DEPLOYING A SEWER ASSET MANAGEMENT STRATEGY USING THE INDIGAU DECISION SUPPORT SYSTEM

P. Debères*, M. Ahmadi*,**, J.C. De Massiac*, P. Le Gauffre**,***, F. Cherqui***,****, C. Werey*****, K. Nirsimloo*

* G2C Environnement, Venelles, France, jc.demassiac@G2C.fr
** INSA-Lyon, LGCIE, F-69621, Villeurbanne, France
*** Université de Lyon, France
**** Université Lyon 1, LGCIE, F-69622, Villeurbanne, France
**** Cemagref UMR GESTE, F-67070 Strasbourg, France

ABSTRACT

This paper presents the first real implementation of INDIGAU asset management toolbox based on French national RERAU methodology. This toolbox allows the utility manager or consultant to define a rehabilitation program using CCTV reports and other indicators such as economic, social or environmental indicators. The methodology is described and each element of the toolbox is briefly introduced: conversion of CCTV reports in EN 13508-2 coding system, assignment of a condition grade to a segment using CCTV report, and combining complementary indicators for assessing the rehabilitation criteria. The INDIGAU toolbox is applied on a length of about 99 km of sewers (10% of the network) of Caen-la-Mer urban community. The segments to be rehabilitated are identified using a multi-criteria analysis. This study shows the feasibility of calculating complementary rehabilitation criteria by combining indicators derived from various sources: visual inspection reports, network monitoring, operation costs, data related to the urban environment. INDIGAU also aims to organize a public-private R&D process: the INDIGAU user club involves utilities (end-users), researchers and the software provider, aiming at fuelling continuous enhancement of the toolbox, sharing of best practices and pooling of case studies for research purposes.

KEY WORDS: CCTV, Asset management, Rehabilitation criteria, Multi-criteria analysis

INTRODUCTION - Main results of the RERAU national project

A sewer asset rehabilitation approach can be decomposed into three phases: 1- Condition assessment, 2- Rehabilitation priority based on segment sorting, 3- Execution of rehabilitation works with the most appropriate technique. Although there are specific tools and techniques dedicated to each of these phases, the key step, condition assessment, depends strongly on human interpretation. Widely used Closed-circuit television inspection (CCTV) inspections provide reliable observation of sewage segments state but variable defect-coding rules and human intervention induce problematic interpretation bias (Dirksen *et al.*, 2011). Since 2003, European Standard EN 13508-2 defines a standard way for coding the defects observed by CCTV. It also defines the format of a digital exchange file which contains the coded defects for each CCTV inspection. The standardization of CCTV inspection "language" and the existence of the exchange file thus laid the foundations for automated CCTV interpretation and pipe sorting.

In the current French regulation there is no specific sewage network renewal requirement or any obligation for its performance, however to ensure asset sustainability, preventive actions should be anticipated. This involves the establishment of a rehabilitation program. Although CCTV is a widely used method to assess condition of sewer networks, the translation of visual inspection into a level of dysfunction remains a difficulty.

The French national project RERAU (Le Gauffre *et al.* 2004), which is mainly devoted to the description and construction of a set of criteria for the rehabilitation of sewerage systems takes into account a wide range of possible section defects. The method consists of constructing and combining different indicators that reflect the conditions of a network segment. Also to ease the use of raw information, all indicators are measured on an ordinal scale of increasing severity from G1 to G4. One of the objectives of this method is to take advantage of all types of available information by defining generic performance indicators (PI) (Matos *et al*. 2003).

From CCTV reports to condition grades

A system proposed by Le Gauffre *et al*,. 2004 allows converting CCTV reports in order to assign a G1-G4 ordinal grade (Chergui, 1996) to each segment. This system is able to take into account the pinpoint defects as well as defects distributed all over a segment by considering both their level of seriousness and extend according to following steps:

- Codification of observations according to European standard EN 13508-2;
- Translation of these codes into basic scores;
- Calculation of the global density of defects by dividing the sum of all basic scores by the length of the segment;
- Assignment of a (G1 to G4) ordinal grade by comparing global density with three thresholds fixed by a cost minimization approach (Ibrahim *et al*,. 2007).

The methodology proposed in the RERAU project needs observation codes using the European standard EN 13508-2. So if the existing data are coded either in a self-made codification by a utility or in a national coding system (in France, AGHTM, 1999, in Germany ATV 1999) it is necessary to translate them to EN 13508-2. Using this standard guarantees the comparability of results and allows mutual capitalization of data. For each dysfunction indicator, experts' opinions are gathered for calibrating thresholds for the 4 different states (Cherqui *et al*,. 2008, Werey *et al*,. 2008). A cost minimization approach proposed by Ibrahim *et al*., 2007 is then applied for thresholds determination.

Combining complementary indicators for assessing inspection or rehabilitation criteria

According to (Le Gauffre *et al*,. 2007)decision criteria are related to a three-level causal chain linking defects to their impacts. Defects present on a segment, characterize the deviation of actual physical condition from the standard condition of an asset. These defects lead to the consequences on facility operation known as dysfunctions. Some dysfunctions could be observed by CCTV or by other investigation procedures. In total these indicators are as follows: infiltration, excessive spillage, exfiltration (loss of seepage), decrease of hydraulic capacity, sand silting, blockage, destabilization of ground-pipe system, degradation due to corrosion, ongoing degradation from roots intrusion, ongoing degradation from abrasion, risk of collapse and flooding.

At the end, these dysfunctions may result, according to the asset's context, to an impact. The context components taken into account to evaluate impacts are known as "vulnerability factors". Le Gauffre *et al*., 2004 shows how to construct 30 investigation and 31 rehabilitation criteria by using 64 dysfunction indicators plus 12 vulnerability indicators. The evaluation of the vulnerability and impacts was studied in the INDIGAU project (Werey *et al*., 2010) taking into account the results of the CARE-S project (Werey et al,. 2005,Werey *et al*., 2007) and giving recommendations for economical assessment of environment vulnerability and impacts.

Decision support tools for prioritizing rehabilitation projects

The INDIGAU R&D project (2007-2010), financed by the French National Research Agency, involved four research centres, one private company (*G2C environnement*) and seven urban utilities. The objective was to produce a collaborative decision-support tool to perform automated condition assessment, multi-criteria sorting of canalisations, and to determine rehabilitation programs.

In addition to scientific issues presented at LESAM 2009 (Cherqui *et al.*, 2009; Le Gauffre *et al.*, 2009), the INDIGAUproject also resulted in a toolbox intended for the use of asset managers and stakeholders. It is available on a web interface providing three functionalities as follows:

1. *Data conversion*: The INDIGAU toolbox introduces a preliminary tool for utilities that have CCTV data coded in former coding systems. It translates the data into EN 13508-2 codes readable in the other INDIGAU tools. Indeed, normalized codes started to be widely used after 2008 even though the European standard has been released in 2003. The conversion tool is semi-automatic and self-learning. By introducing a specific dysfunction, this tool saves the name, description and other introduced details for next uses.

2. INDIGAU performs automated interpretation of CCTV inspections to calculate sewer dysfunction indicators, using interpretation models, on a four-grade scale. The calibration of the interpretation model against an expert-opinion database removes the risk of single-human bias (Cherqui *et al*,. 2008).

3. The INDIGAU toolbox offers a criteria construction workshop and full control of parameters for indicators combination and multi-criteria analysis for prioritizing the segments to be rehabilitated. The outcome of the process is a sorting of individual sewer pipes into three classes corresponding to priority of rehabilitation.

FULL-SCALE IMPLEMENTATION ON A CASE STUDY: URBAN COMMUNITY OF CAEN-LA-MER

Networks and assets of Caen-la-Mer

The Urban Community of Caen-la-Mer which has about 230 000 inhabitants (29 municipalities) is situated in North-west of France. The wastewater system length is about 900 km. The sanitation system is centered on three treatment plants with no capacity problem. The treated wastewater is discharged into the *Orne* River.

INDIGAU toolbox was applied on the sewage network of Caen-la-Mer to define rehabilitation priorities. The project consisted of:

- Grouping available information on Caen-la-Mer;
- Selecting and defining a set of criteria depending on available useful information and by considering needs of utility managers and stakeholders;
- Choosing an accurate set of CCTV reports and converting those not yet in format EN 13508-2 to this format;
- A multi-criteria analysis to assign priority levels to sewer segments;

- Long term asset management recommendations;
- Policy implementation for continuing to use INDIGAU.

AVAILABLE DATA AND SURVEYS

CCTV recording and saving has been done for decades in Caen-la-Mer. However most of the reports have been published on paper. A CD or DVD is also available from 2000 with CCTV reports, images and video inspections. Only few CCTV reports use the EN 13508-2 coding system. Hence a selection should be done before converting the chosen CCTV in old format to EN 13508-2. The selection decision tree is described in the figure below:

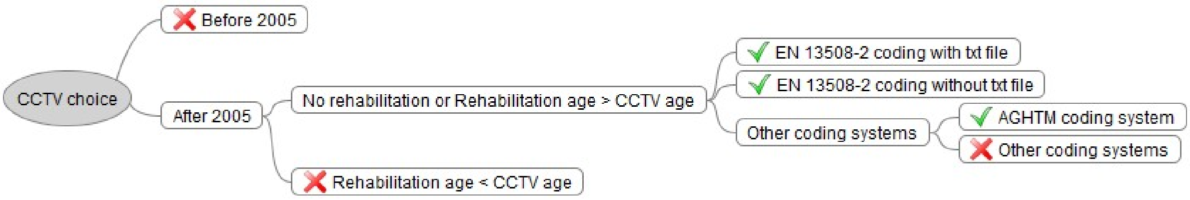

Figure 1: Decision tree of CCTV (X: Not-selected, √: Selected)

All available CCTV reports are not useful because of their age and/or because of the rehabilitation works done on the network since the last inspection. In addition to the previous CCTV surveys, an additional length of 40 km of CCTV inspections has been carried outin catchments with high measured infiltration rates. Figure 2 illustrates the global network and highlights the chosen inspected segments.

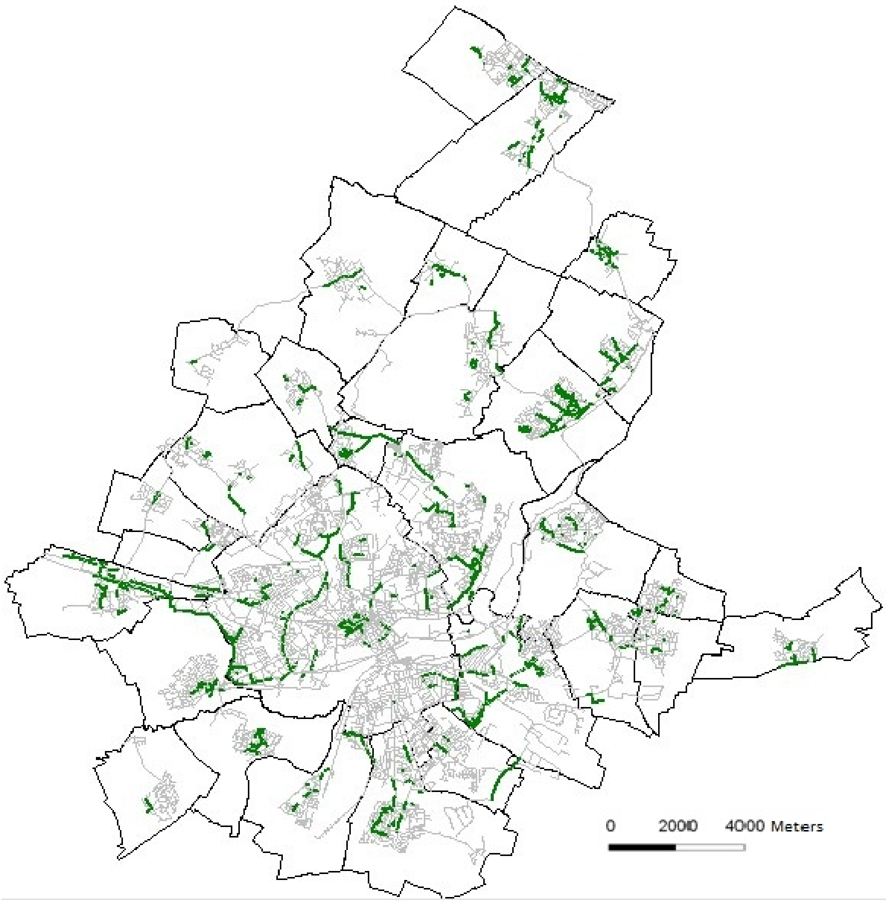

Figure 2: Analyzed segments

The processing of 100 km of raw CCTV data to produce a relevant data set into the INDIGAU system required 8 man-weeks. In addition to EN13508-2 data conversion, significant time was spent on assigning the GIS pipe IDs to CCTV INDIGAU input files : being able to localize pipes from CCTV survey data sets is not only essential for mapping results but also to combine indicators derived from inspection reports with other indicators (EXF2, INF1, V-SN-PON).

Choosing the rehabilitation criteria

For this particular study, a set of criteria was chosen to address the local stakes. Much of the work to be done to aggregate the rehabilitation criteria is the preprocessing of data collected for the indicators. All indicators should be scaled from G1 to G4 (from the best to the worst) and then these values are assigned to the GIS number of each segment. Once all indicators are assessed for each segment, the criteria can be built using these indicators. In this study, 10 rehabilitation criteria were defined and used (table 1). Hereafter a brief description of the criteria is given. At the end a detailed criterion construction procedure will be shown. These criteria are chosen by considering their importance weights, defined by stakeholders to be used in multi-criteria analysis.

Table 1 : Rehabilitation criteria descriptions used to prioritize sections to be rehabilitated and their importance weights

Abbreviation	**Criterion description, considering the consequences of:**	**Weight**
R/PON1/EXF	exfiltration on groundwater and soil quality deterioration	0,17
R/PON2/HYD	reduction in section hydraulic capacity on groundwater quality deterioration	0,09

R/CXS/INF	infiltration on operating costs of the WWTP	0,05
R/CXR1/ENS	silting on cleansing cost	0,05
R/CXR2/BOU	blockage contributing to an extra cost of network operation	0,13
R/CXR3/INF	infiltration on network operation surplus cost	0,14
R/DEB/ENS	siltation leading to flooding risks	0,05
R/DEB/BOU	blockage leading to flooding risks	0,05
R/DEB/HYD	reduction in section hydraulic capacity on flooding risks	0,05
R/TRA1/EFF	sewer possible collapse on traffic and urban disturbance	0,22

These criteria are described in (Le Gauffre *et al.*, 2004). However, their definitions was adapted to the context of the case study. We present three examples: one environmental criterion (R/PON1/EXF), one economic criterion (R/CXR3/INF) and one social criterion (R/TRA1/EFF).

For criterion R/PON1/EXF, three basic indicators are employed as shown in figure 3. At first two basic indicators (water tightness deficiency for exfiltration estimated by visual inspection (EXF4) and risk factors for exfiltration (EXF2) are combined (table 2) resulting to risk of exfiltration (EXF6). Then this composite indicator is combined with vulnerability of soil and groundwater to pollution V-SN-PON.

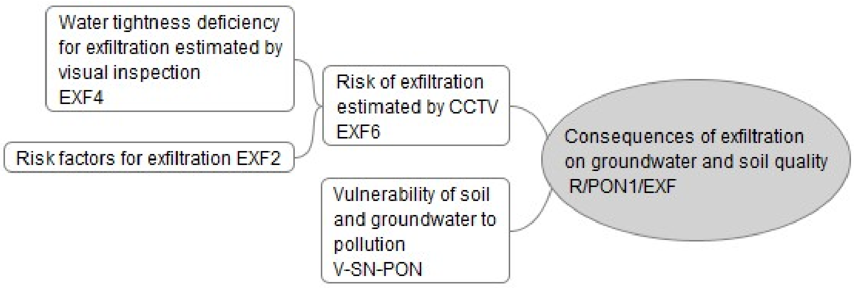

Figure 3: Consequences of exfiltration on groundwater and soil quality criterion construction procedure

Table 2 : EXF6 and R/PON1/EXF evaluation matrix

EXF2 \ EXF4	G1	G2	G3	G4
G1	G1	G1	G1	G1
G2	G1	G2	G3	G4
G3	G1	G3	G4	G4
G4				

→

EXF6 \ V-SN-PON	G1	G2	G3	G4
G1	G1	G1	G1	
G2	G1	G2	G3	
G3	G2	G3	G4	
G4	G3	G4	G4	

Assigning grade G1 to EXF6 (one of the sublevel indicators is equal to G1), means that there is no pollution risk due to exfiltration because the segment is in good condition or either the segment environment does not allow any exfiltration.

As it is mentioned above, most of the work was about translating the existing data to a useful format according to the INDIGAU toolbox.

The translation procedure for assessing the EXF2 into ordinal levels is illustrated hereafter. All segments according to their positions with respect to the groundwater level were regrouped. They were classified in group 1 when the groundwater usually reaches the section, group 2 when it reaches temporary the section and finally group 3 when groundwater never reaches the segment(figure 4). As all the segments depths were not available directly for the whole inspected sewer, a systematic rule was applied to decide in which group each segment would be classified based on the groundwater level: G1 corresponds to groundwater level between 0 and 1 meter, G2 for level between 1 and 5 meters and G3 for level more than 5 meters (figure 4).

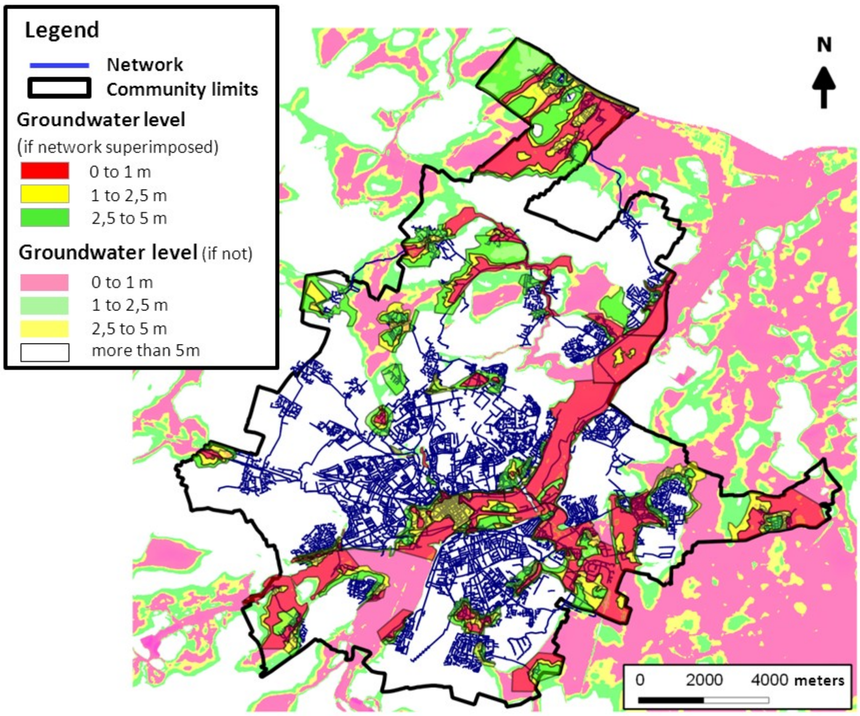

Figure 4: Groundwater level of Caen La Mer

Concerning V-SN-PON, the area was divided into three ordinal grades: G3 when the segment is in a protected area; G2 when the presence of groundwater can lead to a bigger pollution area and finally G1 when groundwater does not exist or it is deep enough to be forgotten.

Figure 5 shows an example of an economic criterion which takes into account the consequences of infiltration on network operation surplus costR/CXR3/INF. Pumping cost is calculated by using the measurements applied on the network for gaging the infiltration water volume. Then this cost vulnerability indicator is combined by an indicator representing the infiltration volume in the catchment. This latter is also combined by risk of infiltration estimated by CCTV indicator.

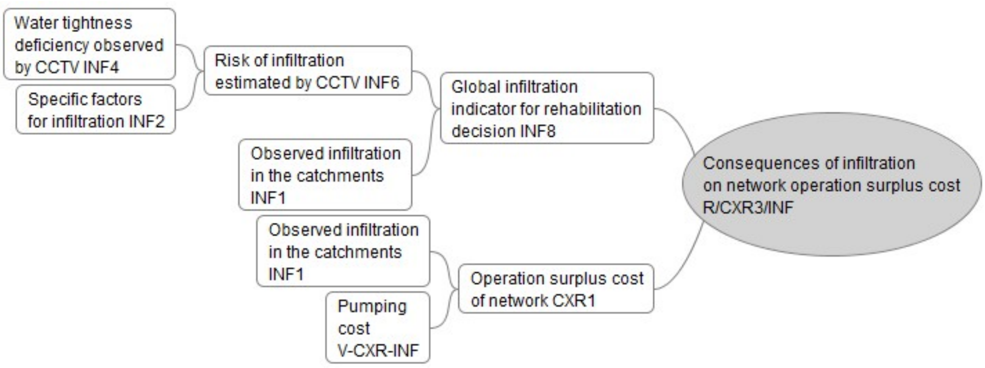

Figure 5: Consequences of infiltration on network operation surplus cost criterion construction procedure

R/TRA/EFF is a criterion taking into account the consequences of a possible collapse on traffic and urban disturbance. It is defined as a combination of six indicators in RERAU methodology. However, a simplified version is implemented in this case study due to lack of information.

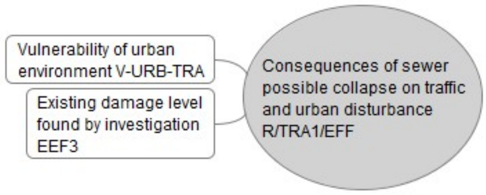

Figure 6: Consequences of sewer possible collapse on traffic and urban disturbance criterion construction procedure used in this study

This criterion is simplified due to the lack of data on ground-pipe system; chemical attack or abrasion. Risk factor for sewer collapse is also forgotten for the same reason. This simplification was in accordance with stakeholders.

MULTI-CRITERIA ANALYSIS

In order to prioritize segments to be rehabilitated, two multi-criteria analysis modules are integrated into the INDIGAU toolbox: ELECTRE TRI (Yu, 1992; Rogers *et al*, 2000) and a simple procedure called "thresholds method" (Cherqui *et al,* 2010). This method uses two threshold values (α, β) to define three priority levels: Green, Orange and Red (successively from low to high priority). Table 3 shows an example of an assessment with the thresholds method.

Table 3 : Assessment of a segment with the "threshold method"

Criterion	**Grade**	**Weight**	**Synthesis**	**Rules to define Priority Level**
R/CXR3/INF	G4	0.14	W4 = 0.14	[(W4 >α) or
R/CXS/INF	G3	0.05		(W3+W4 >β)] => Red
R/DEB/HYD	G3	0.05	W3 = 0.32	
R/TRA1/EFF	G3	0.22		(W3+W4 >α) => Orange
R/PON2/HYD	G2	0.09	W2 = 0.09	
R/PON1/EXF	G1	0.17		
R/CXR1/ENS	G1	0.05		
R/CXR2/BOU	G1	0.13	W1 = 0.45	
R/DEB/ENS	G1	0.05		
R/DEB/BOU	G1	0.05		

For instance, with α = 15% and β = 30%, the sewer segment assessed in Table 3 is assigned a "Red" priority level (W3+W4=0.43 > 0.30). α and β can control the number of segment in each priority level: α controls the number of "green" segments and "β" controls the proportion of "red" and "orange" segments. The simplicity of this approach makes it understandable and helps the stakeholders to control the number of segments to be prioritized.

RESULTS

A multi-criteria analysis allows to prioritize the sections in terms of rehabilitation need from "most urgent" to "not-needed" ones. No constraint was given by the utility in relation to the various unknowns that could help reformulating a rehabilitation program like:

- Duration of works
- Annual rehabilitation budget
- A specific length of network to be rehabilitated

Figure 7 : Segments and their need to rehabilitate

Therefore, 5.5 and 7.7 kilometers of inspected network were found respectively in Red and Orange categories which represent 6% of the inspected network in Red and 8% in Orange (figure 7 **Figure 4**). Table 4 illustrates the multi-criteria analysis results. As it is mentioned above, more than 10 percent of assets were inspected in which 13% should be rehabilitated in short and average terms.

Table 4 : Multi-criteria analysis results

Total length (m)	Inspected length (m)	Green (m)	Orange (m)	Red (m)	Inspection ratio [%]	Total rehabilitation length ratio [%]	Inspected rehabilitation length ratio [%]
931 633	99 467	86 310	7 741	5 416	10.68	0.58	5.45

CONCLUSION

The first implementation of INDIGAU on the Caen-la-Mer network allowed the testing of its full-scale applicability. The condition grade (distress-based evaluation) of a sewer segment is assigned according to a comparison of defects' inventory from CCTV reports (defect coding and deduct values) with a scale of numerical values. This scale is based on experts' opinions from different French utilities. The segments to rehabilitate are then identified using criteria and applying multi-criteria analysis. Criteria used for rehabilitation prioritization are not only based on CCTV reports. As quoted by Dirksen *et al.* (2011), "Because accuracy of visual inspection data is low, other types of information to investigate sewer system functioning is recommended." The implementation of an asset management approach is thus time-consuming and requires an important initial phase to gather raw information. With the INDIGAU toolbox, once all data have been gathered and adequate parameters have been set, 11% of the network of Caen-la-Mer (about 99 km) was assessed within some minutes.

Application on the Caen-la-Mer network has given interesting findings:

- Segment rehabilitation priority sorting is the end of a long chain: feasibility and reliability of analysis which depend significantly on the way utilities produce and store asset condition data and contextual data.
- Rehabilitation priorities can be questioned as rehabilitation works program will only include sections which have been inspected. Only available CCTV reports were used in the Caen case study. However CCTV inspections are run continuously, therefore the sewer network knowledge will increase and multi-criteria analysis will improve consequently. Asset management must be a long term approach.
- Even though it was improved by the EN 13508-2 norm, objectivity of the initial data - CCTV reports - remains a major concern: utilities must pay adequate attention to the way inspections are carried out (Dirksen *et al.*, 2011). Cross-section control can be used to validate operators' or contractors' work.

INDIGAU also aims to organize a public-private R&D process: the INDIGAU user club involves utilities (end-users), researchers and the software provider. This club aims at: (i) promoting a shared language and a shared culture of asset management between members, (ii) improving and sharing best practices and (iii) discussing and improving the INDIGAU tools. This tri-polar partnership provides the scientific team with case studies and data for on-going research, the member utilities with an exclusive toolset, shared expertise and permanent assistance, the consulting company with a leading-edge offer and enhanced customer relations.

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