The purification performance of infiltration basins fitted with pretreatment facilities: a case study

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Abstract In the south-east of France, the evacuation of stormwater by infiltration into the ground is being developed for large aquifer systems such as the ground water in the Rhône valley and in the eastern part of Lyons. A study proposal has been presented to the water management department of the conurbation of Lyons, aimed at quantifying, within a reasonably short space of time, the effects, in terms of transport of pollutants, of the stormwater infiltration system in the underground water in eastern Lyons. To this end, a one year duration experiment was carried out on the Vénissieux infiltration basin which drains stormwater from a 380 hectares industrial catchment area. Its peculiar configuration also made it possible to acquire new knowledge on the qualitative operation of a few pretreatment facilities. After describing the operation of the basin and the experimental protocol, we shall present a body of data that we monitored and our conclusions about the behaviour of the pollution throughout the facilities. Then, we present methods used to assess the pollution removal performance of the infiltration basin and its pretreatment devices, the results obtained, and our conclusions about the impact of the infiltration basin on groundwater and soil.
Keywords Best management practices; experiment; infiltration; pollutant removal performance; urban drainage

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Introduction

For several years, the water management department of the conurbation of Lyons had wished to know the impact on soil and groundwater (in terms of pollution) of its stormwater infiltration systems. The water management department decided, to begin with, to focus its attention on one particular infiltration basin, namely that of the industrial estate of Venissieux, where incoming water is probably the most polluted, and which is fitted with pretreatment facilities. In order to estimate the impact of this infiltration basin and to improve knowledge about the qualitative functioning of its facilities, a one year experiment was carried out in 1995. The object of this paper is to present the experiment, the methods used in order to assess the performance of the facilities, and the main results obtained.

Site description

The Venissieux basin was built in 1975. From 1975 to 1988, the structure only consisted of an infiltration basin of 80,000 m^3 over 2 hectares. The bottom of the structure was covered with a geotextile which was covered with a forty-centimetre layer of sand. The structure was divided into two basins in 1988, the first one comprising a settling impervious area of 1.1 ha and the second one comprising an infiltration area of 0.9 ha. The volume of each basin is about 40,000 m^3. The geotextile and the sand of the infiltration basin were removed in 1990 and respectively replaced by a new geotextile and a fifty-centimetre layer of gravel. The Vénissieux basin drains stormwater from a 380 ha catchment area whose imperviousness coefficient is about 43%. The utilisation of the site can be defined as: industrial: 77%, agricultural: 20%, housing: 3%. The groundwater is situated between 3 and 5 metres beneath the bottom of the infiltration basin.

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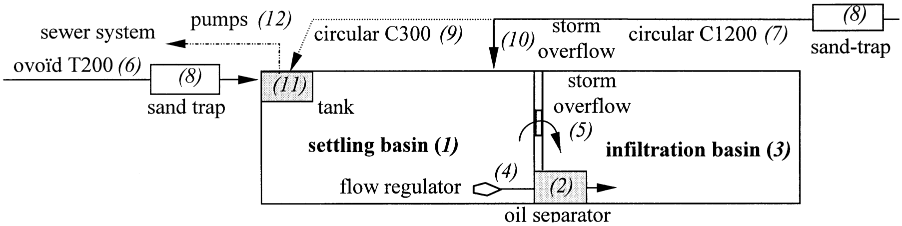

Figure 1 Operation of the Vénissieux basin since 1988

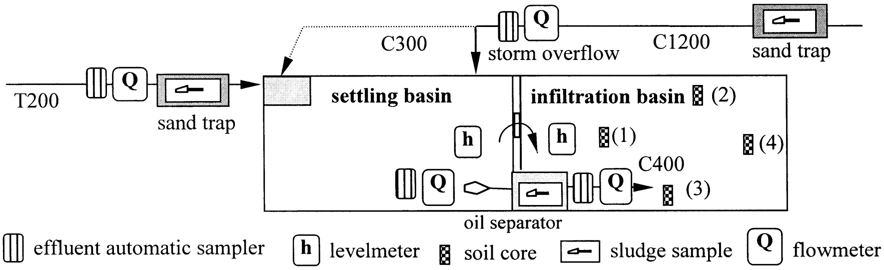

Figure 2 Experimental protocol used for the Vénissieux basin

Operation of the Vénissieux basin since 1988

Stormwater arrives in the basin via an ovoid pipe T200 (6) and a circular pipe C1200 (7) from a separate storm sewer system. Any effluent first passes through two sand traps (8) before entering the basin (see Figure1). In dry weather, some industrial waste water sometimes arrives via this system and is returned to the sewage system by pumps (12). This water arrives either directly from the ovoid pipe or from the circular pipe C300 (9). Dry weather effluents are temporarily stored in a tank (11) just upstream from the pumping system. In wet weather, the waste water contained in the tank mixes with pluvial effluents before entering a settling basin (1). Some pluvial effluents enter the settling basin directly by a stormwater overflow (10). The water of the settling basin passes through a flow regulator (4), an oil separator (2), an infiltration basin (3), and via a storm overflow system (5) when the basin is full.

Metrological follow-up in 1995

The program of experiment was carried out according to the initial objectives of the study (INSA Lyon and SPACE, 1996). These objectives were (see Figure 2) as follows:

- To establish a diagnosis of the "current" functioning of the basin, using quantitative and qualitative (pollution) flow measurements. To this end, inflows and water levels in the basins were measured continuously. In addition, automatic samplers were used at each inlet of the settling basin, at the outlet of the settling basin (upstream of the oil separator), and at the inlet of the infiltration basin (downstream of the oil separator). Thanks to this equipment, 7 storm events were subject to pollution analyses.
- To report on the "long-term" functioning of the pretreatment facilities (settling basin, oil separator, sand traps) during a several months period of their operation. For this purpose, pollution analyses were carried out on the residue removed from the facilities during their cleaning process.
- To report on the "long-term" functioning of the infiltration basin during a 6 year period (1990–1995) of its operation. For this purpose, core samples (analyzed stratum by stratum) were taken in the infiltration area, so as to estimate the accumulation of pollutants in the ground. The soil in the infiltration basin was analyzed in the gravel (0–0.5 m). The

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Table 1 Total event mean concentrations measured at inlets and outlets of the basins

	Event no. 1			Event no. 2			Event no. 3			Event no. 4			Event no. 5			Event no. 6			Event no. 7		
	I	**SB**	**IB**	**I**	**SB**	**IB**	**I**	**SB**	**IB**	**I**	**SB**	**IB**	**I**	**SB**	**IB**	**I**	**SB**	**IB**	**I**	**SB**	**IB**
SS mg/l	39	21	21	64	57	71	64	47	38	51	23	21	128	35	50	37	15	13	135	43	/
Zn µg/l	177	<5	162	327	329	294	262	282	256	267	266	209	681	433	451	303	266	265	126	160	/
Cu µg/l	16	11	13	36	27	29	21	15	14	15	13	12	49	23	23	9	9	10	7	8	/
Pb µg/l	17	13	11	34	17	0.0	24	14	12	<5	<5	65	90	36	42	9	<5	<5	<5	5	/
COD mg/l	41	22	24	28	43	13	101	52	36	43	40	42	126	63	63	47	45	41	/	28	/
oils µg/l	294	664	692	53	262	276	<50	63	<50	<50	<50	<50	1497	1060	858	597	1413	1257	92	92	/

I:settling basin inlet ; / : not analyzed; SB: settling basin outlet (separator inlet); IB: infiltration basin inlet (separator outlet)

Table 2 Results of the analyses of the residue from the sand-traps, the settling basin and the oil separator

		T200 sand-trap	**C1200 sand-trap**	**Settling basin**		**Oil separator**
Cleaning date		**13/10/95**	**13/10/95**	**23/11/94**	**13/10/95**	**23/02/95**
Operation period of the system		**6 months**	**6 months**	**12 months**	**11 months**	**4 months**
Zn	(g/t dry matter)	288	224	1148	1836	168
Cu	(g/t dry matter)	39	219.5	188	230	237
Ni	(g/t dry matter)	111.6	14.2	25	42.8	27.9
Cr	(g/t dry matter)	96	41.6	57	88	61.9
Cd	(g/t dry matter)	1.9	1.95	5	5.6	5.83
Pb	(g/t dry matter)	38.5	120.8	286	338.5	342
Hg	(g/t dry matter)	0.083	0.1	/	0.45	/
Mineral oils	(g/t dry matter)	624	768	10000	6583	37660

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part of solids smaller than 2 mm, and the geotextile were analysed at sites 1, 2, 3. Four core samples, taken mechanically, to a depth of 1.5 m, were analysed at sites 1, 2, 3, 4. An historical analysis of land use, based on aerial photographs, was also carried out.

Behaviour of the pollution in the basin and its facilities

Behaviour of the pollution in the systems during a storm event

Effluent quality at input of the basin: Results are given in Table 1. The quality of inflowing water corresponds to the average of published results (Smullen *et al*., 1999; Mertz, 1999) except for zinc, which seems to be in excess, and lead, which appears scarce. Analyses were also carried out for nickel, chromium and cadmium, whose concentrations were, however, always below the detection threshold (5 µg/l).

Event pollution removal performance of the settling basin: The decrease in suspended solids (SS) due to settling was between 20 and 70%, which is less significant than the decrease obtained in flow-controlled detention basins where the water is motionless (Bachoc *et al.*, 1993). Some recent experimental studies seem to be in agreement with this result (Svensson *et al*., 1996; Zawilski, 1996). Copper and lead were also reduced to a significant extent (between 20 and 50%, except events no. 6 and no. 7 for copper); this constituted a relatively high correlation with the decrease in SS. On the other hand, it was not possible to draw any conclusion about the influence of settling on the other parameters: chemical oxygen demand (COD), and especially zinc. Lastly, concentrations of mineral oils were generally higher after settling. This result, which at first sight seems surprising, may be explained by the fact that, during rain events, highly polluted industrial wastewater stored in the pumping system tank is carried over into the settling basin.

Event pollution removal performance of the oil separator: The results do not provide any solid evidence for the purification effect of the oil separator. In fact, only one significant decrease in concentration (–20%) was observed in the case of mineral oils (event no. 5). Copper concentrations, as measured before and after the separator, were very similar; the system does not, therefore, seem to have any particular effect as regards this metal. For the other parameters, the results were too variable to lead to any conclusions. Some decreases were recorded, but also some increases. The hypothesis of a re-circulation of certain heavy metals is thus not to be ruled out.

Behaviour of the pollution in the systems over a long period

Pollution trapped in the treatment facilities during a several months period of their operation. Main results are given in Table 2.

The residues were found to contain the same heavy metals as the water, but also nickel and cadmium, which were not detected in the water. This result demonstrates the cumulative effect, over a long period, of the low level contribution made by the rain.

Pollution trapped in the infiltration basin during a six years period of its operation (1990–1995): concerning the soil analyses, the results are as follows. There is no significant concentration difference between the 4 core samples analysed in the soil of the infiltration basin, whereas the core sample taken in front of the oil separator is more polluted for all metals. The mean results of the analyses are presented in Figure 3.

The solids smaller than 2 mm are seriously contaminated by heavy metals and mineral oils. There is a clear decrease in concentration when depth increases. This is surprising because the gravel is rough (between 30 and 80 mm), so we expected filtration effect to be slighter. This result shows that the suspended solids trapped in the basin gravel

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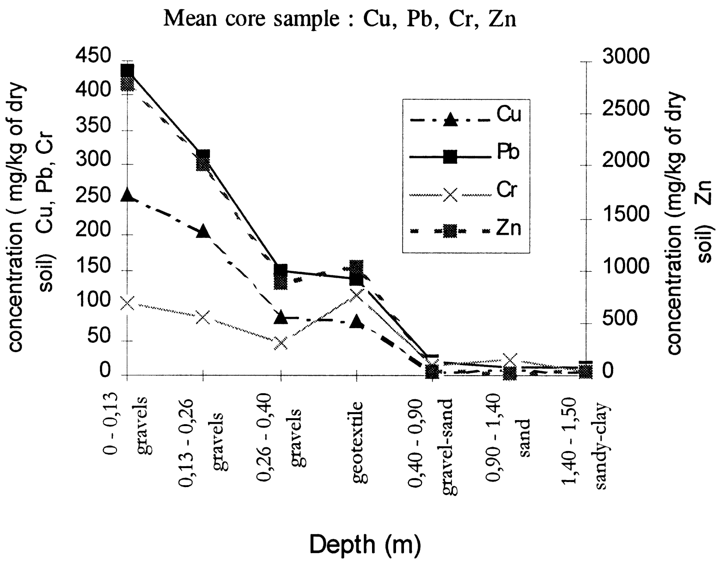
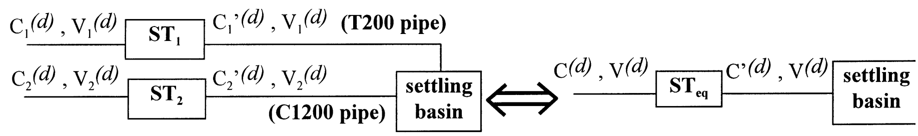


Figure 3 Pollutant concentration in the soil



$V(d)$: total runoff volume = $V_1(d) + V_2(d)$ during *(d)* $C(d)$: total mean concentration of $V(d)$ upstream of ST_{eq}
ST_{eq} : "equivalent" sand trap $C'(d)$: total mean concentration of $V(d)$ downstream of ST_{eq}

Figure 4 Notations used to assess the mean pollution removal performance of the sand traps

have an important adsorption capacity. In this basin, chemical and biological filtration seem to be more effective than mechanical filtration. Beneath the geotextile, despite 20 years of infiltration, the soil has not been contaminated, with regards to the Netherland norms (Lallemand-Barres, 1995). This result either means that the whole pollution amount brought into the infiltration basin was retained above the geotextile, or that a part of this amount passed through the geotextile and was washed down by the groundwater.

"Long-term" pollution removal performance of the basin and its facilities

Estimation of the "long-term" pollution removal performance of the sand traps

We assessed the pollution removal performance of the sand traps between two cleanings, during a 6 month operation period *(d)*, which extends from 13/04/1995 to 13/10/1995.

Method: Because of a lack of certain data due to specific sampling conditions (at input, the configuration of the site constrained both sampling and flow-measurement to be conducted upstream from the T200 sand-trap and downstream from the C1200 sand-trap), and instead of calculating the removal performance of each sand trap, we have chosen to express the performance of one equivalent sand trap. The assumptions are presented in Figure 4. The following notations are used:

$\overline{Ca}$: flow-weighted average concentration of inflowing effluent, calculated from the 7 storm event pollution analyses;

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Table 3 Pollution removal performance of the sand-traps during a six months operation period

SS	Cu	Pb	Zn	Mineral oils
22%	17%	11%	2%	5%

Ca: mean concentration of the total inflowing runoff volume, which would have been sampled during the period *(d)* under the same experimental conditions (this concentration is unknown).

The removal performance of the equivalent sand trap for the period (*d*) is calculated by:

$$P = (C^{(d)} - C'^{(d)}) / C^{(d)} \quad (1)$$

where $C^{(d)}$ and $C'^{(d)}$ concentrations are unknown but can be expressed theoretically as:

$$C^{(d)} = (C_1^{(d)}V_1^{(d)} + C_2^{(d)}V_2^{(d)}) / (V_1^{(d)} + V_2^{(d)}) \quad (2)$$

$$C'^{(d)} = (C_1'^{(d)}V_1^{(d)} + C_2'^{(d)}V_2^{(d)}) / (V_1^{(d)} + V_2^{(d)}) \quad (3)$$

In Eqs. (2) and (3), $V_1^{(d)}$ is the measured runoff volume in the T200 pipe during the (d) period, $V_2^{(d)}$ is the measured one in the C1200 pipe during the same period, and $C_1^{(d)}$, $C_1'^{(d)}$, $C_2^{(d)}$, $C_2'^{(d)}$ are unknown concentrations.

The mean concentration *Ca* can theoretically be expressed as:

$$Ca = (C_1^{(d)}V_1^{(d)} + C_2'^{(d)}V_2^{(d)}) / (V_1^{(d)} + V_2^{(d)}) \quad (4)$$

According to Eqs. (2) and (3) and by using Eq. (4), $C^{(d)}$ and $C'^{(d)}$ can finally be expressed as:

$$C^{(d)} = Ca + (C_2^{(d)} - C'_2{}^{(d)})(V_2^{(d)}) / (V_2^{(d)} + V_1^{(d)}) \quad (5)$$

$$C'^{(\mathrm{d})} = Ca - (C_1^{(d)} - C'_1{}^{(d)})(V_1^{(d)}) / (V_2^{(d)} + V_1^{(d)}) \quad (6)$$

In Eqs. (5) and (6), $C_1'^{(d)} - C_1'^{(d)}$ and $C_2^{(d)} - C_2'^{(d)}$ are assessed by using the runoff volumes $V_1^{(d)}$ and $V_2^{(d)}$ and some measurements in the sludge removed from the sand-trap after the period *(d)*, such as pollutant concentration, volume of sludge, water content, and density of the dry matter.

In Eqs. (5) and (6), the concentration *Ca* is supposed to be equal to $\overline{Ca}$. This assumption is naturally open to criticism. From a statistical point of view, the quantitative characteristics (runoff volume) of the 7 analyzed events are comparable overall with those of events which occurred during the *(d)* period, but in qualitative terms (concentrations in pollutants), their representativeness is difficult to judge.

Results: these are given in Table 3. The mean removal performance of the sand-traps during 6 months is very low for heavy metal and mineral oils, and fairly low for suspended solids. These results tend to confirm that these pretreatment devices trap primarily coarse solids which also are the less polluted (Dartus *et al.*, 1990).

Estimation of the "long-term" pollution removal performance of the settling basin

The "long-term" removal performance of the settling basin, for a year including *n* rain events, is defined as:

$$P = 1 - \left(\sum_{i=1}^{n} Cs_i \cdot V_i \right) \Bigg/ \left(\sum_{i=1}^{n} Ce_i \cdot V_i \right) \quad (7)$$

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V_i: runoff volume brought to (and purged from) the basin for the event *(i)*.
Ce_i and Cs_i: event mean concentration of V_i, respectively, at the inlet and at the outlet of the basin.

Method: For suspended solids (SS) and a few usually specific particle pollutants (Cu, Pb, Zn), Ce_i and Cs_i were assessed by a simple modelling (for more details about modelling, see Bardin, 1999):

- V_i is modelled by using a constant runoff coefficient: $V_i = C.(hp_i - I).S$ (S: catchment area; C: runoff coefficient; hp: precipitation depth; I: initial losses). The model is calibrated on the runoff volumes V_i measured at the inlet of the basin and the precipitated heights hp_i measured on the catchment area for 98 storm events in 1995. The precipitation depths used were obtained by taking the average of the depths measured by two pluviometers situated 1.5 km from the centre of the catchment basin.
- Ce_i is assumed to be a random variable with a lognormal probability distribution (Torno *et al.*, 1986) deriving from the 7 concentrations measured at the inlet of the settling basin. The Monte-Carlo method (stochastic process) is necessary to associate V_i and Ce_i. This log-normal distribution is a "maximalist" one, i.e. it takes into account the fact that the measured concentrations underestimate real concentrations (problems with the position of the strainer on the invert of both T200 and C1200 pipes, its orientation with respect to the line of flow, sampling hose length and reduced suction speed all tend to lead to *Cei* concentrations being underestimated for suspended solids and specific particle pollutants (De Heer, 1992)).
- Except for Zn, Cs_i is modelled as $Cs_i = K(Ce_i)^{\lambda}(Ti)^{\mu}$ where T_i is the retention time of the effluents in the settling basin (defined as the time separating the beginning of filling and the end of emptying of the basin). The model is calibrated on measurements of *Ce*, *Cs*, *T*, corresponding to the 7 analyzed events. T_i is modelled as $T_i = A(V_i)^b(D_i)^c$ where D_i is the dry period before the event. The model is calibrated on measurements of *T*, *D*, and on volumes modelled for 28 events of hydraulic operation of the basin in 1995, and it is validated on 25 events of hydraulic operation of the basin.

Results: For the period 1990–1995, the yearly pollution removal performance of the settling basin is the following one (see Table 4).

The number of analyzed events being insufficient to carry out an individual validation of the qualitative models used to estimate the performance of the basin, certain data not used in modelling were exploited to try to validate overall the results obtained. Two approaches were taken to this end:

- the first one consists in a comparison of the annual amounts of suspended solids trapped in 1994 and 1995 in the basin (estimated by the modelling) to the amounts of suspended solids removed from the basin during the annual cleaning processes (estimated from data provided by the water management department of the conurbation of Lyons). The Table 5 shows that the variation is lower than 16%;
- the second one is a comparison of the real (measured) concentrations in heavy metals of the sludge accumulated in the settling basin in 1994 and 1995, with the "virtual"

Table 4 Yearly pollution removal performance of the settling basin (%) between 1990 and 1995

SS	COD	Cu	Pb	Zn
74 – 79	50 – 55	48 – 55	54 – 60	30

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Table 5 Amount of solids yearly trapped in the settling basin: comparison between models and measurements results

	1994	1995
Models	36.2 t	40.7 t
Measurements	37.7 t	48.3 t

Table 6 Concentrations in heavy metals of solids trapped in the settling basin: comparison between models and measurements results

	1994			1995		
	Pb	Cu	Zn	Pb	Cu	Zn
Virtual concentration of the sludge (g/t d.m.)	245	190	1512	251	191	1789
Measured concentration of the sludge (g/t d.m.)	286	188	1148	338	230	1836

Table 7 Pollution removal performance of the infilration basin during 1990–1995

	Pb	Cu	Zn
Mi (kg)	46	35	715
Mp (kg)	27	17	177
P = *Mp* / *Mi*	59%	48%	25%

concentrations. Virtual concentrations are defined as the ratio of the metal amount trapped with the amount of suspended solids trapped, estimated by the models. The variation is lower than 30% (see Table 6).

Variations are reasonably low, about the same range order as uncertainty impairing measurements. However, before drawing any conclusion about modelling confirmation, it is necessary to improve the reliability of data and to validate the modelling method on other settling basins.

Estimation of the "long-term" pollution removal performance of the infiltration basin

The "long-term" heavy metal removal performance of the infiltration basin, during the 1990–1995 period, was calculated by:

$$P = Mp / Mi \qquad \text{with} \qquad Mi = Me\,(1-\theta) \tag{8}$$

Mi: amount of heavy metal brought into the infiltration basin during 1990–1995
Mp: amount of heavy metal accumulated in the soil of the infiltration basin during 1990–1995
Me: amount of heavy metal purged from the settling basin during 1990–1995
θ: heavy metal removal performance of the oil-separator during 1990–1995

Method: Mp was calculated from the amount of heavy metal accumulated in the gravels and in the geotextile. Contents of metals in the soil under the geotextile, being lower than the Dutch standards for contaminated grounds (Lallemand-Barres, 1995), were not taken into account in the calculations. *Me* was calculated from the amount of heavy metal brought into the settling basin during the 1990–1995 period and its purification performance (see above). Assuming the 7 storm events analyzed during the experiment to be representative (in terms of volume and pollution) of the *n* storm events during 1990–1995, the "long-term"

$$\theta = 1 - \left(\overline{Cs} / \overline{Ci}\right) \tag{9}$$

pollution removal performance of the oil separator was calculated as:
where $\overline{Ci}$ and $\overline{Cs}$ are, respectively, the flow-weighted total mean concentrations at the inlet and at the outlet of the oil separator, calculated on the basis of the 7 storm events analyzed.

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Results: these are given in Table 7. Performances estimated for the two basins (settling and infiltration) are very close. This can be the sign of an analogy of long-term behaviours of these metals in the two basins, which could be explained by the clogging of the ground making the infiltration basin increasingly tight.

The removal performance of the infiltration basin is assessed to a fairly low value for lead, copper, and zinc (from 25% to 59%). This result suggests that a significant amount of these heavy metals passed through the geotextile during the 1990–1995 period. But in addition, contents of these metals in the soil under the geotextile of the infiltration basin are lower than the Dutch standards for contaminated grounds (Lallemand-Barres, 1995). This result may be explained by the fact that the geotextile is fairly close to the water-table, making it possible to washdown heavy metals contained in the soil beneath the geotextile. However, regarding uncertainties due to both measurements and models (see Bardin, 1999) used to calculate the removal performance of the infiltration basin, it is advisable to maintain the greatest prudence in this interpretation, which is for the moment only one assumption.

Conclusions

Regarding the pollution behaviour through the facilities, this study:

- confirms the fairly low effectiveness of sand-traps in capturing heavy metals and hydrocarbons;
- reveals no solid evidence for the pollutant removal efficiency of the oil-separator (increases in oil concentrations are sometimes detected, and a re-circulation of certain heavy metals is not to be ruled-out);
- reveals a cumulative effect of certain pollutants (Cr, Cd, Ni, Hg) that were not detectable in the effluent but appeared in the residues removed from the facilities;
- reveals a "long-term" removal performance of the settling basin which is significant for suspended solids, chemical oxygen demand, lead, and copper, but not really significant for zinc.

Regarding runoff infiltration impact on soil and groundwater:

- this study reveals a significant filtration effect of gravels and geotextile in the infiltration basin, though without any solid indication of the amounts of pollutants that passed through towards the groundwater.
- by assessing the "long-term" removal performance of the infiltration basin during a 6 years operation period, results tend to lead to its effectiveness in capturing heavy metals not being very significant (from 25% to 60%, depending on the heavy metal). However, regarding uncertainties that impair measurements, assumptions used in the models, and the specific close relative positions of geotextile and water-table beneath the Vénissieux infiltration basin, these results must be regarded with caution and considered with the greatest prudence.

The difficulty in conducting this kind of experiment lies in the fact that measurement is carried out in the field, in an uncontrolled environment subject to quantitatively and qualitatively highly variable interferences. It therefore would seem to be necessary, in order to draw any definite conclusions, to prolong such experimentations over long periods, so as to have more representative values. Measurement design needs to be refined and made more reliable, and the study team needs to be much more multidisciplinary, incorporating, in particular, chemists and biologists. Such is the object of the OTHU (Urban Hydrology Field Observatory) which has recently been launched. A long term experiment (10 years) will be carried out on an infiltration basin, especially designed for measurement and for operational drainage issues (OTHU, 1997).

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