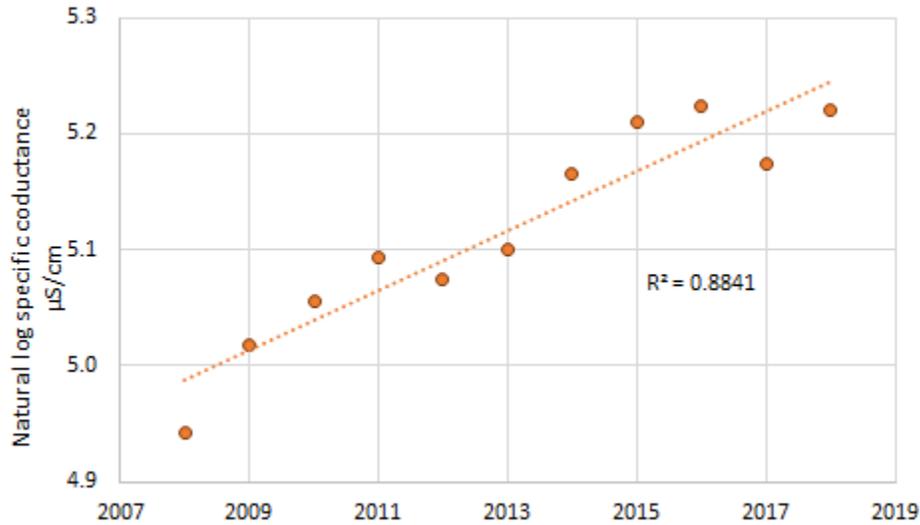


Regional long-term trends in specific conductance



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Northern Virginia Salt Management Strategy

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Cover Figure

Increasing trend in background summer specific conductance for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna). The figure is also provided in the report as Figure 44.

Disclaimer

The opinions expressed in this report are those of the authors and should not be construed as representing the opinions or policies of the United States government or the signatories or Commissioners to ICPRB.

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DRAFT

Introduction

The need to evaluate long-term patterns in specific conductance was identified at the second SaMS Water Quality Monitoring and Research Workgroup meeting, held on February 14, 2019. In response to this request, USGS gage data were downloaded for non-tidal, non-Potomac USGS sites in the region with sufficient periods of record. The following evaluations were conducted:

- [Long-term trends in specific conductance](#);
- [Trends in the magnitude of storm-specific spikes](#) in specific conductance and [how magnitude of spikes in specific conductance relate to precipitation](#);
- [Trends in the duration of storm-specific spikes](#) in specific conductance and [how duration of spikes in specific conductance relate to precipitation](#); and
- [Trends in background summer specific conductance](#).

The sections below describe the data, methods, and results for each of these analyses. Throughout the analyses, “winter” is defined as November 1st through April 30th and “summer” includes the rest of the year (May 1st through October 31st).

Monitoring stations and data

Daily specific conductance data were downloaded on May 15, 2019 from the [USGS Surface-Water Daily Data for Virginia website](#) as minimum, maximum, mean, median values. Instantaneous (15 minute) specific conductance data were obtained on May 16, 2019 from the [USGS Instantaneous Values REST Web Service URL Generation Tool](#) in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

The USGS website was queried for data of non-Potomac USGS sites in Arlington, Fairfax, Loudon, and Prince William counties and the cities of Alexandria, Fairfax, Falls Church, Manassas, and Manassas Park. Eight stations in the specified geographic area were identified with specific conductance measurements (Table 1). Of those, four stood out with sufficient data for inclusion in this analysis, defined as having an unbroken record that started before 2010 and remains in operation.

Table 1. USGS stations measuring specific conductance in the geographic area of interest. Selected gages are shown in **bold text**.

USGS Gage	Location	Sampling	
		Start Date	End Date
01645704	Difficult Run Above Fox Lake Near Fairfax	10/1/2007	4/30/2019
01645762	S F Little Difficult Run Above Mouth Near Vienna	10/1/2007	4/29/2019
01646305	Dead Run at Whann Avenue Near Mclean	11/30/2007	4/30/2019
01656903	Flatlick Branch Above Frog Branch at Chantilly	10/1/2007	4/29/2019
01646000	Difficult Run Near Great Falls	10/2/2007	4/30/2019*
0165389205	Accotink Creek Near Ranger Road at Fairfax	11/19/2011	1/8/2015
01654000	Accotink Creek Near Annandale	2/15/2015	4/28/2019
01654500	Long Branch Near Annandale	2/8/2013	4/28/2019

*No data 2009-2011.

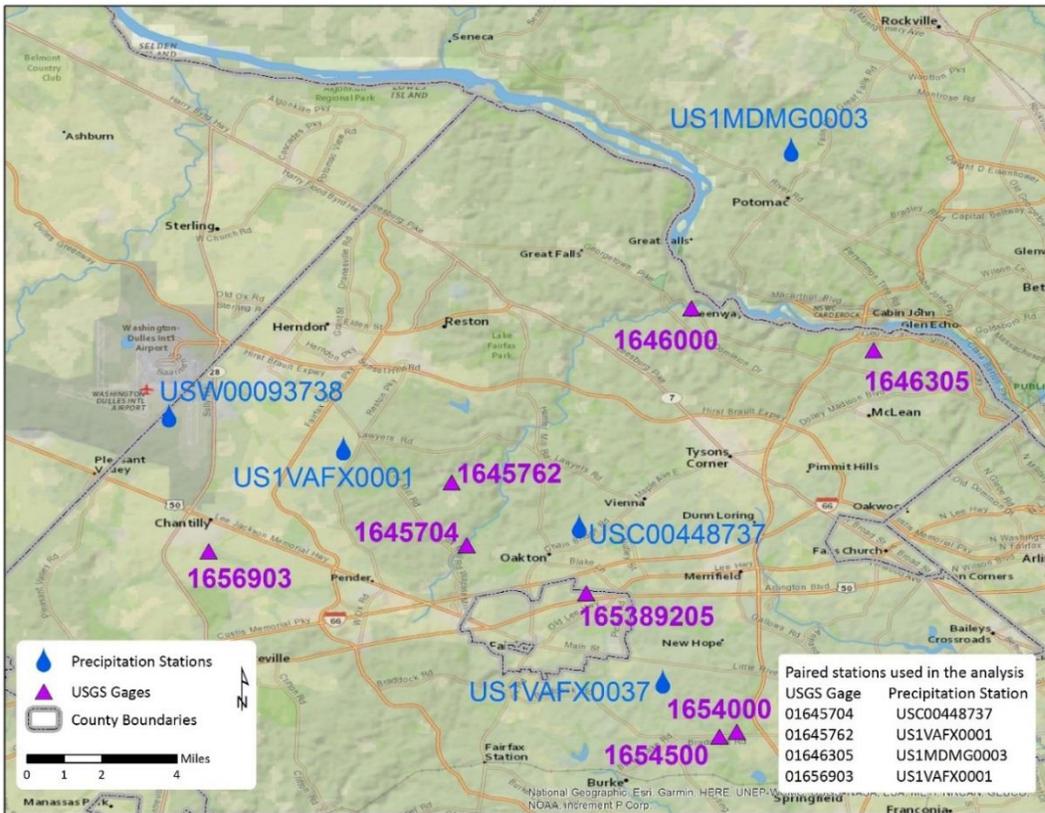
The selected USGS specific conductance monitoring stations were paired with a neighboring precipitation station for further analysis. Daily precipitation data were obtained from [NOAA's Climate Data Online: Dataset Discovery website](#). The list of paired stations is provided in Table 2.

Table 2. Paired USGS gages and NOAA precipitation monitoring stations.

USGS Gage	Precipitation Station
01645704	USC00448737
01645762	US1VAFX0001
01646305	US1MDMG0003
01656903	US1VAFX0001

The locations of USGS specific conductance monitoring stations and nearby precipitation stations are shown in Figure 1.

Figure 1. Locations of USGS specific conductance monitoring stations and NOAA precipitation monitoring stations.



Specific conductance data summary

Summary statistics for the specific conductance data collected at the four USGS gages are provided in Table 3. Seasonal statistics for the same gages are provided in Table 4.

Table 3. Summary statistics for 15-minute specific conductance data collected at selected USGS gages.

USGS Gage	Count	Min	1st Quantile	Median	Mean	3rd Quantile	Max	Std Dev	10th %ile	90th %ile
01645704	390,394	34	299	370	487	479	8,620	456.47	227	830
01645762	382,109	23	153	167	175	187	1,620	55.40	138	200
01646305	388,243	34	248	294	379	349	13,400	486.14	184	488
01656903	390,218	36	366	433	480	517	7,260	266.37	295	643

Table 4. Seasonal summary statistics for 15-minute specific conductance data collected at selected USGS gages.

USGS Gage	Season	Count	Min	1st Quantile	Median	Mean	3rd Quantile	Max	Std Dev	10th %ile	90th %ile
01645704	Summer	189,595	34	264	332	326	385	681	93.97	199	442
	Winter	200,799	80	340	441	638	722	8,620	591.08	273	1150
01645762	Summer	180,457	23	148	164	161	180	381	25.98	130	191
	Winter	201,652	29	158	172	187	193	1,620	70.02	146	222
01646305	Summer	188,356	34	217	270	258	303	1,390	71.86	158	335
	Winter	199,887	42	282	331	492	425	13,400	653.92	230	778
01656903	Summer	191,354	36	344	408	401	471	795	95.44	266	516
	Winter	198,864	87	388	466	556	603	7,260	344.33	330	864

Mean and maximum monthly specific conductance, calculated based on the 15-minute data, are shown by USGS gage in Figure 2 and Figure 3, respectively. Box plots showing the distribution of 15-minute data by month are shown in Figure 4, Figure 5, Figure 6, and Figure 7. The same data are shown by season in Figure 8, Figure 9, Figure 10, and Figure 11. Increases in specific conductance during winter months are visible in these figures.

Figure 2. Mean monthly specific conductance by gage. Mean specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$.

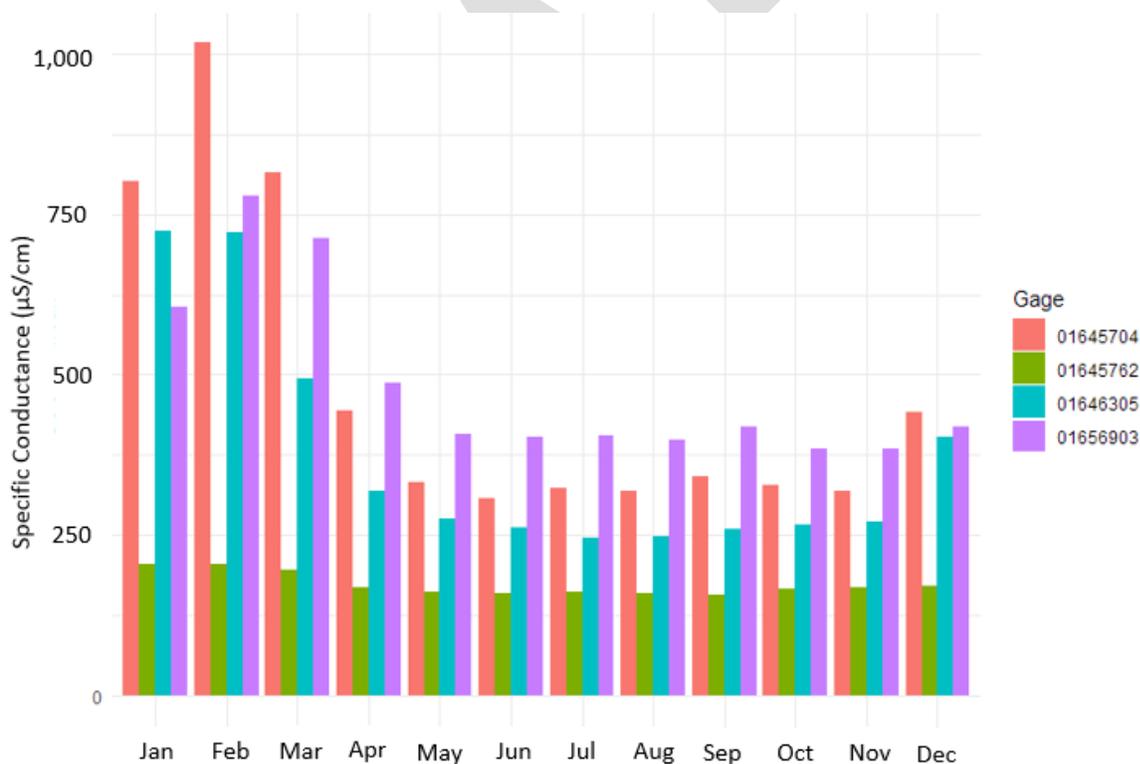


Figure 3. Maximum monthly specific conductance by USGS gage. Maximum specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$.

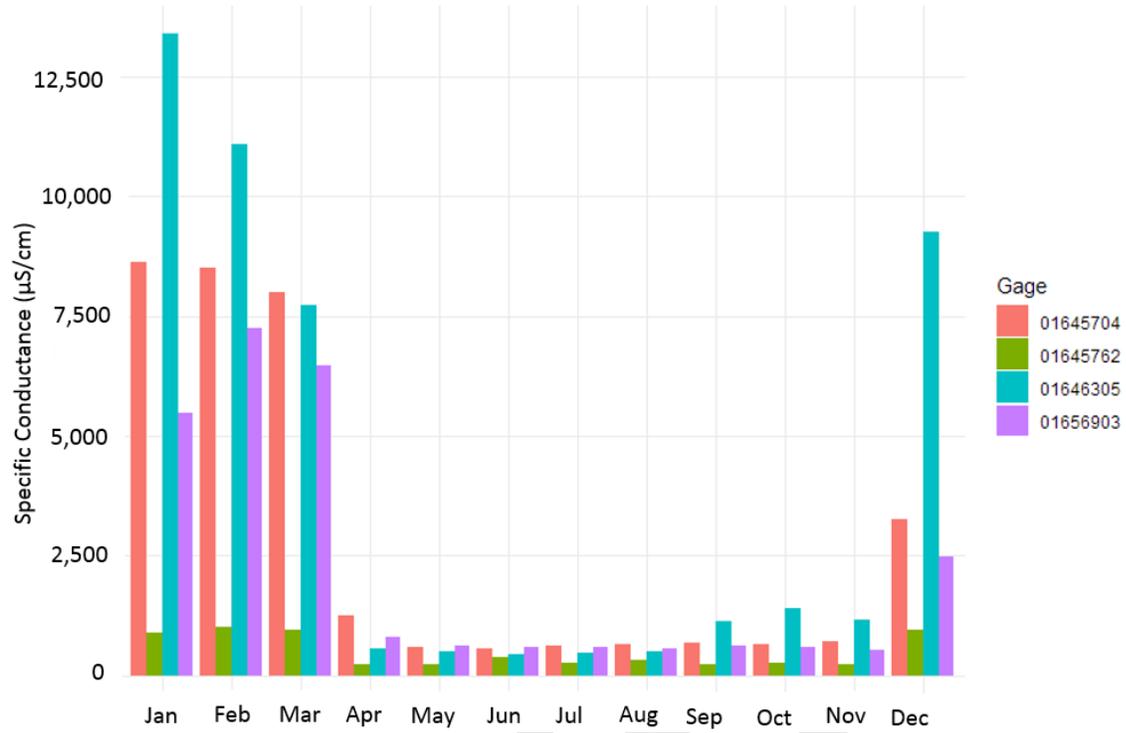


Figure 4. Box plots of 15-minute data by month for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$.

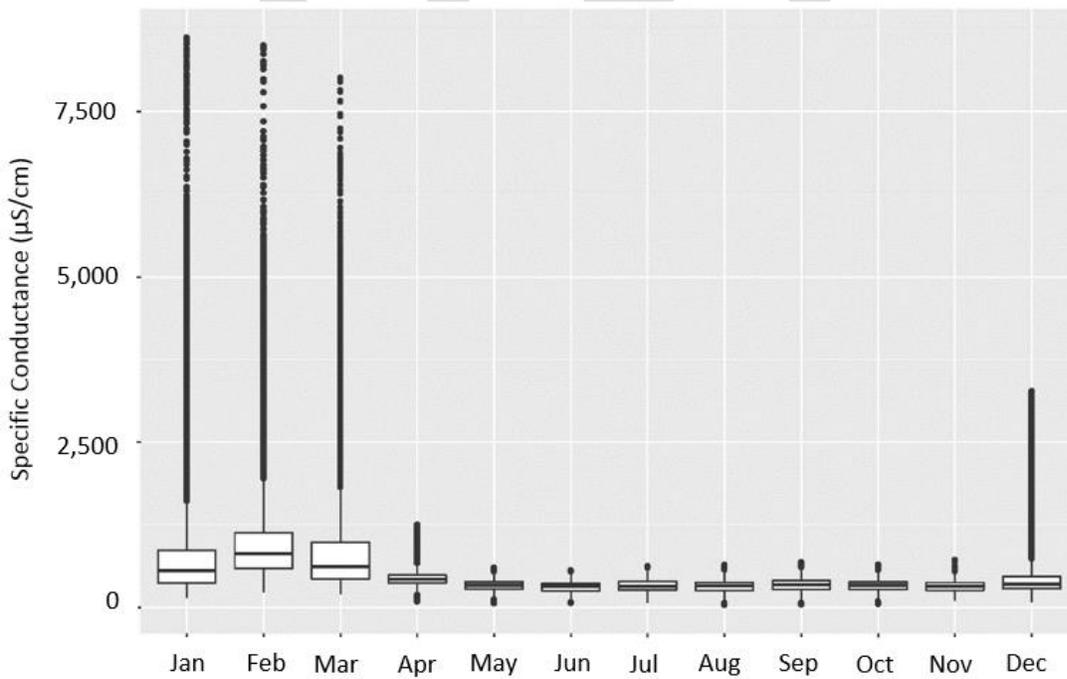


Figure 5. Box plots of 15-minute data by month for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$.

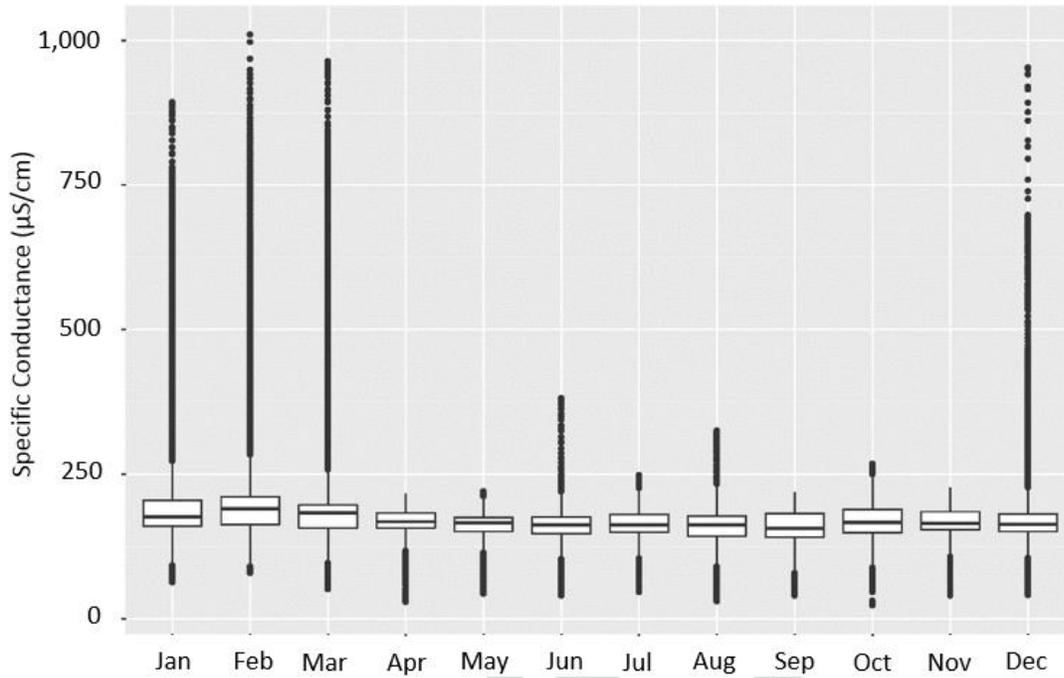
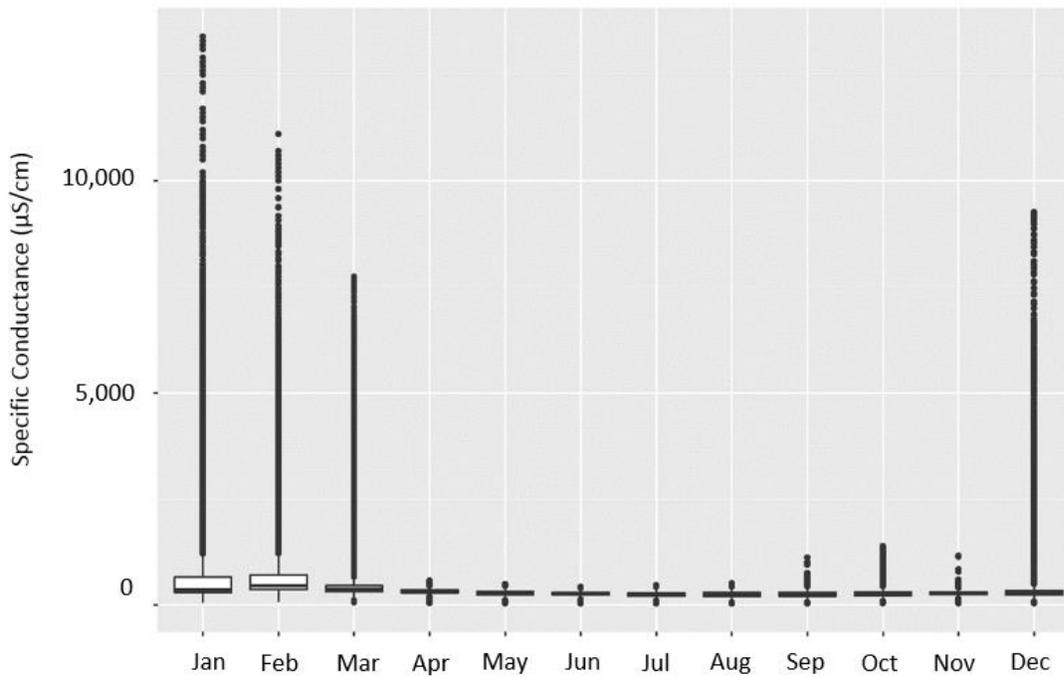


Figure 6. Box plots of 15-minute data by month for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$.



11/5/2019

Figure 7. Box plots of 15-minute data by month for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$.

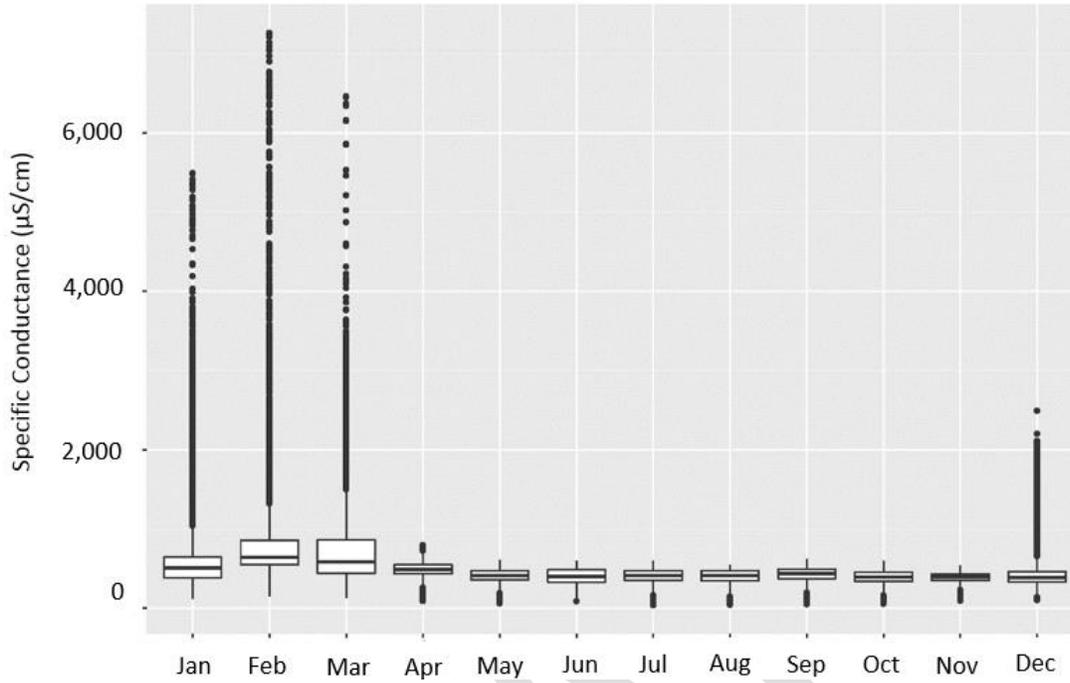


Figure 8. Box plots of 15-minute data by season for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$. The winter season is defined as November 1st through April 30th. The summer season is defined as May 1st through October 31st.

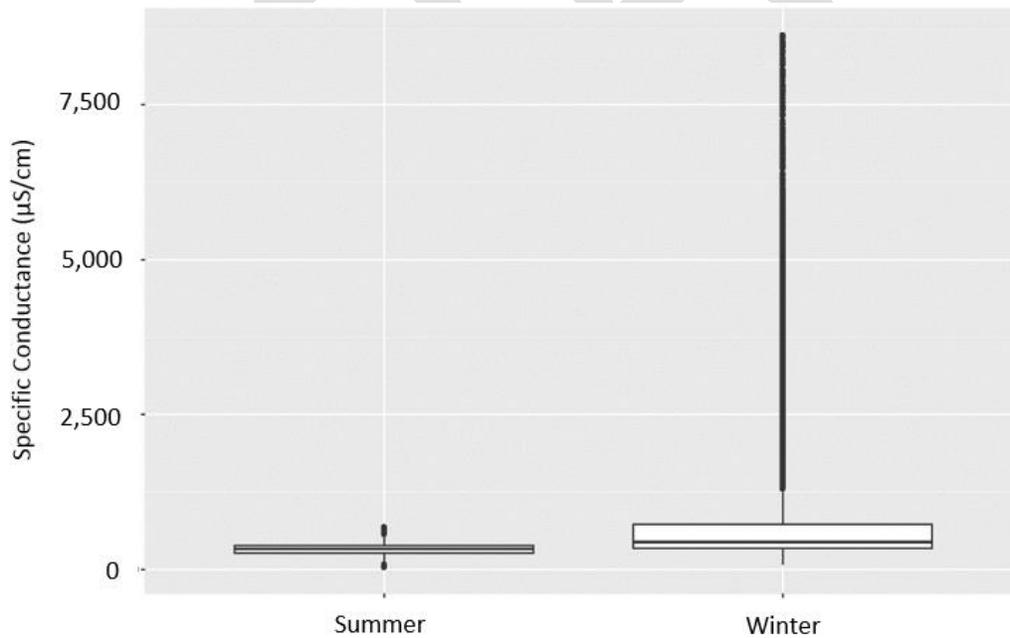


Figure 9. Box plots of 15-minute data by season for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$. The winter season is defined as November 1st through April 30th. The summer season is defined as May 1st through October 31st.

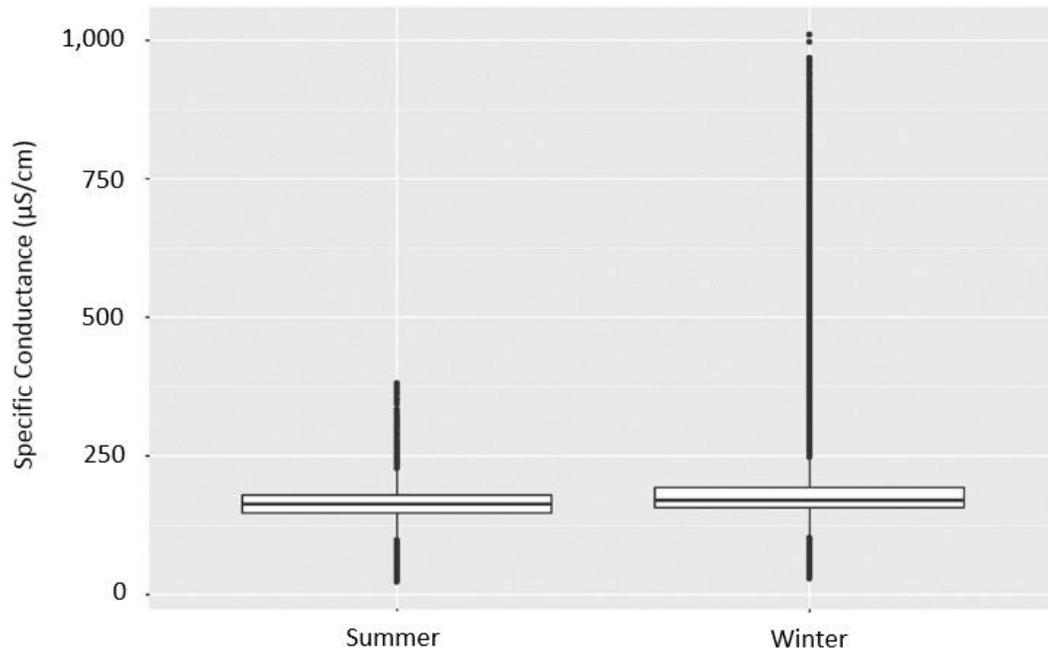


Figure 10. Box plots of 15-minute data by season for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$. The winter season is defined as November 1st through April 30th. The summer season is defined as May 1st through October 31st.

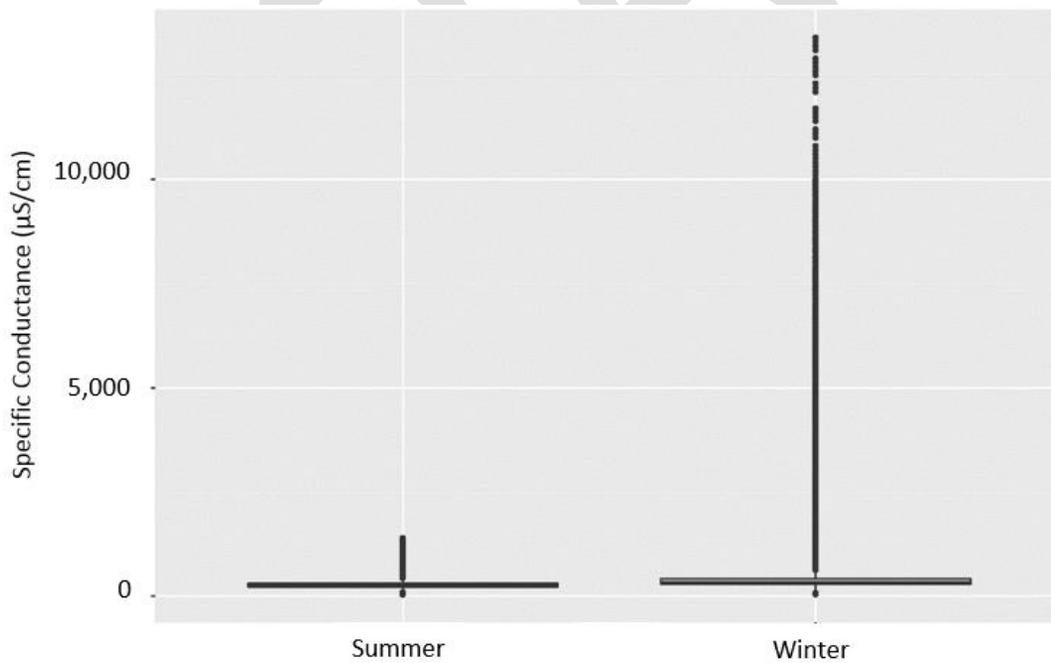
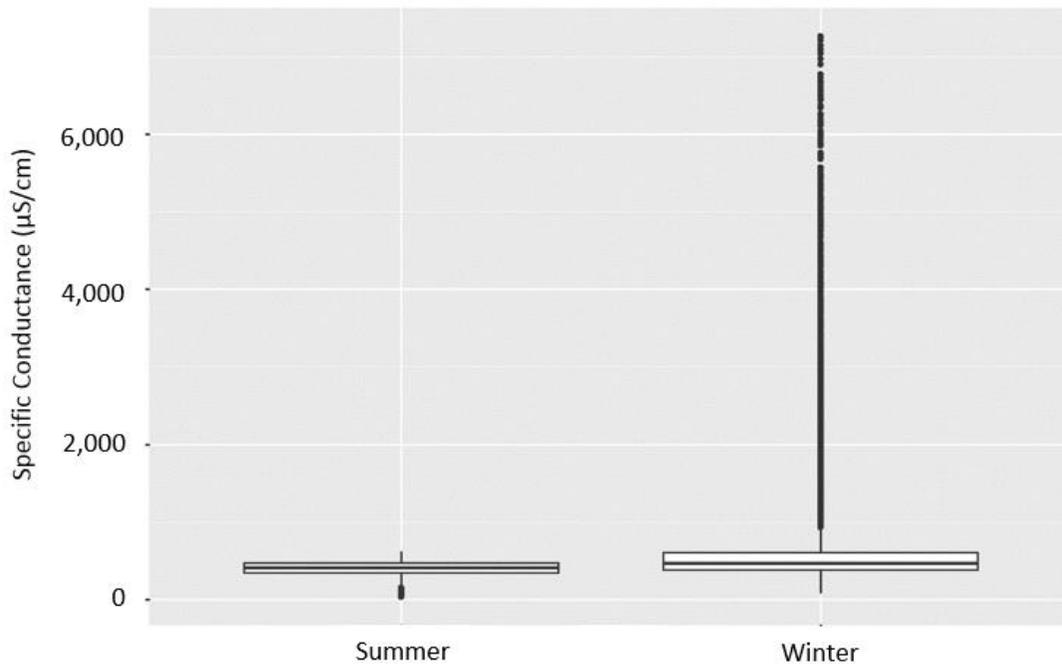


Figure 11. Box plots of 15-minute data by season for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly). Specific conductance values (y-axis) are in units of $\mu\text{S}/\text{cm}$. The winter season is defined as November 1st through April 30th. The summer season is defined as May 1st through October 31st.



Precipitation data summary

Average monthly total precipitation was calculated for the three selected precipitation stations as a way of summarizing the data (Figure 12). Average monthly snowfall totals were also calculated (Figure 13).

Figure 12. Average monthly total precipitation for selected NOAA stations (2007-2019).

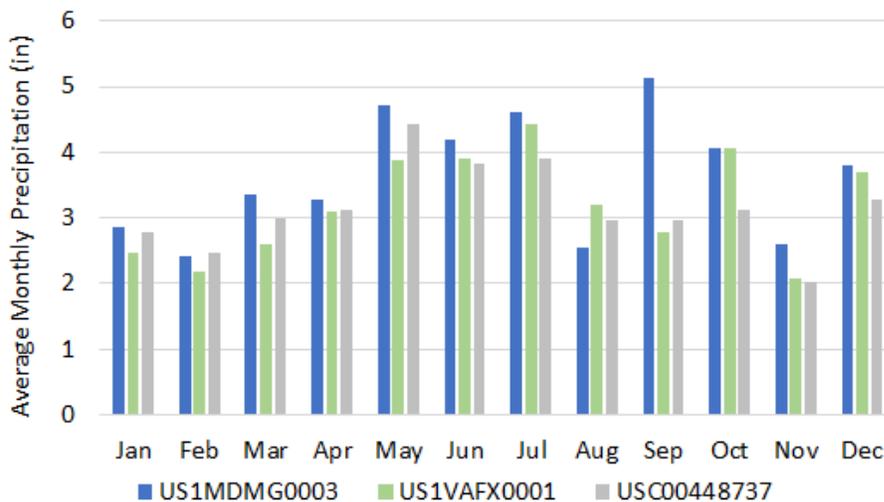
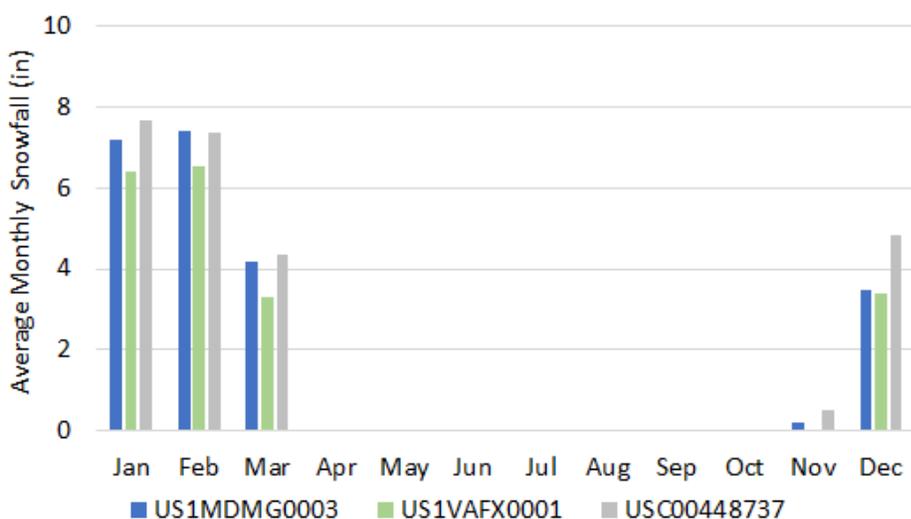


Figure 13. Average monthly total snowfall for selected NOAA stations (2007-2019).



A summary of snowfall totals and number of days for each year (2008-2019) is provided in Table 5. The largest snowfall totals occurred in 2010 for all three stations.

Table 5. Snowfall summary by year for selected NOAA stations (2008-2019). For the purpose of this table, summary information is provided for winter end year. For example, summary information for the year 2008 represents the winter of 2007-2008.

Year	US1MDMG0003 Snowfall		US1VAFX0001 Snowfall		USC00448737 Snowfall		Average Snowfall	
	Days (#)	Total (in)	Days (#)	Total (in)	Days (#)	Total (in)	Days (#)	Total (in)
2008	5	8.8	4	8.3	3	7.1	4.0	8.1
2009	8	10.1	8	9.2	7	11.6	7.7	10.3
2010	12	86.2	13	80.3	13	74.2	12.7	80.2
2011	13	14	10	5.2	13	14.4	12.0	11.2
2012	7	2.6	6	1.2	3	1.7	5.3	1.8
2013	12	10.1	11	7.5	9	10	10.7	9.2
2014	13	34.5	22	44.8	17	44.4	17.3	41.2
2015	16	32.1	22	18.7	17	27.9	18.3	26.2
2016	11	34.9	18	34	8	41.2	12.3	36.7
2017	5	5.1	5	3.4	5	5.3	5.0	4.6
2018	10	11.5	15	5.3	10	10.9	11.7	9.2
2019	12	25.3	18	19.4	13	24.4	14.3	23.0

Long-term trends in specific conductance

Methodology

Long-term trends in 15-minute, median monthly, and median annual specific conductance at the four USGS gages were evaluated by statistical regression and visual evaluation (Figure 14 through Figure 25). Statistically, the 15-minute specific conductance data were modeled as a function of time using R's linear model function (lm()). The linear model function is calculated using an internal time step of seconds. The median monthly and median annual specific conductance data were modeled using Regression analysis in Excel. The time step for the Regression analysis was months and years,

respectively. The regression results were used to determine the statistical significance of the trends in specific conductance from 2007 to 2019. Visual evaluation was used to look at the data in graphical form, confirm results of the regression analysis, and inspect the data for anomalies or other notable features.

Results

15-Minute

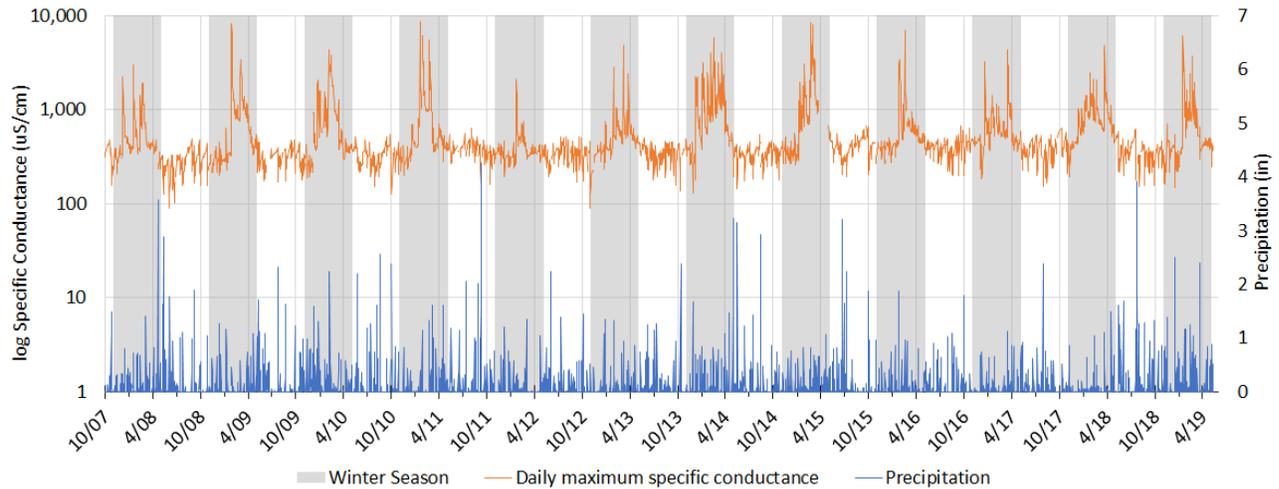
Long-term trends in 15-minute specific conductance show statistically significant increases at the four USGS gages (Table 6). The magnitude of the change in specific conductance at these gages ranges from approximately 16 to 117 $\mu\text{S}/\text{cm}$ over the period of record noted in Table 1 and Table 6. More detailed information for each USGS gage is provided below.

Table 6. Regression summary statistics by gage for trends in 15-minute specific conductance data over the period of record.

Gage	p-value	R ²	Equation	Magnitude of Change over period of record ($\mu\text{S}/\text{cm}$)	Average Annual Increase ($\mu\text{S}/\text{cm}$)	Start Date	End Date
01645704	<0.0001	0.0056	$y=45.8+0.000000321x$	117.32	10.13	10/1/2007	4/30/2019
01645762	<0.0001	0.041	$y=28.4+0.00000011x$	40.18	3.47	10/1/2007	4/29/2019
01646305	<0.0001	0.00009	$y=318+0.000000044x$	15.85	1.39	11/30/2007	4/30/2019
01656903	<0.0001	0.003	$y=29.4+0.00000014x$	51.14	4.42	10/1/2007	4/29/2019

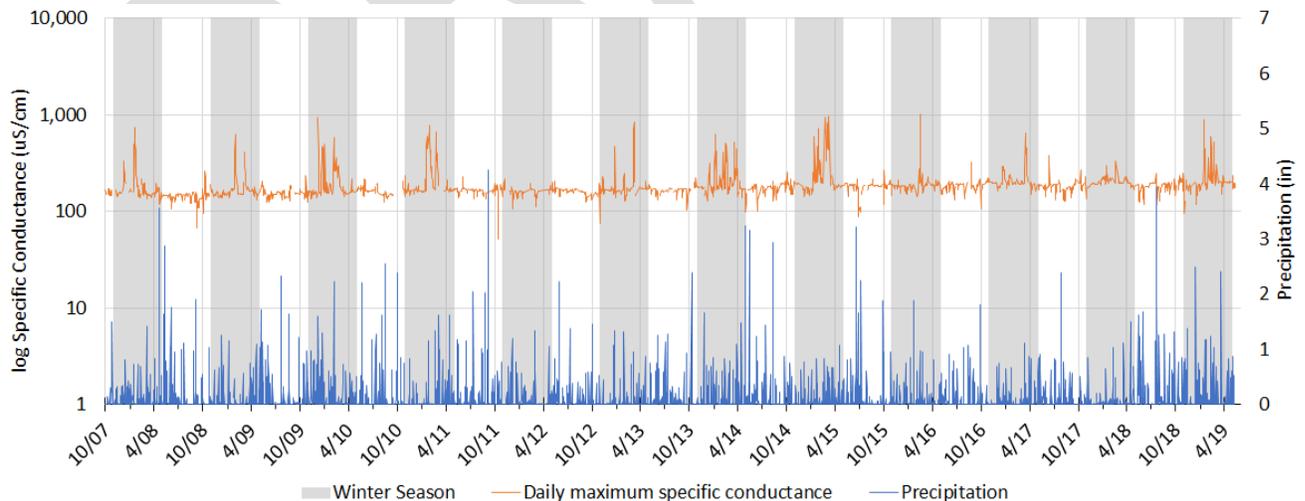
For USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax), there is a considerable, statistically significant, increasing trend in specific conductance since 2007 (based on 15-minute data, $y=45.8+0.000000321x$, $R^2=0.0056$, $p\text{-value}<0.0001$). Over this time period, the magnitude of change in specific conductance is approximately 117 $\mu\text{S}/\text{cm}$. This statistically significant relationship exists despite the many other factors that influence 15-minute fluctuations in specific conductance than simply long-term changes (e.g. land use, percent impervious cover, intensity and duration of precipitation, and rate and timing of winter de-icing material applications). The plot of daily maximum specific conductance and daily precipitation data for the gage is shown in Figure 14. The y-axis for the figure is log transformed for visual convenience; however, the data in the regression analysis of the 15-minute data were not transformed.

Figure 14. Long-term plot of daily maximum specific conductance and daily total precipitation for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax). Winter seasons, November 1st through April 30th, are shaded in gray. The y-axis is log transformed for ease of viewing.



For USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna), there is again an appreciable, statistically significant, increasing trend in specific conductance since 2007 (based on 15-minute data, $y=28.4+0.00000011x$, $R^2=0.041$, $p\text{-value}<0.0001$). Over this time period, the magnitude of change in specific conductance is approximately 40 $\mu\text{S}/\text{cm}$. The plot of daily maximum specific conductance and daily precipitation data for the gage is shown in Figure 15. The y-axis for the figure is log transformed for visual convenience; however, the data in the regression analysis of the 15-minute data were not transformed.

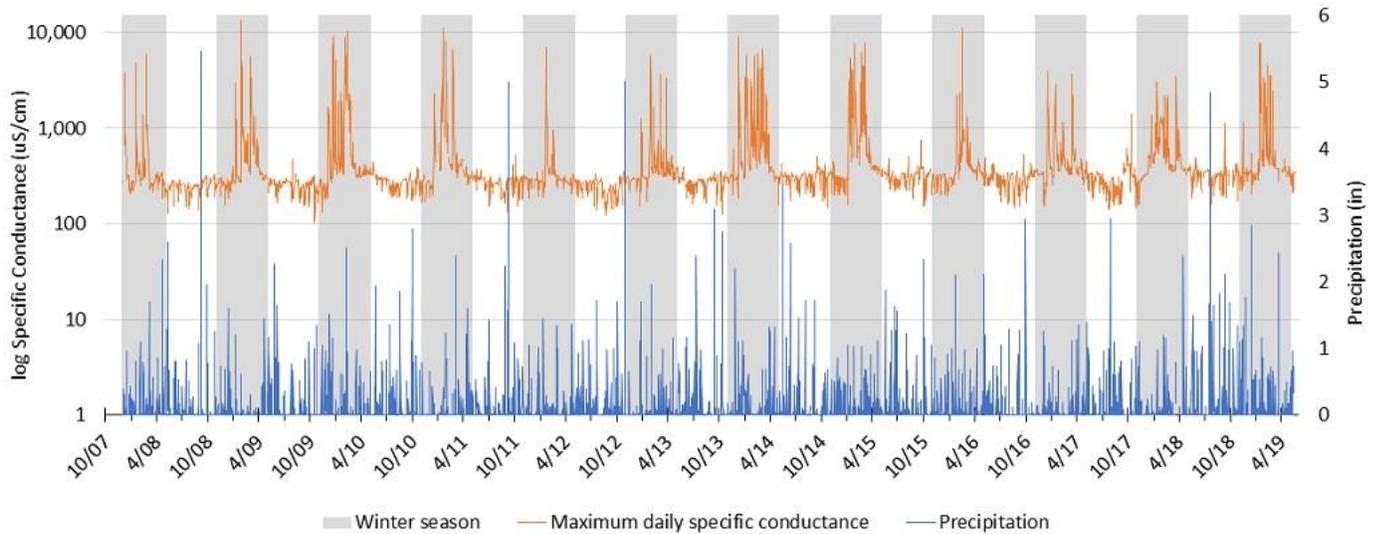
Figure 15. Long-term plot of daily maximum specific conductance and daily total precipitation for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna). Winter seasons, November 1st through April 30th, are shaded in gray. The y-axis is log transformed for ease of viewing.



There is a statistically significant, increasing trend in specific conductance since 2007 for USGS gage 01646305, Dead Run at Whann Avenue Near Mclean, (based on 15-minute data, $y=318+0.000000044x$, $R^2=0.0000895$, $p\text{-value}<0.0001$). The magnitude of change in specific conductance at this gage is approximately 16 $\mu\text{S}/\text{cm}$ over the period of record. The plot of daily maximum specific conductance and

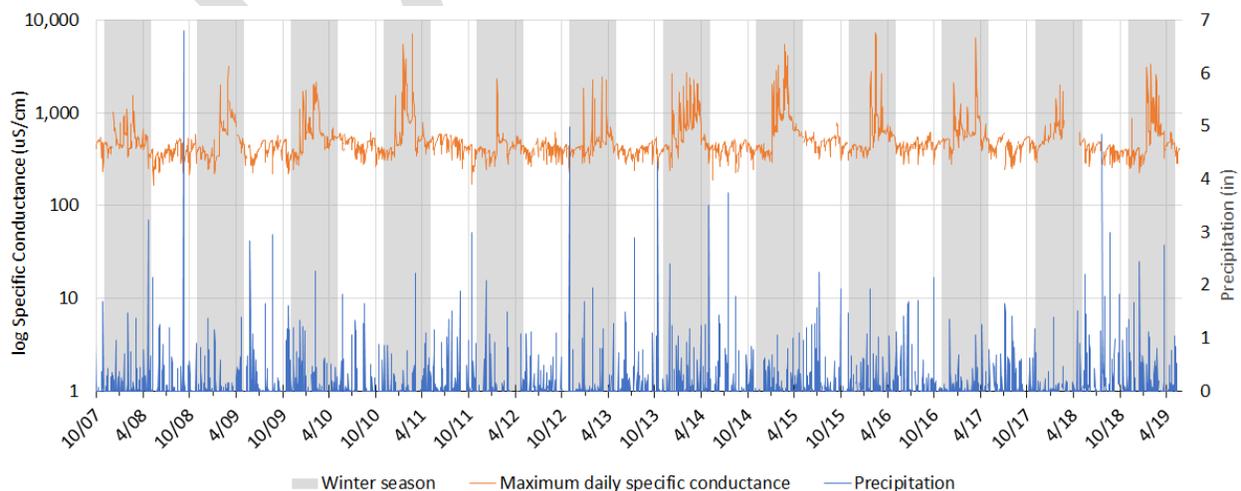
daily precipitation data for the gage is shown in Figure 16. The y-axis for the figure is log transformed for visual convenience; however, the data in the regression analysis of the 15-minute data were not transformed.

Figure 16. Long-term plot of daily maximum specific conductance and daily total precipitation for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean). Winter seasons, November 1st through April 30th, are shaded in gray. The y-axis is log transformed for ease of viewing.



For USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly), there is a considerable, statistically significant, increasing trend in specific conductance since 2007 (based on 15-minute data, $y=29.4+0.00000014x$, $R^2=0.003$, $p\text{-value}<0.0001$). The magnitude of change in specific conductance at this gage is approximately 51 $\mu\text{S}/\text{cm}$ over the period of record. The plot of daily maximum specific conductance and daily precipitation data for the gage is shown in Figure 17. The y-axis for the figure is log transformed for visual convenience; however, the data in the regression analysis of the 15-minute data were not transformed.

Figure 17. Long-term plot of daily maximum specific conductance and daily total precipitation for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly). Winter seasons, November 1st through April 30th, are shaded in gray. The y-axis is log transformed for ease of viewing.



Median Monthly

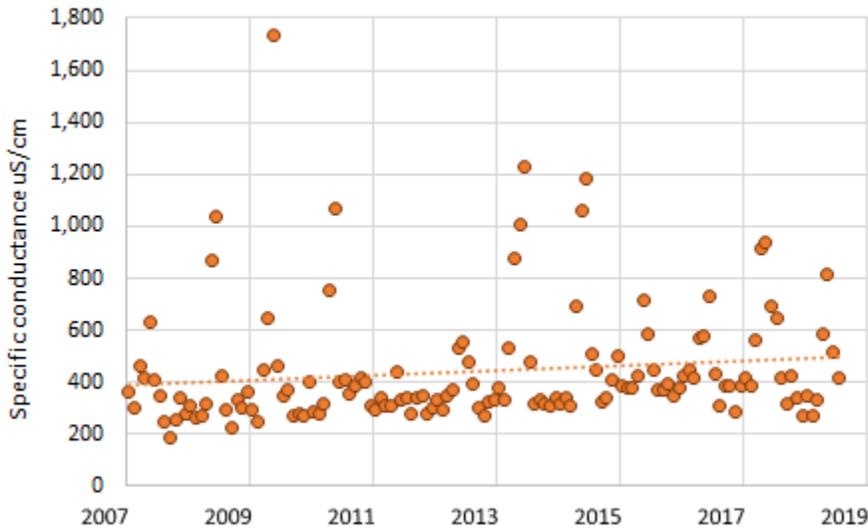
Long-term trends in median monthly specific conductance show statistically significant increases at one of the four USGS gages (Table 7). The three gages with large ranges in specific conductance (Table 3) do not have statistically significant increases. More detailed information for each USGS gage is provided below.

Table 7. Summary statistics for median monthly trends in specific conductance by USGS gage. A p-value above 0.1 is considered not significant, “ns”, for the purposes of this table. Numeric p-values are provided for all relationships in the detailed explanations in the respective results sections.

Gage	p-value	R ²	Equation
01645704	ns	0.0179	$y=0.7613x+392.2862$
01645762	<0.0001	0.4781	$y=0.3276x+148.99$
01646305	ns	0.0087	$y=0.345x+308.1754$
01656903	ns	0.0105	$y=0.3417x+445.6737$

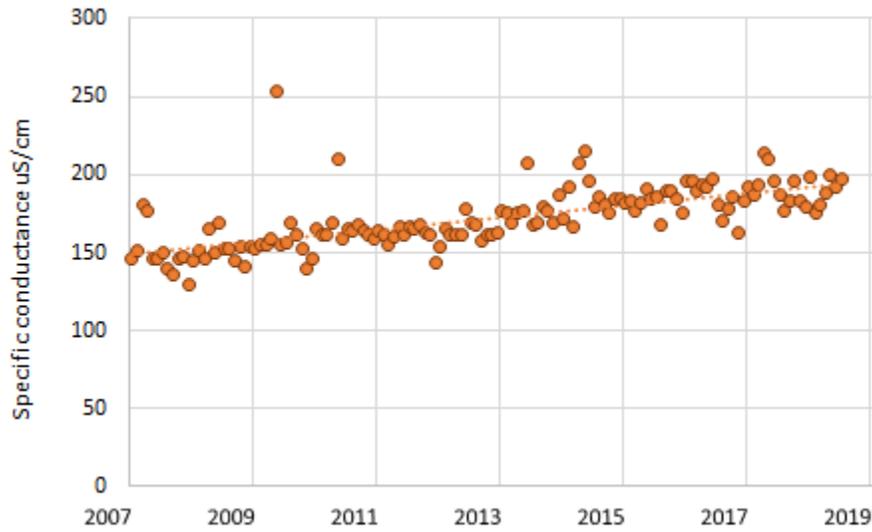
For USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax), there is a visually evident increasing trend since 2007 (Figure 18); however, the trend is not statistically significant (based on median monthly data, $y=0.7613x+392.2862$, $R^2=0.0179$, $p\text{-value}>0.1$).

Figure 18. Long-term plot of median monthly specific conductance for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax).



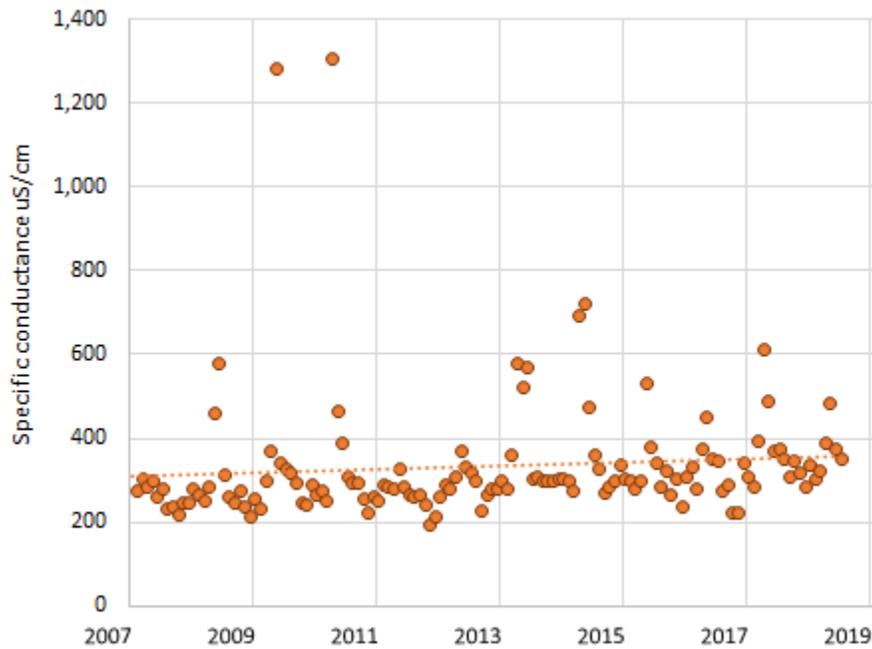
For USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna), there is a statistically significant, increasing trend in median monthly specific conductance since 2007 (Figure 19) (based on median monthly data, $y=0.3276x+148.99$, $R^2=0.4781$, $p\text{-value}<0.0001$).

Figure 19. Long-term plot of median monthly specific conductance for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna).



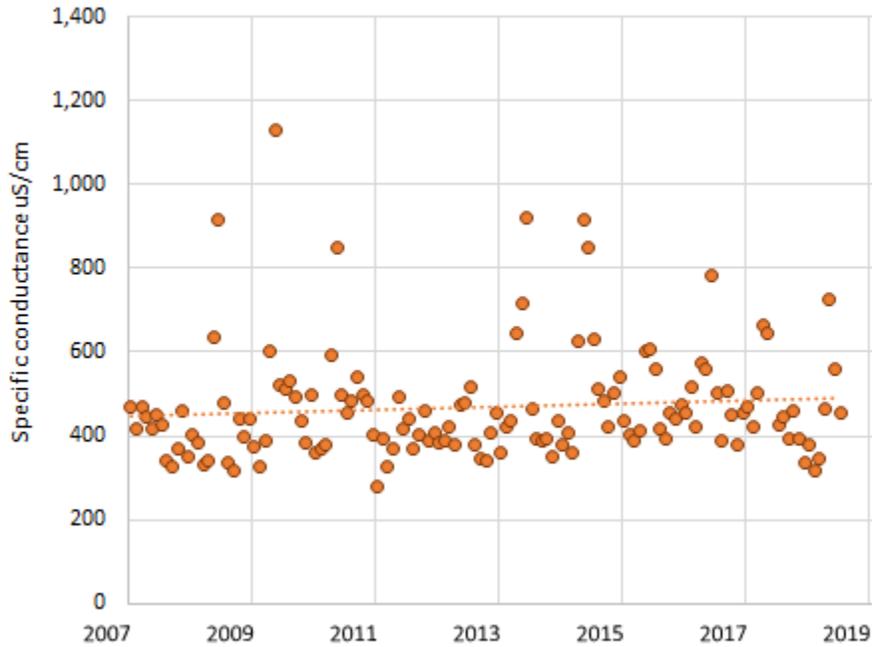
There is a visually evident increasing trend since 2007 for USGS gage 01646305, Dead Run at Whann Avenue Near Mclean (Figure 22); however, the trend is not statistically significant (based on median monthly data, $y=0.345x+308.1754$, $R^2=0.0087$, $p\text{-value}>0.1$).

Figure 20. Long-term plot of median monthly specific conductance for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean).



For USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly), there is a visually evident increasing trend since 2007 (Figure 23); however, the trend is not statistically significant (based on median monthly data, $y=0.3417x+445.6737$, $R^2=0.0105$, $p\text{-value}>0.1$).

Figure 21. Long-term plot of median monthly specific conductance for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly).



Median Annual

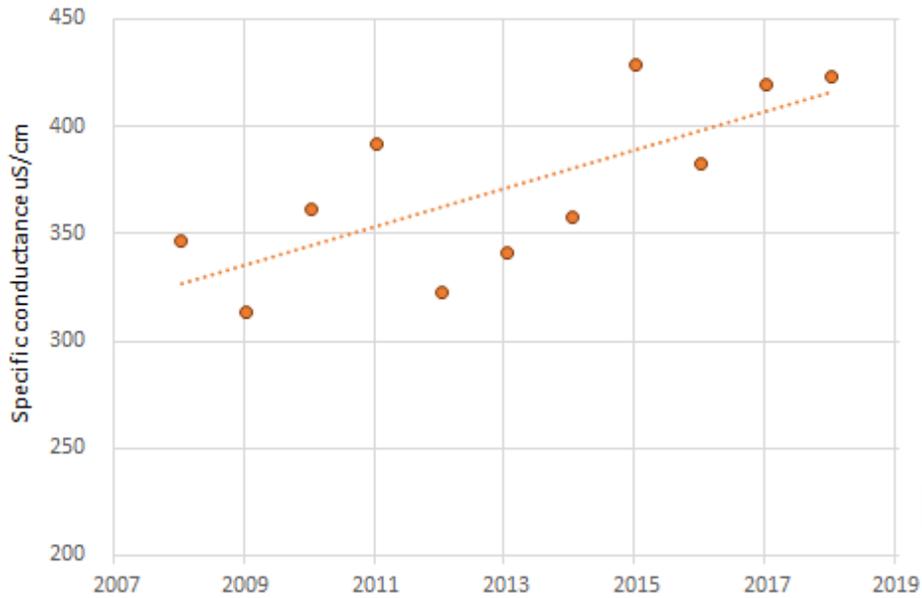
Long-term trends in median annual specific conductance values show statistically significant increases at three of the four USGS gages (Table 8). More detailed information for each USGS gage is provided below.

Table 8. Summary statistics for median annual trends in specific conductance by USGS gage. A p-value above 0.1 is considered not significant, “ns”, for the purposes of this table. Numeric p-values are provided for all relationships in the detailed explanations in the respective results sections.

Gage	p-value	R ²	Equation
01645704	0.01	0.5303	$y=8.9011x+318.1841$
01645762	<0.0001	0.9500	$y=4.5591x+141.9409$
01646305	<0.001	0.7380	$y=6.8532+253.7273$
01656903	ns	0.0649	$y=3.0875+426.4636$

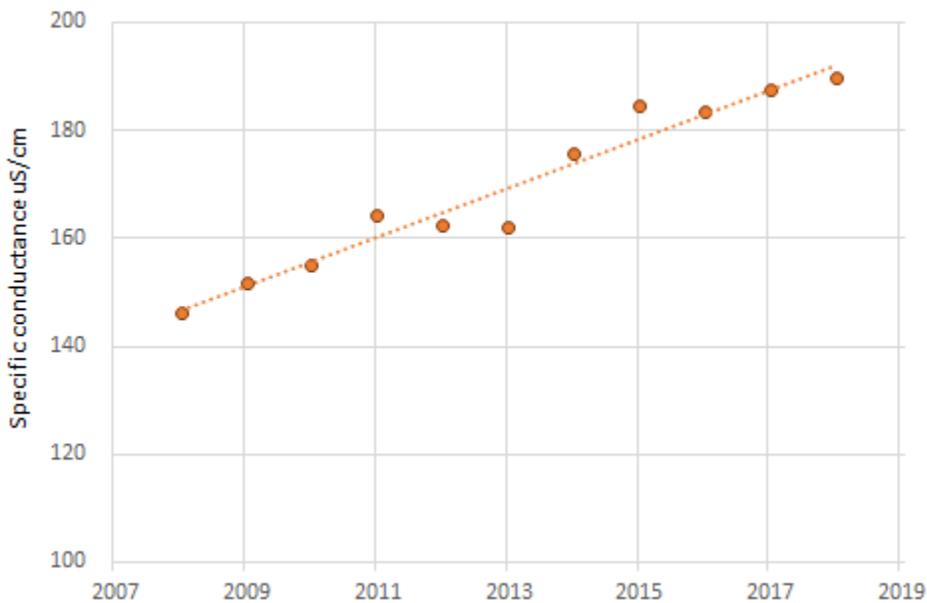
For USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax), there is a statistically significant, increasing trend in median annual specific conductance since 2007 (Figure 22) (based on median annual data, $y=8.9011x+318.1841$, $R^2=0.5303$, $p\text{-value}=0.01$).

Figure 22. Long-term plot of median annual specific conductance for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax).



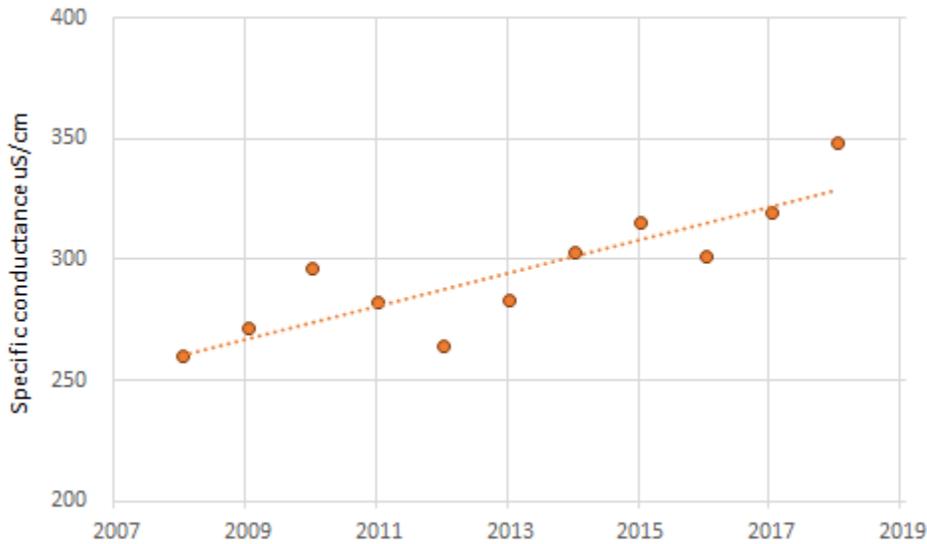
For USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna), there is a statistically significant, increasing trend in median annual specific conductance since 2007 (Figure 23) (based on median annual data, $y=4.5591x+141.9409$, $R^2=0.95$, $p\text{-value}<0.0001$).

Figure 23. Long-term plot of median annual specific conductance for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna).



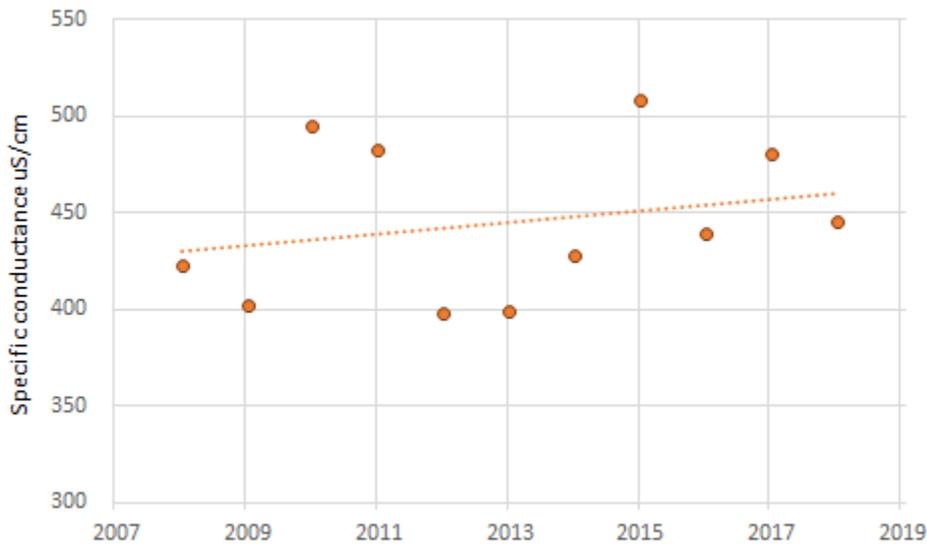
For USGS gage 01646305, Dead Run at Whann Avenue Near Mclean, there is a statistically significant, increasing trend in median annual specific conductance since 2007 (Figure 24) (based on median annual data, $y=6.8532x+253.7273$, $R^2=0.7380$, $p\text{-value}<0.001$).

Figure 24. Long-term plot of median annual specific conductance for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean).



For USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly), there is a visually evident increasing trend since 2007 (Figure 25); however, the trend is not statistically significant (based on median annual data, $y=3.0875x+426.4636$, $R^2=0.0649$, $p\text{-value}>0.1$).

Figure 25. Long-term plot of median annual specific conductance for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly).



Trends in storm-specific spikes

Methodology

Winter¹ spikes in daily and 15-minute specific conductance were identified for the 2007-2019 period for the four selected USGS gages. To identify spikes, the “BaseflowSeparation” function in the R-Package EcoHydRology (Fuka et al. 2018) was used. Traditionally, this function reads a streamflow dataset and produces baseflow and quickflow (i.e. direct runoff). In this context, it was used to statistically separate spikes from background levels. Running the package results in an output file with a background specific conductance and a spike specific conductance for each time step that, when summed, equal the original total USGS concentration. This process was followed for daily and 15-minute data sets for each gage. An example of this separation technique using daily specific conductance data for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax) is provided in Figure 26.

For the purpose of the analyses described in this section, spike events in specific conductance were defined as time steps where background values (from the separation package) were greater than 500 $\mu\text{S}/\text{cm}$ with consecutive periods no more than one hour apart and no more than one storm per day, although the event could span multiple days. Background values above the threshold were used (instead of spike values) because many occurrences of greater than 500 $\mu\text{S}/\text{cm}$ can occur within a short period of time, even within a single precipitation event. Using background values enables selection of “spike events” as opposed to individual spikes. Table 9 shows the number of spike events by USGS gage using this method.

The magnitude of each spike event, quantified in $\mu\text{S}/\text{cm}$, was defined as the maximum specific conductance for that event (as recorded at the gage). The duration of each spike event was quantified in decimal hours as the length of time of the event. Total precipitation was calculated for each spike event as the sum of observed precipitation during the event and in the preceding five days. Rain and snow events were distinguished using available NOAA data. Events were categorized as snow if snow occurred on any day during the event period. If no snow occurred during a particular spike event, then the event was considered a non-snow winter precipitation event. Non-snow winter precipitation types include all other types of precipitation except snow (e.g. rain, freezing rain, and sleet).

¹ For the purposes of this analysis, winter is defined as November 1st through April 30th.

Figure 26. Example separation of background and spike concentrations of daily specific conductance. Precipitation is shown in blue. Spike events are periods of time when the background levels (dark orange) exceed the 500 $\mu\text{S}/\text{cm}$ threshold. This plot was created using daily data for easy viewing. The results presented in the next section are based on the 15-minute data sets.

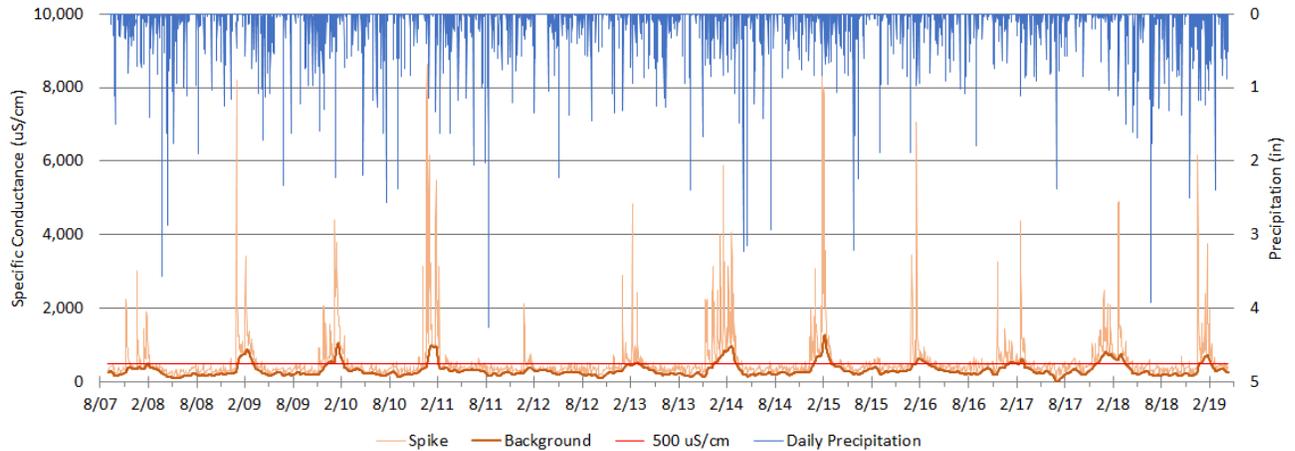


Table 9. Number of spike events by USGS gage.

Gage	Number of Spike Events
01645704	99
01645762	15
01646305	91
01656903	99

A series of regressions were developed based on spike events and the corresponding magnitude, duration, and total precipitation. The next section presents results for trends in magnitude since 2007 (“long-term trends”) and the relationship between spike magnitude and precipitation. The results for trends in duration since 2007 (“long-term trends”) and the relationship between spike duration and precipitation are also presented.

Results

A summary table of regression statistics for trends in storm-specific spikes is provided in Table 10. A p-value above 0.1 is considered not significant, “ns”, for the purposes of this table. Numeric p-values are provided for all relationships in the detailed explanations in the respective results sections.

Table 10. Summary regression statistics for tested relationships.

Winter Spike Characteristic	Regressed With...	Gage	p-value	R ²
Magnitude	Long-term	01645704	ns	0.0103
		01645762	ns	0.0649
		01646305	ns	0.0493
		01656903	ns	0.0052
	Precipitation	01645704	<0.0001	0.3084
		01645762	ns	0.0048
		01646305	<0.0005	0.1434
		01656903	<0.0001	0.3941
Duration	Long-term	01645704	ns	0.0044
		01645762	ns	0.0029
		01646305	ns	0.0003
		01656903	ns	0.001
	Precipitation	01645704	<0.0001	0.4058
		01645762	ns	0.0689
		01646305	<0.0001	0.1588
		01656903	<0.0001	0.6799

In addition to the relationships presented in Table 10, it should also be noted that there is a statistically significant relationship when spike magnitude is regressed with spike duration at all gages except 01645762 (S F Little Difficult Run Above Mouth Near Vienna). That particular gage has the fewest number of storms (n=15).

Magnitude

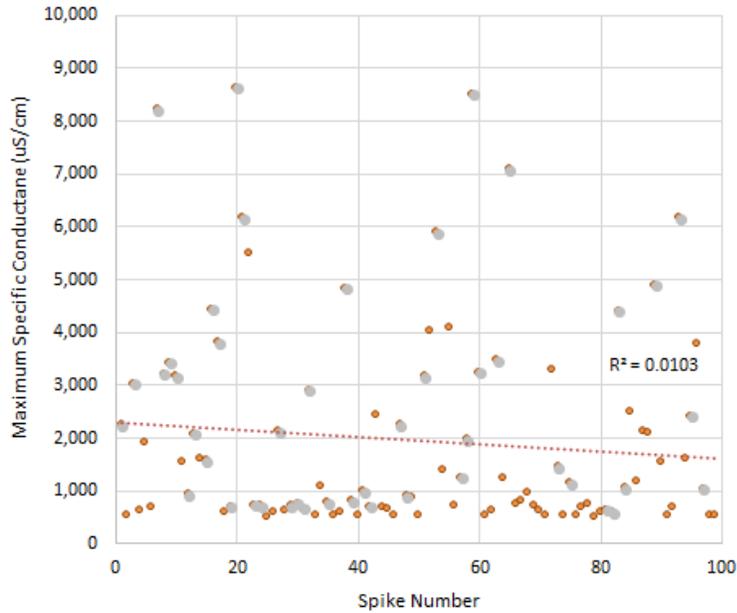
The maximum specific conductance value from the four selected USGS gages for each winter spike event were utilized to evaluate long-term trends in spike magnitude as well as the relationship of spike magnitude to precipitation. The findings are presented below.

Long-term trends in spike magnitude

Long-term trends in spike magnitude are not statistically significant at the four USGS gages. Details of the relationships are provided for each gage in this section.

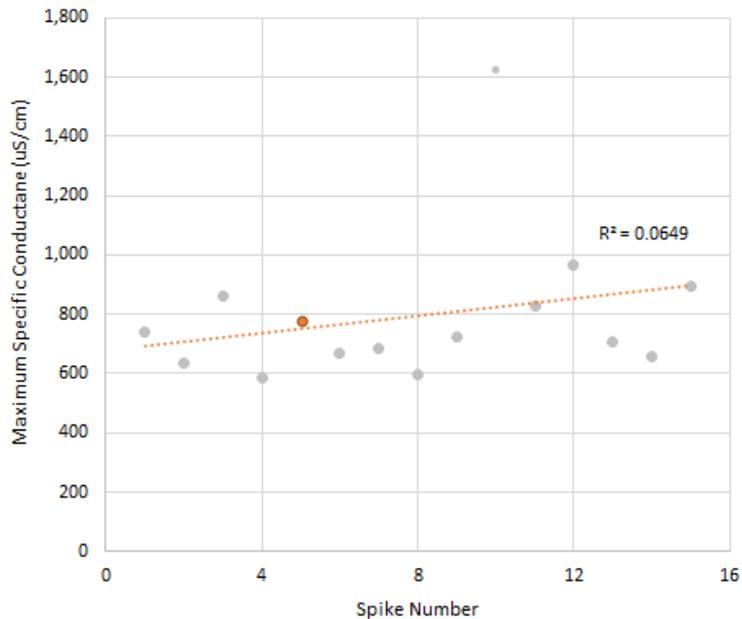
There is a slight visible decrease in winter spike maximum specific conductance values over time for USGS gage 01645704, Difficult Run Above Fox Lake Near Fairfax, (Figure 27, R²=0.0103); however, with a p-value of 0.32, this trend is not statistically significant. The R² value decreases to 0.0007 when only snow events are evaluated.

Figure 27. Long-term trend in winter spike magnitude for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax) for snow events (gray) and non-snow precipitation events (orange).



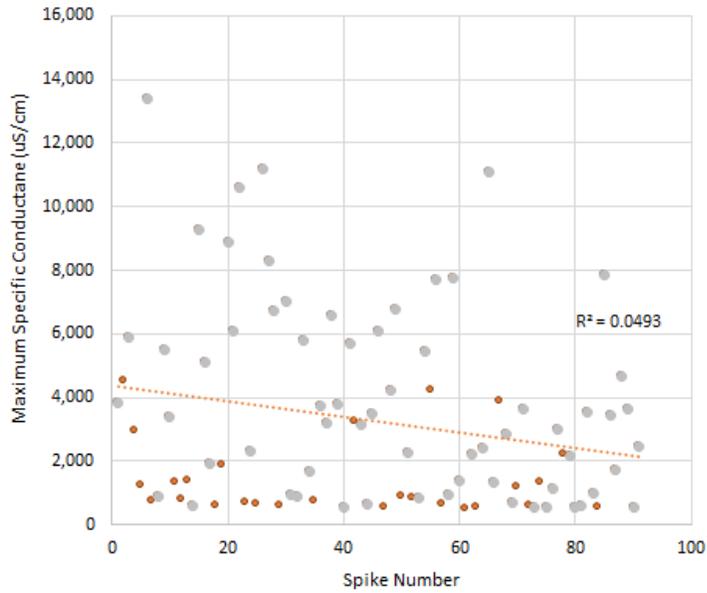
There is an increase in winter spike maximum specific conductance since 2007 for USGS gage 01645762, S F Little Difficult Run Above Mouth Near Vienna, (Figure 28, $R^2=0.0649$); however, with a p-value of 0.36, this trend is not statistically significant. It should be noted that this gage has considerably fewer spike events where background specific conductance exceed 500 $\mu\text{S}/\text{cm}$ ($n=15$) and only one of the spike events is not associated with snow.

Figure 28. Long-term trend in winter spike magnitude for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna) for snow events (gray) and non-snow precipitation events (orange).



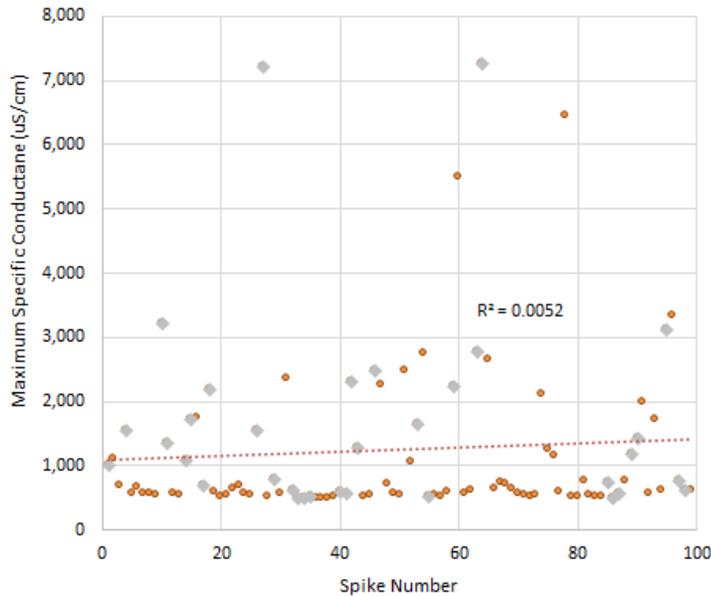
There is a small decrease in winter spike maximum specific conductance values over time for USGS gage 01646305, Dead Run at Whann Avenue Near Mclean, (Figure 29, $R^2=0.0493$); however, with a p-value of 0.34, this trend is not statistically significant. The R^2 value increases to 0.1339 when only snow events are evaluated.

Figure 29. Long-term trend in winter spike magnitude for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean) for snow events (gray) and non-snow precipitation events (orange).



There is a small increase in winter spike maximum specific conductance values over time for USGS gage 01656903, Flatlick Branch Above Frog Branch at Chantilly, (Figure 30, $R^2=0.0052$); however, with a p-value of 0.48, this trend is not statistically significant. The R^2 value decreases to 0.0022 when only snow events are evaluated.

Figure 30. Long-term trend in winter spike magnitude for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly) for snow events (gray) and non-snow precipitation events (orange).

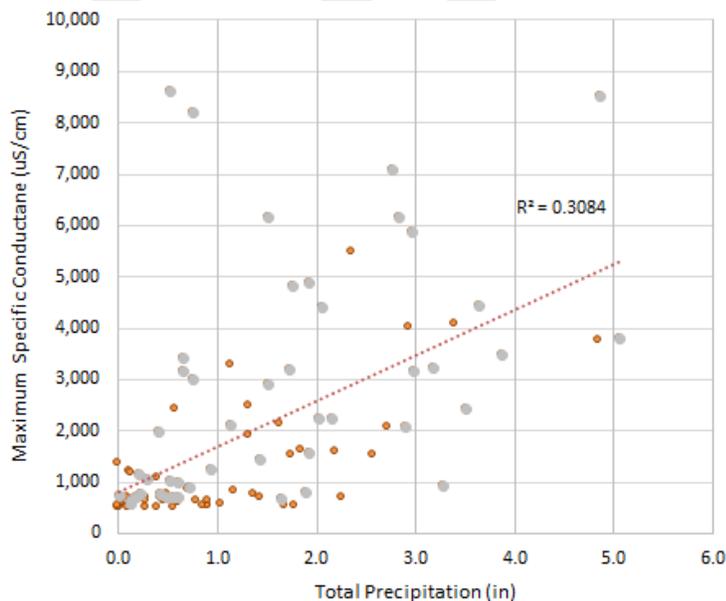


Relationship of spike magnitude to precipitation

There is a statistically significant relationship between spike magnitude and total precipitation for three of the four USGS gages. USGS gage 01645762, S F Little Difficult Run Above Mouth Near Vienna, does not have a significant relationship.

There is statistically significant increase in winter spike magnitude with increased precipitation for USGS gage 01645704, Difficult Run Above Fox Lake Near Fairfax, (Figure 31, $R^2=0.3084$, $p\text{-value}<0.0001$). The R^2 value decreases to 0.2 when only snow events are evaluated.

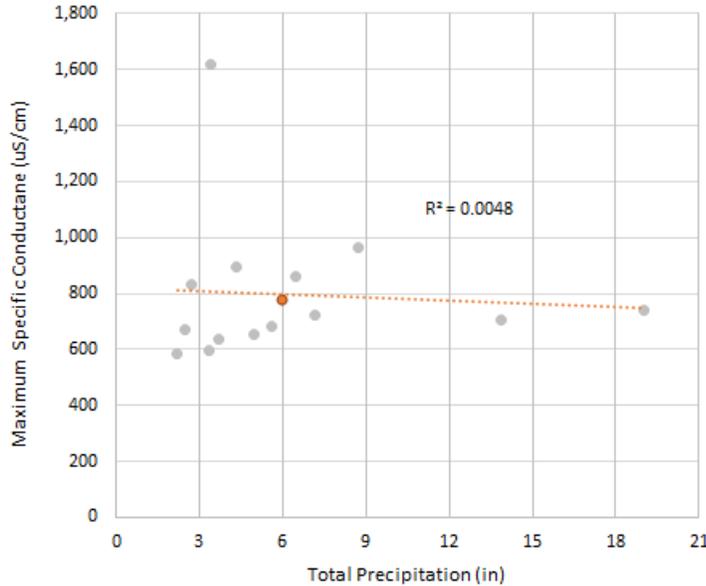
Figure 31. Relationship of winter spike magnitude to precipitation for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax) for snow events (gray) and non-snow precipitation events (orange).



11/5/2019

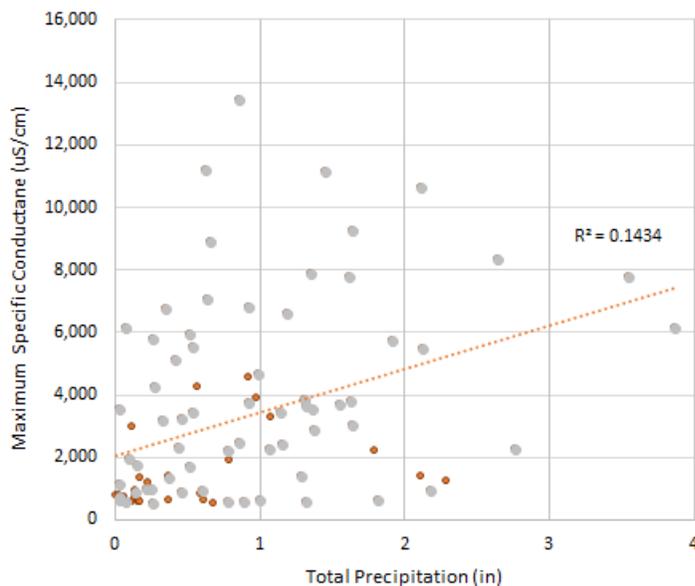
There is not a statistically significant change in winter spike magnitude since 2007 for USGS gage 01645762, S F Little Difficult Run Above Mouth Near Vienna, (Figure 32, $R^2=0.0048$, $p\text{-value}=0.81$).

Figure 32. Relationship of winter spike magnitude to precipitation for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna) for snow events (gray) and non-snow precipitation events (orange).



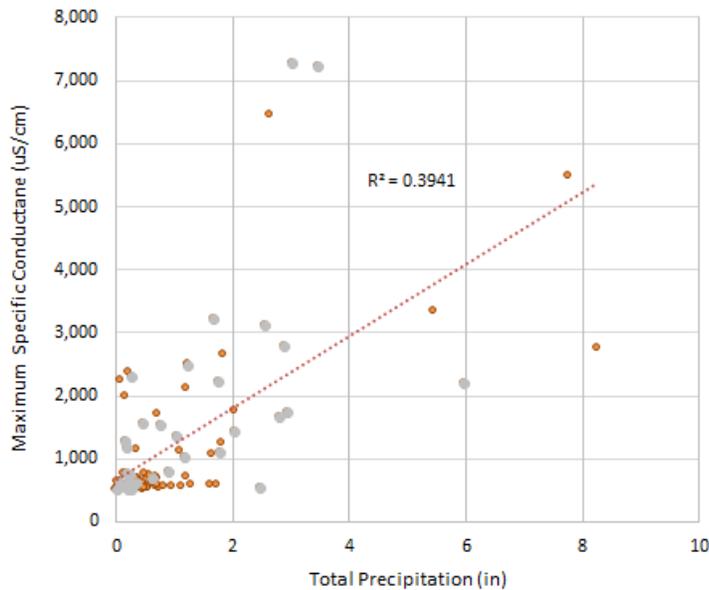
There is statistically significant increase in winter spike magnitude with increased precipitation for USGS gage 01646305, Dead Run at Whann Avenue Near Mclean, (Figure 33, $R^2=0.1434$, $p\text{-value}<0.0005$). The regression model results indicate that precipitation accounts for slightly over 14 percent of the variability in maximum winter specific conductance. The R^2 value decreases to 0.1005 when only snow events are evaluated.

Figure 33. Relationship of winter spike magnitude to precipitation for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean) for snow events (gray) and non-snow precipitation events (orange).



There is statistically significant increase in winter spike magnitude with increased precipitation for USGS gage 01656903, Flatlick Branch Above Frog Branch at Chantilly, (Figure 34, $R^2=0.3941$, $p\text{-value}<0.0001$). The regression model results indicate that total precipitation accounts for almost 40 percent of the variability in maximum winter specific conductance. The R^2 value decreases to 0.3329 when only snow events are evaluated.

Figure 34. Relationship of winter spike magnitude to precipitation for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly) for snow events (gray) and non-snow precipitation events (orange).



Duration

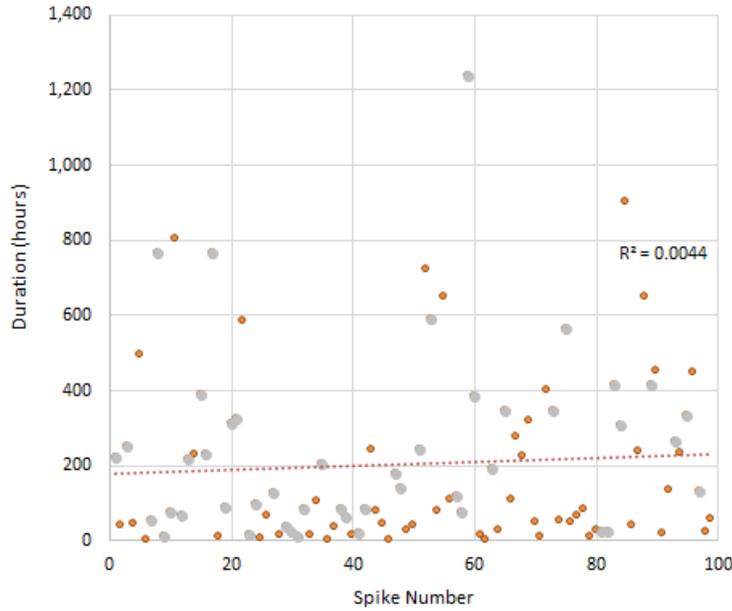
The duration of winter spike events, calculated in hours, at the four selected USGS gages were utilized to evaluate long-term trends in spike duration as well as the relationship of event duration to precipitation totals. The findings are presented below.

Long-term trends in spike duration

Long-term trends in spike duration are not statistically significant at the four USGS gages. Details of the relationships are provided for each gage in this section.

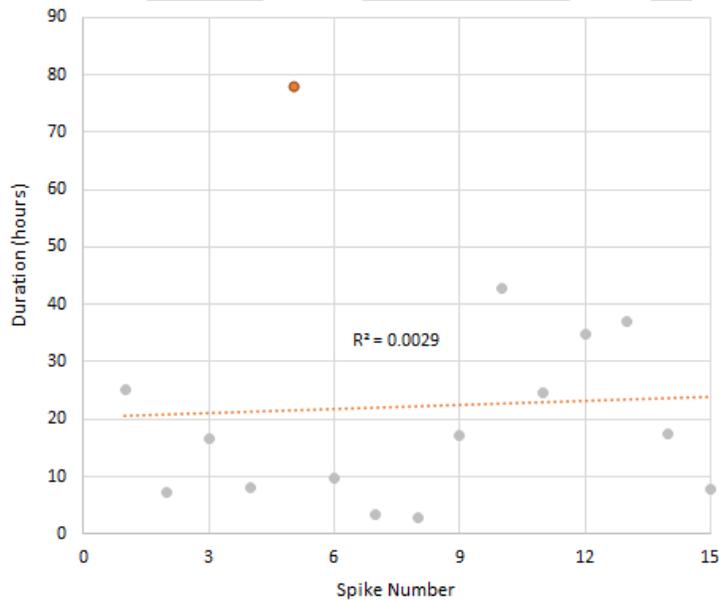
There is a slight increase in winter spike duration over time for USGS gage 01645704, Difficult Run Above Fox Lake Near Fairfax, (Figure 35, $R^2=0.0044$); however, with a $p\text{-value}$ of 0.51, this trend is not statistically significant. The R^2 value increases to 0.0213 when only snow events are evaluated.

Figure 35. Long-term trend in winter spike duration for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax) for snow events (gray) and non-snow precipitation events (orange).



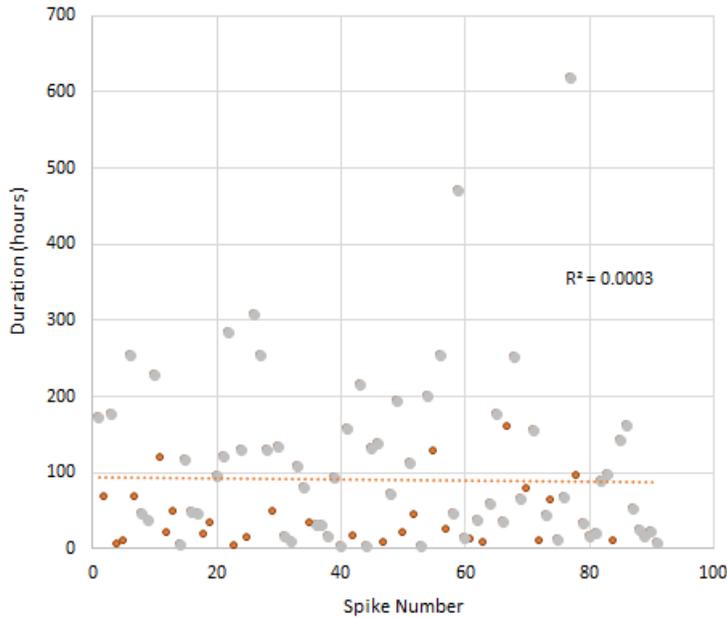
Similarly, there is a slight increase in winter spike duration over time for USGS gage 01645762, S F Little Difficult Run Above Mouth Near Vienna, (Figure 36, $R^2=0.0029$); however, with a p-value of 0.85, this trend is not statistically significant. It should be noted that this gage has considerably fewer spike events where background specific conductance exceed $500 \mu\text{S}/\text{cm}$ ($n=15$) and only one of the spike events is not associated with snow

Figure 36. Long-term trend in winter spike duration for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna) for snow events (gray) and non-snow precipitation events (orange).



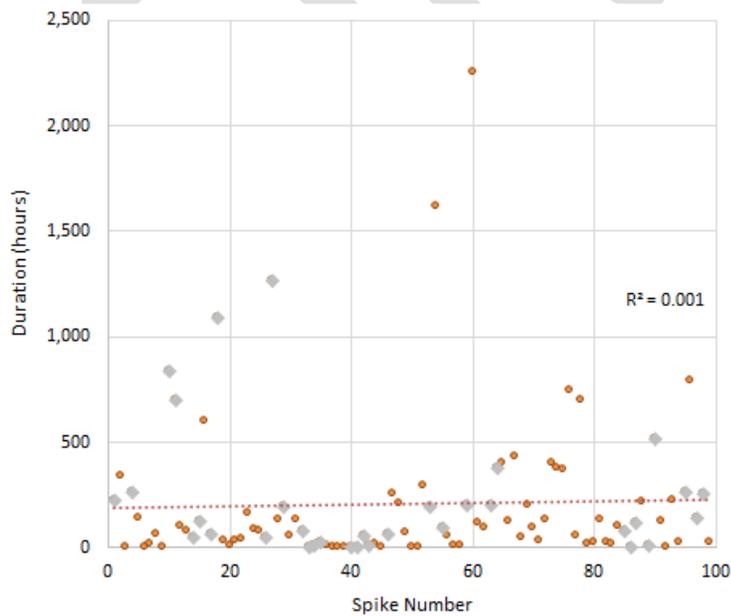
There is very slight decrease over time in winter spike duration for USGS gage 01646305, Dead Run at Whann Avenue Near Mclean, (Figure 37, $R^2=0.0003$); however, with a p-value of 0.87, this trend is not statistically significant. The R^2 value increases to 0.0117 when only snow events are evaluated.

Figure 37. Long-term trend in winter spike duration for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean) for snow events (gray) and non-snow precipitation events (orange).



There is not a statistically significant trend in winter spike duration for USGS gage 01656903, Flatlick Branch Above Frog Branch at Chantilly, (Figure 38, $R^2=0.001$, p-value=0.76). The R^2 value increases to 0.0522 when only snow events are evaluated.

Figure 38. Long-term trend in winter spike duration for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly) for snow events (gray) and non-snow precipitation events (orange).

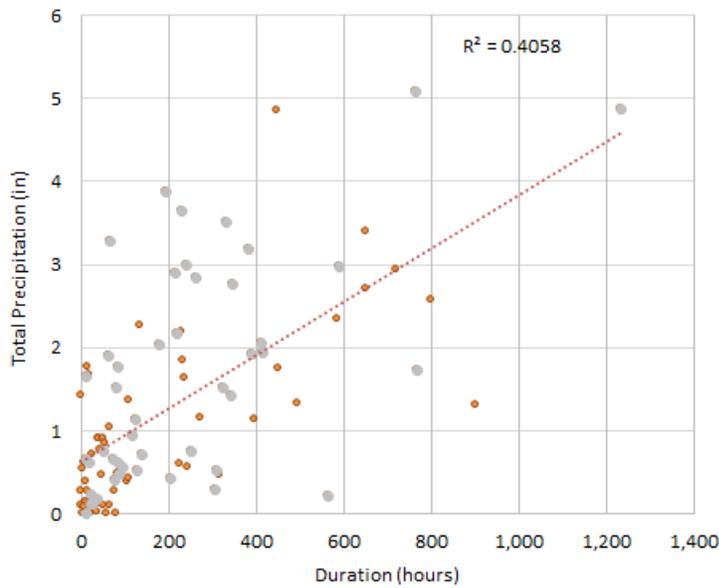


Relationship of spike duration to precipitation

There is a statistically significant relationship between spike magnitude and total precipitation for three of the four USGS gages. USGS gage 01645762, S F Little Difficult Run Above Mouth Near Vienna, does not have a significant relationship.

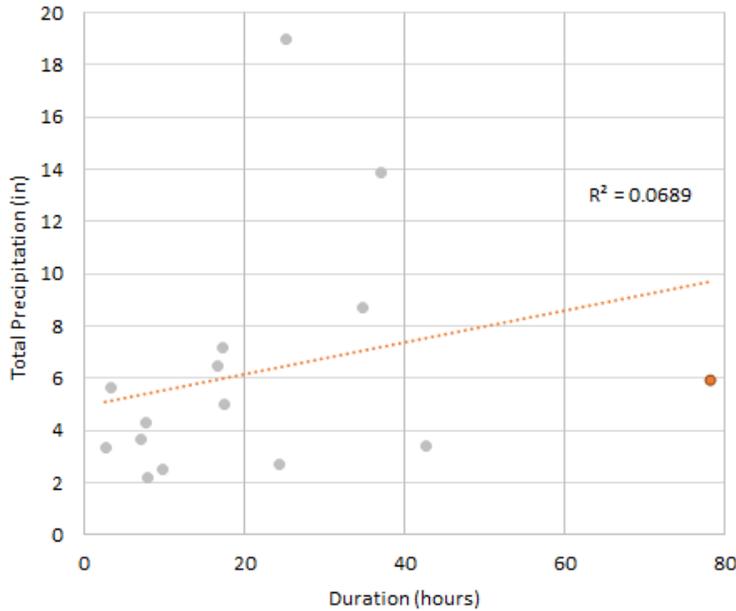
There is statistically significant increase in winter spike duration in specific conductance with increased precipitation for USGS gage 01645704, Difficult Run Above Fox Lake Near Fairfax, (Figure 39, $R^2=0.4058$, $p\text{-value}<0.0001$). The R^2 value decreases to 0.3502 when only snow events are evaluated.

Figure 39. Relationship of winter spike duration to precipitation for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax) for snow events (gray) and non-snow precipitation events (orange).



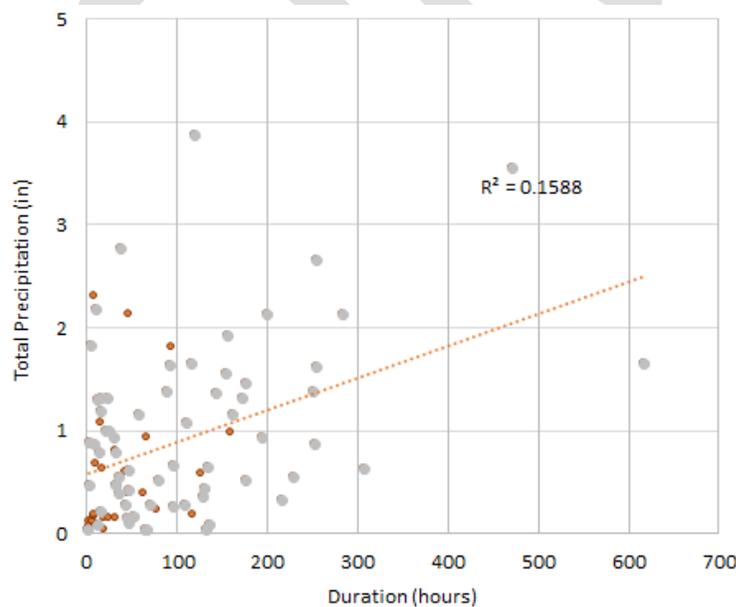
There is not a statistically significant change in winter spike duration in specific conductance with increased precipitation for USGS gage 01645762, S F Little Difficult Run Above Mouth Near Vienna, (Figure 40, $R^2=0.0689$, $p\text{-value}=0.34$).

Figure 40. Relationship of winter spike duration to precipitation for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna) for snow events (gray) and non-snow precipitation events (orange).



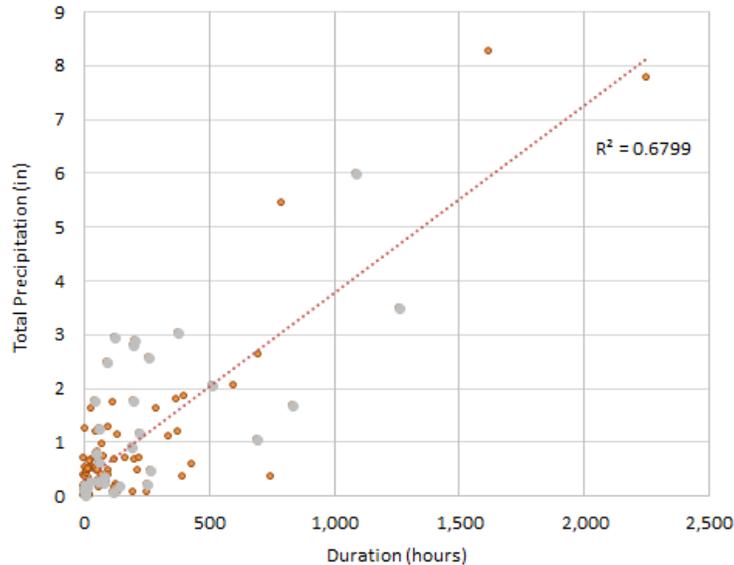
There is statistically significant increase in winter spike duration in specific conductance with increased precipitation for USGS gage 01646305, Dead Run at Whann Avenue Near Mclean, (Figure 41, $R^2=0.1588$, $p\text{-value}<0.0001$). The R^2 value decreases to 0.1407 when only snow events are evaluated.

Figure 41. Relationship of winter spike duration to precipitation for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean) for snow events (gray) and non-snow precipitation events (orange).



There is statistically significant increase in winter spike duration in specific conductance with increased precipitation for USGS gage 01656903, Flatlick Branch Above Frog Branch at Chantilly, (Figure 42, $R^2=0.6799$, $p\text{-value}<0.0001$). The R^2 value decreases to 0.4547 when only snow events are evaluated.

Figure 42. Relationship of winter spike duration to precipitation for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly) for snow events (gray) and non-snow precipitation events (orange).



Trends in background summer specific conductance

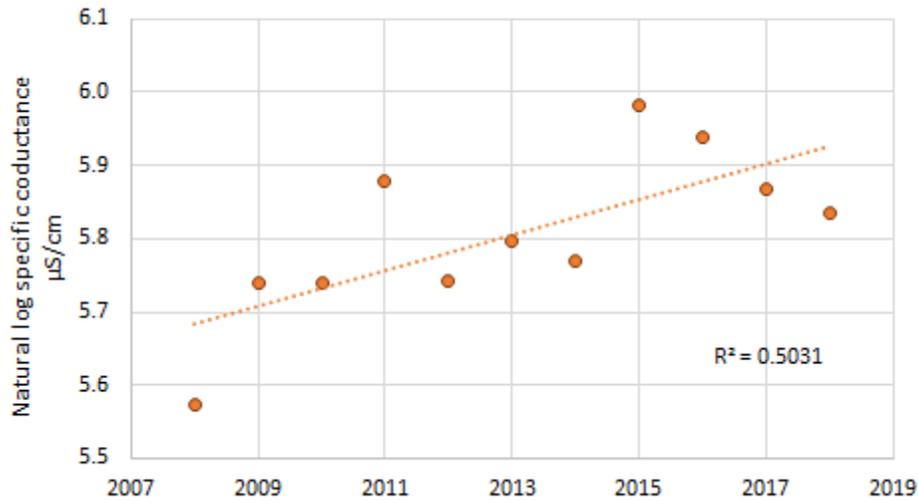
Methodology

Background summer trends in specific conductance were evaluated for the northern Virginia region. First, trends in median summer specific conductance for each year (2007-2019) were evaluated for the four USGS gages. Three versions of this analysis were developed: 1) trends in median summer specific conductance over time (presented in the results section below), 2) trends in flow weighted concentrations over time, and 3) trends in median baseflow concentrations over time where summer was defined as September to October (instead of May to October). Flow weighting and adjusting the definition of summer introduced additional variability and, in general, weakened the trends over time. The results of those investigations (numbers 2 and 3 above) are not presented here. In addition, trends were evaluated for the 15-minute summer data for the selected time period at each gage (Table 11).

Results

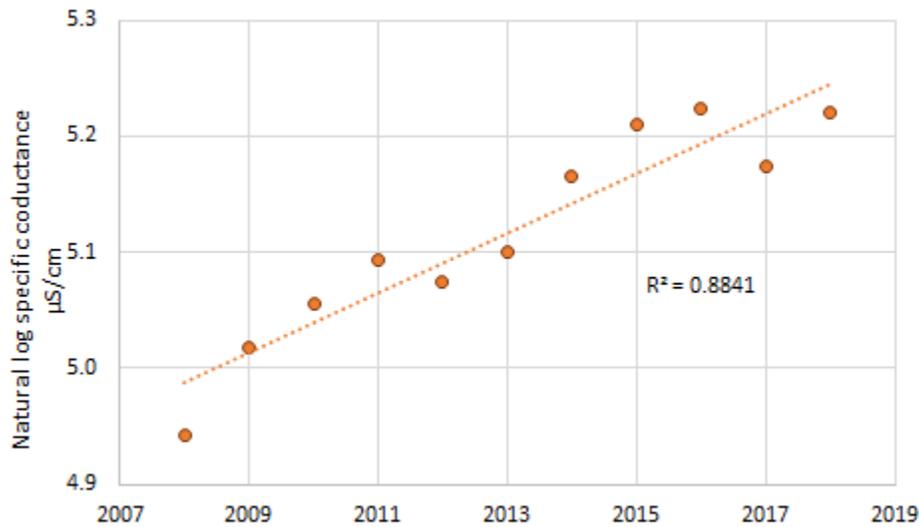
Trends in median concentrations for each year are provided for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax) in Figure 43. The increasing trend visible in the figure is statistically significant with an R^2 value of 0.5031, a $p\text{-value}<0.05$, and an equation of $y=0.0241x-42.796$.

Figure 43. Increasing trend in background summer specific conductance for USGS gage 01645704 (Difficult Run Above Fox Lake Near Fairfax).



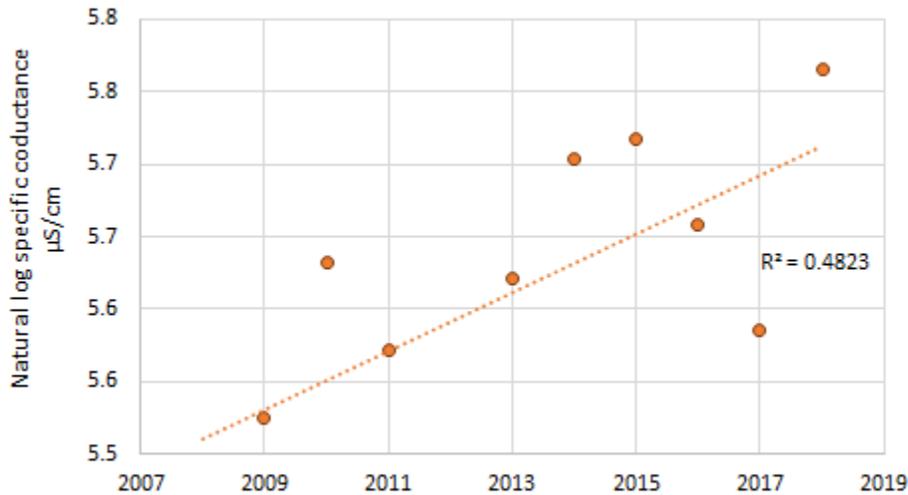
Trends in median concentrations for each year are provided for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna) in Figure 44. The increasing trend visible in the figure is statistically significant with an R^2 value of 0.8841, a p -value < 0.0001 , and an equation of $y = 0.0258x - 46.842$.

Figure 44. Increasing trend in background summer specific conductance for USGS gage 01645762 (S F Little Difficult Run Above Mouth Near Vienna).



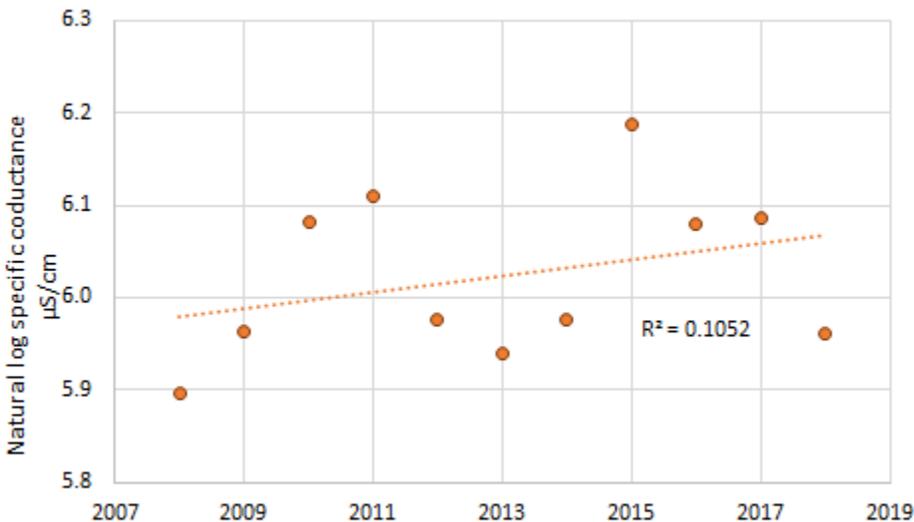
Median specific conductance values from 2007 through 2019 are provided for 01646305 (Dead Run at Whann Avenue Near Mclean) in Figure 45. The increasing trend visible in the figure is statistically significant with an R^2 value of 0.4823, a p -value <0.05 , and an equation of $y=0.0202x-35.089$.

Figure 45. Increasing trend in background summer specific conductance for USGS gage 01646305 (Dead Run at Whann Avenue Near Mclean).



Trends in median concentrations for each year are provided for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly) in Figure 46. The increasing trend visible in the figure is not statistically significant with an R^2 value of 0.1052, a p -value >0.1 , and an equation of $y=0.0088x-11.605$.

Figure 46. Increasing trend in background summer specific conductance for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly).



Regression summary statistics by gage for 15-minute summer specific conductance over the period of record are provided in Table 11. All of the gages show statistically significant, increasing trends;

however, much of the variability in the 15-minute data is explained by other factors as demonstrated by the low R^2 values. Exploration of these other factors (e.g. land use, percent impervious cover, intensity and duration of precipitation, and rate and timing of winter de-icing material applications) is a potential analysis for future exploration.

Table 11. Regression summary statistics by gage for 15-minute summer specific conductance over time.

Gage	p-value	R^2	Equation
01645704	<0.0001	0.07245	$y=-14.9+0.00000025x$
01645762	<0.0001	0.2026	$y=3.06+0.000000115x$
01646305	<0.0001	0.05652	$y=21.6+0.00000017x$
01656903	<0.0001	0.006756	$y=295+0.000000767x$

Conclusions

Over 1.5 million data records were analyzed as part of this assessment. Some statistically significant trends are evident while other relationships may require additional analyses to further flesh out:

- Looking at the observed data, seasonal patterns are visible in the regional precipitation regime and in water quality conditions for specific conductance.
- Trends in long-term, 15-minute specific conductance are difficult to discern due to large variability from other factors like land use, percent impervious cover, intensity and duration of precipitation, and rate and timing of winter de-icing material applications. The increasing trends are, however, appreciable and statistically significant.
- Increasing trends are visually observed in median monthly and median annual specific conductance. Not all of the relationships are statistically significant, however. This is especially the case at gages with large ranges in specific conductance. Median annual specific conductance values exhibited the most statistically significant increases.
- Winter spike magnitudes and durations increase with increasing precipitation based on 15-minute data (except for USGS gage 01645762); however, long-term trends in winter spike magnitudes and durations are not statistically significant.
- Background trends in summer medians are increasing both at a median annual and a 15-minute temporal resolution. The only exception is the non-significant median summer trend for USGS gage 01656903 (Flatlick Branch Above Frog Branch at Chantilly).

Additional analyses of possible interest

The initial analyses of data described in this report bring to light some interesting relationships and potential additional questions of interest. For example, the activities listed below may be worth pursuing:

- Identify areas where more nuanced analyses may be warranted – This cursory evaluation used all available data, packaged software, and standard techniques to generate a first-pass look at the data. As such, the results may be improved with further refinement like case-specific handling of outliers in developing statistical relationships.
- Teasing out the numerous factors that influence the amount and timing of changes in water quality conditions will foster an understanding of the long-term trends noted in this report. These factors may include land use, impervious cover, and the specifics of de-icing material applications for individual storm events:

- Evaluate relationships of land uses in the gaged watersheds to specific conductance – Differences in specific conductance values between gaged watersheds and in any given watershed over time are expected to be related to land use differences. Exploring these relationships may prove valuable in understanding the changing water quality dynamics in northern Virginia.
- Evaluate the response of specific conductance to impervious cover and the associated surface runoff – The amount of impervious cover in a watershed is related to the amount of winter de-icing materials applied.
- Relate storm specific timing and amount of de-icing material applications to specific conductance– Each winter storm is different. The application amount, rate, and timing of de-icing materials are expected to be related both temporally and spatially to the changing water quality conditions.

References

Fuka, D.R., M.T. Walter, J.A. Archibald, T.S. Seenhuis, and Z.M. Easten. 2018. EcoHydRology: A Community Modeling Foundation for Eco-Hydrology, version 0.4.12.1. Available at <https://rdr.io/cran/EcoHydRology/> (downloaded 6/3/2019). Functions can be accessed through <https://rdr.io/cran/EcoHydRology/f/>.