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Challenges in planning for sustainable stormwater management in French cities

A case study of the Grand Lyon

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View from the Porte des Alpes technological park | May 2016
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ABSTRACT

Because of climate change and expanding urbanization, issues concerning the management of stormwater in cities are arising. The increased imperviousness of urban areas cause problems of pollution and environmental protection, and traditional methods of combined or separated sewers are no longer sufficient to handle stormwater flows. Scientists are therefore promoting the sustainable management of stormwater through the use of source control techniques that should be integrated early on in urban planning, but these new solutions are still difficult to implement because of their multi-functionalities. This thesis focuses on the practices and challenges faced by French stormwater stakeholders, with the aim to find solutions to address their specific needs. A literature study was therefore conducted to explain the general context of urban stormwater challenges in France. It was followed by a case study on the metropolitan area of the Grand Lyon, where interviews were carried out with targeted stakeholders in the field of stormwater management.

The research shows that while legislative instruments are present, challenges still exist in the collaboration between the different services and companies involved, where responsibilities are not clearly distributed. There also seems to be a lack of knowledge at several levels in the planning process and especially for maintenance operations, which is emphasized by a lack of follow-up on existing solutions that are forgotten or not correctly used. To face these challenges, several solutions are proposed, including decision-support tools, experience banks, online or on-site information portals, maintenance sheets, and training courses.

Keywords: stormwater, stormwater management, sustainable stormwater management, *techniques alternatives*, urban planning

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Finally, I would like to thank my French girls and my landlords for supporting me during this time with love and amazing food!

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LIST OF ABBREVIATIONS

ADOPTA: *Association pour le Développement Opérationnel et la Promotion des Techniques Alternatives*, or "Association for the Operational Development and Promotion of *Techniques Alternatives*"
ASTEE: *Association Scientifique et Technique pour l'Eau et l'Environnement,* or "Technical and Scientific Association for Water and the Environment"
BMP: Best Management Practices
CEPRI: *Centre Européen de Prévention du Risque Inondation*, or "Flooding Risk Prevention European Center"
CITERES: *Unité Mixte de Recherche Cités, TERritoires, Environnement et Sociétés*, or "Mixed Research Entity on Cities, Territories, Environment, and Societies"
COD: Chemical Oxygen Demand
CSO: Combined Sewers Overflows
DEEP Laboratory: *Déchets, Eau, Environnement, Pollution*, or "Waste, Water, Environment, Pollution"
DTA: *Directive Territoriale d'Aménagement*, or "Territorial Planning Directive"
EPCI: *Etablissement Public de Coopération Intercommunale*, or "Public Establishment for Intercommunal Cooperation"
EVS: *Unité Mixte de Recherche Environnement, Ville et Societe,* or "Mixed Research Entity on Environment, City and Society"
GIS: Geographical Information Software
GRAIE: *Groupe de Recherche Rhône-Alpes sur les Infrastructures et l'Eau*, or "Rhône-Alpes Research Group on Infrastructures and Water"
LID: Low Impact Development
LOD: *Lokalt Omhändertagande av Dagvatten*, or "Local Disposal of Stormwater"
MAPTAM Law: *Loi de modernisation de l'action publique territoriale et d'affirmation des métropoles*, or "Law on modernization of public territorial action and metropolis affirmation"
NOTRe Law: *Loi portant nouvelle organisation territoriale de la République*, or "Law on the new territorial organization of the Republic"
OTHU: *Observatoire de Terrain en Hydrologie Urbaine*, or "Urban Hydrology Observatory"
PAH: Polycyclic Aromatic Hydrocarbons
PLU: *Plan Local d'Urbanisme*, or "Local Urbanism Plan"
PPRN: *Plan de Prévention des Risques Naturels*, or "Natural Risks Prevention Plan"
PPRNI: *Plan de Prévention des Risques Naturels d'Inondations*, or "Natural Risks Flooding Prevention Plan"
SAGE: *Schéma d'Aménagement et de Gestion des Eaux,* or "Planning and Water Management Scheme"
SCoT: *Schéma de Cohérence Territoriale*, or "Territorial Coherence Scheme"
SDAGE: *Schéma Directeur d'Aménagement et de Gestion des Eaux*, or "Planning and Water Management Master Scheme"
SUDS: Sustainable Urban Drainage Systems
Techniques Alternatives: Alternative techniques to traditional sewers
TSS: Total Suspended Solids
VRD: *Voiries et Réseaux Divers*, or "Streets and Other Networks"
ZAC: *Zone d'Aménagement Concerté,* or "Joint Development Zone"

1 Introduction

Questions of sustainable development and climate change have become more and more urgent since the United Nations Conference of 1992 in Rio de Janeiro, and scientists are predicting rises in temperatures from 2 to 6.C by 2100, depending on the efforts that are made (Riebeek, 2010). An important consequence of this is the change in the water cycles of the planet, with increasing precipitation and more frequent violent events in European countries like France or Sweden (Füssel, Jol and Hildén, 2012). In addition to that, urbanization trends all over the world modify runoff patterns and increase pollutant concentrations in stormwater (Barbosa, Fernandes and David, 2012), creating areas that are more vulnerable to flooding and health-related risks.

Therefore, sustainable stormwater management is a growing field of research that municipalities and other affected stakeholders must consider closely to find the best solutions for their cities (Barbosa, Fernandes and David, 2012). Alternative techniques to conventional sewer systems are hence being developed, but there are still several obstacles to their expansion (Stahre and Geldof, 2003).

1.1 Background

In 1992, the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil created the first important, global resolutions for sustainable development with the Agenda 21 (United Nations, 1992). Since then, countries, organizations and people have all tried to work towards the common objective of “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, such as it is defined in the Brundtland Report of 1987 (United Nations, 1987). And in 2015, the United Nations met again to devise a set of 17 new goals for sustainable development by 2030 (United Nations, 2015).

These objectives are vast and encompass the three “pillars” of sustainable development: economic, social, and of course, environmental. Several of these goals are connected to urban stormwater issues (United Nations, 2015):

- #06: Clean water and sanitation
- #11: Sustainable cities and communities
- #13: Climate action
- #14: Life below water

Managing urban stormwater in a sustainable manner is therefore a very relevant concern today, and new solutions are gaining ground all over the world as alternatives to traditional combined sewers.

Stormwater, or *eaux pluviales* in French, is defined as rainwater once it has touched the ground (or any other surface, like rooftops) and flowed on it. It also includes water coming from snow melt, hail, and ice falling or forming on the ground, along with infiltration water (RPDE, no date b). The French term *assainissement*, which can be translated to “sanitation”, usually means the treatment of wastewater but can also include stormwater in some legislative texts or guides (RPDE, no date a); it will be used as such in this report.

Traditionally, stormwater and wastewater in cities are handled by sewer networks, that can be either combined (oldest techniques, in dense city centers, where stormwater and wastewater are conveyed through the same sewers) or separated (new developments, stormwater and wastewater do not travel through the same pipes). However, with increased risks of flooding, environmental pollution, and rising costs, French authorities have started to promote the use of *techniques alternatives* (alternative solutions) to the conventional sewers in the 1990s (Chocat, 1993), with the support of newly created specialized associations (GRAIE in 1985 or ADOPTA in 1997) (GRAIE, 2015; ADOPTA, 2016) and public water agencies (Agence de l'Eau Rhône Méditerranée Corse, no date).

Techniques alternatives have hence developed exponentially since then, but because of their new features and multi-functionalities, there are still several obstacles to their expansion. Lack of knowledge and problems in collaboration have led several research teams to work on decision-aid and planning support tools to help stakeholders design and manage these new infrastructures (Baptista *et al.*, 2007; Billger, Thuvander and Wästberg, 2016; van de Ven *et al.*, 2016).

The Grand Lyon, an urban area in the south-east of France, is seen along with the cities of Bordeaux or Douai as one of the pioneers in the development of *techniques alternatives* (Chocat, Sibeud, *et al.*, 2014); this is partly due to the presence of important research laboratories and water associations (Martin, Ruperd and Legret, 2007). In addition, the metropolis has recently developed a new general sanitation plan which includes several prescriptions on stormwater, and has started a project called *Ville Permeable* ("Pervious city") aimed at overcoming obstacles to the expansion of sustainable stormwater management (Direction de l'Eau du Grand Lyon, 2015b).

1.2 Aims and objectives

With that in mind, the aim of this thesis is therefore to get a better understanding of the current practices and challenges faced by French urban planners in terms of stormwater management, and to find solutions that could address their specific needs. This goal will be achieved through interviews of relevant stakeholders and a case study of the metropolis of Lyon, where significant progress has already been made even though problems may still arise. The specific objectives linked to this thesis are therefore:

- To describe the main challenges for sustainable stormwater management in French urban areas;
- To describe the current practices for stormwater management in terms of:
    - Legislation;
    - Responsibilities (at the national, regional and municipal level);
    - Decision-making and planning processes;
    - Implementation and maintenance;
- To assess the tools developed for stormwater management, including decision-support tools;
- And to assess the needs and demands for improving stormwater management, based on the case study.

The obtained results will also be briefly compared to the findings of the Climate-KIC Climate-Smart Stormwater Management pathfinder carried out at the Water Environment Technology division of Chalmers University of Technology. This project aims at understand the planning processes and challenges faced by stormwater stakeholders in the Gothenburg region.

1.3 Limitations

There are some obvious biases linked to using interviews as method in a research project - these will be developed in more detail in Chapter 2. However, some other limitations include the scope of the thesis, which focuses only on the case study of the Grand Lyon metropolitan area. Some references to other French cities are made (for example by some of the interviewees) but they are not considered in depth; the conclusions will therefore be based on one example only. Due to a lack of time, only three people from different organizations were interviewed, reducing the number of points of views.

Complications also arise because of the different definitions linked to sustainable stormwater management. What is considered sustainable in one place might not be in another, and practices or recommended solutions may vary from one place to another. Sustainable stormwater management solutions also have different names depending on the country and the context: Best Management Practices (BMPs) or Low Impact Development (LID) in the US, Sustainable Urban Drainage Systems (SUDS) in the UK, Lokalt Omhändertagande av Dagvatten (LOD) in Sweden, and finally *techniques alternatives* ("alternative techniques" to conventional sewer systems) in France (Barbosa, Fernandes and David, 2012). As France is the focus of this thesis, this term will be used throughout the report in its French translation, and will be defined more thoroughly in a later part. In addition, a lot of legislative and regulatory terms are also country-specific, so in order to diminish this obstacle, a glossary of acronyms was drafted.

Another limitation comes from the amount of data in French used for the study. Translations from French to English had to be executed, but some language subtleties or nuances might be unintentionally left out or misinterpreted because of missing vocabulary from the researcher, or because no exact translation exists. This is especially true for the interviews, where informal language and spoken speech might be more difficult to translate.

1.4 Outline of the thesis

This thesis is structured in five chapters, with Chapter 1 being the previous introduction. Chapter 2 details the methodology used for the interviews. Chapter 3 is a theoretical review, aimed at giving the reader the background information needed in terms of urban stormwater challenges, French current practices and legislation, and tools to support the development of *techniques alternatives*. The case study is then presented in Chapter 4, with an introduction on the city of Lyon and its metropolitan area, and the outcome of the interviews. Finally, Chapter 5 presents a discussion on the results and proposes solutions tailored at the needs of the different stormwater management decision-makers in Grand Lyon and in France, as well as a comparison with the challenges faced by stormwater stakeholders in Gothenburg.

2 Methodology

In order to meet the specified objectives, a literature study was first conducted on sustainable stormwater management and French practices. Information was collected about the challenges posed by urban stormwater and about available technical solutions such as *techniques alternatives*. The history of French stormwater management was also reviewed along with current French legislation and distribution of the responsibilities that bind the different stakeholders, with a focus on the Grand Lyon area. Finally, a study was done to get a broader view of the support tools available for decision-makers.

The second part of the thesis consisted in carrying out qualitative interviews with different people involved in stormwater management in Lyon. There are many different kinds of interviews, but research interviews aim at obtaining information from knowledgeable people about issues linked to the research project (Gillham, 2000); this definition will hence be applied throughout this thesis.

2.1 Theory on qualitative research interviewing

2.1.1 Definition of qualitative interviews

As Taylor, Bogdan and DeVault (2015) state in *Introduction to qualitative research methods: a guidebook and resource*, there is no perfect research method but one should be chosen taking into consideration research interests, context, and time constraints; for instance, interviews may be useful when research interests are clearly defined and to reach knowledge on events or problems not otherwise accessible. Qualitative, in-depth interviews are mostly used in research instead of closed-questions surveys when a deep understanding is necessary. They can vary in structure, but usually follow three main criteria (Gillham, 2005):

- The questions are open, allowing the interviewee to choose their own answers;
- There is interaction between interviewee and interviewer, who can ask for clarification;
- The interviewer has a purpose which gives the interview its structure.

Taylor, Bogdan and DeVault (2015) also oppose *qualitative interviews* to *structured interviews*: the former are flexible and dynamic while the latter are more standardized, with the same questions being asked to all subjects. Qualitative, in-depth interviews must therefore face several constraints, because of their informal nature. People might not be available for a long time, they might have some apprehension to talk about certain subjects, there might be some political or ethical restrictions on what can be addressed… (Gillham, 2005) And finally face-to-face interviews might be impossible because of geographical constraints, as was the case for this study.

2.1.2 Conducting the interview

A main question is therefore how to select informants. Kvale (1996) points out that one should “interview as many subjects as necessary to find out what you need to know”. Hence, there is no fixed minimum number of informants to carry out a good research; in addition, there seems to be an inverse correlation between the number of subjects and the depth of the interviews: the more people are interviewed, the less detailed the interviews are (Taylor, Bogdan and DeVault, 2015). The approaches used to select informants are varied, but most will try to aim at the maximum diversity in the subjects pool. Time and willingness to participate should also be considered.

During the interview, the first step is to quickly establish a positive relationship between the research and the interviewee, in order to create a comfortable environment in which the interviewee can talk freely about personal experiences and opinions (Dicicco-Bloom and Crabtree, 2006). The aim is to try to approach as much as possible a natural and everyday exchange (Taylor, Bogdan and DeVault, 2015). Therefore, the first questions should be general and open, aimed at starting a conversation. The researcher can then follow-up with unplanned questions, trying to keep them as non-directive as possible so the interviewee can choose their own answers. For example, instead of saying “Didn’t this make you feel strange?” the researcher should ask “How did this make you feel?” (Dicicco-Bloom and Crabtree, 2006). Taylor, Bogdan and DeVault (2015) also encourage the use of an interview guide, consisting of a list of themes to address with all informants. Questions can then be asked spontaneously during each interview, but this gives a structure to keep the interviewer in the right track for his or her research.

Another way to obtain information from an interviewee, when he or she has little time available, is the e-mail interview. This medium, like a face-to-face interview, can give quality personal data because of its informal nature, is much faster to implement, and allows the interviewee to answer at his convenience (Gillham, 2005). It also provides the researcher with a “ready-made” transcription of the respondent’s answers. In addition, the necessity to build a positive relationship is not as strong as for a face-to-face exchange, even if some courtesy rules still have to be followed (Gillham, 2005).

2.1.3 Recording and analyzing data

Answers to qualitative interviews can be recorded in several ways, the most frequent of which are audiotape recording and note-taking (Dicicco-Bloom and Crabtree, 2006) (for email interviews, the written answers of the informant directly act as a transcription of the interview; this will not be dealt with in this paragraph). Technical issues with recording can compromise the results; the researcher should therefore make sure the equipment is correctly working beforehand in order to avoid background noise or inaudible speech. Informants should also be made aware of the recording and need to give explicit consent for it before the interview (Taylor, Bogdan and DeVault, 2015). Note-taking is less time-consuming and allows for direct analysis, with the interviewer already categorizing responses during the interview (Muswazi and Nhamo, 2013).

Finally, once the interview is over the data has to be analyzed. For this, the researcher must go over the recording or the notes taken during the interview in order to highlight the most relevant key points and sort them into categories (Gillham, 2000); one way to do this might be to transcribe the entire interview, but this is very tedious (a one-hour interview needs about five hours to be properly transcribed (*Introduction to Research: Handling Qualitative*

Research Data, no date)). Once the pertinent data has been extracted, it can be coupled with literature information in order to generate an understanding of the intended research questions.

2.1.4 Biases and issues with the method

However, as with any research methods, there are a lot of concerns with qualitative interviewing. They can be technical, ethical or linked to the participants' reliability. The anonymity of the respondents must be maintained when there is a possibility that what they are sharing can jeopardize his or her position in a system (Dicicco-Bloom and Crabtree, 2006), otherwise the interviewee might not willing to share certain information. In addition, the fact that the interview is carried out almost like a conversation means that it can be made of the same distortions which happen in everyday life (Taylor, Bogdan and DeVault, 2015), and the researcher's analysis inevitably involves some kind of subjective interpretation (Gillham, 2005).

Issues can also come from the medium with which the interview was recorded; whether it is, as mentioned before, due to technical problems with the recorder, or because some information was missed out during note-taking. As such, note-taking by itself is often not recommended because of its inability to capture a certain level of detail (Muswazi and Nhamo, 2013) and because of the increased risk of subjectivity from the researcher (*Introduction to Research: Handling Qualitative Research Data*, no date). However, with any kind of recording, participants may feel reluctant to express their true opinions (Muswazi and Nhamo, 2013), and an important level of trust has to be built between the researcher and the interviewee in order to minimize this.

Finally, in the specific case of email interviews, answers might either be too formal or too colloquial. Respondents might also have a tendency to express themselves in a "note" or "list" format, very different from human speech, and not develop fully what them mean (Gillham, 2005). It is therefore important to ask for clarification with follow-up emails if the answers are not deemed detailed enough.

2.2 The interviews in practice

For this thesis, in-depth interviews were carried out with three different people involved in stormwater management in Lyon. Here the interviews were done as a way to complement the literature study and to get personal insights on the problems stormwater stakeholders are currently facing. A member of the Grand Lyon water department was therefore interviewed (interview A), followed by a researcher at the DEEP laboratory (interview B) and a member of an engineering firm working on urban development projects (interview C).

Because of geographical constraints, none of the interviews were effectively "face-to-face"; however, videoconferences were used for two of them in order to approach this technique as much as possible. They will therefore be referred to as "face-to-face" interviews in the following part. As the thesis went by, the method was tested and the format of the interviews varied in order to try to achieve the most scientific results. Indeed, as was explained before, there are several possible biases linked to this research method.

For example, the first interview with the Grand Lyon employee was carried out face to face through Skype: the advantages of this is that is more personal and allows for more exchange between the research and the interviewee. It gives the possibility to easily deepen the subject in order to follow up some relevant answers, or to skip questions that might not be of interest in the end. However, the conversation was in this case not recorded, and the transcription only comes from note-taking throughout the interview (Appendix I). One problem of this is that there is a big influence from the researcher in the results, as:

- Not everything is always written down because of a lack of time,
- Some things might not be comprehensible when re-read and taken out of context,
- The interviewer might (intentionally or not) miss out some aspects of the conversation when taking notes and only write down what matters to him or her.

Therefore, in order to minimize the bias coming from the interviewer, the other two interviews were recorded fully (through tape-recording or written answers) and can be found in Appendix II and III. The exchange with the researcher was also carried out through video-conference, and allowed for a more two-sided conversation.

However, the email format was used for the interview with the engineer, which then resembled more a survey than an actual interview. This was due to a limited availability from his part which only allowed him to answer a few questions. This has the advantage of giving a true image of the interviewee's ideas, unaltered by the researcher's point of view, and of having more structured and clear responses to the actual questions, but does not allow for an extended discussion, and gives much shorter answers.

Overall, such qualitative interviews are bound to be biased in some way as they are necessarily subjective. It is also possible that some people omit certain topics, either because they are afraid of the consequences, do not think it is relevant, or simply forget about it. The relationship between the researcher and the interviewee should also be considered; if they know each other, the exchange will not be the same as if they have just met. However, it is still important to have such points of view (even if there are few), especially when the objective of the research is to identify problems and offer solutions. Table 1 summarizes the setups for each interview.

Table 1: Interview setups

Interview	Company/Organization	Type of interview	Length	Transcription
A	Grand Lyon water department	Videoconference	60 min	Notes
B	DEEP Laboratory	Videoconference	30 min	Full transcription
C	Artelia engineering firm	Email	6 questions	Written answers

To finish, the results from the interviews were analyzed to find the main challenges faced by urban stormwater stakeholders in Lyon. The main problems were identified and solutions were then proposed based on the literature study conducted previously.

3 Theory

In this part, the studied literature will be reviewed in order to understand the main concepts linked to stormwater and sustainable stormwater management. First the challenges created by increased precipitation and its impact on cities will be developed, followed by a presentation of available sustainable solutions, the so-called *techniques alternatives*. A French history of stormwater management will then be introduced, followed by a description of the current legislation and responsibilities of concerned stakeholders. Finally, some decision-support tools and management aids will be presented.

3.1 Urban stormwater challenges

In terms of stormwater, the main problems that arise from urbanization are problems of quantity and of quality. Unpredictable consequences of climate change will cause flooding and contamination issues, especially in less developed countries more vulnerable to such risks (United Nations World Water Assessment Programme, 2015); it is therefore important to assess these risks and understand where they come from.

3.1.1 Urbanization and stormwater flows

Over the last century, urban developments have changed completely the aspect and typology of our cities. While in 1904 93% of United States roads were unpaved, with the development of automobiles, areas with human presence have become almost entirely impervious, especially in cities (Arnold and Gibbons, 1996). Streets, rooftops, but also patios and even compacted soils alter the hydrologic cycle of the whole system, degrading the water resources: infiltration of rainwater through the soil is prevented, and surface runoff increases (EPA, 1999), while the groundwater table is not renewed fast enough (Arnold and Gibbons, 1996). Figure 3.1 shows the relationship between impervious land coverage and water cycle transformation.

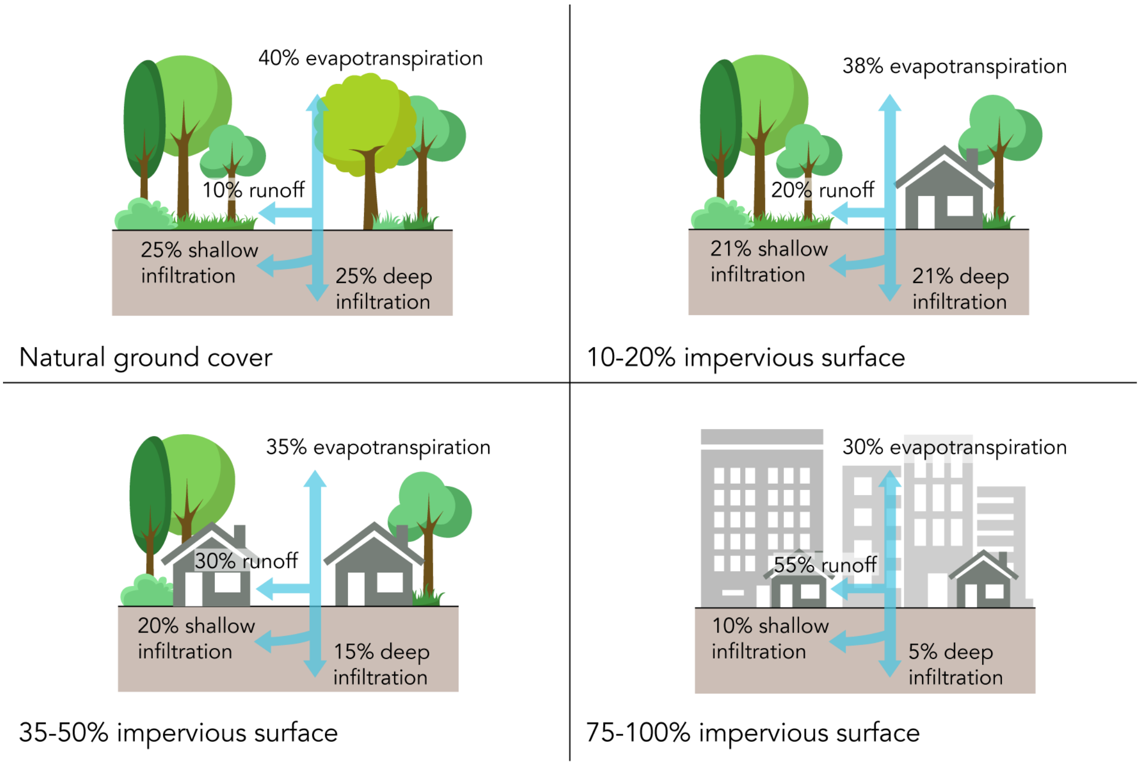


Figure 3.1: Transformation of the water cycle with urbanization. Adapted from (Arnold and Gibbons, 1996)

One consequence of this is that peak flow rates happen sooner and are higher than in natural environments, with a greater runoff volume. The frequency of events surpassing a certain flow rate also increases, with a higher probability that the network's capacity will be surpassed (CEPRI, 2014). In Figure 3.2, the evolution of the flow at the outlet of a watershed is shown against time. In light blue, before urbanization: the flow rate is smaller all along the event and the total volume is smaller. In dark blue, after urbanization: this time the peak flow rate is much more important since the runoff is not slowed by the ground typology, and the total volume to be treated is greater because of the lack of infiltration. In addition, there is an important volume that cannot be handled by the network, which has to overflow somewhere (most often into nearby streams).

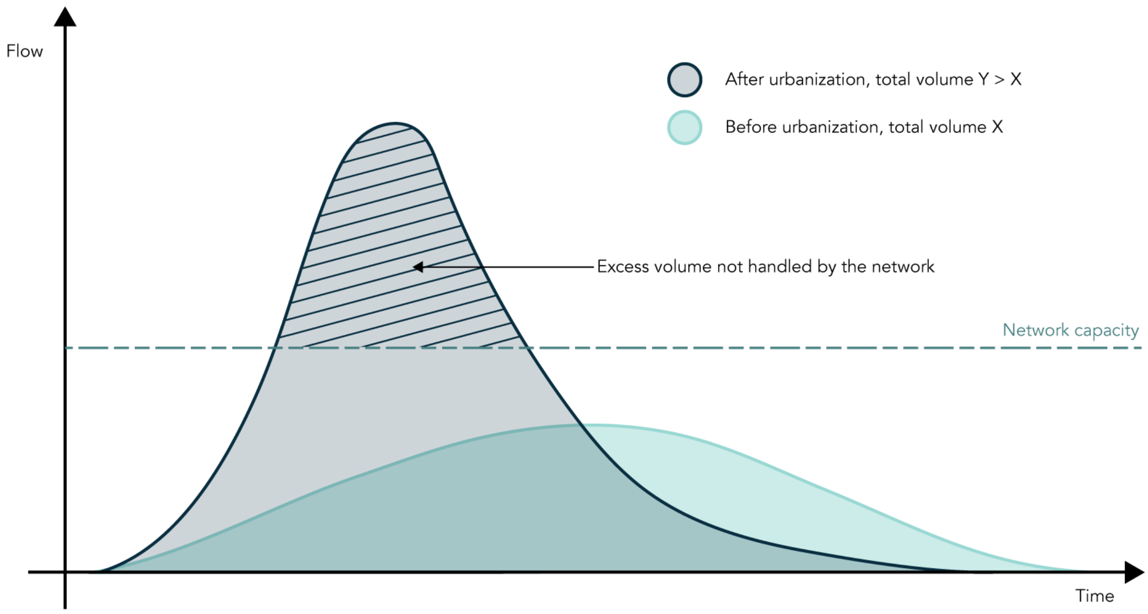


Figure 3.2: Influence of urbanization on kinetics and runoff flows for a watershed after a storm event. Adapted from (CEPRI, 2014)

Increased stormwater runoff also has a great impact on erosion from construction sites, downstream areas and stream banks (Arnold and Gibbons, 1996). The higher volumes of water, mixed with sediment, can widen stream channels and increase water temperature ranges, causing channel instabilities. Some visible examples of this are exposed stream banks, fallen vegetation, and sedimentation, but this also influences stream habitat as the environment is modified to accommodate more rainfall (EPA, 1999).

Another consequence of increased imperviousness is the slow renewal of groundwater tables. Drinking water supply is threatened, as well as water provision from groundwater to local streams, which may diminish if the flow is too low (Arnold and Gibbons, 1996). In addition, the drying up of the soil in cities, due to low rainwater infiltration, may cause differential settlements which may lead to instabilities in the buildings above (Chocat, 2015).

The urban heat island effect is also a consequence of urbanization closely linked to stormwater. It is a phenomenon which is observed when temperature in cities are significantly warmer than in surrounding suburbs and rural areas because of a lack of vegetation (to block solar radiation and cool the air with evapotranspiration) and an increase in the amount of materials with higher thermal properties. Because they release so much heat, cities can then alter local atmospheric flows, allowing air to rise and increasing significantly the amount of rainfall (Seyoum, 2012).

To take care of this excess water, two techniques are traditionally used (EPA, 1999):

- Separated sewers, with one network for wastewater and one for stormwater. In this case stormwater is not mixed with wastewater but is usually released untreated in the environment.
- Combined sewers, where stormwater and wastewater travel through the same pipes to a wastewater treatment plant. In the case of important storm events, the volume of water often exceeds the capacity of the plant; the excess (a mix of waste and stormwater) is hence released through combined sewers overflows (CSO) to the natural environment.

3.1.2 Polluted runoff

In both cases, however, there is untreated stormwater runoff that eventually finds its way to receiving streams and the natural environment. This can be dangerous because stormwater runoff contains several kinds of pollutants which are harmful to aquatic life but also to humans (EPA, 1999). According to the CEPRI (2014), pollutants found in stormwater runoff include:

- Solid waste like leaves, plastics, etc. which can obstruct network pipes;
- Solid and fine minerals from erosion, construction sites, etc. which can plug pipes and absorb heavy metals;
- Atmospheric pollution particles deposited on surfaces;
- Heavy metals from industrial activities, traffic, or construction materials;
- Hydrocarbons from traffic essentially;
- Products linked to land upkeep like road salt or pesticides;
- Organic materials, potentially pathogenic.

While it can be difficult to assess the level of pollution of stormwater runoff, because of the number of parameters involved (type of surface, type of materials, usage…), the Seine-Normandie Water Agency (Gromaire *et al.*, 2013) has carried out research to compare the concentration of well-known pollutants in runoff to threshold values for ecological quality of streams (Gromaire *et al.*, 2013). Figure 3.3 shows the results for roads and parking lots, while Figure 3.4 focuses on runoff from rooftops.

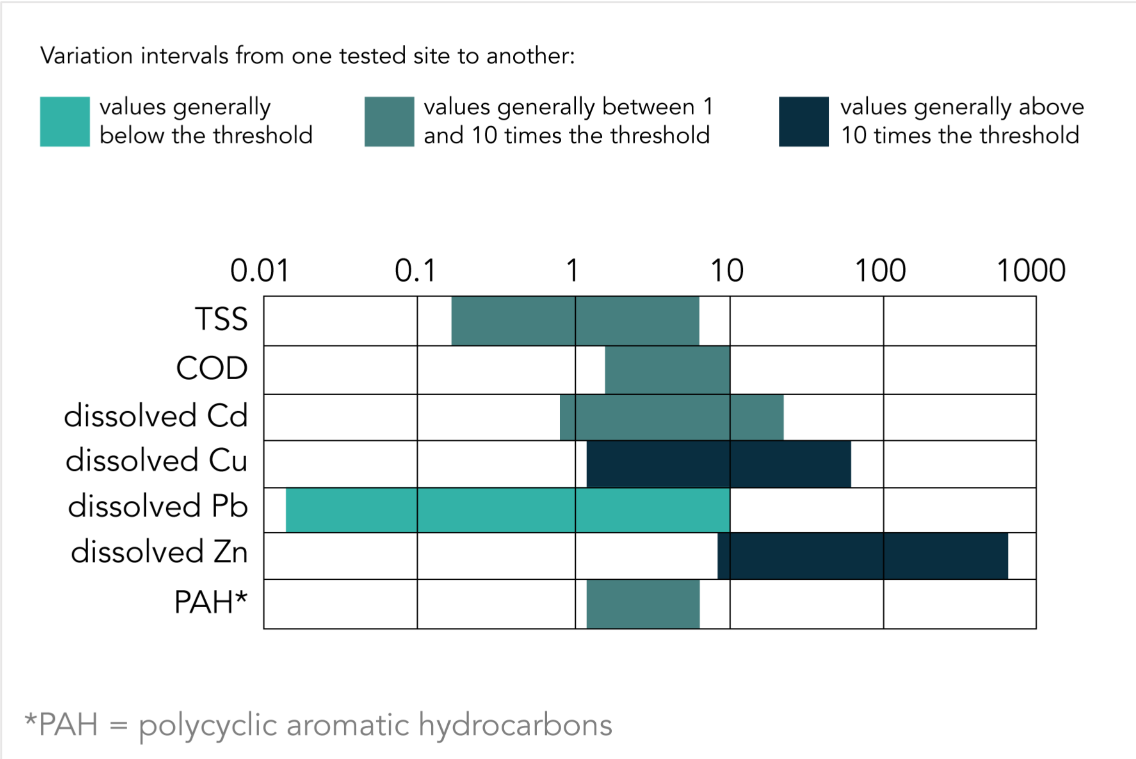


Figure 3.3: Comparison of the average concentrations (C) per site for streets and parking lots with limit values (LV) for water streams (ratio C/LV). Adapted from (Gromaire *et al.*, 2013)

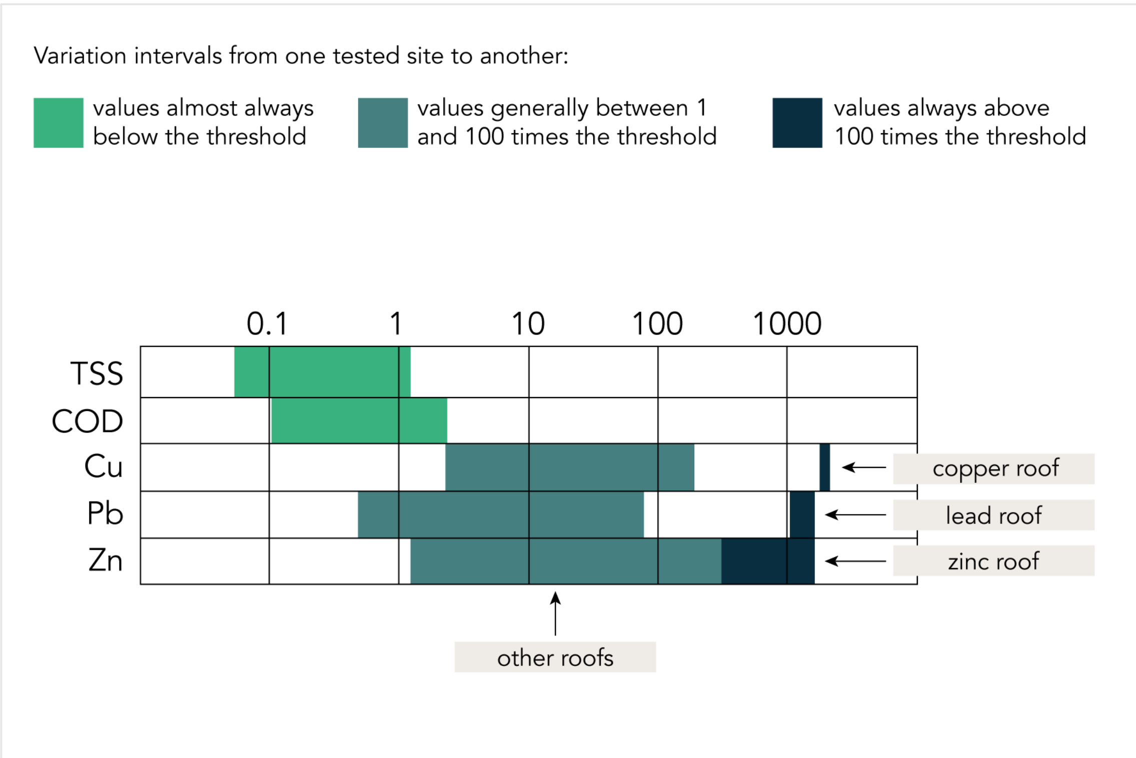


Figure 3.4: Comparison of the average concentrations (C) per site for different types of rooftops with limit values (LV) for water streams (ratio C/LV). Adapted from (Gromaire *et al.*, 2013)

They show that for example, Cu and Zn concentration is often ten times higher than the accepted value for natural streams; this increases to one thousand times higher when the rooftops are made of copper or zinc, respectively. While TSS and COD concentrations are often below the limit for rooftops runoff, they are more important for streets and parking lots; these figures show clearly that in both cases, pollutant concentration is much higher than what is accepted to ensure ecological quality of natural environments.

In addition, during important storm events sewers might become saturated and not be able to treat all of the incoming flow. Since sewers in French cities are often combined (or at least, the separation between wastewater and stormwater is not always perfect), rainy weather overflows are usually a mix of wastewater and stormwater, which is rejected directly to the natural environment. In that case, pollutant concentrations can be two to ten times higher than the norms for wastewater plant discharges (Chocat and GRAIE, 2016).

Finally, pollution in stormwater runoff can be present both in particle form and in dissolved form. While particle contamination can be more or less easily treated by slow techniques of decantation (the particles fall to the bottom from their own weight) or filtration (through filters or soils with or without vegetation), dissolved pollutants can pass through those filters and research is still ongoing to find the best solutions to remove these contaminants (especially pesticides) from stormwater runoff (Sibeud and Pourchet, 2013).

3.1.3 Summary and impacts

Figure 3.5 therefore summarizes the challenges faced by stormwater management stakeholders and citizens due to urbanization:

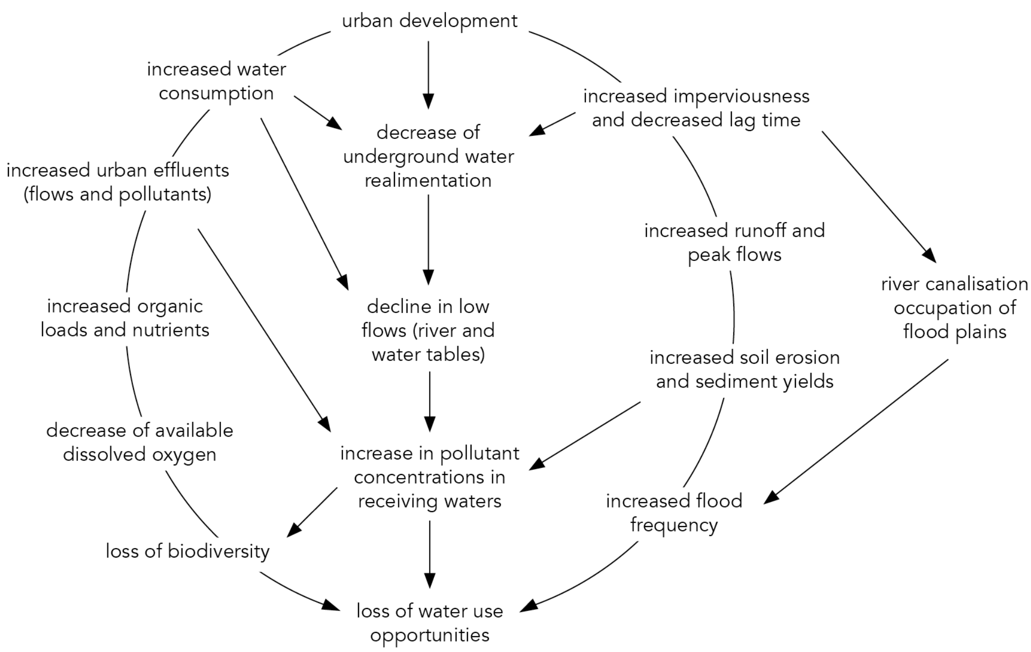


Figure 3.5: Impacts of urbanization on the water cycle. (Chocat *et al.*, 2007)

Unsustainable stormwater management can hence have varied but significant consequences: sudden and violent floods may have severe health impacts on populations as time to evacuate is shortened; exposition to products carried by water and wastewater, humidity, and sludge may also increase the spreading of diseases and contaminations. Economic impacts may also be important as infrastructure damages in dense cities cause losses of money due to restoration needs and breaks in activities. Properties and patrimonial heritage also face risks of destruction. Finally, environmental impacts may be considerable as ecological quality and biological diversity are threatened by stormwater pollution (CEPRI, 2014).

3.2 Sustainable stormwater management and *techniques alternatives*

3.2.1 Principles of sustainable stormwater management

In order to face the challenges posed by urban stormwater, new techniques have been implemented as soon as the 1980s to treat pollution and to regulate flow rates. With time, they developed to include more functionalities and to work at smaller scales when source control was promoted (Chocat *et al.*, 2008), and an integrated approach is now encouraged; one which combines hydraulic and technical criteria with ecological and aesthetic considerations (Lindh, 2013). New urban stormwater management techniques must be adapted to local constraints and be an integral part of the city's urban plan (Lami *et al.*, 2006). In addition to treating flooding and pollution issues, Chocat *et al.* (2008) highlight three main benefits of sustainable stormwater management:

- Urban and landscape aesthetic with the reintroduction of nature in the city;
- Promotion of stormwater as a useful resource;
- And climate regulation interests;

with most techniques combining several of these benefits. Cost optimization and environmental education are also aspects that have to be taken into consideration when implementing sustainable stormwater management (Lami *et al.*, 2006).

Sustainable urban stormwater management solutions, or *techniques alternatives* as they are called in France, can be sorted into two main categories depending on the level at which they handle the stormwater. Source control aims at minimizing the generation and the pollution of stormwater, reducing the needs for costly treatment methods. The objective of treatment control methods, on the other hand, is to clean polluted stormwater and divert it away from traditional sewers (Lindh, 2013). Ideally, both should be associated in order to create a "treatment train" that will reduce pollutants in runoff, reduce runoff volume, and treat the remaining runoff pollutants (Urban Drainage and Flood Control District, 2010).

3.2.1.1 Source control

The first strategy of source control is to disrupt the natural water cycle as little as possible; this means that impervious land coverage must be minimized by using porous materials and permeable surfacing, or by keeping natural land (Luchesi, 2008b). Lindh (2013) acknowledges planning and design actions that can be undertaken to reach this objective:

- Plan for compact urban development and limit growth to areas best suited to it;
- Reduce connection of impervious ground to the stormwater drains;
- Include natural areas which can directly capture stormwater (like ponds);
- Promote the use of pervious surface materials.

Another important aspect of source control is the decrease of stormwater contamination. Most of the significant pollutants in stormwater appear once it touches the ground (or any other surface); indeed, while rainfall is necessarily polluted, it is usually drinkable before it reaches the ground. However, as runoff flows along streets, it cleans and erodes surface materials. Contamination depends on factors like rain intensity, runoff volume, and type of materials encountered, but the main factor remains the distance: stormwater that is infiltrated right where it fell is likely to be much less polluted than stormwater which has traveled a long distance (Sibeud and Pourchet, 2013).

Therefore, source control techniques involve all kinds of disciplines and stakeholders: governments, businesses, and local inhabitants should try to employ water quality friendly materials, build roof runoff control, and prevent soil erosion (California Stormwater Quality Association, 2003). Industrial activities like vehicle washing, waste disposal and outdoor storage should be protected (see Figure 3.6) to prevent their pollutants from reaching the stormwater and structural source controls like coverage or spill containment should be implemented. Procedural source controls can also be used by municipalities and organizations to educate raise awareness throughout the community (Urban Drainage and Flood Control District, 2010).

Figure 3.6: Unprotected storage area where the material can pollute stormwater and directly reach the sewers.
(Urban Drainage and Flood Control District, 2010)

3.2.1.2 Treatment control

Sustainable stormwater treatment solutions use natural processes to efficiently remove pollutants from contaminated stormwater. They can also act as obstacles which slow runoff flow and lessen impacts on sewer networks. Main treatment control techniques include infiltration of runoff to the soil, retention and treatment for later release, slow conveyance of water through vegetated areas, and technological flow-through treatment solutions (California Stormwater Quality Association, 2003).

Most contaminants in runoff are polluted particles, which are efficiently dealt with by decantation and filtration through a significant layer of soil; stormwater can then be released into nearby streams or reach groundwater tables without harm (Lami *et al.*, 2006). In an infiltration system, runoff trickles over permeable surfaces and pollutants settle into the ground, where they can be naturally mitigated. These systems can be open or closed and are often designed to capture the “first-flush” storm event, paired with detention solutions to reduce peak hydraulic flows. Retention and detention basins are used to capture runoff temporarily and release it at a slower rate; in addition, settlement and physical removal of pollutants ensure the quality of the released water. Aquatic plants and microorganisms in retention basins can also increase biological and biochemical pollutant removal. Biofilters can also be used to transport runoff slowly over vegetation, allowing for filtration of sediments and pollutants through biological activity (California Stormwater Quality Association, 2003). Finally, specific, multi-vocational sites like parking lots, playground and parks can be used as temporary storage areas in the case of violent storm events (Lami *et al.*, 2006).

3.2.2 Examples of *techniques alternatives*

3.2.2.1 Swales and ditches

Swales and ditches are long, shallow, and have gentle slopes on the sides. They receive water from pipes or directly from runoff from nearby surfaces, which is then infiltrated through the ground or evacuated by an outlet (Lami *et al.*, 2006); this is shown in Figure 3.7, for both an infiltration-type swale and a retention-type swale. In addition, they are easy to integrate because of their linear shape, and bring greenery that can serve as wildlife habitat (Luchesi, 2008b). Their design and construction is quite simple, they are easy to maintain, and their implementation costs are low (SyAGE, no date). However if the groundwater table is less than a meter deep, infiltration is not possible as pollutants can still be present (Lami *et al.*, 2006).

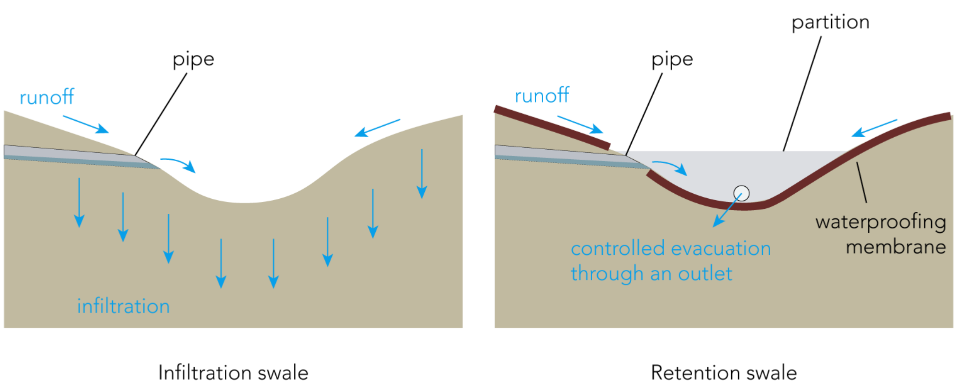


Figure 3.7: Schematic diagram of a swale. Adapted from (Lami *et al.*, 2006)

Swales and ditches need the same type of regular maintenance as urban green spaces: mowing of the grass, picking up of the leaves and garbage… This is especially easy when the slopes are gentle. In addition, special operations need to be undertaken every three to five years to de-compact the soil and ensure infiltration can happen properly (Luchesi, 2008b).

3.2.2.2 Infiltration trenches

Infiltration trenches are quite similar to swales except they are filled with porous materials like gravel or pebbles. Stormwater is brought through pipes or by direct runoff, and is then temporarily stored in the trench. It can then be evacuated through an outlet to the receiving environment or infiltrated through the soil, while the pollutants are captured in the porous material (Luchesi, 2008b). Infiltration trenches can be covered by vegetation or left open, as shown in Figure 3.8.

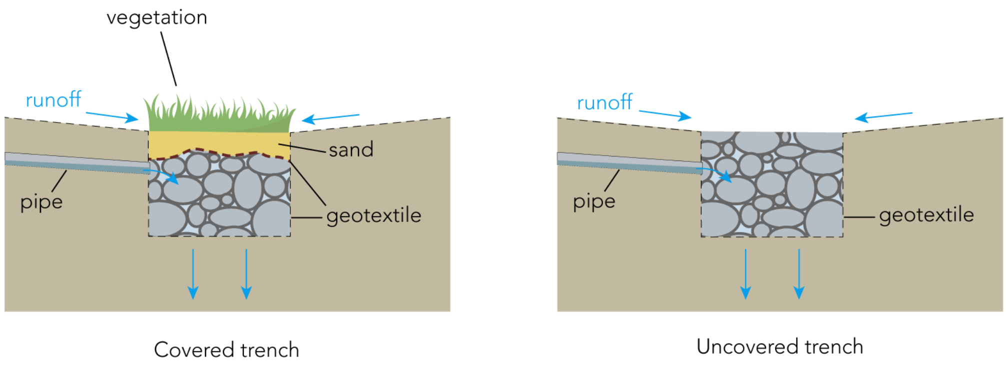


Figure 3.8: Schematic diagram of an infiltration trench. Adapted from (Lami *et al.*, 2006)

Advantages of this *technique alternative* include an easy and controlled installation, low investment costs, an efficient depollution, and an effortless integration even in dense urban areas without requiring too much space (they can be implemented alongside or even under parking lots, streets, biking lanes… (SyAGE, no date)). Finally, they are easy and safe to maintain since they are filled with material, but need to be cleaned regularly to prevent clogging and stagnation of water (Lami *et al.*, 2006).

3.2.2.3 Infiltration wells

Another *technique alternative* often recommended by local authorities is the infiltration well. They are isolated objects and can be deep or not; similarly to the infiltration trenches, their function is to retain water temporarily and let it infiltrate into the soil (or reach a drain) while catching pollutants (Figure 3.9). However, they do not have a very large capacity and can be quickly saturated during violent storm events; in that case they must be associated with other techniques which can take care of the excess water (Luchesi, 2008b).

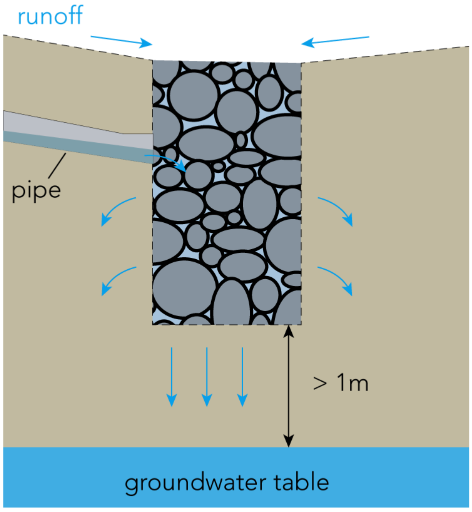


Figure 3.9: Schematic diagram of an infiltration well. Adapted from (Lami *et al.*, 2006)

Much like the other *techniques alternatives* mentioned before, infiltration wells are easy to design, construct, and maintain, with low investment and maintenance costs. Their low demand for space means that they can be used in a variety of contexts, whether it is below a parking lot, a playground, or a private garden. Finally, they need to be accessible so they can be inspected every semester and cleaned from potential clogging (Lami *et al.*, 2006).

3.2.2.4 Porous pavements

Porous structures are pavements which allow the rainfall to be infiltrated right where it falls: this is a source control measure that promotes the limitation of impervious land coverage and the reduction of the stormwater runoff travelled distance. Several kinds of pervious materials and techniques exist (see Figure 3.10) and they are used as a replacement for traditional pavements; for that reason they can be used on any simple project like parking lots, pedestrian lanes, and entryways. They can also be easily coupled with other *techniques alternatives* like swales or trenches. However, costs should be expected to be 10 to 15% higher than for traditional pavements (Luchesi, 2008b).

Figure 3.10: Different types of porous pavements: porous concrete; concrete paving with drainage openings; turf paving. (Luchesi, 2008b)

Annual maintenance must be undertaken, either with vacuum sweepers or high-pressured water, in order to maintain the porosity of the material. For areas with vegetation, chemical fertilizers and weed-killers must be proscribed to prevent contamination of the water (Luchesi, 2008b).

3.2.2.5 Ponds and basins

All of the previously described *techniques alternatives* are small and easily integrated into dense urban areas. Ponds and basins, on the other hand, require more space and more investment, and should be conceived as multifunctional areas (Lami *et al.*, 2006). Sport courts and playgrounds can be used as dry basins which fill up during storm events and retain water temporarily, while wet ponds can be used in decorative gardens with overflows for violent storms, as shown in Figure 3.11. They can work in different manners, whether it is by cleaning the stormwater through the settlement of pollutants (Luchesi, 2008b) or infiltrating it through the soil (Lami *et al.*, 2006).

Figure 3.11: Wet basin in a park and dry basin designed as a sports court. (Lami *et al.*, 2006)

With such type of infrastructures, several precautions must be taken to ensure the safety of local citizens and the correct maintenance of the infrastructure. Water level should not be allowed to rise over one meter, or in this case, direct access must be prevent to reduce drowning risks (Luchesi, 2008b), and specific maintenance is needed to prevent clogging or water stagnation. This also implies that cleaning operatives must have ecological and environmental knowledge to follow water, fauna and flora quality (Lami *et al.*, 2006).

3.2.2.6 Storing and green roofs

Finally, the roofs of buildings should be taken advantage of to reduce stormwater pollution and runoff. Water can be stored temporarily and possibly evaporated and infiltrated if the roof is vegetated, slowing down outflow rates and minimizing contact with harmful materials (Luchesi, 2008b). The main advantages of this technique are its easy adaptation to any type and size of building, while not taking any new space; its relative simplicity; and its thermal functions in the case of green roofs. However, it must be implemented by skilled workers to ensure watertightness and needs to be correctly maintained several times per year; users must also be informed on its functioning and cleaning procedures.

3.3 History of French stormwater management

3.3.1 Technical innovation and the hygienist movement

In the Middle Ages, the need for sewers was already important; in Paris they were open urban streams transporting both waste and stormwater and creating several health hazards.

The role of Paris as the capital of an empire meant that technical innovations were often developed in order to create a model city, and they were encouraged by its government. Therefore, starting from the 16th century, the streams were covered and transformed into sewers (Chocat, 1997).

In the middle of the 17th century, urban water management is handled by engineers, who start to create massive sanitation systems to take care of stormwater. Indeed, before the expansion of water distribution networks, wastewater was not very voluminous and was mostly reused as fertilizer or for the fabrication of cannon powder (Chocat, 1997). However, the great plagues of 1832 and 1884 pave the way for the creation of the “hygienist movement” and the development of the *tout à l’égout* (“all in the sewers” in English), with a direct release to nearby streams and rivers.

This model meant that the state was now taking care of all of the waste and stormwater in the city; some local governments (like in Lyon and Bordeaux for example) were reluctant to do this because of the cost of the construction of sewers and the gains that were obtained from selling wastewater for agricultural usage. For this reason, Lyon built its combined sewers network in 1961 (Cohen, 1998).

This “all in sewers” strategy stopped almost entirely the development of autonomous methods for stormwater management, and rainwater cisterns were becoming obsolete as they gave water of poor quality, easily contaminated and lacking minerals. However, the first attempts that could be related to *techniques alternatives* were absorption wells, destined at infiltrating waste and stormwater to the ground. Engineers were motivated to develop this kind of technique especially for stormwater, but they were soon forbidden because of the fear of contamination and pollution of the groundwater table.

Therefore, alternative solutions for stormwater management were quickly discarded by authorities who saw sewer networks as the only scientific and acceptable solution to managing stormwater. A connection was made by Ward in a speech in 1852, where he compared urban water to blood flowing through an organism; there had to be a continuous movement where water entered pure in the city and left it carrying its wastes (Chocat, 1993). Hiding dirty waters and improving life quality was also an advantage of underground sewers.

However, with the first important rural exodus that followed the Second World War combined with the rapid development of private sanitation equipment, the amount of water coming out of cities increased drastically, with a huge impact on the quality of surrounding environments (Chocat, 1993). This did not make the authorities question their reasoning, and they only prescribed new technical rules for the design and calculations of the sewers, based on the Caquot formula, with the CG 1333 memorandum in 1949. This was aimed at creating standard, safe, and cheap networks in all French cities, and only allowed for traditional sewer solutions. Because of this legal stiffness, engineers were closed off from practices coming from other countries, as they needed to apply the rules of the CG 1333 to get public funding (Chouli, 2006).

3.3.2 Urbanization and rise of environmental awareness

Until the beginning of the 1970s, this method was applied everywhere and facilitated the rapid urbanization due to the thirty-year post war boom, the “Glorious Thirty”. This, along with the development of the automobile and the development of private housing and commercial areas, led to a great increase in impervious surfaces (Lami *et al.*, 2006). National action was taken little by little to support and improve urban life, with the planning of “new cities” and the desire to improve social housing and living conditions. However, urban pollution started to become a concern and green areas were introduced slowly into cities, while environmental concerns arose (Chouli, 2006).

In 1966, the government realized the shortcomings of the CG 1333 memorandum and started a research program on substitute solutions to handle stormwater. Retention basins were also becoming more popular with the help of international engineers, in “new cities”, which were often situated in places where natural evacuation was difficult. This resulted in a new memorandum in 1977 which gave focus to separated sewers and retention basins, storm basins next to wastewater treatment plants to limit overflows, and new, more precise calculation methods (Chouli, 2006). Pollution concerns were therefore combined with economic and flooding considerations.

This new memorandum gave more options to engineers developing stormwater management infrastructures, and regions where flooding risks were important developed these new techniques quickly (like Bordeaux or the Seine-Saint-Denis), but many still chose to keep traditional sewers, because of misconceptions, bad experiences and lack of necessary skills (Dupuy and Knaebel, 1982).

Nonetheless, catastrophic storm events like the floods in Narbonne (1988) and Nimes (1989) or the pollution of the Seine in Paris (1990 and 1991) showed the limits of purely technical responses to stormwater management. This was especially true in long-established cities, where there was little available free space (Petrucci, 2012). Since then, an integrated approach, taking the name of “*techniques alternatives*” has been formalized and promoted by national and local authorities, with three main objectives: decrease flooding risks, limit pollution, and integrate stormwater management into urban planning decisions (Lami *et al.*, 2006).

Initially, though, the development of *techniques alternatives* was slow, and mostly encouraged by a few municipalities helped by research organizations, who published a lot of guidance material and handbooks during the 1990s. Local experiments for urban integration of sustainable stormwater management played an important role in the development of *techniques alternatives*, but private infrastructures usually gave mixed results, because they were badly conceived or maintained. It also happened that the owners were not aware of the existence of *techniques alternatives* on their land. Private constructors did not yet see the advantages to going to a more integrated approach to stormwater management (Petrucci, 2012). However, even though issues still exist, the development of *techniques alternatives* has increased exponentially in recent years.

3.4 Legislation framework and responsibilities

3.4.1 European and national legislation

The French national legislation on stormwater is broad and scattered into different codes and regulations. First of all, the Urban Wastewater European Directive, adopted in 1991 to protect the water environment from the effect of wastewater discharges, has allowed for extended funding to be distributed to renew and renovate sewers, disconnect stormwater, and create storm basins (Ministère de l'Environnement de l'Energie et de la Mer, no date).

In terms of French legislation, the Civil Code defines the status of stormwater, and is applicable to both private individuals and local governments. It states that stormwater is the propriety of the occupier who receives it on his land, but that he cannot refuse stormwater that naturally flows from higher lands. According to the Public Health Code, municipalities can also define prescriptions for and even refuse connections to public networks (O2D Environnement, no date). In addition, the 1992 Law on Water compels municipalities to define zones where imperviousness must be limited and stormwater managed (Ministère de l'Environnement de l'Energie et de la Mer, no date). The Environmental Code, modified by the 2006 Law on Water also defines the project surfaces which have to be submitted to declaration or authorization: above 1 ha and below 20, a declaration suffices, but above 20 ha, an authorization from the state services is necessary. This surface includes the surface of the catchment basin of which the runoff is intercepted (Luchesi, 2008a).

Stormwater management has hence been an optional skill handled by municipalities (or their Public Establishment for Intercommunal Cooperation, or EPCI in French) for a long time. On December 30th, 2006, the law on Water and Aquatic Environments gave municipalities or their EPCI the possibility to create a public administrative service for stormwater, and to collect a tax aimed at giving more resources for sustainable stormwater management, but also at encouraging source control (an abatement was planned in this case) (Garrigues, 2012). However, the tax was quickly removed in 2015 because it did not bring in enough funding; the public service for stormwater management remains but now needs to be included in the general budget (Carré, 2016).

This was then followed by the MAPTAM law in 2014, which made stormwater management an obligatory skill for all municipalities (or their EPCI) (Vincent and Grelier, 2016). Finally, the 2015 NOTRe Law (about the new territorial organization of the Republic), states that "water and sanitation" is now a competence that necessarily falls to the EPCI (Ministère de l'Environnement de l'Energie et de la Mer, no date), even if some elected officials did not agree with it as they felt that precise and local knowledge was necessary for successful stormwater management (Vincent and Grelier, 2016).

3.4.2 Water management tools

In addition to the legislation that defines the different responsibilities, several regulatory tools are available for public planners and engineers to define their policies for sustainable stormwater management.

The first are the Planning and Water Management Master Schemes (SDAGE in French), established with the 1992 Law on Water. There are 7 in metropolitan France and 5 in the overseas territories which are elaborated at the scale of the general hydrographical basin for a period of six years; the third generation of SDAGE has just been approved for the period 2016-2021. The Water Agencies define their orientations and action plans for the upcoming years along with state services and the National Water Office, but also local governments and citizens (Gest'eau, no date c). The different SDAGE have legal effect: this means that all urban planning and water management documents at lesser scales must be compatible with their corresponding SDAGE (Bacot, Brelot and Valin, 2014).

The next level in water management are the optional Planning and Water Management Schemes (SAGE), established at the watershed level since the 1992 Law on Water and reinforced by the 2006 Law on Water. A SAGE must be composed of a sustainable management plan, defining objectives and the means to attain them, supplemented by a set of rules to follow to reach these goals (Bacot, Brelot and Valin, 2014). A SAGE is elaborated collectively by local governments, users (farmers, industrials, landowners…), and the corresponding Water Agency, in order to reconcile regular usage of water with the protection of the environment while taking local characteristics into account. Even though it is not mandatory, it has a legal effect and must be followed by other planning documents and regulations. In 2016, more than 100 SAGE exist and cover 49.1% of the French territory (Gest'eau, no date b). The "milieu contracts" are alternatives that engage stakeholders financially on a voluntary action plan; together with the SAGE, they cover more than ¾ of the country (Gest'eau, no date a).

In addition, Natural Risks Prevention Plans (PPRN) can also be drafted to prevent certain risks linked to stormwater (but not only), like flooding (PPRNI) or mudslides (Luchesi, 2008a). They can for example define areas where imperviousness should be reduced or, on the contrary, where infiltration is forbidden due to the nature of the soils, and are prescribed by prefects following inventory and characterization of the possible hazards (Bacot, Brelot and Valin, 2014). According to the article L2224-10 of the General Local Authorities Code (*Article L2224-10*, 2010), municipalities or their EPCI must also establish a pluvial zoning, delimiting areas where:

- "measures should be taken to limit ground imperviousness and ensure control of the flow and runoff of stormwater";
- "it is necessary to plan installations for collection, eventual storage, and if needed, treatment of stormwater when the pollution they bring to the aquatic environment may greatly reduce efficiency of sanitation apparatus".

Finally, the article L2224-12 of the same Code states that municipalities or their EPCI must come up with a set of regulations concerning sanitation (wastewater and stormwater), defining the work handled by the public services and the obligations of users, owners, and operators (*Article L2224-12*, 2006).

3.4.3 Urban planning tools

One of the main characteristics of urban stormwater management is that while it cannot be decoupled from wastewater management in terms of infrastructures, it must also be associated with urbanism and city planning: indeed, management of urban planning documents and programs is necessary to control ground occupation and water flows (Carré *et al.*, 2010). For that reason, such documents should always be considered when aiming for sustainable stormwater management.

The first level of urban planning documents is the Territorial Planning Directive (DTA). They are created by the state and are not meant to cover the whole territory, but rather for areas with high planning, development, and environmental protection stakes. They can encompass several departments or even regions and today, six exist in France (Berthelot, 2013). A DTA sets national orientations in terms of development and improvement of territories, but also its objectives in terms of the location of important transport infrastructures, equipment, and environmental protection zones (Bacot, Brelot and Valin, 2014).

The Territorial Coherence Scheme (SCoT) corresponds to the next level of planning regulations, instituted by the Solidarity and Urban Renewal law of 2000. Again, it is optional and is born from local initiative from municipalities or their EPCI (Bacot, Brelot and Valin, 2014). It is a long term territorial project which must respect the principles of sustainable development in order to find a balance between urban renewal, controlled urban development, rural development, and protection of natural areas, to diversify urban functions and social mix, and to respect the environment. In 2015, 448 were accepted or in project, covering almost 60% of the national territory (Ministère du Logement et de l'Habitat durable, 2016).

Finally, the smallest level of planning documents is the Local Urbanism Plan (PLU), established at the municipal or intercommunal level. It must respect the SCoT and be compatible with the SDAGE and the SAGE; in addition, the pluvial zoning can sometimes be directly integrated in the PLU (Bacot, Brelot and Valin, 2014). It defines the planning and sustainable development project of the municipality and contains a set of regulations describing ground affectation, construction heights and exterior aspects, areas to showcase or protect, neighborhoods to develop, energy performances, social mix zones, etc. (Direction Générale des Collectivités Territoriales, no date).

3.4.4 Conclusion on stormwater management and legislative tools

Figure 3.12 shows the different levels of French legislation that are related to stormwater management, from European directives to local urban planning documents.

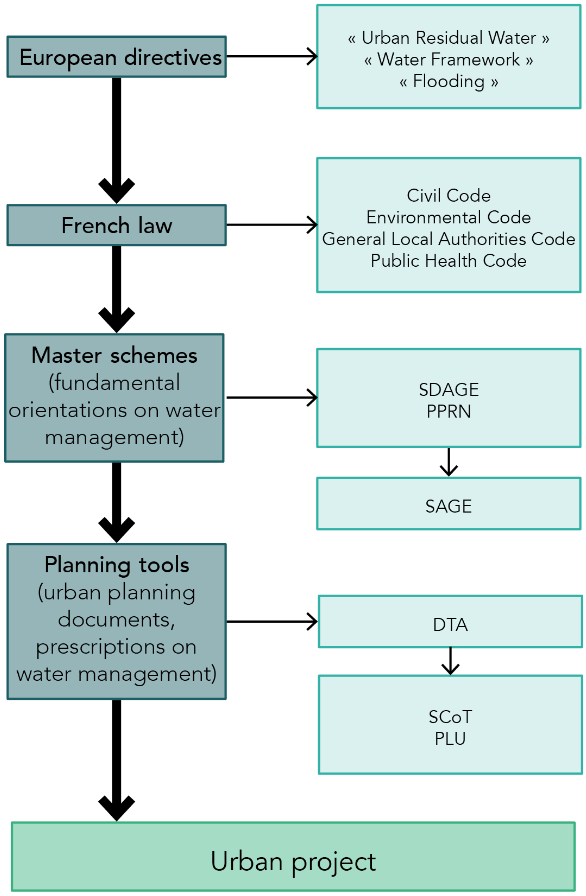


Figure 3.12: Different levels of legislation in French stormwater management. Adapted from (Département de Seine-et-Marne, 2014)

3.5 Decision and communication-support tools

The complexity of planning for sustainable stormwater management is evident. The diversity of stakeholders both in public and private sectors, coupled with complicated legislative frameworks and lack of experience may bring about several concerns which may halt the progress of sustainable stormwater management (Chocat *et al.*, 2008; Caradot *et al.*, 2010; Ellis, Lundy and Revitt, 2011; Boudet, Principaud and Maytraud, 2016). To face these issues, a lot of research has been carried out in the development of tools or aids aimed at helping stakeholders choose the right stormwater management method, but also communicate and work together in order to ensure its proper functioning.

3.5.1 Interactive decision-support tools

The first category of such aids consists of decision-support tools or methods, intended to facilitate knowledge acquisition and decision-making at the design phase. Many of them are web- or computer-based and rely on multicriteria analysis. One example of this is the tool developed under the DayWater research program between 2002 and 2005. It's an adaptative tool that can be used at different scales and by people from different backgrounds, and is accessible on the Internet (Thevenot, 2006). Once logged in, the user can find information and fact sheets about different Best Management Practices, urban dynamics, pollution, risk management, etc., but also a multicriteria analysis tool where he or she can fill in different weights for different technical, environmental, economic, and social criteria. The best solution, based on predefined site characteristics, can then be proposed. A "guided tour" is also available when the user has a specific planning or design problem (*DayWater*, no date).

Researchers have worked a lot on decision-making tools based on multicriteria analysis because this approach allows the combination of a vast number of objectives, while exposing potential conflicts and reducing the possibility of subjectivity. Another example of such a tool is the *AvDren* software, presented by Baptista *et al.* (2007). This tool is based on the definition of a general performance indicator (resulting from the combination of several sub-criteria) and a cost indicator, which can then be calculated for different scenarios through simulation.

Another digital decision-support tool is the one developed by a team of Dutch researchers as part of the Climate-KIC "Blue Green Dream" project (van de Ven *et al.*, 2016). They have created two complementary tools that can be used during the initiative and design phases of a planning project to inform, explore, and test different techniques for sustainable stormwater management. The first is the Climate Adaptation App and is available online (Bosch Slabbers Landscape + Urban Design *et al.*, no date); it can, after selecting a number of filters on the target and the site characteristics, give a number of appropriate solutions. They can then be implemented virtually on a local map in the Adaptation Support Tool (see Figure 3.13), where their effect and impact is calculated (storage capacity, groundwater recharge, runoff reduction…) (van de Ven *et al.*, 2016).

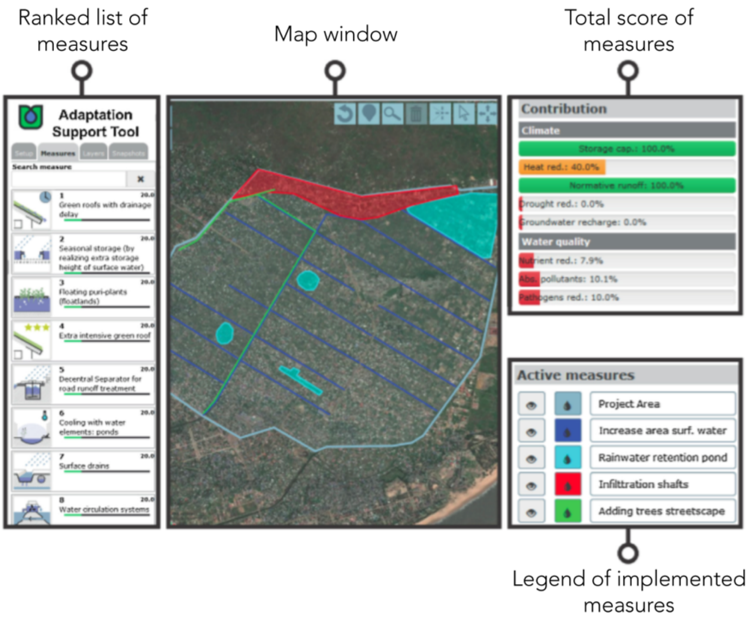


Figure 3.13: Screen components of the Adaptation Support Tool. (van de Ven *et al.*, 2016)

Finally, the expansion of GIS based tools to support stormwater management is also to note. Warwick, Charlesworth and Blackett (2013) have developed maps indicating the best locations for different types of sustainable urban drainage systems based on physical and anthropogenic factors, while Caradot *et al.* (2010) use GIS software to evaluate and model overflow risks in the Grand Lyon and in the city of Mulhouse. Figure 3.14 shows how other researchers go even further by considering human, material and environmental vulnerabilities to map out global vulnerability to hydrologic hazards and link it to run-off or submersible zones (Renard and Chapon, 2010). In all cases, GIS software allows stakeholders to quickly understand priority areas.

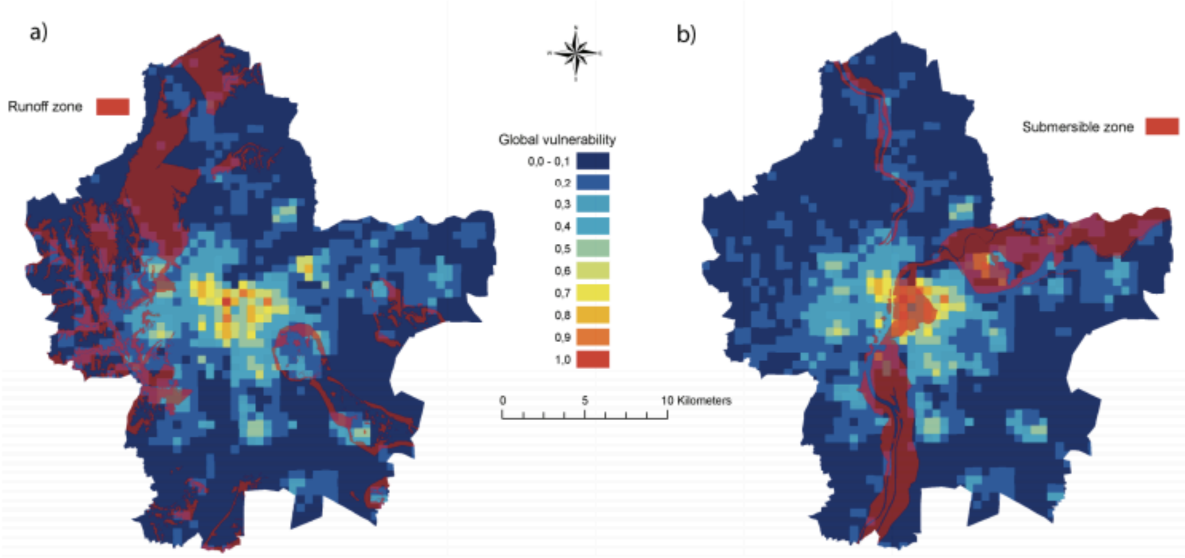


Figure 3.14: Spatial representation of urban runoff risk (a) and urban flooding risk (b) in the Greater Lyon.
(Renard and Chapon, 2010)

3.5.2 Guides and fact sheets

In addition to decision-support tools developed by researchers, a lot of associations, municipalities, and other public organizations have drafted guides and fact-sheets, intended to raise awareness and share general information to stakeholders who wish to gain knowledge about sustainable stormwater management.

Some are mostly informative and aim at spreading knowledge about *techniques alternatives* and the stakes involved, but also about general concerns linked to water. This is the case of the Méli-Mélo project started by the GRAIE and Media Pro and destined for a large audience of French citizens (Chocat, Brelot, *et al.*, 2014). The project's goal is to break popular misconceptions about drinking water, wastewater, and stormwater in cities through the use of humoristic short videos, illustrations, and short texts based on scientific references, which are intended to be "pirated" and shared intensively. In 2016, the GRAIE has also published a set of "true/false" notes answering commonly asked questions and fears about *techniques alternatives* to clarify knowledge of the different stakeholders involved (Chocat and GRAIE, 2016).

Other documents include feedback on urban developments that successfully implemented sustainable stormwater management (Direction de l'Eau du Grand Lyon, 2013), and fact sheets about the most common types of *techniques alternatives* (Lami *et al.*, 2006; Luchesi, 2008b; Mairie de La Mothe-Achard, 2016). They usually describe the advantages of each technique, in what context it can be implemented, and guidelines for their design and calculations.

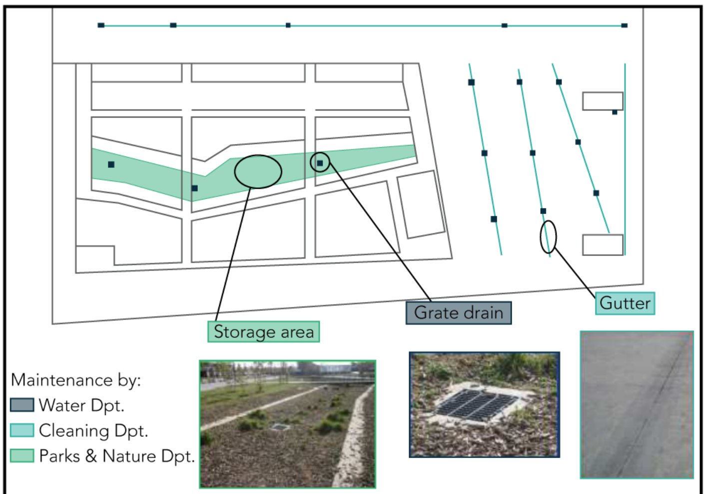
Some organizations have however realized that the problems with sustainable stormwater management did not only come from a lack of knowledge about the *techniques alternatives*, but also from the handling of the project itself. They have therefore created guides with guidance for stormwater project management, encouraging early integration of stormwater issues, collaboration between stakeholders, and monitoring of operations (Gromaire *et al.*, 2013; Van Es *et al.*, 2015). The practical guide of the Communauté d'Agglomération Hénin-Carvin (Van Es *et al.*, 2015) is one of the most extensive with 305 pages, ranging from definitions of *techniques alternatives* to feedback on successful projects and guide sheets for an integrated project approach.

3.5.3 The issue of maintenance

While local authorities already face a lot of issues when designing sustainable stormwater techniques, a specific concern is related to the maintenance (once the infrastructure is in place) because of the diversity of actors involved. This is mentioned in some of the guides introduced before, which reinforce the need to consider the maintenance very early in the process, and suggest regular control to adapt practices if needed (Gromaire *et al.*, 2013).

On the other hand, Boudet, Principaud and Maytraud (2016) have studied management issues in Plaine Commune and have devised "maintenance notebooks" to introduce the actors and stakes of each site, to explain its functioning precisely, and to describe the different maintenance interventions needed and how they should be coordinated. A summary sheet intended for maintenance agents was also drafted so that they could easily understand their role and their tasks on each site (Figure 3.15). A similar system was implemented in the Hauts-de-Seine, with summary sheets on specific sites to build a database of existing infrastructure and of their conduct (Conseil départemental des Hauts-de-Seine, 2015).

Maintenance instructions for the Place du Front Populaire



	Grate drain	Square and gutters	Open natural storage area
Role	Collects water and fills storage area	Collects water	Stores rainwater before releasing it to the underground network
Specificity	Must not be clogged		Can be flooded
Maintenance	Cleansing (2x/year)	Picking up waste (1x/day) Cleaning (occasionnally)	Mowing during half the year Picking up of waste (3x/week)

Contacts:

- Water department: XX-XX-XX-XX-XX
- Cleaning department: XX-XX-XX-XX-XX
- Parks & nature department: XX-XX-XX-XX-XX

Coordination:
The Water Dpt. technician must:
- Check the functioning of the site 2x/year
- Do a control visit in case of exceptional rain

The Parks & Nature and Cleaning Dpts. must:
- Warn the Water Dpt. if they see an unsual state of the site

Figure 3.15: Example of a summary sheet intended for maintenance technicians. Adapted from (Boudet, Principaud and Maytraud, 2016)

4 Case study

4.1 The Grand Lyon metropolitan area

4.1.1 Geographical context

In order to understand specific problems that could arise when planning for sustainable stormwater management, the French urban area of Grand Lyon was chosen as a case study. Lyon is the third-largest city in France behind Paris and Marseille (Journal du Net, 2014); but its urban area is the second largest French urban area with 2 237 000 inhabitants in 2014 (Théobald, 2016). It is located in the Rhone department (69) which is part of the Auvergne-Rhône-Alpes region, in the south-eastern part of France.

Temperatures in Lyon vary from 0 to 6ºC in January to 16 to 28ºC in July on average; the city has a warm and temperate climate. Annual precipitation is around 830 millimeters, with about 105 days with precipitation per year (Météo France, no date). In addition, precipitation is around the same for every month of the year, with a small decrease in the colder months of December to March (Grand Lyon, 2016).

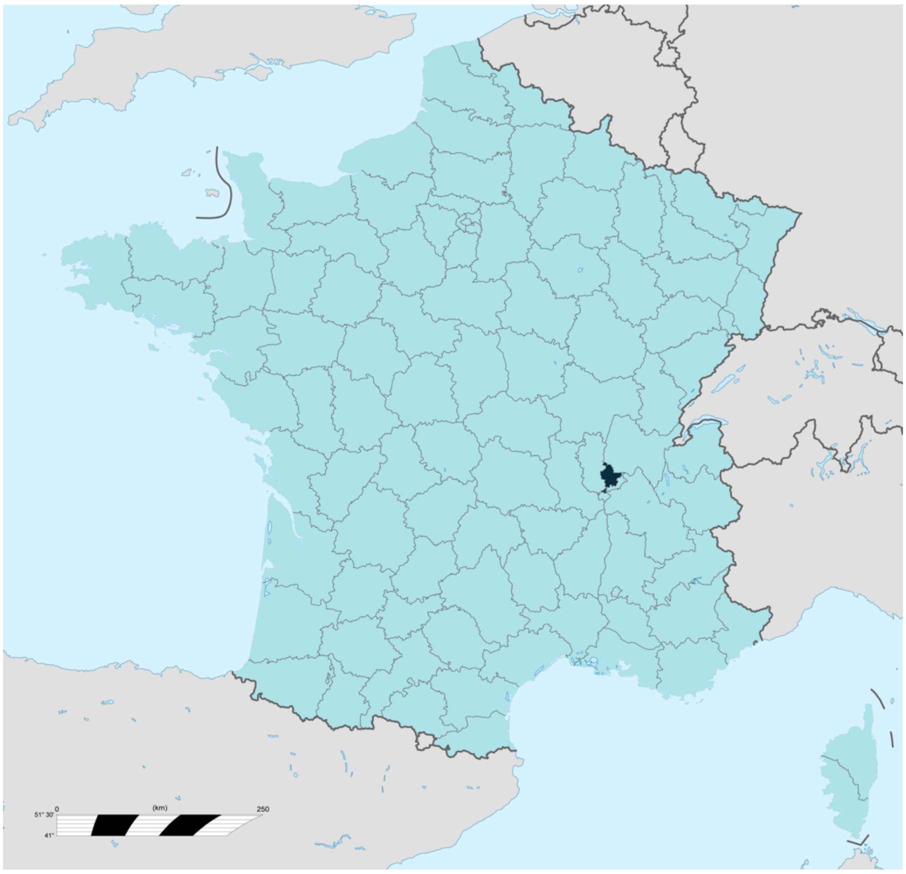


Figure 4.1: Location of the Grand Lyon in France. Adapted from (Sting and Wikialine, no date)

The object of this study is not only the city of Lyon but the *metropolis of Lyon*, also called *Grand Lyon*. Its location in France is shown on Figure 4.1. This area, with a population of 1 281 971 inhabitants in 2014 and covering a surface area of 538 km^2, corresponds the merging of the city of Lyon and 58 of its suburbs in order to create a unique type of regional government (Grand Lyon, no date a).

4.1.2 Administrative status

In France, regional governments (*collectivités territoriales*) exist at different levels: municipalities, departments, and regions (Direction de l'Information Légale et Administrative, 2016d). In addition, there are 36 783 municipalities in France, 32 000 of which have less than 2000 inhabitants (Centre de Gestion du Doubs, no date); therefore, in order to reduce costs, gather expertise, and boost local development and planning schemes (Direction de l'Information Légale et Administrative, 2016b), Public Establishments for Intercommunal Cooperation (EPCI in French) were created and since 2013, every municipality must belong to an EPCI (Direction de l'Information Légale et Administrative, 2016a). They are public structures, elected by direct universal suffrage, who take on mandatory and optional competences given by law or handed over by the member municipalities, such as economic development, social habitat, sanitation, water, cultural development, etc. (Direction de l'Information Légale et Administrative, 2016c). Depending on their size and their status, EPCI may have different names: community of municipalities, urban communities, etc., but also, for the largest ones, *metropolises*. There are currently 14 EPCI that have the name *metropolis* in France: Nice, Bordeaux, Brest, Grenoble, Lille, Montpellier, Nantes, Rennes, Rouen, Strasbourg, Toulouse, Nancy, and Grand Paris and Aix-Marseille-Provence (Baylet and Grelier, 2017).

However, even though it bears the same name, the metropolis of Lyon has a very different status as it is a regional government (much like municipalities and departments) with specific status (Baylet and Grelier, 2017). This is a unique status in France, which allows the metropolis government to take on both the responsibilities coming from the Grand Lyon (which was previously an EPCI) and from the Rhone department on all of the municipalities which it covers (Direction de l'Information Légale et Administrative, 2017). As shown, confusion is hence possible since the Grand Lyon used to be an EPCI, just like all of the other French metropolises. However, in this study both terms will be used interchangeably as they now refer to the same entity; the term "Grand Lyon" was kept for coherence and communication matters.

The responsibilities which fall to the Grand Lyon today include responsibilities from the previous urban community, from the department, but also periodically and on certain missions, from the region and from the state. It can also delegate the management of certain competences back to the municipalities (Direction de l'Information Légale et Administrative, 2017). Its five main domains of action include economic development; education, culture and leisure; solidarity (handicap, elderly, family support…); living environment; and daily services which include water, waste and transport management (Grand Lyon, no date c).

Therefore, all services linked to sustainable stormwater management are handled by the Grand Lyon in theory: water and sanitation, environmental protection, public space cleaning, and urban planning (Grand Lyon, no date c). However, parks & nature services are still usually handled by the individual municipalities.

4.2 Stormwater in the Grand Lyon

4.2.1 Organization and responsibilities

Because of its status, the metropolis of Lyon has control over the entire water cycle on all of its 59 municipalities. While drinking water production and distribution services are managed by an external commissioned company called *Eau du Grand Lyon* ("Water of Grand Lyon"), a branch of Veolia, the Grand Lyon services have kept control of all of the collection, transport and treatment of waste and stormwater in the metropolis (Direction de l'Eau du Grand Lyon, 2015b). These public services are executed by the Water Department of the Grand Lyon, divided into three branches: project development, maintenance and operations, and support functions. The Grand Lyon employs 608 agents, 90% of which do technical work (the rest is administrative staff) (Direction de l'Eau du Grand Lyon, 2015b). Since 2011, the Water Department has a triple ISO certification for its integrated management system in Quality, Environment and Security (Grand Lyon, no date b).

4.2.2 Current practices and issues

Historically, the urban center of Lyon had sewers to transport stormwater outside of the city until the 1950s, when wastewater, which was previously stored in drained pits outside buildings, was connected, creating a combined sewers network. However with the rapid development of the Lyon conurbation between 1960 and 1990, other methods were adopted with separate sewer systems or independent stormwater collection techniques, but with some issues where stormwater sewers were sometimes connected to the wastewater network, creating a pseudo-combined network with a lot of deficiencies (Direction de l'Eau du Grand Lyon, 2015c).

To face this, a first (in 1969) and a second (in 1992) general sanitation plans were drafted based on several principles (Direction de l'Eau du Grand Lyon, 2015c):

- Improve natural environment quality;
- Reach a better compatibility with urban development;
- Control flooding and pollution by stormwater;
- Optimize usage of existing infrastructure.

Therefore, questions of sustainable stormwater management were already being considered more than thirty years ago in the Lyon metropolis.

In 2015, a third general sanitation plan was created for orientation until 2027. Under the Code of regional authorities (*Code régional des collectivités*), any local government of more than 2000 inhabitants must write a plan for its sanitation (which includes wastewater and stormwater) to define general orientations and relevant issues. It sets up a framework for future investments, projects and maintenance operations to improve the community's sanitation system at the medium and long-term scales, and should include a diagnostic, a definition of objectives, and a schedule for their implementation. It has been elaborated in collaboration with the Rhone-Mediterranée-Corse Water Agency, all of the Grand Lyon departments (Streets, Cleaning, Urban Planning, …), the mayors and elected officials of the 59 municipalities, and other public organizations (Direction de l'Eau du Grand Lyon, 2015c).

The 2015-2027 general sanitation plan of the Grand Lyon puts emphasis on four main concerns and orientations:

1) Act at the source to preserve human health and aquatic environments
2) Design and pilot sanitation systems to reduce impacts on the environment
3) Manage and develop existing infrastructure
4) Be near and see far to assist territorial planning

For each of these issues, strategic objectives will be developed in two parts: one for the objectives which involve the heart of the work of water management actors, and one for the objectives that should be built in coordination with all public and private stakeholders involved (Direction de l'Eau du Grand Lyon, 2015c).

In order to reach these objectives all around its territory, the Grand Lyon will adapt to the landscape and geological features of each site to develop and extend its network. Indeed, the west of Lyon is an area with rocky terrain where water does not infiltrate well; separated sewer systems should therefore be favored, while in the East, parcel infiltration is a better solution because of permeability of the soil (Direction de l'Eau du Grand Lyon, 2015a).

In terms of infrastructures, the Grand Lyon metropolis was equipped in 2014 with 3193 kilometers of sewers, divided in:

- 1831 kilometers of combined sewers
- 1340 kilometers of separated sewers, with 913 kilometers for wastewater and 427 kilometers for stormwater.

The sewers are completed by 397 combined sewers overflows (CSO) and 12 wastewater treatment plants, but also 135 retention basins, 56 infiltration basins, 2600 infiltration wells and 116 kilometers of swales or ditches. 30 rainfall stations and 28 monitoring stations are also scattered on the network to check for water quality and better evaluate flows (Direction de l'Eau du Grand Lyon, 2015c). In 2015, the number of kilometers of sewers has increased to 3276, while 38 new CSO have been built along with 40 new infiltration or retention basins. Combined together, this system allows the local authorities to treat more than 475 000 cubic meters of water every day (Direction de l'Eau du Grand Lyon, 2015b).

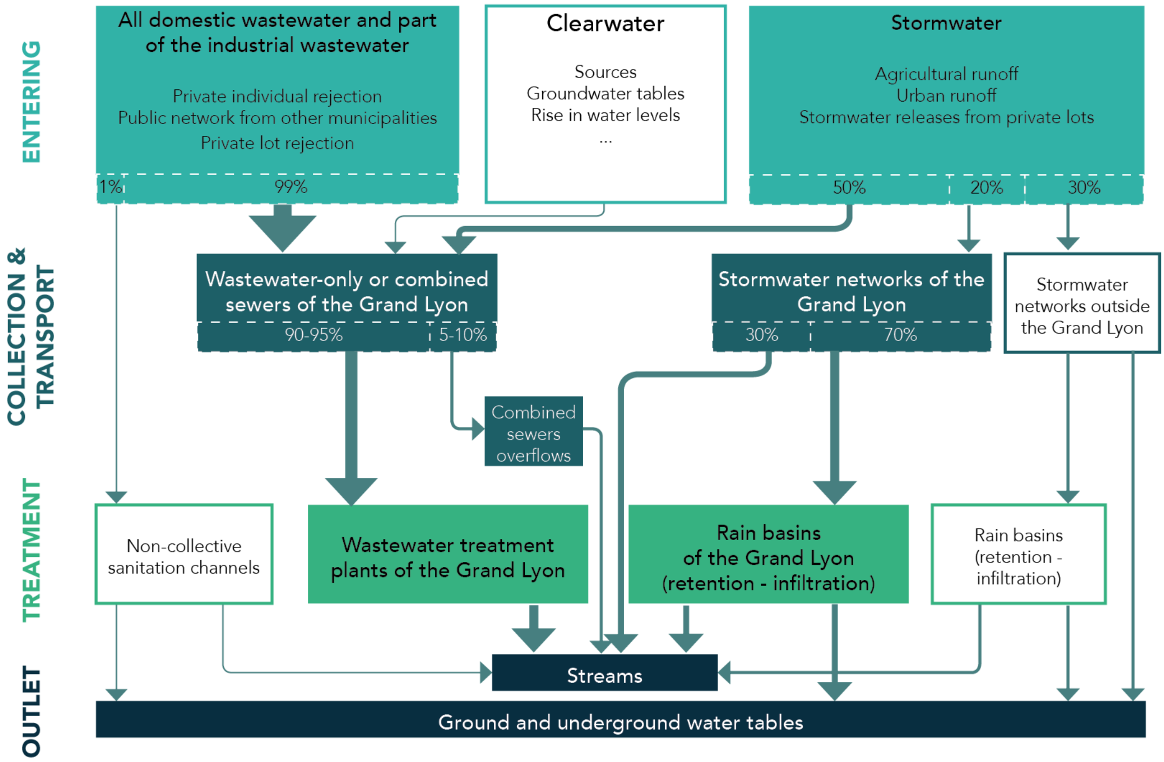


Figure 4.2: Distribution of wastewater and stormwater flows in the Grand Lyon. Adapted from (Direction de l'Eau du Grand Lyon, 2015c)

Figure 4.2 displays how wastewater and stormwater flows are divided throughout the sanitation network. As shown, 50% of stormwater transits through combined sewers and then risks being rejected mixed with wastewater and untreated to the natural environment. Of the stormwater that is collected by the separate sewers of the Grand Lyon, 30% is also directly released into nearby streams.

One practical objective of the general sanitation plan is for example to reach conformity to the July 21, 2015 decree relative to combined sewers overflow (Residual Urban Waters Directive, or RUWD). This decree states that untreated flows should correspond to less than 5% of the total volume, or that combined sewers should overflow less than 20 days per year (Direction de l'Eau du Grand Lyon, 2015b). Figure 4.3 shows the amount of untreated stormwater released to the natural environment for different wastewater treatment plants: there are only two that meets the decree requirements.

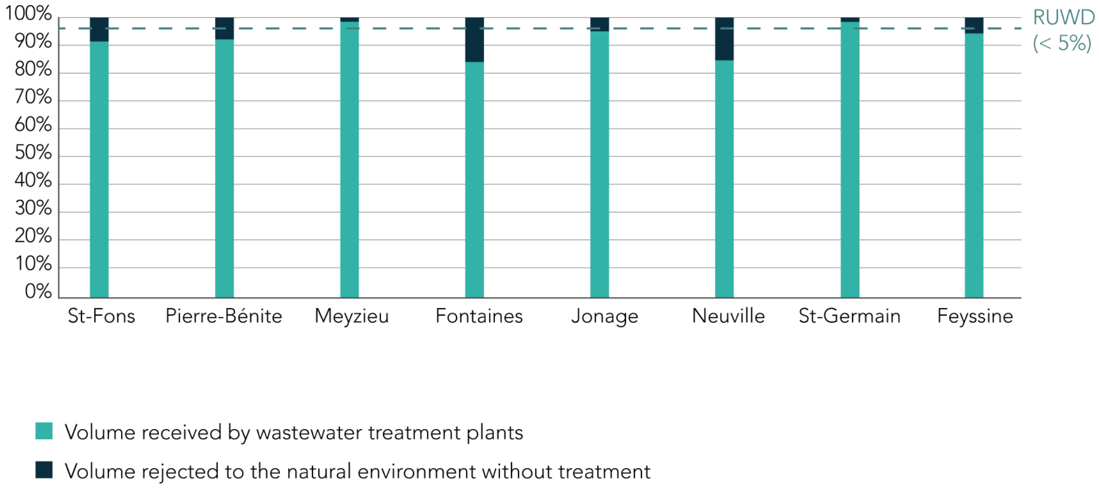


Figure 4.3: Treated water flows and untreated water flows rejected to the natural environment (model results). Adapted from (Direction de l'Eau du Grand Lyon, 2015b)

Other actions will include increasing preventive maintenance, expanding knowledge of private sanitation systems, developing innovation in collaboration with scientists, boosting local collaboration between elected officials, public water services, industrials, and inhabitants, to answer to the sustainable development goals (Direction de l'Eau du Grand Lyon, 2015c). Guides, fact sheets and other publications have already been made available on the Grand Lyon webpage for anyone to access (Grand Lyon, no date d).

4.2.3 Related projects and examples

As the city of Lyon and its surrounding urban areas have developed, sustainable stormwater management has become more and more of a concern and successful initiatives can be found all around the Grand Lyon.

4.2.3.1 The Porte des Alpes industrial park

The Porte des Alpes site in Saint-Priest is an industrial and technological park located in the Eastern part of the Grand Lyon, where stormwater is managed by *techniques alternatives*. Designed between 1995 and 2000, it is one of the earliest and biggest developments of sustainable stormwater management in the area, with a surface of 140 hectares (Thual, 2011) and a cost three times lower than traditional "all pipes" systems (GRAIE, 2014a). Today it is still regarded as one of the best and most successful accomplishments of the Grand Lyon Water Department, and serves as an example for future developments (Direction de l'Eau du Grand Lyon, 2013).

During the design of the site, an integrated approach was conceived from the beginning of the project, calling for collaboration between landscape architects, urban planners, and water experts, but also with streets and parks & nature technicians (Direction de l'Eau du Grand Lyon, 2013). This resulted in the creation of a "cascade management" with swales and infiltration trenches conveying water to five ponds and infiltration basins, as shown in Figure 4.4 (Thual, 2011).

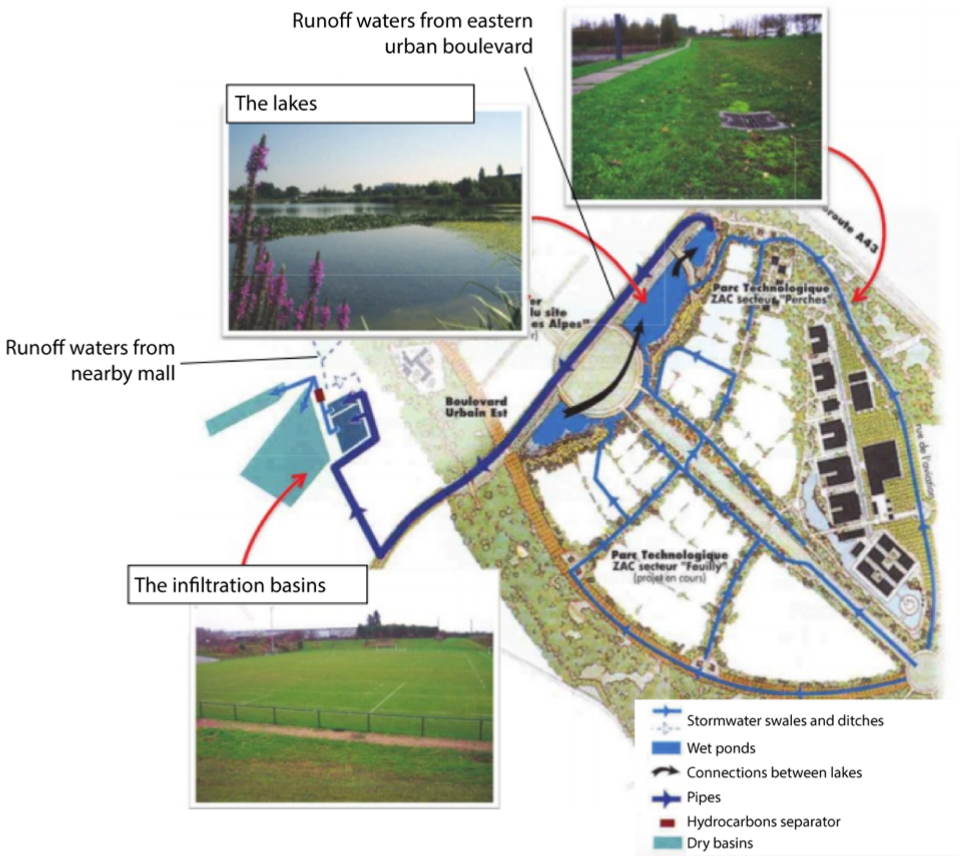


Figure 4.4: Map of the stormwater management techniques at Porte des Alpes. Adapted from (GRAIE, 2014a)

The main qualities of the Porte des Alpes project include (Sibeud and Mazereel, 2007):

- The multi-functionality of the facilities allows them to be well integrated and appreciated by local citizens;
- The cascade design strategy can handle different storm intensities and flood risks;
- The creation of a unique management committee can coordinate different stakeholders;
- And the development of “water culture” can raise awareness to increase longevity of the site.

However, Sibeud and Mazereel (2007) also insist on other aspects which need to be watched carefully. The main one is that when implementing such types of *techniques alternatives*, public services should make sure that their initial function is not forgotten, and this had the tendency to happen in Porte des Alpes. For example, with the development of the technological park and the increase in attendance, the swales have started to be used as pedestrian lanes or wild parking. In addition, real estate developers promote the park and its lakes for marketing reasons, while its initial hydraulic function remains unknown. Finally, one of the dry basins has often been illegally taken over by travelers or for activities such as moto-cross. Technical and hydraulic performances of the site should also be monitored regularly, as there is an increased risk of flooding if the permeability of the soil decreases (GRAIE, 2014b).

4.2.3.2 The neighborhood of La Buire

The neighborhood of La Buire, located in the middle of the city of Lyon in its third *arrondissement*, is a ZAC, or "joint development zone" created in 2004 (Thual, 2011). It is a primarily residential and dense urban area with space for shops on its outskirts, and is designed around a public park of 5000 m^2 which is also used for sustainable stormwater management.

The main *technique alternative* used in this case is a retention-infiltration basin designed like a moat on two sides of the park (see Figure 4.5). Stormwater coming from roofs and private grounds is transported through underground pipes in the 870 m^3 basin, where it stored and then infiltrated directly to the groundwater table. An anti-contaminant geotextile has also been placed under the basin to protect the groundwater table in case of accidental pollution (Thual, 2011).

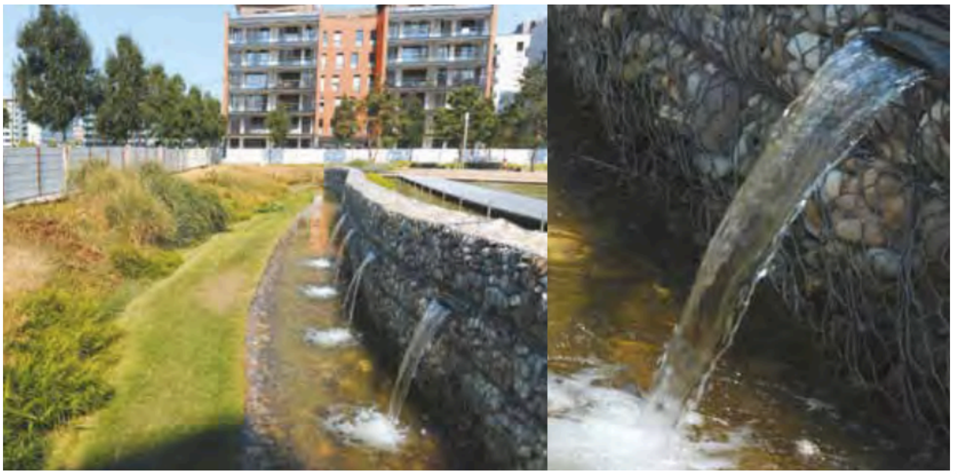


Figure 4.5: Views of the moat in the La Buire park. (Direction de l'Eau du Grand Lyon, 2013)

The technique's integration in the neighborhood is complete: the park also acts as a playground and rest area for local inhabitants, and the nearby school has diverted some of the stormwater to water plants and supply water basins (Direction de l'Eau du Grand Lyon, 2013). The deepest parts of the moat are densely vegetated in order to be impenetrable and prevent risks for young children, while public services have decided, following inhabitants' demands, to close off the park with barriers to reduce incivilities (Thual, 2011).

4.2.3.3 The campus of La Doua

The site of LyonTech - La Doua in Villeurbanne is currently undergoing a vast restoration in order to become an eco-campus. The project aims at reducing energy consumption and improving life quality on campus, but also to make it an experimental and exemplary realization in terms of sustainable development (Cresci, no date). It therefore acts as a support to research and training on sustainable cities and alternative techniques in urban planning, and especially for urban water management (INSA Lyon, no date).

This theme was chosen because of the proximity of the campus to several significant water-related sites (Rhone to the north, groundwater table underneath, La Feyssine wastewater treatment plant) but also because of the importance of the research in this domain being done on the campus, who are testing *techniques alternatives* there and have turned it into a real long-term open-air laboratory (Université de Lyon, GRAIE and LGCIE, no date).

Swales, infiltration trenches, porous parking lots, but also multifunctional retention and infiltration basins, dry rivers and experimental pavements materials have been built around the site. Effort has also been made to reduce imperviousness and increase green areas to limit runoff during storm events. Finally, all of these techniques are instrumented with testing equipment that allows researchers to follow reduction of pollutants and infiltration flows. Studies are also done on the way users and maintenance workers adapt to and handle these *techniques alternatives* (GRAIE, 2016). They are aimed at increasing knowledge on sustainable stormwater management and at developing new innovations, which can then be spread on to the rest of community (Université de Lyon, GRAIE and LGCIE, no date).

4.2.3.4 Ville Permeable

Finally, the *Ville Permeable* ("pervious city" in English) project is a public research project, started by the Grand Lyon authorities in 2015 (Direction de l'Eau du Grand Lyon, 2015b). Focusing on experience feedback from more than 20 years of *techniques alternatives* development in the Grand Lyon, its aim is to identify and share the means to implement in order to transform impervious areas into pervious areas. By transforming little by little the city, the sustainable development objectives may be reached faster and at lesser costs.

To do this, two components of the project have been studied separately (Direction de l'Eau du Grand Lyon, 2015b):

- A technical and economical comparison of *techniques alternatives* with traditional combined and separated sewers has been accomplished by a private consulting firm, to propose new combined policies for Water, Streets and Cleaning departments;
- An urban planning thesis has been requested in collaboration with CITERES and EVS laboratories, to analyze driving factors and obstacles to sustainable stormwater management.

At the end of this research, design and maintenance guides for sustainable, climate-adapted streets and public spaces will be drafted, along with sizing and cost estimation tools to highlight gains and benefits, and propose new policies for the Grand Lyon (Direction de l'Eau du Grand Lyon, 2015b).

4.3 Interviews

As was specified in the method, interviews were carried out with members of different organizations involved in stormwater management. They were done over the months of December 2016 and January 2017 and reflect the personal point of views of each interviewee. This part will introduce them and the context of each interview, along with the main themes that came out of their responses.

4.3.1 Interview A - Grand Lyon water department

The first interview was carried out with a PhD student working for the Grand Lyon Water Department and under Mrs. Sibeud, who is the head of the consulting and construction divisions for everything related to stormwater, wastewater, and drinking water. According to them, the development of *techniques alternatives* in the metropolis is quite successful and has been for a long time, because of the motivation of certain managers but also with the strong links they have with several organizations, associations and research laboratories in the region (like ASTEE, the GRAIE or INSA Lyon). However, some difficulties still exist as sustainable stormwater management is still not an automatic response.

The Grand Lyon Water Department takes part in both public and private development projects. For public projects, everything from design to construction and maintenance is done by the Grand Lyon. In the case of private projects, however, they only intervene during the building permit phase, and this is usually the only time when they can have knowledge of what is planned. This is important because once stormwater management solutions are built by private developers, they are handed back to the Grand Lyon services who are in charge of their maintenance. Careful consideration of the building permit request is therefore necessary to make sure that what is planned will be satisfactory. Even then, it can happen that what is actually built does not correspond to what was presented in the application, or that site characteristics or plans are not transmitted correctly.

In addition to that, there are several obstacles to sustainable stormwater management that the public services of the Grand Lyon must face, according to interviewee A. Even though the law compels them to find other solutions than the traditional network for management of stormwater, many private developers are not always convinced or motivated; especially inside the dense city center, real estate pressure is high and *techniques alternatives* which take up space may not seem profitable enough. Even if developers are willing, this does not guarantee that the work will done correctly: a lot of engineering firms are not yet skilled in *techniques alternatives*; in addition, several university programs of water and environmental sanitation do not have offer any courses on sustainable stormwater management.

Inside the Grand Lyon Water Department, some misconceptions still remain, meaning that some people do not believe *techniques alternatives* to be a good solution (for example, some believe that stormwater cleans the sewers during rain events, and that removing it will mean the need for a more intensive maintenance of the network). Interviewee A also states that the services are overwhelmed and often receive more requests than they can deal with properly. In addition, because of the lengthy duration of public development projects, managers may change and not always share the same view or the same knowledge, slowing down the process even more.

Interviewee A also highlights specific obstacles related to the maintenance of the infrastructures. Because of the nature of the installations, the Water Department maintenance division may not have the expertise or the technical means to manage *techniques alternatives* properly. Additionally, while some employees enjoy the ability to work more in nature, others do not and fear for the status of their job. This is the case of the sewage workers, who benefit from a specific status because of the insalubrity of their work (and hence can work shorter hours and retire early), but who cannot benefit from these advantages once they work outside the sewers maintaining open-air *techniques alternatives*.

The multi-functionality of the installations can also be a burden when sharing responsibilities. Some tasks, such as lawn mowing and landscaping, are still handled by municipalities and not by the Grand Lyon. Interviewee A explains that this can create problems, since they are not the ones initiating the projects but they still have to bear some of the costs. Management agreements are hence created with financial exchanges to help the municipalities, but this is complicated, takes time, and can easily be forgotten when managers change.

Finally, Interviewee A believes that the development of *techniques alternatives* may also be difficult because the industry cannot really take over them. Since they are mostly natural installations, with not much technology involved, there is no monetary benefit to be made over them and hence there is no industry lobby which may push companies to use them more frequently. Citizen adoption is also a key element for their integration in the city, and this is not the case everywhere. Differentiated management is often used to facilitate the maintenance of such techniques, by growing plants that don't need a lot of care, but to many people this give a wild or abandoned feeling. Basins are also condemned because they seem to attract nuisances such as toads or mosquitoes, and increase drowning risks.

When asked about the kind of solutions to face these issues, Interviewee A emphasizes the necessity of legislative tools but points out that they are not enough, since exemptions are always possible and they are not always correctly applied. Some cities like Montreal (in Canada) or Strasbourg, however, check every project for conformity once they are done. Hence, if the control was increased in the Grand Lyon, it could change mentalities, fast, but it is still complicated to implement.

According to Interviewee A, decision-support tools other than technical design software are not really used in the Grand Lyon, but could be a good solution to increase collaboration between the different services from the start of the project. To decrease the lack of knowledge, the focus is put on guides, fact-sheets and campaigns like the Méli-Mélo website developed by the GRAIE. Citizen participation could also be increased by creating agreements with the inhabitants for them to take part in the maintenance of the infrastructures, like it is done in Strasbourg.

Finally, Interviewee A also mentions the *Ville Permeable* project and how it aims at accelerating the development of *techniques alternatives* in the Grand Lyon. The technical and economical study carried out for this project has shown that *techniques alternatives* are generally cheaper, both in terms of investment and maintenance costs, than traditional combined or separated sewers; this knowledge should be used to convince reluctant stakeholders of the benefits of sustainable stormwater management. In addition, Interviewee A has spent time with workers of the different maintenance services to try to understand the problems they faced every day, with the goal of developing maintenance sheets for each site to help the workers understand their specificities.

4.3.2 Interview B - Researcher at the DEEP Laboratory

Interviewee B is an urban hydrology professor and researcher at INSA Lyon who has been working with stormwater management for more than 25 years. She is currently working on the MicroMegas project as part of OTHU (Urban Hydrology Observatory), which is instrumenting and following the *techniques alternatives* that have been installed on the campus of La Doua to monitor their performances and gain more knowledge on them.

During the exchange, Interviewee B explained the role of researchers and their relationships with other stakeholders involved in stormwater management. First of all, the Grand Lyon finances a lot of their research activities and is hence involved in the executive boards of many structures. In addition, the GRAIE, an association that gathers scientists and operations managers (local governments, consulting firms, etc.), works a lot on current issues. In this framework, they have written a book in 1992. Interviewee B is also responsible for training courses and formation programs to spread knowledge about *techniques alternatives*. Finally, her and fellow researchers have been contacted to take part in the formulation of the eastern Lyon SAGE.

Because of her involvement with all of the stakeholders related to stormwater management, Interviewee B has been able to point out some concerns, which, according to her, slow down the development of *techniques alternatives*. First of all, she believes that most of the consulting firms today are competent enough in sustainable stormwater management (they have taken part in trainings or have had access to literature) but that they are not paid enough for the degree of design subtlety they require. Most traditional VRD (Streets and Other Networks) firms are used to more crude and approximate design which is usually fine with traditional infrastructures, and need to spend more time designing and calculating dimensions for *techniques alternatives*. On the contrary, Interviewee B thinks that landscape designers are more enthusiastic and may push for the development of *techniques alternatives*, since they are more closely related to their domain.

In addition, Interviewee B believes that there are still a lot of fears and misconceptions that exist amongst several people in the field. For example, many still believe that infiltration means pollution of groundwater tables, or that *techniques alternatives* will attract mosquitoes and viruses (while it has actually been shown that sewers inspection chambers hold much more mosquitoes and deadly diseases than swales or trenches, which are meant to be dry most of the time). The problem with such fears, according to Interviewee B, is that they lead to the implementation of techniques that are enormous and badly conceived, and which end up costing much more than what simple *techniques alternatives* would.

Finally, there are also problems linked to the lack of knowledge and collaboration problems at the maintenance level. The distribution of the tasks between the different services is not always clear or even accepted; on the other hand, the technicians who are supposed to do the maintenance do not have the proper culture and are not aware of environmental concerns. For example, they will have no trouble using pesticides, while they are precisely the types of pollutants that can still reach the groundwater table; on the other hand, they will be afraid of hydrocarbons, even though they stay on the surface.

In order to face these issues, Interviewee B emphasizes the need to effectively work collaboratively and face to face. She explains that while a lot of guides exist and are made to be as clear as possible, many do not read them properly or still do not understand how to apply *techniques alternatives* in a correct manner. According to her, the best solutions are training and support for local governments: knowledge should be transferred, but not only through literature. She also mentions again the *Ville Permeable* project, where technicians from different services are heard to bring up their specific issues. Collaboration and expression of fears or hesitations are hence key to the good development of sustainable stormwater management.

4.3.3 Interview C - Engineer at a consulting firm in urban planning

The last interview was carried out with an engineer from one of the top 10 French companies in the field of civil engineering and urban planning. Interviewee C is a project manager who works on big urban development operations like joint development zones. Through training courses, some of his projects, and working with specialized colleagues, he has become conscious of the issues linked with stormwater management.

When asked about what are, according to him, the main issues for the development of *techniques alternatives*, interviewee C has mostly technical concerns. Some site constraints, like dense city centers or rugged terrains, may prevent the implementation of trenches or open infiltration systems, as this reduces space available for other uses. In addition, ground pollution is frequent in urban areas and imposes waterproof systems to prevent the migration of pollutants to the groundwater table. Finally, the type of soil is also to be considered as clay is not very permeable and can hence cause problems.

Aside from these technical considerations, Interviewee C also points out that while public services are always very motivated and ask specifically for the implementation of *techniques alternatives* for stormwater management, there seems to be issues coming from the management between the different services (Parks & Nature, Cleaning, and Water department), with no one wanting to take on the financial burden of maintenance.

In terms of solutions, Interviewee C would be more interested in a follow-up on innovations and updates on existing knowledge as the collaboration problems mentioned in the previous interviews do not affect him or his service directly.

5 Discussion

5.1 Challenges faced by urban stormwater stakeholders

Throughout the lifetime of an urban stormwater infrastructure project, several different stakeholders are involved. In the case of the Grand Lyon metropolis, promoters and engineering consulting firms are charged with the design and construction of private projects. The infrastructure built to manage urban stormwater is then retroceded to the services of the Grand Lyon, who take care of its maintenance. In the case of public projects, the design, construction and maintenance are all handled by the Grand Lyon services. Finally, once the technique is installed and because of its location or multi-functionality, citizens will inevitably have to interact with it.

This thesis therefore focuses on the problems and obstacles faced by these three groups of actors in the case of the Grand Lyon:

- Public services, including Water, Streets, Cleaning and Parks & Nature departments of both the Grand Lyon and municipal governments;
- Private promoters, developers and engineering firms;
- Users and local inhabitants.

Researchers and scientists, on the other hand, can be part of each of these groups but will be generally viewed as a separate faction, whose goal is to support and encourage the development of sustainable stormwater management techniques. Associations like the GRAIE, which assembles scientists with members of public services and private companies, can also be counted as part of the research entity.

Each of interviews, along with the literature review and case study carried out in Chapters 3 and 4, have helped identify and classify specific issues for each group, but also more general challenges faced by the field of urban stormwater management.

First, the public services seem to be the group that has the most problems with the development of *techniques alternatives*. This is because of the amount of disciplines involved with urban stormwater, that challenges the traditional organization of the public services. Sustainable stormwater management must be linked with water and sanitation considerations on a technical aspect, but should also recognize the importance of urbanism and urban integration. This means that the departments involved in the management of *techniques alternatives* include the Water Department but also the Streets, Cleaning, and Parks & Nature departments (this last skill is, in the Grand Lyon, a skill still mostly handled by the individual municipalities).

All interviewees have therefore pointed out the collaboration problems between these services but also between the Grand Lyon and its municipalities. It often remains unclear who is really responsible for the *techniques alternatives* and especially for their maintenance; agreements and financial exchanges happen but are not always well defined and can be easily forgotten. Loss of information, between services or as time goes by and managers change, is also an important issue, as the existence of some infrastructures can go unnoticed and pass as part of the landscape easily.

In addition, Interviewee B highlights missing knowledge about the evolution and maintenance of *techniques alternatives* from the maintenance technicians, who might unknowingly compromise their proper functioning by using the wrong machines or treatment methods. Interviewee A also states that some of these workers, whose initial job is done inside sewers and allows them to benefit from a specific social status, are unhappy about the maintenance tasks they do outside for the *techniques alternatives.*

Finally, Interviewee A explains that the members of the public services are overwhelmed by the amount of projects they need to deal with and do not always have the time to go into detail into every one of them. This seems to be also the case for private engineering firms tasked with the design of *techniques alternatives*. According to Interviewee B, they often have financial means adapted to traditional networks design, which is a very different process than sustainable stormwater management design. *Techniques alternatives* may demand finer studies and more time, which these companies often do not have. Interviewee A also believes that many of these people are not skilled enough and that alternative stormwater management is not taught enough in engineering schools.

In terms of their relations with the public services, Interviewee A states that promoters are not yet motivated enough to promote the development of *techniques alternatives* and they will more frequently apply for legal exemptions than try to think of a solution. Even then, the transmission of correct or complete information when the promoters retrocede the installations to the Grand Lyon is not guaranteed. Indeed, Interviewee A mentions examples where the constructed infrastructure did not correspond to the building permit, or where plans of the whole installation did not exist.

Furthermore, real estate pressure is strong (especially in dense urban centers) and promoters may want to make every square meter profitable. *Techniques alternatives* go against this because they do not really bring any monetary value as such, but more for their esthetic and environmental services. In addition, Interviewee A believes that since *techniques alternatives* are actually very simple infrastructures, with little technology involved, there is not really any financial lobby and companies do not always see the benefits in promoting their development.

The last group of stakeholders related to stormwater management is the inhabitants and users. As *techniques alternatives* are meant to be integrated in the city as much as possible, citizens will necessarily have to interact with them, whether they are in parks, along roads, or used as something else (football fields, playgrounds…). For this reason, they can raise issues among locals: according to Interviewee A, many people believe them to be dirty or wild, to attract insects or animals like mosquitoes and toads, or to have unpleasant smells, and many associate them with increased risks of drowning. On the other hand, *techniques alternatives* can also be easily "forgotten" and used as something else or degraded: for parking or garbage in the case of swales along roads, or even for illegal squatting in the case of bigger areas like retention basins.

All of these issues and the groups they involved are summarized in Figure 5.1: Main groups of people involved with stormwater in the Grand Lyon and challenges they face.

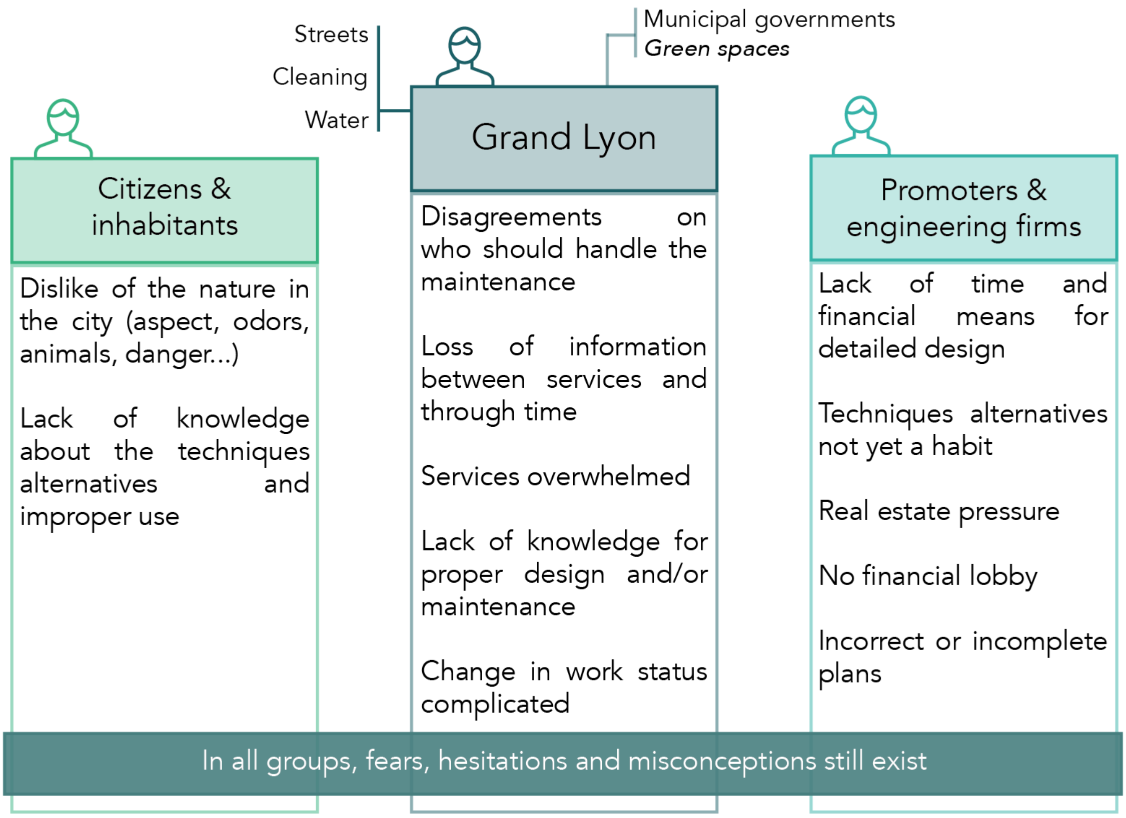


Figure 5.1: Main groups of people involved with stormwater in the Grand Lyon and challenges they face

5.2 Available solutions

In order to face these issues and develop sustainable stormwater management further, three general challenges have been identified: they are areas where work needs to be done to increase the quality and the speed of the implementation of *techniques alternatives*. The three "areas of concern" are *knowledge*, *collaboration*, and *follow-up*, and they need to interact together to really be effective. Indeed, gaining knowledge by itself is important, but it needs to be followed with storing and monitoring and then shared properly in order for the *techniques alternatives* to become truly adopted.

The primary goal of spreading knowledge about sustainable stormwater management is to get rid of fears, misconceptions, or hesitations that people might have. This is true for all of the groups mentioned before. Citizens and users need to be made more aware of the risks and stakes linked to stormwater pollution and flooding; this might help them be more accepting of the implementation of *techniques alternatives* and of the development of nature in the city. By knowing more about them, they will also be less likely to misuse or transform them. But public services and private engineering firms also suffer from a lack of technical and environmental knowledge on sustainable stormwater management. Teaching maintenance staff how to properly sustain such infrastructure will for example increase their performance, as they will be less likely to get contaminated or polluted. Increased knowledge and experience will also increase the quality of *techniques alternatives* and reduce the time needed to design and construct them.

This is one of the reasons why follow-up on sustainable stormwater management is also important. Today it is necessary to increase knowledge about the functioning and performances of the *techniques alternatives* (an example of this is the monitoring done by OTHU), but also to build databases of the different implemented solutions and sites to make sure they are not forgotten. They can allow public services to look back on successful projects, but also ensure that keep on being maintained throughout time and as managers change, and do not lose their original function.

Collaboration is the last of the three areas of concern, and ties the other two together. It is needed to clarify projects, orientations and tasks according to everyone's wishes or means in every group. Inside public services, for example, clear and detailed agreements need to be reached on the distribution of the maintenance work amongst different departments or administrative levels. Collaboration with promoters and engineering firms is also necessary to increase the quality of their work and to make sure that the infrastructure constructed is well defined. Finally, users and citizens should also be included in the projects, as they may have concerns that are worth hearing. Taking this into account will also help their acceptance of *techniques alternatives* and ensure they are properly integrated.

To work on these three areas of concern, different tools and strategies exist. They have been developed in Chapter 3 but also throughout the case study from the answers of the interviewees. Each strategy may be related to one, two or all of the areas of concern at varying degrees. They are represented in Figure 5.2.

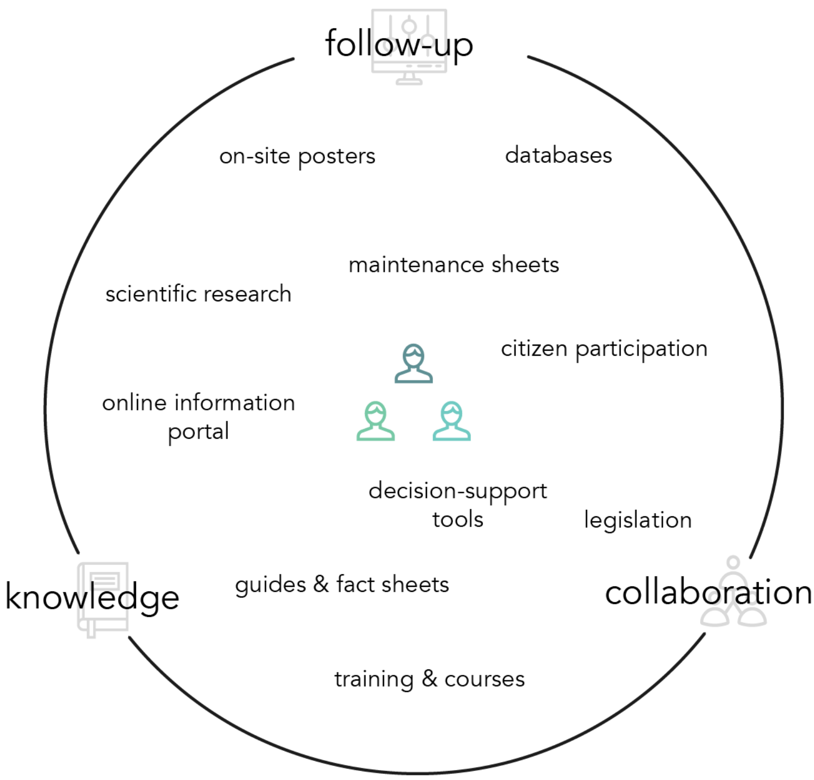


Figure 5.2: Tools to help solve challenges in stormwater management on the three areas of concern

Online information portals (like the one developed by the GRAIE) and guides or fact sheets created by scientists or public services are one the main tools to help spread knowledge about sustainable stormwater management. Citizens can have easy access to online resources that can raise their awareness of the stakes at play, while more detailed guides, including legislative background and technical fact sheets, are intended for operational and project managers. Such guides can be complemented by training done by scientists and associations for engineers and public services, in order to address specific questions and make sure the challenges are understood. Such courses can also be used to gather members of different services to encourage them to work together.

In terms of legislative and organizational strategies, citizen participation could also be reinforced. This can be done at the specific project level or on a bigger urban scale, either by a modification of the law, reducing the project size where consultation is necessary, or on a voluntary basis from the public services. In that case, citizens could become more conscious of the risks of unsustainable stormwater management, but could also raise their concerns and play a part in the definition of the project.

Current legislation could also be modified to clarify and define specifically the administrative and organizational aspects of stormwater management. Status of stormwater and of its treatment should be revised, as well as the responsibilities of each service and governmental level in terms of construction and maintenance of *techniques alternatives*. In particular, a management contract should be drafted between the municipal Parks & Nature departments and the Water Department of the Grand Lyon to clearly characterize the tasks of each of them for every project. Furthermore, official requirements for control and quality still have room to evolve; as Interviewee A mentioned, some city governments inspect every new construction before allowing it to open.

Some other tools aimed at improving knowledge sharing and collaboration between stormwater management stakeholders are decision-support tools. Indeed, they can help managers understand better the concepts of sustainable stormwater management but also how they can be applied locally on their specific project site (see for example the Adaptation Support Tool). This can also help actors discuss available solutions and how to implement them according to everyone's intentions. Decision-support tools can even benefit the "follow-up" area of concern with for example, the inclusion of a database of all previous accomplished projects to give feedback for new developments.

Such a kind of database may also be available locally, at the Grand Lyon for example, available for access from all the different public services. This will allow managers and maintenance workers to be able to quickly go back and see what sites are problematic or need cleaning up. Another interesting idea would be to make part of this database openly available online, so that inhabitants could become more aware of all of the *techniques alternatives* integrated in their local environment. This, along with on-site posters, may help raise awareness amongst citizens so that they realize that the natural areas in their city have a purpose, and so that they become less hostile towards them. Improper uses could also be reduced in that way.

As explained previously, maintenance is a particularly tricky aspect of sustainable stormwater management. Issues with responsibilities can be handled by increased cooperation at the manager level, but to help technicians and maintenance staff perform their tasks correctly and efficiently, maintenance sheets specific to each site can be created. They are composed of a few pages describing the site and its hydraulic and natural installations, as well as the frequency and materials needed for their maintenance. A recap sheet destined specifically for daily use by workers can summarize all this information with visual representations for quick understanding of the site.

Finally, scientists and researchers have a very important role to play in the development of sustainable stormwater management. Their research will of course help increase the available knowledge about *techniques alternatives*, their implementation, and their performances. But as experts, they should also be ready to be called upon to spread this knowledge through training, courses, and writing of technical guides. They can also act as a support function for the other stakeholders, uniting different services and levels through associations in order to help them work together.

5.3 The Climate-KIC STORMAN pathfinder

This thesis was carried out at Chalmers University of Technology in parallel with the Climate-Smart Stormwater Management (STORMAN) Pathfinder, initiated by Climate-KIC and aimed at assessing the needs and demands for a decision-making toolbox for stormwater management, focusing on the city of Gothenburg in Sweden. The objectives were therefore to understand stormwater decision-making and planning processes in Gothenburg as well as highlight the challenges and needs related to the sustainable management of stormwater.

The STORMAN pathfinder constituted of an initial evaluation followed by two workshops gathering different stakeholders from several backgrounds (municipal services, architects, private firms, consultants, promoters, etc.). The first workshop consisted of an identification of responsibilities and challenges for stormwater management stakeholders. The results were then interpreted to propose tool-box functionalities that were assessed during the second workshop.

The main findings concerning the challenges faced by stormwater stakeholders in Gothenburg were related to the planning phase and the lack of frameworks or requirements for sustainable stormwater management. The different actors also pointed out that the distribution of responsibilities and costs was still unclear, and that the lack of knowledge of the solutions was problematic during the operations and maintenance phases. When asked what were their specific needs, many stressed the importance of increased communication and the wish for clearer legislative instruments, but also for more knowledge during all phases of a project (see Figure 5.3).

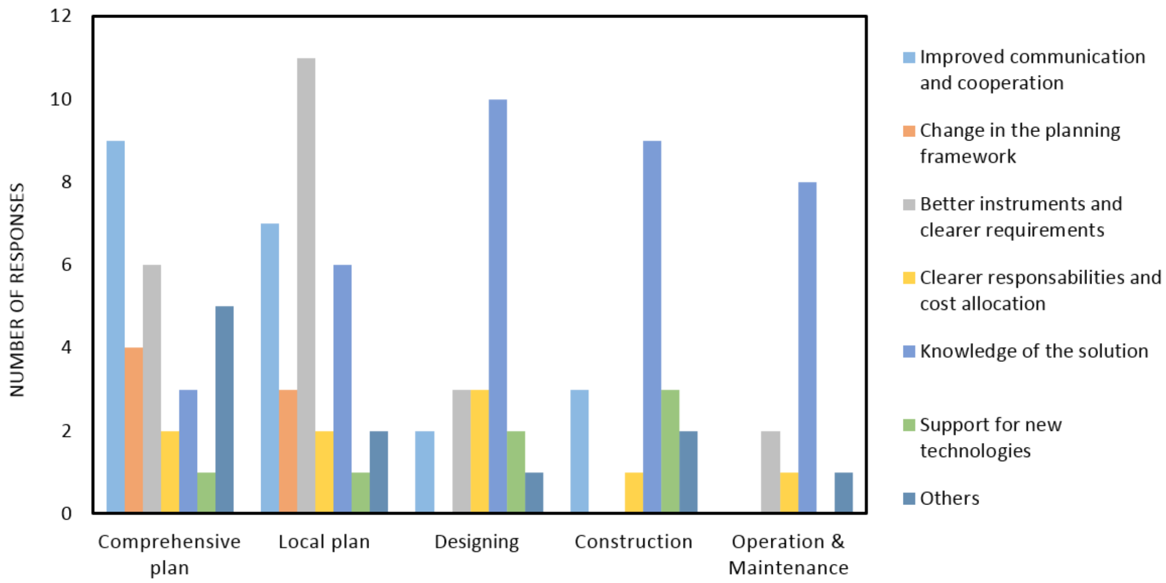


Figure 5.3: Distribution of expressed needs in the different planning stages from the Climate-KIC pathfinder. (Burzio *et al.*, 2017)

A prototype toolbox was therefore proposed by the STORMAN research team. Its functionalities include a communication platform to improve information transfer and stakeholder discussion. It will be complemented with specific tools like an information and experience bank, cost-benefit analysis, or multi-criteria analysis, to be used by stakeholders when relevant.

The results of the STORMAN pathfinder project are hence similar to what has been discovered with this thesis. French legislation and administrative instruments seem to be much more detailed and present than what exists today in Gothenburg. Stormwater stakeholders in France therefore benefit from an already solid framework for decision-making and planning, especially in cities like the Grand Lyon. While Swedish decision-makers seem to face most challenges during the planning phases, the research carried out in this thesis shows that maintenance appears to be a big problem for French stakeholders. However, problems generally linked to lack of knowledge and communication still remain in both countries, as well as the need for an experience bank for follow-up on existing projects.

Therefore, a toolbox like the one developed for the STORMAN pathfinder in Gothenburg could also be of use for French stormwater management stakeholders. The information bank and easy access to knowledge, as well as increased communication, are functionalities that could help solve the challenges they are facing, but the toolbox should include important consideration of the maintenance phase, as well as allow for the implication of technicians and maintenance staff, to be really efficient.

5.4 Limitations and future work

This thesis should be seen as a first step towards understanding the obstacles and limitations to sustainable stormwater management in France. Indeed, the method used is not entirely sufficient to draw general conclusions: only three interviews, although extensive, have been carried out, and only of people who are convinced by or involved in the development of *techniques alternatives*. An interesting complement would therefore be to get the point of view of people who are reluctant to implement them, in order to understand the challenges directly from them.

In addition, having more perspectives would be more important to get a better grasp of the true obstacles to sustainable stormwater management. Indeed, while Interviewee A believed that consulting firms were not skilled enough, Interviewee B thought the issue was linked to financial means: this is therefore a question that should be looked deeper into, especially as Interviewee C, who was part of a consulting firm, did not mention either of these concerns. A more detailed study, for example with workshops like the ones carried out through the STORMAN pathfinder project, would therefore be a good addition for this thesis.

Finally, there is also always some part of subjectivity in this type of interviews. However, the subject and topics were not very personal and all interviewed seemed willing to answer all the questions, without censuring themselves for personal, economical or work-related reasons. It can therefore be reasonably accepted that their answers are trustworthy, but one should keep in mind that each interview only represents one part of the bigger story, hence explaining the different opinions about certain obstacles and challenges.

Focusing on one metropolitan area as a case study is also convenient because it allows the researcher to review into detail its specific aspects, but one should remember that especially for questions related to urban development and policies, practices and habits can differ greatly from one area to the next. The Grand Lyon benefits from several advantages linked to its size, its localization, its legislative instruments, and the particular implication of public and scientific actors in the region. Therefore, the state of sustainable stormwater management practices may not be fully representative of other French cities.

Hence, other areas might not be facing the same problems: there are for example countries where climate change will considerably reduce the amount of precipitation, posing threats to drinking water resources. On the other hand, the STORMAN pathfinder has also shown that stormwater stakeholders in Gothenburg were not ready the face the consequences of increased precipitation because of a lack of legislation and communication.

However, while every city may need to deal with different challenges, this must not stop stormwater management actors and scientists from moving forward, experimenting, and testing the different available solutions. This is already under way in the Grand Lyon, with for example the Ville Permeable project, or through internships with the GRAIE aimed at building a database of innovating *techniques alternatives* in the Auvergne-Rhône-Alpes region.

6 Conclusion

The aim of this thesis was to make an assessment of the advances in terms of sustainable stormwater management in France and more specifically in the Grand Lyon. With stormwater posing increasingly obvious and dangerous threats, both to urban societies and the national environment, new solutions are developed to control it as early as possible, following an approach that integrates stormwater management with common urban planning challenges and processes. However, the nature of these *techniques alternatives* impose new ways of working and designing and new uses that public services, private companies, and local citizens have yet to adapt to completely. Through a case study of the stormwater context in the Grand Lyon and interviews with relevant stakeholders, three main challenges have been identified when dealing with *techniques alternatives*: a lack of knowledge, a lack of follow-up, and a lack of proper collaboration. These three areas of concern are linked and proposed solutions must therefore try to answer to all of them; such solutions include decision-support tools, maintenance sheets, project databases, or information portals. A comparison with a similar ongoing research in Gothenburg, Sweden also showed that similar issues exist in very different cities all over the world. The ground for research in this field is therefore strong and future work should aim at helping all stormwater actors make better, more knowledgeable decisions built on collaboration and integration.

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APPENDIX I – Notes for Interview A

Can you introduce yourself? What is your role in the Grand Lyon?
I am doing a PhD with a CIFRE convention, working both with the Grand Lyon as the "company" and two laboratories in Tours (CITERES) and in Lyon (EVS). I am therefore part of the Water Department in the Grand Lyon, which includes everything related to stormwater, wastewater, and drinking water. Elisabeth Sibeud is the head of both the consulting and construction divisions. My research is done on the maintenance of the different infrastructures.

What is the general strategy for Grand Lyon in terms of stormwater? Is the state of development satisfying?
There is a lot of exchange with different research entities or organisations (like ASTEE), Elisabeth Sibeud is very involved and there is a lot of research being done in Lyon. In addition, there have been some remarkable achievements since the 1990s, with for example the *Porte des Alpes* project. And the regulations forbid the rejection to the conventional sewers for all new projects. Yet we still face a lot of difficulties, it is still not automatic and developers are often trying to find ways to get exemptions.

Can you describe the conception and design of a typical project? How does the department work?

- There are several entities in the Water Department: a consulting division, who takes care of the conception of the public projects, a construction division, and a maintenance division (who maintains all infrastructures). These last two are split into geographical subdivisions. For public projects, they are all involved at different stages in the process.
- For privately projects, the building permit phase is very important since it's the only moment where the Grand Lyon gets knowledge of the project and can give advice. Once the construction is done, the developer hands the infrastructure back to the Grand Lyon who is in charge of its maintenance.
- The maintenance is often handled by several different services (Water department, but also cleaning and green spaces departments).

What are the main obstacles to the development of sustainable stormwater management?

- Private developers are not always convinced or motivated; especially inside the city, there is a high real estate pressure which makes them want to make every square meter profitable. They are also used to doing things "the usual way" and may not want to take the time to think differently.
- Even inside the Water Department, not everyone is convinced that it's a good idea. Some believe for example that removing stormwater from sewers will make them more dirty, as the water coming in during rain events was often used to "clean" the sewers.
- The construction division is overwhelmed, receiving more projects to deal with than it can treat in time
- The maintenance division does not necessarily have the expertise to manage new infrastructure and *techniques alternatives* (for example, mowing grass or picking up trash). Some employees prefer such infrastructure because of the contact with nature, others do not.
- There is also the specific case of the sewage workers, who benefit from a specific work status because of the insalubrity of the job, and therefore are able to work less

hours and retire early. However, the work they do outside of the sewers does not count for these particular advantages, and some are upset about it.

- The different scales and actors involved in a construction project also make it more difficult: even if the developer may be willing, a lot of engineering firms are not skilled or specialized in *techniques alternatives* (for example, students in water and environmental sanitation don't have any courses on the sustainable management of stormwater). For private projects handed back to the Grand Lyon, it may happen that what was constructed does not correspond to what was planned and approved in the building permit, or that there aren't any plans of the infrastructure.
- And even for public projects, often urban development projects go on for several years and project managers may change. The new ones may not share the same views, or not have the same knowledge of sustainable stormwater management, and this may slow down the process.
- In some cases, some maintenance tasks are handled by the municipalities themselves and not by the Grand Lyon services. This can create problems as they are the ones to bear the costs while not really getting any benefits; some management agreements are created, with financial exchanges to help the municipalities carry this burden, but this is legally complicated and takes time. Agreements are also sometimes made orally and disappear once the people responsible for it leave.
- Since *techniques alternatives* are mostly natural installations, there is not much technology involved, and industries cannot really take over them. There is not really any money to be made over *techniques alternatives* so there is no industry lobby which may push companies to use them more frequently.
- Finally, *techniques alternatives* are not always well tolerated by citizens. Often, the municipality tries to create differentiated management to facilitate the maintenance; this means putting plants that don't need a lot of care, but this can give the place a wild, unkept or abandoned feeling. In addition, basins may attract nuisances such as mosquitoes or toads (who make noise), stagnant water may have odors… And people are also afraid of drowning risks.

Can you tell us a little bit more about the Ville Permeable *project?*

- The July 2015 decree on water states that combined sewers overflows must release water into the natural environment no more than 20 times per year (or no more than 5% of the annual volume). Today, with the 420 CSO of the Grand Lyon, there are about 50 releases per year. But 40% of waterproof surfaces are public space, so there is a lot that can be done.
- The aim of this project is to "make the city permeable", and to achieve this, to visit different stormwater management infrastructure to see the problems and convince members of the public services. I spent time with the four different services involved (roads, water, cleaning, and green spaces) to see how they worked on a daily basis, and to bring up problems that are not always expressed.
- A technical and economical study was also carried out by SAFEGE to compare combined sewers, separated sewers, and *techniques alternatives* in terms of performance, infiltration, etc. but also in terms of implementation and maintenance costs. The results of the economic study show that in terms of upfront costs and in terms of maintenance costs, *techniques alternatives* are always cheaper than separated sewers, which are in turn cheaper than combined sewers. However, even if *techniques alternatives* are generally cheaper, they cost more to certain services like cleaning or green spaces departments.

What kind of solutions would you need or could you use?

- First, legislative tools are always necessary even if they are not enough, as exemptions are always possible. A way to make sure that they are correctly applied, though, would be to control everything once the construction is done to verify conformity and to make the developers start over if it's not the case (they do that in Montreal, Canada or in Strasbourg for example). If it's done firmly, it could be a fast way to change things, but it's very complicated to implement, especially seeing the amount of work the water department already has.

- Other than that, we do not really use decision-support tools to help communicate between the different services, but it could be a good idea. There is a design software developed by an intern that is sometimes used for calculations; otherwise it is more customary to use guides or technical sheets.
- The Meli-Melo website, created with GRAIE, has videos and summary sheets about several domains linked to stormwater and water in general. The aim is to use them to spread information and raise awareness on the topic. We also work towards this knowledge-sharing objective with the Ville Permeable project, and aim to create "knowledge sheets" to distribute to the workers to help them identify each site and how it should be maintained.
- Finally, citizen participation and implication could be increased; there is an example in Strasbourg where they create agreements with the inhabitants to maintain the different infrastructures.

APPENDIX II – Transcription of Interview B

So, I don't remember to what extent I told you about my thesis, but the aim is to do an assessment of what is happening in France in terms of techniques alternatives, and especially what kinds of issues the different stakeholders meet, both inside the Grand Lyon and with the inhabitants or the developers for example. I've made a list of questions…
So it's a little bit of social sciences then?

Yes, a little, it's less technical.
No problem.

Can you introduce yourself first quickly, your job and your relations with techniques alternatives?
I am a professor at INSA Lyon, I teach urban hydrology, and I work on research on these techniques alternatives with the DEEP Laboratory. So more on the part that measures and models the performance of these solutions, with a part "on site", with observations and measures on site, and a "decision-aid" part, how to choose etc. We are currently working on a project which is completely in phase with that, which is the MicroMegas project, of which [Interviewee A] must have told you about, which is a project on the campus; you know that on the campus, all of the public spaces have been renovated, and they are all in techniques alternatives. The network is rubbish underneath, so they want to keep it only for wastewater; because on the campus, it was combined, which is very rare in France, on small surfaces like that. Generally, there are separated sewers, and it's not that old, this campus; combined sewers were more popular in the beginning of the 20th century.

Or in city centers?
Yes.
[interruption by a phone call]
And so on this campus, there have been a lot of techniques alternatives implemented, and the idea is to track them, to do metrology on them, so we are instrumenting them; and we are also following them actually in terms of, um, how users take hold of them.

This is what you do with OTHU, right?
Yes! Within the framework of OTHU, right. And within the framework of OTHU, we do other monitoring, on other sites, but it's true that up to now we were on more centralized sites, some big basins, things like that, because the idea was to say that if these big basins didn't have any impact, then the techniques alternatives at a smaller scale will probably not have any either. So it's maybe less simple than this, especially on pollution aspects, but well.

Less impact in what way?
Less impact on groundwater, on receptive environment… less hydraulic impact too.

And what do you think of the development of techniques alternatives in Lyon, is it on the right track, is it good compared to other cities?
Lyon has done it for a long time, especially on its eastern part, because there are plains that are very permeable, and it's the part where the conurbation is developing, so for a long time,

40 or 50 years, they have been putting infiltration wells, things like that. Now, what they do more and more, well they've been doing it for a little while but what they do more and more, is actually techniques much more at the source, and they do - what's original too; well, what's a bit new too, is that until now techniques alternatives were being developed a lot in suburbs, where we were building housing estate, things like that, and now we do a lot of urban refurbishment, or urban renovation. And as part of this urban renovation, the metropolis actually prescribed infiltration; basically, now the doctrine is "we infiltrate first", and if we can't infiltrate, then we do something else, but… And so when you say infiltration, you say techniques alternatives. And what's interesting too is that in the East we did a lot of big basins like the one we monitored with OTHU, which are basins that are pretty mono-functional, this big infiltration basin, we bring in water, we fence it in, we ensure that it's a bit hidden; then we had another generation where we "landscaped" a little bit, but it was still big systems, like the Porte des Alpes site that you know, and now we do smaller structures, little swales, little landscape designs; they're designs that manage stormwater, you know; now we don't really see the technique anymore, and that's really interesting.

In cities, it's almost the only thing that is possible, no?
No, we could also do buried things, like big underground storage basins… Like they do in a number of cities, like in Nancy for example…

Yes, or underneath the Garibaldi street, one of the tunnels will be transformed like that.
Yes, in the Garibaldi street, in a number of operations; some parks are done like that too; almost everywhere now.

Okay. We talked about your research work, but what kind of relationships do you have, you the researchers, with the Grand Lyon and with the involved companies, the consulting firms working on that?
So we, first, in the framework of OTHU, the Grand Lyon finances; it finances a part of the instrumentation and so they are part of the executive board, as is the Water Agency, so we have a permanent dialogue with them; they are also in the pilot committees of a lot of our projects… And the consulting firms, well the consulting firms… it's a bit more erratic, I'd say. We see them more as part of the GRAIE, you know, the research group on water and infrastructures, which is an association that puts in contact scientists and operations managers, whether it is local governments, consulting firms, etc. It's in this framework that we did for example the book in 1994 on techniques alternatives. We wrote a book, we had made a working group and there were road managers, consulting firms, local governments, institutions, etc.

And are the consulting firms… do they feel affected by this type of things?
Oh well now they all do it. They all do it because we ask them to. So, um, they are more or less… how can I say this… They are more or less militant, we can say. Yes. So when we ask them they do it, they know how to design - more or less well, actually, because they still have the culture of big basins, of something easy to design… Because these kinds of small things… The thing with techniques alternatives, the thing with their design, calculating volumes etc. is easy, but then you need to set it on the terrain, I mean, it requires a… it requires a very subtle concept of spaces, of slopes, there must not be water puddles, it needs to be set to the millimeter. So it's not really in their culture, the VRD culture is a little bit more crude, especially with levelling.

But there are a lot of consulting firms that are getting to it, and especially a lot of landscapers; landscape firms are getting to it. It's mostly them that develop this because it's their… they are selling their issues too.
But it's true that traditional VRD… I mean yes, yes they do it, but they are not really promoting it. It's not from them that progress will come. From landscapers, maybe, but it's because we ask them most of the time. But it's because design phases are paid… in France; I don't how it is in Sweden, but here they are paid almost nothing. So we ask them to design for, for nothing, so they work as fast as possible and it annoys them, right. But as soon as they don't really know how to do it, for fine things like this, well they should be paid in consequence; they'd do it willingly, I think, but here… there you go.

And even, just acquiring the necessary skills, you need…
Yes, yes, that's it. And, there's a lot… well [Interviewee A] must have told you about it, but there are a lot of fears going around, we tell them "oh, but you're going to infiltrate, so you're going to pollute the groundwater", they don't always read the literature, while actually we show that it's not always true… or it will attract mosquitoes; there, last time we had a day with the GRAIE, so it was a day with technicians, operational managers, a technical day. So you have 200 people coming, there are interventions from people from local governments, from consulting firms, from us, everyone's chatting and all, and all of a sudden everyone says "yes but now there's mosquitoes, there's the Zika virus, we're all going to die", so… you know; so we did a study actually, with our biologists, that said "well no, there's no reason", but we didn't have numbers, so now - now we have numbers, to show that it's a false issue; so there's that, and all of a sudden it stops everything. In Grenoble, they were starting to say "oh well here, we have too many mosquitoes, and techniques alternatives will bring even more, so stop!" Whereas we realize that, in terms of stormwater management, it's the sewers and the inspection chambers that are mosquitoes nests. And there, it's not an empty word, there you have Zika, you have everything; while techniques alternatives are supposed to be dry, so you have no water.

Yes, I see… So then, well we talked about it a little bit, but what is your role, as scientists, to develop these techniques alternatives and to encourage … the consulting firms that might not be so … motivated?
Well, we do formation programs, so we do courses; I'm taking care of a course in Paris, for a long time, which touches consulting firms mostly on a national level, with the Ecole des Ponts, we do… We are trying to start one in Lyon, so yes… Every year, it was every year, we had two sessions, one session more on the design, and one session more on the awareness. There were planners and all that. We do that… We tried a while ago to write books, but we don't have so much time, so we did one in 1994, we should rewrite it for example, you see. And, via those technical days, the working groups, the GRAIE… Or via some ministry recommendations. And now we are trying to be a bit more present in the… in the working groups when they are formulating local reglementations. For example, not too long ago we were invited to be part of the SAGE of the eastern part of Lyon, and before we didn't go because, you know, it's a lot of work, but we felt that it's also through that - if you have reglementations that are well written, explanatory, etc. We spread knowledge and we realize that even in those institutions, who are in charge of writing these reglementations, they don't read, and you know, for example - it's a sign of the times: they give these reglementations to formulate, at first, to consulting firms who are not always up to date with this knowledge. So now we said, okay, we should at least try to spread what is known.

Yes, I also found a lot of guides from the Grand Lyon…
Yes, there are a lot of guides that we do with OTHU, we try to… But it's true that guides should be made by… either by consulting firms or… I don't know, but we might now always have the right language, the right approach… Or we don't always point out the things that click… So it's more to "co-construct" things with them that's best…

Yes, working together.
Yes, yes.

Okay, and now my big question is, according to you what are the obstacles to the development of these techniques alternatives: is it a question of money, a lack of knowledge, of motivation, of collaboration… I also read articles where, for example, once the infrastructure was built, we kind of forgot about them and in the end they were used for something else … [SB nods] And then, another question is, are the main problems mostly during the design phase, or later, in terms of maintenance?
Well, the big problem today, is probably the maintenance, definitely. So, there's a lack of knowledge… actually, there are problems when adopting these techniques. Either I adopt them, or I don't, either I press for their development, or I don't, and this is more a problem of lack of knowledge of things. Yes, and all of the fears that we have, um, "there will water, we'll drown", well that still exists, I see them during the courses, there are still people who tell me things like that. So there's that, and then… in terms of design, I think it's not so much that they are lacking skills, because people from consulting firms, they're skilled, but… they don't have time. That is that there's a real problem of financing of consulting firms. For me… that's it, I mean that we ask them to do a lot, in a really short time, with really tight means, so they do… what they're paid for, which is not much. And it's not because they're bad, I think, it's because… you see. So money, the problem with money is mostly there. Afterwards, the implementation is not always more expensive, in fact it's actually - studies show that this is what has the lowest investment costs.
Then you have the problem of maintenance. And the maintenance… there's a big lack of knowledge on maintenance because we don't know… people don't know how it's going to evolve, there are a lot of problems also because - sometimes responsibilities are not very… In a local government sometimes you have a park, which manages stormwater, and we don't know who should maintain it; is it the sanitation department, that only have high-pressure water cleaners, or is it the green spaces department? But the green spaces, it's the municipality, not the local government, so, "you're giving us more work, it's not our job, we already don't have enough staff", you see the kind of speeches they get, and it's true that it's an issue, but it's a little bit what [Interviewee A] is doing… There's also a lack of culture in the people that do the maintenance, who are often, for sanitation workers, people who have been fed with flooding concerns, so they are unaware of environmental aspects, and they put pesticides, it doesn't bother them, while this is what might reach down the groundwater; on the other hand they'll get scared of hydrocarbons, but hydrocarbons will stay on the surface… So there are things like that, there's a lack of … environmental skills in the maintenance services, but also in the green spaces departments actually. So, for me, the obstacles are there: on the design but not so much in terms of knowledge, of skills, but more in terms of limited financing of these studies, which ask for a little bit more than usual; and on the maintenance. The investment costs, I think it's a false problem.

Okay. And now, to face this, you're working on decision-aid methods, but this is more… is the goal to make the different services work together, should more guides, more fact sheets, more maintenance sheets be transmitted on the different techniques that are implemented?
Well this is complicated, because, the transfer of knowledge, it's really complicated. We made a lot guides etc., so there is a lot of knowledge available, but… we realize that people don't always read them well, or don't always understand them well; I'm thinking more of training actually, and of the support for local governments. I think it's in the local governments. For example, what Elisabeth Sibeud's service is doing, with the Ville Permeable project, where she puts people together… I think that's the best to transfer things. That is, they are well trained, in a way, because Elisabeth comes to see us, and she also brings us some knowledge on usage, that we, scientists, are not always aware of; and then they have the right speech, they transmit, they get together also because people don't always understand each other… We say, "oh, the planners, they're annoying", but actually, they also have arguments that we don't always integrate very well, or that people from stormwater management don't always integrate well. So… of course you need books and guides to allow knowledge to pass, but I think it should be done more in that way; in Bordeaux for example, when they established the obligation to use techniques alternatives in the 1980s-1990s, they gave support to the consulting firms. They were training the consulting firms themselves, and the consulting firms came to see them, they help them design it…

So it's really cooperation, collaboration between the different services that's missing…
Yes, because actually, since it's very pluri-functional and that this is how it works well, you need everyone to join and everyone to tell they own issues, and everyone to express their fears, so that we can counteract them; because otherwise, [Interviewee A] must have shown this to you, otherwise when that's not the case, fears add up and we do techniques that are monstrous, instead of promoting infiltration, they'll make it watertight with geomembranes, then they'll put concrete because, I don't know, and then then green spaces will come and say "oh but I need to mow the lawn" so they'll make surfaces… and in the end it makes things that don't work, in fine, or that can't be maintained, or that are very expensive. While it's actually things that are very simple, in the beginning.

Okay. And one last thing, I read in an article by Elisabeth Sibeud on feedback on the Porte des Alpes site, and she said somewhere that small techniques like swales and trenches, they're not made to be really durable, that for example if they get colmated or polluted accidentally, it's better to replace them than to clean them… I'm not sure I understood well?
No but it's… either we maintain them… frequently, but we don't really know how to always maintain them very well. So at some point, what needs to be done is to be able to see when they are colmated for example, when they malfunction, and we redo them, because it's nothing actually. A swale… you scrub the soil, you take it off, I mean… it's almost gardening. And thickness is, unlike for infiltration basins, for example; we are studying an infiltration basin in the East of Lyon, it's 200 ha that go into it, you have a thickness of 10, 30 cm of sediments; but here it's nothing, in 20 years, you have something that's not even over a centimeter. So, you know… it's handled pretty easily, in fact… When it doesn't work, we do it again, but it's not expensive. A trench… a trench, it's nothing: if it's colmated on top, you take the rocks, you shuffle them, you take off what colmated, and you're good for 20 more years.

APPENDIX III – Written answers of Interview C

Can you introduce yourself quickly, your job and the kind of projects you work on?
Project manager in urban planning for an engineering consulting firm, working on urban development operations (ZAC for example).

Are you exposed to questions of sustainable urban development, particularly in terms of stormwater management (techniques alternatives)?
Yes, through training courses and consulting projects.

Do you handle this aspect of urban development yourself in your projects, or do you work with other companies specialized in this domain?
Myself, with the help of other colleagues from the company on more complex subjects.

Are there some techniques alternatives that you favor or that you generally do? (for example infiltration trenches, soakaways, detention basins…)
Yes, infiltration trenches and basins are often constructed.

Do you have difficulties implementing this kind of system? For what reasons? (Site constraints, budgetary constraints, difficulties cooperating with involved public services, lack of information…?)

- Implementing trenches or open infiltration systems is often difficult in an already established dense urban fabric (reduced road size) and on rugged terrain.
- Ground pollution sometimes means that the ground must be waterproofed, to prevent the migration of pollutants in the groundwater table in the case of infiltration systems (this is frequent in urban areas).
- The type of soil encountered (clay has low permeability).
- The public water services are often the first to ask for alternative stormwater management, but the problem sometimes comes from the management between services (green spaces and cleaning vs water services), with no one wanting to take on the financial burden of maintenance.

Are these problems that you would like to work on and if so, what kind of solutions are you looking for? (Easier access to information, training, decision or communication-support tools…)
Yes, more in a sense of updating existing knowledge and following innovation as I don't necessarily have the wish to obtain expertise in this domain.