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Need for improved methodologies and measurements for sustainable management of urban water systems

Jean-Luc Bertrand-Krajewski*, Sylvie Barraud, Bernard Chocat

URGC—Hydrologie Urbaine, Insa de Lyon, 20 avenue Albert Einstein, 69621 Villeurbanne cedex, France

Abstract

In natural and artificial Urban Water Systems (UWS), there are strong interactions between urbanization processes, discharges of individual, industrial and collective wastewaters, transfer of pollutants in storm water runoff, and their impacts on natural surface and ground waters. The sustainable management of UWS is becoming very important, and needs new research and action methodologies to get a more integrated knowledge and understanding from scientific, technical, ecological, and socio-economic points of view. In this paper, methodological problems associated with modeling, decision-making tools, definition of objectives, metrology, and multidisciplinarity are identified. An improved and reliable knowledge about the short- and long-term behavior of UWS appears absolutely necessary to evaluate indicators and criteria used in various methodologies aiming at assessing sustainability. A multidisciplinary research project, named OTHU (Experimental Observatory for Urban Hydrology), which aims at providing results, knowledge, and methodologies to assess the sustainability of UWS, is then briefly presented.

Keywords: Sustainable management; Urban water systems

1. Introduction

Urban water systems, especially the waste, storm, and natural water systems, are part of the global urban infrastructure. There are strong interac-

* Corresponding author. Tel.: +33 4 72 43 81 80; fax:+33 4 72 43 85 21.
E-mail address: jlbk@urgc-hu.insa-lyon.fr (J.-L. Bertrand-Krajewski)

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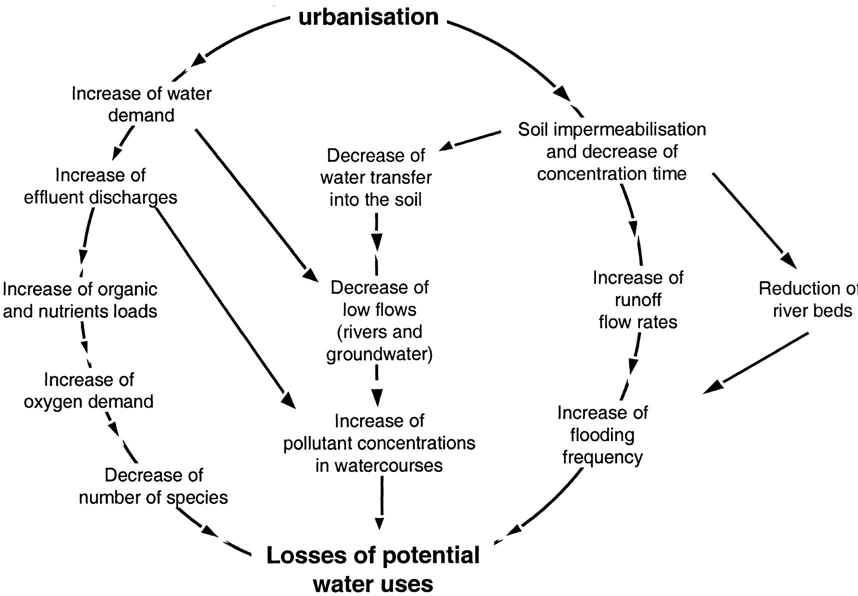

Fig. 1. Impacts of urbanization on aquatic environments (from [4]).

tions between the urbanization process, the resulting discharges of wastewater due to individual, industrial, and collective water consumption, the transfer of pollutants in stormwater runoff, and their impacts on natural surface and ground waters. Some of these numerous interactions are shown on Fig. 1.

For example, the continuous pumping in the Albien groundwater for drinking water production under Paris since the 1840s results in a decrease of the groundwater level of 100 m, and of 10 m only during the last 10 years. The wells were artesian 150 years ago, and now the water shall be pumped from −40 m. In addition to this quantitative problem, the quality is now endangered because the decrease of the Albien water level leads to the transfer of water coming from already polluted adjacent aquifers. This is particularly important when one knows that the Albien is the ultimate drinking water resource for the Paris Urban Area [11]. In such conditions, the question of the sustainability is very acute.

The pollution of water resources due to effluent discharges is well known and documented, and will not be developed in this paper. But many other problems are now becoming significant, with complex conditions and consequences for the urban water systems and their sustainable management. Among them, the following may be mentioned as examples: (a) the decrease of groundwater levels leads to some soil destabilization and to risks for buildings and constructions; (b) the intensive use of aquifer resources for air conditioning in buildings leads to the increase of its temperature, with consequences for the groundwater biocoenosis and biochemical and biological processes affecting the transfer of anthropogenic pollutants through aquifers; (c) the accelerated transfer of urban runoff and effluents to the downstream part of the water system leads to the limitation of local infiltration and breaks the water cycle; (d) natural water systems in the urban environment have been seriously modified and artificialized, associated with the concepts of "resources" and "receiving water" (see, e.g., [8]), while more recently the concepts of "patrimony" and "ecological hydrosystems" have been introduced in the framework of sustainability.

The question of the sustainability of urban water systems and of their management is becoming very important, and needs new research actions to get a better knowledge and understanding from scientific, technical, ecological, and socio-economic points of view. This knowledge is absolutely necessary for any methodology aiming at assessing the sustainability of urban water systems by means of indicators and criteria, which should be based on reliable field data. Two integrated approaches are then necessary: one in the field of time and space scales, one in the field of multidisciplinarity.

2. Limitations of previous approaches

The necessity of an integrated and sustainable management of urban water systems led researchers to develop two complementary approaches and methodologies: modeling and decision making tools.

2.1. Modeling

To manage and/or improve urban water systems, many models have been developed and proposed. The implicit rule is that models will help to get information about the behavior of the systems at a lower cost than field measurements. However, this initial hypothesis (or belief) is not verified. For example, many tens of models have been developed since the end of the 1960s to simulate production and transfer of pollutants in urban drainage systems [3]. As the phenomena are very complex and interdependent, many parameters are necessary to calibrate the models, even the most simple ones. Due to the lack of sufficient and validated experimental data (because of technical and financial reasons given in the next section), these models cannot be really calibrated, tested, and verified. To calibrate them, large amounts of data are required that could sometimes be sufficient to make decisions without using the models but simply by analyzing the data.

It is then difficult to choose the best models and approaches. Some comparisons have shown that most complicated models do not give the best results (e.g., [19]). However, the basic trend consists to develop new models that are more and more complicated and based on the reductionist approach [1]. The confusion between complication and complexity could perhaps explain this difficulty.

Another problem is that models are frequently sectorial or monodisciplinary. So they fail to give valuable results to make decisions for urban water systems characterized by integrated interrelations.

As a final remark, it should also be mentioned that many models are based on the stationarity hypothesis and on short-term processes. This is also a possible cause of their failure in the urban environment where stationarity is not really observed. The diachronic (i.e., long-term) evolution of urban water systems should be taken into account in the framework of sustainability.

2.2. *Decision making*

This approach tries to improve the processes that facilitate the choice of drainage and sewerage strategies with close links with urban planning.

The assistance to decision making requires: (a) a physical representation of technical systems to facilitate their modeling. However, it should be noticed that decision aiding may be based on models that are not completely formalized. In such an approach, any qualitative information can be useful. For example, if it is not possible to attribute a numerical value to the impact of discharges on the aquatic environment, one can use a qualitative representation (the discharges lead to limited, moderate, or severe pollution) or an ordinal one (the discharge X is less polluted than the discharge Y). Nevertheless, qualitative information, if it is not accurate, shall have a high degree of certainty to be useful and relevant; (b) a representation of the actors who influence or take part in the decision-making process. This representation allows an accounting for various criteria and promotes negotiated solutions or decisions. Thanks to this approach, a methodological framework for integrated approach has been defined and some operational tools were produced that accounted for complexity [13,16,18,21].

However, decision aiding declined during the last years in the field of urban hydrology. Following reasons could explain this decline. Existing tools for decision aiding have frequently been built for urbanization development. Methods have consequently been devoted to the interactions between the city and its infrastructure. More recently, the natural environment has been recognized as a significant part, especially in the framework of sustainable management and development. This introduces additional complexity, while environmental assessment is faced with the lack of sufficient and reliable data. To solve these difficulties, methodologies have been based either on the analysis of existing data collected for limited, local, and short-term studies but abusively extrapolated or generalized, or on poorly reliable indicators and criteria assumed to be usable to interpret and qualify trends and/or relationships. Two main consequences result from these simplifications: (1) the risk to make decisions based on very limited or not representative information; and (2) the impossibility to evaluate properly environmental criteria leads to consideration that all strategies are equivalent from the environmental point of view, and to implicitly suppress the environmental aspects in the decision-making process [5].

3. Methodological problems

Three groups of methodological problems have been identified that significantly contribute to the above limits and difficulties by hindering a proper assessment of indicators and criteria for sustainability. No significant progress will be observed in the integrated and sustainable urban water management if these bottlenecks are not solved.

3.1. Clear definition of research and operational objectives

The development of good quality field measurements and information turns out to be essential. However, one of the encountered difficulties relates to setting objectives of monitoring programs. Taking into account the stakes, it appears very important to precisely define the objectives of measurements and to clearly identify the anticipated results and the analysis of data to be acquired. In other words, the first question to be answered is not "what do we want to measure?," as one is often tempted to do, but rather, "what question do we want to answer?." It is obvious that the necessary means of measurement are extremely different whether one wants to monitor the operation of a plant, to detect dysfunction, to improve the plant, or to check the conformity of its operation compared to legal thresholds and requirements, or even to study the factors leading to dysfunction.

The definition of objectives is especially important in urban hydrology because monitoring programs must be multidisciplinary and carried out in collaboration with operators. This preliminary reflection is essential for the monitoring efficiency and also to guarantee a sound functioning between involved partners to avoid misunderstanding about mutual benefits.

It also makes it possible to avoid the temptation of "inventories" ("let us measure a lot of things and we will see what conclusions could be drawn"). Obviously, this practice does not give very efficient results: the exhaustiveness of data is never guaranteed, this solution is economically not realistic, and much information risks to be unused.

The definition of objectives remains a difficult exercise, which constitutes in itself a significant part of any research program. As already mentioned, objectives can be expressed as questions that the monitoring program has to answer. It is, however, important to make legitimate their relevance by means of questions like: (a) who should get the monitoring results, and who else is interested in them? Are the identified objectives materially and economically realistic? What are the appropriate space and time scales? How can the objectives be considered as achieved?

3.2. Concerted and multidisciplinary measurements

Urban water systems and their sustainable management need a multidisciplinary and integrated approach at various time and space scales. Many difficulties are due to the fact that measurements are not concerted and cannot be compared and merged from different research communities (urban hydrologists, limnologists, ecologists, operators of drainage systems, geotechnicians, etc.): (a) time and space scales are very different and sometimes not compatible; (b) the descriptors are different, for example, BOD_5 (Biological Oxygen Demand in 5 days) is usually measured in sewers, but COD (Chemical Oxygen Demand) in treatment plants and TOC (Total Organic Carbon) in surface waters; (c) sampling and analytical protocols are different and sometimes even not compatible.

Integrated view and understanding are then impossible or at least very limited. These difficulties have been recognized and analyzed. Some efforts have been devoted since the second half of the 1990s to a multidisciplinary approach that started with the proposed use of common state variables and descriptors for urban water systems modeling [14,20].

3.3. Quality of the metrology

As any other natural science, urban hydrology, defined as the science of the production, transfer, and impacts of water and pollutants on urban aquatic environment, is based on field observations and measurements. It is not possible to manipulate the research subject (the urban area and the associated aquatic environment) and to modify it in the framework of the experimental design methodology. On the contrary, and due to the numerous and successive different states and conditions of the urban water systems (the first stochastic variable is the rainfall process), researchers need to multiply observations in a permanently revised approach, where measurements and observations are critical to get knowledge, to elaborate hypothesis by induction and to test them with other observations, to design and assess operational devices, and to evaluate the state and the evolution of urban water systems.

In such a process, the metrology is a crucial element. However, for both technical and financial reasons, field measurements in urban water systems are limited in space and time, while many decisions based on insufficient and not representative data are made that concern and affect the urban water systems in usually not reversible conditions. And these decisions frequently involve investment and operation costs that are far beyond the costs of field measurements.

The metrology, as used in many industrial domains, with systematic sensor calibration and assessment of uncertainties, is usually not part of the technical and cultural background of many researchers in urban water systems (at least in France). For example, it is very frequent that flow rates in sewer systems are known with an (in)accuracy of ±50 to ±100%, because minimum calibrations and verifications are not carried out, and because inappropriate sensors are used in inadequate measurement locations. Measurements of pollutant flows and masses are more uncertain: systematic errors for suspended solids concentrations have been observed ranging from −70 to +300% for primary sampling (i.e., sampling in the sewers), of about 10% for secondary sampling (i.e., constitution of a mean sample from primary samples), and of about 20% for analytical errors [6]. The sampling errors are always the most important ones in the sampling and analytical process. However, the investment ratio is about 1 for 1,000 in favor of analysis [10]. The main explanation is the ignorance of the sampling errors. A rational and scientific sampling theory exists [9,10], and demonstrates that usual samplers do not produce representative samples. However, very rare efforts have been done to develop more representative samplers [7] or to seriously assess the nonrepresentativity of actual sampling protocols [2,15,17].

Other aspects are also very important and usually underestimated: (1) data analysis and validation (despite the fact that data are obtained for many decades, very few specific methodologies, techniques, and tools have been developed for urban water data validation, and existing approaches used in some industries are not appropriate); and (2) the quality and the reliability of many sensors and measurement devices should be significantly improved.

A significant progress in metrology is, therefore, absolutely necessary to: (a) systematically assess measurement uncertainties; (b) check and validate the data; (c) improve the sensor quality and reliability; (d) calculate reliable indicators and criteria of sustainability.

4. The OTHU project

To contribute to solve the above-mentioned problems and difficulties, the OTHU (Observatoire de Terrain en Hydrologie Urbaine, i.e., Experimental Observatory for Urban Hydrology) project is now starting in Lyon. It is based on five experimental catchments, where continuous and intensive monitoring will be carried out during about 10 years, taking into account two types of sensitive aquatic environments: one small periurban watercourse, and the Eastern aquifer.

The numerous objectives of the OTHU cannot be detailed in the framework of this paper (for complete information, see [12]), and only main groups of objectives are presented hereafter.

Scientific objectives consist to: (a) improve the knowledge on rainfall and climatology at the urban area scale, and on associated factors that increase the risks of flooding and pollution; (b) improve the knowledge on water and pollutants production and transfer during dry and wet weather; (c) assess the physical, chemical, and biological transformations and processes associated to these pollutants during their transfer in urban water systems (sewer and drainage systems including specific observation of retention tanks and surface infiltration structures); (d) assess the physical, chemical, and biological transformations and processes associated with these pollutants after they are discharged in the aquatic environment, with special attention to small periurban watercourses, unsaturated zones, and aquifers; (e) assess the modifications and the behavior, at various time scales (from some hours to 10 years), of the biocoenosis in surface receiving waters, especially in relation to the increasing urbanization; (f) develop and validate models of pollutant transfers through urban water systems; and (g) improve the metrology, both in drainage systems and in aquatic environment, as the key element for all other objectives. A specific research project is devoted to this topic to define the necessary descriptors and time and space scales in the framework of a coordinated multidisciplinary approach.

Socio-economic and sociologic objectives consist mainly of: (a) assess the risk and consequences of pollution; (b) develop tools for the protection and the restoration of the aquatic environment; (c) develop a strategy for the sustainable management of the urban water system; (d) organize the knowledge transfer and capitalization in the multidisciplinary framework, thanks to really commonly carried out research projects; and (e) assess the additional value due to the multidisciplinary approach by semiexternal sociological observations and evaluation.

A specific public research organism, the "OTHU Research Federation," has been created to lead the project. This federation includes 11 Research Laboratories from six Universities and Engineering Schools in Lyon, with four additional Research Teams. A special contract has been signed with the Urban Community of Lyon, which is a full partner of the project as end-user of the results. The Rhône-Mediterannée-Corse Water Agency is also associated to the OTHU Research Federation.

5. Conclusion

The research methodology, including definition of objectives, rigorous and rational metrology, and multidisciplinary knowledge transfers themselves constitute a research objective. These are necessary conditions to improve our knowledge and associated decision-making processes for sustainable management of urban water systems. Indeed, an improved and reliable knowledge about the short- and long-term behavior of urban water systems is absolutely necessary to evaluate indicators and criteria used in various methodologies aiming at assessing sustainability. The OTHU project is an attempt to associate scientific and methodological objectives in a long-term and multidisciplinary approach of urban hydrosystems.

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