EXECUTIVE SUMMARY

Over the past three decades, both public and private entities have monitored urban stormwater Best Management Practices (BMPs) for many purposes, often related to efforts to comply with the continually evolving federal Clean Water Act. In 1996, the U.S. Environmental Protection Agency (EPA) entered into a cooperative agreement with the American Society of Civil Engineers (ASCE), led by members of the Urban Water Resources Research Council (UWRRC), to initiate the International Stormwater BMP Database ("BMP Database") project. The BMP Database goals were multifaceted, with key goals including development of a standardized set of monitoring and reporting protocols for urban stormwater BMP performance studies and assembling and summarizing historical and on-going BMP study data into a standardized format to facilitate performance analysis. During the initial stages of the BMP Database project, it became clear that better guidance was needed regarding stormwater BMP monitoring, particularly if monitoring results were to be valuable to the broader technical, management, and regulatory community. As a result, the 2002 version of this monitoring manual was developed to promote collection of more useful and representative data associated with BMP studies, as well as more consistent reporting of monitoring results appropriate for inclusion in the BMP Database. Since that time, both the BMP Database project and stormwater management practices have continued to evolve, prompting this second release of the manual.

The purposes of this updated Manual are primarily twofold:

1) Improve the state of the practice by providing and enhancing a recommended set of protocols and standards for collecting, storing, analyzing, and reporting stormwater BMP monitoring data that will lead to better understanding of the function, efficiency, and design of urban stormwater BMPs.

2) Provide monitoring guidance for "Low Impact Development" (LID) strategies at the overall site level (e.g., monitoring overall sites with multiple distributed stormwater controls).

The audience for this Manual is targeted primarily to those who possess a basic level of knowledge regarding stormwater quality, hydrology, and regulatory issues. The EPA website (www.epa.gov) and other state and local websites can be referenced for additional guidance and background information.

This Manual provides guidance for all stages of BMP monitoring programs ranging from the early stages of study design to the end stages of data interpretation and reporting. Guidance is provided for monitoring a broad range of individual BMPs as well as overall site monitoring with multiple distributed BMPs, such as is the case with LID sites. This Manual focuses primarily on the collection, reporting, and analysis of water quantity and quality measurements at the heart of quantitative BMP efficiency projects. It does not address in detail sediment sampling methods and techniques, biological assessment, monitoring of receiving waters, monitoring of groundwater, streambank erosion, channel instability, channel morphology, or other activities that in many circumstances may be as, or more,

useful for measuring and monitoring water quality for assessing BMP efficiency. In some cases, references for additional information on these subjects have been provided. The Manual focuses on these topics:

1) Designing the Monitoring and Reporting Program (Chapter 2): A well-thought out and systematically designed monitoring program is essential to a cost-effective study design that yields meaningful results. The Manual builds upon guidance provided by EPA (2002) in its *Guidance for Quality Assurance Project Plans*, providing additional guidance specific to stormwater BMP monitoring and the BMP Database protocols.

2) Methods and Equipment for Stormwater BMP Monitoring (Chapters 3 and 4): In order to obtain high-quality data in BMP monitoring studies, it is necessary to select the proper precipitation, flow, and water quality sample collection and monitoring equipment and procedures. Chapter 3 provides information and guidance related to flow and precipitation monitoring in the context of BMP monitoring, and Chapter 4 focuses on water quality sample collection and analysis methods.

3) Implementing the Monitoring Program (Chapter 5): In order for well designed monitoring programs to result in high quality data, personnel must be properly trained, equipment properly installed, calibrated and maintained, samples correctly collected and analyzed, and data properly reported. Failures at this stage of the monitoring program can result in data that cannot be used to draw valid conclusions regarding BMP performance.

4) Data Management, Evaluation and Reporting of Results (Chapter 6): Once data have been collected from a monitoring program, the data need to be compiled and managed in a manner that reduces introduction of errors and enables ready access for future reference, and ideally, facilitates incorporation into the BMP Database (www.bmpdatabase.org). A strong data management and reporting system helps to ensure that studies are documented in a manner that enables long-term use of the data and transferability to the local, regional, national, and international state of the practice. As part of this chapter, an overview of data reporting requirements for the BMP Database is provided, describing study features such as test site, watershed, and BMP design characteristics, instrumentation, and monitoring data (precipitation, flow, water quality).

5) BMP Performance Analysis (Chapter 7): Over the past decade, the BMP Database project has developed recommended performance analysis approaches for BMP studies. This chapter describes these methods, as well as pitfalls to avoid misleading interpretation of data.

6) Low Impact Development(LID)/Distributed Controls Monitoring (Chapter 8): Building upon the concepts introduced for monitoring individual BMPs, this chapter provides guidance on specific challenges associated with monitoring distributed controls at the site level, particularly focused on LID. In these types of studies, a variety of practices such as amending soils to promote infiltration of runoff,

disconnecting impervious areas, use of pervious paving materials, implementation of rain gardens on multiple lots, use of swales instead of curb and gutter, and other runoff reduction practices may be implemented. As a result, unique challenges exist in collecting and analyzing the performance of such sites. Although the state of the practice continues to evolve on this topic, this chapter provides basic guidance on properly designing such studies and suggests approaches for meaningful data interpretation.

7) Data Interpretation and Performance Evaluation of LID Studies (Chapter 9): The careful interpretation and evaluation of data is critical in reaching appropriate conclusions about volume reduction and the water quality benefits of LID. Chapter 9 suggests approaches to interpret and evaluate hydrologic and water quality data, both absolutely and in comparison to conventional BMP implementations. Although LID and conventional BMP studies have some similarities, there are also some key differences that warrant LID-specific guidance. A few representative differences include: LID strategies tend to emphasize reduction in volume rather than reduction in concentration; LID studies are less likely to have an "influent stream" conducive to inflow-outflow comparisons; and the time scale of monitoring required to obtain representative data may be much longer than for a conventional studies.

8) LID Case Studies (Chapter 10): This chapter summarizes key aspects of site-level LID studies conducted in Cross Plains, WI; Burnsville, MN; Jordan Cove, CT; and Somerset, MD. All of these studies are based on a paired watershed approach incorporating a reference and test watershed, either geographically or over time.

9) Supplemental Resources on Key Topics (Appendices): Many of the topics addressed in this manual are complex and/or require considerable detail for proper discussion. For this reason, supplemental appendices are provided as follows:

   - Appendix A: Data Entry Forms for International Stormwater BMP Database: Forms useful for recording BMP monitoring study information, key watershed and BMP design criteria, instrumentation and monitoring data for precipitation, flow, and water quality are summarized in Appendix A, corresponding to the data entry spreadsheets used in the BMP Database. The Stormwater BMP Database website (www.bmpdatabase.org) should be referenced to obtain the most current version of these spreadsheets for data entry.

   - Appendix B: Comparison of Data Analysis Approaches: This appendix contains a discussion of the various BMP performance analysis approaches that have been commonly used historically, but are not currently recommended by the BMP Database project. Nonetheless, some of these techniques are used by others, so comments are provided regarding the strengths and weaknesses of each approach.

   - Appendix C: Determining Required Number of Samples: Depending on the objectives established for the monitoring program, the number of samples required for meaningful interpretation of the data can vary substantially. This appendix provides guidance in determining the number of samples needed to

obtain statically significant monitoring data. It also includes charts for estimating the number of samples required to observe a statically significant difference between two populations for a various levels of confidence and power.

- Appendix D: Error Analysis: Properly accounting for errors and uncertainty in BMP monitoring data is important to avoid erroneous conclusions regarding BMP performance. This appendix describes methods for calculating expected errors in field measurements.

- Appendices E and F: Statistical Information: Although this manual does not provide a primer on statistics, Appendix E provides some basic information needed to properly apply statistics in the context of stormwater BMP monitoring. For example, a table for estimating arithmetic descriptive statistics based on descriptive statistics of log-transformed data is included. Appendix F provides basic information related to log-normal distributions.

This Manual addresses methods that were in use at the time it was written. As the state of the practice and the design of monitoring equipment progress, new monitoring approaches and techniques, more sensitive devices, and equipment based on new technologies will likely be employed. Although the technology may change somewhat from that described herein, most of the basic flow and water quality monitoring methods discussed in this document have a long history of use and will most likely remain viable even as new and different technologies emerge.