Improving the EPA Multi-Sector General Permit for Industrial Stormwater Discharges (2019)

DETAILS

195 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-48846-4 | DOI 10.17226/25355

CONTRIBUTORS

Committee on Improving the Next-Generation EPA Multi-Sector General Permit for Industrial Stormwater Discharges; Water Science and Technology Board; Division on Earth and Life Studies; National Academies of Sciences, Engineering, and Medicine

SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine 2019. *Improving the EPA Multi-Sector General Permit for Industrial Stormwater Discharges*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25355.

PREPUBLICATION COPY

Improving the EPA Multi-Sector General Permit for Industrial Stormwater Discharges

Committee on Improving the Next-Generation EPA Multi-Sector General Permit for Industrial Stormwater Discharges

Water Science and Technology Board

Division on Earth and Life Studies

This prepublication version of Improving the EPA Multi-Sector General Permit for Industrial Stormwater Discharges *was provided to the public to facilitate timely access to the publication. Although the substance of the publication is final, editorial changes may be made throughout the text and citations will be checked prior to publication. The final publication will be available through the National Academies Press later this year, 2019.*

A Consensus Study Report of

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

THE NATIONAL ACADEMIES PRESS
Washington, DC
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

Support for this activity was provided by the Environmental Protection Agency. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

International Standard Book Number-13:
International Standard Book Number-10:
Digital Object Identifier: https://doi.org/10.17226/25355

Additional copies of this publication are available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; Internet, http://www.nap.edu.

Printed in the United States of America

Suggested citation: National Academies of Sciences, Engineering, and Medicine. 2019. *Improving the EPA Multi-Sector General Permit for Industrial Stormwater Discharges.* Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/25355

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. C. D. Mote, Jr., is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.nationalacademies.org.**

PREPUBLICATION COPY

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

Consensus Study Reports published by the National Academies of Sciences, Engineering, and Medicine document the evidence-based consensus on the study's statement of task by an authoring committee of experts. Reports typically include findings, conclusions, and recommendations based on information gathered by the committee and committee deliberations. Each report has been subjected to a rigorous and independent peer review process and it represents the position of the National Academies on the statement of task.

Proceedings published by the National Academies of Sciences, Engineering, and Medicine chronicle the presentations and discussions at a workshop, symposium, or other event convened by the National Academies. The statements and opinions contained in proceedings are those of the participants and not endorsed by other participants, the planning committee, or the National Academies.

For information about other products and activities of the National Academies, please visit nationalacademies.org/whatwedo.

PREPUBLICATION COPY

COMMITTEE ON IMPROVING THE NEXT-GENERATION EPA MULTI-SECTOR GENERAL PERMIT FOR INDUSTRIAL STORMWATER DISCHARGES

ALLEN P. DAVIS, *Chair*, University of Maryland, College Park
ROGER T. BANNERMAN, Wisconsin Department of Natural Resources (Retired)
SHIRLEY E. CLARK, Penn State Harrisburg
L. DONALD DUKE, Florida Gulf Coast University, Fort Myers
JANET S. KIELER, Denver International Airport, Colorado
JOHN D. STARK, Washington State University Puyallup
MICHAEL K. STENSTROM,[1] University of California, Los Angeles
XAVIER SWAMIKANNU, University of California, Los Angeles; CalEPA, California Water Board, Los Angeles Region (Retired)

National Academies of Sciences, Engineering, and Medicine Staff

STEPHANIE E. JOHNSON, Study Director, Water Science and Technology Board
CARLY BRODY, Senior Program Assistant, Water Science and Technology Board

[1] See Appendix G, Disclosure of Conflict of Interest.

WATER SCIENCE AND TECHNOLOGY BOARD

Acknowledgments

We would like to express our appreciation to the following people who provided presentations or public comment to the committee.

Fredric Andes, Barnes & Thornburg
William Ashton, Alaska Department of Environmental Conservation
Jim Bachhuber, Brown and Caldwell
June Bergquist, Idaho Department of Environmental Quality
Jim Bertolacini, Wisconsin Department of Natural Resources
Kevin Bromberg, Small Business Administration
Seth Brown, Water Environment Federation and National Municipal Stormwater Alliance
Patrick Burch, West Virginia Department of Environmental Protection
Margarita Chatterton, Rhode Island Department of Environmental Management
Brian D'Amico, Branch Chief, Environmental Protection Agency (EPA's) Office of Science and Technology
Sebastian Donner, West Virginia Department of Environmental Protection
Phillip Flanders, EPA
David Flores, Center for Progressive Reform
Peter Ford, EPA
William W. Funderburk, Jr., Castellón & Funderburk LLP
Greg Gearheart, CalEPA, California State Water Board
Jenelle Hill, EPA
Paul Hlavinka, Maryland Department of the Environmental
Christopher Kloss, EPA
Matthew Lentz, California Stormwater Quality Association
Jeffrey Longsworth, Barnes & Thornburg
James Maroncelli, Washington Department of Ecology
Melinda Pagliarello, Airports Council International–North America
Travis Porter, Washington Department of Ecology
Bryan Rittenhouse, EPA
Edan Rotenberg, Super Law Group
Ken Schiff, Southern California Coastal Water Research Project
Brian Schweiss, Minnesota Pollution Control Agency
Timothy Simpson, GSI Environmental
Richard Smith, Smith and Lowney
Brandon Steets, Geosyntec
Eric Strecker, Geosyntec
Rachel Urban, EPA

Eric Van Genderen, International Zinc Association
Jack Waggener, AECOM
David Wagger, Institute of Scrap Recycling Industries
Laurel Warddrip, CalEPA, California State Water Board
Melissa Wenzel, Minnesota Pollution Control Agency
Ian Wren, San Francisco Baykeeper

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

Peter deFur, Environmental Stewardship Concepts, LLC
Shawn Gibbs, Indiana University
Michael Hanemann, University of California, Berkeley
John Kosco, National Association of Home Builders
Gary Liberson, Gnarus Advisors, LLC
Robert Pitt, University of Alabama
Arthur W. Ray, City of Rockville
Kenneth Schiff, Southern California Costal Water Research Project
Brandon Steets, Geosyntec Consultants
Eric Strecker, Geosyntec Consultants
Melissa Wenzel, Minnesota Pollution Control Agency

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by **George Hornberger (NAE),** Vanderbilt University and **Michael Kavanaugh (NAE),** Geosyntec Consultants. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

Preface

Stormwater is dynamic and complex. Industrial stormwater is only a subset of the stormwater universe, yet complexity is interwoven throughout its generation and management due to the wide range of industrial classifications, the assortment of activities at specific industrial sites, the sizes of these industrial sites, and climate and weather variations. Regulation of industrial stormwater through the Multi-Sector General Permit (MSGP, EPA, 1995, 2000, 2008, 2015) provides federal guidelines that attempt to balance protection of the environment without leading to excess burden on industry. Concerns related to industrial stormwater and the MSGP were highlighted in a 2009 National Research Council (NRC, 2009) report on stormwater in the United States.

In 2017, a committee was created by the National Academies of Sciences, Engineering, and Medicine through support by the Environmental Protection Agency, to address several concerns related to the stormwater monitoring in the MSGP. The committee collected information from individuals and stakeholder organizations representing various interests around the United States and heard from several state industrial stormwater permit regulatory agencies. Much has changed since the first MSGP with respect to understanding the science of stormwater and stormwater treatment, pollutant quantification, and toxicity. The committee considered these advancements and the sensitive balance of environmental protection with business burden. In this report, the committee offers recommendations to address some of the challenges of industrial stormwater, its discharge, and regulation.

Allen P. Davis, *Chair*
Committee on Improving the Next-Generation EPA
Multi-Sector General Permit for Industrial
Stormwater Discharges

Contents

Acronyms and Abbreviations

AD	activity description
AIM	Additional Implementation Measure
BAT	best available technology
BLM	Biotic Ligand Model
BM	benchmark
BMP	best management practices
BOD_5	biochemical oxygen demand (5 day)
CCL	Contaminant Candidate List
CEC	cation exchange capacity
COD	chemical oxygen demand
COV	coefficient of variation
DMR	discharge monitoring report
DOC	dissolved organic carbon
ELG	effluent limitation guideline
EMC	event mean concentration
EPA	Environmental Protection Agency
HDS	hydrodynamic separator
IWTT	Industrial Wastewater Treatment Technology Database
MS4	municipal separate storm sewer system
MSGP	Multi-Sector General Permit
NAICS	North American Industrial Classification System
NAL	numeric action level
NEL	numeric effluent limitation
NELAP	National Environmental Laboratory Accreditation Program
NetDMR	Network Discharge Monitoring Report
NPDES	National Pollutant Discharge Elimination System

NURP	Nationwide Urban Runoff Program
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
QA/QC	quality assurance and quality control
QISP	Qualified Industrial Stormwater Practitioner
SCM	stormwater control measure
SIC	standard industrial classification
SMC	Stormwater Monitoring Coalition
SSC	suspended sediment concentration
SWPPP	stormwater pollution prevention plan
TBEL	technology-based effluent limit
TMDL	total maximum daily load
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
WQBEL	water-quality-based effluent limit

Summary

Industrial stormwater is derived from precipitation and/or runoff that comes in contact with industrial manufacturing, processing, storage, or material overburden and then runs offsite and enters drainage systems or receiving waters. In 1987, Congress significantly expanded the National Pollutant Discharge Elimination System (NPDES) program through amendments to the Clean Water Act to include industrial stormwater runoff conveyed through outfalls directly to receiving waters or indirectly through municipal separate storm sewer systems. This led to a huge increase in the number of industrial facilities that needed to be permitted as point-source discharges. The Environmental Protection Agency (EPA) developed the Multi-Sector General Permit (MSGP) in 1995 to provide permit coverage for the full range of industrial stormwater facilities, grouped by industrial activity. The 2015 MSGP sets the requirements for industrial stormwater management and monitoring in areas where EPA is the permitting authority, including most of Indian country and some federally operated facilities, all U.S. territories, the District of Columbia, and four states (Idaho, Massachusetts, New Hampshire, and New Mexico). The MSGP also serves as a model for states with delegated permitting authority as they develop their own industrial stormwater general permits.

The various industrial stormwater permitting requirements have come under scrutiny since the program's inception. The 2009 National Research Council report *Urban Stormwater Management in the United States* stated that the industrial stormwater program has suffered from poor accountability and uncertain effectiveness at improving the quality of the nation's waters. That report recommended updates to outdated benchmark monitoring requirements and recommended the use of more sophisticated sampling protocols. These issues resurfaced in a recent settlement agreement made between EPA, industries, and environmental groups regarding revisions to the nationwide MSGP for industrial stormwater. As a result of this settlement agreement, EPA asked the National Academies of Sciences, Engineering, and Medicine to convene a committee to study certain aspects of the industrial stormwater program, with an emphasis on monitoring requirements and retention standards (see Box S-1). EPA will use the results of this study to inform its proposed revisions to the 2015 MSGP, which are anticipated in 2020. The committee was not asked to analyze the financial costs of its recommendations; instead, EPA will assess the costs of possible changes in its proposed revision of the MSGP.

BOX S-1
Statement of Task

Three permit programs under the Clean Water Act are used to regulate discharges of stormwater to receiving waters—one for municipalities, one for industrial facilities, and one for construction sites. Of these, industrial stormwater is particularly challenging to control because of the wide range of industrial sectors that must be accounted for, each of which produces a unique suite of contaminants in stormwater. The industrial stormwater permit program includes a small number of individual facility permits as well as general permits that are issued to groups of industries at the state and federal level. The current Multi-Sector General Permit (MSGP) for industrial stormwater covers more than 2,000 facilities nationwide and is used as a framework for dozens of similar state programs.

The National Academies of Sciences, Engineering, and Medicine conducted a study to provide input to EPA as it revises its MSGP for industrial stormwater. The National Academies' committee was tasked to

1. Suggest improvements to the current MSGP benchmarking monitoring requirements. Areas to examine could include

   - Monitoring by additional sectors not currently subject to benchmark monitoring;
   - Monitoring for additional industrial-activity-related pollutants;
   - Adjusting the benchmark threshold levels;
   - Adjusting the frequency of benchmark monitoring;
   - Identifying those parameters that are the most important in indicating whether stormwater control measures are operating at the best-available-technology or best-conventional-technology (BAT/BCT) level of control; and
   - New methodologies or technologies for industrial stormwater monitoring.

2. Evaluate the feasibility of numeric retention standards (such as volumetric control standards for a percent storm size or standards based on percentage of imperviousness).
   - Are data and appropriate statistical methods available for establishing such standards as both technology-based and water quality-based numeric effluent limitations?
   - Could such retention standards provide an effective and scientifically defensible approach for establishing objective and transparent effluent limitations?
   - What are the merits and faults of retention versus discharge standards, including any risks of groundwater or surface water contamination from retained stormwater?

3. Identify the highest-priority industrial facilities/subsectors for consideration of additional discharge monitoring. By “highest priority” EPA means those facilities/subsectors for which the development of numeric effluent limitations or reasonably standardized stormwater control measures would be most scientifically defensible (based upon sampling data quality, data gaps and the likelihood of filling them, and other data quantity/quality issues that may affect the calculation of numeric limitations).

Although the 1995 MSGP was based on sound scientific and public policy principles, the committee found that many of the program elements have been hampered by shortfalls in generating, considering, and acting upon new information. This has resulted in missed opportunities for refining the MSGP monitoring requirements in support of improved stormwater management. In this report, the committee recommends updating MSGP benchmark monitoring requirements and thresholds using a periodic review process to incorporate the latest science and monitoring information into each permit revision. Additionally, the committee recommends allowing more sophisticated monitoring methods, training, and support for enhanced data analysis tools within the MSGP. The committee recommends risk-based tiered monitoring requirements to improve the quality of data from the largest, high-risk facilities, while moderating the burden on the lowest-risk facilities. The major conclusions and recommendations are summarized below.

POLLUTANT MONITORING REQUIREMENTS AND BENCHMARK THRESHOLDS

The primary purpose of the MSGP monitoring program is to ensure that industries are complying with the terms of the permit and appropriately managing stormwater on site to minimize discharges of harmful stormwater pollutants to the local environment. Under the MSGP, all industrial facilities are required to conduct quarterly site inspections performed by the permittee, and approximately 55 percent of permittees are required to conduct chemical-specific benchmark monitoring through quarterly grab samples. If the average of the four quarterly samples exceeds the EPA-established benchmark threshold, monitoring must be continued for another year. Sampling continues until the facility's data show 1 year in which the average of the four quarterly samples meets the benchmark. A benchmark exceedance (based on an average of four samples) is not a permit violation, unless no corrective action is undertaken and exceedances persist. Chapter 2 includes recommendations to improve the benchmark monitoring requirements and thresholds to improve industrial stormwater management.

EPA should require industry-wide monitoring under the MSGP for pH, total suspended solids (TSS), and chemical oxygen demand (COD) as basic indicators of the effectiveness of stormwater control measures (SCMs) employed on site. These parameters can serve as broad indicators of poor site management, insufficient SCMs, or SCM failure, which can lead to high concentrations of these and other pollutants. Industry-wide monitoring of pH, TSS, and COD would also provide a baseline understanding of industrial stormwater management across all sectors. All permitted facilities are currently required to conduct visual monitoring of quarterly stormwater samples, and these additional analyses are relatively inexpensive, minimizing the additional monitoring cost burden. Replacement of COD with total organic carbon (TOC) should be considered once EPA has adequate data to develop a benchmark threshold level.

EPA should implement a process to periodically review and update sector-specific benchmark monitoring requirements that incorporates new scientific information. This process should consider updated industry fact sheets, published literature and industry data, advances in monitoring technology, and other available information, so that the monitoring programs adequately address the classes of pollutants used on site and their potential for environmental contamination. The committee reviewed several sectors where data suggest that stormwater pollutants are common, but little or no benchmark monitoring is required. In some cases, this situation resulted from limitations in the original process where industries self-determined what pollutants to monitor in their group applications, and those results were then analyzed to develop benchmark monitoring requirements. Additional information and data gathering for polycyclic aromatic hydrocarbons (PAHs) could help EPA determine if benchmark monitoring is needed for sectors that have the potential to release PAHs. Periodic monitoring reviews would allow EPA to assess changing industry practices that could affect monitoring needs, new analytical technology for pollutant quantification, as well as current toxicological information. Where data gaps remain, additional sector-specific data-gathering efforts should be initiated.

EPA should update the MSGP industrial-sector classifications so that requirements for monitoring extend to nonindustrial facilities with activities similar to those currently covered under the MSGP. Many facilities and activities generating pollutants of concern in stormwater discharges are not included within the MSGP because the facilities themselves are not considered to be industrial, even though the on-site activities (and associated risks) are similar to those of regulated facilities. These include school bus transportation facilities and fuel storage and fueling facilities. Some states have included these activities in their existing industrial general permits. EPA should examine other facilities with activities similar to regulated facilities and add them to the MSGP so that pollutant risks from these facilities can be appropriately reduced.

Benchmarks should be based on the latest toxicity criteria designed to protect aquatic ecosystems from adverse impacts from short-term or intermittent exposures, which to date have generally been acute criteria. Aquatic life criteria are designed for protection against both short-term (acute) and long-term (chronic) effects on both freshwater and saltwater species. Studies that form the basis of criteria development typically measure acute end points following exposure of aquatic life to consistent pollutant levels for short periods of time, and measure chronic end points following exposure of aquatic life to consistent pollutant levels for longer periods of time. Given the episodic nature of stormwater flow and the likelihood of instream dilution and attenuation, aquatic life criteria based on short-term (acute) or intermittent exposures are typically more appropriate for stormwater benchmark threshold levels than criteria based on long-term (chronic) exposures. Where EPA identifies substantial chronic risks to aquatic ecosystems from intermittent exposures during criteria development, such as for contaminants that bioaccumulate, an equation should be provided to translate chronic criteria for intermittent exposures. In this context, EPA should

- Develop acute aquatic life criteria for benchmarks where they do not currently exist, or where substantial chronic risks to aquatic ecosystems exist from repeated stormwater exposures, develop equations to translate chronic criteria based on intermittent exposures.
- Revisit the application of three benchmarks (iron, arsenic, and selenium) that are currently based on chronic and, in some cases, outdated aquatic life criteria.
- Allow permittees with repeated benchmark exceedances to use the latest aquatic life criteria for selenium and copper to evaluate water quality risk on a site-specific basis and discontinue comparisons to national benchmarks, as appropriate. The latest criteria for selenium and copper include equations for calculating toxicity criteria based on short-term exposure, using additional water chemistry and/or flow data.
- Based on little evidence of adverse effects to aquatic organisms at common levels, suspend or remove the benchmarks for magnesium and iron; benchmarks for these metals can be reinstated if/when acute aquatic life criteria are established or benchmarks are developed based on chronic effects from intermittent exposure.
- Express all benchmarks in the units from which they are derived, to improve communication and reduce reporting errors and provide guidance on the expected level of precision in reported results.

Additional monitoring data collection on the capacity of SCMs to reduce industrial stormwater pollutants is recommended to inform periodic reviews of the benchmark thresholds and identify sectors for which new national effluent limits could help address treatment attainability. Publicly available stormwater data from industrial sites are currently insufficient to determine if there are specific conditions under which industries cannot meet the benchmarks using conventional stormwater treatment systems (e.g., sedimentation, filtration) or if other nontreatment SCMs could reduce concentrations on these sites. Based on limited available SCM performance data, it appears that most standard treatment SCMs can meet the benchmark in at least 50 percent of storm events for TSS and for many pollutants at lower inflow concentrations associated with municipal stormwater. Considering that benchmark exceedance is judged by the average of four sample events, these results suggest that technical achievability is not a major issue for TSS. Limited data suggest that benchmark compliance is more difficult at industrial sites for iron, aluminum, copper, and soft water conditions for lead and zinc; inadequate data are available for other pollutants. To improve our understanding of industrial SCM performance and technical achievability,

- Industries and industry groups should collect scientifically rigorous performance data for common SCMs under typical stormwater conditions to expand the knowledge base and inform future decision making. An appropriate number of storms should be monitored employing proper quality assurance and quality control to ensure data reliability, and design and maintenance information for the SCMs should be provided.
- EPA should encourage industries to collect these data and make them publicly available, such as uploading to the International Stormwater Best Management Practices database.
- EPA should support maintenance of these data for industrial stormwater, just as they are currently supporting the Industrial Wastewater Treatment Technology national database.

For benchmarks based on aquatic life criteria, the additional high-quality data collected can be used to assess the feasibility of achieving the benchmarks with current technology and practices. For technology-based benchmarks, additional data could inform future benchmark revisions to reflect the state of practice, reducing total loads to the extent practicable.

Because of the paucity of rigorous industrial SCM performance data, the development of new numeric effluent limitations (NELs) is not recommended for any specific sector based on existing data, data gaps, and the likelihood of filling them. Any new NEL that is developed would require extensive new data collection. Several sectors can be identified in recent MSGP data with recurrent high concentration discharges. However, the decision to develop new numeric effluent limitations would need to be informed by thorough SCM performance data that clearly document attainability issues by sector and include a large number of permittees that cannot achieve the benchmarks under the increased oversight of the additional implementation measure (AIM) process, which is currently in planning.

STORMWATER SAMPLING AND DATA COLLECTION

The current MSGP benchmark monitoring requirement focuses on low-cost, coarse indicators of site problems, and the usefulness of the data can frequently be hampered by its variability. Stormwater monitoring data display variability that originates from many different sources, including the variability of precipitation within and among storms and changes in operations over the course of time. In Chapter 3, the committee discusses and recommends improvements in sampling design and procedures, laboratory analysis protocols, and data management to reduce error and improve the reliability of monitoring results to support improved stormwater management.

EPA should update and strengthen industrial stormwater monitoring, sampling, and analysis protocols and training to improve the quality of monitoring data. Specifically, EPA should

- Consider a training or certificate program in stormwater collection and monitoring to ensure that required sampling and data collection are representative of stormwater leaving the site to the greatest extent possible.
- Stay abreast of advancements in monitoring, sampling, and analysis technology that can provide more or better quality information for similar or reduced costs and consider these in future revisions of the MSGP.

EPA should allow and promote the use of composite sampling for benchmark monitoring for all pollutants except those affected by storage time. EPA's disallowance of composite sampling and reliance on grab sampling in the interest of discrete characterization of the highest pollutant concentration is not warranted based on the methods used to derive benchmark thresholds. Multiple composite sampling techniques are available that provide more consistent and reliable quantification of stormwater pollutant discharges compared to a single grab sample. Composite samplers have become common in stormwater monitoring as experience with this approach has increased and costs have declined, and the event mean concentrations that result from composite sampling may reduce the likelihood of exceeding the benchmark compared to first flush grab sampling. Composite sampling is not appropriate for pollutants for which the results may vary over time with storage, such as those that transform or degrade rapidly or interact with the atmosphere (e.g., pH).

Quarterly stormwater event samples collected over 1 year are inadequate to characterize industrial stormwater discharge or describe industrial SCM performance over the permit term. Under the MSGP, if a permittee's average of four consecutive quarterly samples meets the benchmark, a waiver is granted for the remainder of the permit term. For permittees with average results that meet the benchmark, the MSGP should require a minimum of continued annual sampling, to ensure appropriate stormwater management throughout the remainder of the permit term. Extended sampling over the course of the permit would provide greater assurance of continued effective stormwater management and help identify adverse effects from modifications in facility operation and personnel over time. Given the natural variability and the limitations of grab samples, substantial uncertainty is associated with using the average of only four stormwater samples. EPA should analyze industrial stormwater data and sector-specific coefficients of variation to recommend additional increases in sampling frequency, consistent with the EPA's determination of an acceptable level of error for this indicator of SCM performance. Additional continued monitoring at a lower intensity throughout the permit would also increase the overall sample size and thereby reduce the uncertainty in the monitoring results.

State adoption of national laboratory accreditation programs for the Clean Water Act with a focus on the stormwater matrix and interlaboratory calibration efforts would improve data quality and reduce error. NPDES laboratory accreditation programs and stormwater interlaboratory calibration efforts would improve the comparability and reliability of monitoring data. To support these efforts, EPA should publish guidance and case studies on interlaboratory calibration specifically focused on the stormwater matrix, including the establishment of performance quantification levels for stormwater samples. These efforts would promote similar procedures at a national level to ensure the comparability and reliability of test results reported to permitting authorities.

To improve stormwater data quality while balancing the burden of monitoring, EPA should expand its tiered approach to monitoring within the MSGP, based on facility risk, complexity, and past performance. The committee proposes four categories:

1. **Inspection only.** Low-risk facilities could opt for permit-term inspection by a certified inspector or the permitting authority in lieu of monitoring. Facilities could be classified as low risk based on facility size (e.g., less than 0.5 or 1 acre of industrial activity), recognizing that size may not fully represent the risk profile, or more accurately based on a detailed assessment of the type and intensity of industrial activities conducted on site, or a hybrid approach.
2. **Industry-wide monitoring only.** All facilities in sectors that do not merit additional pollutant monitoring would conduct industry-wide monitoring for pH, TSS, and COD. These data would provide broad, low-cost indicators of the effectiveness of stormwater control measures on site.
3. **Benchmark monitoring.** Sectors that merit additional pollutant monitoring, based on the most recent data and industry literature review, would conduct sector-specific benchmark monitoring in addition to pH, TSS, and COD which would be collected by all facilities with chemical monitoring.
4. **Enhanced monitoring.** Facilities with repeated benchmark exceedances or those characterized by the permitting authority as large complex sites with high pollutant discharge potential would conduct more rigorous monitoring, in consultation with the permitting authority. These facilities could collect volume-weighted composite samples at multiple outfalls if appropriate. Additional tools and monitoring strategies could be used to assess the water quality impact to receiving waters from stormwater discharge, including wet-weather mixing zones, dissolved metal sampling, and site-specific interpretation of water quality criteria, with additional guidance from EPA. EPA should develop "nonrepresentative storm" criteria to exclude monitoring for events that would not be representative of facility stormwater discharge.

This tiered system would improve the overall quality of monitoring data to inform future iterations of the MSGP while balancing the overall burden to industry and permitting agencies.

To improve the ability to analyze data nationally and the efficiency and capability of oversight by permitting agencies, EPA should enhance electronic data reporting and develop data management and visualization tools. Electronic reporting has only been required of permittees since 2016, and the data management capabilities are still developing to make the most use of this information at the national and state levels. Automated compliance reminders, improved checks on missing or unusual data, and data analysis and visualization capabilities would improve the effectiveness of staff oversight and provide new opportunities to analyze trends. EPA should develop national visualization tools that can be used to easily examine data for patterns, trends, and correlations.

CONSIDERATION OF RETENTION STANDARDS IN THE MGSP

Stormwater retention for infiltration or beneficial use minimizes pollutant loads to receiving waters and reduces damaging peak flows while potentially increasing water availability. Yet, infiltration of industrial stormwater, which can contain hazardous pollutants in toxic amounts, can pose serious risks to groundwater; these risks must be managed to prevent groundwater contamination. Chapter 4 discusses scientific and regulatory factors affecting the applicability of stormwater retention standards for industrial stormwater. Based on the potential environmental benefits, particularly in areas of water scarcity, the committee encourages the use of industrial stormwater retention with infiltration or beneficial use under conditions where groundwater is protected.

Rigorous permitting, (pre)treatment, and monitoring requirements are needed along with careful site characterization and designs to ensure groundwater protection in industrial stormwater infiltration systems. In lieu of other information on the attenuation of contaminants in groundwater before they are transported to the site boundary, infiltrated water should be required to meet primary drinking water standards for inorganic chemicals and organic chemicals, and secondary standards for chloride and total dissolved solids. Water quality should be monitored and evaluated in the infiltration device or at the base of the vadose zone. Many water quality treatment options are available, ranging from natural removal employing in situ soils to standard SCMs to advanced treatment. Industries considering infiltration should evaluate whether potential stormwater contaminants from routinely occurring pollutants as well as accidents and spills are compatible with infiltration and what technologies are required to remove these contaminants prior to infiltration. Chemicals covered by the Safe Drinking Water Act and unregulated chemicals with known human health risks at concentrations of concern should be evaluated. Meeting stringent water quality requirements may make infiltration cost prohibitive at sites with contaminants that pose a high risk of polluting groundwater. Other factors influencing the feasibility of a retention and infiltration system include the land available, soil infiltration rate, soil chemistry, and depth to groundwater.

Site-specific factors and water quality-based effluent limits render national retention standards for industrial stormwater infeasible within the existing regulatory framework of the MSGP. Retention and infiltration or beneficial use is already allowed within the MSGP as one of many possible SCMs. However, the suitability of retention with infiltration or beneficial use is based on site-specific factors that cannot be generalized nationally into retention standards. Issues such as the design storm size, stormwater quality, receiving water quality goals, and site conditions must be known to ensure performance reliability. Additionally, although retention could be designed using site-specific factors as a technology-based effluent limit, industrial stormwater must also comply with water quality-based effluent limits, which are typically concentration based. It is impractical to design stormwater retention to capture all potential rainfall events, and for storm events that exceed the design standard, discharge or bypass will occur that may exceed the benchmarks.

EPA should consider incentives to encourage industrial stormwater infiltration or capture and use where appropriate. The most significant incentive would be assurance that installation of infiltration in accordance with EPA guidance for determining the appropriate design storm provides relief from the corrective action process associated with episodic exceedances of benchmark thresholds during bypass situations. This could be done through a number of regulatory measures, including a mixing zone allowance, establishment of allowable frequencies of stormwater discharge at levels above benchmark threshold, development of water quality standard exceedance allowances for extreme weather events, or establishment of separate water quality criteria for major wet weather events. Finally, EPA could develop guidance and cases studies for demonstrating that exceeding the benchmark during storms with precipitation amounts greater than the design storm do not result in an exceedance of water quality standards.

EPA should develop guidance for retention and infiltration of industrial stormwater for protection of groundwater. The guidance should include information on applied water quality, treatment offered within the infiltration zone, monitoring requirements, natural attenuation of pollutants, groundwater use designations, and possible impacts of pollutant dilution or mobilization in the subsurface. Because of the potential risks to groundwater, industrial stormwater infiltration is not recommended in states that lack the legal authority to manage and enforce groundwater quality.

OVERARCHING MESSAGE

An overarching theme within the report's recommendations is that the MSGP should incorporate the best available science in the MSGP process. Science continues to improve our understanding of the environmental and human health impacts of industrial stormwater. Technologies for water quality monitoring, stormwater treatment, and modeling are advancing at rapid rates, and new data can inform understanding of the performance of stormwater control measures. New tools are being developed to improve toxicological assessments and data management and visualization. As electronic reporting of industrial stormwater monitoring data becomes fully implemented and integrated for all states, large amounts of valuable industrial stormwater data will be available for analysis, evaluation, and identifying areas for improvement. In general, EPA has been slow to adopt new knowledge into its MSGP permit revisions, but the MSGP should not be a static enterprise. Both permitted facilities and the nation's waters would be best served by a progressive and continuously improving MSGP based on analysis of new data and focused data-gathering efforts, advances in industrial stormwater science and technology, and structured learning to develop and evaluate permit improvements.

PREPUBLICATION COPY

1

Introduction

Stormwater is rainfall or snowmelt runoff, which can occur as sheet flow or flow in a conveyance system or downstream waterway. The Clean Water Act, which was developed "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C. § 1251) regulates stormwater in municipal, construction, and industrial settings under the National Pollutant Discharge Elimination System (NPDES; 40 CFR Pt. 122.3) permit program. Industrial stormwater is derived from precipitation and/or runoff that comes in contact with industrial manufacturing, processing, storage, or material overburden and then runs off site and enters drainage systems or streams. Industrial stormwater does not include direct discharges of wastewater or process water from facilities or stormwater associated with activities exempted from the NPDES program, such as certain agricultural activities.

The NPDES was created to provide a regulatory framework for the control and elimination of the discharge of pollutants to surface waters to restore and maintain the integrity of the nation's waters. This program was initially focused on reducing point-source discharges of pollutants from industrial process wastewater and municipal sewage into receiving waters, which are more easily regulated because they emanate from identifiable locations on a relatively consistent basis. The added regulation of stormwater in the NPDES program has been challenging. Stormwater is produced throughout a developed landscape, and its production and delivery are episodic. In 2009, the National Research Council released a comprehensive report on the Environmental Protection Agency's (EPA's) Stormwater Program that covered all sectors of the program, including municipal, industrial, and construction. This study builds on that report, with a focus on industrial stormwater monitoring and management.

THE CLEAN WATER ACT AND INDUSTRIAL STORMWATER MANAGEMENT

The Clean Water Act requires that effluent limits be established to meet state-determined water quality standards. State water quality standards include designated uses, which identify the uses or goals of each water body or segment (such as aquatic life, water supply, and recreation), and numeric or narrative criteria that will protect or restore the designated use. Effluent limits must consider both the technological capability to control or treat the pollutants (technology-based effluent limits or TBELs) and limits necessary to protect the designated uses of the receiving water (water-quality-based effluent limits or WQBELs).

TBELs are applied through nationally developed effluent limitation guidelines (ELGs). National ELGs are developed by EPA through a rigorous process to determine the effluent limits that are achievable using the best available technology within the economic means of the industry. The development process includes studies of pollutant levels, industry surveys, and a detailed analysis of technological controls, plus economic considerations. ELGs are then applied nationally so that there is no economic advantage to operating and discharging pollutants in one state over another. ELGs may be specific to process wastewater discharge or to stormwater discharge, or may be applied to both. Where national ELGs have not been established, a permit writer may develop numeric effluent limits for categories of industries based on best professional judgment. However, these limits must withstand intense industry and public scrutiny as well as be technically defensible in a court of law and, therefore, are more likely at individual sites with extensive data rather than in national or statewide general permits.

WQBELs are established to meet the designated use objectives of individual receiving waters, which are identified, for the most part, by states. Water quality criteria form the basis for WQBELs. A number of complexities refine the designated use criteria, such as specific types of fish and macroinvertebrate populations expected in the water body, the level of exposure to pollutants in drinking water over a lifetime and acceptable cancer risk, and the type and frequency of human immersion expected in a recreational water body. The amount of pollution that a water body can assimilate and still support beneficial use goals is defined through adoption of water quality criteria. Most often, the criteria are pollutant specific and numeric and are designed around a low-flow dry weather condition, with the idea that this condition represents the highest pollutant concentration in a water body. However, stormwater flows will occur during quite different flow and loading conditions than those for which the criteria are typically established. Questions have been raised about the applicability and relevance of these criteria to wet weather conditions, but separate criteria for wet weather allowances have not been developed and implemented for industrial stormwater discharges. WQBELs are established when analyses determine that a discharge causes or has the reasonable potential to cause or measurably contribute to an instream excursion above water quality criteria. For discharges of process wastewater from traditional sources, these WQBELs are typically numeric, and monitoring data are routinely used to inform the analysis for compliance.

Industrial Stormwater Permitting

Although industrial stormwater discharges were included in some individual NPDES permits in the 1970s and 1980s, stormwater permitting was generally limited to relatively large industrial sites with other discharges of process wastewater. At that time, a large number of industrial stormwater discharges had been deemed to be nonpoint sources or sources of diffuse pollution and were unpermitted. In 1987, Congress significantly expanded the NPDES program through amendments to the Clean Water Act to include industrial stormwater runoff conveyed through outfalls directly to receiving waters or indirectly through municipal separate storm sewer systems. Congress provided timelines for expanding industrial stormwater permit coverage and required EPA to report back with information regarding classes of industrial stormwater discharges that were not widely permitted, the nature and extent of pollutants in those discharges, and procedures and methods specific to industrial stormwater discharge control. Congress also clarified that permits authorizing discharges of stormwater associated with industrial activity were required to meet all applicable provisions of the established permitting program, including TBELs and WQBELs.[1]

[1] Water Quality Act of 1987, Pub. L. No. 100-4, 101 Stat. 7 (1987).

The congressional expansion of industrial stormwater permitting meant a large increase in the number of industrial facilities that needed to be permitted as point-source discharges. In 1990, EPA promulgated these requirements, including details around the use of general permits for administrative efficiency. The general permit approach is an administratively efficient and cost-effective alternative to the individual permit application method. It reduces the administrative burden on the permitting authority and on the permit applicant. Instead of each applicant having to characterize representative samples of stormwater discharge, EPA allowed industry groups to submit a group application and characterize their wet weather discharges based on monitoring data collected from a subset of these facilities.

Multi-Sector General Permit

EPA issued the first Multi-Sector General Permit (MSGP) in 1995 as a 5-year permit. It was subsequently revised in 2000, 2008, and 2015, and the current MSGP extends through 2020. The MSGP provides permit coverage through submittal of a "notice of intent," self-certified implementation of a stormwater pollution prevention plan (SWPPP), and implementation of stormwater control measures (SCMs) to reduce pollution levels in the discharge (see Box 1-1). The 2015 MSGP provides permit coverage for industrial sectors listed in Box 1-2, grouped by general industrial activity descriptions and standard industrial classification (SIC) codes.[2] EPA includes a separate group AD for facilities not covered elsewhere, which may be designated by the EPA administrator or a state with delegated permitting authority. Industrial facilities with no industrial activity exposed to rain, snow, snowmelt, and/or runoff can apply to be excluded from the permit coverage.

BOX 1-1
Stormwater Control Measures for Industrial Stormwater Pollution Management

Stormwater control measures (SCMs) include structural and nonstructural practices designed to reduce a permittee's stormwater pollution discharges. Although SCMs vary by industry, they can broadly be grouped into the following categories:

- Pollution prevention—efforts to use only materials that are nontoxic, nonhazardous, and nonpolluting;Good housekeeping—practices to prevent and contain spills and keep contaminants out of stormwater discharges through orderly facilities;Minimizing exposure—efforts to move indoors or cover industrial activities and chemical storage;Managing runoff—diverting stormwater runoff from nonindustrial areas away from industrial areas;Erosion and sediment control, such as mulching or sodding; andStructural pollution treatment.

Nonstructural practices typically are selected first because they are lower cost to operate and maintain. One example of a nonstructural practice is sweeping/vacuuming. Sweeping/vacuuming collects particulate matter that is greater than a certain size range, depending on the efficiency of the sweeper, thus preventing it from being suspended in stormwater during rain events. Sweeping also may be used on many sites that incorporate structural practices because sweeping reduces the suspended solids concentration reaching the SCM during the storm and may reduce the maintenance frequency of the

[2] The North American Industrial Classification System (NAICS) has since supplanted the SIC codes for commercial activity in North America, and EPA provides a translation from SIC to NAICS on its website.

SCM. Covering of stockpiles of materials also has been used by sites to reduce the exposure of pollutant sources to stormwater runoff.

Structural treatment SCMs can be classified based on their removal mechanisms. The two most common processes are sedimentation and filtration. Particulate matter itself is a pollutant and many pollutants of interest in industrial stormwater are associated with particulate matter of various sizes, including many heavy metals and hydrophobic organic compounds. Removal of these associated pollutants can occur concurrently with particulate matter removal using sedimentation and/or filtration, depending on the particle sizes with which the pollutant is associated.

Larger particulate matter can be removed from stormwater via sedimentation or related density-driven processes. For extended detention facilities, quiescent conditions are created in the stormwater flow path, such as in a pond or wetland, allowing particles with settling velocities greater than the surface overflow rate to settle to the bottom of the system, effectively removing them from the stormwater. For smaller detention facilities, such as manufactured sedimentation devices, during storm events, rapid settling of large particles occurs during the storm and quiescent conditions between storms provides additional removal. Periodic removal of accumulated sediment is required to maintain performance and prevent scour of previously trapped materials.

Filtration is used to remove particulate matter that is too small to be removed effectively by sedimentation. Filtration involves allowing the water to pass through a porous medium. Particles are trapped and may attach to the media. Filters, especially sand filters, historically have been used as a polishing technology. In stormwater treatment, sediment forebays or sumps often precede a filtration system to reduce the solids load to the filter surface and reduce the frequency of clogging. Once the system flow rate drops below a prespecified rate, the system is “clogged” and the collected particles must be removed via physical removal of media and particles, or through a backwashing process. Because of the power requirement for backwashing, it is rarely used in stormwater treatment and media replacement becomes the preferred option. Industrial stormwater treatment mechanisms and treatment efficiencies have been discussed in detail by Clark and Pitt (2012).

Removal of pollutants in industrial stormwater that pass through certain-sized laboratory filters (operationally called “dissolved,” even though they may include both complexed and colloid-bound forms of certain pollutants) is usually more difficult and complex than those associated with particulates. Generally, chemically reactive media, such as peat, compost, activated carbon, biochar, zeolite, and surface-modified sands, are used to remove the dissolved pollutants via adsorption or ion-exchange reactions. Similar to clogging with particulate matter, adsorption and ion-exchange media have finite treatment lifetimes, because available surface sites on the media become saturated. Although some media can be regenerated, this rarely happens in practical applications and the media must be replaced. Other advanced treatment technologies are available to remove dissolved contaminants, including reverse osmosis, but such systems are typically not used for stormwater due to their cost and complexity. Removal of dissolved stormwater pollutants has been reviewed by Clark and Pitt (2012) and LeFevre et al. (2015).

Biological transformations of some pollutants can occur in stormwater SCMs under specific conditions. Nitrogen species and many organic compounds, especially hydrocarbons, can undergo aerobic or anaerobic biotransformations, particularly when sufficient time is provided in the treatment system, usually between storm events.

These treatment devices can also be categorized as passive or active systems, based on their mode of operation, including the use of electricity to operate the system and the use of chemicals to enhance treatment. Treatment systems can be further divided into manufactured or nature-based treatment systems, such as ponds, vegetation, and natural filtration media. These factors may affect long-term costs and environmental considerations.

BOX 1-2
Types of Facilities Required to Obtain Industrial Stormwater Permit Coverage

Sector A: Timber Products Facilities
Sector B: Paper and Allied Products Manufacturing Facilities
Sector C: Chemical and Allied Products Manufacturing and Refining
Sector D: Asphalt Paving and Roofing Materials Manufacturers and Lubricant Manufacturers
Sector E: Glass, Clay, Cement, Concrete, and Gypsum Product Manufacturing Facilities
Sector F: Primary Metals Facilities
Sector G: Metal Mining (Ore Mining and Dressing) Facilities
Sector H: Coal Mines and Coal-Mining-Related Facilities
Sector I: Oil and Gas Extraction Facilities
Sector J: Mineral Mining and Processing Facilities
Sector K: Hazardous Waste Treatment, Storage, and Disposal Facilities
Sector L: Landfills and Land Application Sites
Sector M: Automobile Salvage Yards
Sector N: Scrap Recycling and Waste Recycling Facilities
Sector O: Steam Electric Power Generating Facilities, Including Coal Handling Areas
Sector P: Motor Freight Transportation Facilities, Passenger Transportation Facilities, Petroleum Bulk Oil Stations and Terminals, Rail Transportation Facilities, and United States Postal Service Transportation Facilities
Sector Q: Water Transportation Facilities with Vehicle Maintenance Shops and/or Equipment Cleaning Operations
Sector R: Ship and Boat Building or Repair Yards
Sector S: Vehicle Maintenance Areas, Equipment Cleaning Areas, or Deicing Areas Located at Air Transportation Facilities
Sector T: Treatment Works
Sector U: Food and Kindred Products Facilities
Sector V: Textile Mills, Apparel, and Other Fabric Product Manufacturing Facilities
Sector W: Wood and Metal Furniture and Fixture Manufacturing Facilities
Sector X: Printing and Publishing Facilities
Sector Y: Rubber, Miscellaneous Plastic Products, and Miscellaneous Manufacturing Industries
Sector Z: Leather Tanning and Finishing Facilities
Sector AA: Fabricated Metal Products Manufacturing Facilities
Sector AB: Transportation Equipment, Industrial, or Commercial Machinery Manufacturing Facilities
Sector AC: Electronic and Electrical Equipment and Components, Photographic, and Optical Goods Manufacturing Facilities

Under the MSGP, TBELs are provided either through a limited number of ELGs or through a suite of narrative requirements, some of which are specified for particular sectors (discussed further in the next section). WQBELs in the MSGP are narrative and require the discharge “to be controlled as necessary to meet applicable water quality standards.” EPA states that compliance with TBELs and other permit terms and conditions are expected to result in compliance with water quality criteria and standards. The ambiguity of such compliance expectations for industrial stormwater discharges raises questions of enforceability, public involvement, and permittee liability. More specific requirements have been developed locally in situations where industrial stormwater discharges flow to water bodies that do not meet established water quality criteria and standards. These water bodies are considered impaired and the impairment is addressed through development of a total maximum daily load (TMDL). Development of a TMDL is a process that includes identification of the pollutant causing the impairment, the sources of the pollutant, and controls needed to restore the water body to the point where it meets its designated use.

The original strategy for the MSGP envisioned a broad tool for control of industrial stormwater discharges that, over time, would lead to improved control measures, more specific numeric effluent limitations based on monitoring evidence, and reduced pollutant discharges to receiving waters (57 *Federal Register* 11394 (1992)). In 1990, EPA (55 *Federal Register* 222, 48002) outlined an escalating tiered implementation strategy to reduce the discharge of industrial stormwater pollutants. The strategy included general permits that incorporated basic pollution prevention strategies, site inspections, and reporting (Tier 1); watershed permits (Tier 2); industry-specific permits (Tier 3) for sectors shown to be significant sources of stormwater pollutants; and individual permits (Tier 4) tailored to specific facilities that are significant sources of stormwater pollutants. The original implementation strategy has not been realized. Rather than move coverage to watershed permits, industry-specific permits, and individual permits, EPA has continued to provide coverage under a single permit, the MSGP.

The MSGP sets the requirements for industrial stormwater management in areas where EPA is the permitting authority, including most of Indian country,[3] some federally operated facilities, all U.S. territories, the District of Columbia, and four states (Idaho, Massachusetts, New Hampshire, and New Mexico).[4] As of September 2018, the MSGP covered 2,174 facilities (R. Urban, EPA, personal communication, 2018). In most of the country, the MSGP serves as a model for states with delegated permitting authority to adopt their own industrial stormwater general permits. Although some states do not venture beyond the requirements of the MSGP, others tailor their permit to address unique geographic conditions (see Appendix A). For example, states may alter the stormwater sampling frequency, require monitoring of additional water quality parameters, and/or specify use of certain SCMs.

INDUSTRIAL STORMWATER MONITORING IN THE MSGP

Three types of monitoring are specified under the MSGP, intended to promote sound stormwater management and provide indicators of compliance and the effectiveness of stormwater controls:

1. Visual monitoring, where samples of runoff are collected and observed visually for certain water quality characteristics (e.g., color, turbidity, and oil sheen);
2. Benchmark monitoring, where stormwater samples are collected and analyzed in a laboratory for specific pollutants and compared to benchmark thresholds identified in the MSGP; and
3. ELG monitoring, where stormwater samples are analyzed for specific pollutants that are compared for compliance with national ELGs (see also Table 1-1).

[3] Indian country is defined as “a) all land within the limits of any Indian reservation under the jurisdiction of the United States Government…; b) all dependent Indian communities within the borders of the United States …; and c) all Indian allotments.” (18 U.S.C. § 1151).
[4] Idaho recently received NPDES authorization and will begin issuing its own stormwater permits in 2021.

The monitoring requirements complement quarterly site inspections that must be performed and documented by permittees.

The primary purpose of the MSGP monitoring program is to ensure that industries are complying with the terms of the permit and appropriately managing stormwater on site to minimize harmful discharges of stormwater pollutants to the local environment. Monitoring observations can signal shortfalls in stormwater management, and exceedances can be cause for review and reconsideration of SCM selection and implementation. Monitoring results can also be used to quantify improvement in stormwater quality on site based on implementation of stormwater control measures and to identify pollutants not being successfully controlled.

At a program level, MSGP monitoring data should also provide an indication over time whether the quality of industrial stormwater across the country is improving to meet the objectives of the MSGP (EPA, 2015a). Additionally, MSGP monitoring would, ideally, inform future decision making and updates to future general permits, such as refinements in benchmark thresholds over time based on the capabilities of treatment technology. The various types of MSGP-required monitoring are summarized in Table 1-1 and discussed in more detail below.

Visual Monitoring

The MSGP requires all permittees to conduct quarterly visual assessment of stormwater samples from each outfall. For events that result in a discharge, samples must be taken within the first 30 minutes of discharge (if feasible) resulting from a storm event that occurs at least 72 hours following a previously measurable event. The sample is then inspected visually for color, odor, floating or settled solids, suspended solids, oil, sheen, and other indicators of stormwater pollution. These results are documented by the permittee and summarized in an annual report to EPA. If evidence of stormwater pollution is observed, corrective actions are required (EPA, 2015a).

Benchmark Monitoring

EPA recognized the greater cost burden of analytical monitoring over visual monitoring and required analytical monitoring only of sectors that demonstrated a potential to discharge pollutants at concentrations of concern. For the most part, EPA determined which industry sectors required benchmark monitoring using industry-supplied baseline data during a 1992 group application process. The industry group leaders were given the discretion to identify which facilities to sample and for which pollutant. The sampling data requested included a mandatory list of pollutants (pH, oil and grease, biological oxygen demand, chemical oxygen demand, total suspended solids, total nitrogen, nitrite and nitrate, and total phosphorus), commonly referred to as the baseline sampling (EPA, 1992). Industry groups were asked to select other pollutants to analyze for based on lists of pollutants that they deemed to be representative of the industry subsector activity (see Appendix B). The data collected were presumed to be representative of discharges without the implementation of SCMs because, at the time, those discharges were unpermitted. EPA compiled and analyzed the data by industry sector, and where industries were found to contain a wide range of industrial activities or potential pollutant sources, the industries were subdivided further and the data compiled on a subsector basis.

TABLE 1-1 MSGP Monitoring Requirements

Tier	Criteria	Summary of Monitoring	Reporting and Response
Visual monitoring of stormwater discharge	All facilities under the MSGP.	• Quarterly grab sample from each outfall (or representative outfall) taken within the first 30 minutes of discharge. • Observe for water quality characteristics: color, odor, clarity, floating solids, settled solids, foam, oil sheen, and other obvious indicators of pollution.	• Permittee summarizes samples in annual report to EPA. If polluted, permittee must begin corrective action and document the measures taken in the stormwater pollution prevention plan.
Benchmark monitoring	Sectors in the original permit development process that were judged to have elevated pollutant concentrations that could be reduced with SCMs. See list in Table 1-2.	• Quarterly grab sample from each outfall (or representative outfall) taken within the first 30 minutes of discharge. • Pollutants analyzed determined by sector/subsector.	• Report electronically on the Network Discharge Monitoring Report (NetDMR). • If average of four monitoring values exceeds benchmark, facility must determine if modifications of SCMs are necessary and continue monitoring or seek waiver. • If average for four quarterly monitoring values is below the benchmark, no further monitoring is required during the permit term.
Numeric effluent limitations (NELs) monitoring	Sectors A, C, D, E, J, K, L, O, S.	• Grab samples collected once per year at each outfall containing the discharges for regulated activities.	• Report electronically on NetDMR. • If exceedance, permittee is deemed in violation of the MSGP. Permittee must take corrective actions and conduct follow-up monitoring within 30 days or during the next runoff event. When follow-up monitoring is in exceedance, permittee must continue to monitor quarterly until discharge is in compliance.

Based on the group application data, EPA required benchmark monitoring for industrial sectors where pollutants were identified in stormwater at concentrations of concern to receiving waters that could be reduced through implementation of SCMs. EPA also required benchmark monitoring for a few industries that had a high potential for contamination from stormwater discharge that was not adequately characterized by the data generated through the group application process. The different sectors with specific required benchmark monitoring are listed in Table 1-2. The benchmark monitoring requirements in the 1995 MSGP have for the most part carried over to the current 2015 MSGP.

The benchmarks were established as "the pollutant concentrations above which EPA determined represents a level of concern. The level of concern is a concentration at which a stormwater discharge could potentially impair, or contribute to impairing water quality or affect human health from ingestion of water or fish." The benchmarks were also viewed by EPA "as a level, that if below, a facility represents little potential water quality concern" (60 *Federal Register* 50825). For the baseline sampling pollutants, EPA used a mix of approaches to establish technology-based benchmark thresholds (see Table 1-3). For example, for total suspended solids and nitrate plus nitrite, EPA derived benchmarks from the median of the National Urban Runoff Program data. For other pollutants, EPA's benchmark thresholds are largely based on published national or state water quality criteria, using EPA acute criteria where they exist and chronic criteria if no acute criteria exist. Aquatic life water quality criteria provide the basis for 15 of the 23 parameters in the 2015 MSGP for which benchmarks have been established.

Industries required to perform benchmark monitoring (see Table 1-2) must sample pollutants quarterly in the first year of permit coverage. A benchmark sample is collected as a grab sample within the first 30 minutes of stormwater discharge after a rainfall (if feasible) that results in an actual discharge from the site and with an interceding dry period of at least 72 hours. The reported results typically reflect pollutant concentrations for an individual sample but can reflect the average concentration for an outfall for all sampled separate runoff events that occurred during the quarterly monitoring period. Facilities that are required to conduct monitoring but have no stormwater discharge during the reporting period are required to report "no discharge." If the average of the four quarterly results exceeds any of the benchmarks, the monitoring must be continued for another four quarters until the average does not exceed the benchmark. Sampling results exceeding benchmarks (based on an average of 4 samples) is not a permit violation, unless no corrective action is undertaken and exceedances persist. Instead, an exceedance necessitates that the facility operator investigate stormwater control measures and make necessary improvements. Any corrective action taken must be documented as a modification to the facility's SWPPP. If a facility determines that no further pollutant reductions are technologically or economically feasible and benchmark exceedances continue to occur, perhaps due to natural background conditions, run-on from adjacent properties, or other factors, permittees may apply for permission to reduce monitoring frequency or eliminate it (also termed an "off-ramp").

Effluent Limitation Guidelines

EPA has established numeric ELGs for stormwater for 10 subcategories of industrial facilities (see also Table 1-1 and Appendix C);[5] these subsectors are required to monitor at least once per year at each outfall containing the discharges subject to the ELG. An exceedance of a numeric ELG in a single sample is deemed a violation of the MSGP and subject to enforcement action. If an exceedance of an ELG is detected, it must be reported to EPA, and corrective actions are required. After an exceedance, additional monitoring is required at least quarterly until the discharge is within compliance. The numeric effluent limitations in ELGs tend to be substantially higher than benchmark thresholds (with the exception of total suspended solids). ELGs are based on extensive data collection on the performance and capacity of treatment technology.

TABLE 1-2 Industrial Sectors and Subsectors and Their Benchmark Monitoring Requirements

Subsector	Subsector Detail	Parameter
A1	General sawmills and planing mills	Chemical oxygen demand (COD), total suspended solids (TSS), zinc
A2	Wood preserving	Arsenic, copper
A3	Log storage and handling	TSS
A4	Hardwood and wood product facilities; sawmills	COD, TSS
B1	Paperboard mills	COD
C1	Agricultural chemicals	Nitrate plus nitrite; lead, iron, zinc, phosphorous
C2	Industrial inorganic chemicals	Aluminum, iron, nitrate plus nitrite
C3	Soaps, detergents, cosmetics, and perfumes	Nitrate plus nitrite, zinc
C4	Plastics, synthetics, and resins	Zinc
C5	Industrial organic chemicals, paints, lacquers, and pharmaceuticals	None
D1	Asphalt paving and roofing materials	TSS
D2	Miscellaneous products of petroleum and coal	None
E1	Clay product manufacturers	Aluminum
E2	Concrete and gypsum product manufacturers	TSS, iron
E3	Glass and stone products	None
F1	Steelworks, blast furnaces, and rolling and finishing mills	Aluminum, zinc
F2	Iron and steel foundries	Aluminum, TSS, copper, iron, zinc
F3	Rolling, drawing, and extruding of nonferrous metals	Copper, zinc
F4	Nonferrous foundries	Copper, zinc
F5	Smelting and refining of nonferrous metals, miscellaneous primary metal products	None
G1	Active copper ore mining and dressing facilities	TSS, nitrate plus nitrite, COD

[5] ELGs have been established for specific constituents in stormwater for cement manufacturing, petroleum refining, steam electric power generation, timber products processing, coal mining, hard rock mining, mineral mining and processing, and airports.

Subsector	Subsector Detail	Parameter
G2	Active metal mining facilities	TSS, turbidity, pH, hardness, antimony, arsenic, beryllium, cadmium, copper, iron, lead, mercury, nickel, selenium, silver, zinc
H	Coal mines and related areas	Aluminum, iron, TSS
I	Oil and gas extraction facilities	None
J1	Sand and gravel mining	Nitrate plus nitrite, TSS
J2	Dimension and crushed stone and nonmetallic minerals	TSS
J3	Clay, chemical, and fertilizer mineral mining	None
K1	Hazardous waste treatment storage, or disposal facilities	Ammonia, magnesium, COD, arsenic, cadmium, cyanide, lead, mercury, selenium, silver
L1	Landfills, land application sites, and open dumps	TSS
L2	L1 except municipal solid waste landfill areas closed	Iron
M	Automobile salvage yards	TSS, aluminum, iron, lead
N1	Scrap recycling and waste recycling facilities	COD, TSS, aluminum, copper, iron, lead, zinc
N2	Source separated recycling facilities	None
O	Steam electric generating facilities	Iron
P	Motor freight transportation facilities	None
Q	Water transportation facilities	Aluminum, iron, lead, zinc
R	Ship and boat building or repair yards	None
S	Airports	Biochemical oxygen demand 5 day (BOD_5), COD, ammonia, pH
T	Treatment works	None
U1	Grain mill products	TSS
U2	Fats and oils products	BOD_5, COD, nitrate plus nitrite, TSS
U3	Meat, dairy, and other food products and beverages	None
V	Textile mills, apparel, and other fabric products	None
W	Furniture and fixture manufacturing facilities	None
X	Printing and publishing facilities	None
Y1	Rubber products manufacturing	Zinc
Y2	Miscellaneous plastic products and manufacturing industries	None
Z	Leather tanning and finishing facilities	None
AA1	Fabricated metal products, except coating	Aluminum, iron, zinc, nitrate plus nitrite
AA2	Fabricated metal coating and engraving	None
AB	Transportation equipment, industrial, or commercial machinery manufacturing facilities	None
AC	Electronic and electrical equipment and components, photographic, and optical goods manufacturing facilities	None

TABLE 1-3 Sources of MSGP Benchmark Values

Pollutant		Benchmark	MSGP Source
pH		6.0–9.0	Secondary Treatment Regulations (40 CFR 133)
Biochemical oxygen demand (5 day) (BOD_5)		30 mg/L	
Chemical oxygen demand		120 mg/L	"Factor of 4 times BOD_5 concentration—North Carolina benchmark"
Total suspended solids		100 mg/L	National Urban Runoff Program (NURP) median concentration
Nitrate + nitrite nitrogen		0.68 mg/L	
Ammonia[a]		2.14 mg/L	"Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (EPA, 1985)
Total phosphorous		2.0 mg/L	North Carolina stormwater benchmark (from NC WQ standards)
Total magnesium		64 µg/L	"Minimum Level (ML) based on highest Method Detection Limit (MDL) times a factor of 3.18"
Turbidity		50 NTU	"Combination of simplified variations on Stormwater Effects Handbook, Burton and Pitt, 2001 and water quality standards in Idaho"
Total aluminum		750 µg/L	Freshwater Acute Aquatic Life Criteria (EPA, 2006a)
Total antimony		640 µg/L	Water Quality Criteria Human Health for Consumption of Organism (EPA, 2006b)
Total beryllium		130 µg/L	Freshwater LOEL Acute Water Quality Criteria (EPA, 1980a)
Total cadmium	FW[b]	2.1 µg/L	Freshwater: Acute Aquatic Life Criteria (EPA, 2006a) Saltwater: Acute Aquatic Life Criteria (EPA, 2006a)
	SW	40 µg/L	
Total copper[a]	FW[b]	14 µg/L	
	SW	4.8 µg/L	
Cyanide	FW	22 µg/L	
	SW	1 µg/L	
Total lead[a,c]	FW[b]	82 µg/L	
	SW	210 µg/L	
Total mercury	FW	1.4 µg/L	
	SW	1.8 µg/L	
Total nickel	FW[b]	470 µg/L	
	SW	74 µg/L	
Total silver[a]	FW[b]	3.8 µg/L	
	SW	1.9 µg/L	
Total zinc	FW[b]	120 µg/L	
	SW	90 µg/L	
Total iron		1000 µg/L	Freshwater Chronic Aquatic Life Criteria (EPA, 2006a)
Total arsenic	FW	150 µg/L	Freshwater: Chronic Aquatic Life Criteria (EPA, 2006a) Saltwater: Acute Aquatic Life Criteria (EPA, 2006a)
	SW	69 µg/L	
Total selenium[a]	FW	5 µg/L	
	SW	290 µg/L	

NOTE: FW = freshwater, SW = saltwater.[a] "New criteria are currently under development, but values are based on existing criteria."[b] "These pollutants are dependent on water hardness where discharged into freshwaters. The freshwater benchmark value listed is based on a hardness of 100 mg/L. When a facility analyzes receiving water samples for hardness, the permittee must use the hardness ranges provided in Table 1 in Appendix J of the 2015 MSGP and in the appropriate tables in Part 8 of the 2015 MSGP to determine applicable benchmark values for that facility. Benchmark values for discharges of these pollutants into saline waters are not dependent on receiving water hardness and do not need to be adjusted."
SOURCE: EPA, 2015b.

CONTEXT FOR THE STUDY

The various industrial stormwater permitting requirements have come under scrutiny since the program's inception. It is widely recognized that the monitoring program suffers from a paucity of useful data and from inconsistent sampling techniques. Benchmark monitoring has been variously described as overly burdensome to industries and producing data that go unutilized. Some stakeholders question whether benchmark exceedances serve as useful indicators of the effectiveness of implementation of stormwater control measures or potential water quality problems. If problems are observed, others express concern about a lack of enforcement mechanisms to ensure that the issues are effectively addressed. State and local stormwater programs face a shortage of resources to review monitoring data and conduct routine compliance inspections. For these reasons, NRC (2009) concluded that "the stormwater program has suffered from poor accountability and uncertain effectiveness at improving the quality of the nation's waters."

Among dozens of recommendations for improving the stormwater program, the National Research Council (NRC, 2009) report recognized that many of the benchmark monitoring requirements and effluent guidelines for certain industrial subsectors were based on incomplete and outdated information. The report recommended that "Industry monitor the quality of stormwater discharges from certain critical industrial sectors in a more sophisticated manner, so that permitting authorities can better establish benchmarks and technology-based effluent guidelines." The report also noted the lack of a nationwide compilation and analysis of industrial benchmark monitoring data, which could be used to better understand typical stormwater concentrations of pollutants from various industries. Additionally, the report recommended a risk-based approach for industrial stormwater monitoring requirements so as to not unduly burden those industrial facilities with limited exposure to runoff, while also not allowing high-risk sites to escape the more intensive monitoring that would be necessary to ensure compliance with effluent limitations.

These issues resurfaced in a recent settlement agreement made between EPA, industries, and environmental groups regarding revisions to the nationwide MSGP for industrial stormwater. The agreement requires the parties to suspend all legal actions against EPA regarding the revisions to the MSGP until the National Academies of Sciences, Engineering, and Medicine have conducted a study on certain aspects of the industrial stormwater program. In particular, the agreement asked the National Academies' committee to:

1. Suggest improvements to the current MSGP benchmarking monitoring requirements. Areas to examine could include
   - Monitoring by additional sectors not currently subject to benchmark monitoring;
   - Monitoring for additional industrial-activity-related pollutants;
   - Adjusting the benchmark threshold levels;
   - Adjusting the frequency of benchmark monitoring;
   - Identifying those parameters that are the most important in indicating whether stormwater control measures are operating at the best-available-technology or best-conventional-technology level of control; and
   - New methodologies or technologies for industrial stormwater monitoring.

2. Evaluate the feasibility of numeric retention standards (such as volumetric control standards for a percent storm size or standards based on percentage of imperviousness).
   - Are data and appropriate statistical methods available for establishing such standards as both technology-based and water-quality-based numeric effluent limitations?
   - Could such retention standards provide an effective and scientifically defensible approach for establishing objective and transparent effluent limitations?
   - What are the merits and faults of retention versus discharge standards, including any risks of groundwater or surface-water contamination from retained stormwater?

3. Identify the highest-priority industrial facilities/subsectors for consideration of additional discharge monitoring. By "highest priority" EPA means those facilities/subsectors for which the development of numeric effluent limitations or reasonably standardized stormwater control measures would be most scientifically defensible (based upon sampling data quality, data gaps and the likelihood of filling them, and other data quantity/quality issues that may affect the calculation of numeric limitations).

EPA will use the results of this study to inform its proposed revisions to the 2015 MSGP, which are anticipated in 2020. The committee was not asked to analyze the financial costs of its recommendations; instead, EPA will assess the costs of possible changes in its proposed revision of the MSGP.

EPA's proposed revisions of the 2015 MSGP will also address other provisions of the legal settlement that will increase the importance of the benchmark thresholds. The settlement required that EPA develop requirements for "Additional Implementation Measures" (AIM) "substantially similar" to that detailed in Box 1-3. AIM would set specific actions that must be taken upon different levels of exceedance of the benchmarks or repeated exceedances. The specifics of the AIM tiers and the consequences of exceedances have not been finalized, but repeated exceedances of annual averages or large repeated exceedances could require additional structural stormwater control measures if feasible. If exceedances continue, an individual permit may be required. These requirements would provide stronger consequences to benchmark exceedances, thus increasing the significance of the benchmark thresholds.

The committee's report and its conclusions and recommendations are based on a review of relevant technical literature, briefings, and discussions at its five in-person meetings and three web conferences, and the experience and knowledge of the committee members in their fields of expertise. The committee received briefings from a range of experts, including federal, state, and local government officials; practitioners; industry representatives; environmental organizations; and academics (see the Acknowledgments).

OUTLINE OF THE REPORT

Following this Introduction, the Statement of Task is addressed in three subsequent chapters of this report. In Chapter 2, the committee discusses benchmark monitoring requirements and benchmark thresholds. Chapter 3 identifies opportunities for improving industrial stormwater MSGP monitoring, including evaluations of sampling methods, laboratory analysis, and data management. The committee recommends a new tiered approach to monitoring to provide improved stormwater management while reducing burden for small, low-risk facilities. In Chapter 4, the committee evaluates the merits and concerns associated with retention standards for industrial stormwater under the MSGP framework.

BOX 1-3
Additional Implementation Measures (AIM)

The following tiers were outlined in the settlement agreement, and EPA is required to propose for public comment for the next MSGP a substantially similar approach:

> **Tier 1:** If (A) an annual average for a parameter is over the benchmark threshold; or (B) a single sampling event result for a parameter is over 4x the benchmark threshold, then the operator must immediately review the selection, design, installation, and implementation of its control measures to determine if modifications are necessary to meet the benchmark threshold for that parameter. If any modifications are necessary, the operator must implement those modifications….
>
> **Tier 2:** If (A) two consecutive annual averages for a parameter are each over the benchmark threshold; or (B) two sampling event results for a parameter within a two year period are over 4x the benchmark threshold; or (C) a single sampling event for a parameter is over 8x the benchmark threshold (unless the operator immediately documents in its SWPPP that the single event was an aberration, how any measures taken within 14 days of such event will prevent a reoccurrence, and takes a sample during the next qualifying rain event…), then the operator must implement all feasible control measures in the relevant sector-specific fact sheet….
>
> **Tier 3:** If (A) three consecutive annual averages for a parameter are each over the benchmark threshold; or (B) three sampling event results for a parameter within a three-year period are each over 4x the benchmark threshold; or (C) two sampling events for a parameter within a three-year period are each over 8x the benchmark threshold; or (D) four consecutive samples for a parameter are over the benchmark threshold and their average is more than 2x the benchmark threshold, then the operator must install structural source controls (permanent controls such as permanent cover, berms, and secondary containment), and/or treatment controls (e.g., sand filters, hydrodynamic separators, oil-water separators, retention ponds, and infiltration structures) within 30 days…. In addition, the operator does not have to install structural source controls or treatment controls if it adequately demonstrates to EPA within 30 days of the Tier 3 trigger occurrence that its discharge does not result in any exceedance of water quality standards…. The demonstration to EPA, which will be made publicly available, must include the following minimum elements in order to be considered for approval by EPA: (1) the water quality standards applicable to the receiving water; (2) the flow rate of the stormwater discharge; (3) the instream flow rates of the receiving water immediately upstream and downstream of the discharge point; (4) the ambient concentration of the parameters) of concern in the receiving water immediately upstream and downstream of the discharge point demonstrated by full storm composite sampling; (5) the concentration of the parameters) of concern in the stormwater discharge demonstrated by full-storm, flow-weighted composite sampling; (6) any relevant dilution factors applicable to the discharge; and (7) the hardness of the receiving water. …If a facility continues to exceed the benchmark threshold for the same parameter even after installation of structural source controls or treatment controls, EPA may require the operator to apply for an individual permit.

SOURCE: *Waterkeeper Alliance v. U.S. EPA*, 2016.

2

Pollutant Monitoring Requirements and Benchmark Thresholds

This committee was charged with recommending potential improvements to the current Multi-Sector General Permit (MSGP) monitoring requirements, including monitoring by additional sectors not currently subject to benchmark monitoring, monitoring for additional industrial-activity-related pollutants, and adjusting benchmark threshold levels. As discussed in Chapter 1, the Environmental Protection Agency (EPA) is currently developing Additional Implementation Measure (AIM) requirements in response to a legal settlement that would provide actionable consequences for large or repeated benchmark exceedances. These changes place greater emphasis on ensuring that the MSGP uses appropriate benchmarks. In this chapter, the committee provides a broad assessment of the current MSGP benchmark monitoring process and summarizes the most recent MSGP monitoring data. Then, the chapter describes ways to improve pollutant monitoring requirements, including industrial activities not currently covered by the MSGP, industry-wide benchmarks, and sector-specific monitoring requirements. The committee also discusses the adequacy of current benchmark threshold levels, considering recent information on toxicity and treatment attainability.

ASSESSMENT OF CURRENT MSGP BENCHMARK MONITORING

The original 1995 MSGP monitoring scheme was based on program elements embedded in sound administrative, scientific, and public policy principles (60 *Federal Register* 50804). Many of the program elements, however, have been hampered by shortfalls in generating, considering, and acting on new information. This has resulted in missed opportunities for refining the MSGP monitoring requirements in support of improved stormwater management. Some of these key program elements are summarized in Table 2-1.

The pollutant monitoring requirements of the MSGP are particularly dated and have not been substantially updated over time. Many industrial sectors have never collected and reported data for any of the conventional and nonconventional pollutants, toxic pollutants, and hazardous substances listed in Appendix B. With the group application process, industrial sectors were directed to sample for specific pollutants based on their own determination of whether they had knowledge or reason to believe a pollutant may be present in their stormwater discharges.

TABLE 2-1 Evolution of Key MSGP Program Elements Affecting Monitoring Requirements

Factors Affecting Monitoring Requirements	1995 MSGP Approach	Current Assessment
Pollutant Characterization		
Gross characterization of basic chemical parameters in stormwater discharges	Baseline sampling was required, and results were statistically characterized	Has not been repeated since 1992
Characterization of specific pollutants in discharges by sector/subsector	Industries self-determined which pollutants (beyond the baseline sampling pollutants) needed to be analyzed; industry data, where provided, were statistically characterized	Gaps in industry sampling have not been addressed
Evaluation of pollution potential by sector/subsector based on activities, sources, and pollutants	Activities indicated in permit applications were summarized along with likely sources of stormwater contamination and pollutants that may be present	Industry fact sheets have not been updated since 2006. Fact sheets and other sector-specific information have not been used to update MSGP monitoring requirements
Sampling and Analysis		
Availability of sampling methods and protocols	Sampling methods were limited to grab	Sampling methods have not been updated to include more broadly available and representative methods
Availability of sufficiently sensitive analytical test methods	The sensitivity of analytical methods informed choice of benchmarks and monitoring requirements	Improvements in analytical capabilities were incorporated into the 2008 MSGP for some metals, but it remains unclear whether or how updated analytical methodology is considered for other benchmark requirements
Pollutant Reductions		
Capacity of stormwater control measures (SCMs) to reduce pollutant loads	Options for controlling pollutants and the capacities of SCMs were evaluated when setting benchmarks	The 1995 evaluation was limited and has not been comprehensively updated

Consequently, some industrial groups submitted more information than others, causing monitoring data submittal discrepancies among some sectors. The result is a disparity in the relative monitoring burden across sectors. This disparity is shown in Table 2-2 for five example sectors. Sectors M and N1 have benchmark monitoring requirements and Sectors I, P, and R have no benchmark monitoring requirements. Sectors I and R self-determined through the group application process that no sector-specific pollutants needed to be tested in their discharges. In contrast Sectors M, N1, and P determined that pollutant testing was, in fact, necessary, with Sector N1 making that determination for the highest number of pollutants.

Literature reviews generating new information regarding pollutants with industrial activity and their presence in the environment (60 *Federal Register* 189 (1995); O'Donnell, 2005; EPA, 2006c) have not been systematically or comprehensively used to update the MSGP. This reveals missed opportunities to characterize and likely reduce pollution in industrial stormwater discharges.

TABLE 2-2 Benchmark Pollutant Evaluation for Five Sample Sectors

	Oil and Gas Extraction and Refining (Sector I)	Automobile Salvage Yards (Sector M)	Scrap and Waste Recycling Facilities (Sector N1)	Motor Freight, Rail, Passenger, and U.S. Postal Service Transportation Facilities (Sector P)	Ship and Boat Building or Repair Yards (Sector R)
Monitoring Data Supplied in 1992 Industry Group Application (beyond baseline parameters)	None	Aluminum, iron, lead	Lead, zinc, cadmium, copper, zinc, chromium, iron, nickel, arsenic, aluminum, polychlorinated biphenyls (PCBs)	Lead, zinc	None
1995 MSGP Common Pollutants Listed	Total suspended solids (TSS), total dissolved solids, oil and grease, chemical oxygen demand (COD), chlorides, barium, naphthalene, phenanthrene, benzene, lead, arsenic, fluoride pH, acetone, toluene, ethanol, xylenes, antimony	TSS, oil and grease, ethylene glycol, heavy metals, sulfuric acid, petroleum hydrocarbons, chlorinated solvents, acid/alkaline wastes, arsenic, organics, detergents, phosphorus, salts, bacteria, biochemical oxygen demand (BOD)	Hydraulic fluids, oils, fuels, grease and other lubricants, accumulated particulate matter, chemical additives, PCBs, antifreeze, acid, mercury, lead, heavy metals	Fuel, oil, heavy metals, chlorinated solvents, acid/alkaline wastes, ethylene glycol, arsenic, organics, paint, dust, sediment, detergents, salts, phosphorus, sodium chloride, BOD	Paint solids, heavy metals, suspended solids, spent abrasives, solvents, dust, oil, ethylene glycol, acid/alkaline wastes, detergents, fuel, BOD, bacteria
2015 MSGP Benchmark Monitoring Requirements	None	TSS, aluminum, iron, lead	TSS, COD, aluminum, copper, iron, lead, zinc	None	None

CONTEXT OF RECENT MSGP DATA

A review of recent MSGP monitoring results is instructive to evaluate the current state of MSGP benchmark monitoring compliance and provide important context for the committee's findings. More than 17,000 reported results were evaluated from MSGP permitted facilities in the four states where EPA has primacy for the regulations (Idaho, Massachusetts, New Mexico, and New Hampshire), the District of Columbia, U.S. territories, Indian country, and some federal facilities. The data were submitted electronically by permittees under the 2015 MSGP through February 13, 2018. Tables 2-3 and 2-4 summarize the discharge monitoring results. For each pollutant-sector combination, the graphical results are color coded based on the percentage of individual reported results with concentrations above the benchmark (see Table 2-3) or eight times the benchmark (see Table 2-4). Tables 2-3 and 2-4 do not indicate MSGP benchmark exceedances, which are determined based on the average of four quarterly samples, and triggers review of the stormwater pollution prevention plan and 1 year of additional monitoring. However, they provide insight into the sectors and pollutants with frequent elevated discharge concentrations. Eight times the benchmark was selected as indicative of a major elevated discharge concentration, as suggested for the Additional Implementation Measures (AIM) process (see Box 1-3). In order for a data set to be included in Tables 2-3 and 2-4, each pollutant considered had to have a minimum of eight reported results for that subsector. The committee recognizes that for stormwater data analysis more storm event results (18 to 24) are preferable, considering the inherent variability of precipitation events. However, based on the limited available data on industrial sites, a lower threshold of eight reported results was used. Additional pollutant-specific tables and graphs, a description of the data set, specific details on the committee's analysis, and known limitations of the data set are provided in Appendix D.

When evaluating the results by sector, several sectors emerge that have a large percentage of samples with concentrations above the benchmark threshold for more than one pollutant, and even some with a large percentage of samples with concentrations above eight times the benchmarks. For example, in Sector H (coal mines and coal-mining-related facilities), more than half of the samples exceed eight times the benchmark for TSS and 95 percent of the samples exceeded eight times the benchmarks for aluminum and iron. In Sector A2 (wood preserving), more than half of the samples exceeded the benchmarks for COD, copper, and TSS, and 81 percent of the samples exceeded eight times the benchmark for copper. Sector F4 (nonferrous foundries) reported frequent high levels of zinc and copper, with 30 and 50 percent of the samples, respectively, above eight times the benchmark. In Sector N1 (scrap recycling), more than 50 percent of the samples are above the benchmarks for copper, iron, and zinc, while more than 10 percent of samples exceed eight times the benchmarks for aluminum, copper, iron, and zinc.

Additionally, meeting benchmarks proved more difficult for some pollutants than others. No sector was able to meet the magnesium benchmark in more than 50 percent of the samples. Copper, zinc, and iron also showed large percentages of samples above the benchmarks from most sectors.

TABLE 2-3 NetDMR 2015 MSGP Data According to the Percentage of Results Above Benchmarks

Sector	Al	NH_3	As	BOD_5	Cd	COD	Cu	CN	Fe	Pb	Mg	Hg	NO_2+ NO_3	pH	TP	Se	Ag	TSS	Turb	Zn
A1: Sawmills																				
A2: Wood																				
A3: Log storage																				
A4: Hardwoods																				
B1: Paperboard																				
B2: Pulp mills																				
C1: Agricultural																				
C2: Industrial inorganics																				
C3: Cleaning, cosmetics																				
C4: Plastics																				
C5: Medicinals																				
D1: Asphalt																				
E2: Concrete																				
E3: Glass																				
F1: Steel works																				
F2: Iron/steel foundries																				
F3: Nonferrous metals																				
F4: Nonferrous foundries																				
G1: Copper ore																				
G2: Other ores																				
H: Coal mines																				
J1: Construction sand																				
J2: Stone																				
J3: Clay mineral mining																				
K: Hazardous waste																				
L1: Landfills																				
L2: Landfills, not MSW																				
M: Automobile salvage																				
N1: Scrap recycling																				
O1: Steam electric																				
P: Transportation, postal																				
Q: Water transportation																				
R: Ship and boat building																				
S: Air transportation																				
T: Sewage treatment																				
U1: Grain mill products																				
U3: Meat, dairy, tobacco																				
Y1: Rubber																				
Y2: Misc. plastics																				
AA1: Fabricated metals																				
AA2: Fabr. metal coating																				
AB: Machinery																				
AC: Electronics																				

No data	Insufficient data (<8 results)	<10% above benchmark (BM)	10-25% above BM	26-50% above BM	>50% above BM

TABLE 2-4 Categorization of NetDMR Data Based on the Percentage of Results Above Eight Times the Benchmark

Sector	Al	NH_3	As	BOD_5	Cd	COD	Cu	CN	Fe	Pb	Mg	Hg	NO_2+ NO_3	TP	Se	Ag	TSS	Turb	Zn
A1: Sawmills																			
A2: Wood							81%										13%		
A3: Log storage																			
A4: Hardwoods																			
B1: Paperboard																			
B2: Pulp mills																			
C1: Agricultural									13%										25%
C2: Industrial inorganics																			
C3: Cleaning, cosmetics																			
C4: Plastics																			16%
C5: Medicinals											50%								
D1: Asphalt																			
E2: Concrete									17%										
E3: Glass																			
F1: Steel works																			
F2: Iron/steel foundries																			
F3: Nonferrous metals							14%												12%
F4: Nonferrous foundries							50%												30%
G1: Copper ore																			
G2: Other ores																			
H: Coal mines	95%								95%								55%		
J1: Construction sand																			
J2: Stone													11%						
J3: Clay mineral mining																			
K: Hazardous waste											83%								
L1: Landfills																			
L2: Landfills, not MSWLF									17%										
M: Automobile salvage																			
N1: Scrap recycling	13%						26%		18%										13%
O1: Steam electric																			
P: Transportation, postal																			
Q: Water transportation	12%						61%		12%										
R: Ship and boat building							81%												
S: Air transportation									16%										
T: Sewage treatment																		10%	
U1: Grain mill products																			
U3: Meat, dairy, tobacco												13%							
Y1: Rubber																			23%
Y2: Misc. plastics																			
AA1: Fabricated metals							46%												
AA2: Fabr. metal coating																			
AB: Machinery																			
AC: Electronics																			

No data	Insufficient data (<8 results)	0% above 8x BM	1-9% above 8x BM	10-25% above 8x BM	>25% above 8x BM

PREPUBLICATION COPY

Table 2-5 provides a graphical representation of the results of an analysis of electronically submitted benchmark monitoring data from the 2008 MSGP (EPA, 2012). Table 2-5 is presented parallel to Table 2-3. The main exception is that Table 2-5 reflects the percentages of annual averages (based on four quarterly results) that exceeded the benchmark, rather than individual results; thus, the color coding by percentage exceedance is more stringent than that in Table 2-3. Additionally, the monitoring data were not separated into subsectors. The EPA (2012) analysis was based on far fewer data compared to the above analyses, because electronic submission of the MSGP data was not mandated until 2016. Several parameters have data from only one permittee and, in some cases, at only one outfall; therefore, the data are too limited to assess any trend between 2008 and 2015. Nonetheless, several of the same issues from EPA (2012) are apparent when reviewing the recent data in Table 2-3. Again, pollutants frequently above the benchmark include magnesium, copper, iron, and zinc. Without subsector breakdown, comparisons among sectors are more problematic.

Tables 2-3 through 2-5 highlight the ongoing challenges faced by several industrial sectors for which a large portion of facilities have results above the benchmarks under both the 2008 and 2015 MSGP. The remainder of this chapter discusses ways MSGP pollutant monitoring requirements could be improved to enhance industrial stormwater management within the program.

TABLE 2-5 Percent Benchmark Exceedances in 2008 MSGP NetDMR Data Based on Annual Averages as Reported in EPA (2012)

	Al	NH_3	As	BOD_5	Cd	COD	Cu	CN	Fe	Pb	Mg	Hg	NO_2^+ NO_3	TP	Se	Ag	TSS	Zn
A						33	100										16	17
B						0												
C	19								48	0			17	0				100
D																	14	
E									71								19	
F							71		50								0	72
J													25				8	
K		0	0		0	0		0		0	100	0			0	0		
L									91								38	
M	25								52	22							9	
N	53					43	75		88	50							37	67
O									67									
Q	40								33	0								100
U				0		0							20				20	
Y																		0
AA	36								65				26					74

No data reported	<10% above BM as annual average	10-25% above BM as annual average	26-50% above BM as annual average	>50% above BM as annual average

IMPROVING POLLUTANT MONITORING REQUIREMENTS

In this section, the committee reviews the benchmark monitoring requirements within the MSGP. The committee identifies industrial activities not currently covered by the MSGP, discusses the value of industry-wide benchmark monitoring, and analyzes sector-specific pollutant monitoring requirements.

Industrial Activities Not Covered by the MSGP

Industrial facilities in the MSGP are classified within sectors based on the products they generate using the legacy standard industrial classification (SIC) code. The MSGP was intended to cover discharges associated with industrial activity—not just discharges from facilities whose main purpose has been defined as industrial (60 *Federal Register* 50804). SIC codes are not ideal for characterizing the industrial activities that occur at a site with the potential risk of stormwater pollution. Some facilities like gas stations and school bus transportation facilities are not included in the MSGP, because they are not considered to be industrial facilities, even though the environmental risks associated with their outdoor activities may be similar to or greater than other facilities that the MSGP covers.

The MSGP should extend coverage for facilities, including commercial ones, that are not explicitly defined as "industrial" under the National Pollutant Discharge Elimination System stormwater regulation SIC structure if they conduct on-site activities that are equivalent to industrial activity covered under the MSGP. These facilities should be subject to the same monitoring requirements as those industries with like on-site activities. These facilities include

- Timber lots,
- Fuel storage and on-site fueling,
- Vehicle maintenance (e.g., school bus transportation facilities),
- Facilities with numerous parked diesel vehicles,
- Outdoor materials storage that poses stormwater contamination threats (e.g., liquid tanks with operational valves or in poor condition, solids such as salt or wood chips that are exposed to stormwater), and
- Outdoor handling of materials (e.g., filling liquid tank trucks, conveyors handling solids in particulate form).

Some states have done this. Maryland, for example, describes Department of Public Works highway maintenance facilities and school bus facilities as specific types of facilities designated for coverage under the Sector AD of the general permit (MDEP, 2014). Connecticut's general permit includes several activities that have been added to the definition of "stormwater associated with industrial activity" (CT DEEP, 2018). This includes small-scale composting facilities; road salt and deicing material storage facilities; wood processing facilities not otherwise covered, including mulching, chipping, and mulch coloring facilities; and vehicle service and storage facilities (including public works garages) operated by federal, state, or municipal governments.

EPA should identify the industrial, commercial, and retail activities currently excluded by the MSGP's SIC-based approach that have stormwater pollution potential comparable to industrial facilities currently regulated under the MSGP. In their upcoming revisions to the MSGP, EPA should consider ways to include these facilities under the MSGP, with monitoring requirements equivalent to like facilities. This would facilitate improved stormwater management and characterization of discharges at these facilities.

Industry-Wide Benchmark Measurements for All Sectors

A primary goal of the MSGP benchmark monitoring requirements is to indicate the performance of structural and nonstructural SCMs for ensuring the quality of stormwater leaving industrial sites. The committee recommends a suite of water quality parameters for benchmark monitoring by all industrial sites that must do stormwater sampling, including those that currently only do visual monitoring. Such industry-wide monitoring would provide indicators of problems for a wide range of sites and a baseline understanding of industrial stormwater risk for all sectors. Industry-wide monitoring would also provide stormwater quality information that could be compared across all industries regardless of sector, and would help address some of the monitoring disparities that resulted from the group application process. Such monitoring has been recommended by other reviews of the MSGP (O'Donnell, 2005), and several states currently use some degree of industry-wide monitoring (see Appendix A). The committee recommends three industry-wide parameters:

- **pH** detects excess acidic or alkaline substances in the water, and pH excursions indicate corrosive (acidic or basic) and/or toxic concerns. Stormwater discharges that are excessively polluted may not exhibit problems with respect to pH. However, pH excursions that are highly acidic or highly alkaline and do not fall into the benchmark range (6.0-9.0) can be indicative of a major polluting event or process failure and can be impactful to receiving waters. Unexpected pH values also can indicate that a stormwater treatment system is not operating properly. For example, a limestone-based treatment system will typically raise pH, so a low effluent pH may indicate system failure. pH is simple and low cost to measure and is currently required as an industry-wide benchmark by California, Connecticut, and Washington (see Appendix A).
- **Total Suspended Solids (TSS)** is a measure of suspended particulate matter in a water sample. Particulate matter can result from erosion of industrial soils, deposited particulate matter on the drainage area, erosion/corrosion of materials present on the site, and general overall site cleanliness. TSS also provides information about possible high concentrations of numerous other pollutants that will partition onto particulate matter, including phosphorus, many heavy metals, and many hydrophobic organic chemicals. Stormwater TSS concentrations in receiving waters are highly correlated with the concentrations of metals such as copper, lead, and zinc, known to cause freshwater and marine biotoxicity (Schiff and Tiefenthaler, 2011). Several treatment and nonstructural SCMs are available to control TSS (Clark and Pitt, 2012), and TSS can provide information about their performance or the need for additional SCMs at a site (Avila et al., 2008). TSS is a standardized, well-established test. Suspended sediment concentration (SSC; an approved method under 40 CFR 136.3 for filterable residue) was considered as an alternative surrogate for TSS. SSC is

generally judged to be a more accurate measure of particulate matter in stormwater because it will capture all sediment, not just suspended matter. However, use of SSC complicates the monitoring process by requiring an independent sample for this parameter only. Turbidity measurements have also been suggested as an indicator for suspended solids. However, TSS provides a better basis for comparisons against historical data, which are more commonly reported as TSS. TSS is currently required as an industry-wide benchmark by California, Connecticut, and Minnesota (see Appendix A).

- **Chemical Oxygen Demand (COD)** is a surrogate measure of organic pollutants in water (through measure of oxygen demand). It is a conventional water quality parameter with established industrial stormwater benchmarks. In addition to the measure of oxygen demand, high COD can also be indicative of oils and hydrocarbon pollution (Han et al., 2006a) and, as with TSS, can be an indicator of overall site cleanliness. Increases in COD could also indicate problems with the treatment SCM effectiveness, including the need for maintenance. The committee recognized that total organic carbon (TOC), which generally provides the same information of interest as COD, would be a better measure of organic pollution in water for several reasons. TOC analysis is simple, standardized, and easier to automate than COD. TOC analysis uses fewer toxic chemicals and can produce results much more sensitive, precise, and accurate than COD. However, TOC does not have an EPA-established benchmark or history of data as COD does. TOC may also be less effective in measuring colloidal/particulate organic matter. Once an EPA benchmark is developed for TOC, EPA should consider the overall advantages and disadvantages of conversion to TOC monitoring. While both COD and TOC are gross measures of organic pollution, they are not specific enough or sensitive enough to detect possible excursions of toxic pollutants (e.g., polycyclic aromatic hydrocarbons [PAHs]) at moderate/low concentrations. COD is currently required as an industry-wide benchmark by Connecticut (see Appendix A).

All three parameters are direct measures of water quality and are appropriate choices for industry-wide sampling because all three can be indicators of broader water quality problems and the presence of other pollutants. In addition, these industry-wide water quality parameters can provide indications of SCM absence, neglect, or failure, which can lead to high concentrations of potential pollutants. There are well-established standardized analytical procedures for all three recommended industry-wide parameters and analytical determinations are expected to be relatively inexpensive (less than $100 for all three). Considering that all permittees must collect quarterly storm event samples for visual monitoring, the additional cost burden of these analyses is expected to be small.

Review of Pollutant Monitoring Requirements by Sector

For the most part, the monitoring requirements in the MSGP were based on the best information available at the time they were derived. However, based on information gained since the MSGP was developed, changes for a number of sectors are merited. Some sectors are not required to conduct benchmark monitoring. Other sectors are required to monitor for only a very limited number of pollutants (see Table 1-1) and some sectors are not required to monitor for the substances that could potentially be important pollutants that may be discharged in stormwater from their sites. This section reviews the monitoring requirements of the MSGP and discusses areas that the committee recommends to be updated based on the current understanding of risk and pollutant occurrence.

Inconsistent Monitoring Requirements for Similar Sectors with Similar Industrial Activities

Analysis of the sector-specific benchmark monitoring requirements shows inconsistencies across sectors that have comparable industrial activities, highlighting shortfalls in the current MSGP. For example, Sectors M (automobile salvage yards) and N1 (scrap recycling and waste recycling facilities) have similar activities on site but different monitoring requirements (see Table 2-2). Both sectors include material handling and storage, material processing and dismantling, including ferrous and nonferrous metals, equipment maintenance and cleaning, reclaiming and recycling liquid wastes such as used oils and antifreeze, and other operations that occur at industrial facilities often exposed to stormwater. Monitoring requirements for Sector M are TSS, total aluminum, total iron, and total lead, whereas Sector N1 is required to monitor for these parameters and also total copper, total zinc, and COD. As discussed earlier in this chapter, Sector M does not have benchmark monitoring requirements for total copper and total zinc, at least in part, because they did not self-determine through the 1992 group application process that monitoring for these two pollutants was necessary. As such EPA did not have data to evaluate pollutant potential when developing the 1995 MSGP and has not, to date, required Sector M to sample for those parameters. Among the limited monitoring data reported for Sector M from the 2015 MSGP (11 samples), the benchmark for copper was exceeded 82 percent of the time compared to 63 percent for Sector N1 (see Appendix D).

Sectors Not Subject to Benchmark Monitoring

Of the industrial sectors listed in Table 1-2, 10 sectors (including all their subsectors) have no benchmark monitoring requirements in the MSGP. Other sectors have at least some subsectors required to conduct benchmark monitoring, representing varying proportions of the sector facilities. According to EPA, 45 percent of all facilities permitted under the MSGP are not required to conduct benchmark monitoring (R. Urban, EPA, personal communication, 2018). In this section, the committee examines in more detail three of the sectors where no benchmark monitoring is currently required (see also Table 2-2). These analyses highlight the need for updated evaluations of pollutant potential and opportunities for pollutant reduction through implementation of additional SCMs.

Oil and Gas. Sector I includes oil and gas exploration, production, processing or treatment operations, and transmission facilities. A number of chemicals are used at these operations that could contribute to stormwater pollution, including diesel fuel, oil, solvents, drilling fluid, acids, and chemical additives (EPA, 2006a). Ammonia, lead, nickel, nitrate, and zinc have been detected at these sites in stormwater in greater than 10 percent of the reported data (O’Donnell, 2005). No monitoring data on Sector I have been submitted as part of the 2015 MSGP (see

Appendix D). Spills and leaks can also lead to petroleum hydrocarbon contaminants in stormwater, including PAHs, which have been shown to be highly toxic to aquatic life (Incardona et al., 2011; Abdel-Shafy and Mansour, 2016; McIntyre et al., 2016). Chemical-specific monitoring is appropriate for this sector to ensure that stormwater is appropriately managed.

Motor Freight and Transportation Facilities. Sector P includes motor freight and passenger transportation facilities, petroleum bulk oil stations and terminals, rail transportation facilities, and post office facilities. Activities on these sites include vehicle and equipment fluid changes, mechanical repairs, parts cleaning, fueling, and vehicle storage. Chemicals used on site include solvents, diesel fuel and gasoline, hydraulic fluids, antifreeze, and transmission fluids (EPA, 2006b; see Table 2-2). Benchmark monitoring for lead and mercury in addition to pH, TSS, and COD were recommended by O'Donnell (2005) because of the frequency of occurrence in Toxic Release Inventory stormwater data, but the 2015 MSGP does not include any benchmark monitoring requirements for this sector. Although benchmark monitoring is not required nationally, some Sector P monitoring data have been reported in EPA's Network Discharge Monitoring Report (NetDMR). Greater than 25 percent of results had concentrations above the benchmarks for aluminum, copper, and iron. As with Sector I, petroleum hydrocarbon leaks and spills could lead to harmful stormwater discharges of PAHs. The activities in Sector P and risk of stormwater pollution suggest that chemical-specific monitoring within the MSGP would be appropriate.

Ship and Boat Building. Sector R covers ship and boat building or repair yards, which includes activities such as fluid changes, mechanical repairs, parts cleaning, refinishing, paint removal, painting, and fueling. Chemicals used on site include solvents, oil, fuel, antifreeze, and acid and alkaline wastes. As discussed earlier in this chapter, Sector R self-determined through the 1992 group application process that no sector-specific pollutants needed to be tested in their discharges, which was a significant reason for the lack of benchmark monitoring in the 1995 MSGP. This determination has carried over into the 2015 MSGP. O'Donnell (2005) suggested that chromium, copper, lead, nickel, and zinc be considered for future monitoring for Sector R and noted that Toxic Release Inventory stormwater data were limited. Greater than 300 Sector R monitoring data points have been submitted to the NetDMR under the 2015 MSGP. Greater than 25 percent of reported results were above the benchmark for aluminum, copper, and iron (see Appendix D).

Rhode Island recently added benchmark monitoring for aluminum, iron, lead, and zinc for Sector R in their 2013 MSGP (RI DEM, 2013). The Rhode Island Department of Environmental Management determined that Sector R has the potential to generate the same pollutants as water transportation Sector Q because they have common industrial activities. In the 1992 group application process, Sector Q self-determined that aluminum, iron, lead, and zinc needed to be tested in their discharge, and EPA applied benchmark monitoring for those four pollutants to Sector Q in the MSGP. The MSGP monitoring requirements for Sector R are likely insufficient due to shortfalls in the original 1992 group application process.

Need for Periodic Monitoring Reviews

These examples show that monitoring requirements within the MSGP are not consistently applied. Additionally, updates to the benchmark monitoring requirements have not been made over time in spite of data and several analyses showing that specific contaminants are commonly detected or likely to occur in stormwater at these facilities (Harcum et al., 2005; O'Donnell, 2005; EPA, 2012; see also Appendix D). Sector-specific monitoring requirements for all sectors should be rigorously reviewed to assess whether the monitoring requirements are appropriate to ensure control of stormwater pollution and determine whether benchmark monitoring requirements should be adjusted.

The committee recommends the following specific steps be taken to periodically review the MSGP monitoring requirements and update them as appropriate based on new information:

- Prior to each permit renewal, EPA should conduct a literature review and update its industry fact sheets, which describe potential pollutants from common industry activities, pollutant sources, and practices that could reduce pollutant discharge on site.[1] Changes in industry practice over time may introduce new contaminants and render other contaminant monitoring of limited value.
- EPA should continue the process conducted by Tetra Tech in advance of the 2008 MSGP (O'Donnell, 2005) where sector-specific data from the previous MSGP as well as Toxic Release Inventory and Toxic Substances Control Act data are assessed to determine whether the chemical monitoring requirements are adequate to detect stormwater management concerns.
- State industrial stormwater permits should be reviewed for advancements in sector-specific monitoring that would be appropriate for the national permit (e.g., Bulkley et al., 2009).
- New understanding of pollutant effects in the environment and advances in monitoring technology should be evaluated. For example, PAHs were not previously monitored as part of the MSGP process, but aquatic impacts of PAHs are now better understood and analytical technologies have advanced significantly since the 1992 group application. Scientific advances that identify cost-effective monitoring surrogates should also be considered.

This level of analysis should be adequate to substantiate the addition of benchmark monitoring requirements for specific sectors. That said, where EPA finds that the sector review is not substantial enough to withstand the scrutiny of adding benchmark monitoring requirements, as was the case after EPA proposed to add benchmark monitoring for several sectors in the 2006 draft MSGP, the committee suggests an alternative process. Where data are lacking to inform the analysis, additional sector-specific monitoring data should be collected to provide the information necessary to quantify whether stormwater pollutants are present at levels of concern, using a process similar to that used in 1992 for the group applications. The committee recommends that additional monitoring be performed over a 1-year period, at the same outfalls for which industry-wide monitoring is conducted, but without the application of benchmark threshold. These data would then inform future revisions of the MSGP monitoring requirements.

[1] See https://www.epa.gov/npdes/industrial-stormwater-fact-sheet-series

ADJUSTING BENCHMARK THRESHOLD LEVELS

Benchmark threshold levels were established during the early iterations of the MSGP, based on several different criteria and employing several simplifying assumptions. In this section, the committee reviews the latest information on toxicity and technical achievability, relative to the current benchmark levels, and discusses the implications to the benchmark levels.

Updated Toxicity Information

Advancements in the understanding of aquatic toxicology suggest that some benchmark threshold levels may require adjustment to reflect the latest scientific information in meeting the MSGP's intended water quality protection goals. This section reviews the application of water quality criteria toward the benchmark and the need to update benchmarks to reflect the latest aquatic life criteria. Additionally, the committee discusses new benchmarks to better characterize stormwater risks, unnecessary benchmarks, and benchmark units used in documentation and communication.

Application of Water Quality Criteria

Many of the current benchmark thresholds were derived from aquatic life criteria (see Table 1-3). EPA recommends that aquatic life criteria be derived for protection of toxicity for both acute (short-term) and chronic (longer-term) exposure, when possible (EPA, 1985). Given the intermittent nature of stormwater exposures and the likelihood of dilution and attenuation within watersheds, organisms will be exposed to chemicals from stormwater discharges over short time frames. For stormwater benchmarks based on aquatic life criteria, the committee recommends the use of criteria designed to protect for short-term or intermittent exposures when they exist, which, to date, have generally been acute criteria.

Most benchmarks in the 2015 MSGP are set according to acute criteria (see Table 1-3); however, chronic criteria are used in three cases—selenium, arsenic, and iron—each for different reasons. Chronic criteria are established to protect aquatic life against mortality and impacts to growth and reproduction after longer-term exposure.

Selenium. EPA originally considered establishing the selenium benchmark at a value equal to the acute freshwater criteria (20 μg/L; EPA, 1987), but sufficiently sensitive test methods were lacking at that time. Thus, in the MSGP EPA originally set the selenium benchmark at 238.5 μg/L based on the value that could be accurately and precisely quantified (60 *Federal Register* 50825 (September 1995)). In the development of the 2008 MSGP, EPA updated benchmark thresholds for which more sensitive analytical methods were available. For selenium, EPA stated in 2008 that they based the benchmark threshold on chronic criteria (5 μg/L) because at the time of development of the 2008 MSGP, no acute criterion was in effect (EPA, 2008a).

The selenium benchmark based on chronic aquatic life criteria is now outdated. In 2016, EPA released updated ambient aquatic life criteria for selenium, with new chronic freshwater criteria reduced to 1.5 and 3.1 μg/L for still or flowing waters, respectively (EPA, 2016a). However, no concentration-based acute criteria were derived. The updated selenium criteria are unique in that they were derived to specifically account for the bioaccumulative properties of selenium and reproductive effects on fish species and included a translation of the chronic criteria for short-term or intermittent exposure, in lieu of an acute criteria. The translation of the chronic criteria must be calculated based on the background base-flow concentration of selenium in the receiving water and the length of exposure. This complicates the monitoring requirements for selenium given the additional data required to translate chronic criteria to intermittent conditions. Although such intensive data collection would not be desirable for most permittees, enhanced sampling and analysis for facilities with repeated benchmark exceedances would allow EPA to determine if their discharge is causing adverse effects under the site-specific conditions (see also Enhanced Monitoring, discussed in Chapter 3).

Arsenic. Even though an acute criterion of 360 μg/L arsenic had been developed (EPA, 1986), the MSGP benchmark was originally set at 164.8 μg/L based on the analytical detection limit (60 Federal Register 50825 (September 1995)). At the time of the 2008 MSGP review and update for more sensitive detection methods, the updated acute criterion (340 μg/L) was more than two times the previous value. EPA decided not to substantially weaken the benchmark based on concerns about near-coastal freshwater discharges flowing quickly into sensitive saline waters, which had a saltwater acute aquatic criterion of 69 μg/L (EPA, 2008b). Therefore, the benchmark was adjusted to the chronic criterion of 150 μg/L. Unless EPA can justify specific unique concerns for arsenic discharge from freshwater in near-coastal settings that do not apply to all other benchmarks with lower saltwater benchmarks or until it develops a criterion based on intermittent exposure, EPA should adopt the acute aquatic life criterion (340 μg/L) for the arsenic benchmark.

Iron. EPA based the iron benchmark threshold on the chronic criterion (1,000 μg/L) given the lack of an acute criterion, and that decision has remained over the iterations of the MSGP. No acute aquatic life criterion for iron has been developed since the MSGP was originally established.

The committee found very few studies on the acute effects of iron on aquatic organisms, and these studies suggest lethal effects occur well above the current benchmark over longer time periods. For example, an iron concentration of 6,700 µg/L over 48 hours caused acute immobilization in 50 percent of the population (EC50) in *Daphnia magna* (Okamoto et al., 2014). An iron concentration of 2,000 µg/L in humus-free water was lethal to 23 percent of one-summer-old grayling fish after being exposed for 72 hours (Vuorinen et al., 1998). Zahedi et al. (2014) determined that 122,000 µg/L iron is lethal to 50 percent of a population (LC50) of kutum fish over 96 hours. The science upon which the criterion is based is dated and limited (EPA, 1976). The committee suggests that EPA reevaluate the aquatic toxicology literature for acute toxicity studies of iron and develop a benchmark for iron based on acute toxicity. Because iron has relatively low toxicity and bioaccumulation of iron does not pose a substantial hazard to higher trophic levels (Cadmus et al., 2018), it is unlikely that a criterion based on intermittent exposure would be necessary. Given the basis of the iron criterion and the difficulty many facilities have in meeting the benchmark (see Tables 2-3 through 2-5 and Appendix D), EPA should suspend the benchmark for iron until an acute criterion is developed unless EPA can articulate a specific rationale for protecting against chronic effects of iron from intermittent events.

Updating Benchmarks to Match Aquatic Life Criteria

Other aquatic life criteria are currently under revision or have recently been revised. For example, revised acute aquatic life criteria for cadmium have been developed (EPA, 2016b) and will need to be incorporated into the next MSGP revisions (see Table 2-6).

EPA has adopted or is considering more complex approaches to defining aquatic life criteria for some constituents, which could have implications for the MSGP benchmark monitoring requirements. For copper, the most recent aquatic life criteria (EPA, 2007) do not provide a single-concentration acute criterion, but instead provide an equation or model that is used to calculate acute criteria with additional site-specific data. The biotic ligand model for copper, which takes into account the fact that the bioavailability and hence toxicity of certain metals is affected by water chemistry, uses 10 input parameters for toxicity determination.[2] Given the extra sampling burden, the 2015 MSGP did not recommend using the biotic ligand model for copper benchmark monitoring, which is reasonable for a national permit. Nevertheless, in Chapter 3, the committee discusses giving permittees the option to monitor for additional components and to use the biotic ligand model and updated acute criteria if they routinely exceed the benchmark.

Draft 2017 aquatic life criteria for aluminum similarly involve the measurement of multiple parameters to determine the acute criteria based on bioavailability. The new approach to determine aluminum toxicity uses a multiple linear regression method, considering total hardness, pH, and dissolved organic carbon (DOC; DeForest et al., 2018). The 2015 MSGP freshwater aluminum benchmark is set at 750 μg/L (EPA, 1988), but the 2017 draft update recommends increasing the acute criteria to 1,400 μg/L (based on pH = 7, hardness = 100 mg/L, and DOC = 1 mg/L; EPA, 2017). Considering the minimal additional analysis required, the next version of the MSGP should reflect this change, if the new aluminum criteria are finalized.

TABLE 2-6 Outdated Benchmarks or Inconsistencies with Aquatic Life Criteria

	2015 MSGP Benchmark	Source	Current Aquatic Life Criteria	Source
Cadmium	2.1 μg/L	EPA, 2001	1.8 μg/L	Acute; EPA, 2016b
Copper	14 μg/L	EPA, 1980b	BLM	EPA, 2007
Selenium	5 μg/L	EPA, 1987;	1.5 μg/L (lentic) 0.0031 μg/L (lotic) Intermittent equation	Chronic; EPA, 2016a

NOTE: See https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table.

[2] pH, dissolved organic carbon, calcium, magnesium, sodium, sulfate, potassium, chloride, alkalinity, and temperature.

Developing New Benchmarks to Better Characterize Stormwater Risks

PAHs have been shown to be extremely toxic to fish and aquatic invertebrates and are known to bioaccumulate (Incardona et al., 2011; McIntyre et al., 2016). PAHs are expected at industrial sites with petroleum hydrocarbon exposure. However, no benchmark has been set for PAHs for any of the industrial sectors. Analytical methods for determination of PAHs are standardized and readily available (EPA, 2015c). It may appear that COD can be used as a surrogate for PAHs, but PAHs can be toxic at concentrations orders of magnitude lower than the COD benchmark (120 mg/L). Canadian water quality guideline values for PAHs for the protection of aquatic life range from 0.012 µg/L (anthracene) to 5.8 µg/L (acenaphthene) (Canadian CME, 1999). Currently, EPA has no recommended aquatic life criteria for individual or total PAHs. EPA evaluated the need for ambient water quality criteria for PAHs in 1980 and noted at the time that the data regarding aquatic life toxicity were extremely limited (EPA, 1980c). Information gathering and/or preliminary monitoring of PAHs from some sectors would be valuable; such data could be correlated with COD concentrations to help EPA determine if COD is an adequate surrogate for PAH concentrations and impacts or if additional PAH monitoring is needed for sectors that have the potential to release PAHs.

Unnecessary Benchmark: Magnesium

Magnesium is a natural component of surface and groundwater and does not appear to be toxic to a majority of aquatic organisms at concentrations likely to be encountered in most waters, with reported LC50 values ranging from 780 to more than 20,000 mg/L (van Dam et al., 2010). No EPA aquatic life criterion is provided for magnesium. Nevertheless, total magnesium is listed in the MSGP as a benchmark monitoring requirement for Sector K (hazardous waste treatment, storage, or disposal facilities), with a threshold concentration of 0.064 mg/L as a benchmark. Data submitted under the 2015 MSGP show that all samples reported for Sector K exceeded the benchmark, and 83 percent of the samples exceeded eight times the benchmark. It is unclear why magnesium is a required benchmark for this sector, given the lack of toxicity at concentrations likely to be observed in industrial stormwater discharges. Therefore, the committee recommends that magnesium be removed as a benchmark monitoring requirement.

Units

Benchmark threshold levels should be expressed in the same units as the values from which they are derived. For example, benchmark thresholds for parameters such as TSS, total nitrogen, and total phosphorus should be expressed in mg/L and benchmark threshold for metals should be expressed in µg/L. Units of measurement are a foundation of science used to communicate the magnitude of a quantity. The adoption of common units of measurement allows scientists to consistently communicate findings in context and in a manner that eases comparative analysis. In the case of the MSGP, expression of benchmark thresholds for metals in µg/L would promote understanding of the potential consequence of an exceedance relative to the scientific basis from which the benchmark was derived, for example, acute toxicity to aquatic life. This change in expression would also eliminate the need to report sampling results using leading zeros, which can create confusion and the opportunity for reporting error. In the committee's analysis of the 2015 MSGP monitoring data (see Appendix D), there were numerous reported values that appeared to be reporting errors due to incorrect units. Consistent expectations for reporting would also reduce error in the data set.

EPA should also explain the uncertainty and rounding inherent in the expression of criteria upon which benchmark values are derived and provide guidance on the level of precision expected in reported results. Specifically, EPA should describe how many significant figures should be included and when sample results should be rounded. This ensures that the corrective actions triggered by the exceedance of a benchmark have a threshold of significance and a relationship to the scientific basis of the value.

Assessing Technical Achievability

Pollution prevention and nonstructural SCMs are generally the preferred method to address industrial stormwater discharges. Using nonhazardous materials, general site cleanliness, and creating no-exposure scenarios will greatly minimize pollutant discharge concentrations and masses. However, for some sites, structural SCMs including treatment systems will be necessary to meet MSGP benchmark concentrations. For technology-based benchmarks, an important consideration is whether the benchmarks continue to represent the capability of technologies (when combined with appropriate pollution prevention and nonstructural SCMs) for pollution control. For water-quality-based benchmarks, the feasibility of achieving these thresholds with current technology and appropriate site management must be understood. This section examines the capacity of treatment SCMs to meet industrial stormwater benchmarks (see Table 1-2) considering available (albeit limited) data. For this analysis, the committee examined stormwater treatment data from two sources:

1. A study of treatment SCM performance at several industrial sites in the United States by Clark and Pitt (in press) and
2. The International Stormwater Best Management Practices (BMP) Database, which includes mostly nonindustrial sites.[3]

All the data reported represent influent and effluent concentrations at various treatment SCMs, and the results are organized by pollutant. In general, it is expected that pollutant behavior in a treatment device is independent of the industrial sector and, instead, is a function of influent concentration and other chemical characteristics (e.g., association with solids, complexation with inorganic and organic ligands, pH).

The Clark and Pitt (in press) data were collected at industrial sites, including Sectors M, N, R, S, and AB (see details in Appendix E), although separation by industry types is not analyzed here. The data from each site are reported separately, labeled by the type of treatment SCM. The study included three broad categories of treatment SCMs: (1) sedimentation systems (hydrodynamic separator systems, ponds, and wetlands); (2) filtration/adsorption systems; and (3) treatment trains that included two or more serial SCMs.

[3] See http://www.bmpdatabase.org.

The International Stormwater BMP Database includes data on SCM treatment performance from a wide range of studies that meet specific quality control criteria. Data were analyzed for pollutants with MSGP benchmarks and focused on five treatment SCMs considered relevant to industrial stormwater: dry detention ponds, wet retention ponds, wetlands, media filters, and bioretention. The BMP Database contains many more sites than the Clark and Pitt (in press) study, and data for each SCM selected likely represent multiple sites. Additionally, the BMP Database includes multiple land uses, including primarily municipal sites. Because of this, the stormwater concentrations tend to be lower than the Clark and Pitt (in press) industrial data. Detailed design, sizing, and operational/maintenance information was not available for any of these sites, so it cannot be assumed that they are or are not appropriately designed, sized, or maintained.

The Clark and Pitt (in press) and International BMP Database data were analyzed in the same manner. Data analysis was performed to answer the following question: For treatment systems that demonstrated statistically significant removal of a pollutant, were the treatment systems able to reduce influent concentrations that exceeded the MSGP benchmarks (see Table 1-2) to effluent concentrations that met the benchmark? Therefore, the analysis only included influent/effluent data pairs where the influent exceeded the benchmark threshold. As with the 2015 MSGP data analysis, for a data set to be included, each site considered had to have a minimum of eight storm events.

Given the limitations of the data sets, the committee used a simple comparison of the data presented in box plots to assess the capability of the treatment systems to meet the benchmarks. The boxes of the box plots highlight the 25th, 50th, and 75th percentiles of the pollutant concentrations, while the whiskers represent the 10th and 90th percentiles. The committee then examined the percentage of the effluent samples that met the benchmark, by treatment types, categorizing the performance by the percent of the effluent concentrations that met the relevant benchmark according to the components of the box-and-whisker plot (<10, 10-25, 25-50, 50-75, 75-90, and >90 percent). Under the MSGP, the results of four quarterly samples are averaged for evaluation against the benchmark threshold; thus, meeting the benchmark in at least 50 percent of events provides a reasonable likelihood of the average also meeting the benchmark. However, the occurrence of even one very high concentration can lead to an average above the benchmark. The data are plotted on a linear scale (in some cases with split axis) because of the need to clearly visualize performance at concentrations near the benchmark level(s).

The analysis considers seven common industrial stormwater pollutants for which adequate data are available: TSS, total aluminum, total copper, total iron, total lead, total zinc, and chemical oxygen demand. For copper, lead, and zinc, the benchmark is based on the receiving water hardness; therefore, two benchmarks were used for analysis—one for a softer water (60 mg/L hardness) and one for a harder water (200 mg/L hardness). All data reported are from composite samples, typically volume weighted. When compared to the early-storm grab sample of benchmark monitoring, the flow-weighted composite generally would be either equal or lower in concentration.

In this analysis, the data are treated as independent events, an assumption underlying a box-plot analysis. Temporal trends were not analyzed and no conclusions can be drawn regarding rolling averages meeting the benchmark.

Results

To highlight examples of the results of this analysis, the SCM treatment performance for two pollutants, TSS and total iron, are discussed in this section along with the overall findings of the analysis of all pollutants. The remaining pollutant-specific data plots are presented in Appendix E.

Total Suspended Solids (TSS). For the treatment SCMs at industrial sites, neither of the two sedimentation systems met the benchmark for at least 50 percent of the monitored events; the media filter and both treatment train systems met the benchmark for at least 75 percent of the storm events (see Figure 2-1). Data from the International Stormwater BMP Database, which represent slightly lower concentrations, showed that all systems were able to meet the benchmark for at least 50 percent of the monitored storm events; dry ponds, media filters, and bioretention systems were able to meet the benchmark for at least 75 percent or more of the monitored events (see Figure 2-2). These data suggest that several treatment SCMs are available and can be operated in a manner that provides sufficient treatment to meet the TSS benchmark for at least 50 percent of the monitored events.

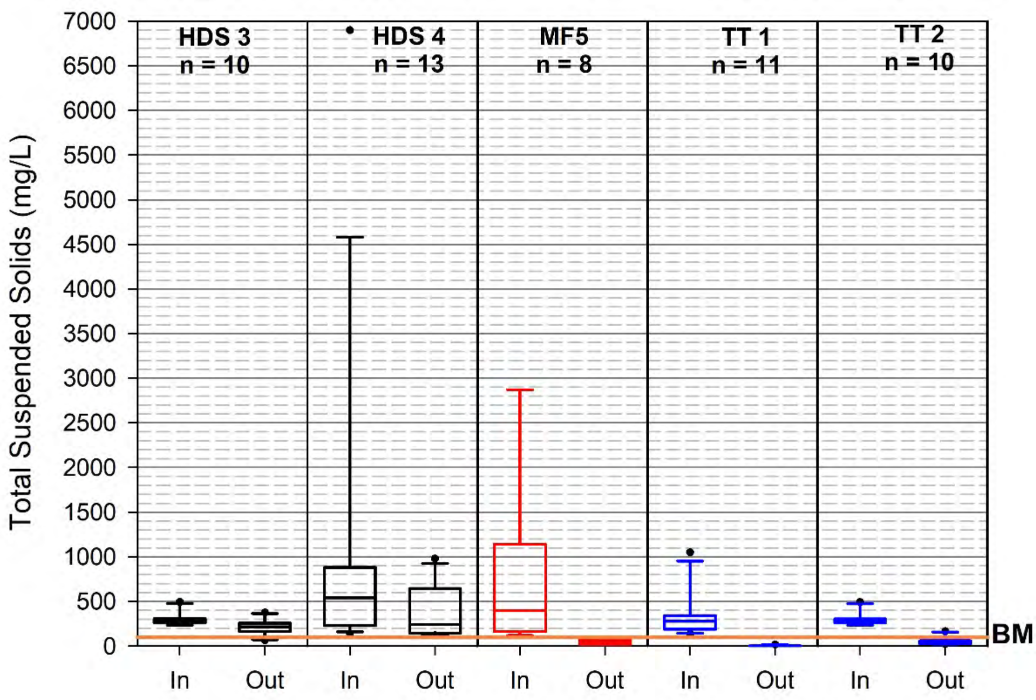

FIGURE 2-1 Total suspended solids (TSS) influent versus effluent concentrations at industrial sites from Clark and Pitt (in press).
NOTE: BM = benchmark; HDS = hydrodynamic separator; MF = media filter; n = number of storm events sampled; and TT = treatment train.

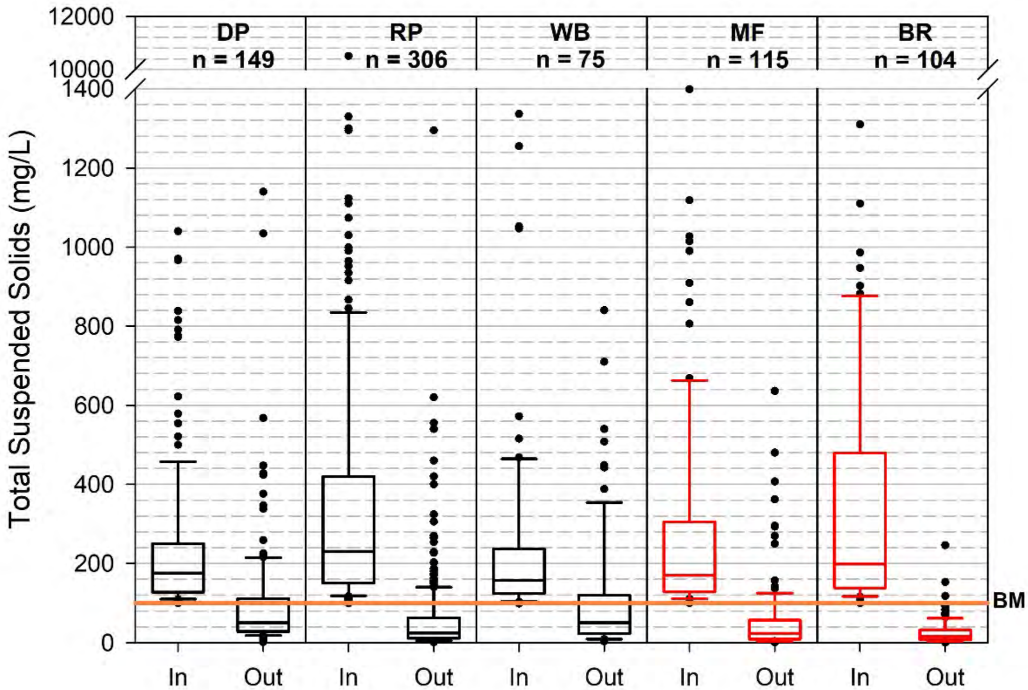

FIGURE 2-2 International BMP Database comparison of influent and effluent concentrations for total suspended solids (TSS).
NOTE: BM = benchmark; BR = bioretention; DP = dry detention ponds; MF = media filters; n = number of storm events sampled; RP = wet retention ponds; and WB = wetlands.

Total Iron. The available data for total iron show a different story. At the Clark and Pitt (in press) industrial stormwater monitoring sites, none of the four systems was able to meet the benchmark concentration for 50 percent, or even 25 percent, of the monitored storm events (see Figure 2-3). Two treatment systems (retention ponds and media filters) from the International Stormwater BMP Database were able to meet the total iron benchmark concentrations for at least 50 percent of the monitored storm events, but the average influent concentrations were substantially lower in this data set (see Figure 2-4). Although the number of industrial sites, treatment types, and storm events were quite limited for the Clark and Pitt (in press) study, the data suggest that industrial sites with high influent concentrations may have difficulty attaining the total iron benchmark, although more data would be needed with more information about the nature of the SCMs to definitively reach this conclusion.

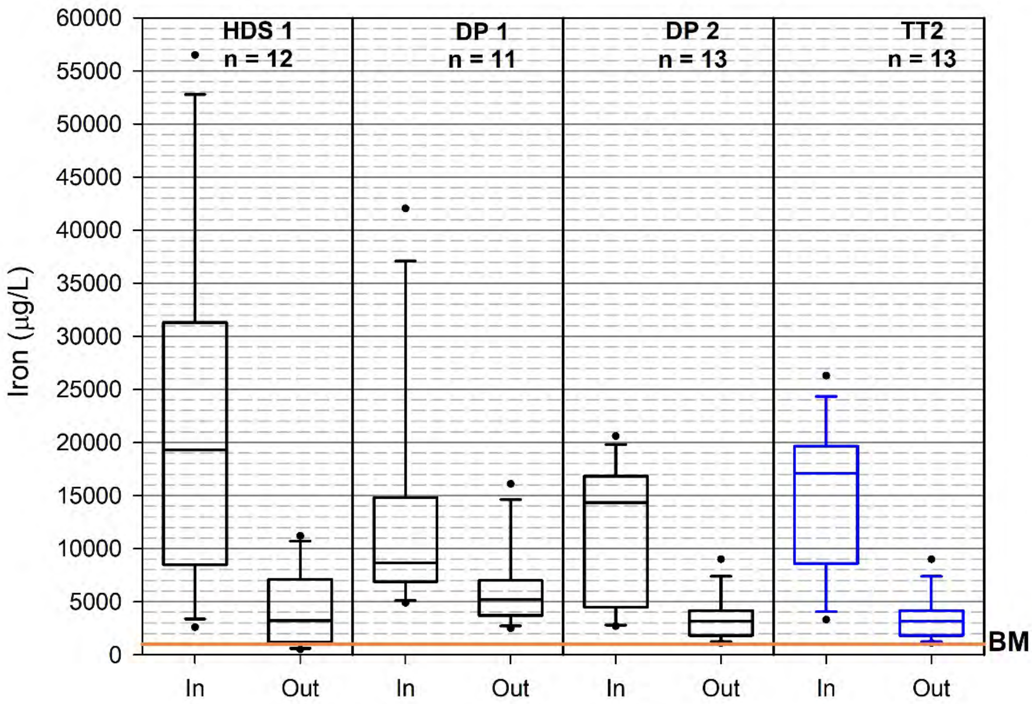

FIGURE 2-3 Total iron influent versus effluent concentrations comparison at industrial sites from Clark and Pitt (in press).
NOTE: BM = benchmark; DP = dry detention pond; HDS = hydrodynamic separator; n= number of storm events sampled; and TT = treatment train.

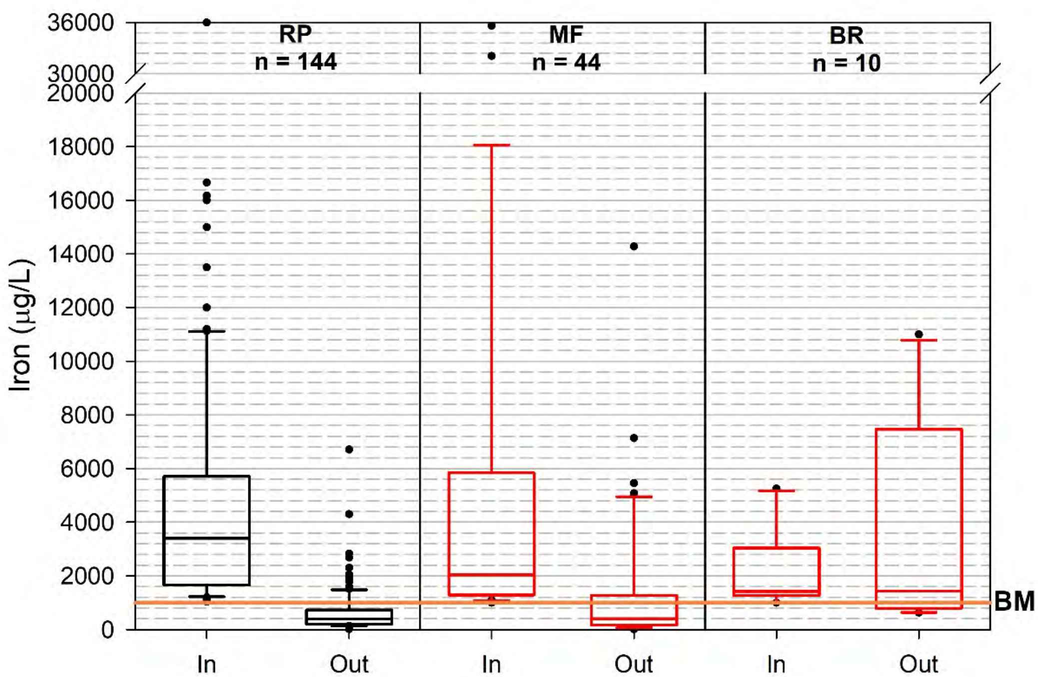

FIGURE 2-4 International BMP Database comparison of influent and effluent concentrations for total iron.
NOTE: BM = benchmark; BR = bioretention; DP = dry detention ponds; MF = media filters; n = number of storm events sampled; RP = wet retention ponds; and WB = wetlands.

Summary of Treatment Systems. Table 2-7 synthesizes the treatment performance results from Figures 2-1 to 2-4 and E-1 to E-13 (see Appendix E) for all of the treatments and pollutants analyzed. The performance is color coded according to the percentage of storm events in which the flow-weighted effluent concentration for that treatment met the benchmark. For example, yellow, red, and magenta shades indicate treatments where 25 to 50 percent, 50 to 90 percent, and >90 percent, respectively, of the effluent event mean concentrations were above the benchmarks. Green shades represent treatments for which at least 75 percent of the effluent event mean concentrations met the benchmark (darker shades reflect better performance). Gray shading represents sites where sufficient data pairs (a minimum of eight storm events in which the influent exceeded the benchmark) for that treatment and pollutant were not available or the removals were not statistically significant—the committee's criteria for inclusion. Table 2-7 shows that for industrial sites, less than a third of the treatment and pollutant types met the inclusion analysis criteria, limiting the data available for drawing conclusions.

TABLE 2-7 Comparison of Treatment Performance, Shown as Percentage of Storm Events with Event Mean Concentrations Above the Benchmark, with Sample Size Noted

System	TSS (100 mg/L)	Total Al (750 µg/L)	Total Copper		Total Iron (1,000 µg/L)	Total Lead		Total Zinc		COD (120 mg/L)
			Soft (9 µg/L)	Hard (28.5 µg/L)		Soft (45 µg/L)	Hard (213 µg/L)	Soft (80 µg/L)	Hard (230 µg/L)	
INDUSTRIAL SITE-SPECIFIC EVALUATIONS										
Hydrodyn. Separator 1		11	12	12	12			12	12	
Hydrodyn. Separator 2										
Hydrodyn. Separator 3	10									8
Hydrodyn. Separator 4	13									
Dry Detention Pond 1			10	10	11	10		10	10	
Dry Detention Pond 2		14	16	16	13	15	9	14	11	
Wetlands										
Media Filter 1										
Media Filter 2										
Media Filter 3			10					18		
Media Filter 4								13	13	
Media Filter 5	8	9	12	9				12		
Media Filter 6			9					16		
Treatment Train 1	11		15					14		
Treatment Train 2	10	14			13	16	9	16	16	9
INTERNATIONAL BMP DATABASE EVALUATIONS (includes many sites)										
Dry Detention Ponds	149		146	65		51		114	53	14
Wet Retention Ponds	306	8	336	110	144	105	31	223	55	11
Wetlands	75		47					55	8	
Media Filters	115		225	43	44	18		252	54	
Bioretention	104		127	39	10			100	33	27

<10% above BM	10-25% above BM	25-50% above BM	50-90% above BM	>90% above BM

NOTE: Numbers of influent/effluent sample pairs displayed in each cell. Gray cells indicate that the system was not included in the analysis because it did not meet the criteria for inclusion. The removal either was not statistically significant or the data set did not include at least eight storm events for that treatment/pollutant where the inflow exceeded the benchmark.

There are several important limitations/caveats to these summaries. Overall, the industrial site-level data are limited to a relatively small number of storm events. Data included in this analysis used a low threshold of inclusion, only eight events. Additionally, both data sets lack sufficient site-level information to make definitive assessments of the capacity of any these treatment types to meet the benchmarks in other locations. In many cases, specific design information about the systems is not known. For the Clark and Pitt (in press) individual site evaluation, many site owners noted that their filter media were proprietary mixes developed by a vendor and optimized for their site pollutants. In the International Stormwater BMP Database, all media filters are placed into a single category, even though the performance of filtration media is known to vary based on the composition of the media (Clark, 2000; Johnson et al., 2003). Although some of the sedimentation device sizes could be determined, the size of the drainage area could not, and, therefore, the appropriateness of device sizing is unknown. Incorporation of specific features, such as energy dissipaters that would prevent scour of captured sediment, is not known. Finally, as noted previously, the data reflect composite samples (typically flow-weighted composites), which are often lower in concentration than first-flush grab samples, as required by benchmark sampling. Thus, treatment technologies and sites shown to meet the benchmark with composite samples may not necessarily meet it consistently with first-flush grab samples. Where composite samples consistently fail to meet the benchmark, the same would be expected when first-flush grab samples are used, although not necessarily from discharge of storage SCMs.

Despite the limitations of the data sets, some general findings emerge. In the site-level industrial evaluation (Clark and Pitt, in press), at least one treatment SCM was capable of meeting benchmarks for at least 50 percent of storm events for TSS, aluminum, copper, zinc, and COD. Multiple sites and treatment SCMs met the benchmarks for at least 50 percent of storm events for TSS, aluminum, copper (soft water), lead (hard water), and zinc (hard water). In contrast, no systems/sites analyzed were able to meet the benchmark for at least 25 percent of storm events for iron or at least 50 percent of events for lead (soft water).

The International Stormwater BMP Database provides a larger data set, but it includes many nonindustrial sites, and on average it has much lower pollutant influent concentrations than the site-level industrial data. Under conditions of lower influent concentrations that might be found more commonly in municipal settings, the International Stormwater BMP Database data suggest that treatment SCMs are available that are effective in reducing concentrations below freshwater benchmark threshold levels in at least 50 percent of the storm events where the influent concentration exceeds the benchmark for TSS, copper, iron, lead, zinc, and COD. Data for aluminum were extremely limited (only eight storms for one treatment type).

The committee cannot say definitively that lower influent concentrations led to more successful treatment performance for these particular sites because of the limited information on design and operation of the SCMs. With median inflow iron concentrations ranging from 1,500 to 3,500 µg/L, two of the three treatment SCMs in the BMP Database met the iron benchmark for at least half of the storm events, while none of the four industrial sites/treatments (with median inflow concentrations of 8,500 to 19,000 µg/L) could meet the benchmark for at least 10 percent of events. Similarly, at the industrial sites where the median inflow zinc concentrations ranged from 500 to 900 µg/L, only one of the treatments met the lower soft-water benchmark. In contrast, in the BMP Database, where median inflow concentrations ranged from 100 to 400 µg/L, four out of five treatments met the soft-water benchmark for at least half of the storms. Although some dependence on influent concentration is found generally in SCM performance, SCM treatment is not linear with influent concentration (Clark, 2000). Some SCMs will discharge pollutant concentrations near a treatment value determined by their design characteristics, independent of influent concentrations up to the design storm size (most storm events rarely approach the design storm size).

The analyses also indicate that all SCMs will not provide equal performance. Dry detention ponds and hydrodynamic separators generally performed poorly compared to other treatment types in both the industrial site evaluation and using the BMP Database. Much of the poor performance likely is attributable to scour of previously captured sediment (Avila and Pitt, 2009). Media filters, treatment trains, wet detention ponds, and bioretention were among the better-performing SCMs.

Three of the industrial sites met the benchmark for TSS for at least 50 percent of storm events, but failed to meet the benchmarks as often for other parameters (e.g., iron, copper, zinc). Even though some guidance documents, such as California Waterboards (2018), state that TSS removal can be used as a predictor of particulate metals removal, these data suggest that attaining the benchmark for TSS at industrial sites is not a sufficient surrogate for meeting the metals benchmark.

Overall, the committee's evaluation of technical achievability is hampered by the acute lack of SCM performance data for industrial stormwater. Table 2-4 highlights the paucity of industrial stormwater data available with which to evaluate the attainability of benchmarks. None of these data is sufficient to determine that certain benchmarks cannot be achieved with existing treatment technology combined with appropriate site management and pollution prevention strategies. It does appear, however, that some type of treatment train approach, where an initial SCM handles part of the pollutant load followed by a second "polishing" treatment, has the potential to meet many of the benchmarks for more than 50 percent of storm events. The initial treatment may be an SCM that specifically targets high-particulate-matter loads or some nonstructural SCM that can reduce input pollutant concentrations.

Although this analysis focuses on treatment and the 2015 MSGP monitoring data are based on benchmark monitoring discharge concentrations, some commonalities are noted. Again, copper, iron, and zinc are the pollutants that have benchmark concentrations that are the most difficult to meet.

This analysis clearly highlights the critical need for more data to assess the achievability of many benchmarks. Specifically, more data would be particularly valuable regarding the treatment performance for iron, but would also be useful for aluminum, copper, lead, and zinc, which in the 2015 MSGP monitoring data show results that commonly exceed the benchmarks across multiple sectors (see Tables 2-3 and 2-4 and Appendix D).

Priorities for Additional Monitoring

The Statement of Task asked the committee to

> Identify the highest priority industrial facilities/subsectors for consideration of additional discharge monitoring. By "highest priority" EPA means those facilities/subsectors for which the development of numeric effluent limitations or

reasonably standardized stormwater control measures would be most scientifically defensible (based upon sampling data quality, data gaps and the likelihood of filling them, and other data quantity/quality issues that may affect the calculation of numeric limitations).

As discussed in Chapter 1, national effluent limitation guidelines (ELGs) are used to set enforceable technology-based effluent limits. ELGs are developed based on performance of specified technologies and can be numeric or narrative. In the absence of ELGs, technology-based effluent limits can also be applied by best professional judgment on the technical capabilities of achieving effluent limits (EPA, 2010).

All technology-based numeric effluent limitations (NELs) that currently apply in the MSGP were developed through the ELG process in the 1970s and 1980s (see list in Appendix B). Additional NELs for industrial stormwater could be developed based on the performance of structural and nonstructural SCMs. Developing new NELs based on the capabilities of treatment technology and other on-site stormwater management practices would require significant amounts of rigorous monitoring data. For this reason, the ELG process has several important advantages over the MSGP process for development of NELs for industrial stormwater. First, although both the MSGP and ELG processes can consider publicly available data on the performance of treatment technology, the ELG process includes the capability to generate additional performance data through targeted sampling, questionnaires, and other means. Key aspects of monitoring SCM performance include study design, sample type and locations, data validation and reporting, and performance analysis (Geosyntec Consultants and Wright Water Engineers, Inc., 2009). These elements of performance monitoring go beyond the capability of what can be prescribed in a national general permit and reported through discharge monitoring reports and annual reports in a useful manner. The ELG process also affords a more focused analysis of treatment technology performance, because it analyzes treatment technology performance on a waste stream by waste stream basis, for specific sectors and subsectors. In contrast the objective of the MSGP is to update permit requirements for many sectors and subsectors at the same time. The ELG process includes a comprehensive consideration of economic factors specifically related to treatment technology performance, and extensive opportunity for public input from planning to final promulgation.

Based on the paucity of industrial SCM performance data available at this time, no specific sectors are recommended for development of new numeric effluent limits solely based on existing data, data gaps, and the current likelihood of filling them. Any new NEL that is developed would require extensive collection of new data. Instead, NELs are appropriate for sectors and pollutants that cannot be effectively controlled within the MSGP and proposed AIM process (see Box 1-3) or for which there are documented benchmark attainability issues, considering implementation of reasonable structural and nonstructural SCMs.

In the committee's review of the 2015 MSGP monitoring data, a few sectors stand out as having a large percentage of samples with high discharges (eight times the benchmark levels), including Sectors H (coal mines and coal-mining-related facilities), A2 (wood preserving), F4 (nonferrous foundries), Q (water transportation), and R (ship and boat building or repairing yards) (see Table 2-4). A few of these sectors reflect only a small number of sites. The AIM process, which is under development, is intended to provide structured mechanisms to improve compliance under the MSGP. Thus, it is premature to judge whether AIM will be effective to reduce these high stormwater pollutant discharges. Those sectors that consistently fail to meet the benchmark under the most intense scrutiny within the AIM process may be appropriate candidates for the development of ELGs, although individual permits may also be a more efficient pathway for sectors with relatively few facilities.

Where benchmark attainability is questionable, industries and industry groups should collect detailed performance data for common SCMs under typical stormwater conditions to expand the knowledge base and potentially identify future sectors and pollutants where numeric effluent limits may be appropriate. Such data should be collected using appropriate quality assurance and quality control (QA/QC) practices for stormwater monitoring and include information on SCM design, sizing, maintenance during monitoring, and on-site characteristics, such as watershed area, land cover, and anticipated pollutants. These monitoring data should be made available via a mechanism similar to (or directly employing) the International Stormwater BMP Database. The open nature of the BMP Database is an opportunity for a wide range of study authors and reviewers to submit performance data with quality assurance reviews. Relatedly, in December 2017, EPA released its Industrial Wastewater Treatment Technology Database (IWTT) as a publicly accessible web application.[4] EPA now conducts routine literature reviews to identify performance data that could be included in the IWTT, and considers performance data in the IWTT in its ELG process (EPA, 2018). Similar EPA efforts for industrial stormwater would strengthen the value of the BMP Database.

For water-quality-based criteria, rigorous treatment performance data are necessary to determine if there are benchmarks that are not attainable based on current technology and best practices for site management and pollution prevention. These data could provide scientific support for the development of new numeric effluent limits via the ELG process to reflect treatment attainability. For benchmarks based on treatment technology, such as TSS, the data could indicate whether current benchmarks represent appropriate performance targets or, in fact, should be lower, based on improvements in the state of practice of structural and nonstructural SCMs.

CONCLUSIONS AND RECOMMENDATIONS

EPA should require industry-wide monitoring under the MSGP for pH, TSS, and COD as basic indicators of the effectiveness of stormwater control measures employed on site. These parameters can serve as broad indicators of poor site management, insufficient SCMs, or SCM failure, which can lead to high concentrations of these and other pollutants. Industry-wide monitoring of pH, TSS, and COD would also provide a baseline understanding of industrial stormwater management across all sectors. All permitted facilities are currently required to conduct visual monitoring of quarterly stormwater samples, and these additional analyses are relatively inexpensive, minimizing the additional monitoring cost burden. Replacement of COD with TOC should be considered once EPA has adequate data to develop a benchmark threshold level.

EPA should implement a process to periodically review and update sector-specific benchmark monitoring requirements that incorporate new scientific information. This

[4] See https://www.epa.gov/eg/industrial-wastewater-treatment-technology-database-iwtt.

process should consider updated industry fact sheets, published literature and industry data, advances in monitoring technology, and other available information, so that the monitoring programs adequately address the classes of pollutants used on site and their potential for environmental contamination. The committee reviewed several sectors where data suggest that stormwater pollutants are common, but little or no benchmark monitoring is required. In some cases, this situation resulted from limitations in the original process where industries self-determined what pollutants to monitor in their group applications, and those results were then analyzed to develop benchmark monitoring requirements. Additional information and data gathering for PAHs could help EPA determine if benchmark monitoring is needed for sectors that have the potential to release PAHs. Periodic monitoring reviews would allow EPA to assess changing industry practices that could affect monitoring needs, new analytical technology for pollutant quantification, as well as current toxicological information. Where data gaps remain, additional sector-specific data-gathering efforts should be initiated.

EPA should update the MSGP industrial sector classifications so that requirements for monitoring extend to nonindustrial facilities with activities similar to those currently covered under the MSGP. Many facilities and activities generating pollutants of concern in stormwater discharges are not included within the MSGP because the facilities themselves are not considered to be industrial, even though the on-site activities (and associated risks) are similar to those of regulated facilities. These include school bus transportation facilities and fuel storage and fueling facilities, such as gas stations. Some states have included these activities in their existing industrial general permits. EPA should examine other facilities with activities similar to regulated facilities and add them to the MSGP so that pollutant risks from these facilities can be appropriately reduced.

Benchmarks should be based on the latest toxicity criteria designed to protect aquatic ecosystems from adverse impacts from short-term or intermittent exposures, which to date have generally been acute criteria. Aquatic life criteria are designed for protection against both short-term (acute) and long-term (chronic) effects on both freshwater and saltwater species. Studies that form the basis of criteria development typically measure acute end points following exposure of aquatic life to consistent pollutant levels for short periods of time, and measure chronic end points following exposure of aquatic life to consistent pollutant levels for longer periods of time. Given the episodic nature of stormwater flow and the likelihood of instream dilution and attenuation, aquatic life criteria based on short-term (acute) or intermittent exposures are typically more appropriate for stormwater benchmark threshold levels than criteria based on long-term (chronic) exposures. Where EPA identifies substantial chronic risks to aquatic ecosystems from intermittent exposures during criteria development, such as for contaminants that bioaccumulate, an equation should be provided to translate chronic criteria for intermittent exposures. In this context, EPA should

- Develop acute aquatic life criteria for benchmarks where they do not currently exist, or develop equations to translate chronic criteria into benchmarks based on intermittent exposures where substantial chronic risks to aquatic ecosystems exist from repeated short-term stormwater exposures. Revisit the application of three benchmarks (iron, arsenic, and selenium) that are currently based on chronic and, in some cases, outdated aquatic life criteria.
- Allow permittees with repeated benchmark exceedances to use the latest aquatic life criteria for selenium and copper to evaluate water quality risk on a site-specific basis

and discontinue comparisons to national benchmarks, as appropriate. The latest criteria for selenium and copper include equations for calculating toxicity criteria based on short-term exposure, using additional water chemistry and/or flow data.

- Based on little evidence of adverse effects to aquatic organisms at common levels, suspend or remove the benchmarks for magnesium and iron; benchmarks for these metals can be reinstated if/when acute aquatic life criteria are established or benchmarks are developed based on chronic effects from intermittent exposure.
- Express all benchmarks in the units from which they are derived, to improve communication and reduce reporting errors and provide guidance on the expected level of precision in reported results.

Additional monitoring data collection on the capacity of SCMs to reduce industrial stormwater pollutants is recommended to inform periodic reviews of the benchmark thresholds and identify sectors for which new national effluent limits could help address treatment attainability. Publicly available stormwater data from industrial sites are currently insufficient to determine if there are specific conditions under which industries cannot meet the benchmarks using conventional stormwater treatment systems (e.g., sedimentation, filtration) or if other nontreatment SCMs could reduce concentrations on these sites. Based on limited available SCM performance data, it appears that most standard treatment SCMs can meet the benchmark in least 50 percent of storm events for TSS and for many pollutants at lower inflow concentrations associated with municipal stormwater. Considering that benchmark exceedance is judged by the average of four sample events, these results suggest that technical achievability is not a major issue for TSS. Limited data suggest that benchmark compliance is more difficult at industrial sites for iron, aluminum, copper, and soft-water conditions for lead and zinc; inadequate data are available for other pollutants. To improve our understanding of industrial SCM performance and technical achievability,

- Industries and industry groups should collect scientifically rigorous performance data for common SCMs under typical stormwater conditions to expand the knowledge base and inform future decision making. An appropriate number of storms should be monitored employing proper QA/QC to ensure data reliability, and design and maintenance information for the SCMs should be provided.
- EPA should encourage industries to collect these data and make them publicly available, such as uploading to the International Stormwater BMP Database.
- EPA should support maintenance of these data for industrial stormwater, as they are currently supporting the IWTT national database.

For benchmarks based on aquatic life criteria, the additional high-quality data collected can be used to assess the feasibility of achieving the benchmarks with current technology and practices. For technology-based benchmarks, additional data could inform future benchmark revisions to reflect the state of practice, reducing total loads to the extent practicable.

Because of the paucity of rigorous industrial SCM performance data, the development of new NELs is not recommended for any specific sector based on existing data, data gaps, and the likelihood of filling them. Any new NEL that is developed would require extensive new data collection. Several sectors can be identified in recent MSGP data with recurrent high concentration discharges. However, the decision to develop new numeric effluent limits would need to be informed by thorough SCM performance data that clearly document attainability issues by sector and include a large number of permittees that cannot achieve the benchmarks under the increased oversight of the AIM process, which is currently in planning.

3

Stormwater Sampling and Data Collection

Sampling is required in the Multi-Sector General Permit (MSGP) because it provides information on the quality of stormwater leaving an industrial site and on the performance of stormwater control measures (SCMs) in reducing pollutant burden. However, stormwater sampling is complicated by the dynamic characteristics of stormwater flow, the diffuse nature of many stormwater flows, and the myriad potential pollutants and pollutant characteristics that may exist on an industrial property. This chapter discusses the many challenges in quantifying pollutant discharges and includes recommendations to enhance the reliability and consistency of stormwater monitoring, laboratory analysis, and data management to improve industrial stormwater management under the MSGP.

CHALLENGES OF QUANTIFYING STORMWATER POLLTUANT DISCHARGE

Quantifying stormwater pollutant concentrations, loads, and subsequent environmental impacts is a challenge due to the variability in activities taking place on the land, storm occurrences, stormwater flows, and pollutant concentrations (Breault and Granato, 2000; Bent et al., 2001). Variations in water quality parameters can occur within a single storm, between storms, seasonally, and annually. Stormwater composition shows great temporal variation, especially in the early stages of runoff, for many reasons. Storms of different intensity (rainfall energy) mobilize and transport pollutants at different times after runoff begins. Runoff from different parts of a facility reaches the sample point at different times. Additionally, different pollutants mobilize after different periods in contact with flowing water.

Generally, stormwater pollutant concentrations will follow a first-flush pattern, with the highest concentrations occurring early in the storm. During the start of a storm, the rainfall is washing the drainage area at its most polluted state. As the duration of the storm continues, the concentrations of pollutants generally fall (e.g., Sansalone and Cristina, 2004; Han et al., 2006a). The difference between concentrations in first-flush runoff and later runoff can be an order of magnitude or more for some pollutants. This is not always the case, however, because changing rainfall intensity during a storm can provide energy mid-storm that may scour the drainage areas and produce high concentrations after the first flush. Concentrations in the effluent of treatment SCMs typically do not vary as much as in untreated stormwater. Treatment SCMs generally will reduce concentration and buffer high- and low-concentration excursions. For SCMs that have stormwater storage, sampling of initial discharge at the outfall may consist mostly of (treated) water that has been stored from the previous storm. Different sampling approaches, therefore, can lead to different results.

Effect of Sampling Methodology

The volume-weighted (or flow-weighted) pollutant concentration, also called the event mean concentration (EMC), provides the most consistent and comprehensive assessment of stormwater pollutant discharges and loads. Pollutant loads are important for understanding longer-term water-body impairments and toxicity concerns. The EMC is defined as the total pollutant mass discharged in the stormwater divided by the total runoff volume for the storm event, as measured at a specific outfall or measurement point:

$$\mathrm{EMC} = \frac{\text{Total Pollutant Mass}}{\text{Total Stormwater Volume}} = \frac{\int_0^{T_d} C\,Q\,dt}{\int_0^{T_d} Q\,dt}$$

where C is the pollutant concentration, Q is the flow rate, t is time, and T_d is the storm duration. Determinations of pollutant mass load or the EMC requires comprehensive understanding of the flows and concentrations occurring over the entire storm event, which can be measurement intensive. A pollutant concentration measured at a single time during a stormwater event cannot be considered to be representative of the EMC.

Different types of sampling schemes can be used to quantify stormwater pollutant discharges, ranging from simple grab samples to volume-weighted automatic composite sampling that supports the calculation of the EMC. Stormwater sampling can be resource intensive, and sampling plan decisions need to balance the benefits of the information obtained against the costs and labor requirements.

Grab Sampling

A grab sample will always be a snapshot of a rapidly changing situation. Trying to infer an EMC from a grab sample is not scientifically justifiable. However, the more controlled and consistent the collection of the grab sample(s), the more valuable and comparable the information becomes. Comparing grab samples that come from stormwater collected at different parts of the respective storm hydrographs will not have meaning. However, if samples are collected at the same (or near-same) sampling time during each storm, grab samples can be more reliable measures of stormwater pollution, subject to the limitations described about differences in rainfall energy in separate storms.

The current MSGP requires benchmark grab sampling to occur within 30 minutes of the start of runoff at the discharge point (see Table 1-1). The concentrations in a sample taken in the first 30 minutes of a storm are likely to be higher than the event mean concentration due to the effect of the first flush (unless the discharge is coming out of a treatment SCM or other device that stores water from the prior storm). Thus, current MSGP monitoring provides a low-cost, coarse indicator of the effectiveness of nonstructural and structural SCMs, and potential stormwater discharge pollution concerns. Carefully collected and analyzed grab samples, as part of benchmark monitoring, have value in this regard.

Sampling the first runoff could add further consistency and comparability to the grab sample data set and reduce monitoring variability. Inexpensive passive first-flush samplers are currently available that automatically capture the initial runoff from a storm. These samplers hold approximately 1 liter and are placed in the field before a storm event. They will fill with the first-flush runoff flow. A float (plastic ball) or other mechanism blocks the collector input once the vessel is full. Commercial first-flush samplers appear to provide useful, reproducible information on runoff water quality (Landsman and Davis, 2018). However, these samplers collect the first flow reaching the collection vessel. This flow could be highly contaminated if it is the first wash of the drainage area, or, conversely, it could be the first flow from stored water in an SCM and be relatively unpolluted. The use of first-flush samplers may eliminate some of the variation associated with direct human collection of samples, such as inconsistent placement of the sample bottle in the stormwater stream and variable time of collection. This type of sampling can also reduce the burden of sampling of remote sites.

An additional problem of grab sampling is lack of mixing of solids and the associated pollutants in the water column. Grab sampling often consists of inserting a bottle into the flow at the end of an outfall, and it is important to realize that the location of sampling within the stormwater flow can introduce variability, particularly when sampling runoff has not been treated in a structural SCM to remove particulates. As a result of poor mixing, sampling near the bottom of the pipe can result in higher total suspended solids (TSS) concentrations than samples collected at the water surface. To address this, bedload samplers have been developed and tested that can be installed in stormwater pipes to capture the solid material that will not be collected in traditional grab sampling or even by automatic samplers (Burton and Pitt, 2002).

Composite Sampling

Composite sampling involves taking multiple samples and combining them to obtain a measure of the overall stormwater condition. Several different techniques of sample compositing are possible, depending on the number of samples collected, if they are weighted by time or stormwater volume, and if they are collected manually or automatically. Generally, the greater the number of samples used in the compositing, the closer the resulting sample is to the EMC of the pollutants in the stormwater (Ma et al., 2009).

Manual Composite Sampling. A reasonably complete picture of pollutant concentrations in stormwater can be attained by collecting a composite sample over some period of time, although not necessarily the entire discharge from a storm. Taking multiple grab samples during a storm event, especially at equally timed intervals, and combining them into a single sample for analysis will provide a closer approximation of the true volume-weighted average concentrations of pollutants in the runoff than single grab samples (Burton and Pitt, 2002; Ma et al., 2009). Extended composite sampling also would likely reduce the likelihood of exceeding a benchmark compared to first-flush sampling because of the expected high first-flush concentration. However, this will come at the expense of increased sampling time and complexity.

Automated Composite Sampling. The most comprehensive approach for assessing pollutant discharges is to install automated composite sampling equipment, connected to stormwater flow measurement devices (calibrated flumes or weirs), both of which are widely available. Composite volume-weighted sampling can be employed to reliably quantify stormwater EMCs and pollutant loads for most pollutants. Protocols for full-storm monitoring are now well established for volume-weighted composite sampling and quality assurance and quality control procedures[1] (Water Quality Program, 2011). Volume-weighted automated composite sampling has multiple advantages. It can reliably collect sample aliquots after passage of specific stormwater volumes to obtain pollutant EMCs. Automated sampling also reduces the labor costs of sampling, although the samplers must be carefully set up and maintained before runoff begins. Additionally, automated samplers can be set to collect samples during a storm that does not occur during normal working hours. Finally, the EMCs resulting from composite sampling are likely to be lower than pollutant concentrations in a grab sample collected during the first flush and therefore may reduce the likelihood of an exceedance that could trigger additional compliance requirements for the discharger. Collection of composite volume-weighted samples over multiple storm events can provide a comprehensive understanding of annual pollutant discharge loads from a site and/or SCM performance over storms of different size.

Nonetheless, automated sampling may not be appropriate for some water quality parameters. For example, samples for bacteria (not an MSGP parameter) are usually not collected with an automatic sampler because of holding time and contamination concerns. Most automatic samplers cannot sample bedload material (e.g., larger solids that are moving in the flow but near the bottom of the pipe or channel and below the sampler intake tube). Therefore, automated sampling may miss sediment and associated pollutants that are traveling very near the pipe bottom. Because they settle quickly, bedload-sized particles are rarely seen in the effluent of structural SCMs. Also, the MSGP uses TSS as the measure of particulate matter, which does not generally include bedload material. The goal, whether in grab or composite sampling, is to find a location where the flow and solids are well mixed (Fischer et al., 1979; Saunders et al., 1983).

Composite volume-weighted sampling can be resource intensive, with initial costs of equipment and installation of the flume/weir, and operational costs with the time and expertise needed to maintain the sampling site, program the samplers, and check equipment calibrations. For a facility, unless required, this level of accuracy may not merit the additional costs, depending on the goals of the sampling scheme.

Other Sources of Error and Variability

Additional choices regarding sampling and analysis, such as sampling design, equipment, analytical protocols, and operator skill, will affect the results. Example sources of sampling and analysis error capable of causing a difference between true water quality at the desired measuring point and water quality measurements are highlighted in Table 3-1.

Sampling variability can result from inconsistencies in selecting the monitoring point. Because of the diffuse nature of stormwater, isolating a specific discharge point may be challenging. Because of the highly variable conditions at industrial facilities, stormwater sampling points can be difficult to define. Facilities regulated under the current MSGP that have multiple discharges may collect their stormwater samples at one discharge point and list it as being representative of all discharge points. This is a valid procedure if the activities taking place on each drainage area are adequately similar. If the land uses are not similar, such an approach

[1] See www.bmpdatabase.org/monitoring-guidance.html.

TABLE 3-1 Example Sources of Sampling Error and Variability in MSGP Stormwater Monitoring Results

	Sources of Error	Ways to Reduce Error
Sampling design	Outfall sampled not representative of all sources Sample not collected at outfall or samples collected at different outfalls	Review of outfall selection Training of sampling personnel Clear identification of sampling point
Sampling procedure	Incorrect type of sampling container Contaminated sample container Improper sampling procedure for intended purpose Improper method of compositing multiple grab samples	Use correct type of sampling container Proper cleaning/rinsing of container Training of sampling personnel
Laboratory analysis	Interlaboratory variability	Establish National Pollutant Discharge Elimination System (NPDES) laboratory accreditation programs with a focus on stormwater matrices Encourage interlaboratory calibration efforts
Data management	Incorrect units reported Incorrect data input	Units clearly specified Electronic reporting with database flags for benchmark exceedances and unusual data

can provide an inaccurate assessment of the pollutant discharges from the site. Where industrial activity is not equally distributed across various discharge points, the MSGP requires that multiple sampling points be included. Complex facilities with a large footprint will need to sample multiple discharge points to represent the myriad activities taking place at the facility.

Once the outfalls are selected, locating an appropriate point in the flow path also is required, as discussed in the previous section on the effects of sampling approaches. The type of equipment used and its installation location also will impact the results (Winterstein and Stefan, 1983; Graczyk et al., 2000; Cristina et al. 2002; Clark et al., 2009). In discharges from large pipes, a single grab sample may not reflect the true volume-averaged or depth-averaged concentration at that sampling time. Collecting samples at different flow depths (depth-integrated sampling) can provide concentrations more representative of the true values (Selbig et al., 2012). Finally, collecting from definable channels is much more repeatable than sheet flow sampling. Sheet flow can be difficult to monitor and multiple samples may have to be collected at different points spatially in order to generate a clear picture of the pollutant concentrations.

Variation in sample processing and analysis protocols can also affect results. The time prior to sample processing in the field or laboratory has been noted as an important factor affecting solids and metals measurements due to the creation and dissolution of flocs in the stormwater over time (Furumai et al., 2002; Kayhanian et al., 2005; Li et al., 2005). The analytical method chosen also can be a factor in variability of results (Gray et al., 2000; Clark and Siu, 2008). Variation in technique and skill among analysts within a single laboratory also has an effect (Clark and Pitt, 2008). In addition to the sources of variability discussed above, other factors that affect sample results could include sample contamination and improper data handling. In all stormwater monitoring situations, it is important to minimize the error and understand and manage the variability.

RECOMMENDED IMPROVEMENTS TO SAMPLING AND ANALYSIS PROTOCOLS

Several opportunities exist to reduce error in industrial stormwater monitoring. In this section, the committee recommends improvements to the MSGP sampling requirements and training for sampling and laboratory personnel. The committee also discusses novel technologies that in the years ahead may offer additional efficiencies and improved accuracy for MSGP monitoring.

Sampling Type

The committee recommends that the Environmental Protection Agency (EPA) allow and promote the use of composite sampling for benchmark monitoring for all pollutants except those that transform or degrade rapidly or are especially time sensitive (e.g., pH). As discussed previously, composite sampling provides more consistent and reliable data and resolves or reduces the problem of intrastorm variability in pollutant concentrations. For sites with treatment SCMs that store water from the previous storm, composite sampling would provide more accurate stormwater discharge results. The committee recognizes that the cost and complexity of managing composite samplers may be more than some permittees want to bear, and therefore, composite sampling should not be required. However, the advantages of composite sampling (including the increased likelihood of meeting the benchmark with an EMC as compared to a grab) may encourage the investment in higher-quality data collection.

The current MSGP requirement for grab samples during the first 30 minutes to capture the first flush is inconsistent with the methods used to derive benchmark thresholds. Technology-based MSGP benchmark thresholds are derived from Nationwide Urban Runoff Program (NURP) values and secondary treatment requirements. NURP values are calculated from event mean concentrations in stormwater discharges that were characterized using composite sampling techniques (EPA, 1983). Secondary treatment requirements are derived from measured performance of publicly owned treatment works over longer time periods, and the values that form a basis for MSGP benchmark thresholds are based on 30-day averaging periods (49 *Federal Register* 37006). Composite sampling over a period up to 24 hours also better aligns with the time period used to express water-quality-based effluent limits in permits. Although EPA recommends that acute aquatic life criteria be expressed as maximum 1-hour average concentrations (EPA, 1985), effluent limits in NPDES permits that are derived from acute aquatic life criteria are expressed as daily average limits (see 40 CFR 122.45(d)). EPA explains in their *Technical Support Document for Water Quality-based Toxics Control* (EPA, 1991) that the 1-hour averaging period was derived primarily from data on response time for ammonia, a fast-acting toxicant. EPA (1991) states that there are scientifically justifiable alternative averaging periods and that, in practice, 1-day periods are the shortest periods for which wasteload allocation modelers and enforcement personnel have adequate data.

Multiple types of composite sampling techniques could be used, including more simplistic manual composite methods that characterize the first few hours of discharge and more complex automated methods that composite samples over a discharge period up to 24 hours. EPA originally required both grab and composite sampling in the 1992 baseline permits and as part of the 1992 group application process. At that time EPA stated that it was necessary to provide information on the first-flush concentration as well as the average concentration of pollutants discharged during an event (57 *Federal Register* 41296). In issuing the 1995 MSGP, EPA allowed the use of grab sampling for the vast majority of permit-required sampling, presumably as a burden reduction (60 *Federal Register* 50828). In issuing the 2008 MSGP, EPA discontinued all remaining composite sampling and essentially disallowed the use of composite sampling in favor of grab sampling to characterize the high pollutant concentration that would occur during a first-flush effect (EPA, 2008b). The limitations of grab samples, including the high variability, are now well understood. Composite sampling technology, which is widely available and relatively inexpensive, could significantly improve the consistency and reliability of stormwater data and should be encouraged.

Monitoring Frequency

The current MSGP allows benchmark monitoring to be stopped for that permit term if the mean concentration of the four previous quarterly measurements is below the benchmark threshold. Given the pronounced variability in the flow and quality of stormwater and the potential for major changes in site management over time, four quarterly samples are insufficient to assess the adequacy of stormwater management at a facility over the course of a permit term of 5 years.

The first concern relates to the number of storm event samples that is sufficient to determine a benchmark exceedance, given the inherent variability in stormwater runoff. Stormwater pollutant concentrations will vary with antecedent dry conditions, stormwater flow rates, industrial activity on the site, and many other factors.

The number of samples required to be statistically confident that the sample mean is less than a specific value, such as a benchmark, is dependent on the acceptable error and the coefficient of variation (COV, standard deviation of the samples divided by the mean) (see Burton and Pitt, 2002; Ott and Longnecker 2015). Figure 3-1 displays the acceptable difference between the stormwater discharge sample mean and the respective benchmark based on the number of samples and COV of the data set (α=0.05; power = 0.80).[2] In an analysis of the National Stormwater Quality Database,[3] Burton and Pitt (2002) determined that coefficients of variation for stormwater runoff across multiple sites when appropriately categorized by land use, region, and sometimes seasons were 0.5 to 1.0 (measured using composite sampling). Use of grab samples and other sources of error and variability (see Table 3-1) will increase the COV.

For example, with a COV of 1.0 (optimistic for grab samples), with collection of only four samples, the acceptable error is 125 percent, as the difference between the measured mean value and the benchmark. Therefore, for a TSS benchmark of 100 mg/L, any quarterly average concentration from 0 to 225 mg/L is statistically indistinguishable from the benchmark. COV greater than 1.0 would produce a larger range. Reducing this range to a scientifically preferred value, such as 20 percent (80 to 120 mg/L TSS) would require 150 samples at 1.0 COV.

---

[2] The Type 1 error rate (α) is the risk of a false positive, where something is assumed to be true when it is actually false. According to Burton and Pitt (2002), "an example would be concluding that a tested water was adversely contaminated, when it actually was clean. The most common value of α is 0.05 (accepting a 5 percent risk of having a Type 1 error)." Power is $1 - \beta$. Type 2 error rate (β) is the risk of "a false negative, or assuming something is false when it is actually true. An example would be concluding that a tested water was clean when it actually was contaminated. If this was an effluent, it would therefore be an illegal discharge with the possible imposition of severe penalties from the regulatory agency" (Burton and Pitt, 2002).
[3] See http://www.bmpdatabase.org/nsqd.html.

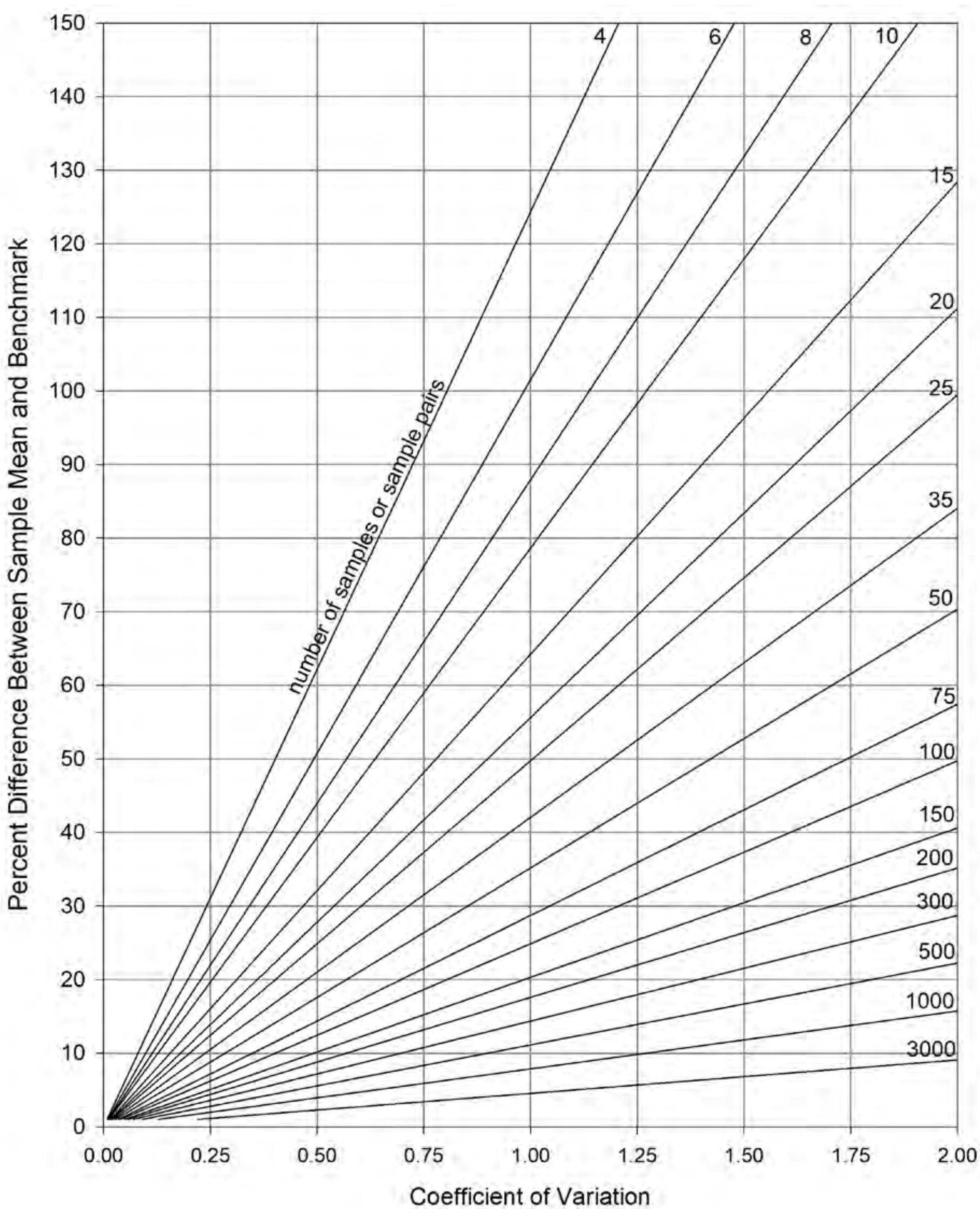

FIGURE 3-1 Number of samples necessary to detect a statistically significant difference between the sample means and the benchmark, given the acceptable relative error (the percent difference between the sample mean and the benchmark that is statistically indistinguishable from the benchmark) and the coefficient of variation at α=0.05 and power of 80 percent. Developed based on Burton and Pitt (2002; p. 231). NOTE: Graph is approximate because it assumes a normal distribution of samples.

Obviously, this level of sampling is unrealistic. Collection of more samples increases the confidence that a site is complying with the requirements by reducing the acceptable error. Ultimately the decision on the number of samples to require is based on what amount of error is acceptable, relative to the cost of the increased monitoring. Technology verification for SCMs used in municipal stormwater requires monitoring of a minimum of 12 storm events (composite sampling) over a range of storm intensities (with other constraints on type of storm, etc. [Water Quality Program, 2011]).

In addition to the drawbacks of a limited sampling population, the MSGP sampling waiver after four samples poses additional temporal concerns, because a facility would then not be required to monitor stormwater for up to 4 years (or more) until the next permit term begins. Various modifications to the facility, changes in activities at the facility, and turnover in site personnel could take place during the period of monitoring relief, all of which could impact the stormwater discharge characteristics. Structural SCM performance can also degrade over time, if not maintained, usually due to clogging in a media filter or sediment buildup that reduces the treatment volume and increases scour in sedimentation devices. Sustained monitoring can help ensure that permittees continue to implement and maintain SCMs consistently during the entire permit period. More frequent continual sampling allows a consistent representation of stormwater discharge as operations and personnel change over the duration of a permit term. Additional sampling throughout the permit term also helps reduce the uncertainty associated with natural variability among storms and wet versus dry years.

Some states have acted to increase the frequency of chemical monitoring beyond that specified in the MSGP (see Appendix A). Washington allows monitoring relief only after having eight consecutive quarterly samples with concentrations less than the benchmark. California allows a reduction in sampling frequency to once per 6 months after four consecutive samples with concentrations less than the benchmarks.

The MSGP should include a minimum of annual sampling for those that qualify for monitoring relief to ensure that appropriate stormwater management continues throughout the permit term and to provide additional data to indicate the effectiveness of SCMs. Furthermore, EPA should also analyze COVs for sector- and site-specific industrial stormwater data to evaluate the benefits of additional increases in sampling frequencies (such as 2 years of quarterly monitoring, or twice annual monitoring for those with monitoring relief) in terms of reductions in acceptable error.

Role of Training for Sampling and Laboratory Personnel

Data and field experience show substantial differences in the reliability of samples collected by facility personnel as compared to trained (watershed agency) personnel (K. Schiff, Southern California Coastal Water Research Project, personal communication, 2018). This difference is attributed to the fact that agency personnel are trained in water, wastewater, and stormwater sampling procedures and pollutant transport concepts and have experience with multiple stormwater situations. In contrast, industrial facility staff may not be trained in stormwater concepts or procedures. Inconsistent sampling at a given facility across multiple storms may result from using untrained personnel or by employing different personnel who implement procedures differently. The committee recommends training and guidance, including the possibility of a training/certificate program in stormwater collection and monitoring, to reduce the variation in sampling design and sample collection.

Water quality analysis of stormwater samples is most often performed by private contract laboratories, but may also be done in house, particularly for facilities of large corporations. Some variation in measured pollutant concentrations can routinely be expected due to variability in laboratory methods, individual behaviors, reporting levels, and degree of quality control, which affect the accuracy and precision of measurements (Clark and Pitt, 2008). For example, for TSS, three methods are approved in 40 CFR 163.3,[4] which yield different results for known concentrations of stormwater solids even when a well-trained analyst is performing the analysis, with results varying by up to 25 percent (Gray et al., 2000; Clark and Siu, 2008). There was added variability when different well-trained analysts measured TSS using one of the methods. Much of this variability was attributed to the methods employed to obtain the aliquot used in the analytical method and the difficulty in capturing larger, heavier particles in the subsampling of the initial sample.

The industrial stormwater matrix poses particular challenges in analysis because many of the pollutants of concerns (e.g., metals, organics) are likely to sorb to solids. For some organics, the difficulty of extracting the pollutant into an aqueous or solvent phase for measurement can result in matrix interferences that reduce the accuracy of the analytical method (EPA, 1986).

Laboratory certification programs evaluate and certify the technical competence of laboratories to perform specific types of testing and measurements. While the Safe Drinking Water Act contains laboratory certification requirements, other major federal environmental statutes including the Clean Water Act do not contain similar requirements. Some states have independently established certification programs for additional environmental media, including wastewater, solid and hazardous wastes, and air samples, and require the use of certified laboratories through their own statues and regulations. The National Environmental Laboratory Accreditation Program (NELAP) exists to promote technical competence of environmental laboratories and develops nationally recognized standards for accreditation.[5] For stormwater, EPA encourages the use of laboratories certified by agencies accredited by NELAP (EPA, 2009a). Minnesota is an example of a state that has a Clean Water Act laboratory accreditation program and requires use of an accredited laboratory in their MSGP (MPCA, 2015). Because stormwater is distinct from wastewater, it is important to understand to what extent the laboratory certification program includes evaluation of technical competence with the stormwater matrix.

Periodic interlaboratory calibration programs represent another approach that has been used to promote the comparability of testing results among laboratories. These programs bring standardization to analytical procedures for stormwater samples. Such programs facilitate communication among laboratory personnel, help set performance-based criteria to measure success, and utilize a locally derived stormwater matrix while improving comparability and reliability of stormwater sampling results used to determine compliance with water quality benchmarks. After interlaboratory coefficients of variation were noted in California that were greater than 40 percent for some stormwater pollutants, the Southern California Stormwater Monitoring Coalition (SMC) developed guidelines and protocols to ensure comparability of

[4] Standard Methods SM 2540D-2011, USGS I-3765, and ASTM D5709-18.
[5] See https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=56216.

laboratory results for stormwater samples (Gossett and Schiff, 2010). The SMC also instituted interlaboratory calibration exercises[6] that have reduced variability (K. Schiff, SCCWRP, personal communication, 2018), but such regional efforts are rare.

To reduce analytical variability and improve the utility of monitoring results, the committee recommends that EPA encourage state adoption of national laboratory accreditation programs for the Clean Water Act with a focus on the stormwater matrix and on reducing the variabilities associated with stormwater pollutants that have been noted above. EPA should initiate and encourage interlaboratory calibration efforts, including the establishment of performance quantification levels developed from samples with a stormwater matrix. EPA should publish guidance and case studies on interlaboratory calibration, with specific focus on known challenges to stormwater analysis (e.g., solids capture, matrix interference). These efforts would promote the comparability and reliability of test results reported to permitting authorities.

New Methodologies or Technologies for Industrial Stormwater Monitoring

In this section, a few examples are offered of potential improvements in monitoring technology for industrial stormwater discharge; some of these are available today, and others may be reasonably expected in a not-to-distant future. Monitoring technology is considered here in the broadest sense and includes hardware, software, sensors, sampling techniques and timing, mobile technologies, and apps.

Visual monitoring information could be addressed with the future development of mobile apps that may be useful in identifying stormwater clarity, sheens, or other visual water quality indicators via still imaging or video. Drone imaging may be useful in visual stormwater discharge monitoring and delineation of drainage areas and covered/exposed areas.

Sensors and real-time control are ubiquitous in process control, water quality measurements, and documenting water quality in drinking water and wastewater treatment facilities of all sizes. Stormwater applications are obviously complicated by the episodic and dynamic nature of stormwater flows and quality. Advances in sensors can lead to improved monitoring of stormwater discharges and SCM performance. Field-employable flow/moisture sensors are available now, as are turbidity, pH, dissolved oxygen, and temperature sensors. Data can be collected in the field in real time over wireless networks. Reliable field turbidity sensors now available could open up the possibility of using turbidity as a surrogate for TSS in future permit terms. For construction site erosion, turbidity, instead of TSS, is used to document performance of erosion control practices in several states, such as Vermont (State of Vermont, 2008).

Field sensors that accurately and reliably measure other water quality parameters are currently available, although they are somewhat costly. A wider range of sensors at lower cost is anticipated to be available in the near future. Newly developed sensors may be able to directly measure concentrations of water quality parameters of interest, or may measure useful surrogates of water quality. The overall result will be more reliable monitoring of industrial stormwater discharges. The use of real-time control of SCM performance using water level/storage information and weather predictions is also possible (Kerkez et al., 2016).

---

[6] See http://socalsmc.org/smc-regional-stormwater-monitoring-comparison-and-evaluation/.

Future revisions of the MSGP monitoring requirements should consider advances in sensor technology and reductions in costs since the previous permit release. By considering the latest technology, EPA can take advantage of opportunities to improve the value of the MSGP monitoring program, providing more or better-quality information for similar or reduced costs.

TIERED APPROACH TO MONITORING

The current MSGP monitoring approach could be substantially improved to provide more useful information on the quality of stormwater discharges and their impact on receiving waters while balancing the net burden to industry and limited agency resources. In this section, a tiered approach, with different levels of inspection or monitoring according to risk, complexity, and past performance of stormwater management, is recommended. This approach is expected to provide better overall protection of the environment and public health.

Proposed Categories of Monitoring

The committee envisions a framework (see Table 3-2) where the most complex, high-risk facilities or those with recurring exceedances would be required to conduct more-sophisticated monitoring to assess their impact to receiving waters and target future improvements to stormwater control measures, consistent with the recommendations of the National Research Council (NRC, 2009). Those facilities required to conduct benchmark monitoring would continue to do so, but a much larger number of facilities that currently conduct only visual monitoring would also monitor for TSS, pH, and chemical oxygen demand (COD) as part of industry-wide monitoring (see Chapter 2). Facilities with low risk and low likelihood of substantial pollutant discharges could replace water quality monitoring with rigorous inspections and reporting. Details of the monitoring categories proposed by the committee are provided below.

Inspection Only (Category 1)

The committee recommends that EPA define and create a category for facilities that could rely on inspection by a permitting authority or certified inspector as a complete alternative to chemical discharge monitoring. Providing an option for inspection in lieu of monitoring can reduce the burden on small, low-risk facilities while improving stormwater management. This recommendation is distinct from how the current MSGP operates. Facilities would be allowed to rely on inspections as an alternative to chemical discharge monitoring if they exhibit a low risk of contributing to water quality problems via stormwater discharge. This determination would be facility based rather than sector based and would be verified by a certified inspector. Given the limited capacity for permitting authorities to perform compliance inspections, the committee envisions that certified inspectors would be contracted by many of the permittees to conduct the inspection. The certified inspector could be an employee of a municipal separate storm sewer system (MS4), a private third-party company, or a parent corporation, as long as the inspector is not directly involved in the day-to-day operation or oversight of the facility being inspected.

TABLE 3-2 Table of Criteria and Implications for Proposed Monitoring Tiers

Tier	Criteria	Summary of Monitoring	Difference from Current MSGP
Category 1: Inspection Only	• The type, extent, and intensity of industrial activities conducted on site meet specified criteria for a low-risk site, and • The facility has been subject to one or more inspections by the permitting authority or a certified inspector during the previous permit term.	Visual only. Facility inspections by the permitting authority or a certified inspector are used as an alternative to chemical monitoring, with inspection report submitted to permitting authority. The permitting authority can deny the chemical monitoring waiver in cases where inspection results demonstrate SCM implementation is inadequate.	New allowance for low-risk sites to replace chemical monitoring with inspection, conducted by permitting authority or certified inspector, at least once per permit term.
Category 2: Industry-Wide Monitoring	Sector/subsectors for which the permitting authority determines, based on recent data and industry literature review, that sector-specific benchmark monitoring is not warranted and facilities do not qualify for Category 1.	Visual and industry-wide (pH, TSS, COD) monitoring in addition to routine facility inspections.	Adds monitoring for pH, TSS, and COD for all facilities subject to the MSGP, except for low-risk facilities in Category 1. EPA decision not to require sector-specific benchmark monitoring should be based on updated, periodic data and literature reviews.
Category 3: Benchmark Monitoring	Sectors/subsectors for which the permitting authority determines, based on most recent data and industry literature review, that potential pollutant levels warrant benchmark monitoring and corrective actions and SCMs are reasonably available for additional pollutant reduction.	Visual, industry-wide (pH, TSS, COD), and sector-specific benchmark monitoring in addition to routine facility inspections.	Similar to current MSGP for sectors with benchmark monitoring, except chemical monitoring requirements are based on updated data and industry literature review. Includes industry-wide pH, TSS, and COD monitoring for all sectors.
Category 4: Enhanced Monitoring	Either • Benchmark monitoring results have triggered the Additional Implementation Measure (AIM) Tier 3 process, or • The permitting authority has determined that more robust monitoring is warranted (e.g., TMDL development or implementation; large, complex sites; inspection identifies major concerns).	Potentially includes composite sampling, possibly at multiple outfalls, to supplement or in lieu of benchmark monitoring.	New category for high-risk complex sites or facilities with repeat exceedances.

NOTE: In all categories, no exposure exemptions may be granted. Additional monitoring may be required for facilities with effluent limitation guidelines (see Appendix B)

BOX 3-1
Inspections with the MSGP

The value of facility inspections to evaluate site conditions and pollutant discharge potential was recognized early in the implementation of industrial stormwater permitting as an important supplement to chemical monitoring. The permitting regulations were modified in 1992 specifically to allow for the use of facility self-inspections as a monitoring tool (57 *Federal Register* 11394 (April 2, 1992)). The 1995 MSGP incorporated the use of facility self-inspections as an alternative to or to supplement discharge monitoring.

The current MSGP has a continued strong reliance on routine facility inspections conducted by the permittee. Inspections must be conducted at least quarterly, and at least once per calendar year the inspection must be conducted during a period when a stormwater discharge is occurring. Inspections must be conducted by qualified personnel, who

> *are those who are knowledgeable in the principles and practices of industrial stormwater controls and pollution prevention, and who possess the education and ability to assess conditions at the industrial facility that could impact stormwater quality, and the education and ability to assess the effectiveness of stormwater controls selected and installed to meet the requirements of the permit (2015 MSGP).*

Compliance inspections are visits by a permitting authority or EPA to officially assess compliance with environmental regulations and requirements (EPA, 2004). EPA's most recent published goal for inspection rates for industrial stormwater states that 10 percent of permitted facilities be inspected each year (EPA, 2014). In meetings with this committee, several state permitting agencies noted that their ability to conduct stormwater compliance inspections at industrial facilities is significantly resource limited. Additionally, inconsistent training of personnel who conduct inspections can hinder the effectiveness of the inspections.

The value of facility inspections to evaluate site conditions and pollutant discharge potential was recognized early in the implementation of industrial stormwater permitting (see Box 3-1). In-person education was highlighted by several state permitting agencies in meetings with the committee as an effective means to improve stormwater management and permit compliance at small industrial sites. Small businesses may also have difficulty collecting reliable monitoring data, because they may have limited financial resources or limited staff to develop monitoring expertise. Many of those businesses, and some larger businesses, operate small facilities that qualify as low risk. For those facilities, both the permittee and the permitting agency could potentially be better served with a rigorous inspection instead of monitoring. A site inspection by a certified inspector would increase the reliability of the results, and the business may welcome the exemption to chemical monitoring.

The committee recognizes the difficulty in defining the characteristics of a low-risk facility. For a site to be considered at low risk of impacting water quality, it should have a low likelihood of discharging toxic substances in toxic amounts, generally have a small area of exposed industrial activity, and be well managed. A simple approach would be to base low pollutant risk on the amount of surface area that contains industrial activities exposed to stormwater. Many very small facilities (e.g., less than 0.5 to 1 acre of industrial activities) have relatively few activities exposed to stormwater that pose a pollution risk to water quality, assuming that the facility is not part of larger network of integrated operations at multiple facilities. Additionally, a site that has little area of exposed industrial activities reasonably may be expected to discharge lower volumes of industrial runoff (and corresponding lower mass load of pollutants) for a given size precipitation event compared to facilities with larger industrial operations. A 1-acre threshold is used to distinguish the relative risk of water quality impacts associated with discharges of stormwater associated with construction activity (EPA, 1999). However, several states established a smaller area threshold for exempting certain erosion controls, especially in high-value watersheds.

A criterion of facility area, although simple to implement, nonetheless is not a robust indicator of risk. A small industrial facility may or may not store hazardous materials, handle materials in large volume, or rely on outdoor equipment or operations that release stormwater pollutants during operation. Small facilities in some industry categories have the potential to generate substantial amounts of pollutants capable of causing harm in receiving waters. In urban areas, clusters of small facilities in aggregate may generate substantial discharges. At the same time, many mid-sized industrial facilities conduct limited activities exposed to stormwater, for which effective management strategies are relatively easy to implement and maintain. Industrial stormwater discharges from these mid-sized facilities would be expected to produce much lower pollutant mass loadings compared to smaller facilities with more active operations. Research has documented substantial variation among facilities of a given sector in the type, extent, and intensity of industrial activities they conduct that may be expected to govern a facility's risk of discharging pollutants (Swamikannu et al., 2000; Cross and Duke, 2008). Because industrial facilities are so highly variable, classifying facility risk is most accurately based on a characterization of the intensities and types of industrial activities conducted at each facility.

Specific criteria could be developed that characterize the presence or absence of activities considered likely to generate stormwater pollutants that could cause water quality problems. The criteria could be similar to those developed for no exposure exemptions, which describe in narrative form all activities that, if present, would preclude a facility from qualifying for the exemption. The criteria envisioned here are admittedly more complex, because they are intended to assess the expected magnitude or scale of pollutants from activities rather than simply the presence or absence of an activity. However, the process of establishing criteria is the same, and EPA can rely on its experience and the experience of the states to define activities that may reasonably be expected to discharge toxic pollutants in toxic amounts during routine operation. Examples of possible criteria for low pollutant discharge risk are presented in Table 3-3. Conformance to the criteria would be verified by an inspection.

Also important in the determination of a low-risk facility is certification that the site is well managed. To assess this the committee recommends that the facility inspection be conducted at least once per permit term and include the elements of a stormwater compliance inspection, such as

- Reviewing the permit and the stormwater pollution prevention plan (SWPPP) and determining whether the SWPPP meets the requirements set forth in the permit;
- Reviewing records, including self-inspection reports, to verify that the permittee is complying with the permit and the SWPPP;
- Walking the site and verifying that the SWPPP is accurate and that the SCMs are in place and functioning; and
- Identifying actions that need to be taken to effectively manage stormwater pollution.

In addition, inspections can provide opportunities to educate facility operators on the most effective steps to improve stormwater management.

TABLE 3-3 Example Criteria for Determining Low-Risk Facilities (Category 1)

Activity	Conditions That Will Attain "Low Risk"
Outdoor temporary storage of "factory floor wastes" such as lumber, containers, and debris	Intent: Low volume of water contacts surfaces where residuals may accumulate. Possible criteria: Containers covered. No process chemicals or hazardous substances. Residuals that may fall to surfaces removed, and surfaces cleaned, in at most 5 days, with verified operating procedure in place.
Outdoor storage of waste, scrap, and equipment believed potentially usable in future	Intent: Should be routinely maintained, unusable items removed, and kept to minimal space, with no items stored long term. Stored on impermeable hard surface. Possible criteria: Storage area no larger than 100 m^2. No materials that contain or have exposed patches of lubricants, fuels, or process liquids. Routinely inspected to remove wastes, with verified operating procedure.
Outdoor materials handling or transport of packaged materials or drums of liquids or particles	Intent: Handling infrequent, materials well packaged, with detailed spill prevention and response procedures in place. Possible criteria: Handling limited to 1 hour of operations daily (weekly average). Verified operating procedure includes inspection after each handling operation to identify, remove, or clean up spills, leaks, and debris.
Vehicles or equipment used outdoors or in plant yard (small trucks, forklifts, hand trucks, etc.)	Intent: Vehicles well maintained so fuels and lubricants do not leak. Possible criteria: Vehicle maintenance, fueling, and cleaning conducted indoors. Vehicles used less than 1 hour per day, weekly average. Vehicles do not operate outdoors during precipitation, or else vehicles are routinely cleaned indoors to keep free of pollutants that may accumulate on vehicle surfaces.
Material handling/loading areas, loading docks or doors	Intent: Limited in number and in frequency of usage. Possible criteria: Materials handled in packaged, boxed, or drum form—no handling of materials in powder, liquid, or slurry form, and no hazardous or toxic materials. No more than three loading docks, with no more than five loadings/unloadings each per week. Verified operating procedures for inspection and cleaning.
Vehicle maintenance	Intent: Vehicle maintenance limited to nonpolluting activities. Possible criteria: No washing of vehicles with accumulated surface residuals except indoors or in areas with separate drains to process wastewater. Vehicle fueling prohibited in locations exposed to stormwater. Lubricant and liquids work only in small amounts (e.g., one oil change volume) with proper trays and spill avoidance/response procedures and on hard surface. Verified operating procedures include inspection and cleaning of these areas.

NOTE: These criteria are intended to lead to a determination that the type, intensity, and extent of industrial activities are unlikely to generate discharges of pollutants of a kind and a quantity that may cause or contribute to water quality problems in receiving waters. The intent is to create a category of facilities that do not meet the rigorous criteria of "no exposure" but encompass facilities with activities that are small but nonzero in spatial extent, frequency, intensity, and/or presence of residuals. These are committee suggestions, but EPA should develop concrete and implementable criteria conditions.

A publicly accessible report filed with the permitting authority would document the findings of the inspection and any specific concerns and recommendations for additional SCMs. Current facility conditions would be compared to previous conditions documented in prior inspection reports. If the inspection indicates substantial concerns, recurrent problems that have remained unaddressed, or a lapse in inspections, the permitting authority or inspector could recommend the facility be placed in another category that would include required chemical monitoring. Local entities such as MS4 permittees, agencies responsible for total maximum daily load (TMDL) implementation, or those responsible for other watershed protection programs could also petition the permitting agency to exclude from Category 1 industry types or individual facilities that are found to be potentially discharging pollutants that are causing or contributing to the impairment of receiving waters.

Because inspection would serve as an alternative to chemical benchmark monitoring, an inspector certification program (see Box 3-2) is recommended to promote confidence in the thoroughness and reliability of results. The certified inspector would evaluate the facility's SCMs and conformance to the criteria for this low-risk category. An inspector certification program would provide a means to certify and track the credentials of the inspector, promote inspector accountability, and help inspectors stay current with the latest developments, skills, and technologies available to promote MSGP permit compliance.

BOX 3-2
California's Industrial Stormwater Practitioner Certification

The California Industrial Stormwater General Permit issued in 2014 establishes requirements for industrial stormwater permittees to have a Qualified Industrial Stormwater Practitioner evaluate and certify the adequacy of corrective actions at industrial facilities when basic numeric action levels or EPA Sector Specific Benchmarks are exceeded (CA NPDES Permit No. CAS000001; Order No. 20014-0057-DWQ). Qualified Industrial Stormwater Practitioners complete a permitting-authority-sponsored or -approved training course and register themselves in the state's electronic database. They are authorized to evaluate SCM implementation and pollutant sources; prepare technical reports, action plans, and extension requests when exceedances persist; and evaluate permit coverage eligibility for new facilities to discharge to impaired waters. If judged to be noncompetent, they can have their certifying eligibility revoked.

Industry-Wide Monitoring (Category 2)

The committee recommends that the MSGP continue to have a category of facilities that are not subject to sector-specific benchmark monitoring based on a determination that they do not have the potential to discharge sector-specific pollutants at a level of concern. However, the committee recommends that all facilities without sector-specific benchmark monitoring conduct industry-wide monitoring for pH, TSS, and COD, as discussed in Chapter 2, in addition to the currently required visual monitoring of stormwater discharge and routine site inspections by facility staff. As also discussed in Chapter 2, the committee recommends that EPA conduct data and literature reviews prior to the next permit renewal and, as a part of each permit renewal, determine whether benchmark monitoring should be added for some industries currently exempted from benchmark monitoring, and whether the pollutant-specific benchmark monitoring requirements for each sector should be revised.

Benchmark Monitoring (Category 3)

Chemical-specific benchmark monitoring in the current MSGP applies to 55 percent of industrial permittees[7] (R. Marcus, EPA, personal communication, 2018). These permittees are classified within sectors for which it has been determined that potential pollutant levels warrant such monitoring and SCMs are reasonably available for additional pollutant reduction (see Table 1-1). The committee recommends ongoing use of this category. Nevertheless, the specific benchmark monitoring requirements should be updated based on recent data and literature to reflect recent knowledge of pollutant toxicity, sector risks, and stormwater management capabilities, as discussed in Chapter 2. All facilities with benchmark monitoring should also conduct industry-wide monitoring for pH, TSS, and COD, in addition to the currently required visual monitoring of stormwater discharge and routine site inspections by facility staff.

Enhanced Monitoring (Category 4)

A fourth category of enhanced monitoring is envisioned for industrial facilities with the highest risk for discharging pollutants that may adversely impact surface waters. This designation should be based on past repeated exceedances of benchmarks (e.g., AIM Tier 3; see Box 1-3), severe concerns raised upon site inspections of Category 1 facilities, or recommendations of the permitting authority for sites that are large and complex with high pollutant discharge potential or where TMDL development and implementation merits additional monitoring. The largest facilities will typically produce the greatest volume of runoff, leading to high risk from high pollutant mass loads. Complex sites could include those with multiple outfalls and varying land uses throughout the industrial site or high-risk chemicals used in exposed areas.

Monitoring plans would be developed as appropriate for the site and the site issues that need to be addressed. For sites with repeated exceedances, facilities may need to monitor at multiple outfalls and to implement volume-weighted composite monitoring to calculate stormwater discharge event mean concentrations to help to determine whether they are causing or contributing to violations of water quality criteria. For the largest and most complex sites, facilities would be expected to develop and implement a sampling program that is spatially and temporally representative of stormwater discharges from all parts of the facility where industrial activities are conducted. This information may be needed to determine whether and where additional stormwater control measures are warranted, including moving exposed industrial activities under cover or enhanced treatment. Should monitoring and subsequent actions be implemented that bring the site into compliance, the permitting authority could evaluate whether the facility can return to Category 1, 2, or 3.

For facilities that use event mean concentrations to determine compliance, some consideration is needed regarding extreme storms. EPA should establish a “nonrepresentative storm” criterion that would exclude event mean concentration data for extreme events that are expected to exceed SCM design criteria. Under extreme conditions, SCM performance will be compromised and stormwater bypass will occur. It is reasonable to expect that the discharge of

---

[7] Data applicable to the states and territories permitted by the federal MSGP and does not include data from states with delegated regulatory authority.

stormwater pollutants associated with industrial activity and the effectiveness of stormwater control measures implemented are most representative for water quality purposes when the sampling is conducted on discharges resulting from frequent storm events and not large extreme events. This event size may be based on a statistical review of long-term rainfall records to establish wet weather precipitation conditions when they become less relevant for water quality. This criterion may be a storm of a certain return frequency such as a 10-year storm, or a multiple of the 90th percentile rainfall depth, or a multiple of the long-term average rainfall depth for the area. Using nonrepresentative storm criteria, a permittee would either not submit EMC data from storms that exceed the criterion or these data would not be evaluated against the benchmarks.

Enhanced stormwater monitoring is considered to be within the financial resources and/or expertise of a major industrial facility and may prove beneficial to the industry by more accurately characterizing the stormwater discharge than by using grab-sample first-flush benchmark monitoring. Full-storm data can provide a much more complete picture of the industrial stormwater discharge from a site. Additionally, when faced with designing treatment SCMs for a high-risk and/or complex site, the flow and water quality data collected by composite sampling are critical to ensuring the sizing and design are appropriate. The MS4 entity could be an active participant with Category 4 facilities, potentially reimbursed to conduct the enhanced monitoring on behalf of the larger facilities in the watershed, so that the data are consistent and useful both at a site level and on a watershed basis.

Benefits of Tiered Monitoring Requirements

The current MSGP includes several levels of monitoring based on expected sector-specific stormwater pollutant discharge. The committee encourages EPA to add both enhanced and reduced levels of monitoring to the existing program. The elimination of benchmark monitoring by low-risk facilities would provide a nonmonitoring option for oversight of these facilities and eliminate some of the most suspect, unreliable monitoring data. This approach also ensures that high-risk industries that are more likely to be significant sources of stormwater pollution invest in the necessary monitoring to confirm that SCMs are effective in reducing pollutants and risks to receiving waters. In total, this proposed framework is expected to reduce the monitoring burden on the lowest-risk facilities while increasing the quality of the data available on the overall population of industrial facilities including the largest, highest-risk facilities. Combined with suggested improvements to monitoring protocols, training, and data management discussed in this chapter, the tiered approach is also expected to increase the usefulness of the data collected toward improving the management of industrial stormwater.

Exemptions, Additions, and Other Permitting Alternatives

Within the tiered framework envisioned by the committee, there are exceptions, additional monitoring, and other permitting options as are currently applicable to the current MSGP.

No Exposure

No-exposure certification is allowed under the current MSGP for sites, regardless of size or complexity, at which “all industrial materials and operations are protected by a storm resistant shelter to prevent exposure to rain, snow, snowmelt, and/or runoff” (EPA, 2015a). With no-exposure certification, required once every 5 years, facilities are exempt from the requirements of the MSGP, including monitoring. Certification requires facility owners to confirm no-exposure conditions by answering specific questions about industrial materials or activities exposed to precipitation and to allow the permitting authority to inspect the property, although such inspections are rarely conducted.

The committee agrees that monitoring is not needed at facilities with no exposure but recommends verification of no exposure by a certified inspector or the permitting authority. Maryland is an example of a jurisdiction that currently requires third-party verification of no exposure.

Effluent Limitation Guidelines

As discussed in Chapter 1, EPA has established effluent limitation guidelines (ELGs) for 10 subsectors of industrial facilities (see Appendix B), with required monitoring at least once per year at each outfall. This ELG monitoring, required by law, would supplement the MSGP monitoring envisioned in Table 3-2.

Individual Stormwater Permit Monitoring

In its original regulatory strategy for industrial stormwater (55 *Federal Register* 222, 48002), EPA identified an individual permit category for situations where the MSGP benchmark monitoring requirements, SWPPPs, and SCMs may be inadequate to address pollution from stormwater discharges associated with industrial activity. Federal regulations empower the permitting authority to exclude facilities from the MSGP and require individual NPDES permits when special considerations such as a large quantity of pollutant discharge, proximity to receiving waters, and the characteristics of pollutants are at issue (40 CFR 122.28(b)(3)). Extensive stormwater discharge characterization for conventional and nonconventional pollutants, toxic pollutants, hazardous substances, and treatment units must be submitted with the permit application. Based on this information, an individual stormwater permit can require more extensive monitoring and/or a greater number of pollutants compared to the MSGP, where benchmark monitoring is determined by standard industrial classification code. Individual permits can also be structured with enforceable discharge criteria expressed as numerical effluent limits, which trigger a permit violation if exceeded. This stricter enforcement of pollutant exceedances can be helpful for sites that represent a high public concern or that raise environmental justice issues. Federal law authorizes any “interested person” to petition the permitting authority to require an individual permit.

Advanced Analyses Possible Under Enhanced Monitoring

Under the AIM process (still to be developed) and the enhanced monitoring category envisioned within the tiered framework for large, complex sites with repeated benchmark exceedances, there are opportunities to use advanced tools and analyses to better understand water quality impacts from individual facilities. These tools, such as wet weather dilution or the biotic ligand model, may require monitoring of receiving water flows or quality, more complex sampling techniques, and modeling, so they are not viewed as tools that should be required of all permittees. Nevertheless, for facilities struggling with repeated exceedances, these advanced tools and analyses can clarify where further SCMs are necessary to protect receiving water quality.

Wet Weather Dilution and Mixing Zones

Many MSGP benchmarks are based on water quality criteria (see Table 1-3) and all MSGP benchmarks are applied at the point of discharge without dilution. By its very nature, industrial stormwater discharges occur during wet weather conditions when the receiving stream is expected to be flowing at some reasonable capacity above base flow, which could provide dilution of stormwater discharges. NPDES regulations allow for municipal and industrial process wastewater discharges to incorporate dilution and an impacted mixing zone when evaluating instream toxicity. According to EPA (2014), a mixing zone is “a limited area of volume of water where initial dilution of a discharge takes place and where certain numeric water quality criteria may be exceeded.” State regulations generally limit these areas based on widths or cross-sectional areas and lengths on a case-by-case basis, and the use of mixing zones is at the discretion of the permitting authority.

Explicit inclusion of a dilution allowance in deriving benchmark thresholds for the MSGP has not been done by EPA and would be challenging, given the state-to-state variability in how mixing-zone allowances are included as part of state water quality standards and the site-specific analysis normally conducted to implement the allowance for a discharge. However, facilities that repeatedly fail to reach benchmarks and are elevated to the upper tiers of the AIM process should be permitted a mixing-zone allowance, as is allowed with municipal and industrial process wastewater dischargers, after the facility has applied all reasonable SCMs. A mixing-zone allowance would allow facility operators to set site-specific criteria that are protective of ambient water quality in the receiving waters.

Calculating a stormwater mixing zone based on best available science may require the use of data sets characterizing upstream flow and water quality conditions and dynamic water quality models to understand the impact of stormwater runoff on receiving waters. These water quality models are typically calibrated with site-specific water quality and hydrology data. Applicable water quality model types may be “far field,” where water quality is influenced by the hydrodynamics of the receiving water, or “near field,” where pollutant concentrations at the discharge location are determined from plumes at the facility outfalls (Gawad et al., 1996; Jirka et al., 1996; Davis, 2018). EPA should develop guidance for using water quality models for calculating stormwater mixing zones.

Alternative Metals Benchmarks

The 2015 MSGP requires total metals analyses (rather than dissolved), but questions have emerged from industry about whether dissolved metal analyses or the biotic ligand model would provide a more accurate assessment of stormwater pollution. Both approaches require more rigorous monitoring that may be a burden if applied uniformly to all permittees. However, if permittees have repeated exceedances of metals benchmarks (see Appendix D), they may benefit from enhanced monitoring of dissolved metals or in support of the biotic ligand model.

Dissolved Metals. Dissolved metals are more biologically available than particulate-bound metals and are more important in assessing pollutant risk. According to EPA (1996), "The primary mechanism for toxicity to organisms that live in the water column is by adsorption to or uptake across the gills; this physiological process requires metal to be in a dissolved form. This is not to say that particulate metal is nontoxic, only that particulate metal appears to exhibit substantially less toxicity than does dissolved metal." Dissolved metals are used to determine acute and chronic aquatic life criteria. According to EPA (1996), dissolved metals are operationally defined as "that which passes through a 0.45 µm or a 0.40 µm filter." With this operational definition, a fraction of the metals measured as dissolved consists of small particulate or colloidal metals that are able to pass through the filter or metals that are complexed with organic ligands, which may not be biologically available. Dissolved metals require field or laboratory filtration within 15 minutes of sample collection (40 CFR 136.3) because metal species continue to change between dissolved, precipitated, and sediment-sorbed forms after the sample is collected.

Several studies have been conducted to characterize metal concentrations in urban stormwater based on total metals (Pitt et al., 2004a,b; Shaver et al., 2007). In a number of stormwater studies, a significant fraction (approximately 30 to 70 percent) of copper, cadmium, and zinc was found in the dissolved form (Pitt et al., 1995; Crunkilton et al., 1996; Sansalone and Buchberger, 1997; Pitt and Clark, 2010). Differences in stormwater chemistry, receiving water chemistry, temperature, and sediment composition will affect the fraction of metals that are bound or dissolved (Weiner, 2008). Runoff that is collected from receiving waters will often have higher amounts of metals in particulate form while stormwater collected from pipes will have a higher dissolved fraction (Clary et al., 2011).

Because dissolved metal concentrations provide a more accurate measure of potential toxicity, it would be reasonable for the MSGP to allow industries that have had repeated exceedances of benchmark levels for total metals to sample for dissolved metals and compare this quantity against the existing benchmark. However, sampling for dissolved metals requires more complex sampling methodology, including filtering within 15 minutes of sampling. Because rapid filtering for dissolved metals puts an additional burden on industry, the committee does not recommend that dissolved metals analyses be required for all permittees covered by the MSGP, but should be an option if all proper sampling procedures are followed.

Biotic Ligand Model. As discussed in Chapter 2, the Biotic Ligand Model (BLM) is an aquatic toxicology tool that is used to determine the bioavailability of metals in aquatic ecosystems. Lethal accumulation values of metals on the gill surface, when fish toxicity is being considered, are used to predict lethal metals concentration values with the BLM (Niogi and Wood, 2004). EPA already uses the BLM as a tool in the Ambient Water Criteria in surface waters (Jarvis and Wisniewksi, 2006), but to develop a BLM, site-specific water quality parameters, including hardness, pH, and dissolved organic carbon, need to be measured. As with dissolved metals discussed in the previous section, the MSGP should allow those who exceed total metals benchmarks to analyze receiving waters to calculate pollutant toxicity associated with a facility's stormwater discharge. However, the facility would need to do additional sampling beyond the current MSGP requirements to acquire the data needed by the BLM.

Watershed-based collaborative relationships among industries, municipalities, and other dischargers could help facilitate the characterization of receiving water chemistry, as required for use of the BLM, at reduced cost. Multiple dischargers could combine resources to appropriately characterize the necessary water quality parameters over a range of flows, seasonal variations, and other important conditions. With these data, BLM modeling could be completed to establish watershed-specific benchmark concentrations for copper for all dischargers to the receiving water. This characterization procedure for copper and the BLM has been done in Oregon (OR DEQ, 2018). Collaborative monitoring could be expanded to other pollutants that need receiving water quality information to determine discharge concentrations.

UPDATING AND UPGRADING CURRENT METHODS OF DATA MANAGEMENT

Submitting, managing and reviewing data collected under the MSGP has been challenging. In 1995 when the first MSGP was issued, EPA's national data system for the NDPES program did not accommodate stormwater permits. It could not address the need to enter the type and numbers of sources and reporting against benchmarks instead of enforceable numeric limits. The data system had been in place since 1982, 5 years prior to Congress's action to expand stormwater permitting (78 *Federal Register* 46011 (2013)). The transition to an updated national data system, the inclusion of stormwater permits in the system, and the eventuality of self-reporting monitoring data into the system has taken years.

With the 2015 MSGP, EPA required as of December 2016 that permittees submit their discharge monitoring reports (DMRs) electronically, including those operating under the EPA or a state MSGP, into the national eDMR data system, unless a waiver is obtained (80 *Federal Register* 64066 (2015)). Prior to 2015, monitoring was often submitted in paper format, making review of these data and permit compliance cumbersome and staff intensive. When EPA reviewed benchmark monitoring data for development of the 2015 MSGP, only 485 of the 1,200 covered facilities required to perform benchmark monitoring submitted their results electronically and many of the records were unusable (EPA, 2012). Data collected outside of the MSGP have no single or linked repository for storage and public access.

As part of the information gathering conducted for this study, states acknowledged that they have been limited in their ability to receive, review, and respond to MSGP monitoring due to staffing shortfalls. However, many states reported that they do have the capacity to review data electronically and that digital reporting improves the effectiveness of staff oversight, particularly in states with limited staffing. Automated searchable data systems streamline environmental compliance. States using these systems can autogenerate reminders and compliance advisories. The level of electronic reporting is increasing as permittees become aware of and adept at electronic reporting, state data systems capabilities grow, and compliance rates increase. States are required to share MSGP monitoring information with EPA via the national data system, and data sharing is increasing. Two particular advantages arising from improving data management tools are an improved capacity to screen data automatically for outliers and errors and to analyze large data sets using data visualization software.

Screening for Errors and Omissions

The new era of automated data systems and electronic self-reporting offers many opportunities for improving data quality. Illegible discharge reports are eliminated. Permittees enter results into screens prepopulated with information on outfalls, sampling frequencies, parameters, and units. If consistent units for benchmarks are used based on the value from which the benchmark was derived, as recommended in Chapter 2, unit errors could be substantially reduced. The systems have the capability of providing permittees immediate electronic feedback, such as by alerting or requiring facilities to check and correct decimal point placement and verify results that exceed the benchmark threshold, helping to reduce transcription errors. Several entries among the 2015 MSGP appeared erroneously high or low, suggesting the data management system could improve its alerts to permittees of outlier data or "less than" values that exceed the benchmark, thereby further reducing errors (see Appendix D).

Electronic data can also improve agency oversight. EPA and states can generate automated reports, which streamlines the identification of omissions and exceedances. More complete information regarding whether a facility did in fact report a discharge during the monitoring period is becoming available.

Data Analysis and Visualization

With improved data quality and more data becoming available through application programming interfaces and web services, the ability to evaluate the data for patterns, trends, and correlations is expected to increase. For example, California Water Boards' data center contains industrial stormwater effluent water quality data and an assessment tool that can be used for quick illustration of query results. These visualizations can then develop "data stories" that help to understand industrial stormwater effluent quality and progress made under the MSGP.

A simple visualization example using California Water Boards' tool compiles the most recent 5 years of data by facility and compares the median value (using a minimum of three samples) to the benchmark. Facilities where the median is below the benchmark are shown on the left side of Figures 3-1 and 3-2 for lead and TSS, respectively, and facilities where the median is above the benchmark are shown on the right side of each figure (note that the scales are different). A comparative analysis by pollutant indicates that TSS is a greater water quality challenge compared to lead for facilities covered by the California equivalent of the MSGP.

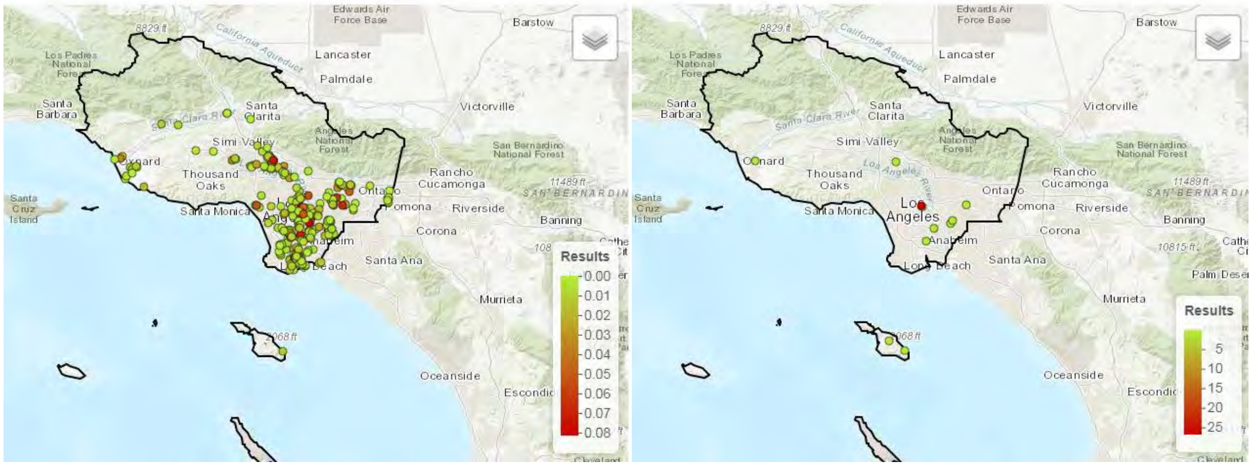

FIGURE 3-1 Median lead concentrations at sites in California Water Board, Los Angeles Region, from monitoring from the past 5 years, with results less than (left) and greater than (right) the benchmark of 82 µg/L.
SOURCE: D. Altare, California Water Boards, personal communication, 2018.

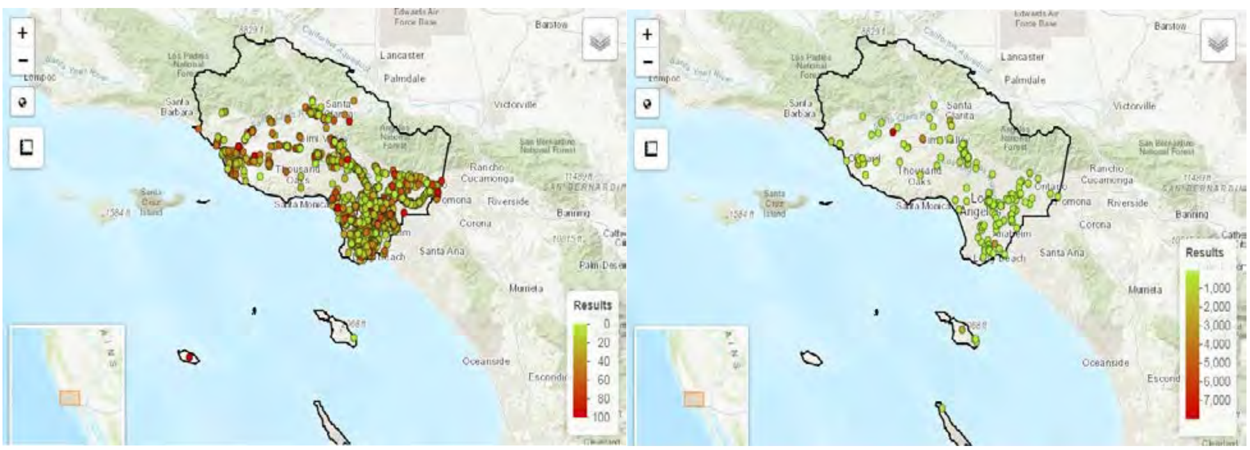

FIGURE 3-2 Median TSS concentrations at sites in California Water Board, Los Angeles Region, from monitoring from the past 5 years, with results less than (left) and greater than (right) the benchmark of 100 mg/L.
SOURCE: D. Altare, California Water Boards, personal communication, 2018.

A quick temporal analysis can be made using this visualization for lead. Given that EPA only included benchmarks in the 1995 MSGP in cases where the median of all samples for a given sector exceeded the potential benchmark value, and that the benchmark threshold for lead has not changed since the 1995 MSGP, the fact that relatively few facilities currently exceed the benchmark indicates that lead pollutant levels have significantly improved during the time period the MSGP has been in place. This may be explained by improvements in pollution prevention measures that have been implemented in this time period, including the removal of lead from gasoline and paints and improved housekeeping at sites. For TSS, the data visualization could be used to target compliance assistance efforts; for example, it could be used to find opportunities where treatment SCMs could supplement existing site measures to reduce pollution discharge levels.

The committee recommends that EPA continue to compile data for facilities operating under the EPA MSGP and state MSGPs nationally and make these data publicly available in a timely manner. The committee also recommends that EPA develop visualization tools that can be used by others to easily examine data for patterns, trends, and correlations.

CONCLUSIONS AND RECOMMENDATIONS

The current MSGP benchmark monitoring requirement focuses on low-cost, coarse indicators of site problems, and the usefulness of the data can frequently be hampered by its variability. Stormwater monitoring data display variability that originates from many different sources, including the variability of precipitation within and among storms and changes in operations over the course of time. In this chapter, the committee recommends improvements in sampling design and procedures, laboratory analysis protocols, and data management to reduce error and improve the reliability of monitoring results to support improved stormwater management.

EPA should update and strengthen industrial stormwater monitoring, sampling, and analysis protocols and training to improve the quality of monitoring data. Specifically, EPA should

- Consider a training or certificate program in stormwater collection and monitoring to ensure that required sampling and data collection is representative of stormwater leaving the site to the greatest extent possible.
- Stay abreast of advancements in monitoring, sampling, and analysis technology that can provide more or better-quality information for similar or reduced costs and consider these in future revisions of the MSGP.

EPA should allow and promote the use of composite sampling for benchmark monitoring for all pollutants except those affected by storage time. EPA’s disallowance of composite sampling and reliance on grab sampling in the interest of discrete characterization of the highest pollutant concentration is not warranted based on the methods used to derive benchmark thresholds. Multiple composite sampling techniques are available that provide more consistent and reliable quantification of stormwater pollutant discharges compared to a single grab sample. Composite samplers have become common in stormwater monitoring as experience with this approach has increased and costs have declined, and the EMCs that result from composite sampling may reduce the likelihood of exceeding the benchmark compared to first-flush grab sampling. Composite sampling is not appropriate for pollutants for which the results may vary over time with storage, such as those that transform or degrade rapidly or interact with the atmosphere (e.g., pH).

Quarterly stormwater event samples collected over 1 year are inadequate to characterize industrial stormwater discharge or describe industrial SCM performance over the permit term. Under the MSGP, if a permittee’s average of four consecutive quarterly samples meets the benchmark, a waiver is granted for the remainder of the permit term. For permittees with average results that meet the benchmark, the MSGP should require a minimum of continued annual sampling, to ensure appropriate stormwater management throughout the remainder of the permit term. Extended sampling over the course of the permit would provide greater assurance of continued effective stormwater management and help identify adverse effects from modifications in facility operation and personnel over time. Given the natural variability and the limitations of grab samples, substantial uncertainty is associated with using the average of only four stormwater samples. EPA should analyze industrial stormwater data and sector-specific coefficients of variation to recommend additional increases in sampling frequency, consistent with EPA's determination of an acceptable level of error for this indicator of SCM performance. Additional continued monitoring at a lower intensity throughout the permit would also increase the overall sample size and thereby reduce the uncertainty in the monitoring results.

State adoption of national laboratory accreditation programs for the Clean Water Act with a focus on the stormwater matrix and interlaboratory calibration efforts would improve data quality and reduce error. NPDES laboratory accreditation programs and stormwater interlaboratory calibration efforts would improve the comparability and reliability of monitoring data. To support these efforts, EPA should publish guidance and case studies on interlaboratory calibration specifically focused on the stormwater matrix, including the establishment of performance quantification levels for stormwater samples. These efforts would promote similar procedures at a national level to ensure the comparability and reliability of test results reported to permitting authorities.

To improve stormwater data quality while balancing the burden of monitoring, EPA should expand its tiered approach to monitoring within the MSGP, based on facility risk, complexity, and past performance. The committee proposes four categories:

1. **Inspection only.** Low-risk facilities could opt for permit-term inspection by a certified inspector or the permitting authority in lieu of monitoring. Facilities could be classified as low risk based on facility size (e.g., less than 0.5 or 1 acre of industrial activity), recognizing that size may not fully represent the risk profile, or more accurately based on a detailed assessment of the type and intensity of industrial activities conducted on site, or a hybrid approach.
2. **Industry-wide monitoring only.** All facilities in sectors that do not merit additional pollutant monitoring would conduct industry-wide monitoring for pH, TSS, and COD. These data would provide broad, low-cost indicators of the effectiveness of stormwater control measures on site.
3. **Benchmark monitoring.** Sectors that merit additional pollutant monitoring, based on the most recent data and industry literature review, would conduct sector-specific benchmark monitoring in addition to pH, TSS, and COD, which would be collected by all facilities with chemical monitoring.
4. **Enhanced monitoring.** Facilities with repeated benchmark exceedances or those characterized by the permitting authority as large complex sites with high pollutant discharge potential would conduct more rigorous monitoring, in consultation with the permitting authority. These facilities could collect volume-weighted composite samples at multiple outfalls if appropriate. Additional tools and monitoring strategies could be used to assess the water quality impact to receiving waters from stormwater discharge, including wet-weather mixing zones, dissolved metal sampling, and site-specific interpretation of water quality criteria, with additional guidance from EPA. EPA should develop "nonrepresentative storm" criteria to exclude monitoring for events that would not be representative of facility stormwater discharge.

This tiered system would improve the overall quality of monitoring data to inform future iterations of the MSGP while balancing the overall burden to industry and permitting agencies.

To improve the ability to analyze data nationally and the efficiency and capability of oversight by permitting agencies, EPA should enhance electronic data reporting and develop data management and visualization tools. Electronic reporting has only been required of permittees since 2016, and the data management capabilities are still developing to make the most use of this information at the national and state levels. Automated compliance reminders, improved checks on missing or unusual data, and data analysis and visualization capabilities would improve the effectiveness of staff oversight and provide new opportunities to analyze trends. EPA should develop national visualization tools that can be used to easily examine data for patterns, trends, and correlations.

4

Consideration of Retention Standards in the Multi-Sector General Permit

The majority of this report has focused on improving the monitoring process as a way of confirming appropriate stormwater management and ensuring compliance with the objectives of the Multi-Sector General Permit (MSGP). This chapter focuses on a different approach to ensuring that industrial stormwater is appropriately managed—retention standards. On-site stormwater retention and infiltration are already included within the MSGP as possible stormwater control measures (SCMs). Nevertheless, this committee was asked to evaluate the feasibility of retention standards as both technology-based and water-quality-based numeric effluent limitations to establish objective and transparent effluent limitations (see statement of task in Chapter 1). The committee was also tasked to discuss whether the appropriate data and statistical methods are available for establishing such standards and the merits and faults of retention versus discharge standards. Retention standards are not assumed to replace monitoring, but would provide another structural approach to control pollutant discharges.

STORMWATER RETENTION

The process of stormwater retention, as envisioned in the committee's task, involves storing the stormwater on site, with the goal that at least a large portion of it will not be discharged to surface waters but will go elsewhere. Possible fate pathways for stormwater after retention include infiltration (see Figure 4-1), some type of beneficial use, and evapotranspiration. This definition of stormwater retention, which is the focus of the committee's analysis, differs from other forms of stormwater retention commonly used in stormwater management that aim to hold water on site for later, more gradual release, possibly after treatment.

Storage for stormwater retention can be provided with a pond or engineered facility such as underground tankage or an underground infiltration facility. The latter example is important when land is either expensive or unavailable. Stormwater retention systems are generally designed based on the volumetric capture of a storm event of a specific size. The targeted event would be large enough so that exceedance of this event size would be relatively rare, because exceedance will result in the discharge of untreated or minimally treated stormwater. Retention designs must also consider the time over which the captured stormwater would be removed, typically through infiltration or beneficial use, so that storage is again available to handle the next storm.

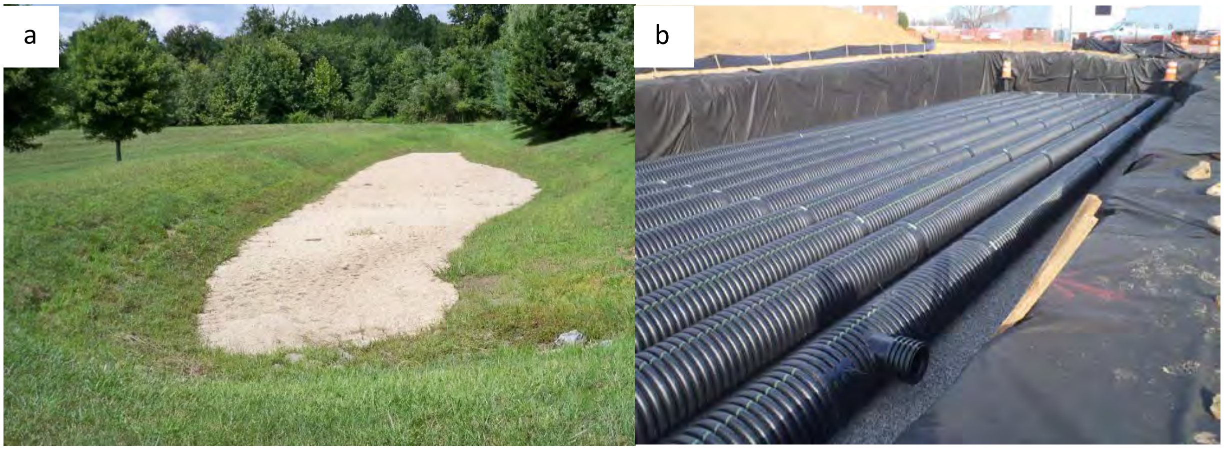

FIGURE 4-1 Aboveground (a) and belowground (b) stormwater retention facilities with infiltration. SOURCES: (a) Montgomery County Department of Environmental Protection; (b) Philadelphia Water Department.

Infiltration is an attractive management option for stored stormwater; it has been used widely and successfully in municipal stormwater applications to reduce stormwater impacts on local water bodies and to recharge groundwater. In addition to simple storage with infiltration, novel SCMs that are infiltration based, known collectively as low-impact development or stormwater green infrastructure, including bioretention basins, permeable pavements, and vegetated filter strips and swales, may be employed for stormwater retention and infiltration (Caltrans, 2010). Infiltration of stormwater requires soil and geologic conditions conducive to the infiltration process, including relatively high-permeability soils. However, for industrial stormwater, concerns due to the likely presence of toxic pollutants that could migrate through the soil to groundwater systems require very careful considerations, especially in terms of pretreatment requirements, before infiltrating. These issues are discussed in more detail later in this chapter.

The two other storage recovery pathways are typically minor for industrial stormwater. Evapotranspiration will require vegetation and a large amount of land area, both of which are not common on most industrial sites. Beneficial use of stormwater may be feasible in areas with extreme water shortages, but its applicability will be highly site specific. It is not expected that on-site stormwater harvesting and use (e.g., firefighting, dust control, washing, toilet flushing) will be practiced at many industrial sites due to the water quality treatment requirements and/or likely small or inconsistent water demand from these applications (NASEM, 2016). To be part of a reliable retention system, the demand for reclaimed water would need to be sufficiently consistent to ensure that storage is made available for the next precipitation event in a reasonable period of time.

RETENTION STANDARDS

Stormwater retention standards are commonly used in municipal stormwater applications to reduce overall stormwater volumes and the associated pollutant mass discharge. States and localities routinely select retention standards as the basis of municipal stormwater management requirements for new construction or redevelopment (see Box 4-1). The retention standards listed in Box 4-1 are specifically based on stormwater volume reduction in accordance with the maximum extent practicable standard for municipal separate storm sewer system (MS4) permits rather than water-quality-based effluent limits (WQBELs). Water quality benefits will result due to the corresponding reduction in pollutant mass load. This approach specifically aims to reduce discharge loads, with less emphasis on specific pollutant concentrations. Other considerations also drive these standards, such as groundwater recharge. Possible application of retention standards in the regulatory context of the MSGP is discussed later in the chapter.

Stormwater retention systems are typically sized according to the retention standard and site-specific information such as the drainage area, the runoff coefficient (land use), and infiltration rate. The retention standard can be based on a specific design storm (see Box 4-2), under which the SCM is expected to operate at full efficiency. Retention systems would capture all of the small and mid-sized storms up to a specific design storm and a portion (usually the initial fraction) of the largest storms, resulting in capture of a large fraction of the overall runoff volume and corresponding contaminant load. Events larger than the targeted storm event and some smaller events that enter the storage when it is not completely empty (such as back-to-back rains) will result in overflow of the storage system and discharge of stormwater and industrial pollutants. Depending on the retention system design, pollutant concentrations in the bypass flow may be less than those that occur early in the storm because the bypass will occur only after substantial prior rainfall, when runoff concentrations are typically lower.

BOX 4-1
Municipal Stormwater Retention Standards

Examples of volume-based stormwater retention standards that have been developed by federal, state, and local governments to manage municipal stormwater are provided in Table 4-1. Most of these standards apply to new construction or substantial redevelopment of a property. California's retention standard applies to all volume-based SCMs used by facilities covered by the Industrial Stormwater General Permit. Environmental Protection Agency (EPA) guidance applies to development projects on federal facilities that are leased, purchased, constructed, or renovated. These retention standards are designed to provide multiple benefits, including improved water quality, downstream resource protection, and peak flow control.

TABLE 4-1 Examples of Retention Standards for Municipal Stormwater

Jurisdiction	Retention Criteria	Reference
Phoenix, Arizona	100-year, 2-hour storm	City of Phoenix (2011)
California	85th percentile, 24-hour storm	California Water Boards (2018)
Federal Facilities	95th percentile, 24-hour storm	EPA (2009b)
Washington, DC	90th percentile storm, 24-hour storm (equal to 1.2 inches)	DDOE (2014)
Washington, Western Region	6-month, 24-hour storm	State of Washington Department of Ecology (2019)
Colorado, Greater Denver area	80th percentile storm (equal to about 0.6 inches)	UDFCD (2018)
Connecticut	1.0-inch storm	CT DEEP (2004)
Ohio	0.9-inch storm runoff volume	Ohio Environmental Protection Agency (2018)

BOX 4-2
Understanding the Design Storm and Cumulative Depth

Design storms for stormwater management are defined based on the probability of occurrence. For example, a 5-year storm represents a storm of a particular rainfall depth over a particular duration that *on average* will occur once over a 5-year period. A 5-year storm has a 20 percent probability of occurring in any given year. Design storms are generally useful to describe larger events, including extreme flood events, and historically have been used to describe drainage-design events. Usually the design storm definition is based on daily rainfall, but some states and localities require shorter intervals, such as 6-hour or 2-hour rainfall rates (see Box 4-1) or a time interval developed from site characteristics.

To illustrate how more common events can be related to storage requirements, the cumulative probability of rainfall below a specific depth can be used. To determine the cumulative probability curve, daily rainfall data appropriate to a site are required. The longest possible rainfall record is desired, and, in many cases, this should be a minimum of 25 years, and preferably 50 years or longer to capture interannual and multidecadal climate variability. Once a sufficient period of rainfall record has been obtained, the analysis begins by sorting the 24-hour rainfall data from smallest to largest depth in a cumulative distribution curve. For a 90th percentile 24-hour storm event, 90 percent of all storm events would have 24-hour precipitation totals less than or equal to that amount. As an example, the lower curve in Figure 4-2 shows the cumulative ranking of daily rainfall depth for a 73-year record at Baltimore/Washington International Thurgood Marshall Airport. These data indicate that 59.8 percent of the total 73-year daily rainfall depths resulted from events that were 1 inch or less; therefore, 59.8 percent of the average annual stormwater will be completely captured in a retention facility designed for a 1-inch capture depth (assuming 100 percent rainfall-to-runoff ratio).

Capture also will occur during larger storms, because the retention facility will fill before bypassing. The upper curve in Figure 4-2 includes this effect. Capturing the first 1 inch of larger storms increases the overall capture to 84.6 percent of the total rainfall. The pollutant mass fraction capture will usually be greater than the volumetric fraction since the retention facility captures the first flush of large storms, which is usually the most contaminated.

Design storm analysis is based on historical data and assumes climate stationarity—the use of previous events to predict those of the future. However, with climate change, historic precipitation records may not capture the full variability or likelihood of future conditions. Forward-looking predictive models may be necessary to properly design future SCMs, considering nonstationarity scenarios.

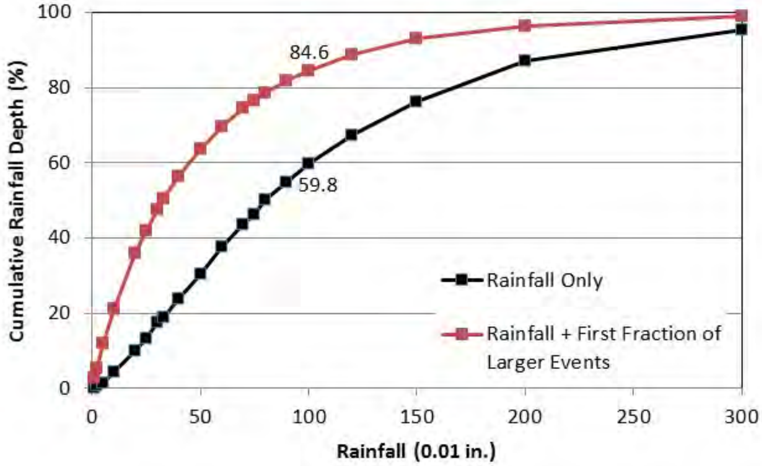

FIGURE 4-2 Cumulative 24-hour rainfall distribution curve (black line) at the Baltimore/Washington International Thurgood Marshall Airport and cumulative percent retention with a given design storm (red line). SOURCE: Data from NOAA National Centers for Environmental Information, https://www.ncdc.noaa.gov/cdo-web/.

Retention standards may also include a requirement of how long the captured stormwater may be stored prior to infiltration or beneficial use, which affects the volume available to capture any subsequent storms. The 2018 amendment to the 2014 California Industrial General Permit requires that discharge reduction SCMs be sized for an 85th percentile, 24-hour storm as a daily volume for on-site retention and infiltration or beneficial use, meaning that the captured stormwater would need to infiltrate or be used on site fully within 24 hours. Sites with insufficient infiltration rates to meet this requirement can increase the size of their retention storage (California Water Boards, 2018). The recommended maximum storage time for stormwater may be influenced by local rainfall conditions (e.g., frequent back-to-back storms) or concerns over vector (primarily mosquito) control.

MERITS AND CONCERNS OF RETENTION FOR INDUSTRIAL STORMWATER

Many states and local governments have developed regulations requiring retention in all new development or significant redevelopment (EPA, 2016c; see Box 4-1). These states, such as Minnesota, New Jersey, and Washington, promote retention by including descriptions of proper infiltration methods in their stormwater manuals. Some states, such as California and Oregon, have developed specific requirements for industrial stormwater retention if it is used as part of stormwater management (OR DEQ, 2017; California Water Boards, 2018). Widespread interest in stormwater retention has mostly focused on common municipal stormwater source areas, such as roofs, parking lots, and roads. Stormwater runoff from industrial facilities, in contrast, differs in its greater potential number of contaminants that pose a risk to groundwater and their higher concentrations. This section examines the merits and concerns when using retention standards for industrial stormwater.

Merits of Retention

Retention of stormwater is a proven way of reducing the impacts of urbanization on the natural hydrological cycle of a watershed, with benefits for surface water quality and flows. If contaminants in stormwater are treated prior to infiltration or adsorbed or filtered out by the soil matrix upon infiltration, stormwater retention reduces the mass of contaminants discharged to surface water (see Box 4-3).

Some bypass will occur in the late stages of retention of extreme storms, and the amount of bypass would be largely determined by the design storm used to size the retention system (see Box 4-2). The amount of bypass is also affected by the infiltration rate, which can change over time. The retention system can be designed to retain the first flush and, if its capacity is exceeded, bypass runoff will occur later in the storm. If a first flush of pollutants typically occurs at the site, capturing the first part of the runoff with an empty retention system provides a higher proportional mass removal compared to an equivalent volume captured later in the storm event (Han et al., 2006b).

Stormwater retention, by preventing discharge, also reduces the peak rates of runoff. High flow rates and magnitudes of stormwater are common in developed areas that have a significant percentage of impervious surfaces. These high stormwater flows can modify or destroy natural habitats due to erosion, known as hydromodification, and cause flood damage. It

BOX 4-3
Summary of Benefits and Concerns with Industrial Stormwater Retention

Benefits:

- If contaminants are removed through treatment or infiltration processes, retention reduces contaminant loads to receiving waters.
- Capture and use or infiltration reduces runoff peak flows.
- Stormwater infiltration recharges groundwater supplies.
- Capture and use reduces water demand from conventional sources.

Concerns:

- Infiltration may cause groundwater contamination or mobilize existing soil or groundwater contamination.
- Not all states have regulatory authority to address groundwater contamination issues, if they occur.
- Lack of maintenance or system failure can lead to surface water contaminant discharges.
- Infiltration requires a large amount of land, while capture and use requires consistent and sufficient water demand.
- Under current regulations, permittees are still responsible to meet water quality requirements in bypass flows that occur in large storm events.

is generally desirable to reduce the maximum rate of runoff, and, in some cases, regulatory agencies have required controls that reduce peak flow rates. Stormwater retention with infiltration also increases groundwater recharge, which increases base flows in streams, providing ecological benefits, reduces saltwater intrusion in coastal areas, and potentially benefits water availability for water supply. Given that many industrial sites are highly impervious and may be quite large, if retention is feasible after consideration of the appropriate restrictions, retention could reduce the runoff from a substantial number of acres in a watershed.

Concerns Associated with Retention

When evaluating the potential for stormwater retention at an industrial facility, extreme caution should be used to ensure that infiltration does not result in groundwater contamination or mobilization of existing soil or groundwater contamination. Many common pollutants found in stormwater, such as heavy metals and toxic organics, have some mobility in the soil column (Armstrong and Llena, 1992; Clark et al., 2010; Treese et al., 2012). Without appropriate treatment, as well as spill prevention and containment, industrial stormwater retention can lead to groundwater contamination well beyond the site boundary that is difficult and costly to remediate. A large percentage of the U.S. population depends upon groundwater for water supply, and groundwater contamination of aquifers used as water supplies can cause major health risks. Groundwater contamination from stormwater infiltration has been documented in various locations around the country. For example, groundwater was contaminated with organic chemicals from stormwater from two industrial sites in Florida (Pitt, 1996) and from drywell infiltration of stormwater (Edwards et al., 2016).

Even when retention systems are designed to protect groundwater quality, systems can fail if not designed or maintained appropriately. Failure can occur because of inadequate information on soil infiltration rates, improper retention basin sizing for the design storm, or insufficient treatment and/or pretreatment. Neglecting the appropriate maintenance protocols that enable the infiltration system to function as designed can also lead to failure.

Concerns over potential groundwater contamination have led some states, such as Minnesota and Wisconsin, and some authors (e.g., Pitt, 2011) to suggest limiting the use of retention for industrial stormwater or simply prohibiting the infiltration of industrial stormwater in most cases. Wisconsin prohibits the infiltration of industrial stormwater, with the exception of rooftops, no-exposure facilities, and parking areas of Tier 2 (light) industries (Chapter Natural Resources [NR] 216.21). Minnesota's stormwater manual prohibits stormwater infiltration at "potential stormwater hotspots" that might have the potential to produce relatively high levels of pollutants in the case of spills, leaks, or illicit discharges, including storage areas, refueling areas, vehicle storage, and material transfer areas.[1] California allows infiltration of industrial stormwater in its general permit and includes state groundwater protection requirements for on-site compliance (California Water Boards, 2018).

To protect groundwater and surface water, states will need the regulatory authority to address failures in maintenance or performance of industrial stormwater retention facilities. However, not all states have the authority to manage groundwater quality and may lack enforcement capacity if contamination occurs. Because of the potential risks to groundwater, industrial stormwater infiltration is not recommended in these states.

Another disadvantage of retention and infiltration basins is the large amount of land required. Existing industrial facilities may not have available and suitable land in which to construct an infiltration basin, and major retrofits are costly. Retention and infiltration are more likely to be useful for new facilities, where construction would be less expensive.

Infiltrated stormwater also has the potential to mobilize existing contaminants in the subsurface. Extensive infiltration can cause existing groundwater contamination plumes to migrate, thereby shifting or spreading their adverse impacts. This is a particular concern in highly industrial areas, which are likely to have existing contaminant plumes in the subsurface. Infiltration can also cause local or regional groundwater mounding that could saturate contaminated soils currently above the saturated zone or under a protective cap, resulting in a release of stored pollution.

A final challenge is that the regulatory framework under the MSGP requires that discharge from these retention facilities, which is expected to occur only under the heaviest storms, comply with the benchmarks. This is a deterrent to use of retention systems for industrial stormwater, because bypass that exceeds benchmark thresholds under high flow conditions may result even after substantial investments to construct such systems that reduce overall pollutant loads. This issue is discussed in more depth at the end of the chapter.

CONSIDERATIONS FOR RETENTION AT INDUSTRIAL SITES

Successful use of retention/infiltration at an industrial facility for treatment of industrial stormwater depends on a full understanding of the characteristics of the potential stormwater pollutants, selection and thorough evaluation of the infiltration site, and appropriate use of

[1] See https://stormwater.pca.state.mn.us/index.php?title=Potential_stormwater_hotspots.

treatment technologies as needed. Certain pollutant or site characteristics will make retention and infiltration inappropriate or cost prohibitive.

Pollutant Characteristics

A key factor that distinguishes industrial stormwater management from typical urban stormwater management is the range of potential pollutants and the likelihood of elevated concentrations. The occurrence and concentrations of stormwater pollutants can vary widely by industrial sector or even individual facilities, based on the materials and chemicals used on site. Therefore, before stormwater retention and infiltration are considered, expected stormwater pollutants at a site should be carefully assessed.

Several pollutant characteristics affect the contamination risks associated with infiltration:

- Abundance (high concentrations and high detection frequencies) in stormwater,
- Toxicity,
- Mobility in subsurface soils where infiltration will occur, and
- Persistence.

Contaminant abundance in site runoff and the toxicity of those contaminants are initial considerations in an evaluation of the suitability of retention and infiltration. If the aquifer is (or could be) used as a water supply or is hydrologically connected with such an aquifer, groundwater pollution is a particular concern because of the human health risks. Contaminated groundwater is notoriously difficult to treat due to the inaccessibility and corresponding lack of knowledge about the pollutant sources, aquifer travel pathways, and possible pollutant treatment mechanisms.

Special care must be taken when considering retention and infiltration of highly soluble pollutants with low adsorption to geomedia or vadose zone soils because these pollutants can be highly mobile. Low-molecular-weight polar compounds tend to be highly soluble and move rapidly in the soil column. Soluble pollutants will not be strongly affiliated with particulate matter and will not be significantly removed via sedimentation, filtration, or other particulate matter removal processes. Instead, chemically reactive filter media may be required to adsorb the pollutant. Water chemistry parameters such as pH, salinity, and hardness may also impact pollutant mobility (FAO, 2000). Examples of known groundwater contaminants from stormwater infiltration include nutrients, metals, organics, total dissolved solids/salts, and bacteria (Pitt, 1996; Datry et al., 2004; Boving et al., 2008; Weiss et al., 2008).

Persistence is an additional consideration. Chemicals likely to biodegrade in the subsurface to harmless byproducts would pose a much lower risk than chemicals that do not biodegrade readily and are likely to persist in groundwater for years. For example, simple hydrocarbons can readily biodegrade in aerobic environments, although maintaining aerobic environments in infiltration zones with extended times of inundation can be problematic. Highly chlorinated organic compounds, however, are resistant to aerobic degradations or may degrade to a product that is highly persistent (e.g., trichloroethylene to vinyl chloride). The biodegradation of some stormwater pollutants has been documented in SCMs, such as hydrocarbons in bioretention media (LeFevre et al., 2012a,b). However, reliance on biodegradation would need to be clearly demonstrated and routinely monitored if part of an industrial stormwater management strategy.

Pitt et al. (1994) identified municipal stormwater pollutants with the greatest potential adverse impacts on groundwater assuming sandy soils with high infiltration rates, low soil organic content, and low adsorption potential (considered a worst-case scenario for contaminant mobility). The listing is based on the pollutant information in municipal rather than industrial stormwater and, therefore, does not include all contaminants likely to be found in industrial stormwater. However, it serves as a general guideline for the types of contaminants that pose concerns for retention and infiltration. The contaminants of moderate risk to groundwater from surface infiltration of municipal stormwater included

- Organic compounds, such as low-molecular-weight polycyclic aromatic hydrocarbons (e.g., pyrene and fluoranthene);
- Nutrients, such as nitrate; and
- Chloride from road salt.

These chemicals all have moderate to high mobility in soils. In municipal environments, heavy metals, such as lead, zinc, and copper, tend to occur in low concentrations and sorb to surface soils and sediments and therefore would be less likely to reach groundwater through infiltration (Dechesne et al., 2004), unless the pH is very low. There are concerns, however, when the groundwater table or a perched lens is near the surface (Squillace et al., 1996; Datry et al., 2004) or when the background soil has a measurable metals content. For example, Ku and Simmons (1986) noted measurable concentrations of chromium in groundwater below stormwater infiltration facilities. Also, deicing salts have the potential to enhance the transport of metals in the subsurface (Kakuturu and Clark, 2015). Extrapolating risk from data from municipal stormwater to industrial settings must be done carefully, considering the many differences in abundance, contaminant occurrence, and site operation.

Pitt et al. (1994) offered general guidelines for infiltrating industrial stormwater to minimize risk to groundwater, assuming that specific evaluation of contaminant mobility and/or treatment is not provided to remove the pollutants:

- Runoff from industrial areas with substantial outdoor storage or with substantial uncovered outdoor operations with heavy machinery use should not be treated by infiltration. Such sites may be expected to have high concentrations of soluble pollutants and potentially wide varieties of contaminants (especially organic compounds). Although much is now known about organic chemical fate and transport, many emerging compounds still have poorly understood treatment, mobility, and toxicity characteristics.
- Runoff from critical source areas, such as vehicle service facilities and large parking areas, require adequate (pre)treatment to reduce groundwater contamination potential before infiltration.
- Snowmelt should be diverted from infiltration devices because of its potential for having high concentrations of soluble salts that are effectively transported through soils to the groundwater. In soils containing clay or high organic matter content, salt can also reduce the soil permeability and render infiltration devices inoperable.

Industrial stormwater containing pollutants with low toxicity, low concentrations, and limited mobility in the subsurface environment will pose the lowest infiltration contamination risks.

Site Suitability

The suitability of a site for detention/infiltration will depend on the stormwater management and treatment processes envisioned on the site. A site evaluation would include determination of the suitability of the site for infiltration and an assessment of the risk of groundwater contamination.

Much work has gone into defining the appropriate physical characteristics of municipal stormwater and highway runoff infiltration systems (; NASEM, 2015; WDNR, 2017).[2] Determining the suitability of a site will include conducting infiltration rate measurements of the native soils. The average infiltration rate will determine the size of the device relative to the size of the drainage area. Many existing industrial sites may lack the land to site an appropriately sized infiltration basin; some sort of subsurface infiltration gallery with underground storage may instead be employed (see Figure 4-1b).

Information about depth to groundwater or perched lenses, depth to bedrock, soil properties, and existing subsurface infrastructure is also necessary. Many industrial areas are located near waterfronts or in low-lying areas, where infiltration would be inappropriate if the depth to groundwater is shallow. Some states specifically prohibit municipal stormwater infiltration systems where depth from the bottom of the infiltration system to groundwater (i.e., seasonal high water table) or bedrock is low (e.g., 3 feet in Minnesota [MPCA, 2015]; 2 feet in Pennsylvania [PA DEP, 2006], 10 feet in Orange County, California [County of Orange, 2013]). Additionally, if the soil texture will not support sufficient infiltration rates or if the rate is too high, leaving inadequate contact time for treatment, the site is not suitable without soil amendments. Some states also prohibit stormwater infiltration if the groundwater is protected as a drinking water supply.

Soil chemical properties, such as soil organic matter content and soil cation exchange capacity (CEC), will control the attenuation characteristics of stormwater pollutants. Adsorption of pollutants, under equilibrium conditions, can be described by a partitioning coefficient, K_d, which describes the ratio of the concentration of pollutant adsorbed to the concentration in solution. The higher the K_d, the greater extent the pollutant will be adsorbed to the soil and the less will remain in solution where it could be transported to groundwater. Values of K_d depend on pollutant characteristics but also on the water chemistry and characteristics of the adsorbent. The sorption of hydrophobic organic compounds will primarily depend on the organic matter content of the soils, with K_d linearly related to the soil fraction organic matter (Schwarzenbach et al., 1993). Specific chemical characteristics of the natural organic matter will play a minor role in the adsorption of pollutants because most natural organic matter has a variety of sorption and ion-exchange sites. Soils with low organic matter content would not be expected to provide significant attenuation and removal of organic pollutants. Values of K_d for various pollutants have been tabulated based on soil properties (e.g., Sauvé et al., 2000). Contact time with the soil is another important parameter that influences removal of pollutants. Although K_d can provide a gross estimate of potential removal given sufficient contact time, the time-based interaction of pollutants with soil will determine the actual fraction of pollutant removed by the soil. Thus, slower infiltration rates will usually result in higher fractions of pollutant removal than faster infiltration rates.

[2] See also https://www.pca.state.mn.us/water/minnesotas-stormwater-manual.

Pollutants, such as heavy metals, metalloids, and phosphorus, will adsorb onto soils via specific bonding mechanisms with chemical sites on the soil matrix. Important factors controlling K_d include the CEC, hydrous oxide content, clay content, and organic matter content. The stormwater pH and other chemical parameters can be controlling factors for attenuation of ionic pollutants (Stumm and Morgan, 1995). Soils with low CEC, hydrous oxide content, clay content, and organic matter content would not be expected to provide significant removal of ionic pollutants. Phosphorus removal will only occur if the background phosphorus level in the soil is low. Many common organic soil amendments have high phosphorus contents, resulting in phosphorus leaching rather than removal. Metals may also sorb to colloidal material or form complexes with organic or inorganic ligands, which can enhance their transport in the subsurface (Fein, 1996; Nowack et al., 1997). These processes and their impact on removal are poorly understood in stormwater.

Unless pretreatment is provided to reduce all pollutants below levels of concern, dry wells or subsurface injection are not appropriate for industrial stormwater infiltration because these systems provide little to no removal of contaminants. Pitt and Talebi (2012) found no statistically significant concentration reductions in stormwater contaminants (nutrients, heavy metals, pesticides, herbicides, bacteria) after infiltrating through at least 4 feet of underlying rock and soil beneath dry wells. Dry wells are only appropriate for disposal of high quantities of water that are of good quality and, as such, are unlikely to be appropriate for industrial runoff.

In addition to site-level analyses, regional analyses of potential effects on stormwater infiltration on existing soil or groundwater contamination may be needed. To reduce the likelihood of mobilizing existing contaminants, known soil contamination sites and groundwater contamination plumes in the region should be inventoried, and the potential impacts of increased groundwater levels should be carefully examined.

On-site Treatment Options

Removal of particulate matter from runoff is necessary for any infiltration system at an industrial facility. Particulate matter removal protects the system by reducing the risk of the infiltration system media clogging, and it also removes the fraction of influent pollutants that are associated with those particles.

If the infiltrating soil characteristics are insufficient to remove the anticipated stormwater pollutants before they reach groundwater, a wide range of additional treatment options can be employed (see Box 1-1). The treatment performance of conventional treatment SCMs for industrial stormwater is summarized by Clark and Pitt (2012) and discussed in Chapter 2 and Appendix D. Soluble pollutants can be difficult to remove, unless an absorbent highly specific to that chemical is used. Extrapolating performance of SCMs from municipal stormwater to industrial settings where pollutants and concentrations are not comparable will require careful analysis of the unit processes themselves and their treatment efficiencies across a wide range of concentrations and water chemistries.

Any treatment of industrial stormwater will result in accumulation of the removed industrial pollutants in the SCMs. Less-mobile pollutants, such as lead, copper, zinc, and hydrophobic organic contaminants, will generally accumulate in sediments at the point of retention and infiltration or sorb onto geomedia (DiBlasi et al., 2009; Jones and Davis, 2013).

Persistence of pollutants in the shallow soil varies depending on the contaminant and the local conditions. Depending on pollutant toxicity and mobility, these soils/sediments may need to be managed to control risks to human health and the environment.

Models such as the Seasonal Soil (SESOIL) compartment model can be used to simulate the water transport, sediment transport, and the fate of the pollutants in the subsurface beneath infiltration facilities. SESOIL has been used to support performance results from dry pond industrial stormwater infiltration (Eppakayala, 2015) and as a screening tool to evaluate groundwater contamination potential of infiltrating MS4 stormwater (Clark and Pitt, 2007).

Infiltrating industrial stormwater can carry high risks. Risks to groundwater from infiltration of industrial stormwater can be greatly reduced by requiring that infiltrated water meet stringent water quality requirements, such as those for drinking water, as defined by the Safe Drinking Water Act. This recommendation would put numeric limits on many pollutants of concern, including many heavy metals, a number of synthetic organic compounds, and nitrate. The use of drinking water standards as cleanup goals for contaminated groundwater is well established. The 2018 amendments to the California equivalent of the MSGP allows infiltration of industrial stormwater if the water meets drinking water quality standards by the time it reaches the base of the unsaturated zone (California Water Boards, 2018). California's amended permit includes all primary maximum contaminant levels (MCLs)[3] as well as secondary standards for total dissolved solids, chloride, specific conductance, and sulfate.[4] However, drinking water standards may not provide a sufficient screening tool because many industrial chemicals that may be highly toxic are not regulated under the Safe Drinking Water Act. EPA's drinking water Contaminant Candidate List (CCL) 4 should also be considered when assessing risks of infiltration to groundwater.[5] If pollutants on this list (but not regulated under the Safe Drinking Water Act) or emerging chemicals of concern to human health are present in stormwater, careful consideration of pollutant removal or treatment options is needed.

In lieu of other information on contaminant attenuation in the groundwater of an industrial site, the committee recommends that industrial stormwater infiltrated to groundwater be treated to meet primary drinking water standards for inorganic chemicals and organic chemicals, and secondary standards for chloride and total dissolved solids. If the aquifer is not suitable for use as a public water supply, this requirement could be relaxed with concurrence of state and local public health agencies. Additionally, other pollutants of concern that may not currently be regulated by the Safe Drinking Water Act should be treated to drinking water risk levels. The industrial facility would need to ensure that this level of quality is met through monitoring, either before the stormwater is applied to the infiltration area or after passing through the infiltration/treatment media at the base of the unsaturated zone.

Some degree of stormwater treatment, possibly advanced treatment, would be required at most industrial sites to meet drinking water quality standards. This may include adsorption of toxic organic compounds via activated carbon or another specialty adsorbent. If the stormwater exceeds drinking water limits for total dissolved solids, chloride, specific conductance, and/or sulfate, costly technologies, such as reverse osmosis or other desalination processes, would be required, likely making infiltration economically unfeasible.

[3] See https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.
[4] See https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals.
[5] See https://www.epa.gov/ccl/chemical-contaminants-ccl-4.

Requiring that infiltrating stormwater meet drinking water standards holds industries to a higher infiltration standard than MS4s. However, such requirements acknowledge the wide range of pollutant types, concentrations, toxicities, and properties expected in industrial stormwater. Stormwater from areas that are not part of the industrial activity would not have to meet the drinking water requirement to be infiltrated; segregation of such stormwater is highly encouraged.

EPA guidelines for infiltrating industrial stormwater would help ensure that industries implement this stormwater management option in a way that is effective in reducing surface water pollution while being protective of groundwater. Such guidance would ideally include the necessary treatment options and costs for different pollutant source areas, considering concentrations, toxicity, persistence, and potential for adsorption onto or ion exchange with the geomedia. The potential for dilution or attenuation in the subsurface could also be addressed.

Design Considerations

Readily available stormwater manuals (e.g., CASQA, 2010) provide details on the proper installation of infiltration systems. Additionally, a growing body of practitioners has experience and knowledge to evaluate where industrial stormwater retention and infiltration retention systems are appropriate. To evaluate the feasibility of retention, a number of data sets are required. As discussed previously, knowledge of the stormwater contaminants (types and concentrations) is necessary on both a chronic and episodic basis. Site conditions, including soil properties, depth to groundwater table, rainfall information, and land availability, are also required. If these properties are favorable, then a preliminary design of a retention system can made. Details must include a design storm and consideration on how that design affects compliance with benchmarks for any bypass.

Many design models, such as WinSLAMM and P8, are available to add confidence to the sizing of an infiltration system. These models can describe both the retention and water quality benefits of an infiltration system. The models can maximize the benefits of a system by accounting for important variables, such as soil type, drainage area size, and rainfall patterns.

REGULATORY CONTEXT FOR RETENTION STANDARDS

Retention with infiltration is an attractive method for stormwater control from industrial facilities when the contaminants do not pose a risk to groundwater and where land is available to install infiltration SCMs. In general, hydrological and statistical methods and data are available (or could be readily obtained) for determining retention requirements to achieve specific objectives for pollutant mass reduction, given site-specific information. Given the site-specific nature of local rainfall patterns and stormwater production and quality, however, it is not possible to recommend a nationwide standard for retention.

As described in Chapter 1, the MSGP must be written to include technology-based effluent limits (TBELs) and WQBELs. Therefore, if numeric retention standards were to be included in the MGSP, it would be within the context of functioning as a TBEL or WQBEL, which is notably distinct from how retention standards have been applied in MS4 permits, which has been in accordance with the maximum extent practicable standard. Given the site-specific nature of the suitability of retention with infiltration at industrial sites, numeric retention standards as a TBEL could not be established in EPA's MSGP or as best-available technology in an effluent limitation guideline. However, retention with infiltration is already an appropriate allowance within the 2015 MSGP requirement to "select, design, install, and implement control measures (including best management practices) to minimize pollutant discharges)" (EPA, 2015a). Because retention with infiltration reduces the overall volume of a discharge, it is an effective means to minimize pollutant discharges through reduction in pollutant mass.

Nonetheless, because of the variable nature of rainfall and stormwater, no retention system can be constructed to contain all stormwater from all events. In some cases bypass discharges that occur in storms beyond the design storm size may be below benchmark thresholds, and in those cases there is a high level of assurance that the discharge that relies on infiltration as a treatment SCM also complies with WQBELs. In other cases, the bypass concentration may exceed the respective benchmark, which will be problematic to industrial facilities desiring to implement retention/infiltration, triggering corrective actions. Some degree of regulatory relief during large-event bypass would need to be implemented to encourage industrial stormwater retention where it is safe and appropriate. The most significant incentive would be assurance that installation of a well-designed retention system provides relief from the corrective action process associated with episodic results above benchmark thresholds associated with bypass.

At least one state has recognized the benefits of industrial stormwater retention in reducing the pollutant load on water bodies and has adapted its permit to facilitate the practice. In Oregon permittees can request a mass reduction waiver if they have implemented stormwater retention with infiltration or beneficial use, if these practices can be shown to reduce the mass discharge of pollutants below the equivalent mass discharge of the benchmarks. Permittees are required to provide data and analysis of this mass discharge reduction and to take corrective actions by reviewing their SCMs and whether additional pollution controls are needed (OR DEQ, 2017).

EPA could encourage infiltration by specifically addressing the uncertainty associated with bypass during events that exceed design conditions. If retention systems are relied upon to meet a WQBEL, a wet weather accommodation could be included that considers dilution or assimilative capacity during extreme storms (see Chapter 3). Allowable frequencies of stormwater discharge at levels above benchmark thresholds could be derived from allowances of frequencies of exceedance of water quality criteria and the duration of exposure upon which the criteria are based. EPA could also develop a water quality standard exceedance allowance for extreme weather events or, as was contemplated in the past (EPA, 1995), establish separate water quality criteria for wet weather events.

If EPA wants to encourage the use of retention with infiltration as a means to reduce pollutant loads and peak flows, assuming infiltration is suitable based on groundwater considerations, it should develop additional guidance on appropriate design storm standards, perhaps in consideration of regional precipitation patterns. Additionally, EPA should develop guidance and cases studies for demonstrating through the Additional Implementation Measure process that discharges above a benchmark threshold that occur only in storms larger than the design storm do not result in an exceedance of water quality standards.

CONCLUSIONS AND RECOMMENDATIONS

Stormwater retention for infiltration or beneficial use minimizes pollutant loads to receiving waters and reduces damaging peak flows while potentially increasing water availability. Yet, infiltration of industrial stormwater, which can contain hazardous pollutants in toxic amounts, can pose serious risks to groundwater; these risks must be managed to prevent groundwater contamination. Based on the potential environmental benefits, particularly in areas of water scarcity, the committee encourages the use of industrial stormwater retention with infiltration or beneficial use under conditions where groundwater is protected.

Rigorous permitting, (pre)treatment, and monitoring requirements are needed along with careful site characterization and designs to ensure groundwater protection in industrial stormwater infiltration systems. In lieu of other information on the attenuation of contaminants in groundwater before they are transported to the site boundary, infiltrated water should be required to meet primary drinking water standards for inorganic chemicals and organic chemicals, and secondary standards for chloride and total dissolved solids. Water quality should be monitored and evaluated in the infiltration device or at the base of the vadose zone. Many water quality treatment options are available ranging from natural removal employing in situ soils to standard SCMs to advanced treatment. Industries considering infiltration should evaluate whether potential stormwater contaminants from routinely occurring pollutants as well as accidents and spills are compatible with infiltration and what technologies are required to remove these contaminants prior to infiltration. Chemicals covered by the Safe Drinking Water Act and unregulated chemicals with known human health risks at concentrations of concern should be evaluated. Meeting stringent water quality requirements may make infiltration cost prohibitive at sites with contaminants that pose a high risk of polluting groundwater. Other factors influencing the feasibility of a retention and infiltration system include the land available, soil infiltration rate, soil chemistry, and depth to groundwater.

Site-specific factors and water-quality-based effluent limits render national retention standards for industrial stormwater infeasible within the existing regulatory framework of the MSGP. Retention and infiltration or beneficial use is already allowed within the MSGP as one of many possible SCMs. However, the suitability of retention with infiltration or beneficial use is based on site-specific factors that cannot be generalized nationally into retention standards. Issues such as the design storm size, stormwater quality, receiving water quality goals, and site conditions must be known to ensure performance reliability. Additionally, although retention could be designed using site-specific factors as a TBEL, industrial stormwater must also comply with WQBELs, which are typically concentration based. It is impractical to design stormwater retention to capture all potential rainfall events, and for storm events that exceed the design standard, discharge or bypass will occur that may exceed the benchmarks.

EPA should consider incentives to encourage industrial stormwater infiltration or capture and use where appropriate. The most significant incentive would be assurance that installation of infiltration in accordance with EPA guidance for determining the appropriate design storm provides relief from the corrective action process associated with episodic bypass that exceeds benchmark thresholds. This could be done through a number of regulatory measures, including a mixing zone allowance, establishment of allowable frequencies of stormwater discharge at levels above benchmark thresholds, development of water quality standard exceedance allowances for extreme weather events, or establishment of separate water quality criteria for major wet weather events. Finally, EPA could develop guidance and case studies for demonstrating that exceeding the benchmark during storms with precipitation amounts greater than the design storm do not result in an exceedance of water quality standards.

EPA should develop guidance for retention and infiltration of industrial stormwater for protection of groundwater. The guidance should include information on applied water quality, treatment offered within the infiltration zone, monitoring requirements, natural attenuation of pollutants, groundwater use designations, and possible impacts of pollutant dilution or mobilization in the subsurface. Because of the potential risks to groundwater, industrial stormwater infiltration is not recommended in states that lack the legal authority to manage and enforce groundwater quality.

REFERENCES

Abdel-Shafy, H. I., and M. S. M. Mansour. 2016. A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. *Egyptian Journal of Petroleum* 25(1):107–123.

APHA (American Public Health Association). 1995. *Standard methods for the examination of water and wastewater, 19th Edition*. Published in conjunction with the American Water Works Association and the Water Environment Federation. Washington, DC: APHA.

Armstrong, D. E., and R. Llena. 1992. *Stormwater infiltration: Potential for pollutant removal*. Chicago, IL: Prepared for the Wisconsin Department of Natural Resources (Madison) and the U.S. Environmental Protection Agency.

Avila, H., and R.E. Pitt. 2009. Scour in stormwater catchbasin devices – experimental results from a full-scale physical model. *Journal of Water Management Modeling* R235-19.

Avila, H., R. Pitt, and S. R. Durrans. 2008. Factors affecting scour of previously captured sediment from stormwater catchbasin sumps. *Journal of Water Management Modeling* R228-13.

Bent, G. C., J. R. Gray, K. P. Smith, and G. D. Glysson. 2001. *A synopsis of technical issues for monitoring sediment in highway and urban runoff*. Northborough, MA: U.S. Geological Survey Open-File Report 00-497.

Boving, T. B., M. H. Stolt, J. Augenstern, and B. Brosnan. 2008. *Environmental Geology* 55(3):571–582.

Breault, R. F., and G. E. Granato. 2000. *A synopsis of technical issues for monitoring trace elements in highway runoff and urban stormwater*. Northborough, MA: U.S. Geological Survey Open-File Report 00-422.

Bulkley, J., D. LeFevre, H. Clark, A. Samples, and R. Berns. 2009. *Wet weather benchmarking report.* University of Michigan, Ann Arbor. Pp. 1-383. Available at http://css.umich.edu/sites/default/files/css_doc/WWfinal.pdf (accessed December 18, 2018).

Burton, G. A., and R. E. Pitt. 2002. *Chapter 5: Sampling effort and collection methods*. Pp. 224–338 in *Stormwater effects handbook: A toolbox for watershed managers, scientists, and engineers*, G. A. Burton and R. E. Pitt, eds. Boca Raton, FL: Lewis Publishers.

Cadmus, P., S. F. Brinkman, and M. K. May. 2018. Chronic toxicity of ferric iron for North American aquatic organisms: Derivation of a chronic water quality criterion using single species and mesocosm data. *Archives of Environmental Contamination and Toxicology* 74(4):605–615.

California Water Boards. 2018. General Permit for Storm Water Discharges Associated with Industrial Activity, NPDES No. CAS000001, Order No. 2014-0057-DWQ, amended by Order No. 2015-0122-DWQ, amended by Order No. 2018-XXXX-DWQ. Available at https://www.waterboards.ca.gov/water_issues/programs/stormwater/docs/industrial/unoff_igp_amend.pdf (accessed January 30, 2019).

Caltrans. 2010. *Treatment BMP technology report*. CSTW-RT-09-239-06. Sacramento, CA: California Department of Transportation. Available at http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-09-239-06.pdf (accessed November 8, 2018).

Canadian CME (Canadian Council of Ministers of the Environment). 1999. *Canadian environmental quality guidelines for the protection of aquatic life*. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. Available at http://st-ts.ccme.ca/en/index.html (accessed November 19, 2018).

CASQA (California Stormwater Quality Association). 2010. *Low impact development manual for Southern California: Technical guidance and site planning strategies*. Prepared for the Southern California Stormwater Monitoring Coalition in cooperation with the State Water Resources Control Board by the Low Impact Development Center. Available at https://www.casqa.org/sites/default/files/downloads/socallid-manual-final-040910.pdf (accessed November 8, 2018).

City of Phoenix. 2011. *Storm water policies and standards: Revisions*. Available at https://www.phoenix.gov/streetssite/Documents/swpolicy.pdf (accessed November 8, 2018).

Clark, S. E. 2000. *Urban stormwater filtration: Optimization of design parameters and a pilot-scale evaluation*. Ph.D. Dissertation, University of Alabama at Birmingham, Birmingham, Alabama.

Clark, S. E., and R. Pitt. 2007. Influencing factors and a proposed evaluation methodology for predicting groundwater contamination potential from stormwater infiltration activities. *Water Environment Research* 79(1):29–36.

Clark, S. E., and R. Pitt. 2008. Comparison of stormwater solids analytical methods for performance evaluation of manufactured treatment devices. *Journal of Environmental Engineering* 134(4):259–264.

Clark, S. E., and R. Pitt. 2012. Targeting treatment technologies to address specific stormwater pollutants and numeric discharge limits. *Water Research* 46(20):6715–6730.

Clark, S. E., and R. Pitt. In press. Industrial stormwater: Sedimentation and filtration effectiveness to meet benchmark concentrations. Submitted to the *Journal of Sustainable Water in the Built Environment*.

Clark, S. E., and C. Y. S. Siu. 2008. Measuring solids concentration in stormwater runoff: Comparison of analytical methods. *Environmental Science & Technology* 42(2):511–516.

Clark, S. E., C. Y. S. Siu, R. Pitt, C. D. Roenning, and D. P. Treese. 2009. Peristaltic pump autosamplers for solids measurement in stormwater runoff. *Water Environment Research* 81(2):192–200.

Clark, S. E., K. H. Baker, D. P. Treese, J. B. Mikula, C. Y. S. Siu, C. S. Burkhardt, and M. M. Lalor. 2010. *Sustainable stormwater management: Infiltration vs. surface treatment strategies.* WERF Report 04-SW-3. London, UK: IWA Publishing.

Clary, J., M. Leisenring, and P. Hobson. 2011. *International stormwater Best Management Practices (BMP) database pollutant category summary: Metals*. International Stormwater BMP Database. Prepared by Wright Water Engineers, Inc. and Geosyntec Consultants, Inc. Available at http://www.bmpdatabase.org/Docs/BMP%20Database%20Metals%20Final%20August%202011.pdf (accessed November 7, 2018).

County of Orange, CA, Department of Public Works. 2013. Technical Guidance Document for the Preparation of Conceptual/Preliminary/ or Project Water Quality Management Plans, Appendix VIII, Groundwater-Related Infiltration Feasibility Criteria (see Appendix VIII.2).

Cristina, C., J. Tramonte, and J. J. Sansalone. 2002. A granulometry-based selection methodology for separation of traffic-generated particles in urban highway snowmelt runoff. *Water, Air, and Soil Pollution* 136(1–4):33–53.

Cross, L. M., and L. D. Duke. 2008. Stormwater regulations for industry: Linking regulatory priorities with water quality protection. *Journal of the American Water Resources Association* 44(1):86–106.

Crunkilton, R., J. Kleist, J. Ramcheck, W. DeVita, and D. Villeneuve. 1996. *Assessment of the response of aquatic organism to long-term in situ exposures of urban runoff*. Pp. 95–111 in *Effects of watershed development and management of aquatic ecosystems*, L. A. Roesner, ed. New York: American Society of Civil Engineers.

CT DEEP (Connecticut Department of Energy and Environmental Protection). 2004. Hydrologic sizing criteria for treatment practices. Chapter 7 in *Stormwater quality control manual*. Available at https://www.ct.gov/deep/cwp/view.asp?a=2721&q=325704 (accessed September 18, 2018).

CT DEEP. 2018. *General permit for the discharge of stormwater associated with industrial activity*. DEEP-WPED-GP-014.

Datry, T., F. Malard, and J. Gibert. 2004. Dynamics of solutes and dissolved oxygen in shallow urban groundwater below a stormwater infiltration basin. *Science of the Total Environment* 329(1–3):215–229.

Davis, L. R. 2018. *Fundamentals of environmental discharge modeling* (Vol. 10). Boca Raton, FL: CRC Press.

DDOE (District Department of the Environment). 2014. *Overview of 2013 stormwater rule and stormwater management guidebook*. Available at https://ddot.dc.gov/sites/default/files/dc/sites/ddot/publication/attachments/2014-0418-DDOT-GI-SWM%20Regs%20and%20GI%20Training.pdf (accessed November 8, 2018).

Dechesne, M., S. Barraud, and J.-P. Bardin. 2004. Spatial distribution of pollution in an urban stormwater infiltration basin. *Journal of Contaminant Hydrology* 72(1):189–205.

DeForest, D. K., K. V. Brix, L. M. Tear, and W. J. Adams. 2018. Multiple linear regression models for predicting chronic aluminum toxicity to freshwater aquatic organisms and developing water quality guidelines. *Environmental Toxicology and Chemistry* 37(1):80–90.

DiBlasi, C. J., H. Li, A. P. Davis, and U. Ghosh. 2009. Removal and fate of polycyclic aromatic hydrocarbon pollutants in an urban stormwater bioretention facility. *Environmental Science & Technology* 43(2):494–502.

Edwards, E. C., T. Harter, G. E. Fogg, B. Washburn, and H. Hamad. 2016. Assessing the effectiveness of drywells as tools for stormwater management and aquifer recharge and their groundwater contamination potential. *Journal of Hydrology* 539:539–553.

EPA. 1980a. *National recommended water quality criteria for beryllium*. LOEL Acute Freshwater. EPA-440-5-80-024 (October).

EPA. 1980b. *Ambient water quality criteria for coppe*r. EPA-440/4-80-036. Washington, DC: U.S. EPA.

EPA. 1980c. *Ambient water quality criteria for polynuclear aromatic hydrocarbons*. EPA 440/5-80-069.

EPA 1983. *Final Report of the Nationwide Urban Runoff Program*. National Technical Information Service (NTIS) Accession Number: PB84-185552. Washington, DC: Water Planning Division. Available at https://www3.epa.gov/npdes/pubs/sw_nurp_vol_1_finalreport.pdf (accessed November 8, 2018).

EPA. 1985. *Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses*. Stephen, C. E., D. I. Mount, D. J. Hansen, J. R. Gentile, G. A. Chapman, and W. A. Brungs. U.S. EPA PB85-227049. Available at https://www.epa.gov/sites/production/files/2016-02/documents/guidelines-water-quality-criteria.pdf (accessed November 1, 2018).

EPA. 1986. Method 8100: Polycyclic aromatic hydrocarbons. Available at https://www.epa.gov/sites/production/files/2015-12/documents/8100.pdf (accessed November 8, 2018).

EPA. 1987. *Ambient water quality criteria for selenium – 1987*. EPA-440/5-87-006. Washington, DC: U.S. EPA.

EPA. 1988. *Ambient water quality criteria for aluminum—1988.* EPA 440/5-86-008. Duluth, MN: Office of Research and Development. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi/2000M5FC.PDF?Dockey=2000M5FC.PDF (accessed February 14, 2019).

EPA. 1991. *Technical support document for water quality-based toxics control*. EPA/505/2-90-00. NTIS Accession Number: PB91-127415. Washington, DC: Office of Water (EN-336). Available at https://www3.epa.gov/npdes/pubs/owm0264.pdf (accessed February 14, 2019).

EPA. 1992. *NPDES storm water sampling guidance document*. EPA 833-8-92-001. Available at https://www3.epa.gov/npdes/pubs/owm0093.pdf (accessed November 8, 2018).

EPA. 1995. Advisory Committee Charter, Urban Wet Weather Flows Advisory Committee, C. Browner, Administrator (signed Jan. 06, 1995). 61 FR 46462. Available at https://www.govinfo.gov/app/details/FR-1996-09-03/96-22380 (accessed December 31, 2018).

EPA. 1996. *The metals translator: Guidance for calculating a total recoverable permit limit from a dissolved criterion*. EPA 823-B-96-007. Washington, DC: EPA Office of Water. Available at https://www3.epa.gov/npdes/pubs/metals_translator.pdf (accessed November 7, 2018).

EPA. 1999. *Report to Congress on the Phase II Storm Water Regulations.* EPA 833-99-001. Washington, DC: EPA Office of Water. Available at https://www3.epa.gov/npdes/pubs/ReptoCong_PhII_SWR.pdf (accessed November 7, 2018).

EPA. 2001. *Update of the ambient water quality criteria for cadmium*. EPA/822/R-01-001. Washington, D.C.: U.S. EPA.

EPA. 2004. *NPDES Compliance Inspection Manual*. EPA 305-X-04-001. July 2004. Washington, DC: EPA Office of Enforcement and Compliance Assurance. Available at https://www.epa.gov/sites/production/files/2013-09/documents/npdesinspect_0.pdf (accessed December 31, 2018).

EPA. 2006a. *National recommended water quality criteria—Aquatic life criteria table*. EPA-822-F-04-010 2006-CMC. Available at https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table (accessed November 8, 2018).

EPA. 2006b. *National ambient water quality criteria – human health criteria table*. EPA-822-F-01-0102006. Available at https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table (accessed November 8, 2018).

EPA. 2006c. *Industrial stormwater factsheet series: Sector R: Ship and boat building or repair yards.* EPA-833-F-06-033. Available at https://www.epa.gov/sites/production/files/2015-10/documents/sector_r_shipbuilding.pdf (accessed November 12, 2018).

EPA. 2007. *Aquatic life criteria – copper.* Available at https://www.epa.gov/wqc/aquatic-life-criteria-copper (accessed November 8, 2018).

EPA. 2008a. *Multi-Sector General Permit for stormwater discharges associated with industrial activity (MSGP).* Available at https://www.epa.gov/sites/production/files/2015-10/documents/msgp2008_finalpermit.pdf (accessed November 1, 2018).

EPA. 2008b. *Multi-Sector General Permit for stormwater discharges associated with industrial activity (MSGP)—Fact sheet*. Available at https://www.epa.gov/sites/production/files/2015-10/documents/msgp2015_fs.pdf (accessed November 1, 2018).

EPA. 2009a. *Industrial stormwater monitoring and sampling guide*. EPA 832-B-09-003. Available at https://www3.epa.gov/npdes/pubs/msgp_monitoring_guide.pdf (accessed November 2, 2018).

EPA. 2009b. *Technical guidance on implementing the stormwater runoff requirements for federal projects under Section 438 of the Energy Independence and Security Act*. EPA 841-B-09-001. Available at https://www.epa.gov/greeningepa/technical-guidance-implementing-stormwater-runoff-requirements-federal-projects (accessed September 18, 2018).

EPA. 2010. National Pollutant Discharge Elimination System (NPDES) Permit Writers' Manual. Available at https://www.epa.gov/sites/production/files/2015-09/documents/pwm_chapt_05.pdf (accessed September 18, 2018).

EPA. 2012. *2008 MSGP Benchmark Discharge Monitoring Report Analysis and SWPPP Compliance Review*. EPA-HQ-OW-2012-0803-0002.

EPA. 2014. *Clean Water Act National Pollutant Discharge Elimination System compliance monitoring strategy 2014*. Washington, DC: Office of Enforcement and Compliance Assurance. Available at https://www.epa.gov/sites/production/files/2013-09/documents/npdescms.pdf (accessed November 7, 2018).

EPA. 2015a. *United States Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) Multi-Sector General Permit for stormwater discharges associated with industrial activity (MSGP).* Available at https://www.epa.gov/sites/production/files/2015-10/documents/msgp2015_finalpermit.pdf (accessed November 1, 2018).

EPA. 2015b. *Multi-Sector General Permit for stormwater discharges associated with industrial activity (MSGP)—Fact sheet*. Available at https://www.epa.gov/sites/production/files/2015-10/documents/msgp2015_fs.pdf (accessed November 1, 2018).

EPA. 2015c. *Method 8310: Polynuclear aromatic hydrocarbons*. Available at https://www.epa.gov/sites/production/files/2015-12/documents/8310.pdf (accessed Nov. 1, 2018).

EPA. 2016a. *Aquatic life ambient water quality criterion for selenium—freshwater 2016.* Available at https://www.epa.gov/sites/production/files/2016-07/documents/aquatic_life_awqc_for_selenium_-_freshwater_2016.pdf (accessed November 12, 2018).

EPA. 2016b. *Aquatic life ambient water quality criteria cadmium—2016.* EPA-820-R-26-002. Available at https://www.epa.gov/sites/production/files/2016-03/documents/cadmium-final-report-2016.pdf (accessed November 12, 2018).

EPA. 2016c. *Summary of state post construction stormwater standards.* Available at https://www.epa.gov/sites/production/files/2016-08/documents/swstdsummary_7-13-16_508.pdf (accessed September 18, 2018).

EPA. 2017. *2017 draft aquatic life criteria for aluminum in freshwater.* Available at https://www.epa.gov/wqc/2017-draft-aquatic-life-criteria-aluminum-freshwater (accessed November 12, 2018).

EPA. 2018. *Industrial wastewater treatment technology database (IWTT).* Available at https://www.epa.gov/eg/industrial-wastewater-treatment-technology-database-iwtt (accessed January 24, 2019).

Eppakayala, V. K. 2015. *Performance evaluation of stormwater treatment controls at an industrial site*. A dissertation. University of Alabama, Tuscaloosa. Available at https://socwisconsin.org/wp-content/uploads/2017/05/Eppakayala_2015_SWTrtmtAtIndustrialSite.pdf (accessed November 1, 2018).

FAO (Food and Agricultural Organiation). 2000. *FAO pesticide disposal series 8: Assessing soil contamination: A reference manual*. Rome: Food and Agricultural Organization of the United Nations.

Fein, J. B. 1996. The effect of aqueous metal-chlorophenolate complexation on contaminant transport in groundwater systems. *Applied Geochemistry* 11(6):735–744.

Fischer, H. B., E. J. List, R. C. Y. Koh, J. Imberger, and N. H. Brooks. 1979. *Mixing in inland and coastal waters*. San Diego, CA: Academic Press.

Furumai, H., H. Balmer, and M. Boller. 2002. Dynamic behavior of suspended pollutants and particle size distribution in highway runoff. *Water Science & Technol*ogy 46(11–12):413–418.

Gawad, S. A., J. A. McCorquodale, and H. Gerges. 1996. Near-field mixing at an outfall. *Canadian Journal of Civil Engineering* 23(1):63–75.

Geosyntec Consultants and Wright Water Engineers, Inc. 2009. *Urban Stormwater BMP Performance Monitoring* (June 2009). Available at www.bmpdatabase.org/monitoring-guidance.html (accessed February 14, 2019).

Gossett, R., and K. Schiff. 2010. *Stormwater Monitoring Coalition Laboratory Guidance Document, Third Edition.* Southern California Coastal Water Research Project Technical Report 615, Costa Mesa, CA. 22 pp. Available at ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/615_SMC_LabGuide3rdEdition.pdf (accessed November 19, 2018).

Graczyk, D. J., D. M. Robertson, W. J. Rose, and J. J. Steuer. 2000. *Comparison of water-quality samples collected by siphon samplers and automatic samplers in Wisconsin.* Middleton, WI: U.S. Geological Survey Fact Sheet FS-067-00.

Gray, J. R., G. D. Glysson, L. M. Turcios, and G. E. Schwarz. 2000. *Comparability of suspended-sediment concentration and Total Suspended Solids data*. Denver, CO: U.S. Geological Survey Water-Resources Investigation Report 00-4191.

Han, Y., S.-L. Lau, M. Kayhanian, and M. K. Stenstrom. 2006a. Characteristics of highway stormwater runoff. *Water Environment Research* 78(12):2377–2388.

Han, Y.-H., S.-L. Lau, M. Kayhanian, and M. K. Stenstrom. 2006b. Correlation analysis among highway stormwater pollutants and characteristics. *Water Science & Technology* 53(2):235–243.

Harcum, J., S. Adair, and J. Collins. 2005. Review of discharge monitoring report data from the MSGP 2000. Technical Memorandum to Jack Faulk. February 10, 2005.

Incardona, J. P., T. L. Linbo, and N. L. Scholz. 2011. Cardiac toxicity of 5-ring polycyclic aromatic hydrocarbons is differentially dependent on the aryl hydrocarbon receptor 2 isoform during zebrafish development. *Toxicology and Applied Pharmacology* 257(2):242–249.

Jarvis, C. M., and L. Wisniewksi. 2006. *An introduction to the biotic ligand model*. U.S. Environmental Protection Agency presentation. May 10, 2006. U.S. EPA Office of Water, Office of Science & Technology. Available at https://acwi.gov/monitoring/conference/2006/2006_conference_materials_notes/Concurrent_SessionI/I4Stress/I4_Wisniewski.pdf (accessed November 7, 2018).

Jirka, G. H., R. L. Doneker, and S. W. Hinton. 1996. *User's manual for CORMIX: A hydrodynamic mixing zone model and decision support system for pollutant discharges into surface waters*. Washington, DC: U.S. Environmental Protection Agency, Office of Science and Technology. Available at https://www.epa.gov/sites/production/files/2015-10/documents/cormix-users_0.pdf (accessed January 24, 2019).

Johnson, P. D., R. Pitt, S. R. Durrans, M. Urrutia, and S. Clark. 2003. *Metals removal technologies for urban stormwater*. WERF 97-IRM-2. Alexandria, VA: Water Environment Research Foundation.

Jones, P. S., and A. P. Davis. 2013. Spatial accumulation and strength of affiliation of heavy metals in bioretention media. *Journal of Environmental Engineering* 139(4):479–487.

Kakuturu, S. P., and S. E. Clark. 2015. Effects of deicing salts on clogging of stormwater filter media and on media chemistry. *Journal of Environmental Engineering* 141(9):04015020.

Kayhanian, M., T. Young, and M. K. Stenstrom. 2005. Limitation of current solid measurements in stormwater runoff. *Stormwater* 6(7):22–30.

Kerkez, B., C. Gruden, M. Lewis, L. Montestruque, M. Quigley, B. Wong, A. Bedig, R. Kertesz, T. Braun, O. Cadwalader, A. Poresky, and C. Pak. 2016. Smarter stormwater systems. *Environmental Science & Technology* 50(14):7267–7273.

Ku, H. F., and D. L. Simmons. 1986. *Effect of urban stormwater runoff on ground water beneath recharge basins on Long Island, New York*. Syosset, NY: U.S. Geological Survey Water-Resources Investigations Report 85-4088.

Landsman, M. R., and A. P. Davis. 2018. Evaluation of nutrients and suspended solids removal by stormwater control measures using high flow media. *Journal of Environmental Engineering* 144(10):04018106.

LeFevre, G. H., P. J. Novak, and R. M. Hozalski. 2012a. Fate of naphthalene in laboratory-scale bioretention cells: Implications for sustainable stormwater management. *Environmental Science & Technology* 46(2):995–1002.

LeFevre, G. H., R. M. Hozalski, and P. J. Novak. 2012b. The role of biodegradation in limiting the accumulation of petroleum hydrocarbons in raingarden soils. *Water Research* 46(20):6753–6762.

LeFevre, G. H., K. H. Paus, P. Natarajan, J. S. Gulliver, P. J. Novak, and R. M. Hozalski. 2015. Review of dissolved pollutants in urban storm water and their removal and fate in bioretention cells. *Journal of Environmental Engineering* 141(1):04014050.

Li, Y., S.-L. Lau, M. Kayhanian, and M. K. Stenstrom. 2005. Particle size distribution in highway runoff. *Journal of Environmental Engineering* 131(9):1267–1276.

Ma, J.-S., J.-H. Kang, M. Kayhanian, and M. K. Stenstrom. 2009. Sampling issues in urban runoff monitoring programs: Composite versus grab. *Journal of Environmental Engineering* 135(3):118–127.

McIntyre, J., R. Edmunds, B. Anulacion, J. Davis, J. Incardona, J. D. Stark, and N. Scholz. 2016. Severe coal tar sealcoat runoff toxicity to fish is prevented by bioretention filtration. *Environmental Science & Technology* 50:1570–1578.

MDEP (Maryland Department of the Environment). 2014. *General permit for discharges from stormwater associated with industrial activities*. Discharge Permit No. 12-SW. NPDES Permit No. MDR0000.

MPCA (Minnesota Pollution Control Agency). 2015. *National Pollutant Elimination System (NPDES)/State Disposal System (SDS) General Permit MNR050000 for Industrial Stormwater Multi-Sector (ISW).* Authorization to discharge stormwater associated with industrial activity under the National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit program. Available at https://www.pca.state.mn.us/sites/default/files/wq-strm3-67a.pdf (accessed November 14, 2018).

NASEM (National Academies of Sciences, Engineering, and Medicine). 2015. *Volume reduction of highway runoff in urban areas: Guidance manual*. Washington, DC: The National Academies Press.

NASEM. 2016. *Using graywater and stormwater to enhance local water supplies: An assessment of risks, costs, and benefits*. Washington, DC: The National Academies Press.

Niogi, S., and C. M. Wood. 2004. Biotic ligand model, a flexible tool for developing site-specific water quality guidelines for metals. *Environmental Science & Technology* 38(23):6177–6192.

Nowack, B., H. Xue, and L. Sigg. 1997. Influence of natural and anthropogenic ligands on metal transport during infiltration of river water to groundwater. *Environmental Science & Technology* 31(3):866–872.

NRC (National Research Council). 2009. *Urban stormwater management in the United States*. Washington, DC: The National Academies Press.

O'Donnell, J. O. 2005. Memorandum re: *Review of 2000 MSGP monitoring requirements and suggested changes*. March 15, 2005. Fairfax, VA: Tetra Tech, Inc.

Ohio Environmental Protection Agency. 2018. *General permit authorization for storm water discharges associated with construction activity under the National Pollutant Discharge Elimination System*. Available at http://epa.ohio.gov/portals/35/permits/OHC000005/Final_OHC000005.pdf (accessed November 8, 2018).

Okamoto, A., M. Yamamuro, and N. Tatarazako. 2014. Acute toxicity of 50 metals to *Daphnia magna*. *Journal of Applied Toxicology* 35(7):824–830.

OR DEQ (Oregon Department of Environmental Quality). 2017. General permit National Pollutant Discharge Elimination System: Stormwater Discharge General Permit No. 1200-Z. Available at https://www.oregon.gov/deq/FilterPermitsDocs/Final1200Zpermit.pdf (accessed November 8, 2018).

OR DEQ. 2018. National Pollutant Discharge Elimination System Industrial Stormwater Permit Evaluation Report No. 1200-Z. October 2018, Final Action. Available at https://www.oregon.gov/deq/FilterPermitsDocs/1200-Zevalreport.pdf (accessed December 31, 2018).

Ott, R. L., and M. T. Longnecker. 2015. *An introduction to statistical methods and data analysis, 7th edition.* Boston, MA: Cengage Learning.

PA DEP (Pennsylvania Department of Environmental Protection). 2006. *Pennsylvania stormwater best management practices manual*. Bureau of Watershed Management. 363-0300-002.

Pitt, R., with contributions from S. Clark, R. Field, and K. Parmer. 1996. *Groundwater contamination from stormwater infiltration*. Chelsea, MI: Ann Arbor Press.

Pitt, R. 2011. *Water quality objectives and failure modes of green infrastructure stormwater components*. 84th Annual Water Environment Federation Technical Exhibition and Conference (WEFTEC). Los Angeles, CA, October 15–19, 2011.

Pitt, R., and S. E. Clark. 2010. Evaluation of biofiltration media for engineered natural treatment systems. Submitted to Geosyntec Consultants. Available at http://unix.eng.ua.edu/~rpitt/Publications/5_Stormwater_Treatment/Media_for_stormwater_treatment/media%20report%20SSFL%20May%2010%202010.pdf (accessed November 19, 2018).

Pitt, R., and L. Talebi. 2012. *Evaluation and demonstration of stormwater dry wells and cisterns in Millburn Township, New Jersey*. EPA Contract: EP-C-08-016.

Pitt, R., S. Clark, and K. Parmer. 1994. Protection of groundwater from intentional and nonintentional stormwater infiltration. Cincinnati, OH: EPA/600/SR-94/051.

Pitt, R., R. Field, M. Lalor, and M. Brown. 1995. Urban stormwater toxic pollutants: Assessment, sources, and treatability. *Water Environment Research* 67(3):260–275.

Pitt, R. E., R. Bannerman, S. Clark, and D. Williamson. 2004a. Chapter 23: Source of Pollutants in Urban (Part 1)—Older Monitoring Projects. Pp. 465–484 in *CHI Monograph 13, Effective modeling of urban water systems*. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt, eds. Guelf, ON: Computational Hydraulics International (CHI).

Pitt, R., R. Bannerman, S. E. Clark, and D. Williamson. 2004b. Chapter 24: Source of Pollutants in Urban (Part 2)—Recent Sheetflow Monitoring. Pp. in *CHI Monograph 13, Effective modeling of urban water systems*. W. James, K. N. Irvine, E. A. McBean, and R. E. Pitt, eds. Guelf, ON: Computational Hydraulics International (CHI).

RI DEM (Rhode Island Department of Environment Management). 2013. *Multi-Sector General Permit Rhode Island pollutant discharge elimination system storm water discharge associated with industrial activity (excluding construction activity)*. RIR500000. Available at http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/pdfs/msgp.pdf (accessed November 14, 2018).

Sansalone, J. J., and S. G. Buchberger. 1997. Characterization of solid and metal element distributions in urban highway stormwater. *Water Science & Technology* 36(8-9):155–160.

Sansalone, J. J., and C. M. Cristina. 2004. First flush concepts for suspended and dissolved solids in small impervious watersheds. *Journal of Environmental Engineering* 130(11):1301–1314.

Saunders, T. G., R. C. Ward, J. C. Loftis, T. D. Steele, D. D. Adrian, and V. Yevjevich. 1983. *Design of networks for monitoring water quality*. Highlands Ranch, CO: Water Resources Publications.

Sauvé, S., W. Hendershot, and H. E. Allen. 2000. Solid-solution partitioning of metals in contaminated soils: Dependence on pH, total metal burden, and organic matter. *Environmental Science & Technology* 34(7):1125–1131.

Schiff, K. C., and L. L. Tiefenthaler. 2011. Seasonal flushing of pollutant concentrations and loads in urban stormwater. *Journal of the American Water Resources Association* 47(1):136–142.

Schwarzenbach, R. P., P. M. Gschwend, and D. M. Imboden. 1993. *Environmental organic chemistry*. New York: John Wiley & Sons.

Selbig, W. R., A. Cox, and R. T. Bannerman. 2012. Verification of a depth-integrated sample arm as a means to reduce solids stratification bias in urban stormwater sampling. *Journal of Environmental Monitoring* 14(4):1137–1143.

Shaver, E., R. Horner, J. Skupien, C. May, and G. Ridley. 2007. *Fundamentals of urban runoff management: Technical and institutional issues, 2nd edition*. North American Lake Management Society.

Squillace, P. J., J. S. Zogorski, W. G. Wilber, and C. V. Price. 1996. Preliminary assessment of the occurrence and possible sources of MTBE in groundwater in the United States, 1993−1994. *Environmental Science & Technology* 30(5):1721–1730.

State of Vermont. 2008. *General permit 3-9020 (2006) for stormwater runoff from construction sites as amended February 2008*. Agency of Natural Resources Department of Environmental Conservation. Available at https://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/StormwaterConstructionDischargePermits/sw_cgp_amended_final.pdf (accessed November 8, 2018).

State of Washington Department of Ecology. 2019. *Stormwater management manual for Western Washington – Draft*. Publication No. xx-xx-xxx. https://fortress.wa.gov/ecy/ezshare/wq/permits/Flare/Draft2019SWMMWW.htm (accessed on Jan. 27, 2019).

Stumm, W., and J. Morgan. 1995. *Aquatic chemistry: Chemical equilibria and rates in natural waters, 3rd edition*. New York: Wiley.

Swamikannu, X., M. Mullin, and L. D. Duke. 2000. *Industrial storm water discharger identification and compliance evaluation in the city of Los Angeles*. Sacramento, CA: California Water Resources Control Board.

Treese, D. P., S. E. Clark, and K. H. Baker. 2012. Nutrient release from disturbance of infiltration system soils during construction. *Advances in Civil Engineering* 2012:393164.

UDFCD (Urban Drainage and Flood Control District). 2018. *Urban storm drainage criteria manual: Vol. 3, stormwater quality*. Available at https://udfcd.org/volume-three (accessed November 8, 2018).

van Dam, R. A., A. C. Hogan, C. D. McCullough, M. A. Houston, C. L. Humphrey, and A. J. Harford. 2010. Aquatic toxicity of magnesium sulfate, and the influence of calcium, in very low ionic concentration water. *Environmental Toxicology and Chemistry* 29(2):410–421.

Vuorinen, P. J, M. Keinänen, S. Peuranen, and C. Tigerstedt. 1998. Effects of iron, aluminium, dissolved humic material and acidity on grayling (*Thymallus thymallus*) in laboratory exposures, and a comparison of sensitivity with brown trout (*Salmo trutta*). *Boreal Environmental Research* 3:405–419.

Water Quality Program. 2011. *Technical guidance manual for evaluating emerging stormwater treatment technologies: Technology assessment protocol—ecology (TAPE)*. No. 11-10-061. Olympia, WA: Washington State Department of Ecology.

Waterkeeper Alliance v. U.S. EPA. 2016. *Settlement agreement*. Available at http://waterkeeper.org/wp-content/uploads/2016/08/Waterkeeper_Alliance_Settlement_Agreement_08162016-EPA-MSGP.pdf (accessed November 1, 2018).

WDNR (Wisconsin Department of Natural Resources). 2017. *Wisconsin Department of Natural Resources conservation practice standard site evaluation for storm water infiltration 1002.* Available at https://dnr.wi.gov/topic/stormwater/documents/SiteEvalForInfiltr1002.pdf (accessed November 8, 2018).

Weiner, E. R. 2008. *Applications of environmental aquatic chemistry, 2nd edition*. Boca Raton, FL: CRC Press.

Weiss, P. T., G. LeFevre, and J. S. Gulliver. 2008. *Contamination of soil and groundwater due to stormwater infiltration practices: A literature review*. University of Minnesota St. Anthony Falls Laboratory: Engineering, Environmental and Geophysical Fluid Dynamics. Project Report No. 515. Available at https://www.pca.state.mn.us/sites/default/files/stormwater-r-weiss0608.pdf (accessed November 19, 2018).

Winterstein, T. A., and H. G. Stefan. 1983. *Suspended sediment sampling in flowing water: Laboratory study of the effects of nozzle orientation, withdrawal rate and particle size*. External Memorandum No. M-168. Minneapolis, MI: University of Minnesota–St. Anthony Falls Hydraulic Laboratory.

Zahedi, S., H. Vaezzade, M. Rafati, and M. Z. Dangesaraki. 2014. Acute toxicity and accumulation of iron, manganese and aluminum in Caspian kutum fish (*Rutilus kutum*). *Iranian Journal of Toxicology* 8(24):1028–1033.

Appendix A

State Industrial Stormwater Permit Benchmark Monitoring Comparison

EPA 2015	Alaska 2015	California 2014	Connecticut 2016	Maryland 2014
Benchmark (BM) monitoring for some sectors.	BM monitoring for some sectors.	BM monitoring for some sectors. Many facilities identify additional site-specific monitoring parameters.	BM monitoring for some sectors.	BM monitoring for some sectors.
Frequency: Quarterly.	**Frequency:** Quarterly.	**Frequency:** Twice every 6 months. Compliance Group participants monitor once every 6 months.	**Frequency:** Once every 6 months.	**Frequency:** Quarterly.
BM Monitoring Waiver: Average four consecutive results below BM. Natural background. No further pollutant reductions are technologically available and economically practicable and achievable reduce to once per year.	**BM Monitoring Waiver:** Average four consecutive results below BM. Natural background. No further pollutant reductions are technologically available and economically practicable and achievable reduce to once per year.	**BM Monitoring Reduction:** After four consecutive results with no numeric action level exceedances, reduce to once every 6 months (once per year for Compliance Group).	**BM Monitoring Waiver:** Average four consecutive results below BM Natural background. Run-on entering from off site. No further pollutant reductions are technologically available and economically practicable and achievable reduce to once per year.	**BM Monitoring Waiver:** Average four consecutive results below BM. Natural background. No further pollutant reductions are technologically available and economically practicable and achievable reduce to once per year.
Additional Sectors Covered (Not in EPA MSGP): N/A.	**Additional Sectors Covered (Not in EPA MSGP):** A coal loading facility (Sector AD).	**Additional Sectors Covered (Not in EPA MSGP):** Preproduction plastics facilities which manufacture, handle, or transport plastics including resin pellets and color powder material.	**Additional Sectors Covered (Not in EPA MSGP):** Small-scale composting facilities; public works and Department of Transportation garages; salt storage facilities.	**Additional Sectors Covered (Not in EPA MSGP):** school bus maintenance facilities; department of public works and highway maintenance facilities, hydrodemolition, and salt terminals.
Mandatory Baseline Monitoring for all Sectors: None.	**Mandatory Baseline Monitoring for all Sectors**: None.	**Mandatory Baseline Monitoring for all Sectors**: Total suspended solids (TSS), oil and grease, and pH.	**Mandatory Baseline Monitoring for all Sectors:** Chemical oxygen demand (COD), TSS, oil and grease, pH, total phosphorus, total nitrogen, nitrate, copper, lead, zinc.	**Mandatory Baseline Monitoring for all Sectors:** None.
Infiltration: Permittees may consider infiltration to minimize pollutants in stormwater discharge.	**Infiltration:** Permittees may consider infiltration to minimize pollutants in stormwater discharge.	**Infiltration:** Permittees may consider infiltration to minimize pollutants in stormwater discharge, with local municipal government approval.	**Infiltration:** Permittees may consider infiltration to minimize pollutants in stormwater discharge.	**Infiltration:** Permittees may consider infiltration to minimize pollutants in stormwater discharge.

EPA 2015	Minnesota 2015	Rhode Island 2013	Washington 2015	West Virginia 2014	Wisconsin 2017
BM monitoring for some sectors.	BM monitoring for all sectors.	BM monitoring for some sectors.	BM monitoring for some sectors	BM monitoring for some sectors.	Monitoring for some sectors. No benchmarks.
Frequency: Quarterly.	**Frequency:** Quarterly.	**Frequency:** Once every 6 months.	**Frequency:** Quarterly.	**Frequency:** Once per 6-month period (collected at least 3 months apart).	**Frequency**: Annual.
BM Monitoring Waiver: Average four consecutive results below BM. Natural background. No further pollutant reductions are technologically available and economically practicable and achievable reduce to once per year.	**BM Monitoring Waiver:** Average four consecutive results below BM. Natural background. Run-on entering from off site. Infiltration and ponding waiver.	**BM Monitoring Waiver:** Average four consecutive results below BM. Natural background. No further pollutant reductions are technologically available and economically practicable and achievable reduce to once per year.	**BM Monitoring Waiver:** Eight consecutive results below BM.	**BM Monitoring Waiver:** Average four consecutive results below BM.	**BM Monitoring Waiver:** Facility inactive or remote. Contamination off site and not associated with facility.
Additional Sectors Covered (Not in EPA MSGP): N/A.	**Additional Sectors Covered (Not in EPA MSGP):** None.	**Additional Sectors Covered (Not in EPA MSGP):** None.	**Additional Sectors Covered (Not in EPA MSGP):** Puget Sound Sediment Cleanup Sites.	**Additional Sectors Covered (Not in EPA MSGP):** Motorsports racing.complexes; shale mining only where the shale mined is not used in manufacturing; salt storage – limited to under 50,000 tons; transloading facilities.	**Additional Sectors Covered (Not in EPA MSGP):** None.
Mandatory Baseline Monitoring for all Sectors: None.	**Mandatory Baseline Monitoring for all Sectors:** TSS.	**Mandatory Baseline Monitoring for all Sectors**: None.	**Mandatory Baseline Monitoring for all Sectors:** Turbidity, oil sheen, pH, copper, and zinc.	**Mandatory Baseline Monitoring for all Sectors:** None.	**Mandatory Baseline Monitoring for all Sectors:** None.
Infiltration: Permittees may consider infiltration to minimize pollutants in stormwater discharge.	**Infiltration:** Specific requirements must be met where used for a BM monitoring waiver. Prohibits new/expanded infiltration at five subsectors based on risk to groundwater.	**Infiltration:** Permittees may consider infiltration to minimize pollutants in stormwater discharge.	**Infiltration:** Does not cover facilities who infiltrate all their stormwater.	**Infiltration:** All facilities must have a groundwater protection plan. Stormwater infiltration authorized unless considered significant sources of pollutants.	**Infiltration:** Stormwater infiltration excluded from permit coverage.

SOURCES

Alaska Department of Environmental Conservation. 2015. *Multi-sector general permit for storm water discharges associated with industrial stormwater (MSGP)*. General Permit No. AKR060000.

Ashton, W., Alaska DEC, personal communication, 2018.

Bertolacini, J., Wisconsin Department of Natural Resources, personal communication, 2018.

Burch, P., West Virginia Department of Environmental Protection, personal communication, 2018.

California Water Boards. 2018. *Preproduction plastics debris program*. CA Water Code, Division 7, Chapter 5.2, Section 13367.

Chatterton, M., Rhode Island Department of Environmental Management, personal communication, 2018.

Connecticut Department of Energy and Environmental Protection. 2016. *General permit or the discharge of stormwater associated with industrial activity*. DEEP-WPED-GP-014.

EPA. 2015. *United States Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) Multi-Sector general permit for stormwater discharges associated with industrial activity (MSGP)*. Available at: https://www.epa.gov/sites/production/files/2015-10/documents/msgp2015_finalpermit.pdf [Accessed November 1, 2018].

Gearheart, G., California State Water Resources Control Board, personal communication, 2018.

Hlavinka, P. Maryland Department of the Environment, personal communication, 2018.

Maryland Department of the Environment. *General permit for discharges from stormwater associated with industrial activities*. Discharge permit no. 12-SW, NPDES permit no. MDR0000.

Minnesota Pollution Control Agency. 2015. *National Pollutant Elimination System (NPDES)/state Disposal System (SDS) general permit MNR050000 for Industrial Stormwater Multi-Sector (ISW).* Authorization to discharge stormwater associated with industrial activity under the National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit program. Available at: https://www.pca.state.mn.us/sites/default/files/wq-strm3-67a.pdf [Accessed November 14, 2018].

Porter, T., Washington Department of Ecology, personal communication, 2018.

Rhode Island Department of Environmental Management. 2013. Multi-sector general permit Rhode Island pollutant discharge elimination system storm water discharge associated with industrial activity (excluding construction activity). RIR500000.

State of Washington Department of Ecology. 2014. *Industrial stormwater general permit: A National Pollutant Discharge Elimination System (NPDES) and state waste discharge general permit for stormwater discharges associated with industrial activities.*

State of West Virginia Department of Environmental Protection. 2014. *General National Pollution Discharge Elimination System water pollution control permit*. Permit no. WV0116025.

Stone, C., Connecticut Department of Energy and Environmental Protection, personal communication, 2018.

Walddrip, L., California State Water Resources Control Board, personal communication, 2018.

Wenzel, M., Minnesota Pollution Control Agency, personal communication, 2018.

Wisconsin Department of Natural Resources. *Chapter NR 216 stormwater discharge permits*. NR 216.002.

Appendix B

Lists of Pollutants from Which Industries Self-Identified the Need for Monitoring in the 1992 Group Applications, Adapted from EPA Form 2F, 1992

TABLE 2F-2 Conventional and Nonconventional Pollutants

Bromide
Chlorine
Total Residual Color
Fecal Coliform Fluoride Nitrate-Nitrite
Nitrogen
Total Organic Oil and Grease
Phosphorus, Total Radioactivity
Sulfate Sulfite Surfactants
Aluminum, Total Barium, Total
Boron, Total
Cobalt, Total
Iron, Total
Magnesium, Total
Molybdenum, Total
Manganese, Total
Tin, Total
Titanium, Total

TABLE 2F-3 Toxic Pollutants

	Toxic Pollutants and Total Phenol	
Antimony, Total	Copper, Total	Silver, Total
Arsenic, Total	Lead, Total	Thallium, Total
Beryllium, Total	Mercury, Total	Zinc, Total
Cadmium, Total	Nickel, Total	Cyanide, Total
Chromium, Total	Selenium, Total	Phenols, Total
	GC/MS Fraction Volatiles Compounds	
Acrolein	Dichlorobromomethane	1,1,2,2,-Tetrachloroethane
Acrylonitrile	1,1-Dichloroethane	Tetrachloroethylene
Benzene	1,2-Dichloroethane	Toluene
Bromoform	1,1-Dichloroethylene	1,2-Trans-Dichloroethylene
Carbon Tetrachloride	1,2-Dichloropropane	1,1,1-Trichloroethane
Chlorobenzene	1.3-Dichloropropylene	1,1,2-Trichloroethane
Chlorodibromomethane	Ethylbenzene	Trichloroethylene
Chloroethane	Methyl Bromide	Vinyl Chloride
2-Chloroethylvinyl Ether	Methyl Chloride	
Chloroform	Methylene Chloride	
	Acid Compounds	
2-Chlorophenol	2,4-Dinitrophenol	Pentachlorophenol
2,4-Dichlorophenol	2-Nitrophenol	Phenol
2,4-Dimethylphenol	4-Nitrophenol	2,4,6-Trichlorophenol
4,6-Dinitro-O-Cresol	p-Chloro-M-Cresol	2-Methyl-4,6 Dinitrophenol
	Base/Neutral	
Acenaphthene	2-Chloronaphthalene	Fluroranthene
Acenaphthylene	4-Chlorophenyl Phenyl Ether	Fluorene
Anthracene	Chrysene	Hexachlorobenzene
Benzidine	Dibenzo(a,h)anthracene	Hexachlorobutadiene
Benzo(a)anthracene	1,2-Dichlorobenzene	Hexachloroethane
Benzo(a)pyrene	1,3-Dichlorobenzene	Indeno(1,2,3-cd)pyrene
3,4-Benzofluoranthene	1,4-Dichlorobenzene	Isophorone
Benzo(ghi)perylene	3,3'-Dichlorobenzidine	Napthalene
Benzo(k)fluoranthene	Diethyl Phthalate	Nitrobenzene
Bis(2-chloroethoxy)methane	Dimethyl Phthalate	N-Nitrosodimethylamine
Bis(2-chloroethyl)ether	Di-N-Butyl Phthalate	N-Nitrosodi-N-Propylamine
Bis(2-chloroisopropyl)ether	2,4-Dinitrotoluene	N-Nitrosodiphenylamine
Bis(2-ethylyhexyl)phthalate	2,6-Dinitrotoluene	Phenanthrene
4-Bromophenyl Phenyl Ether	Di-N-Octyphthalate	Pyrene
Butylbenzyl Phthalate	1,2-Diphenylhydrazine (as Azobenzene)	1,2,4-Trichlorobenzene
	Pesticides	
Aldrin	Dieldrin	PCB-1254
Alpha-BHC	Alpha-Endosulfan	PCB-1221
Beta-BHC	Beta-Endosulfan	PCB-1232
Gamma-BHC	Endosulfan Sulfate	PCB-1248
Delta-BHC	Endrin	PGB-1260
Chlordane	Endrin Aldehyde	PCB-1016
4,4'-DDT	Heptachlor	Toxaphene
4,4'-DDE	Heptachlor Epoxide	
4,4'-DDD	PCB-1242	

TABLE 2F-4 Hazardous Substances

Toxic Pollutant

Asbestos

Hazardous Substances

Acetaldehyde	Dinitrobenzene	Napthenic acid
Allyl alcohol	Diquat	Nitrotoluene
Allyl chloride	Disulfoton	Parathion
Amyl acetate	Diuron	Phenolsulfonate
Aniline .	Epichlorohydrin	Phosgene
Benzonitrile	Ethion	Propargite
Benzyl chloride	Ethylene diamine	Propylene oxide
Butyl acetate	Ethylene dibromide	Pyrethrins
Butylamine	Formaldehyde	Quinoline
Carbaryl	Furfural	Resorcinol
Carbofuran	Guthion	Stronthium
Carbon disulfide	Isoprene	Strychnine
Chlorpyrifos	Isopropanolamine	Styrene
Coumaphos	Kelthane	2,4,5-Trichlorophenoxyacetic acid
Cresol	Kepone	Tetrachlorodiphenyl ethane
Crotonaldehyde	Malathion	2,4,5-TP [2-(2,4,5-Trichlorophenoxy) propanoic acid]
Cyclohexane	Mercaptodimethur	
2,4-D (2,4-Dichlorophenoxyacetic acid)	Methoxychlor	Trichlorofan
Diazinon	Methyl mercaptan	Triethylamine
Dicamba	Methyl methacrylate	Trimethylamine
Dichlobenil	Methyl parathion	Uranium
Dichlone	Mevinphos	Vanadium
2,2-Dichloropropionic acid	Mexacarbate	Vinyl acetate
Dichlorvos	Monoethyl amine	Xylene
Diethyl amine	Monomethyl amine	Xylenol
Dimethyl amine	Naled	Zirconium

Appendix C

Monitoring Parameters Required in Environmental Protection Agency 2015 Multi-Sector General Permit

Parameter	Sectors	Benchmark	ELG
Alpha Terpineol	Hazardous Waste (K), Landfills (L)		0.033-0.042 mg/L, daily maximum; 0.016-0.019 mg/L, monthly avg. maximum
Ammonia	Hazardous Waste (K, K1), Vehicle Maintenance Areas and Airports (S); Landfills (L)	2.14 mg/L (S)	10 mg/L, daily maximum; 4.9 mg/L, monthly avg. maximum (K, L); 14.7 mg/L as N, daily maximum (S)
Aniline	Hazardous Waste (K),		0.024 mg/L, daily maximum; 0.015 mg/L, monthly avg. maximum
Benzoic Acid	Hazardous Waste (K), Landfills (L)		0.119-0.12 mg/L, daily maximum; 0.071-0.073 mg/L, monthly avg. maximum
Biochemical Oxygen Demand (BOD5)	Hazardous Waste (K); Landfills (L); Food (U2), Vehicle Maintenance Areas, Air Transportation Facilities (S)	30 mg/L (S, U2)	140-220 mg/L, daily maximum; 37-56 mg/L, monthly avg. maximum (K, L)
Chemical Oxygen Demand (COD)	Paper (B1), Timber (A1), Food (U2), Hazardous Waste (K1), Metal Mining (G1), Scrap and Waste Recycling (N1), Timber (A4), Vehicle Maintenance Areas, Air Transportation Facilities (S)	120 mg/L	
Fluoride	Chemical and Allied Products (C)		75.0 mg/L, daily maximum; 25.0 mg/L, 30-day avg.
Napthalene	Hazardous Waste Treatment (K)		0.059 mg/L, daily maximum; 0.022 mg/L, monthly avg. maximum
Nitrate plus Nitrite Nitrogen	Chemical and Allied Products (C1, C2, C3), Fabricated Metals (AA1), Food (U2), Metal Mining (G1), Mineral Mining (J1)	0.68 mg/L	

Parameter	Sectors	Benchmark	ELG
Oil and grease	Asphalt Paving and Roofing (D)		15.0 mg/L, daily maximum; 10 mg/L, 30-day average
p-Cresol	Hazardous Waste Treatment (K); Landfills (L)		0.024-0.025 mg/L, daily maximum; 0.014-0.015 mg/L, monthly avg. maximum
pH	Metal Mining (G2), Vehicle Maintenance or Deicing at Air Transportation Facilities (S) Asphalt Paving (D), Grass, Clay, Cement, Concrete, and Gypsum (E), Hazardous Waste (K),Landfills (L), Mineral Mining (J), Electric Power (O), Timber (A)	6.0-9.0 s.u. (G2, S)	6.0-9.0 s.u. (D, E, K, L, J, O, A)
Phenol	Hazardous Waste Treatment (K); Landfills and Land Application Sites (L)		0.026-0.048 mg/L, daily maximum; 0.015-0.029 mg/L, monthly avg. maximum
Phosphorous	Chemical and Allied Products (C1)	2.0 g/L	
Pyridine	Hazardous Waste Treatment (K)		0.072 mg/L, daily maximum; 0.025 mg/L, monthly avg. maximum
Total Aluminum	Automobile Salvage Yards (M1), Chemical and Allied Products (C2), Coal Mines (H1), Fabricated Metals (AA1), Glass, Clay, Cement, Concrete, and Gypsum (E1), Primary Metals (F1, F2), Water Transportation Facilities (Q1), Scrap Recycling (N1)	0.75 mg/L	
Total Antimony	Metal Mining (G2)	0.64 mg/L	
Total Arsenic	Hazardous Waste Treatment (K, K1); Metal Mining (G2), Timber (A2)	FW: 0.15 mg/L (K1, G2, A2) SW: 0.069 mg/L (K1, G2, A2)	1.1 mg/L, daily maximum; 0.54 mg/L, monthly average maximum (K)
Total Beryllium	Metal Mining (G2)	0.13 mg/L	
Total Cadmium	Hazardous Waste Treatment (K1), Metal Mining (G2)	SW: 0.04 mg/L FW: hardness dep. (0.0005 to 0.0053 mg/L)	
Total Chromium	Hazardous Waste Treatment (K)		1.1 mg/L, daily maximum; 0.46 mg/L, monthly avg. maximum

Parameter	Sectors	Benchmark	ELG
Total Copper	Metal Mining (G2), Primary Metals (F2, F3, F4), Scrap Recycling and Waste Recycling (N1), Timber (A2)	SW: 0.0048 mg/L FW: hardness dep. (0.0038 to 0.0332 mg/L)	
Total Cyanide	Hazardous Waste Treatment (K1)	FW: 0.022 mg/L SW: 0.001 mg/L	
Total Iron	Automobile Salvage Yards (M1), Chemical and Allied Products (C1, C2), Coal Mines (H1), Fabricated Metals (AA1), Glass, Clay, Cement, Concrete, and Gypsum (E2), Landfills (L2), Metal Mining (G2), Scrap Recycling and Waste Recycling (N1), Primary Metals (F2), Electric Power (O1), Water Transport Facilities (Q1)	1.0 mg/L	
Total Lead	Automobile Salvage Yards (M1), Chemical and Allied Products (C1), Hazardous Waste (K1), Metal Mining (G2), Scrap Recycling (N1), Water Transportation Facilities (Q1)	FW: hardness dep. (0.014 to 0.262) SW: 0.21 mg/L	
Total Magnesium	Hazardous Waste Treatment (K1)	0.064 mg/L	
Total Mercury	Hazardous Waste Treatment (K1), Metal Mining (G2)	FW: 0.0014 mg/L SW: 0.0018 mg/L	
Total Nickel	Metal Mining (G2)	FW: hardness dep. (0.15 to 1.02 mg/L) SW: 0.074 mg/L	
Total Phosphorous	Chemical and Allied Products (C)		105.0 mg.L, daily maximum; 35 mg/L, 30-day avg.
Total Selenium	Hazardous Waste Treatment (K1), Metal Mining (G2)	FW: 0.005 mg/L SW: 0.29 mg/L	
Total Silver	Hazardous Waste Treatment (K1), Metal Mining (G2)	FW: hardness dep. (0.0007 to 0.0183 mg/L) SW: 0.0019 mg/L	
Total Suspended Solids (TSS)	Timber (A); Asphalt Paving and Roofing (D), Glass, Clay, Cement, Concrete, and Gypsum (E), Primary Metals (F2), Metal Mining (G1, G2), Coal Mines (H1), Mineral Mining (J1, J2), Hazardous Waste Treatment (K), Landfills and Land Application Sites (L); Automobile Salvage Yards (M1), Scrap Recycling and Waste Recycling (N1), Steam Electric Power (O), Food (U1, U2)	100 mg/L (A, D1, E2, F2, G, H1, J, M1,N1, U)	23.0-88 mg/L, daily maximum; 15.0-50 mg/L, 30-day avg. (D, E, K, L, O J)

Parameter	Sectors	Benchmark	ELG
Total Zinc	Hazardous Waste Treatment (K); Landfills and Land Application Sites (L) Timber (A1), Chemical and Allied Products (C1, C3, C4), Fabricated Metals (AA1),Metal Mining (G2), Primary Metals (F1, F2, F3, F4), Scrap Recycling and Waste Recycling (N1), Water Transportation Facilities (Q1), (Y1)	FW: hardness dep. (0.04 to 0.26 mg/L) SW: 0.09 mg/L (A1, C, AA1, G2, F, N1, Q1, Y1)	0.20-0.535 mg/L, daily maximum; 0.11-0.296 mg/L, monthly avg. maximum (K,L)
Turbidity	Metal Mining (G2)	50 NTU	
Woody Debris	Timber (A)		None > 1 in.

Appendix D

2015 Multi-Sector General Permit (MSGP) Data Analysis

The committee obtained MSGP monitoring data that have been reported in the Environmental Protection Agency (EPA) Network Discharge Monitoring Report (NetDMR) database in response to the monitoring and reporting requirements of the 2015 MSGP (see Table 1-1). Stormwater samples are collected by the permittees at stormwater outfalls. An individual facility may have multiple outfalls at a site at which samples are collected. The samples are analyzed for sector-specific pollutants and any additional local requirements, typically by contract analytical laboratories, and the results are reported by the permittee using NetDMR. Permittees certify the data to be accurate and maintain laboratory reports on file, which are available for review upon request and during site inspections. In addition to MSGP benchmark monitoring, local monitoring requirements are often prescribed to inform compliance with effluent limitation guidelines, local or state regulations, or development or implementation of total maximum daily loads (TMDLs; labeled "required monitoring" in the database). The committee analyzed the data to assess the general extent to which individual reported results were above the benchmarks and whether there are sectors or subsectors that have a large percentage of facilities for which individual reported results exceed benchmark threshold values. The results of this data analysis are presented in this Appendix through a series of graphs and tables of descriptive statistics, organized by pollutant. Summary tables are provided in Chapter 2.

The data obtained from EPA represented sites that were required under the 2015 MSGP to report their compliance information to the NetDMR database. The period of record for reported results was from mid 2015 through February 13, 2018. The data include more than 17,000 reported results from MSGP sites in the four states where EPA has primacy for the regulations (Idaho, Massachusetts, New Hampshire, and New Mexico), the District of Columbia, all U.S. territories, Indian country, and some federal facilities throughout the United States. The data analyzed by the committee are available upon request to the National Academies Public Access Records Office.

ANALYSIS METHODOLOGY

The outfall monitoring data were analyzed by pollutant and sector or subsector (see Table D-1 for sector classifications). Standard industrial classification (SIC) codes were used to identify the appropriate sector or subsector for each data point. Where SIC codes were lacking, other identifying information (e.g., "primary permit SIC description") was used to identify the appropriate sector or subsector. One SIC code (1021, copper ores) fell under both G1 and G2 and in these circumstances, the code was assigned G1.

All results reported in the NetDMR database and delivered to the committee were used in the analysis, unless key data or identifying information was lacking. Where reported results lacked SIC codes and the sector could not be determined through other identifying information, those results were excluded from the analysis. Results were also excluded in cases where no units were provided and where the units associated with the result could not be reasonably determined. The number of these excluded reported results are noted as footnotes to the tables that follow. The committee excluded a few reported results that were several orders of magnitude below known detection limits based on the current capabilities of chemical analysis. These exclusions are described in the pollutant-specific descriptions that follow. No high reported results were excluded because although some of the results appear suspect, it was not possible to associate the result with a reporting error with a high level of confidence. There could be additional reporting errors that are masked by the wide range of reported results.

The reported results for each pollutant were converted to consistent units (e.g., mg/L, µg/L), based on Table 1-3. In the analysis, results that were labeled as "less than" a specific value (e.g., some form of analytical detection limit) are analyzed as the value reported. Therefore, "less than 0.01 µg/L" becomes 0.01 µg/L for this analysis. In some cases the "less than" values reported were higher than the benchmark. For example among the silver data reported, four of the reported results were higher than the hardness-specific benchmark (including <20 µg/L and <25 µg/L). For the purposes of this analysis, those results were analyzed and graphed as the value reported. Occurrences of "less than" values exceeding benchmarks are noted in footnotes in the tables where they occur. Similar to the "less than" values, for the few reported values where the data were labeled as "greater than," the value used in the analysis was the value reported, which may represent the upper limit of detection or a reporting error.

The committee performed several levels of verification on this analysis. Three committee members helped review the methodology, and this Appendix was reviewed by staff from the National Academies' Committee on National Statistics and one independent reviewer. The spreadsheets containing the calculations were reviewed in detail by National Academies' staff to check for errors. A few minor errors were detected that were discussed with the committee and subsequently corrected.

In the tables that follow, descriptive statistics are presented for all sectors and subsectors with at least one reported value (statistics generated from Excel), including

- The number of reported values,
- The minimum and maximum (e.g., the range of concentrations observed),
- The median (to highlight the center value of the data), and
- The 75th percentile to show a relatively common upper concentration.

The data were also analyzed by subsector to calculate the percentage of individual reported results that were below the benchmark limit (or four or eight times the benchmark; consistent with suggested Additional Implementation Measure [AIM] thresholds; see Box 1-3). The data were not processed to determine whether data exceeding benchmarks warranted corrective action in accordance with the permit, because that determination is based on the average of four quarterly monitoring values. For pollutants with a benchmark threshold not dependent on hardness, all reported results were analyzed. This includes data (flagged "required monitoring" in the database) that may have been reported for other reasons, such as TMDLs. For the six metals where the benchmark threshold is dependent on receiving water hardness (cadmium, copper, lead, nickel, silver, and zinc), the reported results were compared to the facility-specific hardness-based benchmark entered into the database. Reported results flagged as "required monitoring" that lacked information on a hardness-based benchmark or permit limit or sufficient receiving water quality information to determine the appropriate benchmark were excluded from the analysis. The number of excluded reported results is noted in a footnote to each pollutant with hardness-dependent benchmarks.

The box-plot figures that follow illustrate the 25th, 50th, and 75th percentiles of the data, with the whiskers identifying the 10th and 90th percentiles. Data points outside of the 10th and 90th percentiles are shown as individual data points. Graphs for each pollutant only include sectors with at least eight reported results. Fewer than eight reported results were considered to be too few to provide a reasonable graphical representation of the data range and where the data were primarily centered. For pollutants with a single benchmark, the benchmark value as well as four and eight times the benchmark are plotted for ease of comparison. For the six metals where each sample benchmark is based on the receiving water hardness (cadmium, copper, lead, nickel, silver, and zinc), two benchmarks (plus eight times the benchmark) are presented for comparison based on generic hardness values—one representing a soft water (60 mg/L as $CaCO_3$) and the other representing a hard water (200 mg/L $CaCO_3$). The graphs include "required monitoring" reported results that were not included in the comparison against hardness-related benchmarks.

ANALYSIS LIMITATIONS

The data set has the following limitations. No information is known about the elements of the stormwater pollution prevention plan, including whether structural stormwater control measures were operating on site (and if so, whether those were designed or maintained appropriately) or whether the stormwater quality was managed using nonstructural activities, such as good housekeeping and site sweeping. In addition, no information is provided in the database on the hydrological characteristics of the site or the storm event, such as rainfall intensity or drainage area.

In addition, it was apparent that the data set contained some errors related to reporting. For example, one reported concentration for copper was in the range of 10^{-7} μg/L, which is not achievable given current detection limits for instrumentation. Some very low or high concentrations may have been the result of unit conversion errors.

The data represent more than 2 years of data collection, including the early part of the MSGP permit when all permittees are required to monitor and sample outfalls quarterly, at a minimum. If the average of four quarterly monitoring results meets the benchmark, those permittees are allowed to discontinue monitoring for the remainder of the permit cycle. Those that did not meet the benchmark continued to sample for an additional year. Therefore, the results are likely to be biased toward the higher concentrations, based on those permittees that had to collect additional samples. Therefore, the data should not be used to determine the percentage of permittees that had data exceeding benchmarks. The committee chose to analyze this longer data set rather than only the first year of reported results to capture more storms, given inherent variability in stormwater quality (see Chapter 3). A primary objective of the analysis was to identify sectors and pollutants with recurrent benchmark exceedances, and longer periods of reported results were helpful in this regard. For this 2-plus-year period, the effect would be less than it would be in past MSGP data analyses, which included data over either only year 2 or 4 of the permit (Harcum et al., 2005) or up to 4 years of the permit (EPA, 2012).

TABLE D-1 Industrial Sectors and Subsectors

Subsector	Subsector Detail
A1	General sawmills and planing mills
A2	Wood preserving
A3	Log storage and handling
A4	Hardwood and wood product facilities; sawmills
B1	Paperboard mills
B2	Pulp and paper mills
C1	Agricultural chemicals
C2	Industrial inorganic chemicals
C3	Soaps, detergents, cosmetics, and perfumes
C4	Plastics, synthetics, and resins
C5	Industrial organic chemicals, paints, lacquers, pharmaceuticals
D1	Asphalt paving and roofing materials
D2	Miscellaneous products of petroleum and coal
E1	Clay product manufacturers
E2	Concrete and gypsum product manufacturers
E3	Glass and stone products
F1	Steel works, blast furnaces, and rolling and finishing mills
F2	Iron and steel foundries
F3	Rolling, drawing, and extruding of nonferrous metals
F4	Nonferrous foundries
F5	Smelting and refining of nonferrous metals, miscellaneous primary metal products
G1	Active copper ore mining and dressing facilities
G2	Active metal mining facilities
H	Coal mines and related areas
I	Oil and gas extraction facilities
J1	Sand and gravel mining
J2	Mining of dimension and crushed stone and nonmetallic minerals
J3	Clay, chemical, and fertilizer mineral mining
K1	Hazardous waste treatment storage, or disposal facilities
L1	Landfills, land application sites, and open dumps
L2	L1 except municipal solid waste landfill areas closed
M	Automobile salvage yards
N1	Scrap recycling and waste recycling facilities
N2	Source separated recycling facilities
O	Steam electric generating facilities
P	Motor freight transportation facilities

Subsector	Subsector Detail
Q	Water transportation facilities
R	Ship and boat building or repair yards
S	Airports
T	Treatment works
U1	Grain mill products
U2	Fats and oils products
U3	Meat, dairy, and other food products and beverages
V	Textile mills, apparel, and other fabric products
W	Furniture and fixture manufacturing facilities
X	Printing and publishing facilities
Y1	Rubber products manufacturing
Y2	Miscellaneous plastic products and manufacturing industries
Z	Leather tanning and finishing facilities
AA1	Fabricated metal products, except coating
AA2	Fabricated metal coating and engraving
AB	Transportation equipment, industrial, or commercial machinery manufacturing facilities
AC	Electronic and electrical equipment and components, photographic, and optical goods manufacturing facilities

ANALYSIS RESULTS

The following sections summarize the 2015 MSGP reported results for individual pollutants, sorted by sector or subsector. Some of the pollutants (e.g., antimony, cadmium, cyanide, nickel, mercury, selenium) had a relatively small data set, and some of the subsectors only represent a single facility. The largest data sets include aluminum, copper, iron, lead, total suspended solids (TSS), and zinc. The results are summarized in Chapter 2 and in Tables 2-3 and 2-4.

Aluminum

Figure D-1 shows the NetDMR 2015 MSGP data for aluminum. For most sectors where aluminum was measured, the benchmark (750 µg/L) was achieved by at least 50 percent of the reported results. The exception was Sector H (coal mines and coal–mine-related facilities), which had no reported results that met the benchmark and for which most reported results exceeded a value eight times the benchmark. Among the sectors with at least eight reported results, Sectors N (scrap recycling), P (motor freight transportation), Q (water transportation facilities), and R (ship building) all had frequent individual results that exceeded the benchmark (>35 percent) and many (7–13 percent) had very high values reported. The complete data set is summarized in Table D-2.

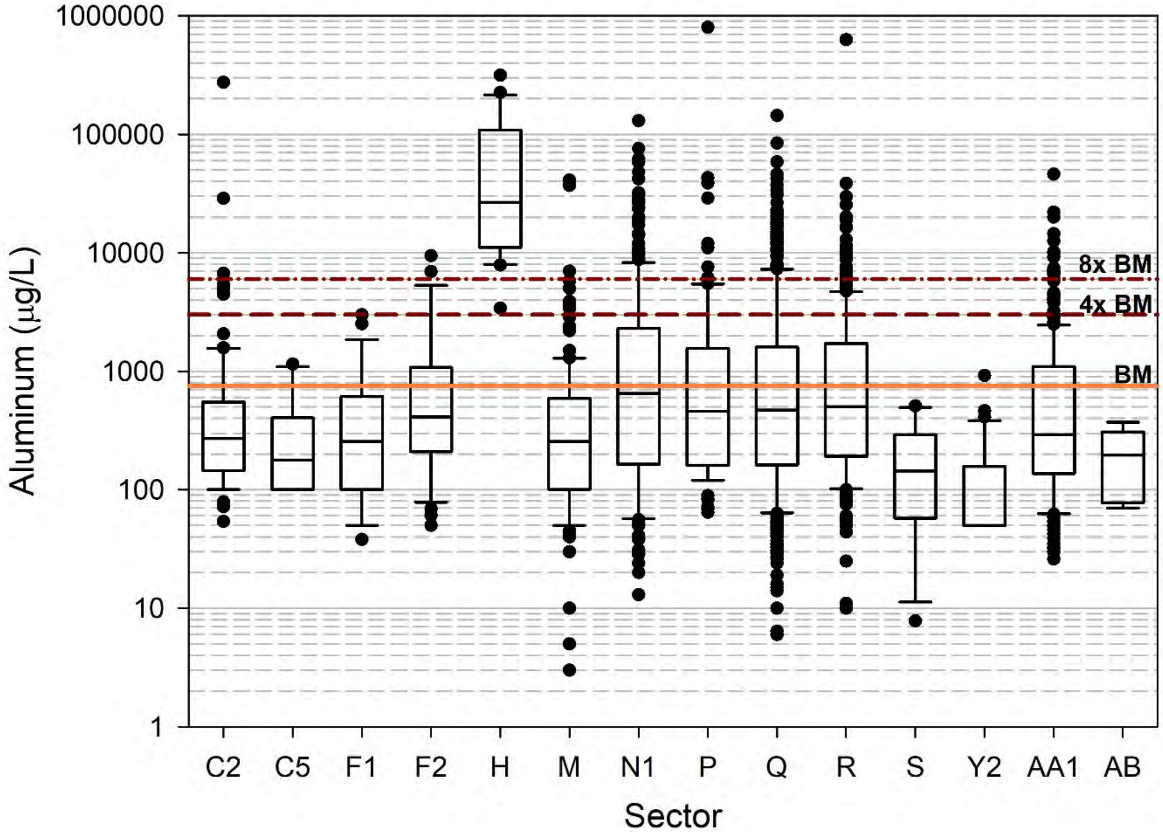

FIGURE D-1 Aluminum results from NetDMR 2015 MSGP reported results through February 2018. Orange line denotes benchmark of 750 µg/L.

TABLE D-2 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Aluminum

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C2	89	5	54	274000	270	540	19	7	3
C5	10	2	<100	1150	178	310	10	0	0
D1	2	1	70	120	95	108	0	0	0
E2	2	1	1900	2100	2000	2050	100	0	0
F1	31	2	38	3000	255	571	23	0	0
F2	52	4	<50	9470	412	1080	27	12	8
F3	6	2	37	270	50	73	0	0	0
H	22	3	3410	315000	26700	99975	100	100	95
J2	1	1	80	80	80	80	0	0	0
M	190	39	3	41000	255	588	18	5	2
N1	318	53	13	130000	649	2290	46	21	13
O	2	1	<100	100	100	100	0	0	0
P	91	10	64	800000	460	1450	38	15	9
Q	577	66	<6	144000	470	1600	38	17	12
R	335	37	10	628000	500	1670	38	16	7
S	10	2	7.8	509	144	261	0	0	0
T	3	1	130	810	310	560	33	0	0
U3	2	1	690	9670	5180	7425	50	50	50
V	4	2	<50	2320	1397	1646	75	0	0
Y2	36	3	<50	920	50	153	3	0	0
AA1	387	35	26	46100	292	1100	30	8	4
AB	8	1	70	370	195	263	0	0	0

NOTE: Twenty-seven reported results were not included because they did not have units or the sector/subsector could not be identified (9 without units, 18 without sector/subsector information).

Ammonia

Figure D-2 highlights the NetDMR 2015 MSGP data for ammonia. In general, most reported results met the benchmark (2.14 mg N/L). The complete data set is summarized in Table D-3.

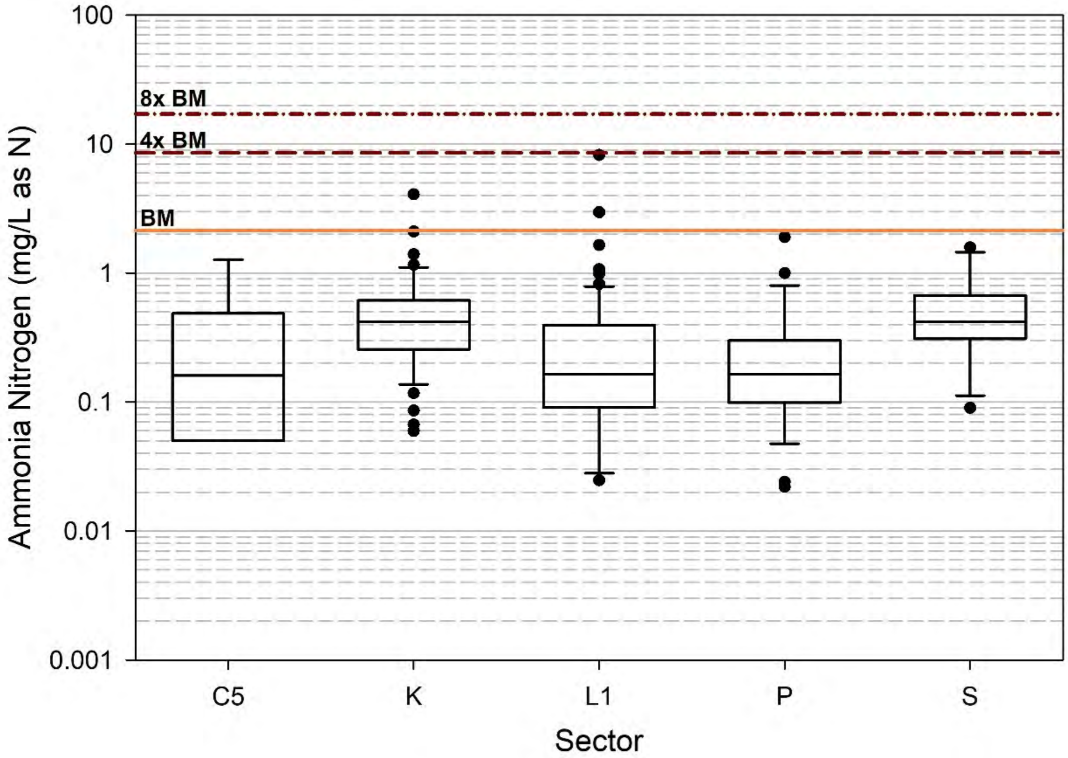

FIGURE D-2 Ammonia results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 2.14 mg N/L.

TABLE D-3 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Ammonia

	No. Reported Results	No. Facilities	Min. (mg/L)	Max. (mg/L)	Median (mg/L)	75th Percentile (mg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C5	8	2	<0.05	1.3	0.16	0.28	0	0	0
K	78	7	0.06	<1000	0.42	0.61	3[a]	1[a]	1[a]
L1	81	14	0.02	8.2	0.16	0.34	4	0	0
L2	1	1	0.04	0.04	0.04	0.04	0	0	0
N1	2	2	0.10	0.75	0.42	0.59	0	0	0
P	38	8	0.02	1.9	0.16	0.29	0	0	0
Q	4	1	0.10	0.45	0.24	0.39	0	0	0
S	11	2	0.09	1.6	0.42	0.66	0	0	0
AA1	2	1	0.05	3.5	1.8	2.6	50	0	0
AC	4	1	0.11	1.1	0.17	0.43	0	0	0

[a] Includes one reported result with reported detection limit exceeding the benchmark (2.14 mg N/L).
NOTE: Four reported results were not included because the sector/subsector could not be identified.

Antimony

Data were reported for antimony for only two sectors and the data were not graphed because there were fewer than eight reported results for each. Table D-4 shows the results for the limited results reported for Sectors G1 and G2, metal mining (ore mining and dressing), both of which were able to meet the benchmark (640 µg/L).

TABLE D-4 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Antimony

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
G1	2	1	<7.5	<20	<14	<17	0	0	0
G2	4	2	<20	<500	<260	<500	0	0	0

Arsenic

Figure D-3 shows the NetDMR 2015 MSGP data for arsenic. For all sectors where arsenic was measured and a sufficient number of reported results were in the database to allow graphing, the freshwater benchmark (150 µg/L) was achieved by greater than 75 percent of the reported data. Sectors K (hazardous waste facilities) and P (motor freight transportation) had one result and two results, respectively, that did not meet the benchmark. The complete data set is summarized in Table D-5.

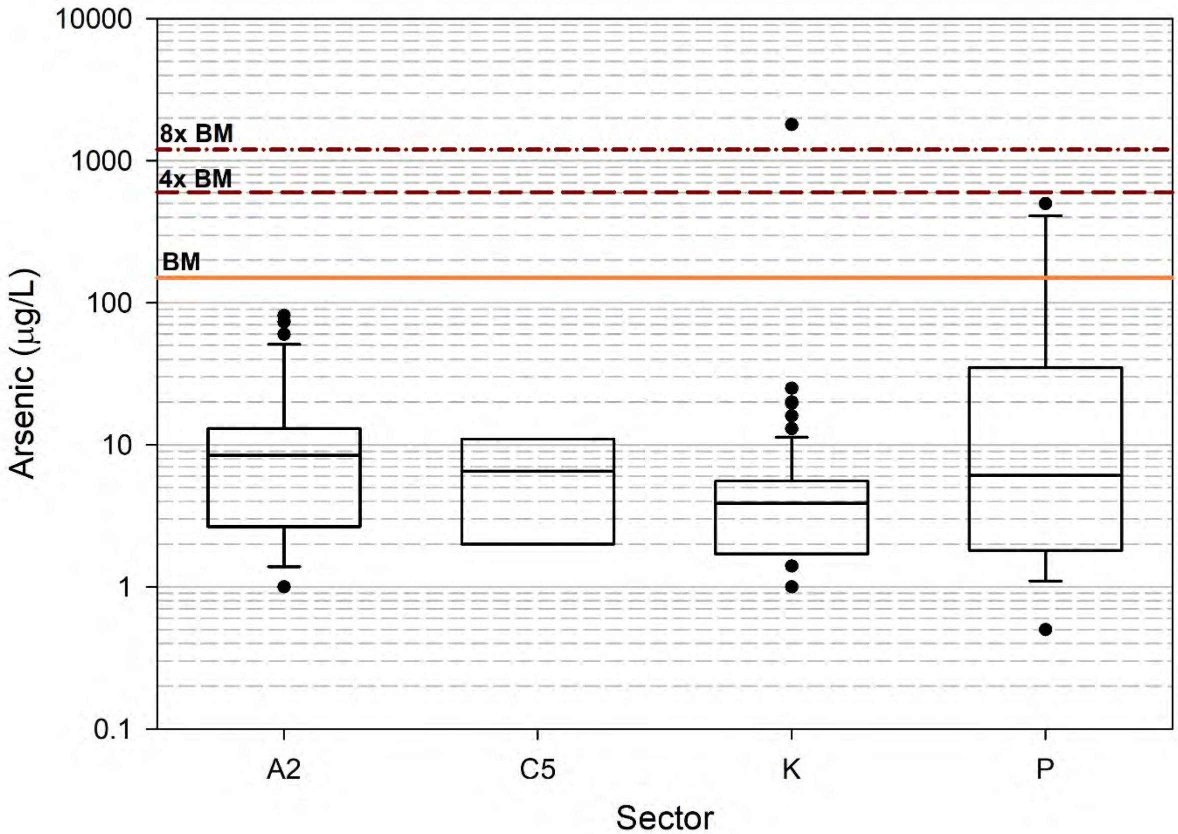

FIGURE D-3 Arsenic results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 150 µg/L.

TABLE D-5 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Arsenic

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A2	34	3	<1	81.5	8.5	13	0	0	0
C3	4	1	<10	<10	<10	<10	0	0	0
C5	8	2	<2	<11	<6.5	<11	0	0	0
G1	4	1	<25	<25	<25	<25	0	0	0
G2	4	2	<25	<40	<32.5	<40	0	0	0
K1	88	7	<1	1800	3.9	5.5	1	1	1
N1	1	1	<5	<5	<5	<5	0	0	0
O	3	1	<5	18	<5	12	0	0	0
P	21	8	0.5	<500	6.1	20	10[a]	0	0
R	5	1	<1	14	1.4	1.9	0	0	0
AA1	3	1	0.22	2.5	0.69	1.6	0	0	0
AC	2	1	<5	6	5.5	5.8	0	0	0

[a] All exceedances were for reported results that had stated detection limits above the benchmark (150 µg/L).

Beryllium

Data were reported for beryllium for only Sectors G1 and G2, metal mining (ore mining and dressing), and were not graphed because there were fewer than eight reported results for each. Table D-6 shows the limited results for the data reported, which were able to meet the benchmark of 130 μg/L.

TABLE D-6 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Beryllium

	No. Reported Results	No. Facilities	Min. (μg/L)	Max. (μg/L)	Median (μg/L)	75th Percentile (μg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
G1	1	1	<2	<2	<2	<2	0	0	0
G2	4	2	<2	<100	<51	<100	0	0	0

Biochemical Oxygen Demand (BOD_5)

Figure D-4 highlights the NetDMR 2015 MSGP data for BOD_5. Of the three sectors with at least eight reported results, most of the data met the benchmark of 30 mg/L for Sectors L1 (landfills) and P (motor freight transportation facilities), but 44 percent of reported results in Sector S (airports) were not able to meet the benchmark. The complete data set is summarized in Table D-7.

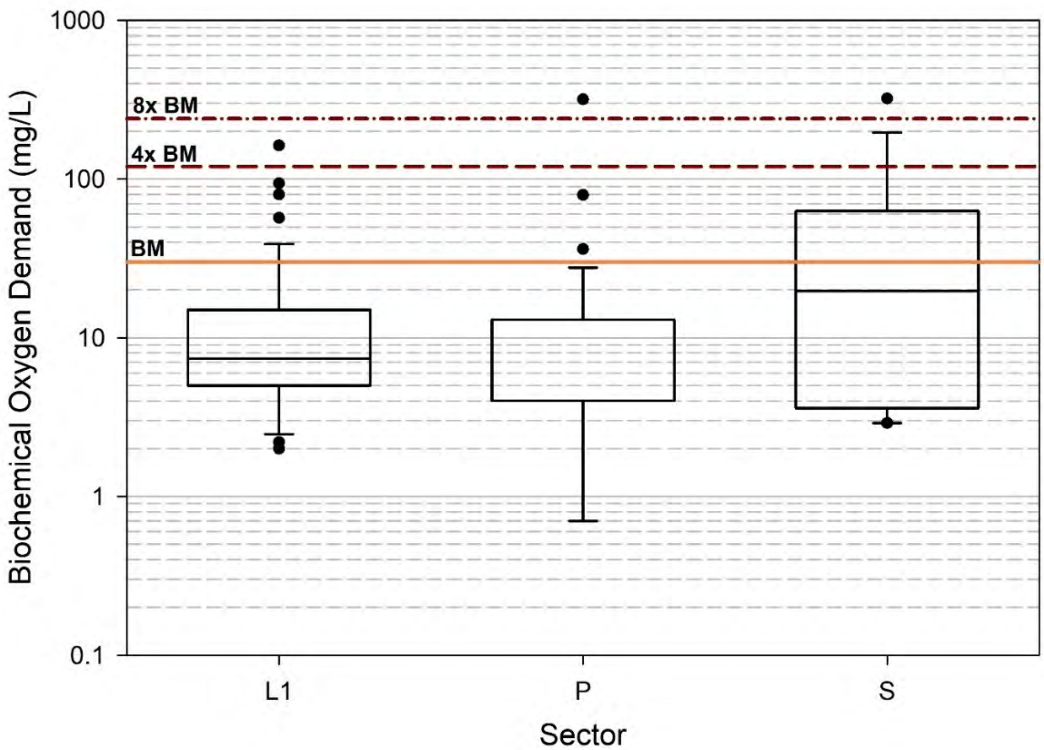

FIGURE D-4 Five-day biochemical oxygen demand (BOD5) results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 30 mg/L.

TABLE D-7 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for BOD_5

	No. Reported Results	No. Facilities	Min. (mg/L)	Max. (mg/L)	Median (mg/L)	75th Percentile (mg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
L1	68	12	<2	163	7.4	15	13	1	0
L2	1	1	78	78	78	78	100	0	0
N1	1	1	9	9	9	9	0	0	0
P	36	4	<0.0015	318	4	13	8	3	3
Q	1	1	13	13	13	13	0	0	0
S	18	2	2.9	322	20	61	44	11	6

Cadmium

Figure D-5 highlights the NetDMR 2015 MSGP data for cadmium. The cadmium benchmark value is determined by the hardness in the receiving water (see Analysis Methodology). For the graphs, two cadmium benchmark values are presented—one representing soft water (60 mg/L as $CaCO_3$; 1.3 μg/L Cd) and one representing hard water (200 mg/L as $CaCO_3$; 4.5 μg/L Cd), although these are presented for visualization purposes only. Benchmarks are based on site-specific hardness values. Of the sectors with at least eight reported results, only Sector K (hazardous waste facilities) exhibited benchmark exceedances (14 percent of reported results).

The figure and the descriptive statistics in Table D-8 include data collected for required monitoring that did not include hardness-specific benchmarks. Data entries without a hardness-specific benchmark were not included for the evaluation of the percentage of reported results that met benchmark thresholds.

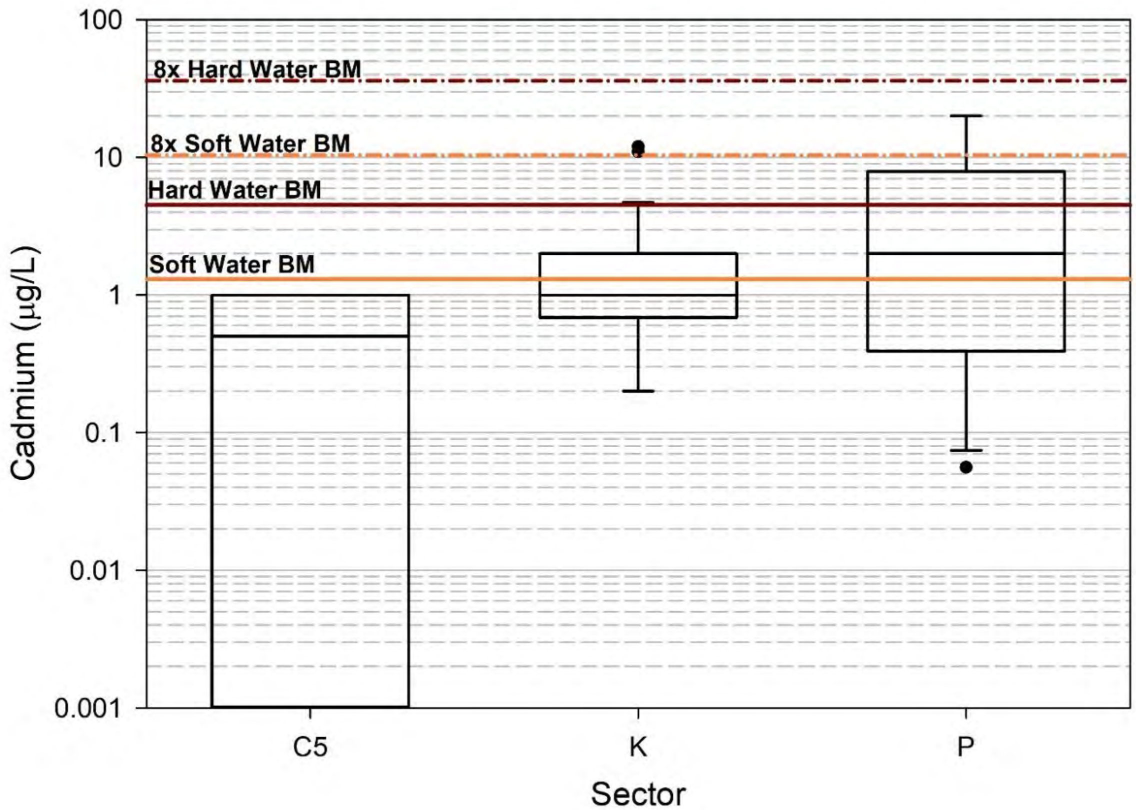

FIGURE D-5 Cadmium results from NetDMR 2015 MSGP reported data through February 2018. Orange lines denote the soft-water benchmark of 1.3 µg/L and hard-water benchmark of 4.5 µg/L, although benchmark compliance is assessed based on site-specific water quality data.

TABLE D-8 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Cadmium

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C5	8	2	0.001	1	0.50	1	0	0	0
G1	2	1	2	2	2	2	0	0	0
G2	5	2	0.1	0.44	0.44	0.44	0	0	0
K	26	5	0.2	12	1	2	14[a]	7	0
N1	7	2	0.5	41	1	4.4	NA	NA	NA
O	2	1	5	5	5	5.0	NA	NA	NA
P	10	4	0.056	20	2	3.4	0	0	0
T	4	1	2	10	3.5	6.3	25[a]	0	0
AA1	3	1	0.00047	2.9	0.23	1.6	0	0	0

[a] Includes one reported result with stated detection limit exceeding the benchmark.
NOTE: NA, required monitoring for purpose other than MSGP benchmark compliance; no regulatory limit established for those sites.
Fifteen reported results were excluded from the hardness analysis because no regulatory limit was established for these sites. In addition to the sectors noted with NA above, the following were excluded from the analysis (the number of data points in parentheses): G2(1), P(5).

Chemical Oxygen Demand (COD)

Figure D-6 highlights the NetDMR 2015 MSGP data for COD. Only Sector A2 (wood preserving) was unable to meet the COD benchmark of 120 mg/L for at least 50 percent of the reported results. The complete data set is summarized in Table D-9. Sectors A2, A4 (hardwood, sawmills), N1 (scrap recycling), and S (airports) reported 5 percent or more of data points in excess of four times the benchmark.

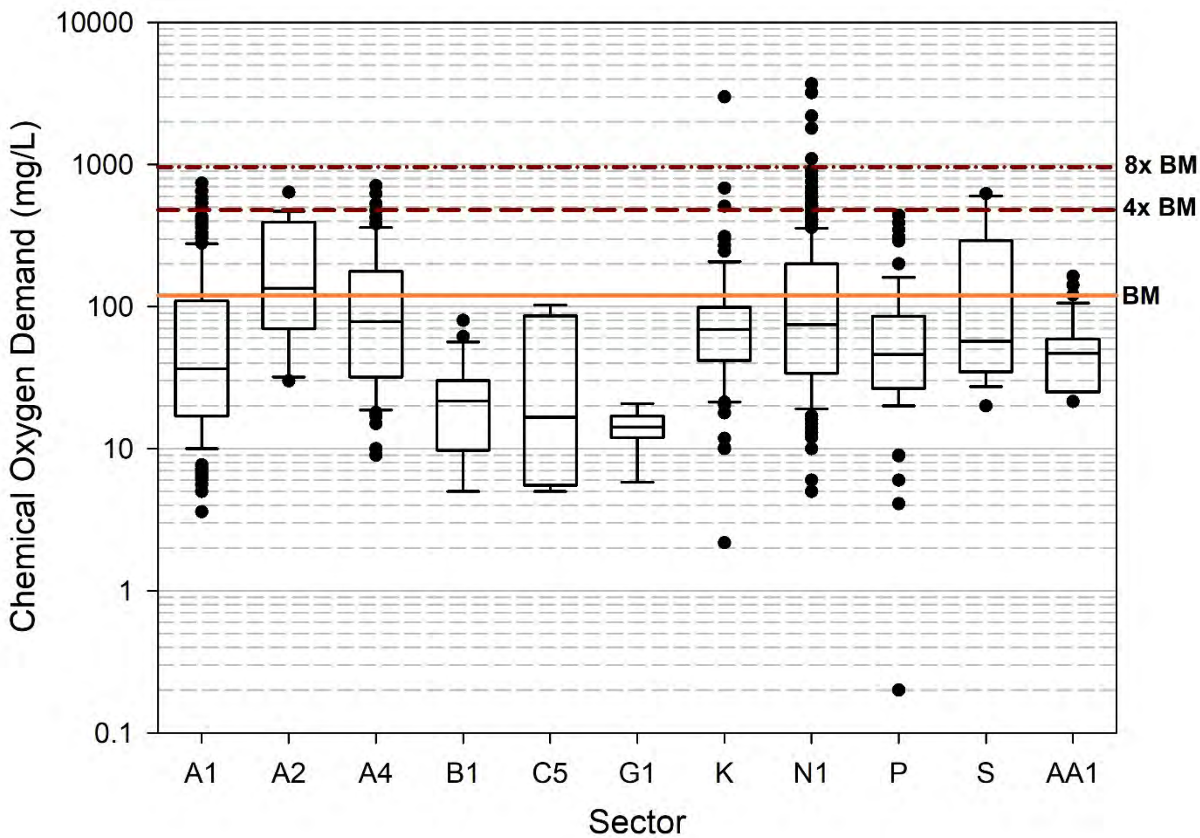

FIGURE D-6 Chemical oxygen demand (COD) results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 120 mg/L.

TABLE D-9 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for COD

	No. Reported Results	No. Facilities	Min. (mg/L)	Max. (mg/L)	Median (mg/L)	75th Percentile (mg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A1	220	28	3.6	740	37	109	21	2	0
A2	19	1	30	640	135	337	58	5	0
A4	66	9	9	711	79	176	36	5	0
B1	22	1	<5	80	22	29	0	0	0
C5	8	2	<5	103	17	66	0	0	0
G1	8	1	5.8	21	14	16	0	0	0
K	88	8	2.2	3,000	69	99	19	3	1
M	6	2	22	150	78	122	33	0	0
N1	303	52	<5	3,700	75	198	36	7	2
P	66	6	0.2	440	46	85	15	0	0
Q	4	2	14	147	23	56	25	0	0
S	18	3	20	625	57	240	33	11	0
AA1	36	2	22	164	47	59	8	0	0

NOTE: Eighteen reported results were not included because they did not have units.

Copper

Figure D-7 highlights the NetDMR 2015 MSGP data for copper. The copper benchmark value is determined by the hardness in the receiving water. For the graphs, two copper benchmark values are presented—one representing soft water (60 mg/L as $CaCO_3$; 9 μg/L) and one representing hard water (200 mg/L as $CaCO_3$; 28.5 μg/L). Two reported results were deleted from the analysis since their reported values were several orders of magnitude below the expected detection limit for copper. Of the sectors that had at least eight reported results, many sectors (A2 [wood preserving], F2 [iron and steel foundries], F4 [nonferrous foundries], M [auto salvage], N1 [scrap recycling], Q [water transportation], R [ship building], AA1 [fabricated metal products]) were unable to meet the benchmark for at least 50 percent of the reported results. Most of these sectors (A2, F4, N1, Q, R, and AA1) also had a large percentage of reported results (at least 25 percent) exceeding eight times the benchmark, and many results were reported that were orders of magnitude higher than this level.

The figure and the descriptive statistics in Table D-10 include data collected for required monitoring that did not include hardness-specific benchmarks. Data entries without a hardness-specific benchmark were not included for the evaluation of the percentage of reported results that met benchmark thresholds.

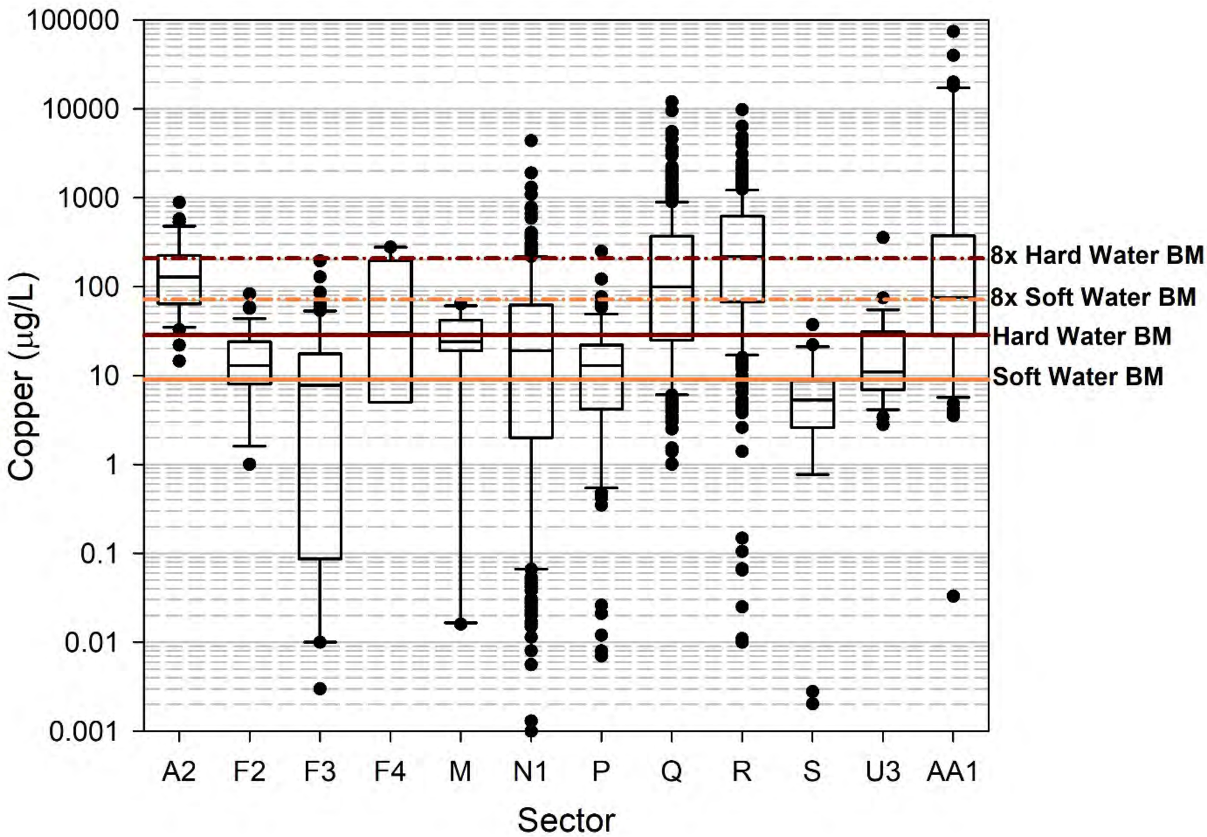

FIGURE D-7 Copper results from NetDMR 2015 MSGP reported data through February 2018. Orange lines denote the soft-water benchmark of 1.3 μg/L and hard-water benchmark of 4.5 μg/L, although benchmark exceedance is assessed based on site-specific water quality data.

TABLE D-10 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Copper

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A2	32	3	15	888	129	213	97	84	81
A4	2	1	7	21	14	18	NA	NA	NA
B2	2	1	<2	8	5	6.5	NA	NA	NA
C4	1	1	22	22	22	22	NA	NA	NA
C5	6	3	6	57	18	22	NA	NA	NA
E2	2	2	20	42	31	37	NA	NA	NA
F2	35	4	<1	83	13	22	63[a]	9	0
F3	100	9	0.003	195	7.8	17	40[b]	22	14
F4	10	2	5	279	31	169	70	60	50
G1	2	1	24	67	45	56	50	0	0
G2	4	2	<3	9.5	6.2	9.5	25	0	0
M	11	2	0.016	64	24	36	82	9	0
N1	330	49	<0.001	4,380	19	62	62[b]	37[a]	26
O	4	1	18	86	30	52	NA	NA	NA
P	97	14	0.007	250	13	22	32[d]	1	1
Q	415	60	1	12,000	100	360	86[c]	73[c]	61[b]
R	335	38	0.01	796,000	219	615	96[c]	90[c]	81
S	22	1	0.0020	37	5.3	8.3	18	0	0
U3	27	6	2.8	357	11	31	NA	NA	NA
V	2	1	18	28	23	26	NA	NA	NA
Y2	1	1	17	17	17	17	NA	NA	NA
AA1	93	5	0.033	74,000	76	370	82	60	46
AC1	7	1	4	30	6	21.5	NA	NA	NA

[a] Includes one result with reported detection limit exceeding the benchmark.
[b] Includes two to four results with reported detection limit exceeding the benchmark.
[c] Includes five to seven results with reported detection limit exceeding the benchmark.
[d] Includes nine results with reported detection limit exceeding the benchmark.
NOTE: NA, Required monitoring for purpose other than MSGP benchmark compliance; no regulatory limit established for those sites.
Nine reported results were not included because they did not have units; eighty-two reported results were excluded from the hardness-based benchmark analysis because no regulatory limit was established for these sites. In addition to the sectors noted with NA above, the following were excluded from the benchmark analysis: A4(2), B2(2), C4(1), C5(6), E2(2), N1(1), O(4), P(24), Q(1), R(1), U3(27), V(2), Y2(1), AA1(1), and AC1(7).

Cyanide

Figure D-8 highlights the NetDMR 2015 MSGP data for cyanide. The sectors with sufficient reported results to graph were able to meet the cyanide benchmark of 22 µg/L for all but one of the reported results in the database (from Sector K, hazardous waste facility). The complete data set is summarized in Table D-11.

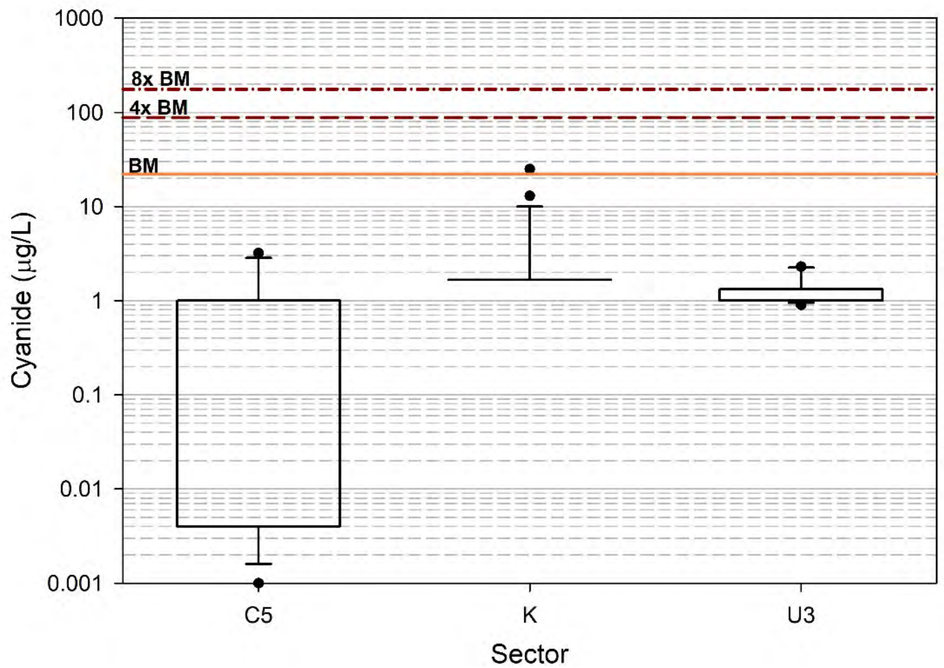

FIGURE D-8 Cyanide results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 22 µg/L.

TABLE D-11 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Cyanide

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A4	1	1	1.9	1.9	1.9	1.9	0	0	0
B2	2	1	<1	<1	<1	<1	0	0	0
C3	4	1	<0.8	2.1	1.4	2.0	0	0	0
C5	11	3	<0.001	3.2	<1	1	0	0	0
E2	2	2	<1	2.4	1.7	2.1	0	0	0
J1	2	2	<2	<2	<2	<2	0	0	0
K	61	4	<0.00001	25	1.7	1.7	2	0	0
P	7	3	1	17	2.8	5.1	0	0	0
Q	1	1	1	1	1	1	0	0	0
U3	14	6	0.9	2.3	1	1.3	0	0	0
Y2	1	1	2.2	2.2	2.2	2.2	0	0	0
AC	4	2	<1	1.6	1	1.2	0	0	0

Iron

Figure D-9 shows the NetDMR 2015 MSGP data for iron. For sectors with at least eight reported results, Sectors A1 (general sawmills), E2 (concrete and gypsum), E3 (glass and stone products), F2 (iron and steel foundries), H (coal mines), L2 (landfills, excluding municipal solid waste), N1 (scrap recycling), and P (motor freight transportation) exceeded the benchmark for ≥ 50 percent of the reported results. At least 10 percent of the reported results in Sectors C1 (agrochemicals), E2, H, L2, N1, Q (water transportation), and S (airports) exceeded eight times the benchmark. About 95 percent of the reported results from Sector H exceeded eight times the benchmark. The complete data set is summarized in Table D-12.

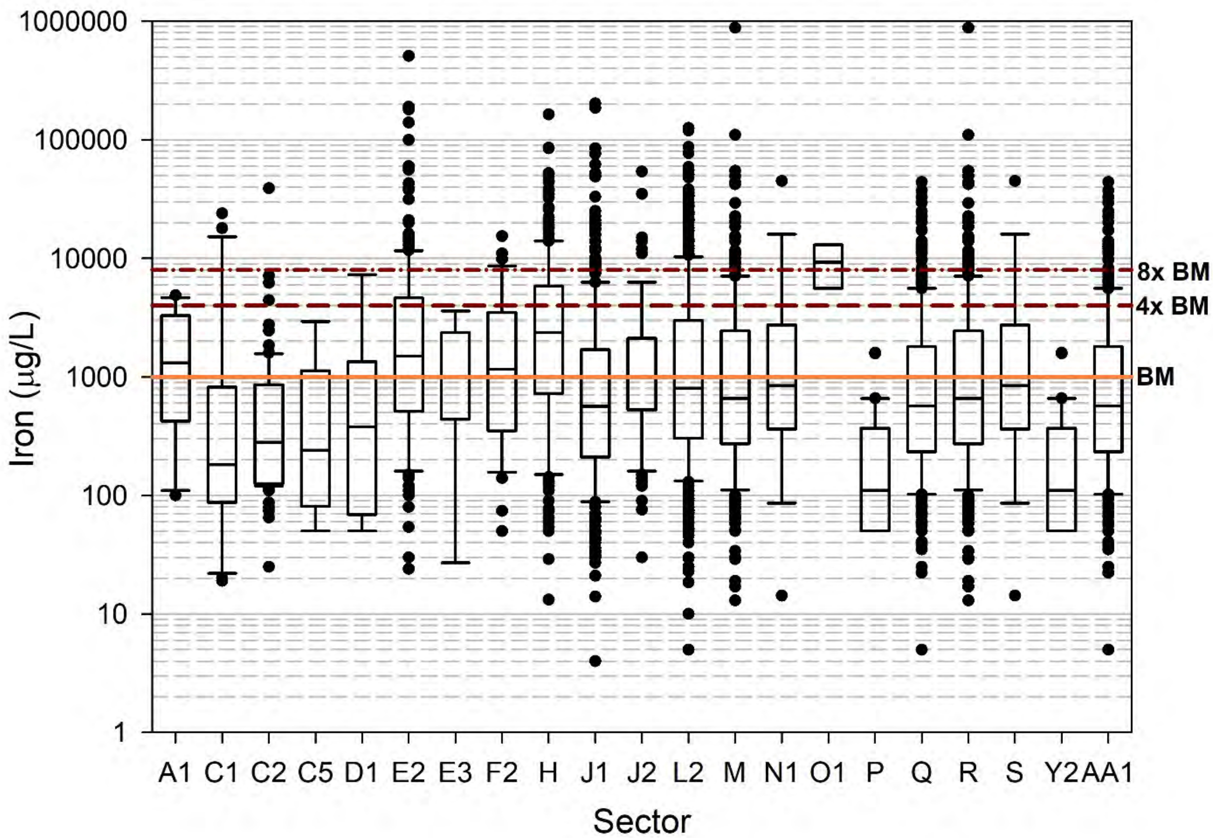

FIGURE D-9 Iron results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 1,000 μg/L.

TABLE D-12 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Iron

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A1	12	1	100	4880	1320	2,398	58	17	0
B2	1	1	<50	<50	<50	<50	0	0	0
C1	23	2	19	24,000	181	752	17	17	13
C2	84	5	25	39,100	280	776	21	5	1
C5	14	2	<50	2,940	240	750	21	0	0
D1	9	3	<50	7,290	380	1,220	33	11	0
E2	228	46	24	510,000	1,500	4,613	59	28	17
E3	8	2	27	3,600	994.5	1,700	50	0	0
F2	34	4	<50	15,400	1,165	2,950	53	24	9
F3	4	1	370	1,010	695	1,003	25	0	0
G1	1	1	<100	100	100	100	0	0	0
G2	4	2	<1,000	1,270	1,135	1,270	50	0	0
H	22	3	5,980	604,000	34,650	113,650	100	100	95
J1	9	2	190	540	280	340	0	0	0
J2	35	7	<50	9,100	250	905	20	11	3
L2	120	14	<50	92,000	1,300	3,493	59	22	17
M	196	39	<13	34,000	400	1,000	24	4	2
N1	329	53	13	164,000	2,360	5,800	69	31	18
O1	420	34	4	203,000	564	1,700	33	15	9
P	89	9	30	54,100	1,010	2,110	52	11	9
Q	626	70	5	126,000	800	2,983	45	20	12
R	345	37	13	881,000	656	2,420	41	17	9
S	19	3	14	45,000	842	2,575	42	16	16
U3	2	1	5,600	13,000	9,300	11,150	100	100	50
Y1	4	1	620	1,800	880	1,200	25	0	0
Y2	30	3	<50	1,600	110	289	7	0	0
AA1	430	35	<5	44,100	566	1,795	37	14	6

NOTE: Twenty-four reported results were not included because they did not have units.

Lead

Figure D-10 highlights the NetDMR 2015 MSGP data for lead. The lead benchmark value is determined by the hardness in the receiving water. For the graphs, two lead benchmark values are presented—one representing soft water (60 mg/L as $CaCO_3$; 45 µg/L) and one representing hard water (200 mg/L as $CaCO_3$; 213 µg/L). Of the sectors that had at least eight reported results, Sector N1 (scrap recycling) had the largest percentage of benchmark exceedances (41 percent), with 7 percent exceeding eight times the benchmark, while Sector R (ship and boat building or repair years) had about 25 percent exceedances compared to the soft-water benchmark.

The figure and the descriptive statistics in Table D-13 include data collected for required monitoring that did not include hardness-specific benchmarks. Data entries without a hardness-specific benchmark were not included for the evaluation of the percentage of reported results that met benchmark thresholds.

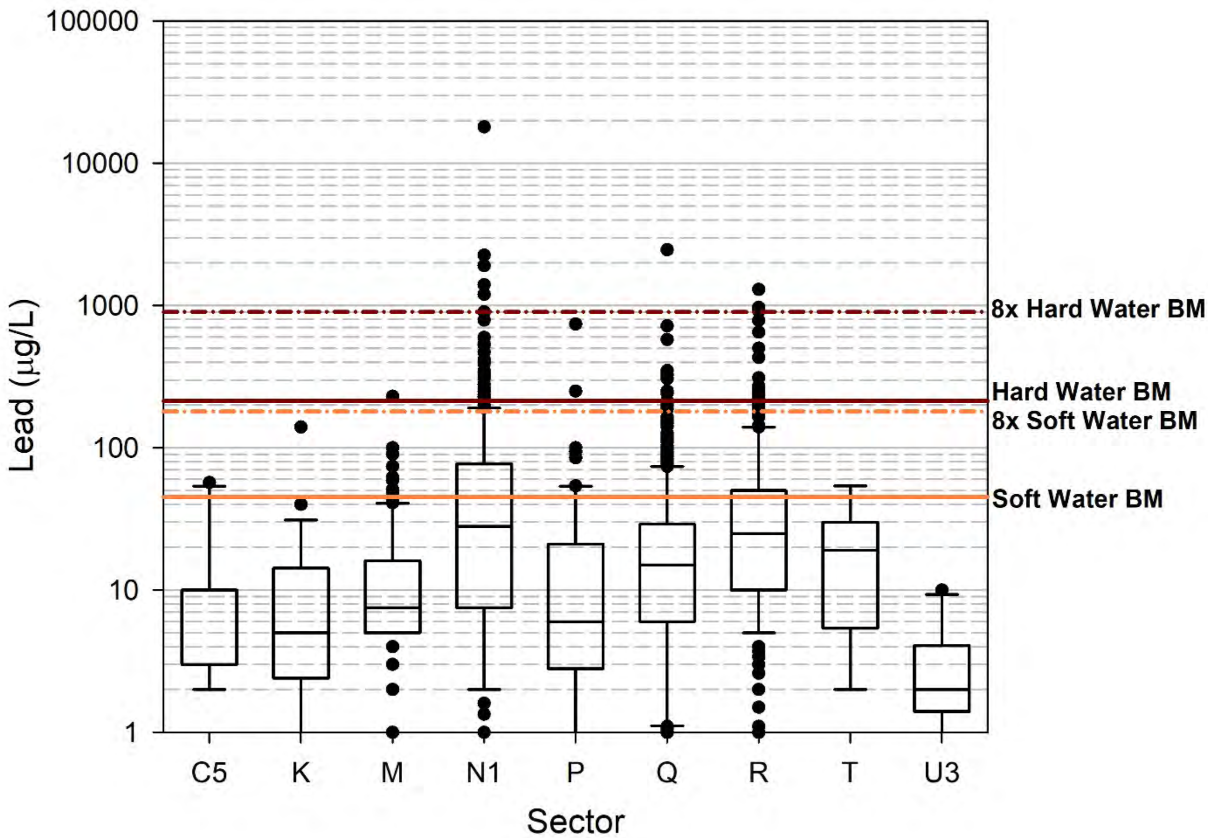

FIGURE D-10 Lead results from NetDMR 2015 MSGP reported data through February 2018. Orange lines denote the soft-water benchmark of 45 µg/L and hard-water benchmark of 213 µg/L, although benchmark exceedance is assessed based on site-specific water quality data.

TABLE D-13 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Lead

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C1	7	2	<3	10	<3	<10	0	0	0
C5	11	3	<2	57	<3	9	10	0	0
D1	2	1	<5	<8	<6.5	<7.2	NA	NA	NA
G1	2	1	<7.5	<7.5	<7.5	<7.5	0	0	0
G2	5	2	<4	44	44	44	0	0	0
K	28	5	<0.5	140	5	13	7	0	0
M	172	39	0.75	230	7.5	16	6	1	1
N1	311	51	0.6	18,000	28	77	41	16	7
O	2	1	<10	<10	<10	<10	NA	NA	NA
P	81	10	0.35	742	6	20	2	2	0
Q	410	57	0.08	2,467	15	29	4[a]	0	0
R	276	35	0.5	1,300	25	50	8[b]	1	0
S	6	1	0.22	3.5	0.47	2.0	0	0	0
T	9	2	2	54	19	29	0	0	0
U3	16	4	<0.5	<10	2	4.0	NA	NA	NA
AA1	6	1	0.37	3.6	1.5	2.9	0	0	0
AC	1	1	4	4	4	4	NA	NA	NA

[a] Includes one result with reported detection limit exceeding the benchmark.
[b] Includes five results with reported detection limit exceeding the benchmark.
NOTE: NA, required monitoring for purpose other than MSGP benchmark compliance; no regulatory limit established for those sites.
Nine reported results were not included because they did not have units; sixty-seven reported results were excluded from the hardness-based benchmark analysis because no regulatory limit was established for these sites. In addition to the sectors noted with NA above, the following were excluded from the benchmark analysis (the number of reported results in parentheses): C5(1), D1(2), G2(1), M(2), N1(8), O1(2), P(28), Q(1), T(5), U3(16), and AC1(1).

Magnesium

Figure D-11 shows the NetDMR 2015 MSGP data for magnesium. Only two sectors had at least eight reported results for graphical analysis. Half of the reported results in Sectors C5 (industrial organic chemicals) and all the reported results in Sector K (hazardous waste facilities) exceeded the benchmark of 64 µg/L. A large proportion of these reported results also exceeded eight times the benchmark. The complete data set is summarized in Table D-14. None of the reported results submitted in either Sectors P (motor freight transportation facilities) or AA1 (fabricated metal) were able to meet the magnesium benchmark.

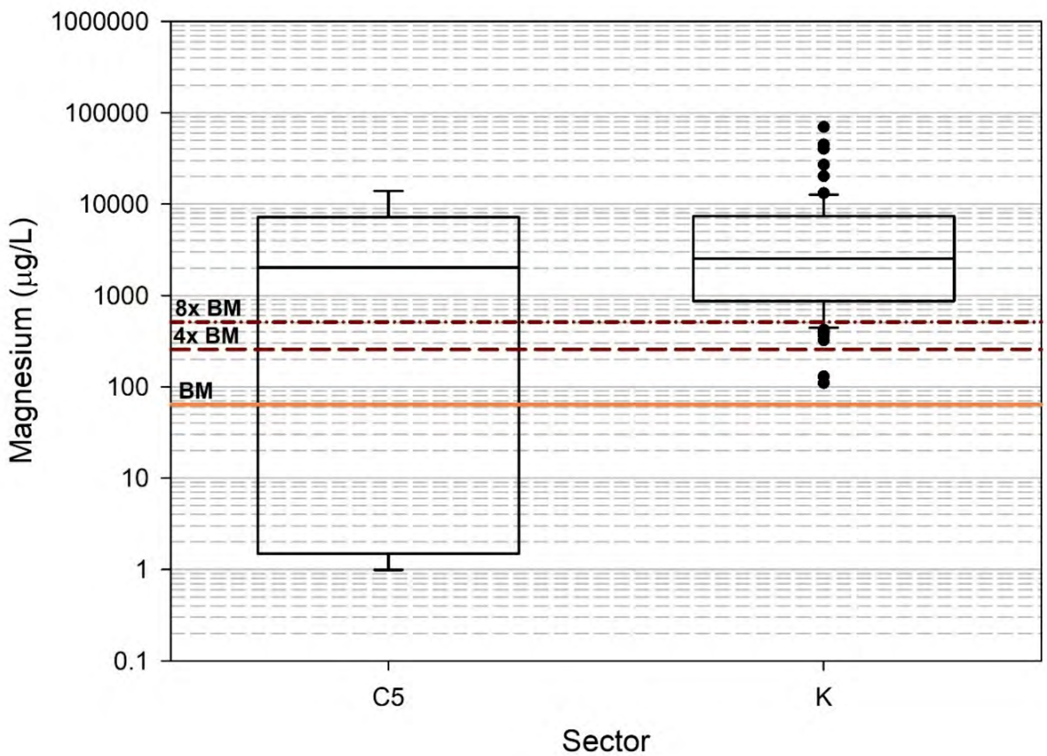

FIGURE D-11 Magnesium results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 64 µg/L.

TABLE D-14 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Magnesium.

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C5	8	2	0.99	13,900	2,031	7,168	50	50	50
K	95	8	110	70,000	2,520	7,295	100[a]	98[a]	83[a]
P	5	1	300	16,000	2,600	11,000	100	100	80
AA1	3	1	505	1,590	1,410	1,500	100	100	67

[a] Includes two results with reported detection limit exceeding the benchmark (and eight times the benchmark).

Mercury

Figure D-12 shows the NetDMR 2015 MSGP data for mercury. For sectors with at least eight reported results, Sectors K (hazardous waste facilities) and U3 (food and beverage production) each exceeded the benchmark of 1.4 µg/L in only one reported result. The plot for Sector U3 was skewed by a single result that was >1,000 µg/L, three orders of magnitude greater than other results in the database. One potential explanation for this is that the result was in micrograms per liter and was reported in milligrams per liter and was converted for these purposes to micrograms per liter by multiplying by 1,000. Because the analytical result is possible, although highly unlikely, it was retained in the analysis. The complete data set is summarized in Table D-15.

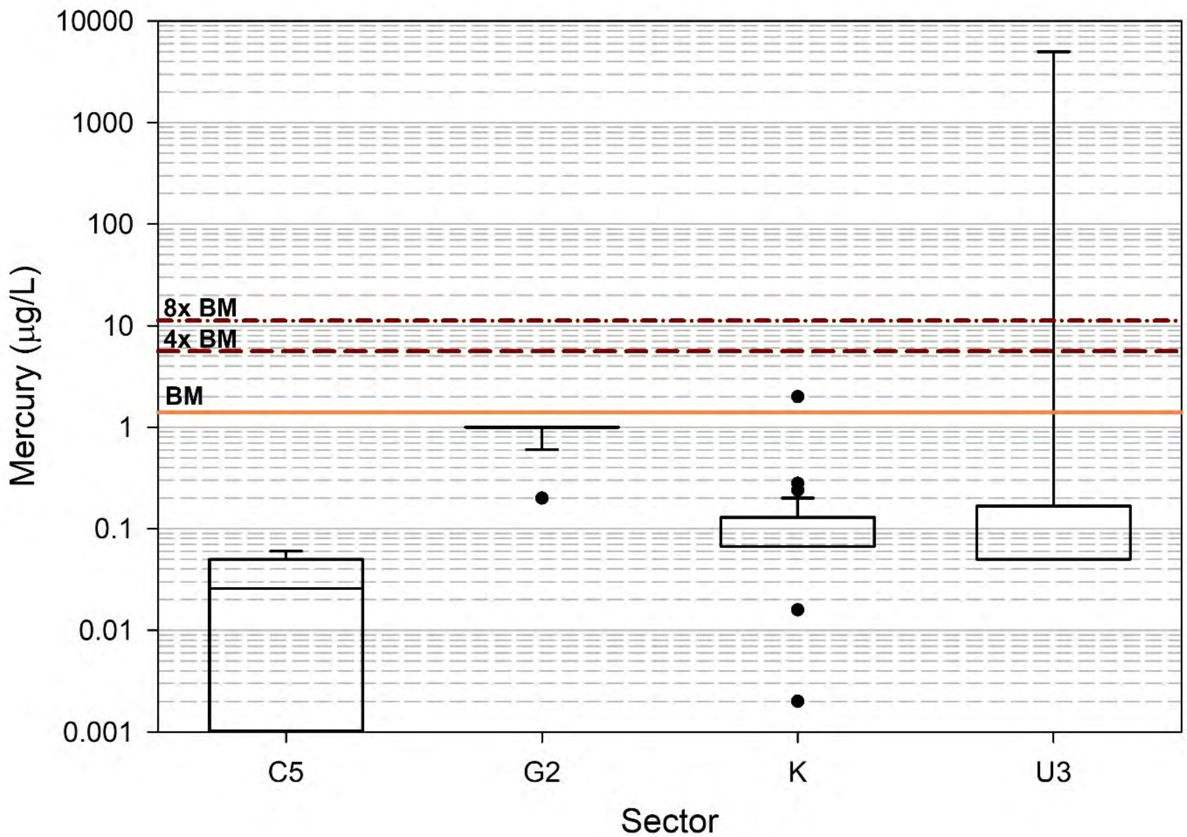

FIGURE D-12 Mercury results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 1.4 µg/L.

TABLE D-15 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Mercury

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C3	4	1	<0.2	<4	<0.3	<1.3	25[a]	0	0
C5	8	2	<0.00001	0.06	<0.026	<0.05	0	0	0
G1	4	1	<0.2	<0.2	<0.2	<0.2	0	0	0
G2	24	3	<0.2	1	<1	<1	0	0	0
K	90	8	<0.002	<2	<0.067	0.12	1[a]	0	0
N1	5	3	<0.1	0.2	<0.2	<0.2	0	0	0
P	4	1	0.027	0.062	0.044	0.049	0	0	0
Q	4	1	0.06	0.29	0.095	0.17	0	0	0
R	5	1	<0.1	<0.15	<0.1	<0.1	0	0	0
U3	8	3	<0.05	5000	<0.05	0.10	13	13	13

[a] Includes one result with reported detection limit exceeding the benchmark.
NOTE: One result not included because the sector/subsector could not be identified.

Nickel

The NetDMR 2015 MSGP data for nickel are summarized in Table D-16. No sector had at least eight reported results for graphical analysis. Those facilities with hardness-specific benchmarks identified all met the benchmarks. Even for the data entries that lacked hardness-specific limits, all the reported results submitted met both the soft-water benchmark of 320 µg/L and the hard-water benchmark of 890 µg/L.

TABLE D-16 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Nickel

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
G1	1	1	<10	<10	<10	<10	0	0	0
G2	4	2	<10	<10	<10	<10	0	0	0
N1	1	1	13	13	13	13	NA	NA	NA
O1	2	1	<25	<25	<25	<25	NA	NA	NA
P	5	3	<25	<250	<25	<250	NA	NA	NA

NOTE: NA, Required monitoring for purpose other than MSGP benchmark compliance; no regulatory limit established for those sites. These eight reported results were excluded from the benchmark analysis.

Nitrite Plus Nitrate

Figure D-13 shows the NetDMR 2015 MSGP data for nitrite plus nitrate. For sectors with at least eight reported results, only Sector C1 (agricultural chemicals) exceeded the benchmark of 0.68 mg/L in more than 50 percent of the reported results, although Sectors C1, J2 (crushed stone), and AA2 (fabricated metal coating) exceeded four times the benchmark in at least 10 percent of the reported results. The complete data set is summarized in Table D-17.

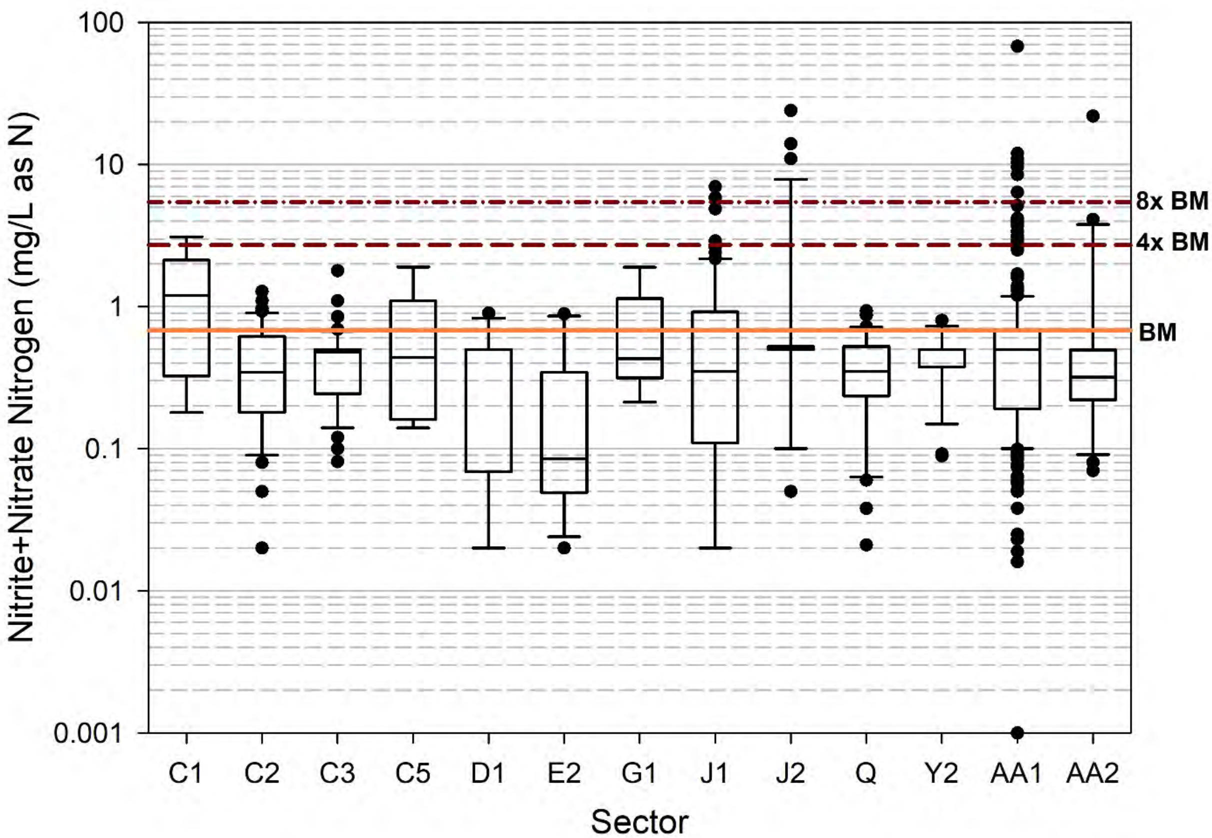

FIGURE D-13 Nitrite+nitrate nitrogen results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 0.68 mg/L.

TABLE D-17 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Nitrite + Nitrate Nitrogen

	No. Reported Results	No. Facilities	Min. (mg/L)	Max. (mg/L)	Median (mg/L)	75th Percentile (mg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C1	8	1	0.18	3.1	1.2	2.0	63	13	0
C2	62	3	<0.02	1.3	0.35	0.60	16	0	0
C3	42	3	0.081	1.8	0.48	0.5	10	0	0
C5	15	2	0.14	1.9	0.44	0.90	33	0	0
D1	11	4	0.02	0.9	0.5	0.5	9	0	0
E2	13	4	<0.02	0.89	0.09	0.16	15	0	0
F2	4	1	0.14	0.46	0.29	0.39	0	0	0
F3	4	1	<0.2	0.97	0.47	0.64	25	0	0
G1	8	1	0.21	1.9	0.43	0.88	38	0	0
J1	99	25	<0.02	7	0.35	0.89	29	4	2
J2	38	5	<0.05	24	<0.5	<0.5	21	13	11
P	3	2	<0.1	0.48	0.17	0.33	0	0	0
Q	31	2	0.021	0.94	0.35	0.52	13	0	0
Y2	26	2	0.089	0.8	0.5	0.5	12	0	0
AA1	357	30	<0.001	<68	0.5	0.68	21[a]	6[b]	2[b]
AA2	20	4	0.07	22	0.32	0.49	20	10	5

[a] Includes seven results with reported detection limit exceeding the benchmark.
[b] Includes one result with reported detection limit exceeding four and eight times the benchmark

pH

Figure D-14 shows the NetDMR 2015 MSGP data for pH. The pH benchmark is set based on maintaining an optimum range for water quality between pH 6 and 9. The complete data set is summarized in Table D-18, including the last column which sums the percentage of reported results in each sector that were below pH of 6.0 or above pH of 9.0. Sectors with at least eight reported results where ≥ 10 percent of the data were outside the pH benchmark range were G1 (copper mining), L1 (landfills), and AB (transportation equipment).

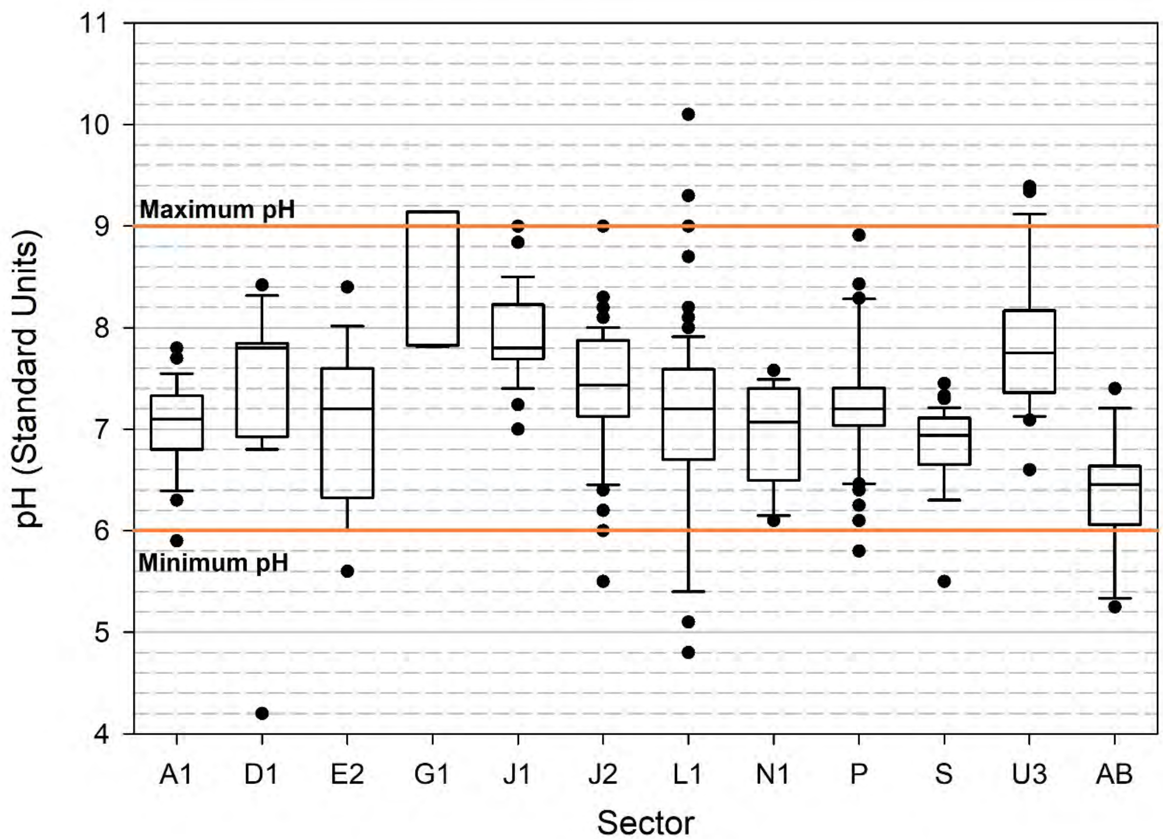

FIGURE D-14 pH results from NetDMR 2015 MSGP reported data through February 2018. Orange lines denote minimum and maximum of optimal pH range of 6.0-9.0.

TABLE D-18 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for pH

	No. Reported Results	No. Facilities	Min.	Max.	Median	75th Percentile	Percent < 6	Percent > 9	Percent outside BM range
A1	78	6	5.9	7.8	7.1	7.3	4	0	4
A3	2	1	6.4	6.8	6.6	6.7	0	0	0
D1	21	8	4.2	8.4	7.8	7.8	5	0	5
E2	24	6	5.6	8.4	7.2	7.6	4	0	4
E3	1	1	7.8	7.8	7.8	7.8	0	0	0
F3	2	1	7.1	7.3	7.2	7.3	0	0	0
G1	10	1	7.8	9.1	7.8	9.1	0	40	40
G2	6	2	7.1	7.4	7.2	7.4	0	0	0
J1	44	8	7.0	<9	7.8	8.2	0	0	0
J2	104	20	5.5	<9	7.4	7.8	2	0	2
L1	118	14	1.6	10.1	7.2	7.6	10	2	12
L2	1	1	7.5	7.5	7.5	7.5	0	0	0
N1	14	6	6.1	7.6	7.1	7.4	0	0	0
O	4	1	6.8	7.2	7.0	7.2	0	0	0
P	57	10	5.8	8.9	7.2	7.4	2	0	2
Q	2	2	0.9	9.2	5.1	7.1	50	50	100
S	38	4	5.5	7.5	6.9	7.1	5	0	5
U3	22	7	6.6	9.4	7.8	8.1	0	9	9
V	4	2	5.9	6.7	6.3	6.5	25	0	25
Y2	7	2	6.4	8.1	7.7	7.9	0	0	0
AA1	2	1	8.3	8.9	8.6	8.7	0	0	0
AB	12	2	5.3	7.4	6.5	6.6	17	0	17

NOTE: Twenty-four reported results were not included because they did not have units or the sector/subsector could not be identified (6 reported results without units; 18 without sector/subsector information).

Phosphorus

Figure D-15 shows the NetDMR 2015 MSGP data for total phosphorus. For sectors with at least eight reported results, only Sector C1 (agricultural chemicals) exceeded the benchmark of 2 mg/L in ≥ 10 percent of the reported results. Sector U3 seemed to have a sample that was an anomaly at 187 mg/L. No other reported result in that sector exceeded 10 mg/L. However, because no information was available to indicate that this was an incorrect entry, the reported result was retained in the analysis. The complete data set is summarized in Table D-19.

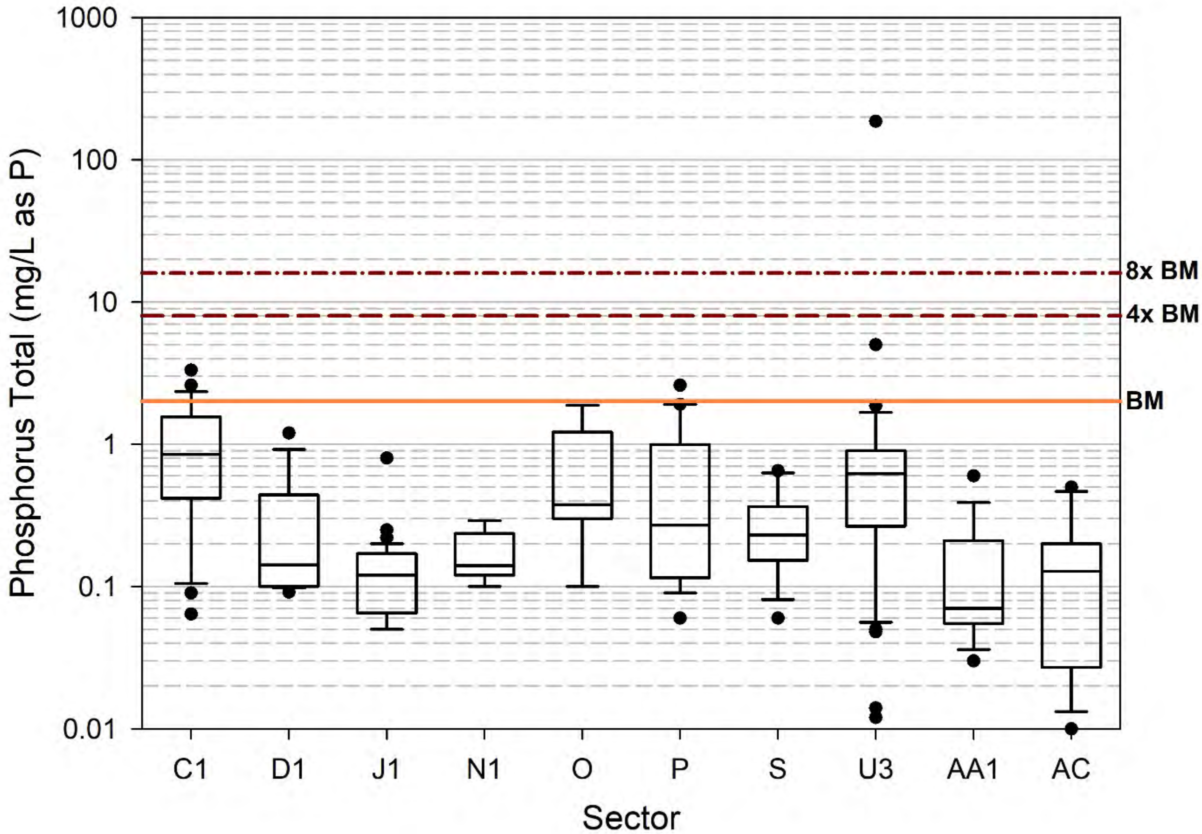

FIGURE D-15 Total phosphorus results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 2 mg/L.

TABLE D-19 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Total Phosphorus

	No. Reported Results	No. Facilities	Min. (mg/L)	Max. (mg/L)	Median (mg/L)	75th Percentile (mg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A4	7	2	0.027	0.77	0.25	0.28	0	0	0
C1	24	2	0.064	3.3	0.85	1.4	13	0	0
C5	6	2	0.037	0.69	0.13	0.17	0	0	0
D1	16	5	0.091	1.2	0.14	0.38	0	0	0
E2	2	2	<0.05	1.2	0.64	0.94	0	0	0
J1	45	9	<0.05	0.8	0.12	0.17	0	0	0
J2	2	2	<0.05	0.29	0.17	0.23	0	0	0
N1	9	3	<0.1	0.29	0.14	0.22	0	0	0
O1	12	2	<0.1	1.9	0.38	1.2	0	0	0
P	25	8	0.06	2.6	0.27	0.92	4	0	0
S	16	5	0.06	0.65	0.23	0.36	0	0	0
T	6	1	0.07	2.6	0.33	0.42	17	0	0
U1	4	1	1.1	7.9	5.9	7.9	75	0	0
U3	42	8	0.012	187	0.62	0.89	7	2	2
AA1	15	2	0.03	0.6	0.07	0.19	0	0	0
AC	11	4	<0.01	0.5	0.13	0.20	0	0	0

NOTE: Two reported results were not included because they did not have subsector/sector information.

Selenium

Figure D-16 shows the NetDMR 2015 MSGP data for selenium for sectors with at least eight reported results. Overall, high reported detection levels make the data more difficult to interpret. Only a few results (7 out of 87) across all sectors were reported that were above the benchmark (5 μg/L) that were not assigned a "less than" descriptor. All reported results for C5 were below the stated detection limit, although some of these detection limits were above the benchmark. The complete data set is summarized in Table D-20.

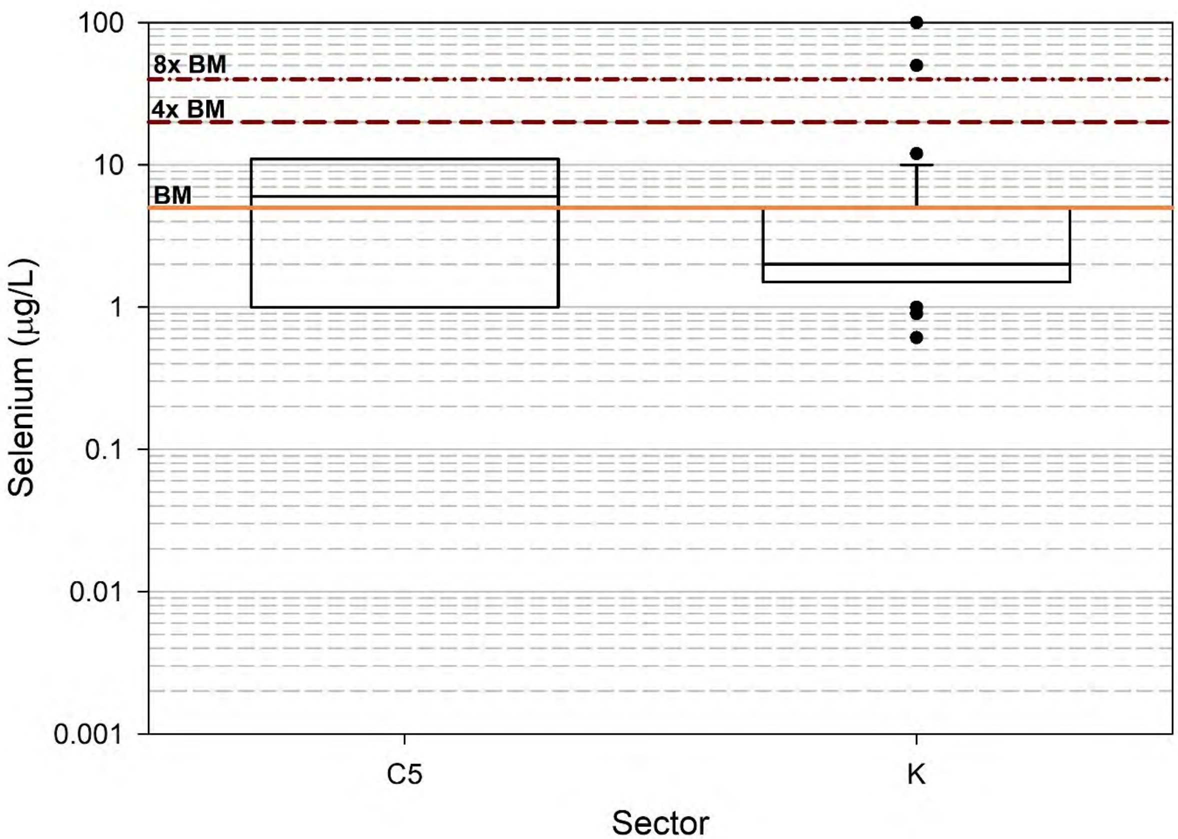

FIGURE D-16 Selenium results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes benchmark of 5 µg/L.

TABLE D-20 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Selenium

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A2	3	1	10	10	10	10	100	0	0
C5	8	2	<1	<11	<6	<11	50[a]	0	0
G2	4	2	<0.003	<5	4	5	0	0	0
J3	8	2	<0.5	6	<1	<2.2	25	0	0
K	60	6	0.61	100	<2	<5	18[b]	3	3
Q	1	1	<3	<3	<3	<3	0	0	0
T1	1	1	<6.1	<6.1	<6.1	<6.1	100[a]	0	0
U3	2	2	2	<3	2.5	2.8	0	0	0

[a] All exceedances were for results that had reported detection limits above the benchmark of 5 µg/L.
[b] Includes nine results with reported detection limit exceeding the benchmark.

Silver

Figure D-17 highlights the NetDMR 2015 MSGP data for silver. The benchmark value for silver is determined by the hardness in the receiving water. For the graphs, two silver benchmark values are presented—one representing soft water (60 mg/L as $CaCO_3$; 1.7 µg/L) and one representing hard water (200 mg/L as $CaCO_3$; 13.8 µg/L). All reported results noted as exceeding the benchmark also were reported as "less than" a detection level that was above the benchmark (see Table D-21).

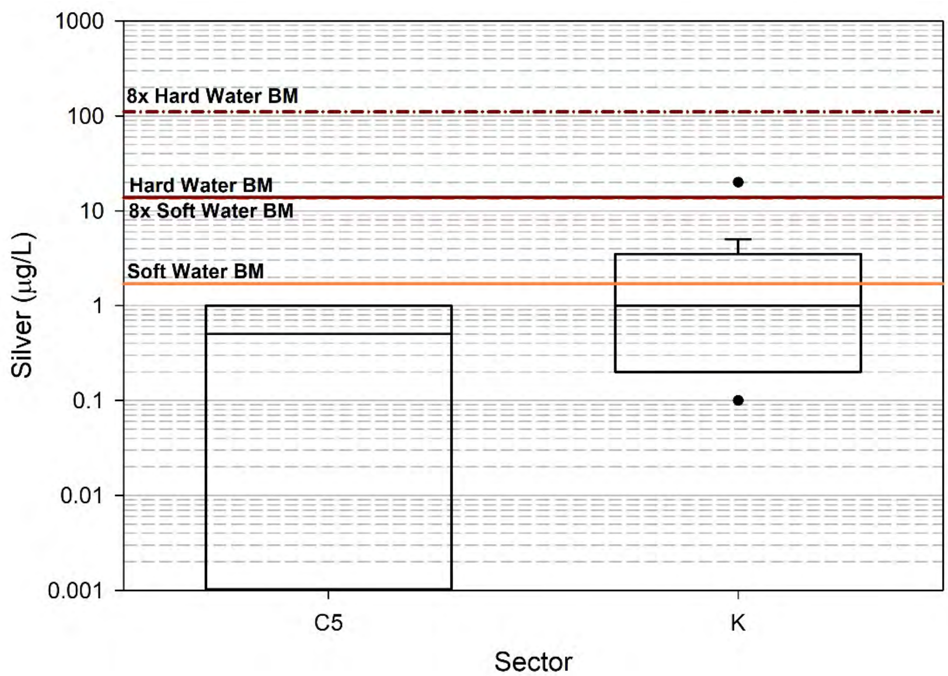

FIGURE D-17 Silver results from NetDMR 2015 MSGP reported data through February 2018. Orange lines denote the soft-water benchmark of 1.7 µg/L and hard-water benchmark of 13.8 µg/L, although benchmark exceedance is assessed based on site-specific water quality data.

TABLE D-21 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Silver

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
C5	8	2	<0.001	1	0.50	1	0	0	0
G1	1	1	<0.1	<0.1	<0.1	<0.1	0	0	0
G2	4	2	0.17	<0.3	0.24	<0.3	0	0	0
K	26	5	0.1	<20	<1	2.7	12[a]	4[b]	0
P	5	1	0.02	0.52	0.15	0.32	0	0	0
T	4	1	<5	<25	<9	<16	25[b]	0	0

[a] Includes three results with reported detection limit exceeding the benchmark.
[b] Includes one result with reported detection limit exceeding the benchmark.

Total Suspended Solids (TSS)

Figure D-18 highlights the NetDMR 2015 MSGP data for total suspended solids compared to the benchmark of 100 mg/L. Considering sectors with at least eight reported results, at least 60 percent of reported results in Sectors A2 (wood preserving), E3 (glass and stone products), and H (coal mines) exceeded the benchmark, and more than 10 percent of the reported results in Sectors A2 and H exceeded eight times the benchmark. The complete data set is summarized in Table D-22.

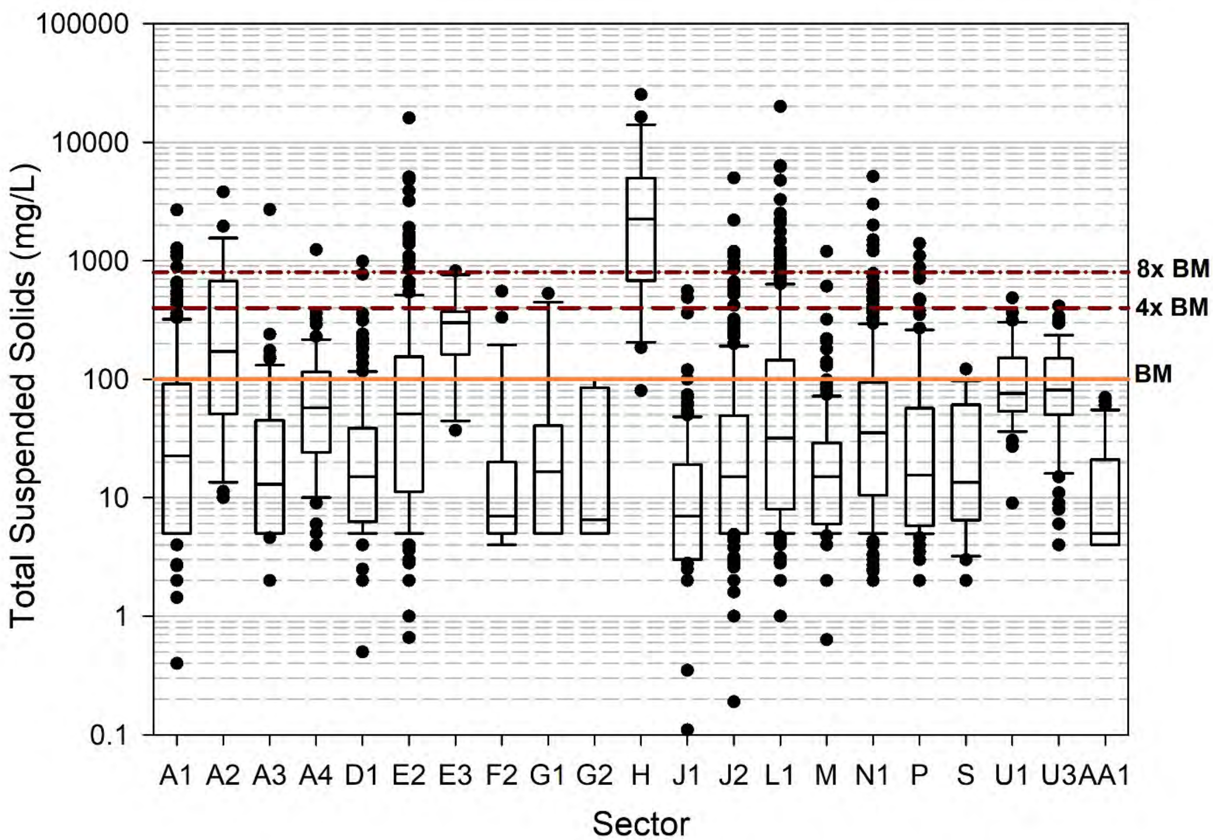

FIGURE D-18 Total suspended solids results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes the benchmark of 100 mg/L.

TABLE D-22 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Total Suspended Solids

	No. Reported Results	No. Facilities	Min. (mg/L)	Max. (mg/L)	Median (mg/L)	75th Percentile (mg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A1	374	28	0.4	2,680	23	90	22	7	3
A2	24	2	10	3,810	172	550	63	21	13
A3	53	10	<2	2,700	13	45	11	2	2
A4	74	9	<4	1,240	58	108	27	3	3
B2	4	1	6.4	63	23	44	0	0	0
D1	150	27	0.5	988	15	36	11	1	1
E2	269	46	0.66	16,000	51	150	35	14	7
E3	11	2	37	820	300	340	82	9	0
F2	27	4	4	553	7	19	11	4	0
G1	12	1	<5	529	17	36	17	8	0
G2	8	3	<5	100	6.5	54	0	0	0
H	22	3	80	25,200	2,250	4,730	95	77	55
J1	211	28	0.11	558	7	19	4	2	0
J2	428	35	0.19	5,000	15	49	14	6	3
L1	461	31	1	20,000	32	145	30	14	8
L2	1	1	1,510	1,510	1,510	1,510	100	0	0
M	185	39	0.63	1,200	15	29	6	1	1
N1	305	52	<2	5,140	35	93	24	7	2
O	6	2	<5	30	6	11	0	0	0
P	138	12	<2	1,400	16	54	18	7	3
Q	4	2	1.5	28	5.6	13	0	0	0
R	5	1	<1	4.8	2.6	2.9	0	0	0
S	20	5	<2	122	1.5	42	5	0	0
T	3	2	20	57	55	56	0	0	0
U1	37	7	9	486	76	149	38	3	0
U3	123	7	4	415	81	150	43	1	0
Y2	1	1	11	11	11	11	0	0	0
AA1	64	1	<4	70	5	19	0	0	0
AB1	3	1	5	30	7	19	0	0	0
AC1	6	2	<5	20	5.5	15	0	0	0

NOTE: Twenty reported results were not included because they did not have units or the sector/subsector could not be identified (19 results without units; 1 result without sector/subsector information).

Turbidity

Figure D-19 highlights the NetDMR 2015 MSGP data for turbidity compared to the benchmark of 50 nephelometric turbidity units (NTU). Of the sectors with at least eight reported results, only D1 (asphalt paving) exceeded the benchmark in more than 25 percent of the reported results. The complete data set is summarized in Table D-23.

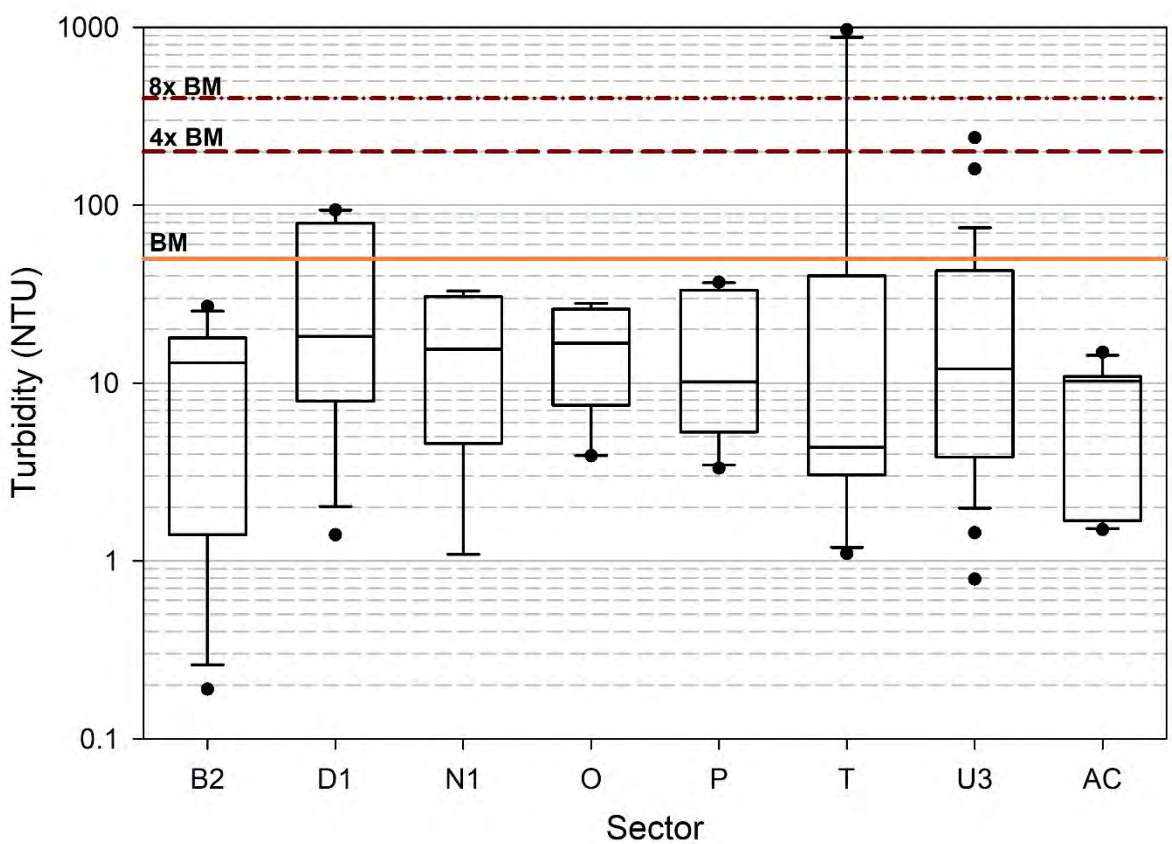

FIGURE D-19 Turbidity results from NetDMR 2015 MSGP reported data through February 2018. Orange line denotes the benchmark of 50 NTU.

TABLE D-23 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Turbidity

	No. Reported Results	No. Facilities	Min. (NTU)	Max. (NTU)	Median (NTU)	75th Percentile (NTU)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A2	3	1	9.4	27	11	19	0	0	0
A3	2	1	7.1	28	18	23	0	0	0
A4	4	1	0.39	77	13	32	25	0	0
B2	11	4	0.19	27	13	17	0	0	0
C5	5	2	4.3	17	4.9	11	0	0	0
D1	10	2	1.4	94	18	70	40	0	0
E2	4	3	<4	236	27	96	25	25	0
G1	1	1	12	12	12	12	0	0	0
G2	3	2	30	50	50	50	0	0	0
J2	2	1	2.2	2.3	2.3	2.3	0	0	0
J3	1	1	11	11	11	11	0	0	0
M	1	1	0.71	0.71	0.71	0.71	0	0	0
N1	8	3	1.1	33	16	28	0	0	0
O	12	2	3.9	28	17	26	0	0	0
P	10	5	3.3	37	10	32	0	0	0
Q	6	3	0.9	36	2	3.1	0	0	0
S	6	2	2.1	110	5.0	15	17	0	0
T	10	2	1.1	970	4.4	27	20	10	10
U3	29	8	0.79	240	12	42	17	3	0
AA1	4	2	0.83	12	7.1	11	0	0	0
AC	11	3	1.5	15	10	42	0	0	0

Zinc

Figure D-20 highlights the NetDMR 2015 MSGP data for zinc. Zinc's benchmark value is determined by the hardness in the receiving water. For the graphs, two zinc benchmark values are presented—one representing soft water (60 mg/L as $CaCO_3$; 80 µg/L) and one representing hard water (200 mg/L as $CaCO_3$; 230 µg/L). Reviewing the data set, several reported results may be outliers because their reported values are below the detection limits of most common methods of analysis. This is likely a transcription error. However, because these values were within the limit of detection of research instruments, the reported results were retained in the analysis. There also were two results that were reported as ≥ 10,000 µg/L (10 mg/L). The result in Sector F3 does not appear to be outside the range reported for other data. However, for Sector Q, the reported result is more than 10 times greater than the other data. Again, there was insufficient information to remove these from the analysis, so they were retained. Of the sectors with at least eight reported results, in Sectors C1 (agrochemicals), C4 (plastics), F1 (steel works), F2 (iron and steel foundries), F3 (rolling, drawing, and extruding of nonferrous metals), N1 (scrap recycling), Q (water transportation), Y1 (rubber products), AA1 (fabricated metal), and AA2 (fabricated metal coating), the reported values exceeded the hardness-specific benchmark for at least 50 percent of the reported results, and at least 10 percent of the reported results in Sectors C1, C4, F3, F4 (nonferrous foundries), N1, and Y1 exceeded eight times the benchmark. The complete data set is summarized in Table D-24.

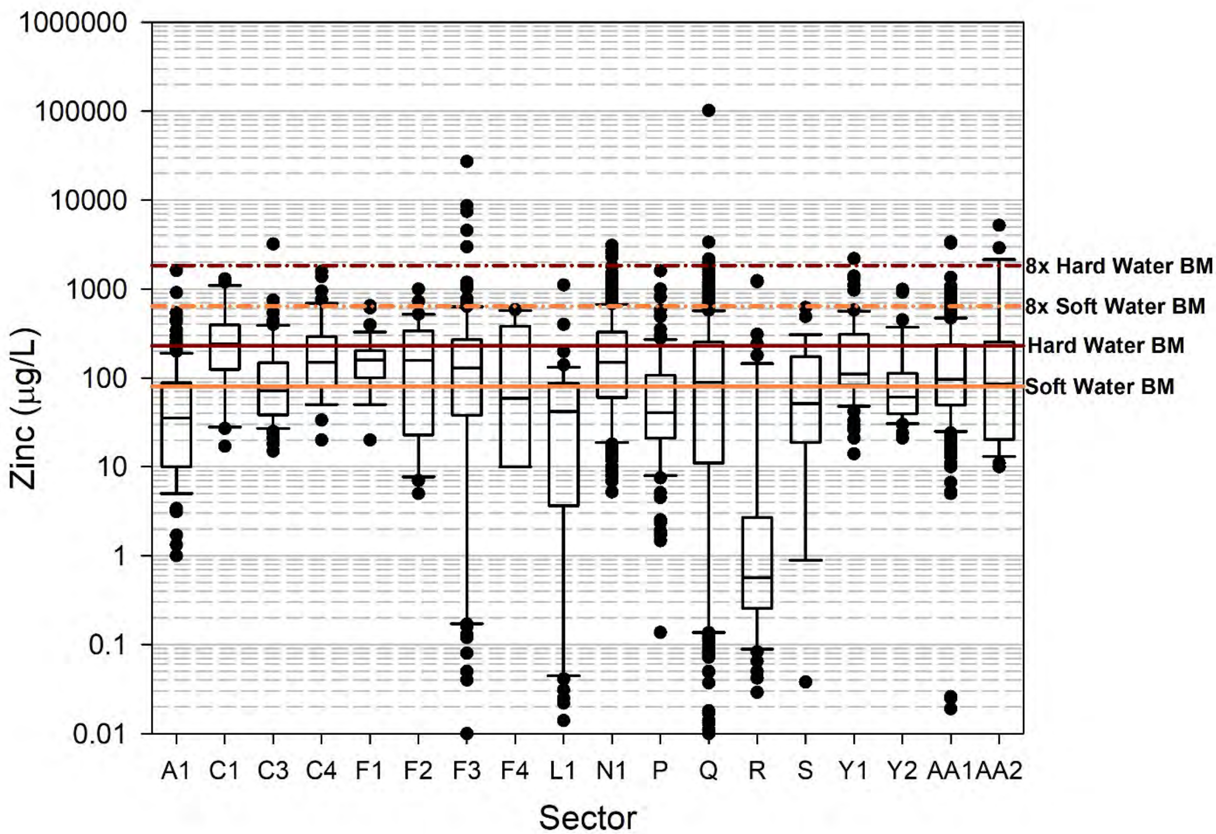

FIGURE D-20 Zinc results from NetDMR 2015 MSGP reported data through February 2018. Orange lines denote the soft-water benchmark of 80 μg/L and hard-water benchmark of 230 μg/L, although benchmark compliance is assessed based on site-specific water quality data.

TABLE D-24 Statistical Summary and Benchmark Comparison of 2015 MSGP Reported Results for Zinc

	No. Reported Results	No. Facilities	Min. (µg/L)	Max. (µg/L)	Median (µg/L)	75th Percentile (µg/L)	Percent > BM	Percent > 4x BM	Percent > 8x BM
A1	210	28	1	1,630	36	87	35	7	1
C1	24	2	17	1,300	243	365	83	29	25
C3	60	4	15	3,210	72	132	48	17	7
C4	44	5	20	1,580	150	284	89	41	16
C5	1	1	675	675	675	675	100	100	100
F1	34	2	<20	650	159	200	91[a]	21	3
F2	36	4	<5	1,000	158	337	61	28	6
F3	111	9	<0.01	27,200	129	268	52	27	12
F4	10	2	<10	587	59	301	50	30	30
G1	2	1	<10	10	10	10	0	0	0
G2	5	2	<30	76	76	76	0	0	0
L1	80	14	0.00016	1,110	42	83	6	1	1
L2	1	1	312	312	312	312	100	0	0
M	6	2	24	160	63	85	0	0	0
N1	316	49	5.2	3,100	150	328	68	32	13
O	4	1	72	855	416	614	NA	NA	NA
P	132	11	0.14	1,600	41	107	11	3	0
Q	564	65	0.000033	102,000	89	253	48[b]	19	8
R	59	4	0.029	1,240	0.56	2.4	12	3	3
S	27	2	0.0096	619	51	165	33	8	0
Y1	64	5	14	2,200	110	290	91	38	23
Y2	34	3	21	992	61	110	68	15	9
AA1	374	35	0.019	3,380	97	235	57	19	7
AA2	24	4	10	5,200	85	165	29	13	8

[a] Includes three results with reported detection limit exceeding the benchmark.
[b] Includes one result with reported detection limit exceeding the benchmark.
NOTE: NA, required monitoring for purpose other than MSGP benchmark compliance; no regulatory limit established for those sites.
Fourteen reported results were not included because they did not have units. An additional four reported results from P1 were excluded from the hardness-based benchmark evaluation because no regulatory limit was established for those sites.

PREPUBLICATION COPY

Appendix E

Additional Data on Technical Achievability of Treatment Stormwater Control Measures

This Appendix expands on the discussion of technical achievability in Chapter 2. The results of stormwater control measure pollutant removal performance for several additional pollutants—aluminum, copper, lead, zinc, and chemical oxygen demand (COD)—are presented here to supplement the data on total suspended solids and iron presented in Chapter 2. Some additional information on the Clark and Pitt (in press) study design is also provided.

ADDITIONAL STUDY DETAILS

The Clark and Pitt (in press) studies were collected from various locations in the United States and represent Environmental Protection Agency Rainfall Zones 1, 2, 3, 6, and 7. Seven studies were of devices whose primary treatment mechanism was sedimentation, while six studies primarily relied on filtration for water quality treatment, and two were treatment trains that relied on sedimentation pretreatment prior to filtration. For the sedimentation systems, the devices were categorized into three classifications: (1) hydrodynamic separator (HDS) devices, (2) ponds, and (3) wetlands. The HDS devices studied were proprietary sediment retention systems; HDS 4 is an inclined plate separator and the remainder are traditional HDS swirl concentrators. The two ponds were conventional dry ponds as described in most state stormwater manuals. The wetland also was designed similarly to the engineered wetlands described in most state manuals. For the filtration systems, the filtration media were proprietary combinations that had been optimized by the vendor for removing site-specific pollutants, especially metals, from the stormwater runoff through physical straining and potentially through adsorption and/or ion exchange. For consistency, label numbers for different pollutant data from the same site remain the same, even if not all sites monitored the same pollutants (e.g., Site HDS 3 is HDS 3 for all pollutants, regardless of whether data for HDS 2 are available for all pollutants). All samples were flow-weighted composites and were collected generally in accordance with the 2009 guidance for collecting data suitable for inclusion in the International BMP Database (Geosyntec Consultants and Wright Water Engineers, 2009).

The analysis of whether the treatment system was able to remove the pollutant of interest and whether it was considered for inclusion in the graphical analysis was tested statistically using the nonparametric analyses available in SigmaPlot/SigmaStat (Systat Software, Inc.). The selected test was the Wilcoxon signed-rank test using a one-tailed analysis of whether effluent was less than the influent. Significance was assumed if the reported p value was ≤ 0.05. The signed-rank test examines the pairs of data for difference. If the Shapiro-Wilk test for normality was passed, then the program defaulted to a paired t-test. The assumption of nonparametric testing was used since stormwater data rarely are normally distributed (Burton and Pitt, 2002).

One committee member performed this analysis, which was then reviewed in detail by another committee member to check for errors. Any errors identified were corrected.

ADDITIONAL POLLUTANT RESULTS

Total Aluminum

At the industrial study sites, only one proprietary sedimentation system and one filtration system were able to meet the benchmark concentration for more than 50 percent of the monitored storm events. For the sedimentation system, this was also the site with the lowest influent concentrations, which may have influenced the treatability (see Figure E-1). The International BMP Database contained limited data on aluminum and only for retention ponds, which were shown to meet the benchmark for between 25 and 50 percent of the monitored storm events (see Figure E-2).

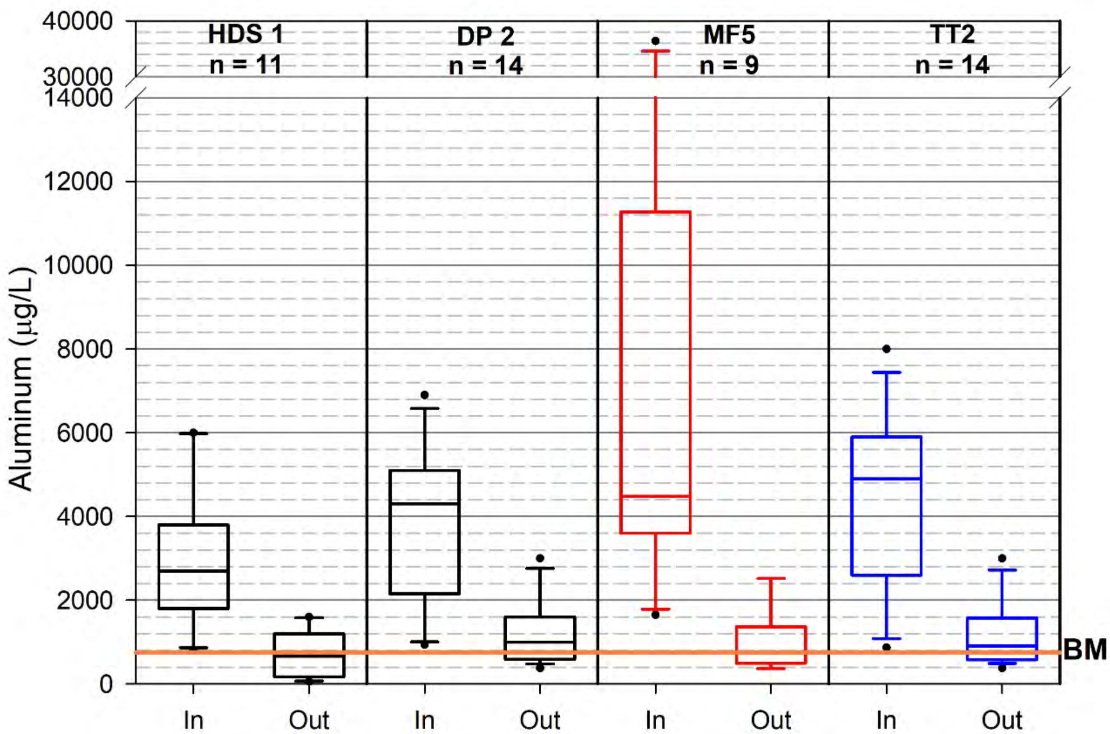

FIGURE E-1 Total aluminum influent versus effluent concentrations. DP = dry detention pond; HDS = hydrodynamic separator;; MF = media filter; TT = treatment train. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

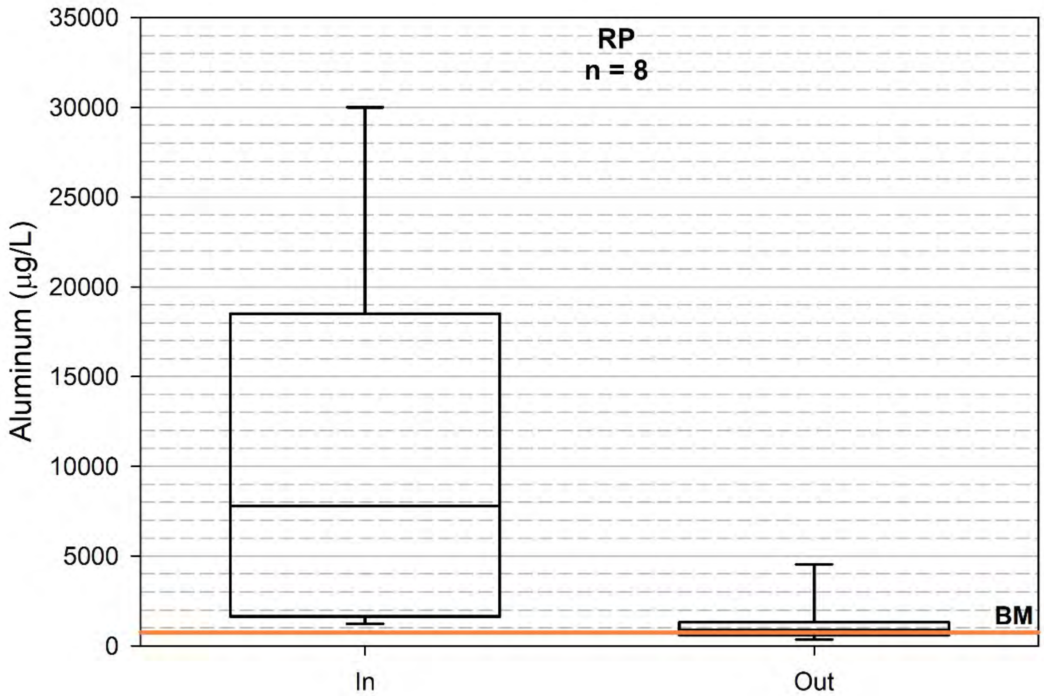

FIGURE E-2 International BMP Database comparison of influent and effluent concentrations for total aluminum. RP = wet retention ponds.

Total Copper

The copper benchmark is hardness dependent; therefore, two sample benchmarks are shown in Figures E-3 and E-4 for the evaluation of technology performance at individual industrial stormwater study sites. One benchmark (9 μg/L) is based on 60 mg/L total hardness, shown in Figure E-3, and the other (28.5 μg/L) is based on 200 mg/L total hardness, shown in Figure E-4. One of the three media filters and the treatment train were able to meet the lower soft-water benchmark for at least 50 percent of the storm events. The treatment train was able to meet the benchmark for >90 percent of the monitored events. For systems with eight storm events with influent concentrations above the hard-water benchmark, only the media filter was able to meet the hard-water benchmark for at least 50 percent of the events monitored.

For the International BMP Database (see Figures E-5 and E-6), all the treatment systems except the dry detention pond were able to meet the soft-water benchmark of 9 μg/L for between 50 and 75 percent of the monitored storm events. For the hard-water benchmark, the dry detention pond and media filter could meet the hard-water benchmark for between 50 and 75 percent of the monitored storm events, while the wet retention pond and bioretention system met the hard-water benchmark for between 75 and 90 percent of the monitored storm events.

PREPUBLICATION COPY

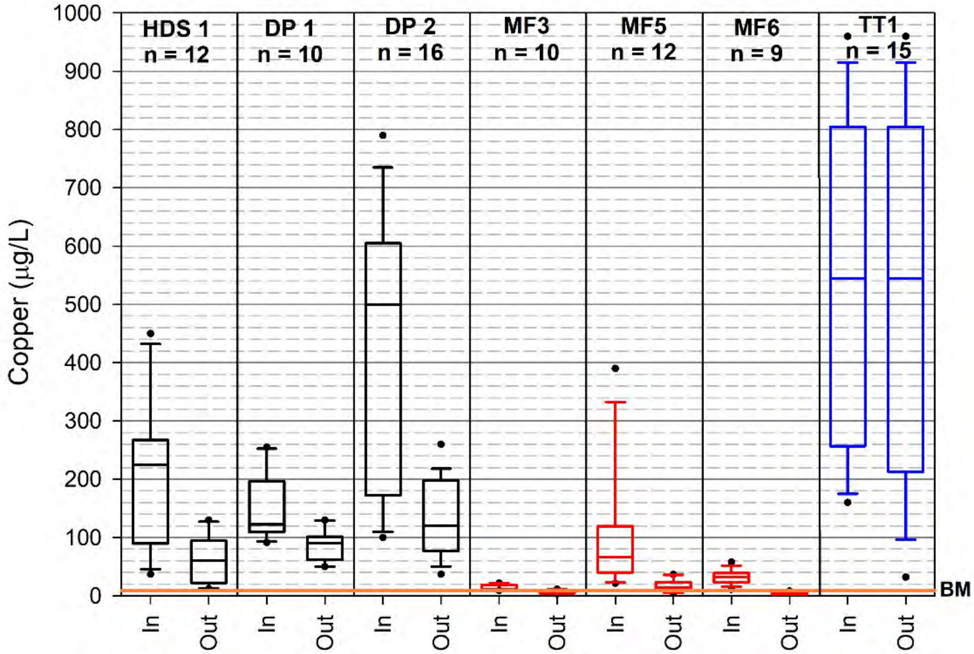

FIGURE E-3 Total copper influent versus effluent concentrations compared to the soft-water benchmark concentration of 9 µ/L. DP = dry retention pond; HDS = hydrodynamic separator; MF = media filter; TT = treatment train. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

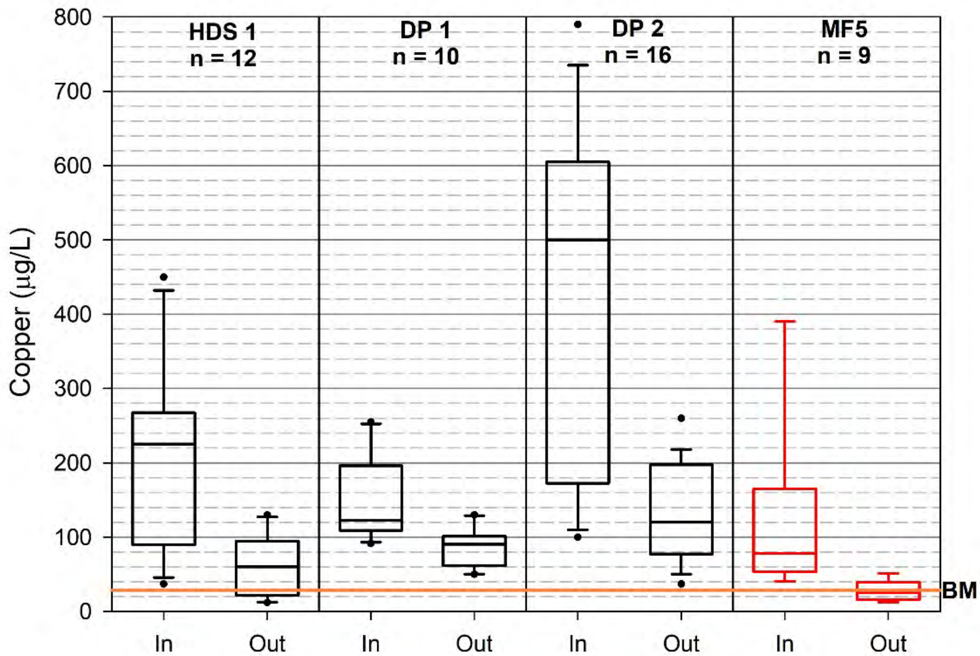

FIGURE E-4 Total copper influent versus effluent concentrations compared to the hard-water benchmark concentration of 28.5 µg/L. DP = dry retention pond; HDS = hydrodynamic separator; MF = media filter. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

PREPUBLICATION COPY

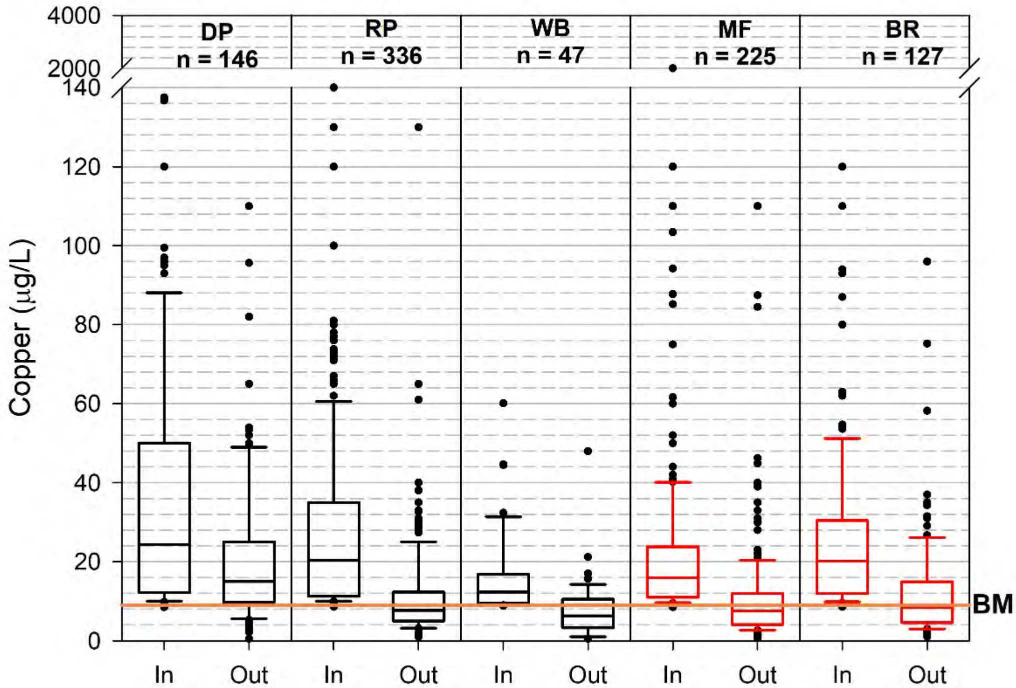

FIGURE E-5 International BMP Database comparison of influent and effluent concentrations for total copper against the soft-water benchmark of 9 µg/L. BR = bioretention; DP = dry detention ponds; MF = media filters; RP = wet retention ponds; WB = wetlands..

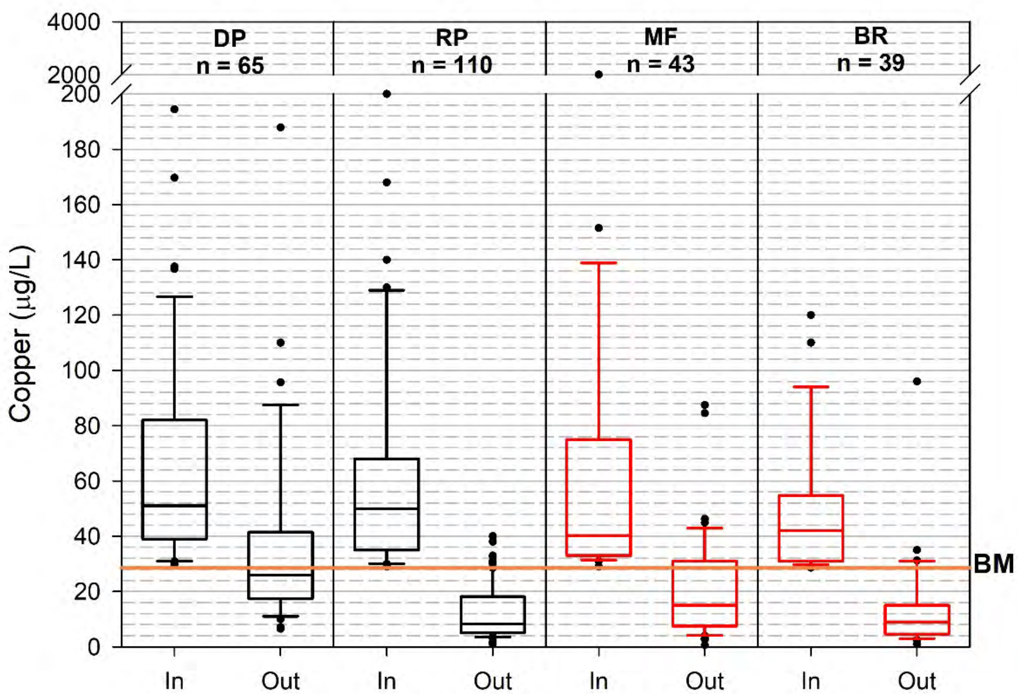

FIGURE E-6 International BMP Database comparison of influent and effluent concentrations for total copper against the hard-water benchmark of 28.5 µg/L. BR = bioretention; DP = dry detention ponds; MF = media filters; RP = wet retention ponds; WB = wetlands..

Total Lead

For lead, the benchmark is set based on the receiving water hardness. None of the treatment systems was able to meet the soft-water benchmark of 45 µg/L for more than 50 percent of the monitored storm events (Figure E-7). For the two systems with sufficient data pairs where the influent concentration exceeded the hard-water benchmark of 213 µg/L (Figure E-8), one dry detention pond and one treatment train were able to meet the effluent hard-water benchmark for between 75 and 90 percent of the monitored storm events. The improved performance when only analyzing data where the influent exceeds the hard-water benchmark likely is due to the strong association of high concentrations of lead with particulate matter that easily settled or was filtered. However, since particle size analysis was not included, this cannot be confirmed from the data set.

The International BMP Database data (Figure E-9) highlights the ability of other categories of stormwater treatment systems to remove total lead from the influent runoff. The dry pond was able to meet the soft-water benchmark for between 50 and 75 percent of the storm events monitored, while the wet retention pond and media filter were able to meet the benchmark for >90 percent of the monitored storm events. However, when comparing to the hard-water benchmark, only the wet retention pond had sufficient influent-effluent pairs where the influent concentration exceeded the hard-water benchmark of 213 µg/L (Figure E-10). The wet retention pond was able to meet the hard-water benchmark for >90 percent of the reported storm events.

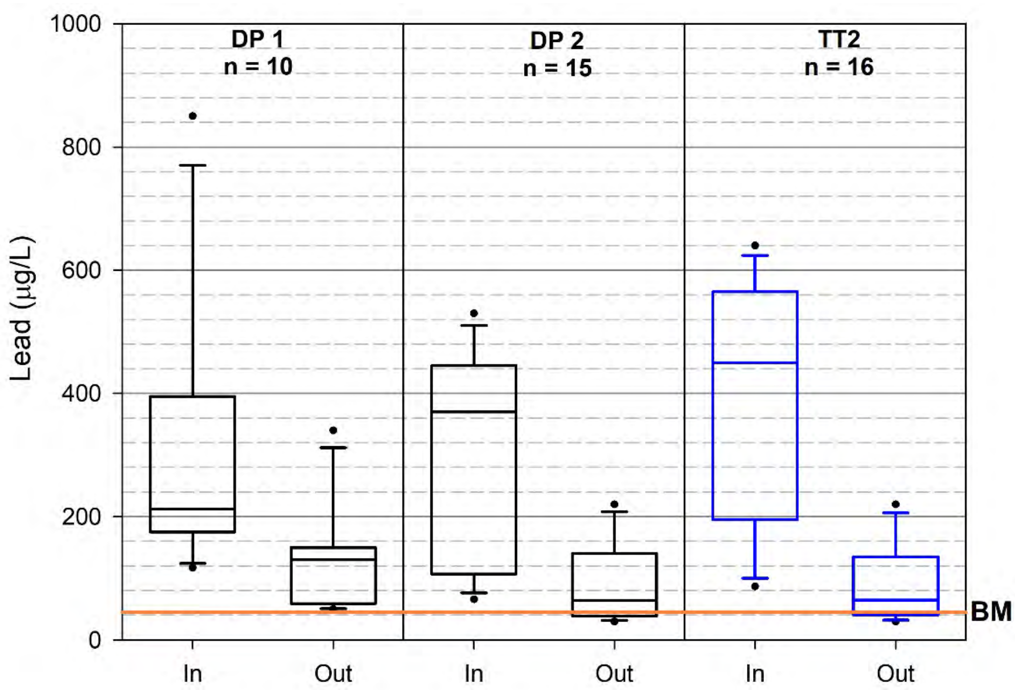

FIGURE E-7 Total lead influent versus effluent concentrations comparison against the soft-water benchmark. DP = dry detention pond; TT = treatment train. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

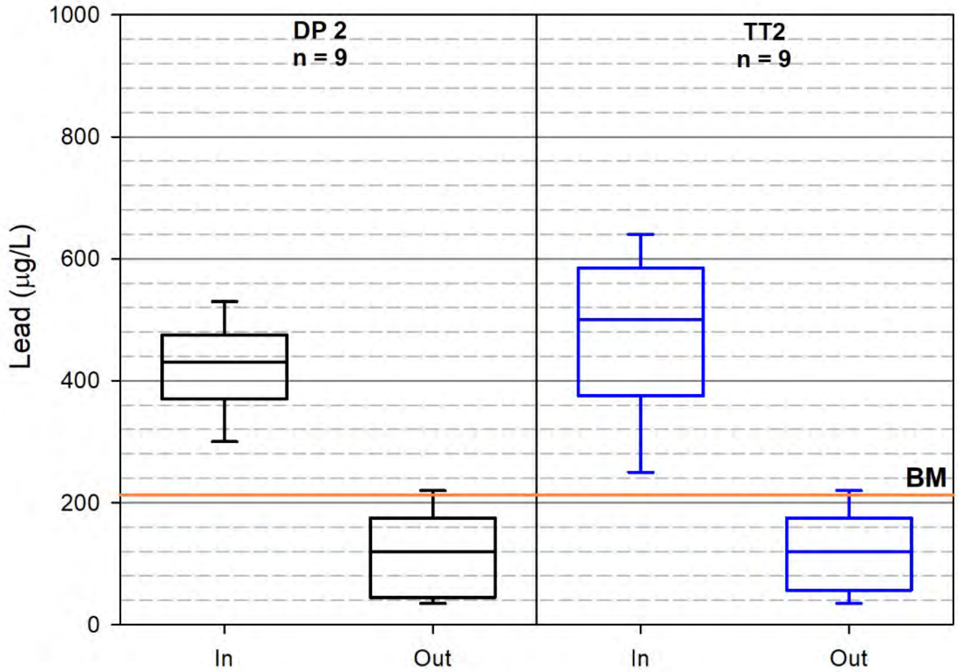

FIGURE E-8 Total lead influent versus effluent concentrations comparison against the hard-water benchmark. DP = dry detention pond; TT = treatment train. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

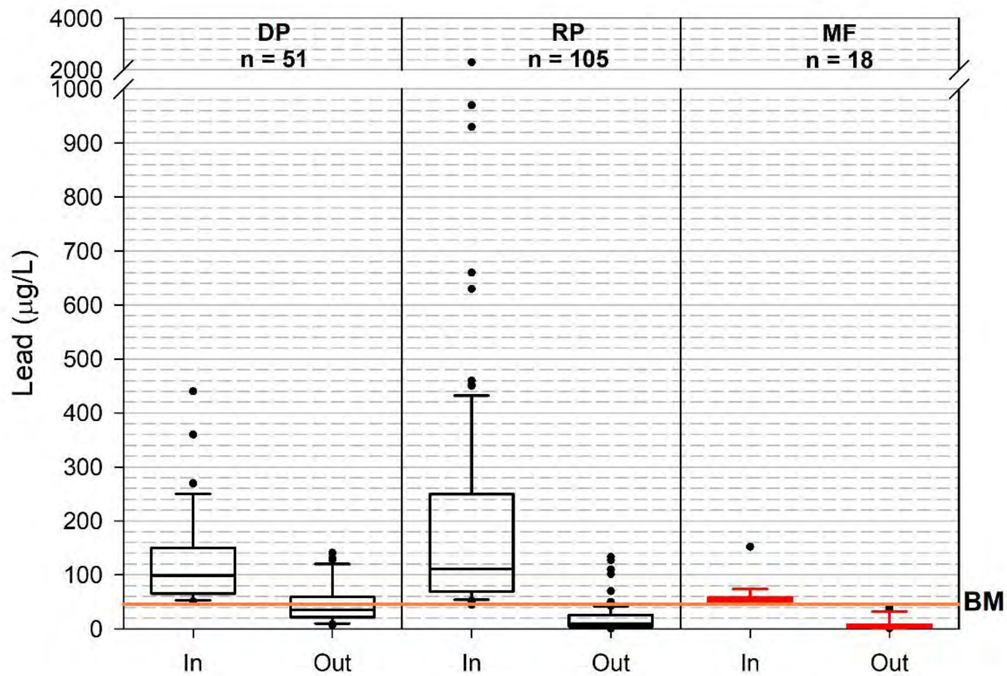

FIGURE E-9 International BMP Database comparison of influent and effluent concentrations for total lead compared to the soft-water benchmark. DP = dry detention ponds; MF = media filters; RP = wet retention ponds.

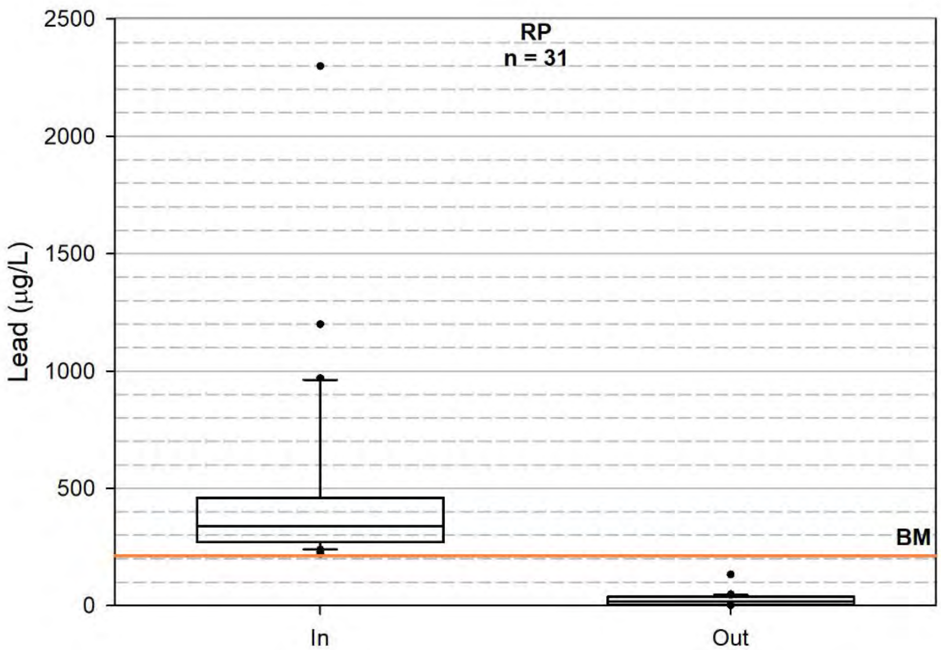

FIGURE E-10 International BMP Database comparison of influent and effluent concentrations for total lead compared to the soft-water benchmark. RP = wet retention ponds.

Total Zinc

Of the three sedimentation devices, four filtration systems, and two treatment trains examined at industrial stormwater sites, only one treatment train had effluent concentrations that consistently met the soft-water benchmark of 80 µg/L (>90 percent of the monitored storm events; see Figure E-11). One sedimentation device and three filtration devices were able to meet the soft-water benchmark for between 25 and 50 percent of the storm events. All other devices were unable to meet the benchmark for more than 10 percent of the storm events.

Three sedimentation systems, one media filter, and one treatment train had influent concentrations that exceeded the hard-water benchmark of 230 µg/L for eight or more storm events (see Figure E-12). For one of the three sedimentation systems and one treatment train, the systems' performance met the hard-water benchmark of 230 µg/L for between 50 and 75 percent of the storm events. The other three systems (two sedimentation and one filtration) met the hard-water benchmark for between 25 and 50 percent of the monitored storm events.

The International BMP Database results (see Figure E-13) highlight the ability of the five types of systems to remove total zinc from the influent runoff in comparison to the soft-water benchmark. Four of the five systems examined (media filter, bioretention systems, wetland, and wet retention ponds) were able to meet the soft-water benchmark of 80 µg/L for >50 percent of the monitored storm events with the media filter and bioretention system able to meet the benchmark for >90 percent of the monitored storm events.

Figure E-14 highlights the ability of the treatment systems to meet the hard-water benchmark of 230 µg/L when their influent concentrations exceeded the hard-water benchmark.

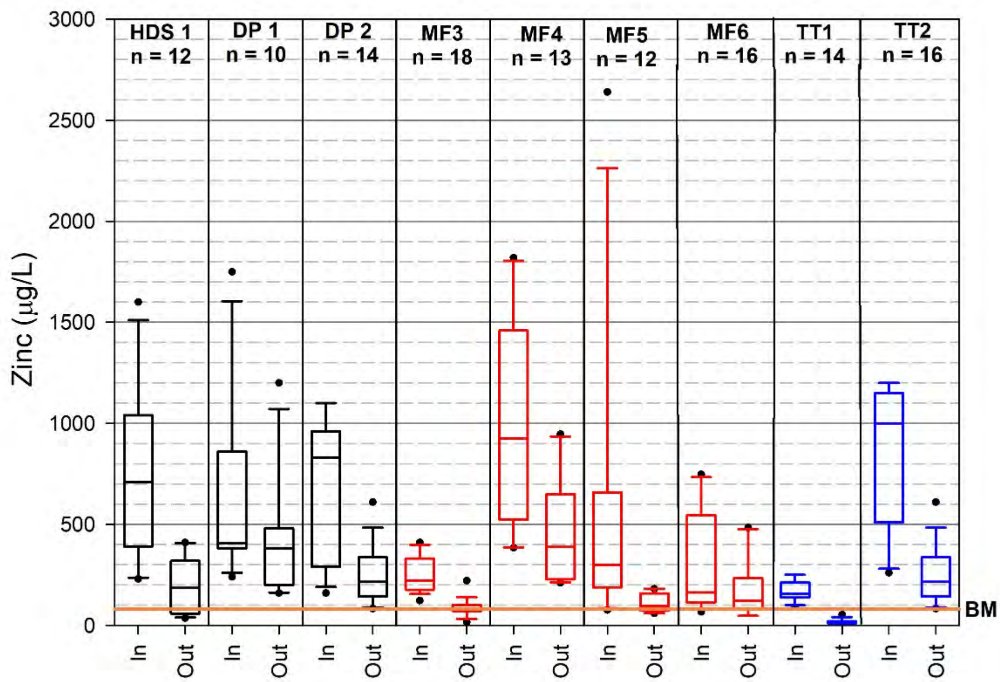

FIGURE E-11 Total zinc influent versus effluent concentrations comparison to the soft-water benchmark. DP = dry detention pond; HDS = hydrodynamic separator;; MF = media filter; TT = treatment train. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

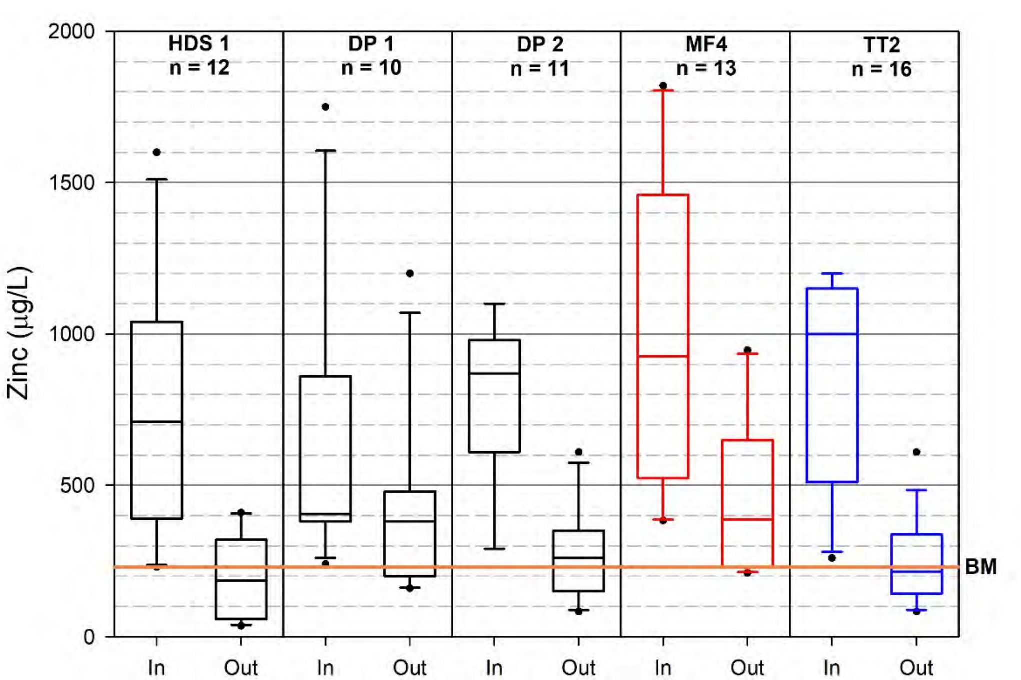

FIGURE E-12 Total zinc influent vs. effluent concentrations comparison to the hard-water benchmark. HDS = hydrodynamic separator; MF = media filter; TT = treatment train. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

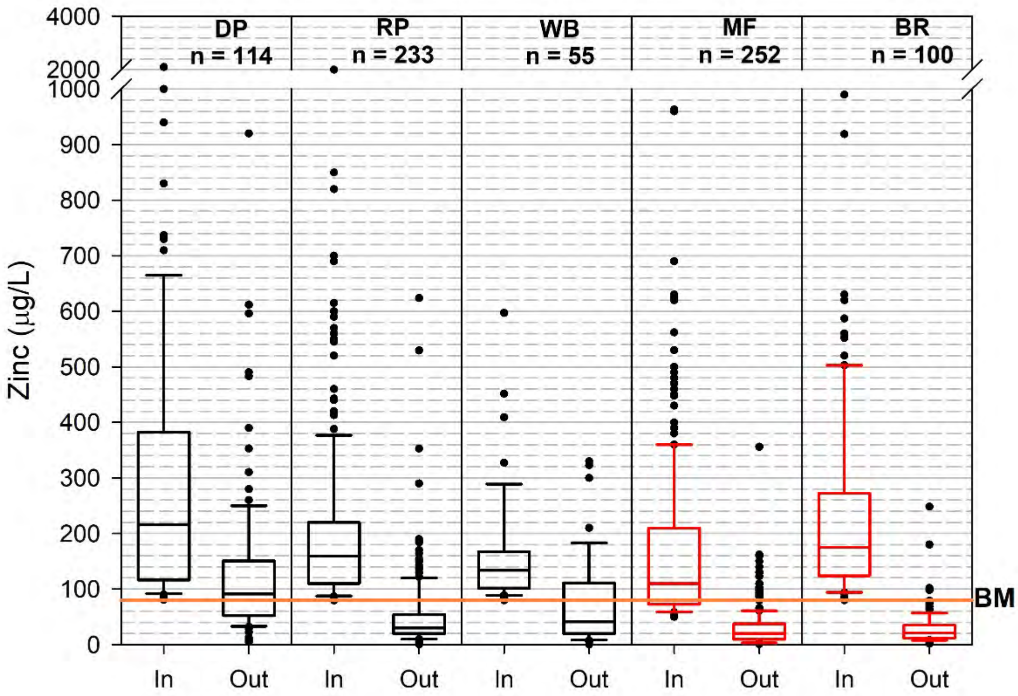

FIGURE E-13 International BMP Database comparison of influent and effluent concentrations for total zinc compared to the soft-water benchmark. BR = bioretention; DP = dry detention ponds; MF = media filters; RP = wet retention ponds; WB = wetlands.

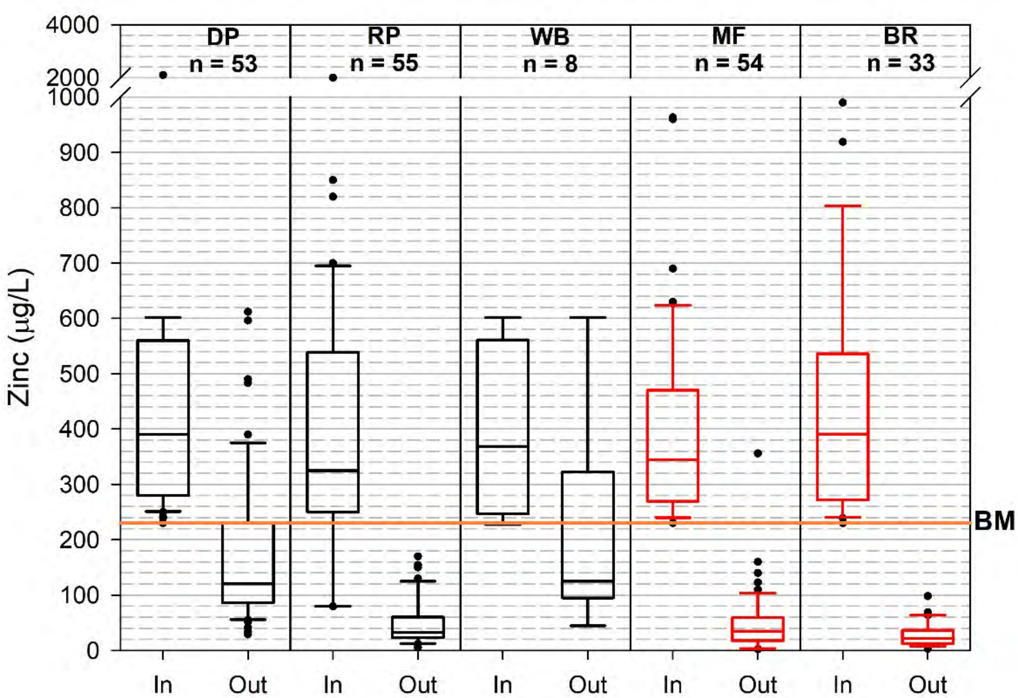

FIGURE E-14 International BMP Database comparison of influent and effluent concentrations for total zinc compared to the hard-water benchmark. BR = bioretention; DP = dry detention ponds; MF = media filters; RP = wet retention ponds; WB = wetlands.

The wet retention pond, the media filters, and the bioretention system were able to meet the hard-water benchmark for >90 percent of the storm events monitored, while the detention pond and wetland were able to meet the hard-water benchmark for between 50 and 75 percent of the storm events.

Chemical Oxygen Demand (COD)

Chemical oxygen demand has been used in the MSGP as a surrogate for other organic contaminants such as hydraulic oils and organic chemicals. For the individual site analysis, only one hydrodynamic separator and one treatment train had sufficient sample pairs with influent concentrations that exceeded the benchmark of 120 mg/L (see Figure E-15). The analysis showed that the hydrodynamic separator was able to meet the effluent benchmark concentration for less than 25 percent of the monitored events while the treatment train could meet the effluent benchmark concentration for between 50 and 75 percent of the monitored storm events.

Data from the International BMP Database show that wet retention pond and bioretention systems were able to reduce COD effluent concentrations to less than the benchmark for >90 percent of the storm events (see Figure E-16). The dry detention pond was able to reduce the influent COD concentrations to below the benchmark concentration for between 25 and 50 percent of the storm events monitored.

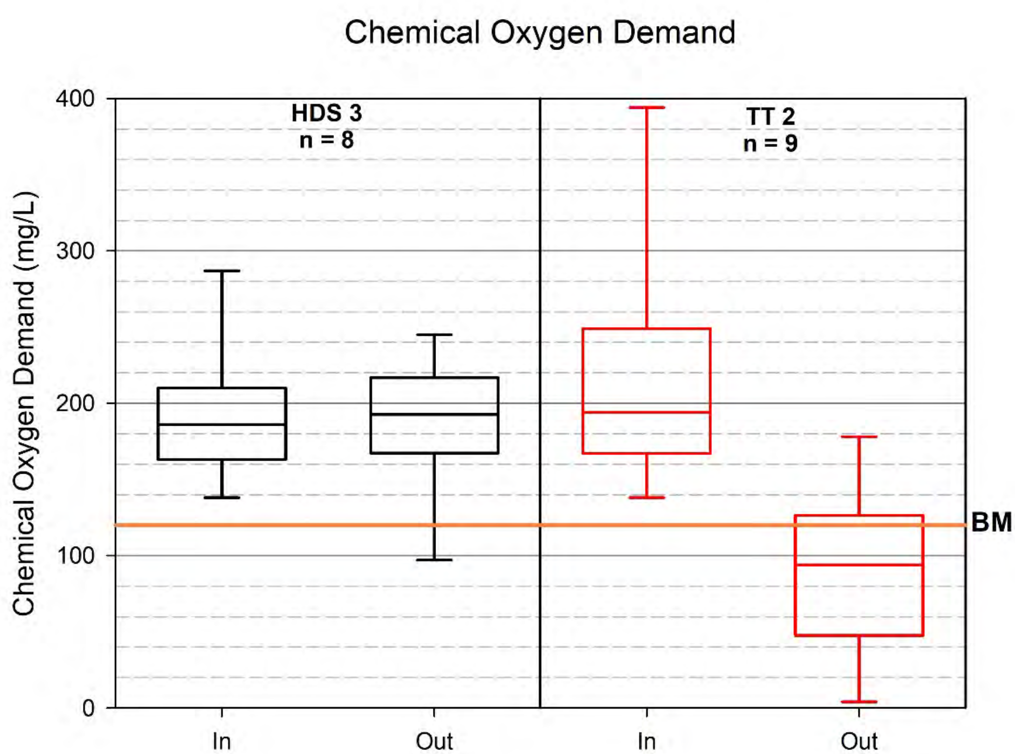

FIGURE E-15 Chemical oxygen demand influent versus effluent concentrations. HDS = hydrodynamic separator; MF = media filter; TT = treatment train. The number of storm-event samples used in each analysis is shown on the graph below each treatment system.

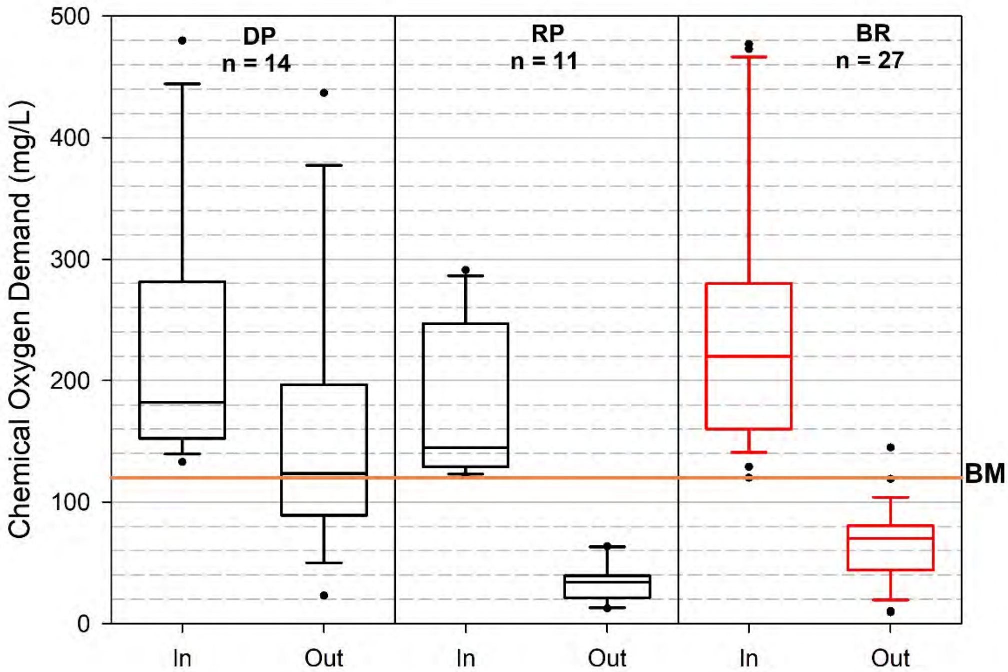

FIGURE E-16 International BMP Database comparison of influent and effluent concentrations for chemical oxygen demand. BR = bioretention; DP = dry detention ponds; MF = media filters; RP = wet retention ponds; WB = wetlands.

Appendix F

Biographical Sketches of Committee Members and Staff

Allen P. Davis, *Chair,* is professor of civil and environmental engineering and Charles A. Irish, Sr. Chair in Civil Engineering at the University of Maryland, College Park. Dr. Davis's interests are in aquatic and interfacial environmental chemistry. For two decades, he has been investigating sources and treatment of pollutants in urban stormwater runoff with a focus on nature-based practices, particularly bioretention. In 2010, he was awarded the A. James Clark School of Engineering Faculty Outstanding Research Award recognizing exceptionally influential research accomplishments related to urban stormwater quality, its management, and the concept of low-impact development. He is author or co-author of more than 120 peer-reviewed journal articles and a text on stormwater management for smart growth. From 2001 to 2010, he was Director of the Maryland Water Resources Research Center. He is currently Editor-in-Chief of the new ASCE *Journal of Sustainable Water in the Built Environment*. He is a Licensed Professional Engineer in Maryland, Fellow of the American Society of Civil Engineers, Fellow of the ASCE Environmental and Water Resources Institute, and a Diplomate, Water Resources Engineer. Dr. Davis holds B.S., M.C.E., and Ph.D. degrees from the University of Delaware.

Roger Bannerman worked as an environmental specialist for the Wisconsin Department of Natural Resources for 41 years. For much of that time, he directed research projects investigating urban runoff. Topics addressed by his studies over the years include the quality of urban streams, identification of problem pollutants in stormwater, toxicity of stormwater pollutants, effectiveness of different stormwater control practices, sources of stormwater pollutants, selection of cost-effective control practices, and benefits of low-impact development. He has applied these results to management plans developed for most urban areas in Wisconsin. This includes the calibration of the urban runoff model called the Source Loading and Management Model. The results of his research projects have been used to develop Wisconsin's administrative rules that regulate stormwater management. Mr. Bannerman received his B.S. degree in chemistry from Humboldt State College and an M.S. degree from the University of Wisconsin in water chemistry.

Shirley E. Clark is a professor of environmental engineering at Penn State Harrisburg and chair of Penn State Harrisburg's graduate programs in environmental and civil engineering. Dr. Clark's research has primarily focused on improving the effectiveness of stormwater treatment systems. She has evaluated two manufactured treatment systems—inclined plate settlers and upflow filter systems—to document their performance for the Environmental Protection Agency's Environmental Technology Verification Program. Her laboratory, in mesocosm studies, optimized bioretention media to treat stormwater runoff at Boeing's Santa Susana facility, including determining media performance for removing pollutants such as dioxin and radionuclides. Her recent industrial stormwater research focused on determining the performance of various treatment systems (hydrodynamic separators, ponds, filters, and chemical treatment systems) in operation at multiple recycling facilities. Dr. Clark holds a B.S. degree in chemical engineering from Washington University, an M.S.C.E. degree in environmental engineering, and a Ph.D. degree in environmental health engineering, both from the University of Alabama at Birmingham.

L. Donald Duke is a professor of environmental studies at Florida Gulf Coast University. He has worked in energy efficiency, water quality analyses, and stormwater management for private consulting firms and served for 2 years in the total maximum daily load unit of the California Water Board, Los Angeles region. Dr. Duke's research interests are in water resources including water quality assessments of natural systems; watershed-scale and regional-scale planning and management strategies; and federal, state, and local policies and programs for flood control. He applies quantitative methods and engineering analyses to environmental data as a means to assess public policies with the intent to assess effectiveness of environmental policies and decision making. Dr. Duke has worked with various federal, state, and local agencies on local and regional-scale management tools, including hazardous waste mitigation and stormwater compliance plans. Dr. Duke earned his B.S. degree in civil engineering and B.A. degree in English from the University of Pennsylvania, and his M.S. and Ph.D. degrees from Stanford University in civil and environmental engineering with a focus on resources planning.

Janet S. Kieler is the director of environmental programs for Denver International Airport. In this role, Ms. Kieler is responsible for directing environmental compliance and performance including environmental planning and analysis related to air quality, water quality, waste, wetlands, and endangered species. Previously, Ms. Kieler served for 11 years as the permits section manager for the Water Quality Control Division of the Colorado Department of Public Health and Environment, where she oversaw the issuance of state and National Pollutant Discharge Elimination System permit actions, compliance monitoring through field inspection and review of self-reported data, data management, and business processes. Ms. Kieler also worked for Denver International Airport previously for 8 years, where she was responsible for industrial stormwater permit compliance, management of contracted operations to recycle captured aircraft deicing fluid, and planning and designing new infrastructure to support collection, storage, recycling, and disposal of spent aircraft deicing fluid. Ms. Kieler also worked 6 years in environmental consulting. Ms. Kieler earned her B.S. in environmental engineering from Northwestern University.

John D. Stark is a professor of ecotoxicology at the Washington State University (WSU). Dr. Stark is also the director of the Washington Stormwater Center and a member of the Puget Sound Partnership Science Panel. He also runs the WSU Salmon Toxicology Research Laboratory. Dr. Stark specializes in ecological risk assessment of threatened and endangered species with particular emphasis on salmon and their food, and has conducted research on the effects of polluted stormwater runoff on salmon and aquatic invertebrate health. He holds a B.S. degree in biology from Syracuse University, a B.S. degree in forest biology from SUNY Environmental Science and Forestry School, an M.S. degree in entomology from Louisiana State University, and a Ph.D. degree in entomology and pesticide toxicology from the University of Hawaii.

Michael K. Stenstrom is Distinguished Professor in the Civil and Environmental Engineering Department at the University of California, Los Angeles. His research and teaching are in the environmental engineering area with emphasis on biological treatment methods and applications of computing technologies to environmental engineering research. Over the past 15 years, Dr. Stenstrom has performed research to characterize stormwater and minimize its impacts on the environment. Dr. Stenstrom's expertise is in process development for stormwater management and wastewater treatment systems, including mathematical modeling and optimization. He applies these mathematical techniques along with statistical methods to urban runoff and stormwater issues. Through his research, he has developed several models for estimating pollutant discharges in stormwater runoff. Dr. Stenstrom received his B.S. in electrical and computer engineering and his M.S. and Ph.D. in environmental systems engineering from Clemson University.

Xavier Swamikannu is an assistant adjunct professor at the Institute of Environment and Sustainability at the University of California, Los Angeles (UCLA). He previously worked for more than 20 years at the California Water Board, Los Angeles region, and served as its chief of stormwater programs, partnering with UCLA faculty to fund research and bring science into public decision making. His research interests include the progress of regulatory policy for water quality protection, its implementation, and effectiveness in the United States and California. Areas of focus include the potential water quality impacts of hydraulic fracturing, eliminating barriers to the implementation of green infrastructure, better understanding of the effectiveness of stormwater control measures, and standardizing water quality modeling methods for use by local governments in surface water pollution control planning. Dr. Swamikannu was a U.S. Fulbright Senior Environmental Leadership Fellow at the Government of India's Central Pollution Control Board. He received his B.S degree in natural and chemical sciences from St. Joseph's College in Bangalore, India, his M.S. degree in environmental sciences from Texas Christian University, and his doctorate degree (D.Env.) in environmental science and engineering from UCLA.

STAFF

Stephanie E. Johnson, study director, is a senior program officer with the Water Science and Technology Board. Since joining the National Academies in 2002, she has worked on a wide range of water-related studies, on topics such as desalination, wastewater reuse, contaminant source remediation, coal and uranium mining, coastal risk reduction, and ecosystem restoration. Dr. Johnson received her B.A. from Vanderbilt University in chemistry and geology, and her M.S. and Ph.D. in environmental sciences from the University of Virginia.

Carly Brody is a senior program assistant for the National Academies' Water Science and Technology Board and the Board on Earth Sciences and Resources. Prior to joining the National Academies in 2017, she interned with the Center for Transboundary Water Management at the Arava Institute for Environmental Studies. She received a B.A. in environmental science and policy and American studies from the University of Maryland, College Park.

PREPUBLICATION COPY

Appendix G

Disclosure of Conflict of Interest

The conflict of interest policy of the National Academies of Sciences, Engineering, and Medicine (http://www.nationalacademies.org/coi) prohibits the appointment of an individual to a committee authoring a Consensus Study Report if the individual has a conflict of interest that is relevant to the task to be performed. An exception to this prohibition is permitted if the National Academies determines that the conflict is unavoidable and the conflict is publicly disclosed. A determination of a conflict of interest for an individual is not an assessment of that individual's actual behavior or character or ability to act objectively despite the conflicting interest.

Michael Stenstrom was determined to have a conflict of interest in relation to his service on the Committee on Improving the Next-Generation EPA Multi-Sector General Permit for Industrial Stormwater Discharges because he serves on the Santa Susana Stormwater Expert Panel, a committee constituted to provide guidance to Boeing and the Los Angeles Regional Water Quality Control Board on stormwater management at the Santa Susana site.

The National Academies concluded that in order for the committee to accomplish the tasks for which it was established, its membership must include at least one person with current experience in, and knowledge of, statistical and numerical methods in the analyses of industrial stormwater data. As described in his biographical summary, Dr. Stenstrom has extensive current experience developing models to estimate pollutant discharges in stormwater runoff, and in applying mathematical modeling and statistical methods to the analysis of urban and industrial stormwater data.

The National Academies determined that the experience and expertise of Dr. Stenstrom was needed for the committee to accomplish the task for which it has been established. The National Academies could not find another available individual with the equivalent experience and expertise who does not have a conflict of interest. Therefore, the National Academies concluded that the conflict was unavoidable.

The National Academies believed that Dr. Stenstrom would serve effectively as a member of the committee, and the committee can produce an objective report, taking into account the composition of the committee, the work to be performed, and the procedures to be followed in completing the study.