International Cartographic Association
Association Cartographique Internationale

Salt River from Summit to Seafloor: A Study of Shaded Relief Techniques for Coastal Environments

Margot Dale Carpenter

Hartdale Maps - hartdalemaps@gmail.com

Abstract: Maps often rely on a stroke to delineate hydrological features. However, at large scales, these boundaries are usually a series of dynamic transitions across terrestrial and aquatic environments, particularly when considering wetlands. Borrowing classic mountain cartography techniques, this paper presents workflows to create a large-scale map of the coastal topography at Salt River, St. Croix, USVI, from summit to seafloor. I include lessons learned from working with disparate datasets, descriptions of customized illuminated shaded relief techniques, and a new way to represent mangroves.

Keywords: coastal topography, coastal cartography, coastal shaded relief, wetland cartography, topobathy, mangroves

1. Introduction

Coastal areas are among the most dynamic places on Earth. Creating a map of these areas in the United States usually requires working across terrestrial, shallow-water, and deepwater datasets from different sources, with varying quality and patchy availability. Using a recent large-scale map of the Salt River Bay in the US Virgin Islands—*Salt River from Summit to Seafloor*—as a departure point, I will present options for accessing the data and creating a cohesive shaded relief map. I will begin with deepwater bathymetry, move to the shallow-water zone, connect these to the terrestrial, and end with options for symbolizing wetlands, particularly mangroves.

2. Gathering Digital Elevation Data

From my experience, the terrestrial elevation data offered by the USGS (United States Geological Survey) tends to be high resolution and complete, while the bathymetric depth data available through NOAA (National Oceanic and Atmospheric Administration) is not. NOAA has taken great strides to improve the quality and availability of their data, but surveying the sea floor can be challenging and expensive.

There are several access windows for prepared elevation datasets. The two I use most often for terrestrial data are TNM (The National Map) Download (v2.0) and 3DEP LidarExplorer. NOAA offers several DEM varieties, but I most often use the ⅓ and 1 arc-second DEMs, topobathy lidar DEMs, and CUDEMs (Continuously Updated Digital Elevation Models). These can be downloaded from two primary windows. The Digital Coast: Data Access Viewer offers topobathy lidar DEMs and CUDEMs. The Bathymetric Data Viewer offers this plus small-scale bathymetric DEMs, including ETOPO data.

Figure 1. Salt River Bay is a reef-protected, mangrove-edged bay located on the north shore of St. Croix, USVI.

It's important to review the metadata to identify the vertical datum and where "zero" is with respect to the tides when downloading elevation data. USGS tends to use MHW (Mean High Water) and NOAA often uses MHW or MLLW (Mean Lower-Low Water). The difference

Proceedings of the International Cartographic Association, 6, 5, 2024. https://doi.org/10.5194/ica-proc-6-5-2024
12th Mountain Cartography Workshop of the ICA Commission on Mountain Cartography, 11–15 April 2023, Snow Mountain Ranch, CO, USA.
This contribution underwent single-blind peer review based on submitted abstracts.

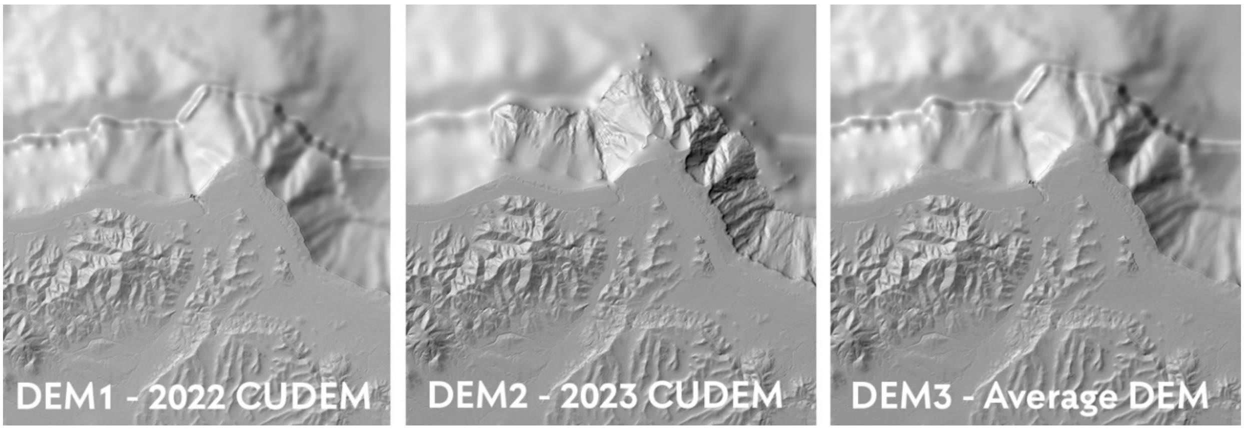

Figure 2. Hillshades represent the DEMs downloaded from NOAA's Bathymetric Data Viewer.

between MHW and MLLW can yield very different coastlines on large-scale maps for areas with a significant tidal range. The vertical values may need to be recalculated so that the terrestrial and bathymetric data agree with each other.

3. Deepwater Bathymetry

Of the several deepwater datasets seen on NOAA's Bathymetric Data Viewer, only two datasets seemed viable for this project. DEM1 was downloaded in early 2022 and DEM2 was accessed in 2023 (Figure 2). Both are 3-meter CUDEMs.

While the 2023 dataset offers greater detail overall, it is blurrier for the deepest waters. The detail seen in the shallower depths will be useful for detailing the mid- and shallow-water areas but, in my view, this dataset will not work as a sole data source for depicting the deepwater areas. Because of the inconsistent data quality, I generated a weighted average DEM that gives two-thirds priority to DEM1 using the following equation: (DEM1 + DEM1 + DEM2)/3. With this new DEM, I was able to maintain a more consistent level of detail across the project area while adding a small amount of texture.

4. Considering Deepwater Light

Before creating the deepwater bathymetric tint, I reviewed how the color of sunlight changes as it descends through the water column. While this is a complex topic, I came away with two essential color notes. In ocean environments, sunlight's full spectrum is present at the surface, but only the indigo blue light will travel deeper than about 200 meters, and below 1000 meters, the ocean is dark (NOAA 2024). To reflect this, the deepwater bathymetric color ramp begins around 200 meters and descends to darker indigo shades (Figure 3).

5. Multi-Directional Deepwater Shaded Relief

Despite the lack of light below 1000 meters, bathymetric relief still relies on the concepts of light and shadow to depict the seafloor at every depth. Because no light travels below 1000 meters, I chose to define the seafloor with shadows rather than introducing sunlight colors. To do this, I modified Tom Patterson's workflow "See the light: How to make illuminated shaded relief in Photoshop 6.0" (Patterson 2024). I repeated this workflow five times, in order to have the materials to create a multi-directional shaded relief. The five hillshades arc across the northwest quadrant in 25-degree increments (Figure 4). This range will effectively delineate any aspects that are lost when using a single 315-degree hillshade. I also modified the procedure again, to mask the bathymetric tint rather than a single color.

In Adobe Photoshop, each of the five hillshades was copied and pasted as a mask layer into one of five duplicates of the bathymetric tint. Then they were adjusted

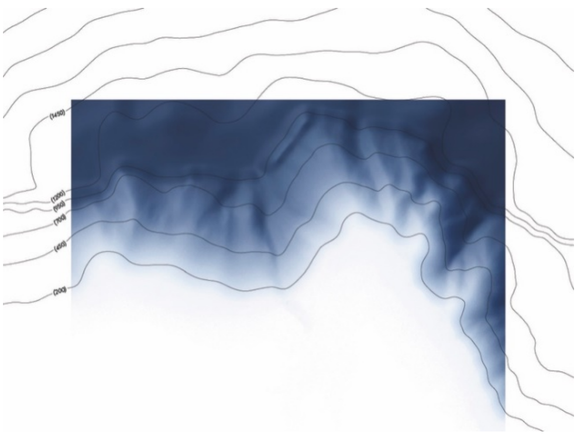

Figure 3. The deepwater bathymetric tint layered with the shaded relief.

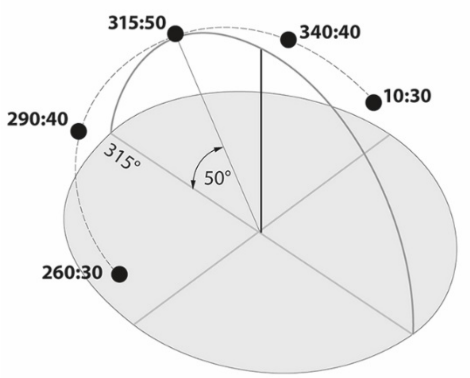

Figure 4. The arc of hillshades denoted by each azimuth and elevation.

Proceedings of the International Cartographic Association, 6, 5, 2024. https://doi.org/10.5194/ica-proc-6-5-2024
12th Mountain Cartography Workshop of the ICA Commission on Mountain Cartography, 11–15 April 2023, Snow Mountain Ranch, CO, USA.
This contribution underwent single-blind peer review based on submitted abstracts.

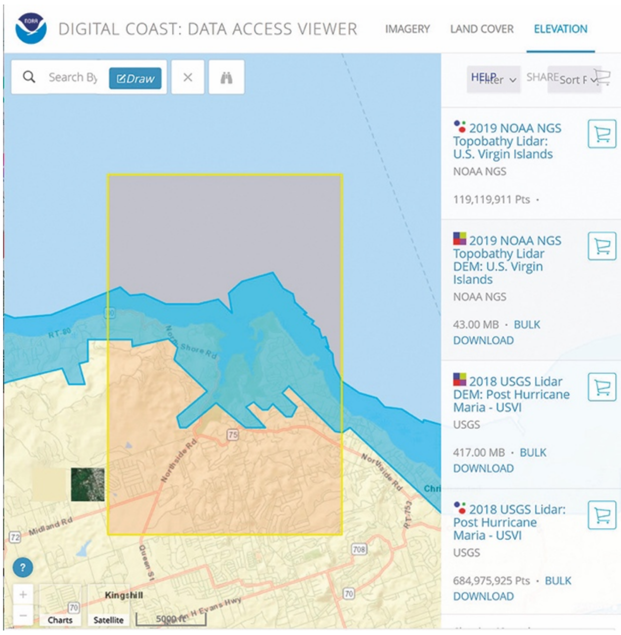

Figure 5. The highlighted 2019 dataset appears to offer complete coverage within its boundary.

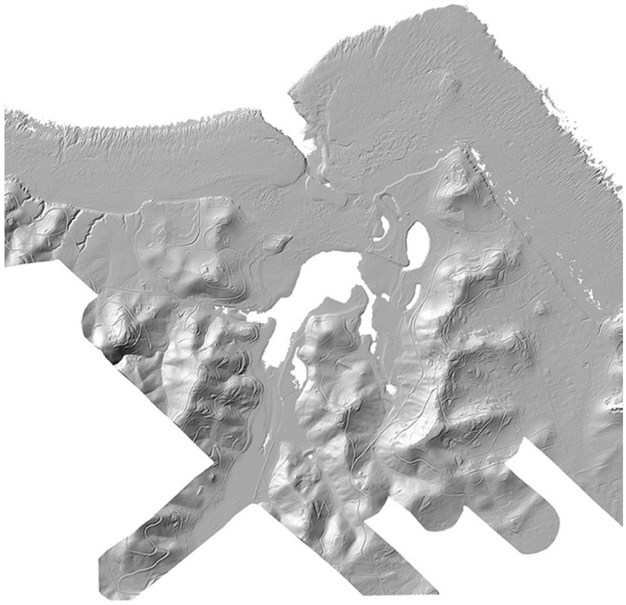

Figure 6. The hillshade of the project area shows significant holes in the data.

to increase the contrast and then inverted to reveal the shadowed aspects. By using Photoshop's multiply blend mode and varying the blend mode percentages, I was able to protect the essential hues of the color ramp while maintaining a great deal of control over the final image. I layered the final shaded-relief image in Adobe Illustrator just above a pale blue vector base layer that defines the tidal limit.

6. Shallow-Water Bathymetry

NOAA's topobathy datasets represent their shallow-water work and, to date, don't yet cover all of the coastal areas of the United States. Most of the topobathy datasets include bathymetric lidar measurements, which are depth limited and vary from thin strips to broad areal coverages. I find it easier to download topobathy data from NOAA's Data Access Viewer than the Bathymetric Data Viewer, and, fortunately, the Salt River Bay area had several years of data to choose from (Figure 5). Even though it has patchy coverage, the 2019 topobathy dataset had the largest extent and a respectable 1-meter resolution. (Figure 6). In every topobathy dataset I've worked with, I have observed missing pockets of data. I estimate that depths are missing either because the water depth was greater than the lidar sensor could measure, or there was a glitch in the mission. I manually filled these in Photoshop but a "void fill" function could also be used.

7. Mid- and Shallow-Water Details

To further develop the overall bathymetric color ramp from the deepwater indigo blues to the shallow aqua colors, and to help stitch together the disparate datasets, I created two more tint layers. The tint for the mid-depths, generated from the 2023 CUDEM (DEM2 in Figure 2), ranges from mid-blue to aqua. The tints for the shallowest zone, created with the 2019 topobathy DEM, pick up the aqua blue and fade to almost white at the shoreline (Figure 7). I limited each layer to its respective depths by masking them with their respective DEMs or using a soft Photoshop eraser. These two layers were added to the Illustrator file via the multiply blend mode and became the base layer that supported the mid- to shallow-water details.

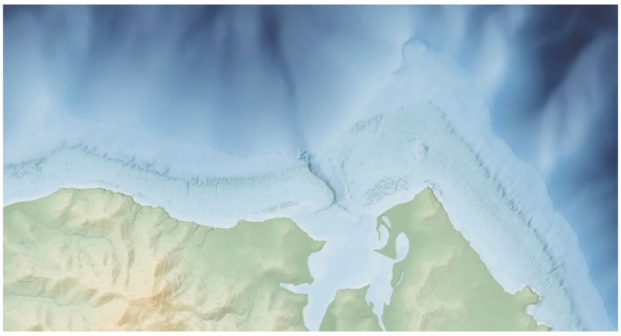

Figure 7. The final mid- and shallow-water layers defining details.

Figure 8. Delineating the highly-textured inner and outer reefs that protect Salt River Bay.

To define the complex inner and outer reef systems that form the protective mantle at the mouth of the bay, I followed a simpler version of the Patterson-based workflow that I used for creating the deepwater shaded relief. But instead of masking a tint layer, I filled an entire layer in Photoshop with a pale, grey-green color and masked that. An arc of three hillshades with azimuths of 290°, 315°, and 340° masked and multiplied the grey-green layers. To limit the image to just the reef structures, I used a large, soft Photoshop eraser to remove the non-descriptive areas and feather in the hillshades (Figure 8).

The 2023 CUDEM (DEM2 in Figure 2) captured a unique balcony-like structure just above the steep drop and did a better job of representing the Salt River Canyon. To delineate these features, I used the same technique as described above but masked a mid-blue color.

8. Terrestrial Shaded Relief

USGS's 1-meter elevation data provided the highest-resolution data available for the full project area, and I used the DEM to generate a hypsometric tint with a classic light-warm-green to orange-gold color ramp (Figure 9). Even though the mountain to the west of Salt River is closest to the viewer and would arguably dominate the visual hierarchy, it is not the primary character; the mangroves and waterscapes are. To work with this, and, again using Patterson's illuminated shaded relief workflow, I created three hillshades with azimuths of 295°, 315°, and 335°, to mask the hypsometric tint. To limit this to the summit, I masked out the lower slopes with the same DEM.

Because the USGS data was the highest resolution available covering the entire coastline, I used the DEM to create the pale-blue vector layer representing the extent of the bay and sea north of it. Knowing that the average tidal range is 30 centimeters and therefore inconsequential at this scale and for this geography, I simply used the "zero" contour line to create the polygon. In Illustrator's layer structure, this layer is opaque, hiding all elements beneath it and creating the base over which all the other hydrological rasters are layered.

9. Representing Wetlands

In my earlier work with the Great Marsh in Massachusetts (Figure 10), I developed a more visually descriptive method based on elevation data to represent the salt marsh, instead of using the standard topographic symbol of herbaceous growth. Because the salt marsh was within USGS's consistent one-meter terrestrial coverage, I could leverage that data with a straightforward hypsometric color ramp from a darker teal green to a warmer yellowish green. At this scale, the darker teal color highlighted the historical and destructive ditching seen throughout the marsh.

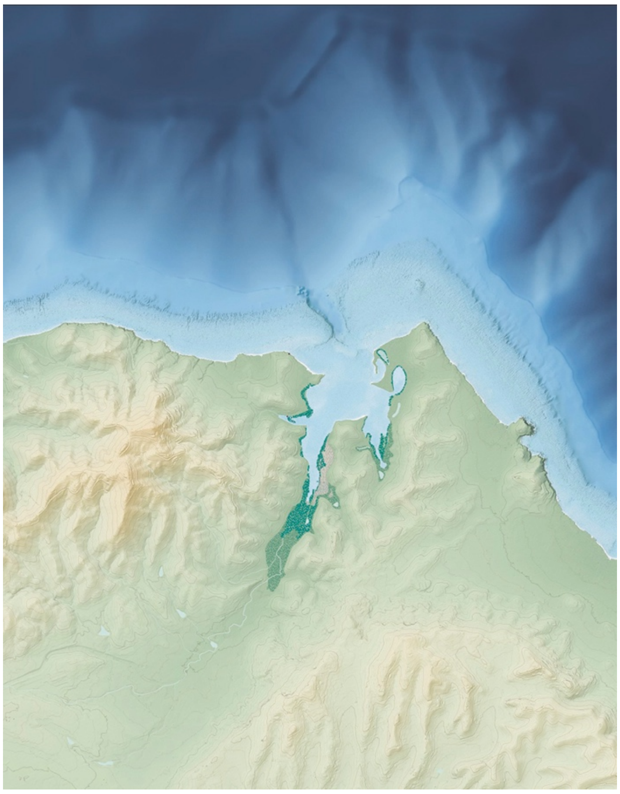

Figure 9. The tallest summit on the map subtly enhanced to improve the visual hierarchy without overwhelming the mangroves.

Figure 10. Map of the Great Marsh. Completed in 2022.

Proceedings of the International Cartographic Association, 6, 5, 2024. https://doi.org/10.5194/ica-proc-6-5-2024
12th Mountain Cartography Workshop of the ICA Commission on Mountain Cartography, 11–15 April 2023, Snow Mountain Ranch, CO, USA.
This contribution underwent single-blind peer review based on submitted abstracts.

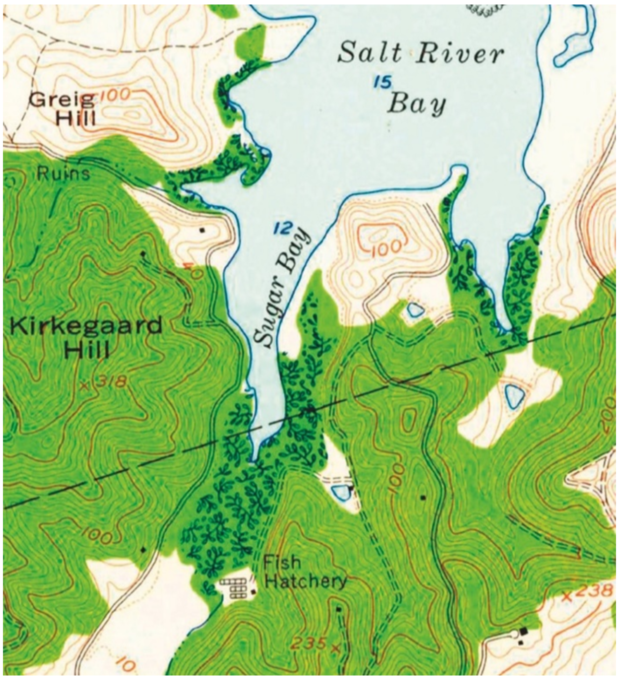

Figure 11. A 1958 USGS topographic map detail used leaves and branches to identify mangroves (United States Geological Survey 1958).

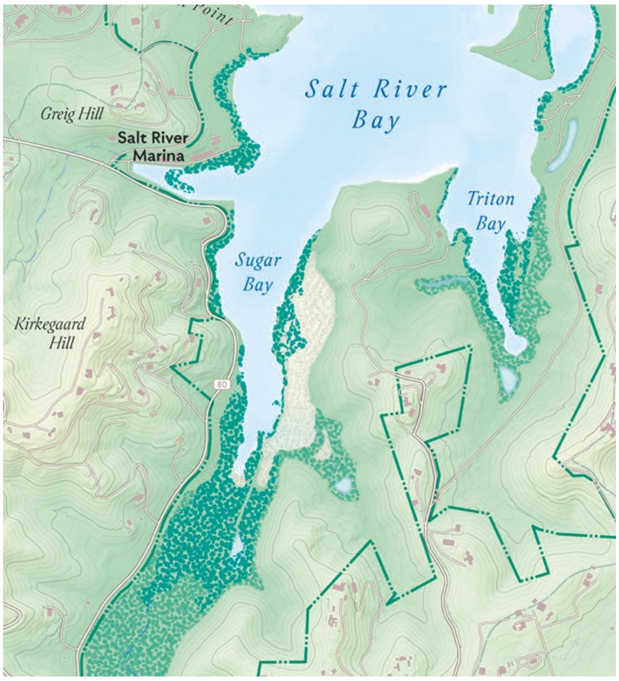

Figure 12. A more scale-appropriate symbol of dense dots of varying sizes.

10. Mangroves

Mangroves, on the other hand, grow above and below the high-water mark. They are woody, dense, and tall shrubs with roots that stabilize the substrate and provide critical habitat for young fish. They have branches that offer protected stands for birds to roost and are now recognized for their ability to store carbon. Their ecological value is widely recognized.

Due to their growth structure and habitat, designing more visually descriptive mangrove symbolization is cartographically challenging. Because mangroves, and many other wetland types, exist on the cusp of land and water, they defy crisp hydrological boundaries. They represent a transition zone between land and water, not an edge.

11. Salt River Bay Mangroves

To represent the Salt River Bay mangroves, I considered a USGS symbol that was more common earlier in the twentieth century and seen in a 1958 USGS topographic map of Salt River (Figure 11, United States Geological Survey 1958). While I think this symbol is more appropriate than the classic herbaceous growth symbol, it seems to represent landscape-scale vines, not woody shrubs. As a result, I created an Illustrator-based symbol of varying dot sizes. While it is not as transparent to the water beneath as I'd like it to be, it does convey dense foliage and works well in Illustrator. To place the slim fringes of mangroves at the top of the visual hierarchy, I used a bright, saturated color (Figure 12).

12. Conclusion

While the workflows described here are customized and involve many layers, they are relatively easy to reproduce. Despite the disparate datasets, it's possible to create a cohesive shaded relief map from summit to sea by targeting a continuous color scheme and relying on Tom Patterson's adaptable Photoshop-based illuminated shaded relief workflow to define and blend in the discontinuous terrain details. Since wetlands of all types are part of any coastal geography, there are opportunities to explore and improve how they are represented, particularly for large-scale maps.

13. References

NOAA. 2024. "Light and Color in the Deep Sea." Accessed January 9, 2024. https://oceanexplorer.noaa.gov/edu/materials/light-and-color-fact-sheet.pdf.

Patterson, Tom. 2024. "See the light: How to make illuminated shaded relief in Photoshop 6.0." *Shaded Relief*. Accessed January 9, 2024. http://www.shadedrelief.com/illumination/.

United States Geological Survey. 1958. *Christiansted Quadrangle.* 1:24,000. 7.5 Minute Series (Topographic). Reston, VA: USGS.

Proceedings of the International Cartographic Association, 6, 5, 2024. https://doi.org/10.5194/ica-proc-6-5-2024
12th Mountain Cartography Workshop of the ICA Commission on Mountain Cartography, 11–15 April 2023, Snow Mountain Ranch, CO, USA.
This contribution underwent single-blind peer review based on submitted abstracts.