

What Stormwater Runoff Contamination Originates from Road Pavements?

1.0 Introduction

People perceive traffic pollution in stormwater runoff as being the contaminants solely derived from a vehicle's engine or tyre/brake wear particles. But what about any contaminants that are released from the road pavements* themselves? And what effects do these contaminants have on human health and our natural environments?

* The term "road pavement" is used by engineers and infrastructure professionals to refer to the actual driving surface of a road. It is this road surface (not the "sidewalk" or pedestrian footpath) that is explored in this paper.

2.0 Road Pavement Structure

Road pavements can be classified as rigid or flexible.

Rigid pavements consist of just one layer above the natural subgrade e.g. concrete roads. They can handle heavy traffic flows and high axle loads with joints existing to control cracking.

Asphalt pavement is an example of a flexible pavement, which consists of multiple layers with the wheel loads of vehicles being transferred particle-to-particle. This is the most common road pavement in the UK and is what is referred to as a 'road pavement' in this blog. Asphalt pavements consist of aggregates, a binder and additives, the type of these depending on the intended traffic loads, the pavement design requirements, subgrade soil strength and the local climate.

2.1 Aggregates

Mineral aggregates within a road pavement refers to the gravel, crushed stone and sand that provide the main structural body of the pavement. This would make up 90% of the asphalt pavement with varying sizes of aggregates. This particle range determines the stability and strength of the structure as well as the permeability of the road pavement.

2.2 Binder

Bitumen is widely used as a binder in asphalt pavements due to its waterproof and adhesion properties. It makes up the other 10% of an asphalt pavement mixture. It is produced through the distillation of crude oil and is a highly viscous, sticky petroleum-based mixture, which binds aggregates together.

The limited natural properties with standard bitumen have resulted in road pavements cracking, rutting or potholes forming with temperature changes and heavy traffic loads. To improve mechanical performance advanced polymer-modified bitumen has been produced, which improves performance, durability and resistance of the material. Polymers used may be plastomers - which improves a road pavements

strength and rutting resistance or elastomers- which enhance elasticity and cracking resistance in road pavements.

2.3 Additives

Certain chemical additives are used in the manufacturing of road pavements depending on the site specifications, intended traffic load and local climate. Additives will modify the characteristics of the road pavement improving certain qualities such as durability, workability, moisture resistance and resistance to rutting or cracking. These can include anti-stripping agents, antioxidants, crosslinking agents, rejuvenators, warm-mix additives and fillers.

3.0 Contaminants Within Road Pavements and their Effects

Friction between vehicle tyres and the road surface abrades road pavements gradually. Particles are released from the set road and entrained in stormwater or surface water runoff. Abrasion of road pavements depends on:

- Road surface type and materials
- Volume and composition of traffic present (high traffic loads will see more abrasion)
- Climate conditions

Possible contaminants that can be released from a road pavement and become entrained within stormwater runoff may include:

3.1 Hydrocarbons

Bitumen is a petroleum-based binder which contains 85-95% of organic hydrocarbons. This includes aliphatic, aromatic and cyclic compounds, but the chemical composition of bitumen differs based on the original composition of crude oil in the manufacturing process. Asphaltenes are a type of heavy hydrocarbons which give bitumen its sticky consistency and make it resistant to weathering due to the strong chemical bonds within its structure.

Hydrocarbons can cause significant aquatic environment degradation as well as the long-term bioaccumulation in soils, sediments and living organisms. If soil structures are altered due to the hydrocarbon contamination, the growth of vegetation and microbial organisms is inhibited. Important natural processes such as decomposition and nutrient cycling are disturbed.

Once in a water body, bioaccumulation into the food chain may take place, meaning hydrocarbons can make their way up food chains to top predators- possible even humans depending on where and what organisms are in the food chain. The contaminated stormwater runoff may also release hydrocarbons into drinking water supplies or waters used for recreational use- thus introducing hydrocarbon concentrations into the human body directly. Human health effects may contain lung damage, cardiovascular disease, reproductive dysfunctions, delayed development in children, neurological damages or cancer risks.

Through the degradation of asphalt binders, Polycyclic Aromatic Hydrocarbons (PAHs) are released. These are highly toxic chemicals which are recognised as major semi-volatile contaminants for food and

the environment. They are hydrophobic, but lipophilic, meaning they are sediment bound in stormwater runoff but are prone to bioaccumulate within aquatic organisms once entering receiving water bodies. They are primarily found bound to fine particles (PM64) within stormwater runoff due to the possible high adsorption rates clays and silts offer. PAHs are known to be carcinogenic, mutagenic and toxic to living organisms including terrestrial and aquatic animals and humans. Read more about PAH pollution at: <https://3ptechnik.co.uk/stormwater-treatment-of-pahs-why-particle-size-distribution-matters-for-suds-design/> and <https://3ptechnik.co.uk/can-permeable-pavement-systems-treat-pahs/>

3.2 Heavy Metals

Bitumen contains concentrations of nickel and vanadium, as well as other heavy metals like iron, copper, lead, chromium, zinc and arsenic. These can leach from road pavements through the degradation of the bitumen binder and adsorb onto fine particles (PM64) that are present in stormwater runoff. This adsorption is because of the larger surface area per unit mass fine particles offer compared to larger, coarser particles. These fine-grained particles are easily entrained within stormwater runoff due to their low settling velocities and often stay in suspension for longer periods of time.

Heavy metals can accumulate in organisms (terrestrial or aquatic) or in environmental soils and sediments and may enter aquatic food chains once released in water bodies. Heavy metals can biomagnify in food chains, which means their concentration increases as it goes up a trophic level. This may lead to increased cancer risks, damaged vital organs in the human body (kidney, liver, lungs), infertility complications or cardiovascular diseases.

3.3 Volatile Organic Compounds

Volatile Organic Compounds (VOCs) can be found in stormwater runoff in both a dissolved phase, where they are more mobile in water environments, or in a particulate-bound phase, where they adsorb onto fine particles sized less than 64 microns (PM64). Many of these chemicals are resistant to degradation and can be transported long distances due to their small size.

Throughout the service life of a road pavement, hundreds of different VOCs may be emitted, mainly from the composition of the bitumen binder. These VOCs can consist of:

- Aliphatic or aromatic hydrocarbons: consisting of various alkenes or alkanes or chemical compounds such as toluene, ethylbenzene or xylene
- PAHs: these semi-volatile compounds for example anthracene and phenanthrene are released from a road pavement during its service life
- Oxygenated compounds: asphalt pavements continuously emit OVOCs (Oxygenated VOCs) such as acetone, benzaldehyde or formaldehyde. These aldehydes often dominate the VOCs released for older or UV-exposed road pavements.
- Sulphur-containing compounds: carbon disulfide and benzothiazole are released from modified road pavements which contain recycled materials such as rubber crumb from old tyres.

Once transported via stormwater runoff into receiving waters, VOCs can accumulate in bottom-dwelling organisms- these organisms are the foundation of food chains. If concentrations are so high, these bottom-dwelling organisms may die, consequently creating a collapse in the whole food chain. This can

cause higher feeding organisms to also die out, or VOCs can accumulate within them, making their way up food chains (possibly bioaccumulating in the human body). To humans VOCs can cause short-term irritation (eyes/ nose/ throat) and can cause headaches and nausea. However, long-term human health risks may include damage to kidneys, liver or the central nervous system with many variants being cancerous.

3.4 Microplastics and Rubber Crumb Particles

If a polymer-modified bitumen binder is used to produce a road surface, microplastics can be released from the road pavement once it is weathered and abraded.

Plastics as an additive into asphalt pavement raises environmental concerns, despite some parties describing the incorporation of plastics as ‘aiding in the global plastic crisis.’ People believe the addition of waste plastics to modify asphalt pavements help reduce plastic waste and microplastic pollution as well as enhancing asphalts performance. However, toxic emissions during production can lead to the release of contaminants into our atmosphere. And more critically the subsequent and inevitable weathering of road pavements that incorporate plastic wastes can release these microplastics into our environments. Waste microplastics that are used may contain various toxic chemicals such as:

- Polycyclic aromatic hydrocarbons
- Volatile organic compounds
- Heavy metals- chromium, copper, nickel, zinc and lead
- Greenhouse gases- methane and ethylene
- Chlorinated compounds
- Per- and poly-fluoroalkyl substances (PFAS)

These chemicals can affect human and ecological health as stated above, as well as microplastics themselves suffocating aquatic habitats and organisms and affecting humans through cell or organ damage, impairing important functions in the body.

So, despite the repurposing of waste plastics, the use of them as asphalt additives only delay their release, contamination and persistence in our environments and doesn’t mitigate the global plastic crisis at all.

The addition of rubber crumb from old tyres also creates another source of pollution through small rubber particles (TWPs= Tyre Wear Particles) potentially entering receiving waters. Its addition is aimed to improve a road pavement’s elasticity and crack resistance but may contain harmful additives such as Mercaptobenzothiazole (MBT), Diphenylguanidine (DPG) or 6PPD-Quinone (6PPD-Q). Read more about these tyre wear particles at: <https://3ptechnik.co.uk/tyre-wear-particles-in-stormwater-why-mbt-and-dpg-chemical-contamination-matters/> and <https://3ptechnik.co.uk/toxic-tyres-a-study-of-6ppd-in-stormwater/>. These three tyre additives are under investigation in recent years due to their potential at polluting environments. The presence of these toxic chemicals can suffocate aquatic habitats and inhibit the growth of microorganisms and diatoms- which are the primary foundation of aquatic food webs. Their survival is key for larger organisms to feed off, without it, higher feeding predators at the top of food webs will struggle to survive- which can include humans. The stability of aquatic habitats is at risk with tyre crumb and microplastics being added to road pavements.

3.5 Greenhouse Gases

Various greenhouse gases are released from bitumen, including carbon dioxide, nitrous oxide, methane and sulphur dioxide. These will enhance the greenhouse effect on the earth which contributes to higher temperatures- worsening the current climate change crisis. Air pollution will worsen, which will become prevalent to humans through the visibility of smog and inhalation effects of irritation.

Greenhouse gases have detrimental effects when introduced to receiving waters. Water temperatures rise meaning less oxygen can be held in the water. This harms aquatic organism populations and can create 'dead zones'. The addition of carbon dioxide can lower the pH of the seawater (ocean acidification) which weakens coral and shells found within the ocean- affecting biodiversity and habitat conditions for fish populations.

3.6 Particulate Matter and Dust

Asphalt degradation leads to particulate matter (PM) and dust generation derived from the mineral aggregates. If entrained in air, transportation distances can be large until deposited via dry or wet deposition. When entrained in water such as stormwater runoff, PM and dust will reach natural water bodies via drainage systems. Local aquatic habitats are affected by this through sediment accumulation changing the natural topography of habitats. Aquatic species will struggle to adapt to new habitat alterations and degraded water qualities.

Overall, the IARC (International Agency for Research on Cancer) classifies bitumen as '*possibly carcinogenic to humans*' (Group 2B). The United Nations' Globally Harmonised System (GHS) is adopted in the UK and the EU through the CLP (Classification, Labelling and Packaging) regulation. This regulation ensures that people who are exposed to the product are aware of the associated risks and how to use it correctly. Through the CLP regulatory system, asphalt and bitumen products are classified with the following health and environmental hazards:

- H314: Causes severe skin burns and eye damage
- H315: Causes skin irritation
- H319: Causes serious eye irritation
- H335: May cause respiratory irritation
- H336: May cause drowsiness or dizziness
- H341: Suspected of causing genetic defects
- H351: Suspected of causing cancer
- H372: Causes damage to organs through prolonged or repeated exposure
- H411: Toxic to aquatic life with long lasting effects

4.0 Possible Mitigation Strategies

There are many different contaminants that could be released from road pavements, all with varying degrees of toxicity to humans and our natural environments. Safer alternatives to current materials would reduce contamination, however, they must have similar properties and therefore outputs as the materials used currently in road pavement production without the cost difference being too extravagant.

These alternatives have not yet been identified, however controlling the distribution of contaminants that come from road pavements will reduce the environmental and health effects that are seen. This can be done through the implementation of Sustainable Drainage Systems (SuDS). By implementing SuDS techniques, the quantity and quality of stormwater and surface water runoff is controlled. As the runoff is directed through the SuDS technique, water treatment steps are taking place, thus reducing the concentration of contaminants within the flow of water.

It is common to deploy multiple SuDS techniques in series in what is called a Treatment Train. This can ensure that different contaminants are targeted to be removed from the flow before it enters any natural water body.

The 3P Technik HydroShark is a hydrodynamic vortex separator which can remove settleable solids out of stormwater runoff before it enters and harms aquatic environments. After this, the 3P Technik HydroSystem provides a space for stormwater to undergo sedimentation, filtration, adsorption and ion exchange in order to remove the smaller most damaging particles that most contamination is bound to (PM64). This creates a clean flow of water into rivers, lakes and oceans, saving our waters as well as animals and humans from harm or health implications.

Hydrocarbons, heavy metal elements, volatile organic compounds, microplastics, rubber crumb particles and particulate matter derived from road pavements can be removed from stormwater runoff through this 3P Technik sedimentation-filtration Treatment Train. Both systems are easy to install and maintain for their design lives, with remobilisation of previously settled solids made impossible, ensuring a contaminant-free flow of water into natural waters.

5.0 Further Global Problems Caused by Road Pavements

The contamination problem gets even worse when other contaminants are deposited onto road pavements- such as road marking particles, tyre wear particles, brake wear particles, exhaust fumes and other non-traffic contaminant sources like atmospheric deposition from nearby industries and littering. These contaminants will accumulate on road pavement surfaces and are transported with road pavement particles via wind or runoff to water bodies or soils.

Road pavement itself also contributes to the urban heat island effect. The dark surface absorbs sunlight and captures solar radiation which increases the temperature of areas with high road pavement content- typically in urban areas and cities. This contributes to climate change and rising global temperatures.

The high usage of road pavements has made areas extremely impermeable as bitumen has great waterproofing properties. This prevents rainfall and stormwater runoff to infiltrate into the ground as the natural hydrological cycle intends it. This paired with climate change implications of more intense and frequent rainstorms, means urban areas are more vulnerable to flooding. Thus, bringing contaminants that are deposited on road surfaces into buildings and homes closer to where humans can inhale or encounter toxic chemicals found within flood water. Drainage networks need to improve to be able to cope with this change of higher volumes of runoff and remove contaminants found within stormwater runoff- traditional drainage networks are not capable of these alterations. The implementation of SuDS

aids in this as the volume of runoff is controlled- delaying peak discharge times, at the same time that treatment steps are undertaken to remove contaminants.

6.0 Conclusion

Road pavements are everywhere and they're constantly being eroded and broken down by traffic and road users. Many different types of contaminants can be released from road pavements which enter stormwater runoff and eventually flowing into receiving water bodies such as rivers, lakes or the ocean. Each contaminant has different effects on habitats, animals and humans when exposed, which risks the total collapse of aquatic ecosystems if toxicity levels go far beyond 'acceptable' levels.

Sustainable Drainage Systems (SuDS) need to be implemented to tackle the issue and risks posed from road pavement erosion and the associated contaminants that are released.

7.0 Further Information

3P Technik's technical team can provide project-specific advice and support. Please contact us to discuss your requirements. Tel: +44 (0)1239 623506, Email: sales@3ptechnik.co.uk.

This article is published on the 3P Technik website: <https://3ptechnik.co.uk/road-runoff-pollution-how-road-surfaces-and-road-markings-release-microplastics-and-toxic-contaminants/>

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