Environmental assessment of two sediments reused in road engineering: feedback after one year of monitoring through the SEDIMED project

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ENVIRONMENTAL ASSESSMENT OF TWO SEDIMENTS REUSED IN ROAD ENGINEERING: FEEDBACK AFTER ONE YEAR OF MONITORING THROUGH THE SEDIMED PROJECT

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ABSTRACT

Road engineering is one way for sediments to be reused and enter the circular economy, instead of being stored in landfill. The so-called “Guide Setra” [1] constitutes the French framework for reusing alternative materials in road engineering, including three kinds of road structures: coated (with an impervious layer), covered (with at least 30 cm of natural material) or uncoated and uncovered.

The Sedimed project investigated those three options, settling lysimeters (uncoated and uncovered) and building experimental road (coated) and landforms (covered), incorporating two marine contaminated sediments from the Toulon bay, France (QN and QC). Leachates were collected and sampled on these three experimental structures, and the pollutants (12 metals – As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn – 3 anions – Cl^-, F^-, SO_4^{2-} – 16 PAH and 3 emerging pollutants detected in the sediments – DBT, TBT and DEHP), were analyzed on every sample, enabling the determination of the total released quantity of each pollutant on a L/S basis (ratio between the volume of water that percolated through the structure and the mass of sediment in the structure).

The total content of organic pollutants of QN would normally disqualify this sediment for road engineering, according to the “Guide Setra”. Yet, only considering the potential impact on groundwater, the released quantities of pollutants are far from very protecting limits.

For both QN and QC, the anions content (Cl^- and SO_4^{2-}) exceeded the “Guide Setra” limits for some structures, indicating that the control of these parameters and the reduction of their global content during the lagooning period might be triggering the reusing options for marine sediments.

Those new data and knowledge is a contribution to the definition of a specific framework for reusing sediments in road engineering.

INTRODUCTION

The Sedimed project was conducted between 2009 and 2016 and contributed to develop new solutions for sediment management and valorization. During the project a soil and sediment treatment centrum (CPEM) was constructed in the Toulon harbour at La Seyne-sur-Mer where a separate R&D platform was established on which the full scale test plots where installed and followed up. The R&D project was financially supported by the Ademe, TPM, l’Agence de l’eau, DGE and MPM. The project was coordinated by Envisan and the other partners were INERIS, Armines, Cerema, ERG and Colas. The coordination of the scientific partners was led by Neo-Sud.

During this project, two sediments from the Toulon Bay (QN and QC) have been extensively studied, analysed and tested for reusing in road engineering, from an environmental and a geotechnical point of view.

FRAMEWORK

The “Guide Setra” was published in 2011 and aims at regulating alternative materials reusing in road engineering. Therefore, it considers three kinds of road structures: coated with an impervious layer (1), covered with at least 30 cm of natural material (2) or uncoated and uncovered (3). Depending on their total and their leachable content in pollutants, alternative materials can or not be used in a road structure.

Figure 1 presents the flow chart defined by the “Guide Setra”, with three levels of investigations: (1) total analysis and leaching test, (2) percolation test, and (3) lysimeters or pilot scale tests. A specific guidance document [2] covers this third level of investigations.

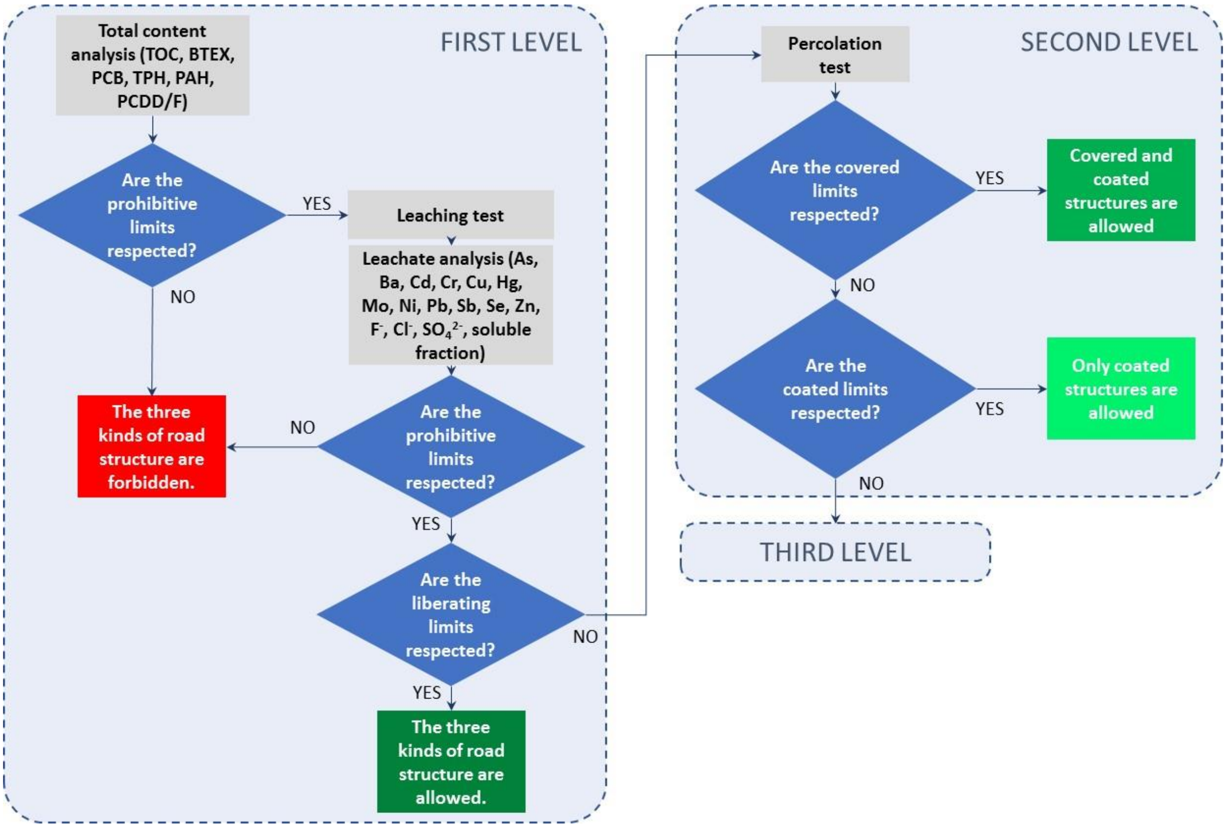

Figure 1: « Guide Setra » flow chart for the reuse of alternative materials in road engineering

For the third investigation level, the “Guide Setra” provides two types of reference values.

The first one aims at preventing from a chronic pollution, and is to compare to the cumulated amount of released pollutants during the whole duration of the pilote test. Therefore, “initial limits” – defined for the same list of pollutants as those mentioned for leachate analysis at the first level – need to be converted into a specific limit for every pilot, with the following formula:

$$specific\ limit = initial\ limit * \min\left(d\ ;\ \frac{P_{eff}}{P_{ref}}\right)$$

where : - the specific limit is given in mg/m²

- the initial limit is given in mg/m²/y
- d is the duration of the experimentation and is given in y
- P_{eff} is the effective rainfall during the experimentation and is given in mm
- P_{ref} is the yearly reference effective rainfall, and equals 100 mm/y for a coated structure and 300 mm/y for a covered or an uncoated and uncovered structure.

The second one aims at preventing from an acute pollution, and is to compare to the highest concentration in pilot eluates.

The pollutants list defined by the "Guide Setra" is supposed to be completed for each material, depending on its specificities. Considering that sediments accumulate a huge variety of contaminants, defining an appropriate list of pollutants and their associated limits remains a major challenge.

In the Sedimed project, PAH and 3 emerging pollutants were analyzed at the third level. When possible, an initial limit was proposed for those contaminants, based on regulatory values for drinking water production, without taking into account any dilution factor, that is a very conservative assumption.

MATERIAL AND METHODS

Investigated sediments

Two sediments from the Toulon Bay were chosen, representing two different types of materials with a different grain size distribution, organic matter and contamination content. The QN sediments are fine sediments extracted from a historically polluted zone whereas the coarser QC sediment was supposed to be cleaner. Both sediments were sieved and have been dewatered by lagooning before being incorporated in the experimental road and landform.

Organic pollutants scope

In addition to the "Guide Setra" pollutants, 16 PAH and 3 emerging contaminants were analyzed in the two sediments: DBT, TBT and DEHP. Those three pollutants were found both in total content and in sediments leachate.

Environmental characterization of sediments

Leaching tests were performed according to the NF EN 12457-2 standard.

Percolation tests were performed according to the NF CEN/TS 14405 standard.

Three lysimeters were set up in Aix-en-Provence. Their individual total surface was 5 m², but the inner section corresponding to the percolation area was 4.14 m². A collecting system was installed to retrieve the percolation and the run-off waters (from the inner and the outer parts of the lysimeters). Leachate collection and analysis started in June 2015 and was stopped in May 2016.

Table 1 : Lysimeter technical data

Lysimeter parameters	Witness	QN	QC
Material	Sand	Alternative material	
Settled on...	24/03/2015	22/04/2015, 06/05/2015	12/06/2015
Mat. height in lys. (m)	1	0.96	1.06
Mat. weight (kg)	5909	5538	8177
Water content (%)	0	33.5	15.6
Dry matter weight (kg)	5909	3685	6900
Dry matter in the inner section (kg) (= « S »)	4893	3051	5714

Figure 2: Three lysimeters and their percolate collecting system

Three experimental landforms were built on Envisan platform in La Seyne-sur-mer in November 2015, and covered with a 30cm layer of land. Leachate collection and analysis started in November 2015 and was stopped in September 2016.

Table 2: Landform technical data

Landform parameters	**Witness**	**QN**	**QC**
Material	Sand	Alternative material	
Mat. weight (kg)	120,320	108,000	130,00
Water content (%)	8.8	23.9	8.5
Dry matter weight (kg)	109,730	82,188	118,950
Landform surface (m²)	91.17	99.95	105.72

Figure 3: Pilot landform and its percolation collecting system

Three experimental road sections were also built on the same place in October 2015, incorporating 30% of sediments in the base layer of the road. Leachate collection and analysis started in November 2015 and was stopped in September 2016.

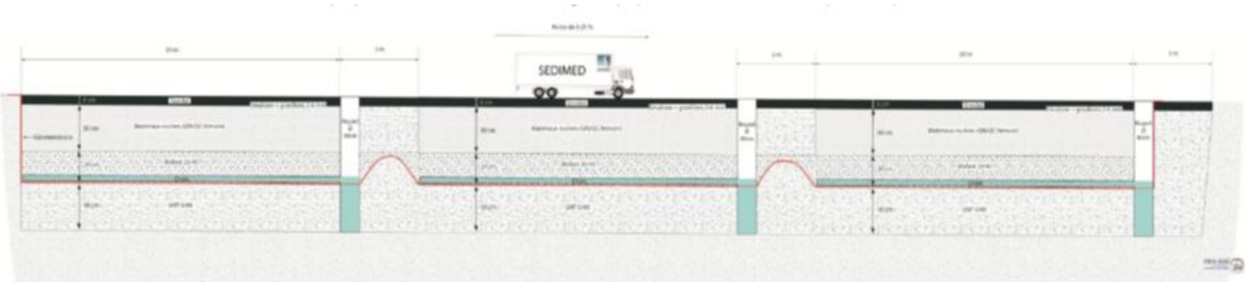

Figure 4: Scheme of the longitudinal section of the three roads

Table 3: Road section technical data

Road section parameters	**Witness**	**QN**	**QC**
Material	Sand	Road mat. incorporating 30% of alt. mat.	
Mat. weight (kg)	54,380*0.3 = 16,314	15,000	16,000
Water content (%)	5.0	12.4	6.6
Dry matter weight (kg)	15,498	13,137	14,938
Road surface (m²)	70	70	70

RESULTS

The analytical results from the different levels of “Guide Setra” applied on QN and QC are presented below. For levels 1 and 2, units are pH units for pH, ng/kg DM for PCDD/F and mg/kg DM for the other parameters. Field colours indicate where limits are exceeded.

- Level 1

Table 4: « Guide Setra » level 1 results for QC and QN

	QC				QN				Guide SETRA limits			
	Raw mat.	Alternative mat.		Road mat.	Raw mat.	Alternative mat.		Road mat.	Liberating limit to be respected by …% of samples			Prohi-bitive limit
		mid-2015 (lys.)	end of 2015 (landf.)			mid-2015 (lys.)	end of 2015 (landf.)		80%	95%	100%	
Total content												
TOC	5,000	5,660	6,770	14,200	59,800	88,100	103,000	35,100				30,000
∑ BTEX	<6	<0.25	<0.25	<0.25	<0.05	<0.37	< 0.25	<0.27				6
∑ 7 PCB	<0.0236	<0.044		<0.07	<0.8	0.32		<0.17				1
TPH (C_{10}-C_{40})	111	184	165	60.1	3,708	7,320	4,250	1,350				500
∑ PAH	<4.45	<3.046	5.753 < < 5.853	<5.17	72.2	240	540	<116.4				50
PCDD/F (I-TEQ WHO, 2005)	0.5 < < 6.6	3.92 < < 5.43	3.5	1.26 < < 3.13		34.6 < < 35.5	31.3	7.01 < < 7.69				10
Leachate content												
pH	8.67	8.4	7.3	12.9	7.9	7.8	7.2	12.9				
As		< 0.05	<0.20	<0.02	<0.2	<0.05	<0.2	0.042	0.5	1	1.5	2
Ba		0.28	0.10	5.93	0.19	0.49	0.29	2.28	20	40	60	100
Cd		< 0.05	<0.002	<0.02	<0.002	<0.05	0.018	<0.02	0.04	0.08	0.12	1
Cr		< 0.05	<0.10	0.27	<0.1	<0.05	<0.1	0.36	0.5	1	1.5	10
Cu		< 0.1	<0.20	0.97	<0.2	0.56	0.46	7.31	2	4	6	50
Hg		< 0.002	<0.001	<0.002	0.0037	<0.002	<0.001	<0.002	0.01	0.02	0.03	0.2
Mo		0.23	0.11	0.83	0.43	0.945	0.70	3.40	0.5	1	1.5	10
Ni		< 0.05	<0.10	<0.2	<0.1	<0.05	<0.1	0.78	0.4	0.8	1.2	10
Pb		< 0.05	<0.10	0.40	<0.1	<0.05	<0.1	1.63	0.5	1	1.5	10
Sb		0.025	0.015	<0.02	0.091	0.074	0.057	<0.02	0.06	0.12	0.18	0.7
Se		< 0.005	<0.01	<0.05	0.033	0.006	<0.01	<0.05	0.1	0.2	0.3	0.5
Zn		< 0.2	<0.20	<0.5	<0.2	3.78	2.18	1.025	4	8	12	50
Fl$^-$		7.01	7.55	<5	5.86	13.8	14.5	<5	10	20	30	150
Cl$^-$		4,541	1,840	652	28,500	10,757	2,580	1,655	800	1,600	2,400	15,000
SO_4^{2-}		3,036	3,068	<59.4	4,575	16,184	19,500	916	1,000	2,000	3,000	20,000
Soluble fraction		15,726	10,800	62,701	52,375	47,105	43,800	59,468	4,000	8,000	12,000	60,000

- Level 2

Table 5: « Guide Setra » level 2 results for QC and QN

	QC		QN			Guide SETRA limits	
	Alternative mat. mid-2015 (lys.)	Road mat.	Raw mat.	Alt. mat. mid-2015 (lys.)	Road mat.	Covered limits	Coated limits
As	<0.28	<0.013	0.15	<0.5	0.040	0.5	0.8
Ba	0.24	6.77	0.17	0.58	1.61	28	56
Cd	<0.28	<0.012	<0.05	<0.5	<0.02	0.16	0.32
Cr	<0.28	0.27	0.015-0.05	<0.5	0.27	2	4
Cu	<0.55	1.21	0.2-0.22	<1.165	8.66	50	50
Hg	<0.002	<0.002	<0.002	< 0.007	<0.002	0.04	0.08
Mo	0.24	0.71	0.07	1.03	3.48	2.8	5.6
Ni	<0.28	0.16	0.05	<0.5	0.85	0.8	1.6
Pb	<0.28	0.18	<0.26	<0.5	1.46	0.5	0.8
Sb	0.02	<0.012	<0.2	0.06	<0.009	0.2	0.4
Se	<0.03	<0.024	<0.1	<0.05	<0.019	0.4	0.5
Zn	<1.1	<0.32	0.59	18.07	0.80	50	50
Fl$^-$	10.58	<5.1	8.96	21.5	<4.98	30	60
Cl$^-$	3,851.54	788	16,204	9,411	1,625	5,000	10,000
SO_4^{2-}	3,088	1557	2,437	13,535	3,024	5,000	10,000

➢ Level 3 - Lysimeters

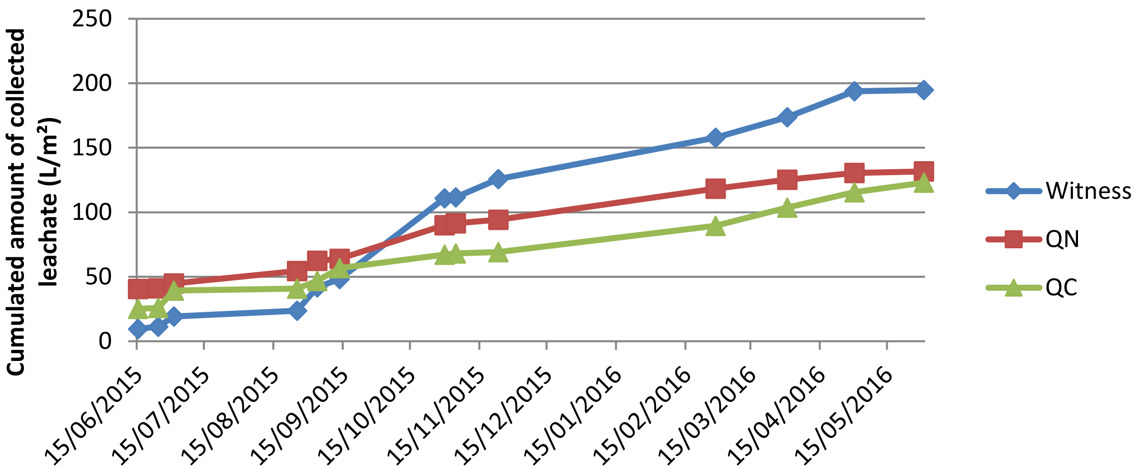

Figure 5: Cumulated amount of collected leachate in the lysimeters (L/m²)

Table 6: Cumulated amount and maximal concentration of released pollutants in the lysimeter eluates

	Chronic release							**Acute release**			
	Wit. (mg/m²)	**QC** (mg/m²)	**QN** (mg/m²)	**Initial lim.** (mg/ m²/an)	**Spec. lim. for wit.** (mg/m²)	**Spec. lim. for QC** (mg/m²)	**Spec. lim. for QN** (mg/m²)	**Wit.** (mg/L)	**QC** (mg/L)	**QN** (mg/L)	**max lim.** (mg/L)
As	3.45	1.58	1.88	10	6.5	4.1	4.4	0.05	0.05	0.05	0.3
Ba	1.63	12.16	8.65	700	455	287	308	0.0439	0.192	0.109	20
Cd	1.57	1.58	2.13	4	2.6	1.6	1.8	0.05	0.05	0.05	0.3
Cr	1.64	2.36	2.50	50	33	21	22	0.022	0.408	0.151	2.5
Cu	0.97	2.23	5.36	625	406	256	275	0.01	0.15	0.1	30
Hg	0.03	0.02	0.02	1	0.65	0.41	0.44	0.00044	0.00032	0.00034	0.03
Mo	2.84	8.46	13.23	70	46	29	31	0.04	0.0933	0.269	3.5
Ni	10.55	462.20	398.05	20	13	8.2	8.8	0.434	18	8.58	3
Pb	1.57	1.58	1.77	10	6.5	4.1	4.4	0.05	0.05	0.05	3
Sb	0.97	0.72	1.07	5	3.3	2.1	2.2	0.02	0.02	0.02	0.15
Se	0.58	0.50	0.41	6	3.9	2.5	2.6	0.01	0.06	0.01	0.2
Zn	51.25	315.45	559.69	625	406	256	275	1.91	11.3	17.3	15
F^-	235	40.85	76	750	488	308	330	1.4	0.54	0.73	40
Cl^-	32,695	1,749,754	1,344,312	125,000	81,250	51,250	55,000	1,150	20,900	11,900	8,500
SO_4^{2-}	13,359	821,963	694,607	125,000	81,250	51,250	55,000	229	8,220	7,000	7,000
Naphtalene	0.0018	0.0008	0.0009	42	27.3	17.2	18.5	0.00003	0.00003	0.00002	0.14
Acenaphthylene	0.0010	0.0006	0.0007	/	/	/	/	0.00001	0.00001	0.00001	/
Acenaphtene	0.0010	0.0006	0.0007	/	/	/	/	0.00001	0.00001	0.00001	/
Fluorene	0.0010	0.0006	0.0007	/	/	/	/	0.00001	0.00002	0.00002	/
Anthracene	0.0010	0.0006	0.0007	42	27.3	17.2	18.5	0.00001	0.00001	0.00002	0.14
Fluoranthene*	0.0010	0.0006	0.0007	0.3	0.195	0.123	0.132	0.00001	0.00001	0.00001	0.001
Pyrene	0.0010	0.0006	0.0007	/	/	/	/	0.00001	0.00001	0.00001	/
Benzo(a)a	0.0010	0.0006	0.0007	/	/	/	/	0.00001	0.00001	0.00001	/
Chrysene	0.0010	0.0006	0.0007	/	/	/	/	0.00001	0.00001	0.00001	/
Benzo(b)f *	0.0010	0.0006	0.0007	0.3	0.195	0.123	0.132	0.00001	0.00001	0.00001	0.001
Benzo(k)f *	0.0010	0.0006	0.0007	0.3	0.195	0.123	0.132	0.00001	0.00001	0.00001	0.001
Benzo(a)p *	0.0007	0.0005	0.0005	0.3	0.195	0.123	0.132	0.0000075	0.0000075	0.0000075	0.001
Dibenzo(a,h)a	0.0010	0.0006	0.0007	/	/	/	/	0.00001	0.00001	0.00001	/
Ind(1,2,3-cd)p *	0.0010	0.0006	0.0007	0.3	0.195	0.123	0.132	0.00001	0.00001	0.00001	0.001
Phenanthrene	0.0012	0.0006	0.0007	/	/	/	/	0.00002	0.00002	0.00002	/
Benzo(ghi)p *	0.0010	0.0006	0.0007	0.3	0.195	0.123	0.132	0.00001	0.00001	0.00001	0.001
∑ 6 PAH (*)	0.0056	0.0035	0.0038	0.3	0.195	0.123	0.132	0.0000575	0.0000575	0.0000575	0.001
DBT	0.0030	0.0006	0.0007	/	/	/	/	0.00013	0.000011	0.000013	/
TBT	0.0153	0.0007	0.0007	0.03	0.020	0.012	0.013	0.0009	0.000013	0.000013	0.0001
DEHP	0.1184	0.0189	0.0353	50.4	32.8	20.7	22.2	0.0048	0.0007	0.0027	0.168

- Level 3 – Landforms

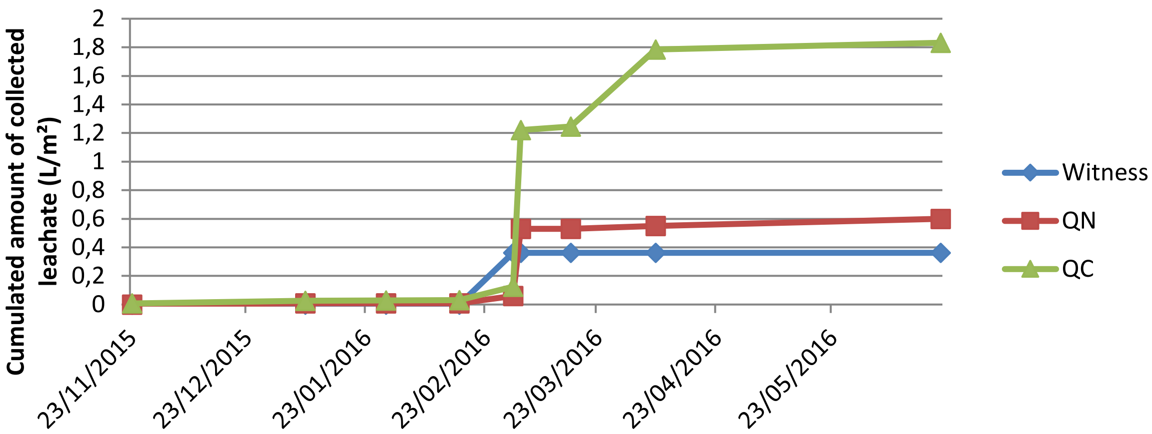

Figure 6: Cumulated amount of collected leachate in the landforms (L/m²)

Table 7: Cumulated amount and maximal concentration of released pollutants in the landform eluates

	Chronic release							Acute release			
	Wit. (mg/m²)	**QC** (mg/m²)	**QN** (mg/m²)	**Initial lim.** (mg/ m²/an)	**Spec. lim. for wit.** (mg/m²)	**Spec. lim. for QN** (mg/m²)	**Spec. lim. for QC** (mg/m²)	**Wit.** (mg/L)	**QC** (mg/L)	**QN** (mg/L)	**max lim.** (mg/L)
As	0.00090	0.0046	0.0019	10	0.01	0.0	0.1	0.005	0.005	0.008	0.3
Ba	0.024	0.15	0.042	700	1	1	4	0.067	0.09	0.076	20
Cd	0.00090	0.0045	0.0014	4	0.00	0.01	0.02	0.005	0.005	0.005	0.3
Cr	0.0022	0.0045	0.0014	50	0.06	0.10	0.31	0.006	0.005	0.005	2.5
Cu	0.0018	0.013	0.023	625	1	1	4	0.01	0.02	0.04	30
Hg	0.000036	0.00018	0.00012	1	0.00	0.00	0.01	0.0002	0.0002	0.00136	0.03
Mo	0.00090	0.011	0.018	70	0.08	0.14	0.43	0.005	0.026	0.033	3.5
Ni	0.00090	0.0045	0.0067	20	0.02	0.04	0.12	0.005	0.005	0.012	3
Pb	0.0036	0.0057	0.0024	10	0.01	0.02	0.06	0.01	0.016	0.013	3
Sb	0.0036	0.018	0.0057	5	0.01	0.01	0.03	0.02	0.02	0.02	0.15
Se	0.0018	0.0089	0.0029	6	0.01	0.01	0.04	0.01	0.01	0.01	0.2
Zn	0.011	0.020	0.50	625	1	1	4	0.03	0.03	0.96	15
F^-	0.090	0.45	0.42	750	1	1	5	0.5	0.5	0.76	40
Cl^-	33	17,533	6,350	125,000	151	250	763	90.6	14,000	11,700	8,500
SO_4^{2-}	271	7,291	2,636	125,000	151	250	763	750	7460	4750	7,000
Naphtalene	0.0000018	0.0000089	0.0000029	42	0.05	0.08	0.26	0.00001	0.00001	0.00001	0.14
Acenaphthylene	0.0000018	0.0000089	0.0000029	/	/	/	/	0.00001	0.00001	0.00001	/
Acenaphtene	0.0000018	0.0000089	0.0000031	/	/	/	/	0.00001	0.00001	0.00001	/
Fluorene	0.0000018	0.0000089	0.0000031	/	/	/	/	0.00001	0.00001	0.00001	/
Anthracene	0.0000018	0.0000089	0.0000044	42	0.05	0.08	0.26	0.00001	0.00001	0.00002	0.14
Fluoranthene*	0.0000018	0.0000130	0.0000222	0.3	0.0004	0.0006	0.0018	0.00001	0.00005	0.00019	0.001
Pyrene	0.0000018	0.0000121	0.0000184	/	/	/	/	0.00001	0.00005	0.00017	/
Benzo(a)a	0.0000018	0.0000106	0.0000134	/	/	/	/	0.00001	0.00003	0.00012	/
Chrysene	0.0000018	0.0000106	0.0000124	/	/	/	/	0.00001	0.00003	0.0001	/
Benzo(b)f *	0.0000018	0.0000140	0.0000179	0.3	0.0004	0.0006	0.0018	0.00001	0.00006	0.00016	0.001
Benzo(k)f *	0.0000018	0.0000103	0.0000079	0.3	0.0004	0.0006	0.0018	0.00001	0.00002	0.00006	0.001
Benzo(a)p *	0.0000014	0.0000103	0.0000146	0.3	0.0004	0.0006	0.0018	0.0000075	0.0000427	0.000138	0.001
Dibenzo(a,h)a	0.0000018	0.0000089	0.0000054	/	/	/	/	0.00001	0.00001	0.00004	/
Ind(1,2,3-cd)p *	0.0000018	0.0000106	0.0000119	0.3	0.0004	0.0006	0.0018	0.00001	0.00003	0.0001	0.001
Phenanthrene	0.0000018	0.0000111	0.0000114	/	/	/	/	0.00001	0.00002	0.0001	/
Benzo(ghi)p *	0.0000018	0.0000115	0.0000134	0.3	0.0004	0.0006	0.0018	0.00001	0.00003	0.00013	0.001
∑ 6 PAH (*)	0.000010	0.000070	0.000088	0.3	0.0004	0.0006	0.0018	0.0000575	0.0001954	0.000728	0.001
DBT	0.0000018	0.0000098	0.0000032	/	/	/	/	0.00001	0.000029	0.000011	/
TBT	0.0000022	0.0000127	0.0000040	0.03	0.00004	0.00006	0.00018	0.000012	0.000036	0.000017	0.0001
DEHP	0.0000543	0.0007166	0.0001916	50.4	0.06	0.10	0.31	0.0003	0.0012	0.0018	0.168

➢ Level 3 - Roads

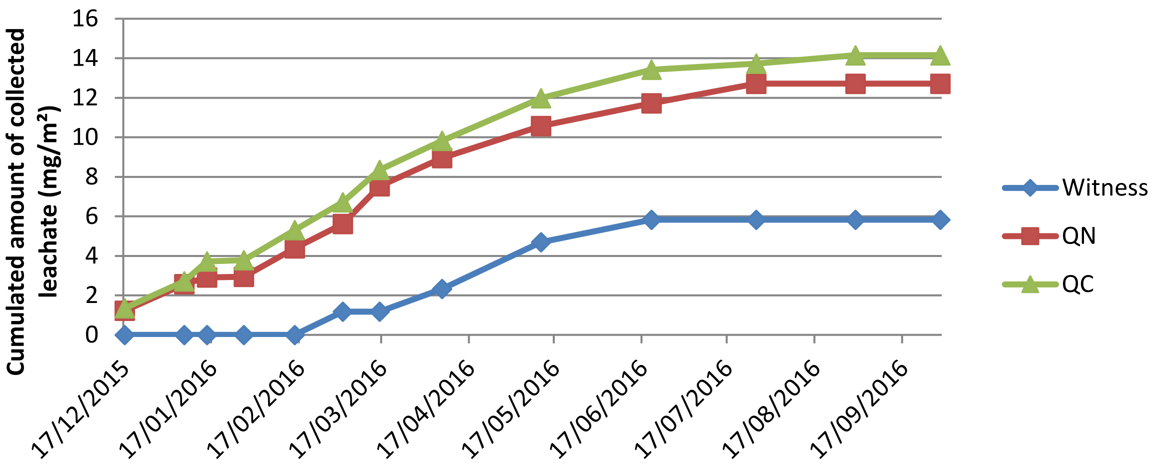

Figure 7: Cumulated amount of collected leachate in the roads (L/m²)

Table 8: Cumulated amount and maximal concentration of released pollutants in the road eluates

	Chronic release							Acute release			
	Wit. (mg/m²)	**QC** (mg/m²)	**QN** (mg/m²)	**Initial lim.** (mg/ m²/an)	**Spec. lim. for wit.** (mg/m²)	**Spec. lim. for QN** (mg/m²)	**Spec. lim. for QC** (mg/m²)	**Wit.** (mg/L)	**QC** (mg/L)	**QN** (mg/L)	**max lim.** (mg/L)
As	0.0146	0.2657	0.0762	10	0.58	1.3	1.4	0.005	0.159	0.018	0.3
Ba	0.4104	0.9989	0.8890	700	41	89	99	0.089	0.109	0.108	20
Cd	0.0146	0.0354	0.0318	4	0.23	0.51	0.57	0.005	0.005	0.005	0.3
Cr	0.0402	0.2825	0.1763	50	2.91	6.36	7.08	0.016	0.034	0.03	2.5
Cu	0.5217	1.2051	6.2335	625	36	79	88	0.38	0.14	1.58	30
Hg	0.0006	0.0014	0.0013	1	0.06	0.13	0.14	0.00021	0.00022	0.00022	0.03
Mo	0.4442	1.2770	3.6323	70	4.08	8.90	9.91	0.309	0.171	0.828	3.5
Ni	0.0395	0.1468	0.4059	20	1.17	2.54	2.83	0.024	0.02	0.1	3
Pb	0.0146	0.0354	0.0369	10	0.58	1.27	1.42	0.005	0.005	0.007	3
Sb	0.0583	0.1416	0.1272	5	0.29	0.64	0.71	0.02	0.02	0.02	0.15
Se	0.0291	0.0708	0.0636	6	0.35	0.76	0.85	0.01	0.01	0.01	0.2
Zn	0.0583	0.1710	0.2062	625	36	79	88	0.02	0.03	0.07	15
F^-	1.46	3.54	3.18	750	44	95	106	0.5	0.5	0.5	40
Cl^-	1,670	11,730	18,397	125,000	7,286	15,895	17,695	1,320	1,960	3,540	8,500
SO_4^{2-}	1,172	6,652	9425	125,000	7,286	15,895	17,695	876	1090	1350	7,000
Naphtalene	0.0001	0.0005	0.0002	42	0.82	1.78	1.98	0.00002	0.00007	0.00003	0.14
Acenaphthylene	0.0000	0.0001	0.0001	/	/	/	/	0.00001	0.00001	0.00001	/
Acenaphtene	0.0001	0.0002	0.0001	/	/	/	/	0.00002	0.00002	0.00002	/
Fluorene	0.0000	0.0001	0.0001	/	/	/	/	0.00001	0.00001	0.00001	/
Anthracene	0.0000	0.0001	0.0001	42	0.82	1.78	1.98	0.00001	0.00001	0.00001	0.14
Fluoranthene*	0.0000	0.0001	0.0003	0.3	0.0058	0.0127	0.0142	0.00001	0.00001	0.00008	0.001
Pyrene	0.0000	0.0001	0.0003	/	/	/	/	0.00001	0.00001	0.00009	/
Benzo(a)a	0.0000	0.0001	0.0001	/	/	/	/	0.00001	0.00001	0.00003	/
Chrysene	0.0000	0.0001	0.0001	/	/	/	/	0.00001	0.00001	0.00003	/
Benzo(b)f *	0.0000	0.0001	0.0001	0.3	0.0058	0.0127	0.0142	0.00001	0.00001	0.00005	0.001
Benzo(k)f *	0.0000	0.0001	0.0001	0.3	0.0058	0.0127	0.0142	0.00001	0.00001	0.00002	0.001
Benzo(a)p *	0.0000	0.0001	0.0001	0.3	0.0058	0.0127	0.0142	0.0000075	0.0000075	0.0000348	0.001
Dibenzo(a,h)a	0.0000	0.0001	0.0001	/	/	/	/	0.00001	0.00001	0.00001	/
Ind(1,2,3-cd)p *	0.0000	0.0001	0.0001	0.3	0.0058	0.0127	0.0142	0.00001	0.00001	0.00002	0.001
Phenanthrene	0.0000	0.0001	0.0001	/	/	/	/	0.00001	0.00002	0.00004	/
Benzo(ghi)p *	0.0000	0.0001	0.0001	0.3	0.0058	0.0127	0.0142	0.00001	0.00001	0.00002	0.001
∑ 6 PAH (*)	0.0002	0.0004	0.0008	0.3	0.0058	0.0127	0.0142	0.0000575	0.0000575	0.0002248	0.001
DBT	0.0001	0.0007	0.0001	/	/	/	/	0.0001	0.00019	0.000015	/
TBT	0.0008	0.0050	0.0002	0.03	0.00058	0.00127	0.00142	0.00071	0.0009	0.000058	0.0001
DEHP	0.0372	0.0579	0.1480	50.4	0.98	2.14	2.38	0.012	0.0097	0.064	0.168

DISCUSSION

- Level 1

For QC, the alternative material respects all the prohibitive limits from the “Guide Setra” first level, and even liberating limits, with the exception of Cl^-, SO_4^{2-} and soluble fraction. However, anions levels might be reduced with a more efficient sediments preparation, that would allow QC to be used in any type of road engineering. Concerning the road material, pollutants leaching is globally reduced, because of the smaller amount of sediments in the material (30%), apart from Ba, Cr, Cu, Mo, Pb – yet, their leaching levels stay under the Setra limits for any type of road engineering. Soluble fraction increases in road material, probably due to the lime and cement input (with an impact on pH too) and exceeds the prohibitive limit of 60,000 mg/kg.

For QN, level 1 results show exceedance of the limit for TPH, TOC, PAH and PCDD/F. Anions leaching is also problematic. According to the « Guide Setra », QN can not be used in road engineering without any further treatment.

- Level 2

For QC alternative material, all limits are respected, apart from Cd. Yet, the indicated value (<0.28 mg/kg DM) is calculated with the detection limits, and is probably not reached. All limits are also respected by the road material.

For QN alternative material, Cl^- and SO_4^{2-} stay beyond covered and/or coated limits, confirming the conclusions of the first level. Cd results presents the same artefact than QC. Concerning the road material, pollutants leaching increases for Ba, Cu, Mo, Ni and Pb, and exceeds the limits for the last three elements. This phenomenon might be linked to the pH increase, determining factor for some metal leaching and/or to a contribution from other components incorporated to the road material.

- Level 3 - lysimeters

Exceedance of the limits are observed for Cd, Ni, Zn, Cl^- and SO_4^{2-}. The high quantification limits mainly contribute to the total release of cadmium. The high levels of Ni might be attribute to the lysimeters steel corrosion and not to the sediment loading, as evidence by the evolution of Ni concentration in eluates after an anti-corrosion system was set up in February 2016.

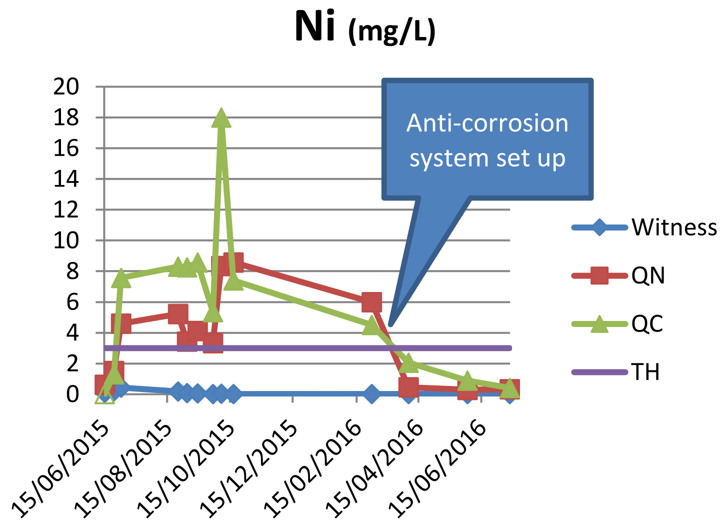

Figure 8: Evolution of Ni concentration in lysimeters eluates

Figure 9: Lysimeters corrosion

No reason has been found to explain the high emission level of Zn in both QC and QN, that had not been noticed at the previous steps.

Cl^- and SO_4^{2-} remain a major issue for those two sediments, both from an acute and a chronic point of view. The TBT acute limit exceeding for the witness lysimètre can probably be attributed to an analytical mistake or a contamination.

- Level 3 - landforms

In a covered scenario as landforms, only anions remain problematic for both QN and QC, even if the second level of the "Guide Setra" approach would have allowed to use QC in a covered system.

- Level 3 - roads

In a coated scenario as roads, no exceeding is observed for QC, in coherence with the two first levels of the "Guide Setra" approach, with the exception of TBT, which is yet probably linked to an analytical mistake or a contamination, considering that the witness road also exceeds the chronic and acute limits for TBT.

For QN, the Cl^- content remains an issue even in this kind of structure.

- Focus on organic pollutants

Apart from TBT, no organic pollutant exceeds the chosen limits, that were derived from regulatory values for drinking water production, without taking into account any dilution factor, that is a very conservative assumption.

CONCLUSION

All levels of the French current framework for environmental evaluation of alternative materials in road engineering have been applied on two contaminated marine sediments from the Toulon Bay. The main experienced difficulty in applying this approach was the lack of a methodology to determinate the organic pollutants to measure and the limits to associate. However, the results tend to show that the impact on groundwater is manageable for these contaminants.

Another limit of the "Guide Sétra" framework was the reference rainfall used for limits calculation, that was far from being reached after one year of monitoring in Aix-en-Provence and La Seyne-sur-mer. This led to consider very low limits at the third level. To avoid such a discordance, three solutions can be proposed: (1) simulate rainfalls on lysimeters, landforms and road structures, (2) make the monitoring last longer than a year, or (3) propose new ways to calculate specific limits, adapted to the local climate.

Yet, for both QN and QC, the main concern remains anions emission, with Cl^- and SO_4^{2-}. Therefore, developing a framework for another way of valorization for marine sediments, where anions release would not be problematic, such as maritime works materials, could enhance marine sediments reuse.

From a scientific point of view, the constitution of a national database collecting and tracking the sites where alternative materials are used might be a way to ensure that other exposure scenario could be evaluated in the future, even after the end-of-life of those road engineering projects.

REFERENCES

[1] Acceptabilité de matériaux alternatifs en technique routière – Evaluation environnementale, Sétra, 2011

[2] Acceptabilité de matériaux alternatifs en technique routière – Aide à la mise en œuvre du niveau 3 de caractérisation environnementale – Volet N°1 : les essais lysimétriques et plots expérimentaux, Cerema, septembre 2015

[3] Etude sur les contaminants émergents dans les eaux françaises – Rapport de l'étude prospective sur les contaminants émergents dans les eaux littorales de la métropole et des DOM, IFREMER, octobre 2014

[4] Etude sur les contaminants émergents dans les eaux françaises - Résultats de l'étude prospective 2012 sur les contaminants émergents dans les eaux de surface continentales de la Métropole et des DOM, INERIS, Juin 2014, DRC-13-136939-12927A

[5] Diagnostic de la contamination sédimentaire par les métaux/métalloïdes dans la Rade de Toulon et mécanismes contrôlant leur mobilité, Thèse de chimie de l'environnement, E. TESSIER, mai 2012