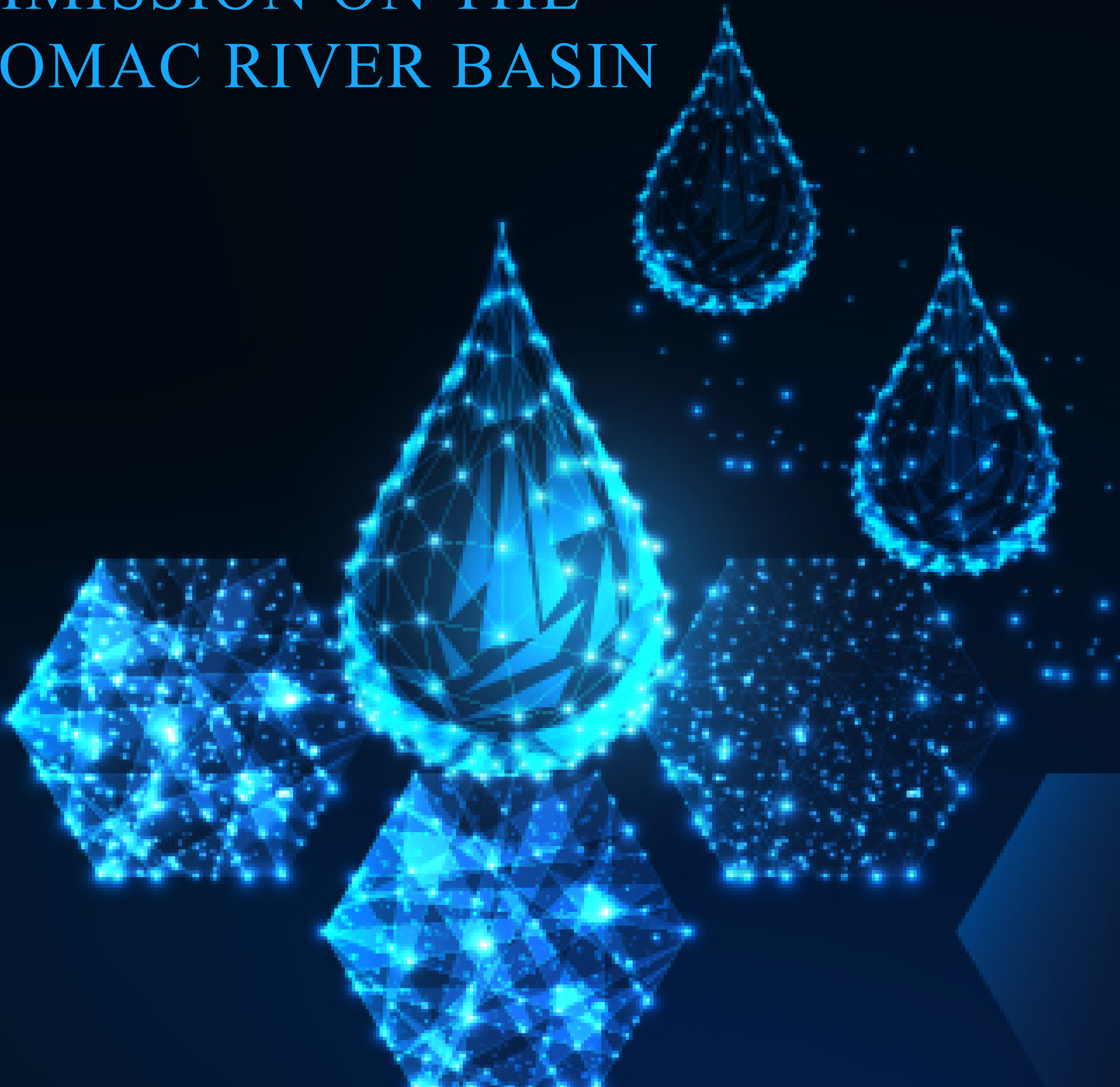
INTERSTATE COMMISSION ON THE POTOMAC RIVER BASIN



Potomac River Water Quality at Great Falls: 1940 - 2019

ICPRB Report #ICP 21-5

This report can be downloaded from the Publications tab of the ICPRB's website, www.potomacriver.org
To receive hard copies of the report, please write:

Interstate Commission on the Potomac River Basin
30 West Gude Dr., Suite 450
Rockville, MD 20850
or call 301-984-1908
or email info@icprb.org

Please direct inquiries about the report or the dataset to info@icprb.org

Acknowledgments

Dr. Norbert A. Jaworski provided ICPRB the annual summary reports he acquired directly from Washington Aqueduct staff and the Excel spreadsheets he created from the data in those reports. Washington Aqueduct staff offered encouragement and technical advice over the course of the project. We thank Anne Spiesman for reviewing the draft report. The project was supported in part by EPA grant I-98339415.

Disclaimer

Suggested citation for this report:

D. Hunter, R. D. Jepsen, C. C. Davis, and C. Buchanan. 2021. Potomac River Water Quality at Great Falls: 1940-2019. **ICPRB Report #ICP 21-5**. Interstate Commission on the Potomac River Basin, Rockville, MD. Available online at: www.potomacriver.org

Potomac River Water Quality at Great Falls: 1940-2019

DeeDee Hunter
Rikke D. Jepsen
Christina C. Davis
Claire Buchanan

Interstate Commission
on the
Potomac River Basin

ABSTRACT

The U.S. Army Corps of Engineers operates Washington Aqueduct and provides drinking water to the Washington, D.C. area. Washington Aqueduct routinely samples its source of water, the Potomac River. Each year, it reports the monthly averages for basic water parameters and several pollutants and metals. Reports since 2001 are available online. Reports from 1905 to 2000, however, had limited distribution and their legibility has faded over time.

Dr. Norbert A. Jaworski recognized the historical value of these reports. To prevent their loss, he digitized the monthly values for several parameters. The Interstate Commission on the Potomac River Basin (ICPRB) later updated his dataset through 2019 and checked the entered data for accuracy. This report focuses on changes in temperature, hardness, pH, total solids, chloride, nitrate, and sulfate over the 80 years since ICPRB was formed in 1940. Visual representations ("heatmaps") and trend analysis show significant increasing trends in all these parameters except nitrate. The report is intended to introduce the historical Washington Aqueduct water quality data to a broader audience and highlight their potential value to Potomac studies.

Cherry Blossoms at Washington Aqueduct. Photo: Anna Hayden

INTRODUCTION

To process Potomac River raw water into safe drinking water, suppliers monitor the water they withdraw from the river and adjust treatment accordingly. Samples are collected frequently and routinely because water quality varies in response to rain events and upstream activities on land. Washington Aqueduct is one of the region's oldest water suppliers. Built in 1859 and operating since 1863, Washington Aqueduct withdraws raw water from the Potomac River near Great Falls and currently supplies drinking water to approximately one million people in Washington, D.C., Arlington County, Virginia, and parts of Fairfax County, Virginia. Washington Aqueduct tests the raw water and treated (finished) water for an array of physical parameters, bacterial contaminants, organics, inorganic ions, and metals.

Some of the surviving laboratory records date to 1905. The earlier measurements were logged on laboratory bench sheets and monthly averages of the measurements recorded in handwritten or typed summary reports each year. Legibility of many of these earlier reports faded over time, and the information they contained was at risk of being lost. Recognizing their historical value, Dr. Norbert A. Jaworski (retired, U.S. Environmental Protection Agency) worked with Washington Aqueduct staff to obtain the reports in their various formats. He entered the raw water results collected through 2011 in an Excel spreadsheet, and his analyses of these data figured heavily in his Potomac River "Treatise" (Jaworski et al. 2007) and journal publications.[1]

Beginning in 2019, ICPRB staff continued Jaworski's efforts by adding the 2012–2019 raw water monthly data to his spreadsheet and performing a rigorous quality assurance (QA) review of all the entered data.

The resulting dataset is exceptional in that it provides more than a century of water quality data for the Potomac River and reveals long-term environmental changes and climatic patterns in the river. This report provides a brief description of the source materials and ICPRB efforts to assemble and QA the data. It also presents an analysis of 80 years (1940–2019) of seven water quality parameters: temperature, pH, total solids, chloride, nitrate, sulfate, and hardness.

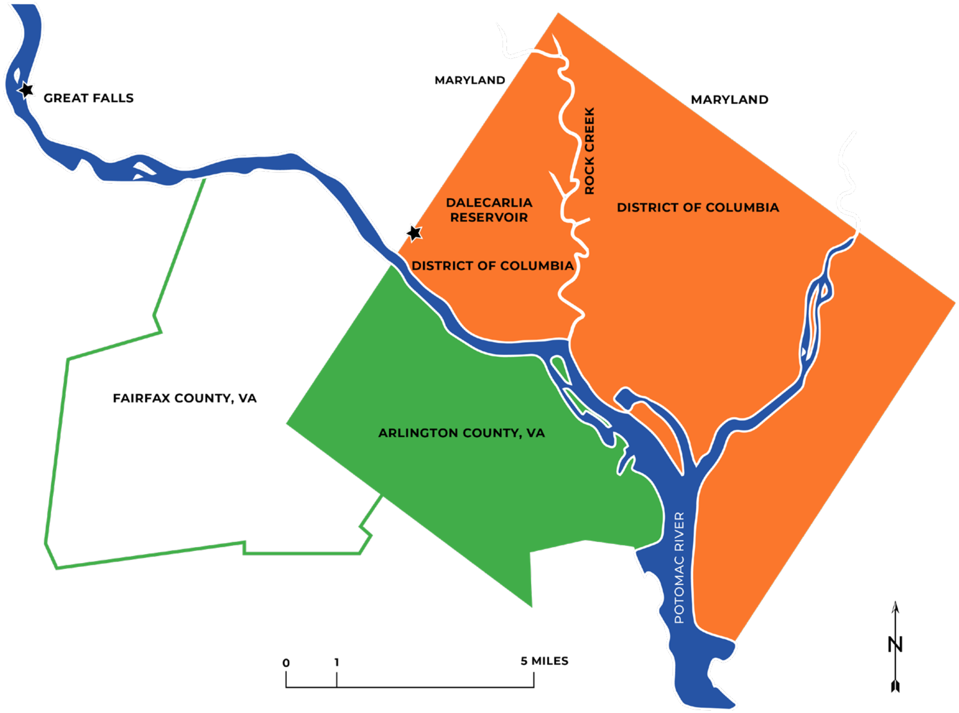
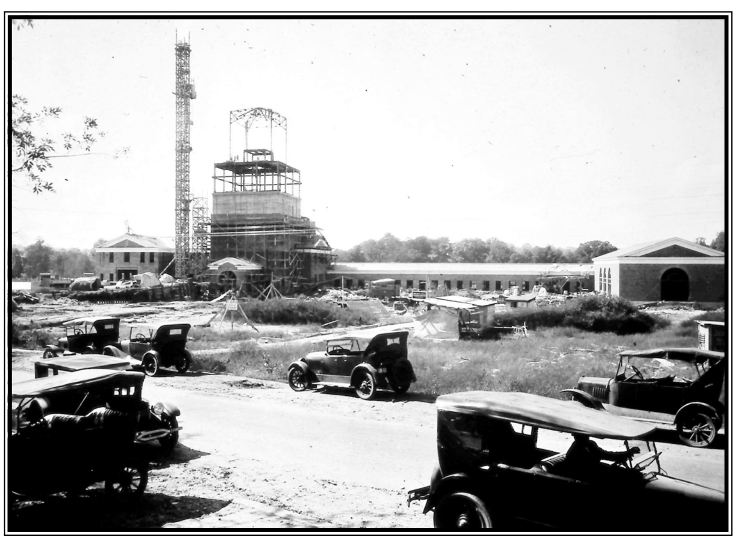


FIGURE 1. Great Falls river intake and the Dalecarlia Reservoir sampling locations

METHODS

Raw water sampling locations were Washington Aqueduct's Great Falls river intake and the Dalecarlia Reservoir **(Figure 1)**. In the reservoir, samples were collected at the inlet (denoted "A" or "same as River") or the outlet (denoted "B" or "after preliminary sedimentation"). When available, comparisons of the monthly averages collected at different locations indicate their values are typically close. Exceptions include turbidity (probably due to particulates settling in the reservoir) and algal counts (likely due to historical intermittent copper sulfate and/or permanganate treatment in the reservoir to control algae). While monthly averages are reported, in some cases only one sample per month was collected or even one sample per quarter. In other cases, the average reflects many samples (A. Spiesman, per. comm.)



Washington Aqueduct construction (1895).
Courtesy of Washington Aqueduct.

Historical records are insufficient to determine which laboratory methods were followed in the early decades, although there is every reason to believe that industry-standard methods were likely used where those existed. Since 1895, when the American Public Health Association first recognized the need for standardized methods for examining bacteria in water, water works laboratory methods and the statistical basis for analytical quality control have evolved and include chemical, microbial, and radiological methods (Clesceri et al. 1999).

For some parameters, technology improvements have increased analytical sensitivity. Levels of contaminants that were once considered below a method's detection threshold and thus unreliable are now considered reliable.

"Washington Aqueduct employed various methods of colorimetry for the analysis of nitrate until the mid-1980s, when ion chromatography was adopted. Over time, advancements in technology and method quality control have likely improved the accuracy and precision of the data, for nitrate and other parameters, especially at the lower end of the reported range."

(A. Spiesman, per. comm.)

DATA MANAGEMENT

ICPRB used a five-step data management process **(Figure 2)** to create a single digital copy of Washington Aqueduct's historical raw water records.

Gather

The source materials are printed copies of the original handwritten or typed annual reports and electronic copies saved in Portable Document Format (PDF).
The earliest copies were made on large light-sensitive sheets of different sizes employing contact print processes traditionally used for architectural and engineering drawings (e.g., blueprint, diazo "whiteprinting"). Later copies were made using xerographic technology. Eventually, computers were used to electronically create the reports and then publish them in PDF format.

Jaworski obtained the pre-2001 reports directly from Washington Aqueduct staff and entered data for the parameters of interest to him in an Excel spreadsheet. He created a second spreadsheet for the 2001–2012 data and digitized values for the same parameters as they became available online.

Jaworski shared his spreadsheets with C. Buchanan (ICPRB) and others at various times starting in 2000. In 2018, he shipped the 1922–2001 source materials in his possession to ICPRB for safekeeping. PDFs of many of these materials were also forwarded to ICPRB in 2019 by Washington Aqueduct staff. ICPRB staff downloaded the annual reports for 2000 onward from [Washington Aqueduct website].

GATHER
Collect and prepare the data for review

REVIEW
Review data for inconsistencies

ENTER DATA
Enter new data and correct existing data

VALIDATE
Confirm data accuracy

IDENTIFY
Identify data gaps and limitations

FIGURE 2. Steps in assembling and preparing data for analysis

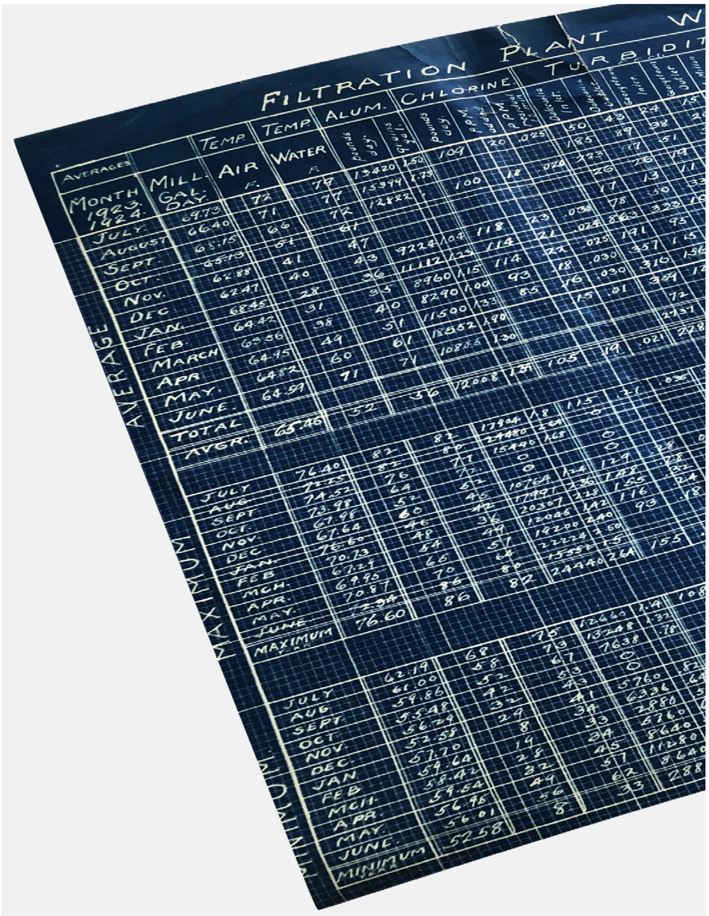


FIGURE 3. Contact print bench sheet (1923-1924)

Review

ICPRB staff met with Washington Aqueduct scientists and engineers in January 2019 to review the source materials and some of the changes in sample collection and processing over time. ICPRB staff manually compared the digital values in Jaworski's spreadsheets to values in the source materials and combined the spreadsheets into a single dataset. Organizing and reviewing the gathered materials was complicated by the multiple copies available in different formats. Multiple copies, however, allowed ICPRB staff to find and use the most legible copy to validate the digital dataset.

Entries in the early source materials produced with contact print processes were in legible, albeit small, handwriting and not faded **(Figure 3).** Typed annual reports were produced starting around 1950. Copies of these reports were sometimes created with early xerographic ("photocopier") technologies and did not replicate or age well. Fading was common and legibility was at times problematic **(Figure 4)**.

Reports after circa 1997 were very legible because they were created with word processing software and published as PDFs.

Enter

ICPRB staff extended Jaworski's work by downloading the annual reports and digitizing the 2012–2018 data in early 2019 and the 2019 data in June 2021. The parameters digitized were the same ones that Jaworski entered: total solids, dissolved solids, turbidity, algal count, total coliform, *E. coli*, calcium, magnesium, silica, nitrate, chloride, sodium, sulfate, potassium, pH, alkalinity, hardness, and water temperature.

Validate

Entry errors in Jaworski's spreadsheets were identified and corrected in this step. The pre-2012 values digitized by Jaworski were compared to the most legible of the several source materials.

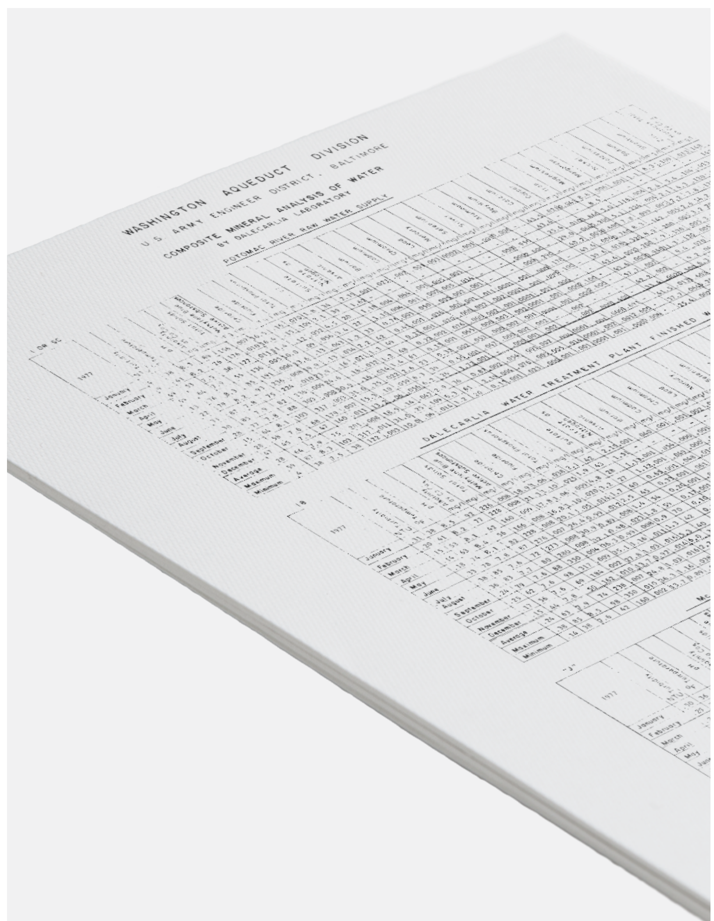


FIGURE 4. Early Xerographic bench sheet (1977)

The effort was particularly challenging due to the volume of data, poor legibility of some source materials, and inconsistencies and changes in some of the reported parameters over time. Corrections due to omissions, duplication, extra characters, and incorrect entries were noted in the ICPRB digital copy to track the changes. Entries of the 2012–2019 Washington Aqueduct data made by ICPRB staff were compared to the annual reports in PDF format.

Identify Data Gaps and Limitations

Some parameters in Washington Aqueduct records were measured consistently with few exceptions every month for the entire 1905–2019 period (e.g., temperature). Others were measured in only some years (e.g., potassium) and/or in certain seasons (e.g., phytoplankton cell counts). Inconsistencies in sampling frequency and changes in reported parameters and methodology occurred more often in the 1930–2000 timeframe. Overall, the number of parameters measured by Washington Aqueduct increased over time.

Detection limits are sometimes indicated in the summary reports with values preceded by "<". Changes in method detection limits can be seen for several parameters. Many values below a method's detection limit are a concern when performing trend analyses. In many instances, however, the improved sensitivity of the laboratory method does not affect trend analyses because river concentrations were much higher than either the old or new detection limits (e.g., nitrate) or were consistently below the detection limits (e.g., many of the metals). However, researchers should be aware of this potential problem.

DATA ANALYSIS

Heatmaps are a graphical tool used to visualize data, where values are represented by a color scale. Here, heatmaps were used to illustrate patterns in water quality over the 80-year period for seven water quality parameters with relatively complete records: temperature, pH, chloride, nitrate, sulfate, hardness, and total solids. Color theory principles were applied to each heatmap to maximize visual pattern effects that communicate water quality through contrasting colors.

Heatmaps were generated using the 'geom_tile()' function in the ggplot2 package (Wickham 2016) in RStudio (v1.1.453).

Several **trend analyses** were performed on the seven water quality parameters to determine if patterns observed in the heatmaps were statistically significant. Gaps in the analysis dataset needed to be addressed before trend methods were applied. Small gaps within a season were filled with the mean value of that year-season. If a year had many gaps or was missing an entire season, the year was excluded (this did not happen often). Four seasons were defined for season-dependent trend analysis: winter (December, January, February); spring (March, April, May); summer (June, July, August); and autumn (September, October, November).

Next, the Breusch-Godfrey test was used to check for autocorrelation (also called serial correlation) in each parameter with the 'bgtest' function in the lmtest package (Zeileis and Hothorn 2002). Additionally, autocorrelation function (ACF) and partial autocorrelation function (PACF) plots were generated with the 'acf' and 'pacf' functions in the stats package (R Core Team 2018). R has several packages that provide modified trend tests that take autocorrelation into account, and since autocorrelation was present for all parameters, modified Seasonal Kendall and Mann-Kendall tests were used for the initial analysis ('csmk' function from trend package (Pohlert 2020) and 'mmkh' function from modifiedmk package (Patakamuri and O'Brien 2020)). In cases where individual seasons were analyzed for trends, the modified Mann-Kendall test was used.

The effect of seasonality was explored before trend analysis was performed. Whether or not seasonality influenced the observed values was determined using boxplots grouped by month (Supplemental Materials). Parameters whose values varied in concentration throughout the year were analyzed using the modified Seasonal Kendall test, and parameters whose values remained fairly stable throughout the seasons were analyzed using the modified Mann-Kendall test.

Trends were also run on the flow-corrected data. Daily mean flows were downloaded for the entire data record from USGS gage 01646502 which is located near the Washington Aqueduct intake at Great Falls and adjusted for upstream water supply withdrawals.

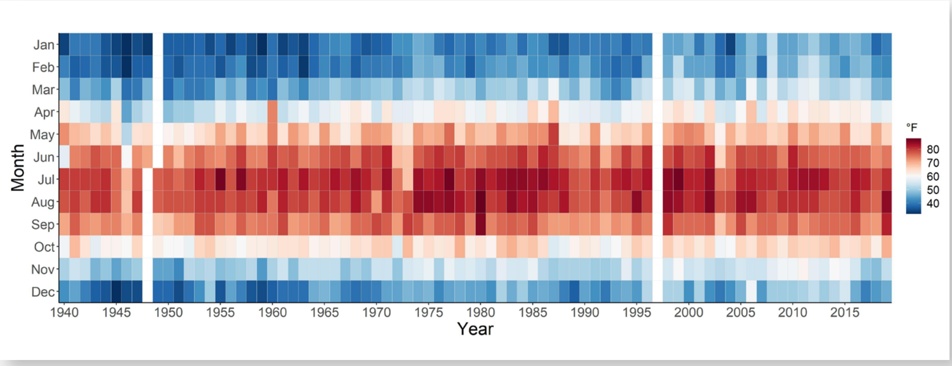
Monthly means (cubic feet per second; cfs) were calculated from the daily means and matched to Washington Aqueduct water quality monthly means. LOWESS (Locally Weighted Scatterplot Smooth) curves were fitted to log-log plots of the water quality and flow monthly means (Supplemental Materials) and the residuals calculated using the 'residuals' function in the stats package (R Core Team 2018). Trend analysis was performed on the residuals of each parameter using the same methods as in the initial analysis.

RESULTS

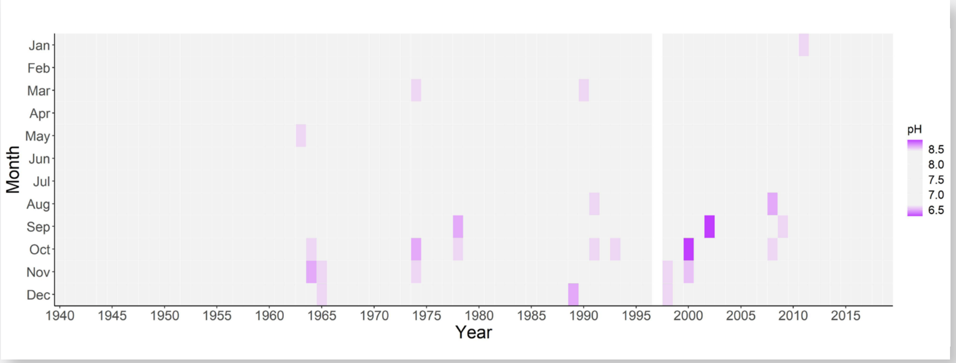
The following **series of heatmaps display the seasonal and interannual patterns** observed in the seven water quality parameters between 1940 and 2019. Year is on the x-axis and month on the y-axis. Colors indicate a parameter's average observed concentration in a given month-year. Colors were chosen using color theory principles to create primary, secondary, and tertiary color structures typically used to represent the given parameters in scientific literature. Data gaps are shown as uncolored cells.

Temperature

Temperature controls the metabolisms of cold-blooded aquatic animals such as fish and macroinvertebrates. These animals only grow and reproduce normally when they experience temperatures they prefer. Since 1940, the measured winter temperatures (December–February) at Great Falls in the Potomac River have increased by about 2.3 degrees F. This can be seen in the heatmap as a lightening of the blue color in winter months over time. Summer temperatures (July–August) seem to have remained fairly stable on average but could be increasing and very high temperatures have been recorded.



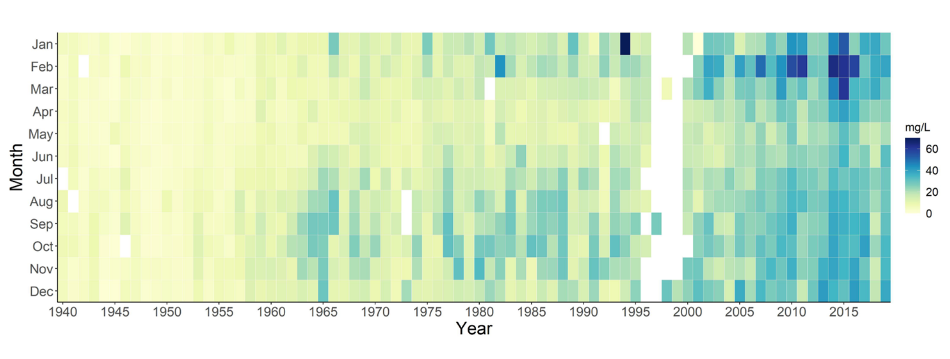
Power of Hydrogen (pH)



The acidity of water is measured by **pH**, or **power of hydrogen**. pH values that are too low (acid) or too high (base) cause animals to struggle or even die. Low pH levels also heighten the toxicity of ammonia and many metals. Large and sometimes rapid changes in pH can happen when dense beds of aquatic plants and algae grow rapidly in summer or when they senesce and die in autumn. A healthy pH in a freshwater river is between 6.5 and 8.5 and Potomac Great Falls levels have generally stayed within these limits. Levels rose significantly and became less acidic between 1940 and 1960 before stabilizing at approximately 7.9 (Supplemental Materials). Values approached the lower and upper limits more often in summer and autumn. Two values—dark purple in the heatmap—exceeded the limits: an acidic pH of 6.29 in October 2000 and a basic pH of 8.80 in September 2002.

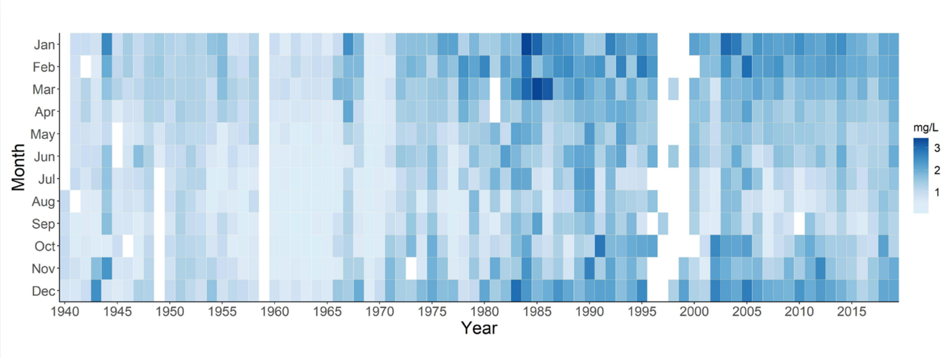
Chloride

Chloride salts, including common table salt, dissolve easily in water. High concentrations can impede the ability of freshwater animals and plants to control their water and salt content (osmoregulation). Concentrations in the Potomac River have risen substantially since 1940. The rise is especially noticeable in winter months, where average concentrations have increased almost 10-fold, from 4.1 mg/L in the 1940s to 37.8 mg/L in the 2010s. Concentrations are also rising in the other three seasons.



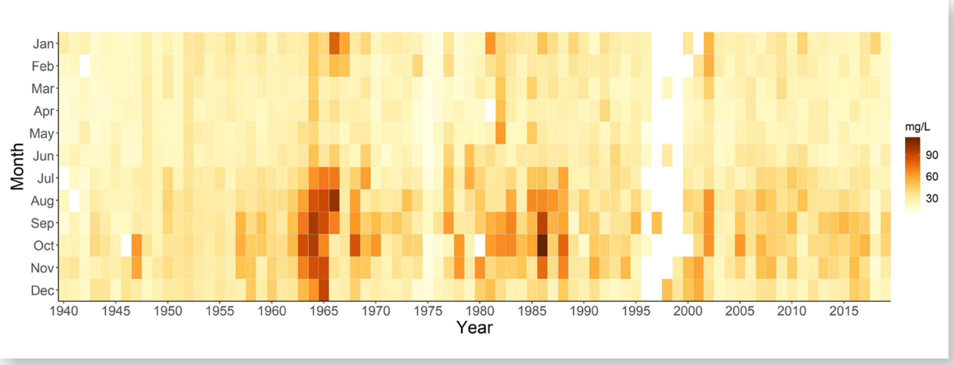
Nitrate

Nitrate, a nitrogen-containing compound, is an essential nutrient for land plants as well as aquatic plants and algae. Too much nitrate in the water, however, will fuel harmful algal blooms, and levels greater than 10 mg/L in drinking water can cause blue baby syndrome.[2] Observed concentrations of river nitrate averaged 0.98 mg/L in the 1940s, peaked at 1.65 mg/L in the 1980s, and fell slightly to 1.56 mg/L in the 2010s, making this a "curvi-linear" trend.



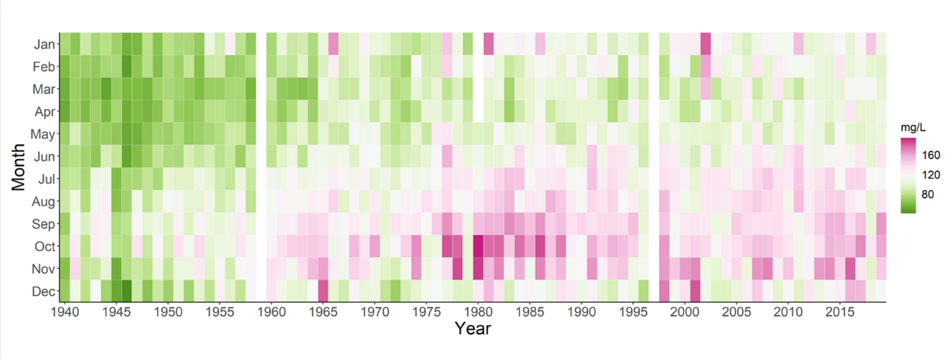
Sulfate

Elevated levels of **sulfate** ($SO4^{-2}$), a sulfur-containing anion, in streams and rivers are indicators of acid rain and acid mine drainage. Sulfate is also found in wastewater discharges and surface runoff. Some sulfate compounds are toxic to aquatic life, such as copper sulfate which is used in reservoirs to kill algal blooms. Sulfate in drinking water is unregulated but US EPA currently recommends a maximum level of 250 milligrams per liter (mg/L) based on taste and odor effects. High sulfate levels have come and gone in Washington Aqueduct raw water data, with peaks occurring in summer months in the 1960s and 1980s.

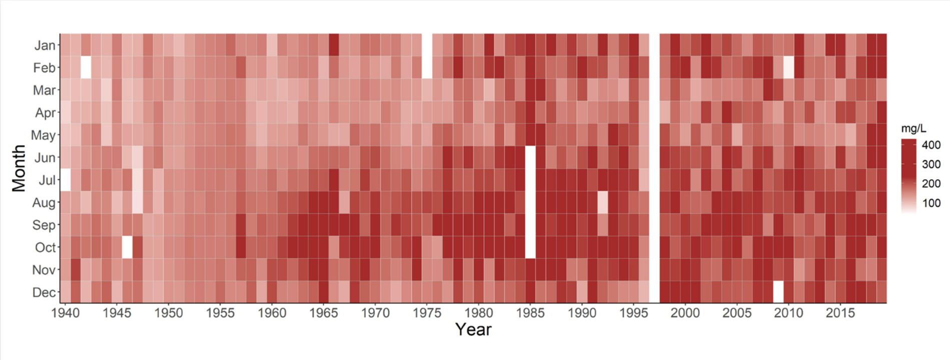


Hardness

Calcium, magnesium, and other multivalent cations dissolved in the water determine water's hardness. When water hardness is less than 30 mg/L as $CaCO_3$, metals have an easier time passing into fish through the gills and can poison or kill the fish. When water hardness is more than 180 mg/L as $CaCO_3$, more soaps and detergents are used in household laundry and dishwashing, and mineral buildup in industrial equipment causes breakdowns. Water hardness in the river has mostly stayed between 30 and 180 mg/L as $CaCO_3$, but overall concentrations are increasing, especially in summer and autumn.



Total Solids



An old but reliable method for measuring the total amount of particles and dissolved matter in water is to completely evaporate a water sample and weigh the residue left behind. **Total solids** include everything from sand particles to dissolved salts, metals, and organic matter (e.g., amino acids). They prevent sunlight from penetrating the water and can block the transfer of oxygen across the gill membranes of aquatic animals. Water suppliers are concerned about particulate solids in the water—especially organic ones—because they tend to carry harmful bacteria and toxic chemicals and are disinfection byproduct (DBP) precursors. Dissolved solids can increase the salinity of streams and rivers to levels that harm freshwater biota and contribute to taste and odor problems. Amounts of total solids in the Potomac River have increased substantially since the 1940s.

TREND ANALYSIS

Five parameters are strongly affected by season: temperature, nitrate, hardness, total solids, and sulfate. The Seasonal Kendall trend test was applied to those data. The Mann-Kendall test was applied to pH and chloride because they did not show strong seasonal effects. Only temperature, chloride, and nitrate displayed significant changes over the 80-year timeframe (Table 1). These trends, however, do not account for the effect of river flow. High flows corresponded to lower chloride, hardness, pH, total solids, and sulfate concentrations, higher nitrate concentrations, and lower ambient river temperatures in the river. Flow correcting the observed data and repeating the trend analysis minimizes these flow effects.

Flow-corrected trends for all parameters except pH were highly significant with p-values less than 0.001; the pH trend was weakly significant with a p-value of 0.013. (The lower the p-value, the more likely the relationship is to be real and not a data artifact). Temperature, pH, chloride, hardness, total solids, and sulfate all increased over the 80-year period **(Table 1).** The increasing trend in observed nitrate concentrations changed to a decreasing trend when the data were flow corrected. Since water temperature is so heavily influenced by season, individual Mann-Kendall tests were also performed for each season's flow-corrected time series with the result that spring, summer, and autumn values showed increases, but winter temperatures did not **(Table 2)**.

TABLE 1. Trend results for monthly averages of seven water quality parameters, 1940 – 2019.
NS, not significant at α = 0.05.

PARAMETER	TREND TEST	P-VALUE (NOT FLOW-CORRECTED)	P-VALUE (FLOW-CORRECTED)	TREND DIRECTION
Temperature	Seasonal Kendall for autocorrelation	< 0.001	< 0.001	Increasing
pH	Mann-Kendall for autocorrelation	NS	0.013	Increasing
Chloride	Mann-Kendall for autocorrelation	< 0.001	< 0.001	Increasing
Nitrate	Seasonal Kendall for autocorrelation	< 0.001	< 0.001	Increasing (not corr.) Decreasing (corr.)
Sulfate	Seasonal Kendall for autocorrelation	NS	< 0.001	Increasing
Hardness	Seasonal Kendall for autocorrelation	NS	< 0.001	Increasing
Total solids	Seasonal Kendall for autocorrelation	NS	< 0.001	Increasing

TABLE 2. Temperature trend results for separate seasons. Analysis done on flow-corrected data.
NS, not significant at α = 0.05.

TEMPERATURE	TEST	P-VALUE	TREND DIRECTION
Winter	Mann-Kendall for autocorrelation	NS	None
Spring	Mann-Kendall for autocorrelation	0.014	Increasing
Summer	Mann-Kendall for autocorrelation	0.013	Increasing
Autumn	Mann-Kendall for autocorrelation	0.008	Increasing

DISCUSSION

As this report demonstrates, digitizing older, hardcopy data can be challenging but is invaluable in preserving an historical record. Data in digital formats also offer exceptional opportunities to analyze natural ecosystems with sophisticated statistical tools. The Potomac is generally considered a well-studied river with many long-term datasets. Its Point of Rocks flow gage (USGS 01638500), for example, was established in 1895 and is one of the nation's oldest continuously operating gages. The Washington Aqueduct source materials, however, are unsurpassed with respect to the amount of water quality information they contain and their length of record. This brief report is intended to introduce the Washington Aqueduct water quality data to a broader audience and highlight some of their historical value.

Water Quality at Great Falls since 1940

Since the start of the Washington Aqueduct monitoring record in 1905, the Potomac basin has seen an almost 5-fold increase in population[3] and significant changes in land and water uses as well as recent signs of climate change. Evidence of these changes is found in the 1940 – 2019 trends of the seven water quality parameters highlighted in this report.

Temperature

Statistically significant increases in temperature since 1940 occurred in the Potomac River at Great Falls in spring, summer, and autumn months. Winter temperatures appear to increase, but once flow-corrected, the increase proved not significant. Overall, average temperature increased 6.0° F. It is too facile to simply attribute the 80-year increasing trends to global warming. A more likely factor was the rapid population growth and attendant land and economic changes during this period that substantially altered the watershed upstream of Great Falls. By the early 20th century, the forests that once cooled surface waters had been logged or replaced with open agricultural lands. Forests were recovering in the middle of the 20th century, but agriculture was giving way to development and, with more people, urban "heat islands" were appearing (e.g., Sprague et al. 2006, Jaworski et al. 2007).

Potomac River Gorge at Great Falls Park

Regardless of the cause(s), rising temperatures in the river are a concern. Warming seasons disrupt the life cycles of aquatic organisms, and very hot summers can kill them. One consequence of warming is the displacement of fish and macroinvertebrate species that prefer colder waters (e.g., brook trout).

pH

At Great Falls, pH rose from 7.6 to 7.9 between 1940 and 1970 and then stabilized. This rise in pH represents a roughly 50 percent decrease in hydrogen ion (H^+) concentrations. The rise occurred before implementation of the Clean Air Act of 1970 and the Surface Mining Control and Reclamation Act of 1977, and mine-impacted headwater streams and small rivers feeding the Potomac mainstem did not recover until much later (e.g., Buchanan and Selckmann 2019).

Thus, the pH rise at Great Falls cannot be attributed to the reduced air emissions and mine remediations prompted by those federal laws. The timing of the rise suggests parts of the Potomac watershed were in the process of recovering from the destructive agriculture practices and large-scale logging of the late 18th and early 19th century (Sprague et al. 2006). A contributing factor could very well be the Great Appalachian Valley bisecting the Potomac watershed. The Valley is underlain by carbonate ("karst") geology, which would tend to reduce the acidity of waters flowing through or across it.

Chloride

Chloride at Great Falls rose significantly between 1940 and 2019, with the highest measured values occurring in winter and early spring. Weathering of rocks and sediment are natural sources of chloride in rivers, but high concentrations also come from winter road salting, fertilizer runoff, and oil and gas production. Road salting during snow and ice storms is now considered the largest source of chlorides to the Potomac and its tributaries in the Washington, D.C. region (e.g., Porter et al. 2020). Moreover, the heatmap shows an increase in chlorides in summer and autumn. This may indicate that groundwater holds chlorides deposited during winter and slowly releases them to the river as baseflow during drier months. Evaporation from the river surface during warm weather could also concentrate chloride in the water. A Salt Management Strategy was recently completed for northern Virginia that identifies practices that minimize the negative impacts of salt uses (VADEQ 2021). Maryland Department of the Environment is beginning a comparable effort.

Nitrate

River nitrate concentrations at Great Falls have been highly variable since 1940. A curvilinear but overall increasing trend is seen in the observed values during the 80-year period; a curvilinear but overall decreasing trend is seen when the values are flow-corrected **(Figure 5)**. Analysis confirms both these trends are real and significant. The slight rise in flow-corrected nitrate after 1979 **(Figure 5, right side)** was also found by Ator et al. (1998) in U. S. Geological Survey data collected nearby. The apparent contradiction in observed and flow-corrected trends appears related to shifts in the nitrate-flow relationship that have occurred over the 80 years (see Supplemental Materials).

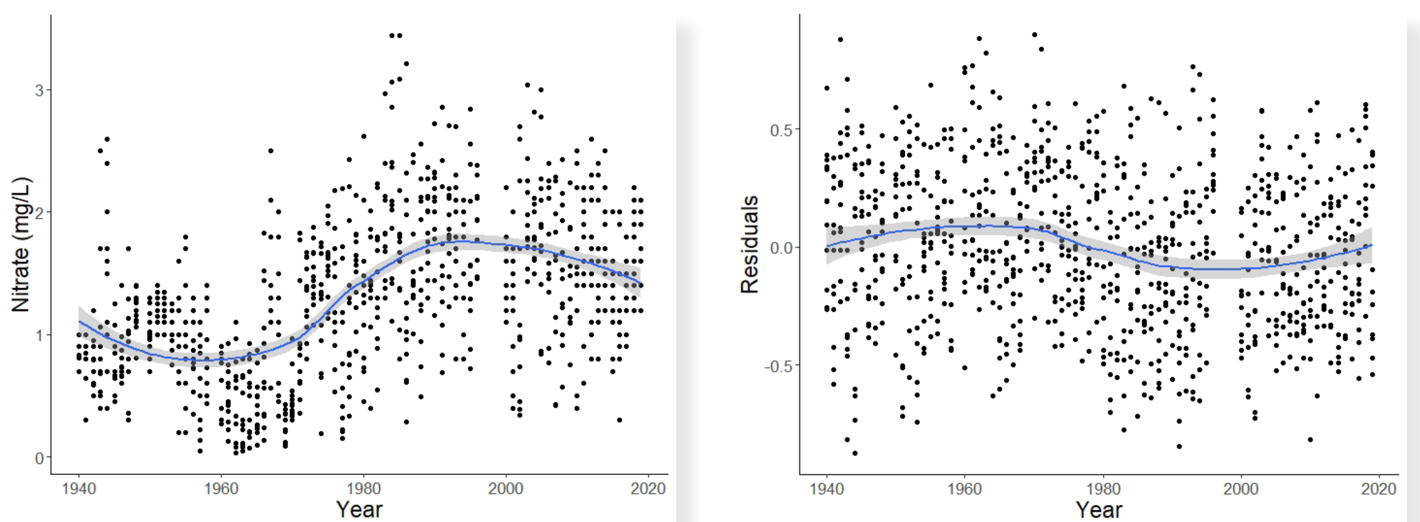


Figure 5. Time series of nitrate concentrations from 1940-2019 with LOWESS curves (blue lines). Left side, observed data not corrected for flow; right side, flow corrected values, or residuals. Residuals are derived from the log-log relationship of nitrate and flow (Supplemental Materials). They are the difference between that relationship (also a LOWESS curve) and each point. Residuals are then plotted against time (e.g., right side graph) and tested for trends.

Potomac River Gorge at Great Falls Park (wide view)

These underlying shifts would have affected the overall 80-year trend result. The shifts were likely caused by changes in the dominant anthropogenic sources of nitrate to the river over time and how and when that nitrate enters the river. Another possible but probably minor factor may be Washington Aqueduct's switch from colorimetry methods to ion chromatography in the mid-1980s (see Methods).

In the past, disruptive agricultural practices, unchecked fertilizer runoff, poor waste water treatment for a growing population, and emissions of coal-burning power plants added large amounts of nitrate into Chesapeake streams and rivers, including the Potomac. One goal of the Bay's "pollution-diet" is reducing the high concentrations of nitrate and other forms of nitrogen in waters entering Chesapeake Bay. The complexity of nitrogen pathways from the watershed to the Bay makes this task difficult. Progress is being made but the U. S. Environmental Protection Agency's [2017 Mid-Point Assessment] found concentrations have not reached levels thought to be protective of the Bay.

Sulfate

Present-day concentrations of sulfate in the Potomac River at Great Falls are generally higher than those found in the river in 1940. The 80-year rise in concentration was uneven, with peaks occurring in summer months in the 1960s and 1970s and again in the 1980s, followed by a slight decline. Natural sources of sulfate in rivers and streams are rock weathering and the breakdown of organic matter. Elevated sulfate levels, however, indicate anthropogenic inputs from atmospheric deposition, mine drainage, runoff, and wastewater discharges. Some of the Potomac raw water measurements may have been affected by the occasional copper sulfate treatments in the Dalecarlia Reservoir to kill algal blooms. The recent, slight decline in sulfate at Great Falls may signal the ongoing recovery from acid rain impacts in the northeast United States.

Hardness

Water hardness increased sharply in the Potomac at Great Falls until about 1980 and then more slowly after that. Despite the overall increase, effects of hardness on equipment and detergent use are likely minimal because values overall remained less than 180 mg/L as $CaCO_3$. Only eight monthly averages greater than 180 mg/L as $CaCO_3$ were reported for the 80 years between 1940 and 2019.

Natural weathering of carbonate rock is the major source of calcium and magnesium, the principal components of water hardness. Carbonate rock ("karst"), which is plentiful in the Potomac basin, contains large amounts of calcium and magnesium. Another carbonate source is the common building material concrete. Acid rain in the mid-20th century accelerated weathering and was a likely cause of the sharp rise in river hardness between 1940 and 1980. The slower rise after 1980 suggests the impacts of acid rain in the basin are diminishing.

Total Solids

Concentrations of total solids have increased substantially in the Potomac River at Great Falls since the 1940s. The steady, long-term increase was likely caused by land and water uses associated with population growth in the watershed.

There are many natural sources of particulate solids in streams and rivers, such as materials sloughed off during the breakdown of organic matter and the resuspension of bottom sediments during rain events. Reducing the amount of particulate solids entering tidal waters is a goal for the Chesapeake Bay (Chesapeake Bay Program 2014).

Various "best management practices" (BMPs) on land are being used to accomplish these reductions. For example, stormwater ponds capture rainwater and settle the suspended particles. The ponds also slow the runoff from impervious surfaces in urban environments, which results in less stream bank erosion.

A long-term upward trend in dissolved solids[4] is indicated by the upward trends in hardness and chloride. Along with upward trends in conductance and alkalinity (not shown in this report), they point to the freshwater salinization syndrome as an emerging issue for the freshwater Potomac River. The syndrome is characterized by concurrent increases in specific conductance, pH, alkalinity, and base cations which include calcium, magnesium, sodium, and potassium (Kaushal et al. 2018). Many natural and anthropogenic sources contribute to increasing salinity in freshwater systems. Over time, salinization corrodes infrastructure, increases metal toxicity to aquatic life, causes ocean acidification, and can increase the costs of supplying drinking water.

The River and the Commission

The 80-year trends presented here implicate a myriad of environmental impacts to the Potomac River, many of which relate to population growth and unsustainable uses of the basin's land and water. Efforts to mitigate these impacts were begun after 1940. They include state and federally mandated upgrades to drinking water and wastewater treatment plants, bans on phosphate detergents, and reductions in coal-burning power plant emissions. A more holistic understanding is emerging of the entire hydrologic system and the landscape that supports it. Computer modeling is helping to identify the actions needed to ensure Potomac waters are drinkable, fishable, and swimmable. Only actual water quality measurements, however, can verify if those efforts are working as intended and how the river ecosystem as a whole is responding.

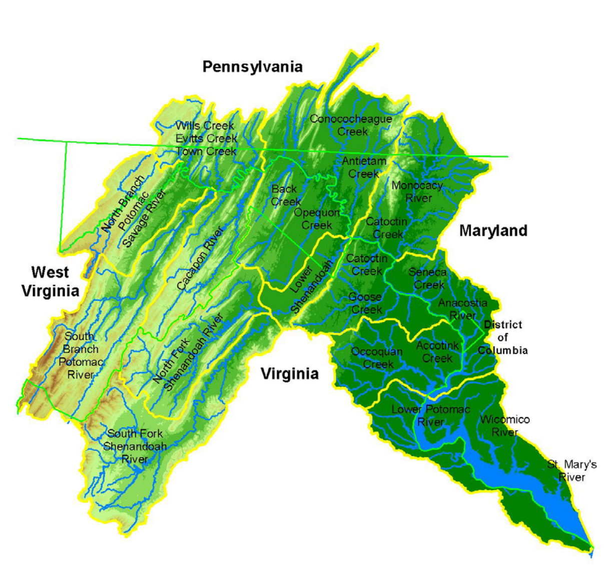
In this report, ICPRB briefly highlights the potential value of an older dataset and the historical perspective it provides. Extensive datasets like this one identify changes happening over several generations and not apparent in shorter-term records. Older records are at risk of being discarded or lost to deterioration because they are typically hardcopy.

The Washington Aqueduct records for some basic parameters span 115 years. Parameters measured in the 1970s, before digitization was common, include an array of metals, pesticides, herbicides, radioactive elements, and other compounds harmful to human health. ICPRB continued Jaworski's work with the belief that digitizing the Washington Aqueduct data could be valuable in studies of the river and its watershed as an ecological unit.

One of ICPRB's roles is "to collect, analyze, interpret, coordinate, tabulate, summarize and distribute technical and other data relative to…pollution and other water problems" in the Potomac River basin (1940 Compact).

What is ICPRB?

ICPRB, or the Interstate Commission on the Potomac River Basin, marked its 80th anniversary in 2020. It helps the basin states and the federal government enhance, protect, and conserve the water and associated land resources of the basin through regional and interstate cooperation. The ICPRB has no regulatory power and focuses efforts on scientific studies, public outreach, building consensus on water issues, and promoting comprehensive water resources planning.



ICPRB has fostered coordination among a growing number of federal, state, and regional organizations that work on discrete areas of the Potomac River basin. This has added value and perspective to the work of these agencies and provided a more complete view of the basin's water quality and solutions to basin-wide issues. ICPRB efforts can be seen in many cooperative studies, and recently in the development of a basin-wide Comprehensive Water Resources Plan. The plan reiterates the need for diverse, readily accessible data to develop and implement sustainable management strategies for the river and its watershed. Efforts to digitize the Washington Aqueduct dataset are not finished and will require further consultation with staff of Washington Aqueduct. ICPRB is hopeful the larger dataset can be completed and made available to future researchers with the caveat that some sampling and methodology details for the early years may never be known. When they are digitized and shared, the data stand a better chance of surviving and informing our understanding of water quality in the Potomac River.

FURTHER READING

Blomquist, J. D., G. T. Fisher, J. M. Denis, J. W. Brakebill, and W. H. Werkheiser. 1996. Water-quality assessment of the Potomac River Basin: basin description and analysis of available nutrient data, 1970-1990. US Geological Survey Water-Resources Investigations Report 95-4221. DOI: 10.3133/wri954221

Eshleman, K. N., and R. D. Sabo. 2016. Declining nitrate-N yields in the Upper Potomac River Basin: what is really driving progress under the Chesapeake Bay restoration? Atmospheric Environment 146:280-289. DOI: 10.1016/j.atmosenv.2016.07.004.

Kaushal, S. S., G. E. Likens, N. A. Jaworski, M. L. Pace, A. M. Sides, D. Seekell, K. T. Belt, D. H Secor, and R. L. Wingate. 2010. Rising stream and river temperatures in the United States. Frontiers in Ecology and the Environment 8(9):461-466. DOI: 10.1890/090037.

Kaushal, S. S., G. E. Likens, R. M. Utz, M. L. Pace, M. Grese, and M. Yepsen. 2013. Increased river alkalinization in the eastern U.S. Environmental Science and Technology 47(18):10302-10311. DOI: 10.1021/es401046s.

Lookingbill, T. R., S. S. Kaushal, A. J. Elmore, R. Gardner, K. N. Eshleman, R. H. Hilderbrand, R. P. Morgan, W. R. Boynton, M. A. Palmer, and W. C. Dennison. 2009. Altered ecological flows blur boundaries in urbanizing watersheds. Ecology and Society 14(2):10. http://www.ecologyandsociety.org/vol14/iss2/art10/.

Rice, K. C., and J. D. Jastram. 2015. Rising air and stream-water temperatures in Chesapeake Bay region, USA. Climate Change 128:127-138. DOI: 10.1007/s10584-014-1295-9.

Saenger, C., T. M. Cronin, D. Willard, J. Halka, and R. Kerhin. 2008. Increased terrestrial to ocean sediment and carbon fluxes in the northern Chesapeake Bay associated with twentieth century land alteration. Estuaries and Coasts 31:492-500. DOI:10.1007/s12237-008-9048-5.

Southworth, Scott, D. K. Brezinski, R. C. Orndorff, J. E. Repetski, and D. M. Denenny. Geology of the Chesapeake and Ohio Canal National Historical Park and Potomac River Corridor, District of Columbia, Maryland, West Virginia, and Virginia: U.S. Geological Survey Professional Paper 1691, 144 p., 1 pl. https://pubs.usgs.gov/pp/1691/.

Polsky, C., J. Allard, N. Currit, R. Crane, and B. Yarnal. 2000. The Mid-Atlantic region and its climate: past, present, and future. Climate Research 14:161-173. https://www.int-res.com/articles/cr/14/c014p161.pdf

REFERENCES

Ator, S. W., J. D. Blomquist, J. W. Brakebill, J. M. Denis, M. J. Ferrari, C. V. Miller, and H. Zappia. 1998. Water quality in the Potomac River Basin, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia, 1992 – 1996. USGS Circular 1166. Available at: https://pubs.usgs.gov/circ/circ1166/circ1166.pdf.

Buchanan, C. and G. M. Selckmann. 2019. The Influence of Jennings Randolph Lake Dam Operations on River Flow and Water Quality in North Branch Potomac River: A Technical Report Supporting Preparation of a Comprehensive Scoping Plan Considering an Update of the Jennings Randolph Lake Water Control Plan. ICPRB Report 19-4. Interstate Commission on the Potomac River Basin, Rockville, MD. Available at: www.potomacriver.org.

Chesapeake Bay Program (CBP). 2014. Chesapeake Bay Watershed Agreement. Available at: https://www.chesapeakebay.net/documents/FINAL_Ches_Bay_Watershed_Agreement.withsignatures-HIres.pdf

Clesceri, L. S., A. E. Greenburg, and A. D. Eaton. 1999. *Standard Methods for the Examination of Water and Wastewater*. 20th Ed. Washington, D.C.: American Public Health Association.

Jaworski, N. A., W. Romano, C. Buchanan, and C. L, Jaworski. 2007. The Potomac River Basin and its Estuary: Landscape Loadings and Water Quality Trends, 1895-2005. Available online: https://www.potomacriver.org/the-potomac-river-basin-and-its-estuary-landscape-loadings-and-water-quality-trends-1895-2005/

Jaworski, N. A., P. M. Groffman, A. A. Keller, and J. C. Prager. 1992. A watershed nitrogen and phosphorus balance: the upper Potomac River basin. Estuaries 15:83-95.

Patakamuri, S.K. and O'Brien, N. (2020). modifiedmk: Modified Versions of Mann Kendall and Spearman's Rho Trend Tests. R package version 1.5.0. Available at: https://CRAN.R-project.org/package=modifiedmk.

Pohlert, T. (2020). trend: Non-Parametric Trend Tests and Change-Point Detection. R package version 1.1.2. Available at: https://CRAN.R-project.org/package=trend.

Porter, A.J., J.S. Webber, J.W. Witt, and J.D. Jastram. 2020. Spatial and temporal patterns in streamflow, water chemistry, and aquatic macroinvertebrates of selected streams in Fairfax County, Virginia, 2007–18: USGS Scientific Investigations Report 2020–5061. 106 p. https://doi.org/10.3133/sir20205061.

Sprague, E., Burke, D., Claggett, S., & Todd, A. (eds.) (2006). The State of Chesapeake Forests. The Conservation Fund, Arlington, VA. Available at: https://www.conservationfund.org/.

R Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/.

Virginia Department of Environmental Quality (DEQ). 2021. Virginia Salt Management Strategy (SaMS): A toolkit to reduce the environmental impacts of winter maintenance practices. https://www.novaregion.org/1498/SaMS-Toolkit

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. ISBN 978-3-319-24277-4. Available at: https://ggplot2.tidyverse.org.

Zeileis A. and Hothorn, T. (2002). Diagnostic Checking in Regression Relationships. R News, 2(3), 7–10. Available at: https://CRAN.R-project.org/doc/Rnews/.

ENDNOTES

1 https://www.researchgate.net/scientific-contributions/Norbert-A-Jaworski-20800785

2 US EPA National Primary Drinking Water Regulations

3 Jaworski reviewed available information and determined the basin population was approximately 1.385 million in 1900. Using U. S. census data, ICPRB calculated the 2010 basin population to be 6.11 million.

4 Washington Aqueduct intermittently recorded dissolved solid concentrations starting in 1922. A continuous record starts in 1999.

Editorial Design: DeeDee Hunter