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Chapter 1

General introduction and book layout

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ABSTRACT

This introductory chapter indicates why well-defined, high-standard, and reliable monitoring is a key aspect in the necessary evolution of urban drainage and stormwater management and why it should become routine practice. It provides a framework, guidelines, and recommendations to define monitoring objectives and means. It also presents the structure and the chapters of the rest of the book.

Keywords: Metrology, monitoring, urban drainage and stormwater management.

1.1 INTRODUCTION

In this book, urban drainage and stormwater management (UDSM) infrastructures (Figure 1.1) designate both traditional grey infrastructures (sewer systems and their related facilities) and growing green infrastructures (green roofs, infiltration trenches, raingardens, etc.) also referred to as sustainable urban drainage systems (SUDS), low impact development (LID), etc. (Fletcher *et al.*, 2015). UDSM has contributed significantly to sustain urban areas as safe, healthy, and comfortable places to live, as such the need to maintain and operate them is beyond discussion. However, due to increasing pressures in

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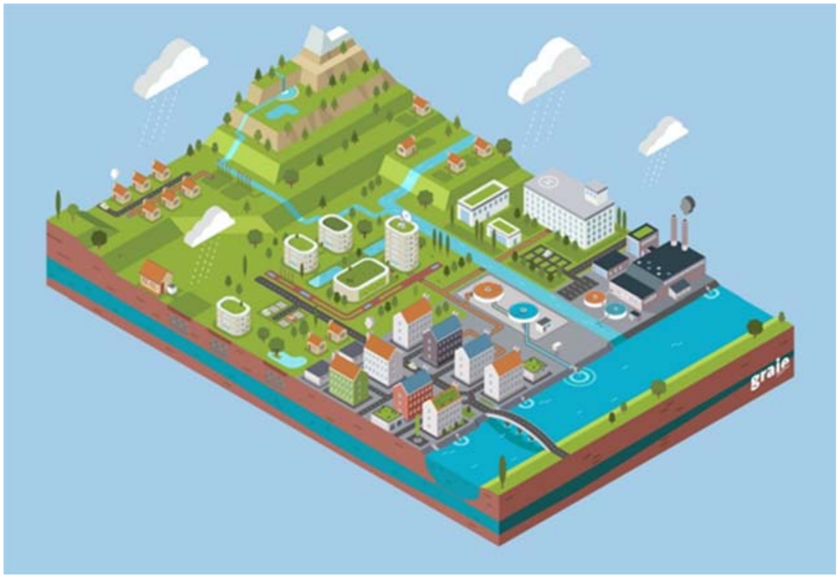

Figure 1.1 Urban drainage and stormwater management systems. *Source*: GRAIE.

terms of climate change, growth of urban population worldwide, need for reducing use of material and energy, environmental and societal demands and restrictions of these infrastructures, the need to better understand the processes that make them work increases over time. This applies to existing systems, in terms of gaining knowledge how to optimize their effectiveness and efficiency, on the one hand, while on the other hand there is a need to transfer experience obtained in designing, operating, and maintaining these systems into guidelines for the design of future systems. The obvious manner to achieve this is by quantifying the relevant processes through observation. However obvious this may seem, such an approach has been applied on a relatively modest scale over the last few decades and is so far limited mostly to the scientific community and to a few forefront practitioners only. The reason for this can only be guessed. Obviously over the years a(n) (informal) code of practice evolved in which inefficiency and acting on very limited knowledge were accepted, while at the same time design rules are largely based on historically developed empirical rules, in most cases supported by some form of extensive hydrological/hydraulic modelling. Indeed, this approach results in systems that do function, be it at an unknown level of effectiveness and efficiency on the one hand, while being responsible for unnecessary, but apparently accepted, hindrance and inefficiency on the other. Further, there exists the impression that the added value of monitoring is largely overlooked in practice as monitoring is often framed as 'expensive, while the results may even contain an unwelcome truth'. This book aims at bringing together and making available knowledge and experience (for the good and the bad) of monitoring UDSM systems obtained over recent decades to enable stakeholders to make decisions on monitoring on a more rational and well-informed basis.

As in any field of (applied) science, models or abstract perceptions of the processes under study are used, along with observations on these processes. The latter can be either qualitative or quantitative, the former can be used for initial validation of process descriptions while the latter are merely used to quantify or provide a reference for models/process descriptions.

In the field of UDSM, the models applied are based on a wide range of engineering sciences like hydraulics, hydrology, (bio)chemistry, geohydrology, and meteorology.

Over recent decades, significant progress has been made in the further development of models and model concepts as well as in obtaining quantifying observations. Schilperoort (2011) reports an interesting evolution: within a time span of 20 years the time needed for technicians, engineers and scientists to obtain one 'correct' data point from a monitoring project in an urban drainage system has decreased by a factor of 1000 (from roughly 15 minutes in the early 1990s to 1 second in 2010). Monitoring, that is, collecting data and information, has made swift progress due to developments in adjacent fields of science and technology, most notably sensor technology, data communication and data processing capabilities. Although these fields are still progressing, the area of water quantity related observational methods seems to have reached a certain maturity in the sense that a balance can be made on the progress of the last two decades. The book that lies before you will therefore focus on metrology in UDSM, restricted to making observations on the quantitative load on UDSM systems (i.e., rainfall and for wastewater systems the wastewater load) and the response of these systems to these loads (i.e., discharges, water levels, in- and exfiltration, evaporation, etc.). Therefore, it will not go into observations on water quality parameters but will be restricted to the hydraulic and (geo)hydrological processes in UDSM systems. Future extensions into water quality or the rapidly developing subject on techniques for inspection of the status of UDSM related assets, are likely to evolve though.

The next two sections discuss metrology and monitoring applied to UDSM. The last section presents the structure and the chapters of the book and its companion website.

1.2 METROLOGY IN A BROADER SENSE REFLECTING ON UDSM

Metrology is the science of 'measuring', a formal definition is given by the International Bureau of Weights and Measurements as '*the science of measurements, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology*' (see: https://web.archive.org/web/20110927012931/http://www.bipm.org/en/convention/wmd/2004/ (visited 23/12/2020)). Another, but largely similar, definition is formulated in the VIM (International Vocabulary of Metrology): '*Metrology includes all theoretical and practical aspects of measurement, whatever the measurement uncertainty and field of application*' (Joint Committee for Guides in Metrology [JCGM], 2012).

Metrology as a science can be traced back to the French revolution that supplied the political motivation for standardization of units to be used in France. One of the most known and acknowledged results from this is the International System of Units (SI system) as we know it today. The main activities within metrology are: (i) define standard units, (ii) materialize these standards and (iii) arrange a system of traceability for units applied in practice to the formal standard units. With respect to UDSM, the latter activity can be identified to be the most relevant, and can be summarized in the question: 'How can we be sure that monitoring data obtained are in line with the standards they reportedly claim to have?' Basically, all activities, decisions and choices made in planning, designing, operating, and reporting on monitoring UDSM systems should be in line with contributing to answer this main metrological question to ensure the sought for data- and information-yield.

Metrology can further be sub-categorized into (i) scientific, fundamental metrology, (ii) applied (technical, industrial) metrology and (iii) commercial/legal metrology. In the field of UDSM one deals, in most cases, predominantly with the second category because UDSM is not a field of fundamental science but should rather be regarded as a hodgepodge of a range of scientific and technological fields. However, in practical cases the third category is applicable as well (e.g., when the operation of systems is delegated to commercial third parties or in cases where a dispute arises on responsibility and accountability for damage due to e.g., flooding). Overall, metrology provides a sound basis on which uniformity with respect to quality assessment and control, and communication with respect to monitoring can be defined.

Like any technical domain, metrology has its own terminology. In this book, the definitions proposed in the VIM (JCGM, 2012) are used. The most important definitions are also given in the appendix of this book, illustrated with examples taken from UDSM.

1.3 MAIN ELEMENTS IN UDSM METROLOGY

As illustrated in Figure 1.2, monitoring should obviously serve some objectives. However obvious this may seem, in many practical cases such objectives are not, or only vaguely, defined. For example: in practice objectives like '*obtaining insight into the functioning*' are frequently formulated. But insight is highly subjective and depends not just on the information it provides. If there is no metric to test whether a monitoring activity has achieved its goal, then there can be no sound basis to evaluate the effectiveness or efficiency of the applied monitoring. Therefore, it is emphasized that it is of utmost importance to formulate an agreed and well-defined objective, prior to starting a monitoring project.

For example: when the objective is to obtain data to calibrate a model, such an objective can be translated into demands being put on the parameters to be monitored (depending on the model chosen and the level of detail sought), the number and exact locations of the monitoring points, and demands on sampling frequency and allowed uncertainties of the measuring data obtained. These subjects directly refer to Chapters 6, 7 and 8 of this book. Another objective may be to evaluate the volume of diluted sewage spilt by CSOs (combined sewer overflows) into receiving water bodies, in such a case, of course, the location and geometry of the CSO construction has to be known along with the allowed uncertainty of the volume. These two conditions narrow down the options at hand, depending on the geometry either a device for discharge measurement can be installed in a conduit (see Chapter 3), or a discharge-flow depth relationship over some device (a weir, an orifice, a Venturi flume) has to be established, depending on the uncertainty allowed, the proper equipment and sampling frequency have to be defined. Examples of more complex objectives (quality based real time control) can be found in literature (Schilperoort, 2011; van Daal-Rombouts, 2017), as well as effects of maintenance on performance of urban drainage systems (van Bijnen, 2018), and long term observation for scientific purposes (see e.g. OTHU – Observatoire de Terrain en Hydrologie Urbaine, http://www.graie.org/othu/ (visited 23/12/2020)).

Taking the objective(s) as a starting point, the information need can be formulated, which in turn is the basis to derive several fundamentally important parameters, such as:

- The quantities to be monitored.
- The minimum timespan or number of events of interest that has to be covered.
- The number and the locations of sensors, considering practical issues like:
    - Accessibility.
    - Availability of power supply and data communication.
    - Sampling frequency.
    - Required or accepted level of uncertainty in the results needed for the objective.

Based on this information a first estimate of the means needed can be made (purchasing or renting equipment, construction activities, maintenance, personnel needed in terms of quantity and qualifications), allowing for a first check of efficiency and effectiveness. If during this stage it becomes obvious that the means needed are more than can be justified, a decision has to be made either to accept

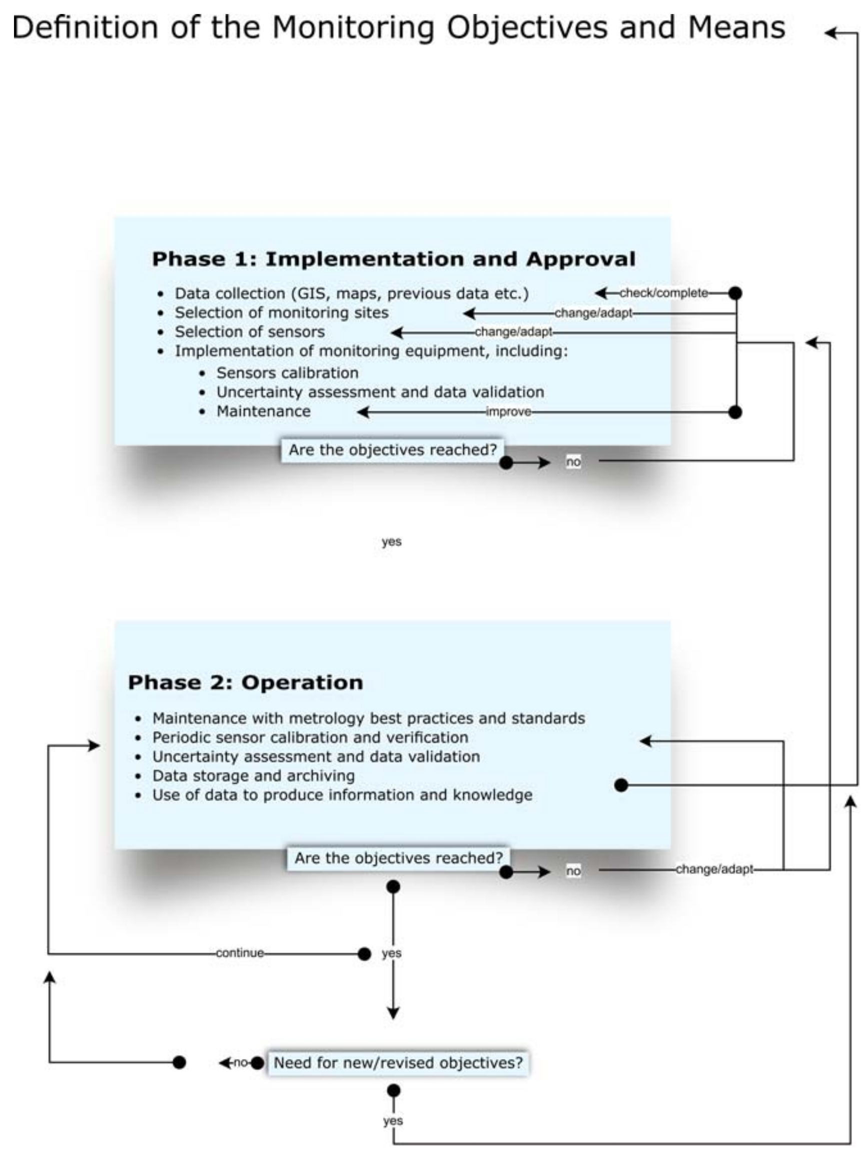

Figure 1.2 Main activities in monitoring. *Source*: Francois Clemens-Meyer (Deltares/TU Delft/NTNU).

lower standards or abandon the initiative completely. If, for example, the objective is to obtain information to justify an investment of 1 million euros and the estimated means to obtain this information amount to costs in the same order of magnitude, questions should be raised. Of course, it has to be emphasized that not all objectives can easily be expressed in monetary terms, therefore in many cases a managerial/political decision has to be made in balancing monitoring costs against achieving environmental or societal objectives. Basically, the task of a scientist/engineer or practitioner is limited to estimating as accurately as possible the expected costs, quality and quantity of the information obtained from a monitoring initiative.

In the case where the initiative passes the first phase, in the sense that the planned activities are expected to achieve the information within the envelope of available means to answer to the objectives set, the operational phase starts.

During operation, the main activity is to make sure that the installed system keeps performing at the desired level, which implies frequent evaluation of all components involved, regular checks of data quality, and calibration of measuring devices along with periodic data analysis to ensure the information obtained meets the standards as defined in the objectives. Ultimately this may lead to adaptations in the set-up, or the equipment applied. Especially in long-term monitoring campaigns, the objectives may be subject to change, requiring a redesign or (major) adaptations (e.g., Walcker *et al.*, 2018). An iterative approach is thus essential, requiring regular evaluation of the obtained data/information. At the present state of the art, we have not yet reached the level of 'plug and play', just installing a system and leaving it alone remains at present, to some extent, a matter of 'plug and pray'.

1.4 STRUCTURE OF THE BOOK AND THE LINKS BETWEEN CHAPTERS

This book contains 12 chapters along with several appendices and a comprehensive body of references for further reading.

The chapters which follow this introduction chapter are listed below.

- Chapter 2 'Sensors for rain measurements' deals with measuring systems and components (including sensors) and globally addresses two main fields: namely rainfall inputs on UDSM systems on the one hand and the systems response to these inputs on the other.
- Chapter 3 'Water level and discharge measurements' is devoted to monitoring inside urban drainage systems, mainly focused on water level, velocity and discharge measurements at different locations in centralized networks.
- Chapter 4 'Measuring the water balance in stormwater control measures' deals with measuring methods, systems and components (including sensors) for decentralized UDSM (SUDS) where several processes have to be accounted for: inflow, outflow, overflow, infiltration, exfiltration, intrusion, evaporation and evapotranspiration.
- Chapter 5 'Data communication and storage' is devoted to a subject that has proven to be of omnipotent importance in the rapid advances monitoring has made in many fields, and certainly in UDSM, namely data communication and storage. The fact that the objects under study normally offer a suboptimal environment for electronic devices makes this part of monitoring extra challenging. Chapter 5 provides a state-of-the-art overview of solutions tried and applied in practice along with an overview of available tools and standards.
- Chapter 6 'Design of monitoring: from macro to micro design'. When designing monitoring networks, a wide range of topics have to be taken into account, including very practical issues to ensure obtaining the information sought, given the objectives of the monitoring project and the available budget in terms of investment and manpower (maintenance, data analysis, sensors calibration). The interlinkage between number and location of measuring devices, sampling frequency and uncertainties of the instruments and methods applied is dealt with in depth.
- Chapter 7 'Operation and maintenance'. Once a monitoring network is in operation, appropriate efforts are required to ensure data/information quality and yield during the operational lifetime. Chapter 7 deals with all aspects involved in this, making a distinction between different systems meant for special purposes (e.g., those answering some specific scientific question vs. systems meant for real time control of wastewater systems that are expected to serve for extended periods of time). Also,

the issue of 'safety and health' is touched upon. A full section is devoted to methods and tools for sensors calibration which is of crucial importance to deliver reliable monitoring results.

- Chapter 8 'Uncertainty assessment' holds a comprehensive treatise on the necessary estimation of uncertainties in measurements. It includes a step-by-step approach illustrated with detailed examples to allow for practical applications, in order to be sure about any uncertainties and communicate them with confidence.
- Chapter 9 'Data validation and data quality assessment'. As measuring devices are prone to being attacked by Murphy (Dickson, 1981), a perfect data-yield is not to be expected under all circumstances. Performing regular data validation is a prerequisite for judging their usability for the purpose for which they are meant to be applied. Further data validation will result in information upon which maintenance activities of the monitoring system are founded. Chapter 9 holds a comprehensive treatise on methods and algorithms developed in the field of UDSM in order to

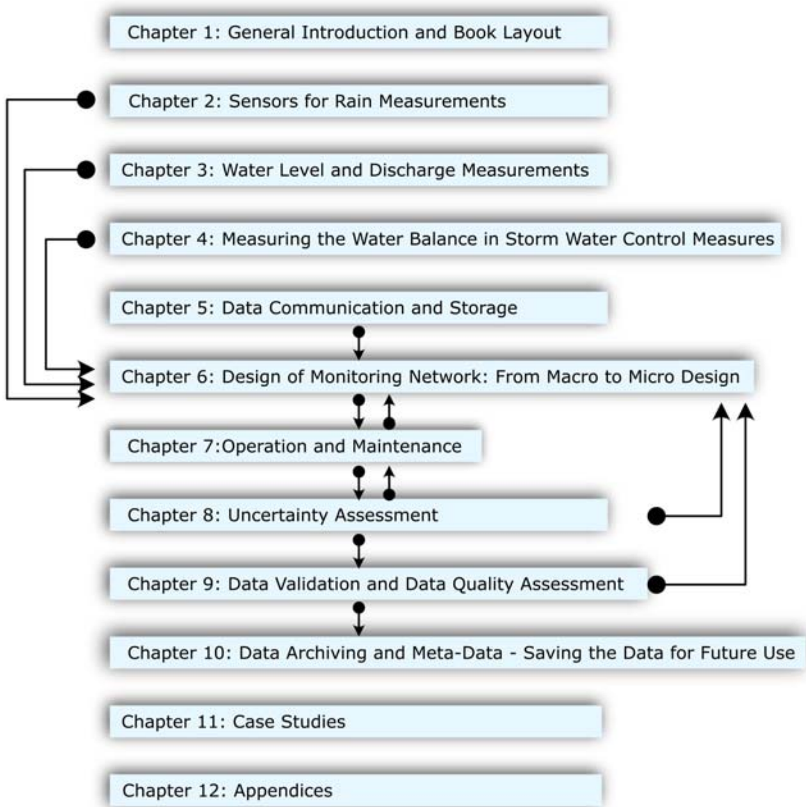

Figure 1.3 Main links between chapters – Chapters 2, 3, 4 and 5 give input for designing a monitoring set-up (Chapter 6). During operation (Chapter 7), data are obtained, that after assessment of their uncertainties (Chapter 8) and their validation (Chapter 9) may give rise to changes in the design (Chapter 6). The data obtained are archived and enhanced with meta data for future use (Chapter 10). Chapters 1, 11 and 12 are related to all other chapters. *Source*: Mathieu Lepot (TU Delft).

effectively and efficiently perform data validation, along with methods on how to report and apply the results.

- Chapter 10 'Data archiving and metadata – Saving the data for future use'. The importance of storing data along with measures to guarantee future accessibility are often overlooked in monitoring projects. As the obtained data often represent considerable value in terms of invested means and scientific effort, this subject is dealt with in some depth in this chapter. Apart from the obligation for researchers and scientific institutions to archive all experimental data, an overview of the different systems applied to date is discussed, as well as means for data sharing between researchers and practitioners.
- Chapter 11 'Data collection in urban drainage and stormwater management systems – Case studies'. To ensure that the content of this report finds its way to both scientists and practitioners, a comprehensive treatise on a range of case studies is discussed in this chapter, illustrating the application of the more theoretical Chapters 1 through 9.
- Chapter 12 'Appendices' provides detailed appendix information for all previous chapters (e.g. VIM definitions, tables, useful links, etc.).

Basically, each chapter can be read/studied separately from the other chapters. However, there are obviously strong inter-relations between several chapters, the most important of which are as indicated in Figure 1.3.

1.5 MESSAGE BOXES

Throughout the chapters, special boxes, as shown in Figure 1.4, are used to emphasize various aspects: key messages, ideas, warnings, and check lists.

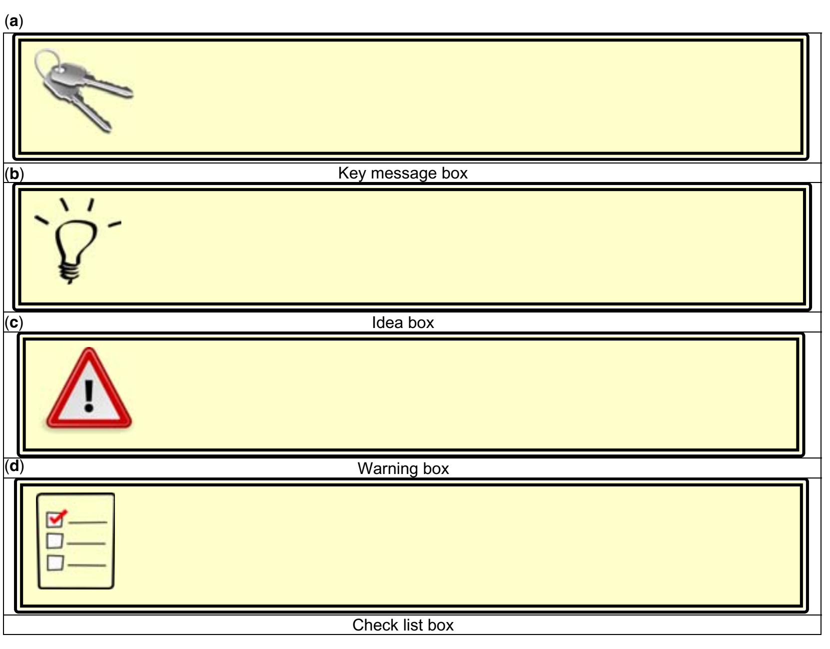

Figure 1.4 (a) Key message, (b) Idea, (c) Warning and (d) Check list boxes. *Source*: Mathieu Lepot (TU Delft).

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