Shallow Groundwater Response to Sea-Level Rise

Alameda, Marin, San Francisco, and San Mateo Counties

Photo: Kristina Hill

California Resilience Challenge 2020 Grant Program | Final grant report submitted to the Bay Area Council

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CALIFORNIA RESILIENCE CHALLENGE

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Acknowledgements

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Thank you to the Advisory Committee, which is composed of representatives from local and regional governments. Members of the advisory committee were instrumental in securing grant funding and providing assistance and feedback to the study team throughout the project. Thank you to all the staff in local governments throughout the four counties who dedicated time to collecting geotechnical reports to support this effort. In addition, we would like to thank the city and county staff that supported the ground truthing efforts to help inform and improve the existing conditions groundwater mapping.

Lastly, we would like to thank Dr. Marcus Griswold, who spearheaded the organization of the Bay Area Groundwater and Sea-Level Rise Workshop in 2019 that raised awareness of the critical need to fill this data gap in sea-level rise adaptation planning.

Executive Summary

The response of shallow groundwater to sea-level rise is a relatively new field of study. For low-lying coastal communities, sea-level rise adaptation efforts must consider the potential for groundwater rise to avoid maladaptation. The need to better understand this slow and chronic threat was identified as a critical data gap in the San Francisco Bay Area's adaptation efforts during a 2019 regional workshop. The consensus in 2019 was that a better understanding of groundwater rise can inform the development of more effective and comprehensive sea-level rise adaptation strategies, especially in low-lying, vulnerable communities subject to flooding from multiple sources.

With funding from the California Resilience Challenge, Pathways Climate Institute LLC and the San Francisco Estuary Institute-Aquatic Science Center gathered and analyzed multiple data sets and collaborated with city and county partners to analyze and map the existing "highest annual" shallow groundwater table and its likely response to future sea-level rise. This effort covers the San Francisco Bay side of four counties (Alameda, Marin, San Francisco, San Mateo). An advisory committee composed of city and county representatives provided essential support by gathering data and reviewing depth-to-groundwater maps. Additional academic and agency advisors participated in project team meetings and informed project direction. This effort produced the following publicly available data and online tools to support adaptation efforts:

- Existing and future condition depth to groundwater GIS data available for download.
- A StoryMap providing background information and graphical representations of the processes and impacts of groundwater rise.
- Web maps showing: (1) existing depth to groundwater; and (2) a comparison of the extent of emergent groundwater to the extent of coastal flooding under various sea-level rise scenarios.

An interpolation-based Geographic Information Systems (GIS) model was used to map the existing highest annual shallow groundwater surface. The model relies on observed depth-to-groundwater measurements, tidal water levels in San Francisco Bay and tidally influenced tributaries, and measured, modeled, or estimated water levels in upstream tributary reaches and managed lagoons and water bodies. Future condition modeling assumes a one-to-one relationship between sea-level rise and groundwater rise, a best estimate in the absence of more advanced modeling accounting for differences in subsurface geology and groundwater flow.

The groundwater maps developed in this study provide a key data source for adaptation planners to use in addressing key adaptation challenges. Groundwater rise will contribute to inland flooding in low-lying coastal communities, with impacts often occurring earlier, and farther inland, than coastal flooding from overtopping of the Bay shoreline (Befus et al., 2020; Bosserelle et al., 2022; Plane et al., 2019; Rahimi et al., 2020). Rising groundwater can also degrade underground infrastructure, mobilize contaminants, and increase liquefaction hazards.

In addition to producing datasets and guidance for use by local governments and other stakeholders, the project team convened a workshop with over 100 attendees in August 2022 to kickstart adaptation planning conversations. Overall, this effort represented a major step forward for the San Francisco Bay region in understanding projected groundwater rise and addressing the adaptation challenge.

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Key Personnel

San Francisco Estuary Institute - Aquatic Science Center:

- Ellen Plane, Environmental Scientist: ellenp@sfei.org (Grant Manager)
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Pathways Climate Institute

- Christine “Kris” May, CEO and Principal: kris.may@pathwaysclimate.com
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- Kristina Hill, Director of the Institute for Urban and Regional Development: kzhill@berkeley.edu

Problem Statement

The significance of rising groundwater and groundwater inundation may create the need to reevaluate sea-level rise driven flooding in some communities to develop effective flood risk reduction strategies (Habel et al., 2020). Failing to account for groundwater rise on the landward side of some flood risk reduction structures (e.g., levees and seawalls) could result in maladaptation if the community continues to flood from below. Strategies that break the connection between coastal and inland groundwater (e.g., cutoff walls), could limit inland groundwater rise due to sea-level rise, while exacerbating inland groundwater rise due to extreme precipitation and preventing the natural coastal outmigration of groundwater.

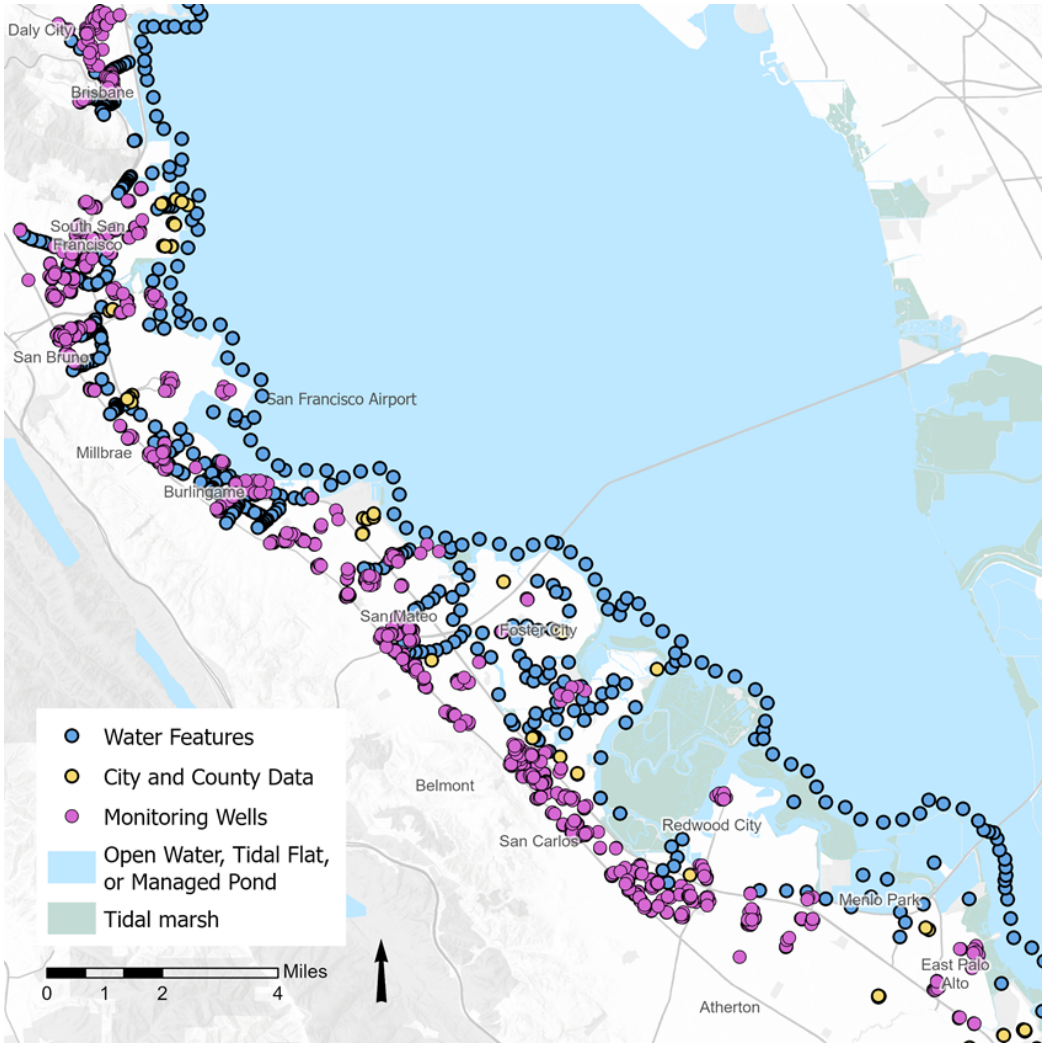
Scientific advances and an understanding of hydrogeology should be integral to coastal zone management and adaptation. In most coastal cities, including the San Francisco Bay region, better projections of future flooding from multiple sources, including groundwater rise, are needed to develop comprehensive adaptation strategies. Addressing the compounding challenges in low-lying coastal areas will require interdisciplinary collaboration, open communication among scientists, decision makers, and the public, bolstered by strong partnerships with policymakers (Michael et al., 2017).

Project Description

This study mapped the existing shallow groundwater table and projected the rise of the groundwater table in response to sea-level rise. The methods build upon previous efforts to map the shallow groundwater table, including the rapid assessment of potential shallow and emergent groundwater hotspots in the Bay Area (Plane et al., 2017, 2019) and the subsequent efforts for the Cities of Alameda and Palo Alto (May et al., 2020; Pathways, 2022).

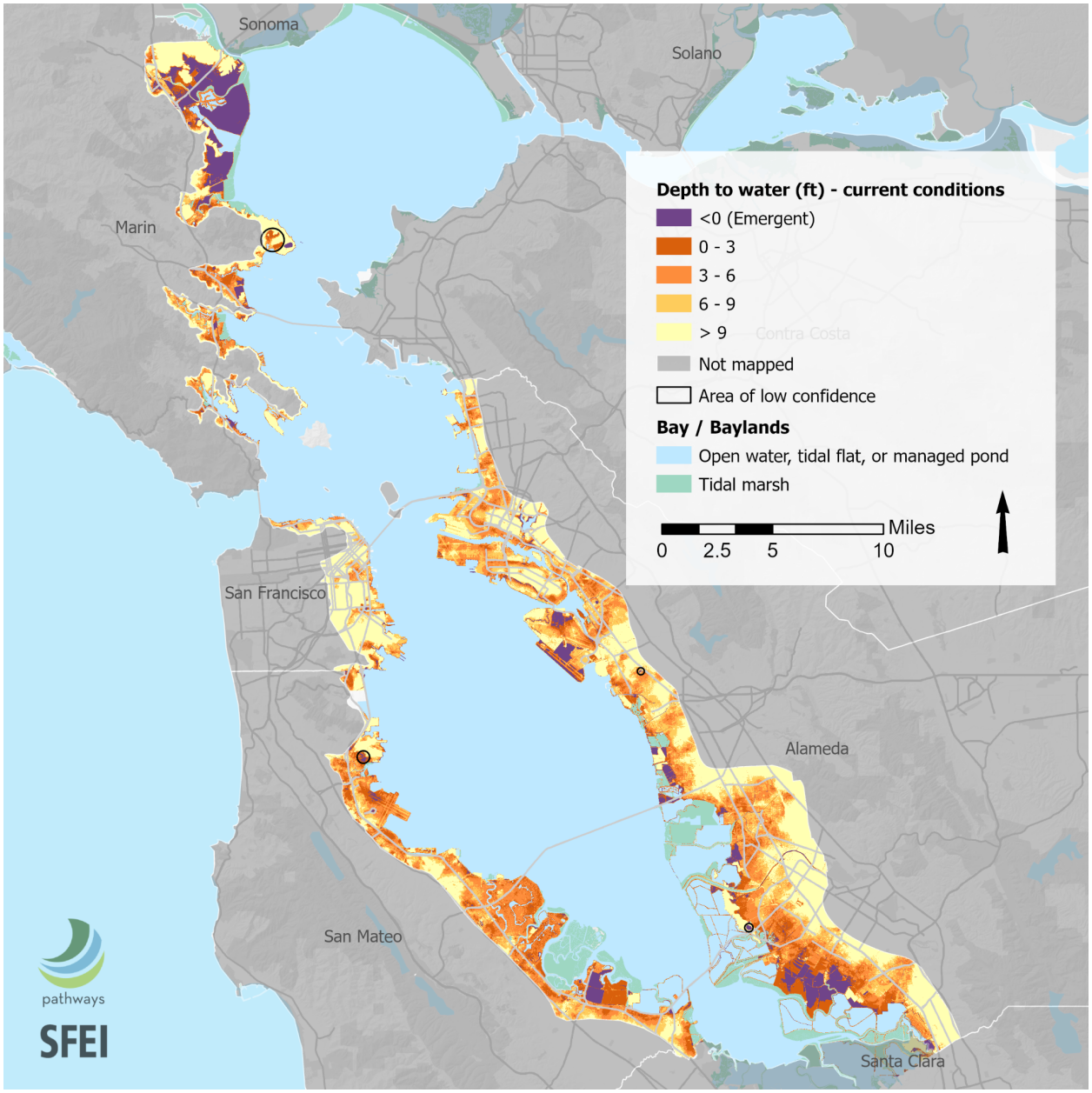
The existing shallow groundwater table was characterized using the following data sources:

- State Water Resources Control Board monitoring well observations
- Geotechnical reports with soil boring logs provided by city and county partners and collected from state agency databases
- San Francisco Bay tidal datums
- Water surface elevations in tributaries and managed ponds and lagoons



Data points compiled to map shallow groundwater in San Mateo County.

Using an interpolation technique in ArcGIS, the data sets described above were transformed into an approximation of the highest annual groundwater table (conditions during a wet winter after rainfall raises groundwater elevations). The groundwater surface was reviewed for irregularities and inconsistencies by the project team and city and county partners. Following the development of the existing conditions layers, the team developed layers approximating future conditions with sea-level rise under 10 different scenarios. The team also furnished additional overlay analyses to augment future-conditions projections.



Existing conditions depth to water map. This layer is the baseline used to create the future conditions maps.

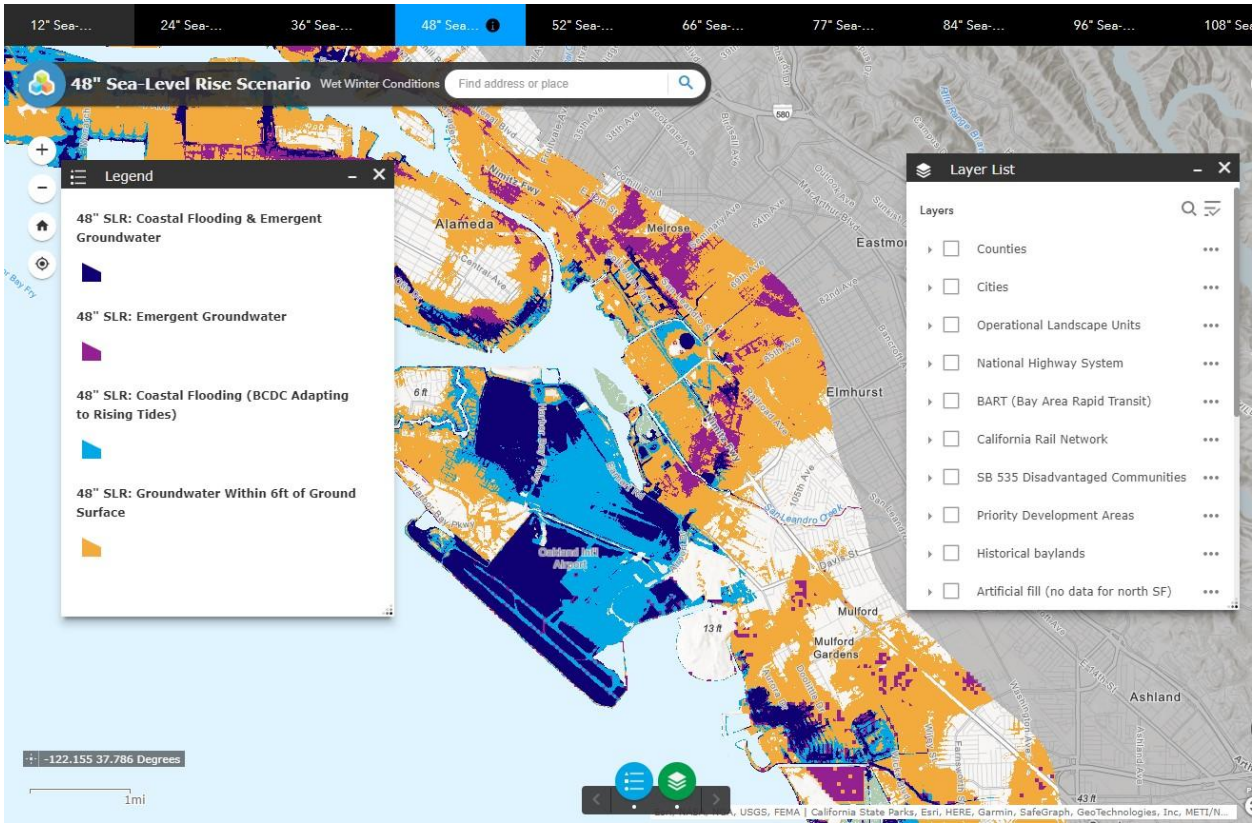
Project Results

Actual outcomes

The project deliverables can be found at
https://www.sfei.org/projects/shallow-groundwater-response-sea-level-rise

Resources include:

- A complete project report describing the challenge of groundwater rise, the methods used in this study, the layers available for use by planners and associated guidance, and outcomes from the adaptation workshop.
- Existing and future condition depth to groundwater GIS data available for download (geodatabase format).
- StoryMap providing background information and graphical representations of the processes and impacts of groundwater rise, accessible to a general audience.
- Interactive web maps showing: (1) existing depth to groundwater; and (2) future conditions under various sea-level rise scenarios.



An overlay analysis comparing the extent of emergent groundwater to the extent of coastal flooding under various sea-level rise scenarios is available via web map.

The study also received extensive media coverage by local and state news outlets:

- LA Times: *New Bay Area maps show hidden flood risk from sea level rise and groundwater*
- Mercury News: *New Bay Area maps show hidden flood risk from sea level, groundwater*
- KQED: *New Study Finds Rising Groundwater Is a Major Bay Area Flooding Risk*
- SF Chronicle: *New map shows where rising groundwater in Bay Area adds flood risks*
- KneeDeep Times: *New Maps Reveal Bay Area Flood Threat From Below*
- SF Examiner: *Rising groundwater is coming for your basement...and everyone's parking garages, sewers, and transportation systems*
- Marin IJ: *Marin's heightened flood risks illustrated in new study*
- KALW: *New study focuses on flood risks from sea level rise & rising groundwater*
- *ABC News: Study uncovers underground flood risk in Bay Area due to storms, climate change*
- KRON4: *Rising groundwater table levels could put these inland areas under water*

Los Angeles Times

$3.66 DESIGNATED AREAS HIGHER © 2023 TUESDAY, JANUARY 17, 2023 latimes.com

6 FATALLY SHOT IN TULARE COUNTY; 2 SOUGHT

Sheriff suspects drug cartel of massacre at a property that officials had raided last week.

BY HARRIET RYAN, JESSICA GARRISON, PAIGE ST. JOHN AND RUBEN VIVES

GOSHEN, Calif. — Six people, including a 6-month-old baby, her teenage mother and an elderly wom-

The silent threat from below

As storms and swells drench the state, new Bay Area maps reveal a hidden flood risk: rising groundwater.

BY ROSANNA XIA

Amid dramatic ocean swells and drenching atmospheric rivers, a new report lays bare a hidden aspect of

The project was featured on the front page of the LA Times on January 17, 2023

The project team also presented this work at a special session on groundwater rise at the National Adaptation Forum in Baltimore, MD in October 2022. Attendees from across the US were interested to learn how they might apply a similar mapping method for shorelines in their home regions.

Barriers encountered

As detailed in the interim grant report, the largest barrier we encountered in this project was inconsistent collection of geotechnical reports with soil boring logs. Due to the COVID-19 pandemic, many of our city and county partners were unable to access these documents (many of which are stored on paper in government offices) in a timely fashion, which resulted in delays in our process. This was a key data source, used to fill geographic gaps in our primary dataset (State Water Resources Control Board monitoring wells). In most cases, we were able to wait until the geotechnical reports could be retrieved. In other cases, we were able to come up with creative solutions to fill data gaps, including finding data from state databases (Caltrans and the Department of Water Resources) and including additional points from hydrological features to smooth the interpolated surface.

Another barrier encountered was in coordinating with local government partners. In some jurisdictions, staff turnover meant that those who had initially signed letters of support promising in-kind services were no longer available to help with the project, which resulted in additional coordination and outreach time to collect input data and review key outputs. In the end, we were successful in establishing new partnerships in jurisdictions where previous staff had moved on.

External factors

The COVID-19 pandemic was the largest external factor affecting the project. Though it did cause delays in data collection that affected the timeline, the project team was still able to complete the planned work within the grant term and deliver final materials on time.

Participating stakeholders

Advisory Committee:

- Erin Smith - City of Alameda
- Hank Ackerman, Michelle Myers - County of Alameda
- Elizabeth Carrade, Michelle Plousee - City of Albany
- Rachael Hartofelis - Metropolitan Transportation Commission
- Katie Van Dyke - City of Berkeley
- Nancy Humphrey - City of Emeryville
- Chris Choo - County of Marin
- Sandra Hamlat. Brian Strong, Mathew Wickens - City and County of San Francisco
- Alyx Karpowicz - San Francisco Bay Regional Water Quality Control Board
- Todd Hallenbeck, Daniel Hossfeld - San Francisco Bay Conservation and Development Commission
- Makena Wong, John Allan, Kim Springer - County of San Mateo

Technical Advisors:

- Kevin Befus - University of Arkansas
- Patrick Barnard, Anne Wein - United States Geological Survey

Representatives from 30 additional organizations attended the adaptation workshop.

Lessons for other communities considering similar projects

- Start with publicly available data if possible. The State Water Resources Control Board's Geotracker monitoring well dataset underpins the success of this effort; it is particularly valuable because wells are measured multiple times per year (seasonal variation is captured) and many of them have a long data time series (20+ years)
- Coordination is key. This project would not have been possible without the assistance of our city and county partners, who collected additional input data and reviewed outputs for accuracy. Engaging with partners early and often throughout the process resulted in a better product and hopefully more effective integration of results by planners.
- Gathering and georeferencing data from handwritten/scanned/PDF reports is time-consuming. Plan ahead if this will be a key input in groundwater mapping.
- Monitoring well data is more reliable than boring logs. Many geotechnical reports only report "first encountered" rather than "equilibrium" depth to groundwater. When groundwater was not allowed to reach equilibrium before measurement, data was often unusable based on comparison with surrounding wells.
- Automate processes whenever possible. Many changes arose throughout the process resulting in re-running analyses many times. We would not have been able to complete the project in a timely manner without creating scripts to automate analyses.

Next steps

The completion of this effort provides a wealth of groundwater information for Alameda, Marin, San Francisco, and San Mateo Counties that can inform climate resilience and adaptation efforts. However, additional work is needed to complete the mapping in Contra Costa, Napa, Santa Clara, Solano, and Sonoma Counties. The San Francisco Bay Regional Water Quality Control Board has agreed to fund mapping for Contra Costa County. Pathways Climate Institute and San Francisco Estuary Institute are working to identifying funding sources to:

- map the remaining counties,
- incorporate groundwater mapping into the ART Shoreline Flood Explorer,
- analyze the potential for rising groundwater to mobilize contaminants, and
- develop outreach and messaging to support communities at highest risk of impacts related to rising groundwater, including vulnerable communities already facing other environmental and climate impacts.

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