Groundwater Surface Estimation in Rhode Island

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Abstract

1 Introduction

The availability of potable water is essential for a variety of reasons include human health, agriculture and tourism in the state of Rhode Island. To quantify environmental impacts and water availability it is important to know where the water is. Within Rhode Island through significant efforts of the Rhode Island Development Council (1948-1959) and the Rhode Island Water Resources Control Board (1959-1964) water wells were cataloged and mapped resulting in almost full coverage of the state for water table and bedrock altitude. Unfortunately, the resulting ground water maps were constructed mostly independently from each other, some maps (typically older ones) are missing important data, and are not easily available as they existed in analog formats across 26 maps. Presented here is a unified data set of water well locations and altitudes of water an bedrock along with interpolated surfaces for most of the state of Rhode Island.

2 Data and Methods

Well data was obtained by hand from published maps, (*Quinn et al.*, 1948; *Richmond and Allen*, 1951; *Bierschenk*, 1954; *Allen*, 1956; *Bierschenk*, 1956; *Allen et al.*, 1959; *Allen and Gorman*, 1959; *Bierschenk and Hahn*, 1959; *Hahn*, 1959b,a; *Johnson and Marks*, 1959; *Bierschenk*, 1959; *LaSala Jr. and Hahn*, 1960; *Mason and Hahn*, 1960; *Allen and Ryan*, 1960; *Pollock*, 1960; *Johnson et al.*, 1960; *LaSala Jr. and Johnson*, 1960; *Randall et al.*, 1960; *Hahn and Hansen Jr.*, 1961; *Johnson*, 1961b,a; *Hansen Jr.*, 1962a; *Johnson*, 1962; *Hansen Jr.*, 1962b; *Schiner and Gonthier*, 1964a,b) and included the well number, location, bedrock altitude, and water table altitude; altitudes were relative to sea level. All distance values were originally reported in feet. Altitudes on the published maps were likely determined by depths ('well depth' or 'depth to the water table') from the topographic elevation. This topographic value would have been determined around the time of the map's publication, however this information is not included within the map.

All well data were manually digitized in QGIS (*QGIS Development Team*, 2025). digitized data is displayed is Figure 1 with values colored as water table altitude from sea level. Gray markers are digitized wells without a water table value. Reasonable data density is seen throughout the state except for quadrangles in the northeast and east, specifically Georgiaville, Pawtucket, Providence, East Greenwich, and Bristol quadrangles.

Water table and bedrock altitudes are strongly correlated with topography. The water table elevation is consistently beneath the land surface; average of −9.731 ft (Figure 2). Bedrock is deeper, averaging −49.297 ft below land surface. Water table elevations, w, map linearly with the topography z as the linear fit slope is close to unity, 0.998 (R^2 : 0.998). Bedrock altitudes, b, exhibit a more complex behavior with a slope of 1.070 (R^2 : 0.957). At low topographic elevations, bedrock is deep in many wells (max: −371 ft) These deep bedrock locations are near the axes of deep north-south trending glacial valleys, primarily Narragansett Bay. Depth to bedrock values in upland wells typically average 15 ft to 20 ft. Use of topographic elevations to predict bedrock depths is not an appropriate model due to the wide range of values at low topographic elevations. We must note that topographic elevations used in each of these linear models are from a recent Digital Elevation Model (DEM) (*RIGIS*, 2013) and differ from the topographic data in the original maps. Altitudes for the water table and bedrock on the original maps were determined from topography and depth to each interface; as such mismatches between the original topographic model and the recent DEM will be reflected in the resulting models.

3 Water table depth model

Groundwater points, z, for which data is available are interpolated onto a regular grid, Z, using an inverse distance weighting using the closest N points, called invdistnn within the gdal software package (*GDAL/OGR contributors*, 2025).

$$Z = \frac{\sum_{i=1}^{m} z_r r_i^2}{\sum_{i=1}^{m} r_i^2} \tag{1}$$

We use $N = 12$ closest points within the interpolation while also limiting the maximum distance, r_i, to $25km$. The maximum distance was chosen to result in a cohesive model across most of the study area. The output grid Z is 250 x 262 with a variable cell size ranging between 822 m to 959 m. Resolution is based on *Hengl* (2006) with "Finest Resolution", selected to keep $p > 0.05$ for the closest point distances, Figure 4.

Before interpolation, we digitize surface water bodies with a defined water table depth of 0 ft. These data contribute additional constraints to sparse data regions and act as a check for more densely sampled regions. Interpolation results are displayed in Figure 5. As suggested by the best-fit linear model of elevation to water table, Figure 2, the water table follows the surface topography. To evaluate confidence in the resulting interpolation a bootstrap of the input data was performed, with 1000 realizations each using 80% of the input data. The resulting standard deviation is presented in Figure6.

Much of the interpolated water table is has a standard deviation around 5 ft with a majority less than 10 ft. A number of isolated points have large variations where either the data is sparse in the north eastern part of the state or where individual measurements are outliers with respect to surrounding points. It is important to note that some regions have a standard deviation near 0 ft; primarily coastal regions and in the bays where data is scarce, Figures 1 and 5. This demonstrates an inability of the standard deviation to describe the uncertainty of this technique, i.e. where data is limited.

A better representation of the uncertainty this model is the mean distance of the input data point to the interpolation, Figure 7. Areas with large mean distances include the edge of the model, central portions of Narragansett Bay and quadrangles without reported water table depths, Georgiaville, Pawtucket, Providence, East Greenwich and Bristol.

4 Discussion

The strong relationship between the topography and water table altitude is striking. Previous work by *Toth* (1963), *Haitjema and Mitchell-Bruker* (2005) and *Gleeson et al.* (2011) suggest a strong relationship between the water table and topography in "topography-controlled" regions with low-permeable aquifers, high recharge rates, and/or relatively subdued topography; characterized by the "water table ratio",

$$\frac{RL^2}{mkHd} = \begin{cases} > 1 & \text{topography controlled} \\ < 1 & \text{recharge controlled} \end{cases} \tag{2}$$

where R is the average annual recharge rate, L is the surface water distance, m is a aquifer geometric factor, k aquifer hydraulic conductivity, H aquifer thickness, and d is maximum depth of the average water elevation, see *Haitjema and Mitchell-Bruker* (2005).

A continental scale compilation of *Gleeson et al.* (2011) demonstrated all three factors are important in New England suggesting a topographic control of the water table. Results presented here demonstrate this strong correlation and show agreement with these previous researchers (*Haitjema and Mitchell-Bruker*, 2005; *Gleeson et al.*, 2011).

In addition, the depth to bedrock is also strongly correlated with topography, but less so than the water table. Consistency of these three surfaces suggests the relatively-flat, glacially-smoothed bedrock surface imparting a strong influence on both the topography and the water table.

Global analysis of groundwater systems by *Michael et al.* (2013) confirm a strong water table dependence on topography, "topography limited". Given the number of parameters impacting the water table behavior in Rhode Island, it may be dependent on changes to permeability and distance to the hydraulic divide, but not changes to recharge.

The range of water table depths, as measured by standard deviation of the residual 9.5 ft, Figure 2, matches well with the relationship between "water table ratio" and the water table depth (see *Gleeson et al.* (2011) Figure 3a) . Topography controlled water tables show consistently shallow depths whereas recharge controlled water tables have a much wider depth range and can have much deeper water tables.

5 Conclusions

A unified dataset of water table and bedrock altitudes is presented as individual points from the original ground water maps along with an interpolated water table altitude for most of the state of Rhode Island. The digitized water and bedrock altitudes and interpolated water table altitudes are strongly correlated with topography. This strong correlation between the water table and topography is impacted by low-permeable aquifers, high recharge rates and relatively flat topography (*Haitjema and Mitchell-Bruker*, 2005).

6 Appendix

Digitial data for this work including the raw digitized data, interpolated surfaces and associated metrics are available online.

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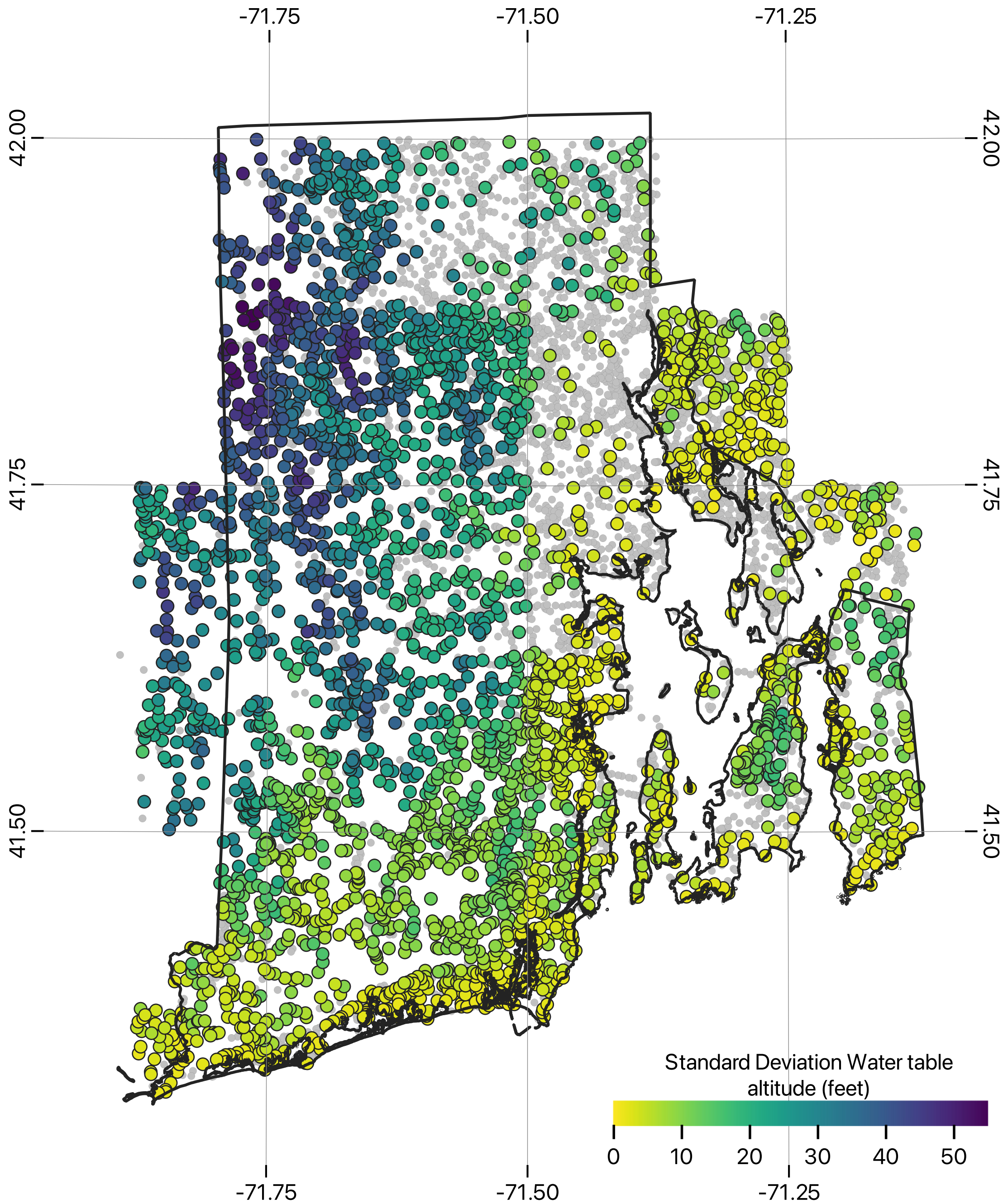

Figure 1: Raw water table altitudes digitized from the original maps. Color represents the altitude reported on for the well and gray is no value reported.

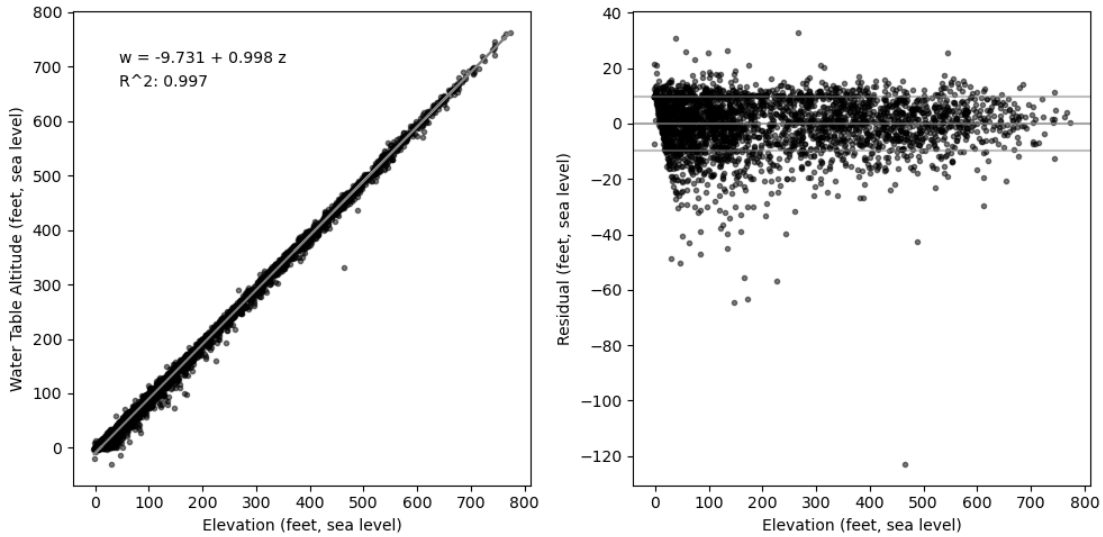

Figure 2: Water table altitude plotted against topographic elevation. Linear fit of the water table altitude against the topographic elevation is $w = -9.731 + 0.998z$ with an R^2 value of 0.997. Residuals for the model are plotted on the right with the mean shown in gray and the standard deviation of the residual shown in light gray.

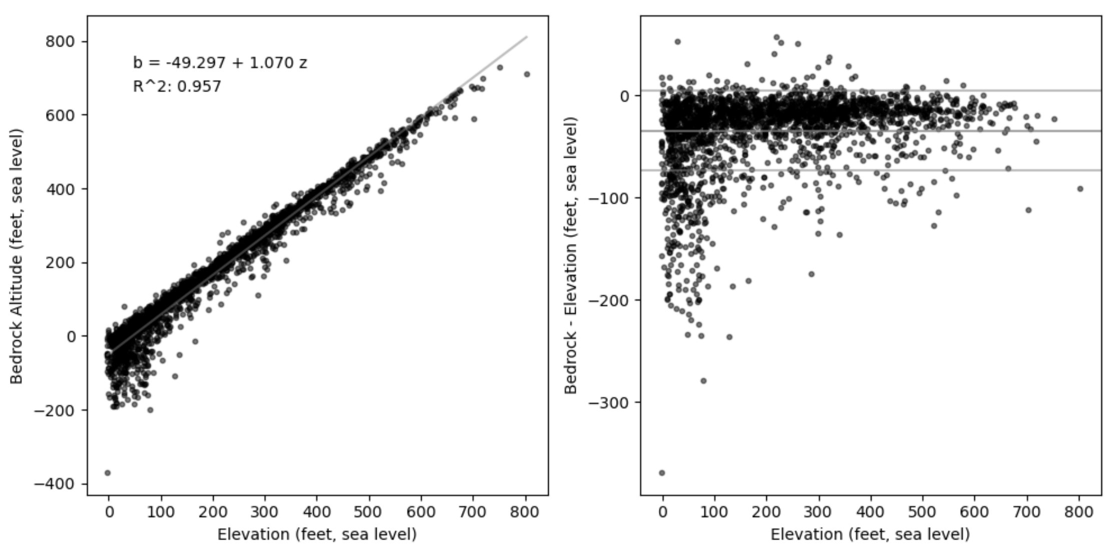

Figure 3: Bedrock altitude plotted against topographic elevation. Linear fit of the bedrock altitude against the topographic elevation is $b = -49.297 + 1.070b$ with an R^2 value of 1.070. Difference between bedrock altitude and elevation, not the linear model, are plotted on the right with the mean shown in gray and the standard deviation of the residual shown in light gray.

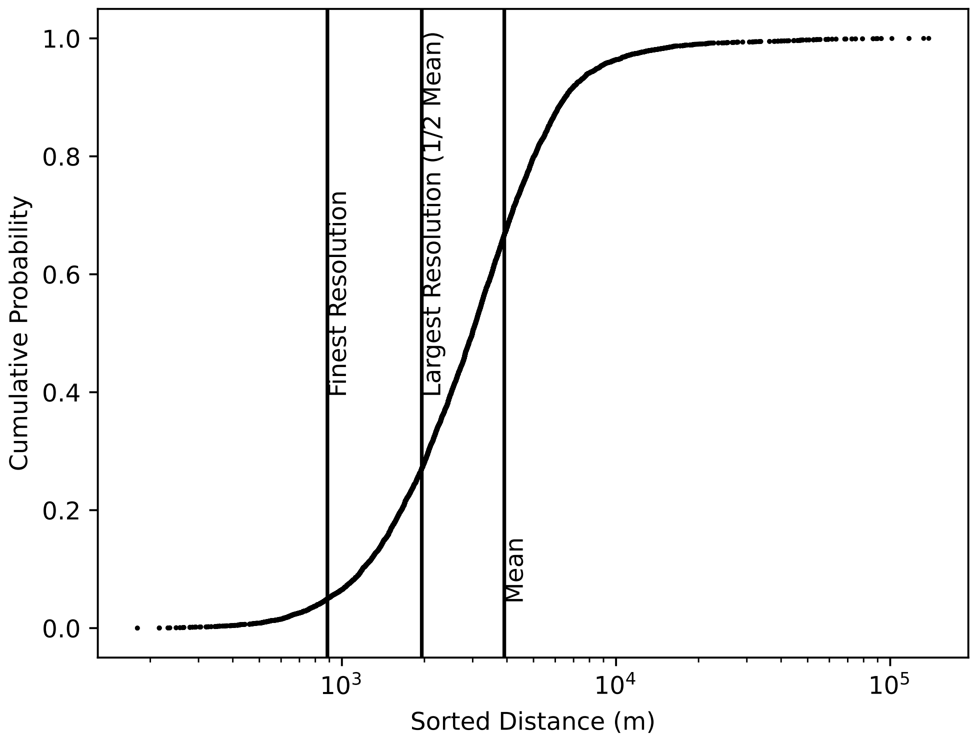

Figure 4: Cumulative probability for closest point distances. Black lines are the mean, largest resolution (defined as 1/2 the mean), and the finest resolution ($p > 0.05$) following *Hengl* (2006). Resolution used is near the finest resolution.

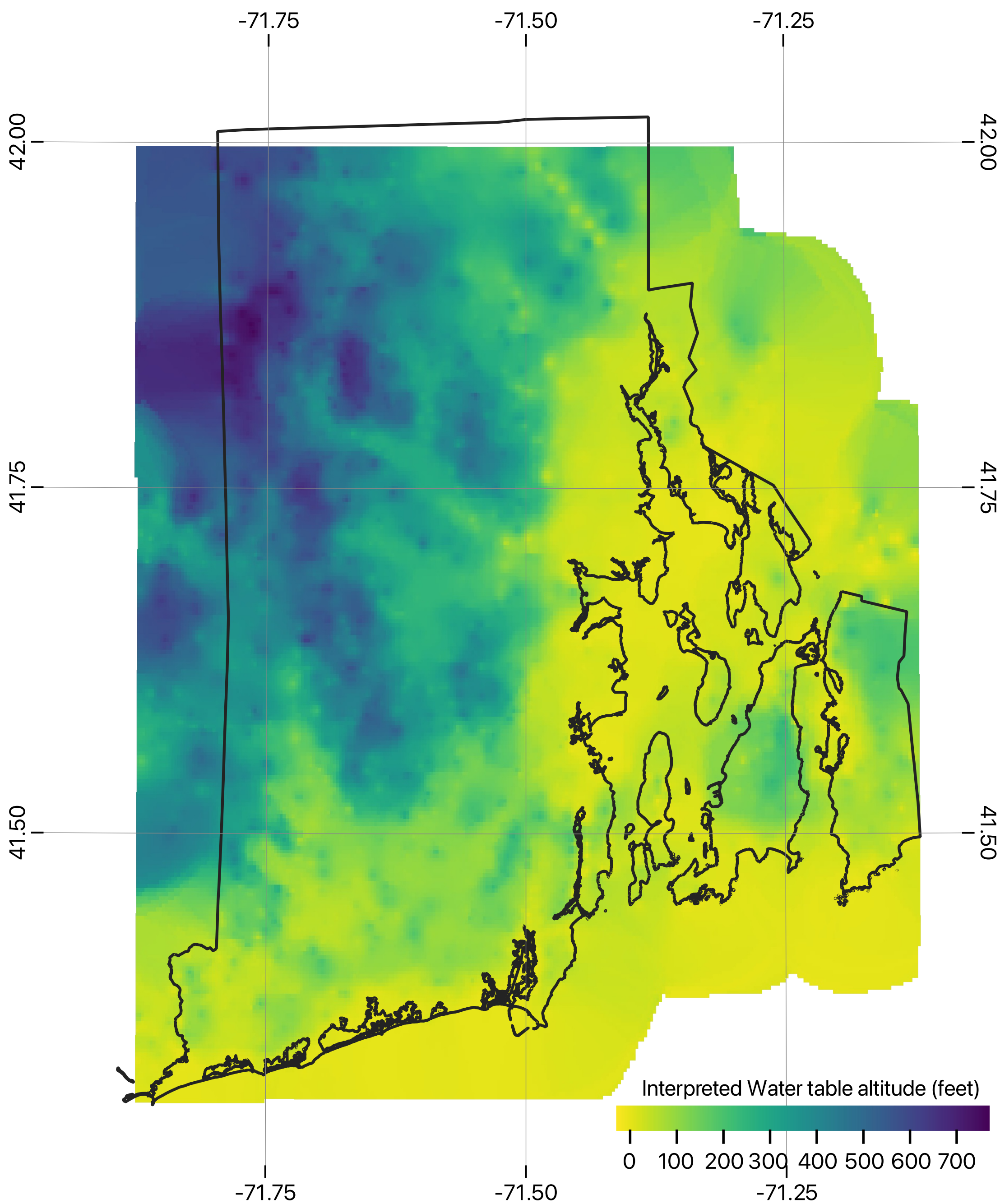

Figure 5: Interpolated water table altitude from sea level in feet.

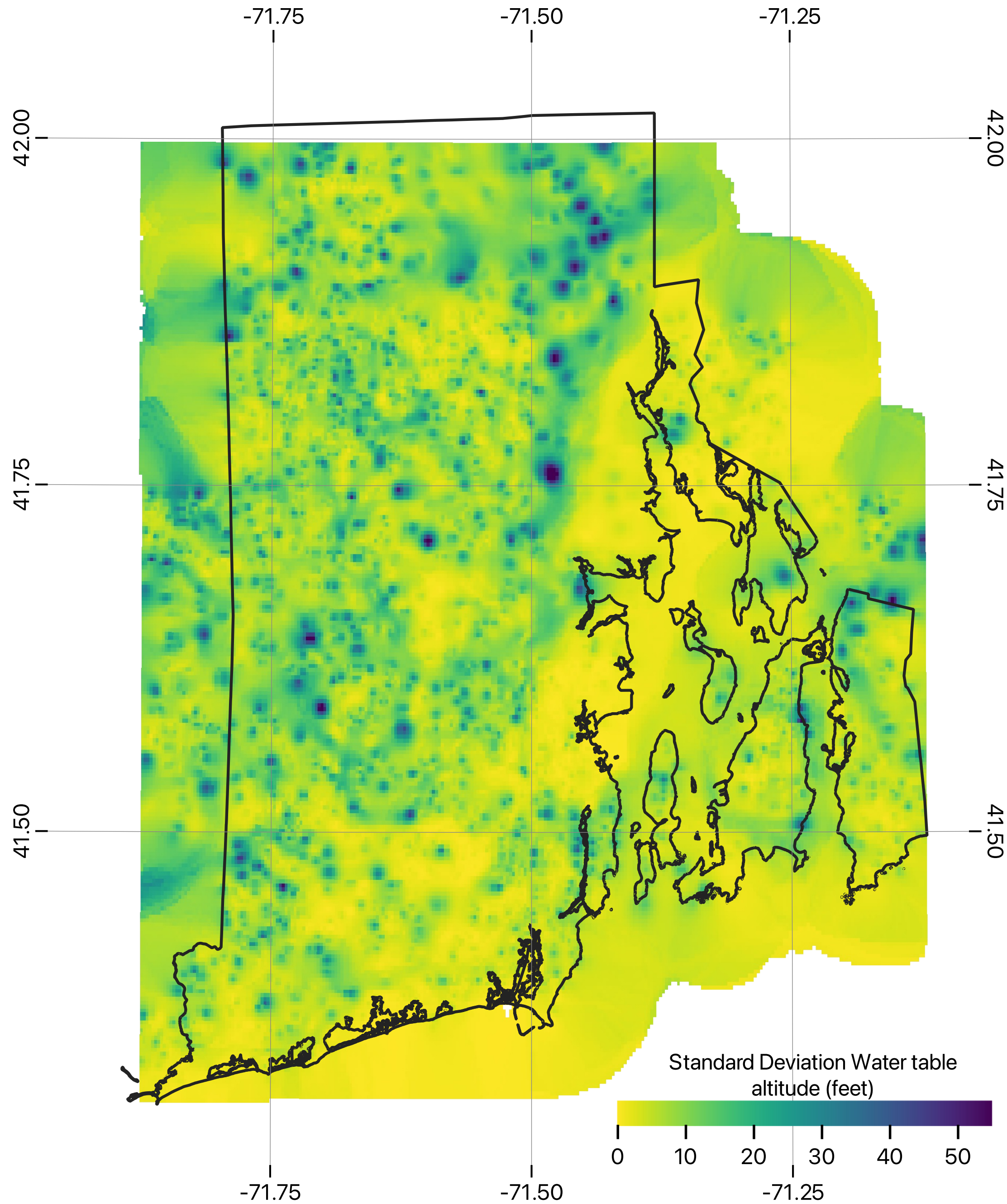

Figure 6: Estimated standard deviation of the interpolated water table altitude from sea level in feet constructed from a bootstrap of 1000 realizations of 80% of the input data.

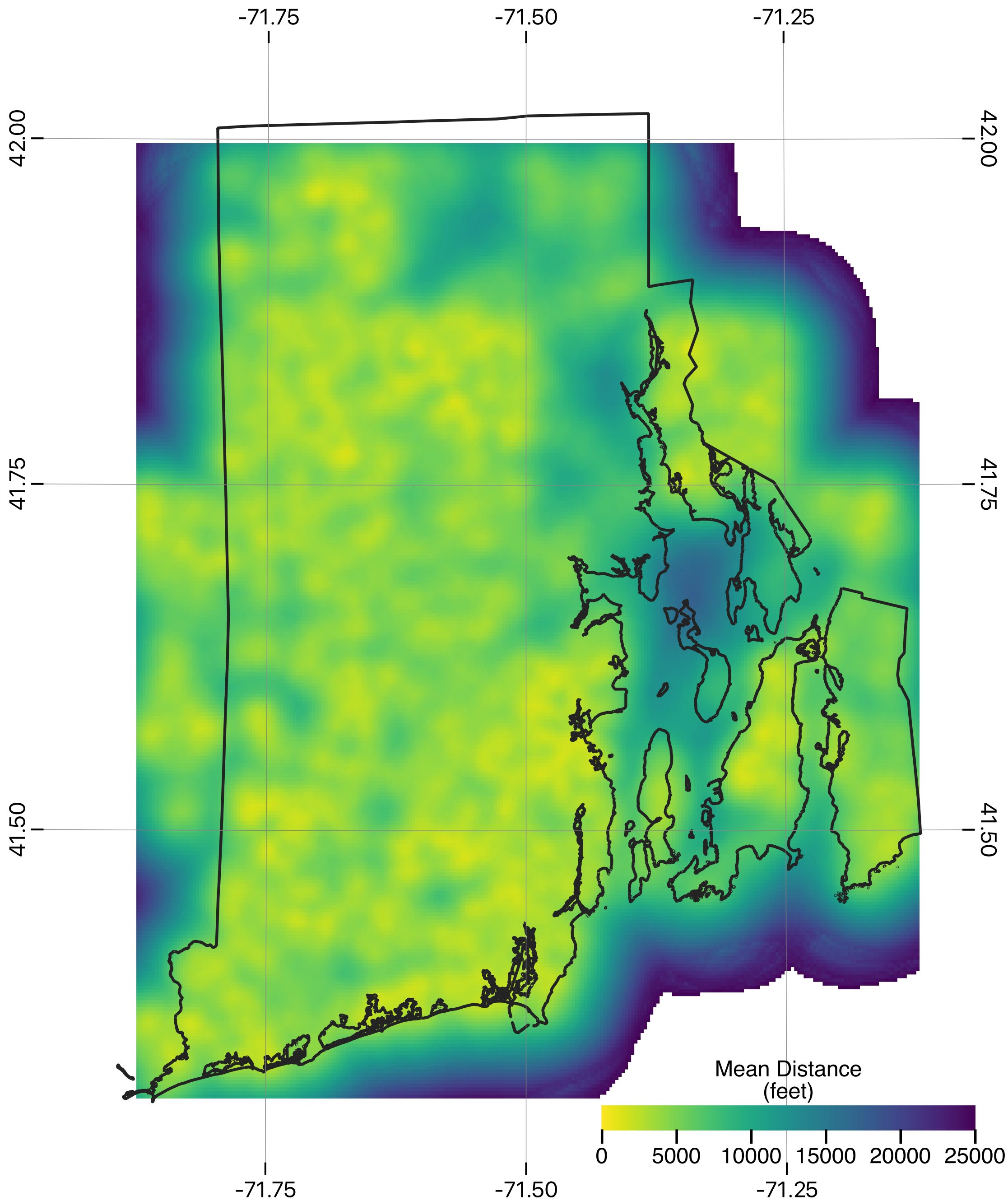

Figure 7: Mean distance from each interpolation point to the set of input data points used within the interpolation. Darker values indicate a lack of close by data points, wells.