Norwegian Institute for Water Research **REPORT**

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Summary

An assessment of environmental risk linked to run-off from artificial turf pitches has been carried out on the basis of studies of the concentration of hazardous substances in materials used in artificial turf pitches and their potential for leaching into water. The risk assessment was carried out in accordance with standard procedures for the risk assessment of chemicals within the EU. The results show that there is a risk of environmental effects in small recipients which receive surface run-off from artificial turf pitches. The factor which contributes most to the environmental risk is zinc, but alkylphenols, and octylphenol in particular, are also predicted to exceed the limits for environmental effects. Other components which were not studied could also provide an additional contribution to the environmental risk. The concentrations of chemicals in run-off from artificial turf pitches are predicted to decrease slowly so that environmental effects may occur over many years. The total quantities of hazardous substances which are leached from an artificial turf pitch are however modest, so that any environmental effects will only be localised.

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Environmental Risk Assessment of Artificial Turf Systems

Foreword

The Norwegian Pollution Control Authority (SFT) commissioned the Norwegian Institute for Water Research (NIVA) to carry out an assessment of environment risk linked to artificial turf pitches. The risk assessment was carried out on the basis of a study of materials used for such pitches undertaken by the Norwegian Building Research Institute (Plesser & Lund 2004).

The risk assessment was carried out by Torsten Källqvist with assistance from August Tobiesen, NIVA.

Oslo, 19 December 2005

Torsten Källqvist

Contents

Translated Norwegian Summary

A simple assessment of environmental risks relating to artificial turf systems has been carried out. The assessment is based on a study of the concentrations and leaching potential of hazardous chemicals used in artificial turf pitches carried out by the Norwegian Building Research Institute. It is assumed that the greatest environmental risk is linked to the leaching of chemicals through surface water run-off in connection with precipitation. In the risk assessment, the effects on the biota in the water phase and in the sediment in a small stream which receives run-off from an artificial turf pitch has been assessed. The degree of dilution in the stream is assumed to be a factor of ten. The assessment shows that there is a risk of environmental effects in both the water phase and the sediment. The factor which contributes most to the environmental risk is zinc, but alkylphenols, and octylphenol in particular, are also predicted to exceed the limits for environmental effects. The leaching of chemicals from the material is predicted to occur slowly, so that environmental effects may take place over many years. The total quantities of hazardous substances which are leached from an artificial turf pitch are modest however, and any environmental effects will only be local.

Original English Summary (*unedited*)

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An environmental risk assessment of artificial turf for sports grounds have been performed, based on an investigation of content and leaking potential of hazardous substances in the materials used. It was found that recycled rubber was the major source of potentially hazardous substances. An exposure scenario where the runoff from a football field is drained to a small creek showed a positive risk of toxic effects on biota in the water phase and in the sediment. The risk was mainly attributed to zinc, but also for octylphenol the predicted environmental concentration exceeded the no environmental effect concentration. The total annual amounts of hazardous substances leaching from a normal sports ground are fairly low which means that any environmental effects are expected to be local only.

1. Background

Artificial turf sports pitches are becoming increasingly widespread in Norway. According to the Norwegian Football Association, there were approximately 300 artificial turf pitches in existence at the end of 2004 and 100 new pitches will be laid during 2005 (www.fotball.no). Because the materials used in artificial turf systems contain hazardous chemicals, questions have been raised as to whether such pitches could cause a health hazard for users and an environmental hazard concerning the distribution of pollution components to the surroundings.

The potentially harmful effects linked to artificial turf systems have been studied by the Norwegian Building Research Institute, Byggforsk (15). In the study, samples of synthetic turf fibre and rubber granulates were analysed for metals and organic toxins. Leaching tests were also carried out in water using fibres and rubber granulates. The results showed that the artificial turf fibres contained copper, zinc, phthalates, alkylphenols, among other things. In the leachate from fibres, zinc was identified as the most important pollution component.

The studies of rubber granulates based on recycled rubber showed considerable variation in the chemical composition of different samples from the same manufacturer. This is probably due to differences in the raw materials used. A number of metals (lead, cadmium, copper, mercury and zinc) and organic pollutants (polycyclic aromatic hydrocarbons (PAH), phthalates, 4-t-octylphenol and iso-nonyphenol) was demonstrated in rubber granulates and many of these components were also found in leachate. Rubber granulate of the EPDM (ethylene propylene diene monomer) rubber type had lower concentrations of hazardous components.

In the report from the Norwegian Building Research Institute, concentrations of hazardous chemicals in fibres and rubber granulate were compared with the Norwegian Pollution Control Authority's normative values for polluted ground and corresponding limits for agricultural soil in Canada. Concentrations in leachate from rubber granulate were compared with limits in the Norwegian Drinking Water Regulation, the Norwegian Pollution Control Authority's classes for environmental quality in freshwater, Canadian Environmental Quality Guidelines and "Predicted No Effect Concentrations (PNEC)" from risk assessments carried out within the EU's programme for existing chemicals. The results showed that the leachate exceeded limits or normative values for a number of components and it was concluded that "An expanded risk assessment with an analysis of possible spreading paths and changes in leaching properties over time is necessary to determine the extent to which the concentrations of zinc, anthracene, fluoranthene, pyrene, phthalates and nonylphenols in the leachate actually are harmful to people and the environment" (15).

This report contains a simple assessment of environmental risk linked to artificial turf systems, based on the documentation in the abovementioned report from the Norwegian Building Research Institute.

2. Methodology

The environmental risk assessment was carried out in accordance with the "Technical Guidance Document" (TGD), which is used in connection with risk assessments for new and existing chemicals within the EU (EC 2003).

The method is based on the calculation of two concentrations of an individual chemical:

- PEC – "Predicted Environmental Concentration", i.e. the predicted concentration in the environment, and
- PNEC – "Predicted No Effect Concentration", i.e. the highest concentration which does not result in harmful effects on the environment.

Finally, the PEC/PNEC ratio was calculated. PEC/PNEC risk quotients of > 1 indicate a risk of environmental effects.

Separate PEC/PNEC calculations can be performed for five "compartments": treatment works, surface water, sediments, terrestrial environment and air.

Risk assessments can be carried out for local scenarios linked to specific pollution sources and recipients or regional scenarios which show the general risk for larger regions.

As regards the environmental effects of artificial turf pitches, spreading via run-off to surface water is predicted to cause the greatest potential risk. It is therefore appropriate to perform a risk assessment which covers water and sediments in watercourses which receive run-off from artificial turf pitches. Input to water treatment works is not assumed to be a problem area, and where it does occur, the degree of dilution of run-off water from artificial turf pitches in the total drainage flow is expected to be so high that the environmental risk is assumed to be insignificant. Input to the terrestrial environment is predicted in the TGD to occur through the use of sludge from municipal treatment works as a soil preparation agent. This scenario has not been assessed for the same reason as that mentioned for treatment works. Some spreading to surrounding areas through the airborne transport of particles and with floodwater could occur. No information is however available on the extent of such spreading, preventing realistic calculations of the risk from being carried out. It is however assumed that the exposure concentrations and the risk of environmental effects in the terrestrial environment will be lower than in sediments in the aquatic environment.

The environmental risk assessment is based on a local scenario, where run-off from an artificial turf pitch is drained to a nearby stream. The water flow in the stream will of course be of significance to the resulting concentrations of chemicals in the recipient. Here, the dilution has been set to a factor of ten, which is the recommended default value for calculating PEC_{local} in the TGD.

The quantity of run-off has been calculated for an artificial turf pitch with an area of 7200m^2 and annual precipitation of 800 mm[1]. This gives a total run-off of 5760m^3 per year. As dilution in the recipient is set to a factor of ten, the mean water flow in the recipient is 110 l/min.

The quantities of fibre turf and rubber granulate are assumed to be 0.8 and 18 kg per square metre respectively (Thale et al. 2004), i.e. a total of 5760 kg artificial turf fibre and 129,600 kg rubber granulate.

The concentrations of various pollution components in the run-off water were taken from the Norwegian Building Research Institute's study of leachate from artificial turf fibre and rubber granulate. Where data was available for a number of samples, the highest concentration for each component was chosen. In the Norwegian Building Research Institute's study, the leachate was investigated by shaking 1 kg of material (fibre or rubber granulate) in 10 litres of water for 24 hours. The water was then filtered and the filtrate analysed. The leachate procedure is based on pr EN 124567-4 and NT ENVIR 005. In the risk assessment it is assumed that the concentrations found in the filtrate represent equilibrium concentrations, i.e. they are independent of the material/water quantity ratio.

3. PEC_{water}

[1] The quantity of precipitation will not affect the risk assessment, as it is assumed that the dilution of run-off is constant at a factor of ten. It will however be of importance for the total quantities of substances which are leached out. 800 mm/year is slightly higher than normal for Blindern, Oslo (763 mm).

Predicted concentrations in surface water (PEC_{water}) have been calculated for the pollution components which were demonstrated to be above the detection level in analyses of leachate of artificial turf fibre and rubber granulate.

These components are listed in Table 1. Maximum concentrations which were found in the study and the samples from which the results originate are also given in this table.

PEC_{water} is calculated from the concentration in the run-off, the dilution in the recipient and the predicted reduction in the water phase as a result of adsorption to suspended particles in water:

$$PEC_{water} = \frac{C_{run-off}}{(1 + Kp_{susp} \times SUSP_{water} \times 10^{-6}) \times DILUTION}$$

Where:

Kp_{susp}	Distribution co-efficient (solid/water) in suspended material	$[l \cdot kg^{-1}]$	Calculated from K_{OC}
$SUSP_{water}$	Concentration of suspended material in the recipient	$[mg \cdot l^{-1}]$ = 15*	

* 15 mg/l is the default value for suspended material in the TGD. It is a realistic value for small watercourses in Norway, but can vary considerably.

Kp_{susp} is calculated from the distribution coefficient organic carbon/water (K_{OC}) and the concentration of organic carbon in the suspended material which is set to 10% (the default value in the TGD). The K_{OC} values for the various compounds are taken from the EU's risk assessment reports or, if no such reports are available, calculated from the distribution coefficient octanol/water (K_{OW}) with the quantitative structure/activity equations from the TGD (Table 5, Chapter 4).

$PEC_{sediment}$ is calculated from PEC_{water} using the formula:

$$PEC_{sediment} = \frac{K_{susp-water}}{RHO_{susp}} \times PEC_{water} \times 1000$$

Where:

$K_{susp-water}$	Volume-based distribution coefficient suspended material/water	$[m^3 \cdot m^{-3}]$	Calculated in EUSES
RHO_{susp}	Density of suspended material	$[kg \cdot m^{-3}]$	= 1150*

* default value in the TGD

$K_{susp-water}$ was calculated using EUSES, a model tool that is used in the TGD.

PEC values for water and sediment are listed in Table 2. $PEC_{sediment}$ cannot be calculated for the most nonpolar phthalates (log K_{OW} > 8) with the model which was used. This does not however represent a problem, as the biological availability of these substances on exposure via water and sediment is so low that PNEC values cannot be calculated.

Table 1. Concentrations of chemicals in water determined in leachate tests on artificial turf fibres and rubber granulates (From Plesser & Lund 2004).

Parameter	**Unit**	**Concentration**	**Sample**
Zinc (Zn)	mg/l	2.29 + 1.00	Granulate 1 + Fibre 3
Total PAH (16)	µg/l	0.87	Granulate 1
Naphthalene	µg/l	0.15	Granulate 1
Acenaphtylene	µg/l	0.27	Granulate 1
Acenaphthylene	µg/l	0.03	
Fluorene	µg/l	0.04	
Phenanthrene	µg/l	0.17	Granulate 2
Anthracene	µg/l	0.03	Granulates 1 and 2
Fluoranthene	µg/l	0.06	Granulates 1 and 2
Pyrene	µg/l	0.13	Granulates 1
Dimethylphthalate (DMP)	µg/l	1.6	Granulate 2
Diethylphthalate (DEP)	µg/l	8.3	Granulate 2
Dibutylphthalate (DBP)	µg/l	3.3	Granulate 1
Benzylbutylphthalate (BBP)	µg/l	0.3	Granulate 2
Diethylhexylphthalate (DEHP)	µg/l	5.6	Granulate 2
Di-n-octylphthalate (DOP)	µg/l	4.4	Granulate 2
Diisononylphthalate (DINP)	µg/l	2.7	Granulate 1
Diisodecylphthalate (DIDP)	µg/l	1.0	Granulate 2
4-t-octylphenol	ng/l	3600	Granulate 1
4-n-nonylphenol	ng/l	43	Granulate 1
iso-nonylphenol	ng/l	1120	Granulate 1

The calculated PEC values in water and sediment are shown in Table 2. The K_{OC} values which were used to calculate $K_{susp\text{-}water}$ are taken from the EU's risk assessments for naphthalene, "Coal Tar Pitch, high temperature" (acenaphthylene, fluorene, phenanthrene, fluoranthene and pyrene), anthracene, dibutylphthalate, benzylbutylphthalate, diethylhexylphthalate, octylphenol and nonylphenol. For other substances, K_{OC} was calculated using a QSAR model for "predominantly hydrophobic chemicals" in accordance with the TGD.

It should be noted that K_{OC} for naphthalene was calculated using a different QSAR model than the other PAHs.

Table 2. Estimated exposure concentrations for water (PEC_{water}) and sediment ($PEC_{sediment}$)

Parameter	**Concentration in run-off (µg/l)**	**Log K_{OW}**	**K_{OC}**	**Kp_{susp} (l/kg)**	**PEC_{water} (µg/l)**	**$K_{susp-water}$ (m^3/m^3)**	**$PEC_{sediment}$ (µg/kg wet weight)**
Zinc (Zn)	3290	-	-	11000[a]	124	27501[a]	2969000
Total PAH (16)	0.87						
Naphthalene	0.15	3.7	1250	125	0.015	32.2	0.42
Acenaphthylene	0.27	3.62	2570	257	0.027	65.2	1.52
Acenaphthene	0.03	4.0	6166	617	0.003	155	0.40
Fluorene	0.04	4.2	9772	977	0.004	245	0.84
Phenanthrene	0.17	4.68	18197	1820	0.017	456	6.56
Anthracene	0.03	4.54	21380	2138	0.003	151	0.38
Fluoranthene	0.06	4.98	58884	5888	0.006	1470	7.05
Pyrene	0.13	5.2	97724	9772	0.011	2440	24.06
Dimethylphthalate (DMP)	1.6	1.66	28	3	0.160	1.04	0.14
Diethylphthalate (DEP)	8.3	2.65	176	18	0.830	5.5	3.97
Dibutylphthalate (DBP)	3.3	4.57	6334	633	0.327	159	45.20
Benzylbutylphthalate (BBP)	0.3	4.84	10481	1048	0.030	315	8.09
Diethylhexylphthalate (DEHP)	5.6	7.6	1803018	180302	0.151	54000	7098
Di-n-octylphthalate (DOP)	4.4	8.54	10408784	1040878	0.026	*	
Diisononylphthalate (DINP)	2.7	8.8	16904409	1690441	0.010	*	
Diisodecylphthalate (DIDP)	1	8.8	16904409	1690441	0.004	*	
4-t-octylphenol	3.6	4.12	2737	274	0.36	69.4	21.64
4-n-nonylphenol	0.043	4.48	5355	536	0.00	135	0.50
iso-nonylphenol	1.12	4.48	5355	536	0.11	135	13.04

a) Values taken from the RA document for Zn (8).

* The values cannot be calculated as K_{OW} is outside the model's area of validity.

4. PNEC

PNEC values for surface water and sediment are taken from the EU's risk assessment documents for the chemicals that have been subjected to such an assessment (see references). For the phthalates DMP and DEP, the preliminary $PNEC_{water}$ values were calculated from available toxicity data in the database of the European Chemicals Bureau (IUCLID). $PNEC_{sediment}$ values were calculated from $PNEC_{water}$ in accordance with the TGD using the following equation:

$$PNEC_{sediment} = \frac{K_{susp-water}}{RHO_{susp}} \times PNEC_{water} \times 1000$$

The results are compiled in Table 3. It should be noted that the assumptions for calculating the PNEC values for sediment differed in each of the risk assessment documents from which they were taken. In some cases, they are based on toxicity data for sediment-inhabiting organisms and in others through the equilibrium equation from $PNEC_{water}$. In addition, the same method was not used for the equilibrium equation in all the documents. For two PAHs (naphthalene and anthracene), PNEC values are available from risk assessments concerning the individual compounds and from the risk assessment for "Coal Tar Pitch, High temperature". The PNEC values for water are fairly similar in the two documents, whilst they differ by a factor of up to 10 for $PNEC_{sediment}$. In this report, the PNEC values for naphthalene and anthracene were taken from the EU's specific risk assessment reports for these substances.

5. Risk quotients

Risk quotients for water and sediment are shown in Table 4. For all the chemicals with the exception of zinc and octylphenol, PEC/PNEC < 0.6 in both water and sediment. The analysis shows that zinc represents the biggest risk with a risk quotient of 40 in water and 341 in sediment.

For octylphenol, the risk quotient was calculated at 2.9 for water and sediment, indicating a risk of toxic effects in both media.

If it is assumed that the toxic effects of related chemicals are additive, the total risk for the three categories PAH, phthalates and alkylphenols can be calculated by summing the risk quotients. This can of course only be done for components present in concentrations above the detection limit in the leachate and for which PNEC values have been determined. For the PAH group, where the risk quotients for the individual substances is < 1, the sum of the risk quotients for water is 1.13, indicating that the collective effect of PAHs could represent a risk for the biota in the water phase.

For the phthalates group, the total of the risk quotients is < 1. For alkylphenols, where octylphenol alone represents a risk, the nonylphenols contribute to the risk quotient for water and sediment of 3.3.

Table 3. PNEC values for water and sediment

Parameter	**Log K_{OW}**	**$PNEC_{water}$ (µg/l)**	**$PNEC_{sediment}$ (µg/kg wet weight)**	**Source (see references)**
Zinc (Zn)		3.1[a]	8000[b]	8
Total PAH (16)				
Naphthalene	3.7	2.4	67.2	6
Acenaphthylene	3.62	0.64	37[c]	10
Acenaphthene	4	3.8	608[c]	10
Fluorene	4.2	2.5	973[c]	10
Phenanthrene	4.68	1.3	1900[c]	10
Anthracene	4.45	0.12	11.9	11
Fluoranthene	4.45	0.12	365[c]	10
Pyrene	5.2	0.023	532[c]	10
Dimethylphthalate (DMP)	1.66	960[d]	868[f]	IUCLID
Diethylphthalate (DEP)	2.65	900[e]	4304[f]	IUCLID
Dibutylphthalate (DBP)	4.57	10	1200	7
Benzylbutylphthalate (BBP)	4.84	7.5	1715	9
Diethylhexylphthalate (DEHP)	7.6	n.d.	100000	12
Di-n-octylphthalate (DOP)	8.54			
Diisononylphthalate (DINP)	8.8	No effect	No effect	5
Diisodecylphthalate (DIDP)	8.8	No effect	No effect	4
4-t-octylphenol	4.12	0.122	7.4	2
4-n-nonylphenol	4.48	0.33	39	3
iso-nonylphenol	4.48	0.33	39	3

[a] $PNEC_{add}$ for water with low hardness, i.e. in addition to the natural background concentration
[b] $PNEC_{add}$, i.e. in addition to the natural background concentration
[c] Calculated from $PNEC_{sediment}$ dry weight with the assumption that the solid phase makes up 20% of the sediment and that the density of the solid phase is 2.5 g/cm^3 (TGD).
[d] calculated from the lowest NOEC in IUCLID (Daphnia, 9.6 mg/l) and Assessment factor = 10
[e] calculated from the lowest NOEC in IUCLID (Algae, 9 mg/l) and Assessment factor = 10
[f] calculated from $PNEC_{water}$

Table 4. Risk quotients (PEC/PNEC) for water and sediment.

Parameter	**PEC/PNEC$_{water}$**	**PEC/PNEC$_{sediment}$**
Zinc (Zn)	40	371
Total PAH (16)		
Naphthalene	0.006	0.006
Acenaphthylene	0.042	0.041
Acenaphthene	0.001	0.001
Fluorene	0.002	0.001
Phenanthrene	0.013	0.003
Anthracene	0.024	0.032
Fluoranthene	0.551	0.019
Pyrene	0.493	0.045
Total PAH	**1.132**	**0.149**
Dimethylphthalate (DMP)	0.0002	0.0002
Diethylphthalate (DEP)	0.001	0.001
Dibutylphthalate (DBP)	0.033	0.038
Benzylbutylphthalate (BBP)	0.004	0.004
Diethylhexylphthalate (DEHP)	0.000	0.071
Di-n-octylphthalate (DOP)		
Diisononylphthalate (DINP)	0.0000	0.0000
Diisodecylphthalate (DIDP)	0.0000	0.0000
Total phthalates	**0.038**	**0.114**
4-t-octylphenol	2.939	2.924
4-n-nonylphenol	0.013	0.013
iso-nonylphenol	0.337	0.334
Total alkylphenols	**3.288**	**3.271**

6. Discharge quantities

The total quantities of the various substances leached from an artificial turf pitch with an area of 7200 m^2 over a period of one year were calculated from the concentrations in the leachate water and the quantity of water which is input through precipitation (800 mm/year = 5760 m^3). The results of these calculations are shown in Table 5. With the exception of zinc, of which approximately 19 kg is leached out over one year, the total quantities of the various substances analysed are low.

Table 5. Estimated total quantities of substances leached from an artificial turf pitch with an area of 7200 m^2 over a period of one year with 800 mm precipitation.

Parameter	**Leachate (µg/l)**	**Leached/year (g)**
Zinc (Zn)	3290	18950*
Total PAH (16)	0.87	5.01
Naphthalene	0.15	0.86
Acenaphthylene	0.27	1.56
Acenaphthene	0.03	0.17
Fluorene	0.04	0.23
Phenanthrene	0.17	0.98
Anthracene	0.03	0.17
Fluoranthene	0.06	0.35
Pyrene	0.13	0.75
Dimethylphthalate (DMP)	1.6	9.22
Diethylphthalate (DEP)	8.3	47.81
Dibutylphthalate (DBP)	3.3	19.01
Benzylbutylphthalate (BBP)	0.3	1.73
Diethylhexylphthalate (DEHP)	5.6	32.26
Di-n-octylphthalate (DOP)	4.4	25.34
Diisononylphthalate (DINP)	2.7	15.55
Diisodecylphthalate (DIDP)	1.0	5.76
4-t-octylphenol	3.60	20.74
4-n-nonylphenol	0.043	0.25
iso-nonylphenol	1.12	6.45

* Of this amount, 14091 g originates from rubber granulate and 4859 g originates from turf fibre.

7. Discussion

The most problematic pollution components from artificial turf pitches originate from rubber granulates based on recycled rubber. The rubber material which is used comes from car tyres. There has long been a focus on the concentrations of hazardous substances in car tyres and the spreading of such substances through the wearing of and leaching from tyres. In a recent study, acute toxicity to water fleas (*Daphnia magna*) was demonstrated in water samples to which 0.5g/l of fine-grained car tyre rubber had been added. Another study demonstrated zinc as the cause of the toxic effects of car tyres (13). There is however considerable variation in the concentrations of toxic components between different types of car tyre. It is therefore not possible to transfer these results directly to the material that is used as rubber granulate in artificial turf pitches, but the results do show that car tyres have the potential to leak toxic compounds.

The risk assessment shows that zinc is the component which represents the greatest risk for environmental effects. The estimated exposure concentrations of zinc in water and sediment are far higher than the preliminary limits for environmental effects (PNEC) proposed in the EU's risk assessment for zinc (8). The amount by which the limit is exceeded is greatest for sediment (PEC/PNEC = 370). There has been some discussion as to whether the $PNEC_{sediment}$ value which is proposed in the most recent version of the risk assessment document for zinc is too low and it is possible that the value will be adjusted. An alternative method of calculation, where $PNEC_{sediment}$ is calculated from $PNEC_{water}$ (normal hardness) through an equilibrium equation gives a $PNEC_{sediment}$ = 187 mg/kg, which is a factor of 23 higher than that used in this risk assessment. With this higher PNEC value, the risk quotient for sediment becomes 16, which still indicates a clear risk of environmental effects.

The toxicity of zinc in water depends on the hardness of the water. In this risk assessment, a $PNEC_{water}$ of 3.1µg/l above the background concentration was used, which applies to water with low hardness (< 24 mg $CaCO_3$/l). Even using a PNEC value for water with a hardness of over 24 mg/l ($PNEC_{water}$ = 7.8 µg/l above the background concentration), the estimated concentration in water ($PNEC_{water}$ = 124 µg/l) clearly exceeds the limit. Calculations of the environmental risk relating to zinc were performed without taking into account the background concentration of zinc. This background concentration will however be so low that it will only have a marginal effect on the risk quotients. The median value for zinc in lakes in Norway has been calculated at 1.1 µg/l (16).

According to the results from the Norwegian Building Research Institute's study, the leaching of zinc from artificial turf pitches will originate from both turf fibre (30%) and rubber granulate (70%). Zinc has previously been demonstrated as being the cause of toxic effects in leachate from car tyres, which is the source material for the rubber granulate (13).

Octylphenol is the organic compound which represents the greatest risk (PEC/PNEC = 2.9). The rubber granulate which was used in the leaching test had a concentration of 33.7 mg/kg, giving a concentration of 3.6 µg/l in the leachate water. The content of octylphenol in car tyres could be considerably higher. In a report by OSPAR (14), it is specified as 0.3%, i.e. 3000 mg/kg. If such a high concentration can occur in the rubber granulate used for artificial turf pitches it is possible that the leachate and the environmental risk could be higher than estimated in this report. There is also some uncertainty as to whether the proposed PNEC values for octylphenol are sufficiently conservative to protect against hormone-disruptive effects. No hormone-disruptive effects caused by octylphenol have however been demonstrated at concentrations lower than $PNEC_{water}$ (0.122 µg/l) (2).

In the leaching test which was carried out by the Norwegian Building Research Institute, 100 g rubber granulate/l was used. No toxicity tests were carried out on the water samples, but in the light of previous studies concerning car tyres it is probable that the leachate could have had acute toxic effects – even after dilution by a factor of 10, which is an assumption in the discharge scenario used in this report. The outcome of the risk assessment is therefore not surprising. It is however possible that components other than those analysed in the rubber granulate and the leachate could also contribute to toxic effects.

In the risk assessment, it has been assumed that the concentrations of various components in filtered water samples from the leachate test are representative of run-off water from an artificial turf pitch. This presupposes that it can be assumed that equilibrium exists between the concentrations in the water phase and in the solid phase (rubber granulate), which is independent of the quantity ratio between granulate and water. In the case of a precipitation episode involving 10 mm of precipitation for example, a total of $72m^3$ of rainwater would come into contact with 144 tonnes of rubber granulate and the granulate/water ratio would be a factor of 18 higher than in the leachate test. It is however reasonable to assume that this will not result in a corresponding increase in the concentrations of the various pollution components in the run-off.

In the study conducted by the Norwegian Building Research Institute, the degree of mobilisation, i.e. the proportion of the pollution components which are leached out into the water phase when the water/granulate mixing ratio is 10 l/kg, was calculated. It would appear that the mobilisation values reported are consistently too low by a factor of ten. Granulate sample no. 1 contained 7500 mg Zn/kg. In the leachate test, the total quantity of zinc was 750 mg/l. Of this, 2.29 mg/l was found in the water phase. This gives a mobilisation of 0.31%. For 4-t-octylphenol, 0.11% of the content in the granulate was mobilised to the water phase.

Annual precipitation of 800 mm over a $7200m^2$ pitch with 18 kg rubber granulate/m^2 gives a water/granulate ratio = 44l/kg. If the equilibrium concentrations in water are assumed to be constant, less than 1.4% of the zinc content and 0.5% of the octylphenol in the granulate will have been leached out after one year. This indicates that the leaching of zinc and organic chemicals could take place over a long period of time. As mentioned in the Norwegian Building Research Institute's report however, potential changes in leaching properties over time should be investigated.

It is stressed that the risk assessment is based on analysis of a limited number of samples of turf fibre and rubber granulate. It is known that the leaching of toxic components varies between different types of car tyre and the representativeness of the available data is therefore uncertain. Although the highest concentrations of chemicals which were found in analyses of leachate water were used as a basis for the risk assessment, the possibility that even higher concentrations could occur in other granulate sections cannot be eliminated. In addition, it is possible that components other than those which were determined through analysis, and which are known constituents in car tyres, could contribute to the risk of environmental effects in recipients which receive run-off from artificial turf pitches.

The risk assessment that was carried out is based on a simplified scenario, where it is assumed that equilibrium exists between concentrations of chemicals in the artificial turf material and water which has been in contact with this material. It is also assumed that the run-off occurs directly to a watercourse and not through infiltration into the ground, which could retain some of the pollution components through adsorption.

Another factor which is not included in this risk assessment is the significance of the spreading of pollution components through fine particles from the artificial turf material being transported with the drainage water. The significance of the particle fraction is not known. In the Norwegian Building Research Institute's study, the samples were filtered before analysis, and the concentrations of chemicals in the particle fraction were not quantified. The concentration of suspended material in the leachate from the rubber granulate was 1.3-2.9 mg/l. If the suspended material had the same composition as the granulate, the concentration of zinc linked to suspended material would be 22 µg/l, whilst the dissolved fraction in the leachate was 2290 µg/l. This indicates that the spreading to water of chemicals bound to fine-grained particles is of little significance for pitches made from recycled rubber granulate. One cannot however ignore the fact that a fine-grained fraction of the rubber granulate is created through erosion as a result of activity on artificial turf pitches, making the leaching of particles more important as the material is exposed to wear.

With the scenario which was used for the risk assessment, in which it is assumed that the run-off from an artificial turf pitch drains into a small stream with a constant dilution factor of ten, the calculations show a risk of environmental effects in water and sediment downstream of the section where the run-off drains into the stream. The extent of the area over which environmental effects can be anticipated will depend on the hydrological conditions in the stream downstream of the artificial turf pitch. As a general rule, the water flow will increase down a watercourse as a result of run-off from a large area, and the concentrations of the substances which are expected to give environmental effects will decrease through dilution, so that the risk quotients will be reduced. The concentrations of degradable organic substances will also be reduced through degradation. The relatively small quantities which are leached out with the run-off over the course of a year (Table 5) indicate that artificial turf pitches are not an important source of pollution and that environmental effects can only be anticipated locally, as shown in the scenario which was used for the risk assessment. The scope of effects from an individual artificial turf pitch will depend on local conditions.

In order to provide a better basis on which to assess the environmental effects of artificial turf pitches, measurements should be made of drainage water from existing pitches. The study should include toxicity tests in order to identify any effects of chemicals which were not covered by the analysis programme in the limited studies which have been carried out.

8. Conclusion

The risk assessment shows that the concentration of zinc poses a significant local risk of environmental effects in surface water which receives run-off from artificial turf pitches. In addition, it is predicted that concentrations of alkylphenols and octylphenol in particular exceed the limits for environmental effects in the scenario which was used (dilution of run-off by a factor of ten in a recipient). The leaching of chemicals from the materials in the artificial turf system is expected to decrease only slowly, so that environmental effects could occur over many years. The total quantities of pollution components which are leached out into water from a normal artificial turf pitch are however relatively small, so that only local effects can be anticipated.

9. References

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