Evaluation of Voluntary Discharge Management System for Reducing High-TDS Events in the Monongahela River Basin

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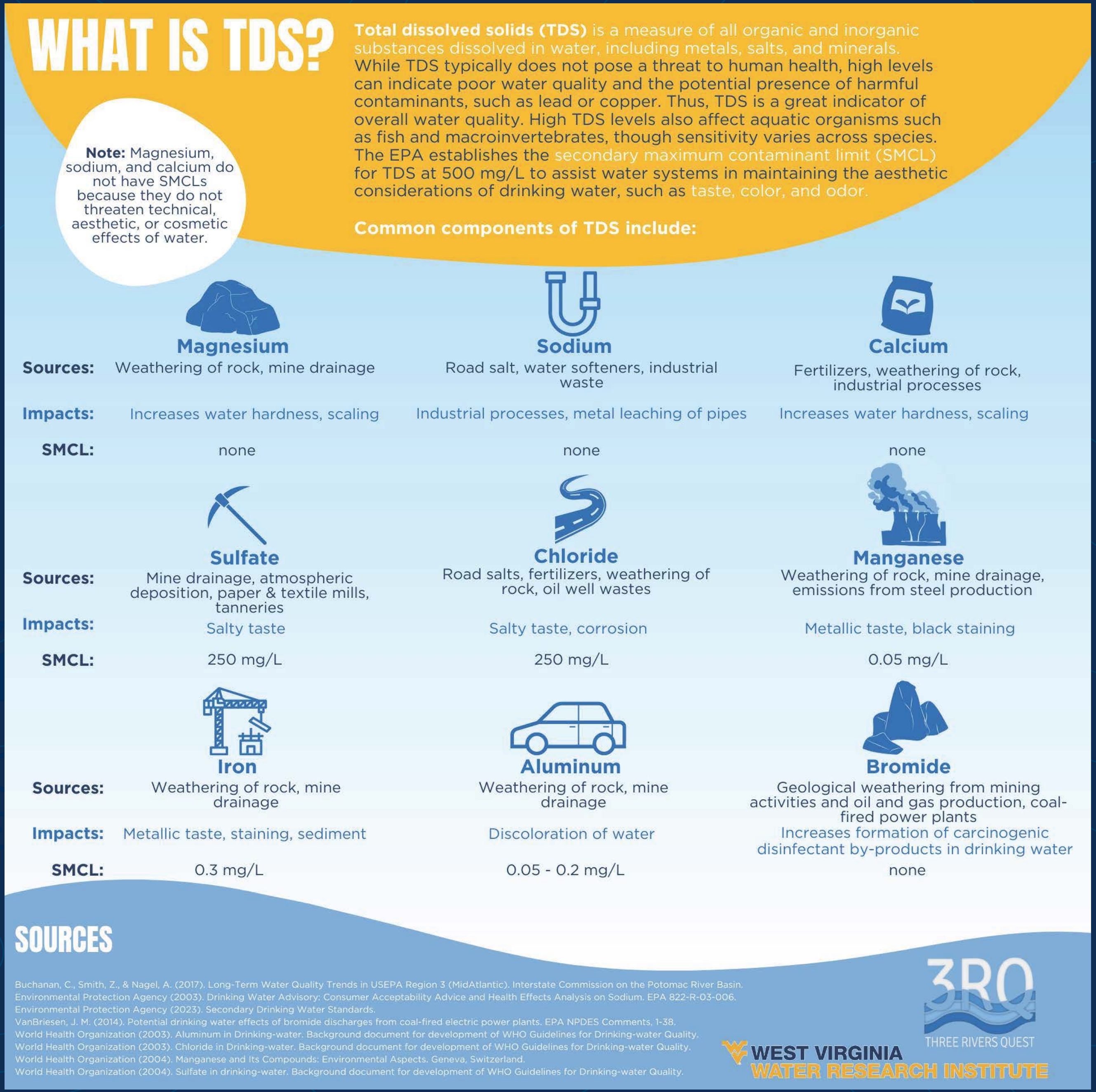
Background

High total dissolved solids (TDS) events in summer/fall 2008

- Complaints from industrial and residential river users; shut down of some municipal water intakes.
- Exceedances of the EPA’s safe drinking water act standards for TDS (500 mg/L).
- Dunkard Creek (tributary) fish kill September 2009.

Potential Drivers of High TDS in the Mon

- Abandoned mine drainage (AMD)
- Treated mine discharges
- Wastewater disposal from oil and gas operations
- Low flow conditions/climate change



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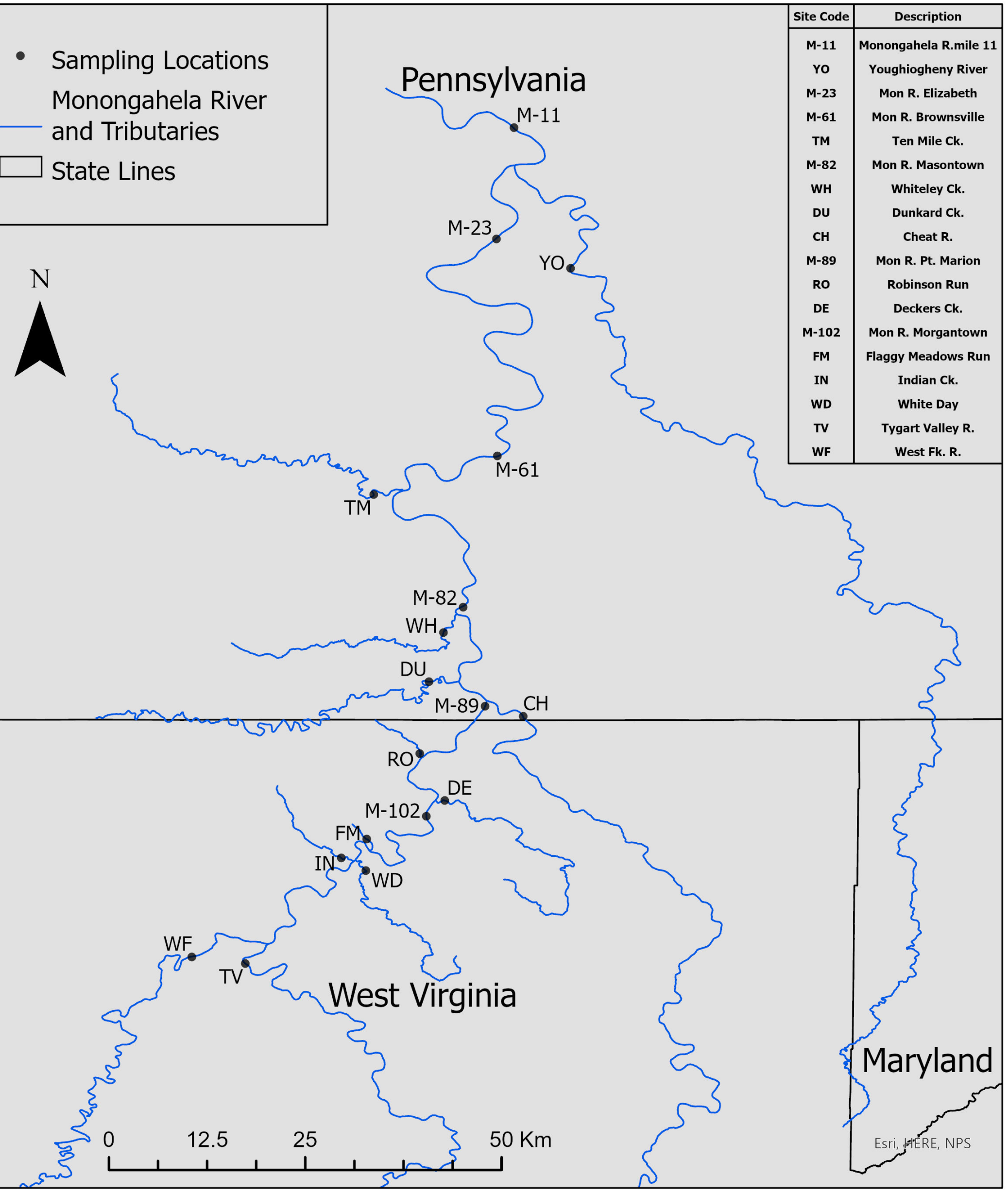
3RQ Monongahela River Sites



Site Code	Description
M-11	Monongahela R.mile 11
YO	Youghiogheny River
M-23	Mon R. Elizabeth
M-61	Mon R. Brownsville
TM	Ten Mile Ck.
M-82	Mon R. Masontown
WH	Whiteley Ck.
DU	Dunkard Ck.
CH	Cheat R.
M-89	Mon R. Pt. Marion
RO	Robinson Run
DE	Deckers Ck.
M-102	Mon R. Morgantown
FM	Flaggy Meadows Run
IN	Indian Ck.
WD	White Day
TV	Tygart Valley R.
WF	West Fk. R.

Monitoring Response

- WVWRI began biweekly sampling of the Monongahela River and major tributaries in July of 2009.
  - Focuses on TDS parameters including metals, sulfate, and halogens.
- Found that treated mine discharges were the controlling factor in the Mon's TDS load.

3RQ THREE RIVERS QUEST Allegheny Monongahela Ohio

Voluntary Discharge Management Plan (VDMP)

- Model developed by WVWRI in partnership with regional coal companies.
  - Accounts for the pumping capacities of 14 major mine pumping and treatment plants in the Upper Mon.
  - Set not to exceed the safe drinking water act (SDWA) standard for TDS in the Mon River with a safety factor of 2 .
  - Allows plant operators to look at the gauge reading and set their pumps to the indicated rate, thereby coordinating the outflows.
- Voluntarily implemented in January 2010.


Image: The Allegheny Front

Other Management Changes

1. Pennsylvania restricts the disposal of shale gas wastewater to publicly owned treatment works (2011).
   - Public wastewater facilities were unable to adequately treat the shale gas wastewater.
2. Construction of a regional reverse osmosis treatment facility for mine discharges (2013).
   - Constructed by Consol Energy.

Project Goals

- Evaluate the effectiveness of the voluntary discharge management program from 2010 to present.
- Identify future recommendations and share findings.

Methods


Rite in the Rain
ALL-WEATHER
ENVIRONMENTAL
№ 550F
3RQ
2nd FIELD

Methods

- Utilized monthly 3RQ data from 2009 – 2022.
  - Analyzed by certified analytical laboratory.
  - Flow obtained from nearest USGS gauge or using WCMS[1].
- Only included sites impacted by the VDMP and 1 control site (13 total).

[1]Watershed Modeling & Characterization System, developed by Strager et al., 2010.

Table 1: Study sites, significance to VDMP, and discharge equation used.

Site Name	Site Code	Significance to VDMP	Discharge Equation
Mon R. Morgantown	M-102	Monongahela River	M89-DE
Mon R. Point Marion	M-89	Monongahela River	M82-WH-DU-CH
Mon R. Masontown	M-82	Monongahela River	USGS gauge 03072655
Mon R. Brownsville	M-61	Monongahela River	(M82+M23)/2
Mon R. Elizabeth	M-23	Monongahela River	USGS gauge 03075070
Mon R. Homestead	M-11	Monongahela River	YO + M23
Dunkard Creek	DU	6 VDMP discharges to stream	USGS gauge 03072000
Tenmile Creek	TM	4 VDMP discharges to stream	DU/2
Whiteley Creek	WH	4 VDMP discharges to stream	DU/2
Indian Creek	IN	2 VDMP discharges to stream	WCMS
Flaggy Meadows Run	FM	1 VDMP discharge to stream	WCMS
Robinson Run	RO	2 VDMP discharges to stream	WCMS
Whiteday Creek	WD	Control	WCMS

Methods Cont.


water MDPI

Article

Effective Management Changes to Reduce Halogens, Sulfate, and TDS in the Monongahela River Basin, 2009–2019

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Abstract: The Monongahela River Basin has an extensive history of fossil fuel development, including coal mining and natural gas extraction. In late summer 2008, total dissolved solids (TDS) concentrations exceeding the United States Environmental Protection Agency's (EPA) secondary drinking water standards were detected. After determining the source, a voluntary discharge management plan (VDMP) was developed by the West Virginia Water Research Institute (WVWRI) and implemented by the coal industry (2010). Additional remediation actions included Pennsylvania's prohibition of produced wastewater in publicly owned treatment facilities (2011) and construction of a reverse osmosis treatment facility (2013). We used a locally weighted polynomial regression in conjunction with a segmented regression to assess the discharge and concentration trends/changepoints for bromide, chloride, sulfate, and total dissolved solids at various locations relative to the three remedial actions. We detected significant ($\alpha < 0.05$) positive trends for discharge and significant negative trends for bromide, chloride, sulfate, and total dissolved solids. In conjunction, we also detected 1–4 changepoints within each model. Additionally, a linear mixed effects model containing discharge and remedial actions was used to measure the effectiveness of each remediation action in reducing TDS over time. Of the three remedial actions, the VDMP by itself was effective in maintaining river sulfate and TDS levels below the secondary drinking water standards (−0.12, p-value = 0.002). The combination of the VDMP with Pennsylvania's produced water prohibition (−0.16, p-value < 0.001) and the combination of the VDMP with the reverse osmosis treatment facility (−0.19, p-value < 0.001) were also effective. The use of all three remedial actions produced the strongest effect (−0.37, p-value < 0.001) Since the implementation of these changes, primarily the VDMP which encompasses most of the watershed, TDS in the Monongahela has not exceeded the EPA's secondary drinking water standards. Future management decisions should include efforts to further expand the VDMP and to monitor changes in land use or severe changes in discharge.

Keywords: water quality management; total dissolved solids; discharge management; reverse osmosis; trend analysis; mixed effects model

check for updates

Citation: Kingsbury, J.W.; Spirnak, R.; O'Neal, M.; Ziemkiewicz, P. Effective Management Changes to Reduce Halogens, Sulfate, and TDS in the Monongahela River Basin, 2009–2019. *Water* **2023**, *15*, 631. https://doi.org/10.3390/w15040631

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1. Introduction

The Monongahela River Basin, a 19,104 square kilometer watershed spanning north-central West Virginia, southwestern Pennsylvania, and western Maryland, has supported a variety of industrial uses throughout its history, most notably historic and present-day coal mining and contemporary oil and gas development. Mine discharges are major sources of sulfate and other salts in the Monongahela River Basin, while oil and gas developments are a major source of halogens such as chloride and bromide. The extent to which these industries have contributed to total dissolved solids (TDS) loading in the Monongahela River is of interest to researchers and water managers. Elevated TDS within the Monongahela River has been shown to impact drinking water during low-flow events [1]. Historically, TDS concentrations in the Monongahela River have exceeded the secondary drinking water standard of 500 mg/L only when flow drops below 2000 cubic feet per second based on

- Data were cleaned by replacing missing data, erroneous data, and extreme outliers with imputation in the statistical program R using the MICE package.
- TDS and sulfate trends were determined using regression analysis with the highest R^2 value.
- Additionally, we draw from the results of our recently published study evaluating management changes within the Monongahela River Basin (Kingsbury et al., 2023).
  - Locally-weighted polynomial regression in conjunction with a segmented regression to assess trends and changepoints.


Results

Mon Mainstem

- Since monitoring began in July 2009, TDS has not exceeded the SDWA standard (500 mg/L).
- Since the implementation of the VDMP in 2010, sulfate has not exceeded the SDWA standard (250 mg/L).
- As expected, higher concentrations are seen during late summer and fall during low flows.

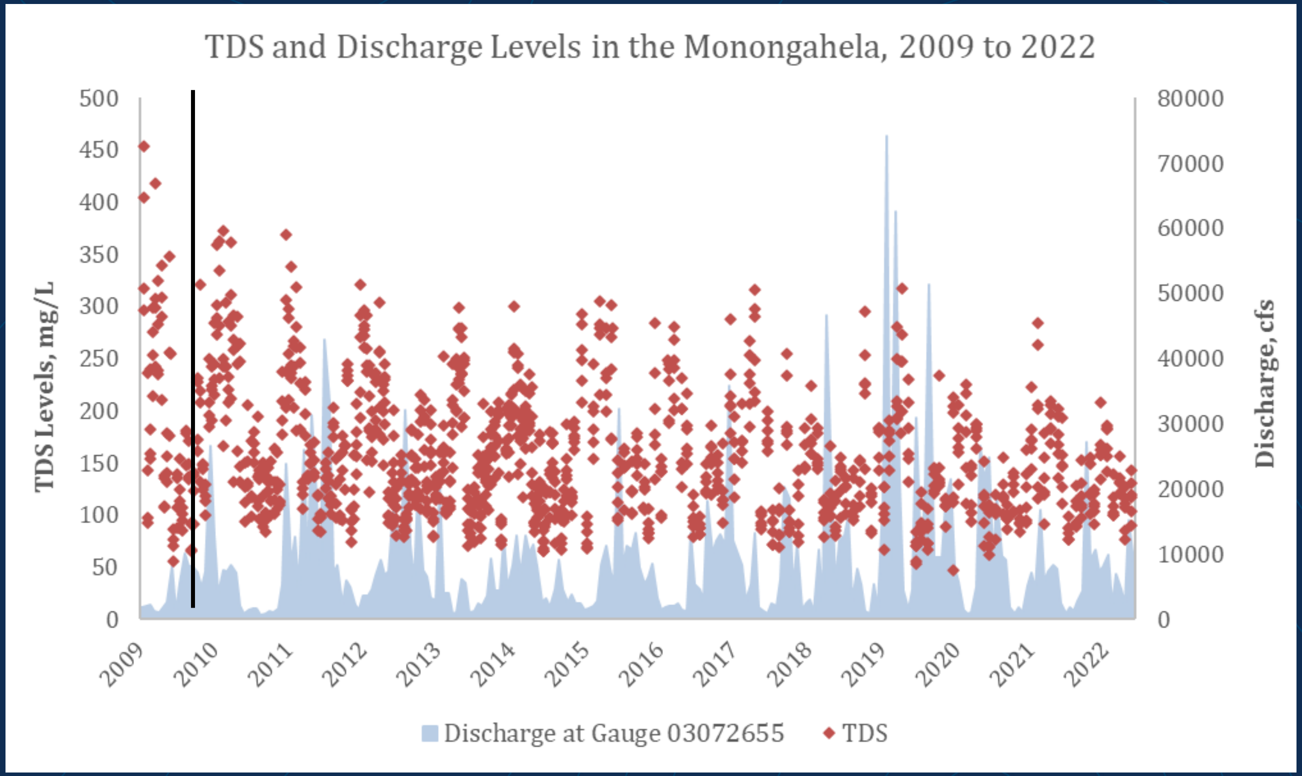
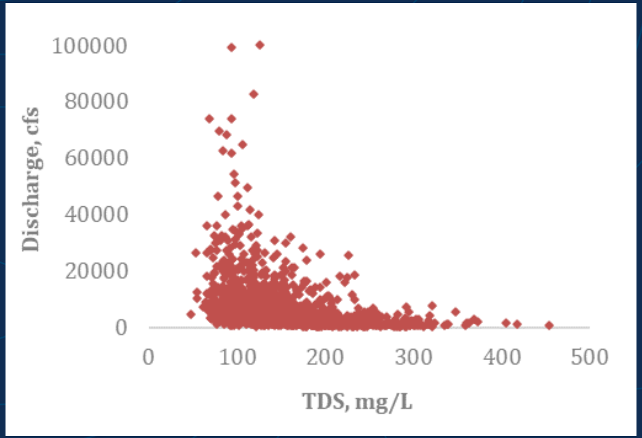
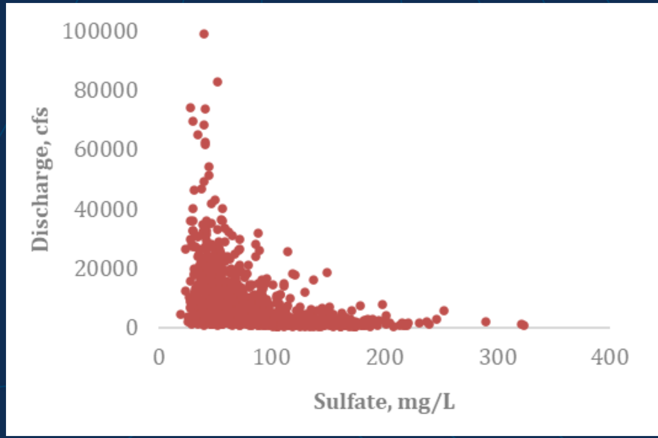


Figure 1: TDS concentrations for all Mon mainstem sites and discharge at USGS gage near Masontown, PA.





Figures 2 & 3: Correlation of discharge with (a) TDS and (b) sulfate from all Mon mainstem sites.

Tributary Trends

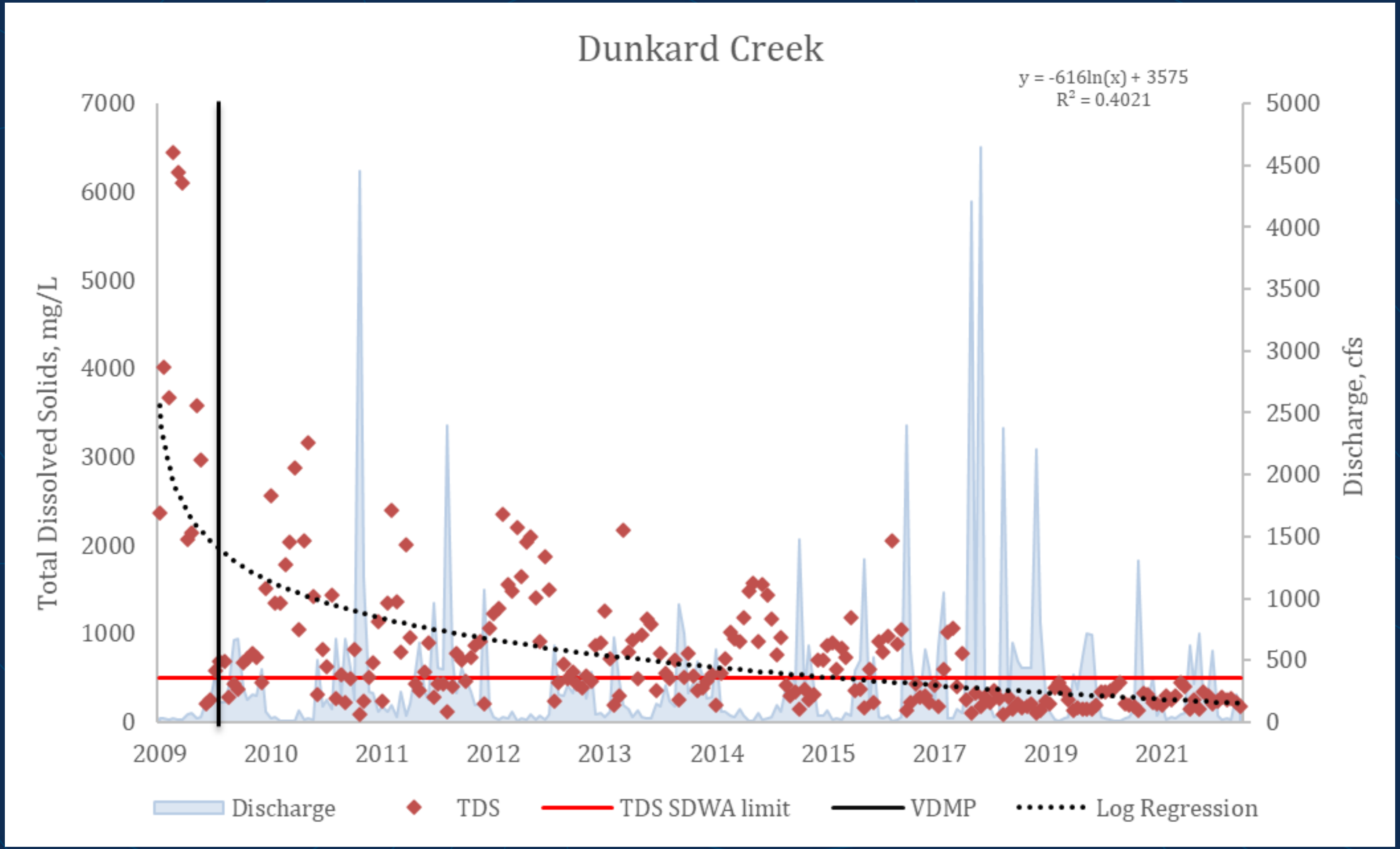
Table 2: R^2 values for regression trend lines for TDS.

Site Name	Site Code	Trend Type	R^2 Value
Dunkard Creek	DU	Logarithmic	0.4021
Tenmile Creek	TM	Linear	0.0019
Whiteley Creek	WH	Power	0.1124
Indian Creek	IN	Linear	0.0374
Flaggy Meadows Run	FM	Linear	0.4168
Robinson Run	RO	Power	0.0339
Whiteday Creek (control)	WD	Linear	0.0103

- TDS and sulfate values vary greatly among the seven Monongahela River tributaries.
- Sulfate trends mirror TDS trends.
- All tributary sites show decreasing trends throughout the study period, though the magnitude and statistical significance vary greatly and were generally low.
- Tributaries with large negative trends included Dunkard Creek and Flaggy Meadows Run.

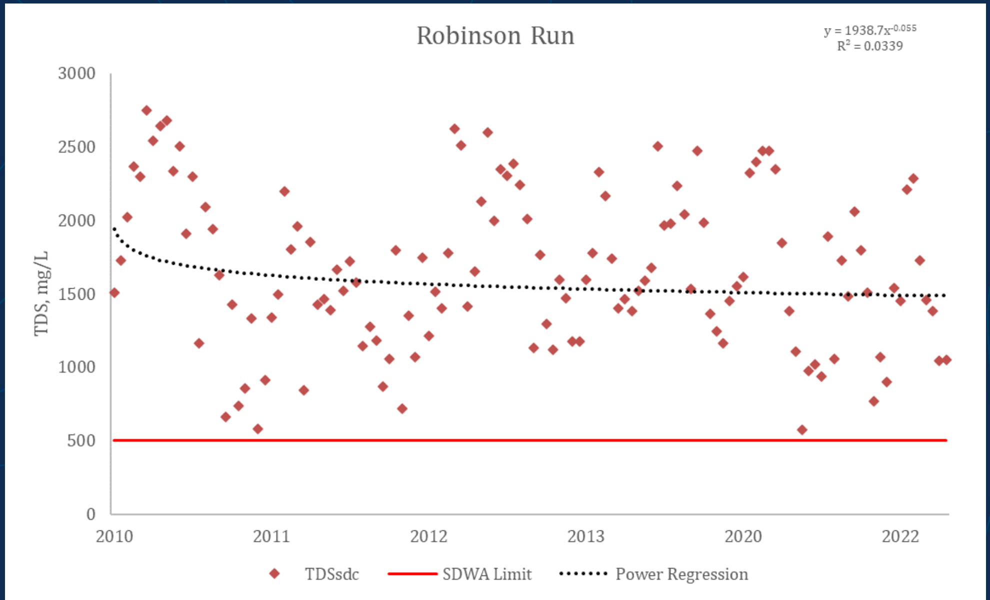
Tributary Trends Cont.

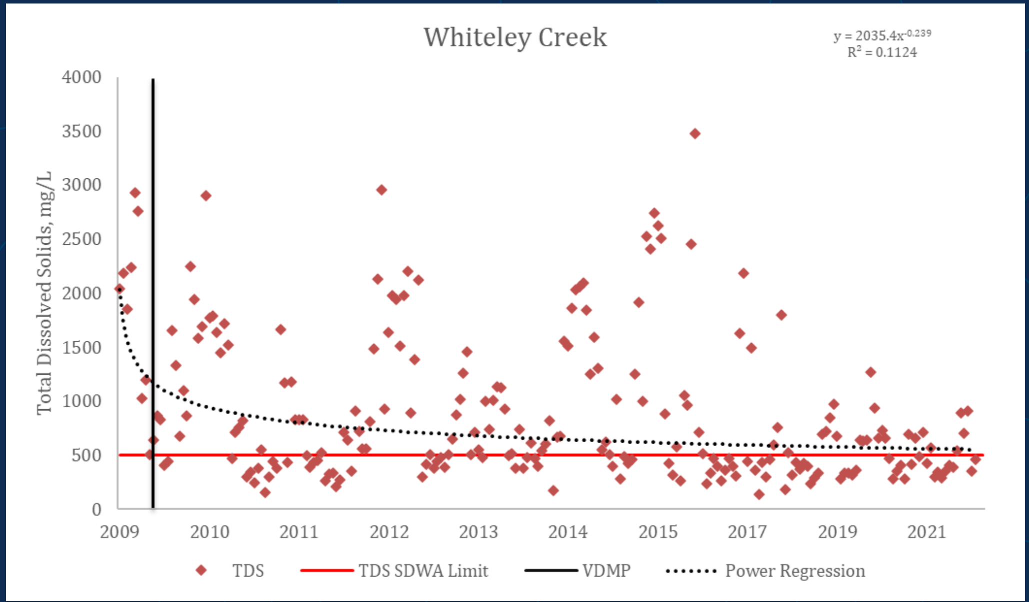
- Dunkard Creek TDS and sulfate levels improved visibly coinciding with the implementation of the VDMP in 2010 and have continued to improve since then.
- Notably, DU values have not exceeded the TDS or sulfate standards since December 2017.

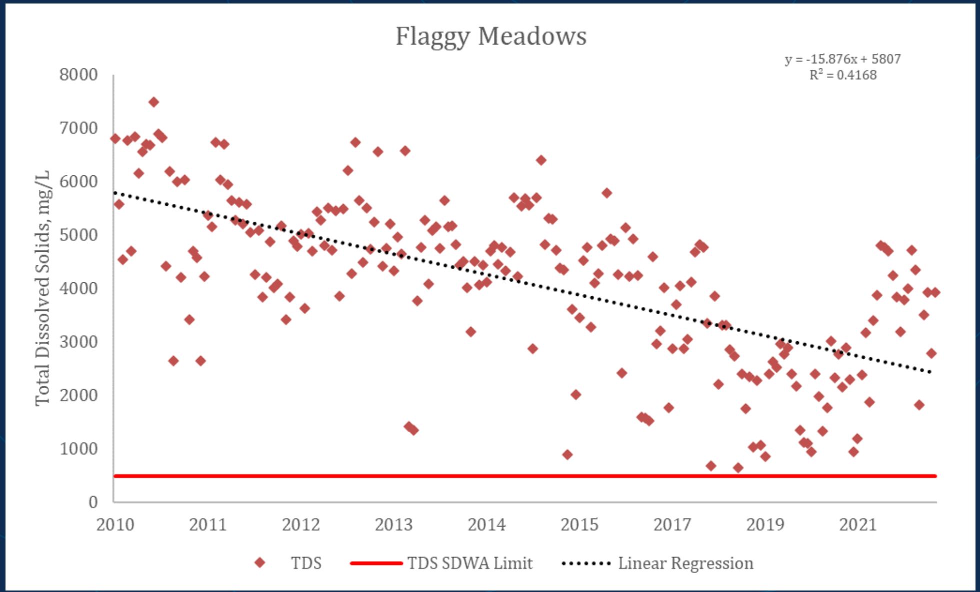


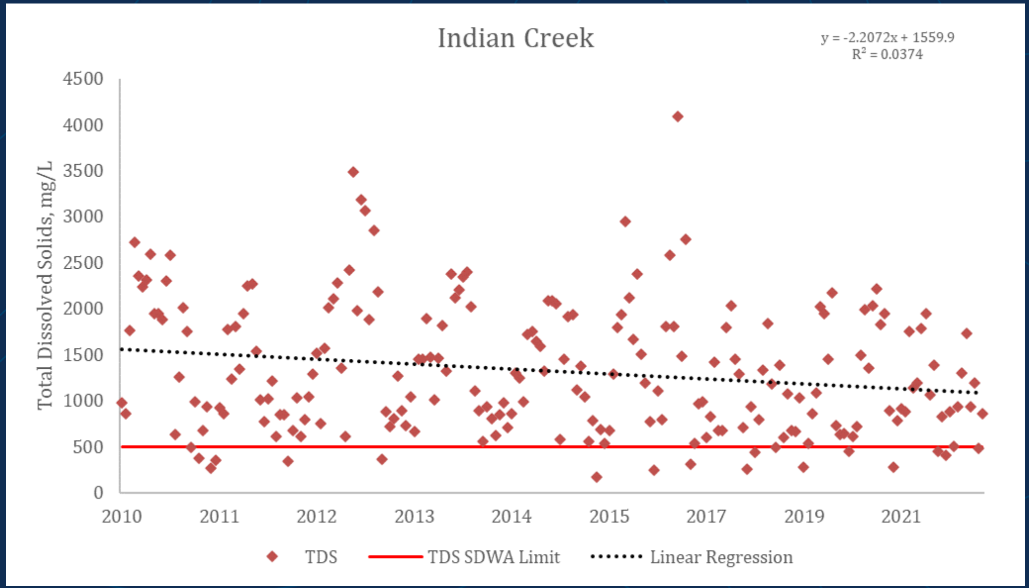
Tributary Trends Cont.

Despite improvements, Flaggy Meadows Run, Robinson Run, Whiteley Creek, and Indian Creek consistently display TDS and sulfate concentrations above the SDWA standards.



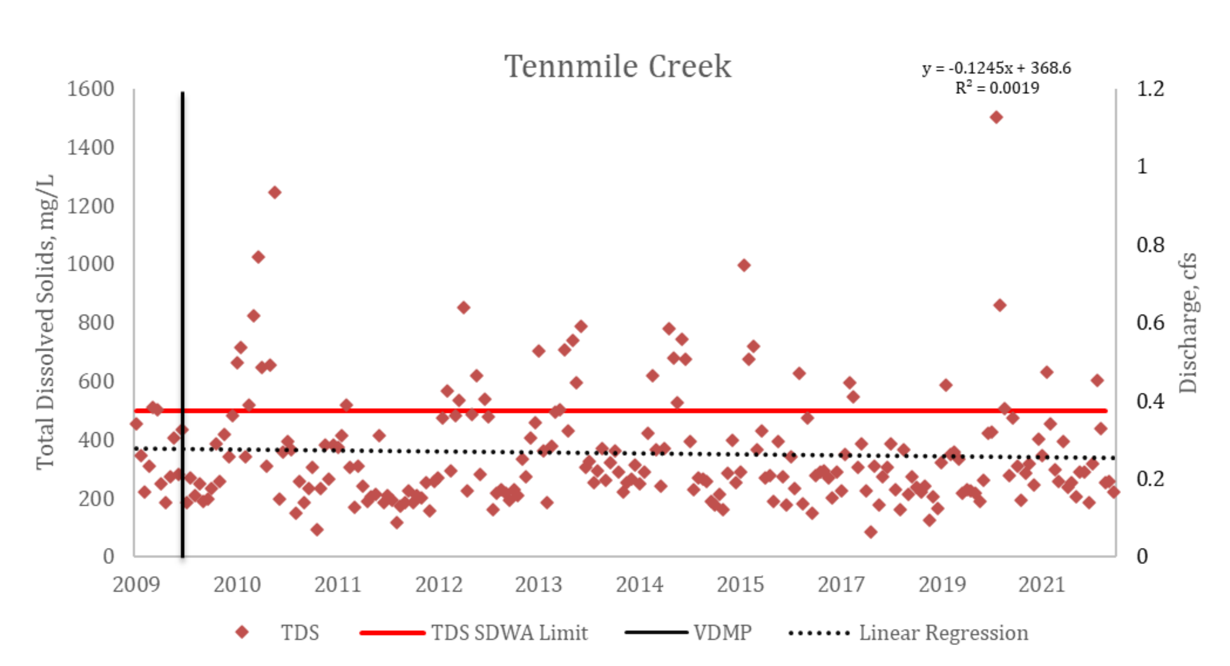


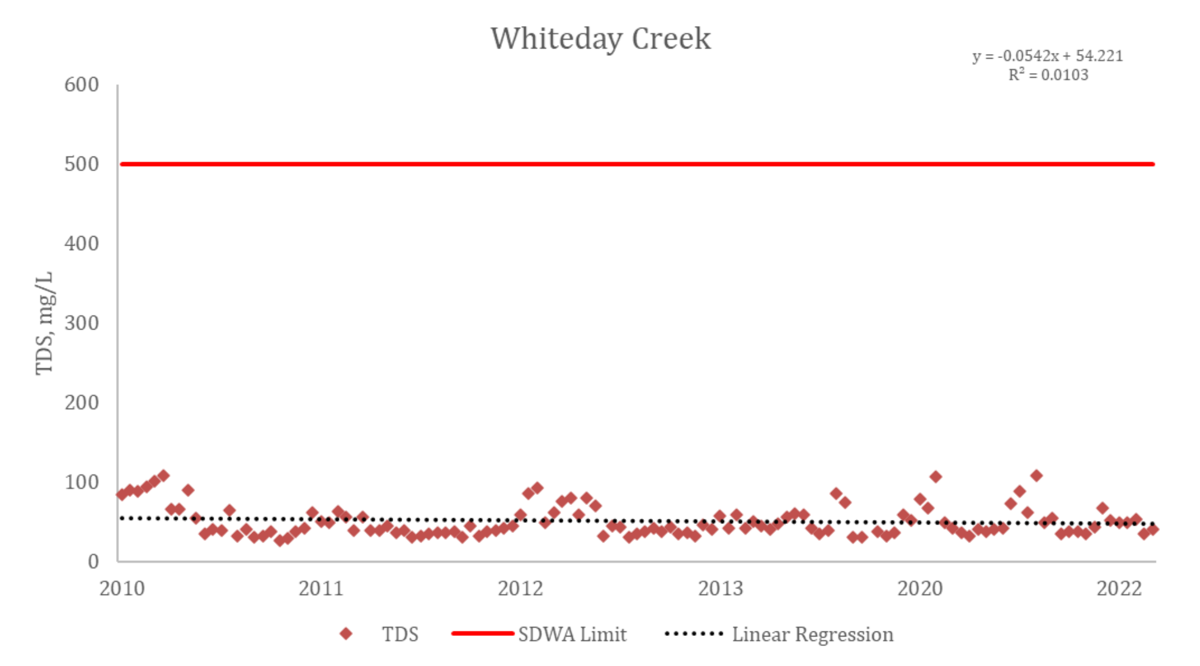


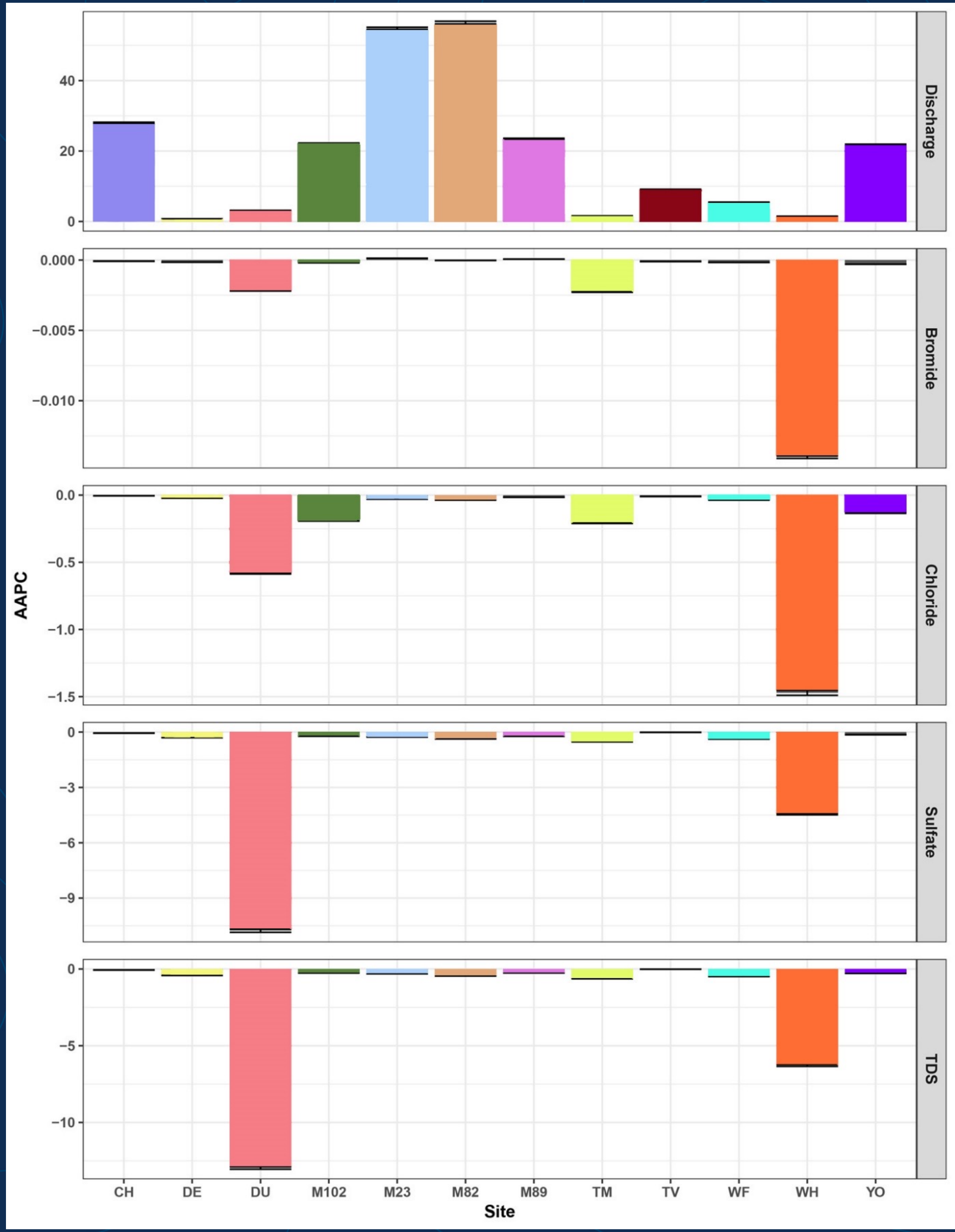


Tributary Trends Cont.

- Tenmile Creek and the control site, Whiteday Creek, displayed no trend.



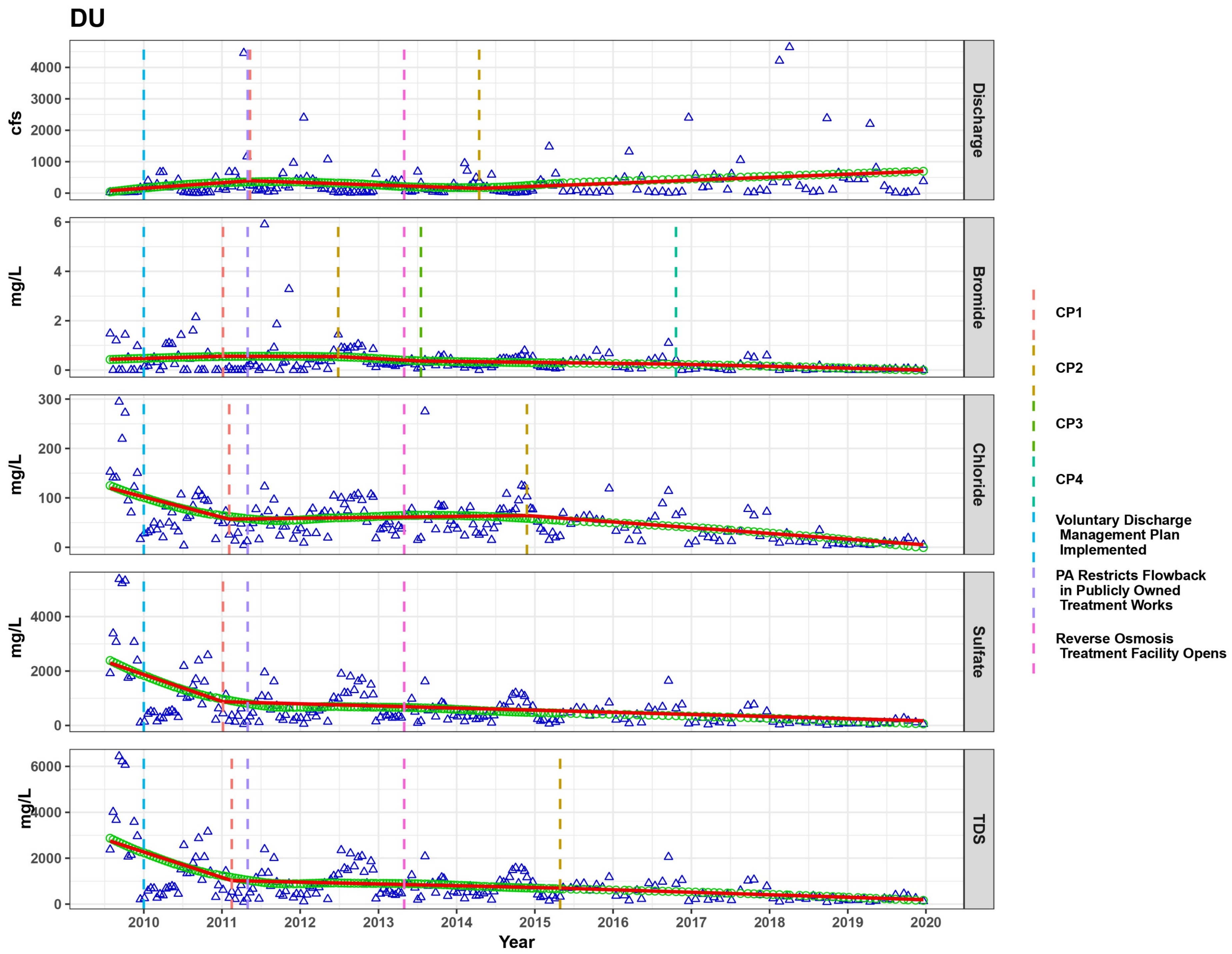




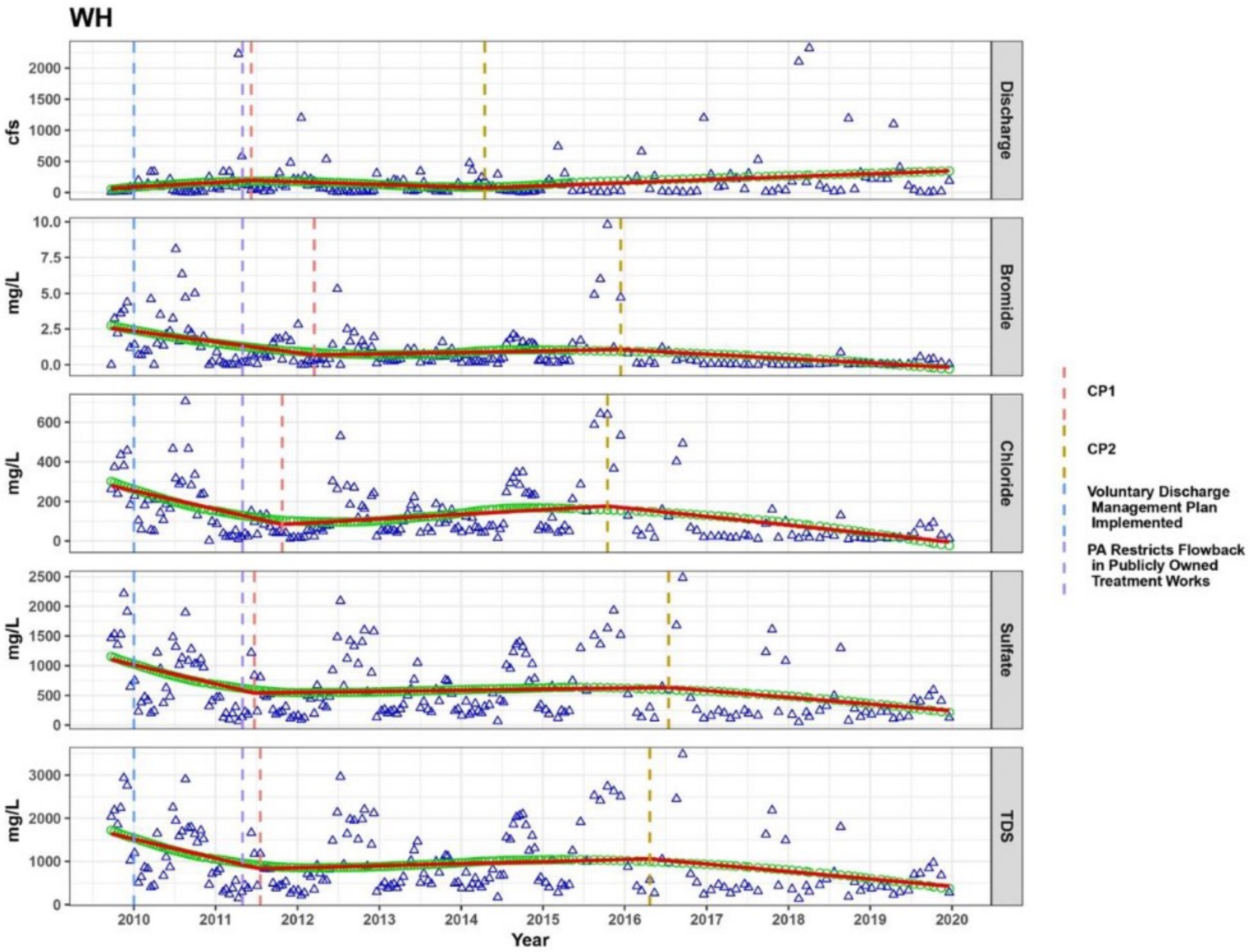
Average annual percent change (AAPC) values across sites (bottom axis) and parameters. Colorized from Kingsbury et al., 2023.

Basin-Wide Trends

- AAPC indicates the average yearly change in a parameter throughout a study period.
    - Positive AAPC = increase in the parameter.
    - Negative AAPC = decrease in the parameter.
- The AAPC in discharge was positive at all sites, indicating an average annual increase in discharge during the study period.
- The AAPC values for Br, Cl, sulfate, and TDS were negative at all sites with the exception of a slight positive AAPC in Bromide at M89 and M23.
- Dunkard Creek exhibited the largest negative AAPC in sulfate and TDS, further indicating a decreasing trend for both parameters.
- Whiteley Creek showed significant negative AAPC values for Br, Cl, sulfate, and TDS.



- Model output for Dunkard Creek showing key dates and changepoints.
- Dashed lines = key dates and changepoints
- Blue triangles = raw data
- Green circles = smoothed data from locally weighted polynomial regression
- Red lines = segmented regression

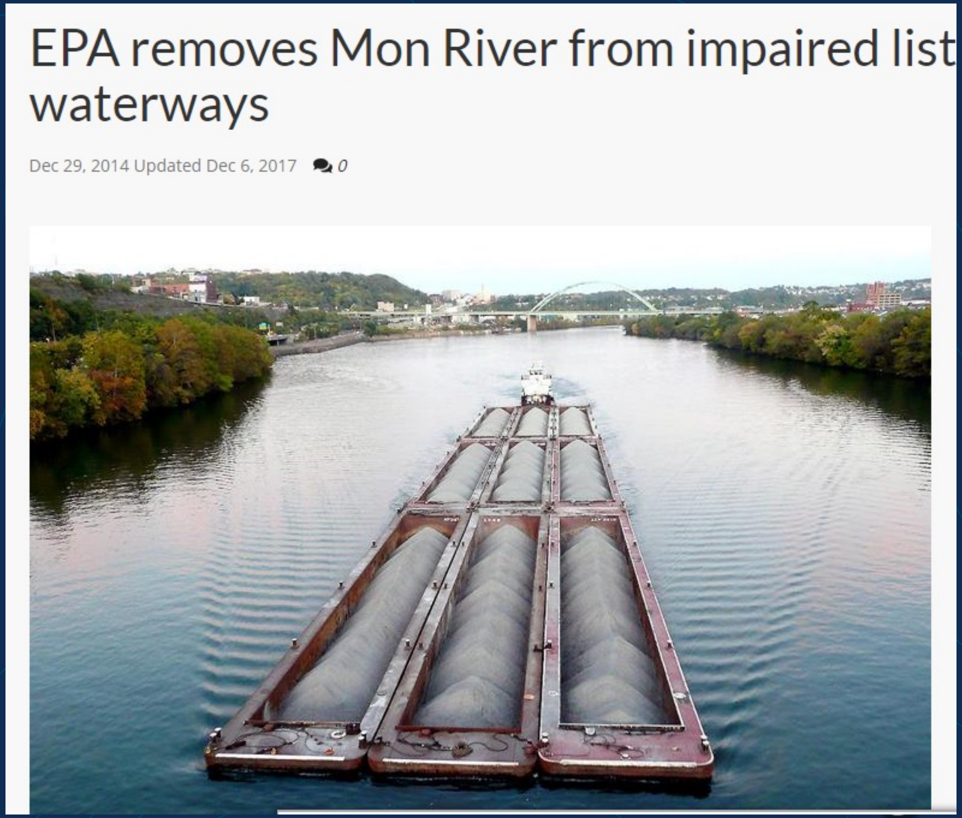


- Model output for Whiteley Creek showing key dates and changepoints.
- Dashed lines = key dates and changepoints
- Blue triangles = raw data
- Green circles = smoothed data from locally weighted polynomial regression
- Red lines = segmented regression


Discussion

Key takeaways

- Substantial improvements at heavily impacted sites (DU, WH, & FM).
- Monongahela is no longer listed as sulfate impaired (delisted 2014).
- Voluntary TMDLs are effective, inexpensive, and rapid remedial actions.
- Continued participation of coal industry is key.

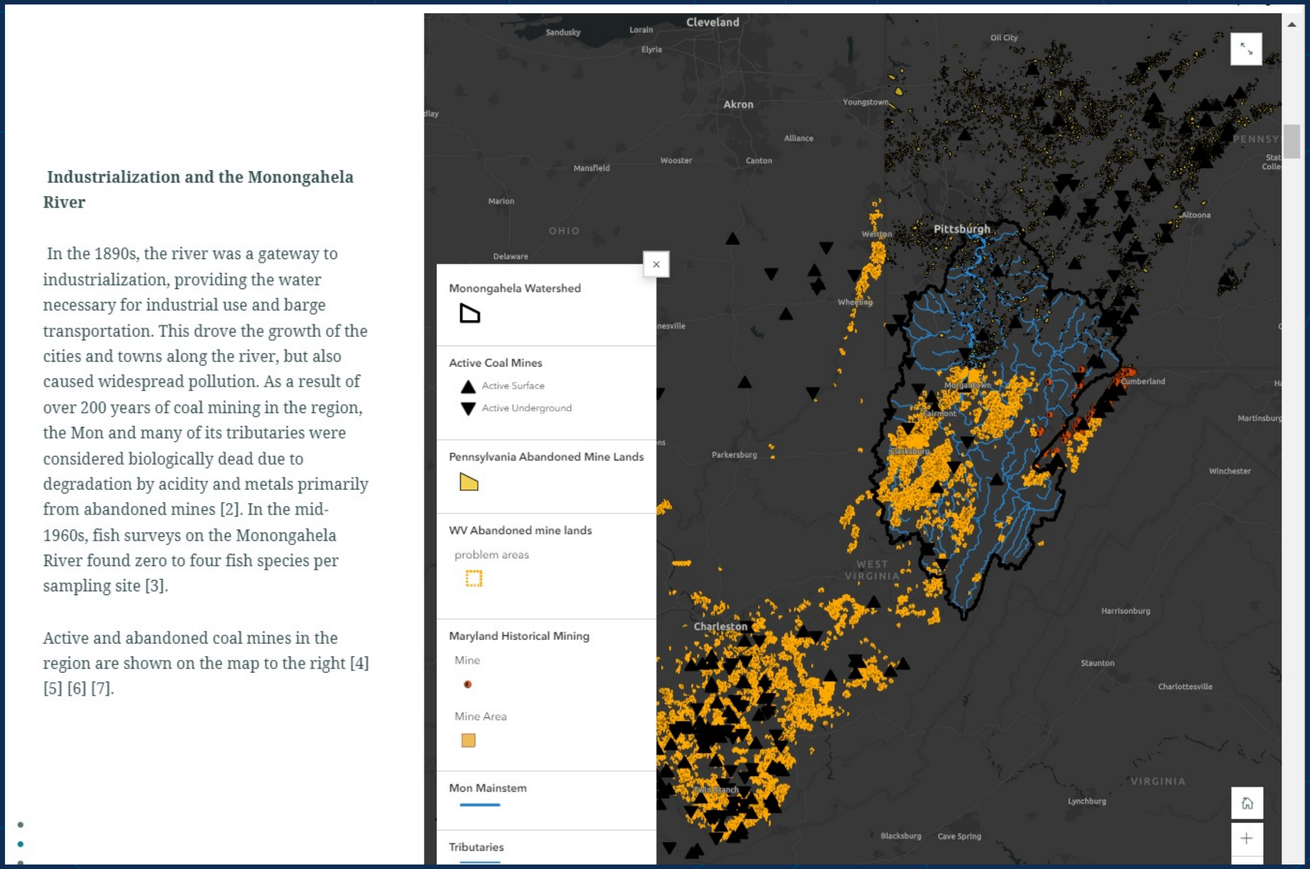


Future Directions

- Further investigations into varying impact of the VDMP on tributaries
  - This could be attributed to how strictly the VDMP is followed, the size and number of treatment facilities, mine pool level variability, and the assimilative capacity of the receiving stream. Outside influences such as changes in industry, development, and land use may also impact tributary TDS concentrations.
- Incorporate additional land use variables into the model.
- Push for additional volunteer dischargement plans with private industry.

Learn More

- [*Water* Publication (Feb 2023)]
- Explore the Monongahela River StoryMap: three-rivers-quest-wvu.hub.arcgis.com/
- Collaborate with 3RQ



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USGS
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Questions?