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Review

The sources, impact and management of car park runoff pollution: A review

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ABSTRACT

Traffic emissions contribute significantly to the build-up of diffuse pollution loads on urban surfaces with their subsequent mobilisation and direct discharge posing problems for receiving water quality. This review focuses on the impact and mitigation of solids, metals, nutrients and organic pollutants in the runoff deriving from car parks. Variabilities in the discharged pollutant levels and in the potentials for pollutant mitigation complicate an impact assessment of car park runoff. The different available stormwater best management practices and proprietary devices are reported to be capable of reductions of between 20% and almost 100% for both suspended solids and a range of metals. This review contributes to prioritising the treatment options which can achieve the appropriate pollutant reductions whilst conforming to the site requirements of a typical car park. By applying different treatment scenarios to the runoff from a hypothetical car park, it is shown that optimal performance, in terms of ecological benefits for the receiving water, can be achieved using a treatment train incorporating permeable paving and bioretention systems. The review identifies existing research gaps and emphasises the pertinent management practices as well as design issues which are relevant to the mitigation of car park pollution.

1. Introduction

The provision of car parking spaces continues to expand as the number of cars increases together with their associated use for work and leisure activities. Current global estimates are that there are 600,000,000 passenger cars and this number continues to grow daily (Ben-Joseph, 2012). Car parks (also referred to as parking lots) have become a key aspect of both transport and land use planning in connection with the development of shopping centres and supermarkets, cinemas, sporting arenas, factories and office complexes. In the USA, it has been estimated that a land area of approximately 9104 km^2 is occupied by car parks (Ben-Joseph, 2012) with 67% being classified as shopping and retail centres (National Parking Association, 2011). European projections indicate the existence of over 28 million parking spaces (Surinach et al., 2011), whilst in the UK, estimates range up to 11.3 million spaces in regulated facilities (British Parking Association, 2013) which equates to a land take of 214 km^2. Environmental and human impacts associated with car parks include excessive traffic movements, inefficient use of land, risks to pedestrians, air pollution and water pollution through the generation of polluted runoff (Mugavin, 1995).

Car parking surfaces are typically impervious (e.g. asphalt, concrete) but may have a gravel base or in more recent cases be constructed using permeable paving materials. Where an impervious car park surface exists, virtually all the incident rainfall, except for that removed by evaporative losses, produces surface runoff which needs to be removed efficiently to prevent localised flooding and to ensure safe driving conditions (Kalantari and Folkeson, 2013). These requirements have driven the installation of effective drainage systems which rapidly transport the surplus water to outlets, often discharging directly to receiving water systems where increased peak flow discharges may result in accelerated receiving stream erosion and down stream flooding. Car parks, like roads, represent a major source of water pollution in urban areas with the range of pollutants typically associated with car park runoff including total suspended solids (TSS), metals, anthropogenic organic compounds, nutrients and microbial contaminants (Gobel et al., 2007). Davis et al. (2010) estimated the amount of

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Glossary

AA	annual average
BMP	best management practice
BOD	biochemical oxygen demand
COD	chemical oxygen demand
DEHP	di(2-ethylhexyl)phthalate
DIDP	diisodecyl phthalate
DIN	dissolved inorganic nitrogen
DINP	diisononyl phthalate
EA	Environment Agency for England and Wales
EMC	event mean concentration
EQS	environmental quality standard
EU	European Union
FIO	faecal indicator organism
GIS	geographic information system
HC	hydrocarbon
HMWB	heavily modified water body
IUPAC	International Union of Pure and Applied Chemistry
LUPI	land use area pollution index
MAC	maximum allowable concentration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PI	pollution index
PM_{10}	particulate matter finer than 10 μm
PMI	pollution mitigation index
PSD	particle size distributions
RE	river ecosysytem
SPI	site pollution index
SUDS	sustainable urban drainage systems
SWMM	Stormwater Management Model
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TPH	total petroleum hydrocarbons
TS	total solids
TSS	total suspended solids
US EPA	United States Environmental Protection Agency
WFD	Water Framework Directive

runoff which would be generated by the area occupied by car parks in Tippecanoe County, Indiana, USA was 900% higher than before the land was converted. Associated increases in pollutant loads were calculated to be by factors of 6.2 for TSS, 3.5 for total nitrogen (TN), 3.0 for total phosphorus (TP) and much greater for metals with a 137-fold enhancement for Zn.

Car park runoff quality, like all diffuse urban runoff quality, can be expected to be highly variable (Freni et al., 2008) and is subject to factors such as catchment surface type, storm intensity and frequency and the antecedent conditions (Greenstein et al., 2004). The latter is considered by many investigators to be an important variable and has consistently been incorporated into modelling relationships to describe the build-up of solids, and their associated pollutants, on urban surfaces. The subsequent wash-off of surface accumulated pollutants contributes significantly to diffuse pollution loads which are subject to mitigation in line with the ambitious targets established by the EU Water Framework Directive (EU WFD, 2000).

To protect the quality of receiving waters, it is evident that changes to traditional drainage practices will be necessary particularly in the face of increasing urbanisation and associated car ownership and use. Traffic is a major contributor to diffuse pollutant loads in many urban and suburban environments. Whereas the management of road runoff quantity and quality typically comes under the remit of highways agencies and municipalities, the large car parks associated with the growing numbers of commercial/retail parks are often owned by private companies, many of whom are as yet unaware of the emerging need to control the quality of water discharging from their sites. In order to contribute to a widening of the knowledge which exists for car park derived pollution, this review initially considers the processes leading to the build-up of surface sediments and associated pollutants and how these aspects influence the quality of car park runoff. The focus is specifically on the behaviours of solids, metals, organic pollutants and nutrients for which the specific sources to car park surfaces are identified in Fig. 1. Subsequently, the available treatment processes and techniques for reducing the polluting potential of stormwater deriving from car parks are discussed and an impact assessment procedure is described for determining the ecological benefits for receiving waters which can be achieved by treating car park runoff.

2. Surface deposition and build up

To date there has been little reported work on the accumulation processes which influence the behaviours of solids and their associated pollutants on car park surfaces with the focus being on road surfaces (e.g. motorway, urban, residential). Busy residential roads are considered to behave similarly to car parks in relation to controlling influences such as traffic densities and speeds. The range of contributing pollutant sources which can potentially be found on car park surfaces are identified in Fig. 1. Total solids (TS), which represent particles smaller than 6 mm, have been traditionally taken as the reference parameter for the consideration of accumulation rates for road, and by inference car park, surfaces.

2.1. Accumulation modelling processes

Most surface pollutant accumulation models are based on semi-empirical formulations in which the antecedent dry period (t) is considered to be an important independent variable. A wide range of mathematical models including linear, power, exponential and Michaelis–Menton functions have been used to describe the temporal build-up process (Huber and Dickinson, 1988). However, the most widely employed predictive relationships for urban surfaces are the exponential (Bertrand-Krajewski et al., 1993; Charbeneau and Barrett, 1998; Deletic et al., 1997; Shaheen, 1975) and power functions (Ball et al., 1998; Egodawatta et al., 2013).

The exponential equation defining pollutant build-up can be expressed as:

$$dP/dt = k_0 - k_r P \quad (1)$$

where P = amount of pollutant per unit area on the catchment surface (kg m^{-2}), k_0 = constant rate of pollutant deposition (kg m^{-2} h^{-1}); k_r = constant pollutant removal rate (h^{-1}) and t = antecedent or inter-event time (h).

Due to the inability of a storm event to completely remove all solids and associated pollutants, modifications to Equation (1) have been introduced to account for the residual or initial amount of pollutant available on the catchment surface after the previous runoff or street sweeping event (Chen and Adams, 2006; Osuch-Pajdzinska and Zawilski, 1998; Zhang and Yamada, 1996).