Analyzing Sediment and Bacterial Pollutant Sources in the Milwaukee River Watershed to Enhance Total Maximum Daily Load (TMDL) Mitigation Strategies

Highlights

- The presence of Total Suspended Solids (TSS) and Fecal Indicator Bacteria (FIB) in urban watersheds is a critical issue affecting water quality and public health. Effective management of these pollutants is challenging because the sources and timing of the loading into water systems is not well characterized.
- Scientists from the University of Wisconsin – Milwaukee's School of Freshwater Sciences conducted a two-year study on the Milwaukee River to understand TSS and FIB sources and loading during wet weather events. Using high-frequency sampling, microbial source tracking, DNA sequencing, and radioisotope signatures, they revealed TSS and FIB sources are disconnected, with TSS originating primarily from agricultural landscapes, while FIB was sourced mainly from urban areas.
- Extreme weather events are the major drivers of pollutant loading, which will only increase with climate change. Existing management strategies may not be equipped to deal with these changing conditions and pollutant loading will worsen if we keep the status quo.
- This research highlights the need for separate management strategies for TSS and FIB. TSS mitigation should target rural, upstream regions, while FIB mitigation should focus on improving wastewater and stormwater infrastructure in urban areas.

Introduction

The presence of TSS and FIB in urban watersheds has emerged as a pressing issue with significant implications for both water quality and public health across the country. TSS and FIB are exacerbated by wet weather events, making effective management strategies challenging to implement. One challenge lies in identifying the timing and locations of pollutant loading, and where mitigation should be focused. Understanding the primary sources of TSS and FIB not only informs management strategies but also provides data to inform public communication about potential risks of coming into contact with the water.

Urban waterways across the U.S. are polluted by many different sources. The Clean Water Act requires Total Maximum Daily Loads (TMDLs) for specific pollutants that are so high the waters are considered "impaired" for not meeting water quality standards. TMDLs are restoration plans that establish the maximum quantity of a pollutant that can be discharged into a waterbody. Complexities arise from the presence of multiple pollutants, from a variety of point and non-point sources, and the impact of precipitation on how those pollutants enter water systems. The Milwaukee River, located in southeastern Wisconsin, is impaired for TSS and FIB and a TMDL for these pollutants was approved by the U.S. Environmental Protection Agency in 2018. Elevated TSS and untreated human and animal waste in the Milwaukee River Basin have led to degraded habitat, low water clarity, and recreational detriments. As a result, impairments to beneficial uses within the basin, such as preservation and enhancement of fish and other aquatic life and recreational use, have occurred.

Definitions

- *Total Maximum Daily Load (TMDL)* – the maximum amount of a specific pollutant that a waterbody can receive on a daily basis and still meet water quality standards.
- *Total Suspended Solids (TSS)* – the collective mass of solid particles suspended in a liquid, typically measured in milligrams per liter (mg/L)
- *Fecal Indicator Bacteria (FIB)* – microbes that are commonly used as indicators of fecal contamination.
    - *Fecal Coliform (FC)* - specific FIB that were measured in this study as colony forming units (CFUs)
- *Combined Sewer Overflow (CSO)* – occurs when stormwater overwhelms water treatment facilities, resulting in untreated sewage entering a waterway.
- *Maximum Extent Practicable (MEP)* **-** Regulator, here WDNR, should adapt continually to both current conditions and effectiveness of Best Management Practices in Municipal Separate Storm Sewer System (MS4) permits to meet water quality. If, after implementing the minimum control measures, there is still water quality impairment associated with discharges from the MS4, WDNR will need to expand or better tailor practices and measurable goals.

Research Questions

- What are the sources of total suspended solids (turbid plumes) in the Milwaukee River?
- Are turbid water plumes associated with human health risks?
- Do microbial signals provide evidence of upstream (rural) versus downstream (urban) pollution sources?

Methods

To understand pollutant loading and sources of TSS and FIB across the Milwaukee River watershed, researchers used a multi-layered approach, including high-frequency sampling, radioisotope signatures, microbial source tracking (MST) bacterial markers specific to humans or animals to differentiate human and agricultural pollution sources, and microbial community DNA sequencing to determine the scale, timing, and source of pollutants in the watershed. In total, 1353 water samples were collected across 13 event periods, 11 of which focused on precipitation. Water and sediment samples underwent analysis for FIB and TSS that included DNA sequencing to identify bacteria associated with human waste.

To study TSS in the river, the researchers placed vertical and horizontal traps at three locations along the Milwaukee River in 2018: two locations in upstream reaches of the river in a primarily undeveloped and agricultural landscape, and one in a downstream urban reach. In 2019, they focused their efforts on the downstream location and collected samples during specific wet weather events. Vertical and horizontal traps collected water and sediment samples at various depths in the water column, while grab sampling provided additional sediment samples from each of the sampling locations. Researchers collected a total of 80 samples for radioisotope analysis and 31 samples for studying the sediment microbial community.

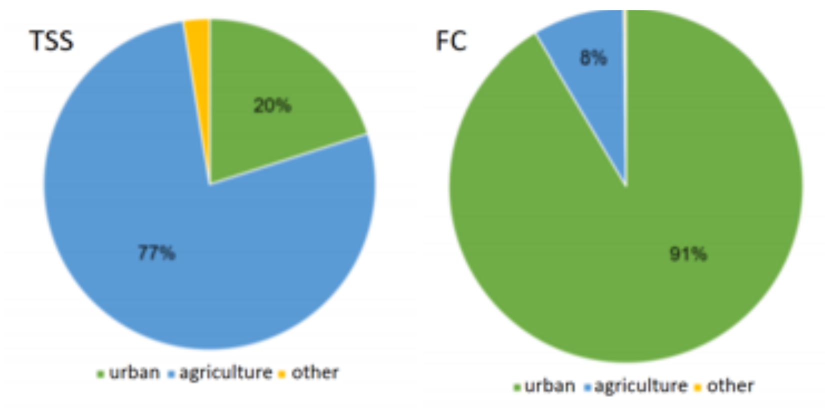

Figure 1 shows the proportions of TSS and FC loads based on microbial source tracking. Upstream agricultural sources contribute a majority of the TSS load measured while downstream urban sources contribute a majority of the measured FC load.

Findings

1. Yearly loading of TSS was estimated at 1.28×10^{7} - 5.14×10^{7} kg to the river. The TMDL estimate of 2.6×10^{7} kg per year falls into the low end of the study's range.
2. TSS exceeded the average TMDL allocation during nearly all rainfall events.
3. Yearly loading of FC was estimated at a range from 9.85×10^{15} - 1.21×10^{17} FC CFU to the river, significantly higher than the TMDL estimate at 4.1×10^{13} FC CFU.
4. TSS and FIB do not come from the same sources. TSS loading is primarily from upstream/agricultural sources, while FIB is primarily from downstream/urban sources.
5. This study used microbial source tracking to show that the urban source of FIB loading was from human waste, thus meaning a high likelihood of pathogens that can harm human health. Also, source tracking indicated agricultural-derived fecal bacteria were transported consistently to the downstream reaches of the river late in the period influenced by rain events.
6. For the group of sample events in this study, the proportion of total FIB load attributed to CSOs was 28%, however, modeling simulations for TMDLs that consider precipitation events across the whole year estimated that CSOs contribute 6% of total FIB. This difference suggests that the group of samples used in this study overrepresented CSO events in relation to other rain events. Rain events, even in the absence of a CSO, delivered significant microbial loads including a substantial influx of human-source FIB into the river. In other words, the sewage pipes leak sewage when it rains. While TSS and FIB both increased dramatically during extreme rain events the pollutants show different dynamics as they come from different locations. TSS loading from rain events is coupled with increased river flow, making the loading more predictable. FIB is not captured well by river flow so high-frequency sampling is needed to determine these specific FIB dynamics and more accurately measure FIB loading.
7. Because large rain events drive significant amounts of TSS and FIB into the system, climate change will likely worsen these current issues as climate models predict these events to increase.

Management Implications

As TSS and FIB are not connected, different management strategies are required to reduce these pollutants in the Milwaukee River watershed and meet established water quality standards. TSS will require mitigation efforts in the upstream, rural reaches of the Milwaukee River, including limiting peak flow to decrease erosion by expanding stormwater retention systems and adding best management practices on agricultural fields. FIB mitigation should be focused in downstream, urban zones where leaky sanitary systems are the likely culprit. TMDL levels are most often exceeded during large storm events. Since climate models predict the frequency of large storm events to increase, managers should plan to increase mitigation strategies to account for increased pulses into the river of storm-related flow.

Ruminant-sourced FIB are primarily measures of bacteria from cows but also can include other sources such as deer, goats, and sheep. Implementing best management practices will help address upstream agricultural TSS loading and FIB associated with cattle operations, which were shown to reach the downstream urban portion of the river. One avenue is by increasing awareness of cost-sharing programs and incentives with the Wisconsin Department of Natural Resources and Wisconsin Department of Agriculture, Trade, and Consumer Protection to local governments and farmers. This research suggests targeting inputs, such as manure application, during the early season to mitigate such impacts.

To address FIB from urban areas, this research suggests strategically using human-source FIB monitoring to identify and fix any cross contamination from sanitary sewage. Further monitoring of the microbial community at high temporal resolutions can be used to detect rapid changes in response to heavy rainfall events and ultimately pinpoint critical periods of pollution runoff and where those loadings originate. Overall, this research suggests that combining microbial community mapping with frequent sampling can be a valuable tool for understanding the transport of pollutants into water systems and identifying priority areas of pollution mitigation efforts.

Another potential avenue of addressing FIB in urban areas is through the MS4 permit. To meet the MS4 permit standard, permits need to include conditions that satisfy the requirements of the Clean Water Act by protecting water quality and reducing the discharge of pollutants to the "Maximum Extent Practicable." The MEP idea purposefully does not have a specific definition so that there can be maximum flexibility in permitting to account for various factors including the best available technology and economics. However, with FIB testing becoming more readily available and a cost-effective option to investigate and eliminate fecal bacteria sources found in storm sewers, the WDNR should continue to update MS4 permits to reflect these changes. A tiered approach to bacteria testing will help permitted municipalities within the Milwaukee River TMDL apply existing science to efficiently target and address fecal bacteria. In a tiered approach, if there is flow from an outfall during dry weather, a sample is taken and tested for pollutant indicators, including fecal bacteria. If FIB is detected, the sample should then be tested for human source bacteria. Using a source specific bacterial indictor will help pinpoint human vs non-human (e.g., nuisance wildlife, dog waste, etc.) sources and aid in developing appropriate mitigation strategies to eliminate illicit discharges of sewage or target agricultural practices to meet the TMDL and protect public health.

Separate strategies to mitigate TSS and FIB will be necessary to reduce the loading of these pollutants and meet the water quality standards, protect public health, and remove the Milwaukee River from the impaired waters list.

Policy Recommendations

- Implement an integrated watershed management approach that considers both TSS and FIB mitigation strategies to meet water quality standards for these pollutants.
- Establish comprehensive and real-time monitoring systems for TSS and FIB, particularly during wet weather events.
- Clarify monitoring procedures and standardize monitoring of these pollutants to better compare over various sources and monitoring entities.
- The WDNR should implement a tiered approach to bacteria testing in all MS4 permits in the Milwaukee River watershed.
- Incentivize agricultural landscape best management practices in upstream, rural zones to reduce TSS and ruminant-sourced FIB. Increase awareness of cost-sharing programs with the WDNR and DATCP for local governments and stakeholders to reduce agricultural nonpoint source TSS runoff.
- Review CAFO permits to reduce TSS and cattle-sourced FIB from agricultural sources.
- Establish a centralized data-sharing platform that integrates multiple data sources including water quality monitoring stations, weather forecasts, and localized microbial DNA sequencing and mapping.
- Launch stakeholder and community engagement campaigns to raise awareness about the sources and impacts of TSS and FIB pollution in water systems.

Citations

McClary-Gutierrez, J. S., Koster, E., Grow, J., Dila, D. K., Klump, J. V., McLellan, S. L., & Newton, R. J. (2023). *High-frequency sampling across precipitation events reveals unique sources and uncoupled loading of urban river pollutants.* Preprint.

Milwaukee Metropolitan Sewerage District. (2020). *P2738: Determining Sediment and Bacterial Sources and Linkages to Inform and Evaluate Total Maximum Daily Load (TMDL) Implementation: Final Report*. June 30, 2020. McLellan, S., Klump, J. Val, Newton, R., McClary-Gutierrez, J., Koster, E., Dila, D., Grow, J. School of Freshwater Sciences, University of Wisconsin-Milwaukee.

Olds H.T., Corsi S.R., Dila D.K., Halmo K.M., Bootsma M.J., & McLellan S.L. (2018). *High levels of sewage contamination released from urban areas after storm events: A quantitative survey with sewage specific bacterial indicators. PLoS Med* Jul;15(7):e1002614. https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1002614.

Scanlan, M. K., Tai, S. (2013). *Marginalized Monitoring: Adaptively Managing Urban Stormwater*. UCLA Journal of Environmental Law and Policy, 31(1). http://dx.doi.org/10.5070/L5311019150.

Wisconsin Department of Natural Resources. *General Permit to Discharge Under the Wisconsin Pollution Discharge Elimination System.* WPDES Permit No. WI-S050075-3. Feb. 10, 2022. https://dnr.wisconsin.gov/sites/default/files/topic/Stormwater/WPDES-WI-S050075.pdf.

Wisconsin Department of Natural Resources & Milwaukee Metropolitan Sewerage District. (2018). *Total Maximum Daily Loads for Total Phosphorus, Total Suspended Solids, and Fecal Coliform Milwaukee River Basin, Wisconsin.* March 19, 2018. (prepared by CDM Smith). https://dnr.wisconsin.gov/topic/TMDLs/Milwaukee/index.html.

Center for Water Policy

University of Wisconsin UW Milwaukee | School of Freshwater Sciences

The Center's mission is to provide world class interdisciplinary solutions to resolve regional, national, and international problems related to the protection, restoration, and conservation of freshwater resources to ensure long term environmental health and quality of life.

Established in 2011 through a $2.6 million Endowment from Lynde B. Uihlein, the Center builds on the research of the School of Freshwater Sciences, the UW System, and networks and partnerships with top scholars, scientists, and policy institutions across the country and around the world.

600 E Greenfield Ave.
Milwaukee, WI 53204

Email: waterpolicy@uwm.edu
Follow us on Twitter and Instagram
@uwmwaterpolicy

PREPARED BY

Joseph Bevington, Water Policy and Science Communications Fellow 2022-2024

Rajpreet Grewal, Water Policy Specialist 2023-2024, Sea Grant UW Water Science-Policy Fellow

Sandra McLellan, Distinguished Professor, Lynde B. Uihlein Professor in Ecosystem Health, UW-Milwaukee's School of Freshwater Sciences

Ryan Newton, Associate Professor, UW-Milwaukee's School of Freshwater Sciences

Melissa Scanlan, Lynde B. Uihlein Endowed Chair and Professor in Water Policy at UW-Milwaukee's School of Freshwater Sciences, Director of the Center for Water Policy