

Reduction of sediment micro-pollution by means of a pilot plant

F. Petavy, V. Ruban, P. Conil and J. Y. Viau

ABSTRACT

Solutions need to be found to manage polluted (organic matter, trace elements, hydrocarbons and PAHs) stormwater sediments while complying with stringent economic and environmental requirements. The cost of transport is a relatively large part of the treatment cost for such sediments, hence the development of a pilot unit that could provide their *in situ* treatment. Seven stormwater sediments were treated by means of the ATTRISED pilot plant, based on sieving and attrition. The objective is to apply a treatment procedure by which as much clean material as possible is recovered, while the pollutants are concentrated in a small volume ready for final destruction or isolation from the environment. Application of the attrition process serves to remove fine particles and contaminants from the surface of sediments and hydrocyclone separations allow to isolate fine contaminated particles (< 60 µm). The results show that particle size separations coupled to an attrition step allow decontamination efficiencies of 76% and 70% for street sweeping and pond sediments, respectively. Although the experiments were carried out on stormwater sediments, all kinds of sediments may be treated by the ATTRISED pilot plant if the mean particle size is greater than 60 µm.

Key words | attrition, pilot plant, pollution, sediments, treatment

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INTRODUCTION

The management of polluted sediments has become a world-wide problem; each year millions of tons of sediments are dredged and a real problem arises regarding their disposal (Färm 2001). In France alone, some 5 million tons (dry weight) are dredged yearly from ponds and road ditches, 1 million tons are extracted from street sweeping and about 1.3 million tons are collected from treatment plants (Durand *et al.* 2004, 2005). However, these sediments are often polluted with heavy metals, hydrocarbons (Lee *et al.* 1997; Färm 2001; Durand *et al.* 2004, 2005) and PAHs (Durand 2003) and can present a risk for the environment and human health. Due to changes in laws and disposal in landfills becoming more restrictive, other solutions such as recycling have to be found.

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Although several studies have focused on pond sediments (Backström 2001; Clozel *et al.* 2006), managers are generally faced with a lack of knowledge of how the by-products from basins could be usefully recovered and reused. The objective of this paper is to show how sediment micro-pollution, including organic matter, heavy metals, hydrocarbons and PAHs, can be reduced by means of a physical treatment; to achieve this objective, the so-called ATTRISED pilot plant was designed, which takes into account actual technical and economic criteria. This work is part of a French project supported by the Seine-Normandy Water Authority, the French Research Ministry and the Highway Engineering Office on the characterization and treatment of stormwater sediments.

MATERIALS AND METHODS

The sediments

The experiments were carried out on polluted sediments from retention ponds and street sweeping collected in France. Seven sediments were chosen for the pilot study and Table 1 presents the selected sites. In each case about 2.5 tons of sediment were taken by means of a backhoe loader. It has to be noted that the sediment from the AhAh pond was very heterogeneous; therefore 2 sediments were distinguished: AhAh1 very fine and AhAh2 much coarser.

Chemical analysis

For the chemical analyses, all the reagents used were analytical grade reagents (Merck Suprapur or Pro Analysis). All glassware was cleaned with 10% nitric acid and rinsed with ultra-pure water. Analyses were carried out on the different fractions of the sediment. Organic matter content (as determined by weight loss at 550°C) and trace elements were determined according to AFNOR standards (1999); the detailed protocols are described in Durand (2003). Hydrocarbons were determined according to AFNOR X31-410 (1994); the extracted solvent used is the chlorofluorocarbon and the Fourier Transform-Infrared (FT-IR) spectroscopy was carried out on a Perkin Elmer Paragon 100. Polycyclic aromatic hydrocarbons (PAH) were determined according to AFNOR XP X33-012 (2000); the sediments were treated with hexane and acetone (v/v) in a soxhlet to extract lipids. The solvent was evaporated and removed with hexane before to be treated on a column of sodium sulfate and aluminium sulfate. The final residue was then analysed by gas chromatography and PAH were detected by application of fluorometric detector. The Quality Assurance procedures

currently used in the Division for Water and Environment from LCPC were applied, covering preparation of samples for testing, performing of tests, conservation of substances for testing and archiving. Quality is also monitored by blank tests, an internal quality check (reference solutions and materials) and an external quality check (inter-laboratory tests on water and sediments).

Principle of treatment

The objective is to apply a treatment procedure by which as much clean material as possible is recovered, while the pollutants are concentrated in a small volume ready for final destruction or isolation from the environment. It is generally admitted (Lee *et al.* 1997, Zanders 2005) that polluted particles are concentrated in the fine fractions of a sediment. However, in recent studies on pond sediments Durand (2003), Clozel *et al.* (2006) showed that the metal distribution within the sediment shows no specific heavy metal enrichment between one fraction and another. Consequently, laboratory tests were carried out to determine the feasibility of using physical processes as a means of separating chemically contaminated sediment fractions from uncontaminated sediment fractions (Petavy & Ruban 2006). Preliminary characterization showed that the highest concentration of contaminants was associated with the fine fractions of sediments (<80 µm), but the coarser fractions (80 µm–2 mm) show nevertheless high concentrations and a recovery is impossible without further treatment. Attrition tests (Figure 1) were conducted to determine whether contaminants could be removed from the particle surfaces through scrubbing actions. A production of fine particles (<80 µm) from the attrition process is noted and the pollutant concentrations in this fraction are very high (Petavy & Ruban 2006).

Table 1 | Location and characteristics of the studied sediments

	Nature	Location in France	Size (m ²)	Traffic (veh/day)
AhAh (Paris)	Retention	Crosne (Paris)	593	–
Lyon	Infiltration	A 47 (Lyon – St Etienne)	620	72,200
Flavigny (Nancy)	Retention	Flavigny sur Moselle	3,000	30,740
Cheviré (Nantes)	Infiltration	S W of Nantes	780	80,000
Bordeaux	Street sweeping	Bordeaux centre	–	–
Lille	Street sweeping	Lille centre	–	–

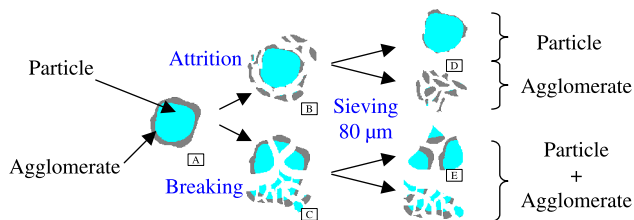


Figure 1 | Principle of attrition.

Attrition scrubbing performance and, therefore, the percentage of fine particles produced are generally studied by varying a number of parameters, including the cutoff threshold, residence time (Strazisar & Seselj 1999), solid density (Feng *et al.* 2001; Gül *et al.* 2005) and impeller speed (Shigley & Mischke 1993). Although many questions and relationships between variables remain unsolved, several series of attrition tests were already performed on sand, yet sediments have never been studied.

The pilot plant

Preliminary laboratory tests were carried out and showed that attrition can be valuably used to remove fine particles coated on coarser ones. It was therefore decided to design a pilot plant based on sieving and attrition. The principle of the ATTRISED pilot plant is described in Figure 2.

Static screen

In order to remove the coarse debris, the materials pass over a static screen with a 30 mm aperture. The oversize fraction (>30 mm) is collected and eliminated with the domestic waste. The fraction less than 30 mm is then forwarded to a vibratory screen through a conveyor.

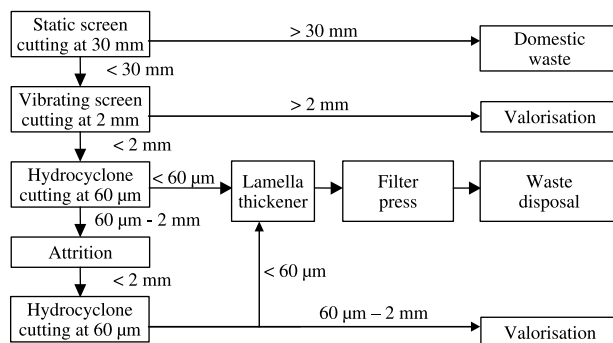


Figure 2 | Scheme of the pilot plant.

First separator

It includes two vibratory screens and a hydrocyclone. The material <30 mm is passed over a vibratory screen with a 2 mm aperture while being intensely sprayed with high pressure water sprays. The 2 mm–30 mm fraction is stockpiled without further treatment. The undersize fraction (<2 mm) is injected under a pressure of 1.5 bar into a hydrocyclone. This equipment is used for sediment with less than 20 or 25% solids to separate coarse and fine grain fractions. The size of separation is about $60\ \mu\text{m}$. The hydrocyclone overflow stream which contains the finer particles $<60\ \mu\text{m}$ is steered towards the physicochemical treatment of water. The $>60\ \mu\text{m}$ fraction is therefore partially dewatered with a second vibratory screen ($60\ \mu\text{m}$ aperture) before being introduced into the attrition scrubber.

Attrition equipment

This machine has two cells each with a vertical tree and three levels of stirring paddles supplied by an electric engine of 3 kW.

Second separator

It includes a hydrocyclone to separate the fine particles produced during the attrition and a vibratory screen to dewater the hydrocyclone underflow stream which contains the coarser particles ($>60\ \mu\text{m}$). The treated sediments ($>60\ \mu\text{m}$) are collected at the exit of the vibratory screen. As for the first separator, the fine particles are treated with the overflow stream by a physicochemical treatment.

Water treatment

The hydrocyclone overflow streams are injected into a lamella thickener. The fine particles sediment after the addition of a flocculant. The resulting clarified water is reused within the circuit while the clarifier sludge is dewatered in a filter press.

RESULTS AND DISCUSSION

Characterization of the bulk sediment

Table 2 presents the particle size distribution (d_{10} , d_{50} , d_{90} , $\% < 63\ \mu\text{m}$) and the chemical characteristics of the studied

Table 2 | Characteristics of the studied sediments

	d10	d50 μm	d90	<63 $\mu\text{m}\%$	OM* %	THC† mg kg ⁻¹	Phe‡ $\mu\text{g kg}^{-1}$	Cr	Cu mg kg ⁻¹	Pb	Zn
Cheviré	8	109	1,890	40	15.6	3,540	388	69	306	138	1,180
Flavigny	55	1,110	4,112	10	4.1	1,688	2,690	2,979	111	59	315
AhAh1	3	25	210	71	12.0	4,955	683	68	139	244	631
AhAh2	24	797	2,933	13	5.2	2,533	268	29	72	69	268
Lyon	5	47	1,970	56	10.8	794	510	74	104	148	405
Bordeaux	74	901	3,995	9	6.1	1,297	232	58	65	122	281
Lille	7	231	3,612	35	5.9	823	727	202	97	106	356
Dutch target value						50	45	100	36	85	140
Dutch intervention value						5,000		380	190	530	720

*OM: Organic Matter.

†THC: Hydrocarbons.

‡Phe: Phenanthrene.

sediments. Trace elements, hydrocarbons and phenanthrene concentrations are compared to the target and intervention values of the Dutch Standards for polluted soils used as reference (Spierenburg & Demanze 1995). Although these threshold values have no legal significance in France, they are frequently used as reference values to interpret the presence of certain substances in soils.

Particle analysis indicate that in the 4 ponds and 2 street sweeping sediments, the particle size distributions are very different. The main consequences of these heterogeneous distributions will be the percentages of each treated fraction. In contrast to Lyon and AhAh1 sediments which are very fine with 71 and 56% of particles less than 63 μm , all other sediments have a d50 higher than 100 μm and present interesting physical characteristics for this treatment. Among the studied sediments, all are contaminated by organic or inorganic pollutants. Three of them, Cheviré, AhAh1 and Lyon, have organic matter percentages higher than 10%, value required for reuse by the technical guidelines on embankment and capping layer construction (SETRA-LCPC 2003). Furthermore, the organic matter percentages must be lower than 3% for a high rank reuse (SETRA-LCPC 2003) and in the other sediments, OM concentrations range from 4.1 (Flavigny) to 6.1 (Bordeaux street sweeping). Bulk sediments also have very high hydrocarbon concentrations ranging from 794 mg kg⁻¹ for Lyon to 4,955 mg kg⁻¹ for AhAh1 sediments. Furthermore, HAP, and especially phenanthrene concentrations, are also studied in the bulk sediments and their concentrations are

largely higher than the Dutch Standard (45 $\mu\text{g kg}^{-1}$). Most of the sediments also have high metal concentrations. The Cheviré sediments are heavily contaminated with trace elements, especially with copper (306 mg kg⁻¹) and zinc (1,180 mg kg⁻¹) whose concentrations are higher than the Dutch Standard intervention values. The Flavigny pond is very contaminated with chromium (2,979 mg kg⁻¹) whose concentrations are 8 times higher than the Dutch Standard intervention values. Lyon sediments are less polluted, yet copper, nickel, lead and zinc concentrations lie between the target and intervention values. The street sweeping sediments are also contaminated with trace elements, specially Lille sediments with all metal concentrations lying above the target values.

Pilot plant treatment

Although 7 sediments were treated, the results presented here will concern 2 sediments only, one from the Cheviré infiltration pond in Nantes and one from street sweeping in Lille.

Solid mass balances

Four main fractions are extracted from the pilot plant (Figure 2) according to their particle sizes: > 30 mm, 2 mm – 30 mm, 60 μm – 2 mm and < 60 μm . The solid mass balances of each fraction for Cheviré and Lille sediments are presented in Figures 3 and 4.

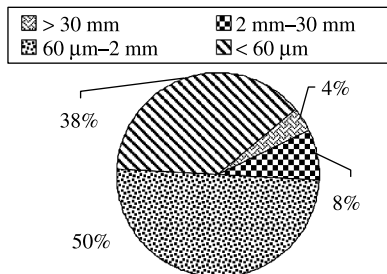


Figure 3 | Solid mass balances of each fraction from Cheviré sediments.

The screen oversize product (> 30 mm) consists of plastic bottles, wood fragments, pebbles etc... This fraction, which makes up a small part of the samples with 4% for Cheviré and 2% for Lille sediments, will be collected and eliminated with the domestic waste without physical and chemical characterizations. The < 60 µm fraction resulting from the treatment of the process water amounts to 38% for Cheviré and 22% for Lille. In their laboratory studies Petavy & Ruban (2006) show that this fraction is heavily polluted and will be landfilled. The 2 mm–30 mm and the 60 µm–2 mm fraction which amounts to 58% for Cheviré and 76% for Lille by weight of the sediment, may be reused, if their chemical, environmental and geotechnical characteristics are in agreement with the different use requirements.

Characterization of the treated fractions

Our objective is to study the micro pollution distribution between the different treated fractions in order to isolate polluted fractions and reuse clean fractions. Except for the > 30 mm fraction considered as a domestic waste, organic matter (OM), hydrocarbon (THc), phenanthrene (Phe) and trace element concentrations are determined in the different fractions resulting from the sediment treatment (Figures 5 and 6).

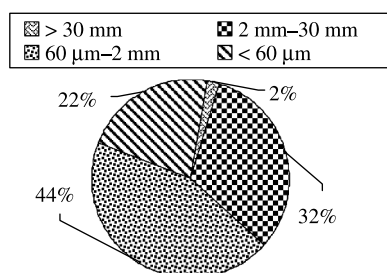


Figure 4 | Solid mass balances of each fraction from Lille sediments.

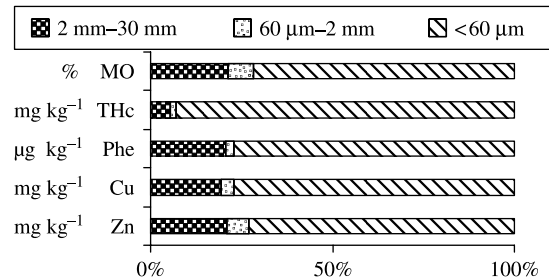


Figure 5 | Micro-pollution distribution in the treated fractions from Cheviré sediments.

As can be seen from Figures 5 and 6, physical treatment allows a drastic decrease in micro-pollutant concentrations in the 2 mm–30 mm and 60 µm–2 mm fractions, while the pollutants concentrate in the finest fraction less than 60 µm. Indeed, the < 60 µm fraction is heavily polluted with organic matter percentages ranging from 16.5% for Lille to 25.2% for Cheviré, high concentrations of hydrocarbon and phenanthrene with 1,318 mg kg⁻¹ and 964 µg kg⁻¹, respectively for Lille sediments and 6,431 mg kg⁻¹ and 691 µg kg⁻¹, respectively for Cheviré sediments. Furthermore, trace element concentrations are also very high with for example, 2,275 mg kg⁻¹ of zinc for Cheviré and 222 mg kg⁻¹ of copper for Lille sediments. If the fraction less than 60 µm must be landfilled, the two other fractions are largely decontaminated and may be reused in case the geotechnical characteristics are good. The 60 µm–2 mm fractions for Cheviré and Lille sediments are largely decontaminated with 108 and 308 mg kg⁻¹ of hydrocarbons, 20 and 323 µg kg⁻¹ of phenanthrene, respectively. Furthermore, the low trace element concentrations are within acceptable limits (Baize 1997) and the organic matter percentages lower than 3% are compatible with a high rank reuse (SETRA-LCPC 2003). As for the 60 µm–2 mm fractions, the 2 mm–30 mm fractions are largely decontaminated and more specially for Lille sediments with

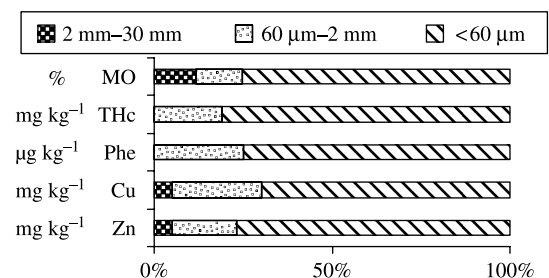


Figure 6 | Micro-pollution distribution in the treated fractions from Lille sediments.

16 mg kg⁻¹ of copper, 58 mg kg⁻¹ of zinc and 2.6% of organic matter which allow a high rank reuse. For Cheviré, in spite of an important reduction of the pollution between the bulk sediment and the 2 mm–30 mm fraction (7.5% OM versus 16%; 383 mg kg⁻¹ of hydrocarbons versus 3540; 20 µg kg⁻¹ of phenanthrene versus 388 and 650 mg kg⁻¹ of zinc versus 1,180), the organic matter percentage is higher than 3% and this fraction can be only reused in case of non stringent uses.

Attrition step performances

A sample of the 60 µm–2 mm fraction was taken before the attrition equipment (60 µm–2 mm B) and the pollutant concentrations are determined in order to study the efficiency of this step (Figures 7 and 8). According to laboratory tests (Strazisar & Seselj 1999; Bayley & Biggs 2005; Petavy & Ruban 2006), attrition scrubbing performances are interesting in order to remove further contaminant coatings and isolate polluted fine particles. In this study, the difference between the 60 µm–2 mm fraction before (60 µm–2 mm B) and after (60 µm–2 mm A) the attrition step is particularly remarkable. For the Cheviré sediments (Figure 7), organic matter drops from 6.3 to 2.5%, hydrocarbons and phenanthrene concentrations are 108 mg kg⁻¹ and 20 µg kg⁻¹, respectively, whereas they are 851 mg kg⁻¹ and 186 µg kg⁻¹ before attrition step. Trace element concentrations also indicate the large effect of the attrition equipment in sediment pollution control. For Lille sediments (Figure 8), the attrition effect on the pollutant concentrations is less important than for the Cheviré sediments. Indeed, for Lille sediments, the percentages of micro-pollution reduction ranges from 10% for copper to 60% for phenanthrene whereas this

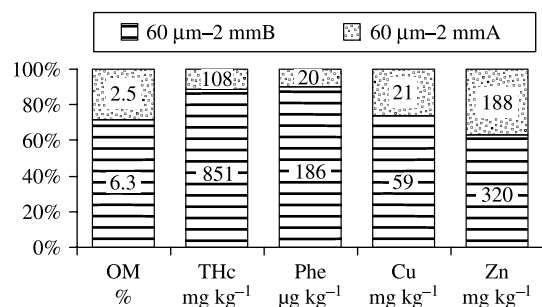


Figure 7 | Micro-pollution distribution in the treated fractions from Cheviré sediments.

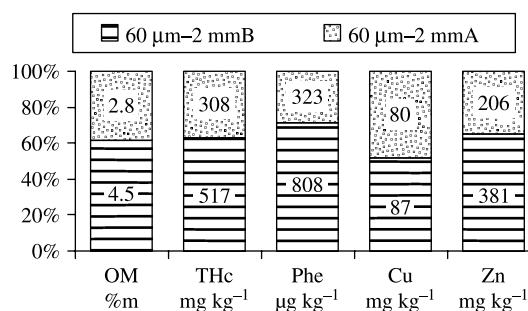


Figure 8 | Micro-pollution distribution in the treated fractions from Lille sediments.

percentage varies from 40% for zinc to 90% for hydrocarbons and phenanthrene in the case of Cheviré sediments. Although the attrition step allows to remove pollutants, the effect depends on the quantity of agglomerated fine particles in the 60 µm–2 mm fractions.

Possibilities of reuse

Among the 4 fractions extracted from the pilot plant, 2 will be either eliminated as domestic waste (>30 mm) or land-filled (<60 µm). Seven sediments were treated, resulting in 14 fractions (60 µm–2 mm and 2 mm–30 mm for each sediment), it appears that up to 70% of a sediment can be reused after the proposed treatment. Geotechnical tests based on the recommendations of the technical guidelines on embankment and capping layer construction (SETRA-LCPC 2003) were also carried out on the treated fractions. Among the 14 treated fractions, a high rank reuse as road embankments or capping layers will be possible for 7 fractions. For organic matter content comprised between 3 and 10% (5 fractions), a recovery will be only possible as pipe embankments. Only 2 fractions do not comply with the guidelines because their OM concentrations are too high (>10%). In a context of sustainable development, these treated sediments are a valuable source of material, likely to answer to the strong demand for embankments.

CONCLUSION

This study shows that stormwater sediments, i.e. pond and street sweeping sediments, can valuably be processed by means of a physical treatment. A pilot plant based on screening and attrition was designed, which concentrates

metallic and organic pollutants in the fine particles allowing the reuse of the coarse, unpolluted fractions.

These results are most encouraging, which lead us to collaborate with industrial partners for the development of a mobile treatment plant based on the principles of ATTRISED pilot unit. The constant changes in environmental laws and disposal in landfills becoming more restrictive, sediment treatment by means of a mobile unit appears quite promising and competitive with regard to the solutions actually proposed (incineration, landfill).

Sediment treatment is a wide problem largely exceeding stormwater and the ATTRISED process could be used for the remediation of river dredging sediments or sediments from sewer networks. Finally, the results of this innovative research could be used to prepare a technical guide aimed at helping managers with the treatment and reuse of stormwater sediments.

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REFERENCES

- AFNOR X31-410 1994 Soil quality—Determination of mineral oil content—Method by infrared.
- AFNOR X33-012 2000 Characterisation of sludge—Determination of polynuclear aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB).
- AFNOR 1999 *Association Française de Normalisation (AFNOR), Qualité des sols (Soil Quality) 1, 2*. AFNOR, Paris, France.
- Backström, M. 2001 Particle trapping in grass swales. In: *Proceedings 4th International Conference NOVATECH*, **1**, 391–398.
- Baize, D. 1997 *Teneurs totales en éléments traces métalliques dans les sols (Total contents of trace metal elements in Soils)*, report for INRA, Paris, France.
- Bayley, R. W. & Biggs, C. A. 2005 Characterisation of an attrition scrubber for removal of high molecular weight contaminants in sand. *Chem. Eng. J.* **111**, 71–79.
- Clozel, B., Ruban, V., Durand, C. & Conil, P. 2006 Chemical and mineralogical assessment of the origin and mobility of heavy metals (Cd, Zn, Pb, Cu, Ni, Cr) in contaminated sediments from retention and infiltration ponds. *Appl. Geochem.* **21**, 1781–1798.
- Durand, C. 2003 *Caractérisation physico-chimique des produits de l'assainissement pluvial. Origine et transfert des métaux traces et des polluants organiques (Physico-chemical characterization of runoff water sediments. Origin and becoming of trace metals and organic pollutants)*. PhD thesis, University of Poitiers, Poitiers, France.
- Durand, C., Ruban, V. & Amblès, A. 2004 Mobility of trace metals in retention pond sediments. *Environ. Technol.* **25**, 880–888.
- Durand, C., Ruban, V. & Amblès, A. 2005 Characterisation of the organic matter present in contaminated sediments from water retention ponds. *J. Appl. Anal. Pyrol.* **73**, 17–28.
- Färm, C. (2001). Accumulation of sediment and heavy metals in a storm-water detention pond. In: *Proceedings 4th International Conference NOVATECH, Lyon, France*. **1**, 589–604.
- Feng, D., Lorenzen, L., Aldrich, C. & Maré, P. W. 2001 Ex situ diesel contaminated soil washing with mechanical methods. *Miner. Eng.* **14**, 1093–1100.
- Gül, A., Kayataz, Y. & Önal, G. 2005 Beneficiation of colemanite tailings by attrition and flotation. *Miner. Eng.* **19**, 368–369.
- Lee, P. K., Touray, J.-C., Baillif, P. & Ildefonse, J.-P. 1997 Heavy metal contamination of settling particles in a retention pond along the A-71 motorway in Sologne, France. *Sci. Total Environ.* **201**, 1–15.
- Petavy, F. & Ruban, V. 2006 Conception of a pilot plant for the treatment of stormwater sediment. In: *Proceedings 6th international conference NOVATECH*, **3**, 1277–1284.
- SETRA-LCPC. 2003 *Technical Guidelines on Embankment and Capping Layers Construction (abbreviated to its French acronym GTR, 1992)*. Report published by LCPC under the number 51123111. Paris, France.
- Shigley, J. E. & Mischke, C. R. 1993 *Mechanical Engineering Design*. McGraw Hill, New York.
- Spienburg, A. & Demanze, C. 1995 Pollution des sols: comparaison et application de la norme hollandaise (Soil pollution: comparison and application of the Dutch standards). *Environnement et Technique* **146**, 79–81.
- Strazisar, J. & Seselj, A. 1999 Attrition as a process of comminution and separation. *Powder Technol.* **105**, 205–209.
- Zanders, J. M. 2005 Road sediment: characterization and implications for the performance of vegetated strips for treating road run-off. *Sci. Total Environ.* **339**, 41–47.