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Review

Water quality impacts of bridge stormwater runoff from scupper drains on receiving waters: A review

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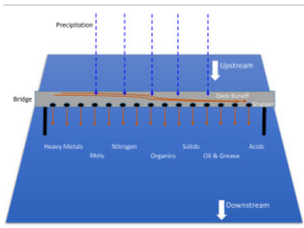
Highlights

- Sources and impacts of stormwater pollution are numerous.
- Highway runoff and bridge deck runoff have similarities and differences.
- Factors affecting bridge deck runoff quality are swaying.
- Water quality parameters are various and treatment options are viable.
- Stochastic Empirical Loading and Dilution Model is a convenient projection tool.

Abstract

This article provides insight into the environmental significance of bridge deck stormwater runoff from scupper drains on receiving water bodies through a review of over eighty sources of information including research and review articles, technical reports and government websites. This article discusses sources and impacts of stormwater pollutants and presents potential methods for predicting impacts of stormwater runoff on receiving waters from highways and bridges. Records of similarities and possible differences between highway and bridge deck stormwater runoff are provided, and the significance of scupper drains as points of runoff discharge from bridges is discussed. Factors that influence bridge deck stormwater runoff quality include the location of the bridge, dimensions of the bridge deck, composition of the road surface, age of the bridge, design and maintenance of the drainage system, traffic volume, and intensity and frequency of rainfall events. Several pollutants of concern are discussed, such as heavy metals, polycyclic aromatic hydrocarbons, solids, nutrients, oil, grease, polychlorinated biphenyls, and perfluorinated compounds. This review also discusses available methods for treatment of bridge deck runoff and the challenge of applying these methods for treatment of bridge deck runoff, as compared to treatment of highway runoff. Finally, this article considers the application of the stochastic empirical loading and dilution model (SELDM), a joint product of the U.S. Geological Survey and the Federal Highway Administration, to predict and assess the potential effects of runoff on receiving waters.

Graphical abstract



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Introduction

Bridge deck stormwater runoff is considered a non-point source of contamination to receiving waters. Bridge deck stormwater runoff can be a matrix to a variety of contaminants produced from different sources. Major sources for the array of contaminants can include but are not limited to traffic, atmospheric fallout, degraded bridge deck and road components, construction activities and industrial emissions (Stormwater Runoff From Bridges, 2012; Bartelt Hunt et al., 2015; Bartelt Hunt et al., 2012; Blomberg and TJ, 2016; Malina et al., 2005; Smith et al., 2018; Swadener et al., 2014; Nwaneshiudu, 2004; Perkins and HY, 2010; Taylor et al., 2014; Tan et al., 2018; Thomas, 2002; Winston et al., 2015). Although the impact of bridge deck stormwater runoff is commonly stated by many researchers to be much less than other point and non-point sources of pollutants, its accumulative influence on sensitive water bodies and aquatic habitats must be considered as a contributing source of water contamination.

Bridges are often constructed as crossings over water bodies, which makes their direct impact a matter of concern for the water bodies they span. Roadway segments that are constructed directly on a roadbed can efficiently utilize the slopes of the roadbed to reduce water quality impacts, allowing for sheet flow and directing runoff to treatment facilities such as roadside swales and vegetated filter strips. In contrast, roadway segments that are constructed on a bridge structure may allow runoff to fall directly from the bridge deck to the water bodies beneath the bridge. Such direct drainage can amplify the impact of bridge deck runoff on water bodies (Alisa, 2007; Blomberg and TJ, 2016; Taylor et al., 2014). The implementation of structural controls for bridge deck runoff presents a practical challenge due to the cost and complexity of the design, construction, and maintenance of such facilities (Goonetilleke et al., 2017; Barbosa et al., 2012; Taylor et al., 2014; Qiao et al., 2018). Direct drainage of bridge deck stormwater runoff can represent a widespread source of water contamination.

Population growth is a major cause of alterations to runoff water characteristics and quality, as it is the motivating force behind increased urban development and anthropogenic activities. Urban development leads to the rapid expansion of impervious cover in watersheds which results in significant modifications to the surrounding environment. Such changes are numerous and can include reduction in times of concentration of runoff, higher peak flows, altered sedimentation/erosion processes, changes in water quality, reductions in biodiversity and damage to infrastructure (Malina et al., 2005). Anthropogenic activities are the primary cause of airborne, terrestrial and aquatic pollution (Georgia Stormwater Management Manual, 2001; Winston et al., 2015).

As stormwater spreads across the surface of the bridge deck, it accumulates and transports an array of pollutants and solid substances located on the deck surface. In addition to the pollutants carried onto the bridge deck by crossing vehicles, pollutants are also introduced by atmospheric fallout in the form of particulate matter and toxins. Other sources of contamination include degradation of bridge surfaces, wear of vehicle components and road maintenance operations. (Blomberg and TJ, 2016; Karlsson et al., 2011). Contaminants can reach surface water from the bridge deck by the discharge of runoff through scupper drains and gutter systems, which are engineered discharge points constructed in the deck surface.

Among the vehicles that cross bridges are trucks that transport hazardous materials and other pollutants of concern. Toxic substances can be introduced to the bridge deck when leaks or spills occur (USEPA, 1996c; USEPA, 2001a; Alisa, 2007; Grant et al., 2003). Therefore, it can be anticipated that bridge decks can convey substances of explosive, flammable, toxic, radioactive or acidic properties (Blomberg and TJ, 2016).

Contaminants in bridge stormwater runoff have varying properties and sizes as they can be ions, molecules or particles and can include: hydrated ions, dissolved molecules, dissolved, colloidal, and gravitational particles and suspended matter. Thus, the evaluation of stormwater quality and the projection of its impact on receiving waters is intricate (Alisa, 2007). Traffic alone accounts for the formation and introduction of many chemicals in road and bridge stormwater runoff such as polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and semi VOCs, oil and grease, asbestos, lead (Pb), cadmium (Cd), and copper (Cu) (USEPA, 1996c; USEPA, 2001a; Alisa, 2007; Grant et al., 2003; Trombulak and FC, 2002). Galvanization of bridge components adds to the heavy metals load of zinc, copper and iron (Stormwater Runoff From Bridges, 2012; Field and SD, 2002; Malina et al., 2005; Nwaneshiudu, 2004; Winston et al., 2015). Acute and chronic toxicity can be induced in aquatic life and humans under prolonged and sometimes instant exposure to heavy metals, while other salts contribute to aquatic life toxicity and can impair water quality and make it unsuitable for human consumption (Perkins and HY, 2010).

Particulate matters (PMs) have the power to adsorb and transport various other pollutants from the atmosphere such as carbon monoxide (CO), nitrogen oxides (NO_X), VOCs and semi VOCs, sulfur dioxide (SO_2), methane (CH_4), and toxins including benzene, toluene, ethyl benzene and xylene (BTEX), butadiene and formaldehyde, among others, and can introduce these pollutants to the aquatic environment when they settle with precipitation. Moreover, PMs can catalyze the interaction and transformation of such pollutants into other toxic compounds and by-products that can get introduced to receiving waters via bridge scupper and gutter drainage systems (Alisa, 2007; Perkins and HY, 2010).

When rain falls onto a bridge deck, it can increase the risk that a driver will lose control of vehicle by skidding or hydroplaning. The design of gutter systems and scupper drains is important as it mitigates this risk (Design of Bridge Deck Drainage, 1993). Vehicular accidents increase the chance of noxious emissions, leaks and spills. In addition, water may collect corrosive substances and initiate corrosive reactions on bridge components. This can result in structural damage. Runoff can also generate erosional effects, including the loss of embankment material and the settlement of concrete slabs.

Gutter systems are parts of the bridge deck that can be utilized to convey stormwater runoff close to the curb. It can be a part or all of a lane or a shoulder with a limited width adjacent to the curb. Scupper drains are vertical openings designed in the bridge deck or curb through which stormwater runoff can flow off the bridge deck. These structures in the bridge deck are points of discharge for stormwater runoff into water bodies below, and are important to consider when sampling for water quality analysis from the bridge deck (Design of Bridge Deck Drainage, 1993; Bartelt Hunt et al., 2012; Buckler and GG, 1999; Thomas, 2002).

Regulations are set by government agencies and bodies to help control the impact of non-point contamination including that from bridge deck runoff. The Clean Water Act of 1972 and other laws and regulations implemented by federal and state agencies serve to protect water bodies, wildlife, and humans from the severe sequences of contamination. The U.S. Environmental Protection Agency (USEPA) publishes water quality criteria including a continuously updated list of contaminants of concern and emerging contaminants (USEPA, 2001b; Nwaneshiudu, 2004). The USEPA also recommended criteria maximum concentrations (CMCs) and criteria continuous concentrations (CCCs) for several metals and toxic constituents in freshwater and saltwater (USEPA, 1998; Nwaneshiudu, 2004).

The USEPA has established and updated watershed planning criteria for protection and improvement of water quality (USEPA, 1996a; USEPA, 1996b; Thomas, 2002). Moreover, several recommendations for bridge management measures were made by the USEPA. The USEPA recommends management practices regarding bridge deck runoff that include: 1) directing pollutant loads away from bridge decks by diverting runoff waters to land for treatment, 2) restricting the use of scupper drains on bridges <400ft in length and on bridges crossing over very sensitive ecosystems, 3) designing new bridges to avoid sensitive ecosystems, 4) On bridges with scupper drains, to provide equivalent urban runoff treatment in terms of pollutant load reduction elsewhere on the project to compensate for the loading discharged off the bridge (USEPA, 1993; Thomas, 2002).

This article reviews literature on sources of stormwater pollution, predictive modeling for water quality impacts, a comparison of highway stormwater runoff and bridge deck stormwater runoff, the impact of runoff on receiving waters, water quality parameters relevant to bridge deck stormwater runoff, and an overview of an efficient simulation tool that can accurately anticipate potential effects of runoff from scupper drains on water quality, particularly the Stochastic Empirical Loading and Dilution Model (SELDM). Moreover, a discussion on sustainable management strategies for bridge deck stormwater runoff and their accompanied challenges and constraints, and available treatment options for bridge deck stormwater runoff is provided.

Section snippets

Types of pollutants, their sources and impact classification

Bridge deck and highway stormwater runoff can hold a large array of chemicals due to continuous exposure to various sources of contamination. Of the common constituents that can be found in bridge deck runoff are heavy metals, inorganic salts, aromatic hydrocarbons, suspended solids, and compounds that are shed by vehicles such as oil, grease, rust, and rubber particles (Stormwater Runoff From Bridges, 2012; HJ, 1999; Thomas, 2002). All of these components are commonly produced from motorized…

Water quality of highway and bridge deck stormwater runoff

It is well established that both highway runoff and bridge deck runoff can transport various chemicals of urgent concern to fresh water bodies that can impact human and aquatic ecosystems with exposure. This infers that the constituents of runoff from highways and bridge decks are essentially similar since the sources are the same (Bartelt Hunt et al., 2012). However, in a study on characterization of stormwater runoff from bridge decks in eastern Massachusetts, it was shown that the…

Rainfall events and rainfall intensities

It is recognized that various types of contaminants are airborne and can be emitted from different sources such as industrial emissions and traffic. These contaminants can settle with rainfall onto water bodies and surfaces creating toxic conditions to aquatic and terrestrial organisms (Carpenter et al., 1998; Newman et al., 1992; Clair et al., 2003). Moreover, settling airborne particulate matters can adsorb and catalyze the transformation of different contaminants such as volatile organic…

Heavy metals

Heavy metals were extensively found to exist in bridge deck and highway stormwater runoff. The sources of heavy metals in bridge deck runoff are reported to be primarily transportation related and from galvanization of bridge beams (Stormwater Runoff From Bridges, 2012; Bartelt Hunt et al., 2012; Malina et al., 2005; Swadener et al., 2014; Perkins and HY, 2010; Taylor et al., 2014; Winston et al., 2015). In addition, heavy metals were observed to be released from roadway construction and…

Treatment of bridge deck stormwater runoff

Several approaches were implemented for treatment of bridge deck runoff. These commonly include bioretention systems or rain gardens, infiltration systems, filtration techniques, biological treatment and finally disinfection. All of these processes can be implemented for bridge deck runoff as well as highway runoff treatment. However, the greatest challenge for bridge deck runoff remains to be the runoff conveyance.…

The stochastic empirical loading and dilution model (SELDM)

Modeling tools can be beneficial in cases such as absence of field data and absence of knowledge of concentrations of pollutants that can create harmful impacts, in order to assist in the consideration of potential future impacts. If an accurate modeling tool is available, this can allow resource agencies and government branches to precisely anticipate the potential impacts associated with bridge deck runoff from scuppers on receiving water bodies and sensitive species. The development of SELDM …

Conclusions

In this article, a detailed study of different sources of information including literature research journals and published reports was conducted aiming to shed light on sources and impacts of bridge deck stormwater pollution. Different aspects were discussed including types of pollutants and their sources with grouping of their several impacts. Currently, there is a need for further research on efficient means for highway and bridge deck runoff interception and treatment, in addition to further …

Acknowledgement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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> …Benzene and nitrobenzene incidents occurred in the Songhua River in Heilongjiang Province in 2005 and the leakage of industrial wastewater containing arsenic in Yangzonghai Lake in Yunnan Province in 2008 caused severe water pollution (Tang et al., 2014). Bridge deck runoff, tunnel sewage, and atmospheric deposition are the primary topics of research in the area of bridge/tunnel construction (Bakr et al., 2020; Müller et al., 2020). Kim et al. (2007) indicated that pollutants with higher concentrations in the bridge deck runoff were often observed in the 'first flush' of a rainfall event, which was particularly common for highly soluble pollutants such as nutrients, ionic metals, and organic compounds.…

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