APUSS

Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems

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DELIVERABLE 9.1

INFILTRATION AND EXFILTRATION PERFORMANCE INDICATORS

Sewer systems performance assessment methodology and formulation

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1. INTRODUCTION

Sewer systems constitute a very significant asset in European cities. Their structural quality and functional efficiency are key factors in guaranteeing the transfer of domestic and trade wastewater to treatment plants without infiltration or exfiltration. European standard EN 752-2 indicates basic performance criteria applicable to any sewer system.

Among these criteria, the following two are especially relevant for the objectives of the APUSS project: receiving waters should be protected against pollution; and the structural integrity of urban sewer systems (USS), including watertightness, should be guaranteed. However, many sewer systems across Europe suffer from significant infiltration and/or exfiltration. Both problems are critical on a long-term basis for sustainable water management.

Infiltration of groundwater is particularly detrimental to treatment plant efficiency but can greatly decrease the performance of sewer systems by increasing the frequency of surcharging, flooding and overflows as well as increasing pumping volumes and operational costs. Infiltration can lead to hydraulic overloading of wastewater treatment plants (WWTP). The result is lower treatment efficiency and increased operational costs. When a significant rate of infiltration is occurring, sewers are rehabilitated when the drop in hydraulic performance causes additional costs and hydraulic problems.

Exfiltration leads to groundwater pollution, which may affect, on medium and long terms, the quality of the resource, especially for drinking water production, but also for industrial, agricultural and recreational uses. It may also affect other surface receiving waters. Degradation of the quality of water resources will affect the quality of living and public health in Europe.

The quality of sewer systems in terms of infiltration and exfiltration (I/E) is a crucial aspect of the management of water in the city, in European countries. European standards EN 752 require that sewer systems are watertight. However, this objective is not easily reached due to:

- the ageing of pipes (some parts of sewer systems in European cities are more than 100 years old);

- bad construction quality (poor quality of pipe material, inadequate laying conditions, ignorance or underestimation of the effects of geotechnical and road traffic conditions, etc.);
- lack of, or insufficient, maintenance;
- lack of appropriate investment and rehabilitation strategies;
- high costs of construction and rehabilitation.

The limited financial resources allocated to the management and rehabilitation of sewer systems make clear the need of rehabilitation strategies based on an integrated approach of the systems.

The need is very clear for methods and tools to support the integrated diagnosis of sewer systems, considering both the hydraulic, structural and environmental performances, and help define priorities and solutions for their rehabilitation. The systematic use of computer models is certainly a correct path towards the solution of the problem. Simulation models are an invaluable aid in the assessment of the system's response to a wide range of events and operational scenarios. However, the type of results returned by such models can be complex and far from intuitive, frequently making their interpretation difficult and less than objective when it is necessary to compare between different situations. Monitoring data also needs to be correctly processed and interpreted in order to give the right information about rehabilitation needs. The fact is, measuring the performance and ultimately assessing the level of service provided by sewer system are genuinely difficult tasks, given the multiple factors and viewpoints involved, and the lack of a unified approach or a single clear-cut definition of performance (Cardoso *et al.*, 1999).

Performance indicators and performance assessment are helpful tools, widely used in many sectors of industry in supporting economic and financial decision making.

This report presents the definition of performance indicators as well as the methodology and the formulation for performance assessment of sewer systems, regarding infiltration and exfiltration.

2. OBJECTIVES

The overall objective of this work is to develop a methodology to assess the performance of sewer systems in a systematic, standardised and quantifiable basis. The result is an objective framework for performance assessment that can be used to decision support for planning the rehabilitation and maintenance of sewer systems. This will allow not only an integrated analysis of the system in order to identify and hierarchise critical areas as well as an evaluation and comparison of potential benefits achieved by the implementation of alternative solutions.

The specific application considered herein is the sewer systems performance evaluation with regard to infiltration of clean water into foul sewers and exfiltration of sewage into receiving waters. Aspects such as hydraulic, environmental and structural behaviour are to be considered. The links between the other components developed in the APUSS are illustrated in Figure 1. The experimental results obtained are stored in a database. These data, together with model parameters and time series events will be used in the models as well as topology and ground description stored in AQUABASE. From the models, sets of results are going to be produced. These results together with data stored in AQUABASE are the inputs for the *Perf* (performance assessment) tool.

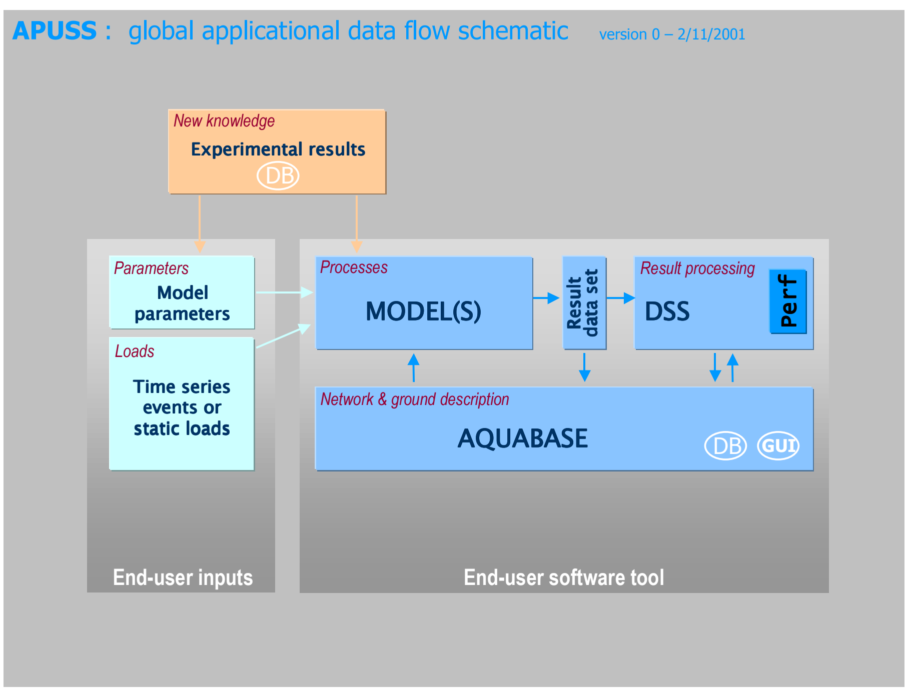

Figure 1 - Data flow scheme

3. INFILTRATION INTO SEWERS

Infiltration is water that enters into a sewer system from ground through defective pipes, pipe joints, damaged lateral connections or manhole walls (ASCE&WEF, 1994). It is often related to high groundwater levels but can also be influenced by storm events or leaking water mains.

The rate of groundwater infiltration depends on:

- the number and size of sewer, joint and manhole defects;
- the head available (height of groundwater level above the sewer);
- the rainfall season being higher during the winter period;
- the sewer deepness;
- antecedent wetness;
- type of surrounding soil, being higher in permeable soils.

Infiltration affects the operation of sewer and treatment systems namely through:

- reducing of the hydraulic capacity;
- increasing of overflow frequency and volume, from combined and separate domestic systems;
- increasing of sewers surcharging and flooding in streets and private properties;
- increasing of pumping;
- of pumping, sewer system and treatment costs;
- reducing treatment efficiency;
- increasing storage volume;
- increasing by-passing.

Infiltration is thus closely related with structural, hydraulic and environmental performance. Design criteria usually allocate a part of the sewer system capacity to infiltration, as this is a component always present in sewer systems. However, in practice, the estimated design values are largely over passed (White *et al.*, 1997; Ainger *et al.*, 1998; Ellis, 2001).

4. EXFILTRATION FROM SEWERS

Exfiltration from sewers is untreated wastewater that leaks to the ground through cracks in defective pipes, pipe joints, damaged lateral connections or manhole walls. It may contain high levels of suspended solids, pathogen microorganisms, toxic pollutants, floatables, nutrients, oxygen demanding organic compounds, oil and grease and other pollutants. Exfiltration is highly dependent on groundwater levels and can be related to the occurrence of infiltration (Amick and Burgess, 2000). Exfiltration affects the performance of sewer systems namely through:

- posing risks to the health of people and to the environment (streams, lakes, groundwater);
- causing failure to comply with water quality standards in streams, lakes, groundwater;
- compromising aquatic life and habitat;
- impairing the recreational use of watercourses.

Exfiltration rates depend on:

- the number and size of sewer, joint and manhole defects;
- the age of the sewers;
- the height of groundwater level above the sewer;
- the materials;
- the depth of flow in the sewer;
- the type of surrounding soil, being higher in permeable soils.

Exfiltration is thus closely related to structural, hydraulic and environmental performance.

5. PERFORMANCE ASSESSMENT

5.1 Methodology

The principal requirements laid down for a performance assessment methodology in the field concerned were: flexibility, in order to accommodate with ease the different sensitivities, interpretations or objectives of the analysis; a certain degree of standardisation in order to facilitate a multi-disciplinary approach, where the various aspects to be considered may be brought down to the same quantified basis; and a quantitative, numerical base - the envisaged tool should be translatable computationally in order to afford intensive use, either from within or as postprocessor to the current modelling techniques or monitoring data.(Cardoso *et al*., 1999).

The methodology consists in the selection and development of three components, for each aspect of performance to be analysed (Coelho and Alegre, 1997; Coelho, 1997) (Figure 2):

a) The numerical value of a sewer network property or state variable, which is deemed to be expressive of the particular aspect being scrutinised (infiltration or exfiltration). The values of state variables, for any given state or scenario of interest, will either be generated by hydraulic or water quality simulation models, or come from reliable monitoring records. It must be noted that the methodology is valid whatever the source of the values for the state variables. If simulation models are utilised, their assumptions and simplifications are by necessity inherited by the present method. One further aspect to note is that the accuracy of the methodology cannot be greater than that of the original information about the network's state variables. Whatever the source of the data, the method is essentially based on a performance-oriented interpretation of it. It can hardly compensate for poorly calibrated models or other sources of inaccuracy, even though it can be used as an aid to gaining sensitivity to the origins of such errors.

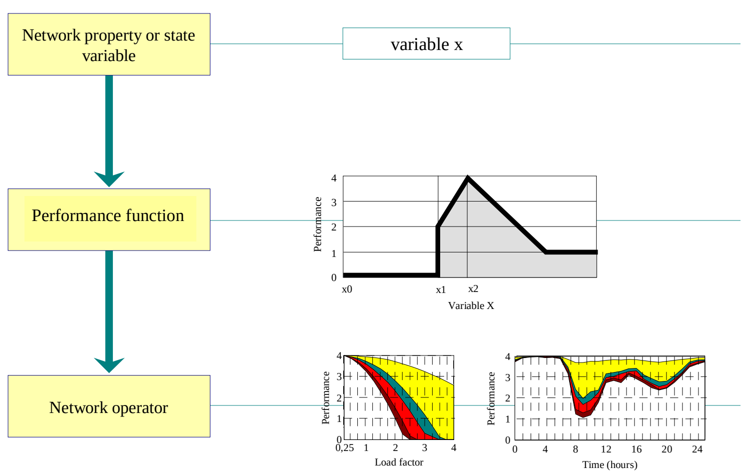

Figure 2 – Performance assessment methodology scheme

b) A performance function that plots the performance value credited to the state variable or network property, at network element level, over a given range. The performance value varies between a no-service and an optimum-service situation, and the curves are supposed to classify the state variable or network property as a function of the values it takes. The basic idea is primarily related to the concept of level of service, hence the "no-service to optimum service" classification, with the curves interpreting a common-sense, standardised grading of performance. The curves are arbitrary by nature and essentially translate how the decision variable is rated for a given purpose over an operative range. This is where the flexibility of the methodology resides, although there is every advantage in keeping the shape of the curves as simple as possible. The convention adopted here uses a 0 to 4 scale, with the following meanings: 4 - optimum, 3 - adequate, 2 - acceptable, 1 - unacceptable and 0 - no service.

c) A network operator, which allows the performance values at element level to be aggregated across the system or parts of it. This might simply be an average, a weighted average, a maximum or minimum value, etc.. The type of operator depends on the objective of the analysis. In case the methodology is applied at an aggregated level there is no need of this operator.

Hence, this method yields values of performance evaluation for every element of a system as well as for the system as a whole. There is a global value that is achieved through a particular operator in order to represent the performance assessment of the network, and conversely, a population of elementary values, which lends itself to a basic statistical treatment. The two are combined together graphically in diagrams where performance is plotted against a series of operational conditions, e.g. summer, and winter periods (system graph) or the simulation of a specific event (event graph).

5.2 Formulation

5.2.1 Definition of performance indicators for infiltration

Taking into account the relevant factors that can cause infiltration in sewer systems, a set of performance indicators was defined in order to assess the impact of infiltration on the performance of sewer systems (Table 1).

Table 1 - Performance Indicators for infiltration

Definition	Unit	Designation	Concept/Explanation
Qinf /Qfull	(%)	Infiltration full capacity utilization	*The proportion of the sewer's full section flow capacity used up by the infiltration flow. This indicator makes no distinction between the possible origins of infiltration (such as joints, manholes, etc.). Its value may be assessed for a single sewer, for groups of sewers (subsystems) or for the entire system. The data needed is the full flow capacity of the sewer or group of sewers, which is normally available if the topology, geometry and material of the pipes is known. This indicator supplies information on the hydraulic performance of the analysed sewer(s), but gives no indication as to the net infiltration flow. For example, for a network branch with 3 consecutive sewers of growing capacity but with a constant infiltration flow, the indicator might be worth 60%, 30% and 10% (upstream to downstream) simply because the capacity was growing, while effectively the infiltration flow was of the same magnitude throughout.*
Qinf /Qavdwf	(%)	Infiltration proportion of dry weather flow	*The infiltration flow expressed as a percentage of the daily mean dry weather flow. This indicator does not take into account the different origins of infiltration. Its value may be assessed for a single sewer, for groups of sewers (subsystems) or for the entire system. It requires measurements or estimates of the dry weather flow. A drawback of this indicator is its dependency on the values of the dry weather flow. For example, a 1 km-long 1000 mm sewer with an infiltration flow of 50 m3/day would rate as a low-infiltration case in the light of the Portuguese regulation 23/95. The value of the indicator would be 0.5% in a system with a dry weather flow of 8640 m3/day, and 1.2% in another where the dry weather flow would be 4320 m3/day. When applied to the flow that reaches the WWTP, this indicator gives an estimate of the weight of infiltration flow on treatment costs. In this respect, it may be expressed either as a volume percentage or as a cost percentage.*
Qinf /nº of manholes	(m^3/s)	Infiltration flow per manhole	*Mean infiltration flow per manhole unit. Manholes are an important source of infiltration. This indicator gives an idea of the influence of the number of manholes on total infiltration. It should be evaluated in sewers or groups of sewers of equal length, for comparisons, in order to avoid a bias related to the infiltration along the pipes, which is ignored by this indicator. Infiltration taking place in service connections is equally disregarded. The data needed is the total number of manholes.*
Qinf /nº of service connections	(m^3/s)	Infiltration flow per service connection	*Mean infiltration flow per service connection. Service connections are an important source of infiltration. This indicator gives an idea of the influence of the number of service connections on total infiltration. The data needed is the total number of service connections.*
Qinf /sewer length	(m^3/s/km)	Infiltration flow per unit sewer length	*Mean infiltration flow per unit length of sewer. This indicator does not take into account the influence of infiltration taking place in manholes or service connections. Again, the indicator may be calculated for sewers, groups of sewers or entire systems. The data needed is the total length of sewers contributing to the section where it is being calculated. This indicator will give relevant results in systems where infiltration takes place predominantly along the sewers.*
Qinf /sewer longitudinal area	(m^3/day/(cm.km))	Infiltration flow per unit sewer wall area	*mean infiltration flow per unit area of sewer wall. This indicator does not take into account the influence of infiltration taking place in manholes or service connections. Again, the indicator may be calculated for sewers, groups of sewers or entire systems. The data needed is the total wall surface area of the sewers contributing to the evaluation point. This indicator will give relevant results in systems where infiltration takes place predominantly along the sewers.*

5.2.2 Definition of performance indicators for exfiltration

Performance indicators applicable to sewers totally or partially above the groundwater level, whenever the exfiltration flow is known, are presented in Table 2.

Table 2 - Performance Indicators for sewers totally or partially above the groundwater level

Definition	Unit	Designation	Concept/Explanation
Qexf /nº of manholes	(m^3/s)	Exfiltration flow per manhole	*Mean exfiltration flow per manhole unit. Manholes are an important source of exfiltration. This indicator gives an idea of the influence of the number of manholes on total exfiltration. It should be evaluated in sewers or groups of sewers of equal length, for comparisons, in order to avoid a bias related to the exfiltration along the pipes, which is ignored by this indicator. Exfiltration taking place in service connections is equally disregarded. The data needed is the exfiltration flow and the total number of manholes..*
Qexf /nº of service connections	(m^3/s)	Exfiltration flow per service connection	*Mean exfiltration flow per service connection. Service connections are an important source of exfiltration. This indicator gives an idea of the influence of the number of service connections on total exfiltration. It should be evaluated in sewers or groups of sewers of equal length, for comparisons, in order to avoid a bias related to the exfiltration along the pipes, which is ignored by this indicator. The data needed is the exfiltration flow and the total number of service connections.*
Qexf /sewer length	($m^3/s/km$)	Exfiltration flow per unit sewer length	*Mean exfiltration flow per unit length of sewer. This indicator does not take into account the influence of exfiltration taking place in manholes or service connections. Again, the indicator may be calculated for sewers, groups of sewers or the entire systems. The data needed is the exfiltration flow and the total length of sewers contributing to the section where it is being calculated. This indicator will give relevant results in systems where exfiltration takes place predominantly along the sewers.*
Qexf /sewer longitudinal wet area	($m^3/day/(cm.km)$)	Exfiltration flow per unit sewer wet wall area	*Mean exfiltration flow per unit area of wet sewer wall. This indicator does not take into account the influence of exfiltration taking place in manholes or service connections. Again, the indicator may be calculated for sewers, groups of sewers or the entire systems. The data needed is the exfiltration flow and the wet wall surface area of the sewers contributing to the evaluation point. This indicator will give relevant results in systems where exfiltration takes place predominantly along the sewers.*

Whenever it is possible to assess an overall value of exfiltration flow for a catchment or subcathment, the proposed indicator can be applied using mathematical modelling or monitoring is *(Exfiltration Performance Indicator)*:

$$EPI = \frac{Q_{Exfiltration}}{Q_{Total}} = f\,(structural\ condition,\ ground\ water\ level,\ permeability) \quad (1)$$

where $Q_{exfiltration}$ is the exfiltration flow (volume of exfiltration during a certain period) and Q_{total} is the total flow (wastewater volume collected by the sewer system in a certain period it can be used an average dry weather flow or full pipe flow) (see Figure 3).

This value gives an indication of the structural condition of the system and thus the need for rehabilitation.

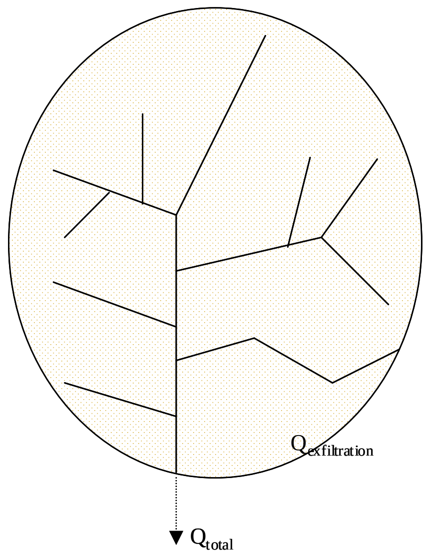

Figure 3 – Schematic of a catchment

Indicators to evaluate sewer systems whenever there is information on their characteristics but exfiltration flow cannot be measured can be proposed as indicators that translate the potential of exfiltration occurrence.

A proposal for a parameter that represents potential flow exfiltration (*K*) is given below, as a function of sewer, manhole or service connection “structural condition” (good, medium, bad), “groundwater level” below invert or within invert and soffit of the pipe (0%, 50%, 100%), “soil permeability” (high, medium, low)]. Each position in the matrix (Table 3) can be filled in for sewers, manholes and service connections.

An exfiltration threshold K_t must be defined considering that any value of exfiltration below this threshold is neglected. This depends on the system location (sensitivity of the surrounding media, proximity to a source of water supply or to the water supply pipes, etc.

Table 3 – Matrix of potential flow exfiltration for sewers, manholes and service connections

SC – Good *Gwl – 0%* *SP – High* *K = a*	*SC – Good* *Gwl – 0%* *SP – Medium* *K = b*	*SC – Good* *Gwl – 0%* *SP – Low* *K = c*	*SC – Medium* *Gwl – 0%* *SP – High* *K = d*	*SC – Medium* *Gwl – 0%* *SP – Medium* *K = e*	*SC – Medium* *Gwl – 0%* *SP – Low* *K = f*	*SC – Bad* *Gwl – 0%* *SP – High* *K = g*	*SC – Bad* *Gwl – 0%* *SP – Medium* *K = h*	*SC – Bad* *Gwl – 0%* *SP – Low* *K = i*
SC – Good *Gwl* – [0 – 50%] *SP – High* *K = j*	*SC – Good* *Gwl* – [0 – 50%] *SP – Medium* *K = l*	*SC – Good* *Gwl* – [0 – 50%] *SP – Low* *K = m*	*SC – Medium* *Gwl* – [0 – 50%] *SP – High* *K = n*	*SC – Medium* *Gwl* – [0 – 50%] *SP – Medium* *K = o*	*SC – Medium* *Gwl* – [0 – 50%] *SP – Low* *K = p*	*SC – Bad* *Gwl* – [0 – 50%] *SP – High* *K = q*	*SC – Bad* *Gwl* – [0 – 50%] *SP – Medium* *K = r*	*SC – Bad* *Gwl* – [0 – 50%] *SP – Low* *K = s*
SC – Good *Gwl* – 100% *SP – High* *K = t*	*SC – Good* *Gwl* – [0 – 100%] *SP – Medium* *K = u*	*SC – Good* *Gwl* – [0 – 100%] *SP – Low* *K = v*	*SC – Medium* *Gwl* – [0 – 100%] *SP – High* *K = w*	*SC – Medium* *Gwl* – [0 – 100%] *SP – Medium* *K = x*	*SC – Medium* *Gwl* – [0 – 100%] *SP – Low* *K = y*	*SC – Bad* *Gwl* – [0 – 100%] *SP – High* *K = z*	*SC – Bad* *Gwl* – [0 – 100%] *SP – Medium* *K = z1*	*SC – Bad* *Gwl* – [0 – 100%] *SP – Low* *K = z2*

An *Indicator of Potential for Exfiltration* for the **sewers** can be calculated using the following formula:

$$IPE_S = \frac{\sum_{i=1}^{n} L_i \, x \, K_s \; (where\ K_s \geq K_{st})}{L_{total}} \qquad (2)$$

where n is the total number of sewers, L_{total} is the total sewer length, L_i is the length of each sewer, and the subscript s means sewer.

An *Indicator of Potential for Exfiltration* for **manholes** can be calculated using the following formula:

$$IPE_M = \frac{\sum_{j=1}^{p} j \, x \, K_m \; (where\ K_m \geq K_{mt})}{p_{total}} \qquad (3)$$

where p is the total number of manholes in the system and the subscript m means manhole.

An *Indicator of Potential for Exfiltration* for **service connections** can be calculated using the following formula:

$$IPE_{SC} = \frac{\sum_{q=1}^{r} q \, x \, K_{SC} \; (where\ K_{SC} \geq K_{SCt})}{r_{total}} \qquad (4)$$

where r is the total number of service connections in the system and the subscript sc means service connection.

The *Indicator of Potential for Exfiltration* for the whole system may be a weighted average of the partial indicators, according with the main contribution of each component to the exfiltration:

$$IPE = w_1 \times IPE_S + w_2 \times IPE_M + w_3 \times IPE_{SC} \quad (5)$$

A *performance function* can be defined such as the one presented in the Figure 4 where 4 is optimum, 3 is good and 2 is the acceptability threshold; below 2, performance is unacceptable, with 1 translating very poor performance and 0 a no-service situation.

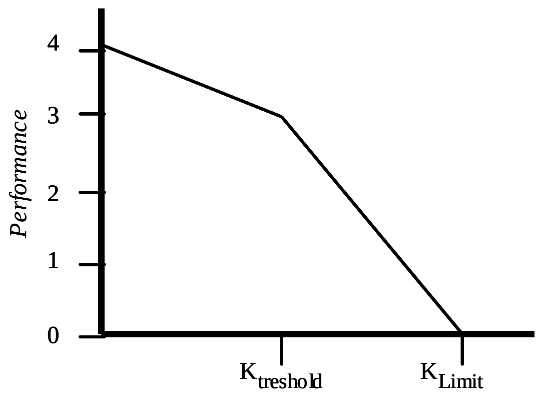

Figure 4 - Performance function

5.3 Scope of application

The application of this methodology can be done at an aggregated level or at pipe level. The aggregated level should be used if information is available only at the catchment scale (data on infiltration or exfiltration at the outlet). In this case, the results obtained are a table of the calculated PI for the catchment as a whole (Figure 5).

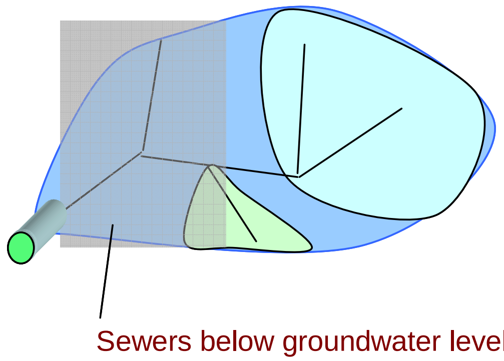

Figure 5 – Scheme of the aggregated application of PI

Application at pipe level may be used whenever there is information at that scale, i.e., data on infiltration or exfiltration pipe by pipe (Figure 6). In this case, the results obtained are performance graphs showing both an average performance curve and performance percentile bands (Figure 7).

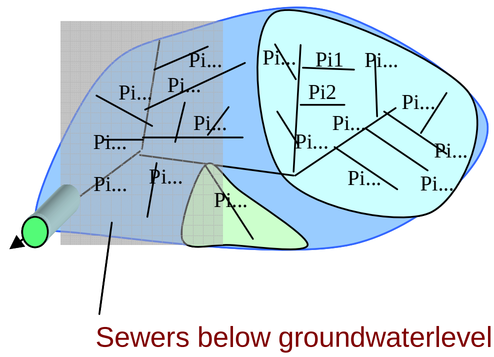

Figure 6 – Scheme of the pipe by pipe application of PI

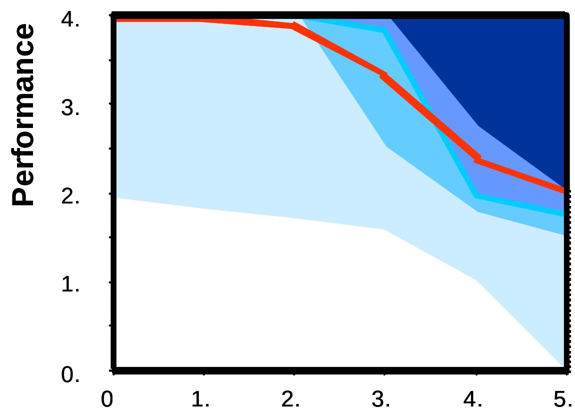

Figure 7 – Performance graph

5.4 Illustrative application

The application of this methodology and formulation is presented for a sewer system with fictitious data. The town of Borel has a separate sewer system built in 1975/76, with a catchment area of 5 ha. The pipe material is ceramic and the total sewer length of the sub-catchment is 571.3m (Figure 8). Full flow at the downstream section (Q_{full}) is 1814.4 m3/day or 0.021 m3/s; infiltration flow is (Q_{inf}) 52.5 m3/day or 0.0006 m3/s; and the average dry weather flow (Q_{avdwf}) is 138.24 m3/day or 0.0016 m3/s. From Table 1, seven indicators for infiltration were applied to the system data at an aggregated level. The results are presented in Table 4.

The application at pipe level was carried out considering two scenarios for sewer system performance evaluation: summer and winter. In the summer scenario the infiltration flow in the system is lower than in the winter scenario (Figure 9). This corresponds to step *a)* of the methodology presented in § 5.1.

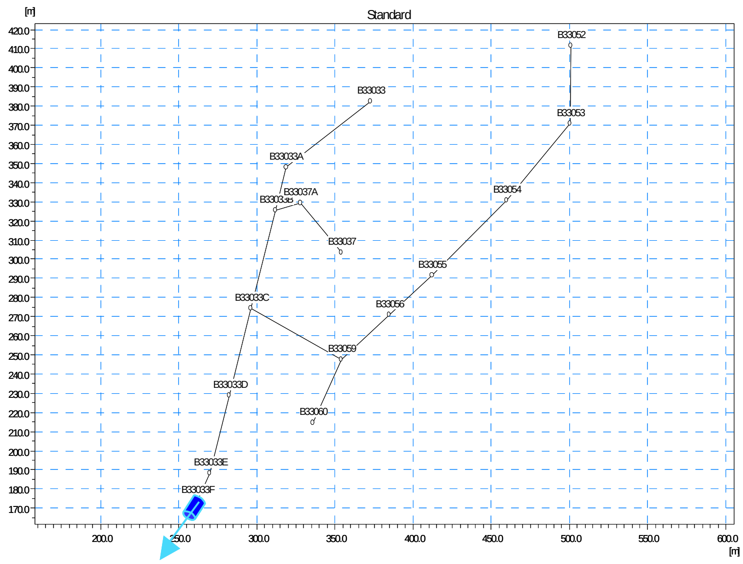

Figure 8 – Borel sewer system

Table 4 – Performance Indicators for Borel system

Qinf /Qfull	(%)	2.89
Qinf /Qavdwf	(%)	37.98
Qinf /nº of manholes	(m^3/day)	3.50
Qinf /nº of house connections	(m^3/day)	-
Qinf /sewer length	(m^3/day/km)	82.76
Qinf /sewer longitudinal area	(m^3/day/(cm*km))	1.32
Qinf /(Qavdwf- Qinf)	(%)	61.23

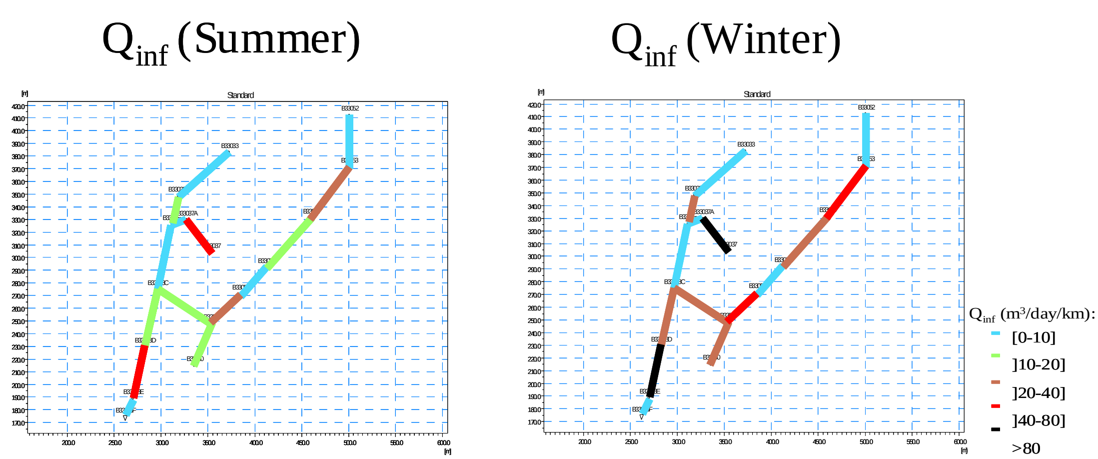

Figure 9 – Scenarios for the Borel sewer system performance evaluation

The performance function designed based on the Portuguese Regulation for sewer systems outside buildings is the one presented in (Figure 10).

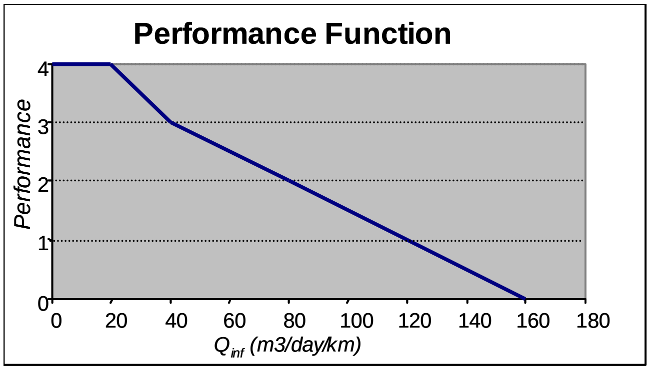

Figure 10 – Performance function for infiltration flow

This function was applied to each pipe, following step *b)* of the methodology (§ 5.1). Then step *c)* was carried out using a simple average as the network operator, which allows the performance values at element level to be aggregated across the network. Percentile bands were also calculated. The resulting performance graph is shown in Figure 11. It is possible to see that the optimum performance (*4*) corresponds to the situation of no infiltration in the system. As expected, using the performance function established, the average performance decreases as infiltration increases. For the summer scenario, the average performance is adequate in spite of about 25% of the pipes having lower performances. The system is heterogeneous regarding infiltration, as the bands are very wide. Both in summer and winter there are some sewers with problems (where performance reaches the zero) that, if rehabilitated, could improve the overall performance of the system. For the winter scenario the average performance achieves the acceptable level and about 50% of the pipes are performing unacceptably (below 2). About 25% of the system is performing optimally for the two scenarios considered for analysis.

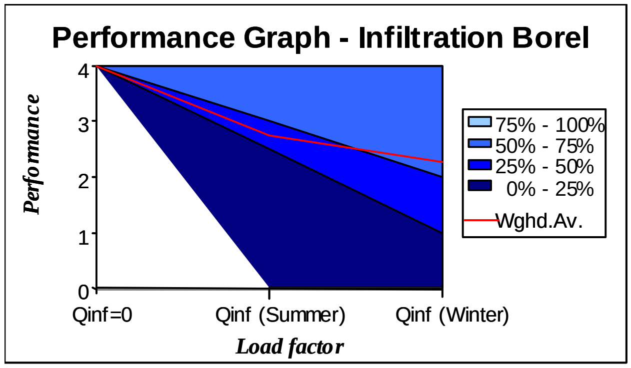

Figure 11 – Performance function for infiltration flow

6. FINAL REMARKS

A methodology and formulation for the performance assessment of sewer systems regarding infiltration and exfiltration, to be used under APUSS, was described in this report. The following task is the application of this methodology to real case studies within the APUSS project. This will be carried out as soon as data is available), in order to test and verify the methodology, and will be the subject of a further report. Availability of data is a critical issue for the achievement of the objectives of this workpackage.

BIBLIOGRAPHY

Cardoso, M.A., Coelho, S.T., Matos, J.S., Matos, R.M (1999). A new approach for diagnosis and rehabilitation of sewerage systems through the development of performance indicators. In: Proc. of 8th International Conference on Urban Storm Drainage, Sydney, Australia.

Cardoso, M. A.; Matos, R. S.; Alegre, H.; Coelho, S. T. (2000a). Performance assessment of water supply and wastewater systems. Workshop on Performance Indicators in Urban Drainage, University of Hertfordshire, Hatfield, UK.

Cardoso, M.A., Almeida, M.C., Brito, R.S. (2000b) – Benefits of Hydraulic Analysis of Separate Domestic Systems Through Mathematical Modelling. In Proc. of IX National Meeting on Water, Wastewater and Waste, Loures, Portugal (In Portuguese).

Coelho S.T. (1997). Performance in Water Distribution – a Systems Approach, John Wiley & Sons Inc., New York, USA.

Coelho S.T., Alegre H. (1997). Performance analysis in water distribution. In: Proc. 21st Intl. Water Supply Congress – Madrid 1997, IWSA – Intl. Water Services Association, London, UK.

Coelho S.T., Alegre H. (1998). Performance indicators for water supply and wastewater drainage systems, ICTH report, LNEC, Lisbon, Portugal (in Portuguese).

DHI (2000) – MOUSE, An Integrated Modelling Package for Urban Drainage and Sewer Systems. Reference Manual. Danish Hydraulics Institute, Denmark.

IHS (1994) – The Wallingford Procedure. Training Course notes.

Matos J. S. (1992). Aerobiose e septicidade em sistemas de drenagem de águas residuais. PhD thesis, Department of Civil Engineering, Technical University of Lisbon, Portugal (In Portuguese).

Amick, R.S., Burgess, E.H. (2000) – Exfiltration in sewer systems, EPA/600/R-01/034 USA.