

Can Permeable Pavement Systems Treat PAHs?

1.0 Introduction

Conventional pavements promote surface water runoff generation, where the water flows over the sealed surface into drains as quickly as possible. This runoff then includes any pollutants that were present in or on the pavement before the rain event.

Permeable Pavement Systems (PPS) in contrast are a stormwater management strategy considered to be more environmentally friendly by allowing infiltration of water into the ground. This reduces the volume of surface stormwater runoff and contributes to slowing and controlling the rate of flow of stormwater, while also treating the stormwater by removing toxic chemical compounds and pollutants from the water.

But what is the fate of the sediments and contaminants removed within a PPS? Do they degrade, escape or accumulate?

2.0 What are PAHs and why do they matter?

Stormwater runoff often consists of large volumes of micro-pollutants, including Polycyclic Aromatic Hydrocarbons (PAH). These toxic chemicals are generated during incomplete combustion of organic matter, such as coal, oil, wood or even from active volcanoes. Vehicles also release large concentrations of PAHs into our environment from exhaust fumes, tyre or break wear and oil leakages. PAH are a large group of chemicals that contain two or more aromatic rings and are recognised as major food and environmental contaminants.

2.1 Exposure routes for humans

PAH exposure routes include inhalation, ingestion or direct skin contact. Risk from inhalation of airborne PAH that are bound to particulate matter is at its highest in urban areas, industrial estates or high trafficked areas where the concentration of cigarette smoke, vehicle exhaust fumes or combustion is high. Rain acts as a natural cleansing agent where airborne contaminants are removed from the atmosphere through wet deposition and so the contaminants are incorporated into the stormwater runoff.

Cooking and eating food that is charred, roasted, fried or grilled produces PAHs and can enter the human body. Particle-bound PAH may settle and contaminate crop soil and therefore crops that humans/ animals consume. Consuming seafood from high concentration PAH areas or drinking from contaminated water supplies may bring on risks posed by PAH to humans and animals.

Direct skin contact with contaminated particles from soil or water can cause PAHs to absorb into human skin due to their high lipophilic characteristics.

2.2 Risks to humans, animals and the wider environment

PAH pollution poses significant risk to environmental and human health. Low-molecular weight PAHs (two to three aromatic rings) show acute toxicity in humans but lack carcinogenic properties. However high-molecular weight PAHs (four to seven aromatic rings) have reduced toxicity but are more carcinogenic and able to cause mutations and deformities in both humans and animals. The potential short-term effects for humans from PAH exposure include headaches, nausea, vomiting or acting as an irritant to the nose, eyes, throat and skin. The potential long-term effects from PAH contamination for humans include:

- Damage to liver, kidney, lungs or red blood cells
- Respiratory disorders like asthma or chronic obstructive pulmonary disease
- Heart/ cardiovascular disease
- Weakened immune system
- Cancer (lung, breast, oesophageal, skin)
- Fertility issues for both females and males- affecting the growth and development of the unborn child

PAHs are washed into stormwater runoff, which runoff eventually ends up in water bodies such as rivers, lakes, groundwaters and oceans. The toxic chemicals can bioaccumulate in both aquatic and non-aquatic life forms and pose similar risks as they do to humans- such as reproductive problems and possibly cancer. This PAH contamination leads to water quality degradation.

2.3 Persistence within the environment

High-molecular weight PAHs are more resistant to degradation and therefore more persistent in the wider environment. Most PAHs are found as particulate bound contaminants.

Despite being hydrophobic, PAHs are lipophilic, and therefore dissolve in lipids, fats or oils. Because of this, PAHs are prone to bioaccumulation in aquatic environments as they cannot dissolve easily and so bioaccumulate within aquatic and terrestrial organisms due to their lipophilic behaviour. This behaviour allows them to pass through biological cell membranes.

The solubility of PAHs in water depends on the molecular weight of the specific PAH. Generally, the solubility in water decreases with the increase in molecular weight but with overall low solubility. Low-molecular weight PAHs, containing two-three aromatic rings, can dissolve in water more readily than high-molecular weight PAHs.

2.4 Particle Size Distribution of PAHs

Due to the relatively low solubility of PAHs in water, PAHs are typically found bound to particles. These particles are fine-grained smaller particles like clays and silts, as they offer a larger surface area per unit mass compared to larger particles for PAH to adsorb to.

Fine grained particles are those of size measuring less than 64µm, often called PM64 (clays and silts). They are more difficult to remove from stormwater runoff than coarser particles. Yet, as fine-grained

particles adsorb the highest concentrations of PAHs and therefore pose the highest contamination risk, their removal, often permanent removal, is essential for safer environmental conditions.

3.0 What are Permeable Pavement Systems?

PPS allow the infiltration of rainwater and surface water runoff through their surface. This prevents the pooling of water on surfaces to occur and slows the flow of water entering rivers, thus reducing flood risk. Permeable pavements and the sub-base can act as a mechanical filter that captures unwanted pollutants from the water and is a good example of a sustainable drainage infrastructure technique. Impermeable surfaces encourage water to flow overland and increases flood risk in urban areas, while also transporting all pollutants into receiving water bodies.

3.1 Types of PPS

There are three basic types of permeable pavement systems (BS 7533): Type A (Full infiltration systems), Type B (Partial infiltration systems) and Type C (Fully lined systems). The type of which is used at a site is dependent on:

- Permeability of the soil subgrade
- Groundwater table level
- Groundwater vulnerability and protection to contaminants
- Risk of contamination from polluted/ brownfield sites
- Structural stability of the ground
- Local flood risks and control

These factors determine whether or not infiltration (in full, partial or none) at a site is appropriate. Each one consists of the basic layers of PPS stated below, but may require additional components such as impermeable membranes, underdrains or pipework located typically at the base of the system. This paper assumes a Type A PPS is installed at a site which allows for full/ direct infiltration of water from the surface into the underlying ground with no additional pipework or membranes needed.

3.2 Layers / Structure of PPS

The different layers that exist within a PPS support the structure of the permeable pavement. This sub-base structure allows for some water storage, the distribution of traffic load and the improvement of infiltration/ drainage capacities. There are many different types of PPS, the most common being permeable block paving and porous asphalt. They consist of the same layered structure of:

- Surface layer: smooth, skid resistant surface you see
- Bedding course
- Base course
- Geotextile layer: separates the layers and prevents mixing of the differently sized materials used
- Soil subgrade

The layers within a PPS also act as a filter for infiltrating waters and can remove pollutants through the processes of:

- **Adsorption:** Materials within the layers of permeable pavements can bind particles to their surfaces. This can be activated carbon and biochar as well as clays being added to either the bedding or base course. They have high surface areas and high ion exchange capacities to bind with PAHs.
- **Physical filtration:** The size of the trapped particles depends on the size of the voids between materials in each layer- larger particles are more easily filtered out and retained.
- **Biodegradation:** Naturally occurring microbial organisms (e.g. bacteria, fungi and algae) that are present in permeable pavement layers can convert PAHs into smaller, less harmful molecules over time. This will work somewhat with time on PAHs with low-molecular weights such as naphthalene and acenaphthene due to their shorter half-lives of less than 39 days (*EPA*). Larger PAHs- such as Benzo[b]fluoranthene or Indeno[1,2,3-cd] pyrene- with higher-molecular weights which have longer half-lives (>300 days) will accumulate with time as the rate of biodegradation is lower. Many SuDS designers fail to understand that half-lives over 365 days means that concentrations must increase in any subbase or soil, and that the intermediate compounds may also be toxic.

4.0 How effective are PPS in the real world?

Whilst being able to retain PAHs effectively, PPS tend to be implemented in low traffic areas or roads with speeds of less than 30mph and can be used in:

- Car parks- more on the smaller size
- Private driveways
- Pedestrian/ Cycle paths
- Lightly trafficked areas
- Schools/ playgrounds
- Fire access roads
- Infrequent HGV traffic

The use of PPS in high traffic areas is less common due to its structural strength being less durable than conventional impermeable pavements. The main concerns are the high vehicle load turning and braking and therefore causing the surface layer to rut or spall or for blocks to spread out. This means that aggregate layers beneath the surface move and pores collapse, creating an unstable surface for vehicles to travel on.

The highest concentrations of PAHs in stormwater will be near industrial/ commercial areas, power plants, potential spill sites or where vehicle traffic density is moderate to high. Permeable pavements would not typically be installed at these specific sites due to the constant pressure from the vehicle loads, including often heavy goods vehicles with high axle and tyre loadings.

The CIRIA SuDS Manual advises that if there is a high risk of silt loads on the surface, permeable pavements should be avoided (*Chapter 20, page 393*). There is a positive correlation between fine fraction particles- silts and clays, with the total PAH content. Therefore, if there is a high concentration of PAH in water, it can be assumed that there is a high concentration of fine particles like silts, and the use of permeable pavements should be reconsidered for the site.

Permeable block paving is used extensively in private driveways and domestic settings with low traffic loads. Porous asphalt is implemented where higher water permeability is needed or for larger driveways with still low traffic loads. PAH concentrations are low in these areas and therefore are typically of less concern from a stormwater treatment perspective.

With the presence of PAHs in a PPS, PAH species will accumulate over time due to their slow degradation. This contamination of the layers within the system has an effect on the microorganisms and earthworms that inhabit the space, predominantly in the soil subgrade (the native soil that has been compacted but is still sufficient with its permeability rates). The soil subgrade can be found at the base of the PPS, typically around 400mm below the surface- thicknesses of each layer differs depending on the original ground conditions and designed application (type of PPS and location of implementation- driveway, car park etc). Effects on earthworms and microorganisms include the impairment of immune and metabolic functions due to the toxic chemicals that infiltrate through, affecting their growth, reproduction and survival. Maintenance of the system must occur to ensure its effective implementation in reducing stormwater runoff and pollutant loads entering receiving water bodies. This will reduce the total PAH content and lessen the risks to microorganisms present. Renewal of the PPS will include the extraction of materials in the base layer, which may require treatment before disposal, especially if the contamination originates from high traffic flows and contains toxic chemicals like PAHs or heavy metals.

5.0 Conclusion

Permeable Pavement Systems are an example of a Sustainable Drainage System (SuDS) and are encouraged to be incorporated where performance will be effective. They can help to restore the natural hydrological balance and can reduce pollutant concentrations, as much as 50% reduction has been seen for a vacuum swept permeable full depth asphalt in USA (*Hozler and Poor, 2024*). However, high concentrations of PAHs are found in areas with high traffic loads at industrial/commercial and urban sites, where permeable pavements would typically not be installed as the surface cannot withstand heavy loads.

To effectively remove these toxic PAH compounds from heavily trafficked area stormwater runoff, the installation of filtration systems would work, within the treatment train. Manufactured treatment devices such as the 3P Technik HydroShark or the 3P HydroSystem can retain fine particles from stormwater runoff- these are the particles where PAHs are bound to. This will reduce contamination of water bodies and aid in reducing human and animal risks. The HydroSystem 1.500 can also be implemented for heavy traffic areas and industrial sites while also taking up no extra surface space, with easy maintenance access. This allows, with proper maintenance, for the retained sludges to be permanently removed from the soil or water environments. This will improve water qualities in receiving waters as well as posing less health risks to humans and animals from these toxic chemicals.

6.0 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/can-permeable-pavement-systems-treat-pahs/>

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