USGS science for a changing world

In cooperation with MassDEP

SNEP Symposium June 2024

Effects of Sea-Level Rise and Climate Change on the Fresh Groundwater-Flow System of Martha's Vineyard, Massachusetts

Timothy D. McCobb[1], Madeleine Holland[1], Carole D. Johnson[1], Eric A. White[2], Jason R. Sorenson[3], and Hayley G. Lind[1]

[1]U.S. Geological Survey New England Water Science Center, Northborough, MA [2]U.S. Geological Survey Hydrologic Remote Sensing Branch, Water Mission Area, Storrs, CT

INTRODUCTION

Shallow, unconfined aquifers such as the one underlying the island of Martha's Vineyard, Massachusetts, are vulnerable to the effects of sea-level rise (SLR) and climate change. Potential effects of rising sea level include changes in the altitude and depth of the water table, freshwater/saltwater interface position, and the volume of stream base flow. Projected increases in air temperature and changes in precipitation magnitude and seasonal distribution may affect the future amount and timing of groundwater recharge.

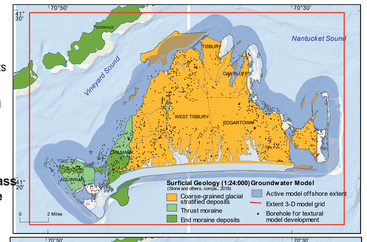
The U.S. Geological Survey, in cooperation with the Massachusetts Department of Environmental Protection, is investigating the effects of SLR and climate change on the groundwater resources of Martha's Vineyard by evaluating the hydrologic and water quality response to changing climate over time.

HYDROGEOLOGIC FRAMEWORK

The generalized geology that comprises Martha's Vineyard can be characterized by:

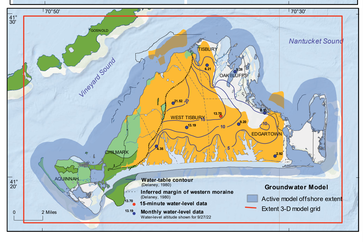
- A broad, flat outwash plain of coarse-grained Pleistocene glacial deposits
- A thin terminal moraine beneath the eastern outwash
- Thrust and end moraines of compact sandy tills over layers of fines along the western coastline
- At least 600 feet of Cretaceaous and Tertiary coastal-plain sediments underlying the surficial units (Delaney, 1980)

As part of this study, the lithology of over 1,600 boreholes were classified, assigned hydraulic conductivity values, and a textural model of the sediment distribution was developed.



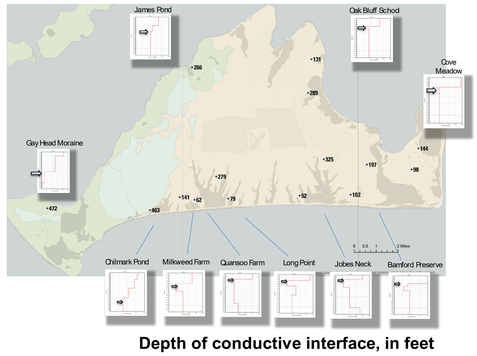
The hydrologic system underlying Martha's Vineyard can be characterized by:

- A productive, unconfined water-table aquifer in the outwash area mounded toward the northwest
- A mix of unconfined, confined, perched, and artesian conditions in the western moraines
- Annual precipitation of ~46 in/yr of which less than 50% recharges the aquifer
- Transition from freshwater/saltwater (interface) near the center of the Island at about 500 feet below land surface



Geophysical Surveys of Depth to Bedrock and Freshwater/Saltwater Interface

Initial field geophysical surveys of the depth to bedrock (passive seismic method) resulted in identification of the northwest-to-southeast sloping bedrock surface ranging from ~500 to -1,125 feet below the North American Vertical Datum of 1988 (NAVD88). Time-Domain Electromagnetic surveys indicated that the depth to the freshwater/saltwater (FW/SW) interface (52–472 feet below land surface) varies greatly with distance from shore, proximity to coastal ponds, and geologic setting.

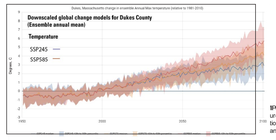


Depth of conductive interface, in feet

USGS scientist operating the Time-Domain Electromagnetics (TDEM) equipment to determine depth to the freshwater/salt-water interface in May 2023

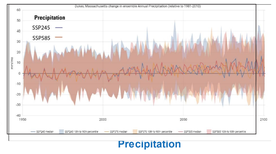
CLIMATE CHANGE AND RECHARGE

The model is being used in conjunction with air temperature and precipitation data from downscaled general circulation models (GCMs) for projected future emissions representing best-case and worst-case scenarios. The GCM data are being used to inform a Soil-Water-Balance (SWB) model to determine spatially variable, projected recharge through the 21st century.



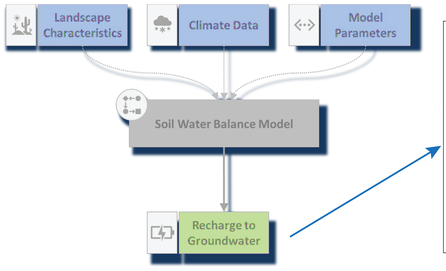
Temperature

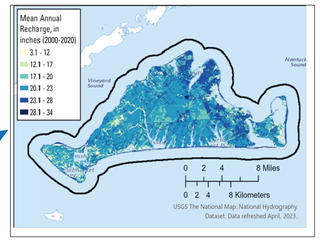
IPR datasets uncer. USGS tional Climate ange Viewer



Precipitation

Soil Water Balance (SWB) Model for Spatially-Variable Recharge



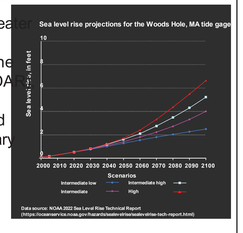


Advantages of SWB:

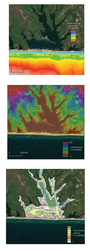
- ✓ Provides seasonal distribution of recharge
- ✓ Provides spatial distribution of recharge
- ✓ Can simulate recharge under different land cover conditions
- ✓ Can use modeled climate data to simulate future recharge under climate change scenarios

SEA-LEVEL RISE AND SHORELINE POSITION

Sea-level rise projections through 2100 at Woods Hole, MA range from greater than 2 feet to greater than 6 feet depending on the global climate change scenarios (NOAA, 2022). To simulate the effects of sea-level change on the fresh groundwater system, onshore Light Detection and Ranging (1-m LIDAR) and offshore and coastal pond bathymetries were merged to determine potential sea-level positions at 0–6 feet (1-ft increments). The position and elevation of the sea-level surfaces are represented as time-varying boundary conditions for ocean (constant head) and coastal ponds (general-head) features.



Topographic and Bathymetric Datasets

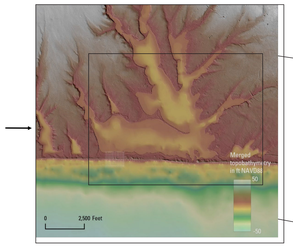


Offshore Bathymetry (NOAA, 2016)

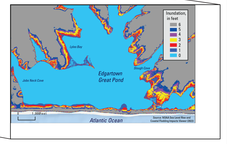
LIDAR Elevation March/April 2021 (Sheriff's Meadow Foundation)

Pond Bathymetry (Various sources actual/estimated)

Merged Elevation Datasets, in ft NAVD88



Example positions of sea-level inundation at 0-6 feet

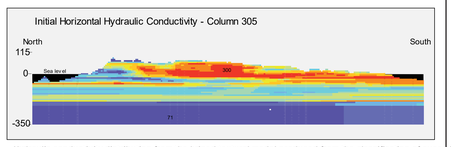


GROUNDWATER FLOW AND TRANSPORT MODELING

We will evaluate the spatial and temporal impacts to the hydrologic system from climate change and SLR using a MODFLOW-6 groundwater flow and transport model. Results will inform current and future drinking-water availability and conditions under which management and conservation measures may be needed.

Model Information:

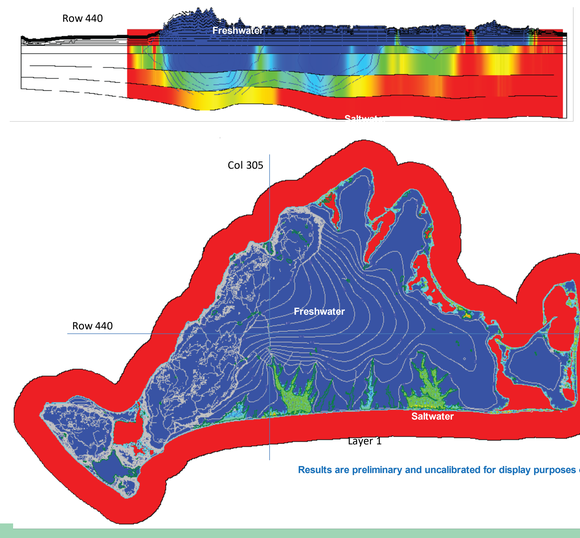
- MODFLOW-6 model
  - Flow and Transport (saltwater density)
- Active extent ½ mile offshore
- 100 ft x 100 ft resolution
- 16 layers (thickness 4.5 – 340 ft)
- Transient period (2000-2100)
  - 2000-2023 (monthly)
  - Future (seasonal/monthly)
- Stresses include municipal pumping and wastewater flow



Hydraulic conductivity distribution from the kriged textural model produced from the classification of over 1600 boreholes

Example illustrating hydraulic heads and saltwater concentrations from the flow and transport mode

Prior to scenario simulations and analyses, the model will be calibrated to continuous and discrete water levels, streamflow, and observations of the freshwater/salt water interface using parameter estimation techniques (PEST)



Results are preliminary and uncalibrated for display purposes only.

PLANNED ANALYSES

The model will be used to evaluate SLR and climate model predictions on:

- General hydrologic budget
- Water-table (WT) shape and position
- Estimates of high-water levels (depth-to-water maps) and groundwater inundation mapping
- Position of FW/SW interface, especially near supply wells
- Groundwater exchange in selected embayments (ecologically sensitive coastal waters)
- Water-management scenarios as developed with stakeholder input (MassDEP, Martha's Vineyard Commission, water suppliers, towns)

For more information:

References

Delaney, D. F., 1980, Ground-water hydrology of Martha's Vineyard, Massachusetts: U.S. Geological Survey Hydrologic Atlas 618 (10.3133/ha618)

NOAA, 2022, Sea-level rise viewer, webpage accessed at https://coast.noaa.gov/slr/ on March 1, 2023

OCM Partners, 2024: 1887 - 2016 USGS CoNED Topobathy DEM (Compiled 2016): New England, https://www.fisheries.noaa.gov/inport/item/49419.

U.S. Department of the Interior
U.S. Geological Survey

Preliminary Information-Subject to Revision.