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Mass balance of rubber granulate lost from artificial turf fields, focusing on discharge to the aquatic environment

A review of literature

Title:
Mass balance of rubber granulate lost from artificial turf fields, focusing on discharge to the aquatic environment

Compiled for:
Genan A/S
Jegindøvej 16
8800 Viborg

Compiled by:
Teknologisk Institut (Danish Technological Institute)
Teknologiparken
Kongsvang Allé 29
8000 Aarhus C
Bio- and Environmental Technology

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Authors:
Hanne Løkkegaard
Bjørn Malmgren-Hansen
Nils H. Nilsson

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1 Summary

Recent years have seen increasing focus on the spread of microplastics to the aquatic environment.

Consequently, focus on the microplastics that end up in the environment, including rubber granulate from artificial turf fields, has also grown.

Artificial turf fields have become popular in Denmark and the rest of the world.

A typical 11-man football field uses 60-120 tonnes of rubber granulate (infill), with more added (refill) to the field to maintain the thickness of the granulate layer, ensuring that the artificial grass fibres retain the support they need from the granulate and maintaining the playing performance of the field.

Most granulate used on artificial turf fields is ELT ('End of Life Tyres') granulate, based on shredded, worn-out tyres. This report focuses exclusively on ELT granulate used on artificial turf fields. Please note that ELT granulate is often referred to in the literature as 'SBR granulate' (Styrene-Butadiene Rubber), despite the fact that other types of rubber are used in tyres too. SBR rubber is the main ingredient used in tyre tread, but natural rubber is also a major rubber type used in tread.

Earlier reports imply that around 3-5 tonnes of granulate refill is added per year (based on data from the suppliers). A new study, performed by Lindberg International in 2018 in Denmark, concluded that the average amount of refill per field (11-man football field) is 2.2 tonnes. This report is based on the latter.

It is also based on a study of Danish and international literature on the subject, from which we can conclude that the existing knowledge of the spreading patterns of rubber granulate is very limited. What knowledge there is, is based on very few actual measurements, and in some instances, only on laboratory-based studies. This report focuses on the spreading of microplastics to the environment, with special focus on how microplastics spread to the aquatic environment and on the compaction of infill, commonly as well as in scientific literature referred to as the compaction of artificial turf fields, as a result of their use.

Compaction was assessed based on one scientific article dealing with the compacting of rubber granulate in detail, but primarily through laboratory experiments. However, a few field measurements of playing performance have been performed on four fields, which indicate 8.2–14.6% compaction. The authors of this report chose to use other spreading modes of rubber granulate to calculate possible compaction, as the data available for assessment of compaction are insufficient. On the basis of the mass balance, an overall assessment of the need for infill granulate on a typical Danish field due to compaction indicates something in the range of 1,470-1,900 kg p.a., which corresponds to between 13 and 17% compaction, slightly higher than the range found in the article. It should be noted that the calculations in this report show that an increase in rubber granulate on the actual field of between 1.1 and 1.9 tonnes p.a. (the range depends on other loss) will imply that the layer thickness will increase by between 3 and 5 mm over 10 years. It will therefore not be possible to determine whether a lesser amount of rubber granulate is added to the field. Such an assessment is made no less difficult by the fact that the rubber granules already lie in an uneven layer. Please also note that this report does not include compaction

of the sand layer, which can also have significance. 13-17% compaction is therefore deemed to be realistic.

The loss of deposited material to the soil and paved areas surrounding the football fields is estimated to be about 250 kg p.a. per field, but this is based on very few measurements, and is a very uncertain estimate.

It has not been possible to make a better estimate than around 250 kg p.a., which was measured in Holland, where field build-up can differ from field build-up in Denmark. Field measurements will be required to verify the actual loss from Danish fields.

Loss via adherence to the footwear and clothing of players was estimated based on an extensive Norwegian study at an average of 40 kg/field p.a., depending on how much the field is used.

SWECO conducted extensive studies of loss of infill from artificial turf fields due to snow clearance. SWECO found that the loss due to snow clearance accounted for about 11% of infill added in Sweden. However, the amount can vary significantly from field to field, depending on activity on the field and climatic conditions. The real loss is therefore estimated to be from 0–11%.

Very few measurements have been taken of the discharge of rubber granulate to the sewers, and they only include loss to the sewers, and not to the aquatic environment after being treated in sewage works, after passing through storm drains. Dutch measurements show a loss to the sewers of around 6-10 kg p.a., whilst Swedish studies indicate a higher loss of 200-340 kg p.a. Total loss to the sewers is deemed to be in the range of 10-200 kg p.a., which implies discharge to the aquatic environment after passing through storm drains or treatment in sewage plants of around 2.5-36 kg p.a. Considerable uncertainty surrounds these figures, as the data are based on Dutch and Swedish studies, which can be based on the field system design that differ from those in Denmark. A new study shows that many steps have been taken in Denmark to avoid the spread of rubber granulate to the environment through open fences, seepage and sealed drains, for example. It can therefore be expected that discharge to the aquatic environment of rubber granulate is at the low end of the range.

Based on the above figures for mass balance, a total mass balance for rubber granulate has been calculated and is presented in Figure 1.

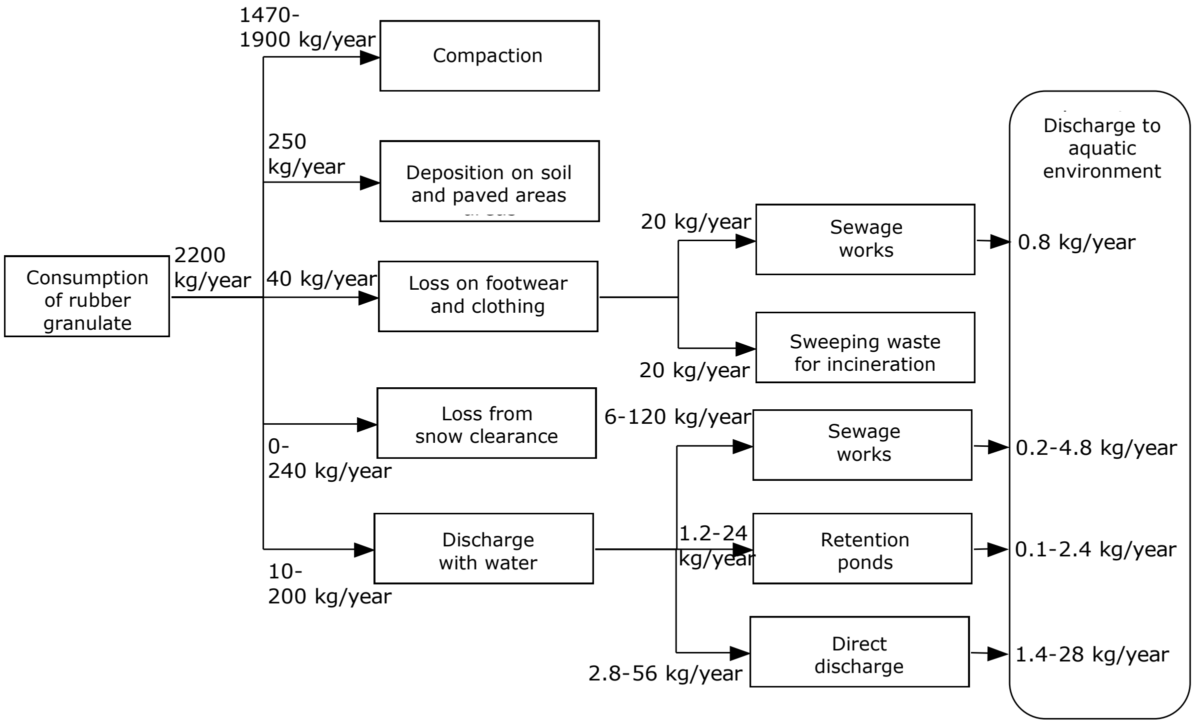

Figure 1 Breakdown of mass balance for rubber granulate after inclusion of the latest literature. The figures are based on best estimate, referring to measurements and assessments, but are subject to considerable uncertainty. To achieve reliable figures, further measurements are needed.

The large span indicate that the study is based on very few measurements, and more extensive measurement programmes are needed before a final conclusion can be made on the spreading patterns of rubber granulate – and the quantities for each pattern. The estimated mass balance is thus a best estimate, based on available data.

2 Background/breakdown

Genan A/S asked the DTI to perform critical evaluation of mass balance for rubber granulate from artificial turf fields, focusing on loss to the environment in the form of rubber, especially discharge to the aquatic environment.

The objective of the project is to perform a literature review of national and international literature concerning the spread of rubber granulate from artificial turf fields to the environment, with the aim of obtaining greater understanding of the same.

The literature review concerning the routes taken by rubber granulate, especially to the aquatic environment, focuses on the latest literature, which is primarily based on Danish, Norwegian, Swedish and Dutch studies. Other countries have not yet begun to focus on the issue to the same degree. The review will also look at a report written by Lindberg

International in 2018 for Genan, with regard to: 1) estimating the amount of rubber granulate used to maintain fields in Denmark (infill), and 2) obtaining an understanding of maintenance activities on artificial turf fields in Denmark. The report is based on contact with 81 clubs with 89 artificial turf fields, equivalent to 26% of the total in Denmark.

The literature review also includes a new data collection for 256 artificial turf fields in Denmark performed in 2018, using a range of parameters important to the spread of rubber infill (see Appendix 1).

The study covers field size, amount of rubber granulate infill and sand infill, infill type (ELT, TPE, EPDM), field system design (including the use of PAD or E-layers), limiting measures designed to prevent the spread of infill to the environment, and details concerning water drainage.

The background to Genan's requirement for a critical review of the literature is that the company wants an update of the mass balance for rubber granulate, based on the most valid measurements and evaluation of their spreading patterns.

The literature review and evaluations focus exclusively on '3G fields' (3rd generation), which are by far the most common type of artificial turf fields in Denmark. 3G fields have a built-in drainage system at the bottom. The synthetic grass usually consists of polyethylene fibres attached to a perforated backing, which can also be based on polyethylene to make recycling of the carpet easier. Infill in the form of granulate and sand is used between the fibres to stabilise them, and to achieve the desired playing performance. The lifetime of artificial turf fields in these calculations is presumed to be an average of 10 years.

An evaluation of the amount of particles formed by abrasion of the synthetic grass fibres and their possible spread to the environment is not included in this literature review.

Neither is any evaluation of sand compaction included.

3 Mass balance for rubber focusing on discharge to the aquatic environment

The DTI performed a detailed evaluation of the mass balance for microplastics (exclusively in the form of ELT rubber granulate from tyres in this study) to be able to make a more extensive evaluation of the spreading patterns of rubber granulate into the environment based on the literature, see Figure 2.

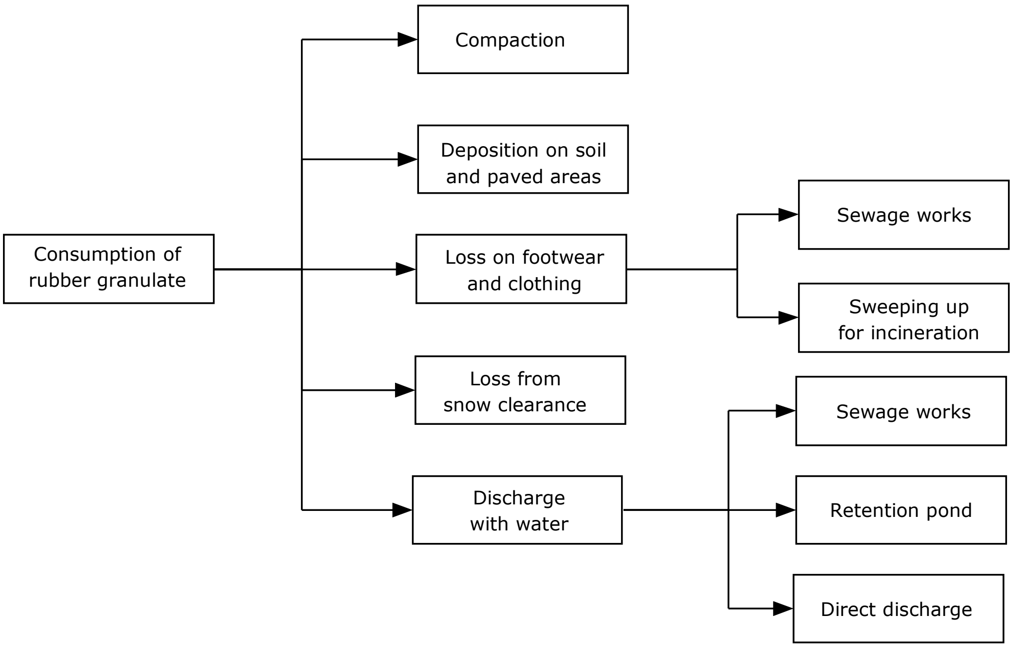

Figure 2 the spreading patterns of rubber granulate.

We did not evaluate discharge of rubber particles to the groundwater in the project, as this is expected to be negligible.

3.1 Consumption of rubber granulate

It is hard to compile precise figures on how much rubber granulate is added to artificial turf fields annually, as the variations between fields and maintenance routines is considerable. This is due to such factors as the weather (snow and rain), intensity of use and the field structure, e.g. whether a shock-absorbing underlay is used (shock PAD), which is foamed plastic, or an E-layer, which is rubber granulate with polyurethane as binder. Experience has shown that a smaller amount of rubber granulate infill is required on fields with PAD and E-layer underlays, as both types help to create elasticity, preventing the rubber from compacting to such a high degree. Shock-absorbing PADs and E-layers are typically used when expensive infill is required, such as EPDM and TPE granulate (IVL C 183) to reduce compaction and thus the need for infill. But PADs are also used where infill based on ELT granulate is used. A new study of practice in Denmark shows that approx. 16% of 256 fields use PADs, and a further approx. 23% use an elastic underlay (E-layer). Because approx. 90% of fields have ELT infill, a significant number of them use an elastic underlay to reduce compaction and thus reduce the amount of infill.

Surfaces are often filled up with infill leaving 15-20 mm of the synthetic fibre projecting. REf = Smart Connection Consultancy – January 2017 (www.smartconnection.net.au).

The fact that different practices are used in different countries with regard to maintenance should also be taken into consideration, along with the differences in weather referred to earlier having an effect on the amount of rubber granulate used for infill. Finally, the age and the system design of the fields can also influence the need for infill.

Extra infill can be required only a few months after a field is first used due to compaction (to compensate for the infill being compacted by use, leaving insufficient infill to support the fibres sufficiently). The need will increase when moisture is present during installation.

Compared to installation and running costs, the costs of refill are modest, because the use of infill on that basis can be higher than needed in relation to the playing performance of the fields.

This literature study found the following sources stating annual supplied amounts of rubber granulate infill in Denmark, Sweden, Norway and Holland.

Table 1 Amounts of rubber granulate infill per annum. Data in the table are based on full size fields.

Source	Country	Field/age	Material	Low kg p.a.	Ave. kg p.a.	High kg p.a.
(Kjær, 2013) and (Lassen, 2015)	DK	DBU – estimate	ELT	3,000	4,000	5,000
(Lindberg, 2018)	DK	Data from 89 fields	ELT		2,200	
(Wallberg, 2016)	S	A 2 x 11 player field	EPDM	3,000	3,500	4,000
(Magnusson, 2017)	S			2,000	2,500	3,000
(Hofstra, 2017)	NL	Rotterdam/1	ELT		580	
(Hofstra, 2017)	NL	Amsterdam/9	ELT		2,200	
(Hofstra, 2017)	NL	Hoogeveen/10	ELT		0	

A recent Danish study (Lindberg, 2018) conducted a survey of 81 clubs with 89 artificial turf fields, equivalent to 26% of the total in Denmark. Based on the results of that study, an average amount of rubber granulate infill of 2.2 tonnes p.a. is used, including weighting for the 29 fields which had not used infill. This amount is lower than that given in (Kjær, 2013) and (Lassen, 2015).

The amount of infill given in (Lindberg, 2018) is based on data from the three Danish suppliers of rubber granulate, which shows that they sold 590 tonnes of infill material in 2017 for maintenance of existing fields. The clubs surveyed used on average 2.2 tonnes p.a. per field, which equates to total use in Denmark of 750 tonnes p.a. for maintenance purposes. The suppliers project infill use to be 2.5-5 (3.75) tonnes/field/p.a. (Lindberg, 2018). The recommended annual addition of infill is thus approx. 70% greater than that stated by the sports clubs surveyed. The figure stated of 2.2 tonnes refill per year per field is regarded as a more valid basis from which to work than the recommended figure.

A Swedish study (Magnusson, 2017) states a typical infill quantity per field of 2-3 tonnes per field per annum. The amount is based on enquiries made to different local authorities.

The amount stated in a Dutch study (Hofstra, 2017) is from 0-2,200 kg p.a. for three fields. Given the limited number of fields in the Dutch study, it is deemed to be impossible to generalise based on the Dutch pattern of use, but it does at least show that there are considerable variations in practice with regard to infill granulate consumed.

Overall, the best data to use moving forwards is from the Danish study, which stated average use of 2.2 tonnes/field/p.a. (Lindberg).

3.2 Compaction

After the initiation of the use phase for artificial turf fields, they go through an ageing effect caused by the weather and the activities conducted on them. The latter in particular causes ageing due to the mechanical effect applied by the players.

Play on the field causes an increase in density due to compression of the infill. As stated earlier, compression in this context is referred to as 'compaction'.

The weather (and particularly rain) is deemed to accelerate compaction, as water acts as a lubricant on rubber, enhancing the process in which rubber granulate particles can slide in relation to each other and compact (stma.org, 2018).

Ageing over time is indicated by increasing hardness of the field, and a decline in playing performance. FIFA has drawn up standards for playing performance, which are contingent on whether the fields are to be used for community and amateur football, or professional-level football. There are different methods for measuring hardness (F355, 2016). Playing performance is tested by measuring the resilience of a ball dropped from a given height. An artificial athlete is also used to measure playing performance compared to concrete as a non-elastic reference.

A major contribution to ageing is the compaction of the rubber granulate during use. Compaction redistributes the granules, reducing the amount of space between them and increasing the density. Sand will also get mixed in during the process of compaction.

If all the spaces of enclosed air could be removed, the resultant density of the granulate would be approx. 1.16 g/cm^3, which is an average density for tyre rubber. This is of course impossible, due to the surface structure of rubber granulate, and because rubber cannot be compacted.

The typical density of ELT rubber granulate used for artificial turf infill is approx. 0.45 g/cm^3.

According to (Flemming, Forrester, & McLaren, 2015) based on loading cycles in laboratory experiments, rubber granulate could be compacted from 0.45–0.50 g/cm^3 (loose state) to a density of 0.65–0.73 g/cm^3 (compacted state).

The reference (Flemming, Forrester, & McLaren, 2015) is the only source that goes in-depth with regard to factors involved in the compaction process. This group of scientists conducted measurements of density, including:

- Loose state
- after compaction using a roller a given number of times (0, 50 and 500 times)
- after 10 drop measurements (equivalent to stamping)
- after raking the study field.

The drop measurements were performed according to a standard method, by dropping a 20 kg weight a distance of 55 mm attached to a spring with an accelerometer. The measurement determines reduction of force when the weight is stopped by the rubber granulate, and return force when it rebounds. The actual test simulates the field being compacted by players and then raked. The article states that the loose density was 0.46 g/cm^3.

After compaction by being rolled 50 times, density rose to approx. 0.53 g/cm^3, and after being rolled 500 times, to 0.64 g/cm^3. Density after drop measurements can rise to 0.73 g/cm^3, and in the event of decompaction, 0.46 g/cm^3 was achieved without rolling, 0.47 g/cm^3 after being rolled 50 times and 0.51 g/cm^3 after being rolled 500 times.

The relative changes in density for compacted to decompacted state are 0% without rolling, 12.7% after rolling 50 times and 25.5% after rolling 500 times. Consequently, the test shows that density slowly increases in laboratory-simulated compaction/decompaction. Increases in density are non-linear.

Whether the data can be transferred to full-scale fields is contingent on the maintenance regimes used. Changes were thus measured in the study on four artificial turf pitches in relative density (compacted vs. decompacted state) from 8.2 to 14.6% (approx. 3-4 mm change in layer thickness, although including sand). This more or less equates to the effect of being rolled 50 times in the laboratory experiment. The measurements have considerable standard deviation of 1.6-2.3 mm in layer thickness, which can be expected on a field on which infill moves around during play, or if the granulate is not evenly distributed when the field is established.

Due to compaction, the maintenance of artificial turf fields must include raking to loosen the granulate, improve elasticity and thus enhance playing performance. Raking also maintains the ability of the field to drain.

Concerning raking, (Lindberg, 2018) states that 93% of 81 Danish clubs surveyed use raking as part of maintenance, which is why the figures with raking should be used for Danish conditions.

3.2.1 Theoretical considerations concerning the effect of decompaction and the addition of infill

Estimates concerning the effect of compaction etc. have been compiled in the following.

The calculations presume the typical use of a total amount of infill of 110 tonnes per field (Lassen, 2015) with a loose density of 0.46 g/cm^3 before compaction, and a typical infill layer thickness for a 3G field of approx. 30 mm (Flemming, Forrester, & McLaren, 2015). Given a rate of infill addition of 2.2 tonnes p.a., as found in (Lindberg, 2018), the layer thickness changes by 0.6 mm per year (providing there is no loss), and the field is raked to around the same layer thickness/density each year. Such a minor difference cannot be detected.

But we do know that a certain amount of loss occurs to the surroundings due to use of the field. Given that loss, the amount that accumulates on the field is reduced. A Dutch study (Hofstra, 2017) estimates such loss to be around 330 kg per field, while (Lassen, 2015) presumes it to be 50% of infill added.

If we presume a loss equivalent to the Dutch study of 330 kg p.a., accumulation of infill on the field will increase by 17% over 10 years (5 mm higher layer if density is maintained by raking). Given a loss of 50%, equivalent to 1,100 kg p.a., accumulation will equate to 10% over 10 years (3 mm higher layer if density is maintained by raking). An accumulation of 3-5 mm is deemed in both instances to be measurable with high accuracy, but is not deemed to be sufficient for the person responsible for operation and maintenance of the field to notice any difference.

(Flemming, Forrester, & McLaren, 2015) states that the density – in a laboratory experiment – can rise over time, based on the number of times rolling and raking are performed. However, there are no data to indicate whether a full-scale field's original density is completely restored by normal practice with raking. Very little compaction is required to reduce layer height by the 10-17% added over 10 years. Consequently, laboratory studies have shown that artificial turf fields can be relatively easily compacted by 17% if rolled 50 times (0.46 to 0.538 g/cm^3).

If the final mass balance from Figure 1 is used to determine compaction, it can be calculated that compaction must equate to 1,460 kg p.a. – approx. 1,900 kg p.a. of accumulated material, which means that compaction of 13-17% is required to maintain the same layer height after raking.

The calculated figures for compaction via the mass balance are deemed to be slightly higher compared to the measurements taken by (Flemming, Forrester, & McLaren, 2015). The slightly higher figures can also be the result of a slight growth over the years in the granulate layer that cannot be easily registered by the ground staff. Please also note that the fact that the distribution of infill on various fields will differ can also play a role. Finally, the above evaluation does not include possible compaction of the underlying sand layer. The figures calculated for compaction are therefore deemed to lie within a realistic range.

A better estimate can only be achieved by detailed studies, which look in particular at loss of granulate to the surrounding areas and to drainage. Based on measurements of the amount of infill on the field before and after a given period of time and infill amounts added during that period, verification can be performed of whether the mass balance for the field is correct.

3.3 Deposits on the ground and paved areas

Infill rubber granulate can be lost from artificial turf fields to the immediate surroundings (which can be in the form of e.g. grass belts and slabbed paths). The Dutch study (Hofstra, 2017) measured loss to grass belts and paved (slabbed) areas for three Dutch fields.

Areas of 1 m^2 were studied on the slabbed areas for infill amounts. Samples were taken on grass belt areas 0.5 m wide and 5 cm deep.

Total measured infill spread to slabs and grass was 260-300 kg p.a.

Table 2 Loss of rubber granulate to the immediate surroundings.

Field	Loss to grass belt kg p.a.	Loss to paved area kg p.a.
Rotterdam	260	1
Amsterdam	240	60
Hoogeveen	240	40

(Lindberg, 2018) includes quotations from interviews. Some of the interviewees stated that they sweep up the rubber granulate found on slabs, and if the granulate is clean, put it back on the field again.

The loss of deposited material to the soil and paved areas is estimated to be about 250 kg p.a. per field, but this is based on very few measurements, and is a very uncertain estimate.

A large number of fields have been enclosed or partially enclosed by open fences in Denmark (over 90% – see Appendix 1). Infill barriers have been installed around approx. 20% of the fields, with 'sluice gates' installed at the exit for approx. 20% of them. It can therefore be expected that loss to the environment cannot be higher than the approx. 250 kg p.a. recorded in the Dutch study.

However, field measurements are needed to verify loss from Danish fields.

3.4 Loss on footwear and clothing

There is considerable divergence between the literature sources found with regard to the amount of infill granulate lost from the fields through it adhering to footwear and clothing.

But one thing most do point out is that granulate adheres to footwear and clothing in wet weather in particular.

Some of the rubber particles will end up in the changing room, where they will be swept or vacuumed up and deposited as rubbish. It can also be expected that other particles will fall off footwear and clothing on the way to or in the home, where they will be swept or vacuumed up or washed off, and thus end up in a sewage plant, where most will be retained.

Studies have been performed Norway, Sweden and Holland.

The Norwegian study is by far the most thorough of the three (Forskningskampanjen, 2017) for amounts of rubber particles collected. 286 schools from 144 local authorities took part in the study. Data is based on 592 games on 343 fields and with 12,591 players. After each game, the players collected all particles from footwear and clothing, and measured the amount in a measuring jug. The results varied from 1.4 ml in dry weather to 3.7 ml in wet weather, with an average of 2 ml per player per game. This equates to approx. 0.9 g per player per game. The data converts to a loss of 40 kg per field per annum.

In the Dutch study (Hofstra, 2017), a loss of 12 kg per field per annum was calculated based on loss from all players in a junior A-team. In the Swedish reference (Wallberg, 2016), which was not an actual study, a loss of 10 grams per player per game was presumed. Based on that figure, there will be a loss of 440 kg per field per annum. The presumed loss is deemed to be excessive when compared to the Norwegian study.

It can be generally concluded that the Norwegian study is the most valid on the basis of the extensive statistical data produced. The loss from footwear and clothing is therefore evaluated as being 40 kg per field per annum.

3.5 Loss from snow clearance

Snow clearance is referred to by several sources as a possible and significant reason for the removal of infill from artificial turf fields. But there are also good suggestions for how this cause of spreading can be limited.

It is hard to put concrete figures on the loss of infill from snow clearance, as the amount of loss is heavily contingent on how much snow falls in a given year, and there can be very large regional variations in snowfall in a single country. Artificial turf fields are used to a large degree in the winter, when fields composed of natural grass are closed. There are some artificial turf fields that are closed in the winter.

The maintenance practice applied when individual fields are covered by snow can also vary considerably. The regime used can depend on a nearby place to put snow removed from the field, where it can temporarily remain until it melts. Another important factor is the chances of avoiding the snow pile being soiled during the storage period (leaves, other vegetation etc.).

Suppliers of artificial turf fields include snow clearance as part of their general instructions for maintenance. They generally recommend using a snow blower, which makes the least impact on the field.

Powder snow can be removed with a snow machine with rotating brushes, but these are not an option for heavy, wet snow. A snowplough may be necessary in such circumstances. A snowplough cannot be too heavy and must operate at least one centimetre above the fibre height. A snowplough must also be fitted with a rubber layer or other soft material.

In the event of very large amounts of snow, the instructions recommend seeking professional help.

There are six quotations in (Lindberg, 2018) concerning caring for artificial turf fields in the winter. One quotation from interviews with 81 clubs states that snow is shovelled over onto a heated 20 x 20 metre artificial turf field. When the snow melts, infill is brushed back onto the field. One of the interviewees also estimated that 1 tonne of infill is lost on average every year due to snow clearing and via adherence to footwear and clothing.

Snow is generally removed in different ways from the fields, and when it has melted, the infill removed with the snow is brought back to the field. One source states using a snow blower, which throws the snow well away from the field, which means that infill contained in the snow cannot be reused on the field. The use of snow blowers is not recommended by several sources.

SWECO state in (Wallberg, 2016) that every time snow is removed using a snow plough, approx. 20-30 litres of infill are removed, but also add that some of it is returned. The amount of infill removed is much bigger for 'soft' snow. SWECO estimate that 11% of infill loss from artificial turf fields is due to snow clearance, but that the amount can vary enormously from field to another, depending on activity levels. The loss of infill that SWECO arrived at is based on interviews with groundkeepers for artificial turf fields in different Swedish local authorities, and by presuming that 1/3rd is returned to the fields and the 2/3rds end up as waste.

Many Swedish fields are not used in the winter, and loss figures for them are therefore zero. The field that was the object of Widström's study was laid in 2013 and is well-cared for. There was no need for infill before June 2016. The field is located in Södertalje, not far from Stockholm.

The conclusions drawn in Planmiljø 2018 are highly interesting (B. Bauer et al., 2018).

It states on page 11 that maintenance of artificial turf fields in Norway is a very important factor in relation to the spread of microplastics in the form of infill material, especially in the winter. Whether the fields are located in the cold or the warm part of Norway is of considerable importance. The fields close to the coast receive the least snowfall and lose the least infill, whilst the northerly, inland fields lost granulate due to snow clearance.

It also states that four of the coastal fields have been in operation for 10 years, and still weighed exactly the same when recycled as when they were new, and that infill was never added. The amount of infill used on fields in relatively warm, coastal areas is therefore low. The cold, northerly fields need approx. 10-20 times more infill added as a result of snow clearance. The report states that one way of preventing large-scale loss is better control of snow clearance. No actual mass balance is given though, nor the amounts of infill added per field per annum.

It has to be concluded that, overall, inappropriate snow clearance (e.g. the use of snow blowers) can mean a relatively high loss of granulate in hard winters with a lot of snow. Given the milder winter climate predicted for Denmark, it can be expected that loss of infill from Danish fields will be reduced in the years to come, in line with Norway's experience on its coastal fields. It is relatively easy to introduce maintenance routines for snow clearance that eliminate the loss of infill (Environment Protection Agency guide, 2018) (P. Sundt, 2016).

It is estimated that loss from snow clearance can fall in the range of 0-11% of infill added.

3.6 Discharge to the sewage system

When it comes to spreading of rubber granulate to the storm drain system, the knowledge found in the literature is very unreliable, as it is based on estimates and a very small number of measurements of the amount of sediment in drains and ditches, which were not performed systematically, and that do not cover the full water flow. One source did measure in the water flow, but it is uncertain whether that source includes the full discharge of rubber granulate. There is also uncertainty concerning the system design of foreign fields in relation to Danish, nor were measurements performed on the Danish fields. Factors concerning seepage and open/closed drains in particular can have considerable influence on the discharge of rubber granulate to the aquatic environment.

Literature from Denmark, Sweden and Holland was included in the evaluations. The study from Appendix 1, which looks at the system design of Danish fields with regard to discharge of water, is also included.

3.6.1 Drainage conditions in Denmark

The study of the structure of Danish fields shows that 85% of rainwater seeps into the ground or is drained (Figure 3). Most of the rainwater that falls on sports fields will seep through, which means very minimal discharge of rubber granulate can be expected.

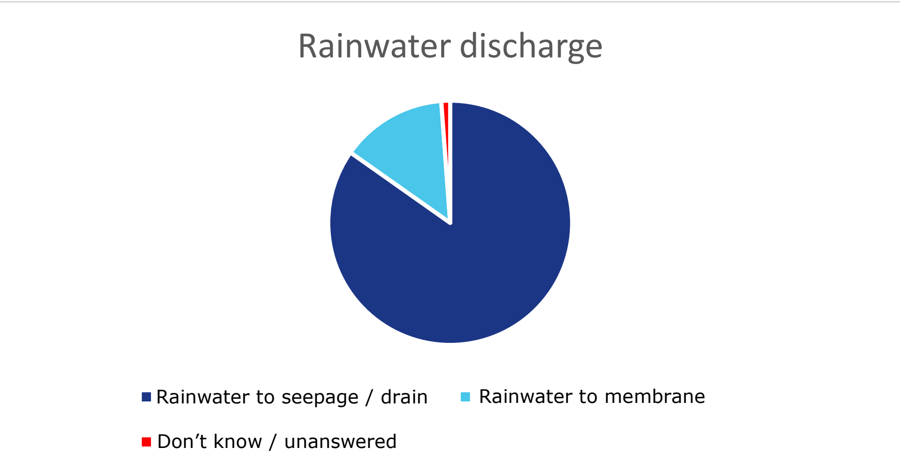

Figure 3 Discharge of rainwater.

18% of survey respondents state that drains go to the sewers, which means that 82% is discharged via rainwater (Figure 4). Approx. 50% of rainwater is discharged directly in Denmark, with the other 50% drained to the public sewers. The details given mean that a total of 60% of the water is discharged to the sewers and 40% to the storm drains.

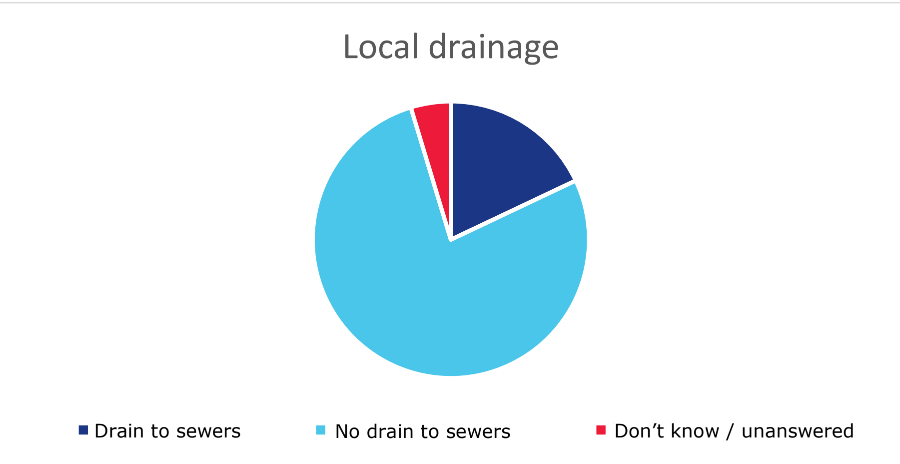

Figure 4 discharge to the local storm drains.

With regard to the drainage of rainwater, 25% of respondents to surveys said that water goes to a retention pond, and 41% state that it is drained directly to a recipient. 33% of respondents gave no answer (Figure 5). (Lassen, 2015) presumes that 30% is discharged to retention ponds, which is deemed to be a representative presumption, especially as there were only a few responses with regard to rainwater discharge.

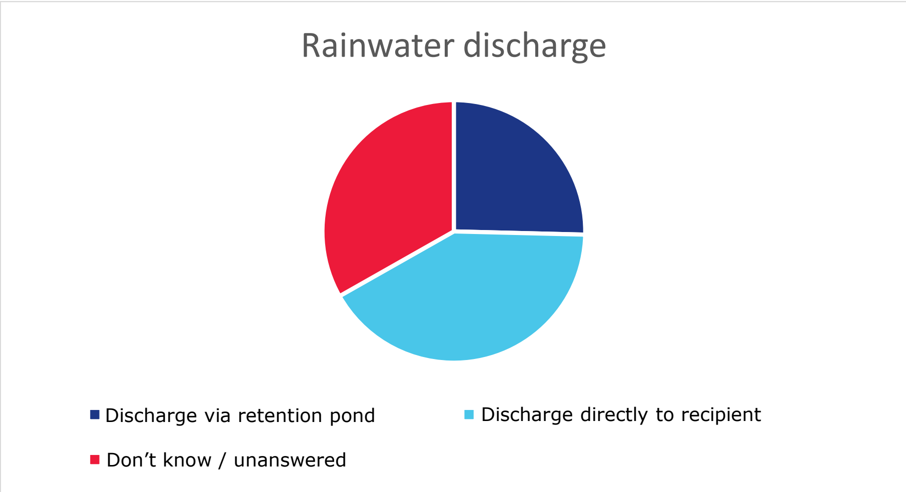

Figure 5 Discharge via retention ponds/directly to recipient.

The study in Denmark also shows that only about approx. 4% of the fields were observed to have open drains. On that basis, it can be concluded that rubber granulate cannot enter the drainage system in the vast majority of cases, and any water drained from artificial turf fields is primarily that which has seeped through.

A very low level of rubber is expected to pass through the filter layer, but there can be holes caused, for example, by earthworms in the soil. The primary sources of rubber granulate in the aquatic environment in Denmark will therefore come from:

- surface runoff of rubber granulate directly into ditches etc. during very heavy rain
- the effects of wind, when e.g. rubber granulate is adsorbed on leaves, which are blown into ditches etc. by the wind.
- loss from machinery used to care for artificial turf fields, and discharged to rainwater drains, for example, which are not linked to the artificial playing field.

3.6.2 Measurements of granulate discharge to the sewers

The most extensive work done to identify the flow of microplastics through the drainage system is COWI's report from 2015 (Lassen, 2015) compiled for the Environmental Protection Agency. The report is based on theoretical evaluations which in turn are partially based on measurements and on literature studies. The report conclusions are also used in COWI's report on artificial turf fields from 2018 (Kjølholt, 2018), which estimated that total discharge of microplastics from artificial turf football pitches (infill granulate and fragments dislodged by wear from artificial grass fibres) is 450-790 tonnes p.a. Infill granulate is estimated to have a rate of discharge to the environment of 380-640 tonnes p.a. The calculations were performed based on 254 fields in Denmark.

The same report (Kjølholt, 2018) deems the primary spreading patterns for total microplastic from artificial turf fields to be:

- Surrounding soil (85-90%): 360-751 tonnes p.a.
- Drainage to the sewers (covers rainwater and waste water) (5-20%): 23-158 tonnes p.a.
  - Of which, to surface runoff: 1-9 tonnes p.a. (based on 3–6% of microplastic is discharged to the aquatic environment).

The Dutch study (Hofstra, 2017) measured the amounts of infill removed with surface run-off. 10 kg p.a. for the Amsterdam pitch and 6 kg p.a. for Hoogeven were measured. The measurements were performed by mixing samples of sludge/surface soil from ditches around the fields into a combined sample that could be analysed for rubber particles. These figures thus represent the rubber found after sedimentation in the catch basin. It is not known if smaller particles can escape in the event of very heavy rain. Measurement using a form of filter would be more precise.

(Wallberg, 2016) estimates (but does not prove) that 750 kg ends up in drains and waste water from a football club with four artificial turf fields (approx. 187 kg per pitch). This amount is solely based on the amount the players remove on their footwear and clothes. No account was taken of whether compaction occurs. The loss is deemed to be highly over-estimated compared to the Dutch measurements of 6-10 kg per pitch p.a.

Extensive fieldwork was conducted as part of a final thesis at Stockholm University (Widström, 2017) on four artificial turf fields in the municipality of Södertälje, to measure sediment in storm drains. The measurements were only performed on the sediment in the catch basins, and there is no information on whether (or over how long) the sediment had built up, nor on how much rain had fallen while the sediment accumulated. The measurements can therefore only be used to demonstrate that rubber granulate is discharged to the sewers, and that some of the granulate is caught in the catch basins installed. The measurements show that 0.7–43 kg granulate can accumulate per catch basin. The catch basins primarily receive runoff from the artificial turf fields. The measurements cannot be used to arrive at a precise conclusion on the discharge of granulate per annum, as the period of time for collection of the granulate in the catch basins is not mentioned, but they can give an indication that up to 43 kg can accumulate per catch basin, which, given there are 4 such basins, gives an amount of around 200 kg. These measurements do not include evaluation of the flow coming from the fields after sedimentation in the catch basins.

A master's thesis from the KTH technical university in Stockholm (Regnell, 2017) also found considerable variations by taking measurements with a microscope, concluding that maximum 340-370 kg p.a. can reach the drains.

Simon Magnussen of Luleå Technical University in Sweden (Magnussen, 2017) conducted a study of runoff from artificial turf fields. The study evaluated the content of ELT rubber granulate in drain water (after sedimentation in a catch basin) based on zinc concentration, and presuming that zinc only originates from ELT rubber. The study found that maximum 0.7 kg rubber granulate runs off per field per annum. This figure is much lower than that found elsewhere from measurements of sediment in catch basins. It is an expression of that element of discharge that does not settle in catch basins and ditches, and thus can be expected to discharge directly into the aquatic environment. But it is uncertain whether, for example, particles that are washed away during very heavy rain are included in the analysis, and the calculation can therefore be considered as an underestimate of discharge.

A Norwegian report (P. Sundt, 2016) has studied microplastics, and based on the Danish evaluation data estimates that approx. 70 kg is lost to water per field.

Overall, there is considerable variation in the measurement results for discharge of rubber granulate to the sewers. The measurements vary from 6 kg per field p.a. to several hundred kg per field p.a. There is considerable uncertainty as to how the figures should be interpreted because of variation in local conditions, such as differences in field system design and drainage, which influence the measured discharge of rubber granulate. If the storm drains have closed drains, it will not be possible to lose rubber granulate directly into them. Accumulation through seepage will also minimise loss to the sewer system, but there can still be minor concentrations of rubber in the drain water and rubber granulate can be discharged to ditches with runoff water or by the wind. Finally, machines can carry rubber granulate from the fields to paved areas. It is estimated that loss to the sewers amounts to 10-200 kg per field p.a. This range is based on foreign measurements, but a lot has been done in Denmark to limit spreading to soil and the aquatic environment, and Denmark is therefore expected to be at the lower end of the range.

The next section evaluates how much of that loss gets into the aquatic environment.

4 Mass balance based on best estimate from the literature

4.1 Evaluation of the discharge of rubber granulate to the aquatic environment

COWI presumes the following breakdown of drain flows: 50% of the runoff from artificial playing fields goes via combined sewer pipes to sewage plants, whilst 50% is discharged via storm drains, as it is presumed that half of the Danish sewer system is separated. Approx. 30% of the rainwater discharge goes via retention ponds, where sedimentation occurs before discharge to the recipient.

The Danish study of artificial turf fields shows that 18% of all water is piped directly to the sewer, but in Denmark, 50% of rainwater goes to the public sewers and thus to the sewage plant. The total therefore for artificial turf fields will be approx. 60% discharged to the sewers (sewage plant) and approx. 40% to storm drains, see Figure 6.

The latest measurements of the removal of microplastics in sewage plants indicate that they remove approx. 99% of microplastics, (Løkkegaard, 2017). The sewage plants are particularly efficient at removing particles larger than 300 µm. However, unintentional discharge does occur from the storm drains during very heavy rain. This discharge is estimated to comprise 3% of the total amount of sewage.

The measurements of discharge to the storm drains all indicate that sedimentation of granulate occurs in catch basins and ditches. Around one third of storm drain discharge in Denmark also goes through wet retention ponds, which are dimensioned to remove particles greater than 10-100 µm (Technical Guide, EU LIFE-TREASURE, 2009), which means that sedimentation of rubber granulate occurs in the retention ponds, which is why the discharge of rubber granulate through such ponds can be deemed to be minimal. It is estimated that 10% of rubber granulate ends up in the recipients, and 90% is retained in the retention ponds.

All that's left is to evaluate direct discharge. There is considerable uncertainty as to how much settles in catch basins and how much is discharged with rainwater. This breakdown will depend very much on rain intensity, and municipal discharge routines for storm drains.

Only specific measurements will be able to determine the actual movements of rubber granulate in the storm drains. It is estimated that 50% of rubber granulate settles in catch basins and does not reach the aquatic environment.

Figure 6 shows an overview of percentage breakdown of water flows from a Danish artificial playing field.

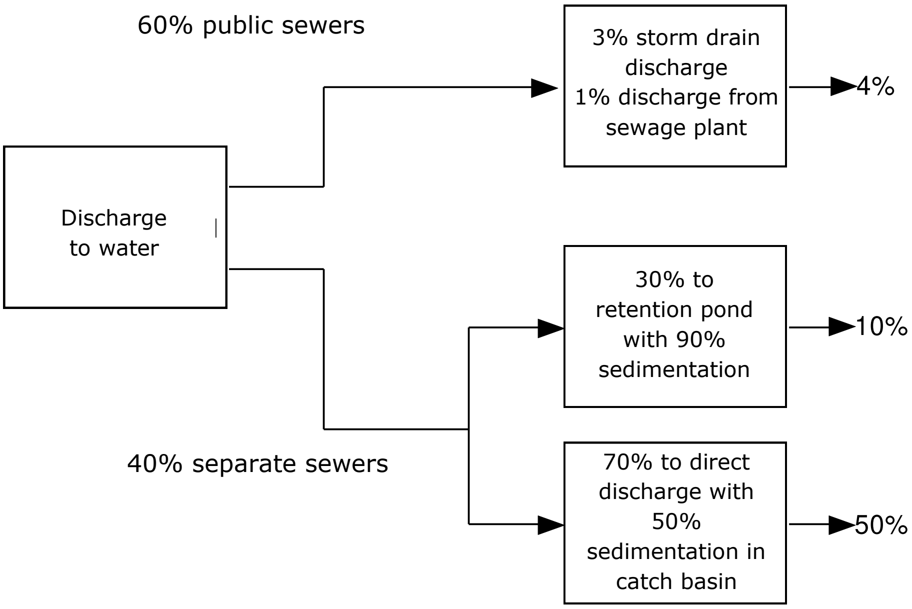

Figure 6 Breakdown of water flows through the sewers and estimated degrees of removal of rubber granulate in technical plants.

Based on the criteria given in Figure 6, discharge of 10-200 kg p.a. per field to becomes total discharge to the aquatic environment equivalent to 2.5-36 kg p.a. per field. This is equivalent to discharge of 0.8-12 tonnes p.a. for the 340 fields in Denmark in 2017, which is comparable to the figures evaluated in Denmark, for which discharge to the aquatic environment has been estimated at 1-9 tonnes p.a. based on 254 fields (Kjølholt, 2018).

4.2 The total mass balance for rubber granulate

The total mass balance for rubber granulate is illustrated in Figure 7.

The mass balance should, however, not be taken at face value, as no measurements have yet been taken of discharge of rubber granulate in Denmark, and only by doing so can it be determined what levels of concentration are involved.

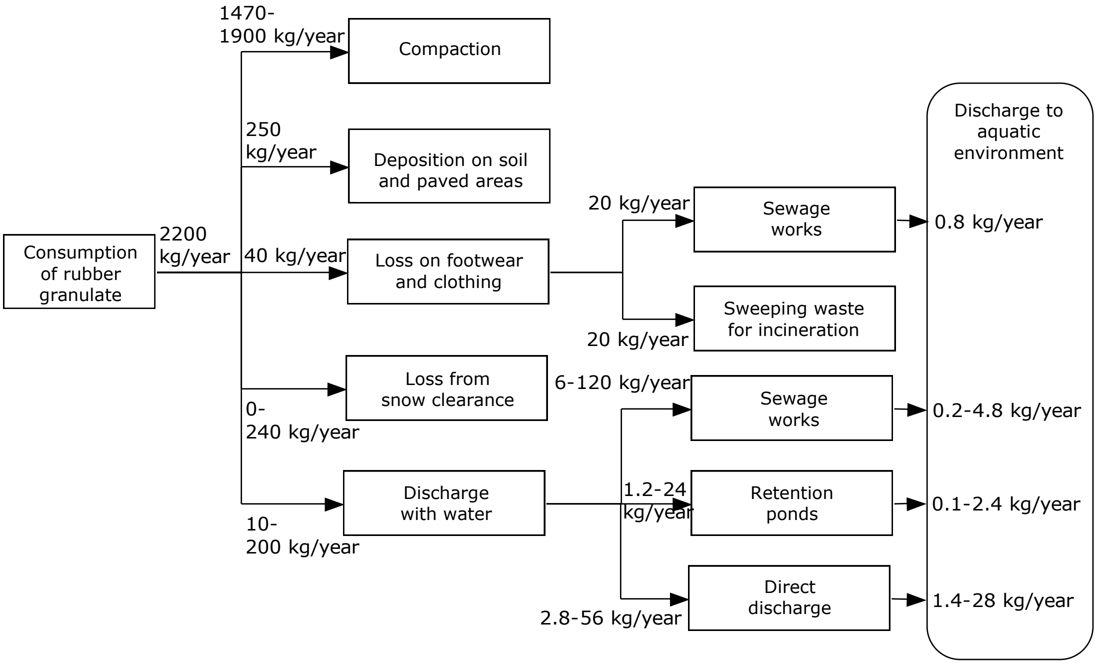

Figure 7 Distribution of mass balance for all Danish artificial turf fields for rubber granulate after inclusion of the latest literature. The figures are based on best estimate, referring to measurements, but are subject to considerable uncertainty. To achieve reliable figures, further measurements are needed.

In the mass balance in Figure 7, rubber granulate that accumulated by compaction is calculated as added infill minus loss, and loss is the sum of:

- deposits on soil and paved areas
- loss from adhesion to footwear and clothes
- loss from snow clearance
- discharge with water.

Based on the figures in the report, it can be concluded that maximum estimated compaction is equivalent to 2,200 – (250+40+0+10) = 1,900 kg. This was calculated on the basis of the latest figures in the ranges from the mass balance.

Based on the mass balance, the minimum compaction is equal to 2,200 – (250+40+240+200) = 1,470 kg.

Depositing on soil and paved areas is based on Dutch studies (Hofstra, 2017).

Loss through adherence to footwear and clothes is based on Norwegian studies (Forskningskampanjen, 2017).

Maximum loss from snow clearance is based on Swedish studies, which state that 11% of the loss of infill can stem from snow clearance, but there are also fields which are not used in the winter, and therefore do not lose infill from snow clearance (Wallberg, 2016).

The lowest values in the range for discharge of amounts of water are based on figures from Dutch studies (Hofstra, 2017), but the maximum amounts are based on those found in drains (Widström, 2017).

Abbreviations

ELT: End of Life Tyres

SBR: Styrene-Butadiene Rubber

EPDM: Ethylene Propylene Diene Monomer rubber

TPE: Thermoplastic Elastomers

PAD: Foam plastic underlay

E-layer: Elastic water-permeable underlay consisting of rubber granulate bound with polyurethane

Microplastic: Rubber granulates/particles are included in the definition of microplastic

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Appendix 1 Questionnaire concerning the structure of Danish fields

Genan has gathered data from 256 fields in questionnaires completed by the following suppliers and consultants:

Source of data	No. of fields	Type
WSG fields	50	Supplier
Orbicon	63	Consultant
Jess Wessberg	35	Consultant
NKI	34	Supplier
Sportsbyg	12	Supplier
Dines Jørgensen & Co	62	Consultant

The data received has been processed by the Danish Technological Institute (DTI). Table 1 shows data for infill used and artificial turf system.

Table 3 Field structures.

	Total	%
ELT	229	89.5
TPE	13	5.1
EPDM	5	2.0
Don't know/unanswered	9	3.5
System without PAD	153	59.8
System with PAD	42	16.4
System with E-layer	58	22.7
Don't know/unanswered	3	1.2

Table 4 shows the average size of the fields and the infill and sand amounts used per field. The average area was determined as 8,865 m^2, which only deviates 1.5% from the area of 8,742 m^2 determined for 89 fields in (Lindberg, 2018)

Table 4 Field sizes and infill/sand added.

	Average	Std. dev.
Field size (m^2)	8,865	3,385
Infill amount (kg/m^2)	11.6	4.5
Sand amount (kg/m^2)	16.0	2.9

Table 5 shows a breakdown concerning the structure of the field that can limit the spread of infill to surrounding areas.

Table 5 Limiting measures concerning the spread of infill to surrounding areas.

	Total	%
Enclosed	211	82.4
Partially enclosed	21	8.2
Not enclosed	14	5.5
Don't know/unanswered	10	3.9
Infill barriers	50	19.5
'Sluice' at exit	46	18.0

Table 6 states the breakdown concerning water discharge.

Table 6 Breakdown concerning water discharge.

	Total	%
Open drains	11	4.3
Storm drain	69	27.0
Rainwater to seepage/drain	217	84.8
Rainwater to membrane	36	14.1
Don't know/unanswered	3	1.2
Drain to sewers	46	18.0
No drain to sewers	198	77.3
Don't know/unanswered	12	4.7
Storm drain to retention pond	65	25.4
Storm drain directly to recipient	106	41.4
Don't know/unanswered	85	33.2