Assessing Infiltration and Exfiltration
on the Performance of Urban Sewer Systems

Contract number : EVK1-CT-2000-00072 APUSS
Project homepage : http://www.insa-lyon.fr/Laboratoires/URGC-HU/apuss

DELIVERABLE 3.3

MODEL RELATING THE AMOUNT OF WATER GAINED OR LOST TO THE HOUSE CONNECTION CHARACTERISTICS

D. Kohout, I. Princ, J. Pollert
CTU

June 2004

Swiss Federal Institute
for Environmental Science
and Technology

Table of content:

Part I.

1. Interactive matrix of damages

The interactive matrix is a tool for assessing of relationships between detrimental effects (damage) and their causes. The output from this matrix, the total mark (w), represents the catchment conditions and the degree of pipe damages is based on skilful evaluation of each damage, as well as on the results from CCTV inspection.
The total mark (w) entered to equations (**3**) and (**4**) as for reference and large catchment.

The classification of damage is undertaken with a five-grade scale in decreasing seriousness of the damage as follows:

1- emergency conditions
2- serious damage
3- damage of larger range
4- damage of small range
5- small damage

An example of the overall damage of a sewer network including house connections is given in *Tab.1*, where CCTV inspection have been carried out by Sewer Net Administrator according Standard ATV M143/2a.

Tab.1: Matrix of damage (example)

		damages												
		leakage joints			blocking				cracks			others		
		bad joints	sewer connections	manhole connections	sediments	incrustation	roots	overlap pipe to sewer	lengthwise	crosswise	lost of pipe wall	abrasion	deformation	corrosion
factors	high permeability	1	1	1	4	5	5	5	1	1	1	5	-	3
	med permeability	3	3	3	5	5	4	5	3	3	2	5	-	4
	material	2	2	2	5	5	4	5	3	3	2	5	-	5
	type of area	3	3	3	3	4	1	5	4	4	4	4	-	4
	rain	1	1	1	1	1	3	1	3	3	4	3	-	5
	life time	1	1	1	3	1	1	4	1	1	1	3	-	3
	maintainance	3	3	3	3	3	4	3	1	1	1	3	-	3
	implemantation	1	1	1	5	5	-	3	4	2	5	5	-	5
	aggressive background	-	-	-	-	-	-	-	-	-	-	-	-	-
	aggressive water	-	-	-	-	-	-	-	-	-	-	-	-	-
	heavy traffic	1	1	1	5	5	5	4	1	1	3	5	-	5
	pulsating GWL	-	-	-	-	-	-	-	-	-	-	-	-	-
	age	2	2	2	4	2	3	5	2	2	2	2	-	2
	subsoil settlement	5	3	4	-	-	-	3	3	1	5	-	1	-
damages	**average value**	2,1	1,9	2,0	3,8	3,6	3,3	3,9	2,4	2,0	2,7	4,0	1,0	3,9
	total mark (w)	**2,7**												

Average value – average mark of damage for each cause.
Total mark (*w*) – medium value of average values.

2. Infiltration/Exfiltration measuring

Infiltration (resp. Exfiltration) amount [$l.s^{-1}.m^{-1}$] is measured in selected reference catchment and entered to equations (**1**) and (**2**). For measurement methods refer to section *Part II.* or documents *Deliverable D3.1 and D3.2*.

3. Scaling-up

In terms of assessing infiltration (resp. exfiltration) rate, scaling-up means extension of small reference catchment conditions to a large catchment.

The infiltration rate in a large catchment I_{LC} (resp. exfiltration rate from a large catchment E_{LC}) is given by equation (**1**) resp. (**2**). This relationship is derived from the infiltration value in the reference catchment I_{RC}, (resp. exfiltration value in reference catchment E_{RC}), when these values of infiltration and exfiltration rate in reference catchment I_{RC} and E_{RC} are measured in situ, according to the methodology described in documents *Deliverables D3.1 and 3.2 (Part II.).*

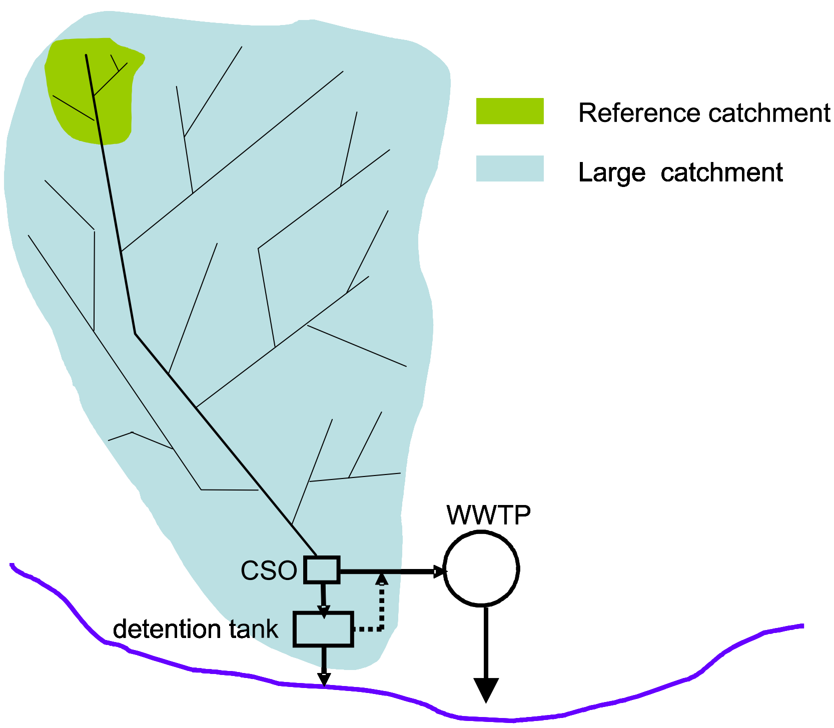

Fig. 1: Relationship between reference and large catchments.

Reference catchment is a part of a large catchment, as seen in *Fig.1* and has the same type of buildings, age of pipe, similar geology and hydrology, etc.

For infiltration or exfiltration assessment from a large catchment, the following equations are used:

$$I_{LC} = I_{RC} \cdot \frac{\sum L_{LCi}}{\sum L_{RCi}} \cdot \frac{(A - w_{LC})}{(A - w_{RC})} \quad (1)$$

$$E_{LC} = E_{RC} \cdot \frac{\sum L_{LCi}}{\sum L_{RCi}} \cdot \frac{(A - w_{LC})}{(A - w_{RC})} \quad (2)$$

where:

I_{LC}, resp. E_{LC}	infiltration/exfiltration in large catchment [$l.s^{-1}$]
I_{RC}, resp. E_{LC}	Infiltration/exfiltration in reference catchment [$l.s^{-1}$]
Σ L_{RCi}	total length of HC pipe in reference catchment [m]
Σ L_{LCi}	total length of HC pipe in large catchment [m]
w_{RC}	reference catchment evaluation [-]
w_{LC}	large catchment evaluation [-]
A	value expressing the pipe condition according to standard using for classification of damages for optic inspection. For example, according to standard ATV, A is equal to 5.

4. Extreme cases – evaluation of catchments (w_i)

Three extreme cases which may occur within an evaluation of both catchments are described as follows:

4.1. Reference catchment and large catchment with similar conditions (homogenous) $w_{RC} = w_{LC}$

$$\frac{(A - w_{LC})}{(A - w_{RC})} = 1$$

Therefore infiltration in a large catchment is given by the following equation:

$$I_{LC} = I_{RC} \cdot \frac{\sum L_{LCi}}{\sum L_{Ri}} \quad (3)$$

and exfiltration from a large catchment:

$$E_{LC} = E_{RC} \cdot \frac{\sum L_{LCi}}{\sum L_{Ri}} \quad (4)$$

The infiltration (resp. exfiltration) value from the large homogeneous catchment is calculated proportionally to the ratio of house connection pipe length in the reference and large catchment, multiplied by the infiltration rate from the reference catchment.

4.2. Large catchments with small damage

$w_{LC} = A$, $w_{LC} \neq w_{RC}$

$$\frac{(A - w_{LC})}{(A - w_{RC})} = 0$$

thus

$$I_{LC} = 0 \text{ , respective: } E_{LC} = 0 \tag{5}$$

In the case of large catchments evaluation with small damages only, there is an assumption of no Infiltration and Exfiltration. Therefore Infiltration (resp. Exfiltration) rate in a large catchment is given by Infiltration (resp. Exfiltration) value from the reference catchment:

$$I_{LC} = I_{RC} \tag{6}$$

$$E_{LC} = E_{RC} \tag{7}$$

4.3. Reference catchments with small damage

$w_{RC} = A$, $w_{RC} \neq w_{LC}$

$$\lim_{w_{RC} \to A} \frac{(A - w_{LC})}{(A - w_{RC})} = \infty \tag{8}$$

thus

no Infiltration (resp. Exfiltration) in reference catchment

In this case, a new reference catchment must be selected in order to measure the Infiltration (resp. Exfiltration) rate.

Part II.

The assessment of Infiltration/Exfiltration on a large catchment starts with an evaluation of the reference catchment, using the interactive matrix and measurement infiltration/exfiltration to house connection using methods described as follows:

5. INFILTRATION

Infiltration into house connections (hereinafter referred to as HC) occurs upon fulfilment of the following conditions:

- the pipe is damaged,
- the level of surrounding water (ground-water or percolation of rainwater) lies above the damaged places,
- the damaged place is surrounded by permeable soil or a cavern.

5.1. Individual house connections

5.1.1. Procedure

The measurement of the amount of water infiltrated to a HC comprises the identification of the defect and the measurement itself.

The application of particular measurement methods depends on the manner of connection of the HC to the sewer system, which reflects the complexity of installation of the measuring equipment and the measurement itself. Different methods are applied for the individual measurement of a single HC and for the lumped measurement of a group of HC.

Measurement of infiltration into a single HC
Infiltration to a single HC is measured as the amount of water infiltrated into a HC, whereas the inflow from households is eliminated by blocking the inspection manhole and pumping the sewage into the sewer system.
The installation of the measuring equipment and the measurement differ according of the connection of the HC to the sewer system:

A) Cleaning of the household connection
The household connection must first be cleaned mechanically or by flushing to enable the movement of the TV camera vehicle.

B) Checking by TV camera
For the examined connection, a TV camera is used to assess its conditions and any places of infiltration of external water. The check is begun against the gradient of the bottom of the pipe. The defects are evaluated upon discovery by an operator, or by a technician viewing the recording. When viewing the image, the number of joints, the length, the material, the pipe diameter, constructional defects, and the condition of the pipe are checked. The defects are usually assessed according to ATV classification as grades 1 – 5 (grade 1 = largest extent of damage, 5 = small defect).

Alternative connections are as follows:
a) Connection of HC in manhole
b) Connection of HC to passable sewer
c) Connection of HC to non-passable sewer

a) Connection of HC to manhole
One possibility to perform the measurement is to install a measuring volumetric tank at the place of connection of the HC to the manhole and measure the time required to fill the tank several times, i.e. $I = \Sigma\ I_i/n$, and $I_i = V_i/\Delta t_i$, where “I” is infiltration rate, “n” is number of measurements, “V_i” is volume of the measuring volumetric tank, and “Δt_i” is time required to fill the tank.

Another alternative is to use a passable sealing balloon, which is easily installed at the end of the HC. The sack is equipped with a transparent vertical pipe and a release valve. The vertical pipe enables observation of the gradual levelling of the surfaces in the HC and in the vertical pipe, i.e. V = f (t).

b) Connection of HC to passable sewer

The procedure is similar to that described for alternative **a),** with the exception that the outflow is ensured using a hose at the balloon. The HC must be sealed, in any case, with a passable balloon.

c) Connection of HC to non-passable sewer

This manner of connection is the most common and the measurement is most difficult in this case, since the sealing balloon cannot be installed from the main sewer. The blocking balloon must be pushed from the inspection manhole or two balloons can be used in the main gutter. Such installations carry the risk of the balloon(s) being locked in the extension or gutter. Measuring of the infiltration is similarly difficult, since the water level can be observed only either using a camera placed in the HC, or by using a float in a narrow pipe inserted into the HC.

5.2. Group of house connections

A large urban drainage area, from infiltration point of view, is constituted of, at least two main sewers in catchment with a group of several house connections, which are connected to the main sewers.

In the proposed methodology, only catchments with homogeneous characteristics are considered. Homogeneity is based on identical catchment shape, type of build-up area and population, analogous geologic and hydrogeology conditions, etc. The infiltration evaluation in an homogeneous urban large drainage area is based on a measurement in a local reference catchment, which has identical or similar characteristics to the large catchment. Consequently, the local infiltration rate can be computed proportionally on the large catchment.

In the case of a large catchment with heterogeneous characteristics, it is possible to isolate small „reference“ catchments within the large catchment, make measurements on each of them and give a global result for the entire catchment (sum of small catchment infiltration flows and/or average of flow rates).

The methodology is based on the monitoring of minimal discharges during the night in a small reference catchment and the chemical analyses of samples collected during the night for comparison with the minimal discharges. These chemical analyses indicate the dilution of wastewater. This result, which represents pollution of wastewater, is compared with usual values of wastewater pollution from daylight hours. The appropriate indicators of pollution are COD ($mg.l^{-1}$), $N\text{-}NH_4^+$ ($mg.l^{-1}$), temperature (^oC), conductivity ($S.m^{-1}$). These parameters are typical for wastewater.

Another alternative is to specify the total flow volume, including infiltration and wastewater, as follows:

$$V = \int_0^T Q(t)dt \qquad (9)$$

The total infiltration flow is calculated from the water consumption W obtained from flowmeters in the connected households:

$$I = V - W \quad (10)$$

If the measurements from flowmeters are unavailable, the water consumption in the area can be estimated as follows:

$$W = n \cdot T \cdot q \quad (11)$$

where "n" is number of inhabitants of the area, "T" is the duration of measurement, the same as the upper limit of the integral in equation (**9**), and "q" is the specific water consumption per inhabitant per day: (e.g. q = 110 litres × person^{-1} × day^{-1}, the approximate value for a residential suburb in Prague). However, in this case the value of W is only an approximation and the infiltration calculated from it is rather uncertain.

The total infiltration is computed from the results of the reference catchment [Infiltration = f (X_1 , X_2 …..X_n)]. Each variable Xi represents e.g. groundwater table position, soil permeability, pipe abrasion etc. The overall standard deviation is estimated with respect to individual error contributions as following:

$$\sigma I = \sqrt{\sum_{i}^{n} \left(\frac{\partial I}{\partial X_i} \cdot \sigma X_i \right)^2} \quad (12)$$

$$I = \hat{I} \pm \sigma I \quad (13)$$

The assessment of infiltration on a large homogeneous catchment starts with an evaluation of the reference and the monitored catchments using the interactive matrix (*see Tab.1.*). This matrix shows the comparison between both catchments in significant items.

In the case where the difference between the acquired infiltration data from the reference catchment and the catchments evaluation in the interactive matrix is less than 30% (based on long term experiences and literature), the infiltration rate from larger homogeneous catchment is calculated proportionally, according equations above mentioned in *Part I.*

6. EXFILTRATION

The general constructional state of HC pipe, including point of connection to the main sewer, corresponds to potential leakage amount of waste water to the soil environment.

The leakage of sewage water from household sewer connections occurs only upon the fulfilment of the following conditions:

- the pipe must be damaged (cracks, broken joints, holes, ...),
- the ground water level (GWL) is lower than the level of the pipe,
- the pipe is placed in a permeable environment.

6.1. Procedure

Obtained data from a reference catchment constituted by a single main sewer and by a several HCs can be used for extending on a larger catchment (scaling up). Nevertheless, these data have to be extrapolated only in one type of area or in area with similar conditions such as type of build-up area, pipe age, pipe constructional state, hydrogeology conditions, etc.

6.1.1. Evaluation of a small catchment

A basis for evaluation of small catchment is interactive matrix elaborating. This matrix consists of the information about types of damage occurring on HC pipe and main sewer pipe. Evaluation is resulting from CCTV inspection and professional evaluation of damage on a pipe.

A relation matrix indicates insignificant defects, and the most significant defects that require attention. Mutual interactions are classified using a five-grade scale (with 1 being the emergency condition and 5 describing a small defect). Total mark for factors, damages and CCTV inspections is the median of average values. Results from this matrix evaluate the reference catchment and pipes from structure conditions point of view.

6.1.2. Exfiltration amount measuring

The exfiltration is measured on a pipe section between both end-manholes and with all connected HC pipes. The methodology of assessment of the leakage volumes is based on testing the water-tightness of the pipe. A decrease in the water level and time are measured for a closed section of a main sewer filled with water. The decrease of the water level is measured in an upstream manhole. The change of the water level corresponds to a change in volume, ΔV, over time, Δt (Exfiltration = dV / dt). The main sewer can be considered as a type of HC pipe in terms of a similar conditions - DN, geology, flow rating, type of area, etc.

Procedure steps *(see Fig. 2)*:

a) Cleaning of the household connection
The household connection must first be cleaned mechanically or by flushing to enable the movement of the TV camera vehicle.

b) Checking by TV camera
For the examined connection, a TV camera is used to assess its conditions and any places of infiltration of external water. The check is commenced against the gradient of the bottom of the pipe. The defects are evaluated upon discovery by an operator, or by a technician viewing the recording. When viewing the image, the number of joints, the length, the material, the pipe diameter, constructional defects, and the condition of the pipe are checked. The defects are assessed according to ATV classification as grades 1 – 5 (grade 1 = largest extent of damage, 5 = small defect).

c) Closing of HC with sealing balloon:
For installation of sealing balloons, a good sealing after inflating along wetted perimeter is required. After placement, the balloon is sealed by being inflated, using an air compressor, in order to seal off a portion of the pipe. Steel wire is used to fix the balloon and remove it after the test.

Number of balloons depends on the number of house connections and number of inlets to the manhole. First, the sealing balloon has to be installed at manhole M2 on connecting main sewer. Further balloons can block all inlets to the manhole M1.

Rubber balloons, manufactured by VAPO, UPONOR, MULLER, etc., are used. The dimensions of the balloons are selected in correspondence with the dimensions of the examined piping.

d) Filling main sewer and HC pipes with clear water.

e) Measurement of volume per time at manhole M1 (see *Fig.2)* - observing decrease of water level:
the pipe is filled with water from a tank up to an overpressure of 0.01 MPa or 1.0 m of water high in the inspection manhole (maximum).

If the tested segment is subject to leakage, a drop in water level can be observed over a period of time. The decrease can be observed directly in the inspection manhole M1.
The duration of the test is usually from 30 to 60 minutes. The test should be repeated minimally once. Before repeating the test, the balloons are released and the tested segment is flushed and prepared for repetition of the test. The time for repeating of the test are set in accordance with the condition of the pipe and the quantity of potentially leaking wastewater. The second measurement concludes the inspection (deflation of the sealing balloons, flushing of the pipe and evaluation of the results). Rerun time of the second measurement depends on a local condition, e.g. on saturation rate of soil environment. In the case of extensive damage of the HC, the duration of the test may be shortened.

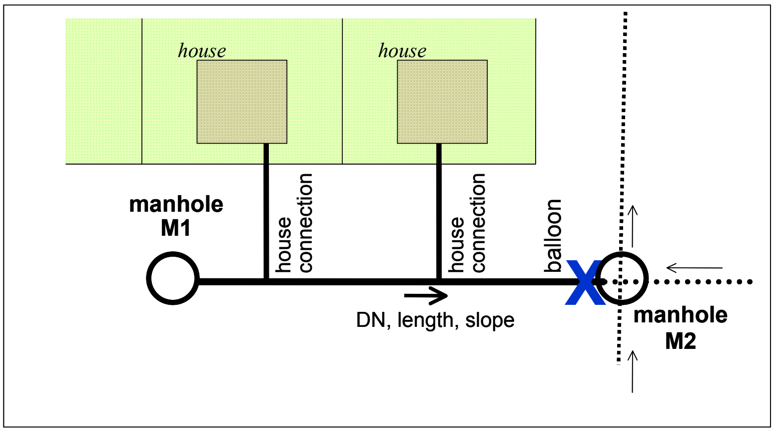

Fig. 2 : *Example - Layout of the experimental site. Measurement of the two HC pipes and connecting sewer*

6.1.3. Evaluation amount of exfiltration

The leaked amount is calculated as the change in volume, ΔV, (calculated from the water level decrease) over time Δt for different water levels. The resulting value can be recalculated per metre of the HC length or per number of joints, using equations and procedures mentioned in *Part I.*