ARTIFICIAL TURF SPORTS FIELDS AND THE WATER ENVIRONMENT – PUBLIC PERCEPTION, EVIDENCE AND THE UNKNOWN

J. Reddish, Opus International Consultants, New Zealand
Dr M. Jennings-Temple, STRI Group, Australia

ABSTRACT

Enhancing community access to sports facilities, particularly in urban environments, is a challenge around the world. One aspect of this is to improve sports fields' capacity, recognising the significant increase in demand brought about by increasing population density. The technological improvements associated with artificial turf, and their international approval through FIFA and the International Rugby Board, have resulted in a rapid increase in their use globally as a means of significantly increasing sports field capacity.

Historically the areas set aside for sports fields, have often been 'left over', flood prone land. While some sports fields are configured as multi-purpose assets (e.g. as floodplain storage as well as recreation), the rapid increase in artificial turf use and the associated capital investment, has led to the development of these sites coming under increased scrutiny.

Whilst improving sports field capacity is important, improving the livability of cities requires emphasis and deliberate focus on sustaining and valuing the environment. In some locations, in New Zealand and abroad, the public have raised concerns regarding the impact artificial turf sports fields will have on the downstream water environment. This paper outlines both the public perception of artificial turf, the international research to date, and importantly where gaps in understanding remain. The paper sets out currently available information about the effects artificial turf sports fields can have on downstream aquatic health, as well as the impact flooding has on these surfaces.

The paper concludes that there are substantial knowledge gaps regarding how synthetic turf interacts with and influences the water environment. The accurate and careful citing of research results from competent studies may be required to address user concerns when developing fields. Designs should be precautionary in nature such that fields are not located in areas prone to flood risk or overland flow. Furthermore, catchpit protection to intercept macro-particles (i.e. crumb rubber and detached fibres) should also be considered mandatory. Long-term, the results of new research should be brought into the discussion to ensure that all possible impacts of artificial turf are fully understood and considered when designing and installing artificial turf fields.

KEYWORDS

Artificial Turf, Sports Fields, Water Quality, Water Sensitive, Third Generation, Crumb Rubber

BACKGROUND

Local authorities and private organisations invest significant amounts of money to increase the usage capacity of sports fields. Artificial turf sports fields can withstand many more hours per week of active play than natural turf fields, so where user demand for sports surfaces exceeds the capacity of even the highest quality natural turf fields, artificial turf fields are being strategically located to absorb this demand.

The construction of artificial turf fields requires the introduction of highly specified, permeable materials (i.e. sand, crumb rubber gravel and subsoil pipe networks) that can remove surface water through the profile and off-site via a stormwater system, bypassing the bulk soil. The success and longevity of the entire system requires the permeable materials to remain free of fine material that may reduce the porosity of the drainage media.

However, public reserves commonly serve multiple functions, and artificial turf sports fields may be located within an area subject to periodic flooding due to overland flow, the local stormwater network capacity being exceeded, or intentional stormwater detention. The effects of flooding on the condition, quality and lifespan of artificial turf surfaces is not well understood. Additionally, the potential for these surfaces to negatively affect stormwater quality and downstream infrastructure and ecology is unclear. The absence of readily available, or conflicting, evidence can lead to scrutiny by the public.

This paper broadly describes the public perceptions of artificial turf based on a review of online blogs, websites, and author experience from consulting with the public. With much of the focus on artificial turf and human health, this paper seeks to collate current understanding, and provide guidance for those planning or maintaining artificial turf, on water environment context, specifically by asking:

What are the effects of the water environment on artificial turf?

What are the effects of artificial turf on the water environment?

PUBLIC PERCEPTION OF ARTIFICAL TURF

The authors do not have an in depth knowledge of the health effects associated with artificial turf. The information below presents a range of views to provide context to the discussion in environmental effects. There is conflicting information from suppliers and sport lobby groups compared to information presented by consumer groups on both the human health and environmental impact of artificial turf. Both sides reference their own sources and research to support their side of the argument.

For example, a leading supplier states:
The issue is not new and has been researched and debated for over a decade. All of that research to date concludes that there is no evidence that there is any elevated human health or environmental risk from ingesting, breathing, or skin contact with synthetic turf grass fibres or the infill or from any storm water run-off.
(McKenzie, 2015)

Another suppler states:
"There is no credible link between crumb rubber and cancer"

Conversely, the toxipedia blog states:

The tire rubber is a synthetic mix of dangerous chemicals designed to enhance the performance and wear for cars and trucks; tires were never designed to be played on by children.

In some cases both sides of the argument use the same source of information, but cherry-pick the bits that suit their argument. The Synthetic Turf Council quoted the Connecticut Department of Public Health saying: *"The use of outdoor and indoor artificial turf fields is not associated with elevated health risks"* (Synthetic Turf Council, 2010)

Toxipedia also quoted the Connecticut Department of Public Health stating:

Thirteen compounds were included in the cancer risk assessment. Cancer unit risks were obtained from standard toxicology databases for four of those, two of those included human epidemiologic data. Unit risk estimates for the other nine carcinogens were estimated, assumed or obtained from nonstandard sources.

Many of the arguments against artificial turf in the United States use questions raised by a soccer coach, Amy Griffin. Her key concerns are that:

1. Crumb rubber includes dangerous chemicals, e.g. PAHs and heavy metals, such as lead
2. The grass fibres include dangerous chemicals, such as chromium and lead.
3. These chemicals can volatilize as fumes, sink into skin, be inhaled as dust, or leach into the environment.
4. The presence of these chemicals is leading to health issues for children and athletes (e.g. increased cases of cancer) and ecological impact on flora and fauna.

The Safe Healthy Playing Fields Coalition in Maryland, USA include the following environmental arguments for avoiding the use of artificial turf:

- *Both the synthetic turf and the rubber must be disposed of when the field reaches its life capacity (8-10 yrs). Natural grass fields require renovation less frequently with much reduced renovation costs.*
- *Synthetic fields do not cool the environment like natural turf.*
- *Synthetic fields and natural grass fields have similar irrigation requirements since both need irrigation in warmer months and little to no irrigation in cooler months.*
- *Synthetic fields do not help to filter air and water pollutants.*
- *Synthetic fields do not fix CO_2 (carbon-dioxide) and release O_2 (oxygen) as do natural grass fields.*
- *The net carbon loss for a synthetic field is high, whereas a natural grass field will have a net carbon gain despite the need for fertilizer and some pesticide inputs to maintain a natural grass.*

More specifically with respect to the water environment, they also state that:

Storm water run-off from synthetic turf fields has been found to contain zinc. Zinc is poisonous to aquatic life forms such as daphnia, at the bottom of the food chain.

Further contributing to this concern, the Toxipedia blog states:

the use of tires in artificial turf has the potential to pollute our environment with PAHs, phenols and zinc and that runoff from an artificial turf field draining to a local creek can pose "a positive risk of toxic effects on biota in the water phase and in the sediment." Other metal contaminants found to leach from tire crumb rubber include zinc, selenium, lead and cadmium. Zinc has also been shown to leach from the artificial turf fibers.

In New Zealand, the 'Friends of Fowlds Park' and the 'Friends of Michaels Ave Reserve' community groups opposed Auckland Council's development of artificial turf surfaces at the respective fields on a range of matters, including environmental effects, visual impact and the smell.

The debate has been fueled further by the media. In 2014, NBC News in the United States ran a television article *'How Safe is the Artificial Turf your Child Plays On?'* (Rappleye, 2014). The article quoted Dr. Joel Forman, associate professor of pediatrics and preventive medicine at New York's Mt. Sinai Hospital, saying:

> *"None of [the studies] are long term, they rarely involve very young children and they only look for concentrations of chemicals and compare it to some sort of standard for what's considered acceptable…….If you never study anything," said Dr. Forman, "you can always say, 'Well there's no evidence that's a problem,' but that's because you haven't looked. To look is hard." "I would like to see some more research," he concluded.*

The consumer health website Healthline.com raises concerns in their 2015 article *Parents, Athletes Sound Alarm Over Potentially Toxic Artificial Turf Playing Fields*, with the subheading:

> *Soccer goalies seem to be getting cancer at a high rate, prompting calls for more research into crumb rubber used on fake grass fields* (Radcliffe, 2015)*.*

Conversely, the article quotes a different doctor saying:

> *"The concern has been over a number of athletes developing cancer — lymphomas, in particular — but I don't think there's been any solid epidemiological research that relates the two," Dr. Arthur L. Frank, Ph.D., a professor in the Dornsife School of Public Health at Drexel University, said in an interview with Healthline. Frank also notes that certain types of cancer — such as Hodgkin's lymphoma — are not uncommon among young people and can have many causes.*

To date the focus of much of the debate has been the potential impact on human health, however impact (or lack of impact) on the environment is often included to add weight to the argument on either side.

Part of the issue facing the use of artificial turf is *"studies to date have not shown an elevated health risk from playing on fields with tire crumb rubber, but these studies have limitations and do not comprehensively evaluate the concerns about health risks from exposure to tire* crumb rubber." (US EPA, 2016). This leaves gaps that can exacerbate public concern.

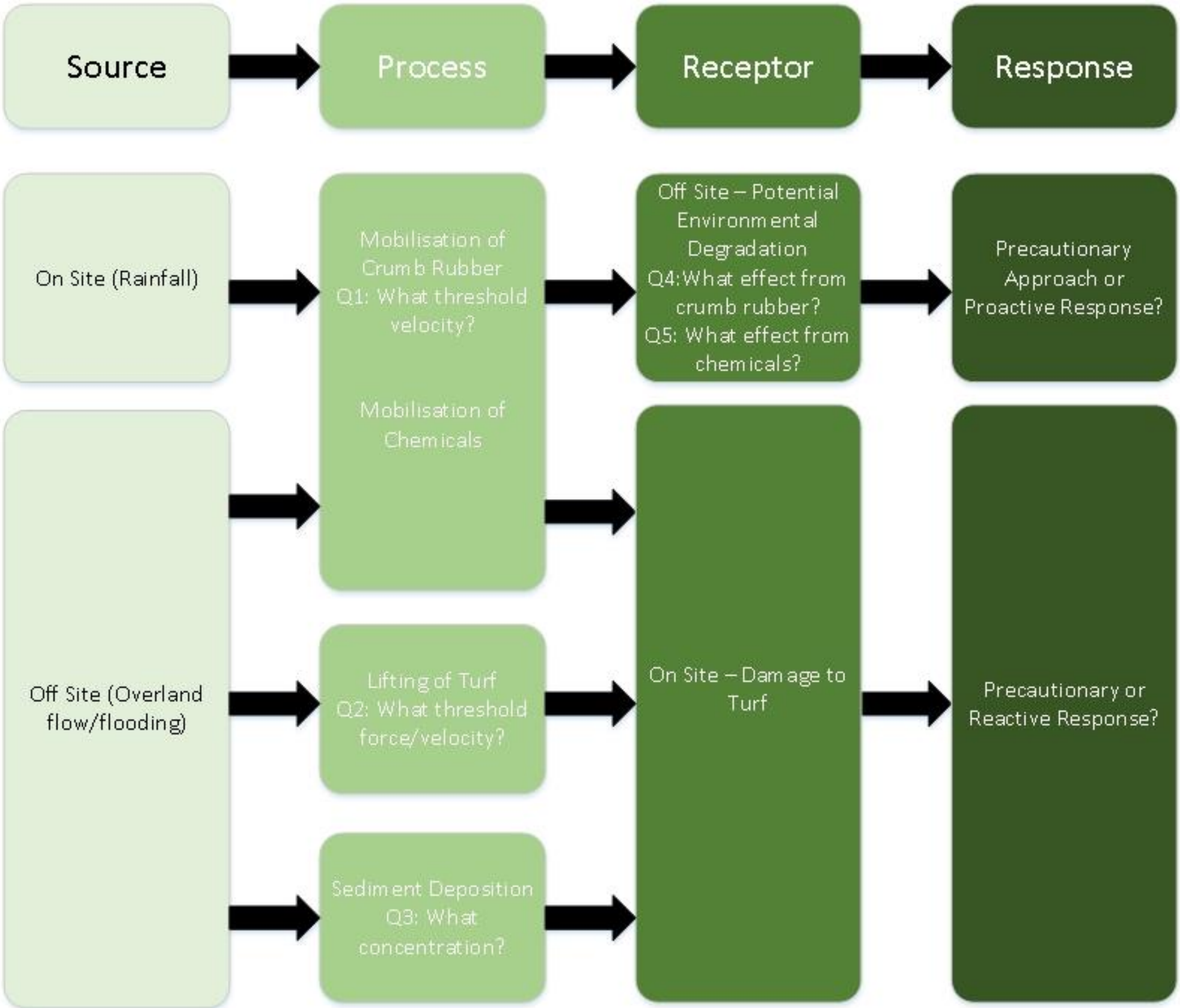
A potential hope on the horizon to end much of the debate is that the US EPA are currently undertaking a multi-agency study called the *Federal Research Action Plan on Recycled Tire Crumb used on Playing Fields and Playgrounds.* This study, due to be completed in 2017, seeks to study key environmental and human health questions. The scope indicates it is likely to be the most comprehensive study to date.

FRAMING THE PROBLEM

To help respond to the water environmental impact questions, a simple framework has been established (Figure 1) and key information gaps identified. The gaps fall within the process and receptor stages of the diagram and can be described in the following five questions:

- Q1: What threshold velocity mobilises crumb rubber?
- Q2: What force or velocity is required to lift artificial turf?
- Q3: What concentration of sediment in floodwater will damage artificial turf?
- Q4: What are the downstream effects of crumb rubber?
- Q5: What are the downstream effects of chemicals used on artificial turf?

Figure 1: Processes affecting artificial turf and the water environment



RESEARCH AND ANALYSIS

Q1: What velocity mobilises crumb rubber?

In the Auckland region to-date, there have been no recorded examples of significant losses of crumb rubber from artificial surfaces to the stormwater system. However, this may primarily be a result of the relatively recent adoption of third generation surfaces in Auckland, rather than a definitive assessment of the risk. A desktop assessment of the Michaels Avenue Reserve artificial turf sports field in Ellerslie (Meikle, 2013) indicated there is a low risk of crumb rubber entering the downstream environment due to low velocities, relative densities and hydraulic drag. However, there appears to be no research on velocities that will mobilise crumb rubber, and there is conflicting advice from manufacturers and suppliers regarding whether crumb rubber will be washed away (Outdoor Synthetic Surfaces, 2013).

Like sand, there is limited cohesive force to bind crumb rubber together. However, whereas sand (2.65g/cm^3) is significantly denser than water (1.0g/cm^3), crumb rubber is approximately 1.2g/cm^3 (Rogers et al, unknown).

Based on the relative densities, crumb rubber should not float, however a simple test (Figure 2) indicates that while the majority of crumb rubber sinks, some does float. This is potentially due to inconsistencies in the density of individual crumb rubber particles, attached air bubbles or air-filled voids. Therefore, under the right conditions, site runoff, overland flow or flooding could indeed result in its migration within a sports field or off-site.

Figure 2: Crumb Rubber Floating

Source: M. Jennings-Temple

Recently installed fields in Auckland such as Michaels Avenue Reserve No. 1 and the new artificial turf fields at Seddon Park are showing evidence of minor quantities of crumb rubber being trafficked off the site onto concrete footpaths, which could then be washed into the drainage network during rainfall events (refer Figures 3 and 4).

Figure 3: Crumb rubber and detached artificial grass fibres trafficked and/or washed from the adjacent field

Figure 4: The migration of artificial grass fibres off artificial turf onto nearby hardstanding areas which may then be washed into the local stormwater network

Ideally, artificial turf sports fields would not be located in overland flow paths or floodplains. If they are, a site-specific assessment will be required, potentially using hydraulic modelling outputs to inform the risk of migration of crumb rubber off-site, or appropriate mitigation (e.g. redirection of overland flowpaths). Crumb rubber mobilization may also have an adverse effect on the longevity of artificial turf if it is not topped-up or redistributed and use of the surface continues.

There appears to be little research available regarding the velocity at which crumb rubber will mobilise, however a simple comparison of the potential shear stress can be carried out using equations for dimensionless shear stress to understand the magnitude of difference compared to sand, for example.

Table 1: Comparison of Sand and Crumb Rubber Relative Shear Stress

Material Type	**Sand**	**Crumb Rubber**
Density (g/cm3)	2.65	1.2
Typical Diameter (mm)	0.1	1.0
Particle Volume (mm^3)	0.0005	0.5
Particle Mass (mg)	0.001	0.6
Dimensionless Shear Stress	1	0.83

While the absolute values for shear stress above are not relevant, Table 1 indicates that the force, and therefore velocity of water required to mobilise crumb rubber may be in the same order as that required to mobilise sand. As a crumb rubber particle's density approaches that of water it is more likely to float and therefore the velocity required to mobilise it will significantly drop.

The cohesion (low friction) between crumb rubber particles and the low density of the rubber suggests that relatively low overland flow velocities will result in particle movement but actual velocities that result in this movement are unknown and cannot therefore be correlated with rainfall events of a particular intensity, the gradient of the field or the length of the slope.

Q2: What force/velocity is required to lift artificial turf?

In Southmoreland, Pennsylvania 50mm of rain in August 2013 resulted in "rushing water pushed under the turf surface, rippling and crinkling it." (Paterra, 2013)

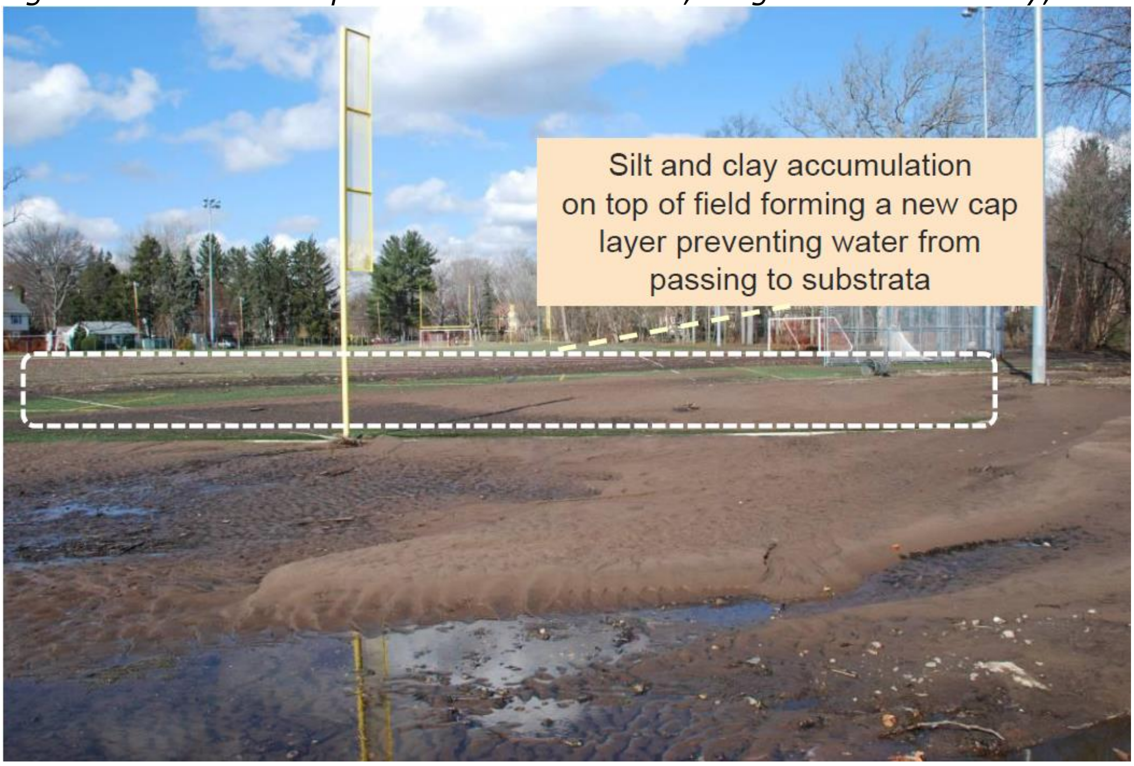
Figure 6: Russ Grimm Field, Southmoreland, Pennsylvania

Source: Sean Stipp, Tribune Review

112mm of rain in Cincinnati in September 2016 damaged turf, requiring its replacement. Air bubbles formed below the turf at Springs Lake Park fields. The sports field owners believed the field drainage system couldn't cope with the heavy rainfall. In March and April 2011 two flood events in Ridgewood, New Jersey resulted in significant damage to artificial turfs. The sports fields are located within the 1 in 100 year floodplain. Sediment was deposited and the turf pulled up. Crumb rubber was washed into the nearby stream.

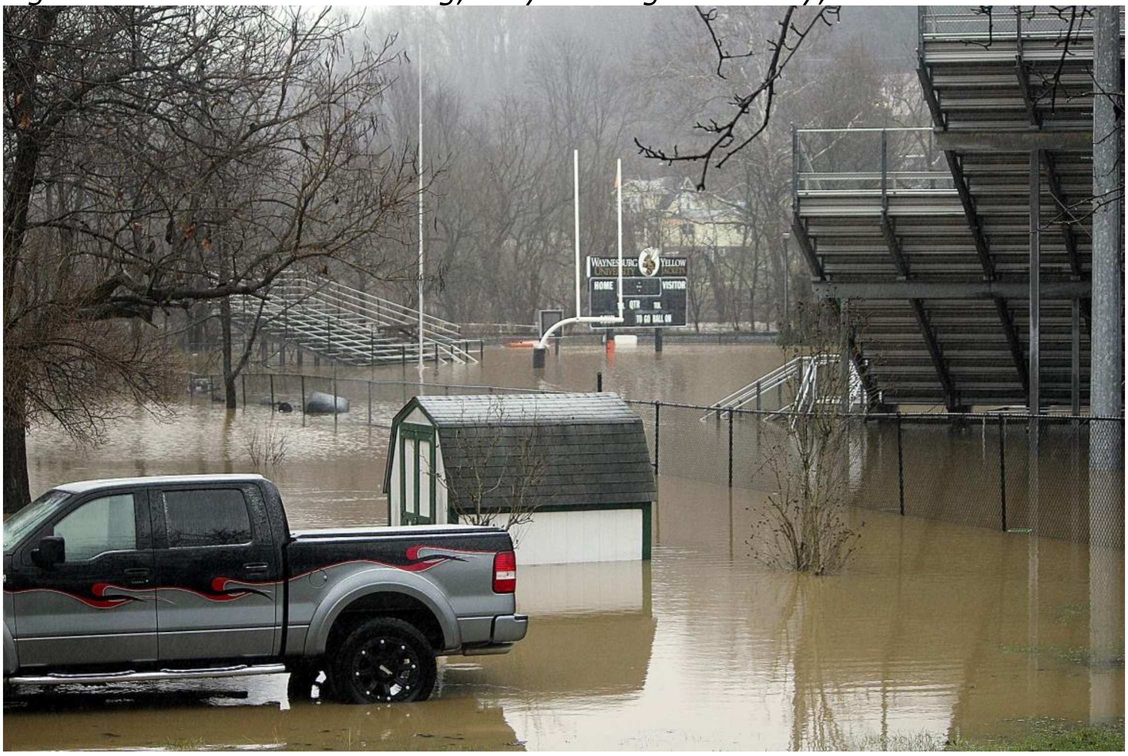
Figure 7: Flooding across artificial turf, Ridgewood New Jersey, March 2011

Figure 8: Sediment deposition on artificial turf, Ridgewood New Jersey, March 2011



In December 2016 1.2-1.5m deep overland flow “severely damaged” the artificial turf at Waynesburg University (Jones, 2016).

Figure 9: Artificial turf flooding, Waynesburg University, December 2016



Source: Bob Niedbala, Observer/Reporter

There appears to be little research available regarding the velocity and duration of flow that will begin lifting a turf. However, the evidence to date demonstrates water damage is caused through three main mechanisms:

1. Washing of crumb rubber off the turf surface
2. Friction force of water on the surface leading to 'rippling'
3. 'Ballooning' of the turf. In one instance (Cincinnati) this was considered to be caused by air pressure from a downstream pump system. In other cases the authors consider it may be caused by water pressure between the turf and subgrade.

Despite a number of storm events damaging artificial turf in the United States, information on the hydraulics required to lift artificial turf is only anecdotal.

Q3: What concentration of sediment in floodwater will damage artificial turf?

Artificial turf fields are not intended to receive fine sediment and their maintenance deliberately includes physical operations that clean the infill layers (a stabilizing infill; typically sand, and a performance infill; typically crumb rubber), removing fine particles that may reduce its porosity. Following flooding, any sediment deposition on the surface or within the infill may result in a reduction in drainage performance. Where necessary, machinery can be brought in from overseas to remove the contaminated infill, allowing clean infill to be installed (Peter Leeves, former Tiger Turf CEO, Personal Communication 7th March 2013), although this will delay the re-opening of the field post-flood.

Under extended flooding or flood events that feature flood water with a heavy sediment load, the material may percolate through the turf layer and into the underlying permeable sub-base and drainage systems. Artificial turf fields feature a permeable base comprised of aggregate layers; where flooding has resulted in sediment deposition throughout the permeable sub-base and drainage backfill, total reconstruction of the surface may be necessary – costing in the order of $1.6-2 million per sports field (Talbot, 2012).

The lifespan of artificial turf sports fields may be shortened by flood events that result in frequent but minimal deposition of fine sediment, which may leave negligible surface evidence but will accumulate in the permeable materials over time. Generally, the finer the sediment and further the sediment has travelled through the permeable backfill/base materials, the greater the adverse effect on the system lifespan. However, the lack of local evidence suggests that flood events that result in sediment deposition do not occur on a frequent basis in Auckland.

Q4: What are the downstream effects of crumb rubber?

The cost effectiveness of artificial turf is in part derived from the opportunity to reuse recycled car tyres. The downside is that car tyres have a well-established range of chemicals bound within them.

Opponents of artificial turf identify potential downstream effects from crumb rubber based around leaching of chemicals and heavy metals, including:

1. Elevated chemical levels in water bodies;
2. Bioaccumulation in fauna;
3. Affecting flora growth;
4. Contamination of water supply sources;
5. Harm to fauna if crumb rubber pellets are swallowed.

The Ministry for the Environment (Norquay, 2004) note there are a number of variables that affect contamainants leaching from tyres, including:

1. Particle size – smaller particles will leach more readily.
2. Chemical environment – acidic conditions will leach contaminants more readily.
3. Permeability of soil – faster through more permeable soil.
4. Distance to downstream receptors – the greater the vertical distance to the groundwater table or to streams the more diluted leachate becomes.
5. Contact time with water – the longer the contact time the greater the potential to leach.
6. Flow of water – the faster the flow of surface water the more dilute the contamination. The slower the horizontal flow in groundwater, the smaller the spread.

The perceived and actual environmental effects of crumb rubber have led to laboratory testing and field testing results being published. Research results vary with local conditions, testing methodology, type of crumb rubber and age of the field. Jennings-Temple (2011) notes that toxicity to plants and wildlife from crumb rubber could occur in two ways:

1. From direct exposure to the crumb rubber pellets; or

2. From chemicals leached from the crumb rubber

With respect to the former Jennings Temple (2011) notes:

"Direct exposure includes the mixing of crumb rubber into soil or sediments that plant roots come into contact with or the accidental ingestion of the pellets by aquatic life and/or birds. Due to the lack of research specifically considering crumb rubber, proxies are considered; plastic pellets (Graham, 2008) and carbon black (Sullivan, 2006). Plastic pellets have a detrimental effect on the digestive tract of fish and birds and the same is assumed to be true of rubber pellets. When rubber dust was mixed with soil as a potting mix, plant growth was stunted (Sullivan, 2006) and where 2% crumb rubber was mixed

with sand, there was a decline in plant growth (Tucker, 1997); both thought to be symptoms of carbon black (a constituent of car tyres) and/or the leaching of zinc.

Research has not focused on chemical losses from artificial turf fields under ponded water or flood conditions but has identified that stormwater runoff samples from artificial turf frequently contain elevated levels of heavy metals, PAHs, and other compounds associated with tyres (Li et al, 2010; Lim and Walker, 2009). The studies utilise different assessment methodologies (laboratory *vs.* in-situ monitoring) and different sample sizes, but there are no published studies that have carried out long-term, automated sampling and monitoring of stormwater quality from an installed field.

The majority of chemicals and metals observed in the various international studies were at concentrations lower than New Zealand Drinking Water Standards (refer Appendix 1). Some contaminants were at concentrations higher than the Australian and New Zealand Environmental and Conservation Council (ANZECC) Water Quality Guidelines for aquatic systems. It is important to note that the 'baseline' condition water bodies are assessed against in the ANZECC Guidelines is a pristine New Zealand mountain stream, and therefore significantly higher than a lowland stream or urban stream.

Appendix 1 summarises a selection of water quality sampling results from published data. The leaching results in Appendix 1 represent the potential quantity of contaminant within the leachate directly from the crumb rubber. It does not consider any stormwater treatment available on the site nor the dilution effect dependent on flow at the time of testing. Soluble versus particulate contaminants are also not differentiated. It therefore does not represent the actual concentration of contaminants that may arrive at a downstream receiving environment. This is a point that, in the view of the authors, is misunderstood by public reviewers of technical scientific literature.

To provide further context, Table 2 describes the concentration for zinc and copper in the artificial turf sampling in Appendix 1 compared to values described in Auckland Council's Contaminant Load Model for roads (Auckland Council, 2010), which are a similar order of magnitude.

Table 2: Comparison of artificial turf runoff with road runoff

Contaminant	**Artificial Turf Sampling (mg/L)**	**Land Use**	**CLM Value - Mean Annual concentration (mg/L)***
Zinc	0.002-0.5	Roads with 1000-5000 vehicles/day	0.01-0.2
		Roads with 5000-20,000 vehicles/day	0.05-0.6
Copper	0.001-0.03	Roads with 1000-5000 vehicles/day	0.0035
		Roads with 5000-20,000 vehicles/ day	0.015 – 0.04

* Local sampling range (low to high) set out in Tables 15, 16, and 17 of the CLM

The variability in sampling results, and limited data from turf, make a definitive conclusion difficult, however the runoff quality from an artificial turf may be similar to a typical Auckland urban road. It is important to note that artificial turf presents a tiny fraction of a catchment area compared to urban roads as well as a less direct pathway to the downstream environment than a road due to the highly textured nature of the artificial turf surface and the infiltration pathway into subsoil drainage. The current threshold for requiring stormwater treatment as part of a new road is 5000 vehicles per day in Auckland's Unitary Plan. Based on the data available, artificial turf is within an order of magnitude of this threshold.

Further, stormwater treatment guidelines in Auckland (TP10) note:

> *When comparing concentrations with water quality criteria, it should be borne in mind that individual samples may exceed the [event mean concentration (EMC)] by a large factor. Exceeding water quality guidelines does not necessarily lead to effects on the environment. An EMC value in stormwater may exceed water quality guidelines "in pipe" but may not following dilution in receiving water. Water quality criteria are therefore more often used as an indicator of receiving environmental health rather than a regulatory standard.* (Auckland Council, 2003)

The limited turf 'grab' sampling data described in Table 2, and comparison to annual mean concentrations, should therefore be used with caution, in the absence of long term monitoring.

Auckland Council are currently undertaking a study at Michaels Ave Reserve artificial turf that may help provide further information to enable a local analysis to be undertaken. The study will assist in quantifying the local risk of contaminant release due to rainfall and weathering of crumb rubber. Initial analysis (unpublished) undertaken by Auckland Council indicates a potential 'first flush' effect, with higher initial concentrations of contaminants. Further data and analysis of the results is required before definitive conclusions and comparisons with water quality standards can be drawn.

In the absence of guidance, a precautionary approach is recommended in the design of turf drainage systems that control the migration of crumb rubber, off site through the use of catch pit filters.

Q5: What are the downstream effects of chemicals applied during turf management?

Artificial turf sports fields require very different management compared to natural turf sports fields. Failure to adequately remove organic material will impede drainage and create conditions in which moss, mould, algae and bacteria will grow. Shaded areas of the pitch and areas that are not well used (i.e. the corners of the fields) may also experience the establishment of moss, mould, algae and bacteria. Products typically applied to artificial turf sports fields may include:

- Disinfectant and deodoriser;
- Anti-static agent;
- Algae/moss and mould control;
- Water-based stain remover;
- Oil-based stain remover.

Commonly-applied artificial turf chemicals can be irritants to humans, harmful if swallowed and can be harmful to aquatic organisms, however anecdotal evidence suggests fields in New Zealand receive infrequent doses of any of these artificial turf management chemicals.

Nonetheless, it is unclear what quantity of these products is retained in the turf system and how much is lost under 'typical' rainfall events. As such it is currently not possible to predict how much will be released into the receiving environment under a rainfall or flood event.

Furthermore, many urban streams are considered to have moderately elevated nutrient concentrations and often poor water quality. De-coupling the known cumulative, region-wide impact of applied chemicals and fertilisers (e.g. CSOs, farming, gardens) from other nutrient or chemical pollution sources, and specifically artificial turf surfaces, is virtually impossible without catchment-wide water quality testing.

CONCLUSIONS

- Artificial turf use has increased significantly to meet the demands of greater usage on a limited number of fields. However, sports fields have often been established in less desirable areas of a city, such as in flood plains, within overland flow paths or in areas specifically intended to act as temporary stormwater detention areas in the event of a large rain event that may pose a local flood risk. The use of synthetic turf fields in these situations is problematic due to the need to keep the highly-specified system free of debris and the increasing public concern about some of the system components used in artificial turf systems.

- Public perception is becoming an increasing barrier to the development of artificial fields. Community groups have successfully challenged and prevented artificial turf installation in New Zealand and around the world, often relying on emotive arguments and cherry-picking from studies, which fuels misinformation and confusion. Despite this, the questions raised by concerned user-groups about the interaction between artificial turf and the water environment are pertinent.

- The potential for crumb rubber to migrate off fields has not been previously quantified. Under high rainfall events and/or where overland flow occurs, crumb rubber has been observed on footpaths and in dish drains adjacent to fields. The velocity required to mobilise sand may be a good comparator for crumb rubber, however it was noted that the specific density of crumb rubber is highly variable and even low-velocity flows over the surface may result in particle movement. Field testing or dynamic modelling is required to develop a detailed understanding of how crumb rubber can mobilise under high intensity rainfall conditions. In the absence of this, a precautionary approach should be adopted, including avoiding artificial turf surfaces in overland flowpaths or floodplains, and providing a treatment component (e.g. catchpits filters).

- The potential for chemicals associated with the constituents of artificial turf to be leached from the system has been researched in various locations, with varying and often contradictory results. All studies have their limitations and most that consider the quality of water leached from a surface have done so by using laboratory-based techniques to mimic the effects on outdoor fields of weathering and use. Those that took sample in-situ generally took very few samples. The study at Michaels Avenue Reserve in Auckland is the first long-term study that uses automated water samplers in a constructed field. The results are currently unpublished but will contribute significantly to industry knowledge. The leaching potential of chemicals used in turf management is also unclear. There have been no studies on the extent of leaching of turf management chemicals under 'normal' conditions, under flood events, or to what extent these chemicals are retained in the infill after application.

- The effect of major floods on turf fields is clear: usually turf carpet movement, infill movement and substantial deposition of silt and sediment that would need to be removed from the surface. In the worst case, an entire field would need to be reconstructed. What is unclear are the effects of frequent, small-scale flood events on turf and drainage potential; something possible where fields are installed in flood plains or overland flow paths. While each individual event would be expected to be minor, over time, the infill would become clogged, drainage performance would reduce and the performance of the system would be expected to decline. However, data on this does not exist and best-practice would be to ensure fields are not likely to be subject to flooding, either by avoiding placing them in locations that may flood, or good design to protect them.

- There is limited data on the impact of crumb rubber particles on the receiving environment. Possible effects have been inferred based on the effects of car tyres on streams, of animals ingesting small pellets and the effect on plant growth when grown in plant pots containing crumb rubber and soil, although these are likely to vastly overstate the effect of a limited quantity of crumb rubber pellets in the receiving environment. The sampling data to date indicates the majority of potential contaminants were at concentrations below New Zealand Drinking Water Standards. The runoff quality from an artificial turf sports field may be similar to a typical Auckland urban road, albeit a tiny fraction of the catchment area and less direct pathway to the receiving environment compared to a road. In the absence of long term monitoring data it is difficult to draw a definitive conclusion.

- The potential impact of crumb rubber in the receiving environment, is therefore a significant knowledge gap and needs to be understood for small doses (i.e. from crumb rubber trafficked off-site) to large doses (i.e. after a severe flood or storm even with significant infill loss).

- The extent of leaching of chemicals applied during turf management activities and the effect of leached turf management chemicals on downstream water environments is unknown.

Overall, while the data on ingestion, inhalation and off-gassing risks from artificial turf studies has been well researched, there are substantial knowledge gaps regarding how synthetic turf interacts with and influences the water environment and the ecology of the receiving environment for surface run-off and drainage water. In the short term, the accurate and careful citing of research results from competent studies may be required to address user concerns when developing fields. Designs should be precautionary in nature such that fields are not located in areas prone to flood risk or overland flow. Furthermore, catchpit protection to intercept macro-particles (i.e. crumb rubber and detached fibres), preventing them from entering the stormwater system, should also be considered essential. Long-term, the results of new research should be brought into the discussion to ensure that all possible impacts of artificial turf are fully understood and considered when designing and installing artificial turf fields.

ACKNOWLEDGEMENTS

Special thanks to Warren Bird of Opus International Consultants for reviewing this paper and suggesting improvements.

REFERENCES

1. Abernethy, S G, Montemayor, B P and Penders, J W (1996) 'The Aquatic Toxicity of Scrap Automobile Tires', Toronto: Ontario Ministry of Environment and Energy
2. Auckland Council (2010) Development of the Contaminant Load Model. Auckland Regional Council Technical Report 2010/004
3. Cheng, H., Hu, Yuanan., Reinhard, M. (2014). Environmental and Health Impacts of Artificial Turf: A Review. *Environmental Science and Technology*. *48* (4). 2114–2129
4. Jennings-Temple, M (2011). Human and Environmental Health Concerns Associated with Artificial Sports Fields. *Proceedings of the 6th NZ Turf Conference and Trade Show*, Hamilton, NZ. 27-29th June 2011. 72-84.
5. Jones, M. (2016) Flood damages Waynesburg U. football field. [online] http://www.observer-reporter.com/20161220/flood_damages_waynesburg_u_football_field [Accessed 21 February 2017]
6. Kleimann, J (2011, 17 April). [online] Updated: Fields Closed After Flood; District's Cleanup Costs Not Yet Known. Ridgewood-GlenRock Patch. Retrieved from http://ridgewood.patch.com/articles/big-floods-again-damage-fields#photo-5686086 [Accessed 20 June 2013]
7. Lim, L and Walker, R (2009) *An assessment of chemical leaching, releases to air and temperature at crumb-rubber infilled synthetic turf fields*. New York State Department of Environmental Conservation: New York State Health Department. May 2009.
8. McKenzie, J (2015). [online] SBR Rubber – It's a question of safety. Retrieved from: http://tigerturf.com/nz/sbr-rubber-its-a-question-of-safety. [Accessed 7 March 2017]
9. Meikle, K (2013). Michaels Ave Artificial Soccer Field Stormwater Drainage Systems. Letter to Mike Gallagher, Auckland Council, 23 January 2013 from Babbage Consultants.
10. Norquay, K. (2004). End of Life Tyre Management: Storage Options – Final Report for the Ministry for the Environment, NZ.
11. Office of Environmental Health Hazard Assessment (OEHHA) (2007) Evaluation of the Health Effects of Recycled Waste Tires in Playground and Track Products. For the Integrated Waste Management Board, California. Retrieved from http://www.calrecycle.ca.gov/publications/Documents/Tires%5C62206013.pdf [Accessed 10 May 2011].
12. Outdoor Synthetic Surfaces (2013). [online] Crumb Rubber FAQ retrieved from http://outdoorsyntheticsurfaces.com/recycled-rubber-products/crumb-rubber/ [Accessed 15 January 2013]
13. Paterra, P. (2013). Southmoreland tackles flood-damaged turf. [online] Retrieved from: http://triblive.com/news/westmoreland/4594945-74/field-southmoreland-turf#axzz2dI94S2nZ. [Accessed 21 February 2017]
14. Radcliffe, S (2015). [online] Parents, Athletes Sound Alarm Over Potentially Toxic Artificial Turf Playing Fields. Retrieved from: http://www.healthline.com/health-news/parents-athletes-sound-alarm-over-potentially-toxic-artificial-turf-playing-fields-111115 [Accessed: 7 March 2017].
15. Rappleye, H. (2014). [online] How Safe is the Artificial Turf your Child Plays On? Retrieved from: http://www.nbcnews.com/news/investigations/how-safe-artificial-turf-your-child-plays-n220166 [Accessed 7 March 2017].
16. Rogers, J N; Vanini, J T (unknown date). Topdressing with Crumb Rubber from Used Tires on Athletic Fields and Other High Traffic Turf Areas. Department of Crop

and Soil Sciences, Michigan State University retrieved from http://infohouse.p2ric.org/ref/11/10504/html/biblio/htmls/crh1.htm [Accessed 234 June 2013]

17. Safe Healthy Playing Fields Coalition (2017). [online] Retrieved from: http://www.safehealthyplayingfields.org/environment [Accessed 7 March 2017]
18. Sullivan, J.P (2006) An Assessment of Environmental Toxicity and Potential Contamination from Artificial Turf using Shredded or Crumb Rubber', Ardea Consulting for Turfgrass Producers International.
19. Synthetic Turf Council (2010). [online] Overview of the Research on Crumb Rubber in Synthetic Turf. Retreived from: http://www.stma.org/sites/stma/files/pdfs/FINAL_Summary%20of%20Research%20on%20Crumb%20Rubber%20v6.pdf [Accessed 7 March 2017]
20. SynTurf (2013). [online] Artificial Turf Flooding. www.SynTurf.org. Retrieved from http://www.synturf.org/waterdamage.html [Accessed 23 June 2013]
21. US Environmental Protection Agency (EPA), Centre for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (CDC/ATSDR), US Consumer Product Safety Commission (CPSC)/directorate for Health Sciences (2016). Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds" Status Report.
22. Talbot, T (2012). Sports NZ Guidance Document for Sports Field Surfaces. Opus International Consultants.

APPENDIX 1 – CRUMB RUBBER AND WATER QUALITY DATA

Where data is not available the relevant section of the table is left blank.

Potential Contaminant	Potential Crumb Rubber Leachate (mg/L) in field runoff sample					NZ Drinking Water Standards (2008) (mg/L)	ANZECC Guidelines (mg/L)			Typical Levels in Auckland Water-courses	Conclusion
	Moretto (2007)	Lim & Walker (2009)	Bristol & McDermott (2008)	Hofstra (2008)	Cheng and Reinhard (2010)		Irrigation (Long Term Value)	Aquatic Systems	Recreational Water		
Description	Newly installed field in France	1 year old field in New York	Three fields in California 1-2 years old	Five fields in the Netherlands 5-6 years old	One year old field in California						
Heavy Metals											
Antimony		<0.0023				0.02					Lower than drinking water standard. No ANZECC Guidelines
Arsenic	0.001-0.0147	<0.0018				0.01	0.1	0.024	0.05	0.0006	Lower than drinking water standard and ANZECC Guidelines
Barium					0.01-0.043	0.7			1		
Beryllium		9.6×10^{-5}					0.1				Lower than ANZECC Guidelines
Cadmium		0.00035	<0.001			0.004	0.01	0.0002	0.005		Lower than drinking water standard, but slightly
Chromium		0.0022				0.05	0.1	0.001	0.05	0.006	
Cobalt					0.002-		0.05	0.0015			

Potential Contaminant	Potential Crumb Rubber Leachate (mg/L) in field runoff sample					NZ Drinking Water Standards	ANZECC Guidelines (mg/L)			Typical Levels in Auckland Water-	Conclusion
					0.007						higher than ANZECC Guidelines.
Copper	0-0.011	0.0054			0.001-0.034	1	0.2		1	0.017	Lower than drinking water standard and ANZECC Guidelines
Iron					0.003-0.114	0.2	0.2		0.1	0.238	Lower than drinking water standard and ANZECC Guidelines
Lead	0-0.014	0.0017	<0.001	0.016 (mean)		0.01	2	0.0034	0.05	<0.02	Potential to be higher than NZ Drinking Water Standards or ANZECC Guidelines. Likely less than existing background level in the aquifer.
Manganese					0.007-0.011	0.04	0.2	1.9	0.1	0.01	Lower than drinking water standard and ANZECC
Mercury		0.00013				0.007	0.002	0.0006	0.001		
Nickel		0.0088			<0.001-	0.08	0.2	0.011	0.1	0.001	

Potential Contaminant	Potential Crumb Rubber Leachate (mg/L) in field runoff sample					NZ Drinking Water Standards	ANZECC Guidelines (mg/L)			Typical Levels in Auckland Water-	Conclusion
					0.009						Guidelines
Selenium		<0.00019	<0.002			0.01	0.02	0.011	0.01		Lower than drinking water standard and ANZECC Guidelines
Silver		<0.00054						0.00005	0.05		
Thallium		<0.0019									Lower than drinking water standard
Zinc	0.074-0.488	0.0595	<0.002-0.036		0.129-0.473	1.5	2	0.008	5	0.03	Lower than drinking water standard, but slightly higher than ANZECC Guidelines.
Poly-aromatic hydrocarbons (PAHs)*											
Benzopyrene					2x10-6	0.0007			1x10-5		Lower than drinking water standard and ANZECC Guidelines
Naphthalene					0.011				0.016		