available: dnr.maryland.gov/ccs/Documents/AMESreportFinal_MDDNR.pdf, [Accessed: 29 October 2024]..

88 T.E. Dahl and S.M. Stedman, "Status and trends of wetlands in the coastal watersheds of the Conterminous United States 2004 to 2009," U.S. Department of the Interior, Fish and Wildlife Service and National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 2013.

89 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," ***Ecosystem Health and Sustainability***, 3(1):e01258, 2017 (cites Flynn et al 2015; McKee and Mendelssohn 1989).

90 Ibid. (cites Desantis et al. 2007).

91 Ibid.

92 K. C. Haering and J. M. Galbraith, Department of Crop and Soil Environmental Sciences, Virginia Tech and D. Clearwater, Wetlands and Waterways Program, MDE, "Literature Review for Development of Maryland Wetland Monitoring Strategy: Background Information on Maryland's Wetland

Another human action-- artificial drainage in the form of canals, ditches and drains are common in many counties-- increases the amount of land vulnerable to saltwater intrusion. By lowering the overall elevation of drained lands, and by creating large-scale hydrological effects as a result of rerouting water flows, artificial drainage can increase saltwater intrusion not only in areas adjacent to canals, ditches and drains, but also in nearby areas without artificial drainage.[93] A study in eastern North Carolina-- a coastal plain region similar to Maryland's Eastern Shore in elevation, saltwater proximity, and the extent of artificial drainages-- identified wetlands as the most vulnerable to saltwater intrusion among all land use types.[94]

On the other hand, a certain amount of coastal freshwater wetlands and coastal brackish wetlands will migrate landward over time as sea level rises: that is, as these wetlands disappear or transition to saltmarshes, as sea level rises, formerly dry land will become wet and will transition into new freshwater or brackish wetlands. For example, agricultural land has been shown to transition to wetland vegetation with increasing sea level rise and saltwater intrusions.[95]

## Threats, Concerns, and Impacts

Although certain existing wetlands will be lost due to saltwater intrusion, as sea level rises a certain amount of new freshwater and brackish wetlands will be gained (through wetland migration) and new saltmarsh will be created as well. The benefits of these new wetlands will partially offset impacts from the loss of existing wetlands.

The ability for wetlands to migrate depends on whether human-made barriers, such as bulkheads or berms, or impervious cover such as roads, prevent upland areas from becoming wet enough to support new freshwater or brackish wetlands. Small-scale, earthen levees are common landscape features and are poorly documented because they may have been installed and abandoned many generations ago. However, these features may have an outsized effect on the ability of marshes to migrate in the Chesapeake Bay region.[96]

Loss of freshwater and brackish wetlands may lead to a decline in the abundance and biodiversity of animal species within the Chesapeake Bay and Coastal Bays watersheds that depend on these wetlands, along with a decline in the abundance of plants that make up freshwater and brackish wetlands. For example, researchers identified fewer freshwater wetland-dependent fish species within portions of Blackwater National Wildlife Refuge impacted by sea level rise and saltwater intrusion. [97]

Saltwater intrusion also reduces the primary production of existing coastal freshwater wetlands; as salt stress and hydroperiods increase above plant species tolerances, above and belowground biomass of wetland plants decreases.[98] Less primary production leads to less accretion of wetland soils, which as sea level rises increases vulnerability to flooding and further saltwater intrusion.[99]

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Types," Prepared for MDE, Wetland and Waterways Program, September 2009.

93 Bhattachan, A, et al., "Evaluating the effects of land-use change and future climate change on vulnerability of coastal landscapes to saltwater intrusion," ***Elem Sci Anth***, 6: 62, 2018. [Online]. Available: doi.org/10.1525/elementa.316 or elementascience.org/articles/10.1525/elementa.316/. [Accessed 17 November 2019].

94 Ibid.

95 Gedan, K. B., Epanchin-Niell, R., and Qi, M., Rapid land cover change in a submerging coastal county, Wetlands, 40, 1717-1728, 2020; Mondal et al., The spread and cost of saltwater intrusion in the US Mid-Atlantic. *Nature Sustainability*, 6(11), 1352-1362, 2023; Epanchin-Niell, Rebecca S., Thompson, A., Han, X., Post, J., Miller, J., Newburn, D., Gedan, K., Tully, K., "Coastal agricultural land use response to sea level rise and saltwater intrusion," 2023 Annual Meeting, July 23-25, Washington D.C. 335970, Agricultural and Applied Economics Association, 2023. [Online] Available: https://ageconsearch.umn.edu/record/335970?ln=en, [Accessed: 29 October 2024].

96 Emily Hall, Grace D. Molino, Tyler C. Messerschmidt, and Matthew L. Kirwan. "Hidden levees: Small-scale flood defense on rural coasts". *Anthropocene*, Volume 44, December 2023.

97 Love, J.W., Gill, J. and Newhard, J.J, "Saltwater intrusion impacts fish diversity and distribution in the Blackwater River drainage (Chesapeake Bay watershed)," ***Wetlands***, 28: 967, 2008.

98 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," ***Ecosystem Health and Sustainability,*** 3(1):e01258, 2017 (cites McKee and Mendelssohn 1989, Neubauer 2011).

99 Zhu, C., Langley, J.A., Ziska, L.H., Cahoon, D.R. and Megonigal, J.P., Accelerated sea-level rise is suppressing CO2 stimulation of tidal marsh

Saltwater intrusion also alters biogeochemical cycles. For example, saltwater intrusion leads to increased desorption of inorganic nitrogen and phosphorus from wetland soils,[100] which can contribute to water quality problems. The effect of saltwater intrusion on methane and carbon dioxide emissions from wetlands needs to be studied further.[101] Also, although a typical effect of saltwater intrusion of wetlands is decreased carbon storage, the scientific community has not reached consensus on this issue;[102] a recent study shows that intrusion of alkaline saltwater may lead to increased carbon sequestration in freshwater wetlands.[103]

Note that recent research indicates that the freshwater-saltwater interface (saltwater wedge) appears to reverse around saltmarshes.[104]

# Additional Research

The following research (mapping, forecasting, monitoring) is recommended to adequately address the risk of saltwater intrusion to Maryland's wetlands:

## First Priority

**Periodically update how sea level rise and saltwater intrusion will change the types and amounts of wetlands in Maryland.** DNR completed an assessment in 2011 and 2019 of future wetland loss due to sea level rise using the Sea Level Affecting Marshes Model (SLAMM); see the Wetlands Adaptation to Sea Level Rise layers in the Maryland Coastal Atlas. The total loss and change in type of wetlands due to sea level rise or saltwater intrusion also should be reevaluated and the risk assessed. Lastly, the state could consider in future updates of the loss of wetlands due to sea level rise a similar and additive analysis on the loss and change in type of wetlands due to saltwater intrusion, and might want to consider alternative models to SLAMM for forecast comparisons, as well as whether marsh migration is or is not keeping up with sea level rise.[105] In the Blackwater 2100 plan, the SLAMM model was used to identify future changes in tidal wetland area and habitat type within Blackwater National Wildlife Refuge.[106] Other factors that might not be taken into account sufficiently by the SLAMM model could be considered as well: (e.g., understanding the relationship between saltwater intrusion and saltmarsh elevation change (saltmarsh accretion rate) is important, given that a lower rate of elevation change in tidal freshwater wetlands would mean they may more quickly become inundated due to sea level rise).[107]

**Identify priority existing wetlands at risk and adaptation actions.** Once vulnerable wetlands are identified, the state could update its 2009 study that prioritized which of Maryland's coastal wetlands to target for protection or restoration – see mde.maryland.gov/programs/Water/WetlandsandWaterways/AboutWetlands/Pages/prioritizingareas.aspx – incorporating new knowledge regarding ecosystem service values of particular areas in Maryland – see dnr.maryland.gov/ccs/Pages/Ecosystem-Services.aspx – and which of these wetlands may be

productivity: A 33-year study, *Science Advances*, 8(20), 2022.

100 Herbert, E. R., et al., "A global perspective on wetland salinization: ecological consequences of a growing threat to freshwater wetlands," ***Ecosphere***, 6(10):206, 2015. [Online]. Available: dx.doi.org/10.1890/ES14-00534.1. [Accessed: 17 November 2019].

101 Ibid.

102 Ibid.

103 Ardón, M. et al., "Drought and saltwater incursion synergistically reduce dissolved organic carbon export from coastal freshwater wetlands," ***Biogeochemistry***, 127: 411–426, 2016.

104 Hingst, M.C. et al., Beyond the Wedge: Impact of Tidal Streams on Salinization of Groundwater in a Coastal Aquifer Stressed by Pumping and Sea-Level Rise, *Water Resources Research*, Pre-Print.

105 Chen, Y., Kirwan, M.L. Climate-driven decoupling of wetland and upland biomass trends on the mid-Atlantic coast. *Nat. Geosci.*, 15, 913–918, 2022.

106 Lerner, J.A., et al., Blackwater 2100: A strategy for salt marsh persistence in an era of climate change, The Conservation Fund and Audubon MD-DC, 2013.

107 A. H. Baldwin, M. S. Kearney and J. C. Cornwell, University of Maryland, "Forecasting the response of tidal freshwater marshes to increasing salinity and higher tides due to sea level rise," Funded Projects, National Institute for Climatic Change Research Coastal Center at Tulane University.

able to migrate further inland (if migration corridors exist) or to be lost or transformed to saltmarsh. In addition, the Marshes for Tomorrow landscape-scale restoration plan will evaluate brackish wetlands and saltmarsh in the Delmarva Peninsula where restoration activities would improve persistence and habitat quality for saltmarsh sparrow and other marsh birds.

## Second Priority

**Determine the economic and environmental impact of the future landscape of wetland types and amounts in Maryland.** Although a certain amount of existing wetlands will be lost due to sea level rise or saltwater intrusion, new wetlands will be created. On the other hand, newly migrated wetland areas could differ in function than existing wetlands due to the speed that the landscape is changing and the character of adjacent upland land uses. The transition of agricultural lands that are at risk to saltwater intrusion can also support wetland migration. A forecast to determine the economic and environmental impact of the future landscape of wetlands in Maryland would be useful. Developing the forecast depends on understanding the impact of surficial groundwater use on Maryland's wetlands. If an aquifer is overused, this can lead to reduced delivery of freshwater to certain coastal wetlands, which can further increase saltwater impacts. Groundwater use in most wetland systems plays a larger role than sea level rise in driving saltwater intrusion;[108] whether this is the case in Maryland could be explored. If this is the case, then Maryland could explore the utility and impact of modifications to groundwater withdrawals from the surficial aquifer. Aside from groundwater, input of water into wetlands can come from direct precipitation, stream flow, overbank flow from streams and rivers, surface runoff or tides.[109]

For tidal wetlands, USGS has made available national and regional maps of tidal marshes' estimated lifespans, based on its extent of vegetated cover and open water, elevation, sediment supply, and predicted rate of sea-level rise, as part of the Coastal Hazard Mapper.[110]

## Third Priority

**Assess the impact of the future changes to Maryland's wetlands on state greenhouse gas mitigation and Chesapeake Bay restoration efforts.** According to a recent synthesis paper on salinization impacts on wetlands,[111] understanding the effects of saltwater intrusion on wetlands on carbon dioxide and methane emissions, and on the overall carbon balance of wetlands, will "require systematic investigations of multiple steps regulating organic matter breakdown." A 2011 Maryland study found that saltmarshes had significantly lower methane emissions than other wetlands, but higher and more variable methane emissions in brackish wetlands.[112] Also, the rate of loss of nitrogen and phosphorus from affected wetland soils, as well as from affected agricultural soils, due to saltwater intrusion, needs to be determined, in conjunction with the rate of uptake of these nutrients due to migrating wetlands and new saltmarsh. Once this is determined, modelers could determine how to best modify the Chesapeake Bay model to assess what type of nutrient loading change, if any, would occur.

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108 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," ***Ecosystem Health and Sustainability***, 3(1):e01258, 2017 (cites Ferguson and Gleeson 2012).

109 K. C. Haering and J. M. Galbraith, Department of Crop and Soil Environmental Sciences, Virginia Tech and D. Clearwater, Wetlands and Waterways Program, MDE, "Literature Review for Development of Maryland Wetland Monitoring Strategy: Background Information on Maryland's Wetland Types," Prepared for MDE, Wetland and Waterways Program, September 2009.

110 USGS Coastal Change Hazards Portal, [Online], Available: marine.usgs.gov/coastalchangehazardsportal/, [Accessed: 29 October 2024].

111 Herbert, E. R., et al., "A global perspective on wetland salinization: ecological consequences of a growing threat to freshwater wetlands," ***Ecosphere***, 6(10):206, 2015. [Online]. Available: dx.doi.org/10.1890/ES14-00534.1. [Accessed: 17 November 2019].

112 Poffenbarger, H.J., Needelman, B.A. and Megonigal, J.P., "Salinity Influence on Methane Emissions from Tidal Marshes," ***Wetlands***, 31: 831, 2011.

**Complete a study to inform the development of a Maryland wetland adaptation plan.** Given the many ecosystem services provided by coastal wetland: fisheries production, carbon sequestration, coastal erosion/shoreline stabilization, tourism and recreation, water quality, and biodiversity support,[113] and the few studies that have quantified how these services change, the state could develop a Maryland-specific study of how these wetland ecosystem services could change (or not change) as saltwater intrusion increases, and as coastal wetlands migrate, are lost, or are transformed, over time. This type of study can inform policymakers and resource managers regarding the best types and locations for wetland restoration and management projects.[114]

## Adaptation Measures

Until a forecast of the future landscape of wetland types and amounts in Maryland due to sea level rise and/or saltwater intrusion is completed, the state will not know which existing high priority freshwater or brackish wetlands are threatened, whether corridors exist to allow for sufficient migration of coastal wetlands, and whether the state should focus any of its efforts on protecting certain high priority wetlands as climate change impacts continue.

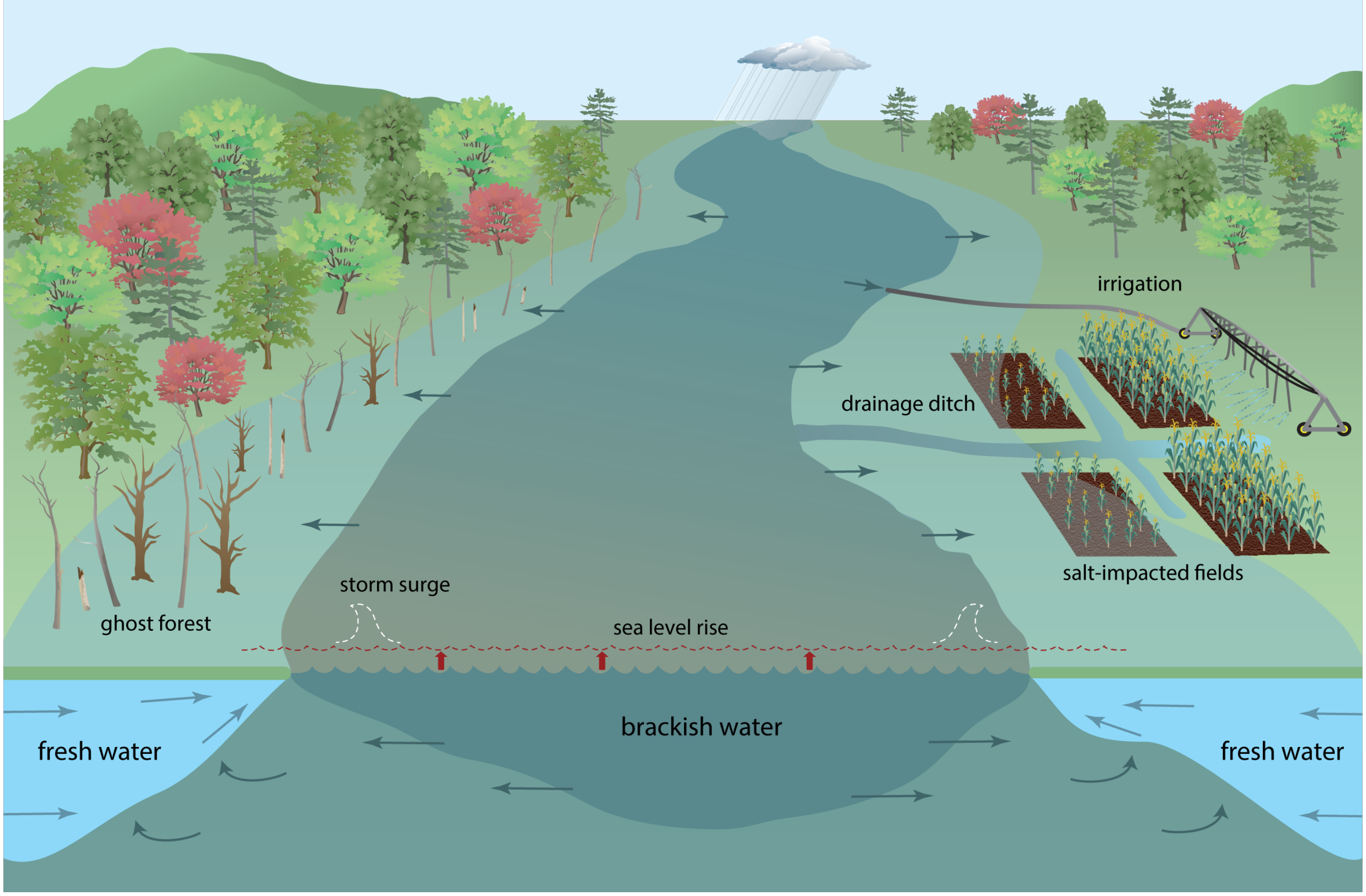
Ultimately a Maryland wetland adaptation plan, which includes identifying opportunities for the migration of coastal wetlands, and in some cases, measures to make high priority wetlands more resilient would be beneficial. Between 2022 and 2023, an interagency workgroup developed draft goals, policy and project ideas, along with a draft outline, of a Maryland wetland adaptation strategy. Work is continuing in 2024-2025 to draft the document. Appendix D discusses possible adaptation measures for protecting high priority wetlands in place.

***Photo courtesy of Chesapeake Bay Program***

113 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," ***Ecosystem Health and Sustainability***, 3(1):e01258, 2017 (cites Blair et al. 2015).

114 Ibid. (cites Rugai and Kassenga 2014).

Collectively, the increased salinity has already made some of Maryland's coastal farmland unusable, and is altering the ecological landscape of Maryland's wetlands and coastal forests.




***Source: UMCES-IAN***

# Coastal Forests

## Resource

The mid-Atlantic coastal forests stretch from the eastern shores of Maryland and Delaware to just south of the Georgia-South Carolina border. In Maryland, this region follows along the Atlantic Ocean, coastal bays, and Chesapeake Bay coastlines on the relatively flat lower Atlantic Coastal Plain and extends inland to the edge of the Piedmont. On the Eastern Shore of Maryland, prominent coastal forest features are wetland and riparian. Maryland is host to over 300,000 acres of forested wetlands, with most of these wetland areas located around the Chesapeake Bay and to the east.[115] In the southernmost counties, loblolly pine/shortleaf pine represent the most prevalent forest-type group,[116] and the majority of the state's loblolly pine (***Pinus taeda***) resource is found on the Eastern Shore.

Coastal forests are some of the most effective habitats for reducing flood impacts and risks to communities. These forests offer habitat for forest-dwelling species, protect drinking water, serve as buffers for rivers and bays against sedimentation and nutrient enrichment, and provide economic and other benefits.[117]

Seventeen percent of Maryland's forest lands are in wetland areas. The Lower Eastern Shore counties of Caroline, Dorchester, Wicomico, Worcester and Somerset are home to 61% of the forested wetland areas. Species composition is similar in Eastern Shore forested wetland and non-wetland areas: mainly red maple (***Acer rubrum***), American holly (***Ilex opaca***), black gum (***Nyssa sylvatica***) and loblolly pine; however, the relative dominance in terms of number of trees, is different. Black gum and loblolly pine are found in greater numbers within wetland areas since these species can grow in wetter environments and are more salt-tolerant than some of their competitors.[118] The Eastern Shore is also the northernmost limit for bald cypress (***Taxodium distichum***).

Seventy-two percent of Maryland's forest land is privately owned; private owners include individuals, families, corporations, and other private entities. The remaining 28% is in public ownership, with the largest public owner being the state of Maryland.[119]

Timber plays a significant role in Maryland's economy and the forestry industry has significant links to other industries. The forest products industry is the second largest employer on the Eastern Shore.[120] Healthy, managed forests are linked to a healthy and resilient Chesapeake Bay; forest land losses increase the potential for a detrimental effect on restoration efforts for the Chesapeake Bay. The loss of forest lands to saltwater intrusion places additional stress on the forestry industry.

## Drivers of Salinization

Over the past 100 years, sea levels have risen by 1 foot in Maryland, and under a Current Commitments scenario, the best estimate of sea level rise in 2100 is another 2.7 ft.[121] The natural ecosystem transition along the upward slope from the shore from saltmarsh to coastal forest that has evolved over time is being impacted by the sea level rise moving the high tide mark inland. This relatively quick sea level rise does not allow time for

115 USDA, U.S. Forest Service, Northern Research Station, "Maryland's Forests 2008," Resource Bulletin NRS-58, 2011.

116 USDA, U.S. Forest Service, "Forests of Maryland, 2016," Resource Update FS-136, 2017.

117 The Conservation Fund, "State of Chesapeake Forests," ed. Sprague, et al., 2006.

118 USDA, U.S. Forest Service, Northern Research Station, "Maryland's Forests 2008," Resource Bulletin NRS-58, 2011.

119 USDA, U.S. Forest Service, "Forests of Maryland, 2016," Resource Update FS-136, 2017.

120 USDA, U.S. Forest Service, "2016 Maryland Forest Health highlights," [Online]. Available: fs.usda.gov/foresthealth/docs/fhh/MD_FHH_2016.pdf. [Accessed 29 October 2024].

121 Boesch, D. F., et al, Sea-level Rise Projections for Maryland 2023. University of Maryland Center for Environmental Science, Cambridge, MD, 2023.

woody vegetation to migrate, and the coastal forest tree species that are not salt tolerant are being lost to the saltwater.

As saltwater intrusion and salinization works its way into these low lying forested lands through groundwater and surface flooding, as well as land subsidence, the health of the trees is impacted by the increased salinity and shoreline erosion. In some cases, the edge of the wooded land will be eroded and trees no longer able to stand will topple over; decomposing toppled trees and stumps can become new transitioning salt marshes. The conversion of forest into saltmarshes creates new wetlands that feed and shelter fish and shellfish; so, while one ecosystem is in decline, another is rising. In non-erodible areas, for comparatively salt tolerant tree species such as loblolly pine or red cedar (*Juniperus virginiana*), the impacts and decline in health may be slower while less salt tolerant species may decline quicker. Salt tolerant shrub species, such as Southern wax myrtle (*Morella cerifera*), may become much more common in the forest understory.[122]

The transition from forest to wetland can be highly uneven and dead standing trees can persist for decades. Depending on species, some may decompose while others are present for decades and result in a different wetland type.[123] Where soils have become inundated with saltwater, the tree root networks collapse and then drown, creating "ghost forests."

During storm events and spring tide cycles, salt water floods further inland into the coastal forest, infiltrating and saturating the soils, and increasing soil salinity. Like the case with agricultural fields, the network of ditches originally designed to provide drainage of the landscape is now working as conduits, providing channels for the saltwater to reach further inland.

## Threats, Concerns and Impacts

Due to saltwater intrusion, forests have converted to wetlands within the Chesapeake Bay watershed and the rate of conversion has increased over time.[124]

The 2022 Maryland Forest Health Survey (completed through aerial survey by the Forest Pest Management Unit of MDA) identified 84,831 acres of forest on the Lower Eastern Shore affected by saltwater intrusion; most of the affected acres, 60,575, were in Dorchester County. Assuming a conservative estimate of 200 trees per acre (a sparse forest), the number of affected trees is roughly 17 million. Some of the affected forests were identified far upstream of the Chesapeake Bay within tidal tributaries. The large majority of the mapped forests were either very severely or severely affected by saltwater intrusion. The data trend is increasing: 18,116 affected acres in the 2013 survey, 50,406 in 2016, 50,365 in 2020, and 84,831 in 2022.[125] Although these forests have not yet become saltmarshes, the survey identified different levels of damage to the tree canopy from very light to very severe. When the health of the coastal forest is weakened by saltwater intrusion, the wooded habitats are also more susceptible to infestations such as from the southern pine beetle.

The Eastern Shore of Maryland provides habitat for migratory birds and forest-dependent species that are considered "recovering species": Delmarva fox squirrel (***Sciurus niger cinereus***), American bald eagle (***Haliaeetus leucocephalus***), and the migrant peregrine falcon (***Falco peregrinus***). There are several Lower Eastern Shore wildlife refuges, including Blackwater National Wildlife Refuge, that were designated to protect these important

122 Sward et al., "Shrub expansion in maritime forest responding to sea level rise". *Frontiers in Forests and Global Change*, 6, 2023.

123 Erik Myers, The Conservation Fund, personal communication, September 2019.

124 Over the past 100 years, 100,000 acres of forest in the Chesapeake Bay watershed have converted to wetlands and the rate of coastal forest loss is four times greater now than it was during the 1930s. As communicated by Matthew Kirwan in "'Ghost forests': What they are and why they're becoming more common," CBS News, August 1, 2017. [Online]. Available: cbsnews.com/news/ghost-forests-what-they-are-why-theyre-becoming-more-common/. . [Accessed: 29 October 2024]. Also, see Kirwan, M.L., Gedan, K.B, Sea-level driven land conversion and the formation of ghost forests, Nat. Clim. Chang., 9, 450–457, 2019. [Online]. Available: doi.org/10.1038/s41558-019-0488-7 [Accessed: 29 October 2024].

125 USDA, U.S. Forest Service, "Maryland 2022 Forest Health highlights," [Online]. Available: https://www.fs.usda.gov/foresthealth/docs/fhh/MD_FHH_2022.pdf. [Accessed 14 September 2024].

ecosystems.[126] The visible signs of saltwater intrusion, "ghost forests" are easily recognized, especially around Dorchester County. Tree die off is also apparent in parts of Wicomico, Worcester and Somerset counties, although not as severe as Dorchester.[127]

Woodlands along some coastal areas of Maryland are failing to regrow because of increased flooding; this is occurring even when there are abundant seedlings and an open canopy, conditions that would generally result in woodland growth.[128] Tree species that are sensitive to the increased levels of salt tend to die back and are replaced by fewer native species and with more non-native species that are more salt tolerant. Invasive species such as ***Phragmites australis*** are an early colonizer of the "ghost forests," quickly becoming the dominant plant species and outcompeting other vegetation.[129] The invasive lineage of the common reed (*Phragmites australis*) expands across the landscape into the accommodation space formed by retreating coastal forests.[130] [131]

During colonial times, the forests on the Delmarva Peninsula were heavily harvested for timber and agriculture. Many of the lands that have regenerated into today's forests still show signs of human activity in the soil, where legacy nutrients from fertilizer applications are still detectable above natural concentrations. As these forest soils become intruded, excess nutrients may be unlocked from the soils and leach into adjacent waters[132] while carbon stored in soil and tree biomass is lost, much of it eventually ending up in the atmosphere.[133]

During rain events, stormwater runoff naturally drains and filters through these low-lying coastal forests; providing water storage. The coastal forests also protect upland areas from storm surges. As the condition of these ecosystems are degraded, the adjacent inland areas face higher risk of storm damage from coastal waters (the ability to buffer storm surges) as well as flooding from rain events.

# Additional Research

The following research (mapping, forecasting, monitoring) is recommended to adequately address the risk of saltwater intrusion to Maryland's coastal forests:

## First Priority

**Collect data on the degradation of coastal forests to help quantify the rate of increase in "ghost forests."** Partner with other organizations to identify appropriate techniques for managing the land to optimize woodland health; evaluate forest management for balance of forest services, wetland migration and other ecosystem services.[134]

**Continue to periodically conduct status and trends analyses** using existing land cover data to determine coastal forest conditions, identify historical changes and determine the rate of conversion from coastal forest to "ghost forest."

126 USDA, U.S. Forest Service, Northern Research Station, "Maryland's Forests 2008," Resource Bulletin NRS-58, 2011.

127 Matt Hurd, Maryland DNR Forest Service, personal communication, 16 January 16 2019.

128 T. Culbreth, et al., "Helping your woodland adapt to a changing climate," eds. T. Saxby, M. Griswold and C. Wicks [Online]. Available: ian.umces.edu/pdfs/ian_report_427.pdf. [Accessed 29 October 2024].

129 K. Tully, K. Gedan, R. Epanchin-Niell, et al., "The Invisible Flood: The Chemistry, Ecology, and Social Implications of Coastal Saltwater Intrusion," ***BioScience***, Volume 69, Issue 5, pp. 368–378, 2019.

130 Smith, J., "The role of Phragmites australis in mediating inland salt marsh migration in a mid-Atlantic estuary", PloS one, 8(5), 2013.

131 Shaw et al, "Environmental limits on the spread of invasive Phragmites australis into upland forests with marine transgression", Estuaries and Coasts, 45(2), pp.539-550, 2021.

132 D. Weissman, UMD, "Our Changing Chesapeake: Adapting agricultural lands to sea level rise and saltwater intrusion,"ESRI Story Map. [Online]. Available: storymaps.arcgis.com/stories/3d7859380ffa4bd08e7d5540bcf1870d, [Accessed: 29 October 2024].

133 Elliott Campbell, DNR, personal communication, 25 September 2019.

134 Proposed by Matt Hurd, DNR Forest Service.

**Develop a vulnerability index for forests prone to salinization.** Building upon the existing land cover change and trend analyses, develop a vulnerability index to assist property owners in determining management options and opportunities.

## Second Priority

**Identify and track the effects of salinization on forest health, building upon the Maryland Forest Health Survey.** Use high resolution imagery combined with cutting-edge automated feature extraction techniques to map tree canopy decline, assign mortality severity value to forest stands, and develop a web mapping decision support tool to provide quick and easy access to the information for resource managers, decision makers, and the public.[135] [136]

**Learn to differentiate sources of tree mortality, and investigate where multiple drivers of tree mortality may be interacting.** For example, where tidal freshwater forests are dominated by ash trees, they are being greatly affected in Maryland by the emerald ash borer outbreak,[137] and this effect can superficially resemble coastal retreat due to salinization. Because other stressors such as drought are known to make trees more susceptible to pest outbreaks, there are outstanding questions about the effect of saltwater intrusion on forests' susceptibility to pests such as the southern pine beetle.

**Use LiDAR to identify forest areas with berms (berms assist with restricting the inland surface flow of saltwater).** Assist landowners with identifying vulnerable forest lands and provide guidance on management decisions.

**Understand tradeoffs (environmental and economic) of different proactive and reactive responses to saltwater intrusion and salinization on forests by landowners.**

**Work with Critical Area staff to develop guidelines** for the removal of dead trees to support habitat for certain saltmarsh bird species (reduces predator threat)[138] and evaluate establishment of *Phragmites australis* in the transitioning habitat. Removal of live trees with the goal of marsh migration is not recommended; experimental trials resulted in high tree recruitment where live trees were felled, even in coastal forest edge areas that had been believed to be close to transition.[139]

## Third Priority

**Study the resilience of more biodiverse coastal forest stands to saltwater intrusion** to determine if modified forest management approaches could reduce the overall vulnerability of coastal forests to saltwater intrusion;[140] examine the consequences and tradeoffs of the different forest adaptation strategies for landowners and ecosystem services; and identify potential barriers to implementation.

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135 Currently being studied by Heather Disque, MDA Forest Pest Management.

136 Chen, Yaping, and Matthew L. Kirwan. "A phenology-and trend-based approach for accurate mapping of sea-level driven coastal forest retreat." *Remote Sensing of Environment*, 281: 113229, 2022.

137 Unpublished work by Andy Baldwin, UMD. Presentation to Maryland Native Plant Society.

138 Lerner, J.A., et al., "Blackwater 2100: A strategy for salt marsh persistence in an era of climate change," The Conservation Fund and Audubon MD-DC, 2013.

139 Walters et al. 2021. Experimental tree mortality does not induce marsh transgression in a Chesapeake Bay low-lying coastal forest. Frontiers in Marine Science, 8, p.782643.

140 K. Tully, K. Gedan, R. Epanchin-Niell, et al., "The Invisible Flood: The Chemistry, Ecology, and Social Implications of Coastal Saltwater Intrusion," ***BioScience***, Volume 69, Issue 5, pp. 368–378, 2019.

## Adaptation

Several adaptation measures are recommended for evaluation to assist coastal forests and forest landowners. Maryland's coastal zone comprises a rich mosaic of different habitats, including agricultural lands, coastal forests, salt marshes, brackish and freshwater wetlands, and extensive riparian corridors. This diverse habitat is important to the Chesapeake Bay and its spectrum of ecosystem services. The loss of coastal forest or reduction below minimum thresholds could have a significant impact on individual species and quality of life. To help ensure sufficient amounts and biodiversity of coastal forests, planning could be conducted to enhance existing efforts by agencies, nongovernmental organizations and landowners to evaluate the potential for migration or establishment of coastal forests and how the landscape ecology will be impacted by these changes. Ideally this would lead to strategic land conservation, which will allow coastal forest species to naturally migrate as conditions change.

In addition, state and/or nongovernmental organizations could provide additional education and assistance for landowners, including development of an outreach program.[141] Management options for landowners include monitoring high-water line marks and salinity levels, replacing dead trees with salt-tolerant shrubs and grasses, creating living shorelines, using natural stabilization techniques to protect shorelines and streambanks, and increasing the width of forest buffers along shorelines and streams.[142] To help landowners continue to generate income from the land as salinization occurs, assistance providers also could identify alternative uses for inundated forest land, such as promoting sika deer and duck hunting. Assistance providers also could encourage landowners who wish to harvest the timber from their lands to watch for signs of saltwater intrusion and plan the harvest before the quality of the timber is affected. Working with a licensed forester to develop and/or update their forest stewardship plan will provide guidance on the appropriate timing of the harvest.

***Photo courtesy of  Carlin Stiehl, Chesapeake Bay Program***

141 K. McClure and A. Kedmenecz. FS-2022-0645. May 2023. Losing Your Trees to the Sea? Options for Maryland's Coastal Woodland Owners. University of Maryland Extension and Maryland Sea Grant. [Online], Available: extension.umd.edu/resource/losing-your-trees-sea-fs-2022-0645/ [Accessed: 29 October 2024].

142 T. Culbreth, et al., "Helping your woodland adapt to a changing climate," eds. T. Saxby, M. Griswold and C. Wicks [Online]. Available: ian.umces.edu/pdfs/ian_report_427.pdf. [Accessed 29 October 2024].

# Infrastructure

## Resource

When considering the effects of saltwater intrusion and salinization, there are various forms of infrastructure that have the potential to be affected. The above ground infrastructure components such as roadways, bridges, and utility poles can be easily seen, but there are others, such as structural foundations, underground utility lines (electric, water, and internet), sewer pipes, septic systems, and water intake pipes for water supplies that are less visible. Saltwater intrusion and salinization damages the integrity of building materials through increased groundwater salinity. A multitude of building materials such as concrete, steel, and wood can be impacted by reducing their strength, stability and life expectancy as detailed in the Threats, Concerns and Impact section below.[143]

## Drivers of Salinization

As addressed in the previous chapters, saltwater is moving into the state's surface waters, soils, and various coastal habitats (wetlands and forests). Rising sea levels could expose more land along coasts and tidal tributaries to seawater, and therefore introduce additional risk of inundation and intrusion from above. Excessive groundwater pumping over many years allows lateral intrusion along the coast, which causes saltwater intrusion in freshwater surficial aquifers, where it can interact with coastal infrastructure.

As discussed in the Aquifers chapter, under the ocean floor and in some coastal areas of Maryland, there is a meeting point between salty groundwater and fresh groundwater. This meeting point is typically deeper landward because saltwater is denser and naturally pushes inward (although this saltwater wedge is reversed around saltmarshes).[144] This interface moves when groundwater levels drop or sea level rise occurs. Reduced fresh groundwater tips the interface "seesaw" and causes salty groundwater to move further inland.

This movement threatens the viability and lifespan of coastal infrastructure, even if they are not located directly on the water; however, at this time, there is limited data on where saltwater intrusion is occurring within Maryland's surficial aquifer. Improved surficial aquifer monitoring is necessary to assess the risk to coastal infrastructure from saltwater intrusion.

In addition, coastal flooding and rising tides due to sea level rise periodically bring salt onto the land, causing salinization. Infrastructure in close proximity to tidal waters would be impacted by this soil salinization.

**Research is needed to determine which coastal areas in Maryland have infrastructure that is vulnerable to the impacts of saltwater intrusion and salinization.**

143 Iqbal, W., et al. Assessment of Residential Construction due to Sea-Level Rise and Saltwater Intrusion, ASCE Inspire, 516–528, 2023.

144 Hingst, M.C. et al., Beyond the Wedge: Impact of Tidal Streams on Salinization of Groundwater in a Coastal Aquifer Stressed by Pumping and Sea-Level Rise, Water Resources Research, Pre-Print.

## Threats, Concerns and Impacts

While there is limited documentation available on the impact of saltwater intrusion or salinization on infrastructure, and even less that specifically address Maryland's infrastructure,[145] there are issues identified in other coastal jurisdictions that can be considered. With similar conditions, Maryland can learn from other coastal states. Specifically, Delaware has seen the effects of sea level rise and saltwater intrusion in recent years. Delaware is an especially low-lying state which makes it more vulnerable to the impacts of saltwater on its coastal infrastructure.[146]

### Impacts to Infrastructure

A vulnerability assessment was conducted in Slaughter Beach, Delaware to determine the risk of saltwater impacts from compound inundation effects combined with changes to hydrodynamic forces due to higher water levels over time. From this, the study concluded that more than 25 percent of coastal buildings exposed to seawater are vulnerable to structural issues in the future. The most vulnerable type of infrastructure was found to be single-family one-story residential buildings.[147] While not specifically identifying structures vulnerable to saltwater intrusion and salinization, this study can be used as a template to identify vulnerable structures in other low-lying coastal areas with similar attributes as Slaughter Beach.

Many homes on Maryland's Eastern Shore have crawl spaces underneath the home. A company on the Jersey Shore that specializes in crawl space installation and evaluation provides online information on the effects of saltwater on crawl space integrity. The high salt content in seawater can have deteriorating effects on metal and concrete, which compromises the structural integrity of crawl space foundations. These effects can cause rusted hinges, warped frames, and compromised seals. This leads to further issues within the home, such as foundation settling and cracks that facilitate moisture infiltration. Increased presence of moisture subsequently can lead to mold, mildew, wood rot, corrosion of electrical and plumbing systems, and compromised stability.[148] Although anecdotal, this highlights the need to investigate crawl space vulnerability to saltwater impacts.

Water with higher salt concentrations is more corrosive than freshwater, and deteriorates the material used to make water lines and pipes. Pipes made of metals are at higher risk because the salt promotes ionic interactions which lead to increased corrosion. In cities with older infrastructure, saltwater intrusion's corrosive effects on pipes can cause lead contamination in the freshwater supply. Even today, lead pipes are still in use and even those that do not have lead pipes often use lead solder. Residents are typically unaware that they have lead water lines, unless they have had tests conducted. This lack of awareness makes saltwater impacts to water lines especially harmful. This also has potential equity implications for communities.

There are certain conditions that cause pipeline failure from saltwater impacts. Environmental stress on pipe joints can cause cracking which must be immediately repaired in order to limit the impacts. Sudden drops in temperature during the winter months also lead to a reduction in pipe strength. When water in the pipe freezes, it causes pressure to increase and can lead to pipe bursts. The lifetime of iron pipes is currently between 80 and 100 years, but this can be significantly shortened due to the factors listed above.[149] The size of the pipe also determines the pressure it can tolerate. For example, pipes with smaller diameters have higher rates of corrosion and failure because of their thin walls. Corrosion is the main cause for pipe breaks.[150]

145 B. A. de Almeida and A. Mostafavi, "Resilience of Infrastructure Systems to Sea-Level Rise in Coastal Areas: Impacts, Adaptation Measures, and Implementation Challenges," Sustainability, MDPI, Open Access Journal, vol. 8(11), pages 1-28, November, 2016. [Online]. Available: mdpi.com/2071-1050/8/11/1115. [Accessed: 29 October 2024].

146 Iqbal, W., et al., Assessment of Residential Construction due to Sea-Level Rise and Saltwater Intrusion, ASCE Inspire, 516–528, 2023.

147 Ibid.

148 Jersey Shore Crawlspace Enhancement, Understanding the impact of saltwater intrusion on Crawlspace integrity, [Online], Available: www.jerseyshorecrawlspace.com/understanding-the-impact-of-saltwater-intrusion-on-crawlspace-integrity/, [Accessed: 29 October 2024].

149 Tansel, B., and Zhang, K., Effects of saltwater intrusion and sea level rise on aging and corrosion rates of iron pipes in water distribution and wastewater collection systems in coastal areas, 2022, [Online], Available: doi.org/10.1016/j.jenvman.2022.115153, [Accessed: 29 October 2024].

150 Ibid.

Facilities that draw from surface waters (e.g., water treatment plants, energy generating plants) also have the potential for corrosion of pipes and mechanical systems as the freshwater-saltwater interface of surface waters moves inland. If biological treatment of water is used at a facility, the increased salinity could kill the beneficial bacteria and make treatment less effective.[151]

Ft. Lauderdale, Florida, has been plagued with an abundance of sewer spills as a result of damaged water and sewage pipes. What makes this city especially vulnerable is the age of their pipes and low-lying elevation. A recent statistic shows that 45 percent of the city's pipes are older than 50 years. Saltwater intrusion is another factor. Between a quarter and a third of the city's pipes are made from materials that are at risk of corroding from saltwater. This includes cast iron and clay pipes. Most were installed before the shift to less corrosive materials was made in the area. Water transports sediment, which infiltrates pipes as they corrode and speeds up corrosion from the inside due to friction. One example of this occurred on December 10th, 2019, when a 54-inch pipe broke and was worn down to about an eighth of an inch thick on the bottom, while the top remained 6 times thicker. This resulted in 2.5 million gallons of sewage running through the streets of the Tarpon River neighborhood.[152]

President Biden issued a federal emergency for New Orleans's saltwater intrusion threat to its Mississippi River drinking water intakes in late September 2023. People living closest to the Gulf of Mexico near the Mississippi River Delta lost access to safe drinking water as early as June 2023, requiring officials to closely track the saltwater's encroachment upstream.

Officials were concerned about saltwater corroding the city's lead pipes and subsequent health impacts for the service area's more than 1.2 million residents. Luckily, an underwater levee or sill that helped block saltwater gave authorities more time to implement emergency measures.

Saltwater intrusion remains a concern for New Orleans. These impacts are also still being felt by many of the smaller, lower-income communities closer to the Gulf.[153]

This threat is becoming a reality, when the Mississippi River recorded its lowest water levels in 2022, and water levels in the Gulf of Mexico have been steadily increasing every year since the mid-20th century. Similar conditions have been observed in Miami, Houston, and other low lying cities along the East Coast. These examples highlight the potential damage from saltwater impacts in the future.

The subsurface utilities and structures that interact with sediment and water with increased salinity have the potential for accelerated degradation and corrosion. Both potable water and wastewater pipes are at risk of corrosion; a wastewater pipe failure could result in untreated wastewater being accidently diverted to a waterway and have major environmental impacts.[154]

151 A. Blumenau, et al., "Effects of Sea Level Rise on Water Treatment & Wastewater Treatment Facilities," student project sponsored by the Massachusetts Department of Environmental Protection, Worcester Polytechnic Institute, 2011. [Online]. Available: https://digital.wpi.edu/concern/student_works/ht24wj84r?locale=zh, [Accessed 29 October 2024].

152 Bryan, S. and Barszewski, L. "Bursting pipes keep plaguing Fort Lauderdale. Here's why it's happening — and more," South Florida Sun Sentinel, June 11, 2023, [Online], Available: www.sun-sentinel.com/2019/12/24/bursting-pipes-keep-plaguing-fort-lauderdale-heres-why-its-happening-and-more/ [Accessed: 29 October 2024].

153 Starling, M., Driehaus, E., and Sheth, A., New Orleans's Saltwater Intrusion Scare Is a Reminder of a Nationally Looming Threat, Sierra, October 31, 2023, October 31, [Online], Available: www.sierraclub.org/sierra/new-orleans-s-saltwater-intrusion-scare-reminder-nationally-looming-threat, [Accessed: 29 October 2024].

154 A. Blumenau, et al., "Effects of Sea Level Rise on Water Treatment & Wastewater Treatment Facilities," student project sponsored by the Massachusetts Department of Environmental Protection, Worcester Polytechnic Institute, 2011. [Online]. Available: https://digital.wpi.edu/concern/student_works/ht24wj84r?locale=zh, [Accessed 29 October 2024].

## Combined impact of sea level rise and salinity

Although this plan focuses on saltwater intrusion and salinization, when considering impacts to coastal infrastructure, Maryland should consider the impact of sea level rise in conjunction with salinity increases since they are directly linked. With the rising shallow surficial aquifer levels, the inundated soils will affect the ability of designed drainage systems to treat and infiltrate stormwater runoff and introduced salinity can impact stormwater treatment efficacy.[155] [156] Additionally, the increased groundwater inundation and higher groundwater elevation exerts uplifting forces on buried infrastructure,[157] increasing the risk of failure to the system. Finally, groundwater rise has the potential to mobilize and transport contaminants from hazardous waste sites, several of which are located in low-lying coastal areas on Maryland's Chesapeake Bay shores.[158]

# Additional Research

In 2019, a search of published literature and outreach to Maryland utilities resulted in limited documentation of saltwater intrusion and salinization risks to infrastructure.. In 2024, more information and research, although still limited, has been identified and reflected here. **Overall, research is needed to determine which coastal areas in Maryland have infrastructure that is vulnerable to the impacts of saltwater intrusion and soil salinization.** Also, additional research and outreach is recommended to identify any management plans that are already in place by local utilities and to eventually develop guidance. As identified in the examples noted above, saltwater impacts have the potential to reduce the lifespan of infrastructure such as roads, bridges, and buildings and additional data is needed to assist in the long term management and maintenance of impacted infrastructure.

## First Priority

**Determine which coastal areas in Maryland have infrastructure that is vulnerable to the impacts of saltwater intrusion and salinization.** A first step should be to fund a pilot surficial aquifer monitoring project for one or more areas of the Eastern Shore that are expected to be most at risk. Priority could be focused on underserved and/or overburdened communities.

**Identify vulnerable facilities that currently use surface waters based on their location in the watershed.** Whether used for water treatment, in manufacturing operations, cooling systems, etc., determine the potential of saltwater impacts to systems.

**Identify existing underground infrastructure within the coastal plain** (i.e., wells, natural gas, energy transmission lines, internet, wastewater and water systems). To set priorities, determine or estimate the building materials used and the age of the infrastructure.

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155 A, Behbahani, R. Ryan, E. McKenzie, Impacts of salinity on the dynamics of fine particles and their associated metals during stormwater management, Science of The Total Environment, Volume 777, 2021.

156 Sayers, P., C.L. Walsh, and R.J. Dawson, "Climate Impacts on flood and coastal erosion infrastructure," Infrastructure Asset Management, 2, 69-83, 2015.

157 Noi, L.V.T. and V. Nitivattananon, "Assessment of vulnerabilities to climate change for urban water and wastewater infrastructure management: case study in Don Nai river basin, Vietnam," Environ. Dev., 16 119-137, 2015.

158 K. Hill, et al., Rising coastal groundwater as a result of sea-level rise will influence contaminated coastal sites and underground infrastructure, ESS Open Archive, May 25, 2023.

## Second Priority

**Develop a risk map identifying projected saltwater/freshwater interface.** To assist with long range, maintenance and operational planning, develop a map tool indicating the landward limits of the interface within surficial aquifers and the particular areas along the coast and adjacent to tidal tributaries[159] most likely to have an infrastructure exposed to saltwater intrusion.

**Develop adaptation measures and guidance based on the identified vulnerable facilities and infrastructure.** From the list of identified vulnerable facilities and infrastructure, including open ditch drainage systems and septic systems, categorize the types of water used and develop a guidance document for operators, property owners and others based on the different water uses and infrastructure material.

## Third Priority

**Investigate building code opportunities** to include taking preventative measures against saltwater impacts which may include using different structural building materials, strategic design and pipe materials and technology, innovation and regulatory updates to support use of new infrastructure adaptations for homes to increase compatibility with saltwater impacts (e.g. small in-house systems for drinking water and sewage treatment; different home construction opportunities including current efforts to elevate houses). Discuss the risk reduction benefits of these measures with insurance companies.

**Identify what areas in Maryland are still using lead pipes and service lines**, and encourage homeowners to have their water tested for toxic traces of lead.

**Study life expectancies of building materials and potential health impacts of material degradation or failure.** Study the impact of salinization and alkalinization of freshwater concurrently.

# Adaptation

Research has been conducted over recent years to determine the best building material for coastal homes that are at high risk of being impacted by saltwater. Wood has proven to be an unreliable structural material because of its tendency to erode quickly, resulting in significant loss in strength as well as wood rot. This can be seen in coastal pilings that absorb saltwater and are left with salt crystals embedded in them after the water evaporates. As the wood expands and contracts due to thermal cycling, the crystals tear apart the wood fibers and cause the surface to mottle. For these reasons, the movement has been away from using wood for infrastructure.

Aluminum, on the other hand, has been seen more in coastal infrastructure due to its high strength, light weight, and abundant availability. Aluminum does have a tendency for galvanic corrosion, which is an electrochemical process that occurs between two metals. Sodium chloride can cause aluminum to corrode at the joint of the structure, which raises concerns for health and safety.

Fiberglass is also being used more in coastal environments because of its anti-corrosive properties. It does not absorb water, and therefore is minimally affected by wet conditions. Fiberglass is resistant to both galvanic and electrochemical corrosion, making it a suitable building material. It can also be used as an addition to existing structures to improve strength.

Steel is the most common choice for coastal infrastructure because it is more resistant to corrosion. However, even steel can deteriorate when constantly exposed to seawater.[160]

159 Hingst MC, McQuiggan RW, Peters CN, He C, Andres AS, Michael HA., Surface Water-Groundwater Connections as Pathways for Inland Salinization of Coastal Aquifers, Ground Water, Sep-Oct; 61(5):626-638, 2023.

160 Strongwell, The Effects of Seawater on 4 Different Structural Materials, [Online], Available: www.strongwell.com/news/effects-of-seawater-4-different-structural-materials/ [Accessed: 29 October 2024].

As previously mentioned, saltwater can cause structural damage to crawl spaces and basements in homes. To mitigate this, there are a few steps that homeowners can take to be prepared. There are preventative measures that can be installed such as vapor barriers and drainage systems to prevent the accumulation of moisture. Furthermore, sealing foundation cracks and reinforcing the home's structure can strengthen the foundation against saltwater. Routine evaluations can identify signs of saltwater so that maintenance can be done to address issues in a timely manner. Taking proactive measures is the best way to preserve the structural integrity of a property.[161]

Recommended near-term adaptation measures include educating coastal homeowners and other property owners on the potential damage caused to their infrastructure due to saltwater impacts and sea level rise. This may include routine inspections and repair plans. Experts could provide information on the estimated time before structural failure or damage would occur.

Since it can be costly to repair the damage done to property as well as the public infrastructure, the question is whether this damage will be covered by insurance. It is important to note that there is nothing in statute that requires the coverage of this type of damage. The answer to this question will depend on the particular insurance policy language as well as the circumstances surrounding the cause of the damage. As a general rule, most homeowners insurance policies limit their coverage of damage to instances of 'direct physical damage' to a covered property. As such the policyholder would likely need to have evidence that the saltwater in the water system was the direct cause of the damage to the pipes or plumbing. Even if the policyholder is able to show direct physical damage, many policies contain language that expressly excludes damage, which occurs as a result of 'corrosion' or discharge of 'pollutants'. Insurance carriers will likely argue that saltwater is a 'pollutant', and that the damage is a result of 'corrosion'. The policy language in commercial policies varies widely; therefore, business owners should consult with an insurance advisor to understand whether their policy will cover damage caused by saltwater impacts. At this time, the effect of implementation of adaptation measures on insurance policies is unknown.

***Photo credit: Greg Kahn/Grain***

161 Jersey Shore Crawlspace Enhancement, Understanding the impact of saltwater intrusion on Crawlspace integrity, [Online], Available: www.jerseyshorecrawlspace.com/understanding-the-impact-of-saltwater-intrusion-on-crawlspace-integrity/, [Accessed: 29 October 2024].

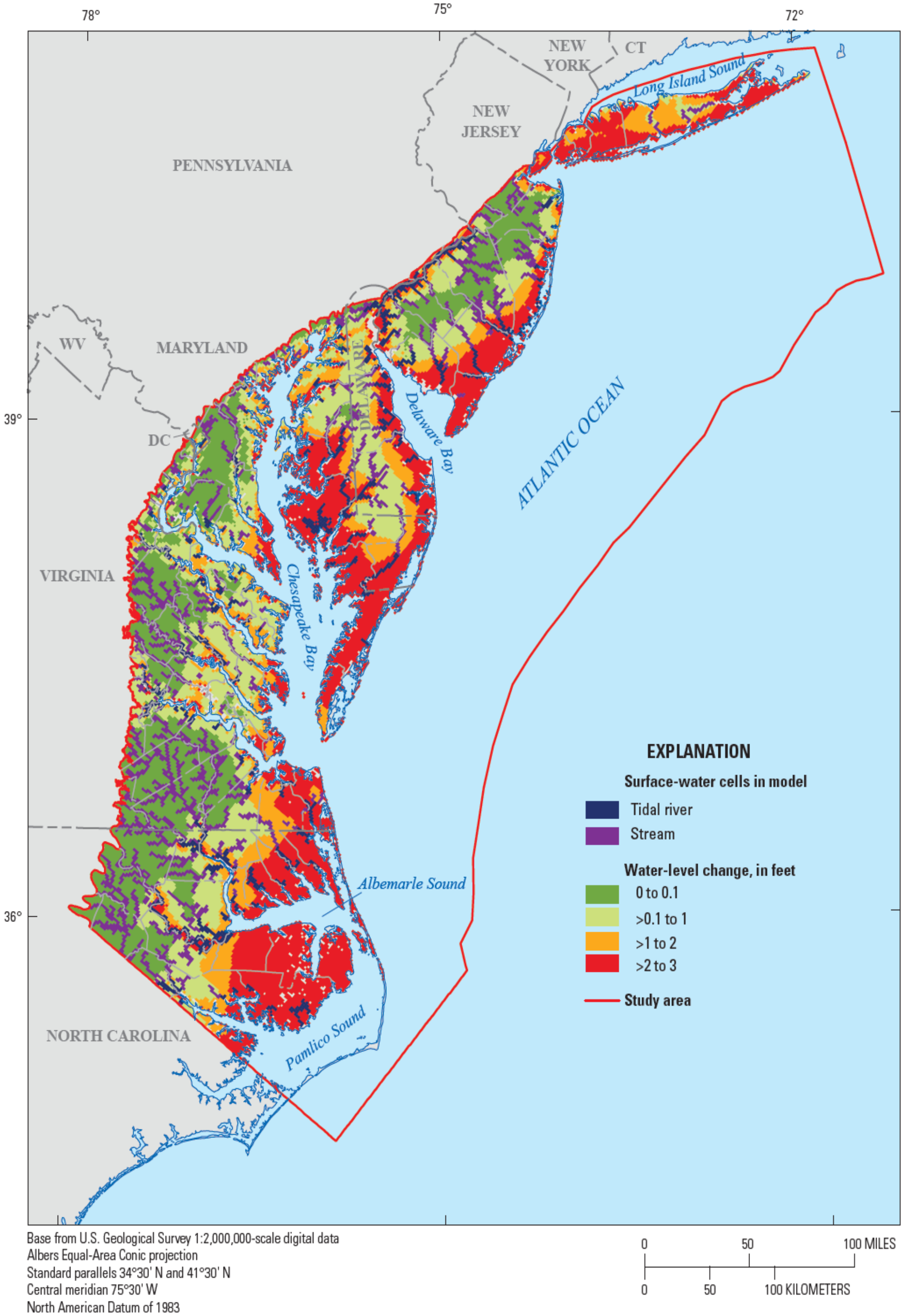


**Figure 4. Model-simulated increase in water levels in the surficial aquifer in response to a 3-foot increase (expected by 2100) in the current sea level position across the Northern Atlantic Coastal Plain aquifer system.[162]**

162 Masterson, J.P., et al., Assessment of groundwater availability in the Northern Atlantic Coastal Plain aquifer system from Long Island, New York, to North Carolina, USGS, Professional Paper 1829, 76 p., 2016. [Online]. Available: pubs.er.usgs.gov/publication/pp1829. [Accessed: 29 October 2024].

# Long Term Plan Implementation

As described in the 2020-2024 progress chapter, significant research and adaptation efforts have occurred to support implementation of this plan; however, most of the research recommendations from the 2019 plan have not been addressed.

Although the state agencies have an important role in investigating, implementing, and/or requiring the adaptation measures recommended in this plan, most of the research recommended in this plan would require a variety of institutions, including federal (e.g., National Science Foundation), state (e.g., University of Maryland Sea Grant, University of Maryland Agro-Ecology Center), and private (e.g., foundations), to provide sufficient financial support to university and government researchers.

Forming a permanent Salinity Resilience Network of researchers, grantmaking organizations, policy-makers, and others centered on investigating the research recommendations of this plan is necessary. Staffing of meetings of this network, along with periodic conferences to share results, determine needs, and identify next steps, should be carried out by a state agency, grantmaking organization, or university department whose mission encompasses the broad range of topics and issues covered by this plan.

The state agency workgroup that guided the development of this plan will continue to meet to coordinate state agency actions and to discuss its role in supporting the proposed Salinity Resilience Network. The workgroup will report to the Adaptation and Resiliency Working Group of the Maryland Commission on Climate Change and the Maryland Office of Resilience.

Models, monitoring and expertise across agencies could be shared to link saltwater intrusion and salinization to related coastal margin issues, such as wetland and forest migration corridors, agricultural sustainability, and stormwater management.

Different adaptation approaches will differ in their potential costs and benefits to landowners, as well as the expected returns to society.[163] The state could assess these and consult with constituents as it considers different adaptation approaches.

As improved data, modeling and forecasting become available regarding saltwater intrusion and salinization, the information could be integrated within existing technical assistance tools available from the state, such as the DNR Coastal Atlas (dnr.maryland.gov/ccs/coastalatlas/Pages/default.aspx).

Appendix A lists the different adaptation policies discussed in each chapter.

Appendix C lists additional adaptation policies occurring elsewhere within the nation and globally as of 2019. These policies could be assessed further.

163 K. Tully, K. Gedan, R. Epanchin-Niell, et al., “The Invisible Flood: The Chemistry, Ecology, and Social Implications of Coastal Saltwater Intrusion,” BioScience, Volume 69, Issue 5, pp. 368–378, 2019.

# Acronyms

**ARWG** – MCCC Adaptation and Resiliency Workgroup
**COMAR** – Code of Maryland Regulations
**DNR** – Maryland Department of Natural Resources
**EPA** – United States Environmental Protection Agency
**GWU** – George Washington University
**ha** - hectares
**IAN** – UMCES Integration and Application Network
**MCCC** – Maryland Commission on Climate Change
**MDA** – Maryland Department of Agriculture
**MDE** – Maryland Department of the Environment
**MGD** – million gallons per day
**mg/L** – milligrams per liter
**MGS** – Maryland Geological Survey
**PMT** – Phosphorus Management Tool
**ppt** – parts per thousand
**SIVI** – saltwater intrusion vulnerability index
**SLAMM** – Sea Level Affecting Marshes Model
**SMCL** – Secondary Maximum Contaminant Level
**STWG** – MCCC Scientific and Technical Workgroup
**SWI** – saltwater intrusion
**TDS** – total dissolved solids
**UMCES** – University of Maryland Center for Environmental Science
**UMD** – University of Maryland
**USDA** – United States Department of Agriculture
**USGS** – United States Geological Survey


***Photo credit: U.S. Fish and Wildlife Service, Northeast Region***

# Summary of adaptation policies discussed in the plan, and available technical and financial resources

## Adaptation Measures

Adaptation measures are actions that individuals, government, businesses, and nongovernmental organizations can implement to reduce the vulnerability or impact of climate change, including from saltwater intrusion and salinization, on resources and land types.

This plan identifies possible adaptation measures based on input from the state agency workgroup, subject matter experts, and stakeholders. Some adaptation measures are not yet available but are recommended now to address ongoing saltwater intrusion and salinization impacts, others are available now for implementation on an as-needed basis, while several could be explored further to determine their feasibility or utility in Maryland.

Overall, the state should pursue a reasonable response rather than a rush to regulate. Feedback and guidance should be gathered from stakeholders regarding innovative approaches and strengths and weaknesses of possible adaptation technologies, policies, programs, projects and plans, as well as the identification of possible roles for stakeholders in implementing likely adaptation measures.

## Adaptation measures incomplete or not yet happening but recommended now:

### Farmers/Agricultural Land

1) Develop a framework that compares federal and state programs (e.g. easements, federal Environmental Quality Incentives Program and wetland reserve programs, MDA Maryland Agricultural Water Quality Cost-Share) that facilitate land use transitions (e.g. to saltmarsh, or herbaceous buffers) for salt-impacted farmland and provide guidance for establishing and implementing the most appropriate practices
2) Establish additional education and assistance for farmers to address and prepare for salinization. Provide guidance on soil testing, crops and restoration species that may be more salt and inundation tolerant. Provide information about potential financial sources and technical support for restoration activities.
3) Promote the use of more sophisticated water control structures to prevent the inflow of saline waters into field drainage systems. Provide guidance on establishment of new drainage ditches to avoid creation of new conduits of saline waters.
4) Develop and maintain maps depicting the spatial extent of saltwater intrusion on farmlands to target intervention efforts.
5) Work with federal partners to allow crop insurance, or another mechanism, to compensate farmers for lands lost to saltwater intrusion.

### Wetlands

1) Develop a statewide wetland adaptation plan, which would include identifying opportunities for migration of coastal wetlands, and in some cases, measures to make high priority wetlands more resilient.

## Coastal Forests

1) Facilitate alternative uses for inundated forest land, such as promoting sika deer or duck hunting.
2) Establish additional education and assistance for forest landowners to address and prepare for salinization, including development of a landowners' outreach program.

## Infrastructure

1) Educate coastal homeowners and other property owners on the potential damage caused to their infrastructure due to saltwater intrusion, soil salinization, and sea level rise. This may include routine inspections and repair plans. Provide information on estimated time before structural failure or damage would occur.
2) It can be costly to repair damage to residential and public infrastructure, so it is necessary to work with insurance companies as well as the state government to investigate potential coverages. Facilitate conversations between local, county, and state government around coverages, adaptation solutions, and technical and financial assistance.

# Adaptation measures currently available:

## Aquifers

1) Continue to implement existing MDE regulations that limit saltwater contamination of freshwater supplies in coastal areas by ensuring that wells do not become a conduit for saltwater.
2) Shift water sources (e.g., to unaffected confined aquifers or surface waters) by adjusting water withdrawals from the existing water source or developing a balanced use of deeper aquifers.
3) Increase water treatment capabilities (desalinization, reverse osmosis, distillation, and deionization).
4) Request additional analysis and/or monitoring when permits are requested for water management strategy areas.
5) Consider water conservation measures when water withdrawal requests are evaluated.

## Farmers/Agricultural Land

1) Pursue federal subsidized crop insurance.
2) Planting of salt-tolerant crops (e.g., sorghum) that have marketability, but have a lower value than traditional crops (e.g., corn).
3) Consider alternative incentive programs (e.g., conservation easements, wetland programs, or revenue sources such as hunting leases) to financially support transitions out of agriculture when farming becomes unprofitable.

## Coastal Wetlands

1) Implement land management practices to facilitate wetland migration, including buffers, setbacks, invasive control, and seeding.

## Coastal Forests

1) Work with a licensed forester to develop and/or update Forest Stewardship Plans to obtain guidance on the appropriate timing of harvests.
2) Replace dead trees with salt-tolerant wetland species.

3) Increase the width of forest buffers along shorelines and streams.

## Adaptation measures that could be explored further to determine their feasibility or utility in Maryland:

### Aquifers and Surface Water Users

1) Apply proven, sound scientific approach to create a hydraulic barrier against saltwater intrusion.
2) Create recharge basins to replenish surficial aquifer with freshwater.

### Farmers/Agricultural Land

1) Continue to identify and then plant salt-tolerant crops (including table crops) that have market potential and develop markets as necessary to support crops that are more resilient. Advance federal incentives to plant salt-tolerant crops.
2) Tailor state-level incentive programs to salt-damaged lands that are financially competitive with collecting crop insurance but provide more environmental benefits (e.g., storm surge protection, improve water quality, store carbon).
3) Identify areas of salt-impacted farmland where cost-effective siting of solar facilities could occur.

### Infrastructure

1) Request that the Coast Smart Council consider protection of state investments from potential impacts of saltwater intrusion and salinization through updated construction guidelines and best practices for building roadways and structures.

***Photo credit: Jerry Jackson/Baltimore Sun***

## Technical and Financial Resources

Government agencies and some nongovernmental organizations have technical and/or financial resources to assist landowners, water suppliers, farmers, households and others in Maryland with responding to and planning for sea level rise and other hazards influenced by climate change. Some also have specialized knowledge and experience in dealing with saltwater intrusion and/or salinization. For additional information and assistance, please contact:

- U.S. Department of Agriculture, Climate Hubs- climatehubs.usda.gov/.
- U.S. Department of Agriculture, Natural Resources Conservation Service- nrcs.usda.gov/wps/portal/nrcs/site/national/home/
- National Oceanic and Atmospheric Association, Office of Coastal Management Digital Coast- coast.noaa.gov/digitalcoast/
- U.S. Environmental Protection Agency, Climate Change Adaptation Resource Center- epa.gov/arc-x
- Maryland Department of Agriculture- mda.maryland.gov
- Maryland Department of Natural Resources, Forest Service- dnr.maryland.gov/forests
- Maryland Department of Natural Resources, Chesapeake and Coastal Service- dnr.maryland.gov/ccs
- Maryland Department of the Environment, Climate Change Program- mde.maryland.gov/programs/Air/ClimateChange
- Maryland Department of Health, Environmental Health Bureau- phpa.health.maryland.gov/OEhfp/Pages/environmental.aspx
- Maryland Department of Planning- planning.maryland.gov
- Maryland Department of Transportation, Environmental Programs- www.mdot.maryland.gov/tso/Pages/Index.aspx?PageId=36
- University of Maryland Extension- extension.umd.edu/
- University of Maryland Sea Grant- mdsg.umd.edu
- University of Maryland Center for Environmental Science- umces.edu/
- University of Maryland College of Agriculture and Natural Resources, Plant Science & Landscape Architecture- psla.umd.edu/
- University of Maryland College of Agriculture and Natural Resources, Harry R. Hughes Center for Agro-Ecology- agnr.umd.edu/research/research-and-education-centers-locations/harry-r-hughes-center-agro-ecology/
- Local Soil Conservation Districts- mda.maryland.gov/resource_conservation/pages/technical_assistance.aspx
- County Health Departments- health.maryland.gov/Pages/departments.aspx
- Eastern Shore Land Conservancy- eslc.org
- The Nature Conservancy, Maryland/DC Chapter- www.nature.org/en-us/about-us/where-we-work/united-states/maryland-dc/

## Communication and Outreach

To ensure communities, farmers and landowners are aware of the threat of saltwater intrusion and salinization, as well as the availability of technical and financial resources, the state could develop a communications and outreach plan that makes use of existing avenues and programs, including the University of Maryland Extension, soil conservation districts, local environmental health departments, the University of Maryland Sea Grant, the Maryland Climate Leadership Academy, and the Education, Communication and Outreach Working Group of the Maryland Commission on Climate Change.

# Appendix B

## 2020-2024 Progress implementing the 2019 Plan

While developing the 2019 Plan, it was quickly realized there were many questions about saltwater intrusion and salinization but limited data and research was readily available. The 2019 Plan identified additional data and research needed to guide Maryland's response to the impacts of saltwater intrusion and salinization. Over the past five years, progress has been made in many areas but there is still more work to be done. The following highlights progress made by the many partners working on these issues.

### Aquifers

**2020**

- MGS began work in five coastal plain counties adjacent to the Bay to compile and assess chloride data (in groundwater) from federal, state, and county datasets.
- Hydraulic gradients for five confined aquifers surrounding the Chesapeake Bay were mapped using 2019 groundwater-level data.

**2023**

- MGS secured funding to compile and provide quality assurance of groundwater quality data from coastal plain counties and assess available federal groundwater quality data.

**2024**

- MGS designed a water quality database schema and compilation of federal datasets is in progress. Anticipated to be completed by the end of 2024.

**Ongoing 2020-2024**

- Coastal plain aquifer framework is being revised and enhanced by MGS with new data as part of an update to the Aquifer Information System (funded by MDE).
- Anne Arundel County initiated a pilot aquifer recharge program using potable water as a test. Although the project does not address saltwater intrusion directly, the findings could be considered in coastal areas where saltwater intrusion is an issue.
- Worcester County is actively managing for saltwater intrusion with treated wastewater by maximizing infiltration into surficial aquifers with increasing spray irrigation and infiltration tools.

### Surface Waters

**2021**

- To assist in identifying and cataloging ditches, Chesapeake Bay Program staff communicated that land cover datasets were being translated into three, 58-class, land use datasets using a variety of local (e.g., tax parcels) and regional (e.g., soils and roads) ancillary datasets. The development of hydrography data consisting of 1-meter resolution (1:2400-scale) fluvial features such as channels, gullies, and ditches were also being developed.

**2024**

- NSF grant awarded to team to develop SaltCast- a modeling tool to forecast salt concentrations in tidal rivers and estuaries from one day to several decades in advance. They are prototyping the tool in the Chesapeake Bay.

## Agriculture

**2020**

- Agricultural researchers in Maryland, D.C., Delaware and Virginia collaborated to develop and perfect methods for identifying areas of current and future salt-impacted farmland.
- DNR easement pilot project underway using a Wetland Adaptation Buffer and Coastal Resilience Management Plan, funded by Program Open Space.
- MDP facilitated and participated in discussions between DNR and University of Maryland researchers on possible components of coastal resiliency. MDP presented it to ARWG in November 2020 to gather feedback.
- MDP facilitated discussions among agricultural researchers and subject matter experts, sharing updates on current research projects and identifying opportunities to assist each other.

**2021**

- DNR obtained additional feedback on the easement pilot project using Mentimeter from the ARWG in February 2021. Discussions included finding opportunities for combining mitigation with the pilot project. DNR and MDE discussed the possibility of finding opportunities for combining mitigation with the pilot.
- MDA MACS program now funds up to 100% (no cost-share) wetland creation on farms.
- Maryland, D.C., and Delaware agricultural researchers held a stakeholder meeting with Eastern Shore farmers to share research updates and to gather feedback on current on-the-ground farming challenges.
- USDA Climate Hub finalized its Salinization on Working Lands manual.
- MDP facilitated discussion between University of Maryland and Maryland Sea Grant regarding survey efforts to farmers to identify responses to salt-impacted farmland.
- Several Maryland state agencies participated in U.S. Climate Alliance regional discussions with other states in the regions regarding how farmers are contending with salt-impacted land and whether they are creating barriers to wetland migration. Through these discussions, we learned that North Carolina farmers especially are making use of water control structures to combat salinization, but the technology does not seem applicable for Maryland's Eastern Shore.
- MDA MACS program now funds 100% (no cost-share) for water control. Also, counties are installing tidal-based weirs to control tidal flooding- some might help with this issue.

**2022**

- A short 10-week NASA DEVELOP project assessed Land Use Land Cover change over time to monitor marsh migration and loss of agricultural land. Forecasted Land Use Land Cover highlighted agricultural land at risk to the impacts of salinization. This project found St. Mary's, Somerset, and Dorchester counties were most at-risk to losing agricultural land to SWI.
- DNR began evaluating additional parcels for consideration for new coastal resiliency easements. DNR will continue to coordinate with MDA on these projects.
- Tully/Mondal/Miller/Gedan academic group were awarded a National Fish and Wildlife Foundation grant project in collaboration with the Hughes Center to evaluate native grass species ability in salt impacted fields to provide ecosystem services.
- Tully/Mondal/Miller/Gedan/Epanchin-Niell received Hughes Center Agro-Ecology grant funding to research agricultural at-risk areas, salinity distributions, and the timing of potential transitions, facilitating timely adaptation.

**2023**

- Maryland Sea Grant published a summary from their Coastal Farming Challenges virtual workshops.
- Preparation of "Climate Vulnerability of Maryland Agriculture" report was initiated at the University of Maryland, including a section on saltwater intrusion led by Epanchin-Niell.
- Mondal et al. published findings from research on remote sensing of salt patches on agricultural land,

including documentation of extent, change, and estimates of economic impacts.

- Epanchin-Niell et al. complete analysis of agricultural land use change in response to saltwater intrusion, including change crop choice and transition to wetland as adaptation options.

**2024**

- Salinity Affected Lands in Transition Conference held in Cambridge, MD in June. More than 180 participants attended from the mid-Atlantic and Southern US, representing academic institutions, state and federal agencies, non-profit organizations, private industry, and farmers. The conference shared research findings, highlighted case studies for salt-intruded lands, and facilitated networking among individuals to move toward building solutions for landowners and farmers operating in the coastal zone.
- Draft "Climate Vulnerability of Maryland Agriculture" report completed, which included estimates of current and predicted distributions of salt-affected agriculture in Maryland.
- MDA, in partnership with DNR and Dr. Tully, submitted a Regional Conservation Partnership Program grant request to USDA, inclusive of funding for engagement and land transition program development in Somerset County.

# Wetlands

**2020**

- U.S. Climate Alliance funded project indicates expected amounts of wetland loss versus potential for wetland migration, resulting in a net loss of wetlands, and where migration is expected to happen (or is expected to be blocked by other land uses).
- MDP facilitated discussion among subject matter experts at DNR and with the state agency saltwater intrusion workgroup to develop overarching goals. MDP presented the statewide wetland adaptation plan goals to the ARWG in November 2020 to gather feedback.

**2021**

- DNR obtained guidance from the ARWG in February regarding necessary components for a statewide wetland adaptation plan using Mentimeter from the ARWG in February 2021.
- DNR Ecological Effects of Sea Level Rise research project continued and will inform the plan.
- Chesapeake Bay Program Climate Resiliency Workgroup obtained Goal Implementation Team funding for a Marsh Adaptation Workshop, to be developed.

**2022**

- DNR Ecological Effects of Sea Level Rise grant project resulted in an updated SLAMM forecast.
- USGS released updated unvegetated to vegetated ratio analysis for Chesapeake Bay. This index is indicative of marsh stability and helps to identify vulnerable marshes that could benefit from restoration. It is being integrated in the March Protection index update.
- DNR in collaboration with George Mason University and The Nature Conservancy, released an updated model using data through 2019. The new model predicts the future location and size of wetlands resulting from sea level rise. Using this model, DNR initiated a revision of its wetland adaptation layer within the DNR Coastal Atlas (2050 and 2100, possibly 2070 wetland extent) using a sea level rise scenario that follows the recent state sea-level rise guidance document. DNR ranked (high, medium, low) the wetland adaptation areas based on the size of wetlands, ecological importance of the areas, persistence of the wetlands, uplands to be converted, soil type, green infrastructure areas, etc. Eleven new data layers are now available on the Coastal Atlas. DNR also used the model results to begin updating its Marsh Protection Index.
- The Chesapeake Bay Program released a Wetlands Action Plan for the watershed, with Maryland state agencies contributing an appendix for Maryland. The Maryland Plan summarizes existing initiatives in the state and suggests further actions to help the state reach the goals laid out in the Chesapeake Bay Agreement Wetlands Outcome.

- The Nature Conservancy MD/DC are developing a suite of land protection tools to promote coastal adaptation known as the [Resilient Protection Frameworks]. These include portable Coastal Resilience Easements language, a template to develop Coastal Resilience Management Plans, an Incentivizing Action Plan to fund and institutionalize Coastal Resilience Easements and Coastal Resilience Management Plans and landowner/practitioner social science research to better understand the human dimensions of marsh migration and landscape transition under climate change.

**2022-2023**

- A subteam of the state agency saltwater intrusion team implemented an MCCC recommendation to identify existing, revised, or new policies and programs that would facilitate successful wetland migration over time. The subteam completed an outline for a draft Maryland wetland adaptation strategy. Results were presented and discussed with the MCCC ARWG.
- Marshes for Tomorrow project is developed and initiated. The project will evaluate brackish wetlands and saltmarsh in the Delmarva Peninsula where restoration activities would improve persistence and habitat quality for saltmarsh sparrow and other marsh birds.

**2024**

- EPA awarded a Climate Pollution Reduction Grant to the Atlantic Conservation Coalition (North Carolina, South Carolina, Maryland, and Virginia) and The Nature Conservancy to leverage the carbon sequestration power of natural and working lands. In Maryland, grant funds will be used for afforestration, agroforestry, and improved forest management, as well as practices to protect, restore, and support the migration of coastal marshes. Marsh practices will include marsh restoration, living shorelines, tidal connectivity restoration, and the development and implementation of Coastal Resilience Management Plans on private properties with conservation easements.
- In 2024, the General Assembly amended Maryland's Critical Area law to require the Critical Area Commission to assess and adapt the Critical Area for climate resiliency. Climate resiliency is defined to include wetland migration, among other impacts. The Commission will be developing regulations to carry out these new requirements, which will also be incorporated into local Critical Area Programs. These new regulations will allow for protection of wetland migration corridors through buffers and setbacks, transfer of development rights or similar conservation strategies, planting or related management strategies, and other land use planning principles. Regulations will be initially promulgated in 2026.

**Ongoing**

- Beneficial reuse projects like Poplar Island to improve near-term resiliency of wetlands and vulnerable coastlines.

## Coastal Forests

**2021**

- Maryland DNR provided support to Morgan State University Patuxent Environmental & Aquatic Research Laboratory social scientists to explore recreational hunting management preferences, and regional economic impacts related to sika deer on Maryland's Eastern Shore. The survey targeted resident and non-resident sika deer hunters in the 2021-2022 hunting season to generate information about hunter preferences, behaviors, and spending in Maryland.
- USDA Climate Hub finalized its Salinization on Working Lands manual.

**2023**

- Morgan State University Patuxent Environmental & Aquatic Research Laboratory published survey findings focusing on hunter acceptance of regulations, hunter preferences and willingness to pay associated with sika deer hunting and hunter trip expenditures.
- UMD Extension developed a fact sheet for coastal woodland landowners concerned about saltwater intrusion Losing Your Trees to the Sea? Options for Maryland's Coastal Woodland Owners.

- Eastern Shore Land Conservancy hosted a Forest Resiliency workshop that included state resources, data, mapping, planning tools, and guidance materials to support forest land resilience.

**2024**

- The United States Forest Service released the Coastal Ghost Forest Mapping Project- Regions 8 and 9 story map and data layers, displaying ghost forests along the east coast of the United States, including over 40,000 acres on Maryland's Eastern Shore.

**Ongoing**

- MDA Forest Pest Management periodically conducts aerial surveys to identify salt-impacted coastal forests. The findings are included on the USDA Southeast Climate Hub's Coastal Ghost Forest Mapping Project dashboard.

## Infrastructure

**2023**

- In February, EPA awarded funding to a team of researchers to study septic tank failures due to sea-level rise and saltwater intrusion in coastal areas of Maryland.

**Ongoing**

- MDE permitting database and mapping tool incorporates wetland and waterway records of all the natural gas energy transmission, water, etc. that are located under wetlands, Wetlands and Waterways Permits Interactive Search Portal.

# Appendix C

## Additional adaptation policies occurring elsewhere within the nation and globally

The following are research findings in support of Maryland's saltwater intrusion plan from Danielle Naundorf, while an intern with the Harry R. Hughes Center for Agro-Ecology in 2019, regarding adaptation policies occurring outside of Maryland in response to saltwater intrusion and salinization.

### Introduction

Saltwater intrusion (SWI) is an imminent issue affecting Maryland's long term economic outcomes and the quality of life for its residents. By looking at tactics adopted by other states and countries, there may be lessons learned for Maryland to take the necessary steps to mitigate against this issue. This document is organized by the six main resources impacted – aquifers, agriculture, wetlands, coastal forests, aquatic species, and infrastructure.

### Aquifers

#### Policy

One of the most common forms of mitigation included creating policy restrictions and innovations that attempt to control the amount of pumping from wells near coasts, and moderate water withdrawals. This has already been done to some extent in Maryland. An example is Kent Island, where the amount of withdrawal permits is fixed.

Innovative solutions have included creating "zoning" areas as done in Georgia where it allows for a more nuanced policy approach depending on different sub-regions.[164] This could be useful in Maryland for allowing for more localized restrictions depending on the particular aquifer from which water is being drawn. Potential unintended consequences include communities feeling unfairly targeted, or reduced development in those regions most affected.

In 2014, Soquel Creek, California declared a groundwater emergency largely due to SWI.[165] Because of this, the community began relocating wells away from the coast, and prompted an extensive study to assess the feasibility of artificial recharge.

Creating partnerships between government agencies, nonprofits, and citizen groups can help push mitigation efforts forward. For example, in 2009 the Pajaro Valley Water Management Agency worked with the city of Watsonville to open a water recycling plant in California. Also in California, "Pure Water Monterey" is a partnership between Monterey Regional Water Pollution Control Agency and the Monterey Peninsula to produce recycled water from industrial wastewater, farm drainage, and stormwater.[166]

164 *Draft Coastal Georgia Water and Wastewater Permitting Plan for Managing Salt Water Intrusion*

165 *Here Comes the Sea: The struggle to Keep the Ocean out of California's Coastal Aquifers - Brett Walton, 8/23/15*

166 *Here Comes the Sea: The struggle to Keep the Ocean out of California's Coastal Aquifers - Brett Walton, 8/23/15*

In 2014, California passed the Sustainable Groundwater Management Act, which requires the state to take action. Even in areas where policy required action, it could take upwards of 15 years to implement a real program.[167]

**Artificial Recharge**

As is well documented, when the pumping rate exceeds natural recharge rate of aquifers, the

incidence of SWI increases. An option to counteract SWI is to introduce artificial recharge.

Some options include injecting freshwater or extracting saltwater, or a combination of both.

This technique was supported by multiple sources.[168] This would allow residents to continue using existing land and wells. Maryland would need to do an assessment of what the costs would be compared to the benefits; however, this generally seems like a more affordable and sustainable option than using reverse osmosis or desalination.

**Alternative Water Sources**

Using alternative water sources was frequently cited as a tool that states like California, and countries such as China and the Netherlands have used to decrease the pressure on aquifers. Examples include collecting rainwater, building pipelines to transport water from less stressed aquifers, and recycling used water. An example of this being done is Hilton Head Public Service District building a pipeline to the mainland in 1999 to bring water to the island.[169]

**Relocation or Redesign of Wells**

Wells contributing to SWI can be removed and installed in another location to reduce the impact. It is also suggested that horizontal wells may be more efficient than vertical wells when paired with freshwater injection or saltwater extraction.[170]

**Physical Barriers**

Physical barriers are one of the most invasive methods of reducing the impact of saltwater intrusion. These barriers can be used to retain groundwater and inhibit SWI, and are notably used in Japan. In Italy, there were instances of using gypsum to create a physical barrier.[171] This does not seem to be a likely or recommended solution for addressing SWI.

167 *California Groundwater Law Tests State's Capacity to Oversee a Vital Resource - Brett Walton 8/16/15*

168 *Mitigation of Seawater Intrusion by Pumping Brackish Water - Mohsen M. Sherif and Khaled I. Hamza, 2001 USGS. Ground-Water Resources for the Future - Atlantic Coastal Zone. US Geological Survey Fact Sheet 085-00;2000. Mitigating Saltwater Advance Using Horizontal Wells: Risk Based Comparison of Different Approaches - D. Labregere, J. P. Delhomme and A. Priestley, 2006*
*Cost-Effective Method to Control Seawater Intrusion in Coastal Aquifers - Hany F. Abd-Elhamid, Akbar A. Javadi, 2010*

169 *USGS. Ground-Water Resources for the Future - Atlantic Coastal Zone. US Geological Survey Fact Sheet 085-00;2000.*
*Here Comes the Sea: The struggle to Keep the Ocean out of California's Coastal Aquifers - Brett Walton, 8/23/15*
*Overdraft and Saltwater Intrusion Strain the Floridan Aquifer - Brett Walton, 11/5/2010*
*Saltwater Intrusion and agriculture: A Comparative Study between the Netherlands and China - Yuxin Duan, 2016*
*Effect of Salinity Intrusion on Food Crops, Livestock, and Fish Species at Kalapara Coastal Belt in Bangladesh - Alam et al, 2017*
*Restore or Retreat? Saltwater Intrusion and Water Management in Coastal Wetlands - White and Caplan 2017*

170 *Mitigating Saltwater Advance Using Horizontal Wells: Risk Based Comparison of Different Approaches - D. Labregere, J. P. Delhomme and A. Priestley, 2006*

171 *Saltwater Intrusion and agriculture: A Comparative Study between the Netherlands and China - Yuxin Duan, 2016*

# Agriculture

### Salt Tolerant Crops

SWI affects crops by increasing the salinity and changing the nutrient composition in the soil. This issue can be addressed by growing more salt tolerant crops, such as sorghum. The Eastern Shore crop market developed alongside the poultry industry, which may make alternative crops less appealing. Some crops that have been highlighted from the Netherlands as salt- tolerant include potato, seakale, strawberry, and seaweed.[172]

### Desalination Plants/ Water Reuse

Desalination plants allow water that is contaminated with salt to have the salt removed and reused. Desalination has been explored in Ocean City, Maryland but it is expensive, which may limit its viability.

There are other options for water reuse that were discussed in the aquifer section above. Opportunities such as water reuse by taking industrial water or water from large cities and repurposing it for agriculture irrigation, may be a viable solution to address increases in SWI due to water demands for irrigation.

There have also been examples for how rainwater harvest has been used in China to supplement irrigation needs. It is unclear how helpful this would be in Maryland on a wide scale.

### Genetically Modified Crops

In Vietnam, there have been experiments with genetically modifying rice to be more salt- tolerant.[173]

# Wetlands

### Controlled Conversion to Wetlands

Mitigation strategies for dealing with SWI in agricultural or residential areas often may be a controlled conversion to wetlands. That is, accepting that the land use will have to change and facilitating this conversion in the healthiest possible way.

Generally, addressing the issues that can exacerbate SWI, like overpumping and climate change, will work towards improving wetlands.

### Coastal Forests

Like wetlands, there were not many transferable lessons from other states or countries, but some general mitigation strategies may help protect coastal forests.

### Tidal Wetlands

Conversion of land to tidal wetlands may protect coastal forests from erosion and flooding. During more serious storm events, tidal wetlands can act as a buffer and protect coastal forests from being inundated with water containing high levels of salt. However, saltwater inundation is sometimes discussed separately from saltwater intrusion.

### Physical Barriers

As discussed above, physical barriers can be used to reduce the impact of SWI. Barriers are invasive, but could be a viable solution to protect the most vulnerable coastal forests.

### Aquatic Species

There were no recommendations found that directly addressed aquatic species. A more expansive literature review may find additional results.

### Infrastructure

172 *Saltwater Intrusion and agriculture: A Comparative Study between the Netherlands and China - Yuxin Duan, 2016*

173 *Saltwater Intrusion and agriculture: A Comparative Study between the Netherlands and China - Yuxin Duan, 2016*

*Adaptation in Construction*

Saltwater can be incredibly damaging to infrastructure due to the corrosive effects of salt.

It is suggested to build various coastal defenses like putting houses on stilts, and raising bridges and roads. There are also salt-tolerant concrete options that could be used for building more resilient infrastructure.[174] Utilizing more salt-tolerant building materials is an obvious recommendation Maryland can pursue to mitigate against SWI damage.

174 *Sea-Level Rise and its Impact on Wetlands, Water, Agriculture, Fisheries, Aquaculture, Public Health, Displacement, Infrastructure and Adaptation - Golam Kibria 2016*

# Appendix D

## More details about existing saltwater intrusion in aquifers and potential users at risk

Documented instances of saltwater intrusion into Maryland aquifers (both surficial and confined) have occurred in Anne Arundel, Charles, Harford, Dorchester, Queen Anne's, Somerset, and St. Mary's counties and Baltimore and Ocean cities (Table 1).

**Table 1. Areas of documented saltwater intrusion in Maryland's coastal plain.****

| Location | Aquifer(s) | Status | Monitoring Activity | Nature of Intrusion | Reference |
|---|---|---|---|---|---|
| Annapolis Neck/ Mayo Peninsula (Anne Arundel County) | Aquia | Relatively stable interface | Sampled in 1988-90 and 2005; Mayo Peninsula sampled in 2018 | Near shore unconfined | Fleck, et. al., 1996; Gemperline, et. al., 2018 |
| Baltimore Harbor (Baltimore City) | Patapsco, Patuxent | Unknown | None | Pumping induced through paleochannel in confining layer in Baltimore Harbor and near shore unconfined | Chapelle and Kean, 1985; Atkinson, et. al., 1986) |
| Indian Head (Charles County) | Patapsco | Unknown | None | Pumping induced through paleochannel in confining layer in Potomac River and near shore unconfined | Hiortdahl, 1997 |
| Kent Island (Queen Anne's County) | Aquia | Trend lines remain stable with a mixture of no change, increasing, and slightly decreasing chloride concentrations | Monitored every five years (pre-2016 every year) | Pumping induced through paleochannel in confining layer beneath Chesapeake Bay | Drummond, 1988; Periodic unpublished reports |

| Location | Aquifer(s) | Status | Monitoring Activity | Nature of Intrusion | Reference |
|---|---|---|---|---|---|
| Ocean City | Ocean City, Manokin | Relatively stable to some increase in chloride concentration. General increase in chloride concentrations over time; however, chloride levels are treated to below secondary standards in water provided by the Town. | Monitored frequently | Upconing from deeper strata. Pumping induced from Atlantic Ocean | Achmad and Wilson, 1983; Achmad and Bolton, 2012 |
| Western Somerset County | Manokin | Unknown | None | Unflushed salty water from subcrop beneath Chesapeake Bay; possible pumping induced | Werkheiser, 1990 |

**** Miller et al. (EPA 660/2-74-056, 1974, Ground Water Contamination In The Northeast States) listed Dorchester, Harford and St. Mary's counties as having areas of documented saltwater intrusion; however, information regarding the aquifers impacted, monitoring activity, the nature of intrusion, and the status of the issue are all unknown.**

Additionally, in Anne Arundel County, high levels of chlorides are also widespread throughout the deeper portion of the Aquia aquifer in Arnold, Annapolis, Riva, Edgewater, Mayo, Galesville, West River, Shadyside, Churchton, and Deale. High chloride levels affect the shallower portion of the Magothy Aquifer in Arnold, Annapolis, and Edgewater.[175]

Of the following water suppliers who make use of the surficial aquifer, MGS has periodically raised concerns about potential saltwater intrusion into the Chestertown water supply; however, the most recent county well report does not indicate that this is currently an issue.[176] The following water supplies are not necessarily at risk of saltwater intrusion; however, given that they make use of the surficial aquifer, more focused study of these supplies (e.g., identifying hydraulic gradients) would be helpful.

175 Bill Dehn, Anne Arundel County Department of Health, personal communication, 27 June 2019

176 Drummond, D.D., "Hydrogeology, simulation of ground-water flow, and ground-water quality of the upper coastal plain aquifers in Kent County, Maryland," MGS, Report of Investigations 68, 1998. [Online]. Available: mgs.md.gov/publications/report_pages/RI_68.html. [Accessed: 29 October 2024]; Overbeck, R.M., Slaughter, T.H., and Hulme, A.E., "The water resources of Cecil, Kent and Queen Anne's Counties," Bulletin 21, 1958. [Online]. Available: mgs.md.gov/publications/report_pages/BULL_21.html. [Accessed: 29 October 2024]

**Table 2. County and Municipal Water Suppliers in Maryland that rely on surficial aquifer water sources for at least part of their needs**

| Water Supplier | Surficial aquifer water source description |
|---|---|
| City of Salisbury | Salisbury has two well fields (Paleochannel and Park well fields).<br>The City maintains a weir across the South Prong of the Wicomico River at Route 12 (Snow Hill Road). The City's Park wells are located adjacent to the ponded South Prong upstream of the weir. This weir elevation is about 3.3 ft above mean sea level. The weir separates the tidal water downstream from the freshwater in the South Prong of the Wicomico River and ensures that the water in the pond is fresh. The weir protects the City's Park well field from tidal influences.<br>The Paleochannel well field uses a significant amount of water from the surficial aquifer, but is not at risk from saltwater intrusion due to the distance from tidal waters. |
| Chestertown | Chestertown uses the Aquia aquifer (which is unconfined in Chestertown) and also the Magothy aquifer. The well field is less than 1,000 feet from the Chester River. Historically, the Aquia aquifer has experienced problems with saltwater intrusion from the Chester River; however, utilization of the deeper, confined Magothy aquifer has helped to manage the problem. |
| Fruitland | The Town of Fruitland maintains a well field in the surficial aquifer adjacent to Morris Mill Pond at South Division Street. |
| Hurlock | The Town of Hurlock maintains a well field in the surficial aquifer. |
| Sharptown | The Town of Sharptown maintains a well field in the surficial aquifer. Wells are more than 1,500 feet from the Nanticoke River. |
| Vienna | The Town of Vienna maintains a well field in the surficial aquifer. Wells are about 3,000 feet from the Nanticoke River. |
| Worcester County (Ocean Pines) | Worcester County provides water to the Community of Ocean Pines from the surficial aquifer. Wells are about 3,000 feet from the Shingle Landing Prong of the Saint Martins River. |
| Town of Berlin | The Town of Berlin maintains a well field in the surficial aquifer. |
| Worcester County (Briddletown) | Worcester County provides water to the community of Briddletown from the surficial aquifer. Wells are about a mile east of Berlin. |
| Worcester County (Mystic Harbor) | Worcester County provides water to the community of Mystic Harbor from the Pocomoke aquifer, which at that location may be hydraulically connected to the surficial aquifer. Wells are about 3,500 feet from the Coastal Bays. |

The following statistics provide a sense of Marylanders' use of the surficial aquifer compared to other, less vulnerable water supplies. The statistics, however, do not provide any indication at this time of how many of these water users are at risk.

In 2011, approximately 110 million gallons per day (MGD) of the surficial aquifer were permitted for use:[177] about 28 MGD in Dorchester County, and about 25, 24 and 20 MGD by Wicomico, Caroline and Worcester counties.[178] The majority of the water withdrawn from the surficial aquifer is used for seasonal irrigation of farmland on Maryland's Eastern Shore, although the surficial aquifer also is used by a number of Eastern Shore municipalities and many households using private wells.[179]

About 210,000 Maryland households in the coastal plain (of about 2.2 million households in Maryland as of 2015) rely on their own private water supply,[180] either from the surficial aquifer (Eastern Shore) or confined aquifers (Southern Maryland).

Few of Maryland's aquifers are likely to be predominantly salty;[181] however, the last regional analysis and mapping of the extent of salty groundwater in Maryland's coastal plain aquifers was completed in 1989.[182] Subsequently, USGS conducted a regional assessment of the extent of saltwater intrusion in the Northern Atlantic Coastal Plain using data and published interpretations of chloride concentrations available since the previous 1989 study.[183] More localized mapping of saltwater intrusion in specific aquifers within certain locations has also been conducted over the past decades by MGS and USGS.

Note: The surficial lowland aquifer in southern Maryland was used historically to a very limited extent for domestic supply,[184] but it is not used much for water supply today. Its use today is likely almost non-existent.

177 Andreasen, D.C., Staley, A.W., and Achmad, G., Maryland Coastal Plain Aquifer Information System: Hydrogeologic framework, Maryland Geological Survey, Open-File Report 12-02-20, 121 p., 2013.

178 Ibid.

179 Ibid.

180 Maupin, M.A., et al., "Estimated use of water in the United States in 2010," USGS, Circular 1405, 56 p., 2014. [Online]. Available: pubs.usgs.gov/circ/1405/. [Accessed 29 October 2024].

181 Andreasen, D.C., Staley, A.W., and Achmad, G., Maryland Coastal Plain Aquifer Information System: Hydrogeologic framework, Maryland Geological Survey, Open-File Report 12-02-20, 121 p., 2013.

182 Meisler, H., "Occurrence and geochemistry of salty ground water in the northern Atlantic Coastal Plain," USGS, Professional Paper 1404-D, 51 p., 1989.

183 Charles, E.G., "Regional chloride distribution in the Northern Atlantic Coastal Plain aquifer system from Long Island, New York, to North Carolina," USGS, Scientific Investigations Report 2016–5034, 37 p., appendixes, 2016. [Online]. Available: pubs.er.usgs.gov/publication/sir20165034. [Accessed: 29 October 2024].

184 Otton, E.G., Ground-water resources of the Southern Maryland Coastal Plain, MGS, Bulletin 15, 347 p., 1955.



# Adaptation measures for protecting high priority wetlands in place

Adaptation measures are feasible in many situations where freshwater or brackish wetlands are impacted by saltwater intrusion, including proactive water management or wetlands restoration.[185]

Some wetland adaptation measures are not likely to be applicable to Maryland. For example, dams in Maryland generally are used to either generate power or to create a reservoir for drinking water. As a result, no additional freshwater flows could be gained through modified dam management activities.[186] Providing for additional freshwater flows to wetlands, for example, through modifying dam management activities, is an adaptation measure that is feasible for combating salinization of wetlands in other regions.[187] That said, other methods for increasing freshwater flows to vulnerable wetlands or for maximizing recharge of aquifers underlying vulnerable wetlands could be examined. Examples of these methods include engineered structures, restoration projects, and improving soil health;[188] however, some of these methods also can have unwanted ecological impacts.

Some adaptation measures might not provide sufficient benefit: for example, when considering the amount of time a particular area of wetland can be protected before eventual inundation by sea level rise compared to the cost. To illustrate this point, Blackwater National Wildlife Refuge installed a weir in 2007 to reduce saltwater flow into a portion of the refuge. The installation of the weir was completed to support fish communities dependent on freshwater wetlands by limiting saltwater intrusion (due to an existing canal).[189] However, the approach of weir installation or similar measures to block saltwater intrusion occurring due to existing canals, culverts or tide gates within the refuge is not a part of the Blackwater 2100 plan, the most recent Blackwater National Wildlife Refuge plan to address forecasted climate change impacts, in part because almost all of the refuge's existing wetlands are expected to be inundated by sea level rise by 2100, making such measures ultimately ineffective.[190]

In another example where the costs might be higher than the benefits- at least at a larger, regional scale-- the use of water control structures within ditches might be too expensive to install and maintain within every ditch in areas with extensive drainage networks, such as the Lower Eastern Shore, in order to control saltwater intrusion. Also, water control structures, and particularly one-way flap gates, when overtopped with coastal saltwater during severe coastal storms may then in turn impede drainage of that saltwater.[191] On the other hand, more sophisticated water control structures might be an important adaptation measure to at least protect the

185 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," *Ecosystem Health and Sustainability*, 3(1):e01258, 2017.

186 Bruce Michael, personal communication, 26 March 2019.

187 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," *Ecosystem Health and Sustainability*, 3(1):e01258, 2017.

188 Ibid

189 Final Programmatic Report. Blackwater River Wetland, Fisheries, and Watershed Restoration. #2005-0001-042. February 2008. Prepared by: John W. Gill, U.S. Fish and Wildlife Service Maryland Fishery Resources Office, Annapolis, MD, and Joseph W. Love and Joshua Newhard, University of Maryland Eastern Shore, Department of Natural Sciences, Princess Anne, MD. Prepared for: Friends of Blackwater National Wildlife Refuge, Inc.

190 Daniel Strain, The Future of Blackwater, Come High Water: Sea Level Rise and Chesapeake Bay, Chesapeake Quarterly, October 2014, vol. 13, no. 2 & 3, Maryland Sea Grant, [Online], Available: www.chesapeakequarterly.net/sealevel/main6/, [Accessed: 29 October 2024].

191 Bhattachan, A, et al., "Evaluating the effects of land-use change and future climate change on vulnerability of coastal landscapes to saltwater intrusion," Elem Sci Anth, 6: 62, 2018. [Online]. Available: doi.org/10.1525/elementa.316 or elementascience.org/articles/10.1525/elementa.316/. [Accessed 29 October 2024].

most vulnerable ecosystems to saltwater intrusion.[192]

Thin sediment layer placement to increase wetland surface elevation and fill in eroded portions of wetlands can be a helpful adaptation measure depending on the potential for inundation by sea level rise and the resource value of the wetland.[193] Gaining a better understanding of Maryland's sediment load balance and wetland health/condition (including internal ponding) would help the state estimate the likelihood of wetlands requiring this type of intervention.

Maryland might also want to establish a plan that outlines wetland adaptation actions to pursue following a hurricane or other severe storm. If certain vulnerable coastal freshwater and brackish wetlands in Maryland are unlikely to recover naturally after significant saltwater flooding, the state might want to take proactive measures (e.g., wetland plantings) to facilitate that recovery.[194]

The value of a particular wetland adaptation measure depends on the costs and benefits, including the amount of time available before the wetland will be inundated by sea level rise, the resource value of the targeted wetland, and the likelihood of the value of the wetland being replaced through coastal wetland migration or transformation into saltmarsh. This means that sea level rise forecasts will impact decision-making regarding the value of a particular wetland adaptation measure. As sea level rise forecasts change, wetland adaptation plans should be revisited.

192 Ibid.

193 Lerner, J.A., et al., Blackwater 2100: A strategy for salt marsh persistence in an era of climate change, The Conservation Fund and Audubon MD-DC, 2013.

194 White E., and D. Kaplan, "Restore or retreat? Saltwater intrusion and water management in coastal wetlands," *Ecosystem Health and Sustainability*, 3(1):e01258, 2017.

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Publication Number: 2024-104

December 2024