The South Carolina Water Monitoring Portal – A Hub for South Carolina Water Quality Monitoring Data

Duncan R. Williamson[1], Norman S. Levine[2], Brooke R. Saari[3], and Landon Knapp[4]

AUTHORS: [1]Research Assistant, College of Charleston Environmental and Sustainability Studies Graduate Program and South Carolina Sea Grant Consortium, 287 Meeting St., Charleston, SC, 29401, USA. [2]Professor, College of Charleston Department of Geology and Environmental Geosciences, 66 George St., Charleston, SC, 29424, USA. [3]Coastal Environmental Quality Program Specialist, South Carolina Sea Grant Consortium, 287 Meeting St., Charleston, SC, 29401, USA. [4]Coastal Resilience Specialist, South Carolina Sea Grant Consortium and College of Charleston Department of Geology and Environmental Geosciences, 287 Meeting St., Charleston, SC, 29401, USA.

Abstract. The South Carolina (SC) Water Monitoring Portal is an ArcGIS-based, geospatial application that incorporates water quality data from a variety of sources and projects them onto an interactive map. This application will provide those interested in accessing and retrieving South Carolina water quality data with a free and easy-to-use tool that allows for spatial visualization, interaction with, and direct download of data. At the time of this publication, the application accesses roughly four million water quality data records collected by seventeen different organizations. To allow users to seamlessly find and access the data they need, filters are available to query the data to match the user's needs. Once users find the data applicable to them, they can download and export it into various formats. The application also allows groups and organizations to indirectly upload their own water quality data to have it incorporated into the application. With these capabilities in a spatial format, this application has the potential to provide many benefits. For example, in academia it could be utilized in both classroom and research settings, and regulatory agencies could use this application to communicate water quality from a spatial viewpoint, potentially fostering a better understanding of water quality to stakeholders. The management and protection of our state's waters are difficult to achieve when the data pertaining to water quality isn't easily accessible or available in a user-friendly format. The SC Water Monitoring Portal has the potential to aid in the protection and management of our state's waters as it makes water quality data more accessible and the retrieval of data more user-friendly. The SC Water Monitoring Portal is hosted on the South Carolina (SC) Sea Grant Consortium and the College of Charleston's Lowcountry Hazards Center websites, making it available to anyone interested in water quality data in the State of South Carolina (available online: www.scseagrant.org/SCWMP).

INTRODUCTION

Following Hurricane Joaquin in 2015, a SC Sea Grant Consortium-supported tool was created with goals of coordinating and capturing where water quality samples were being taken, what organizations were sampling, and what was being tested. This tool, however, did not receive the necessary upkeep or marketing for it to be appropriately utilized. On August 12, 2021, the SC Sea Grant Consortium's Coastal Environmental Quality Program hosted a workshop that brought together stakeholders from various organizations around the state with a focus on a renovation of the previous tool based on the needs and wants of the stakeholders and their vision for its future. The stakeholder feedback determined

that a new tool, the SC Water Monitoring Portal, would be created with increased emphasis on data visualization and accessibility. The development of the SC Water Monitoring Portal began in August 2021 and is now complete.

The application allows users to see water quality data collection sites, and view, filter, and download the water quality data contained therein. The application's spatial format and ability to allow users to interact with and download data allows for ease-of-use, while also providing added functionality that existing applications lack. For example, the South Carolina Department of Health and Environmental Control (SCDHEC) SC Watershed Atlas (SCDHEC 2023) shows many different types of water quality monitoring sites but does not physically house water quality data within the appli-

cation for direct retrieval. Another example is the United States Geological Survey (USGS) National Water Dashboard (Miller et al. 2022) which only contains a handful of water quality monitoring stations in South Carolina (~50 stations) compared to the number included in the SC Water Monitoring Portal (~7,600 stations). Additionally, the data contained in the previously created SC Sea Grant Consortium tool was not extensive and was confined to coastal shoreline counties, as designated by the National Oceanic and Atmospheric Administration (NOAA) (NOAA n.d.; Ache et al. 2015). To expand that coverage, the SC Water Monitoring Portal encompasses data from across the entire state while also drawing data from additional coastal sources.

The SC Water Monitoring Portal retrieves data from the federal water quality data dissemination system: the Water Quality Portal (WQP) (WQP 2023). The WQP is a nationally accepted data dissemination system used to submit and retrieve water quality data across the United States (Shumway et al., 2021). The system was created and is managed by the Environmental Protection Agency (EPA), the USGS, and the National Water Quality Monitoring Council (NWQMC). The WQP retrieves data from the Water Quality Exchange (WQX), the EPA's water quality monitoring data repository, and allows users open access to the standardized data therein. A wide range of organizations and groups have submitted data to this repository, including governmental agencies, tribes, watershed groups, volunteer organizations, and universities. While the WQP is a useful tool to access the data contained in the WQX, there is currently no way to visualize the data from a spatial perspective within the portal. A user needing data covering a specific geographic area is asked to provide either: 1) four bounding coordinates that encompass the data (without a map to determine the coordinates), 2) a state name, 3) a county name, or 4) a hydrologic unit code (HUC) to narrow down the data request. This, however, can be limiting to a user with a unique area from which they would like to retrieve data (i.e., a polygon with greater than 4 vertices), for those not attuned to HUCs/coordinates, or users without a highly specific data request. To overcome these limitations, the SC Water Monitoring Portal provides a highly visual interface that allows users to view, filter, and download all South Carolina-based water quality data contained in the WQX.

MODEL DEVELOPMENT

The SC Water Monitoring Portal was created using a suite of ESRI products. ArcGIS Pro was used for data manipulation, ArcGIS Online and ArcGIS Enterprise were was used for data management, and ArcGIS Web App Builder was used to create the application. ArcGIS Web App Builder was chosen from the suite of products within ArcGIS Online to create

the SC Water Monitoring Portal due to its ability to configure fully featured applications without implementing code.

All South Carolina water quality data distributed by the WQP were downloaded and moved into ArcGIS Pro for data manipulation. The data were then trimmed by removing fields that were deemed not pertinent for use in the SC Water Monitoring Portal. The data were then divided into groups based on the organization that collected the data. The organizations with the three highest volumes of data were the SCD-HEC, USGS, and EPA. All organizations that had minimal data records were aggregated and termed "Others." Additional geographic data were also generated in ArcGIS Pro including SC counties, watersheds (HUC 10), and sub-watersheds (HUC 12). A layer with information regarding data volume counts for each county was also generated using various geoprocessing tools available in ArcGIS Pro. These data were then exported from ArcGIS Pro to ArcGIS Online for the data to be integrated into this platform. From ArcGIS Online, the data were imported into a web map interface, and the symbology was altered so that the water quality data were color-coded based on the organization that collected the data. Additional data layers were then added to the web map interface by means of a REST, or representational state transfer, web service. A REST web service works, in this instance, as a means of referencing and retrieving data from another web-based source without having to physically store it. Using this REST web service, approved TMDL (total maximum daily load) site data and impaired waters – 303(d) site data were referenced and retrieved from the SC Watershed Atlas (SCDHEC 2023). The web map interface, along with all the data contained therein, was then migrated into ArcGIS Web App Builder to create the application.

At the time of publication, the application contains roughly four million data records. Due to the high volume of data, various filters were created to allow users to narrow down the return of data and make it easier to find data pertinent to their needs. Currently, there are six different filters that users can utilize: location-based filters (county level, watershed level (HUC 10), and sub-watershed level (HUC 12), a time filter, an organization filter, and a water quality parameter filter. These filters can be used alone or in conjunction with each other to narrow down the return of data, e.g., County: Charleston, Parameter: pH, Time Period: Nov 1999–Dec 2001. See Figure 1 for a depiction of the various filters included in the application and how they can be combined to make a data request more specific.

After utilizing the filtering capabilities available, additional tools were added and are available to provide further functionality and increase ease of use for users. See Table 1 for a list of the different tools, a description of how they function, and a depiction of how they function. Within the application, there is also a link to an ArcGIS Story Map that
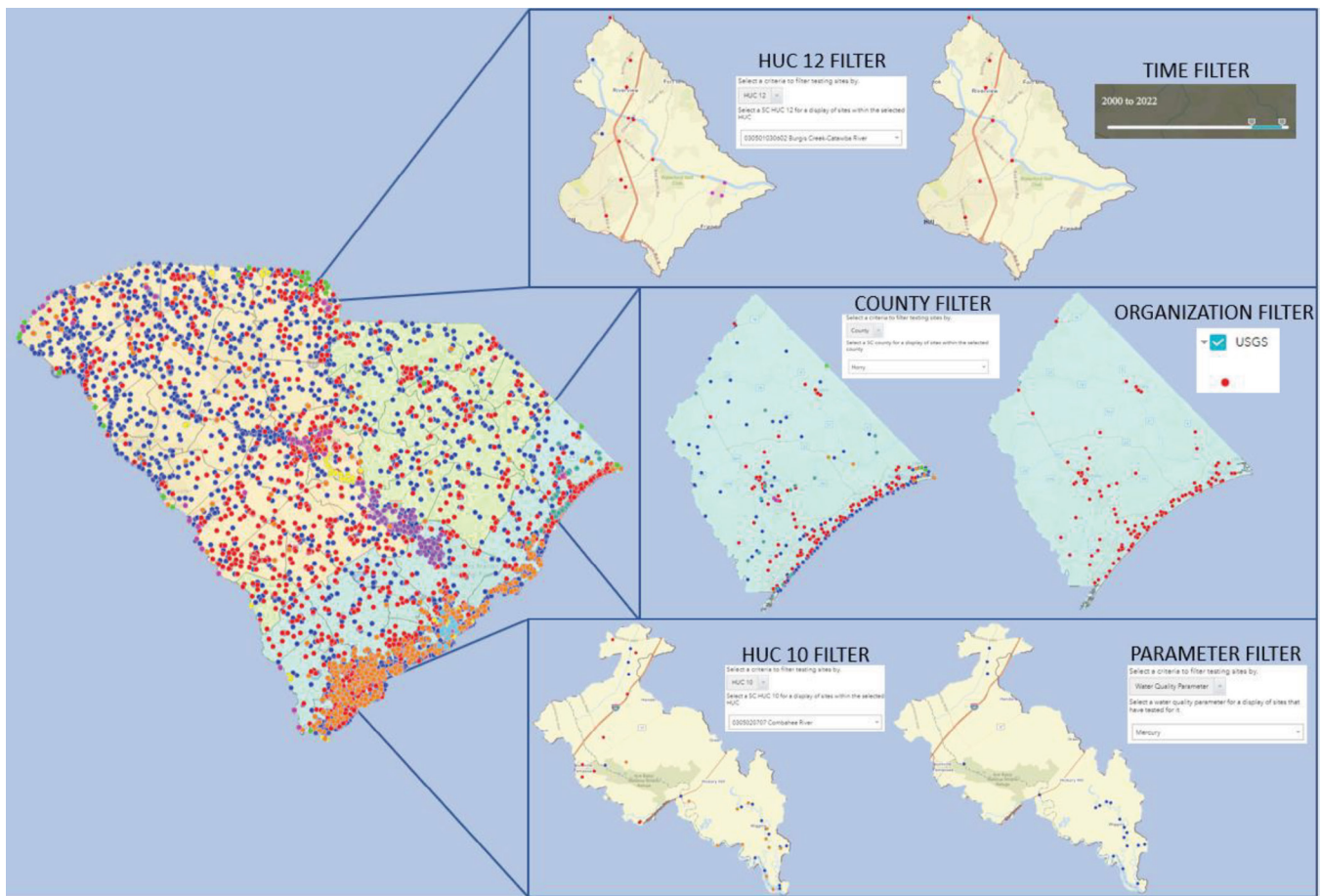
Figure 1. Depiction of the different filters included in the SC Water Monitoring Portal.

provides users with step-by-step directions and video tutorials on how to properly use the application.

Once the application was completed from a developmental standpoint, it was sent to beta testers for feedback. This feedback was extremely helpful in shaping improvements to the application's interface and inspiring the addition of some of the tools that the application lacked prior to beta testing.
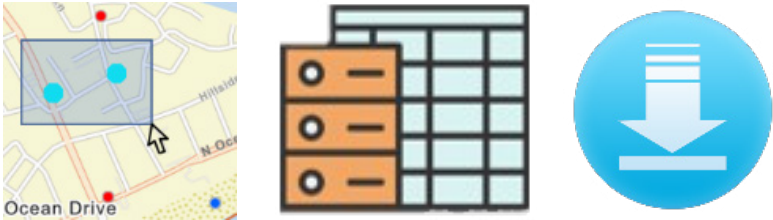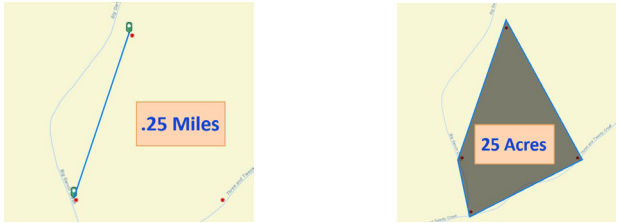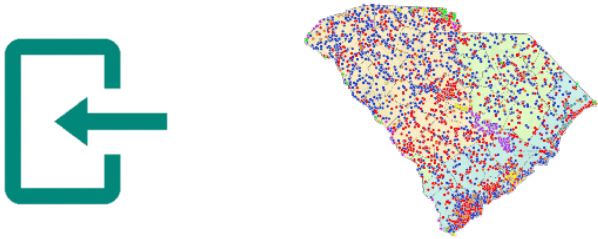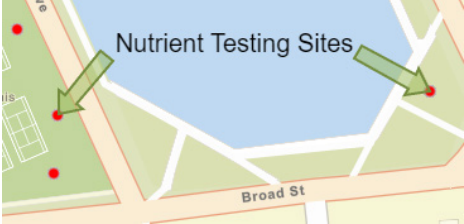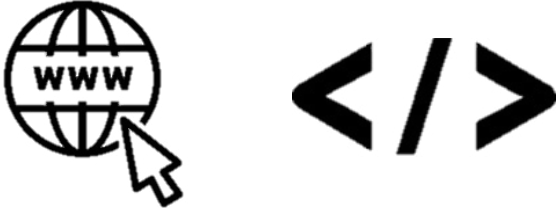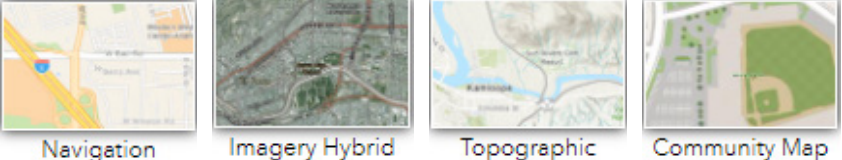
RESULTS

The functions and tools previously described are fully operational within the application. These functions implemented in this spatial format, with direct data availability, are what sets this application apart from other applications. See Figure 2 for a view of the application's interface with labels indicating the location of each of the tools. The application is currently hosted on the SC Sea Grant Consortium and College of Charleston's Lowcountry Hazards Center websites (available online: www.scseagrant.org/SCWMP). Updates to the data contained in the application will occur quarterly to include new data. However, with the

WQX now performing quality assurance and quality control (QA/QC) on newly submitted data, there will be a natural time lag between when 1) data gets submitted to the WQX, 2) when it gets accepted by the WQX, and 3) when it gets submitted to the WQP for dissemination.

While the SC Water Monitoring Portal has been developed and completed, the development team experienced issues with its operability throughout the development process. Previously, when the application was opened and the entire state was within the zoom extent, the application struggled with loading all the data on the map, i.e., >1 minute to load and draw the data. If a user attempted to pan around the map and/or zoom in and out, the application would likely experience a crash. It was determined that these issues were due to constraints built into the implementation of the ArcGIS Online server where our data was being stored. This cloud-based server, which is available for general use, could not handle the request load for the volume of data contained in the SC Water Monitoring Portal. After discussions with the ESRI server online implementation teams, it was determined that the standard ArcGIS portal method of implementation

Table 1. List of additional tools that accompany the filtering capabilities within the SC Water Monitoring Portal.

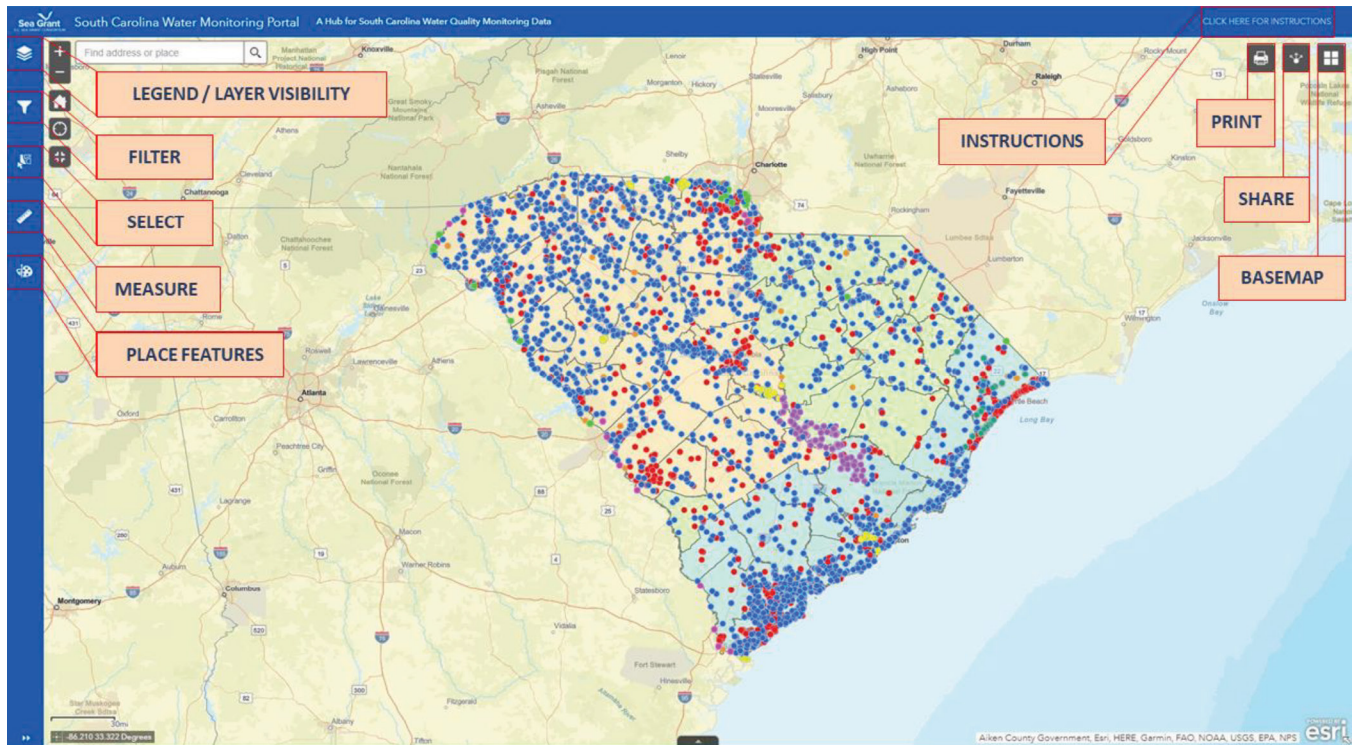| Tool Name	Description of Function	Depiction of Function
Select Tool	Select, view, and download data	
Legend/Layer Visibility Tool	View data layers and associated symbology. Toggle on/off data layers	
Measurement Tool	Measure distances and areas	
Print Tool	Export imagery	
Place Features Tool	Place points, lines, shapes, or text on the map (compatible with Print Tool)	
Share Tool	Generates a URL for sharing the application and HTML code for embedding the application	
Basemap Tool	Switch between different basemaps	

Figure 2. The interface of the SC Water Monitoring Portal with labels added to highlight available tools.

would not be suitable for our configuration of the SC Water Monitoring Portal. These issues were extremely problematic, but the development team found a course of action that resolved the issues of the application crashing and taking extensive amounts of time to render data. This was ultimately achieved by utilizing an ArcGIS Enterprise portal located in the Lowcountry Hazards Center at the College of Charleston that could be configured directly and serve as a data store for the SC Water Monitoring Portal. The steps undertaken by the development team to relieve the application of its memory constraints are discussed below.

The first course of action of the development team was to utilize a REST web service, like how SC Watershed Atlas data were already being retrieved, to display the data and allow for data downloads without storing data within the application itself. In this scenario, a REST web service would allow the SC Water Monitoring Portal to reference and retrieve updated data from the WQP automatically. The REST web service acts as the mediator between the ArcGIS Online server and the WQP by sending a query to the WQP and directing the data that meets the query's criteria to the ArcGIS Online server. This data is then displayed in the SC Water Monitoring Portal through communication with the ArcGIS Online server that is referencing WQP data. This solution was unsuccessful because the REST web services for results data that the WQP offers are currently not functioning in an ArcGIS environment, and the date for their reinstatement has not

been determined yet (Jesse Boorman-Padgett, pers. comm., 10/12/2021; unreferenced, see "Acknowledgements"). The WQP REST web services are not currently compatible with ArcGIS-based servers because of their inability to process large data volumes that are contained and distributed by the WQP. This scenario may be a solution in the future as WQP REST web services will become available at a later date (J. Boorman-Padgett, personal communication, 10/12/2021). Implementing REST web services will be the first course of action for the development team upon its release, as it would enhance the capabilities of the SC Water Monitoring Portal by allowing for direct use of data from the primary source while eliminating the memory constraints of housing data on our server. Additionally, it would significantly decrease the amount of upkeep that the application requires through the current process of manual data retrieval and integration from the WQP.

Our second course of action to address portal issues was to limit the scale at which the application began to load the water quality data. We implemented this limit so that when the application is opened, no water quality data is loaded or displayed. Instead, we generated water droplet symbols that overlay each county and summarize the data volume contained. The symbols are sized based on the volume of water quality data collected in that county and can be selected from this zoomed-out state to view the count of data records. The implementation of this solution significantly reduced the

amount of strain on the application at startup. It increased performance while still giving users a generalized idea of where the data is geographically located. Users must then zoom in to a smaller extent or apply filters to narrow down the data return (which automatically zooms you to the extent of that data request) to view the actual water quality data.

Our last and most recent solution has physically increased data display speeds. The water quality data was moved and is now maintained on a registered (federated) ArcGIS Enterprise portal located on a server maintained by the Lowcountry Hazards Center at the College of Charleston. Managing the data this way avoids copying the data to the local ArcGIS Online server and has sped up the recall and display functions of the application. This solution will also facilitate the integration of the WQP REST web services when they become available because the formats between the two systems will be compatible.

DISCUSSION

The SC Water Monitoring Portal describes abilities for groups or users to have their data uploaded directly to the application. The development team initially identified direct data upload capabilities as a goal for the application; however, it has been determined that users should instead be directed to upload their data to the WQP. These data are subsequently ingested into the SC Water Monitoring Portal when the application is updated. The reason for this is that data standardization is a crucial component in maintaining the operability and integrity of the application. It has been noted that water quality data are much more valuable and can be used beyond their original intended use when they are published in a standardized format (Sprague et al. 2017). With the WQX maintaining standardization of any data distributed by the WQP, it is logical to retrieve data for our application from this already standardized source which is also now going through QA/QC measures. At the time of this publication there are roughly four million water quality data records included in the SC Water Monitoring Portal. These data were collected at ~7,600 different water quality sampling sites by seventeen different organizations.

The SC Water Monitoring Portal was recently submitted to beta testing and feedback was received regarding suggested improvements to the application. Beta testing is invaluable in the development of software like this application, and the feedback that is generated cannot be emulated by a development team alone (Neff and Stark 2004). The feedback that was received included changes to the interface of the application, revisions in wording, and many updates to the application's functionality. This feedback was incorporated into the application and highlights the importance of prioritizing a "beta testing phase" in the development of an application. Now that beta testing has concluded and feed-

back has been incorporated, the application is now deployed and is hosted on both the SC Sea Grant Consortium and the Lowcountry Hazard Center websites. The SC Water Monitoring Portal can now serve as a hub for water quality data access and retrieval in the State of South Carolina.

ACKNOWLEDGEMENTS

REFERENCES

Ache BW, Crossett KM, Pacheco PA, Adkins, JE, Wiley PC. "The coast" is complicated: A model to consistently describe the nation's coastal population. Estuaries and Coasts. 2015;38:151–155.

Miller MP, Burley TE, and McCallum BE. Visit the U.S. geological survey's national water dashboard: U.S. geological survey general information product 213. 2022. https://doi.org/10.3133/gip213.

National Oceanic and Atmospheric Administration (NOAA). Defining Coastal Counties. PDF: (n.d.). [Retrieved 2023 Mar 20]. https://coast.noaa.gov/data/digitalcoast/pdf/defining-coastal-counties.pdf.

Neff G, Stark D. Permanently beta. Society Online: The Internet in Context. 2004;173:188.

SC Department of Health and Environmental Control (SCDHEC). SC Watershed Atlas; 2023. https://gis.dhec.sc.gov/watersheds/.

Shumway L,J Mullin CA, Rabon B, YoungDA. Guest commentary - South Carolina water quality monitoring data elevated for research, decision making, and the internet of water. Journal of South Carolina Water Resources. 2021;8(2). DOI: 10.34068/JSCWR/08.02.03

Sprague LA, Oelsner GP, Argue DM. Challenges with secondary use of multi-source water-quality data in the United States. Water Research. 2017;110:252–261. DOI:10.1016/j.watres.2016.12.024.

Water Quality Portal (WQP). Washington (DC): National Water Quality Monitoring Council (NWQMC), United States Geological Survey (USGS), Environmental Protection Agency (EPA); 2023. https://www.waterqualitydata.us.