Science of the Total Environment 610–611 (2018) 613–622

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Enhanced roadside drainage system for environmentally sensitive areas

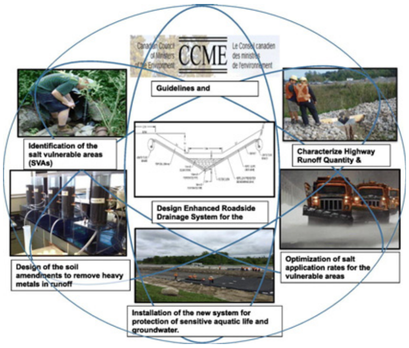
William R. Trenouth [a], Bahram Gharabaghi [a,*], Hani Farghaly [b]

[a] School of Engineering, University of Guelph, Guelph, Ontario N1G 2W1, Canada
[b] Ontario Ministry of Transportation, 301 St. Paul Street, St. Catharines, Ontario L2R 7R4, Canada

HIGHLIGHTS

- Presented a novel design for roadside drainage system to protect sensitive areas
- Presented a comprehensive scientific design framework for regulatory compliance
- Constructed, instrumented and monitored field-scale test site for three years
- The new design can be used to protect sensitive aquatic life and groundwater.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 April 2017
Received in revised form 8 August 2017
Accepted 9 August 2017
Available online 17 August 2017

Editor: D. Barcelo

Keywords:
Environmentally sensitive areas
Highway runoff
Roadway runoff
Aquatic life
Groundwater
Road salts
Heavy metals

ABSTRACT

Stormwater runoff from roadways that encroach upon environmentally sensitive areas (ESAs) is one of the leading causes of degradation in urbanizing watersheds around the world. This is due to toxicity of the pollutant cocktail commonly found in roadway runoff, including heavy metals and sediments, as well as road salts from winter maintenance operations. This paper presents a novel design of an enhanced roadside drainage system (ERDS); an improved roadside drainage system that is intended to protect groundwater recharge zones and sensitive aquatic species in ESAs. The methods highlighted in this paper can be used to select soil amendments and size filter media for ERDS based on a combination of anticipated roadway pollutants and loads, treatment media efficacy and capacity, and consideration of applicable regulatory guidelines. The design of the ERDS must ensure compliance with the regulatory guidelines related to the protection of groundwater recharge zones as well as the receiving streams to protect priority species living therein. The performance monitoring results from a pilot-scale ERDS are presented to provide guidance for the key novel aspects of the design.

1. Introduction

Stormwater runoff from large roadways has been recognized as a leading cause of water quality impairment worldwide, impacting both sensitive surface water and groundwater resources (Crabtree et al., 2006; EPA, 2010; Francey et al., 2010; Istenič et al., 2012; Pan and Miao, 2015; McIntyre et al., 2015; Barkdoll et al., 2016; Sattar et al., 2017). An estimated 50% of the suspended solids and 70% of the

---

[*] Corresponding author at: Water Resources Engineering, Room 2417, Thornbrough Building, School of Engineering, University of Guelph, 50 Stone Road East, Guelph, Ontario N1G 2W1, Canada.

E-mail addresses: wtrenout@uoguelph.ca (W.R. Trenouth), bgharaba@uoguelph.ca, http://www.uoguelph.ca/~bgharaba/index.htm (B. Gharabaghi), hani.farghaly@ontario.ca (H. Farghaly).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.081

polycyclic aromatic hydrocarbons (PAHs) in the receiving waters of the United States have been attributed to highway runoff (Tsihrintzis and Hamid, 1997).

Despite restrictive spatial envelopes which often preclude the implementation of robust stormwater controls, road authorities charged with the task of maintaining safe, driveable road conditions during severe winter storm events are coming under increasing pressure to protect salt vulnerable areas (SVAs; Betts et al., 2014; Betts et al., 2015). Numerous studies have documented that both aquatic and terrestrial ecosystems can be adversely affected by exposure to high chloride concentrations associated with the typical use of road salts, and that drinking water supplies may also be put at risk (Novotny et al., 1999; Health Canada, 2001; CCME, 2011; Environment Canada, 2013).

However, road runoff in seasonally cold climates frequently carries within it a substantial physicochemical pollutant burden containing not only the aforementioned total suspended sediments (TSS) and PAHs, but road salt (NaCl), nutrients such as total phosphorus and total Kjeldahl nitrogen, petroleum hydrocarbons and heavy metals, including Cr, Co, Cu, Ni, Zn and Pb, amongst others (Nason et al., 2012; LeFevre et al., 2014; Andradottir and Vollertsen, 2015; Ernst et al., 2016; Wang et al., 2016; Ilyas and Muthanna, 2017). To estimate the long-term pollutant burden derived from trafficked areas, Trenouth and Gharabaghi (2016) compiled a dataset comprised of 940 monitored roadway runoff events from fourteen sites located in five countries (Canada, USA, Australia, New Zealand, and China) and developed comprehensive models for the prediction of roadway runoff quality.

Roadside swales which incorporate properly designed vegetated filter strips (VFS) have been shown to remove >90% of TSS, in addition to the metals, nutrients and other deleterious compounds sorbed to particle surfaces (Gharabaghi et al., 2001; Trowsdale and Simcock, 2011; Pack et al., 2004; Akan, 2014; Wang et al., 2016). However, VFS systems are of limited utility in terms of their ability to remove fine, colloidal particles from suspension, and have little ability to remove dissolved contaminants from solution. These shortcomings have resulted in a shift to more advanced stormwater practices which seek to optimize the balance between cost and performance in environs facing heightened degradation (Istenič et al., 2012; O'Neill and Davis, 2012; Page et al., 2015).

1.1. Receiving water quality guidelines

The Canadian Council of Ministers of the Environment (CCME) – an intergovernmental forum for collective action on environmental issues – has promulgated a suite of guidelines intended to protect aquatic life from pollutants ranging from heavy metals to chlorides and even sediments (CCME, 2002, 2011). For sediments and chlorides the CCME guidelines explicitly consider both the concentration as well as the duration of organismal exposure (CCME, 2002, 2011). The framework of such guidelines is a tacit acknowledgement of both the complexities as well as the uncertainties surrounding the management of environmental systems (Trenouth et al., 2013).

1.2. Designing enhanced systems

Recent research has focused on the ability of novel soil amendments to remove high concentrations of both dissolved and particulate-bound metals from direct highway runoff (DHRO) and its synthetic analogue. Amendments such as blast furnace and basic oxygenated furnace slag from steel mills were shown to remove upwards of 98% of some metal species, even when simultaneously exposed to high concentrations of road salts (NaCl) (Trenouth and Gharabaghi, 2015c). This last point warrants further consideration, as brackish winter runoff from areas subject to typical winter maintenance activities has been implicated in colloidal dispersion, preferential cationic displacement and the remobilization of particulate matter and other pollutants (Hillel, 1998).

Road salt management presents an issue which is particularly vexing as road salts (typically in the form of NaCl, and to a lesser extent MgCl2) dissociate in solution to form a product which is highly mobile, toxic to aquatic life and potentially hazardous to human health (CCME, 2011; Ostendorf, 2013; Corsi et al., 2015). Conversely, the utility of road salts as an anti-icing agent which aids in the preservation of winter commuter safety and the protection of human life is impossible to ignore (Trenouth et al., 2015).

(1) The above literature review highlights the need for a novel design approach for a roadside drainage system for the protection of the environmentally sensitive areas while limiting the construction and maintenance operational needs and costs. Protection may be best achieved through consideration of both the quantity and quality of roadway runoff as well as the lifetime pollutants load expected over the design life of a treatment system. Such a design approach must also consider the ambient receiving water quality of downstream areas, as well as the efficacy of any soil amendments that may be included within the matrix of the proposed filtration media. No clear approach currently exists which considers the full suite of receiving stream impacts, groundwater vulnerability, treatment media efficacy and anticipated pollutant loadings as part of a unified design methodology. In light of the identified research needs, the main objective of this work was to provide roadway engineers tasked with the design of stormwater management infrastructure with guidance for a systematic and comprehensive ERDS design methodology for the management of stormwater from roadways located in ESAs. The design methodology should be built on both demonstrated groundwater protection efficiency and the receiving water quality benefits of the ERDS in the context of winter road salt applications. Second, our work sought to;
(2) Demonstrate how the ERDS design methodology can be used to size filter media for heavy metals removal to improve runoff quality to meet applicable regulatory standards, and use computed mean daily unit area loads (MDUALs) to calculate minimum required capacity of the ERDS to ensure performance longevity, and;
(3) Critically review existing regulations and guidelines applicable to the design of ERDS and comment on the suitability of existing water quality guidelines insofar as they facilitate the successful design of stormwater treatment approaches, in the context of a field example.

2. Materials and methods

2.1. Conceptual model

This work presents a novel comprehensive design methodology that requires knowledge of the anticipated types and loadings for various pollutants of concern. As such, the first step is to characterize the local receiving waters and to build an understanding of the ambient water quality conditions and an inventory of any sensitive aquatic species which may be living therein (Trenouth and Gharabaghi, 2015b). This permits the development of a list of the priority pollutants of concern and any associated regulations or guidelines which may be applied to their discharge. Such information can then be cross-compared against the known or anticipated runoff water quality from the roadway in question. Ideally, background data on runoff water quality across different seasons from different sections of the roadway should be used to develop a characterization of the event mean concentrations and long-term loadings for various pollutants of concern (Trenouth and Gharabaghi, 2016; Supplemental Fig. 1). However, given the costs and logistical challenges associated with field data collection this is frequently not the case. Correspondingly, the use of predictive models may be used in lieu of empirical data (Schmueli, 2010).