



Long-Term Water Quality Trends in USEPA Region 3 (Mid-Atlantic)

FINAL REPORT

September 27, 2017

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Water Protection Division
Philadelphia, PA 19103-2029



ICPRB Report 17-5
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This report is available for download from www.potomacriver.org.

Disclaimer

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Acknowledgements

This project was supported by funds from the United States Environmental Protection Agency through CWA§106 grant 98339413 to the Interstate Commission on the Potomac River Basin, an interstate compact river basin commission of the United States government and the compact's signatories: Maryland, Virginia, Pennsylvania, West Virginia, and the District of Columbia.

Cover image

Potomac River mainstem monitoring station at Knoxville, MD. Photo by Gordon Michael Selckmann.

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Summary

The Interstate Commission on the Potomac River Basin (ICPRB) assembled and analyzed ambient water quality data in the United States Mid-Atlantic region to investigate long-term trends in non-tidal streams and rivers. The purpose was to identify broad-scale water quality trends since the 1970s, when the U. S. Congress enacted the Clean Water Act, the Clean Air Act, and other pollution-related legislation. Water quality parameters selected for study are those important to aquatic life and human health, and are influenced by anthropogenic disturbance.

Data were limited to those downloadable from the [STOrage and RETrieval \(STORET\) Legacy Data Center](#) and [Water Quality Portal](#) (WQP) as of November 2015, although data from West Virginia's Ambient Water Quality Monitoring Network through 2012 were eventually added. ICPRB identify over 1,195 sites in EPA Region 3 with records for one or more water quality parameters collected in the 44-year period between 1972 and 2015. The dataset is not comprehensive and still needs significant QA/QC to harmonize various parameters.

ICPRB developed an interactive, flexible, computer application (App) to better examine and quality assure data. This "Water Quality Data Explorer" App allows users to check station geographic coordinates and locate nearby flow gages, visually assess sampling frequency, identify outliers, determine if minimum detection limits (MDLs) are influencing apparent trends, view seasonal patterns and flow-normalized time series, and review metadata and related literature. ICPRB intends to continue building the App and populate it with additional data. The App will eventually be made available online through the www.potomacriver.org website where it can help analysts and decision-makers evaluate water quality trends.

The risk inherent in drawing conclusions about water quality trends based on data with often unknown quality, and uneven temporal and spatial coverage, eventually dissuaded ICPRB staff from applying anything more than a step-trend analysis to the data. Parameter values in two 17-year periods, 1972 – 1988 and 1999 – 2015, were compared using this simple trend method.

Broad-scale, long-term step-trends in multiple parameters are evident in the mid-Atlantic and demonstrate progress in accomplishing some desired outcomes of the 1970s legislation. Phosphorus and organic carbon concentrations have decreased significantly, allowing streams and rivers to recover from eutrophication. Reductions in "acid rain" and acid mine drainage are alleviating acidification of surface waters and reducing concentrations of toxic metals.

Recent short-term trends in some water quality parameters are leveling off or reversing, suggesting earlier accomplishments are becoming overwhelmed by continued population growth in the region. Trend results also are pointing out some emerging issues in the region. Higher levels of total dissolved solids, chloride, and specific conductance reflect the impacts of more landscape disturbance, road salt application, and possibly hydraulic fracturing for natural gas.

Long-Term Water Quality Trends in USEPA Region 3 (Mid-Atlantic)

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9-12-2017

Introduction

The recent literature abounds with trend studies on water quality data collected by long-term monitoring programs. Many of these programs were instituted in the United States in the 1970s in response to the 1972 Clean Water Act and subsequent environmental laws. They first relied on field staff to collect water samples. Collection methods now include automatic samplers (“continuous monitors”), semipermeable membrane device (SPMD) samplers, flow-through samplers, and satellite imagery. Sampling frequency over time typically has been uneven as funding and programmatic objectives changed. Biases caused by uneven sampling frequencies, inadequate sample numbers, measurements below detection limits, analytical method changes, streamflow impacts, and outliers are often found. Trend results for individual stations can vary and are at times contradictory, depending on the period(s) analyzed, the trend method applied, the data’s inherent variability, and the degree of non-linearity in the trends. However, the risk of finding trends where none occur, and *vice versa*, is diminishing as the period of record lengthens. A preponderance of long-term trends in the same direction can indicate success in accomplishing major legislative goals.

The Interstate Commission on the Potomac River Basin (ICPRB) recently undertook a project to assemble and analyze ambient water quality data from non-tidal stream and river stations with long-term records. The purpose was to evaluate the general direction of water quality trends since the 1970s. The study area is the Mid-Atlantic regional district (Region 3) of the U. S. Environmental Protection Agency (USEPA), which consists of Pennsylvania (PA), Delaware (DE), Maryland (MD), West Virginia (WV), Virginia (VA), and the District of Columbia (DC). The parameters selected for study are those important to aquatic life and influenced by anthropogenic disturbance. Data were drawn from the [STORAGE and RETRIEVAL \(STORET\) Legacy Data Center](#) and the [Water Quality Portal](#) (WQP), although data from West Virginia’s Ambient Water Quality Monitoring Network were eventually added. Legacy STORET is a static, open access database containing historical (pre-1999) ambient water quality data of undocumented quality, most of which was collected by U.S. state, tribal, and federal agencies. The WQP contains publicly available data submitted by over 400 state, federal, tribal, and local agencies to three national data systems: the USEPA STORET Data Warehouse, the U.S. Geologic Survey (USGS) National Water Information System (NWIS), and the U.S. Department of Agriculture (USDA) Sustaining the Earth’s Watersheds-Agricultural Research Data System (STEWARDS). ICPRB identify 1,195 sites in Region 3 with records for one or more water quality parameters that continuously or intermittently span a 44-year period between 1972 and 2015. The data download and preparation steps are described in Appendix A.

ICPRB also searched the literature for long-term water quality trend studies in Region 3 streams and rivers. Multiple studies have analyzed station trends in the region. The USGS performed many of these studies and their reports are available through the [USGS Publications Warehouse](#). Other trend studies were performed by universities, and federal, state, and interstate agencies. In early 2017, USGS released its [interactive trend mapper](#), a visualization tool showing trends in 51 water-quality parameters and 38 aquatic-life metrics across the nation for four time periods: 1972-2012, 1982-2012, 1992-2012, and 2002-2012. Their initial dataset of water-quality and ecology records from approximately 480,000 sites

and more than 600 organizations was rigorously screened and eventually reduced to approximately 1,400 sites nationally that met stringent criteria (Oelsner et al. 2017).

We came to the following conclusions after assembling and QA'ing the Region 3 dataset, selecting sites with records extending to the 1970s, and reviewing the available trend studies:

- 1) Sampling frequencies in Region 3 vary drastically between and within programs, so grouping data into set time periods and applying data density requirements to each period results in a substantial loss of stations and data, and consequently a large drop in spatial coverage;
- 2) Set time periods do not necessarily correspond to the timing of specific management actions on individual streams (e.g., WWTP upgrades, BMP implementation, acid mine drainage mitigation); and
- 3) A parameter's concentration typically does not increase or decrease consistently (monotonic) over long periods, even when flow-normalized, so simple up/down/no change trend symbols can be misleading.

The risk inherent in drawing conclusions about water quality trends based on data with often unknown quality and uneven temporal and spatial coverage eventually dissuaded us from applying many of the available trend analysis methods to our selected data. We decided to build an interactive computer application using a variety of visualization tools that could help us quality assure (QA) the available data. We felt this application could help other data managers and analysts QA the data. Users would be able to interactively explore the data characteristics at individual monitoring sites, review seasonal patterns, visualize actual and flow-normalized time series in the data, and flag or correct problematic data. The quality assured data should allow decision-makers to view water quality trends with more confidence, and better evaluate if changes are due to land and water resource management actions.

Although the online application will most likely be more useful to water quality professionals, we also performed a straightforward step-trend analysis to get a general sense of changes occurring in EPA Region 3 since the 1970s. The results were compared to a few of the published trend studies for the region. We limited the analysis to non-tidal streams and rivers to avoid, among other things, the confounding influences of ocean water inputs and tidal action.

Data Download and Preparation

Data downloaded from Legacy STORET and the Water Quality Portal (WQP) were merged to form the initial water quality database for EPA Region 3. Below is a summary of how the data were prepared. A detailed description of the data preparation, including the R-scripts used during processing, is available in Appendix A. Legacy STORET became defunct and was archived after 1998; therefore, it only contains data submitted to EPA prior to 1999. Large quantities of historical data are still only accessible from the Legacy STORET database. Some of the Legacy STORET data were re-submitted and are available through the WQP. However, the WQP primarily contains data from 1999 and later. The Legacy STORET and WQP data cannot be easily merged. Parameter names in the Legacy STORET and WQP databases rarely matched, and within each of these two data sources there were inconsistent names provided by different agencies for the same parameter. Many of the column names also are not consistent. ICPRB made several efforts to match parameter names and columns from the two data sources. In many ways, the WQP format was more descriptive and comparable columns were not found in the Legacy STORET database; thus, information gaps exist in the merged database.

We noticed recent (post 1999) WVDEP data were mostly absent in the WQP download. Data through 2012 had been given to ICPRB by WVDEP for another project (Buchanan and Mandel 2015) and were added to this study's Region3 database.

ICPRB parameter codes (and in some cases conversion steps) were created and assigned to the original parameter names in the data obtained from Legacy STORET and WQP. Parameter names in Legacy STORET data were evaluated, matched if possible, and given common ICPRB parameter codes with the help of Mary Ellen Ley, a chemist who until recently was the Quality Assurance Officer at the Chesapeake Bay Program. Parameter names in the WQP data went through a similar review in-house at ICPRB and were then matched with the ICPRB codes. The original parameter names, values, and units were retained and additional columns contained the standardized parameter name, parameter value, reporting units, and the conversion factor applied. Potentially valid data were not used if their parameter identifications were uncertain. For example, the various forms of dissolved, particulate, organic, and inorganic nitrogen and phosphorus could not be classified to our satisfaction. These data would have been helpful in identifying likely sources of the two nutrients.

Daily flow values were associated with water quality measurements when possible. Water quality values can be skewed by flow, which ultimately affects trend interpretations (e.g., Langland et al. 2012). The influence of flow can be reduced through a flow correction step. Mean daily flow data collected at USGS flow gages in Region 3 were downloaded from <https://waterdata.usgs.gov/usa/nwis/rt>. Water quality parameters measured at USGS gage stations could be directly related to flow values. Other water quality stations were associated with nearby flow gages. Gages and stations were matched using ArcMap (version 10.2) spatial join with a search radius of two miles and the match option set to closest. Matches were manually verified to assure that the matched gage and station(s) were located on the same stream. Any gage-station combination that had an inflowing stream with a Strahler stream order greater than 1 between the gage and station were discarded. Only long-term gages with start date of < 1980 and end data of >= 2000 are included. For more information, please see Appendix B.

Water Quality Data Explorer

The Water Quality Data Explorer application (App) was created with the R package “shiny” (Chang et al. 2017) and is accessible through the ICPRB webpage (www.potomacriver.org). EPA Region 3 data are organized and presented in a variety of ways to illustrate different aspects of the data. Currently, the App emphasizes trend visualization, spatial visualization, detailed tabular information, and summary of the tabular information. An App was developed because a more traditional text document quickly becomes overwhelmed and difficult to navigate if additional data are incorporated. The App enhances the user’s ability to explore the data and provides scalable framework for supplementary data.

The data scrutiny and trend methods applied in the USGS [interactive trend mapper](#) (described in Oelsner et al. 2017) are more robust and the analysis more sophisticated than the straightforward step-trend approach used in this study. If the App user identifies differences between the two products, we recommend the user place more confidence in the USGS (2017) trends. Also, if the user’s objective is to identify long-term trends with a specific analysis method, we recommend the user analyze the data (available for download via the App) with their selected method. We maintain the shiny App is most useful for data exploration. It includes many parameters and sites that did not meet the strict requirements of Oelsner et al. (2017), but provides the user with more information with which to formulate hypotheses. In the future, we hope it can provide flexibility in exploring trends for periods specified by the user.

In the existing STORET-WQP database created for EPA Region 3, there are approximately 1,195 stations represented by at least one of the 54 selected water quality parameters. We found many inter- and intra-source inconsistencies in the reported units, laboratory analysis methods, and other metadata as well as what appear to be data entry errors. Although the preliminary data munging steps aim to standardize the data, many factors, such as inconsistent sampling frequencies or collector bias, cannot be easily standardized. We recommend that the user perform their own QA/QC measures prior to making any formal conclusions.

PostgreSQL Database

The STORET-WQP data for EPA Region 3 data are organized in a PostgreSQL database and is available upon request. This was done to avoid loading all the data into the App at once or manipulating all the data in R while the App is running, both of which crash the App. The user is prompted to identify specific stations and parameters for examination, and only the data of interest are imported to the App from the PostgreSQL database. Querying in SQL is generally faster than within R; therefore, the query is defined in R, sent and processed in SQL, and the results from the query are returned to R. The “DBI” package is used to connect to the database (R Special Interest Group on Databases (R-SIG-DB) et al. 2017), the “pool” package is used to manage connections (Borges 2017), and the “dplyr” package is used to simplify database queries (Wickham et al. 2017).

Application Features

The App is accessible via a web browser and is composed of a sidebar and five tabs: Figures, Map, Data, Metadata, and Relevant Publications. Dynamic inputs are provided in the sidebar, which dictate the data represented in the five tabs. The App opens on the Figures tab, which provides several figures that summarize the data and allow the user to quickly become familiar with the selected data. An interactive map is provided in the Map tab to allow the user to visualize geographic features and other nearby sampling stations. In some instances, it is helpful to explore the primary data to elucidate patterns observed in the first two tabs. The Data tab allows the user to filter through the primary data to explore additional factors that may influence the reported values, such as a change in the laboratory used, a change in methodology, or a change in location. A large amount of information is provided in the Data

tab, which can be difficult to discern important factors; the Metadata tab was created to summarize the Data tab and other features that may influence the observed trends. Finally, the Relevant Publications tab provides the user with additional sources to further explore or understand an observed trend.

Sidebar

The sidebar is a fixed panel in the App that allows the user to query the data, provides a summary of important aspects of the data, and allows the user to download the data (**Figure 1**). Users can switch between tabs but the content of the tabs is determined by selections made in the sidebar. The sidebar values will not change with the selection of a new tab. Two radio buttons determine if the user queries by parameter (default) or by site. The hierarchy of three dropdown menus (i.e., Parameter, HUC8, and Site) is determined by the radio button selection. Selections made in dropdown menus upstream of one or more dropdown menus alters the choices available in the downstream dropdown menus. The order that the dropdown menus appear reflects their hierarchy. Often, the user will be interested in exploring the data available for a selected parameter and can rapidly switch between all the available sites for the selected parameter. The user may be interested or become interested in all the data available for a site. By selecting the “Site” radio button, under “Query by”, the user can easily sift through all the available parameters for the site selected in the dropdown menu. Additionally, the HUC-8 dropdown menu makes it easy to filter the sites to a sub-basin of interest. This can be helpful when using either query hierarchy.

Under the dropdown menus is a short summary of the selected data. The first section provides information about the parameter: parameters units, number of outliers removed (see Metadata Tab), the percentage/number of censored data points (see Metadata Tab), and list of other parameters available for the selected site. Following the previous section, the “Site Information” section, provides a quick reference to several useful site variables.

The selected site is repeated for clarity at the top of the “Site Information” section. Site variables Agency, Latitude, Longitude, and Depth have the potential to contain more than one element, which will be separated by commas. More than one element is possible because the element may have changed overtime, may justifiably have more than one unique value, or be an artifact of combining multiple databases into one database. For example, there are instances where the Latitude and Longitude of a site changed because the site had to be moved to a different location. There are also instances where Latitude and Longitude changed because more precise GPS equipment was being used. If any elements contained empty rows, then “Blank” is reported. Start and End Dates provide a quick reference to the temporal extent of the available data but can often be misleading because the sampling frequency between these two dates is often inconsistent. All depths in the App are limited to less than 1 m (see

The sidebar contains the following sections:

- Query by:** Radio buttons for "Parameter" (selected) and "Site".
- Parameter:** Dropdown menu with "TEMP" selected.
- HUC 8:** Dropdown menu with "All HUCs" selected.
- Site:** Dropdown menu with "2-APP110.93" selected.
- Units:** deg C
- Outliers Removed:** 0
- Censored Data:** 0% (n = 0)
- Available Parameters:** DO, PH, SPCOND, TEMP, TN, TP, TSS
- Site Information:**
 - Site: 2-APP110.93
 - Agency: 21VASWCB
 - First Date: 03/24/1970
 - Last Date: 01/21/2016
 - State: Virginia
 - Latitude: 37.30725, 37.3073
 - Longitude: -78.38925, -78.3893
 - Depth (m): Blank, 0.3048, 0.999744
 - Replicate: Blank
 - Composite: Absent
- Gage Information:**
 - Flow Gage: 2039500
 - Agency: USGS
 - Flow Gage Location: APPOMATTOX RIVER AT FARMVILLE, VA
 - Latitude: 37.3070965
 - Longitude: -78.388607
- Download:** Two buttons: "Download Plots" and "Download Table".
- Logos and Text:**
 - United States Environmental Protection Agency logo.
 - Text: "United States Environmental Protection Agency. This tool was developed with support from U. S. Environmental Protection Agency (CWA A§106 I-98339413) and the Interstate Commission on the Potomac River Basin."
 - Interstate Commission on the Potomac River Basin logo.
 - Text: "Interstate Commission on the Potomac River Basin. To enhance, protect, and conserve the water and associated land resources of the Potomac River and its tributaries through regional and interstate cooperation. <https://www.potomacriver.org>"

Figure 1. The sidebar from the Water Quality Data Explorer.

Metadata Tab) but multiple sampling depths may still be present in the data. Rows in the database with no reported depth are assumed to be surface samples (i.e., Blank). This assumption may be wrong. If parameter values appear strange, the presence of Blank, in the Depth element, could be a good indicator that depth needs to be explored further. The Replicate element indicates if the data represents one of several samples collected at the same time and location. Furthermore, if any of the samples are composited, then the Composite element reports “Present”; otherwise, the Composite element returns “Absent.” Below the “Site Information” section is the “Gage Information” section, which contains elements that are similar to the previous section but pertain to an associated flow gage, if one exists.

At the bottom of the sidebar is a Download section. Currently the user can click on two buttons to retrieve plots or the primary data table. The “Download Plots” button will download plots in the Figures tab as a .PNG file. Clicking on “Download Table” will download the table in the Data tab as .CSV file.

Figures Tab

The Figures tab provides two or three plots that illustrate a parameter’s values between 1972 and 2016 (**Figure 2**). Plots are created using the R-package, ggplot2 (Wickham 2009). During data preprocessing, the sampling point closest to the center of each month was select to represent each month-year; therefore, the highest possible sampling frequency is one sample per month per year.

A heatmap always appears at the top of the tab, where the x-axis represents years and the y-axis represents months. For each parameter, a color gradient is created between light blue (#56B4E9) and orange (#E69F00). In some instances, thresholds were set to identify extreme values and are colored a solid red (#CD4F39). Interpreting the color gradient cannot be generalized. Thus, light blue does not always indicate “good” conditions and orange does not always indicate “bad” conditions. The color gradient was determined either by Best Professional Judgement (BPJ) or by the available data. For most parameters, the gradient range was established by finding the minimum and maximum of all the data available for a given parameter in the database. This standardized gradient range allows heatmaps for one parameter to be directly compared across multiple sites. Heatmap gradients for DO, PH, TALK, HARDNESS, TEMP, and SPCOND were created using BPJ. For example, temperature in freshwater streams is not expected to go below 0°C or above 29°C; therefore, the TEMP gradient ranges from 0-29°C and any value outside of this range colored red to signify extreme values. The heatmaps allow the user to quickly assess if the selected site and parameter represent a “normal” condition.

The plot below the heatmap present the data in a scatterplot with a locally-weighted regression (LOESS) curve inserted. The x-axis represents time (month) and the y-axis represents the selected parameter’s values at a given site. Uncensored scatterplot points are plotted as light blue circles and censored points are plotted as purple squares. The LOESS curve and its 95% confidence interval are shown. The ggplot2 stat_smooth function default, n = 80, is used to signify that 80 points are used for local fitting of the regression line. The LOESS curve illustrates patterns in the actual data.

If a flow gage was associated with the selected site, then a second scatter plot is generated to view a flow-corrected time series. Each value of the selected parameter and its associated daily mean flow are transformed with the common logarithm (\log_{10}). All zero or missing values are excluded. The \log_{10} value of the parameter is plotted against the \log_{10} value of flow, and a LOESS curve showing the relationship is generated (but not shown) and the residuals calculated. A third plot is then shown on the page. The x-axis represents time (month), the y-axis represents the residuals, and the inserted LOESS curve is the trend in the parameter with the effect of flow removed. Flow-correction can reveal when patterns observed in the previous LOESS plot that are a result of flow and not a particular management action.

EPA Region 3 Water Quality Trends



Figure 2. An example of the “Figures” tab from the Water Quality Data Explorer.

Map Tab

The Map Tab uses the “leaflet” R package (Cheng et al. 2017) to produce a scalable, interactive map (**Figure 3**). App users are limited to the geographic extent of EPA Region 3. Areas outside of the region are slightly washed-out to make the study area stand out. All the sites in the database that monitor the selected parameter are plotted on the map. The selected site is represented by an orange circle (#E69F00) and is slightly larger than the other symbols to emphasize its position. Additionally, if it was possible to associate a flow gage with selected site, then the flow gage is plotted as a dark blue circle (#0072B2). Associated flow gages were not always in the immediate vicinity of the site from which the parameter(s) were collected. Visualizing the distance between the site and the associated flow gage is generally more informative than numeric distance value reported in a table. If flow-corrected values produce an unexpected pattern, the interactive map may inform the user of an intermittent anthropogenic or natural factor between the site and the flow gage that could elucidate the observed pattern. Other sites in the database, associated with the selected parameter, are depicted as gray circles (#999999). Including the additional sites allows the user to quickly estimate how many sites are available for the selected parameter, where spatial data gaps exist, and identify sites near the selected site. Finally, by clicking on a point, a pop-up window will appear with site information.

EPA Region 3 Water Quality Trends

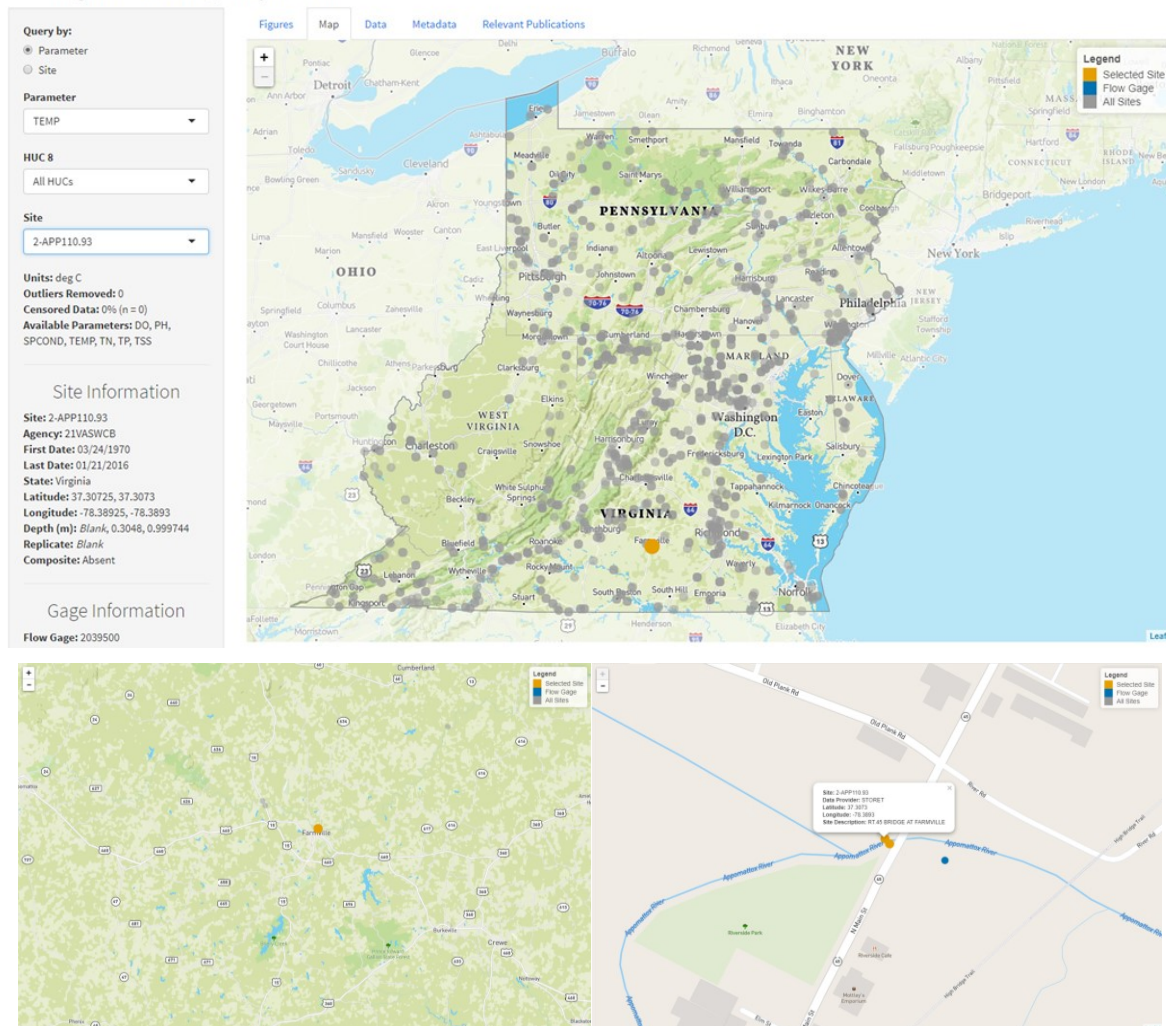


Figure 3. An example of the “Map” tab from the Water Quality Data Explorer. The two lower windows exemplify the ability to zoom in and out of the map.

Data Tab

The Data tab provides an interactive table of the selected parameter and site (**Figure 4**) using the “DT” R-package (Xie 2016). Each column can be sorted and a search box can be used to filter the data. This table is a true representation of the data; it has not been manipulated or summarized in anyway. Generally, it is not helpful to view the data in this format because it is almost impossible to determine any patterns; however, this tab can be very helpful at answering questions that were developed while looking at other tabs. For example, the user may observe a sharp downward trend in the plots from the Figure tab. Looking at the primary data table may inform you that the trend is due to a change in sampling technique. On the other hand, the table may inform you that samples were being collected at the site to monitor the effect of a Best Management Practice.

EPA Region 3 Water Quality Trends

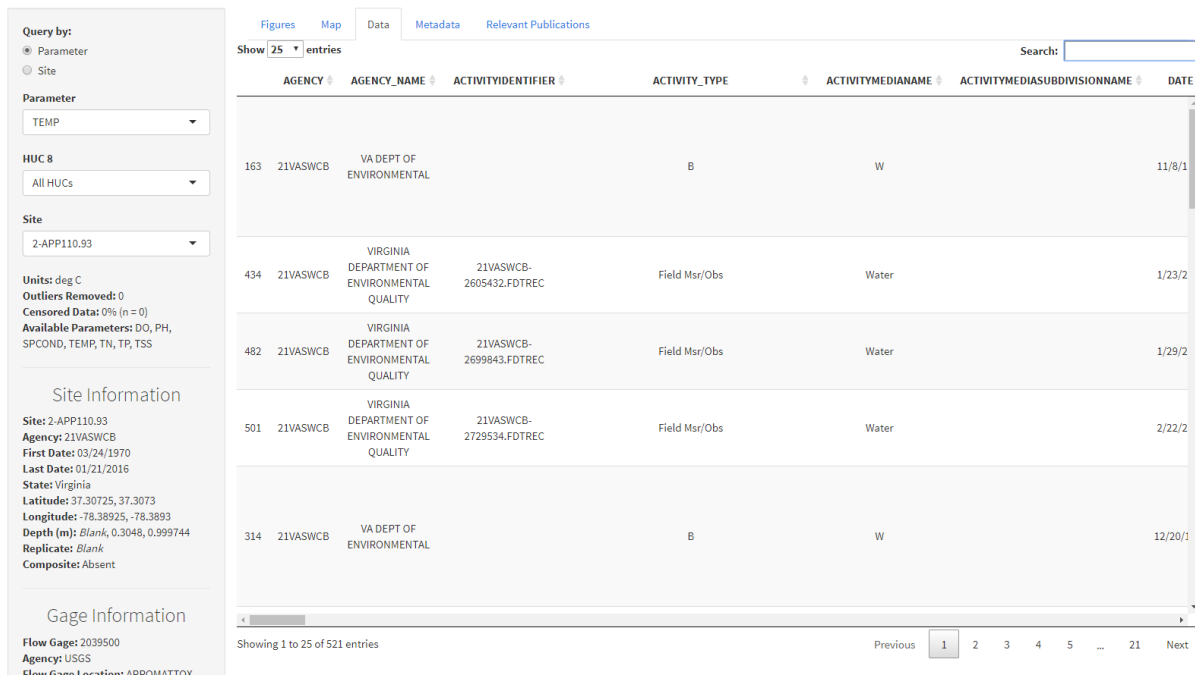


Figure 4. An example of the “Data” tab from the Water Quality Data Explorer.

Metadata Tab

In general, the Metadata tab provides a more detailed version of the information available in the sidebar (**Figure 5**). This tab is currently divided into five sections: 1) Identifying Outliers, 2) Censored Date, 3) Parameter Standardization, 4) Site Information, and 5) Depth. Each section is intended to inform the user of a particular process or to provide more information than can be stored in the sidebar.

The first section, Identifying Outliers, provides a description of how outliers were classified. The interquartile range (IQR) of all a parameter’s data in the database was first calculated. The IQR was multiplied then by 4.5 to obtain a standard value for assigning outlier fences. The standard value was subtracted from the lower quartile to define the lower outlier fence, and added to the upper quartile to define the upper outlier fence. Parameter values below the lower fence or above the upper fence were omitted from the Figures tab. The remaining tabs are not influenced by the removal of outliers.

Censored data refers to data that were below a detection limit. If the parameter value was indicated as below detection limit, then the parameter value was represented by half the value of the specified detection limit. Any site-parameter with more than 50% censored data was omitted from the database. These steps occurred during database organization, and therefore, have the potential to influence information in the sidebar or any of the tabs.

The Parameter Standardization section aims to provide a quick summary of the parameter data reported from the different data providers. A generic script summarizes parameter information for any number of unique data providers associated with the selected site and parameter. The original reported parameter name, units, and, if applicable, USGS parameter code are supplied. Similar to the sidebar, if any rows contain missing values, then “Blank” is returned. When provided and applicable, a detection limit type and value are reported to further supplement the “Censored Data” sidebar element. Finally, any unit conversion that was applied is presented after “Conversion Applied”. In the database, all the units were

standardized by parameter. The “Conversion Applied” element provides the user full transparency regarding if and how the original parameter value was manipulated.

Site Information is similar to the Parameter Standardization section but provides a summary of site data by data provider. The information is comparable to the sidebar but additional information that would not fit in the sidebar panel are reported.

The final section, Depth, provides a summary of how depths were handled in the App. For this analysis, only samples collected at the surface (0 m) or near the surface (≤ 1 m) were utilized. Samples with missing depth values were assumed to be collected at the surface. This assumption may not always be correct. Therefore, the user should be cautious whenever the depth is reported as 'Blank.' Depths greater than 1 m were excluded to create a more standardized output for all stations and parameters. Including all samples collected at depths deeper than 1 m may skew the data.

EPA Region 3 Water Quality Trends

Query by:

Parameter
 Site

Parameter

TEMP

HUC 8

All HUCs

Site

2-APP110.93

Units: deg C
Outliers Removed: 0
Censored Data: 0% (n = 0)
Available Parameters: DO, PH, SPCOND, TEMP, TN, TP, TSS

Site Information

Site: 2-APP110.93
Agency: 21VASWCB
First Date: 03/24/1970
Last Date: 01/21/2016
State: Virginia
Latitude: 37.30725, 37.3073
Longitude: -78.38925, -78.3893
Depth (m): Blank, 0.3048, 0.999744
Replicate: Blank
Composite: Absent


Gage Information

Flow Gage: 2039500
Agency: USGS
Flow Gage Location: APPOMATTOX RIVER AT FARMVILLE, VA
Latitude: 37.3070965
Longitude: -78.388607

Download

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[Download Table](#)



United States Environmental Protection Agency
This tool was developed with support from U. S. Environmental Protection Agency (CWA 45106 (1-98339413) and the Interstate Commission on the Potomac River Basin.

Figures Map **Data** Metadata Relevant Publications

Identifying Outliers

All of data within the database was divided into subsets based on parameter. For each parameter subset, the Interquartile Range (IQR) was multiplied by 4.5 to obtain a standard value for assigning outlier fences. The standard value was subtracted from the lower quartile, to define the lower outlier fence, and added to the upper quartile, to define the upper outlier fence. Parameter values below the lower fence or above the upper fence were omitted from the Figures tab. The remaining tabs are not influenced by the removal of outliers.

Lower Fences: -66.75
Upper Fences: 98.25
Outliers Removed: 0

Censored Data

Censored data refers to data that was below a detection limit. If the parameter value was indicated as below detection limit, then the parameter value was represented by half the value of the detection limit. Any site/parameter where more than 50% censored data, was omitted from the database. These steps occurred during database organization, and therefore, have the potential to influence information in the sidebar or any of the tabs.

Parameter Standardization

Data Provider: E-STORET
Reported Parameter: WATER TEMP CENT
Reported Units: degrees C
USGS Code: Blank
Detection Limit Type: Blank
Detection Limit Value: Blank
Conversion Applied: Blank

Data Provider: STORET
Reported Parameter: temperature, water
Reported Units: deg C
USGS Code: Blank
Detection Limit Type: Blank
Detection Limit Value: Blank
Conversion Applied: Blank

Site Information

Data Provider: E-STORET
Agency Formal Name: VA DEPT OF ENVIRONMENTAL
Site Name: RT,45 BRIDGE AT FARMVILLE (CO. OF PRINCE EDWARD) / 02-NORTH-ATLANTIC / 2-JAMES
Activity Name: W
Activity Type Code: B

Data Provider: STORET
Agency Formal Name: VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY
Site Name: RT,45 BRIDGE AT FARMVILLE
Activity Name: Water
Activity Type Code: Field Msr/Obs

Depth

For this analysis, only samples collected at the surface (0 m) or near the surface (≤ 1 m) were utilized. Samples with missing depth values were assumed to be collected at the surface. This assumption may not always be correct. Therefore, the user should be cautious whenever the depth is reported as “Blank”.

Depths greater than 1 m were excluded to create a more standardized output for all stations and parameters. Including all samples collected at depths below 1 m may skew the data.

Below are all of the depths found in the database. When the data table is downloaded all of the available depths will be included.
Depth (m): 0.3048, 0.999744

Figure 5. An example of the “Metadata” tab from the Water Quality Data Explorer.

Relevant Publications Tab

During the process of writing this report, we acquired a list of articles and reports with information related to one or more parameters in EPA Region 3. The sources were summarized into a table and are presented in the Relevant Publications tab (**Figure 6**). Only information pertinent to the selected parameter is shown. This is not a summary of all available sources in EPA Region 3 and the information in the source may not always be useful, but providing a list of potential external sources enables the user to rapidly expand their literature search or better understand an observed pattern.

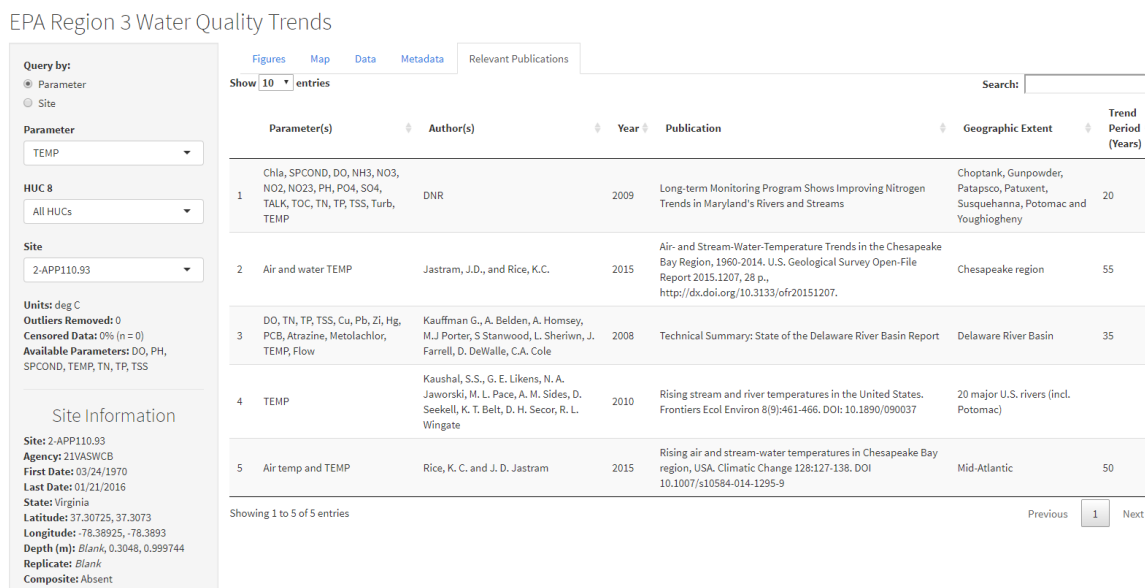


Figure 6. An example of the “Relevant Publications” tab from the Water Quality Data Explorer.

Future Work

There are many ways that the App could be improved but we have identified three potential tasks for work in the near future. The first task is to incorporate more advanced filtering tools on the Data tab. Currently, the Data tab presets a table with 100 columns, which can be difficult to navigate. The filter tools might allow the user to subset the columns/rows using very specific arguments and subset the data by pre-defined groups (e.g., columns related to site information, gage information, or parameter information). This improvement better equips the user to explore the primary data table.

Second, a more sophisticated set of querying and download tools would allow the user flexibility in selecting data to explore. The sidebar download button currently allows the user to download data related to the site and parameter selected in the sidebar. It provides a simple way of obtaining data for further investigation. It does not allow the user to specify a time period or exclude all censored data, for example. A download tab could be created that would allow the user to filtered data prior to downloading. This tab could also allow the user to perform more general queries of the database. The default download parameters could be set to the selected parameter and site but the user could decide to download more parameters and/or more sites. Potentially the user could download all the available site/parameter data at once. However, this will most likely cause the App to crash, and a query size limit would be necessary.

Third, a preliminary analysis tab which provides the user with a few simple statistical tests may enable the user to form, further solidify, or deny hypotheses related to the selected data. Due to the complexity of the data, the analysis tools would need to be generic in nature. This tab would come with the

recommendation that the analyses are preliminary and data should be downloaded, inspected, groomed, and assessed with independent tools prior to making any formal conclusions. Again, this App is intended for data exploration. Some possible analyses may be step-trends with Wilcoxon-Rank Sum test or Seasonal Kendall test. These tests would require the user to specify various parameters, such as the two time periods to be used in the Wilcoxon-Rank Sum test or the seasons to be used in the Seasonal Kendall test. Depending on the selected statistical test, various figures and tables would be generated to aid in interpretation. Ultimately, the preliminary analysis tab would provide the user with further insight into whether it is worth their time to explore their hypothesis further.

Long-Term Trends in Non-Tidal Streams and Rivers

When a station’s time series had sufficient data, we evaluated long-term trends using a step-trend approach. We compared two 17-year periods separated by ten years: 1972 – 1988 (“base”) and 1999 – 2015 (“recent”). The 1972 – 1988 base period represents a time when resource managers and the public were increasingly concerned about instances of severe environmental degradation and Congress was enacting major legislation to regulate pollutants in waters of the United States (e.g., 1970 Clean Air Act, 1972 Clean Water Act, 1974 Safe Drinking Water Act, 1976 Toxic Substances Control Act, and 1977 Surface Mining Control and Reclamation Act). The 1999 – 2015 recent period is the same length as the 1972 – 1988 base period and we feel is sufficiently removed from the base period to allow an independent comparison of the two periods.

If two or more samples were collected in a month, the data point closest to the middle of that month was selected for trend analysis. The remaining data were not used in the trend analysis. Stations with parameters having more than 50% censored values (values below the minimum detection limit) were excluded. Stations with fewer than twenty samples in one or both 17-year periods were also excluded.

The data used in the step-trend analysis were not flow-corrected. As indicated in Buchanan and Mandel (2015), time periods of seventeen years may be long enough to minimize bias created by episodic high and low streamflows. Changes in one parameter at one station should not be interpreted as evidence of a response to legislation. However, a preponderance of trends in the same direction in one parameter can potentially be linked to implementation of resource policies.

Parameter values in the two periods were compared with the non-parametric Wilcoxon-Mann-Whitney Rank Sum test for each station meeting the data requirements. The p-values of 0.05 and 0.01 were used to determine if substantial and very substantial step changes, respectively, occurred. **Table 1** shows the number of stations with increasing trends, no trend, and decreasing trends for each parameter.

Table 1. Numbers of water quality monitoring stations with at least one negative (NEG), non-significant (NS), or positive (POS) long-term parameter trend ($p < 0.05$). The suffix “F” indicates the dissolved fraction of the element or compound was analyzed; the suffix “W” indicates the combined dissolved and particulate (whole water) fractions were analyzed.

PARAMETER NAME	CODE	NEG	NS	POS	Total
Aluminum (total)	AL_W	13	3	0	16
Calcium (filterable)	CA_F	1	3	2	6
Calcium (total)	CA_W	9	29	23	61
Chloride (filterable)	CL_F	0	1	8	9
Chloride (total)	CL_W	4	5	14	23
Dissolved oxygen	DO	26	299	67	392
Dissolved organic carbon	DOC	1	1	45	47
Dissolved organic nitrogen	DON	5	1	0	6
Iron (filterable)	FE_F	0	2	0	2
Iron (total)	FE_W	98	34	0	132
Hardness	HARD	3	23	29	55
Non-carbonate hardness	HARD_NONCARB	2	1	0	3
Hot acidity	HOT_ACIDITY	3	5	15	23
Potassium (total)	K_W	0	3	1	4

PARAMETER NAME	CODE	NEG	NS	POS	Total
Magnesium (filterable)	MG_F	2	2	2	6
Magnesium (total)	MG_W	0	2	2	4
Manganese (total)	MN_W	78	39	2	119
Sodium (filterable)	NA_F	0	3	2	5
Sodium (total)	NA_W	2	2	0	4
Ammonium (filterable)	NH4_F	34	6	10	50
Nitrite (filterable)	NO2_F	40	12	2	54
Nitrite (total)	NO2_W	32	25	1	58
Nitrite-nitrate (filterable)	NO23_F	2	6	0	8
Nitrite-nitrate (total)	NO23_W	78	40	14	132
Lead (total)	PB_W	14	0	0	14
pH	PH	5	18	53	76
Particulate organic nitrogen	PON	9	18	18	45
Sulfate (filterable)	SO4_F	12	13	0	25
Sulfate (total)	SO4_W	10	7	8	25
Specific conductivity	SPCOND	51	84	151	286
Alkalinity	TALK	1	24	76	101
Total dissolved nitrogen	TDN	4	2	2	8
Total dissolved phosphorus	TDP	25	10	6	41
Total dissolved solids	TDS	0	8	15	23
Temperature	TEMP	3	456	6	465
Kjeldahl nitrogen (filterable)	TKN_F	4	2	0	6
Kjeldahl nitrogen (total)	TKN_W	50	12	17	79
Total nitrogen	TN	57	20	22	99
Total organic carbon	TOC	21	15	6	42
Total organic nitrogen	TON	5	1	0	6
Total phosphorus	TP	227	30	6	263
Total suspended solids	TSS	79	51	2	132
Turbidity	TURB_NTU	0	3	4	7
Zinc (total)	ZN_W	50	17	3	70

Results of the step trend analyses are discussed below by parameter and compared to the findings of a few other studies in Region 3. Each parameter is briefly introduced with general information drawn from Wetzel (2001), Lampert and Sommer (1997), the [USEPA](#) and [World Health Organization](#) (WHO) websites, or water quality standards of state agencies in Region 3.

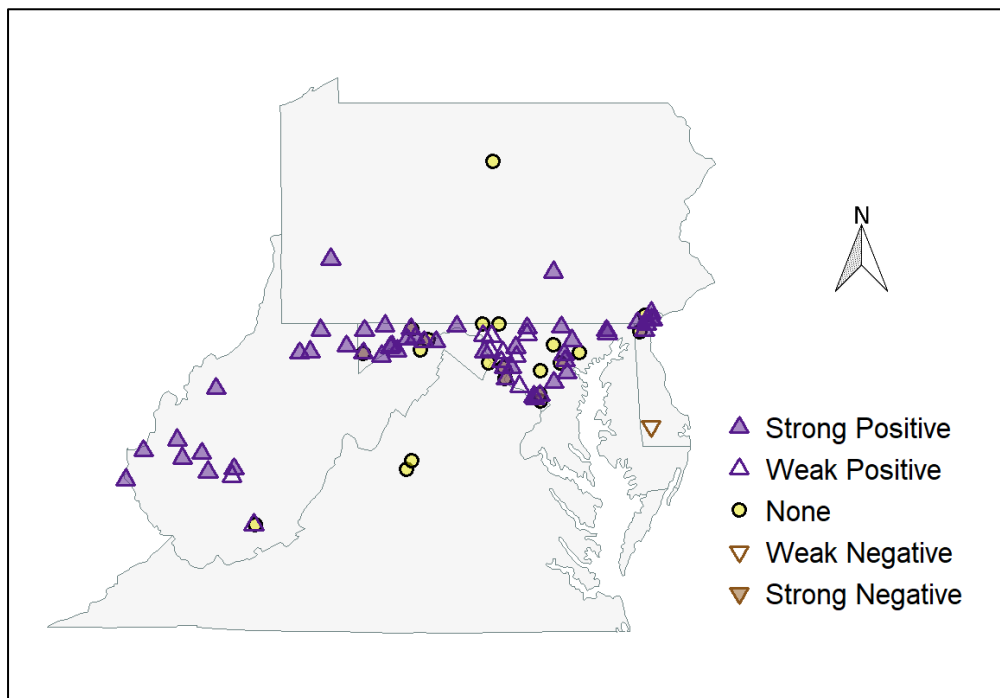
Alkalinity (TALK)

Alkalinity measures the buffering capacity of water, or its ability to neutralize acids. Total alkalinity is the concentration of dissociated anions—primarily carbonate and bicarbonate but also phosphate, hydroxyl, borates, silicates, sulfides, dissolved ammonia (NH₄_F), nitrate, and other bases—available to bind with free cations, including H⁺. Alkalinity is reported as mg CaCO₃/liter even though it can be comprised of different anions. It links dynamically to many water quality parameters, so assessing a waterbody's alkalinity is important to understanding the system's health. First order streams with low alkalinity often do not have the mineral content for adequate buffering capacity, making them vulnerable to rapid changes in pH. Landscape disturbances and dissolution of bedrock and cement-based structures by acid rain can increase the alkalinity in runoff to very high levels. Very high levels can interfere with calcium uptake in plants and animals. In conjunction with high sulfate (SO₄_F, SO₄_W), high alkalinity can degrade underwater grasses (e.g., Pulido et al. 2012). Alkalinity greater than 30 – 40 mg CaCO₃/liter in conjunction with hardness (HARD) less than 150 mg/liter appears to make streams and rivers in West Virginia more susceptible to the formation of filamentous green algae (Summers 2008).

Alkalinity measurements at eighty-four (84) stations in Region 3 met this study's step-trend data requirements: 62 (73.8%) showed increasing trends, 21 (25.0%) showed no trends, and 1 (1.2%) showed decreasing trends. Of the increasing trends, TALK concentrations rose 4% to 1,175% between the base and recent periods. In the base period, median concentrations ranged between 2.0 and 186.0 mg/liter as CaCO₃. In the recent period, median values were overall higher, ranging between 7.5 and 193.0 mg/liter as CaCO₃.

The USGS (2017) study identified long-term (1982 – 2012) increasing trends in alkalinity at 20 of 23 Region 3 stations, all located in MD and PA. Short-term trends for the recent period (2002 – 2012), however, showed 16 of 50 stations in MD and PA with decreasing or no trends, suggesting rises in alkalinity were leveling off in some areas. In contrast to the long-term WV trends (shown in the figure below), Buchanan and Mandel (2015) found no recent short-term trends (1996 – 2012) at 19 stations, indicating a leveling off in concentration. Kaushal et al. (2013) identified significant increasing long-term trends (1960s – 2010) at 35 of 53 stations in Region 3 but did not investigate short-term trends.

In general, alkalinity—and stream buffering capacity—rose throughout Region 3 after the 1970s. The rise appears to be leveling off in at least some areas. In the 1960s and 1970s, widespread declines in stream TALK corresponded to high acid deposition rates and rising stream concentrations of sulfate (e.g., Harned et al. 2010). Clow and Mast (1999) suggested that reductions in acid deposition would lead to a widespread recovery of stream alkalinity and buffering capacity only after acid deposition rates became substantially less than the rates of cation (e.g., calcium, magnesium) resupply to streams through chemical weathering of soils and rocks. Acid deposition accelerates the chemical weathering of rocks and soils, particularly in carbonate-dominated (karst) geology such as the Great Appalachian Valley. Weathering eventually translates into higher amounts of TALK in groundwater and surface runoff. Kaushal et al. (2013) found widespread increases in stream TALK and calcium in the eastern United States after the 1970s, with the most rapid rises occurring at sites with the highest inputs of acid deposition and highest elevations. Comparisons of the increasing rates with other environmental factors indicate that, while the strongest predictor of river alkalinization rates is carbonate lithology, the most rapid alkalinization rates were caused by human-accelerated chemical weathering due to acid deposition in addition to the previously known impacts of mining and land use disturbance (Kaushal et al. 2013). TALK increases in the Schuylkill and North Branch Potomac Rivers could also be related to acid mine drainage remediation (Stets et al. 2014). The recent leveling off of the TALK trends suggests the rates of acid deposition and cation resupply to streams are returning to equilibrium.



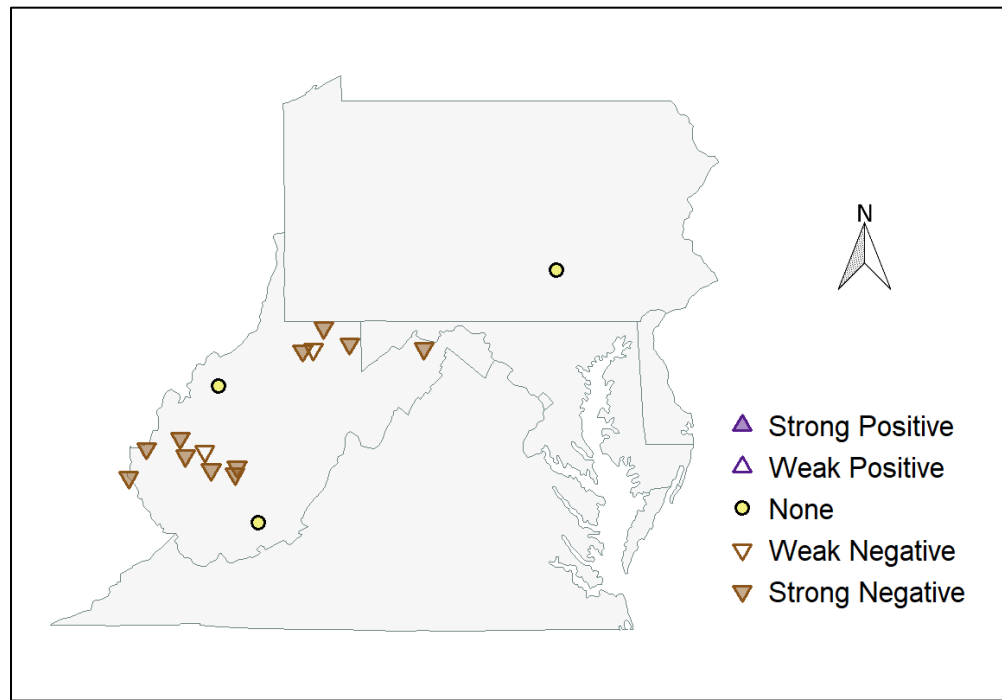
Total Alkalinity (TALK)

Aluminum (AL_W)

Aluminum is the most abundant metallic element in the earth's crust. It is used to precipitate phosphorus in waste water treatment plants and is a component of sludge waste. In water, aluminum solubility increases rapidly when pH drops below 4.5, allowing ionic concentrations to rise. Ionic aluminum is highly reactive and toxic in aquatic environments. For example, it bonds to fish gill membranes, reducing gill permeability and oxygen uptake. Dissolved organic carbon (DOC) and hardness also influence the level of aluminum toxicity. Aluminum is mutagenic and carcinogenic to humans. The World Health Organization and USEPA recommend an upper limit of 0.20 mg/liter dissolved aluminum in drinking water. USEPA recently updated guidelines for [aluminum aquatic life criteria](#).

One station in Pennsylvania and fifteen stations in West Virginia met the AL_W data requirements for this study's step-trend analysis: 3 (18.8%) showed no trend and 13 (81.3%) showed decreasing trends. In the base period, median concentrations ranged between 0.12 and 0.74 mg/liter. In the recent period, median values were overall lower, ranging between 0.05 and 0.40 mg/liter.

Lawrence et al. (2015) found "exchangeable aluminum" has decreased in the soil O horizon in eastern Canada and northeastern United States, corresponding to less acid deposition, declines in soil SO_4^{2-} , and increases in soil pH. They concluded acid deposition effects on forest soils have begun to reverse, resulting in partial chemical recovery of surface waters in that region. In the Mid-Atlantic, lower acid deposition rates should also decrease the levels of aluminum dissolved in soils and result in lower AL_W concentrations in surface waters. Recent short-term (1996 – 2012) AL_W trends in West Virginia were mostly not significant ($p < 0.05$), in contrast to strong downward long-term (1970s – 2012) trends. This suggests AL_W concentrations are leveling off, at least in West Virginia streams (Buchanan and Mandel 2015).



Total Aluminum (AL_W)

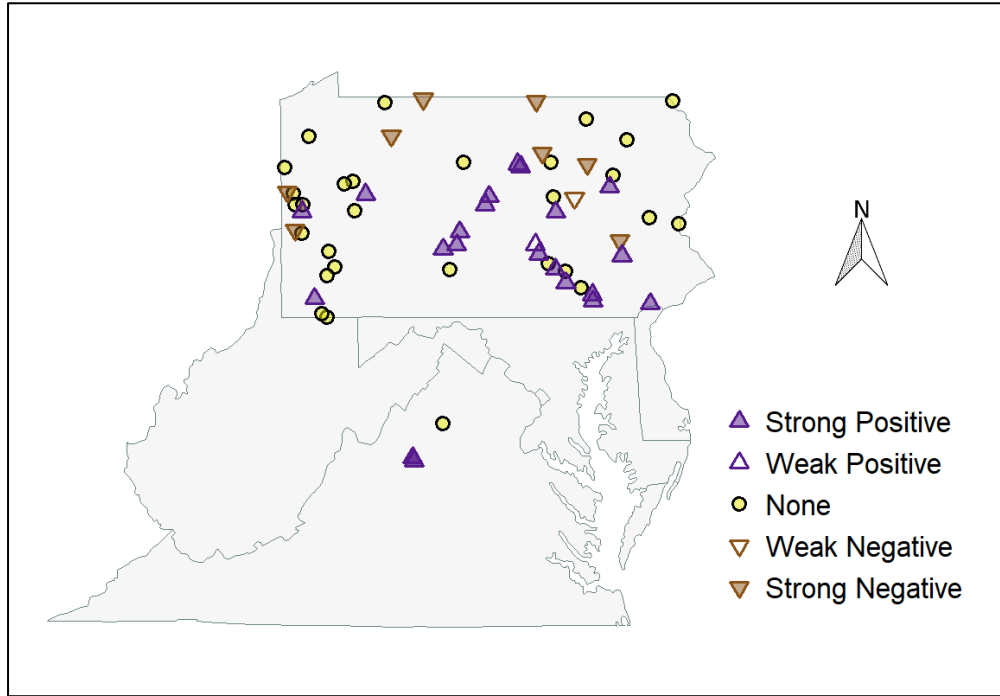
Calcium (CA_W, CA_F)

Calcium is a soluble, divalent, metallic cation abundant in the earth's crust. The element is essential in cellular processes and functions of all living organisms and is important in the carbon cycle of aquatic ecosystems. Limestone is composed of several crystalline forms of calcium carbonate (CaCO_3). Other calcium-bearing minerals include marble, dolomite, gypsum, and apatite. Calcium compounds are generally soluble in water and a major source of calcium in streams and rivers is chemical weathering of calcium-bearing soils and rocks. Industrial processes and fertilizers are additional sources of calcium to streams and rivers. Acid deposition increases the rate of chemical weathering, which is evident in soils and eventually surface waters as faster loss rates of base cations such as calcium (Lawrence et al. 2015). Calcium is one of the two cations principally responsible for water hardness (HARD), and the bicarbonate produced by the dissociation of CaCO_3 is important in buffering streams and rivers against large swings in acidity.

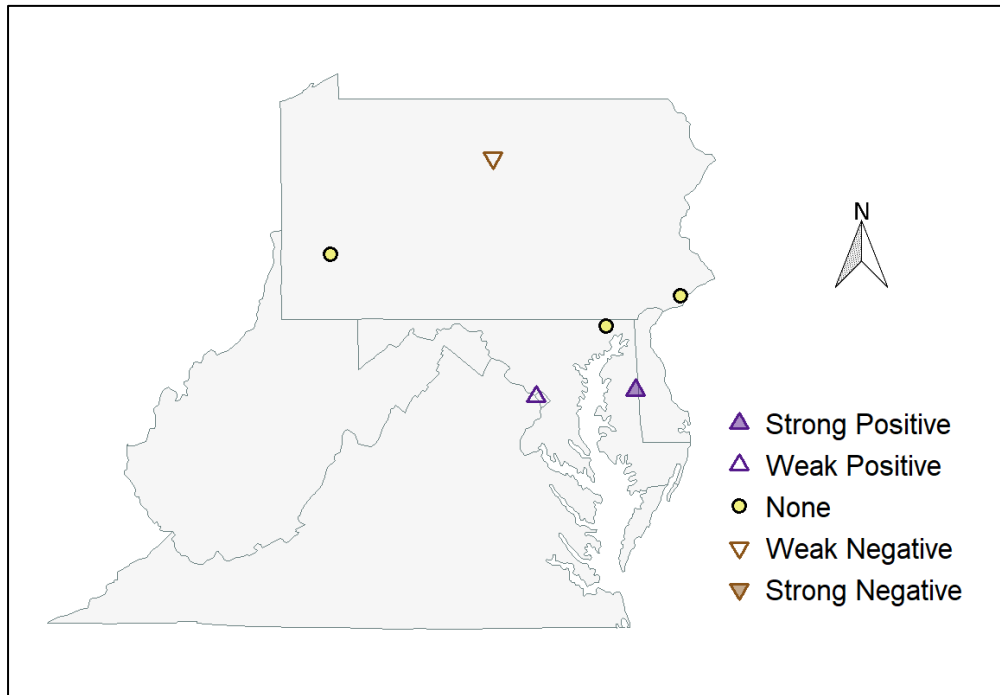
Sixty-one (61) stations in Region 3, most in PA, had sufficient CA_W data to calculate long-term trends: 23 (37.7%) showed increasing trends, 29 (47.5%) showed no trend, and 9 (14.8%) showed decreasing trends. In the base period, median CA_W concentrations ranged between 5.9 and 130.0 mg/liter. In the recent period, median concentrations were somewhat lower, ranging between 2.4 and 94.3 mg/liter.

Six (6) other stations had sufficient measurements to determine long-term trends in the dissolved calcium fraction, CA_F: 2 increasing, 3 showing no trend, and 1 decreasing.

It is difficult to generalize from these results to the entire Region 3 because most of the stations were in PA. Other trend studies in Region 3 have found similarly mixed results. Kaushal et al. (2013) identified one long-term increasing calcium trend and no decreasing trends at their five Region 3 sites. The USGS (2017) identified no long-term (1972-2012) calcium trends in the region, but did find a mix of short-term (2002-2012) trends. Lawrence et al. (2015) make the point that calcium levels in northeastern U. S. forest soils still are recovering from the peak acid deposition rates. They found a mix of increasing and non-significant trends in calcium in the soil O horizon. Stets et al. (2014) found some calcium increases related to agricultural uses of lime. Acid mine remediation would be another potential source of higher calcium levels in streams. The few upward CA_W and CA_F trends evident in this study are likely due to declining acid deposition rates since the 1970s and recovery of cation-depleted forest soils in at least some areas of Region 3.



Total Calcium (CA_W)



Dissolved Calcium (CA_F)

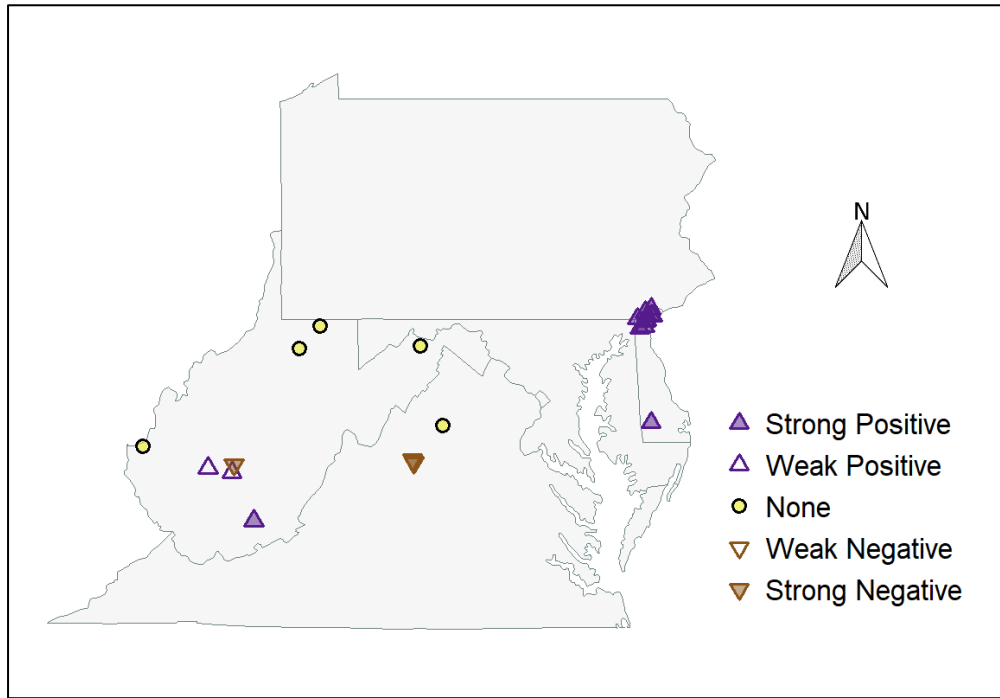
Chloride (CL_W, CL_F)

Chloride refers to the concentration of chlorine anions (Cl⁻) in water. Chlorine associates with various cations to form highly soluble salts. The most common chloride salts are sodium, potassium and calcium chlorides. Although many chloride salts are considered essential nutrients, excess amounts can be harmful, particularly in fresh water systems where they impede normal osmoregulation (biological regulation of internal water and salt content). Chemical weathering is a natural source of chlorides in freshwater systems, but excessive chloride concentrations often can be attributable to road salt, fertilizer runoff, oil and gas related activities, and other landscape disturbance.

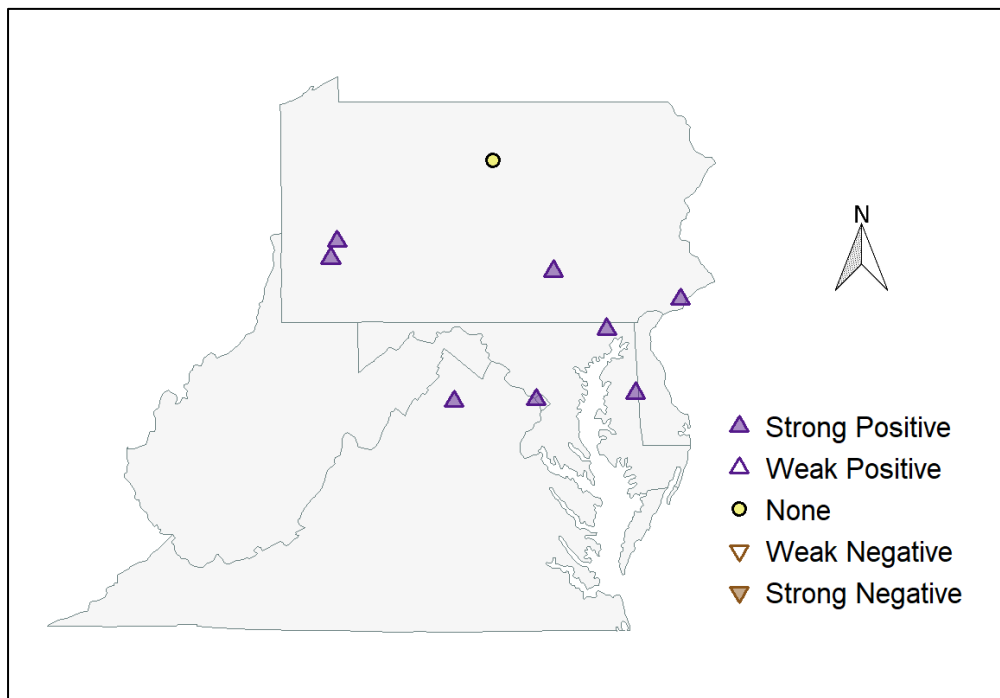
Twenty-three (23) stations in Region 3 had sufficient CL_W data to calculate long-term trends: 14 (60.9%) showed increasing trends, 5 (21.7%) showed no trend, and 4 (17.4%) showed decreasing trends. Of the increasing trends, CL_W concentrations rose 17% to 168% between the base and recent periods. In the base period, median concentrations ranged between 4 and 25 mg/liter. In the recent period, median values were higher, ranging between 3 and 59 mg/liter. Eleven of the fifteen stations were in the northern corner of DE, and their trends were uniformly increasing.

Nine (9) stations had long-term records for chlorine from filtered samples (CL_F). Chlorine salts are highly soluble, therefore CL_F values should be comparable to CL_W values. One station showed no trend and 8 showed increasing trends, with concentrations rising 25% to 106% between the base and recent periods.

It is difficult to generalize from these results to the entire Region 3 because of the uneven station distribution in the region. However, other trend studies have demonstrated a tendency towards increasing chloride concentrations in different parts of Region 3, especially in recent, short-term periods. Buchanan and Mandel (2015) in their West Virginia study found that, while roughly half of the long-term (1970s – 2012) chloride trends were decreasing, about half of short-term (1996 – 2012) trends were increasing. Corsi et al. (2015) found increasing river chloride trends (1980 – 2010) in snow-affected urban watersheds, including the Schuylkill, Patuxent, and Potomac, with the largest seasonal increases occurring in winter. In raw water piped from the Potomac River to the Washington D.C. Dalecarlia Reservoir for water supply, chloride concentrations have increased nearly 9-fold over a 108-year period (1905 – 2012), from an average of 2.95 mg/liter in the first decade to 26.12 mg/liter in the last decade (N. Jaworski, pers. comm.). There are several sources of chloride in surface waters, but a dominant and presently increasing source in urban areas appears to be road salt.



Dissolved Chloride (CL_W)



Total Chloride (CL_F)

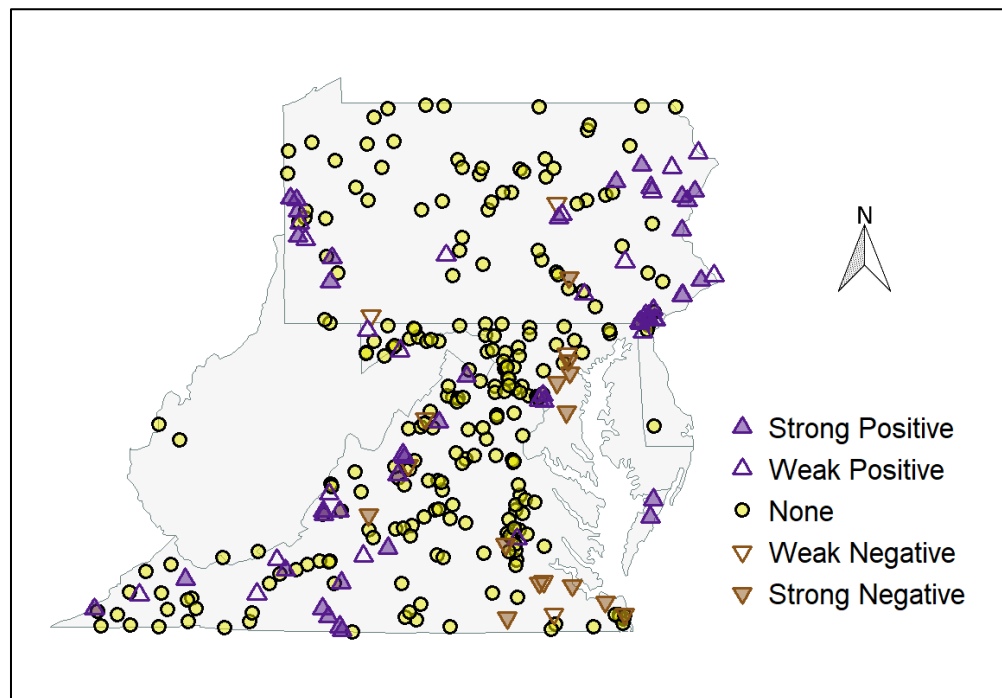
Dissolved Oxygen (DO)

Dissolved oxygen is the amount of oxygen dissolved in water. Oxygen is generated during photosynthesis; it is consumed by respiration and decomposition of organic matter. Concentrations in streams and rivers are influenced by temperature, salinity, pressure, and turbulence. Low DO concentrations are generally found in warm waters where nutrient inputs and biological productivity are high. Diel (daily) patterns of daytime highs and nighttime lows are typical. DO levels below 5.0 mg/liter stress many types of aquatic life, and prolonged periods of DO below 2.0 mg/liter can result in fish kills.

Three hundred and thirty-one (331) stations in Region 3 had sufficient DO data to calculate long-term trends. Given the typical diel swings in DO caused by photosynthetic production of oxygen, it is not surprising that 246 (74.3%) showed no trends, with only 66 (19.9%) showing increasing trends and 19 (5.7%) showing decreasing trends. In the base period, median concentrations ranged between 5.7 and 12.2 mg/liter. In the recent period, median values were nearly the same, ranging between 5.1 and 12.4 mg/liter.

The fact that there are more positive (66) than negative (19) trends in DO suggests nutrient reductions are perhaps beginning to ease the impacts of eutrophication caused by excess nutrients (see also phosphorus below). Overall, DO improved or showed no trend at 94.3% of the Region 3 study sites. In their study of 30 Delaware streams, Kauffman and Belden (2010) found DO improved or showed no trend in 73% of streams since 1990 and in 32% of streams since 1970/1980.

A more precise method for investigating eutrophication effects on DO would be an examination of long-term changes in the diel (daily) ranges of DO concentrations as well as exceedances of lower thresholds. High frequency (15 min – 1 hour) DO measurements that facilitate this kind of analysis are becoming more available (e.g., Kauffman et al. 2011).



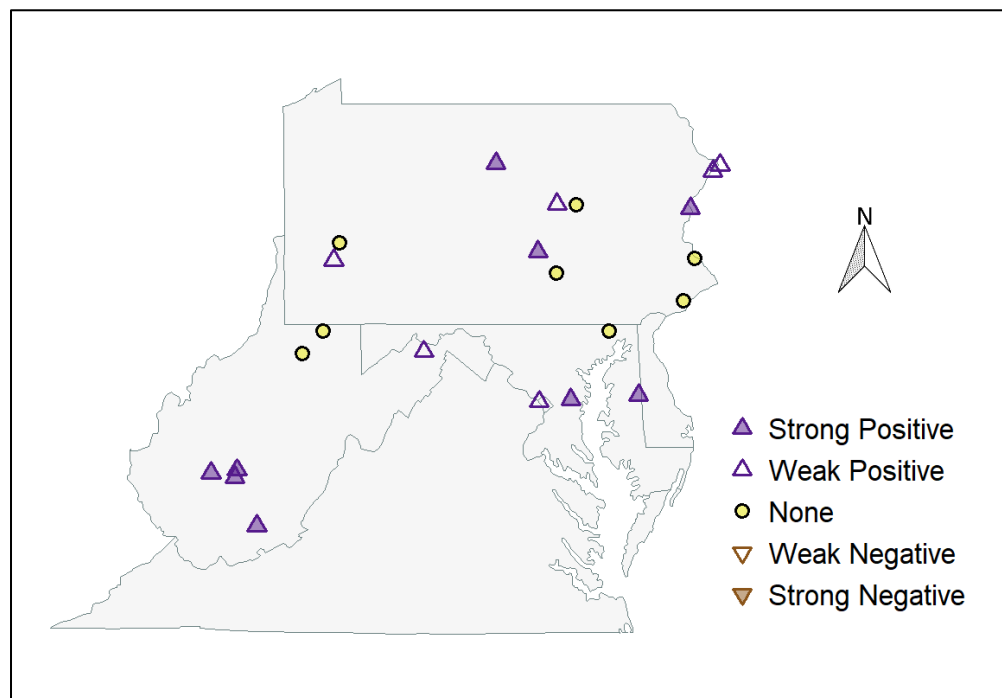
Dissolved Oxygen (DO)

Dissolved Solids, Total (TDS)

Total dissolved solids are the sum of all inorganic and organic substances suspended in water in molecular, ionized, or colloidal forms that can pass through a filter. Total dissolved solids are measured by evaporating a known volume of filtered water and weighing the resulting residue. One use of TDS measurements is to evaluate the aesthetic (e.g., taste, odor, or color) properties of drinking water. High values indicate the presence of chemical contaminants and potential toxicity to aquatic organisms. TDS is directly correlated to conductivity. USEPA guidelines recommend less than 500 mg/liter TDS in finished drinking water.

Twenty-three (23) stations in PA, MD, VA, and WV had sufficient TDS data to calculate long-term trends: 15 (65.2%) showed increasing trends and 8 (34.8%) showed no trend; no stations showed decreasing trends. Of the increasing trends, concentrations rose 7% to 48% between the base and recent periods. Concentrations at station 6272 (West Fork River mile 12) in WV were highest, with a base median of 466.0 mg/liter and a recent median of 444.0 mg/liter. Elsewhere, median concentrations ranged between 27.0 and 220.0 mg/liter in the base period and between 34.5 and 236.0 mg/liter in the recent period.

TDS concentrations are increasing in Region 3 over the long-term. Over the short-term, however, trends are mixed. Buchanan and Mandel (2015) found WV stations that showed upward long-term trends also showed no trend or a negative trend in the recent short-term (1996 - 2015). Anning and Flynn (2014) found a mix of upward, downward, and no trends in flow-adjusted TDS concentrations in Region 3 in the 1980 - 2009 period. Given the known correspondence between TDS and specific conductance (SPCOND), and the strong long-term increasing trends in SPCOND (see elsewhere in this report), we suspect many of the mixed short-term TDS trends are due to limitations of the analysis methods or inherent variability in the data rather than actual reversals of long-term trends.



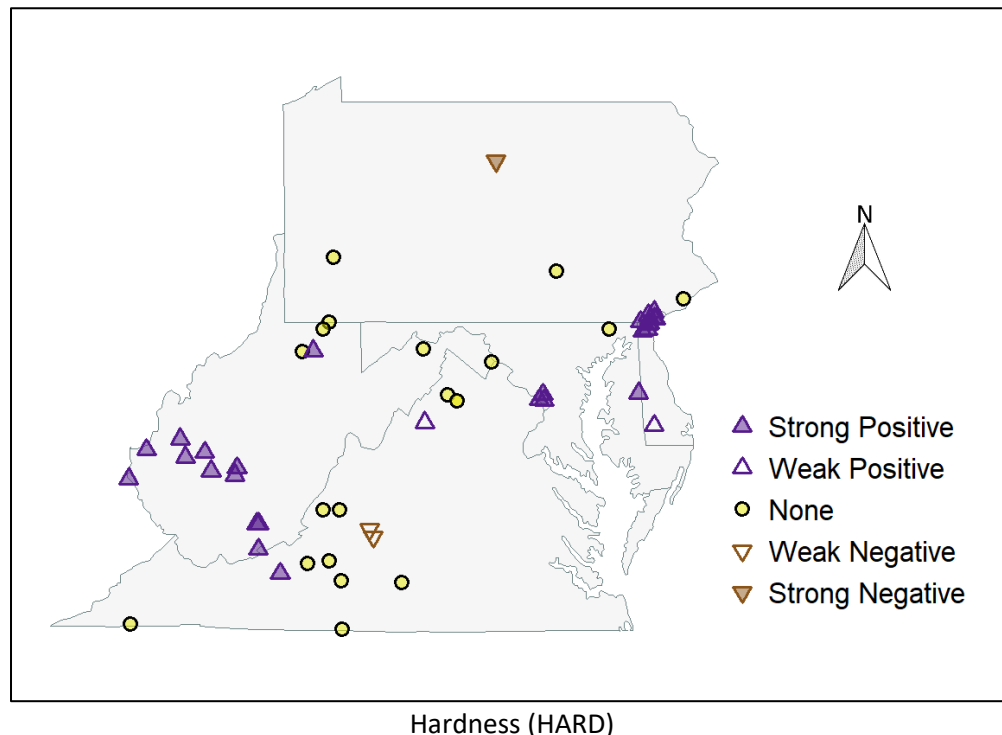
Total Dissolved Solids (TDS)

Hardness (HARD)

Hardness in fresh waters refers to the amount of soluble, divalent, metallic cations, the most common of which are calcium (Ca^{2+}) and magnesium (Mg^{2+}). Water hardness affects aquatic organisms by influencing metal toxicity and nutrient availability. When cation levels are low, usually less than 30 mg/liter (“soft” water), the permeability of tissue membranes (e.g., fish gills) increases and allows for greater metal uptake. High or low hardness is not thought to have direct detrimental effects on humans. However, a water hardness (HARD) of more than 180 mg/liter (“very hard” waters) requires more soaps and detergents in household laundry and dishwashing and results in mineral buildup on industrial equipment and breakdowns. Hardness is used to determine the applicable criteria for dissolved cadmium, chromium, copper, lead, nickel, silver and zinc.

Fifty-two (52) stations had sufficient HARD data to calculate long-term trends: 29 (55.8%) showed increasing trends, 20 (38.5%) showed no trend, and 3 (5.8%) showed decreasing trends. Of the increasing trends, HARD concentrations rose 9% to 94% between the base and recent periods. Median concentrations ranged between 14 and 270 mg/liter as CaCO_3 in the base period and between 13 and 263 mg/liter as CaCO_3 in the recent period.

The mixed long-term trend results for HARD resemble the mixed results for its components, calcium and magnesium, in Region 3 (see elsewhere in this report). Long-term trends in HARD are increasing predominantly along the western and eastern sides of the region. In contrast, concentrations are relatively high and not changing in the Great Appalachian Valley, which runs diagonally across the center of the region from southwest to northeast. The Great Appalachian Valley is underlain by carbonate-based (karst) geology, making it capable of recovering more quickly from the high acid deposition rates of the 1960s and 1970s.



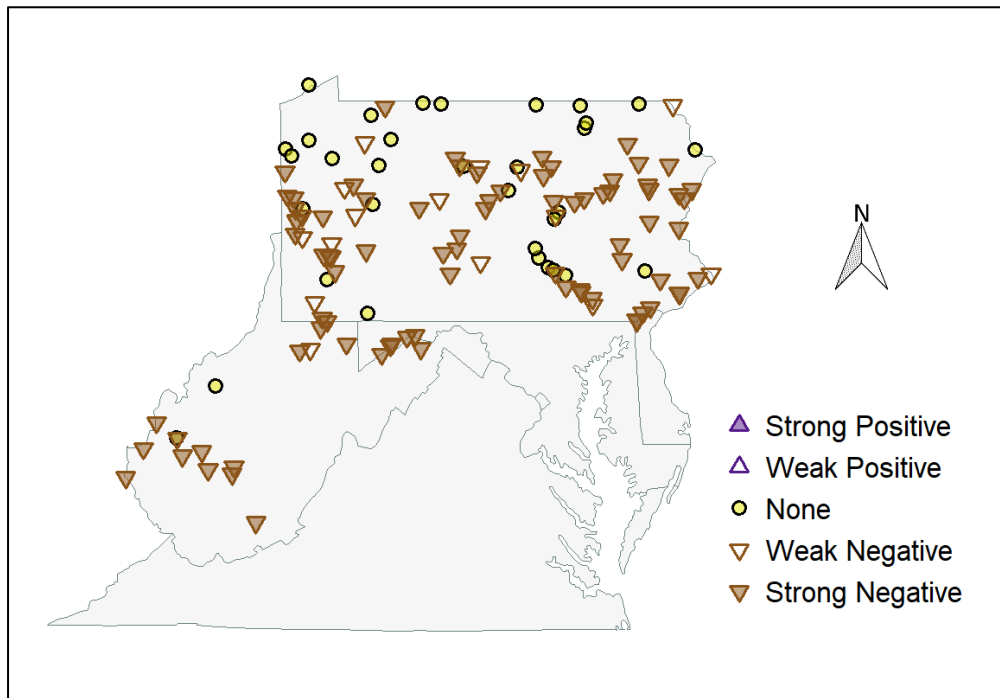
Iron (FE_W)

Iron is by mass the fourth most common element in the earth's crust. It has a wide range of oxidation states, from -2 to +6, and reacts strongly with oxygen and water. Iron-protein compounds, including hemoglobin, myoglobin, cytochrome P450, and many critical enzymes, facilitate oxygen transport and biochemical reactions in all living organisms. High concentrations of dissolved iron can be toxic to aquatic life in acidic (low pH) environments. At more neutral pH levels, iron's orange precipitates can coat the surfaces of fish gills and impede oxygen uptake. Human contact with the iron precipitates has no detrimental effects. USEPA recommends an upper limit of 0.3 mg/liter in finished drinking water to minimize color and taste issues.

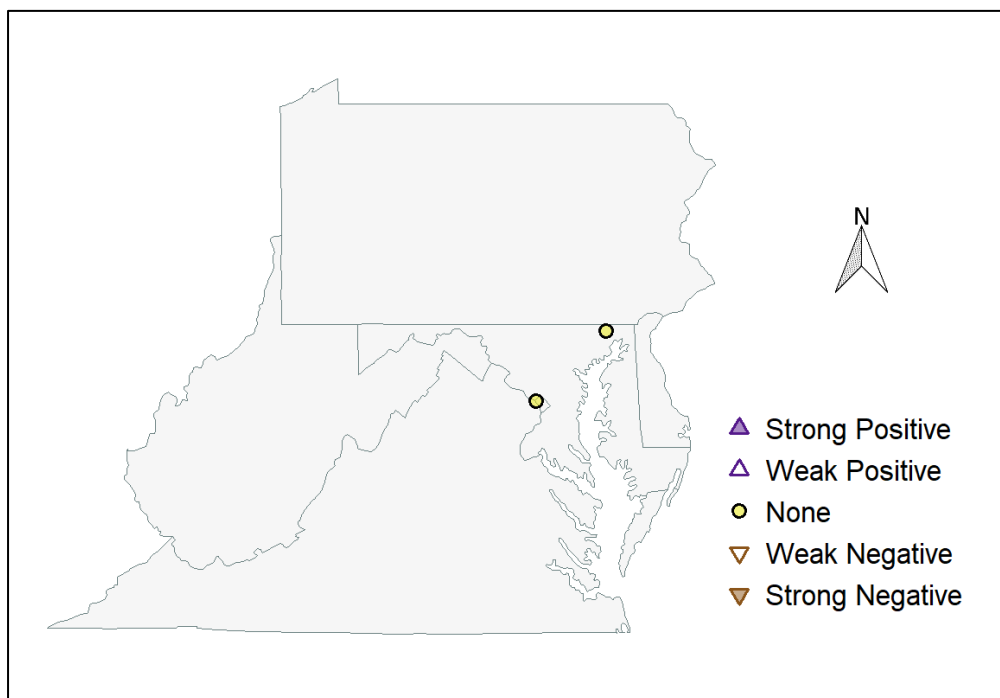
One hundred thirty-two (132) stations had sufficient data to calculate FE_W long-term trends: no station showed an increasing trend, 34 (25.8%) showed no trend, and 98 (74.5%) showed decreasing trends. Of the decreasing trends, concentrations declined 13% to almost 100% between the base and recent periods. Median concentrations ranged between 0.07 and 2.51 mg/liter in the base period and between <0.01 and 1.13 mg/liter in the recent period.

Long-term trends in dissolved iron (FE_F) could be determined at two stations. Both were not significant.

The preponderance of long-term downward trends in PA, western MD, and WV indicates similar trends in FE_W are likely occurring elsewhere in Region 3. These trends may be leveling off in some areas, as suggested by the absence of significant short-term (1996 – 2012) trends at 20 of 26 (76.9%) WV sites (Buchanan and Mandel 2015).



Total Iron (FE_W)



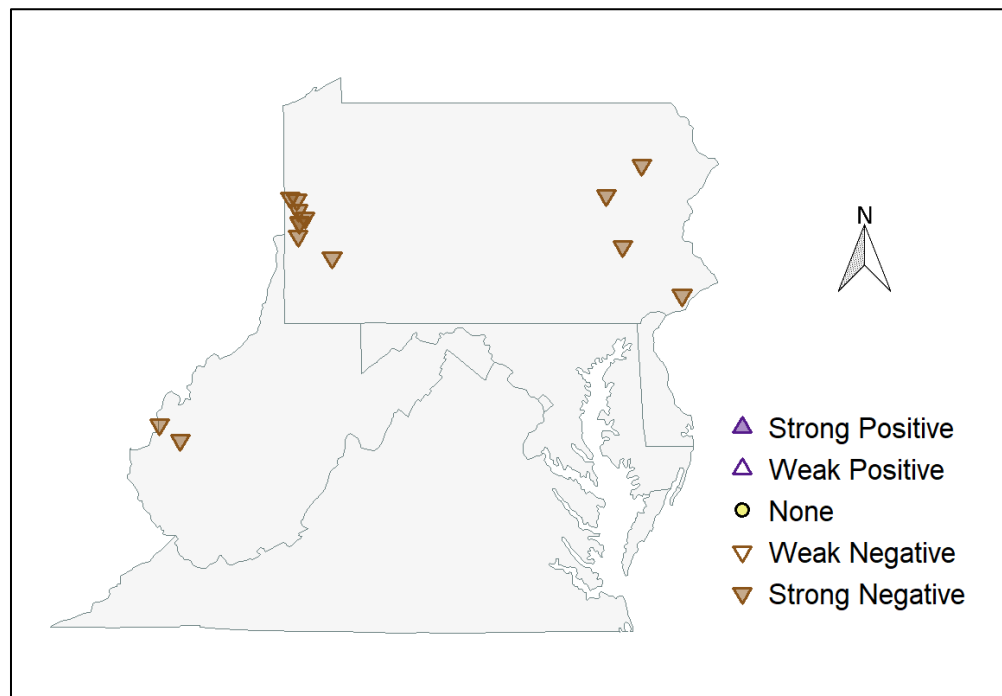
Dissolved Iron (FE_F)

Lead (PB_W)

Lead compounds are generally hard to dissolve and often occur as particulates adsorbed to plants and sediments. Lead is an extremely toxic substance in all its forms. Lead concentrations peaked in the atmosphere and waterways when it became popular as an additive in petroleum-based products such as gasoline and paint. It is also used in lead-acid batteries, solder, drinking water pipes, stoneware, stained glass, and lead shot ammunition. Environmental regulations in the mid-1980s reduced or eliminated many non-battery uses of lead. New contamination come chiefly from coal burning facilities without scrubbers and from improper wastewater discharges and battery storage. The EPA action level for lead concentrations in drinking water at customer taps is 15.0 µg/liter. Recommended stream water quality levels for lead are 65.0 µg/liter for acute and 2.5 µg/liter for chronic standards.

Fourteen (14) stations had sufficient PB_W data to calculate long-term trends: all showed decreasing trends, with concentrations declining 59% to almost 100% between the base and recent periods. In the base period, median concentrations ranged between 4.7 and 22.2 µg/liter. In the recent period, median values were much lower, ranging between <1.0 and 2.4 µg/liter.

The results of this and other studies suggest long-term lead trends are downward in Region 3. The downward trends have been attributed to the decreased use of leaded gasoline and the ban on lead-based paints. In the short-term, however, the downward trends may be slowing. Kauffman et al. (2008) found some short-term (1990 – 2005) trends in PB_W are showing no change at sites in the Delaware River Basin. In the recent short-term (1996 – 2012), Buchanan and Mandel (2015) found no trends in dissolved (filterable) lead at any West Virginia sites. In an earlier short-term (1974 – 1981) period, Alexander and Smith (1988) and Smith et al. (1987) found dissolved lead trends that were either constant or downward.



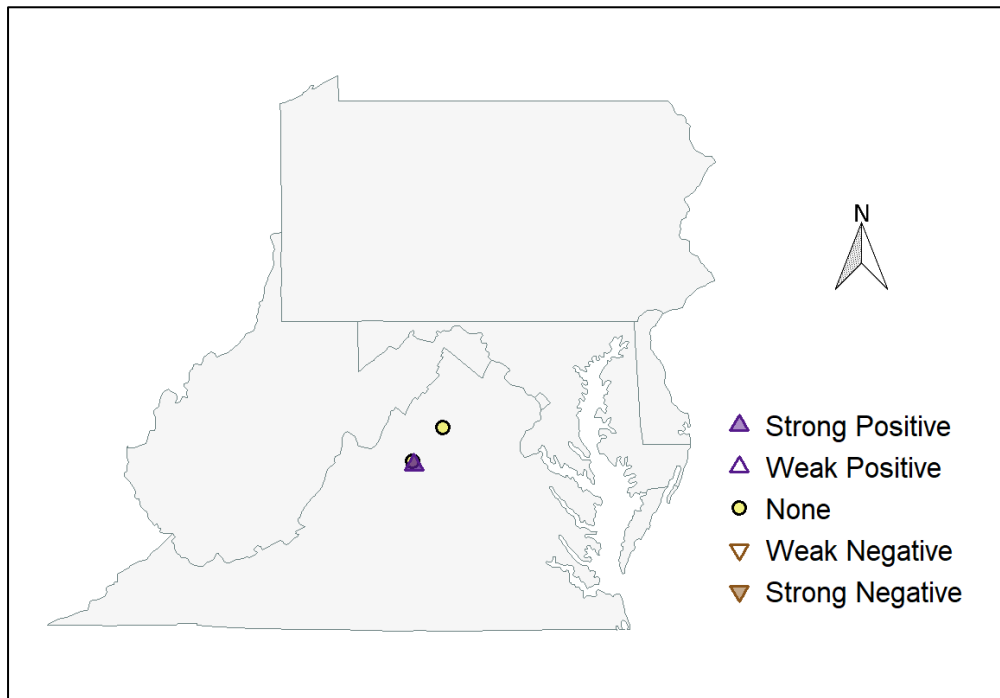
Total Lead (PB_W)

Magnesium (MG_W, MG_F)

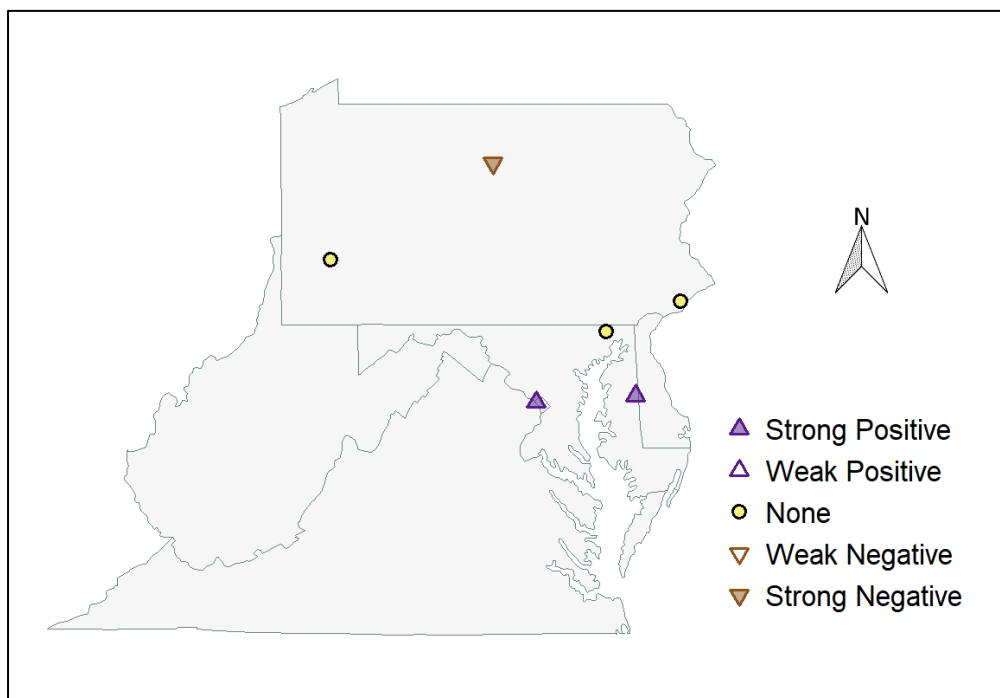
Magnesium is an abundant, highly soluble, divalent, metallic cation that readily forms metal alloys and magnesium salts. There are numerous natural sources of magnesium, many of which are commercially important. It is an essential element found in many enzymes of living organisms, and it is the ion at the center of chlorophyll's chlorine ring. Natural weathering is an important source of magnesium in streams and rivers. Mg^{2+} is one of the cations principally responsible for water hardness (HARD). No detrimental effects of magnesium in drinking water are known.

Only six and four stations in Region 3 have sufficient MG_F and MG_W data, respectively, to calculate long-term trends. Of the six MG_F stations, 2 showed increasing trends (+15%, +23%), 3 showed no trend, and 1 showed a negative trend (-6%). Of the four MG_W stations, 2 showed increasing trends (+7%, +14%) and 2 show no trend.

Long-term trends in MG_W and MG_F are showing a slight tendency to increase, echoing the pattern of Region 3 long-term trends in water hardness and calcium (see elsewhere in this report). Short-term trends are not clear. In WV, Buchanan and Mandel (2015) found 4 (15.4%) increasing, 22 (84.6%) no change, and no decreasing trends in MG_W in a recent, short-term period (1996 – 2012). In PA, USGS (2017) found 1 no change and 5 decreasing trends in another recent short-term period (2001 – 2012).



Dissolved Magnesium (MG_W)



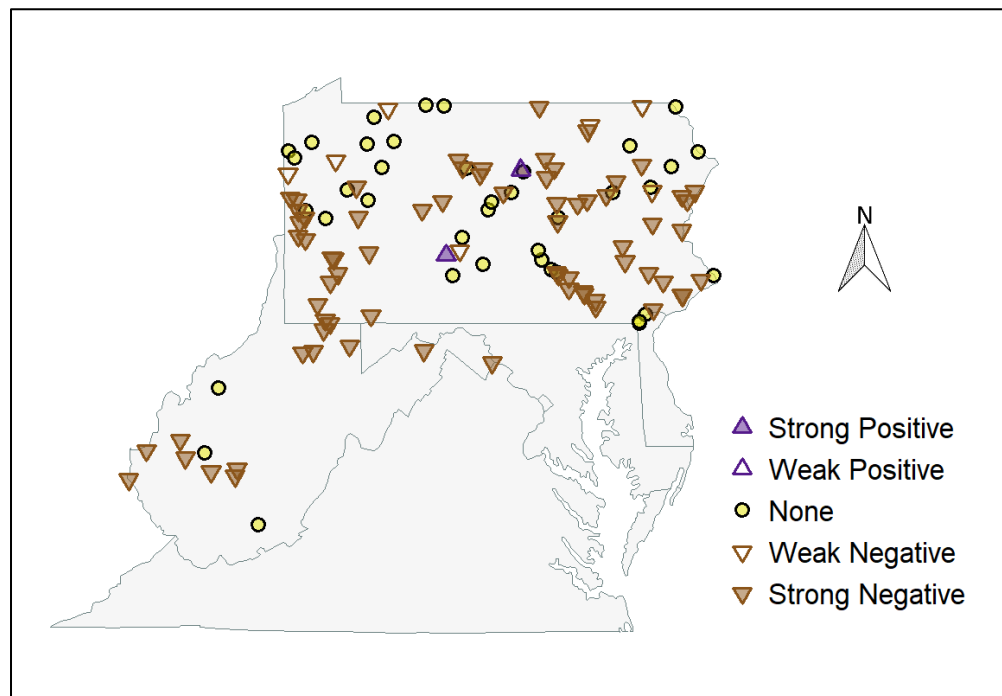
Total Magnesium (MG_F)

Manganese (MN_W)

Manganese is an abundant metallic element often alloyed with iron and other metals. Anthropogenic sources of manganese include gasoline emissions (prior to 2000) and fertilizers. Manganese is one of the few toxic essential nutrients in aquatic environments. It is necessary for nitrate assimilation and photosynthesis, and is a co-factor in multiple enzyme systems of animals. Manganese deficiencies reduce the ability of plants to break down water into hydrogen and oxygen because of manganese's role as an electron transporter. In animals, manganese deficiencies result in reduced growth and development. High concentrations of manganese darken water and increase turbidity. When consumed, high concentrations of manganese physiologically stress human lung, brain and kidney functions and chronic exposure to high concentrations can harm human neurological functioning. USEPA's manganese guideline for finished drinking water is 50 µg/liter.

One hundred and nineteen (119) stations in Region 3 had sufficient MN_W data to calculate long-term trends: 2 (1.7%) showed increasing trends, 39 (32.8%) showed no trends, and 78 (65.5%) showed decreasing trends. Of the decreasing trends, concentrations declined between 14% and 84% between the base and recent periods. In the base period, median MN_W concentrations ranged between 12 and 2,960 µg/liter. In the recent period, median concentrations were substantially lower, ranging between 10 and 1,750 µg/liter.

The preponderance of long-term downward trends in PA and WV indicates similar trends are probably occurring elsewhere in Region 3. Like iron, lead, aluminum, and alkalinity, recent short-term (1996-2012) trends in manganese may be leveling off (Buchanan and Mandel 2015).



Total Manganese (MN_W)

Nitrogen

Nitrogen occurs in many compounds, including elemental nitrogen (N_2), nitrite (NO_2^-), nitrate (NO_3^-), the animal waste products ammonium (NH_4^+), urea, and uric acid, and organic compounds essential for life such as amino acids, proteins, nucleic acids, and ATP (adenosine triphosphate). The many nitrogen forms are often measured separately and then added/subtracted to derive the concentrations of specific groups of nitrogen compounds. In excess amounts, nitrogen contributes to eutrophication. Anthropogenic sources of excess nitrogen to aquatic systems include energy production, wastewater discharges, and fertilizers.

Total Nitrogen (TN)

Total nitrogen measures the nitrogen (N) content of all nitrogen compounds. TN is calculated several ways from other, measured nitrogen compounds. A common method is to add total Kjeldahl nitrogen (TKN_W) and dissolved nitrate-nitrite (NO23_F). Total maximum daily loads (TMDLs) have been established for TN delivered to Chesapeake Bay from each tributary.

Eighty-one (81) stations in Region 3 had sufficient data with low numbers of MDL-affected records to calculate long-term TN trends: 5 (6.2%) showed increasing trends, 20 (24.7%) showed no trends, and 56 (69.1%) showed decreasing trends. Of the decreasing trends, concentrations declined between 7% and 57% between the base and recent periods. In the base period, median concentrations ranged between 0.545 and 6.450 mg/liter as N. In the recent period, median concentrations were measurably lower, ranging between 0.465 and 5.110 mg/liter as N.

Total Dissolved Nitrogen (TDN)

Long-term data for total dissolved nitrogen were found at 8 stations (not shown). The composition of this parameter is not certain but the results are somewhat comparable to trends for ammonium (NH_4), and nitrite- nitrate (NO_{23}). Stations showed decreasing trends at 4 stations, no trend at 2 stations, and increasing trends at 2 stations.

Ammonia Nitrogen (NH4_F)

Aquatic invertebrates and bacteria produce ammonia as a metabolic waste product. It is readily taken up by plants and algae as a nutrient. Ammonia is soluble in water and its ionic form, ammonium (NH_4^+), bonds with various cations to form salts. The proportion of ammonium decreases and ammonia increases as temperature and/or pH increase. Ammonia in high concentrations and under certain pH and temperature conditions has direct toxic effects on aquatic organisms. Sources of excess ammonia in streams and rivers include municipal sewage and agricultural runoff. EPA has developed ambient ammonia criteria for freshwater life based on salmonid fish and bluegill sunfish, the most sensitive endpoints to date: 17.0 mg/liter acute exposure and 1.9 mg/liter chronic exposure at pH 7 and 20°C (US EPA 2013).

Forty (40) stations in PA, MD, WV, and VA had sufficient NH4_F data with low numbers of MDL-affected records to calculate long-term trends: none showed an increasing trend, 7 (17.5%) showed no trend, and 33 (82.5%) showed decreasing trends. Of the decreasing trends, NH4_F concentrations across all seasons declined 20% to 97% between the base and recent periods. In the base period, median concentrations ranged between 0.009 and 0.488 mg/liter as N. In the recent period, median values were overall lower, ranging between 0.004 and 0.088 mg/liter as N.

Nitrite and Nitrate (NO2_F, NO2_W, NO23_F, NO23_W)

Nitrite and nitrate are inorganic, oxidized compounds of nitrogen. The dissolved forms are nutrients readily taken up by plants and bacteria. High nitrite and nitrate concentrations in drinking water can cause serious illness in infants (blue-baby syndrome), hence their concentrations in drinking water are

regulated. High concentrations also impact aquatic biological communities and several states also have aquatic life use criteria for nitrite.

Long-term trends for NO₂_F were found at 11 stations: concentrations increased at 1 station, did not change at 6 stations, and decreased at 4 stations.

Long-term trends for NO₂_W were found at 57 stations: concentrations did not change at 24 (42.1%) stations and decreased at 33 (57.9%) stations.

Long-term trends for NO₃_F were found at 8 stations: concentrations did not change at 6 stations and decreased at 2 stations.

Long-term trends for NO₃_W were found at 132 stations: concentrations increased at 14 (10.6%) stations, did not change at 40 (30.3%) stations, and decreased at 78 (59.1%) stations. Of the decreasing trends, NO₃_W concentrations declined 9% to 96% between the base and recent periods. In the base period, median concentrations ranged between 0.05 and 5.60 mg/liter as N. In the recent period, median values were slightly lower, ranging between <0.01 and 4.54 mg/liter as N.

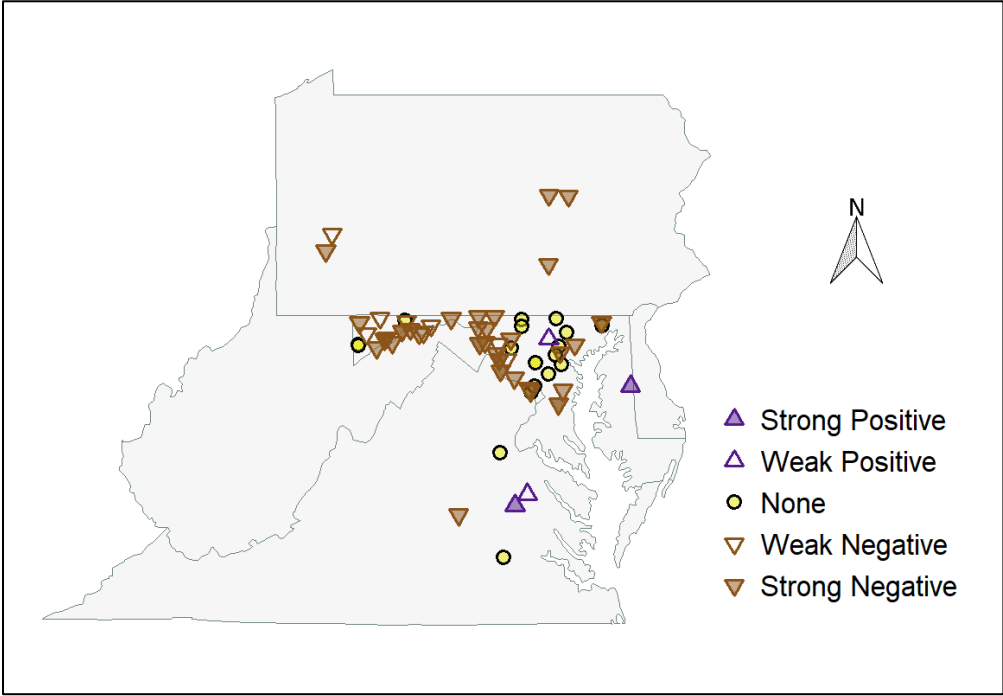
Kjeldahl Nitrogen (TKN_F, TKN_W)

Kjeldahl nitrogen is the amount of nitrogen found in all organic compounds plus ammonium (NH₄⁺). The measurements do not quantify the amount of dissolved nitrite-nitrate (NO₂3F). Sources of organic nitrogen can be natural (e.g., seasonal dieoffs of underwater grasses, excretion and decomposition of aquatic life) and anthropogenic (e.g., wastewater, manure, fertilizer).

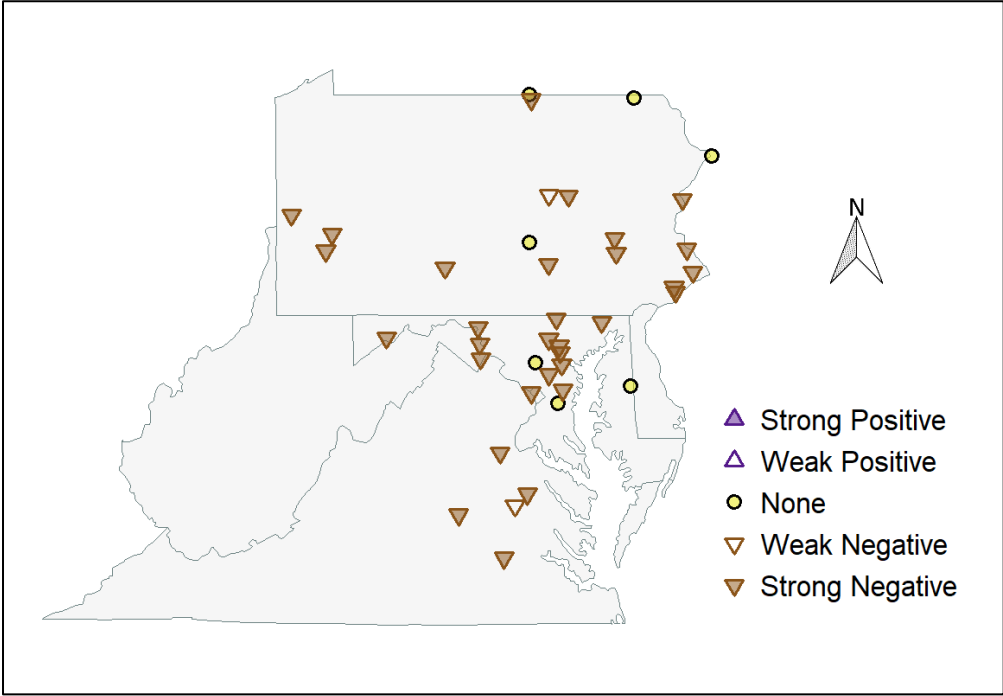
Sixty-three (63) stations in Region 3, most in PA, had sufficient TKN_W data to calculate long-term trends: no station showed an increasing trend, 13 (19.7%) showed no trend, and 53 (80.3%) showed decreasing trends. Of the decreasing trends, concentrations declining 3% to 48% between the base and recent periods. In the base period, median concentrations ranged between 0.25 and 1.30 mg/liter as N. In the recent period, median concentrations were lower, ranging between 0.21 and 0.73 mg/liter as N. All but seven of the TKN_W stations are in MD.

Long-term trends for dissolved Kjeldahl nitrogen (TKN_F) also could be determined at six of the 63 stations. Four stations showed decreasing trends (-37% to -59%); two showed no trend. Changes in TKN_W and TKN_F at the six stations paralleled each other closely.

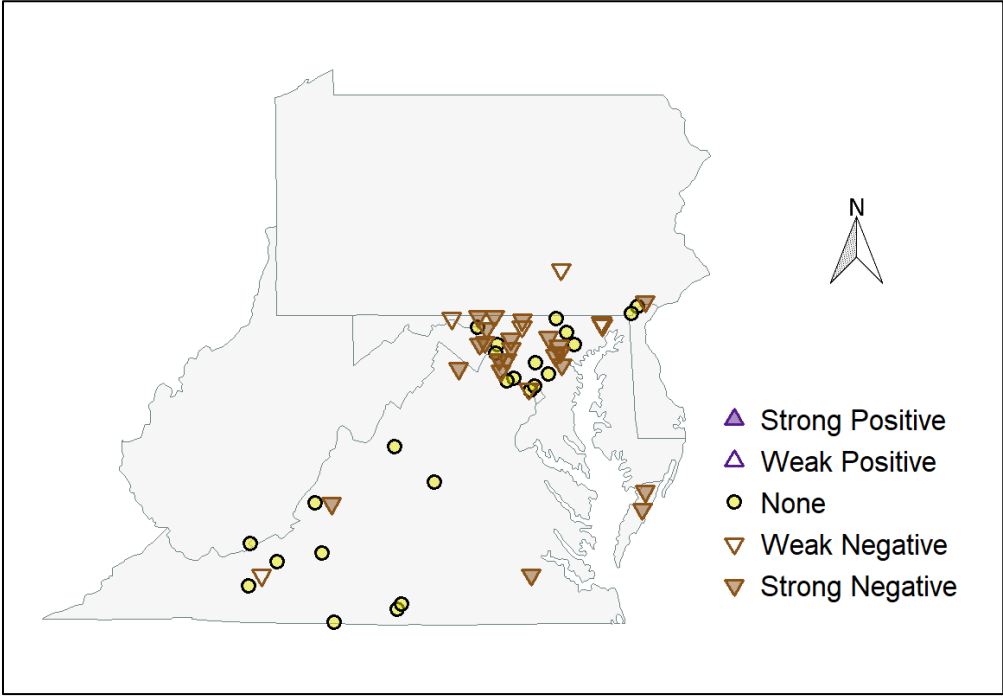
Long-term data sets for parameters expressed simply as forms of organic nitrogen were also found: “total organic nitrogen” (TON) and “dissolved organic nitrogen” (DON) at 6 USGS stations, and “particulate organic nitrogen” (PON) at a Maryland station (TF1.2). It is not clear if these are the equivalents of TKN_F and TKN_W, but they are likely very close. Concentrations were decreasing at all 7 stations (not shown).



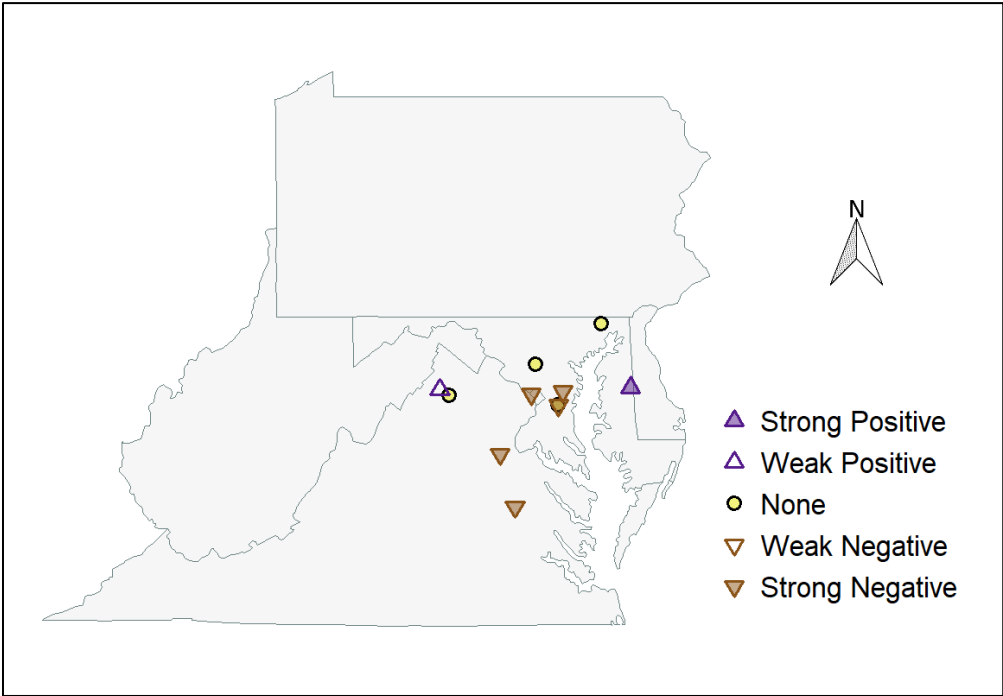
Total Nitrogen (TN)



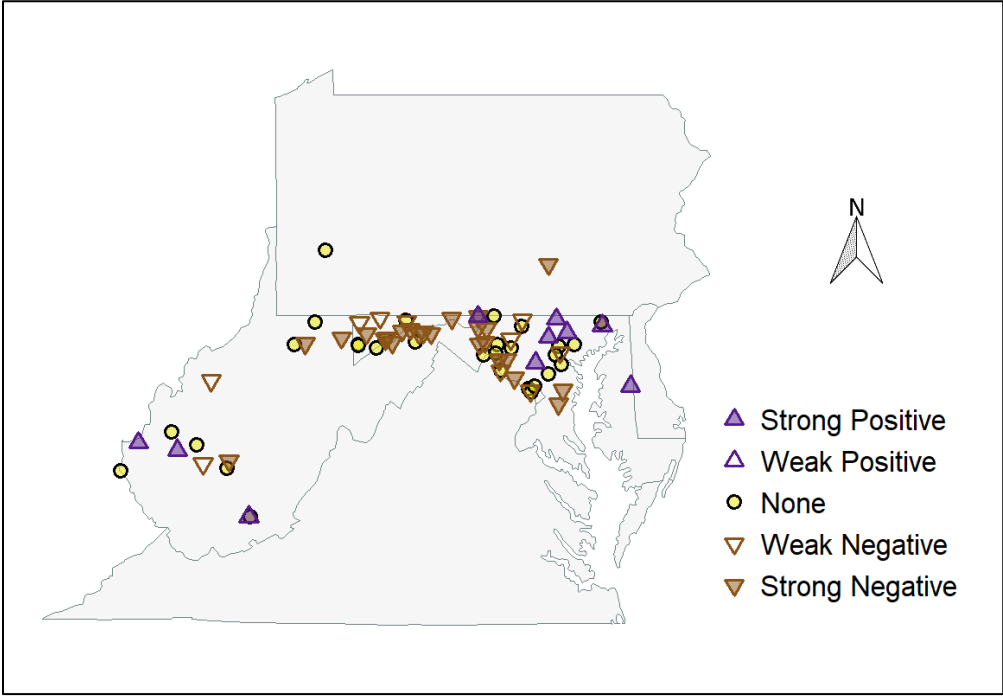
Dissolved Ammonia (NH4_F)



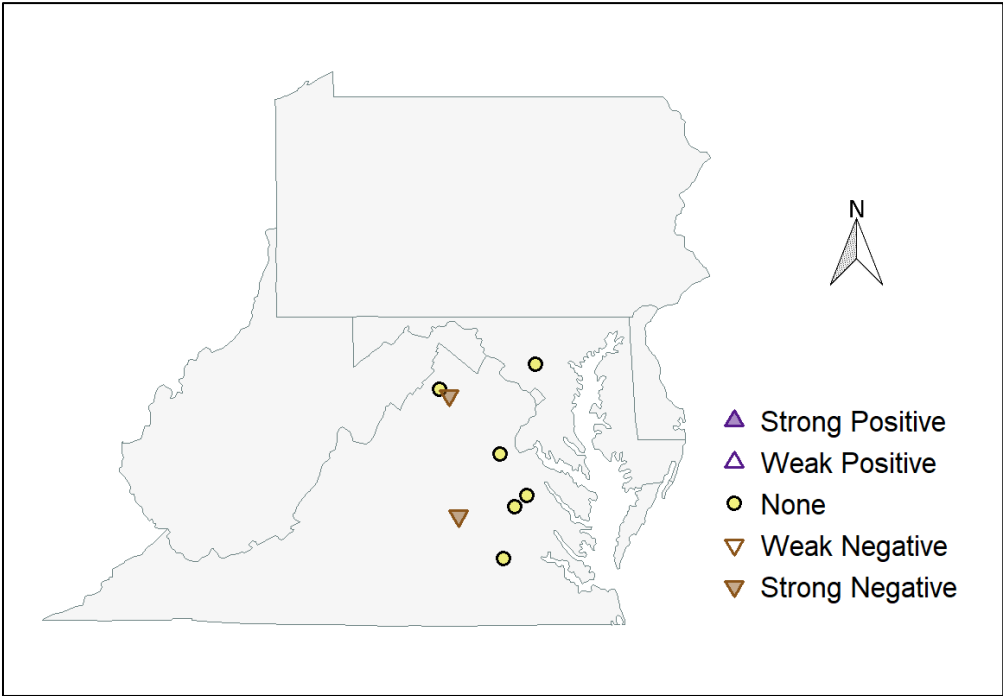
Total Nitrite (NO2_W)



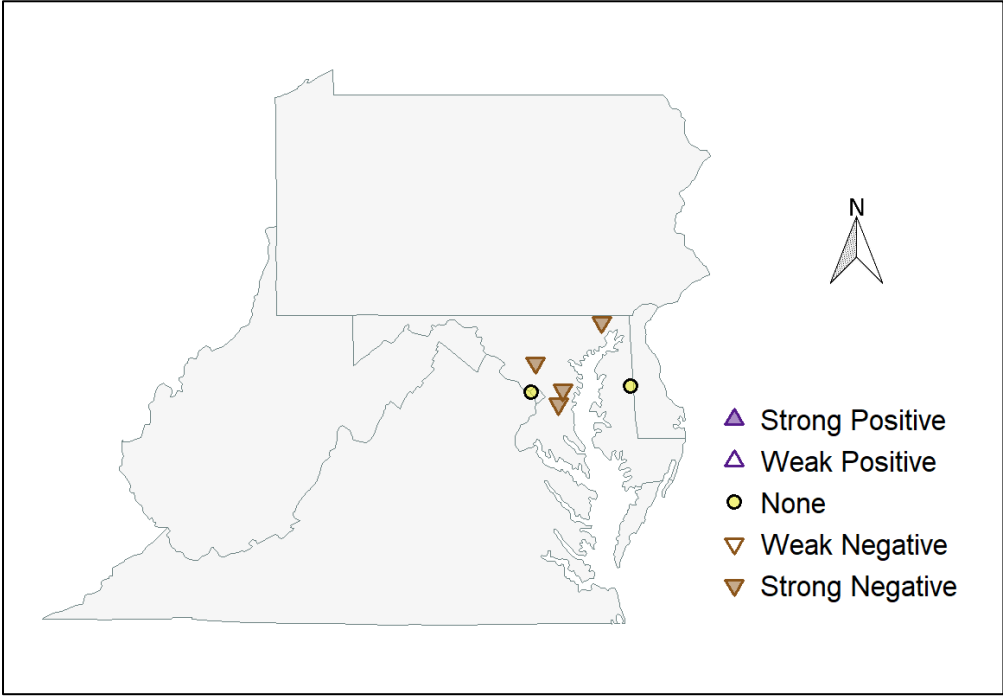
Dissolved Nitrite (NO2_F)



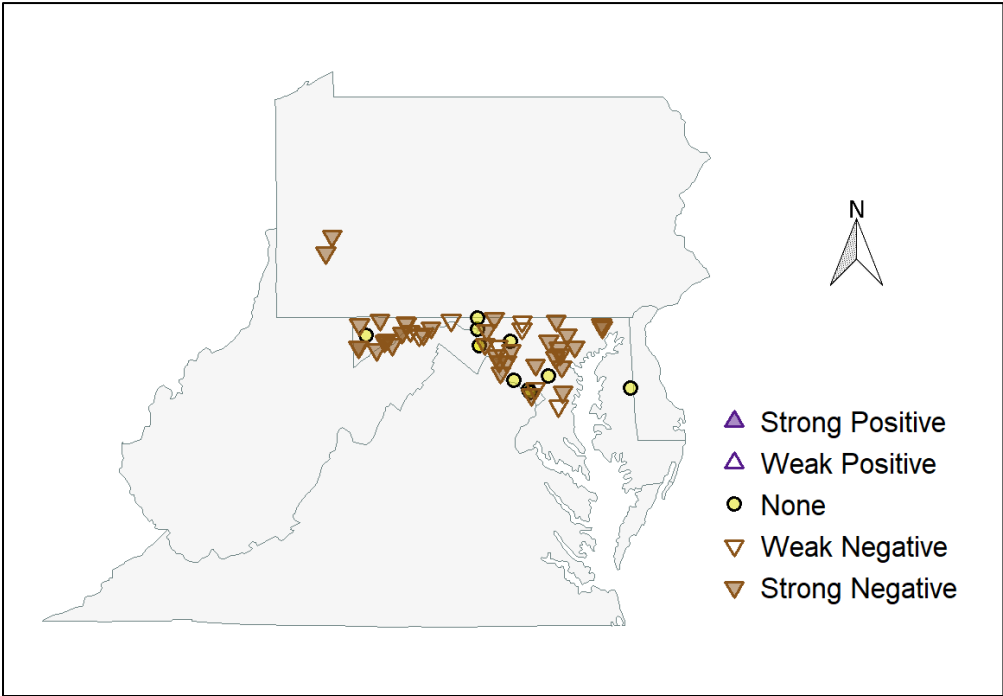
Total Nitrite-Nitrate (NO23_W)



Dissolved Nitrite-Nitrate (NO23_F)



Dissolved Kjeldahl Nitrogen (TKN_F)



Total Kjeldahl Nitrogen (TKN_W)

Specific conclusions about nitrogen trends across Region 3 are not possible based on this study's results alone because the spatial coverage of nitrogen data available through the WQP is poor and the MDLs in some cases were very high. The overall direction of change in the various nitrogen forms seems to be downward, but upward trends in total nitrogen and nitrite-nitrate were evident at some stations. Multiple researchers have documented a mix of increasing, unchanging, and decreasing TN trends in parts of Region 3 using various trend methods over different time periods (Blomquist 1995, Harned et al. 1995, Kauffman et al. 2008, MDDNR 2009, Kauffman et al. 2011, Langland et al. 2012, McGonigal and Shallenberger 2015, Buchanan and Mandel 2015, USGS 2017). Trends in TN's component nitrogen forms – NO₃_F, TKN_F, and NH₄_F – also have been documented. Harned et al. (1995) found many upward short-term (1980 – 1989) trends in NO₂_W, NO₃_W, and TKN_W at lower VA stations soon after the 1970s legislation. USGS (2017) found predominantly downward trends in these three parameters in a later period, between 1982 and 2012. Eshleman et al. (2013) found long-term (1986 – 2009) downward trends in nitrate in nine forested Appalachian Mountain watersheds. In a recent short-term period, USGS (2017) found an increase in the number of stations showing no trend or upward trends, suggesting the long-term downward trends may be reversing in some areas. Buchanan and Mandel (2015) found similar results for NO₃ at 22 WV stations, where long-term (1970s – 2012) trends were downward at 21 stations but short-term (1996 – 2012) trends were for the most part not significant. Argerich et al. (2013) found no nitrate trends and decreasing ammonium trends over the long-term (1987 – 2007) at the Fernow Experimental Forest in WV, but found upward nitrate trends and no ammonium trends over the short-term (1996 – 2007). Taken together, the results suggest that regional long-term trends in nitrogen have trended downward, but patterns of change are not consistent across Region 3 in TN and the many nitrogen forms, and may be reversing in some areas in the short-term.

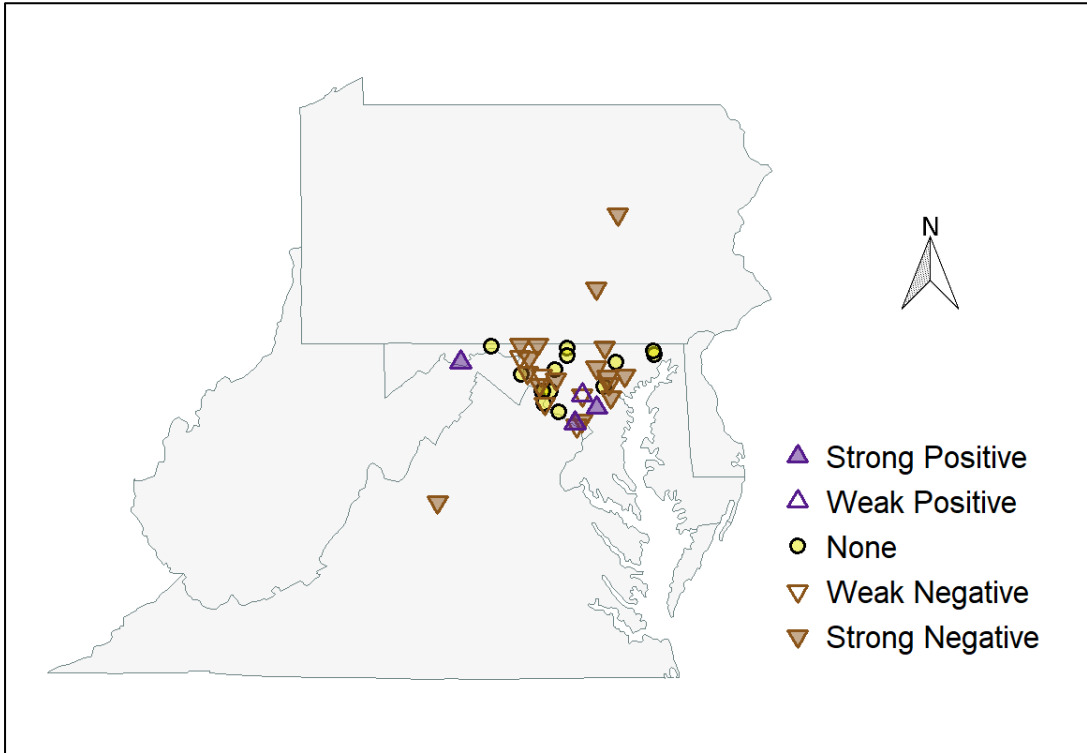
Organic Carbon (TOC, DOC)

The carbon in dissolved and particulate organic compounds is derived from plant or animal decomposition, and is distinct from “inorganic carbon” (dissolved carbon dioxide, bicarbonate, and carbonic acid). Dissolved organic carbon (DOC) refers to the fraction that passes through a fine-mesh filter (e.g., 0.45 micron); total organic carbon (TOC) refers to both fractions. TOC and DOC are non-specific measures of organic matter in the water. Metabolic waste and decaying matter from aquatic biological communities are natural sources of TOC and DOC. Some organic carbon comes from sewage and agricultural runoff pollution. Eutrophic waters typically have high levels of TOC and DOC. Organic matter in raw water chlorinated at treatment facilities produces chlorinated disinfection by-products (DBPs) in finished drinking water which are carcinogenic. DBPs, and by inference the amount of organic matter in raw water that is to be chlorinated, are now regulated by environmental agencies.

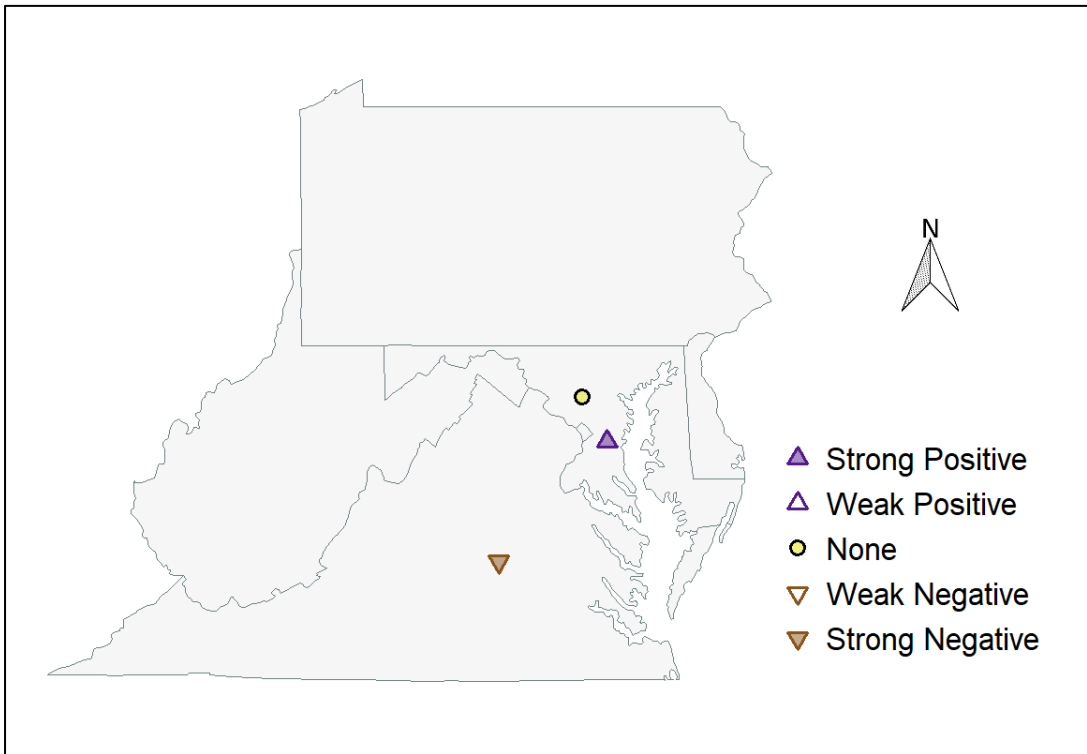
Thirty-nine (39) stations in Region 3 had sufficient TOC data to calculate long-term trends: 4 (10.3%) showed increasing trends, 14 (35.9%) showed no trends, and 21 (53.8%) showed decreasing trends. Of the decreasing trends, concentrations declined 18% and 67% between the base and recent periods. In the base period, median TOC concentrations ranged between 1.65 and 6.40 mg/liter. In the recent period, median concentrations were measurably lower overall, ranging between 2.00 and 5.80 mg/liter. Thirty-six (36) of the TOC stations were in MD.

Only three (3) stations had sufficient data to calculate long-term DOC trends. One was increasing (+27%), one showed no trend, and one was decreasing (-25%). Concentrations were between 2 and 5 mg/liter.

Despite the poor spatial coverage of TOC across Region 3 and the lack of DOC data downloaded from the WQP, we believe long-term trends are probably decreasing overall. Most of the region’s wastewater treatment plants received at least primary treatment in the mid-20th century and secondary and tertiary treatment upgrades have been made since 1985. Efforts have also been made to connect combined sewer overflows (CSOs) in cities to treatment plants. These improvements should have substantially reduced organic carbon inputs to surface waters. In the 1980s in lower VA, Harned et al. (1995) found consistent downward trends in TOC. In the Susquehanna River basin, USGS (2017) found downward trends in TOC between 1992 and 2012 and McGonigal and Shallenberger (2015) found some small reductions in TOC concentrations between the mid-1980s and 2013.



Total Organic Carbon (TOC)



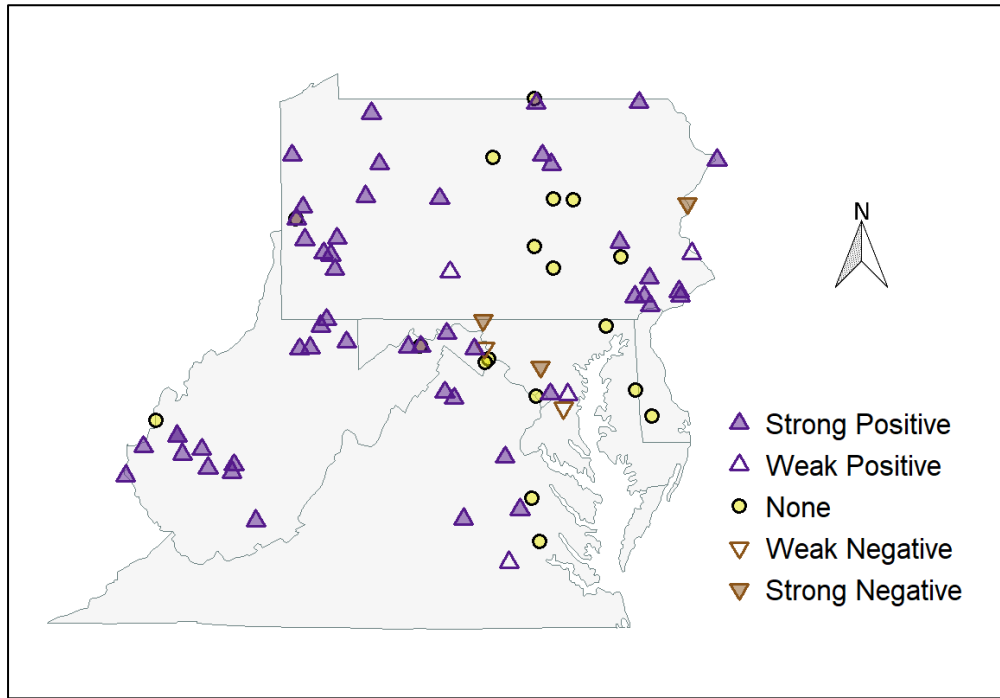
Dissolved Organic Carbon (DOC)

pH (PH)

pH is the negative log of the concentration of hydrogen ions (H^+) in water. H^+ concentration controls the acidity or basicity of water and, thus, is one of the most influential properties of water. H^+ concentrations are strongly moderated by the bicarbonate-carbonate equilibrium system in waters with high alkalinity. However, highly productive nutrient enriched systems can force large diel (daily) swings in pH to occur. As pH levels fall below 6.0 or rise above 9.0, physiological stress occurs in many aquatic organisms. Lower pH levels (increasing acidity) also heighten the toxicity of ammonia and many metals. Coal mining practices and “acid rain” from industrial air pollution substantially disrupted the bicarbonate-carbonate equilibrium system in eastern US waterways in the second half of the 20th century. Regulation of active coal mines and reclamation of abandoned mine lands, through the 1977 Surface Mining Control and Reclamation Act, has since reduced acid drainage in the affected lands. Clean air regulations, beginning with the 1970 Clean Air Act, have nationally reduced atmospheric sulfur dioxide (SO_2) and nitrogen oxides (NO_x) gases, and particulate sulfates and nitrates.

Seventy-six (76) stations in Region 3 had sufficient pH data to calculate long-term trends: 53 (69.7%) showed positive trends, 18 (23.7%) showed no trend, and 5 (6.6%) showed negative trends. The positive trends reflect declines in H^+ concentrations of 11% to 96% between the base and recent periods. In the base period, median pH levels ranged between 5.9 and 8.2. In the recent period, median pH levels were measurably higher overall, ranging between 6.4 and 8.5.

Roughly two-thirds of long-term sites in Region 3 showed increasing trends in pH, signaling an overall decrease in H^+ concentrations since the 1970s. In a comparison of data from 1987 and 2012, Methratta et al. (2014) found numerous increasing trends in pH and acid neutralizing capacity (ANC) in Maryland streams. Buchanan and Mandel (2015) and Jastram et al. (2013) also found many surface water sites exhibiting long-term increases in pH, but noted a relatively large proportion of recent short-term trends that were not significant ($p < 0.05$) or declining. Trend aberrations could be due to variations in annual rainfall over short periods (Jastram et al. 2013). Another explanation is the declines in acid deposition have begun to reverse forest-soil acidification, resulting in a chemical recovery of surface waters and stabilization of pH values (Lawrence et al. 2015). Continuous monitoring sondes still record large diel pH swings in some locations in Region 3, indicating nutrient enrichment is exceeding the stream’s capacity to buffer pH swings related to high primary production.



pH (PH)

Phosphorus

Phosphorus is a highly reactive, non-metallic element that is an essential nutrient for all living organisms. Phosphorus has many oxidation states, and strongly bonds to other elements and compounds. Dissociated phosphorus in water occurs chiefly as ortho-phosphate (PO_4^-) but may include other dissolved forms, hence the term “total dissolved phosphorus” (TDP). Phosphorus is a key component of nucleic acids (DNA, RNA), adenosine triphosphate (ATP), and the phospholipids that form cellular membranes. Aquatic plants have developed metabolic processes for absorbing and storing phosphorus for future use. When present in excess concentrations, however, phosphorus is one of the primary causes of eutrophication. Wastewater and fertilizers in runoff are the chief anthropogenic sources of excess phosphorus to aquatic systems. Total maximum daily loads (TMDLs) have been established for TP delivered to Chesapeake Bay from each tributary.

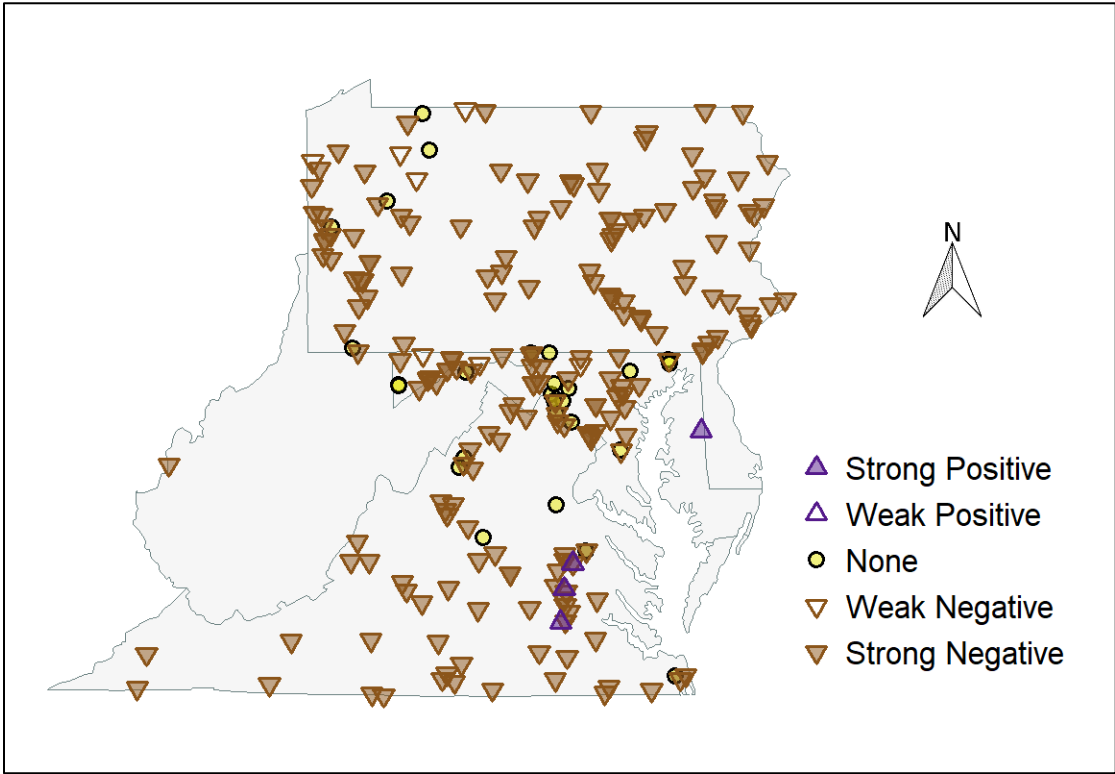
Total Phosphorus (TP)

Two hundred and forty-eight (248) stations in Region 3 had sufficient data to calculate long-term TP trends: 4 (1.6%) showed increasing trends, 29 (11.7%) showed no trend, and 215 (86.7%) showed decreasing trends. Of the decreasing trends, concentrations declined 7% to 98% between the base and recent periods. In the base period, median concentrations ranged between 0.020 and 1.540 mg/liter. In the recent period, median concentrations were considerably lower, ranging between 0.011 and 0.270 mg/liter.

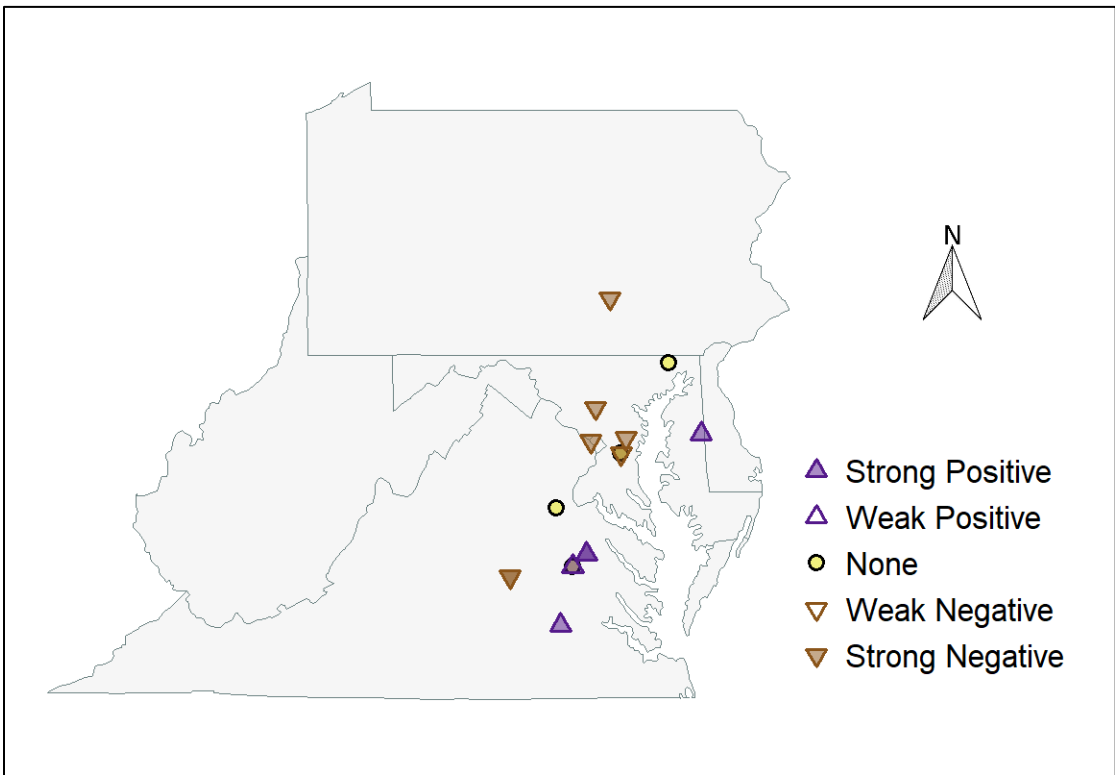
Total Dissolved Phosphorus (TDP)

Sufficient data to calculate trends in TDP were collected at sixteen (16) sites. Between the base and recent periods, seven sites show trends decreasing 33% - 90%; five sites show trends increasing 15% - 55%; four sites show no trend. The TDP trends closely mimic the corresponding TP trends at 15 of the 16 stations, suggesting TDP and TP are in chemical equilibrium with each other. In the base period, median concentrations ranged between 0.010 and 0.260 mg/liter. In the recent period, median concentrations were considerably lower, ranging between 0.008 and 0.037 mg/liter.

The numerous long-term declines in TP have been observed in Region 3 and are largely attributed to phosphate-detergent bans and wastewater treatment plant upgrades (Blomquist et al. 1996, Harned et al. 2010, Kauffman et al. 2008, 2011). Langland et al. (2012), Sprague et al. (2009), Buchanan and Mandel (2015), and others have noted TP declines leveling off in the most recent short-term periods in Chesapeake Bay tributaries. Some of this can be attributed to variability in TP related to seasonal application of fertilizers to farms and lawns (Kauffman and Belden 2010). A more likely cause is population growth in the region and increased wastewater volume.



Total Phosphorus (TP)



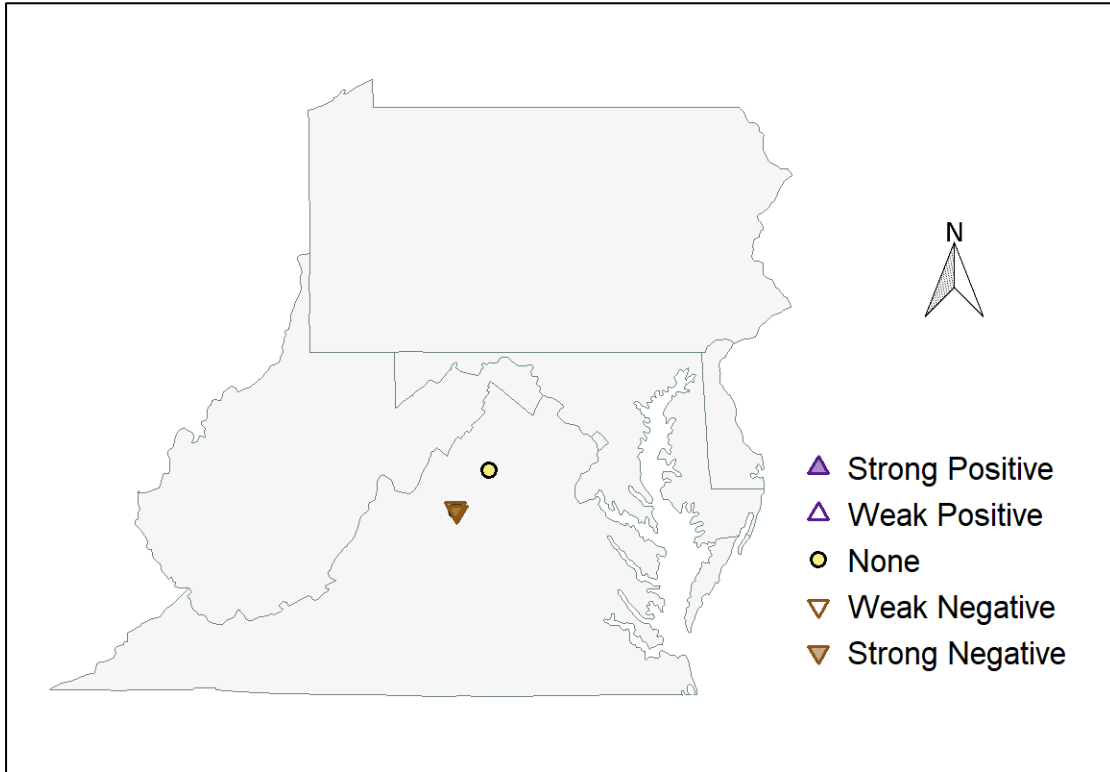
Total Dissolved Phosphorus (TDP)

Sodium (NA_W, NA_F)

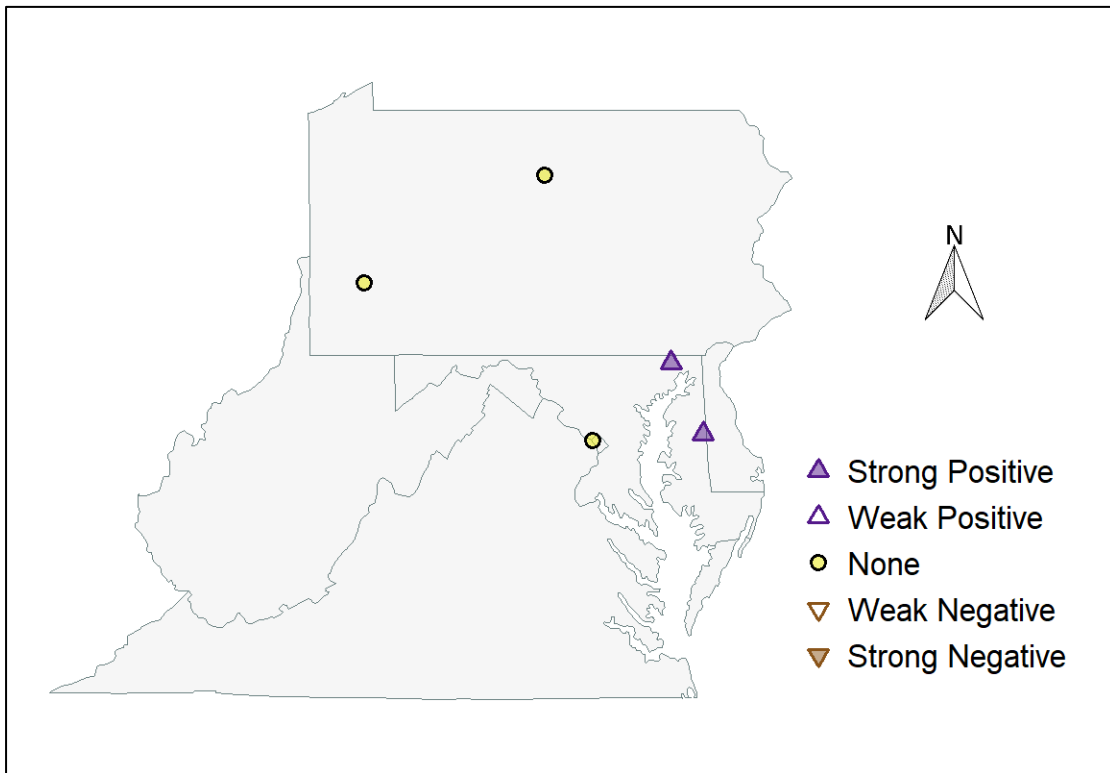
Sodium is an abundant, reactive alkali metal and a component of many minerals and salts, including table salt (NaCl). Animals require sodium in their diets to support metabolic, osmotic, and neurological functions. Plants normally contain little sodium, but the requirements of some cyanobacteria can be high. Many sodium salts are highly soluble and the monovalent sodium cation (Na⁺) contributes to water's conductivity. In coastal areas, ocean spray and groundwater are natural sources of sodium. In undisturbed, inland streams and rivers, natural processes control sodium concentration and its seasonal variability is small. Industrial and domestic sources and road salting can substantially raise sodium concentrations.

In this study, five stations had sufficient NA_F data and four stations had sufficient NA_W data for long-term trend analysis. Two stations showed decreasing trends, two showed increasing trends, and five showed no trend.

Several studies have documented increasing sodium trends in Region 3 (e.g., Sun et al. 2010, Kaushal et al. 2005, Buchanan and Mandel 2015, USGS 2017). Sun et al. (2010) attributes the long-term increases in sodium (and chloride) to an increasing in road salt used in winter. Large-scale landscape disturbance due to development is likely another cause.



Total Sodium (NA_W)



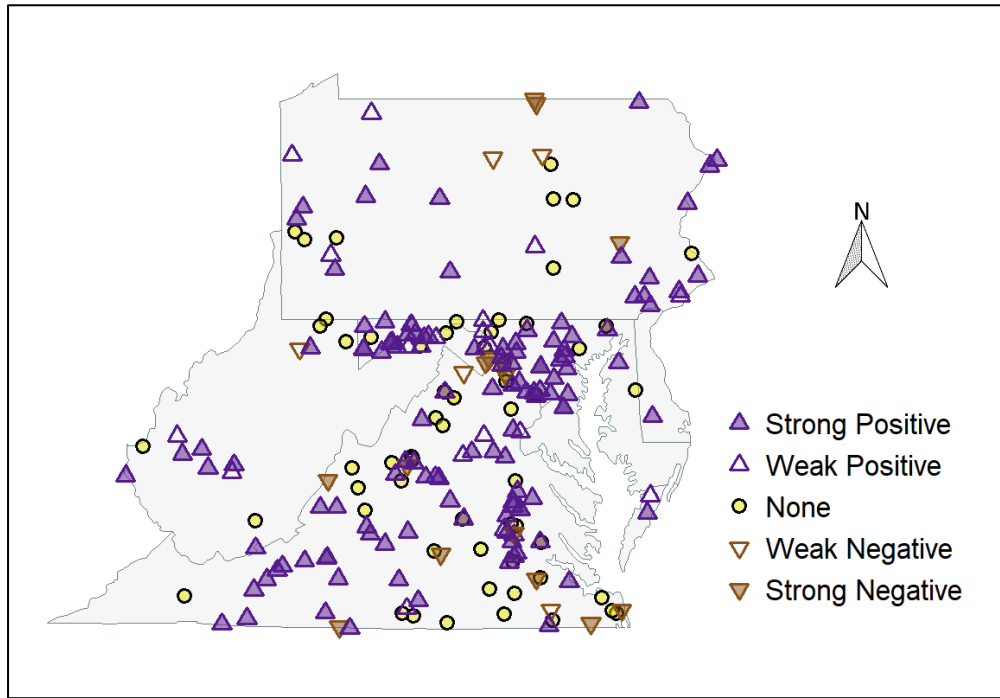
Dissolved Sodium (NA_F)

Specific Conductance (SPCOND)

Conductance is a measure of water's ability to transmit electricity and indicates the water's salinity. The strength of the electrical current depends on the concentrations of all electrolytes, or dissolved ionic substances, in the water. The cations of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) and the anions bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), sulfate (SO_4^{2-}), and chloride (Cl^-) normally dominate the ionic composition of fresh water. Runoff and discharges to streams and rivers can substantially raise ion concentrations and increase conductivity. Temperature influences conductivity; therefore, conductance measurements are adjusted to a common temperature (25°C) for comparison purposes. Plants and animals physiologically adapted to fresh water are stressed by specific conductivity levels greater than approximately 300-500 $\mu\text{S}/\text{cm}$ (USEPA 2011, 2016).

Two hundred and twenty-seven (227) stations in Region 3 have sufficient data to calculate long-term trends in SPCOND: 146 (64.3%) showed increasing trends, 61 (26.9%) showed no trend, and 20 (8.8%) showed decreasing trends. Of the increasing trends, conductance rose between 3% and 98%. In the base period, median conductance values ranged between 17 and 3,510 $\mu\text{S}/\text{cm}$. In the recent period, median conductance values shifted higher and ranged between 18 and 3,652 $\mu\text{S}/\text{cm}$.

SPCOND is rising overall in Region 3. Trends in SPCOND are similar to trends in total alkalinity, calcium, chloride, sodium, total dissolved solids, and hardness. These elements and compounds are ionic when dissolved in water, and thus capable of gaining/losing electrons and transmitting electricity. Although some SPCOND trends may be related to changes in acid deposition rates, Harned et al. (2010) concluded multiple land-surface sources such as increased landscape disturbance, population growth, and wastewater inputs are also responsible for some increasing SPCOND trends.



Specific Conductivity (SPCOND)

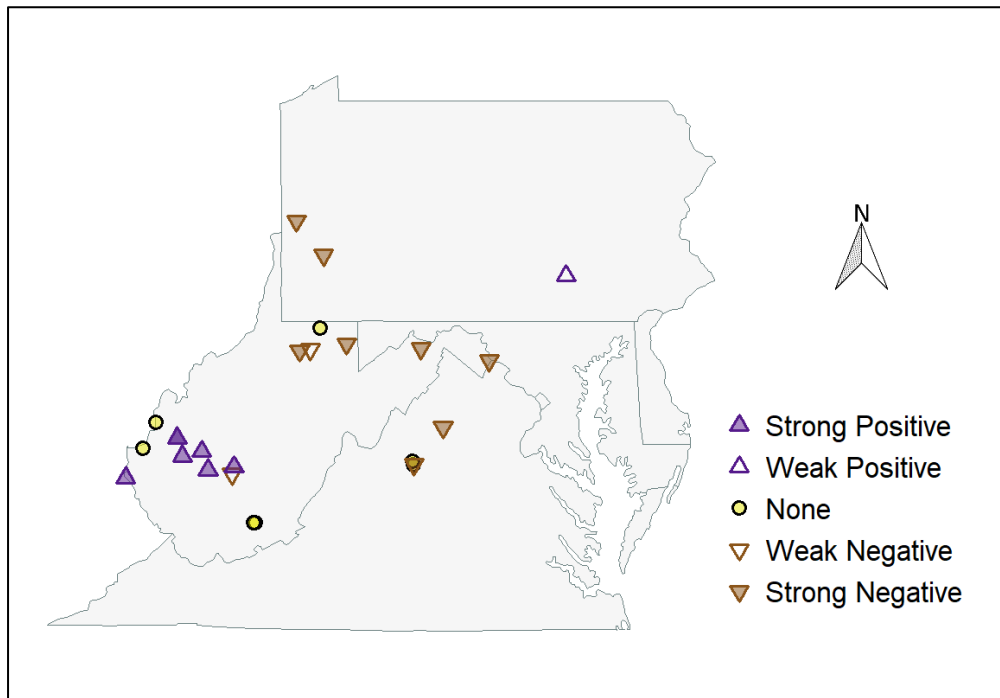
Sulfate (SO₄-F, SO₄-W)

Sulfate is an anion comprised of one sulfur and four oxygen atoms (SO₄²⁻). The element sulfur is an essential plant nutrient that forms sulfate in well-oxygenated waters. Sulfate can be a major contaminant in natural waters, and elevated levels indicate anthropogenic inputs from atmospheric deposition, mine drainage, agricultural runoff, and wastewater discharges. Sulfate increased sharply in stream water in the 1960s and 1970s due in large part to sulfuric and nitric acid emissions from coal-fired electric power plants, vehicles, oil refineries, and industry. Sulfuric acid (H₂SO₄) is a highly corrosive compound that readily dissociates in water. The USEPA guideline for sulfate in drinking water is a concentration less than 250 mg/liter.

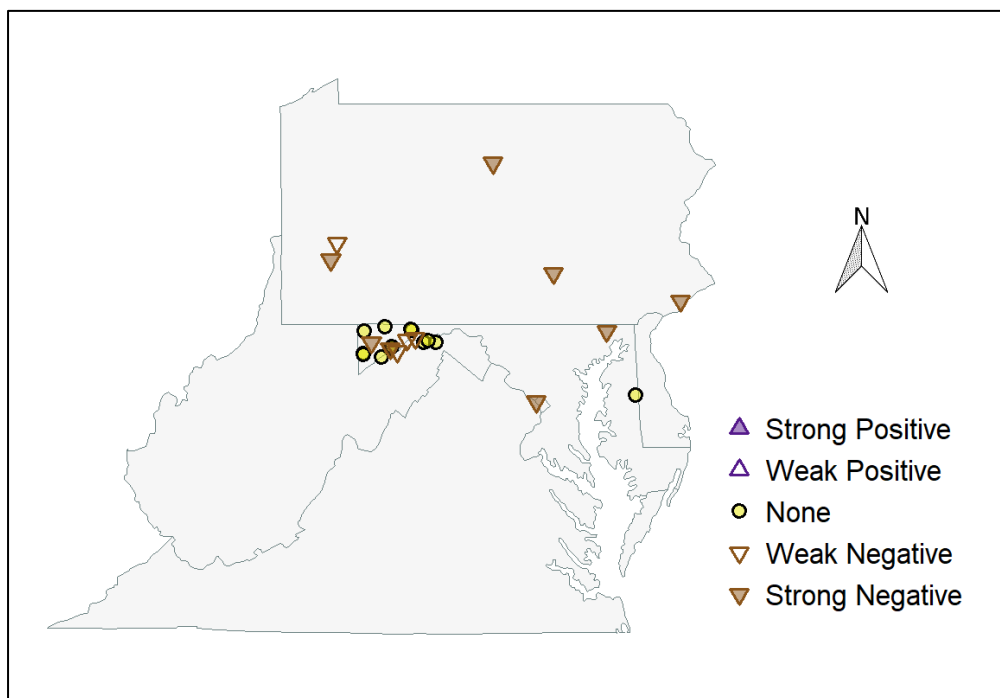
Twenty-five (25) stations in Region 3 had sufficient SO₄-F data to calculate long-term trends: no stations showed increasing trends, 13 (52%) showed no trend, and 12 (48%) showed decreasing trends. Of the decreasing trends, concentrations declined 7% and 67% between the base and recent periods. In the base period, median concentrations ranged between 7.8 and 575.0 mg/liter. In the recent period, median concentrations were lower, ranging between 6.7 and 503.0 mg/liter.

Twenty-five (25) different stations had sufficient SO₄-W data to calculate long-term trends: 8 (32%) showed increasing trends, 7 (28%) showed no trend, and 10 (40%) showed decreasing trends. Of the increasing trends, concentrations rose 19% and 127% between the base and recent periods. Of the decreasing trends, concentrations declined between 4% and 39% between the base and recent periods. In the base period, median concentrations ranged between 11 and 290 mg/liter. In the recent period, median concentrations were slightly lower, ranging between 10 and 220 mg/liter.

These results suggest that while trends in dissolved sulfate (SO₄-F) may be decreasing overall, trends in total sulfate—which includes dissolved as well as particulate sulfates—may be mixed. Some sulfate compounds are typically insoluble and form particles (e.g., calcium sulfate, lead sulfate); they do not influence levels of dissolved sulfate. In the Allegheny and Monongahela river basins, Sams and Beer (2000) point out the connection between acid drainage from coal production and increasing sulfate trends in the Dunkard Creek and Stonycreek River watersheds. They also point out the coincidence of decreasing sulfate trends with decreases in coal production in the Blacklick Creek and Loyalhanna Creek watersheds. Jastram 2013 found long-term trends in the Blue Ridge physiographic province, an area hard-hit by acid rain, were improving (decreasing) on basaltic and carbonate geology, non-existent on siliciclastic geology, and still increasing on granitic geology. Stets et al. (2014) relate decreases in sulfate (and nitrate) in the Schuylkill and North Branch Potomac rivers to remediation of acid mine drainage.



Total Sulfate (SO4_W)



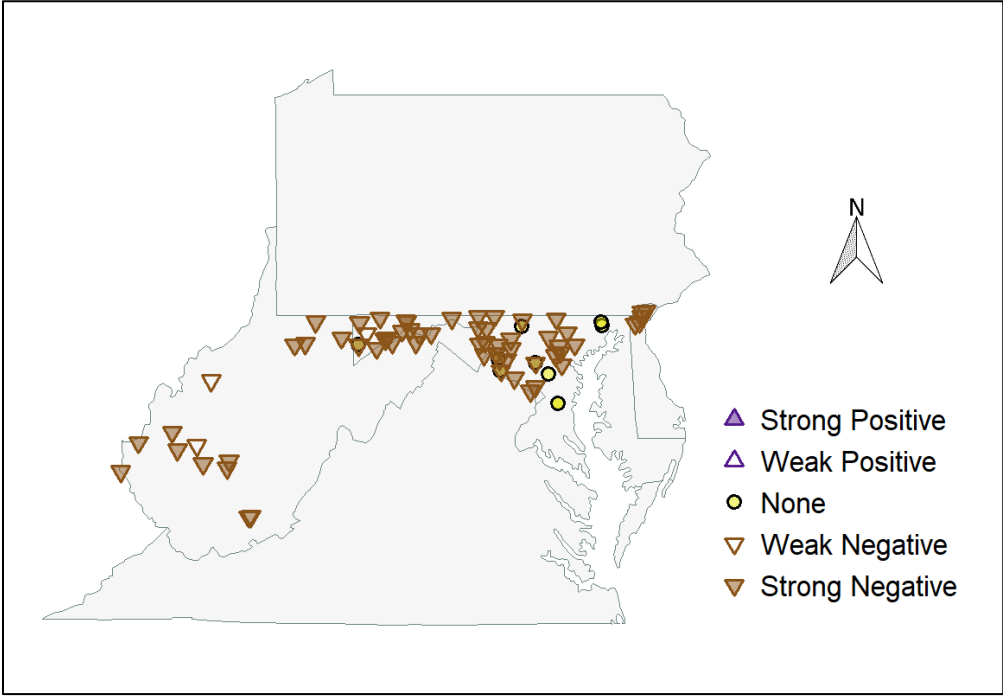
Dissolved Sulfate (SO4_F)

Suspended Solids, Total (TSS)

Total suspended solids are the sum of all inorganic and organic particles, including sediments suspended in water that do not pass through a filter (typically 0.7 microns). TSS is measured by drying and weighing material captured on the filter. TSS often correlates with turbidity, or the cloudiness of the water. Many human activities affect TSS concentrations in rivers and streams, including impoundments, irrigation practices, run-off, and discharges. High TSS levels can reduce in-stream photosynthetic productivity and impede respiration in aquatic animals. TSS is also associated with increased bacterial counts because bacteria are often attached to the suspended sediment particles. TSS is listed as a conventional pollutant in the Clean Water Act. Total maximum daily loads (TMDLs) have been established for suspended sediments delivered to Chesapeake Bay.

Seventy-four (74) stations in Region 3 had sufficient TSS data to calculate long-term trends: no stations showed increasing trends, 10 (13.5%) showed no trend, and 64 (86.5%) showed decreasing trends. Of the decreasing trends, concentrations declined 23% and 98% between the base and recent periods. In the base period, median concentrations ranged between 5.0 and 452.0 mg/liter. In the recent period, median concentrations were considerably lower, ranging between 2.4 and 14.0 mg/liter. Most of the stations are in MD, WV, and northern DE.

TSS is strongly affected by high flow events (Gellis et al. 2004), and the largest deliveries of sediments to receiving waters occur during and just after high flow events. Most samples used in this trend analysis are collected as part of routine monitoring programs. We hypothesize that most of the data are not biased by high flow events and instead represent moderate and low flow concentrations. Spatial coverage of the data is not good, but the evidence suggests TSS has trended downward in Region 3 over the long-term but may be leveling off or trending upward over the short-term. USGS (2017) found TSS at 6 of 8 (75%) stations trending downward over a long-term period (1982 – 2012), but only 10 of 30 (30%) trending downward over a short-term period (2002 – 2012). Buchanan and Mandel (2015) found downward trends at all WV stations over the long-term (1970s – 2012). However, only 6 of 26 stations showed downward trends over the short-term (1996 – 2012). Kauffman et al. (2010) found predominantly long-term downward trends in DE since the 1970s, but only 11 of 30 (37%) stations showed downward trends after 1990. The initial TSS declines were likely due to soil erosion and sediment controls on new construction and to agriculture conservation programs led by the USDA Natural Resources Conservation Service and the county conservation districts (Kauffman 2008). Recent urban growth and increases in impervious surface may be overwhelming those initial gains.



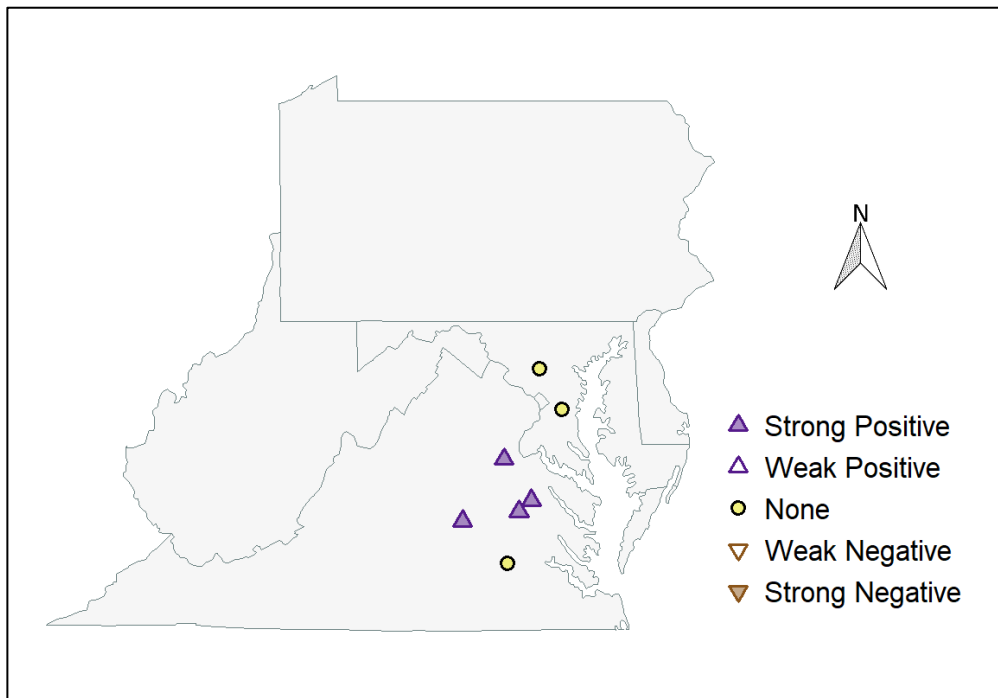
Suspended Solids (TSS)

Turbidity (TURB_NTU)

Turbidity measures the cloudiness of the water, and specifically the amount of light scattered at right angles by particles suspended in the water. Turbidity typically correlates with TSS, and can be used as an indicator or indirect measure of suspended solids.

Seven (7) stations had sufficient TURB_NTU data to calculate long-term trends: 3 showed no trend and 4 showed increasing trends with concentrations rising 63% to 120%. Two stations are in MD, and five in VA.

Papers about long-term trends in turbidity are relatively uncommon in the Mid-Atlantic. Since the parameter correlates strong with TSS, we suspect future analysis will show generally increasing trends in turbidity.



Turbidity (TURB_NTU)

Temperature (TEMP)

Water temperature is the most measured water quality parameter in the STORET-WQP dataset we analyzed. It is a universal driver of biological productivity and chemical equilibria in streams and rivers. Long-term trends in temperature are usually obscured by seasonal and diel (daily) cycles, which are driven largely by the net amount of solar energy directly absorbed as well as inputs from groundwater and anthropogenic sources. The presence or absence of riparian vegetation substantially affects the ranges of seasonal and diel change in water temperature. Signs of climate change, if present, are typically subtle compared to the much larger influences of anthropogenic disturbance.

Four hundred and four (404) stations in Region 3 had sufficient TEMP data to calculate long-term trends. As expected, very few show differences between the base and recent periods: 6 (1.5%) increased, 395 (97.8%) did not change, and 3 (0.7%) decreased. Considering that the alpha level (α) selected to test trend significance was 0.05, there is a 5.0% chance that a station trend has been misclassified.

Proportionally more stations show significant differences when water temperatures are analyzed by month or by season. This occurs despite the inherent variability in monitoring program sampling times, sampling frequency, and weather patterns present prior to sampling. Overall, 5.5% of station-months showed significant increases in water temperature while 2.3% showed decreases ($p < 0.05$). The largest percentages of change were increasing trends in January (7.5%), July (7.6%), and October (8.8%). The pattern is a little clearer for station-seasons: 6.8% showed increases and 3.5% showed decreases. The largest percentages of change were increasing trends in summer (11.6%) and winter (7.2%). Summer also had a relatively large percentage of decreasing trends (6.7%), which made it the most variable trend season.

With additional data, over a longer time period, water temperature trends become more apparent in Region 3. For the 55-year (1960 – 2014) period, Jastram and Rice (2015) and Rice and Jastram (2015) found stream water temperature increasing significantly at 53 of 129 (41.1%) of their mid-Atlantic region stations. Temperatures decreased significantly at 7 (5.4%) stations and remained unchanged at 69 (54.5%) stations. Increases were greatest in the southern part of the study area.

Stream restoration and protection goals typically promote riparian buffers to reduce nutrients and sediments entering streams. As the overall acreage of riparian buffers increases in response to restoration and protection activities, the greater canopy cover over streams and small rivers should moderate daily temperature extremes and lower the median water temperatures. In time, a greater percentage of decreasing water temperature trends in streams could be expected, especially in summer months. Countering this canopy shading effect is more surface runoff with elevated temperatures that can be expected from increasingly developed landscapes.

Percentages of station-months and station-seasons that showed significant decreasing (Neg), significant increasing (Pos), and unchanging (NS) water temperature step-trends ($p < 0.05$). Seasons: spring = March – May, summer = June – August; autumn = September – November; winter = December – February. (Station numbers are lower because not all station-months or station-seasons meet the data requirements for the step-trend analysis.)

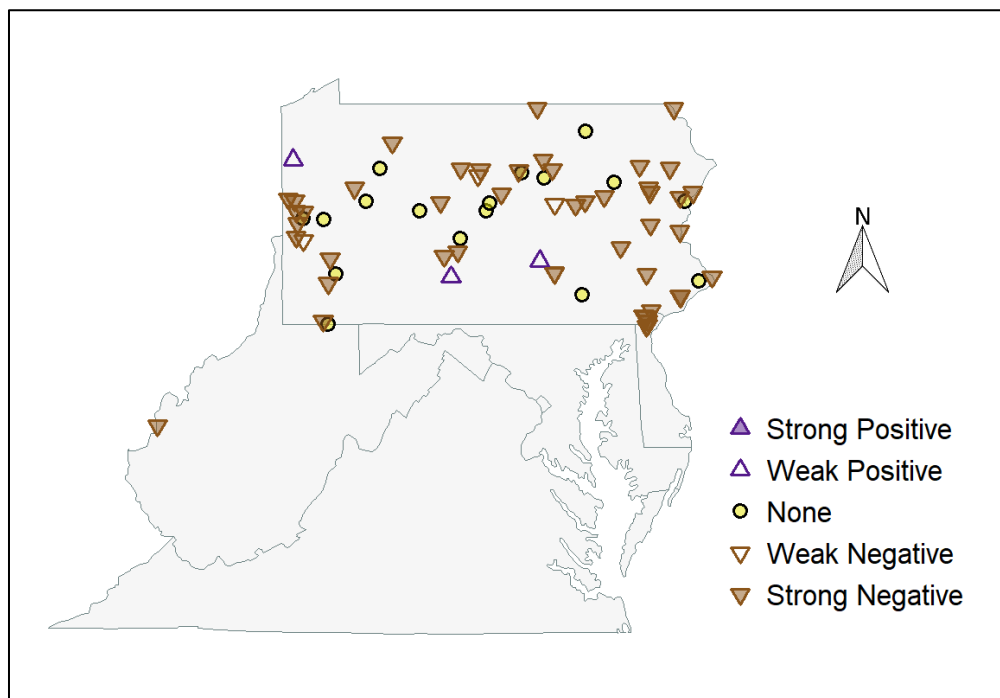
	Neg	NS	Pos	# Stations
Month				
Jan	1.4%	91.2%	7.5%	362
Feb	2.6%	93.1%	4.2%	379
Mar	5.2%	93.0%	1.8%	384
Apr	1.1%	92.8%	6.2%	373
May	3.5%	90.4%	6.1%	395
Jun	3.7%	91.3%	5.0%	378
Jul	2.9%	89.6%	7.6%	384
Aug	3.1%	92.5%	4.4%	386
Sep	0.8%	94.6%	4.7%	387
Oct	0.8%	90.3%	8.8%	373
Nov	0.8%	93.6%	5.7%	388
<u>Dec</u>	<u>1.9%</u>	<u>94.0%</u>	<u>4.1%</u>	<u>365</u>
Total	2.3%	92.2%	5.5%	4554
Season				
Spring	0.5%	95.3%	2.0%	404
Summer	6.7%	81.7%	11.6%	404
Autumn	0.5%	93.3%	6.2%	404
<u>Winter</u>	<u>4.2%</u>	<u>88.6%</u>	<u>7.2%</u>	<u>402</u>
Total	3.5%	89.7%	6.8%	1614

Zinc (ZN_W)

Zinc is an essential trace element and naturally present in low concentrations in streams and rivers. Higher concentrations are found in agricultural fertilizers, fungicides, insecticides, and in industrial waste water associated with mining. Elemental zinc itself is not a pollutant, but some of zinc's compound forms can become toxic to aquatic organisms. The presence of elevated zinc in a water sample will likely reflect industry, mining, or agricultural inputs.

Seventy (70) stations in Region 3 had sufficient ZN_W data to calculate long-term trends: 3 (4.3%) stations showed increasing trends, 17 (24.3%) showed no trend, and 50 (71.4%) showed decreasing trends. Of the decreasing trends, concentrations declined between 6% and 94% between the base and recent periods. In the base period, median concentrations ranged between 10.0 and 545.0 mg/liter. In the recent period, median concentrations were considerably lower, ranging between 5.6 and 216.0 mg/liter.

Long-term data for zinc are available for WV but many measurements fall below MDLs and data for the recent period are sparse, so these data were not used in the current study. Using another trend method, Buchanan and Mandel (2015) found total zinc declining at 4 stations, remaining constant at 16 stations, and rising at 3 stations. In the short-term (1996 – 2012), dissolved zinc improved (declined) or remained constant at all WV stations. Kauffman et al. (2008) report that zinc has improved or remained constant since 1990 at all 18 non-tidal DE stations.



Zinc (ZN_W)

Conclusions and Lessons Learned

Congress responded to public alarm about growing water quality degradation in the 20th century by enacting laws to regulate pollutants entering United States waters. This included the 1970 Clean Air Act, 1972 Clean Water Act, 1974 Safe Drinking Water Act, 1976 Toxic Substances Control Act, and 1977 Surface Mining Control and Reclamation Act. We examined some broad-scale environmental outcomes of these laws in EPA Region 3 by comparing pollutant concentrations in a 1972 – 1988 base period to those in a 1999 – 2015 recent period. The two periods are sufficiently separated in time to allow evaluation of the effectiveness of actions taken to-date to implement and uphold the laws.

Long-term Trends

The strong downward trends in phosphorus are testament to the effectiveness of wastewater treatment plant upgrades and phosphate detergent bans in reversing eutrophication. Similarly, the increases in surface water pH to safe levels, and related changes in alkalinity, hardness, aluminum, and to some extent sulfate, are strong evidence for the effectiveness of reducing “acid rain” and acid mine drainage. Some trends in acid-affected parameters have leveled off in recent times, which could suggest the region’s bicarbonate-carbonate equilibrium system is returning to a relatively stable level, with greater capacity to buffer H⁺ fluctuations. Long-term downward trends in lead can be attributed to a decreased use of leaded gasoline and a ban on lead-based paints. Downward trends in manganese can be related to declines in automobile and manufacturing emissions.

Some long-term regional trends were not clear because downloads from Legacy STORET and the WQP lack data for multiple parameters from several states. Regional trends in nitrogen were also difficult to discern because of changing MDLs and the inconsistent mix of nitrogen forms that were measured and reported. Data capturing dissolved oxygen’s diel (daily) changes would be more suited for detecting long-term trends in this parameter than the single measurements traditionally reported for sampling station visits. Similarly, analyses of seasonal water temperatures are better suited for detecting long-term trends than the step-trend method used in this study.

Some long-term trends clearly indicate problems emerging in the region. Broad-scale increases are occurring in total dissolved solids, chloride, and specific conductivity. All of these parameters can harm aquatic life and increase water supply costs. Potential sources of these contaminants include winter road salt application, hydraulic fracturing for natural gas, and landscape disturbance, especially in riparian corridors. Long-term declining trends in TSS are now leveling off or reversing. Some of this can be attributed to urban growth and increases in impervious surface.

Water Quality Data Explorer

Merging Legacy STORET and WQP data for Region 3 created a very large dataset that was not easy to quality assure. With such datasets, analysts spend a lot of time becoming familiar with the data in order to identify gaps and method changes and avoid unintentional biases and data entry errors. Familiarity with the data can be facilitated by viewing (exploring) the data quickly in multiple ways, e.g., graphically, spatially, and in tabular form. It is also beneficial to view various data presentations alongside one another.

A Water Quality Trend Explorer App was developed with the R-package, shiny, to help users rapidly explore the water quality data for 1,195 Region 3 sites in the STORET-WQP dataset. Users query the data by selecting a site and parameter of interest. The queried data are then presented in a variety of formats on several tabs. This allows the user to quickly scan the data to identify potential data quality issues as well as apparent patterns and trends. Data are first presented on the “Figure” tab as a heatmap, a scatterplot with a LOESS overlaid, and, when applicable, a flow corrected scatterplot with a

LOESS overlaid. Spatial assessments are possible with the interactive map provided under the “Map” tab. The “Data” tab presents the primary data in an interactive table and the “Metadata” tab provides a summary of useful information acquired from the “Data” tab. Finally, the “Relevant Publications” tab provides the user with sources that may be useful for interpreting the data. The Water Quality Trend Explorer App facilitated rapid QA/QC of this project’s merged STORET-WQP dataset. It is adaptable and could be used to view and explore other large water quality datasets.

Lessons Learned

Data gaps, the lack of standard parameter names in the available Legacy STORET and WQP data, and changing MDLs impeded our ability to identify broad-scale water quality trends in EPA Region 3. We also found that traditional, linear trend methods applied to long-term data sets do not support nuanced, multi-faceted investigations of the ongoing environmental responses to regulatory action and direct restoration efforts.

Data Gaps

Significant gaps were found in the EPA Region 3 data downloaded from Legacy STORET and the WQP. In many cases, the post-1998 data collected by several state agencies were missing from the WQP. One gap was recent data collected by West Virginia Department of Environmental Protection (WVDEP). The agency had given ICPRB this data to analyze for another project (Buchanan and Mandel 2015), so the data were appended to the EPA3 trends database and included in the trend analysis. Other gaps due to the lack of recent data are evident in the long-term trend maps (above) of parameters commonly measured in the field such as temperature, pH, dissolved oxygen, and specific conductivity.

Parameter Standardization

ICPRB staff attempted to address the lack of standard parameter names several times. Mary Ellen Ley, a chemist who until recently was the Quality Assurance Officer at the Chesapeake Bay Program, helped evaluate and match parameter names in the legacy STORET data. Parameter names in the WQP data went through a similar review in-house at ICPRB. The effort to standardize names and assign common ICPRB parameter codes consumed a lot of time, and we are not convinced we were successful in all cases. Potentially valid data were not used if their parameter identifications were uncertain. This lack of standardized parameter codes eliminated water quality data that may have helped fill gaps in spatial coverage and better interpret water chemistry changes in the region’s streams and rivers.

Changes in Minimum Detection Limit (MDL)

The importance of being aware of method MDLs and accounting for changes in MDLs over time cannot be overstated. MDL is the lowest concentration of a parameter that can be measured with confidence. Differences in MDL can occur when a laboratory changes method, or when a monitoring program uses multiple laboratories with different methods. Parameter values below the MDL are often discarded by data analysts and the MDL, or half the MDL, value is used in their place. This practice can result in apparent trends where none occur. In this study, a parameter’s values were excluded from a station’s step-trend if one or both time periods had more than 50% censored values (values below the MDL). This is a relatively lenient analysis “rule” intended to keep most of the data points in the analysis. Some trends illustrated in the maps above are probably inadvertently misrepresenting their station’s actual trends due to values below the MDL. However, we believe conclusions can be drawn if a preponderance of trends in the region agrees.

Trend Analysis Methods

Evident in our analyses and in numerous published trend studies is the importance of trend period and method. Concentrations of water quality parameters that the 1970s environmental regulations were intended to correct have shown long-term changes. Many are leveling off in the recent short-term. In

some instances, this appears to signal recovery (e.g., alkalinity); in others, it may be evidence of new pollution sources (e.g., TP). Non-monotonic trends were one reason for developing the R-package “shiny” app. The app provides a flexible visualization tool and relies on non-linear (LOESS) regressions to examine changes in trend over time. Also, users can identify specific dates when watershed-specific management actions occurred and observe changes in water quality before and after that time.

Recommendations

1. Fill existing data gaps in Region 3 by directly approaching state agency monitoring programs and encouraging them to submit data to the WQP. Provide assistance if needed in navigating the WQP data submission procedures.
2. Make a concerted effort to standardize Legacy STORET and WQP parameter names with chemists familiar with the field and laboratory analysis. Where possible, migrate the Legacy STORET database into the WQP.
3. For water quality monitoring programs supported by EPA, require laboratories to meet specified high quality assurance standards and achieve low MDLs.
4. Configure the App so users can independently select the periods before and after implementation of specific management actions and decide if water quality changes should be associated with those actions. Incorporate datasets that currently are not available through STORET or WQP.

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Appendix A - Data Preparation

Introduction

Data were acquired from Legacy STORET and the Water Quality Portal (WQP) to assess long-term water quality trends in EPA Region 3. This document outlines the process for standardizing and joining the data acquired from these two sources.

Notation

This document describes the process of preparing data for analyses by integrating text with associated R-code. Chunks of code will be displayed in gray boxes, preceded by descriptive text. Within the text, code and associated variables (e.g., column names and column variables) will be distinguished with a light-gray background (*example*). Throughout the analysis, R-packages are loaded into the environment to utilize functions that are not available in base-R. Bold text was used to signify packages in the text. The R operator, `::`, identifies the function and the package from which the function was obtained. For example, `dplyr::filter` indicates that the `filter` function is being applied from the **dplyr** package.

Many of the code chunks end in the function `rm()`, which is a base-R function for removing objects from the environment. Removing objects from the global environment reduces clutter and the strain on RAM.

Load Packages

Packages utilized in this analyses are loaded into the environment. The **tidyverse** does not represent a single package, but rather, a collection of packages that are loaded simultaneously with the call below. The **tidyverse** provides several packages that aid in data manipulation. For more information regarding the **tidyverse** please visit <https://www.tidyverse.org/>.

```
library(tidyverse)
library(RPostgreSQL)
```

Reproducibility

R-packages are constantly updated and can create issues when re-visiting a script several months or years later. The **checkpoint** package stores all of the necessary package information that is need to reproduce this document.

```
#checkpoint::checkpoint("2017-17-08")
```

PostgreSQL

PostgreSQL was used to store and organize data associated with this analysis.

Connect to PostgreSQL Database

A connection to the PostgreSQL database is made in the script below to allow tables to be imported from or exported to the database. This connection will be used throughout the remainder and will be identified with object name `con`.

```
source("conn_postgresql/conn_postgresql.R")
#on.exit(dbDisconnect(con), add = TRUE)
```

The code above is sourced from a hidden script for security reasons. However, the code below exemplifies how to establish the connection.

```
con = dbConnect("PostgreSQL",
  user = "your_username",
  password = "your_password",
  dbname = "your_database_name",
  host = "localhost",
  port = 5432)
on.exit(dbDisconnect(con), add = TRUE)
```

Legacy STORET

STORET stands for "STORAge and RETrieval." STORET was a United States Environmental Protection Agency (USEPA) database that was created in 1965. The database became defunct at the end of 1998 and was archived. However, the database is still accessible through the Legacy Data Center (<https://www3.epa.gov/storet/legacy/gateway.html>). In October of 2015, EPA Region 3 state data was acquired from the Legacy Data Center as tab delimited TXT files. The data was download and stored in individual folders by state. Each folder was divided into multiple folders representing data from applicable counties.

Download and Aggregate

Legacy STORET data was downloaded by State/County and organized in folders accordingly. Multiple text files were downloaded for each State/County. The files in the suffix "_res", "_sta", or "inv". Data files with the suffix "_res" contained information pertaining to the parameter measures. Data files with the suffix "_sta" contained station information. Data files with the suffix "_inv" contained summary statistics for each parameter in each county. Furthermore, queries from Legacy STORET are divided into multiple files if the text file exceeds ~26.5 Mb.

The following function, `get_Legacy`, was created to import all of the files in a specified working directory with a common suffix and append them to create a single table. The `home.dir` argument allows the user to specify the root folder or working directory from which the files will be imported. The `file.pattern` argument specifies the suffix of interest (i.e., "_res", "_sta", or "_inv"). When the `verbose = TRUE` (default), sub-directory and the file being imported are printed in real time within the R-Studio Console. No print statements will appear in the Console if `verbose = FALSE`. During data preparation, I recommend `verbose = TRUE` because if an error occurs, the print statements make it easier to find the file causing the issue. Additionally, the print statements provide some reassurance that the function is working and did not cause your computer to freeze.

The `get_Legacy` function first identifies all of the sub-directories (i.e., sub-folders) contained within the specified `home.dir`. `file.pattern` is used to specify the file suffix that will be used to select and import files from each sub-directory. Files are imported using `data.table::fread()`, to quickly import the tab-separated data. Any file size with 60 or fewer bytes was skipped because these files did not include data. Additionally, the first row is excluded because it only contains

dashes (-). For each sub-directory, the data frames are appended together using `dplyr::bind_rows`. Finally, `dplyr::bind_rows` is used again to append all of the newly appended sub-directory data frames into a single data frame.

```

get_legacy <- function(home.dir, file.pattern, verbose = TRUE){
  # List of directories.
  dirs <- list.dirs(path = home.dir)
  #-----
  county.list <- lapply(seq_along(dirs), function(dir.i) {
    if (verbose == TRUE) print(dirs[dir.i])
    # List all of the files with the specified pattern.
    files.list <- list.files(path = dirs[dir.i],
                           pattern = glob2rx(file.pattern))
  #-----
  town.list <- lapply(seq_along(files.list), function(town.i) {
    if (verbose == TRUE) print(paste0("...", files.list[town.i]))
    # Specify file directory.
    file.dir <- file.path(dirs[dir.i], files.list[town.i])
  #-----
    if (file.size(file.dir) > 60) {
  #-----
    # Specify column names.
    if (grepl("res", file.pattern)) {
      # Import each tab-separated file that contains the specified pattern.
      # Ignore the header and the first two rows.
      town.df <- data.table::fread(file.dir,
                                  sep = "\t",
                                  colClasses = list(
                                    character = c(1:6, 10:16,
                                                  18, 20, 22:24),
                                    numeric = c(7:9, 17, 19, 21)
                                  ),
                                  data.table = FALSE,
                                  na.strings = c("", " ", "NA"))
  #-----
      #
      colnames(town.df) <- c("Agency", "Station", "Station.Name",
                            "Agency.Name", "State.Name", "County.Name",
                            "Latitude", "Longitude", "Result.Value", "R",
                            "HUC", "PARAMETER_NUMBER", "Start.Date",
                            "Start.Time", "End.Date", "End.Time",
                            "Sample.Depth", "UMK",
                            "Replicate.Number", "CS",
                            "COMPOSITE_GRAB_NUMBER", "CM",
                            "Primary.Activity.Category",
                            "Secondary.Activity.Category")
  #-----
      # Make sure the "Result.Value" column is class numeric.
      # In some instances, characters are reported in the "Result.Value"
      # column. These appear to be some sort of code but the code was not
      # readily interpretable. Therefore, when the values are converted to
      # class numeric, a warning will appear saying "NAs introduced by
      # coercion". These values are removed because they contain no useful
      # information.
      town.df <- town.df %>%
        dplyr::mutate(Result.Value = as.numeric(Result.Value)) %>%
        dplyr::filter(!is.na(Result.Value))
    } else {
      if (grepl("sta", file.pattern)) {
        # Import each tab-separated file that contains the specified pattern.
        # Ignore the header and the first two rows.

```

```

town.df <- data.table::fread(file.dir,
  sep = "\t",
  colClasses = list(
    character = c(1:6, 9:10, 12:15, 17:20),
    numeric = c(7:8, 11, 16)
  ),
  data.table = FALSE,
  na.strings = c("", " ", "NA"))
#-----
  colnames(town.df) <- c("Agency", "Station", "Station.Name",
    "Agency.Name", "State.Name", "County.Name",
    "Latitude", "Longitude", "HUC",
    "Rchmile.Segment", "Miles.Up.Reach",
    "Rchonoff", "Rchname", "Station.Alias",
    "Station.Type", "Station.Depth",
    "Depth.Units", "S", "G", "Description")
} else {
  if (grepl("inv", file.pattern)) {
    # Import each tab-separated file that contains the specified
    # pattern. Ignore the header and the first two rows.
    town.df <- data.table::fread(file.dir, sep = "\t",
      colClasses = list(character = c(1:3, 6:9),
        numeric = c(4:5, 10)),
      data.table = FALSE,
      na.strings = c("", " ", "NA"))

    #-----
    colnames(town.df) <- c("Code", "Short.Name", "Long.Name",
      "Num.Stns", "Num.Obs", "First.Date",
      "Last.Date", "Min.Value", "Max.Value",
      "Average")
  }
}
}

#-----
# Exclude the first row, which only contains "-".
town.df <- town.df[-1, ]
# Return the new data frame.
return(town.df)

}
})
#-----
# Bind all of the imported files together.
county.df <- dplyr::bind_rows(town.list)
# Return the new data frame.
return(county.df)
})
#-----
# Bind all of the county data frames together.
final.df <- dplyr::bind_rows(county.list)
# Return the new data frame.
return(final.df)
}

```

The `get_legacy` function is used below to import and prepare tab-separated files with the suffix "_sta" or "_res". This will take several minutes. If your computer is running out of memory, try dividing the data up by state. To do this, specify a sub-directory (sub-folder) of the main

directory as the *home.dir*. For example, on my computer I could set the *home.dir* to "D:/ZSmith/Projects/WQ_Trends/R_Data/Legacy STORET/Raw Data/Maryland", which would only import files within the Maryland folder. Importing all of the data at once requires a lot of memory, but importing smaller data sets may help with memory allocation.

```
# Specify the main directory.
main.dir <- "D:/ZSmith/Projects/WQ_Trends/R_Data/Legacy STORET/Raw Data"
#-----
# Prepare files with the suffix "_sta".
sta.df <- get_legacy(home.dir = main.dir,
                    file.pattern = "*_sta*.txt",
                    verbose = FALSE) %>%

  dplyr::filter(
    # Keep only the rows where the "Station.Type" column contains the word
    # "STREAM" or "SPRING".
    grepl("STREAM|SPRING", Station.Type),
    # Column "G" indicates that the station measures groundwater.
    # Remove these stations.
    is.na(G))
#-----
# Prepare files with the suffix "_res".
res.df <- get_legacy(home.dir = main.dir,
                    file.pattern = "*_res*.txt",
                    verbose = FALSE) %>%

  # Semi_join keeps only the rows in x (res.df) that have a match
  # in y (sta.df).
  dplyr::semi_join(sta.df, by = c("Agency", "Station")) %>%
  # Remove any duplicated rows.
  distinct()
#-----
# Remove sta.df after semi_join with res.df.
rm(sta.df, get_legacy)
```

Several of the LEGACY STORET columns contain codes (i.e., *R*, *Param*, *UMK*, *CS*, *CM*, *Primary.Activity.Category*, and *Secondary.Activity.Category*). Metadata for these codes are available at <ftp://ftp.epa.gov/storet/exports/docs/>. A glossary of Legacy STORET terms was also available.

The parameter codes and the unit codes are imported below.

```
main.dir <- "D:/ZSmith/Projects/WQ_Trends/EPA3_Trends/data"
# Import the parameter codes and remove unnecessary columns.
folder.dir <- "Legacy_STORET/Parameter Code and Reporting Units/legacy_parameters.csv"
param <- file.path(main.dir, folder.dir) %>%
  data.table::fread(data.table = FALSE, na.strings = c("", " ", "NA")) %>%
  dplyr::select(-TOTAL_OBSERVATIONS, -PERCENTS_1972_1977,
               -PERCENTS_1967_1971, -PERCENTS_PRE_1967)
#-----
# Import the reporting unit codes.
folder.dir <- "Legacy_STORET/Parameter Code and Reporting Units/legacy_reporting_units.csv"
r.units <- file.path(main.dir, folder.dir) %>%
  data.table::fread(data.table = FALSE, na.strings = c("", " ", "NA"))
rm(main.dir, folder.dir)
```

The data frames containing the codes are joined with the *res.df* using *dplyr::left_join*.

```
legacy.df <- res.df %>%
  dplyr::mutate(PARAMETER_NUMBER = as.numeric(PARAMETER_NUMBER)) %>%
```



```
dplyr::left_join(param, by = "PARAMETER_NUMBER") %>%
dplyr::left_join(r.units, by = "REPORTING_CODE")
# Remove res.df, param, and r.units to save space.
rm(res.df, param, r.units)
```

Data Manipulation Specific to EPA Region 3 Long-Term Trends

The following script is not as general as the script above and pertains to data manipulation specifically for the EPA Region 3 long-term trends project.

`dplyr::filter` was used to keep samples without a reported sample media (""), Effluent or Influent (E), Other (O), Sludge (S), or Water (W).

```
legacy.df <- legacy.df %>%
  dplyr::filter(SAMPLE_MEDIA %in% c("", "E", "O", "S", "W")) %>%
  rename_all(toupper)
```

Subset by Selected Stations

ICPRB selected a set of Legacy Stations that met very coarse sampling frequency requirements. These stations are imported below and used to subset the Legacy data frame.

```
# Specify a new directory.
icprb.dir <- "data/Legacy_STORET/Claire_Specifications"
# Import and subset the the Legacy data by the stations specified by ICPRB.
legacy.df <- file.path(icprb.dir, "Legacy_Stations_05_03_2016.csv") %>%
  data.table::fread(data.table = FALSE, na.strings = c("", " ", "NA")) %>%
  rename_all(toupper) %>%
  dplyr::semi_join(legacy.df, ., by = "STATION")

rm(icprb.dir)
```

Subset by Selected Parameter

Additionally, a subset of parameters was selected by ICPRB. The selected parameters are imported below. In this table, we identified the parameters of interest by parameter code and the parameters "Full Name". We identified parameter codes that represented the same/similar parameters and assigned a standardized parameter name. In many instances, it appears that some agencies were more descriptive of the parameters being measured and received a different parameter code than the agencies that were less descriptive. In other instances, the parameters had different reporting units. The reporting units were also standardized in the "UNITS" column. Parameter codes that required conversion to the standardized units were flagged in the "Convert" column.

```
legacy.df <- dplyr::tbl(src = con, from = "legacy_sel_params",
  na.strings = c("", " ", "NA")) %>%
  data.frame() %>%
  rename_all(toupper) %>%
  filter(KEEP == TRUE) %>%
  select(PARAMETER_NUMBER, ICPRB_NAME, ICPRB_UNITS) %>%
  dplyr::inner_join(legacy.df, ., by = "PARAMETER_NUMBER")
```

Conversions

The `RESULT.VALUE` value is duplicated as column `ICPRB_VALUE` and, when applicable, the `ICPRB_VALUE` is converted to the defined standard units. Therefore, the `RESULT.VALUE` column remains unaltered, allowing the original value to always be referenced. Additionally, if a conversion was applied, the conversion factor was specified in the `ICPRB_CONVERSION` column.

```
group.1000 <- c(1070, 82033, 82035, 82034)
legacy.df <- legacy.df %>%
  mutate(
    # Perform conversion of applicable parameters.
    ICPRB_VALUE =
      case_when(
        PARAMETER_NUMBER == 11 ~ (RESULT.VALUE - 32) / 1.8,
        PARAMETER_NUMBER %in% group.1000 ~ RESULT.VALUE * 1000,
        PARAMETER_NUMBER == 409 ~ RESULT.VALUE * 50000,
        PARAMETER_NUMBER == 71846 ~ RESULT.VALUE * 0.777,
        PARAMETER_NUMBER == 71851 ~ RESULT.VALUE * 0.226,
        #PARAMETER_NUMBER == 32230 ~ RESULT.VALUE / 1000, # chLorophyll a
        TRUE ~ RESULT.VALUE
      ),
    # Specify the conversion applied.
    ICPRB_CONVERSION =
      case_when(
        PARAMETER_NUMBER == 11 ~ "(x - 32) / 1.8",
        PARAMETER_NUMBER %in% group.1000 ~ "x * 1000",
        PARAMETER_NUMBER == 409 ~ "x * 50000",
        PARAMETER_NUMBER == 71846 ~ "x * 0.777",
        PARAMETER_NUMBER == 71851 ~ "x * 0.226",
        #PARAMETER_NUMBER == 32230 ~ "x / 1000", # chLorophyll a
        TRUE ~ as.character(NA)
      )
  )
rm(group.1000)
```

Manage Composite data

In the `CS` column codes "H" and "L" represent the maximum of a composite and minimum of a composite, respectively. These rows were removed, leaving only codes "A" (Average), "N" (Number of observations for the sample), and "D" (Replicate Sample). A new character column, `COMPOSITE_STATISTIC`, is created to make it easy to interpret the `CS` codes. Similarly, a `COMPOSITE_METHOD` column was created to interpret the codes found in column `CM`.

```
legacy.df <- legacy.df %>%
  # Remove Composite Statistics (column = "CS") codes "H" (Max) and "L" (Min).
  filter(!CS %in% c("H", "L")) %>%
  mutate(
    # Flag Composite Statistic (CS) code "A" (Average) and "N" (Number of
    # observations for the sample). N does not appear to be a meaningful code.
    COMPOSITE_STATISTIC =
      case_when(
        CS == "A" ~ "Average",
        CS == "N" ~ "Number of observations for the sample",
        CS == "D" ~ "Replicate Sample",
        TRUE ~ as.character(NA)
      ),
  )
```

```

# Flag Composite Method (CM) for shiny meta-data.
COMPOSITE_METHOD =
  case_when(
    CM == "C" ~ "Samples collected continuously",
    CM == "G" ~ "Samples are collected as a grab",
    CM == "B" ~ "Samples are not composited",
    TRUE ~ as.character(NA)
  )
)

```

Manage Censored Data

The `R` column represents "Result Remarks". Rows with `R` codes "B", "J", "N", "O", "P", and "V" were determined to be inapplicable to this study and were subsequently removed. A `CENSORED` column was created to identify any censored data. If the `R` column contains "K", "L", "M", "T", "U", or "W", then the data are classified as "Censored". The remaining rows are classified as "Uncensored".

```

legacy.df <- legacy.df %>%
# Remove Result Remark (column = R) B, J, N, O, P, and V.
dplyr::filter(!R %in% c("B", "J", "N", "O", "P", "V")) %>%
dplyr::mutate(
# Flag as censored data.
  CENSORED =
    dplyr::if_else(
      R %in% c("K", "L", "M", "T", "U", "W"), "Censored",
      "Uncensored"
    )
)

```

If the "Censored" data comprised more than 50% of data observed for a parameter and station (site), then the data was removed because a large proportion of censored data has the potential to skew results.

```

censored.df <- legacy.df %>%
  group_by(AGENCY, STATION, ICPRB_NAME, CENSORED) %>%
  summarise(COUNT = length(CENSORED)) %>%
  group_by(AGENCY, STATION, ICPRB_NAME) %>%
  mutate(TOTAL = sum(COUNT)) %>%
  filter(CENSORED == "Censored") %>%
  mutate(PERCENT = COUNT / TOTAL * 100) %>%
  filter(PERCENT > 50)
# Remove data with > 50% Censored values.
legacy.df <- anti_join(legacy.df, censored.df,
  by = c("AGENCY",
        "STATION",
        "ICPRB_NAME"))
rm(censored.df)

```

Format and Filter Dates

Dates are formatted as "month/day/year" and times are formatted as "hour:minutes". All dates prior 1970 are removed from the data set.

```

legacy.df <- legacy.df %>%
  mutate(START.DATE = lubridate::ymd(START.DATE),
         START.DATE = as.Date(START.DATE, format = "%m/%d/%Y"),
         END.DATE = lubridate::ymd(END.DATE),

```

```

END.DATE = as.Date(END.DATE, format = "%m/%d/%Y"),
START.TIME = as.POSIXct(START.TIME, format = "%H%M"),
START.TIME = format(START.TIME, "%H:%M"),
END.TIME = as.POSIXct(END.TIME, format = "%H%M"),
END.TIME = format(END.TIME, "%H:%M"),
YEAR = format(START.DATE, "%Y") %>%
# Remove samples collected prior to 1970.
filter(YEAR >= 1970) %>%
select(-YEAR)

```

Sample Depth

All sample depths were converted to meters (m) and all samples collected at a depth greater than 1 m were removed. Samples without a specified depth (*NA*) were assumed to have been collected at the surface.

```

# Convert all depths reported as feet to meters.
# Remove samples that were not collected at the surface.
legacy.df <- legacy.df %>%
mutate(SAMPLE.DEPTH = as.numeric(SAMPLE.DEPTH) * 0.3048) %>%
filter(SAMPLE.DEPTH <= 1 |
is.na(SAMPLE.DEPTH))

```

Specific Modifications

Site *422107* was collected by the Delaware River Basin Commission in Philadelphia, PA. Some of the samples for this station were incorrectly identifying the samples as having been collected in Delaware. The script below assigns the *Pennsylvania* to the all of the rows associated with station *422107*. This modification reduces the chance of creating a duplicate result.

Additionally, District of Columbia in the *STATE.NAME* column is represented as *District Of CoLumbia*. The capital "O" in "of" creates data duplication issues when the same site is also represented by a string with a lowercase "o". Therefore, *District of Columbia* was adopted as the standard.

```

legacy.df <- legacy.df %>%
dplyr::mutate(STATE_NAME = if_else(STATION == "422107",
"Pennsylvania",
STATE.NAME),
STATE.NAME = if_else(STATE.NAME == "District Of Columbia",
"District of Columbia",
STATE.NAME))

```

Column Standardization

This section standardizes column classes, adds additional columns, modifies column names, and rearranges the columns to make it possible to join the Legacy STORET data with the WQP data.

A table was created where the Legacy STORET column names and the WQP column names are represented in two columns. None of the column names matched between the two data sources but many of the columns represented the same data type. For example, the Legacy STORET column, "STATION", and the WQP column, "MonitoringLocationIdentifier", both represent the sampling site. Column names that represented the same data type were aligned row-wise and a standardized column name was provided in a third column. If an equivalent

column was not found in one of the databases, then the column was retained and appears in the standardized column name unaltered. In general, the column names from WQP were favored and utilized in the standardized column name. However, there are multiple instances where a shorter, more intuitive name was utilized. Finally, a `CLASS` column was added to signify which class a column name should represent (e.g., `character`, `numeric`, or `date`). The table is imported and visible below.

```
standard.names <- dplyr::tbl(con, "column_names",
                           na.strings = c("", " ", "NA")) %>%
  data.frame()

standard.names %>%
  dplyr::select(-NOTES) %>%
  knitr::kable()
```

The standard names table is used to identify which standard columns are missing from `Legacy.df`. Missing columns are added to `Legacy.df` and filled with `NA`.

```
add.cols <- standard.names %>%
  filter(!LEGACY_COLUMNS %in% names(legacy.df),
         !ICPRB_COLUMNS %in% "") %>%
  pull(ICPRB_COLUMNS)
legacy.df[, add.cols] <- NA
```

All of the column names are converted to the standard column names (`ICPRB_COLUMNS`).

```
sub.cols <- standard.names %>%
  dplyr::filter(LEGACY_COLUMNS %in% names(legacy.df))
sub.cols <- sub.cols[match(names(legacy.df), sub.cols$LEGACY_COLUMNS), ]
names(legacy.df) <- ifelse(names(legacy.df) %in% sub.cols$LEGACY_COLUMNS,
                           sub.cols$ICPRB_COLUMNS, names(legacy.df))
```

The columns are then arranged to the standard format found in the `standard.names` data frame.

```
icprb.cols <- filter(standard.names, !ICPRB_COLUMNS %in% "") %>%
  pull(ICPRB_COLUMNS)
legacy.df <- legacy.df[, match(icprb.cols, names(legacy.df))]
```

Using the `CLASS` column from `standard.names`, a list of column names are extracted for each data class (i.e., `character`, `numeric`, and `date`).

```
char.cols <- standard.names %>%
  filter(CLASS == "character") %>%
  pull(ICPRB_COLUMNS)

num.cols <- standard.names %>%
  filter(CLASS == "numeric") %>%
  pull(ICPRB_COLUMNS)

date.cols <- standard.names %>%
  filter(CLASS == "date") %>%
  pull(ICPRB_COLUMNS)
```

Using `dplyr::mutate_at`, the columns are converted to the appropriate class.

```
legacy.df <- legacy.df %>%  
  mutate_at(vars(num.cols), funs(as.numeric(.))) %>%  
  mutate_at(vars(char.cols), funs(as.character(.))) %>%  
  mutate_at(vars(date.cols), funs(as.Date(.)))
```

Objects that are no longer needed are remove from the environment.

```
rm(standard.names, add.cols, sub.cols,  
   icprb.cols, char.cols, num.cols, date.cols)
```

Water Quality Portal

The STORET Data Warehouse is currently EPA’s main data repository. Data in the STORET Data Warehouse was submitted to Modernized STORET (1999-September 2009) or through the Water Quality Exchange (WQX) framework.

“The Water Quality Portal (WQP) is a cooperative service sponsored by the United States Geological Survey (USGS), the Environmental Protection Agency (EPA) and the National Water Quality Monitoring Council (NWQMC). It serves data collected by over 400 state, federal, tribal and local agencies.” (<https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange#data>)

STORET is updated weekly on Thursday evenings and NWIS is updated every 24 hours. The STORET Data Warehouse does contain data prior to 1999, but only if an agency resubmitted data previously submitted to Legacy STORET or if the agency initially submitted their data after 1998. No data was transferred from Legacy STORET.

Downloading Data

In 2015, EPA Region 3 state data was downloaded using the WQP (<https://www.waterqualitydata.us/>).

Some of the state file sizes exceeded the downloadable limits of the WQP; therefore, some of the states were downloaded in multiple data calls. The following specifications were used to download the data.

Download Notes

- 1) **State:** each state selected individually
- 2) **Site Type:** Stream
- 3) **Sample Media:** Water
- 4) **Characteristic Group:**
 - a) Inorganics, Major, Metals
 - b) Inorganics, Major, Non-Metals
 - c) Inorganics, Minor, Metals
 - d) Inorganics, Minor, Non-Metals
 - e) Nutrient
 - f) Organics, Other

- g) Physical
- 5) **Select data to download:** sample results (physical/chemical metadata)
- 6) **File format:** comma-separated
- 7) **Select data to download:** separate CSV files were downloaded for "Site data only" and "Sample results (physical/chemical metadata)"

Import WQP Data

Importing and binding all of the EPA Region 3 data together results in over 12.5 million rows of data. A subset of parameters was selected for this study. The table of selected parameters is imported from the PostgreSQL database and used to filter the data as it is imported.

```
wqp.sel.params <- dplyr::tbl(con, "wqp_sel_params",
                           na.strings = c("", " ", "NA")) %>%
  data.frame() %>%
  dplyr::filter(KEEP == TRUE) %>%
  select(-KEEP)
```

The function below, `import_bind_wqp_param`, imports the primary data downloaded from the WQP. Blank variables (i.e., "" or " ") are replaced with *NA* and all columns are imported as class character while importing the data. All of the data is imported as class "character" (`colClasses = c("character")`) because many of the columns that should contain only numeric data contain character strings. For example, the `ResultMeasureValue` column should only include numeric values but in some cases includes character strings, such as "None", "Mild", and "Moderate".

If a data frame is supplied for the `import_bin_wqp_param` variable `wqp.df`, then imported data is appended to the supplied data frame.

```
import_bind_wqp_param <- function(wqp.df, wqp.sel.params,
                                 main.dir, file.name) {
  common.cols <- c("CharacteristicName", "ResultSampleFractionText",
                  "ResultMeasure_MeasureUnitCode",
                  "ResultAnalyticalMethod_MethodName", "ProviderName",
                  "ResultAnalyticalMethod_MethodIdentifier",
                  "ResultAnalyticalMethod_MethodIdentifierContext")

  #-----
  final.df <- file.path(main.dir, file.name) %>%
  data.table::fread(data.table = FALSE,
                   na.strings = c("", " ", "NA"),
                   colClasses = c("character"),
                   showProgress = FALSE) %>%
  rename_at(vars(contains("/")), funs(sub("/", "_", .))) %>%
  mutate(CharacteristicName = tolower(CharacteristicName)) %>%
  dplyr::inner_join(wqp.sel.params, by = common.cols)

  if (!is.null(wqp.df)) final.df <- bind_rows(final.df, wqp.df)

  return(final.df)
}
```

Each CSV file is imported using the `import_bind_wqp_param` function and subsequently joined with the previously imported file.

```

# Set the working directory
backup.dir <- "D:/ZSmith/Backup"
folder.dir <- "EPA3_Trends_August_2017/EPA3Trends/Data/WQP/Raw Data"
main.dir <- file.path(backup.dir, folder.dir)
#-----
# Import the raw state data
wqp.df <- import_bind_wqp_param(NULL, wqp.sel.params,
                               main.dir, "wqp_dc_raw.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_de_raw.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_md_raw_1.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_md_raw_2.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_md_raw_3.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_md_raw_4.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_md_raw_5.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_pa_raw.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_va_raw.csv") %>%
import_bind_wqp_param(wqp.sel.params, main.dir, "wqp_wv_raw.csv")

```

Remove objects that are no longer needed from the environment.

```
rm(wqp.sel.params, main.dir, backup.dir, folder.dir, import_bind_wqp_param)
```

Subset Data

The code below removes rows that are not applicable to this study. If the *ResultDetectionConditionText* classified the sample as "Not Reported" or "Systematic Contamination", the sample was removed. Rejected sample results (*ResultStatusIdentifier* == "Rejected") were also removed. This study focuses on surface water, therefore, *ActivityMediaSubdivisionName* rows classified as "Groundwater", "Hyporheic zone", or "Wet Fall Material" were removed from the data. Columns *ResultTimeBasisText*, *SubjectTaxonomicName*, and *SampleTissueAnatomyName* were removed from the data frame because they did not contain data relevant to this study (the columns were filled with *NA*).

```

wqp.df <- wqp.df %>%
# Make sure the ActivityDepthHeightMeasure_MeasureValue
# is classified as numeric.
mutate(ActivityDepthHeightMeasure_MeasureValue =
       as.numeric(ActivityDepthHeightMeasure_MeasureValue)) %>%
filter(
# Keep only samples collected near the surface (< 1m).
# If the sample did not have a reported depth,
# then the depth was assumed to be at the surface.
# Therefore, keep NAs.
ActivityDepthHeightMeasure_MeasureValue < 1 |
  is.na(ActivityDepthHeightMeasure_MeasureValue),
# Remove Quality Control values which create approximate duplicates.
!grepl("Quality", ActivityTypeCode),
# Remove values categorized as "Not Reported" or
# "Systematic Contamination."
!ResultDetectionConditionText %in% c("Not Reported",
                                     "Systematic Contamination"),
# Remove unwanted result status.
!ResultStatusIdentifier %in% "Rejected",
# Remove unwanted Activity Media
!ActivityMediaSubdivisionName %in% c("Groundwater",
                                     "Hyporheic zone",
                                     "Wet Fall Material"),
# Remove unwanted result status.

```



```

!ResultStatusIdentifier %in% "Rejected",
# Keep only data collected after 1969.
ActivityStartDate >= 1970-01-01) %>%
# Remove inapplicable columns. These columns are filled with NAs.
select(-ResultTimeBasisText,
       -SubjectTaxonomicName,
       -SampleTissueAnatomyName)

```

Censored Data

Data below the supplied detection limit was identified and classify it as "Censored". The remaining data is classified as "Uncensored". If the data was censored, then the *DetectionQuantitationLimitMeasure_MeasureValue*, divided by two, is used to replace the *ResultMeasureValue*. Additionally, the *ResultMeasure_MeasureUnitCode* is replaced by the *DetectionQuantitationLimitMeasure_MeasureUnitCode*, when the data is classified as censored. Any remaining *NA* values in the *ResultMeasureValue* column are removed from the data.

```

wqp.df <- wqp.df %>%
  mutate(DetectionQuantitationLimitMeasure_MeasureValue =
    as.numeric(DetectionQuantitationLimitMeasure_MeasureValue),
    ResultMeasureValue = as.numeric(ResultMeasureValue),
    CENSORED = dplyr::if_else(
      is.na(ResultDetectionConditionText),
      "Uncensored",
      "Censored"
    ),
    ResultMeasureValue =
      dplyr::if_else(
        CENSORED == "Censored",
        DetectionQuantitationLimitMeasure_MeasureValue / 2,
        ResultMeasureValue
      ),
    ResultMeasure_MeasureUnitCode =
      dplyr::if_else(
        CENSORED == "Censored",
        DetectionQuantitationLimitMeasure_MeasureUnitCode,
        ResultMeasure_MeasureUnitCode
      )
  ) %>%
  filter(!is.na(ResultMeasureValue))

```

If the "Censored" data comprised more than 50% of data observed for a parameter and *MonitoringLocationIdentifier* (site), then the data was removed. A large proportion of censored data has the potential to skew results.

```

censored.df <- wqp.df %>%
  group_by(OrganizationIdentifier,
           MonitoringLocationIdentifier,
           ICPRB_NAME,
           CENSORED) %>%
  summarise(COUNT = length(CENSORED)) %>%
  group_by(OrganizationIdentifier,
           MonitoringLocationIdentifier,
           ICPRB_NAME) %>%
  mutate(TOTAL = sum(COUNT)) %>%
  filter(CENSORED == "Censored") %>%
  mutate(PERCENT = COUNT / TOTAL * 100) %>%
  filter(PERCENT > 50)

```

```
wqp.df <- anti_join(wqp.df, censored.df,
                   by = c("OrganizationIdentifier",
                          "MonitoringLocationIdentifier",
                          "ICPRB_NAME"))
rm(censored.df)
```

Unit Standardization

The `ResultMeasureValue` was converted to a standardized set of units when applicable.

```
mult.1000 <- c(87:89, 314:316, 563, 614:617, 658:659)
div.1000 <- c(45, 222:225, 233:234, 294:295, 354, 418, 646, 841:842)
ca.ueq <- 85:86
cl.ueq <- 109:111
no23w.n <- 203
mg.ueq <- 312:313
pp.p <- 544
k.ueq <- 612:613
na.ueq <- c(656:657, 660)
so4.ueq <- 717:719
nh4.mg <- c(71:72, 75:76)
```

The conversion factor utilized is identified in the `ICPRB_CONVERSION` column.

```
wqp.df <- wqp.df %>%
  mutate(
    # Apply the necessary conversions by row.
    ICPRB_VALUE = case_when(
      ICPRB_CODE %in% mult.1000 ~ ResultMeasureValue * 1000,
      ICPRB_CODE %in% div.1000 ~ ResultMeasureValue / 1000,
      ICPRB_CODE %in% ca.ueq ~ ResultMeasureValue / 1000 * 20,
      ICPRB_CODE %in% cl.ueq ~ ResultMeasureValue / 1000 * 35.5,
      ICPRB_CODE %in% mg.ueq ~ ResultMeasureValue / 1000 * 12,
      ICPRB_CODE %in% pp.p ~ ResultMeasureValue / 1000 * 0.326,
      ICPRB_CODE %in% k.ueq ~ ResultMeasureValue / 1000 * 39,
      ICPRB_CODE %in% na.ueq ~ ResultMeasureValue / 1000 * 23,
      ICPRB_CODE %in% so4.ueq ~ ResultMeasureValue / 1000 * 48,
      ICPRB_CODE %in% nh4.mg ~ ResultMeasureValue * 0.226,
      TRUE ~ ResultMeasureValue
    ),
    # Identify the conversion applied.
    ICPRB_CONVERSION = case_when(
      ICPRB_CODE %in% mult.1000 ~ "x * 1000",
      ICPRB_CODE %in% div.1000 ~ "x / 1000",
      ICPRB_CODE %in% ca.ueq ~ "x / 1000 * 20",
      ICPRB_CODE %in% cl.ueq ~ "x / 1000 * 35.5",
      ICPRB_CODE %in% mg.ueq ~ "x / 1000 * 12",
      ICPRB_CODE %in% pp.p ~ "x / 1000 * 0.326",
      ICPRB_CODE %in% k.ueq ~ "x / 1000 * 39",
      ICPRB_CODE %in% na.ueq ~ "x / 1000 * 23",
      ICPRB_CODE %in% so4.ueq ~ "x / 1000 * 48",
      ICPRB_CODE %in% nh4.mg ~ "x * 0.226",
      TRUE ~ as.character(NA)
    )
  )
)
```

Remove objects that are no longer needed from the environment.

```
rm(mult.1000, div.1000, ca.ueq, cl.ueq, no23w.n,
   mg.ueq, pp.p, k.ueq, na.ueq, so4.ueq, nh4.mg)
```

Site Information

Information pertaining to the sampling site is downloaded separately from the WQP, and therefore, must be imported and merged with the reported value. The `import_bind_wqp_site` function makes it easy to import and append together the site information downloaded by state.

```
import_bind_wqp_site <- function(wqp.site, main.dir, file.name) {
  final.df <- file.path(main.dir, file.name) %>%
  data.table::fread(data.table = FALSE,
                    na.strings = c("", " ", "NA"),
                    colClasses = "character") %>%
  rename_at(vars(contains("/")), funs(sub("/", "_", .)))

  if (!is.null(wqp.site)) final.df <- dplyr::bind_rows(final.df, wqp.site)

  return(final.df)
}
```

The site information for each state is imported and appended to form a single data frame, `wqp.site`.

```
site.dir <- "D:/ZSmith/Backup/EPA3_Trends_August_2017/EPA3Trends/Data/WQP/Raw Data/Site_Data"
#####
wqp.site <- import_bind_wqp_site(NULL, site.dir, "wqp_site_dc.csv") %>%
  import_bind_wqp_site(site.dir, "wqp_site_de.csv") %>%
  import_bind_wqp_site(site.dir, "wqp_site_md.csv") %>%
  import_bind_wqp_site(site.dir, "wqp_site_pa.csv") %>%
  import_bind_wqp_site(site.dir, "wqp_site_va.csv") %>%
  import_bind_wqp_site(site.dir, "wqp_site_wv.csv")
```

Remove objects that are no longer needed from the environment.

```
rm(site.dir, import_bind_wqp_site)
```

Only columns pertaining to the sites location are retained using `dplyr::select`. The `StateCode` provided by the WQP was translated to the appropriate character string. `dplyr::group_by_at` is used to group by all columns but `VerticalCoordinateReferenceSystemDatumName`. Grouping by these columns allows for the identification of duplicate rows using `dplyr::mutate(dup = n())`.

`dplyr::filter` can then be used to remove any rows with `dup > 1` or any rows in the `VerticalCoordinateReferenceSystemDatumName` column that contain `NA`.

```
wqp.site <- wqp.site %>%
  dplyr::select(OrganizationIdentifier, OrganizationFormalName,
               MonitoringLocationIdentifier, MonitoringLocationName,
               HUCEightDigitCode, LatitudeMeasure, LongitudeMeasure,
               HorizontalCoordinateReferenceSystemDatumName,
               VerticalCoordinateReferenceSystemDatumName,
               StateCode) %>%
  dplyr::mutate(STATE = case_when(
    StateCode == "10" ~ "Delaware",
    StateCode == "11" ~ "District of Columbia",
    StateCode == "24" ~ "Maryland",
```

```

StateCode == "42" ~ "Pennsylvania",
StateCode == "51" ~ "Virginia",
StateCode == "54" ~ "West Virginia",
TRUE ~ "ERROR"
)) %>%
dplyr::select(-StateCode) %>%
dplyr::distinct() %>%
dplyr::group_by_at(vars(-VerticalCoordinateReferenceSystemDatumName)) %>%
dplyr::mutate(dup = n()) %>%
dplyr::filter(!(dup > 1 &
                is.na(VerticalCoordinateReferenceSystemDatumName))) %>%
dplyr::ungroup()

```

Before the site information can be joined with the reported parameter values there are a few issues that need to be addressed. There is a discrepancy in the OrganizationFormalName between the parameter data ("DOW - RIBS") and the station data ("New York State DEC Division of Water") for the New York State DEC. On the WQP website, entering the string "New York State DEC Division of Water" into the "Organization ID:" box creates a valid query. Entering "DOW - RIBS" does not create a valid query; therefore, "DOW - RIBS" is replaced.

Additionally, two USGS sites, "USGS-0162101710" and "USGS-0162101790", are removed because there is no associated site information related to these site names. A query of the WQP also does not return any information for these site names.

```

wqp.df <- wqp.df %>%
  dplyr::mutate(
    OrganizationFormalName = dplyr::if_else(
      OrganizationFormalName == "DOW - RIBS",
      "New York State DEC Division of Water",
      OrganizationFormalName)
  ) %>%
  dplyr::filter(!MonitoringLocationIdentifier %in% c("USGS-0162101710",
                                                    "USGS-0162101790"))

```

The reported parameter values are joined with the site information using the three common columns: 1) *OrganizationIdentifier*, 2) *OrganizationFormalName*, and 3) *MonitoringLocationIdentifier*.

```

by.names <- c("OrganizationIdentifier", "OrganizationFormalName",
             "MonitoringLocationIdentifier")
wqp.df <- dplyr::left_join(wqp.df, wqp.site, by = by.names)

```

Column Standardization

This section standardizes column classes, adds additional columns, modifies column names, and rearranges the columns to make it possible to join the WQP data with the Legacy STORET data. The standard name table, *standard.names*, is imported below. For more information about this table, please review the **Column Standardization** subsection under the **Legacy STORET** section.

```

standard.names <- dplyr::tbl(con, "column_names",
                           na.strings = c("", " ", "NA")) %>%
  data.frame()

```

The standard names table is used to identify which standard columns are missing from *wqp.df*. Missing columns are added to *wqp.df* and filled with *NA*.

```
add.cols <- standard.names %>%
  dplyr::filter(!WQP_COLUMNS %in% names(wqp.df),
                !WQP_COLUMNS %in% "") %>%
  dplyr::select(ICPRB_COLUMNS) %>%
  dplyr::pull()
```

```
wqp.df[, add.cols] <- NA
```

All of the column names are converted to the standard column names (*ICPRB_COLUMNS*).

```
sub.cols <- standard.names %>%
  dplyr::filter(WQP_COLUMNS %in% names(wqp.df))
sub.cols <- sub.cols[match(names(wqp.df), sub.cols$WQP_COLUMNS), ]
names(wqp.df) <- dplyr::if_else(names(wqp.df) %in% sub.cols$WQP_COLUMNS,
                               sub.cols$ICPRB_COLUMNS,
                               names(wqp.df))
```

The columns are then arranged to the standard format found in the *standard.names* data frame.

```
icprb.cols <- standard.names %>%
  dplyr::filter(!ICPRB_COLUMNS %in% "") %>%
  dplyr::pull(ICPRB_COLUMNS)

wqp.df <- wqp.df[, match(icprb.cols, names(wqp.df))]
```

Using the *CLASS* column from *standard.names*, a list of column names are extracted for each data class (i.e., *character*, *numeric*, and *date*).

```
char.cols <- standard.names %>%
  filter(CLASS == "character") %>%
  pull(ICPRB_COLUMNS)

num.cols <- standard.names %>%
  filter(CLASS == "numeric") %>%
  pull(ICPRB_COLUMNS)

date.cols <- standard.names %>%
  filter(CLASS == "date") %>%
  pull(ICPRB_COLUMNS)
```

Using *dplyr::mutate_at*, the columns are converted to the appropriate class.

```
wqp.df <- wqp.df %>%
  mutate_at(vars(num.cols), funs(as.numeric(.))) %>%
  mutate_at(vars(char.cols), funs(as.character(.))) %>%
  mutate_at(vars(date.cols), funs(as.Date(.)))
```

The WQP data frequently contains the agency string within the *SITE* string. For example, the prefix *21VASWCB-* of the *21VASWCB-9-BCK015.88* site name is the code for the Virginia Department of Environmental Quality. The agency code is not concatenated with the site name in the Legacy STORET database. These agency portions of the string are removed to simplify appending this data frame with other data frames. If the *SITE* names are different, even by a single character, it can be difficult to identify duplicate rows.

```
wqp.df$SITE <- paste0(unique(wqp.df$AGENCY), "-") %>%
  paste0(collapse = "|") %>%
  gsub(".", "", wqp.df$SITE)
```

Additionally, some of the *AGENCY* column character strings contain the suffix "_WQX". This suffix is removed to standardize the agency name and simplify the merge with other data frames.

```
wqp.df$AGENCY <- gsub("_WQX", "", wqp.df$AGENCY)
```

Remove objects that are no longer needed from the environment.

```
rm(standard.names, add.cols, sub.cols, icprb.cols,  
   char.cols, num.cols, date.cols, wqp.site, by.names)
```

West Virginia Additional Data

We noticed recent (post 1999) WVDEP data were mostly absent in the WQP download. Data through 2012 had been given to ICPRB by WVDEP for another project (Buchanan and Mandel 2015), and was subsequently added to the EPA Region3 database.

Import

The data are imported from an excel file using `readxl::read_excel`. Only columns applicable to our data base were retained.

```
main.dir <- "D:/ZSmith/Projects/WQ_Trends/EPA3_Trends/data/WVDEP"  
file.name <- "WV_Data_from_WVDEP_2015Study.xlsx"  
file.dir <- file.path(main.dir, file.name)  
  
wv.param <- readxl::read_excel(file.dir, sheet = 1)  
  
wv.station <- readxl::read_excel(file.dir, sheet = 2) %>%  
  dplyr::select(SITE, COUNTY_NAME, STATE_NAME,  
               HORIZONTALCOORDINATEREFERENCE SYSTEM DATUM NAME,  
               LONGITUDE, LATITUDE)
```

The two data frames were joined using the common column `SITE`.

```
wv.df <- left_join(wv.param, wv.station, by = "SITE")
```

Column Standardization

Following the same procedure used for the Legacy STORET and WQP data, the WVDEP data were standardized to make it possible to join the WVDEP data with the other data sets. For more information, please review the **Column Standardization** subsection under the **Legacy STORET** section.

```
standard.names <- dplyr::tbl(con, "column_names",  
                             na.strings = c("", " ", "NA")) %>%  
  data.frame()  
  
add.cols <- standard.names %>%  
  filter(!ICPRB_COLUMNS %in% names(wv.df),  
         !ICPRB_COLUMNS %in% "") %>%  
  pull(ICPRB_COLUMNS)  
wv.df[, add.cols] <- NA  
  
icprb.cols <- filter(standard.names, !ICPRB_COLUMNS %in% "") %>%
```

```

pull(ICPRB_COLUMNS)
wv.df <- wv.df[, match(icprb.cols, names(wv.df))]

char.cols <- standard.names %>%
  filter(CLASS == "character") %>%
  pull(ICPRB_COLUMNS)

num.cols <- standard.names %>%
  filter(CLASS == "numeric") %>%
  pull(ICPRB_COLUMNS)

date.cols <- standard.names %>%
  filter(CLASS == "date") %>%
  pull(ICPRB_COLUMNS)

wv.df <- wv.df %>%
  mutate_at(vars(num.cols), funs(as.numeric(.))) %>%
  mutate_at(vars(char.cols), funs(as.character(.))) %>%
  mutate_at(vars(date.cols), funs(as.Date(.)))

```

Remove objects that are no longer needed from the environment.

```

rm(standard.names, add.cols, icprb.cols, char.cols, num.cols, date.cols,
   main.dir, file.name, file.dir, wv.param, wv.station)

```

Join Data

In this section, the data from Legacy STORET, WQP, and the additional data from WVDEP are joined together to form a single table (i.e., data frame). The data are further groomed and prepared to be exported to a PostgreSQL database.

Combine Data

The columns in the three data frames (i.e., *legacy.df*, *wqp.df*, and *wv.df*) were standardized to make it simple to append the data frames into a single data frame. The data frames are appended using `dplyr::bind_rows`, the rows are sorted using `dplyr::arrange`, and the columns are rearranged using `dplyr::select()` and `dplyr::everything()`.

```

join.df <- dplyr::bind_rows(legacy.df, wqp.df, wv.df) %>%
  dplyr::distinct() %>%
  dplyr::arrange(AGENCY, SITE, ICPRB_NAME, DATE, REPLICATE_NUMBER, DEPTH) %>%
  dplyr::select(AGENCY, SITE, ICPRB_NAME, DATE, CENSORED, everything())

```

MONTH and *YEAR* columns are added to the data frame to make it easier to query the database by date.

```

join.df <- dplyr::mutate(join.df,
  DATE = as.Date(DATE),
  MONTH = format(DATE, "%m"),
  YEAR = format(DATE, "%Y"))

```

Remove objects that are no longer needed from the environment.

```

rm(legacy.df, wqp.df, wv.df)

```

Filter Out Tidal Sites

Tidal sites, identified using the Chesapeake Bay Program CEDR database, are omitted from the data frame. This study is focused on freshwater streams.

```
t.dir <- "data/tidal/CEDR_MonitoringLocation_WQ_tidal_cbuchanan_04aug17.csv"
tidal.df <- data.table::fread(t.dir, data.table = FALSE)
join.df <- dplyr::anti_join(join.df, tidal.df,
                           by = c("SITE" = "MonitoringLocationName"))
```

Specific Site Alterations

Some of the sites required the reported values to be manipulated. Many sites in the database have multiple latitude and longitude values as a result of the sampling location being moved, more accurate GPS equipment being utilized, or reporting errors. In the majority of cases we did not alter the reported latitude and longitude; however, the sites below required additional attention. All of the sites below are located near a geopolitical border. Minor differences or errors associated with the reported latitude and longitude values resulted in locations for the same site being located in two states. The majority of sites were classified into one state using Best Professional Judgement (BPJ). Coordinates associated with sites *TDA01* and *TOR01* from "E-STORET" did not correspond well with the provided site description. *TDA01* is described as a monitoring station for Dalecarlia reservoir, located along the border of Maryland and D.C., but the coordinates place the site in Virginia. Similarly, *TOR01* is described as a monitoring station for Oxon Run, located in Maryland, but the coordinates place the site on the Virginia side of the Potomac River. This may be due to a difference in the horizontal coordinate system being used to plot the points; however, no horizontal coordinate system was provided to correct this issue. Using BPJ, we decided to keep these points but change the latitude and longitude values to those reported in "STORET" for these sites. Finally, the site name, *WQN0501*, appears to be associated with a sampling location ~0.5 miles south of the Maryland and Pennsylvania border and ~0.5 miles above the border. Both sites are located directly on the stream, and therefore, appear to have the correct coordinates. We decided the best way to handle this site was to add a "_PA" and "_MD" suffix to the end of the site name to distinguish this site as two locations.

```
join.df <- join.df %>%
  dplyr::mutate(
    STATE_NAME = case_when(
      SITE == "NBP0326" ~ "West Virginia",
      SITE == "NBP0534" ~ "Maryland",
      SITE == "POT1596" ~ "Maryland",
      SITE == "POT1830" ~ "Maryland",
      SITE == "RCR01" ~ "Maryland",
      SITE == "TDA01" ~ "Maryland",
      SITE == "TOR01" ~ "Maryland",
      TRUE ~ STATE_NAME
    ),
    LATITUDE = case_when(
      SITE == "TDA01" & PROVIDERNAME == "E-STORET" ~ 38.9458667,
      SITE == "TOR01" & PROVIDERNAME == "E-STORET" ~ 38.81588333,
      TRUE ~ LATITUDE
    ),
```



```

LONGITUDE = case_when(
  SITE == "TDA01" & PROVIDERNAME == "E-STORET" ~ -77.10698333,
  SITE == "TOR01" & PROVIDERNAME == "E-STORET" ~ -77.00643333,
  TRUE ~ LONGITUDE
),
SITE = case_when(
  SITE == "WQN0501" & STATE_NAME == "Pennsylvania" ~ "WQN0501_PA",
  SITE == "WQN0501" & STATE_NAME == "Maryland" ~ "WQN0501_MD",
  TRUE ~ SITE
))

```

Filter Low Parameter Frequency

Parameters of interest with a low number of reporting values (< 100) were present in the data set because they were associated with stations with at least one other parameter with a high number of reporting values (>= 100). Previous specifications were to pull a specific list of stations and a specific list of parameters, but parameters were not strictly associated with a particular station. The script below counts the data by Site and Parameter, and removes rows associated with Site/parameters with < 100 counts.

```

sub.df <- join.df %>%
  dplyr::group_by(SITE, ICPRB_NAME, YEAR) %>%
  dplyr::summarise(COUNT = length(AGENCY)) %>%
  dplyr::filter(COUNT >= 10) %>%
  dplyr::group_by(SITE, ICPRB_NAME) %>%
  dplyr::summarise(COUNT = length(COUNT)) %>%
  dplyr::filter(COUNT >= 10) %>%
  dplyr::select(1:2)

join.df <- dplyr::semi_join(join.df, sub.df, by = c("SITE", "ICPRB_NAME"))

```

Remove objects that are no longer needed from the environment.

```
rm(sub.df, t.dir, tidal.df)
```

Flow Gage

Parameter sites were associated with USGS flow gages when possible. Most sites were not sampled at the same exact location as the USGS gage. Therefore, sites were associated with nearby USGS gages.

The **RODBC** package is used to connect to an MS Access database containing a table of USGS gages associated with parameter sites. `RODBC::odbcConnect()` is used to connect to the MS Access database and `RODBC::odbcCloseALL()` is used to terminate the connection. `RODBC::sqlFetch()` is used to import tables from MS Access as data frames. When the tables are imported from MS Access, the data is processed using a custom function, `prep_df`. `prep_df` converts all column names to uppercase using `dplyr::rename_all()` and all leading/trailing white space is removed from the data frame using `trimws()`.

```

prep_df <- function(x) {
  x %>%
  dplyr::rename_all(toupper) %>%
  lapply(trimws) %>%

```

```
data.frame(stringsAsFactors = FALSE)
}
```

Connect to the EPA3_WQT MS Access database and import the "Sites" and "Sites_AdditionalInfo" tables.

```
library(RODBC)

channel <- RODBCon::odbcConnect("EPA3_WQT")

tab.sites <- RODBCon::sqlFetch(channel, "Sites", stringsAsFactors = FALSE) %>%
  prep_df()

tab.sites.additional <- RODBCon::sqlFetch(channel, "Sites_AdditionalInfo",
  stringsAsFactors = FALSE) %>%
  prep_df()

RODBCon::odbcCloseAll()
```

Connect to the WQT_June MS Access database and import the "Site_Gage_List" and "LTQ_GageInfo" tables.

```
channel <- RODBCon::odbcConnect("WQT_June")

tab.gages <- RODBCon::sqlFetch(channel, "Site_Gage_List",
  stringsAsFactors = FALSE) %>%
  prep_df() %>%
  dplyr::select(ICP_ID, AGENCY, SITE, GAGE_ID) %>%
  dplyr::distinct()
#tab.gage_flow <- sqlFetch(channel, "LTQ_Data", stringsAsFactors = FALSE)
tab.gage.info <- RODBCon::sqlFetch(channel, "LTQ_GageInfo",
  stringsAsFactors = FALSE) %>%
  prep_df()

RODBCon::odbcCloseAll()
```

The gage information is then stored as an individual table in the PostgreSQL database.

```
dbWriteTable(con, "gage_info", tab.gage.info,
  overwrite = TRUE, row.names = FALSE) %>%
  invisible()
```

The latitude and longitude values from the `tab.sites` data frame are rounded to the fifth decimal places to eliminate minor differences in the reported latitude and longitude values for the same site.

```
tab.sites[, c("LATITUDE", "LONGITUDE")] <- tab.sites %>%
  dplyr::select(LATITUDE, LONGITUDE) %>%
  sapply(as.numeric) %>%
  round(5) # six recommended by Nagel but did not merge correctly.
```

The `DUP_ID` column is removed from `tab.sites` because it creates duplicates when merged with `tab.gages`.

```
tab.sites <- tab.sites %>%
  dplyr::select(-DUP_ID) %>%
  distinct()
```

Merge the site and gage information with the data with the *join.df* data frame.

```
final.df <- join.df %>%  
  dplyr::left_join(tab.sites, by = c("AGENCY", "SITE", "SITE_NAME",  
                                   "LATITUDE", "LONGITUDE")) %>%  
  dplyr::left_join(tab.gages, by = c("ICP_ID", "AGENCY", "SITE"))
```

Remove objects that are no longer needed from the environment.

```
rm(join.df, tab.sites, tab.sites.additional,  
    tab.gages, tab.gage.info, channel, prep_df)
```

The *final.df* contains data from Legacy STORET, the WQP, and additional data from WVDEP. The combined data can now be subjected to further QA/QC and/or analysis.

Appendix B - Flow Gages Matched with Water Quality Monitoring Stations

The table below presents all the USGS flow gages that ICPRB staff were able to match with water quality monitoring stations in the merged Legacy STORET and WQP dataset.

Note: At the beginning of this project, the stations present in the Legacy STORET data were used to limit the stations queried from the WQP. Later in the project, this limitation was removed because it prevented approximately 400 stations from the WQP from being included in the analysis data set. Because this change happened later during project development, there was no opportunity to attempt to associate USGS flow gages with the approximately 400 additional stations. Gages associated with the WV ambient water quality monitoring sites are also not included. Therefore, this table provides useful flow gage information for many sites but is not complete.

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01427510	DELAWARE RIVER AT CALLICOON NY	NY	41.75666667	-75.0575	NAD83	WQN0185	41.7644	-75.0619	933.25
01427510	DELAWARE RIVER AT CALLICOON NY	NY	41.75666667	-75.0575	NAD83	WQN0185	41.765	-75.053333	987.92
01439500	Bush Kill at Shoemakers, PA	PA	41.08815078	-75.03767469	NAD27	WQN0139	41.088056	-75.038056	33.71
01439500	Bush Kill at Shoemakers, PA	PA	41.08815078	-75.03767469	NAD27	WQN0139	41.0883	-75.0375	22.13
01442500	Brodhead Creek at Minisink Hills, PA	PA	40.998706	-75.1426788	NAD27	WQN0137	40.9933	-75.1375	741.53
01442500	Brodhead Creek at Minisink Hills, PA	PA	40.998706	-75.1426788	NAD27	WQN0137	40.999722	-75.148333	488.73
01447500	Lehigh River at Stoddartsville, PA	PA	41.1303626	-75.625467	NAD27	WQN0126	41.1303	-75.6258	28.80
01447500	Lehigh River at Stoddartsville, PA	PA	41.1303626	-75.625467	NAD27	WQN0126	41.130278	-75.625833	32.13
01447720	Tobyhanna Creek near Blakeslee, PA	PA	41.0848082	-75.6054666	NAD27	WQN0142	41.084722	-75.605833	32.23
01447720	Tobyhanna Creek near Blakeslee, PA	PA	41.0848082	-75.6054666	NAD27	WQN0142	41.0844	-75.6053	47.43
01450500	Aquashicola Creek at Palmerton, PA	PA	40.8062047	-75.5979643	NAD27	WQN0131	40.793333	-75.6125	1882.89
01451000	Lehigh River at Walnutport, PA	PA	40.7570395	-75.60296388	NAD27	WQN0125	40.7531	-75.6025	439.07
01451000	Lehigh River at Walnutport, PA	PA	40.7570395	-75.60296388	NAD27	WQN0125	40.753056	-75.603056	442.27
01451500	Little Lehigh Creek near Allentown, PA	PA	40.5823197	-75.48296088	NAD27	WQN0129	40.582222	-75.483333	33.31
01453000	Lehigh River at Bethlehem, PA	PA	40.6153761	-75.3787914	NAD27	WQN0124	40.614444	-75.384722	512.23

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01454700	Lehigh River at Glendon, PA	PA	40.6692656	-75.23628808	NAD27	WQN0123	40.686667	-75.208889	3015.41
01454700	Lehigh River at Glendon, PA	PA	40.6692656	-75.23628808	NAD27	WQN0123	40.6667	-75.2383	331.70
01463500	Delaware River at Trenton NJ	NJ	40.22166667	-74.7780556	NAD83	332079	40.221389	-74.778889	77.32
01463500	Delaware River at Trenton NJ	NJ	40.22166667	-74.7780556	NAD83	WQN0101	40.2192	-74.7783	274.58
01463500	Delaware River at Trenton NJ	NJ	40.22166667	-74.7780556	NAD83	WQN0101	40.219167	-74.778333	278.45
01465500	Neshaminy Creek near Langhorne, PA	PA	40.1739982	-74.9568342	NAD27	422107	40.173889	-74.957222	35.17
01465500	Neshaminy Creek near Langhorne, PA	PA	40.1739982	-74.9568342	NAD27	WQN0121	40.1742	-74.9572	38.36
01465500	Neshaminy Creek near Langhorne, PA	PA	40.1739982	-74.9568342	NAD27	WQN0121	40.173889	-74.957222	35.17
01467048	Pennypack Cr at Lower Rhawn St Bdg, Phila., PA	PA	40.05011137	-75.0326713	NAD27	WQN0165	40.043889	-75.020833	1223.40
01470500	Schuylkill River at Berne, PA	PA	40.5225932	-75.99826819	NAD27	WQN0113	40.522222	-75.998333	41.57
01470500	Schuylkill River at Berne, PA	PA	40.5225932	-75.99826819	NAD27	WQN0113	40.5219	-75.9978	86.57
01470960	Tulpehocken Cr at Blue Marsh Damsite near Reading	PA	40.3706482	-76.0252159	NAD27	WQN0175	40.368333	-76.022778	330.00
01470960	Tulpehocken Cr at Blue Marsh Damsite near Reading	PA	40.3706482	-76.0252159	NAD27	USGS-01470960	40.37065	-76.02522	0.40
01471000	Tulpehocken Creek near Reading, PA	PA	40.36898166	-75.9791015	NAD27	WQN0117	40.368889	-75.979444	30.85
01472000	Schuylkill River at Pottstown, PA	PA	40.2417631	-75.6515752	NAD27	WQN0111	40.2419	-75.6511	43.18
01472000	Schuylkill River at Pottstown, PA	PA	40.2417631	-75.6515752	NAD27	WQN0111	40.241667	-75.651389	19.10
01472157	French Creek near Phoenixville, PA	PA	40.15149064	-75.601305	NAD27	USGS-01472157	40.15149	-75.6013	0.43
01474000	Wissahickon Creek at Mouth, Philadelphia, PA	PA	40.01539	-75.2068459	NAD27	WQN0115	40.0147	-75.2067	77.59
01474500	Schuylkill River at Philadelphia, PA	PA	39.9678905	-75.1885123	NAD27	422107	39.951944	-75.1825	1842.89
01474500	Schuylkill River at Philadelphia, PA	PA	39.9678905	-75.1885123	NAD27	USGS-01474500	39.96789	-75.18851	0.20
01477000	Chester Creek near Chester, PA	PA	39.8690009	-75.4082494	NAD27	WQN0172	39.8675	-75.408611	169.43
01477800	SHELLPOT CREEK AT WILMINGTON, DE	DE	39.7609722	-75.5186944	NAD83	USGS-01477800	39.76097	-75.51869	0.45

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01478000	CHRISTINA RIVER AT COOCHS BRIDGE, DE	DE	39.63738889	-75.72788889	NAD83	106141	39.641389	-75.741667	51.34
01478000	CHRISTINA RIVER AT COOCHS BRIDGE, DE	DE	39.63738889	-75.72788889	NAD83	106141	39.63746	-75.72848	51.34
01479000	WHITE CLAY CREEK NEAR NEWARK, DE	DE	39.6992222	-75.67502778	NAD83	105011	39.70725	-75.65249	2127.74
01479000	WHITE CLAY CREEK NEAR NEWARK, DE	DE	39.6992222	-75.67502778	NAD83	105011	39.706944	-75.6525	2127.74
01480000	RED CLAY CREEK AT WOODDALE, DE	DE	39.76280556	-75.6365	NAD83	103031	39.76288	-75.63658	10.73
01480000	RED CLAY CREEK AT WOODDALE, DE	DE	39.76280556	-75.6365	NAD83	103021	39.729722	-75.636944	3672.12
01480000	RED CLAY CREEK AT WOODDALE, DE	DE	39.76280556	-75.6365	NAD83	103031	39.7625	-75.636389	10.73
01480617	West Branch Brandywine Creek at Modena, PA	PA	39.9617734	-75.8013341	NAD27	USGS-01480617	39.96177	-75.80133	0.51
01480870	East Branch Brandywine Creek below Downingtown, PA	PA	39.9687191	-75.6732715	NAD27	USGS-01480870	39.96872	-75.67327	0.16
01481000	Brandywine Creek at Chadds Ford, PA	PA	39.8698328	-75.5932623	NAD27	USGS-01481000	39.86983	-75.59326	0.37
01481000	Brandywine Creek at Chadds Ford, PA	PA	39.8698328	-75.5932623	NAD27	WQN0105	39.8694	-75.5931	50.00
01481500	BRANDYWINE CREEK AT WILMINGTON, DE	DE	39.7695	-75.5766944	NAD83	104021	39.770278	-75.579167	187.38
01481500	BRANDYWINE CREEK AT WILMINGTON, DE	DE	39.7695	-75.5766944	NAD83	104041	39.796944	-75.575278	3048.41
01481500	BRANDYWINE CREEK AT WILMINGTON, DE	DE	39.7695	-75.5766944	NAD83	104011	39.758889	-75.554167	2053.56
01481500	BRANDYWINE CREEK AT WILMINGTON, DE	DE	39.7695	-75.5766944	NAD83	104021	39.76983	-75.57884	187.38
01481500	BRANDYWINE CREEK AT WILMINGTON, DE	DE	39.7695	-75.5766944	NAD83	104011	39.76004	-75.55609	2053.56
01483700	ST JONES RIVER AT DOVER, DE	DE	39.1637222	-75.5190833	NAD83	USGS-01483700	39.16372	-75.51908	0.38
01484100	BEAVERDAM BRANCH AT HOUSTON, DE	DE	38.90577778	-75.51275	NAD83	USGS-01484100	38.90578	-75.51275	0.25

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01485000	POCOMOKE RIVER NEAR WILLARDS, MD	MD	38.38888889	-75.3244444	NAD83	USGS-01485000	38.38889	-75.32444	0.40
01487000	NANTICOKE RIVER NEAR BRIDGEVILLE, DE	DE	38.7283333	-75.5618611	NAD83	USGS-01487000	38.72833	-75.56186	0.38
01488500	MARSHYHOPE CREEK NEAR ADAMSVILLE, DE	DE	38.84969444	-75.6731111	NAD83	USGS-01488500	38.84969	-75.67311	0.50
01491000	CHOPTANK RIVER NEAR GREENSBORO, MD	MD	38.99719444	-75.7858056	NAD83	CHO0626	38.99783	-75.78553	74.46
01491000	CHOPTANK RIVER NEAR GREENSBORO, MD	MD	38.99719444	-75.7858056	NAD83	CHO0626	38.997222	-75.786111	26.62
01491000	CHOPTANK RIVER NEAR GREENSBORO, MD	MD	38.99719444	-75.7858056	NAD83	CHO0626	38.997056	-75.786778	85.60
01491000	CHOPTANK RIVER NEAR GREENSBORO, MD	MD	38.99719444	-75.7858056	NAD83	USGS-01491000	38.99719	-75.78581	0.62
01493500	MORGAN CREEK NEAR KENNEDYVILLE, MD	MD	39.28002778	-76.0145556	NAD83	USGS-01493500	39.28003	-76.01456	0.45
01518700	Tioga River at Tioga Junction, PA	PA	41.95257385	-77.1152486	NAD27	WQN0324	41.9572	-77.115	514.24
01518700	Tioga River at Tioga Junction, PA	PA	41.95257385	-77.1152486	NAD27	WQN0324	41.9575	-77.115833	549.29
01520000	Cowanesque River near Lawrenceville, PA	PA	41.99674048	-77.1399724	NAD27	WQN0320	41.987778	-77.148333	1212.80
01531500	Susquehanna River at Towanda, PA	PA	41.76535278	-76.4407743	NAD27	WQN0305	41.765278	-76.441111	29.20
01531500	Susquehanna River at Towanda, PA	PA	41.76535278	-76.4407743	NAD27	WQN0305	41.7653	-76.4386	180.86
01532000	Towanda Creek near Monroeton, PA	PA	41.7070195	-76.4846654	NAD27	WQN0318	41.7081	-76.4861	169.25
01534000	Tunkhannock Creek near Tunkhannock, PA	PA	41.55841008	-75.89464168	NAD27	WQN0317	41.558056	-75.895	49.38
01534000	Tunkhannock Creek near Tunkhannock, PA	PA	41.55841008	-75.89464168	NAD27	WQN0317	41.5572	-75.8942	139.31
01536000	Lackawanna River at Old Forge, PA	PA	41.35924619	-75.744359	NAD27	WQN0313	41.3583	-75.7439	111.84
01536000	Lackawanna River at Old Forge, PA	PA	41.35924619	-75.744359	NAD27	WQN0313	41.359167	-75.744722	31.61

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01536500	Susquehanna River at Wilkes-Barre, PA	PA	41.2509149	-75.8807518	NAD27	WQN0302	41.2492	-75.885	403.67
01540500	Susquehanna River at Danville, PA	PA	40.95814218	-76.6191222	NAD27	WQN0301	40.9589	-76.6197	97.19
01540500	Susquehanna River at Danville, PA	PA	40.95814218	-76.6191222	NAD27	WQN0301	40.958056	-76.602778	1375.79
01540500	Susquehanna River at Danville, PA	PA	40.95814218	-76.6191222	NAD27	USGS-01540500	40.95814	-76.61912	0.30
01541000	West Branch Susquehanna River at Bower, PA	PA	40.89700655	-78.6769726	NAD27	WQN0406	40.8969	-78.6775	46.03
01541000	West Branch Susquehanna River at Bower, PA	PA	40.89700655	-78.6769726	NAD27	WQN0406	40.896944	-78.677222	22.15
01541200	WB Susquehanna River near Curwensville, PA	PA	40.9614471	-78.5191906	NAD27	WQN0405	40.961389	-78.519444	22.30
01541500	Clearfield Creek at Dimeling, PA	PA	40.97172406	-78.4058533	NAD27	WQN0422	40.985833	-78.406111	1567.95
01541500	Clearfield Creek at Dimeling, PA	PA	40.97172406	-78.4058533	NAD27	WQN0422	40.9858	-78.4058	1564.14
01543000	Driftwood Br Sinnemahoning Cr at Sterling Run, PA	PA	41.4133959	-78.1969524	NAD27	WQN0420	41.413333	-78.197222	23.61
01543000	Driftwood Br Sinnemahoning Cr at Sterling Run, PA	PA	41.4133959	-78.1969524	NAD27	WQN0420	41.4133	-78.1969	11.52
01545000	Kettle Creek near Westport, PA	PA	41.31950954	-77.873882	NAD27	WQN0434	41.3194	-77.8733	50.24
01545000	Kettle Creek near Westport, PA	PA	41.31950954	-77.873882	NAD27	WQN0434	41.319444	-77.873611	23.84
01545600	Young Womans Creek near Renovo, PA	PA	41.38951168	-77.6908191	NAD27	USGS-01545600	41.38951	-77.69082	0.20
01546500	Spring Creek near Axemann, PA	PA	40.88978334	-77.794168	NAD27	WQN0415	40.89	-77.7942	24.22
01546500	Spring Creek near Axemann, PA	PA	40.88978334	-77.794168	NAD27	WQN0415	40.889722	-77.794444	24.24
01550000	Lycoming Creek near Trout Run, PA	PA	41.41840957	-77.03274598	NAD27	WQN0409	41.4181	-77.0328	34.68
01550000	Lycoming Creek near Trout Run, PA	PA	41.41840957	-77.03274598	NAD27	WQN0409	41.418333	-77.033056	27.28
01551500	WB Susquehanna River at Williamsport, PA	PA	41.23618985	-76.996634	NAD27	WQN0402	41.228889	-77.019167	2055.69
01551500	WB Susquehanna River at Williamsport, PA	PA	41.23618985	-76.996634	NAD27	WQN0402	41.2289	-77.0189	2034.65

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01552000	Loyalsock Creek at Loyalsockville, PA	PA	41.32507836	-76.91246379	NAD27	WQN0408	41.325278	-76.911944	48.84
01552000	Loyalsock Creek at Loyalsockville, PA	PA	41.32507836	-76.91246379	NAD27	WQN0408	41.325	-76.9111	114.50
01553500	West Branch Susquehanna River at Lewisburg, PA	PA	40.96758498	-76.8763543	NAD27	WQN0401	40.9669	-76.8792	251.31
01553500	West Branch Susquehanna River at Lewisburg, PA	PA	40.96758498	-76.8763543	NAD27	USGS-01553500	40.96758	-76.87635	0.66
01553500	West Branch Susquehanna River at Lewisburg, PA	PA	40.96758498	-76.8763543	NAD27	WQN0401	40.967222	-76.879167	240.15
01553700	Chillisquaque Creek at Washingtonville, PA	PA	41.0617522	-76.68023479	NAD27	WQN0425	41.061111	-76.680556	76.14
01554000	Susquehanna River at Sunbury, PA	PA	40.8345293	-76.8266349	NAD27	WQN0203	40.8514	-76.8069	2505.72
01554000	Susquehanna River at Sunbury, PA	PA	40.8345293	-76.8266349	NAD27	WQN0203	40.854167	-76.805833	2798.50
01555000	Penns Creek at Penns Creek, PA	PA	40.86674917	-77.0483088	NAD27	WQN0229	40.8672	-77.0489	70.64
01556000	Frankstown Br Juniata River at Williamsburg, PA	PA	40.4631283	-78.199732	NAD27	WQN0224	40.476111	-78.1775	2374.60
01556000	Frankstown Br Juniata River at Williamsburg, PA	PA	40.4631283	-78.199732	NAD27	WQN0224	40.4717	-78.1867	1459.33
01558000	Little Juniata River at Spruce Creek, PA	PA	40.61256655	-78.1405645	NAD27	WQN0217	40.609167	-78.136389	517.33
01558000	Little Juniata River at Spruce Creek, PA	PA	40.61256655	-78.1405645	NAD27	WQN0217	40.6089	-78.1361	555.71
01562000	Raystown Branch Juniata River at Saxton, PA	PA	40.21591249	-78.2652901	NAD27	WQN0223	40.215	-78.2647	113.15
01562000	Raystown Branch Juniata River at Saxton, PA	PA	40.21591249	-78.2652901	NAD27	WQN0223	40.215833	-78.265556	24.31
01562000	Raystown Branch Juniata River at Saxton, PA	PA	40.21591249	-78.2652901	NAD27	USGS-01562000	40.21591	-78.26529	0.28
01567000	Juniata River at Newport, PA	PA	40.47841677	-77.1291484	NAD27	USGS-01567000	40.47842	-77.12915	0.38
01567000	Juniata River at Newport, PA	PA	40.47841677	-77.1291484	NAD27	WQN0214	40.4789	-77.1283	89.75
01567000	Juniata River at Newport, PA	PA	40.47841677	-77.1291484	NAD27	WQN0214	40.478333	-77.129444	26.74
01568000	Sherman Creek at Shermans Dale, PA	PA	40.32341928	-77.1688703	NAD27	WQN0243	40.3228	-77.1686	72.50

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01570000	Conodoguinet Creek near Hogestown, PA	PA	40.2522222	-77.0211111	NAD83	USGS-01570000	40.25222	-77.02111	0.26
01570500	Susquehanna River at Harrisburg, PA	PA	40.25481164	-76.8860846	NAD27	USGS-01570500	40.25481	-76.88608	0.43
01570500	Susquehanna River at Harrisburg, PA	PA	40.25481164	-76.8860846	NAD27	WQN0202	40.2564	-76.8844	227.24
01570500	Susquehanna River at Harrisburg, PA	PA	40.25481164	-76.8860846	NAD27	WQN0202	40.2575	-76.886667	302.57
01574000	West Conewago Creek near Manchester, PA	PA	40.08231745	-76.7199675	NAD27	WQN0210	40.0814	-76.7181	189.05
01574000	West Conewago Creek near Manchester, PA	PA	40.08231745	-76.7199675	NAD27	WQN0210	40.081111	-76.718611	176.98
01574500	Codorus Creek at Spring Grove, PA	PA	39.8787104	-76.8533073	NAD27	WQN0208	39.887222	-76.835833	1768.28
01576000	Susquehanna River at Marietta, PA	PA	40.0545413	-76.5307992	NAD27	WQN0201	40.0286	-76.5167	3121.03
01576000	Susquehanna River at Marietta, PA	PA	40.0545413	-76.5307992	NAD27	WQN0201	40.054444	-76.531111	28.71
01576500	Conestoga River at Lancaster, PA	PA	40.05009748	-76.2771798	NAD27	WQN0205	40.05	-76.2775	29.38
01576787	Pequea Creek at Martic Forge, PA	PA	39.90593409	-76.32829298	NAD27	WQN0204	39.9056	-76.3281	40.59
01577500	Muddy Creek at Castle Fin, PA	PA	39.77260378	-76.3157919	NAD27	WQN0259	39.7728	-76.3161	34.22
01577500	Muddy Creek at Castle Fin, PA	PA	39.77260378	-76.3157919	NAD27	WQN0259	39.773056	-76.316389	71.66
01578310	SUSQUEHANNA RIVER AT CONOWINGO, MD	MD	39.6579133	-76.1741754	NAD27	SUS0109	39.655833	-76.175833	271.19
01578310	SUSQUEHANNA RIVER AT CONOWINGO, MD	MD	39.6579133	-76.1741754	NAD27	SUS0109	39.656083	-76.175361	227.20
01578310	SUSQUEHANNA RIVER AT CONOWINGO, MD	MD	39.6579133	-76.1741754	NAD27	USGS-01578310	39.65791	-76.17418	0.54
01578310	SUSQUEHANNA RIVER AT CONOWINGO, MD	MD	39.6579133	-76.1741754	NAD27	SUS0109	39.65267	-76.17072	653.15
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	MD	39.50366667	-76.8848611	NAD83	NPA0165	39.482667	-76.882361	2341.20

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01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	MD	39.50366667	-76.8848611	NAD83	NPA0165	39.4828	-76.8821	2328.68
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	MD	39.50366667	-76.8848611	NAD83	NPA0165	39.50053	-76.88333	372.29
01586000	NORTH BRANCH PATAPSCO RIVER AT CEDARHURST, MD	MD	39.50366667	-76.8848611	NAD83	NPA0165	39.503889	-76.885833	87.15
01589000	PATAPSCO RIVER AT HOLLOFIELD, MD	MD	39.31030556	-76.7924167	NAD83	USGS-01589000	39.31031	-76.79242	0.57
01589300	GWYNNNS FALLS AT VILLA NOVA, MD	MD	39.34588889	-76.7331944	NAD83	GWN0115	39.347222	-76.734167	170.08
01589300	GWYNNNS FALLS AT VILLA NOVA, MD	MD	39.34588889	-76.7331944	NAD83	GWN0115	39.3428	-76.7264	678.63
01589300	GWYNNNS FALLS AT VILLA NOVA, MD	MD	39.34588889	-76.7331944	NAD83	GWN0115	39.34598	-76.73413	81.27
01589300	GWYNNNS FALLS AT VILLA NOVA, MD	MD	39.34588889	-76.7331944	NAD83	GWN0115	39.342667	-76.726694	664.72
01589440	JONES FALLS AT SORRENTO, MD	MD	39.3917222	-76.6609444	NAD83	JON0184	39.392222	-76.661667	83.38
01589440	JONES FALLS AT SORRENTO, MD	MD	39.3917222	-76.6609444	NAD83	JON0184	39.3911	-76.66103	69.46
01589440	JONES FALLS AT SORRENTO, MD	MD	39.3917222	-76.6609444	NAD83	JON0184	39.393278	-76.662083	198.61
01591000	PATUXENT RIVER NEAR UNITY, MD	MD	39.23825	-77.0557222	NAD83	PXT0972	39.2393	-77.0562	123.65
01591000	PATUXENT RIVER NEAR UNITY, MD	MD	39.23825	-77.0557222	NAD83	PXT0972	39.239194	-77.056472	123.18
01591000	PATUXENT RIVER NEAR UNITY, MD	MD	39.23825	-77.0557222	NAD83	PXT0972	39.23818	-77.05605	29.35
01591000	PATUXENT RIVER NEAR UNITY, MD	MD	39.23825	-77.0557222	NAD83	PXT0972	39.238333	-77.056111	34.81
01591000	PATUXENT RIVER NEAR UNITY, MD	MD	39.23825	-77.0557222	NAD83	USGS-01591000	39.23825	-77.05572	0.19
01592500	PATUXENT RIV NEAR LAUREL, MD	MD	39.1157222	-76.87375	NAD83	PXT0809	39.11557	-76.8734	34.66

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01592500	PATUXENT RIV NEAR LAUREL, MD	MD	39.1157222	-76.87375	NAD83	PXT0809	39.1168	-76.8749	155.58
01592500	PATUXENT RIV NEAR LAUREL, MD	MD	39.1157222	-76.87375	NAD83	PXT0809	39.116667	-76.875278	168.70
01594000	LITTLE PATUXENT RIVER AT SAVAGE, MD	MD	39.13441667	-76.8161667	NAD83	USGS-01594000	39.13442	-76.81617	0.47
01594440	PATUXENT RIVER NEAR BOWIE, MD	MD	38.95591667	-76.6936944	NAD83	USGS-01594440	38.95592	-76.69369	0.53
01595200	STONY RIVER NEAR MOUNT STORM, WV	WV	39.26954905	-79.2622625	NAD27	USGS-01595200	39.26955	-79.26226	0.24
01595200	STONY RIVER NEAR MOUNT STORM, WV	WV	39.26954905	-79.2622625	NAD27	550554	39.269444	-79.2625	23.61
01595500	NORTH BRANCH POTOMAC RIVER AT KITZMILLER, MD	MD	39.39388889	-79.1816944	NAD83	NBP0689	39.39418	-79.18172	32.43
01595500	NORTH BRANCH POTOMAC RIVER AT KITZMILLER, MD	MD	39.39388889	-79.1816944	NAD83	NBP0689	39.38935	-79.17936	543.22
01595500	NORTH BRANCH POTOMAC RIVER AT KITZMILLER, MD	MD	39.39388889	-79.1816944	NAD83	NBP0689	39.389222	-79.179583	549.79
01595500	NORTH BRANCH POTOMAC RIVER AT KITZMILLER, MD	MD	39.39388889	-79.1816944	NAD83	NBP0689	39.395556	-79.180833	199.65
01595500	NORTH BRANCH POTOMAC RIVER AT KITZMILLER, MD	MD	39.39388889	-79.1816944	NAD83	USGS-01595500	39.39389	-79.18169	0.40
01595800	NORTH BRANCH POTOMAC RIVER AT BARNUM, WV	WV	39.4451111	-79.1108056	NAD83	NBP0534	39.44513	-79.1108	2.16
01596500	SAVAGE RIVER NEAR BARTON, MD	MD	39.57005556	-79.1019444	NAD83	USGS-01596500	39.57006	-79.10194	0.62
01599000	GEORGES CREEK AT FRANKLIN, MD	MD	39.49391667	-79.0446944	NAD83	GEO0009	39.4936	-79.0447	35.20
01599000	GEORGES CREEK AT FRANKLIN, MD	MD	39.49391667	-79.0446944	NAD83	GEO0009	39.49388	-79.045	26.63
01599000	GEORGES CREEK AT FRANKLIN, MD	MD	39.49391667	-79.0446944	NAD83	GEO0009	39.493528	-79.044944	48.25
01599000	GEORGES CREEK AT FRANKLIN, MD	MD	39.49391667	-79.0446944	NAD83	GEO0009	39.494167	-79.045	38.30
01600000	NORTH BRANCH POTOMAC RIVER AT PINTO, MD	MD	39.56680556	-78.8395556	NAD83	NBP0326	39.565833	-78.839167	113.13

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01600000	NORTH BRANCH POTOMAC RIVER AT PINTO, MD	MD	39.56680556	-78.8395556	NAD83	NBP0326	39.56682	-78.83922	28.91
01600000	NORTH BRANCH POTOMAC RIVER AT PINTO, MD	MD	39.56680556	-78.8395556	NAD83	NBP0326	39.56677	-78.83891	55.67
01600000	NORTH BRANCH POTOMAC RIVER AT PINTO, MD	MD	39.56680556	-78.8395556	NAD83	USGS-01600000	39.56681	-78.83956	0.62
01600000	NORTH BRANCH POTOMAC RIVER AT PINTO, MD	MD	39.56680556	-78.8395556	NAD83	NBP0326	39.56667	-78.839167	36.80
01601500	WILLS CREEK NEAR CUMBERLAND, MD	MD	39.6696111	-78.7880278	NAD83	WIL0013	39.66992	-78.78925	110.43
01601500	WILLS CREEK NEAR CUMBERLAND, MD	MD	39.6696111	-78.7880278	NAD83	WIL0013	39.66175	-78.780528	1085.38
01601500	WILLS CREEK NEAR CUMBERLAND, MD	MD	39.6696111	-78.7880278	NAD83	WIL0013	39.662222	-78.779167	1119.56
01601500	WILLS CREEK NEAR CUMBERLAND, MD	MD	39.6696111	-78.7880278	NAD83	WIL0013	39.6619	-78.7803	1083.89
01603000	NORTH BRANCH POTOMAC RIVER NEAR CUMBERLAND, MD	MD	39.62180556	-78.7734167	NAD83	USGS-01603000	39.62181	-78.77342	0.57
01604500	PATTERSON CREEK NEAR HEADSVILLE, WV	WV	39.44314946	-78.8219649	NAD27	USGS-01604500	39.44315	-78.82196	0.43
01608500	SOUTH BRANCH POTOMAC RIVER NEAR SPRINGFIELD, WV	WV	39.44703879	-78.6541817	NAD27	550468	39.446944	-78.654444	24.93
01608500	SOUTH BRANCH POTOMAC RIVER NEAR SPRINGFIELD, WV	WV	39.44703879	-78.6541817	NAD27	USGS-01608500	39.44704	-78.65418	0.20
01609000	TOWN CREEK NEAR OLDTOWN, MD	MD	39.5532222	-78.555	NAD83	TOW0030	39.552917	-78.553639	121.88
01609000	TOWN CREEK NEAR OLDTOWN, MD	MD	39.5532222	-78.555	NAD83	TOW0030	39.55304	-78.55339	139.95
01609000	TOWN CREEK NEAR OLDTOWN, MD	MD	39.5532222	-78.555	NAD83	TOW0030	39.554167	-78.554444	115.36
01609000	TOWN CREEK NEAR OLDTOWN, MD	MD	39.5532222	-78.555	NAD83	TOW0030	39.55333	-78.55528	26.90
01610000	POTOMAC RIVER AT PAW PAW, WV	MD	39.53891667	-78.45638889	NAD83	POT2766	39.5385	-78.45565	78.63

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01610000	POTOMAC RIVER AT PAW PAW, WV	MD	39.53891667	-78.45638889	NAD83	POT2766	39.538528	-78.45475	147.45
01610000	POTOMAC RIVER AT PAW PAW, WV	MD	39.53891667	-78.45638889	NAD83	POT2766	39.53865	-78.45449	166.02
01611500	CACAPON RIVER NEAR GREAT CACAPON, WV	WV	39.5823158	-78.3097312	NAD27	USGS-01611500	39.58232	-78.30973	0.48
01613000	POTOMAC RIVER AT HANCOCK, MD	MD	39.69755556	-78.17788889	NAD83	POT2386	39.69483	-78.18648	797.00
01613000	POTOMAC RIVER AT HANCOCK, MD	MD	39.69755556	-78.17788889	NAD83	POT2386	39.6974	-78.1763	137.44
01613000	POTOMAC RIVER AT HANCOCK, MD	MD	39.69755556	-78.17788889	NAD83	POT2386	39.697306	-78.176556	117.69
01613000	POTOMAC RIVER AT HANCOCK, MD	MD	39.69755556	-78.17788889	NAD83	POT2386	39.698333	-78.1825	405.01
01614500	CONOCOCHIEGUE CREEK AT FAIRVIEW, MD	MD	39.71638889	-77.8247778	NAD83	USGS-01614500	39.71639	-77.82478	0.23
01614500	CONOCOCHIEGUE CREEK AT FAIRVIEW, MD	MD	39.71638889	-77.8247778	NAD83	WQN0501	39.7081	-77.8331	1164.96
01614500	CONOCOCHIEGUE CREEK AT FAIRVIEW, MD	MD	39.71638889	-77.8247778	NAD83	CON0180	39.71583	-77.82445	68.14
01614500	CONOCOCHIEGUE CREEK AT FAIRVIEW, MD	MD	39.71638889	-77.8247778	NAD83	CON0180	39.715944	-77.825333	68.62
01614500	CONOCOCHIEGUE CREEK AT FAIRVIEW, MD	MD	39.71638889	-77.8247778	NAD83	CON0180	39.716389	-77.825833	90.51
01614500	CONOCOCHIEGUE CREEK AT FAIRVIEW, MD	MD	39.71638889	-77.8247778	NAD83	CON0180	39.716	-77.8251	51.28
01616500	OPEQUON CREEK NEAR MARTINSBURG, WV	WV	39.42371047	-77.9386084	NAD27	USGS-01616500	39.42371	-77.93861	0.15
01618000	POTOMAC RIVER AT SHEPHERDSTOWN, WV	WV	39.4347222	-77.80138889	NAD83	USGS-01618000	39.43472	-77.80139	0.26
01618000	POTOMAC RIVER AT SHEPHERDSTOWN, WV	WV	39.4347222	-77.80138889	NAD83	POT1830	39.435	-77.801111	39.05
01618000	POTOMAC RIVER AT SHEPHERDSTOWN, WV	WV	39.4347222	-77.80138889	NAD83	POT1830	39.434972	-77.802917	134.49
01618000	POTOMAC RIVER AT SHEPHERDSTOWN, WV	WV	39.4347222	-77.80138889	NAD83	POT1830	39.4351	-77.8027	120.46

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01618000	POTOMAC RIVER AT SHEPHERDSTOWN, WV	WV	39.4347222	-77.80138889	NAD83	POT1830	39.43648	-77.80175	197.68
01619000	ANTIETAM CREEK NEAR WAYNESBORO, PA	MD	39.71625	-77.60663889	NAD83	ANT0366	39.71628	-77.60722	49.95
01619000	ANTIETAM CREEK NEAR WAYNESBORO, PA	MD	39.71625	-77.60663889	NAD83	ANT0366	39.716389	-77.6075	75.45
01619000	ANTIETAM CREEK NEAR WAYNESBORO, PA	MD	39.71625	-77.60663889	NAD83	ANT0366	39.716	-77.6082	136.74
01619000	ANTIETAM CREEK NEAR WAYNESBORO, PA	MD	39.71625	-77.60663889	NAD83	ANT0366	39.715889	-77.6085	164.58
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	MD	39.44977778	-77.7301944	NAD83	ANT0044	39.45	-77.731111	82.69
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	MD	39.44977778	-77.7301944	NAD83	ANT0044	39.4504	-77.7317	146.90
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	MD	39.44977778	-77.7301944	NAD83	ANT0044	39.45025	-77.731917	157.31
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	MD	39.44977778	-77.7301944	NAD83	ANT0044	39.44962	-77.72957	56.54
01619500	ANTIETAM CREEK NEAR SHARPSBURG, MD	MD	39.44977778	-77.7301944	NAD83	USGS-01619500	39.44978	-77.73019	0.45
01622000	NORTH RIVER NEAR BURKETOWN, VA	VA	38.3404051	-78.9136385	NAD27	1BNTH014.08	38.344722	-78.916667	548.04
01622000	NORTH RIVER NEAR BURKETOWN, VA	VA	38.3404051	-78.9136385	NAD27	1BNTH014.08	38.3447	-78.9167	547.31
01625000	MIDDLE RIVER NEAR GROTTOS, VA	VA	38.26179616	-78.8619703	NAD27	1BMDL001.83	38.2619	-78.8622	23.20
01625000	MIDDLE RIVER NEAR GROTTOS, VA	VA	38.26179616	-78.8619703	NAD27	1BMDL001.83	38.261944	-78.862222	27.50
01626000	SOUTH RIVER NEAR WAYNESBORO, VA	VA	38.0576362	-78.90807949	NAD27	1BSTH027.85	38.057222	-78.908056	46.07
01626000	SOUTH RIVER NEAR WAYNESBORO, VA	VA	38.0576362	-78.90807949	NAD27	1BSTH027.85	38.0572	-78.9081	48.50
01627500	SOUTH RIVER AT HARRISTON, VA	VA	38.21874208	-78.8366915	NAD27	1BSTH007.80	38.218611	-78.8375	72.35
01627500	SOUTH RIVER AT HARRISTON, VA	VA	38.21874208	-78.8366915	NAD27	1BSTH007.80	38.2186	-78.8375	72.61

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01628500	S F SHENANDOAH RIVER NEAR LYNNWOOD, VA	VA	38.32262796	-78.7547457	NAD27	1BSSF100.10	38.3123	-78.771	1827.88
01628500	S F SHENANDOAH RIVER NEAR LYNNWOOD, VA	VA	38.32262796	-78.7547457	NAD27	1BSSF100.10	38.312778	-78.770278	1745.34
01629500	S F SHENANDOAH RIVER NEAR LURAY, VA	VA	38.6462305	-78.5347329	NAD27	1BSSF054.20	38.646	-78.5352	48.08
01629500	S F SHENANDOAH RIVER NEAR LURAY, VA	VA	38.6462305	-78.5347329	NAD27	1BSSF054.20	38.646	-78.535222	49.71
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	VA	38.91400059	-78.21083388	NAD27	1BSSF003.56	38.913611	-78.210056	80.18
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	VA	38.91400059	-78.21083388	NAD27	USGS-01631000	38.914	-78.21083	0.34
01631000	S F SHENANDOAH RIVER AT FRONT ROYAL, VA	VA	38.91400059	-78.21083388	NAD27	1BSSF003.56	38.9133	-78.2098	118.77
01632000	N F SHENANDOAH RIVER AT COOTES STORE, VA	VA	38.63706254	-78.852803	NAD27	1BNFS093.53	38.637222	-78.8525	31.80
01632000	N F SHENANDOAH RIVER AT COOTES STORE, VA	VA	38.63706254	-78.852803	NAD27	1BNFS093.53	38.6372	-78.8525	30.51
01632900	SMITH CREEK NEAR NEW MARKET, VA	VA	38.69345016	-78.6427935	NAD27	1BSMT004.60	38.6939	-78.6433	66.65
01632900	SMITH CREEK NEAR NEW MARKET, VA	VA	38.69345016	-78.6427935	NAD27	1BSMT004.60	38.693889	-78.643333	67.70
01633000	N F SHENANDOAH RIVER AT MOUNT JACKSON, VA	VA	38.74567048	-78.6389042	NAD27	1BNFS070.67	38.7459	-78.6387	31.08
01633000	N F SHENANDOAH RIVER AT MOUNT JACKSON, VA	VA	38.74567048	-78.6389042	NAD27	1BNFS070.67	38.745556	-78.639167	26.17
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	VA	38.9767759	-78.3361152	NAD27	USGS-01634000	38.97678	-78.33612	0.62
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	VA	38.9767759	-78.3361152	NAD27	1BNFS010.34	38.976667	-78.336944	72.88
01634000	N F SHENANDOAH RIVER NEAR STRASBURG, VA	VA	38.9767759	-78.3361152	NAD27	1BNFS010.34	38.9768	-78.3368	59.44
01634500	CEDAR CREEK NEAR WINCHESTER, VA	VA	39.0812176	-78.3294486	NAD27	1BCDR013.29	39.077778	-78.326111	479.06
01634500	CEDAR CREEK NEAR WINCHESTER, VA	VA	39.0812176	-78.3294486	NAD27	1BCDR013.29	39.0779	-78.3258	485.40

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01635500	PASSAGE CREEK NEAR BUCKTON, VA	VA	38.95816564	-78.2666685	NAD27	1BPSG001.36	38.9589	-78.2667	81.62
01635500	PASSAGE CREEK NEAR BUCKTON, VA	VA	38.95816564	-78.2666685	NAD27	1BPSG001.36	38.958889	-78.266667	80.35
01637500	CATOCTIN CREEK NEAR MIDDLETOWN, MD	MD	39.42725	-77.5561667	NAD83	CAC0148	39.4275	-77.555833	39.96
01637500	CATOCTIN CREEK NEAR MIDDLETOWN, MD	MD	39.42725	-77.5561667	NAD83	CAC0148	39.425667	-77.559278	320.46
01637500	CATOCTIN CREEK NEAR MIDDLETOWN, MD	MD	39.42725	-77.5561667	NAD83	CAC0148	39.4258	-77.559	292.34
01637500	CATOCTIN CREEK NEAR MIDDLETOWN, MD	MD	39.42725	-77.5561667	NAD83	CAC0148	39.42747	-77.55632	27.77
01638480	CATOCTIN CREEK AT TAYLORSTOWN, VA	VA	39.25510206	-77.5763778	NAD27	1ACAX004.57	39.255	-77.576667	27.42
01638480	CATOCTIN CREEK AT TAYLORSTOWN, VA	VA	39.25510206	-77.5763778	NAD27	1ACAX004.57	39.255	-77.5767	30.04
01638500	POTOMAC RIVER AT POINT OF ROCKS, MD	MD	39.2735833	-77.5431111	NAD83	POT1595	39.27385	-77.54348	43.48
01638500	POTOMAC RIVER AT POINT OF ROCKS, MD	MD	39.2735833	-77.5431111	NAD83	POT1595	39.2735	-77.5437	51.66
01638500	POTOMAC RIVER AT POINT OF ROCKS, MD	MD	39.2735833	-77.5431111	NAD83	POT1595	39.273361	-77.543944	76.01
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	MD	39.67905556	-77.23452778	NAD83	MON0528	39.679611	-77.236222	157.90
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	MD	39.67905556	-77.23452778	NAD83	MON0528	39.6792	-77.2349	35.74
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	MD	39.67905556	-77.23452778	NAD83	MON0528	39.67917	-77.235	42.46
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	MD	39.67905556	-77.23452778	NAD83	USGS-01639000	39.67906	-77.23453	0.53
01639000	MONOCACY RIVER AT BRIDGEPORT, MD	MD	39.67905556	-77.23452778	NAD83	MON0528	39.679167	-77.235	42.36
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	MD	39.4028333	-77.3660833	NAD83	MON0155	39.3878	-77.3811	2111.88

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	MD	39.4028333	-77.3660833	NAD83	MON0155	39.387667	-77.381361	2137.35
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	MD	39.4028333	-77.3660833	NAD83	MON0155	39.386111	-77.380833	2249.97
01643000	MONOCACY RIVER AT JUG BRIDGE NEAR FREDERICK, MD	MD	39.4028333	-77.3660833	NAD83	MON0155	39.38647	-77.38085	2218.03
01644000	GOOSE CREEK NEAR LEESBURG, VA	VA	39.01955309	-77.5774918	NAD27	1AGOO011.23	39.018333	-77.576667	153.16
01644000	GOOSE CREEK NEAR LEESBURG, VA	VA	39.01955309	-77.5774918	NAD27	1AGOO011.23	39.0179	-77.5761	219.61
01646000	DIFFICULT RUN NEAR GREAT FALLS, VA	VA	38.97594346	-77.24581439	NAD27	1ADIF000.86	38.975833	-77.246111	28.48
01646000	DIFFICULT RUN NEAR GREAT FALLS, VA	VA	38.97594346	-77.24581439	NAD27	1ADIF000.86	38.9758	-77.2461	29.43
01646502	POTOMAC RIVER (ADJUSTED) NEAR WASH, DC	MD	38.94955517	-77.1274789	NAD27	POT1184	38.948	-77.1275	172.66
01646502	POTOMAC RIVER (ADJUSTED) NEAR WASH, DC	MD	38.94955517	-77.1274789	NAD27	POT1184	38.9482	-77.1273	151.24
01646502	POTOMAC RIVER (ADJUSTED) NEAR WASH, DC	MD	38.94955517	-77.1274789	NAD27	POT1184	38.948056	-77.1275	166.44
01646502	POTOMAC RIVER (ADJUSTED) NEAR WASH, DC	MD	38.94955517	-77.1274789	NAD27	POT1184	38.948083	-77.127611	163.84
01649500	NORTHEAST BRANCH ANACOSTIA RIVER AT RIVERDALE, MD	MD	38.96025	-76.9259722	NAD83	USGS-01649500	38.96025	-76.92597	0.19
01658000	MATTAWOMAN CREEK NEAR POMONKEY, MD	MD	38.59613889	-77.05602778	NAD83	USGS-01658000	38.59614	-77.05603	0.23
01658500	S F QUANTICO CREEK NEAR INDEPENDENT HILL, VA	VA	38.5873427	-77.4285958	NAD27	USGS-01658500	38.58734	-77.4286	0.47

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
01663500	HAZEL RIVER AT RIXEYVILLE, VA	VA	38.59178867	-77.9649962	NAD27	3-HAZ009.58	38.5931	-77.9658	161.60
01663500	HAZEL RIVER AT RIXEYVILLE, VA	VA	38.59178867	-77.9649962	NAD27	3-HAZ009.58	38.593056	-77.965833	158.52
01664000	RAPPAHANNOCK RIVER AT REMINGTON, VA	VA	38.53067996	-77.8136045	NAD27	3-RPP147.10	38.53	-77.8139	79.78
01666500	ROBINSON RIVER NEAR LOCUST DALE, VA	VA	38.32513047	-78.0955557	NAD27	3-ROB001.90	38.325	-78.095556	14.49
01666500	ROBINSON RIVER NEAR LOCUST DALE, VA	VA	38.32513047	-78.0955557	NAD27	3-ROB001.90	38.325	-78.0956	15.00
01667500	RAPIDAN RIVER NEAR CULPEPER, VA	VA	38.35040774	-77.9749972	NAD27	3-RAP030.21	38.358889	-77.973611	949.62
01667500	RAPIDAN RIVER NEAR CULPEPER, VA	VA	38.35040774	-77.9749972	NAD27	3-RAP030.21	38.359	-77.9731	968.50
01667500	RAPIDAN RIVER NEAR CULPEPER, VA	VA	38.35040774	-77.9749972	NAD27	USGS-01667500	38.35041	-77.975	0.35
01668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	VA	38.30846178	-77.52915268	NAD27	USGS-01668000	38.30846	-77.52915	0.31
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	VA	37.76764189	-77.3322018	NAD27	USGS-01673000	37.76764	-77.3322	0.26
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	VA	37.76764189	-77.3322018	NAD27	8-PMK082.34	37.7678	-77.3322	17.55
01673000	PAMUNKEY RIVER NEAR HANOVER, VA	VA	37.76764189	-77.3322018	NAD27	8-PMK082.34	37.767778	-77.332222	15.21
01674000	MATTAPONI RIVER NEAR BOWLING GREEN, VA	VA	38.061801	-77.3858142	NAD27	8-MPN094.79	38.060278	-77.384722	194.36
01674000	MATTAPONI RIVER NEAR BOWLING GREEN, VA	VA	38.061801	-77.3858142	NAD27	8-MPN094.79	38.0603	-77.3847	193.21
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	VA	37.88388889	-77.16527778	NAD83	8-MPN054.17	37.883889	-77.165	24.44
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	VA	37.88388889	-77.16527778	NAD83	8-MPN054.17	37.8839	-77.165	24.47
01674500	MATTAPONI RIVER NEAR BEULAHVILLE, VA	VA	37.88388889	-77.16527778	NAD83	USGS-01674500	37.88389	-77.16528	0.23
02011400	JACKSON RIVER NEAR BACOVA, VA	VA	38.04234707	-79.8814439	NAD27	2-JKS058.60	38.0425	-79.881944	47.15

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02011400	JACKSON RIVER NEAR BACOVA, VA	VA	38.04234707	-79.8814439	NAD27	2-JKS058.60	38.0425	-79.8819	43.57
02011500	BACK CREEK NEAR MOUNTAIN GROVE, VA	VA	38.0695688	-79.8970003	NAD27	2-BCC004.71	38.0699	-79.8976	64.31
02011500	BACK CREEK NEAR MOUNTAIN GROVE, VA	VA	38.0695688	-79.8970003	NAD27	2-BCC004.71	38.069444	-79.897222	23.93
02013100	JACKSON RIVER BL DUNLAP CREEK AT COVINGTON, VA	VA	37.7887362	-80.00061319	NAD27	2-JKS023.61	37.788611	-80.000833	23.88
02013100	JACKSON RIVER BL DUNLAP CREEK AT COVINGTON, VA	VA	37.7887362	-80.00061319	NAD27	2-JKS023.61	37.7886	-80.0008	22.39
02015700	BULLPASTURE RIVER AT WILLIAMSVILLE, VA	VA	38.19540308	-79.57032338	NAD27	2-BLP000.79	38.195278	-79.570556	24.70
02015700	BULLPASTURE RIVER AT WILLIAMSVILLE, VA	VA	38.19540308	-79.57032338	NAD27	2-BLP000.79	38.1953	-79.5707	34.97
02016000	COWPASTURE RIVER NEAR CLIFTON FORGE, VA	VA	37.79179587	-79.7594917	NAD27	2-CWP002.58	37.791944	-79.759444	17.00
02016000	COWPASTURE RIVER NEAR CLIFTON FORGE, VA	VA	37.79179587	-79.7594917	NAD27	2-CWP002.58	37.7919	-79.7594	14.13
02021500	MAURY RIVER AT ROCKBRIDGE BATHS, VA	VA	37.90735266	-79.42198289	NAD27	2-MRY038.10	37.9033	-79.4167	647.63
02021500	MAURY RIVER AT ROCKBRIDGE BATHS, VA	VA	37.90735266	-79.42198289	NAD27	2-MRY038.10	37.903333	-79.416667	647.18
02024000	MAURY RIVER NEAR BUENA VISTA, VA	VA	37.76263275	-79.3914251	NAD27	2-MRY014.78	37.7522	-79.3922	1161.64
02024000	MAURY RIVER NEAR BUENA VISTA, VA	VA	37.76263275	-79.3914251	NAD27	2-MRY014.78	37.752222	-79.392222	1159.31
02029000	JAMES RIVER AT SCOTTSVILLE, VA	VA	37.7973651	-78.491398	NAD27	2-JMS189.31	37.7972	-78.4917	32.32
02030000	HARDWARE RIVER BL BRIERY RUN NR SCOTTSVILLE, VA	VA	37.81264259	-78.4552862	NAD27	2-HRD011.57	37.8125	-78.455	29.78
02031000	MECHUMS RIVER NEAR WHITE HALL, VA	VA	38.10263608	-78.5927935	NAD27	2-MCM005.12	38.1026	-78.5932	35.91
02031000	MECHUMS RIVER NEAR WHITE HALL, VA	VA	38.10263608	-78.5927935	NAD27	2-MCM005.12	38.102556	-78.593194	36.26

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
02034000	RIVANNA RIVER AT PALMYRA, VA	VA	37.8579192	-78.2658373	NAD27	2-RVN015.97	37.858056	-78.266944	98.63
02034000	RIVANNA RIVER AT PALMYRA, VA	VA	37.8579192	-78.2658373	NAD27	2-RVN015.97	37.8581	-78.2669	95.71
02035000	JAMES RIVER AT CARTERSVILLE, VA	VA	37.67097957	-78.0858328	NAD27	USGS-02035000	37.67098	-78.08583	0.25
02035000	JAMES RIVER AT CARTERSVILLE, VA	VA	37.67097957	-78.0858328	NAD27	2-JMS157.28	37.6711	-78.0858	13.68
02035000	JAMES RIVER AT CARTERSVILLE, VA	VA	37.67097957	-78.0858328	NAD27	2-JMS157.28	37.670278	-78.086944	125.26
02037500	JAMES RIVER NEAR RICHMOND, VA	VA	37.5632022	-77.5469314	NAD27	2-JMS117.35	37.561583	-77.543806	329.54
02037500	JAMES RIVER NEAR RICHMOND, VA	VA	37.5632022	-77.5469314	NAD27	2-JMS117.35	37.5616	-77.5438	328.96
02039500	APPOMATTOX RIVER AT FARMVILLE, VA	VA	37.3070965	-78.388607	NAD27	2-APP110.93	37.30725	-78.38925	59.54
02039500	APPOMATTOX RIVER AT FARMVILLE, VA	VA	37.3070965	-78.388607	NAD27	2-APP110.93	37.3073	-78.3893	65.50
02041650	APPOMATTOX RIVER AT MATOACA, VA	VA	37.2251505	-77.475263	NAD27	2-APP016.38	37.2253	-77.4764	102.28
02041650	APPOMATTOX RIVER AT MATOACA, VA	VA	37.2251505	-77.475263	NAD27	USGS-02041650	37.22515	-77.47526	0.27
02041650	APPOMATTOX RIVER AT MATOACA, VA	VA	37.2251505	-77.475263	NAD27	2-APP016.38	37.225278	-77.476389	100.95
02042500	CHICKAHOMINY RIVER NEAR PROVIDENCE FORGE, VA	VA	37.43625765	-77.0608027	NAD27	USGS-02042500	37.43626	-77.0608	0.35
02045500	NOTTOWAY RIVER NEAR STONY CREEK, VA	VA	36.90014978	-77.3996996	NAD27	5ANTW075.48	36.898917	-77.4005	154.32
02045500	NOTTOWAY RIVER NEAR STONY CREEK, VA	VA	36.90014978	-77.3996996	NAD27	5ANTW078.20	36.899	-77.4005	146.21
02045500	NOTTOWAY RIVER NEAR STONY CREEK, VA	VA	36.90014978	-77.3996996	NAD27	5ANTW078.20	36.898889	-77.400556	159.41
02049500	BLACKWATER RIVER NEAR FRANKLIN, VA	VA	36.7626499	-76.89829369	NAD27	USGS-02049500	36.76265	-76.89829	0.33
02052000	MEHERRIN RIVER AT EMPORIA, VA	VA	36.69014954	-77.5405364	NAD27	5AMHN052.34	36.6899	-77.5414	82.02

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02052000	MEHERRIN RIVER AT EMPORIA, VA	VA	36.69014954	-77.5405364	NAD27	5AMHN052.34	36.689833	-77.541139	64.31
02054500	ROANOKE RIVER AT LAFAYETTE, VA	VA	37.23652179	-80.2092089	NAD27	4AROA227.42	37.2369	-80.2092	42.08
02054500	ROANOKE RIVER AT LAFAYETTE, VA	VA	37.23652179	-80.2092089	NAD27	4AROA227.42	37.236944	-80.209167	47.11
02056900	BLACKWATER RIVER NEAR ROCKY MOUNT, VA	VA	37.0451406	-79.8441993	NAD27	4ABWR032.32	37.045	-79.844444	26.83
02056900	BLACKWATER RIVER NEAR ROCKY MOUNT, VA	VA	37.0451406	-79.8441993	NAD27	4ABWR032.32	37.045	-79.8444	23.76
02058400	PIGG RIVER NEAR SANDY LEVEL, VA	VA	36.9459767	-79.5247508	NAD27	4APGG008.42	36.9486	-79.5181	661.13
02058400	PIGG RIVER NEAR SANDY LEVEL, VA	VA	36.9459767	-79.5247508	NAD27	4APGG008.42	36.948611	-79.518056	665.19
02062500	ROANOKE (STAUNTON) RIVER AT BROOKNEAL, VA	VA	37.03944444	-78.9457222	NAD83	4AROA097.46	37.0403	-78.9514	514.55
02062500	ROANOKE (STAUNTON) RIVER AT BROOKNEAL, VA	VA	37.03944444	-78.9457222	NAD83	4AROA097.46	37.040278	-78.951389	513.14
02072000	SMITH RIVER NEAR PHILPOTT, VA	VA	36.7806925	-80.0247647	NAD27	4ASRE043.54	36.7875	-80.009167	1587.32
02072000	SMITH RIVER NEAR PHILPOTT, VA	VA	36.7806925	-80.0247647	NAD27	4ASRE043.54	36.7875	-80.0092	1584.73
03010500	Allegheny River at Eldred, PA	PA	41.963398	-78.3861287	NAD27	WQN0807	41.965	-78.3856	183.36
03010500	Allegheny River at Eldred, PA	PA	41.963398	-78.3861287	NAD27	WQN0807	41.965	-78.386111	178.05
03011800	Kinzua Creek near Guffey, PA	PA	41.76645099	-78.71863999	NAD27	WQN0855	41.766389	-78.718611	7.30
03015000	Conewango Creek at Russell, PA	PA	41.9381145	-79.133101	NAD27	WQN0832	41.938056	-79.133333	20.33
03015000	Conewango Creek at Russell, PA	PA	41.9381145	-79.133101	NAD27	WQN0832	41.9381	-79.1331	1.61
03015500	Brokenstraw Creek at Youngsville, PA	PA	41.8525587	-79.3172708	NAD27	WQN0831	41.8525	-79.3175	20.14
03015500	Brokenstraw Creek at Youngsville, PA	PA	41.8525587	-79.3172708	NAD27	WQN0831	41.8519	-79.3172	73.48
03016000	Allegheny River at West Hickory, PA	PA	41.5708949	-79.4078243	NAD27	WQN0805	41.569722	-79.405833	211.35
03016000	Allegheny River at West Hickory, PA	PA	41.5708949	-79.4078243	NAD27	WQN0805	41.57	-79.4056	210.73

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03017500	Tionesta Creek at Lynch, PA	PA	41.60200599	-79.0500392	NAD27	WQN0830	41.6017	-79.0494	63.27
03017500	Tionesta Creek at Lynch, PA	PA	41.60200599	-79.0500392	NAD27	WQN0830	41.601944	-79.050278	21.09
03020500	Oil Creek at Rouseville, PA	PA	41.4817261	-79.6953304	NAD27	WQN0868	41.481667	-79.695556	19.98
03020500	Oil Creek at Rouseville, PA	PA	41.4817261	-79.6953304	NAD27	WQN0868	41.4819	-79.6958	43.78
03022540	Woodcock Creek at Blooming Valley, PA	PA	41.6906115	-80.04811219	NAD27	4WCRW0004	41.690694	-80.048056	10.31
03025500	Allegheny River at Franklin, PA	PA	41.3895027	-79.8203322	NAD27	WQN0804	41.389444	-79.819444	74.69
03027500	EB Clarion River at EB Clarion River Dam, PA	PA	41.5531176	-78.5961347	NAD27	WQN0825	41.544444	-78.613889	1768.25
03028000	West Branch Clarion River at Wilcox, PA	PA	41.57533955	-78.69224919	NAD27	WQN0824	41.575278	-78.6925	22.02
03029500	Clarion River at Cooksburg, PA	PA	41.3306189	-79.2089298	NAD27	4CLA10049	41.331389	-79.208889	85.69
03029500	Clarion River at Cooksburg, PA	PA	41.3306189	-79.2089298	NAD27	WQN0822	41.330556	-79.209167	21.07
03029500	Clarion River at Cooksburg, PA	PA	41.3306189	-79.2089298	NAD27	WQN0822	41.3314	-79.2086	91.14
03030852	Clarion River at Callensburg, PA	PA	41.1297847	-79.5542134	NAD27	4CLA10016	41.129861	-79.554694	41.29
03030852	Clarion River at Callensburg, PA	PA	41.1297847	-79.5542134	NAD27	WQN0843	41.129722	-79.555	66.51
03030852	Clarion River at Callensburg, PA	PA	41.1297847	-79.5542134	NAD27	WQN0843	41.1297	-79.5542	9.49
03031500	Allegheny River at Parker, PA	PA	41.10061789	-79.68116	NAD27	WQN0803	41.101944	-79.679444	206.39
03031500	Allegheny River at Parker, PA	PA	41.10061789	-79.68116	NAD27	WQN0803	41.1017	-79.6794	190.82
03032500	Redbank Creek at St. Charles, PA	PA	40.9945093	-79.3942088	NAD27	WQN0820	40.9944	-79.3928	119.31
03032500	Redbank Creek at St. Charles, PA	PA	40.9945093	-79.3942088	NAD27	WQN0820	40.994444	-79.394444	21.10
03034000	Mahoning Creek at Punxsutawney, PA	PA	40.93923105	-79.00836738	NAD27	WQN0861	40.9219	-79.0058	1938.71
03034000	Mahoning Creek at Punxsutawney, PA	PA	40.93923105	-79.00836738	NAD27	WQN0861	40.921944	-79.006389	1928.92
03036000	Mahoning Creek at Mahoning Creek Dam, PA	PA	40.9275653	-79.2911508	NAD27	WQN0819	40.9269	-79.2917	87.27
03036000	Mahoning Creek at Mahoning Creek Dam, PA	PA	40.9275653	-79.2911508	NAD27	WQN0819	40.9275	-79.291389	21.36
03036500	Allegheny River at Kittanning, PA	PA	40.82034197	-79.531434	NAD27	WQN0802	40.8203	-79.5317	22.95
03039000	Crooked Creek at Crooked Creek Dam near Ford City	PA	40.7203422	-79.5114332	NAD27	WQN0818	40.718056	-79.536111	2103.39

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
03040000	Stonycreek River at Ferndale, PA	PA	40.28563049	-78.9205806	NAD27	WQN0817	40.293611	-78.918889	898.62
03041000	Little Conemaugh River at East Conemaugh, PA	PA	40.34590716	-78.8825244	NAD27	WQN0816	40.33	-78.907222	2745.60
03041500	Conemaugh River at Seward, PA	PA	40.4192377	-79.0261404	NAD27	WQN0811	40.419167	-79.026389	22.54
03042000	Blacklick Creek at Josephine, PA	PA	40.4770127	-79.1867009	NAD27	WQN0814	40.473333	-79.183611	485.96
03044000	Conemaugh River at Tunnelton, PA	PA	40.4545117	-79.3908724	NAD27	WQN0810	40.4539	-79.3908	68.29
03044000	Conemaugh River at Tunnelton, PA	PA	40.4545117	-79.3908724	NAD27	WQN0810	40.454444	-79.391111	21.62
03047000	Loyalhanna Creek at Loyalhanna Dam, PA	PA	40.45888889	-79.4494444	NAD83	WQN0812	40.464722	-79.451389	669.30
03048500	Kiskiminetas River at Vandergrift, PA	PA	40.6045099	-79.5519887	NAD27	WQN0809	40.606111	-79.560833	770.46
03048500	Kiskiminetas River at Vandergrift, PA	PA	40.6045099	-79.5519887	NAD27	KI10.9R	40.605556	-79.554167	218.22
03050000	TYGART VALLEY RIVER NEAR DAILEY, WV	WV	38.809275	-79.8817342	NAD27	550452	38.809167	-79.882222	44.11
03057000	TYGART VALLEY RIVER AT COLFAX, WV	WV	39.4350866	-80.1325789	NAD27	550574	39.435278	-80.133472	79.93
03058000	WEST FORK R BL STONEWALL JACKSON DAM NR WESTON, WV	WV	39.00452778	-80.4733611	NAD83	4WFS10201	39.002222	-80.476389	367.36
03058000	WEST FORK R BL STONEWALL JACKSON DAM NR WESTON, WV	WV	39.00452778	-80.4733611	NAD83	USGS-03058000	39.00453	-80.47336	0.26
03061000	WEST FORK RIVER AT ENTERPRISE, WV	WV	39.42230818	-80.2759187	NAD27	550487	39.423389	-80.276111	121.39
03070420	Stony Fork Tributary near Gibbon Glade, PA	PA	39.76424306	-79.58698789	NAD27	USGS-03070420	39.76424	-79.58699	0.39
03072000	Dunkard Creek at Shannopin, PA	PA	39.7592449	-79.9706152	NAD27	WQN0714	39.7603	-79.9728	221.26
03072000	Dunkard Creek at Shannopin, PA	PA	39.7592449	-79.9706152	NAD27	WQN0714	39.760556	-79.973333	275.15
03073000	South Fork Tenmile Creek at Jefferson, PA	PA	39.92313056	-80.072558	NAD27	WQN0713	39.9228	-80.0725	37.11

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03073000	South Fork Tenmile Creek at Jefferson, PA	PA	39.92313056	-80.072558	NAD27	WQN0713	39.923056	-80.072778	20.59
03074500	Redstone Creek at Waltersburg, PA	PA	39.9800758	-79.7642085	NAD27	WQN0712	39.98	-79.764444	21.84
03076500	YOUGHIOGHENY RIVER AT FRIENDSVILLE, MD	MD	39.6536111	-79.4083056	NAD83	YOU0925	39.6529	-79.40846	80.17
03076500	YOUGHIOGHENY RIVER AT FRIENDSVILLE, MD	MD	39.6536111	-79.4083056	NAD83	YOU0925	39.653333	-79.408333	31.01
03076500	YOUGHIOGHENY RIVER AT FRIENDSVILLE, MD	MD	39.6536111	-79.4083056	NAD83	YOU0925	39.652806	-79.408694	95.53
03077500	Youghiogheny River at Youghiogheny River Dam, PA	PA	39.80535485	-79.3642019	NAD27	WQN0709	39.8075	-79.3636	244.01
03077500	Youghiogheny River at Youghiogheny River Dam, PA	PA	39.80535485	-79.3642019	NAD27	WQN0709	39.8075	-79.363889	240.00
03077500	Youghiogheny River at Youghiogheny River Dam, PA	PA	39.80535485	-79.3642019	NAD27	4YOU12313	39.811528	-79.361667	719.91
03078000	CASSELMAN RIVER AT GRANTSVILLE, MD	MD	39.70219444	-79.13638889	NAD83	CAS0479	39.701972	-79.136639	32.75
03078000	CASSELMAN RIVER AT GRANTSVILLE, MD	MD	39.70219444	-79.13638889	NAD83	CAS0479	39.70207	-79.13641	13.95
03078000	CASSELMAN RIVER AT GRANTSVILLE, MD	MD	39.70219444	-79.13638889	NAD83	USGS-03078000	39.70219	-79.13639	0.50
03078000	CASSELMAN RIVER AT GRANTSVILLE, MD	MD	39.70219444	-79.13638889	NAD83	CAS0479	39.70198	-79.13677	40.48
03078000	CASSELMAN RIVER AT GRANTSVILLE, MD	MD	39.70219444	-79.13638889	NAD83	CAS0479	39.703889	-79.14	362.79
03082500	Youghiogheny River at Connellsville, PA	PA	40.01752778	-79.5932222	NAD83	WQN0707	40.0175	-79.593889	57.09
03083500	Youghiogheny River at Sutersville, PA	PA	40.2402222	-79.8066944	NAD83	USGS-03083500	40.24022	-79.80669	0.45
03083500	Youghiogheny River at Sutersville, PA	PA	40.2402222	-79.8066944	NAD83	WQN0706	40.2411	-79.8053	153.81
03083500	Youghiogheny River at Sutersville, PA	PA	40.2402222	-79.8066944	NAD83	WQN0706	40.24	-79.806667	24.82
03085000	Monongahela River at Braddock, PA	PA	40.39118024	-79.8581042	NAD27	USGS-03085000	40.39118	-79.8581	0.36

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03085000	Monongahela River at Braddock, PA	PA	40.39118024	-79.8581042	NAD27	WQN0701	40.405278	-79.881389	2525.86
03085000	Monongahela River at Braddock, PA	PA	40.39118024	-79.8581042	NAD27	WQN0701	40.4056	-79.8808	2509.52
03085500	Chartiers Creek at Carnegie, PA	PA	40.4006247	-80.0964444	NAD27	WQN0914	40.4	-80.098611	196.95
03086000	Ohio River at Sewickley, PA	PA	40.5492342	-80.2056148	NAD27	USGS-03086000	40.54923	-80.20561	0.62
03101500	Shenango River at Pymatuning Dam, PA	PA	41.49810898	-80.46006929	NAD27	WQN0911	41.4972	-80.4611	132.95
03101500	Shenango River at Pymatuning Dam, PA	PA	41.49810898	-80.46006929	NAD27	WQN0911	41.498056	-80.460278	18.43
03102500	Little Shenango River at Greenville, PA	PA	41.42199889	-80.376178	NAD27	WQN0913	41.426111	-80.373889	496.20
03102500	Little Shenango River at Greenville, PA	PA	41.42199889	-80.376178	NAD27	WQN0913	41.4258	-80.3739	464.09
03103500	Shenango River at Sharpsville, PA	PA	41.2661668	-80.4725697	NAD27	WQN0910	41.267778	-80.470556	246.49
03103500	Shenango River at Sharpsville, PA	PA	41.2661668	-80.4725697	NAD27	WQN0910	41.2675	-80.47	261.89
03105500	Beaver River at Wampum, PA	PA	40.88867389	-80.3370083	NAD27	WQN0906	40.888611	-80.337222	19.36
03105500	Beaver River at Wampum, PA	PA	40.88867389	-80.3370083	NAD27	WQN0906	40.8889	-80.3367	36.21
03106000	Connoquenessing Creek near Zelenople, PA	PA	40.8170092	-80.2422837	NAD27	WQN0907	40.816944	-80.242222	8.94
03106000	Connoquenessing Creek near Zelenople, PA	PA	40.8170092	-80.2422837	NAD27	WQN0907	40.8167	-80.2419	47.29
03106500	Slippery Rock Creek at Wurtemberg, PA	PA	40.8839524	-80.2336726	NAD27	WQN0922	40.8839	-80.2336	8.46
03106500	Slippery Rock Creek at Wurtemberg, PA	PA	40.8839524	-80.2336726	NAD27	WQN0922	40.884167	-80.233889	30.07
03107500	Beaver River at Beaver Falls, PA	PA	40.76339848	-80.3150629	NAD27	USGS-03107500	40.7634	-80.31506	0.30
03107500	Beaver River at Beaver Falls, PA	PA	40.76339848	-80.3150629	NAD27	BR-5.3M	40.763333	-80.315278	19.60
03107500	Beaver River at Beaver Falls, PA	PA	40.76339848	-80.3150629	NAD27	WQN0905	40.763333	-80.315278	19.60
03107500	Beaver River at Beaver Falls, PA	PA	40.76339848	-80.3150629	NAD27	WQN0905	40.7661	-80.3169	338.43

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
03107500	Beaver River at Beaver Falls, PA	PA	40.76339848	-80.3150629	NAD27	BR-5.3R	40.763333	-80.315278	19.60
03108000	Raccoon Creek at Moffatts Mill, PA	PA	40.62784405	-80.337563	NAD27	WQN0903	40.627778	-80.337778	19.65
03108000	Raccoon Creek at Moffatts Mill, PA	PA	40.62784405	-80.337563	NAD27	WQN0903	40.6281	-80.3369	63.02
03155000	LITTLE KANAWHA RIVER AT PALESTINE, WV	WV	39.0589686	-81.38956408	NAD27	550482	39.055278	-81.390833	425.61
03164000	NEW RIVER NEAR GALAX, VA	VA	36.6473497	-80.978969	NAD27	9-NEW148.23	36.646389	-80.977778	151.16
03164000	NEW RIVER NEAR GALAX, VA	VA	36.6473497	-80.978969	NAD27	9-NEW148.23	36.6464	-80.9778	148.90
03165000	CHESTNUT CREEK AT GALAX, VA	VA	36.6459613	-80.9192444	NAD27	9-CST010.45	36.681139	-80.917333	3919.38
03165000	CHESTNUT CREEK AT GALAX, VA	VA	36.6459613	-80.9192444	NAD27	9-CST010.45	36.6811	-80.9173	3915.17
03167000	REED CREEK AT GRAHAMS FORGE, VA	VA	36.93900995	-80.8872997	NAD27	9-RDC009.00	36.939056	-80.886917	34.58
03167000	REED CREEK AT GRAHAMS FORGE, VA	VA	36.93900995	-80.8872997	NAD27	9-RDC009.00	36.9391	-80.8869	37.09
03171000	NEW RIVER AT RADFORD, VA	VA	37.14179254	-80.56922499	NAD27	9-NEW081.72	37.138611	-80.575	624.48
03171000	NEW RIVER AT RADFORD, VA	VA	37.14179254	-80.56922499	NAD27	9-NEW081.72	37.1386	-80.575	625.18
03175500	WOLF CREEK NEAR NARROWS, VA	VA	37.30567654	-80.8497993	NAD27	9-WFC003.69	37.3058	-80.8497	16.33
03175500	WOLF CREEK NEAR NARROWS, VA	VA	37.30567654	-80.8497993	NAD27	9-WFC003.69	37.305833	-80.849722	18.72
03176500	NEW RIVER AT GLEN LYN, VA	VA	37.3728986	-80.8606347	NAD27	9-NEW030.15	37.372222	-80.861944	138.56
03176500	NEW RIVER AT GLEN LYN, VA	VA	37.3728986	-80.8606347	NAD27	9-NEW030.15	37.3722	-80.8619	136.68
03176500	NEW RIVER AT GLEN LYN, VA	VA	37.3728986	-80.8606347	NAD27	USGS-03176500	37.3729	-80.86063	0.45
03184000	GREENBRIER RIVER AT HILLDALE, WV	WV	37.64012018	-80.805083	NAD27	550480	37.64	-80.805278	21.84

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
03192000	GAULEY RIVER ABOVE BELVA, WV	WV	38.2334395	-81.1809415	NAD27	550441	38.226667	-81.154167	2469.75
03197000	ELK RIVER AT QUEEN SHOALS, WV	WV	38.47093228	-81.2840057	NAD27	550477	38.471944	-81.284722	128.96
03200500	COAL RIVER AT TORNADO, WV	WV	38.33898309	-81.841518	NAD27	550476	38.338889	-81.840833	61.03
03203600	GUYANDOTTE RIVER AT LOGAN, WV	WV	37.84232616	-81.9759574	NAD27	550397	37.847222	-81.995	1769.48
03208500	RUSSELL FORK AT HAYSI, VA	VA	37.20705367	-82.2956993	NAD27	6ARSS025.40	37.2071	-82.2958	10.36
03208500	RUSSELL FORK AT HAYSI, VA	VA	37.20705367	-82.2956993	NAD27	6ARSS025.40	37.207083	-82.295778	7.74
03478400	BEAVER CREEK AT BRISTOL, VA	VA	36.63177439	-82.1337425	NAD27	6CBEV021.07	36.63175	-82.128278	491.00
03488000	N F HOLSTON RIVER NEAR SALTVILLE, VA	VA	36.89678115	-81.7462293	NAD27	6CNFH083.32	36.88675	-81.768444	2280.89
03488000	N F HOLSTON RIVER NEAR SALTVILLE, VA	VA	36.89678115	-81.7462293	NAD27	6CNFH083.32	36.8868	-81.7684	2274.72
03490000	N F HOLSTON RIVER NEAR GATE CITY, VA	VA	36.60871119	-82.567931	NAD27	6CNFH008.78	36.611222	-82.567417	283.88
03490000	N F HOLSTON RIVER NEAR GATE CITY, VA	VA	36.60871119	-82.567931	NAD27	6CNFH008.78	36.6089	-82.5674	52.19
03524000	CLINCH RIVER AT CLEVELAND, VA	VA	36.9448295	-82.1548569	NAD27	6BCLN271.50	36.9433	-82.1551	171.90
03524000	CLINCH RIVER AT CLEVELAND, VA	VA	36.9448295	-82.1548569	NAD27	6BCLN271.50	36.943306	-82.154944	170.03
03524500	GUEST RIVER AT COEBURN, VA	VA	36.92926938	-82.4562619	NAD27	6BGUE006.50	36.9295	-82.456333	26.50
03524500	GUEST RIVER AT COEBURN, VA	VA	36.92926938	-82.4562619	NAD27	6BGUE006.50	36.9295	-82.4563	25.95
03527000	CLINCH RIVER AT SPEERS FERRY, VA	VA	36.64870849	-82.7504384	NAD27	6BCLN211.00	36.648611	-82.749722	65.33
03527000	CLINCH RIVER AT SPEERS FERRY, VA	VA	36.64870849	-82.7504384	NAD27	6BCLN211.00	36.6486	-82.7497	67.49
03529500	POWELL RIVER AT BIG STONE GAP, VA	VA	36.86898536	-82.7754387	NAD27	6BPOW180.78	36.869056	-82.775778	31.43

Gage ID	Gage Name	State	Gage Latitude	Gage Longitude	Datum	Site ID	Site Latitude	Site Longitude	Distance (m)
03531500	POWELL RIVER NEAR JONESVILLE, VA	VA	36.66203367	-83.0948928	NAD27	6BPOW143.53	36.662556	-83.093972	101.29
03531500	POWELL RIVER NEAR JONESVILLE, VA	VA	36.66203367	-83.0948928	NAD27	6BPOW143.53	36.6626	-83.094	102.21