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Microplastics in freshwater sediments: An investigation of stream sediments downstream of artificial football turfs

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Master in Natural Resource Management

Preface

This thesis marks the end of my Master´s degree in Natural Resource Management at the Norwegian University of Life Sciences (NMBU), spring 2018. Writing this master thesis has been a long and exciting journey, which at times also has been very demanding. The process has provided me with in-depth knowledge in the exciting field of microplastics and knowledge about the process of scientific studies and writing.

First, a special tanks goes to my supervisor Susanne Claudia Schneider, and my assistant supervisor Bjørnar Andre Beylich for your support and guidance through this project. This thesis would not have been possible to complete without your help. Furthermore, I would like to thank the Norwegian Institute of Water Research (NIVA) for access to facilities and loan of all kind of equipment I needed to implement my analyses. Working at NIVA has been a great experience in all regards! I would also like to thank Gunhild Borgersen for nice conversations, while I stumbled through sediment samples in search of tiny rubber granulate particles.

Finally, I want to thank June Grassdal Gundersen for your patience and support throughout this process. In times where motivation and desire to work have been low you and Thilde have always been there.

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Abstract

Due to climate conditions and a high demand of playing time there has been a rapid increase in the number of artificial football turfs in Norway in the last two decades. A rising concern linked to these turfs is the use of rubber granulate particles as infill and their possible emission to the environment. Estimations from Norway and Sweden indicate that the spreading of these particles potentially is one of the largest sources to microplastic emissions in the two countries. Presently there is little knowledge about the fate and abundance of these particles in the environment, and it is unclear to which extent granulate particles from artificial football turfs are spread to adjacent streams and rivers.

In this thesis, sediment samples from seven streams in Oslo, Asker and Bærum municipalities were examined, to investigate whether granulate particles from artificial football turfs are released to adjacent watercourses. Sediment samples were taken both upstream and downstream the turfs. 117 sediment samples were analysed, taken from four upstream and 28 downstream sampling stations. Each sediment sample represented a volume of 0,14 litre and was taken from the upper five cm of the sediment. Except three turfs, all the investigated turfs were used during winter time. In addition, they were all connected to watercourses either through drainage pipes or by surface runoff. To extract granulate particles, a combination of sieving and visual identification was used.

In total, granulate particles were found in 85,4% of the downstream sediment samples. The amount of granulate particles varied greatly between the streams and ranged from 0,0008 to 6,67g per sample (equals to 0,006 to 47,3 g/litre). The number of granulate particles ranged from 1 to 1672 particles/sample (equals to 1 to 11830 particles/litre). Generally, there were found more granulate particles at stations located closest to the turfs, compared with those further downstream. However, granulate particles also were found at all upstream stations, as well as up to 4.3 km downstream, indicating that granulate particles have the ability to spread far and “randomly”, i.e. not only downstream along waterways. In addition, it appears that the location of the turfs, winter operations and the placement of snow during winter time is crucial in terms of the amount of granulate particles that are released to adjacent waterways. The results from this study show that spreading of rubber granulate from artificial football turfs to adjacent waterways is a major problem, and measures must be implemented to prevent further spreading in the future.

Sammendrag

På grunn av klimaforhold og en stor etterspørsel etter spilletid har det vært en rask økning i antallet kunstgressbaner i Norge de siste to tiårene. En økende bekymring knyttet til disse banene er bruken av gummigranulat som fyllingsmateriale og de mulige utslippene av granulat partikler til miljøet. Estimater fra Norge og Sverige indikerer at spredning av slike partikler potensielt kan være en av de største kildene til mikroplast utslipp i de to landene. Det finnes i dag lite kunnskap om skjebnen og mengden av disse partiklene i miljøet, og i hvilken grad gummigranulat fra kunstgressbaner blir spredt til nærliggende bekker og elver er uklart.

I denne studien ble det undersøkt sediment prøver fra syv bekker i Oslo, Asker og Bærum kommune, hvor målet var å undersøke om granulat partikler fra kunstgressbaner blir sluppet ut til nærliggende vassdrag. Sediment prøver ble tatt både oppstrøms og nedstrøms kunstgressbanene. Totalt ble 117 sediment prøver analysert, fordelt på fire oppstrøms og 28 nedstrøms prøve stasjoner. Hver sediment prøve representerte et volum på 0,14 liter og ble tatt fra de øverste fem cm av sedimentet. Bortsett fra tre baner, hadde alle banene i studien vinterdrift. I tillegg var alle banene tilknyttet nærliggende vassdrag, enten gjennom overflate avrenning eller gjennom dreneringsrør. For å identifisere granulat partiklene ble det benyttet en kombinasjon av sikting og visuell identifisering.

Totalt ble granulatpartikler funnet i 85,4 % av alle nedstrøms prøver. Mengden i disse prøvene varierte stort mellom de ulike bekkene, fra 0,0008 til 6,67 g per prøve (tilsvarende 0,006 til 47,3 g/liter). Antallet granulatpartikler varierte fra 1 til 1672 partikler/prøve (tilsvarende 1 til 11830 partikler/liter). Generelt ble det funnet flere granulat partikler i prøvene som ble tatt nærmere banene, sammenlignet med de lenger nedstrøms. Det ble også funnet granulatpartikler ved alle oppstrøms stasjoner og opptil 4,3 km nedstrøms. Dette er en indikasjon på at partiklene har muligheten til å spre seg langt og «tilfeldig», dvs. ikke bare nedstrøms for banene. I tillegg, ser det ut til at lokaliseringen av banene, vinterdrift og plassering av snø gjennom vinteren har stor påvirkning på mengden granulatpartikler som spres til nærliggende vassdrag. Dette studie viser at spredning av gummigranulatpartikler fra kunstgressbaner til nærliggende vassdrag er et stort problem, og tiltak må iverksettes så fort som mulig for å hindre videre spredning i fremtiden.

Abbreviations

Plastic polymers

PE	Polyethylene
PE-HD	High-density polyethylene
PE-LD	Low-density polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethanes
PVC	Polyvinyl chloride

Rubber granulate types

EPDM	Ethylene Propylene Diene Monomer
SBR	Styrene Butadiene Rubber
TPE	Thermo Plastic Elastomer

Other

GAM	Generalized Additive Model
NaCl	Sodium Chloride
NIH	Norwegian School of Sport Science
NIVA	Norwegian Institute of Water Research
PAH	Polycyclic aromatic hydrocarbons
POPs	Persistent organic pollutions
SVOCs	Semi-volatile organic compounds
VOCs	Volatile organic compound

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1 Introduction

1.1 Plastics in general

In today´s society, plastic has become indispensable and an essential part of the modern lifestyle. In everyday life, plastic is found in almost every item used: from clothes to smartphones and vehicles to cosmetic products. Plastics are inexpensive, versatile, lightweight, durable and formable. The wide variety of properties results in a nearly unlimited number of possible applications, which makes plastic superior to many other materials. Due to the high demand, plastic production has increased rapidly since the mass production started in the middle of the 20th century (Andrady & Neal, 2009). During the last 70 years, the annual production has increased from 1.5 million tons in the 1950s (PlasticsEurope, 2015) to an estimated 335 million tons in 2016 (PlasticsEurope, 2018).

Plastic are synthetic organic polymers, mainly derived from organic products such as coal, oil and gas (Ivleva et al., 2017). In addition to fossil fuels, polymers can also be manufactured from cellulose and other renewable resources like corn, potatoes and vegetable oils (PlasticsEurope, 2016). The plastic family is large, and consist of a great variety of polymers with different properties, from the soft and formable to the hard and solid. The wide range of properties is made through the addition of different chemicals and additives in the manufacturing process (Andrady & Neal, 2009). Although there are hundreds of plastic materials that are commercially available, there are only a few polymers that make up over 80 % of the total demand (PlasticsEurope, 2018). Polypropylene (PP), low-density polyethylene (PE-LD), high-density polyethylene (PE-HD) are the three most commonly used plastic polymers, while polyvinyl chloride (PVC), polyurethanes (PUR), polyethylene terephthalate (PET) and polystyrene (PS) are also widely used in various applications (PlasticsEurope, 2018).

Despite all the benefits plastic provides, there are also several negative effects linked to our massive plastic consumption. One of the biggest environmental challenges today is the rising amount of plastic that accumulates in the environment. Although there has been a steady increase in collected plastic waste through official schemes in the last ten years (PlasticsEurope, 2018), there are still large amounts of plastic waste that find its way to the environment. According to Barnes et al. (2009) up to 80 % of the waste that accumulates in our surroundings consists of plastic. Inappropriate waste management together with indiscriminate disposal are the major causes for the discharge (Barnes et al., 2009). Food packaging, carrier bags and soda bottles are examples of items that easily are transported to the environment when not treated properly. Plastic litter that is released to the environment can cause serious problems for wildlife. Ingestion of plastic and entanglement in litter may lead to suffering, starving or in worst case death (Florian Thevenon et al., 2014). Plastic can also contain hazardous substances like persistent organic pollutions (POPs) and heavy metals (Rochman et al., 2013) that might have negative impacts on wildlife.

The accumulation of plastic is particularly visible in marine environments, where plastic debris is found everywhere from the seafloor, throughout the water column and along beaches and coastlines worldwide (Barnes & Milner, 2005; Barnes et al., 2009). Estimations made by Jambeck et al. (2015) show that 4.8 to 12.7 million tons of land-based plastic waste are entering the world´s oceans every year. The total amount of plastic that is found in the world's oceans is unknown, but several global studies have tried to estimate the quantity of floating debris (Cózar et al., 2014; Eriksen et al., 2014; Law et al., 2014; Sebille et al., 2015). Eriksen et al. (2014) estimated the total weight of plastic in the world´s ocean to be almost 270 000 tons, consisting of a minimum of 5.25 trillion particles. The fate of plastic that has entered the ocean, is mainly determined by the density of the particles. Polymers such as PET that have a higher density than seawater will sink to the seabed, while less dense particles like PP and PE will remain fluent in the water column (Avio et al., 2017). However, the density of plastic particles can be altered over time. Processes like biofouling and the colonization of organisms on plastic surfaces can increase the weight of the particles, changing their buoyancy, which causes them to sink, some to the seafloor while other will remain in the water column (Fazey & Ryan, 2016; Lobelle & Cunliffe, 2011).

1.2 Microplastic and emissions from artificial football turfs

Plastic in the environment appears in different shapes and sizes, but it's mainly the largest objects that catch people's attention. In recent years, however, smaller pieces of plastic, known as "microplastic", have gotten more attention because of the abundance and environmental concerns linked to these particles. Microplastic is defined as all plastic particles < 5 mm (GESAMP, 2015). These are divided in two categories depending on their origin; primary and secondary microplastics (GESAMP, 2015). Primary microplastics are pieces that are manufactured to be small, such as virgin plastic pellets (Cole et al., 2011). These particles are frequently used in care products like cosmetics and facial-cleansers (Fendall & Sewell, 2009), but also in air blasting technology, to remove rust and paint from boats (Gregory, 1996). By contrast, secondary microplastics are a result of the degradation and fragmentation of larger plastic debris, due to mechanical abrasion and UV radiation (Browne et al., 2007; O'Brine & Thompson, 2010). There are several sources and pathways that contribute to microplastic emissions to the aquatic and terrestrial environment, and identifying these is of great importance to prevent further release to the surroundings. A rising concern related to microplastic emissions, is the rapid increase in artificial football turfs and the possible loss of rubber granulate particles to the environment. This concern was strengthened in 2016, when Mepex on behalf of the Norwegian Environment Agency issued a report that stated that microplastics from artificial turfs was one of the largest sources to primary microplastic emissions in Norway (Sundt et al., 2016).

In the last two decades, the number of artificial football turfs has increased rapidly in Norway. According to the Norwegian football association (2018) there were 1058 full size artificial football turfs (68×105m) in Norway in the beginning of 2017. In addition, there were over 500 smaller artificial turfs. The reason for this rapid expansion, is due to the many advantages artificial football turfs have in relation to natural football pitches. One of the biggest differences is that artificial turfs can be used throughout the year. While harsh Norwegian weather conditions make natural football pitches unplayable during winter time, artificial football turfs can be used regardless of weather. As a result, natural football pitches in Norway have very limited user time (100-250 hour/year) throughout the football season. In contrast, artificial turfs can be used all year around, with a normal user time of 1500 – 2000 hours per year. Turfs with underneath heating, can extend the user time further, towards 2500 hours per year (Kulturdepartementet, 2015). Another aspect with artificial football turfs is that they are more hard-wearing and easier to maintain, compared to natural football pitches (Cheng et al., 2014), which is an important aspect for many football clubs with limited economy and resources.

Artificial football turfs consist of several layers (Figure 1), with a top layer of synthetic fibers (polyethylene) designed to mimic natural grass (Bauer et al., 2017). To support the turf fibers and make the pitch more playable, an infill is applied. The infill can consist of different materials, but usually small rubber granulates are used. The size of these particles varies for 0,8 to 3 mm (Genan, 2017; Ragn-Sells, 2018), and therefore falls under the category of microplastics. Today there are several types of granulates that are available for use on artificial turfs, and almost every type is based on rubber. The most commonly used granulate type is Styrene Butadiene Rubber (SBR), which are granulate particles made from recycled car tires, that are chopped into small pieces. In Norway, approximately 90% of all artificial turfs use this kind of granulate (Borgersen & Åkesson, 2012), while 83% in a global perspective (FIFA, 2017). Ethylene Propylene Diene Rubber (EPDM) and Thermoplastic Elastomer (TPE) are other types of rubber based granulate. These types are based on virgin rubber, either from a mix of synthetic and natural rubber or industrial rubber (Cheng et al., 2014).

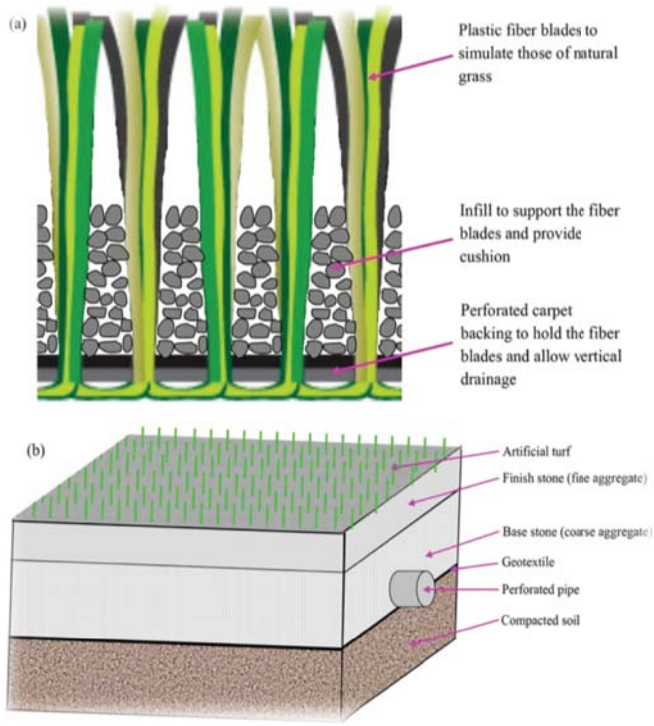


Figure 1. Illustration of the structure of an artificial turf (Cheng et al., 2014)

According to Unisport (2017) TPE granulate has better environmental characteristics than EPDM due to the lack of vulcanize (hardening) processes in manufacturing. This also makes TPE granulate recoverable in contrast to EPDM (Unisport, 2017). There are few alternatives to rubber granulate in Norway. One alternative is eCork. This granulate is a natural product based on cork (Unisport, 2017), but very few artificial football turfs use this type of granulate.

The amount of granulate that is used on artificial turfs varies with the size of the turfs, but in average its assumed that a normal artificial football turf contains about 75 – 125 tons of rubber granulate (Sundt et al., 2016). The total amount of granulate used in Norwegian artificial turfs was in 2012 estimated to 76 000 tons (Borgersen & Åkesson, 2012), but with a steady increase in the number of artificial turfs, the number is probably even higher today. In addition to the amount of granulate that is added to the turf when it is build, there are also added granulates at an annual basis due to losses in connection with maintenance, winter operations, storm water and through clothes and shoes used by athletes. In a survey conducted by Rambøll (2017), Norwegian football clubs stated that they in average add 5.5 tons annually, but the amount varies greatly from turf to turf and is generally higher on turfs that have winter operations.

An important aspect related to the increase of artificial football turfs is the potential environmental and health risks associated with the use of rubber granulates as infill. The main concern is related to the use of recycled tire rubber (SBR), as it's known that these particles contain a variety of toxic metals such as lead, zinc and cadmium (Bocca et al., 2009; Cheng et al., 2014; Menichini et al., 2011). In addition, several studies have shown that recycled tire granulate used in outdoor and indoor facilities like playgrounds and artificial football turfs also contains hazardous organic chemicals such as polycyclic aromatic hydrocarbons (PAH), phthalates, volatile organic compound (VOCs) and semi-volatile organic compounds (SVOCs) (Celeiro et al., 2014; Celeiro et al., 2018; Llompart et al., 2013; Marsili et al., 2015). Although studies have shown presence of hazardous substances, there are currently few concerns related to negative health effects from using recycled tire rubber. According to the European Chemical Agency, the exposure of toxic substances such as PAHs, metals and phthalates are below the concentrations that would lead to health problems (ECHA, 2017). This is supported by a study conducted by Van Rooij and Jongeneelen (2010), who found minimal uptake of PAH in football players, after intensive training and match sessions. Furthermore, studies have shown that the use of artificial football turfs did not present higher exposure risks than surrounding urban areas (Schilirò et al., 2013), while the inhalation risk of gases and dust from vehicular traffic was higher compared to those due to playing football on artificial turfs (Ruffino et al., 2013).

There are currently few studies that have investigated to which extent rubber granulates is effecting non-human organisms. A study conducted by Pochron et al. (2017) on earthworms response to crumb rubber in soil samples, showed that earthworms were not affected in terms of survival or stress response. In addition, several studies have shown that hazardous substances from recycled rubber granulate are transferred to runoff water, soil and air (Bocca et al., 2009; Celeiro et al., 2014; Pochron et al., 2017), indicating that possible interactions may occur. While there consist little information on the effects of granulate particles on non-human organisms, there is extensive literature available on the effects of other microplastics on wildlife. Although microplastics occurs in many different habitats, it is especially the effects on marine organisms that have been studied. A serious problem related to microplastic entering the marine environments is the ingestion of particles. Today ingestion of microplastics are well documented in a wide variety of organisms of different trophic levels, from small filter-feeders like mussels (Browne et al., 2008) to larger organisms such as fish (Lusher et al., 2013; Silva-Cavalcanti et al., 2017; Vendel et al., 2017). The ingestion may cause serious deleterious effects like internal abrasions and gut blockages which can lead to starvation (Gall & Thompson, 2015). In addition, toxicity derived from the plastic monomers and additives, may cause endocrine disruption and cancer (Wright et al., 2013). Although few currently negative environmental and health effects associated with the use of recycled rubber granulates are documented so far, there still are knowledge gaps regarding the content and concentrations of substances and the environmental fate of these particles. Imported tires or granulate particles entering the EU, may also have different compositions and concentrations of substances compared to those that are produced in the EU today (ECHA, 2017). Consequently, further investigations are needed to assess potential impacts recycled rubber granulates may have on humans and the environment.

The discharge of microplastic from artificial turfs is mainly caused by the loss of rubber granulate. In 2016 the total annual loss of granulate particles in Norway was estimated to be 3000 tons (Sundt et al., 2016). This is a huge number considered that the total microplastic emissions in Norway was estimated to 8000 tons in 2014 (Sundt et al., 2014). Relatively similar estimations are made in Sweden where the annual loss of granulates was calculated to be 2300 - 2900 tons (Magnusson et al., 2016). In addition to granulates, there are also losses of artificial grass (synthetic fibers) from the turfs, but these emissions are unknown. There are several possible pathways how granulate particles may be transferred to the environment. In Norway, many artificial turfs are used throughout the winter season, and snow removal is therefore crucial. Piles of snow with granulate are gathered around the artificial turfs, and when these melt during the spring a lot of granulate is left outside the turfs (Figure 2). With rain and flooding, these particles could easily be transported to the environment, especially if the artificial football turfs are located near rivers or streams. Granulates are also transported to the environment through drainage pipes and chambers, which are placed around the turfs. A lot of granulate particles also find their way to the nearest area around the turfs. In addition, granulates are transported away from the turfs via clothes and shoes used by football players.

Figure 2. Pile of snow with granulate particles, outside an artificial football turf.

1.3 Aim of study

In today´s literature there is little knowledge about where the granulate particles end up and how much is spread to different locations, like the nearest area around the turfs or to nearby waterways. A report conducted by Coutris et al. (2018), showed that large amounts of granulates were found in soil samples in the nearest area around artificial football turfs. All of the investigated turfs were used during wintertime and the amount of granulate found varied from 1,7 kg/m^2 to 15,1 kg/m^2. Despite the fact that many streams and rivers lie close to artificial turfs, the spreading of granulate particles to adjacent streams and rivers has not yet been investigated. The aim of this study was to investigate whether granulate particles from artificial football turfs are released to adjacent streams, quantify how much is found in streams, and how far the granulate particles may be spread along streams. Possible measures to prevent further release will also be discussed.

2 Materials and Methods

2.1 Sampling areas

Five artificial football turfs were selected because of their proximity to rivers and streams. The football turfs were located in three different Norwegian municipalities, in the South East of Norway (Figure 3).

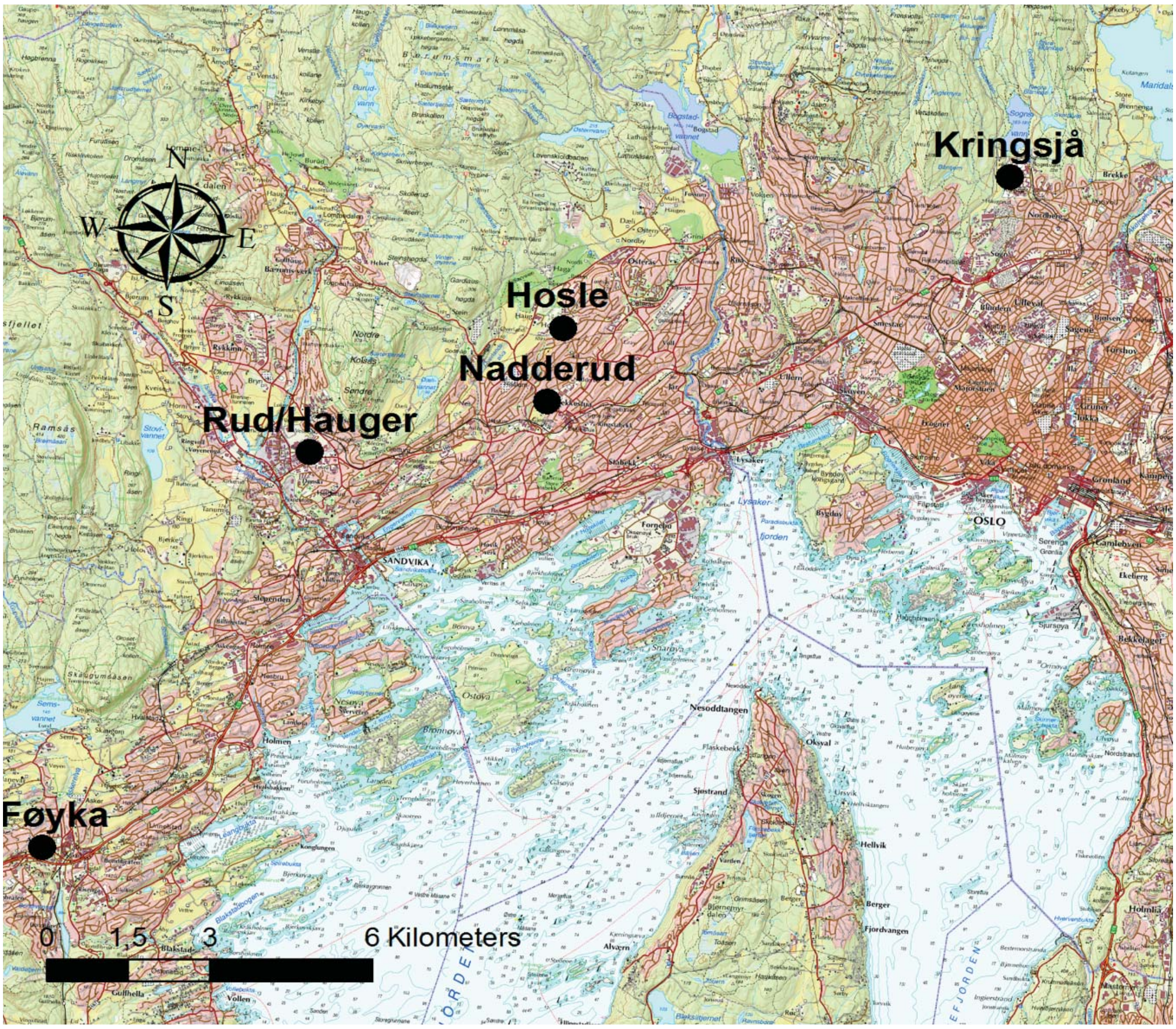


Figure 3. Map of the study area, with the selected artificial football turfs highlighted in black.

2.1.1 Føyka artificial football turf

Føyka artificial football turf (59°50′3.85″N 10°25′31.29″E) was built in 2004 and is located in Asker municipality. The turf is used all year round, and in wintertime, snow from the turf is stored in big piles at the southwest end. Just outside the turf, a lot of granulate was found on the ground down towards a stream, that is located south of the turf. In addition to surface runoff, water from the turf also drains through drainage pipes that end up in a small stream, called

Drengsrudbekken. Water from these pipes has not previously been filtered, but in recent years, filters have been inserted to prevent release of granulate to the environment. Drengsrudbekken has varying flow velocity and sedimentation conditions. The catchment of Drengsrudbekken lies in a urban area and the stream passes E18 (highway), upstream of Føyka. About 400 meters downstream of Føyka, Drengsrudbekken flows into the Asker river. This is a larger river, with a higher flow velocity and a lot of fine sediment. In total, there were taken sediment samples from eight stations at Føyka, one upstream and seven downstream of the football turf, in Drengsrudbekken and the Asker river (Figure 4).

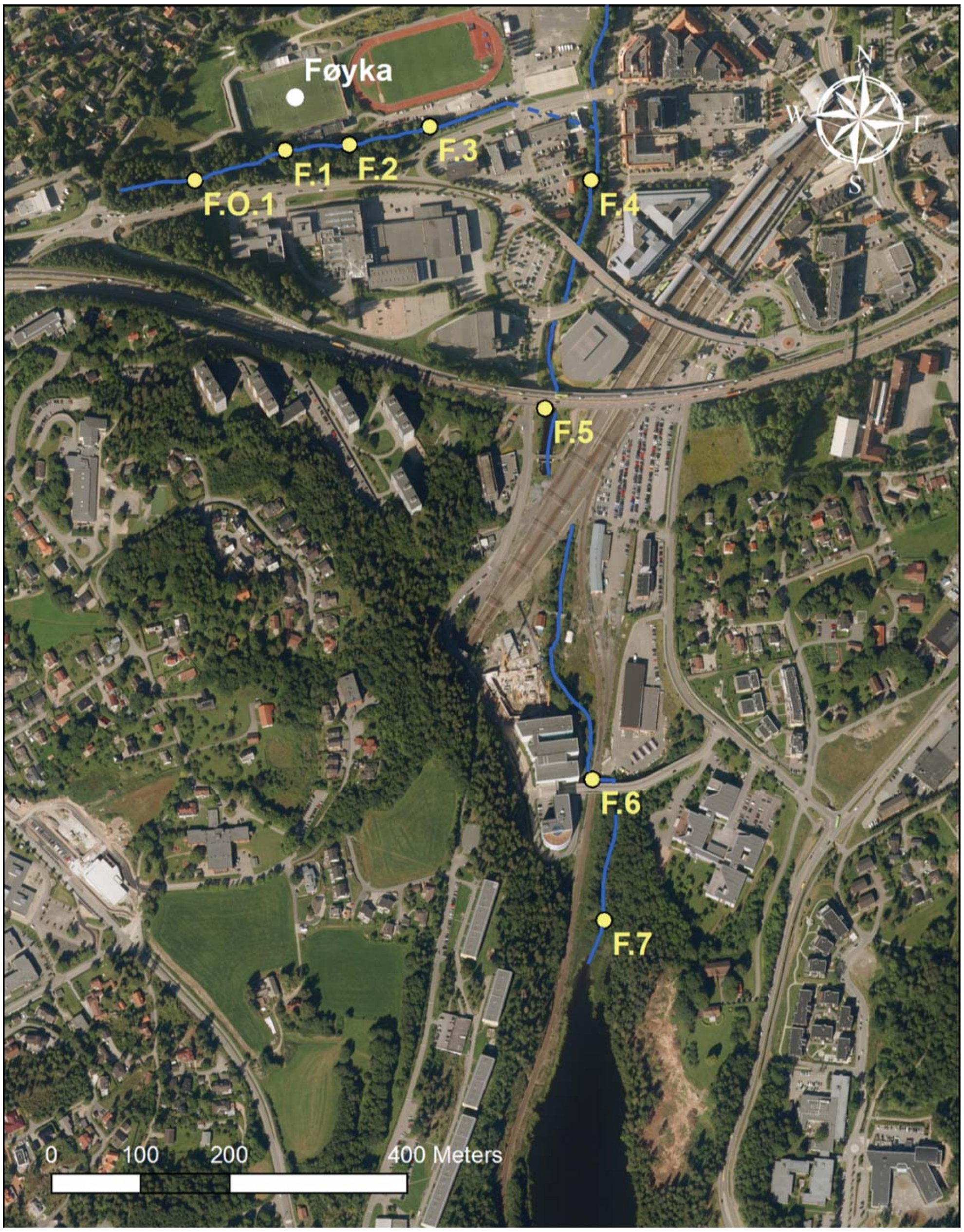


Figure 4: Map of the sampling area, with Føyka artificial turf highlighted in white. Yellow dots indicate the different sampling stations, while the dotted line shows the area where Drengsrudbekken is placed in pipes.

2.1.2 Nadderud artificial football field

Nadderud artificial football field (59°55′12.74″N 10°34′48.27″E) consists of two turfs and is located in Bærum municipality. Both turfs are used throughout the year and are ploughed during wintertime. The winter operation causes granulate to accumulate in the immediate surrounding of the turfs. Around some of the drainage chambers granulate was plainly visible. The drainage chambers did not contain filters to prevent release of granulate to the environment. Water from both turfs drains to Nadderudbekken, through drainage pipes. Nadderudbekken is mostly placed in underground pipes and the outlet is at Blomsterkroken (N.1, Figure 5) about 1.9 km downstream of Nadderud football field. At Blomsterkroken, Nadderudbekken runs into Øverlandselva, which is a larger river. Further down in the watercourse Øverlandselva flows into a bigger lake, called Engervannet. The catchment of Nadderudbekken lies in an urban area with a lot of houses, roads and other human influence. In total, there were taken sediment samples from seven stations located in Nadderudbekken and Øverlandselva (Figure 5). In addition, there was one upstream station in Eiksbekken (E.1), about 4 km northeast of the turfs (Figure 6).

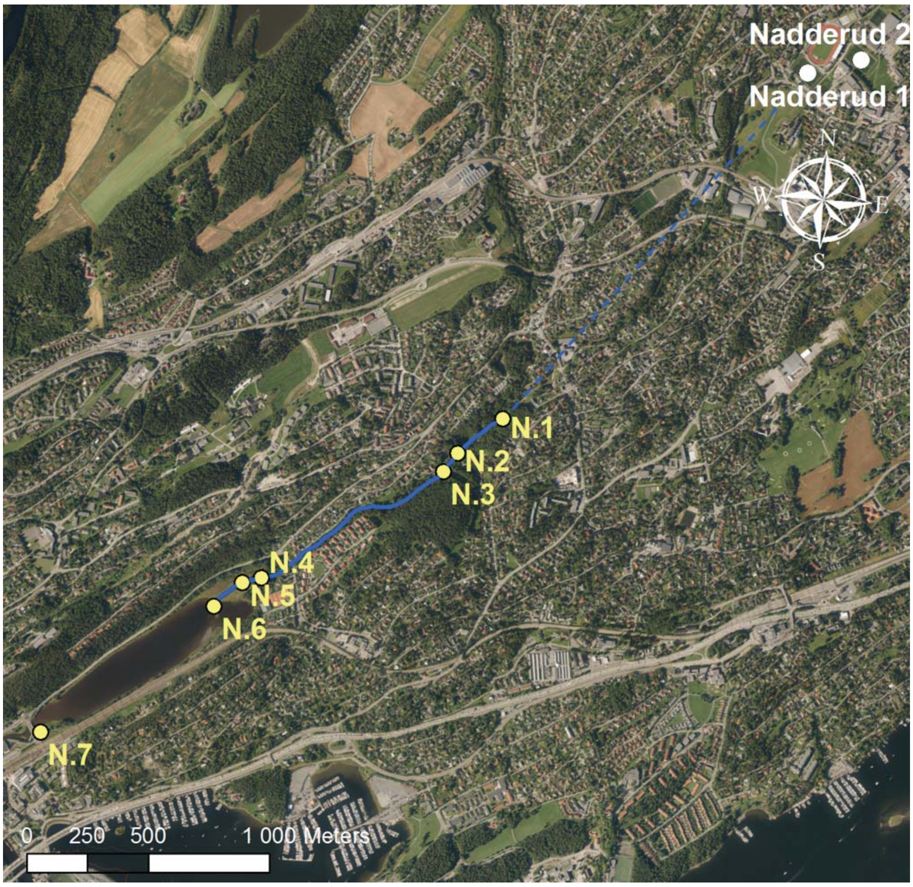


Figure 5: Map of the sampling area, with Nadderud artificial turfs highlighted in white. Yellow dots indicate the different sampling locations, while the dotted line shows the area where Nadderudbekken is placed in pipes.

2.1.3 Hosle artificial football turf

Hosle artificial football turf (59°56′0.55″N 10°35′1.38″E) is located in Bærum municipality. The football turf is used throughout the year, and is ploughed during wintertime. Large amounts of granulate were found in the immediate surroundings of the turf. In particular, large quantities of granulates were found in the forest and grasslands along the western side of the turf. In some places, there was granulate 10-15 meters outside the turf, probably indicating that snow blowers are used during wintertime. The drainage chambers around the turf were often surrounded with a lot of granulates and did not contain any kind of filtration system. Water from the turf drains through underground pipes that end up in a small stream, called Hoslebekken. The stream gets its water supply from surrounding agricultural fields. Today only the first 600 meters of the stream is open, the remaining part is placed in pipes, that runs into Nadderudbekken further down the watercourse. In total, there were taken sediment samples from four stations downstream of Hosle artificial turf, in Hoslebekken (Figure 6). In addition, there was one upstream station in Eiksbekken (E.1), about 2.7 km northeast of the turf (Figure 6). Which also served as the upstream reference for Nadderud artificial football turf.

Figure 6: Map of the sampling area, with Hosle artificial turf highlighted in white. Yellow dots indicate the different sampling locations.

2.1.4 Rud artificial football turf

Rud artificial football turf (59°54′30.00′′N 10°30′12.13′′E) is located in Bærum municipality. The turf is used all year round. Also here, a lot of granulate was found in the immediate surroundings of the turf. Water from the turf drains through drainage pipes to a little stream south of the turf, called Dælibekken. The drainage chambers did not contain filters to prevent release of granulate to the environment. About 800 meters downstream the turf, Dælibekken runs into Sandvika river. This is a large river that ends up in Sandvika, where it flows into the Oslofjord. The catchment of Dælibekken lies in a forest area east of the turf, but the stream also runs through an urban area before it passes Rud. In 2017, Hauger artificial turf opened, it lies about 100 meters east of Rud. In total, there were taken sediment samples from six stations at Rud, one upstream and five downstream, in Dælibekken and the Sandvika river (Figure 7).

Figure 7: Map of the sampling area, with Rud and Hauger artificial football turf highlighted in white. Yellow dots indicate the different sampling locations, while the dotted line shows the area where Dælibekken is placed in pipes.

2.1.5 Kringsjå artificial football park

Kringsjå football park (59°57′54.69″N 10°43′37.29″E) consists of three artificial turfs, and is located in Oslo municipality. Of the three turfs, only Kringsjå 1 (Figure 8) is used during winter time. Apart from Kringsjå 2, where there was some granulate lying around the turf, there was little granulate visible in the immediate surroundings of the other turfs. According to Bymiljøetaten, who is responsible for the turfs, none of the turfs drains to Songsvannsbekken through drainage pipes (Kristian V. Østby 2018, personal communication, 7 February). The catchment area of Songsvannsbekken lies in Nordmarka (forest area), and the stream has its origin from Songsvann (little lake), which lies north of the turfs. In addition to the turfs at Kringsjå, there is an artificial turf at the Norwegian school of sport science (NIH), which is also used during winter time. In total, there were taken sediment samples from six stations in Songsvannsbekken, one upstream and five downstream the turfs (Figure 8).

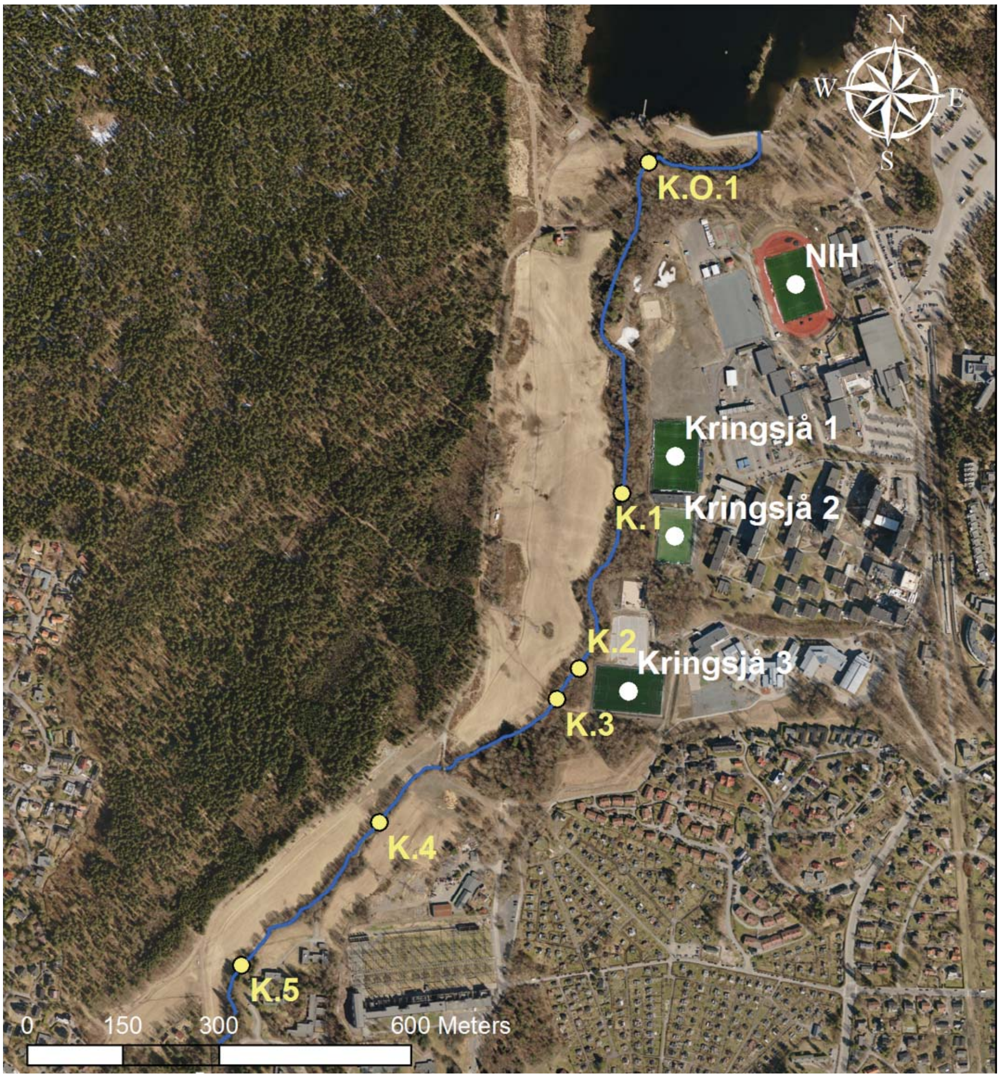


Figure 8: Map of the sampling area, with Kringsjå and NIH artificial turfs highlighted in white. Yellow dots indicate the different sampling locations.

2.2 Fieldwork and sediment sampling

Sediment samples were taken at all sites during June and August 2017. Each sediment sample was collected using a sediment-core sampler with a diameter of six cm (Figure 9). The upper five cm (representing a volume of 0.14 L) were cut with a metal plate, and the content was transferred into glass jars of 200 ml. In some locations with deeper sediments, samples from deeper sediment (5-10 cm) also were recovered. The samples were taken in areas where the sediment was sandy rather than stony, as we assumed that granulate particles settle in the same place as fine particulate material. At each site, a minimum of three sediment samples were collected. Most of the samples were taken at the river side, but in some rivers and streams it was shallow enough to take samples also midstream. For further details of the various sample locations, see appendix table A-1 to A-5.

Figure 9: Picture of sediment sampling, downstream of Føyka artificial football turf. Photo: Bjørnar Beylich.

2.3 Method testing

A method test was conducted, to optimize a method for recovering granulates from sediments. Three alternatives were tested, density separation with a sodium chloride-sugar solution (NaCl/sugar), density separation with water, and sieving. For all methods ten sediment samples of 200 ml were tested. To each test sample ten SBR granulates and ten EPDM granulates were added. The sediment used for the method testing was obtained at Songsvann (59°58′10.74′′N 10°43′43.14′′E), upstream of Kringsjå football park. This sediment was chosen because of little human influence in the catchment area, such that it was highly unlikely that the sediment was contaminated with granulate particles.

2.3.1 Sieving

For the sieving, a sieve tower was used. This contained sieves with different mesh sizes of; 4mm, 1mm, 500µm, 250µm, 63µm. The sediment samples were sieved in wet condition, with the addition of filtered water (tap water filtered with a 50µm filter). The content of the different mesh sizes was transferred to small plastic boxes and dried at 75°C for 24 hours. After drying, 1mm and 500µm samples were examined for granulates with a stereomicroscope (Wild Heerbrugg, M8).

2.3.2 Density separation

For the density separation with NaCl/sugar, a solution containing sodium chloride (NaCl), sugar (sucrose) and water was mixed (1L water, 500g sugar and 400g NaCl). After mixing the solution, it stood for 24 hours until it was completely saturated (density of 1,24 g/ml). Then 300 ml of saturated solution was thoroughly mixed with a sediment sample. The top liquid layer was then emptied over a sieve tower to separate the particles. Like the sieved samples, these were also transferred to small plastic boxes and dried, before 1mm and 500µm samples were examined with a stereomicroscope. The density separation with water was carried out in the same way as described above, but here only water was added and mixed with the sediment samples.

2.4 Laboratory work

In order to analyse the sediment samples from the streams, sieving was used. The choice of method was based on the method test, where sieving gave the highest recapture of granulate from the sediment (Table 1 in the results). The sieving was done in the same way as described above. After sieving, all samples were dried at 75°C for 24 hours. Based on the fact that the sizes of granulate particles used on artificial football turfs varies between 0,8 to 3 mm (Genan, 2017; Ragn-Sells, 2018), only 1mm and 500µm samples were analysed with a stereomicroscope. Due to limited time and very time consuming analysis work, 117 out of 124 samples were analysed at the 1mm sieve. The samples that were excluded, were taken from stations with over three samples taken in total. A minimum of three samples were analysed for each station. For the 500 µm sieve, we did not expect to find many particles, because the rubber particles that are used mostly were lager than 0,8 mm (Genan, 2017; Ragn-Sells, 2018). But in order to check in which degree wearing of particles occurred, a small number (8 out of 124) of the 500µm samples were also analysed. All plastic-like particles were collected in small glass vials for further analysis. The glasses were named and numbered according to site and sample. The samples were later reviewed again, where granulate particles visually were separated from other plastic particles. The visual sorting was based on colour (black or green, depending on type of granulate), consistency (rubbery) and shape (fragments with uneven surfaces). Finally, all the samples were weighed, with an electronic weigh (Sartorius Extend).

2.5 Estimation of the number of granulate particles

In order to estimate the number of granulate particles in the sediment samples from their weight, a linear relationship between the number and the weight of granulate particles was established. The function was based on the weight of granulate particles found in the sediment samples. The weight of one to twenty randomly selected particles was noted, and this was repeated ten times before an average weight was calculated. Based on the average weight values, a linear regression was fitted in Microsoft ® Excel (Figure 10). Function: $y = 0{,}004x – 0{,}0001$, $R^2 = 0{,}99$; Pearson correlation coefficient = 0,99; $p << 0{,}001$).

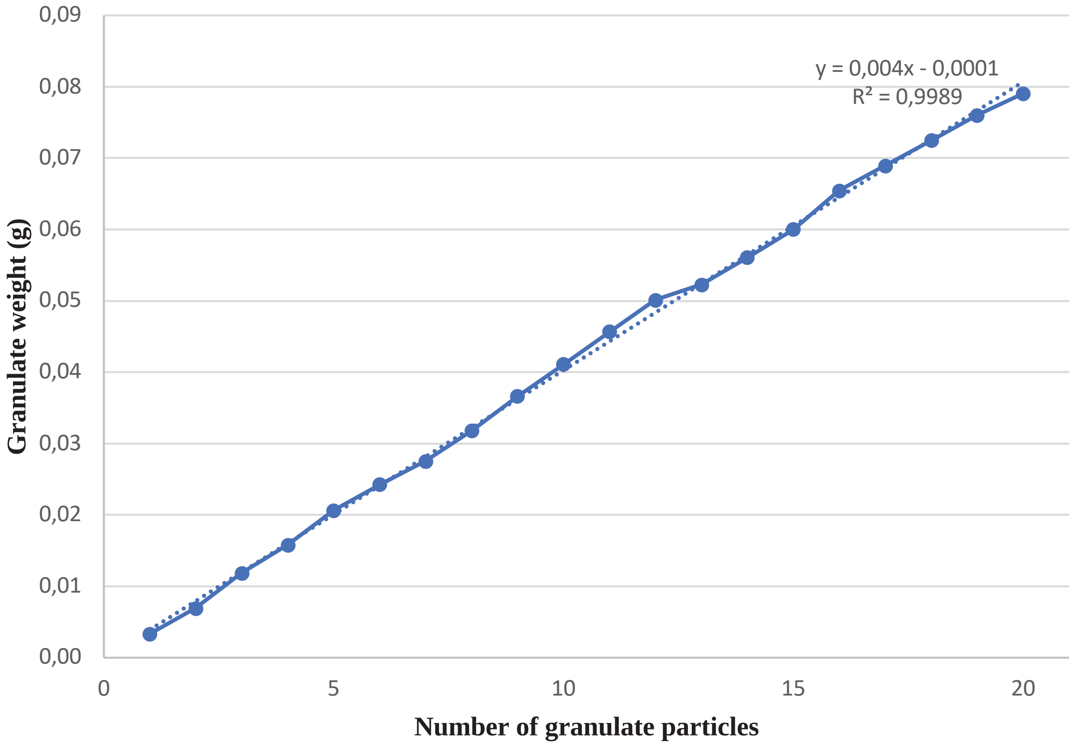


Figure 10: Relation between number and weight of granulate particles.

2.6 Estimation of the amount of granulate in sediments

For two stream reaches, the amount of granulate which is present in the entire stream section was estimated. Reach 1 is the area in Drengsrudbekken from station F.1 to station F.3 (Fig 11). It covers a distance of 171 m, and is approximately 2 m wide. Reach 2 is the area in the Asker river from station F.4 to station F.7 (Figure 11). It covers a distance of 880 m and is approximately 8 m wide. Distance and width estimations were measured by use of an measuring tool, in the map service Norgeskart (Kartverket, 2018). The distance is measured along the river, not in a direct line. The two sites were chosen because they were comparatively homogenous in terms of sedimentation and flow conditions, which was important so the estimates cold be performed with some confidence.

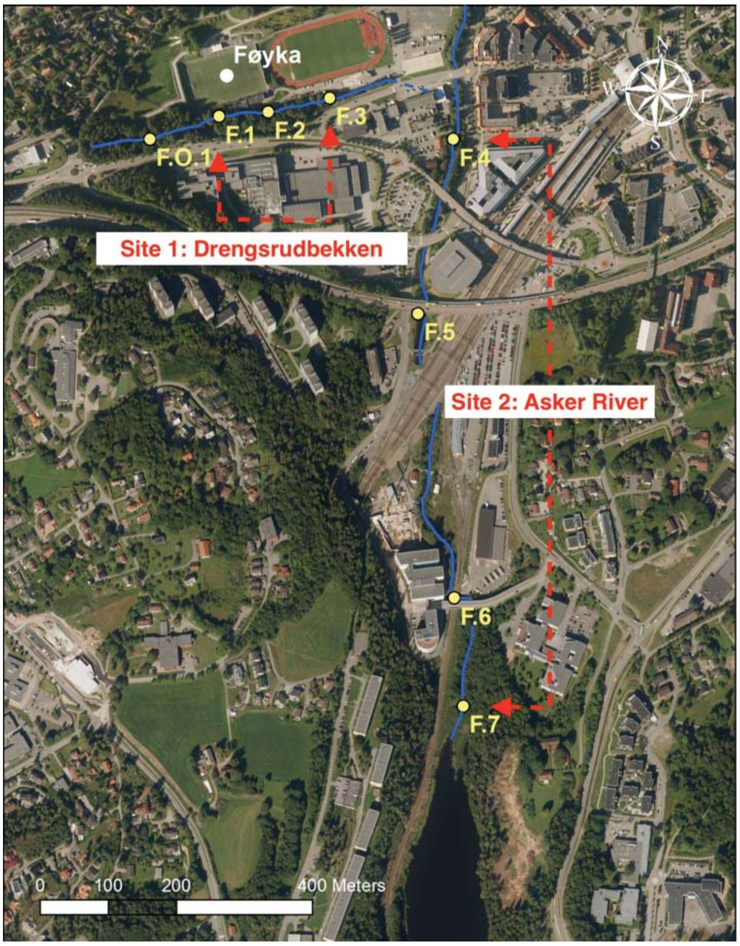


Figure 11: Test sites for estimation of the amount of granulate in the sediments

Furthermore, the surface area for both sites was calculated (length * width). Based on the weight values of granulates found in the sediment samples taken at Drengsrudbekken (F.1 to F.3) (Appendix A-6) and in the Asker river (F.4 to F.7) (Appendix A-6), an average weight value for each site was calculated. This value represents the average content in one sample (0,14 L) in the selected area. The average weight value for one sample was then used to calculate the average amount of granulate per m^2 for each site. Finally, the total weight of granulate in the top five cm of the stream in the entire selected reaches were estimated. This was done by multiplying the average amount of granulate per m^2 with the surface area (m^2) of the two sites.

2.7 Maps

All maps were made in ArcMAP 10.4.1. Coordinates were retrieved from the application Google maps (Google, inc). All map layers (Ortofoto) were downloaded from Geonorge website (2018). WGS84 was used as coordinate system.

2.8 Data analyses

Microsoft ® Excel for Mac 2017 (16.11) was used for all data handling, production of tables and calculations. Because data were not normally distributed, a Wilcoxon non-parametric test was preformed to detect differences in the number of extracted particles between sieving and density separation. To investigate whether there was a relationship between the weight of granulate particles in the sediment samples and the distance from the turfs, a Generalized Additive Model (GAM) was fitted, using the mgcv package in R (Wood, 2006). Granulate weight was used as response variable, and distance from the turfs as predictor variable. GAM was chosen because of its flexibility and that it can show possible nonlinear relationships. The Wilcoxon non-parametric tests, Generalized Additive Model and boxplots were all generated by the open source statistical program R Studio, version 1.0.136. For all boxplots the black line in the boxes illustrates the median, while the boxes represents the middle 50% of values for the samples. The whiskers represent the maximum and minimum values of granulate found at each station.

3 Results

3.1 Method testing

Of the three different methods that were tested, sieving gave the highest recapture of granulates, with 199 out of 200 particles found (Table 1). For the density separation with NaCl/sugar, 193 out of 200 were found, whereas for density separation with water 33 out of 200 particles were recaptured. There were no significant differences in recapture between sieving and density separation with NaCl/sugar (Wilcoxon test, $p = 0.0545$). In contrast, density separation with water performed significantly poorer than sieving ($p = 8.171e-05$), and also than density separation with NaCl/sugar ($p=0,00015$). Despite there was no significant differences between sieving and NaCl/sugar, sieving was the chosen method, because it nevertheless performed better than NaCl/sugar. In addition, sieving was also less time consuming and laborious compared to the NaCl/sugar method.

Table 1: Number of granulate particles recaptured with the tree different methods.

SampleNR	Sieving	Density separation with NaCl/sugar	Density separation with water
Sample 1	20	19	1
Sample 2	20	20	3
Sample 3	20	20	3
Sample 4	20	18	8
Sample 5	19	20	2
Sample 6	20	18	3
Sample 7	20	20	2
Sample 8	20	19	1
Sample 9	20	20	2
Sample 10	20	19	8
Granulates recaptured	199/200 (99,5%)	193/200 (96,5%)	33/200 (16,5%)

3.2 Microplastic extraction from the different sample sites

Downstream of the artificial football turfs, there were taken sediment samples from 28 sample stations. Of the 28 downstream stations, granulate particles were found at all stations (Table 2). In total, 103 downstream sediment samples were analysed, of which 88 (85,4 %) samples contained granulates particles, while in 15 samples no granulates were found (Table 2). At Føyka and Kringsjå there were respectively two and one sample that did not contain granulates, in contrast to the other turfs where there were four samples without granulate.

Table 2: Total number of downstream stations and samples, and the number of stations and samples that contained granulate particles for the different sites.

Location	Total number of downstream stations	Downstream station with granulate	Total number of downstream samples	Downstream samples with granulate
Føyka	7	7	30	28
Nadderud	7	7	25	21
Hosle	4	4	12	8
Rud	5	5	17	13
Kringsjå	5	5	19	18
Total	28	28 (100 %)	103	88 (85,4 %)

Upstream of the artificial football turfs, there were taken sediment samples from four sample stations. Granulate particles were found at all stations. In total, 14 sediment samples were analysed, of which, six (42,9 %) samples contained rubber granulates, while in eight samples no rubber granulates were found (Table 3).

Table 3: Total number of upstream stations and samples, and the number of stations and samples that contained granulate particles for the different sites.

Location	Total number of upstream stations	Upstream station with granulate	Total number of upstream samples	Upstream samples with granulate
Føyka	1	1	5	1
Nadderud	1	1	3	2
Hosle	*	*	*	*
Rud	1	1	3	2
Kringsjå	1	1	3	1
Total	4	4 (100 %)	14	6 (42,9 %)

* Nadderud and Hosle has the same upstream sample location (Eiksmarka)

3.3 Detailed results from the individual sites

3.3.1 Føyka

In total, granulate particles were found in all stations downstream of Føyka artificial football turf. The amount of granulate that was extracted from the sediment samples varied from 0,0049 g to 6,67 g per sample (equal to 0,035 to 47,3 g/L), while the number of granulate particles ranged from 1 to 1672 particles/sample (Figure 12, Appendix A-6). There were considerable differences between the different sampling stations. Generally there was a higher amount of granulate particles found in the sediments from Drengsrudbekken (F.1 - F.3) compared to the Asker river (F.4 - F.7). The highest amount of granulate was found at station F.1, with 6,7 g in one sample, which equals about 1670 particles. This was also the station with the largest variation between the samples, expressed by the low median value. In the Asker river there were also found granulate in deeper sediments (5-10 cm depth) at station F.4D.

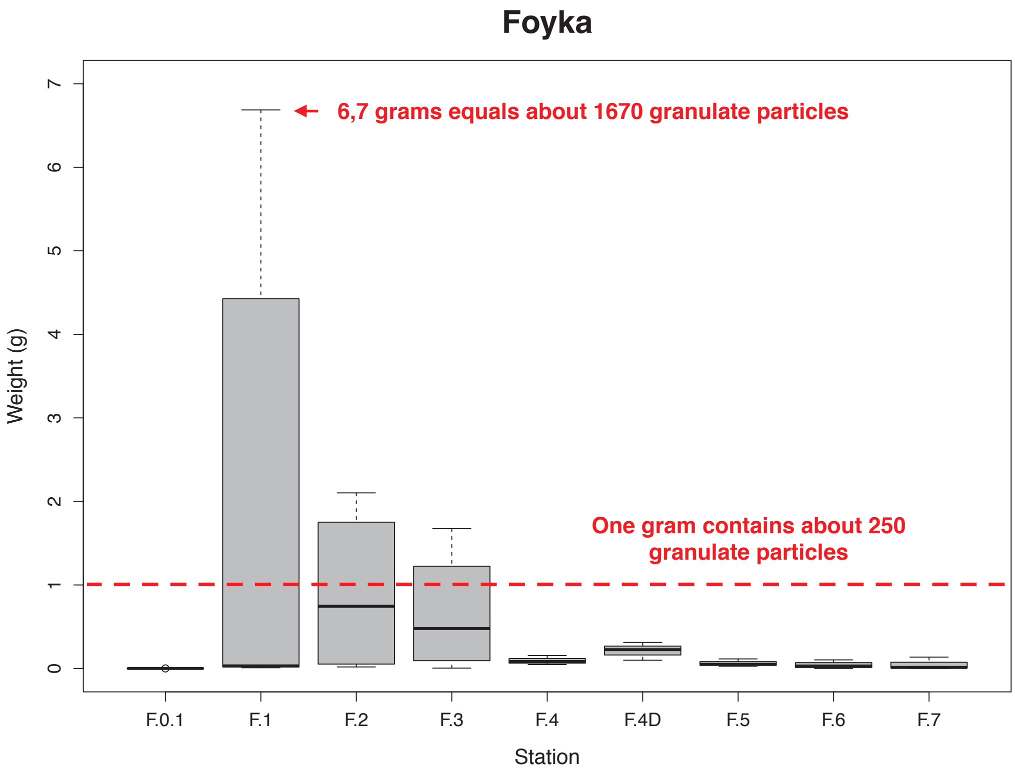
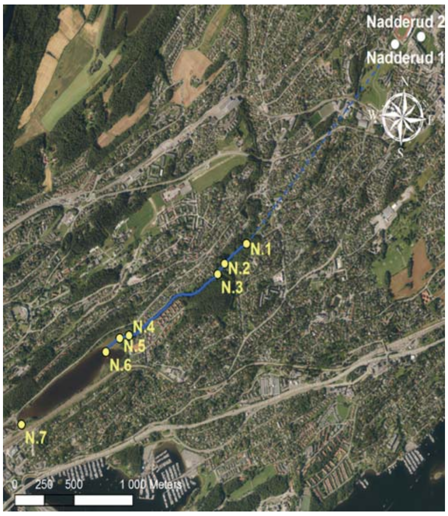


Figure 12. Weight range for granulate particles extracted from sediment samples (0-5cm) taken from Drengsrudbekken and the Asker river. Samples from location F.4D were taken from deeper sediment (5-10cm). For further details see appendix table A-6.

3.3.2 Nadderud

At Nadderud the weight of granulate found in the sediment samples ranged from 0.0004 g to 0,5872 g per sample (equal to 0,0028 – 4,156 g/L) and the number of granulate particles ranged from 1 to 147 particles/sample (Figure 13, Appendix A-7). The largest amount of granulate was extracted at location N.1D, with 0,59 g which equals about 147 particles. At location N.1 there was found granulate both in the upper and deeper sediments. At the stations in the Øverlands river (N.2-N.7) there were generally smaller amounts of granulate found, except for the station N.3 where it was found up to 0,42 g per sample. There were also found granulate particles on the other side of Engervannet (N.7), a station which is located 4,3 km downstream of the turfs at Nadderud. In addition, there were found granulate in the upstream samples taken at Eiksbekken (E.1).



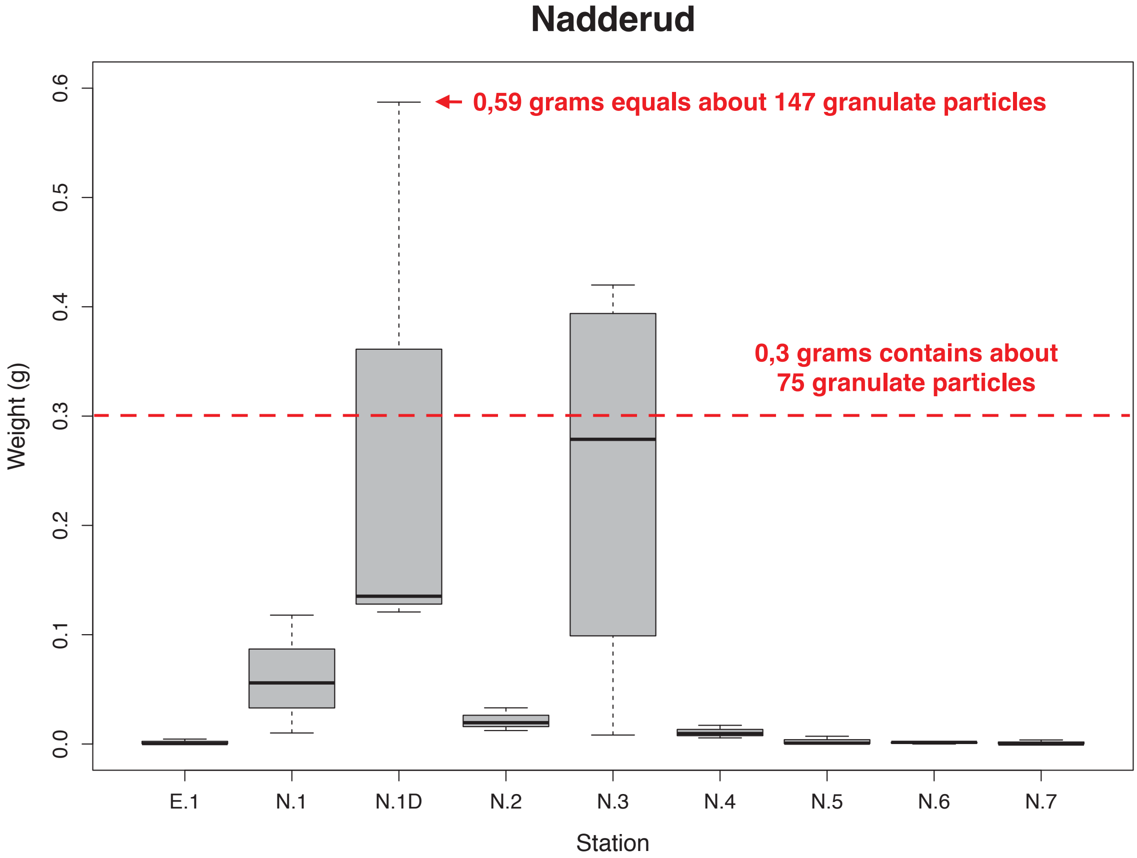


Figure 13. Weight range for granulate particles extracted from samples taken from the upper 5 cm of sediment, in Eiksbekken, Nadderudbekken and the Øverlands river. Samples from location N.1D is taken from deeper sediment (5-10cm). For further details see appendix table A-7.

3.3.3 Hosle

At Hosle the weight range for granulate particles in the different sediment samples varied from 0,0004 g to 0,3883 g per sample (equals to 0,0028 to 2,75 g/L) and the number of granulate particles ranged from 1 to 97 particles/sample (Figure 14, Appendix A-8). Station F.3 differs greatly from the other stations with a considerably higher content of granulate particles in the sediments. At this station there were found up to 0,39 g of granulate pre sample, equivalent to 97 granulate particles. There were also found granulate particles in the upstream station (E.1) taken in Eiksbekken.

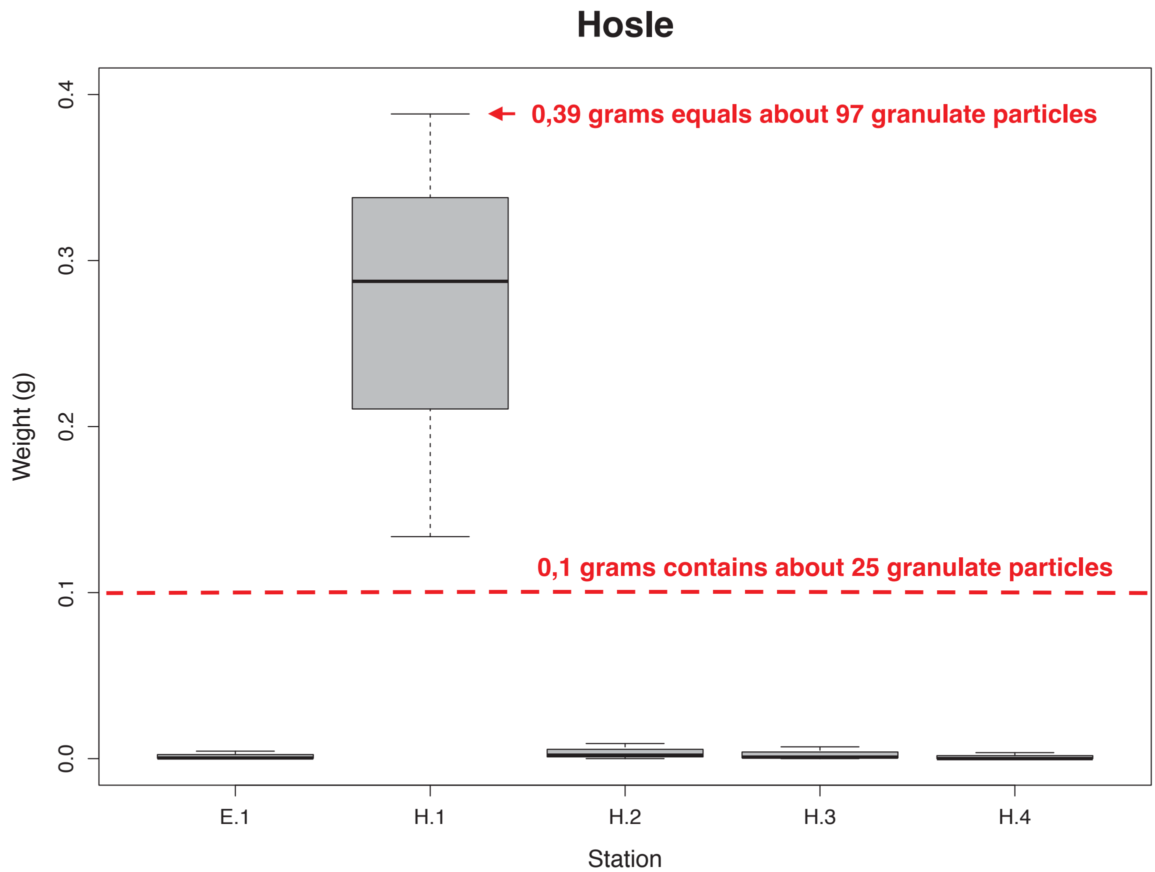
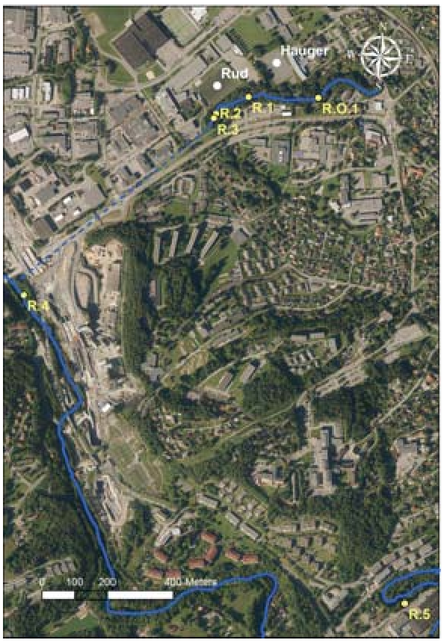


Figure 14. Weight range for granulate particles extracted from samples taken from the upper 5 cm of sediment, in Eiksbekken and Hoslebekken. For further details see appendix table A-8.

3.3.4 Rud

At Rud the amount of granulate that was extracted from the sediment samples varied from 0,0009 g to 1,1 g per sample (equals to 0,0064 to 7,78 g/L) and the number of granulate particles ranged from 1 to 275 particles/sample (Figure 15, Appendix A-9). Downstream in Dælibekken (R.1 to R.3) there were large differences in the amount of granulate found, with considerably higher numbers of granulate at station R.3 compared to station R.1 and R.2. At Sandvika river (R.4 to R.5) the highest amount was found at station R.4, but there were also found granulate particles in all samples taken at station R.5, despite the long distance (3,7 km) downstream of Rud and Hauger. The highest amount of granulate was found at station R.3 with up to 1,1 g per sample, which equals to about 275 granulate particles. In addition, there were also found granulate particles in the upstream station R.O.1.



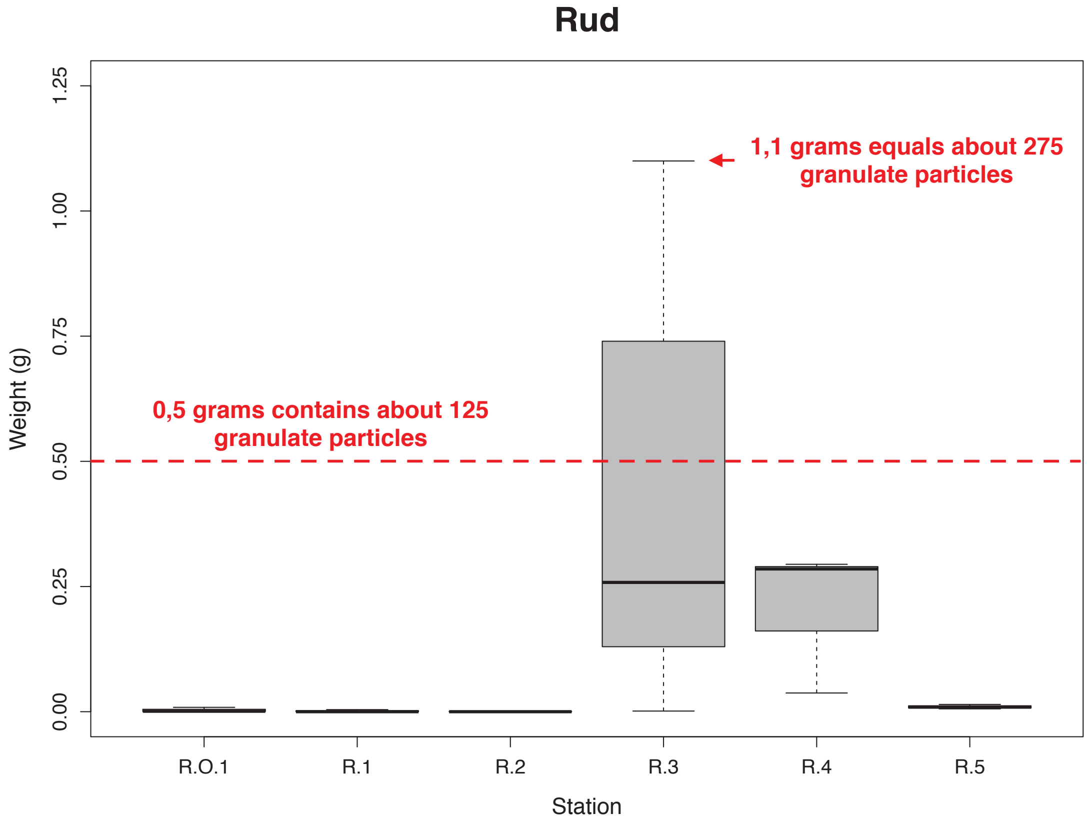
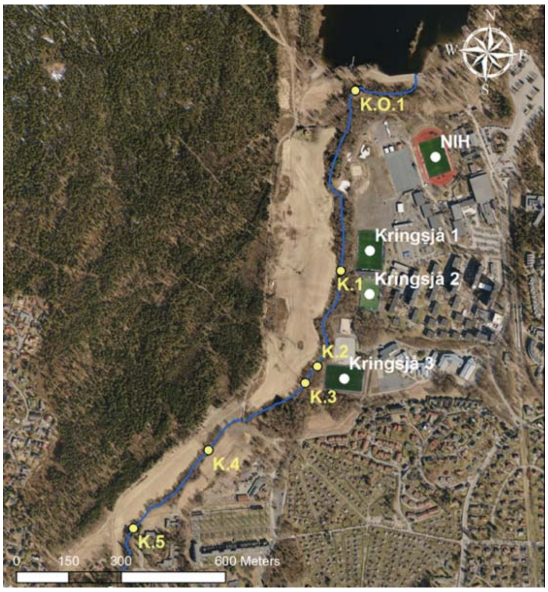


Figure 15. Weight range for granulate particles extracted from samples taken from the upper 5 cm of sediment, in Dælibekken and Sandvika river. For further details see appendix table A-9.

3.3.5 Kringsjå

At Kringsjå the amount of granulate that was extracted from the sediment samples varied from 0,0006 g to 0,33 g per sample (equal to 0,0042 to 2,15 g/L) and the number of granulate particles ranged from 1 to 83 particles/sample (Figure 16, Appendix A-10). In Songsvannsbekken station K.1 and K.3 differs greatly form the others, with a generally higher amount of granulate found. At both stations there were found up to 0,3 g of granulate per sample, which equals to about 75 granulate particles. At station K.3 there was also found granulate in deeper sediments. In addition, there were also found granulate particles in the upstream station K.O.1.



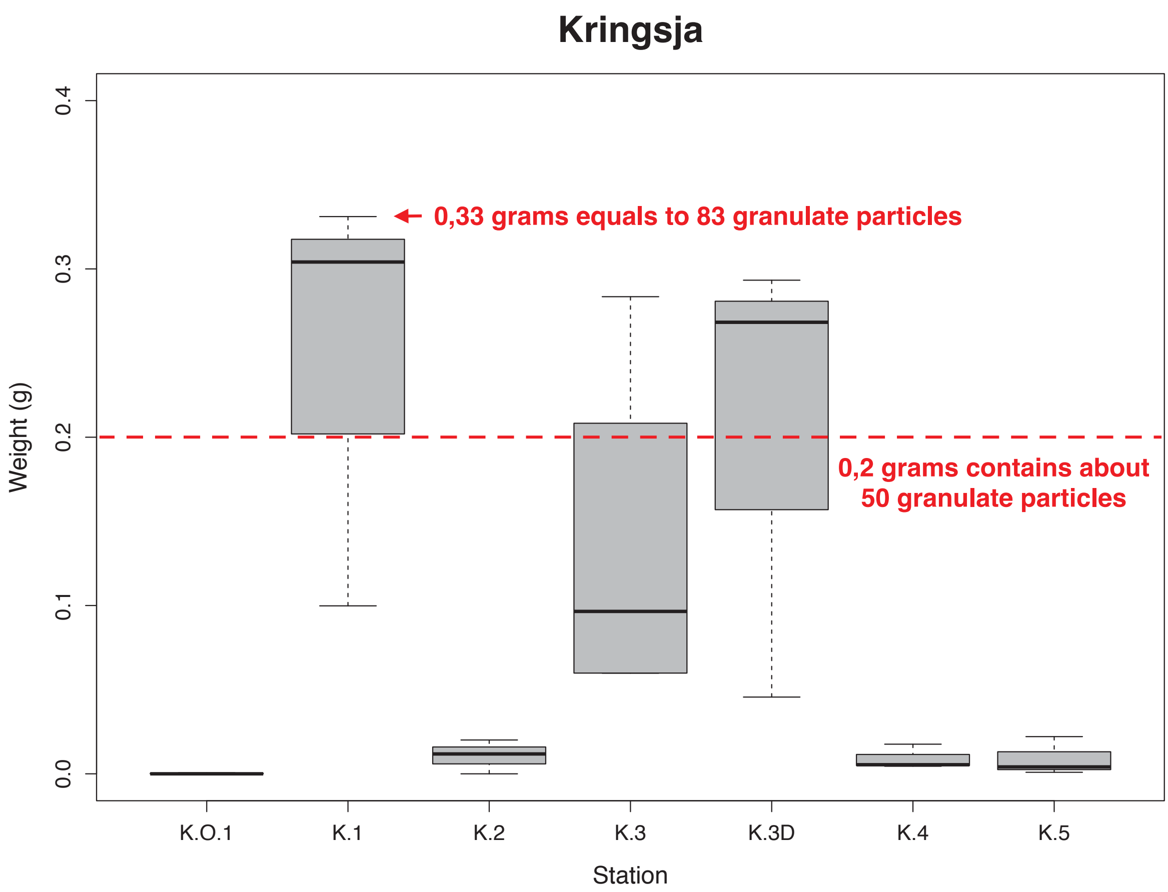


Figure 16. Weight range for granulate particles extracted from samples taken from the upper 5 cm of sediment, in Songsvannsbekken. Samples from location K.3D is taken from deeper sediment (5-10cm). For further details see appendix table A-10.

Table 4 and 5 gives a summary over the number of particles and their weight found downstream of each artificial football turf.

Table 4: The weight of granulate particles at all sampling sites (n representing the number of samples taken downstream of each site).

Sampling site	n	Weight (mean)	Median (g)	Max (g)	Min (g)
Føyka	30	0,63	0,09	6,67	0,009
Nadderud	25	0,09	0,01	0,59	0,0008
Hosle	12	0,07	0,003	0,39	0,0009
Rud	17	0,17	0,009	1,09	0,0009
Kringsjå	19	0,10	0,05	0,33	0,0009
All sites	103	0,26	0,02	6,67	0,0008

Table 5: Number of particles found at all sampling sites (n representing the number of samples taken downstream of each site).

Sampling site	n	Number of particles (mean)	Median (g)	Max (g)	Min (g)
Føyka	30	157	21	1672	1
Nadderud	25	21	3	147	1
Hosle	12	17	1	97	1
Rud	17	42	2	275	1
Kringsjå	19	26	11	83	1
All sites	103	65	6	1672	1

A Generalized Additive Model (Gam) was performed to investigate whether distance from the turfs was related to the amount of granulate particles that are found in the sediments. The distance from the artificial turfs has a significant effect (P = 0,029) on the amount of granulate particles found downstream, which means that the amounts of granulate particles in the sediments decreases with the distance from the turfs (Figure 17).

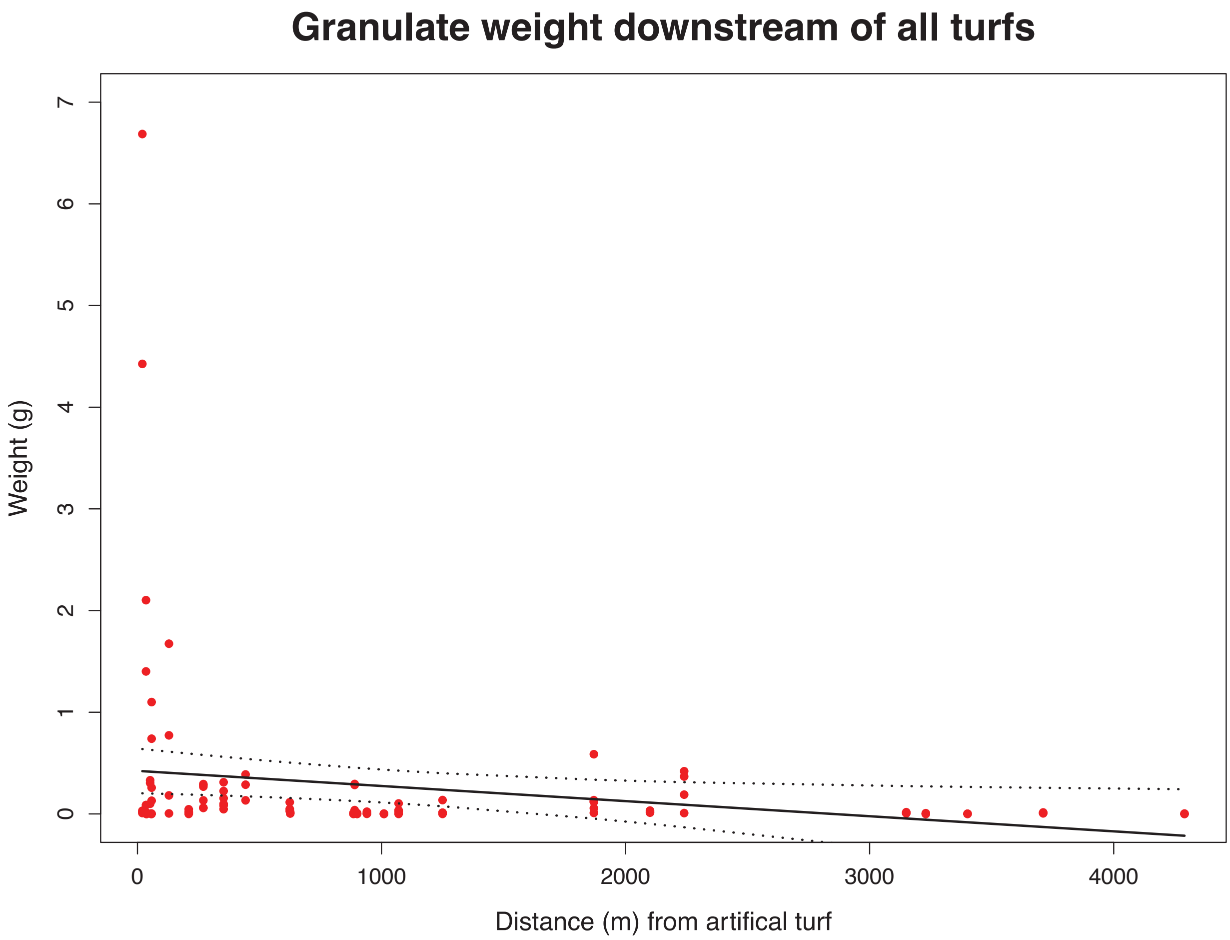


Figure 17. Gam (generalized additive model; ± 2 SE) of granulate weight (g) found in downstream samples, plotted against distance (m) from the turfs.

3.4 Extraction of granulate particles between 0.5 and 1 mm

In order to investigate whether granulate particles smaller than 1 mm occur in the sediment of adjacent waterways, eight sediment samples (one for each station) from Føyka were analyzed. Of these samples, granulate particles were found at all downstream stations, ranging from 0,0014 to 0,0664 g/sample (Figure 18). The largest amount was found at station F.1. No granulate particles smaller than 1 mm were found in the upstream sample.

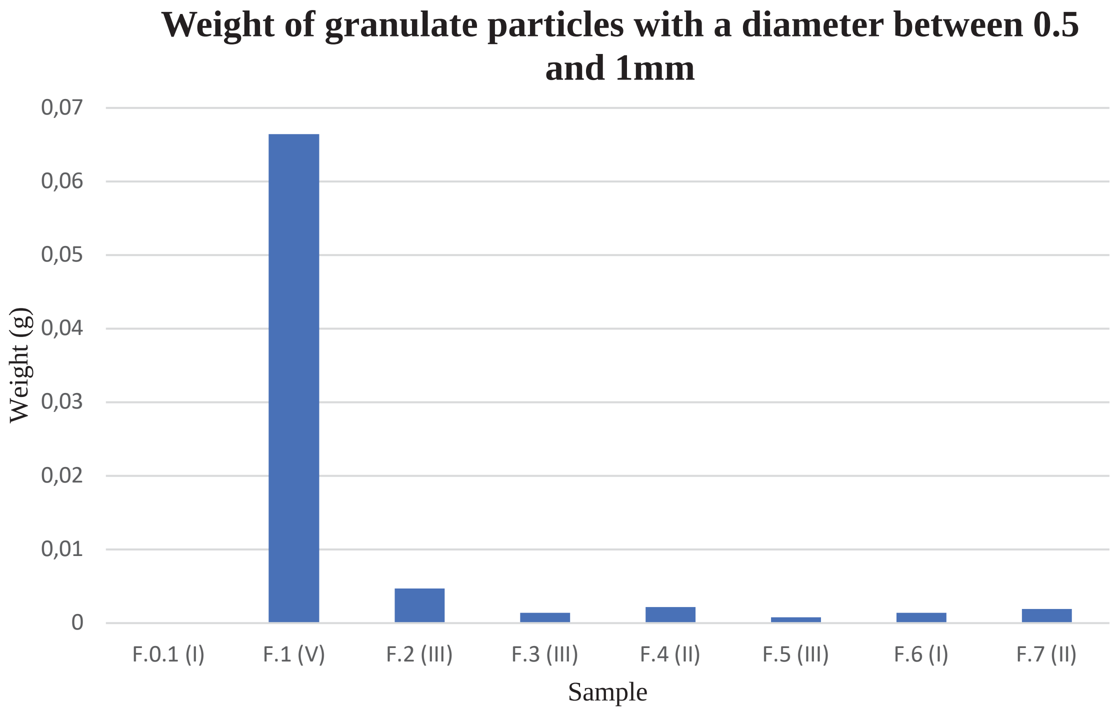


Figure 18. Weight of granulate particles with a diameter between 0.5 and 1mm, from eight different stations along Drengsrudbekken and Asker river close to Føyka artificial football turf.

3.5 Estimations of the amount of granulate in entire stream sections

For two relatively homogeneous sections of Drengsrudbekken and the Asker river, the total amount of granulate particles in the stream was estimated. In Drengsrudbekken, the total weight of granulate particles in a 171 m long section was estimated to be 153 kg (Table 4). This corresponds to about 19 used car tires, with an average weight of 8 kg (Norsk Dekkretur, 2018). In the Asker river, the total weight of granulate particles in a 880 m long stretch was estimated to 165 kg. This correspond to about 21 used car tires, with an average weight of 8 kg (Norsk Dekkretur, 2018).

Table 4. Estimated weight of granulate in the top five cm at site 1 in Drengsrudbekken and site 2 in the Asker river.

	Site 1: Drengsrudbekken	**Site 2: The Asker river**
Distance	171 m	880 m
Average width	2 m	8 m
Surface area (m^2)	342 m^2	7040 m^3
Surface area cylinder (m^2)	0,0028 m^2	0,0028 m^2
Average weight (g) per sample	1, 27 g	0,066 g
Average weight (g) per m^2	447 g/m^2	23 g/m^2
Estimated amount (kg)	**153 kg**	**165 kg**

4 Discussion

4.1 Rubber granulate abundance in stream sediments

The results from this study show that granulate particles form artificial football turfs are released to adjacent streams. To my knowledge, there are no previous studies that have shown the presence of granulate particles in river or stream sediments. Despite the lack of studies related to the presence of granulate particles, several studies have shown the presence of other microplastic particles in river sediments. In the German rivers Rhine and Main, Klein et al. (2015) found between 21.8 and 932 mg/kg (i.e. 228 – 3763 particles/kg) microplastic in river sediments. A recent study from rivers in Shanghai (China) showed an average number of 80,2 microplastic items 100 g^{-1} dry weight sediment. Comparing these results to the findings in this study is difficult, because of the different methods and units of measurements that are being used. As of today there is no standardized method to retrieve microplastics from sediment samples, and the units in which the results should be reported are not standardized either.

Despite these difficulties, it is evident that the highest amount of rubber granulate found in this study (6,67 g/sample) is much larger than the amounts of microplastics found in the German rivers Rhine and Main (Klein et al., 2015). Also the maximum number of microplastic particles found in this study (1672 particles/sample) is much higher than the findings in the river sediments from China and Germany. This difference is rather surprising, considering that samples from these studies are taken from large rivers with a much higher human impact, compared to those in this study. Considered that the results from these studies also contain findings from smaller size fractions (down to 1 μm) than 1mm, makes the difference even more remarkable. A possible explanation is the short distance between the source of emission (football turfs) and the sites where the sediment samples were taken. The highest amount of rubber granulate that was found in this study (6,67 g/sample) was from a site located only 20 m downstream of one turf (F.1, Føyka).

The number of particles found in this study is also very high compared to microplastic findings in other Norwegian rivers. Buenaventura (2017) found a maximum of 113 particles/L in the Akers river, while 4 particles/L were extracted from Alna river sediments (Bottolfsen, 2016). Both these studies have analyzed sediments from rivers that are relativrly similar to those in this study, and the high numbers found in this study therefore underline the large contribution of artificial football turfs to microplastic pollution.

4.2 Differences among the streams

One of the main findings in this study was the large variation in the quantity of rubber granulate particles that were found downstream of the various turfs. In average the largest amounts were found in Drengsrudbekken downstream of Føyka, while in Hoslebekken the least amount of granulate particles was found (Table 4 and 5). It is important to understand the reasons for these differences, as this knowledge is crucial for development of effective measures to prevent further spread of granulate particles in the future.

4.2.1 Winter operations and snow removal

The difference in the amount of granulate particles between the various streams may be due to several reasons. A possible explanation for the large differences among the streams is winter operations and the placement of snow during winter time. According to studies conducted by Ottesen et al. (2012) and Rambøll (2017) winter operation is an important source for spreading of granulate particles to the environment. The observations throughout the fieldwork in this study supports this perception, as there in general were observed much larger quantities of granulate particles around the turfs with winter operations compared with those without. However, it is not possible to show that the difference between the streams is due to winter operations, based on the data from this study. The reason for this is that almost every turf in this study had winter operations and the few turfs that did not, Hauger, Kringsjå 2 and Kringsjå 3 (Figure 7 and 8) were either relatively new or located close to streams that were affected by other turfs. Hauger artificial turf was opened only a few months before the field work was carried out, so it is unlikely that this turf has contributed with granulate particles to Dælibekken. Kringsjå 2 and Kringsjå 3 are located downstream of Kringsjå 1 and NIH which both have winter operations, it is therefore impossible to say if the granulate findings in the streams are due to emissions from the turfs with winter operations or those without.

Another explanatory factor may be the placement of snow during winter time. At Føyka, big piles of snow have in several years been stored in an area down towards Drengsrudbekken. These piles of snow have contributed with large emissions of granulate particles to the environment, which was plainly visible during the field observations. The large amount of granulate in this area was also documented by Coutris et al. (2018), who found up to 15,1 kg granulate/m^2 in soil samples taken down towards the stream. This is huge amounts considered that an average artificial football turf contains about 16 kg granulate/m^2 (Hann et al., 2018).

Based on this information and that the distance between the turf and the stream is relatively short (10-20m) and steep, granulate particles from this area have probably easily been transported into the stream during periods of heavy rain and storm water. This likely explain the larger amount of granulate particles downstream of Føyka compared to the other turfs and shows that the placement of snow during winter time may have an effect on the amount of granulate particles that are released to adjacent waterways. In addition, all drainage chambers at Føyka contain filters to prevent release of granulate particles to the stream, which supports the perception that winter operations is a large contributor to the release of granulate to the environment.

At Rud, Nadderud and Hosle there were observed similar amounts of granulate particles outside the turfs, as those who were observed at Føyka. Despite these observations there were found less particles in the stream sediments downstream of these turfs, which indicate that other factors than winter operations affects the amount of granulates that are released to the stream. These differences may be explained by other factors such as the placement of the turfs, distance to waterways, drainage systems or the terrain between the turfs and the stream.

4.2.2 Location of the turfs

Another possible explanation for the large differences among sites, might be the placement of the turfs, which affects the distance granulate particles have to travel before they are released into a nearby waterways. At Føyka, Drengsrudbekken is located very close to the turf, which means that granulate particles have a short distance to travel before they are released to the stream. In periods with heavy rain or storm water they may easily be transported into the stream, while at the other sites, the transportation of granulate particles is longer and more complex, and includes transportation through drainage systems or over larger areas of land. For example at Nadderud, granulate particles have to travel 1,9 km in drainage pipes before they are released to the stream. The long distance these particles have to travel will probably affect the amounts that are released to the waterways.

4.2.3 Drainage systems

In addition to the distance granulate particles have to travel before they are released to adjacent waterways, the transportation trough drainage systems might also effect the spreading of these particles. In general, most drainage systems contain sand traps, which prevents heavier particles from being transported further down the drainage pipes. As granulate particles have a higher density than freshwater some amounts of particles will most likely settle in these chambers. Ottesen et al. (2012) found high amounts of granulate particles in sand traps from four different artificial football turfs in Trondheim (Norway), which indicates that these contribute to lower emissions of granulate particles to nearby waterways. However, sand traps in connection to the turfs in this study were not investigated, so in which extent these contribute to lower amounts of granulate particles to the streams is unknown.

4.2.4 Stream characteristics

The characteristics of the various rivers and streams might also affect the amount of granulates found in the sediment samples. In general, the topography and flow velocity varied greatly between the waterways. Based on the fact that microplastic particles tend to settle in areas with low water velocity (Nizzetto et al., 2016; Vianello et al., 2013), there is reason to believe that sedimentation conditions and the choice of sampling locations may have affected the amount of granulates found in the sediment samples.

In summary, the differences between the streams are likely explained by a combination of several factors. Firstly, it seems like the distance between the turfs and the waterways is crucial in terms of the amount that were found in the sediments. This is shown with the high amounts of granulate particles found in Drengsrudbekken (Føyka), compared to the other streams. The high quantities of granulates found in Drengsrudbekken are also probably highly affected by winter operations and the placement of snow during winter time. Secondly, it appears that the drainage systems might also have an influence on the amount of granulate particles that are released into the waterways. At Nadderud, Hosle and Rud there were found lower quantities of granulate particles downstream of the turfs compared to Føyka, although there were observed similar amounts of granulate particles outside these turfs. Based on the fact that granulate particles found downstream of Nadderud, Holse and Rud most likely are transported through drainage systems, as there are no other natural pathways which granulate particles are transported to the streams, drainage systems might have an effect on the amounts that are released to the streams. One explanation might be that a lot of granulate are captured in sand traps inside these drainage systems. However, more studies are needed to investigate whether these sand traps are contributing to lower emissions to adjacent waterways.

The presence of granulate particles at Kringsjå (Up to 0,33 g/L, Figure 16) was unexpected, because there are no drainage pipes from the turfs that leads out in Songsvannsbekken (Kristian V. Østby 2018, personal communication, 7 February). In addition, the area between the turf and the stream is about 50 m and consists of a lot of vegetation, which might influence transportation of particles trough surface runoff. If we exclude drainage pipes as possible pathway; the following other factors may explain the occurrence of granulate in the stream. A possible explanation might be that these particles originate from the artificial turf at the Norwegian School of Sport Science, which are located several hundred meters north of the turfs at Kringsjå. Unfortunately, I have not managed to obtain information regarding drainage systems from this turf, so to which extent the turf at Norwegian School of Sport Science is contributing to granulate particles in Songsvannsbekken is unknown. Another possible explanation to these findings is that granulate particles have been spread form winter operations from Kringsjå 1 (Figure 8), as this turf has been used during wintertime in over ten years. As the area between the turf and the stream is relatively steep, granulate particles might have been spread into the stream through storm water.

4.3 Differences within the streams

In addition to the large differences between the streams, there were also large variations in the amount of granulate particles found in samples and stations within the various streams. This was especially visible in the samples taken in Drengsrudbekken and Dælibekken, were the number of granulate particles found ranged respectively from 1 to 1672 per/sample and 1 to 275 per/sample (Figure 12 and 15), although the samples were taken within a range of a few square meters. These findings is relatively similar compared to other studies of microplastic in river sediments i.e. Castañeda et al. (2014) who found mean densities of microplastics ranging from 7 to 136 926 microbeads/m^2 in sediment samples from the Canadian river St. Lawrence. This patchy distribution of granulate particles, may likely be explained by local environmental factors such as shifting water currents, flood events or river topography, that will affect the sediment deposition. Although this study did not specifically compare the sediment samples with regard to the content of fine particular matter and the amount of granulate found, the perception is that granulate particles tend to settle in areas with low water flow rates, with a high content of fine particular matter. This perception is similar to findings in other studies, e.g. Vianello et al. (2013) who found that microplastics in the lagoon of Venice, tend to accumulate in low-energy areas. Nizzetto et al. (2016) also stated that river sections with lower water currents are likely hotspots for microplastic deposition.

Generally there was a higher amount of granulate particles found in sediment samples closest to the turfs (Figure 17). This finding is most likely explained by the proximity to the emissions (football turfs). Despite this result, there were some sample stations with low amounts of particles found, even though they were located near the turfs. At Rud there were found very few granulate particles in the first two downstream stations (R.1 and R.2). These findings may be explained by low emissions from Hauger artificial football turf, as this turf was opened in spring 2017, only a few months before the fieldwork was carried out. The absence of winter operations at Hauger may also explain the low amounts of particles found in the stream, because winter operations is assumed to be one of the most important contributors to the release of granulate particles to the environment (Bauer et al., 2017; Rambøll, 2017).

Although most granulate particles were found in the samples that were located closest to the turfs, there were also found particles in those furthest away. At Nadderud granulate was found 4,3 km (N.7) downstream, while at Rud (R.5) it was found 3.7 km downstream. This indicates that granulate particles may be transported over long distances, despite the fact that they are denser than freshwater. What makes the finding at station N.7 so interesting is that this station was located on the other side of Engervannet, which is a small lake (1,1 km long). One possible explanation is that the granulate particles have been transported with water currents in periods with flooding or strong winds. Throughout the method testing there were observed floating granulate particles with air bubbles attached to them. If this also occurs in natural surroundings, it may be an explanatory factor to the long transportation of these particles. In addition, it may be other possible explanations to the granulate finding at station N.7. Granulates particles may also have been transported directly via clothes and shoes used by football players or through wastewater in connection with washing of clothes that have been used on artificial turfs. Since the station is located in an area with a lot of mud and low water levels, there is also a possibility that the particles have been transported through water fowl faeces, as they use such areas in the search for food. A recent study conducted by Spanish researchers found a high prevalence of microplastics in faeces of three water fowl species (Gil-Delgado et al., 2017). The three species that were analysed was European coot (*Fulica atra*), mallard (*Anas platyrhynchos*) and shelduck (*Tadorna tadorna*) which are all very common in Norway. Although this study has shown that water fowl potentially are able to transport microplastics, there is currently no literature showing that this is the case for granulate particles. The finding of granulate particles at station R.5 at Rud is also interesting, because the outlet of Sandvikselva to the Oslo fjord is located only 1 km downstream of this station, which indicates that rubber granulates from Rud most likely is transported to the marine environment.

Another interesting finding is that granulate particles were found at all stations located upstream the turfs. Considered that the catchments of Drengsrudbekken, Dælibekken and Eiksbekken lie in urban areas with a lot of human influence, transportation from clothing and shoes used on artificial football turfs may explain this finding. There is also a possibility that these particles originate from other installations that use rubber granulate, such as playgrounds, athletics courts or horse riding courses (Borgersen & Åkesson, 2012), but to which extent installations like these are present in the catchments is unknown. Transportation by water fowl is also a possible explanation to the upstream findings, particularly at Kringsjå, as the catchment of Songsvannsbekken does not contain urban areas. In addition, particles found at this site may also originate from people, as Songsvann is a popular area for recreational activities such as walking, jogging or swimming. The particles found upstream of Kringsjå clearly shows that granulate particles also are transported to unpolluted areas, as there are no urban areas in the catchment of Songsvannsbekken.

In addition to the granulate particles that were found at the 1mm sieve, there were also found smaller granulate particles with a diameter between 1 and 0.5 mm, at all downstream stations at Føyka (Figure 18). This shows that smaller particles than 1mm also are released from the artificial turfs. The extent to which these particles originate from the production of rubber granulates or from wear and tear of particles on the turf or in the stream is uncertain.

4.4 Study limitations

As several of the streams in this study run through urban areas with a lot of human influence, there is a probability that there are other sources that contribute to rubber granulate emissions apart from the artificial football turfs that were investigated. As mentioned, the use of granulate particles is common in playgrounds, athletics courts and in horse riding courses (Borgersen & Åkesson, 2012). However, the results of this study show the concentration of granulate particles is greatest closest to the turfs (Figure 17), which suggests that the turfs are the main source to the emissions, rather than other sources. The results in this study might also have been affected by the visual identification that was used to separate granulate particles from other microplastic particles. As the visual identification was based on color, consistency and shape rather than chemical composition, there is a possibility that some of the particles that were thought to be granulate, might have been other types of microplastic, or the other way around. Although there is a possibility that particles may have been identified incorrectly, my opinion is that there is highly likely that the identified particles are granulate due to their characteristic appearance, which makes them differentiable from other microplastic particles.

4.5 Implications of the study

4.5.1 Measures to prevent further release of granulate particles from artificial football turfs

Due to the climate conditions and a high demand for playtime all year around, the increase in new artificial football turfs will most likely continue in the years to come. Based on this, and the amount of granulate particles that disappears from artificial football turfs each year, it is important to look for possible measures to prevent further spreading of granulate particles to the environment in the future.

Based on the observations throughout the field work and the findings in this study it is highly likely that most of the spread and loss of granulate particles is due to winter operations, where the use of snow blowers and other equipment causes snow with granulates to aggregate outside the turfs. This perception is supported by Rambøll (2017), who found that turfs with winter operations in general is adding more granulate to the turfs at an annual basis, compared to turfs without winter operations. According to Rambøll (2017), the best option to prevent loss of granulate particles from turfs with winter operations is to place snow from the turfs in suitable areas throughout the winter season. Flat areas, with a solid surface (asphalt) or with a fiber cloth is recommended as this prevents dispersal and makes collection of granulate particles easier (Rambøll, 2017). As shown through this thesis, it is especially important to avoid gathering snow in sloping areas or close to adjacent waterways, as granulate easily is spread to adjacent streams. In addition, it should also be established guidelines for use of snow blowers, as these may potentially spread granulates over large areas. Another important observation was that almost none of the investigated turfs had filters in the drainage chamber to prevent release of granulate particles to the drainage systems. This is an important measure, since the spreading of granulate particles from some artificial turfs (e.g. Nadderud and Hosle) only is possible through drainage pipes, as there are no other natural pathways through which granulate may be released to adjacent waterways. A study conducted by Ottesen et al. (2012) showed the high effect of such filters as they barely found any granulate particles in drainage chambers with filters compared to those without filters.

To prevent spreading of granulates from athletes, there should be established areas where granulate particles from clothing and shoes can be removed before leaving the turfs. According to Rambøll (2017), very few Norwegian football clubs (6%) have introduced such measures today. A suggestion to this may be a grind outside the turf, where particles can be removed and later collected. There should also be established procedures for collecting rubber granulates throughout the year. Granulates that are lying outside the turfs can potentially be spread to surrounding areas, especially in periods with heavy rain or strong winds. Regular collection of granulates will therefore prevent the possibility of granulates being transported to the environment. In addition to the implementation of measures that already has been discussed, it is important that establishment of new artificial football turfs is placed in areas with low risk of spreading of granulate particles to adjacent waterways. In connection with new turfs, there should also be established physical barriers around the paths to prevent losses to the environment. Possible measures are summarized in table 7.

Another possible solution is the use of environmentally friendly alternatives to rubber granulates, such as cork or other types of organic infill. Although cork performs well in many areas, there is a problem during wintertime, as these particles absorb water and may harden at low temperature (Bauer et al., 2017) which makes them unsuitable for artificial turfs with winter operations. A recent study conducted by Bauer et al. (2017) concluded that as of today there are no infill on the marked that are superior to rubber granulate in terms of key characteristics such as environmental and health performance, usability, price, maintenance and aesthetics. Although environmental friendly granulate may be the solution in the future, more research is needed to find suitable materials that can replace rubber granulates. Based on this, measures like those mentioned above are extremely important to implement, as rubber infill most likely will be the preferred material in the years to come.

To my knowledge, there is currently little information available regarding problems with release of granulate particles from artificial football turfs in other European countries, than

Norway and Sweden. This is rather strange, considered that estimations show that there consist over 51 000 artificial turfs in Europe (Hann et al., 2018). As it is assumed that winter operations are the main contributor to the emission of granulate particles to the environment, this may be one explanation, as many European countries don't have snow during winter time.

Table 7. Measures to reduce the emissions of rubber granulate to the environment.

Measures to reduce the emissions of rubber granulate
• Guidelines for use of snow blowers and other snow clearing equipment • Use of filters in all drainage chambers • Procedures for removing granulate particles from clothing and shoes, i.e. a grind were particles can be removed and later collected • Specific areas for snow storing through the winter season. Flat areas, with a fiber cloth for collection is preferable • New artificial football turfs should be placed in areas where the possibility of spreading to adjacent waterways is minimal • Physical barriers around the turfs, preventing granulate to spread to the environment

5 Conclusion

The results from this study confirm that rubber granulate particles from artificial football turfs are being spread to adjacent rivers and streams. Based on field observations and findings, it is highly likely that snow removal during winter operations is the biggest contributor to the spreading of granulate particles to the environment. In addition, it appears that the location of the turfs and the placement of snow during winter operations is crucial in terms of the amount of granulate particles that are released to adjacent waterways. Furthermore, granulate particles were found up to 4,3 km downstream and at all upstream stations, including the station upstream of Kringsjå, were the entire catchment area was free of artificial football turfs. This indicates that the granulate particles have the ability to spread far and "randomly", i.e. not only downstream along waterways.

Considered the findings in this study and the possible large emissions of granulate particles from artificial football turfs, it is important that guidelines and measures for the use of granulate particles as infill are established as soon as possible to prevent further release into the environment. Furthermore, more research is needed on environmental friendly materials that can replace rubber granulates in the future. These actions are important, as the spreading of rubber granulate particles leads to an increased amount of microplastic in the environment that may have deleterious effect on wildlife.

6 Reference

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7 Appendix

7.1 Sample station information

Table A-1. Site numbers, description of location, number of samples, distance from the turf, sediment type and GPS coordinates from the various sample stations at Hosle. Distance from the turf was measured by use of an measuring tool, in the map service Norgeskart (Kartverket, 2018). The distance is measured along the river, not in a direct line.

Site no.	Description	Number of samples	Distance from turf	Sediment type	GPS Coordinates
E.1	Nadderud upstream (Eiksbekken). Samples were taken by Eiksmarka school, right before Eiksbekken flows into underground pipes. Weak stream and a lot of sedimentation.	3*	About 2,7 km (upstream)	A lot of org. matter, sand, silt	59.94867 10.62144
H.1	Hosle downstream (Hoslebekken). Samples were taken in the middle of the stream. The stream was very small and narrow in this area. Weak current and little sedimentation	3	443m	A lot of sand and some silt and org. matter	59.93032 10.57791
H.2	Hosle downstream (Hoslebekken). Samples were taken further down the stream, in an area with a lot of sedimentation and some erosion from the surrounding riverbank. Muddy ground and a lot of sedimentation.	3	885m	A lot of sand, silt and org. matter	59.92661 10.57642
H.3	Hosle downstream (Hoslebekken). Samples were taken in a little pond right before a culvert, in an area quiet area with weak current. Very similar to site H.3.	3	900m	A lot of sand, silt and org. matter	59.92648 10.57652
H.4	Hosle downstream (Hoslebekken). Samples were taken directly before Hoslebekken disappears into underground pipes. The area was very similar to H.2 and H.3, with a lot of sedimentation a weak current.	3	1010m	A lot of sand, silt and org. matter	59.92553 10. 57699

*Nadderud and Hosle has the same upstream sample station

Table A-2. Site numbers, description of location, number of samples, distance from the turf, sediment type and GPS coordinates from the various sample stations at Føyka. Distance from the turf was measured by use of an measuring tool, in the map service Norgeskart (Kartverket, 2018). The distance is measured along the river, not in a direct line.

Site no.	Description	Number of samples	Distance from turf	Sediment type	GPS Coordinates
F.O.1	Føyka upstream (Drengsrudbekken). Light current and little sedimentation. Downstream of E18 (highway).	5	100m	A lot of Gravel, sand	59.83353 10.42347
F.1	Føyka downstream (Drengsrudbekken). Weak current and little sedimentation. A lot of granulate seen on the ground, all the way down to riverside. Snow for the turf is gather her during winter season.	5	20m	Stones, gravel sand	59.83389 10.42523
F.2	Føyka downstream (Drengsrudbekken). Weak current and much sedimentation. Granulate found in the river surface. Different sedimentation across the stream.	4	35m	Gravel, sand, fine sand	59.83399 10.42650
F.3	Føyka downstream (Drengsrudbekken). Very weak current and much sedimentation. Granulate found in the river surface	4	129m	Gravel, sand, fine sand	59.83423 10.42808
F.4	Føyka downstream (Askerelva). Samples taken at the output from Drengsrudbekken. Samples taken from the riverside. Medium current, much sedimentation at the riverside. Samples taken from both 0-5 cm and 5-10 cm of the sediment.	6	353m	Gravel, sand, fine sand	59.83380 10.43138
F.5	Føyka downstream (Askerelva). Samples taken were the river runs under E18. Weak current and much sedimentation.	3	624m	Gravel, sand, fine sand, org. matter	59.83148 10.43078
F.6	Føyka downstream (Askerelva). weak current and variations in sedimentation. Both areas with fine and rough sediments.	4	1070m	Gravel, sand, fine sand, org. matter	59.82778 10.43223
F.7	Føyka downstream (Askerelva). Samples taken at the output of Askerelva, by Bondivann. Very quiet area, almost no current. Much sediment	4	1250m	Sand, fine sand, a lot of org. matter	59.82637 10.43267

Table A-3. Site numbers, description of location, number of samples, distance from the turf, sediment type and GPS coordinates from the various sample stations at Nadderud. Distance from the turf was measured by use of an measuring tool, in the map service Norgeskart (Kartverket, 2018). The distance is measured along the river, not in a direct line.

Site no.	Description	Number of samples	Distance from turf	Sediment type	GPS Coordinates
E.1	Nadderud upstream (Eiksbekken). Samples were taken by Eiksmarka school, right before Eiksbekken flows into underground pipes. Weak stream and a lot of sedimentation.	3	About 4 km (upstream)	A lot of org. matter, sand, silt	59.94867 10.62144
N.1	Nadderud downstream (Nadderudbekken). Samples were taken in a sediment basin, by the outlet of Nadderudbekken (Blomsterkroken). Before this point the stream flows in underground pipes. Relative high current and much sedimentation. Samples taken from both 0-5 cm and 5-10 cm of the sediment.	11	1,87km	A lot of gravel and sand, some silt and org. matter	59.90671 10.55940
N.2	Nadderud downstream (Øverlandselva). Samples were taken at the riverside. Rapid current and little sedimentation.	3	2,1km	A lot of gravel and sand, some silt	59.90533 10.55624
N.3	Nadderud downstream (Øverlandselva). Samples were taken at the river side. Weak current and medium sedimentation. A lot of vegetation in the area where the samples were taken. Granulate found.	6	2,24km	Mainly sand and org. matter, some silt.	59.90462 10.55530
N.4	Nadderud downstream (Øverlandselva). Samples were taken at the river side. Weak current and muddy river bed with a lot of sedimentation.	3	3,15km	Sand, silt and clay	59.90025 10.54248
N.5	Nadderud downstream (Øverlandselva) Samples were taken at the river side. Weak current and muddy river bed with a lot of sedimentation. Very similar to site N.4	3	3,23km	Sand, silt and clay	59.90003 10.54111
N.6	Nadderud downstream (Engervannet). Samples were taken at the output of Øverlandselva, where the river meets Engervannet. Muddy ground and a lot of sedimentation.	3	3,4km	Sand, silt, clay and org. matter	59.89909 10.53914
N.7	Nadderud downstream (Engervannet). Samples were taken at the southwest side of Engervannet, by the beginning of Sandvikselva. Muddy ground and a lot of sedimentation.	3	4,29km	Sand, silt, clay and org. matter	59.89402 10.52705

Table A-4. Site numbers, description of location, number of samples, distance from the turf, sediment type and GPS coordinates from the various sample stations at Rud. Distance from the turf was measured by use of an measuring tool, in the map service Norgeskart (Kartverket, 2018). The distance is measured along the river, not in a direct line.

Site no.	Description	Number of samples	Distance from turf	Sediment type	GPS Coordinates
R.O.1	Rud upstream (Dælibekken). Samples were taken in a quiet area of Dælibekken, about 100m above Hauger artificial football turf. Quiet area of the stream with weak current and a lot of sediment.	3	92m	Sand, silt, clay and org. matter	59.908224 10.508856
R.1	Rud downstream (Dælibekken). Samples were taken at the riverside. The area was very similar to R.O.1. Quiet area of the stream with weak current and a lot of sediment.	3	57m	Sand, silt and org. matter	59.908123 10.505077
R.2	Rud downstream (Dælibekken). Samples were taken at the riverside, in an area where the stream was divided into two. Weak current and a lot of sediment.	3	37	A lot of sand and some silt and org. matter	59.907607 10.503383
R.3	Rud downstream (Dælibekken). Samples were taken below the output of the drainage pipes from the Rud artificial turf. Samples were taken at the river side in a quiet area.	5	58m	A lot of sand and some silt and org. matter	59.907475 10.503270
R.4	Rud downstream (Sandvikselva). Samples were taken at the riverside in Sandvikselva, about 50 meters downstream from the output of Dælibekken. Little sedimentation due to rapid stream in Sandvikselva.	3	890m	A lot of sand and gravel	59.902338 10.493649
R.5	Rud downstream (Sandvikselva). Samples were taken about 3.7 km downstream from Rud. Inn a quiet area of Sandvikselva, with little current and a muddy riverbed.	3	3711m	Sand, silt, clay and org. matter	59.894680 10.515385

Table A-5. Site numbers, description of location, number of samples, distance from the turf, sediment type and GPS coordinates from the various sample stations at Kringsjå. Distance from turf was measured by use of an measuring tool, in the map service Norgeskart (Kartverket, 2018). The distance is measured along the river, not in a direct line.

Site no.	Description	Number of samples	Distance from turf	Sediment type	GPS Coordinates
K.O.1	Kringsjå upstream (Songsvannsbekken). Samples were taken in a quiet area of the stream, about 50 meters downstream from lake Songsvann. Little sedimentation.	3	414m	A lot of sand and silt, but also org. matter.	59.969511 10.725705
K.1	Kringsjå downstream (Songsvannsbekken). Samples were taken at the river side in a very quiet area of the stream. A lot of vegetation along the banks of the stream.	3	52m	Sand, silt, clay and org. matter	59.964850 10.725554
K.2	Kringsjå downstream (Songsvannsbekken). Samples were taken at the riverside, below the output of the drainage pipes from Kringsjå. Quiet area, with weak current and a lot of sedimentation.	4	210m	Sand, silt and org. matter	59.962354 10.724675
K.3	Kringsjå downstream (Songsvannsbekken). Weak current and little sedimentation. Granulate where found in the top layer of the riverbed. Samples taken from both 0-5 cm and 5-10 cm of the sediment.	6	270m	Sand, silt and some org. matter	59.961905 10.724121
K.4	Kringsjå downstream (Songsvannsbekken). Quiet area downstream, with a lot of sediment and muddy ground.	3	626m	Sand, silt, clay and org. matter	59.960016 10.719386
K.5	Kringsjå downstream (Songsvannsbekken). Quiet area downstream, with a lot of sediment and muddy ground. Very similar to K.4.	3	940m	Sand, silt, clay and org. matter	59.957885 10.715803

7.2 Sediment sample information

Table A-6: The weight of granulate per sample, estimated weight per litre and estimated number of granulate particles per sample and per litre for the various sediment samples taken at Føyka.

Sample Nr.	Granulate weight (g) per sample	Estimated granulate weight (g) per litre	Estimated number of granulate particles per sample	Estimated number of granulate particles per litre
F.O.1 (I)	0,0006	0,004	1	1
F.O.1 (II)	0,0000	0,000	0	0
F.O.1 (III)	0,0000	0,000	0	0
F.O.1 (IV)	0,0000	0,000	0	0
F.O.1 (V)	0,0000	0,000	0	0
F.1 (I)	0,0309	0,219	8	55
F.1 (II)	0,0089	0,063	2	16
F.1 (III)	0,0185	0,131	5	33
F.1 (IV)	4,4258	31,322	1106	7831
F.1 (V)	6,6865	47,321	1672	11830
F.2 (I)	0,0184	0,130	5	33
F.2 (II)	1,4014	9,918	350	2480
F.2 (III)	2,1023	14,878	526	3720
F.2 (IV)	0,0876	0,620	22	155
F.3 (I)	0,0049	0,035	1	9
F.3 (II)	0,7729	5,470	193	1368
F.3 (III)	0,1819	1,287	46	322
F.3 (IV)	1,6740	11,847	419	2962
F.4 (I)	0,0827	0,585	21	146
F.4 (I) 5-10cm	0,2250	1,592	56	398
F.4 (II)	0,1542	1,091	39	273
F.4 (II) 5-10cm	0,0986	0,698	25	174
F.4 (III)	0,0466	0,330	12	82
F.4 (III) 5-10cm	0,3115	2,205	78	551
F.5 (I)	0,1147	0,812	29	203
F.5 (II)	0,0486	0,344	12	86
F.5 (III)	0,0276	0,195	7	49
F.6 (I)	0,1030	0,729	26	182
F.6 (II)	0,0362	0,256	9	64
F.6 (III)	0,0000	0,000	0	0
F.6 (IV)	0,0226	0,160	6	40
F.7 (I)	0,1362	0,964	34	241
F.7 (II)	0,0122	0,086	3	22
F.7 (III)	0,0119	0,084	3	21
F.7 (IV)	0,0000	0,000	0	0

Table A-7: The weight of granulate per sample, estimated weight per litre and estimated number of granulate particles per sample and per litre for the various sediment samples taken at Nadderud.

Sample Nr.	Granulate weight (g) per sample	Estimated granulate weight (g) per litre	Estimated number of granulate particles per sample	Estimated number of granulate particles per litre
E.1 (I)	0,0045	0,032	1	8
E.1 (II)	0,0000	0,000	0	0
E.1 (III)	0,0004	0,003	1	1
N.1 (I)	0,0559	0,396	14	99
N.1 (II)	0,0101	0,071	3	18
N.1 (II) 5-10cm	0,1208	0,855	30	214
N.1 (III) 5-10cm	0,1352	0,957	34	239
N.1 (IV) 5-10cm	0,5872	4,156	147	1039
N.1 (V)	0,1179	0,834	30	209
N.2 (I)	0,0195	0,138	5	35
N.2 (II)	0,0123	0,087	3	22
N.2 (III)	0,0331	0,234	8	59
N.3 (I)	0,0082	0,058	2	15
N.3 (II)	0,1897	1,343	47	336
N.3 (III)	0,4199	2,972	105	743
N.3 (I) B	0,3678	2,603	92	651
N.4 (I)	0,0171	0,121	4	30
N.4 (II)	0,0056	0,040	1	10
N.4 (III)	0,0096	0,068	2	17
N.5 (I)	0,0008	0,006	0	1
N.5 (II)	0,0071	0,050	2	13
N.5 (III)	0,0000	0,000	0	0
N.6 (I)	0,0020	0,014	1	4
N.6 (II)	0,0000	0,000	0	0
N.6 (III)	0,0015	0,011	1	3
N.7 (I)	0,0000	0,000	0	0
N.7 (II)	0,0000	0,000	0	0
N.7 (III)	0,0037	0,026	1	7

Table A-8: The weight of granulate per sample, estimated weight per litre and estimated number of granulate particles per sample and per litre for the various sediment samples taken at Hosle.

Sample Nr.	Granulate weight (g) per sample	Estimated granulate weight (g) per litre	Estimated number of granulate particles per sample	Estimated number of granulate particles per litre
E.1 (I)	0,0045	0,032	1	8
E.1 (II)	0,0000	0,000	0	0
E.1 (III)	0,0004	0,003	1	1
E.1 (I)	0,3883	2,748	97	687
E.1 (II)	0,2875	2,035	72	509
E.1 (III)	0,1337	0,946	33	237
E.2 (I)	0,0091	0,064	2	16
E.2 (II)	0,0000	0,000	0	0
E.2 (III)	0,0021	0,015	1	4
E.3 (I)	0,0071	0,050	2	13
E.3 (II)	0,0009	0,006	1	2
E.3 (III)	0,0000	0,000	0	0
E.4 (I)	0,0000	0,000	0	0
E.4 (II)	0,0036	0,025	1	6
E.4 (III)	0,0000	0,000	0	0

Table A-9: The weight of granulate per sample, estimated weight per litre and estimated number of granulate particles per sample and per litre for the various sediment samples taken at Rud.

Sample Nr.	Granulate weight (g) per sample	Estimated granulate weight (g) per litre	Estimated number of granulate particles per sample	Estimated number of granulate particles per litre
R.O.1 (I)	0,0000	0,000	0	0
R.O.1 (II)	0,0009	0,006	1	2
R.O.1 (III)	0,0087	0,062	2	15
R.1 (I)	0,0000	0,000	0	0
R.1 (II)	0,0000	0,000	0	0
R.1 (III)	0,0041	0,029	1	7
R.2 (I)	0,0000	0,000	0	0
R.2 (II)	0,0009	0,006	1	2
R.2 (III)	0,0000	0,000	0	0
R.3 (I)	0,0013	0,009	1	2
R.3 (II)	0,1298	0,919	32	230
R.3 (III)	0,7399	5,236	185	1309
R.3 (IV)	1,0999	7,784	275	1946
R.3 (V)	0,2582	1,827	65	457
R.4 (I)	0,2851	2,018	71	504
R.4 (II)	0,0374	0,265	9	66
R.4 (III)	0,2944	2,084	74	521
R.5 (I)	0,0091	0,064	2	16
R.5 (II)	0,0057	0,040	1	10
R.5 (III)	0,0145	0,103	4	26

Table A-10: The weight of granulate per sample, estimated weight per litre and estimated number of granulate particles per sample and per litre for the various sediment samples taken at Kringsjå.

Sample Nr.	Granulate weight (g) per sample	Estimated granulate weight (g) per litre	Estimated number of granulate particles per sample	Estimated number of granulate particles per litre
K.O.1 (I)	0,0000	0,000	0	0
K.O.1 (II)	0,0006	0,004	1	1
K.O.1 (III)	0,0000	0,000	0	0
K.1 (I)	0,3311	2,343	83	586
K.1 (II)	0,0998	0,706	25	177
K.1 (III)	0,3041	2,152	76	538
K.2 (I)	0,0118	0,084	3	21
K.2 (II)	0,0000	0,000	0	0
K.2 (III)	0,0201	0,142	5	36
K.2 (III) 5-10cm	0,0456	0,323	11	81
K.3 (I)	0,2835	2,006	71	502
K.3 (II)	0,0599	0,424	15	106
K.3 (III)	0,1331	0,942	33	236
K.3 (III) 5-10cm	0,2683	1,899	67	475
K.3 (IV)	0,0598	0,423	15	106
K.3 (IV) 5-10cm	0,2933	2,076	73	519
K.4 (I)	0,0054	0,038	1	10
K.4 (II)	0,0045	0,032	1	8
K.4 (III)	0,0176	0,125	4	31
K.5 (I)	0,0009	0,006	0	2
K.5 (II)	0,0221	0,156	6	39
K.5 (III)	0,0041	0,029	1	7

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