Development of a framework to support the systematic identification of surface receiving waters vulnerable to highway traffic pollution

Développement d'un guide pour l'identification systématique des milieux récepteurs vulnérables à la pollution autoroutière

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RÉSUMÉ

Malgré des jeux de données incomplets, les décideurs, les autorités routières nationales et les agences de protection de l'environnement sont de plus en plus tenus de décider comment, quand et où les eaux de ruissellement provenant des autoroutes doivent être traitées. Afin de répondre à ce besoin, un système de notation destiné à faciliter l'identification systématique des eaux de surface vulnérables à la pollution routière a été mis au point dans le cadre du projet de ruissellement routier CEDR PROPER. Considérée comme une extension de l'évaluation des risques, l'approche développée prend en compte l'impact différentiel d'un aléa identifié (i.e. ruissellement autoroutier) dans un environnement local (eaux réceptrices de surface). En faisant appel à la co-identification de critères en combinant une revue de la littérature scientifique et des discussions avec les parties prenantes, la nature et le type d'influence d'une série de paramètres sont décrits et notés. Les résultats de ce processus seront intégrés à une évaluation des exigences législatives relatives à la construction, à l'exploitation et à la maintenance des autoroutes afin de supporter le développement d'un outil d'aide à la décision permettant aux parties prenantes d'identifier les eaux réceptrices vulnérables à la pollution autoroutière.

ABSTRACT

Irrespective of incomplete data sets, policy-makers, National Road Authorities and environmental protection agencies are increasingly required to make decisions on how, when and where highway runoff should be treated. As a contribution to addressing this need, a vulnerability scoring system to support the systematic identification of surface waters vulnerable to highway traffic pollution has been developed within the CEDR PROPER road runoff project. Viewed as an extension of risk assessment, the developed approach considers the differential impact of an identified hazard (i.e. highway runoff) within a local environment (the surface water receiving body). Involving the co-identification of criteria through a combination of a review of the research literature and stakeholder discussions, the nature and type of influence of a range of parameters is described and scored. The results of this process will be integrated with an evaluation of legislative requirements relating to highway construction, operation and maintenance to inform development of a decision support tool to enable stakeholders to identify receiving waters vulnerable to highway traffic pollution.

KEYWORDS

Highway pollution, surface waters, vulnerability scoring system

1. INTRODUCTION

The main objective of the EU Water Framework Directive (EU WFD, 2000) is to ensure all of Europe's waters achieve 'good status' by 2027 at the latest. 'Good status' for surface waters is defined through both ecological and chemical conditions as a healthy ecosystem with low levels of chemical pollution. To fulfil their requirements, Member States need to establish water quality objectives for water bodies and, where problems are identified, propose appropriate mitigating measures. River Basin Management Plans (RBMPs) and accompanying Programmes of Measures explain these proposals and how they will be achieved. The overall objective is to protect the whole water body and to initiate a coordinated response to solve identified problems. However, with 47% of the EU's surface waters reported not to have achieved 'good ecological status', considerable further efforts are required (EEA, 2014).

Whilst agricultural practices are recognised as key diffuse pollution pressures on water quality in many RBMPs, the role of urban diffuse pollution is less certain. As a category, urban diffuse pollution includes runoff from a range of sources such as roads, pavements, roofs and misconnections, and therefore the exact contribution from traffic activities is not readily ascertainable. However, several detailed studies have reported a change in the nature or composition of receiving water ecologies in receipt of highway runoff, with differences in species composition, abundance and feeding behaviour identified. Despite this, the challenge of establishing a causal relationship remains, as even highway runoff discharges identified as exceeding certain environmental quality standards are not consistently associated with poor ecological status (and vice-versa). Irrespective of this, it is recognised that end-users e.g. National Road Administrations, are required to make decisions now on when, where and how highway runoff should be treated. As a contribution to addressing this need, this paper presents a vulnerability scoring system to support the systematic identification of surface waters vulnerable to highway traffic pollution.

2. METHODOLOGY

Assessments of vulnerability consider the differential impact of an identified hazard (e.g. highway runoff) within a local environment (i.e. the surface water receiving body under consideration). This integration of knowledge sets can be applied using a conventional risk assessment approach where likelihood of occurrence is a function of extrinsic activities (e.g. traffic data, climate) and magnitude of impact is informed by an assessment of the inherent characteristics of the receiving water (e.g. water hardness, pH etc.). Drawing on the existing literature, a series of criteria (and supporting indicators) have been proposed to support development of a vulnerability scoring tool. The aim is to enable stakeholders to systematically screen surface waters bodies to identify those most vulnerable to receiving road runoff. As well as identifying the criteria themselves, the nature and type of influence of each parameter is described and an indication of how changes in the parameter can increase or decrease highway pollution loadings (i.e. likelihood of occurrence) and vulnerability of receiving waters (i.e. magnitude of impact) provided.

3. RESULTS AND DISCUSSION

Recent reviews of pollutant concentrations discharging from highways and the vulnerability of surface waters to road related pollution (e.g. Revitt et al., 2018, Barbosa and Fernandes, 2018) have identified that the term ‘vulnerable receiving water’ is used in a variety of contexts leading to different definitions and interpretations. For example, the term has been used in relation to:

- Hydrological aspects: e.g. increased vulnerability to highway runoff during low-flow conditions
- Chemical aspects: e.g. highway runoff poses a greater risk to ‘soft water’ receiving waterbodies with regard to metal pollution
- Ecological aspects: e.g. water bodies that are host to sensitive species are particularly vulnerable
- Geological aspects: e.g. chalk aquifers are often described as vulnerable especially following de-icing operations

The term vulnerable receiving water is also used in relation to anthropogenic factors such as:

- Actual / planned use of the water body: e.g. water bodies identified as sources of drinking water are vulnerable and hence given legislative protection
- Surrounding land use: receiving waters in urban areas are also vulnerable to discharges from CSOs and aerial inputs; rural receiving waters are vulnerable to inputs from agriculture runoff
- Traffic characteristics have been identified as influencing receiving water vulnerability

The literature associated with each of the above definitions has been reviewed to identify and critique available knowledge in relation to type of impact and influencing factors. As an example of the output from the approach, factors influencing the inherent (hydrological, geological, chemical and ecological) characteristics of surface water vulnerability are summarised in Tables 1, 2 and 3. Each influencing factor is considered in terms of whether it exerts a primarily beneficial or detrimental impact. Finally, a relative score is allocated to each impact on a scale of -5 to +5 with an increasingly positive score indicating increasing improvements in the receiving water and an increasingly negative score signifying greater potential challenges for the health of a receiving surface water. Scores were allocated in collaboration with the CEDR PROPER International Advisory Board (see www.proper-cedr.eu/iab.html) through a process involving identification of the most beneficial and most detrimental effects (awarded the highest and lowest scores, respectively), with remaining effects allocated scores relative to these endpoints.

Table 1 Characterisation of geological and hydrological impacts on surface receiving waters

Type of impact	Influencing factor	Nature of receiving water impact	Examples of beneficial (+ve score) or non-beneficial (-ve score) effects
Geological	Natural weathering of rocks and soils	Provides essential minerals and nutrients	Contributes to maintaining the health and vitality of aquatic ecosystems (+1)
Hydrological due to highway runoff inputs	Increased flows	Changes to pool riffle sequences	Reduction in receiving water habitats (-2)
	Scouring of basal sediments	Increased mobilisation and transport of sediments with a shift from coarse to fine sediment distribution	Loss of channel diversity due to channel migration, degraded habitat quality; inhibition of aquatic plant, macroinvertebrate and fish growth (-2)
	Enhanced dilution capacity	Potential to reduce pollutant levels below toxic thresholds	Protection of sensitive biota (+3)
	First flush effect	Possibility of high pollutant loads being delivered to receiving water during early stages of a storm event	Elevated levels of toxicity during initial stages of a storm event (-3)

Table 2 Characterisation of chemical impacts on surface receiving waters

Type of impact	Influencing factor	Nature of receiving water impact	Examples of beneficial (+ve score) or non-beneficial (-ve score) effects
Chemical	Increased total suspended solids loadings	Particulates acts as sites for metal and PAH sorption	Possible small reduction in toxicity due to pollutant adsorption likely balanced by increased turbidity and biotic impacts (0)
	Elevated sodium chloride levels due to winter maintenance activities	Chloride can facilitate release of metals due to ion exchange and formation of chloro-complexes; mobilisation of DOC and associated release of PAH to soluble phase	Aquatic biota demonstrate different sensitivities to high salt levels; encouragement of drift behaviour and possibility of increased toxicity (-4)
	Receiving stream water hardness	Ca and Mg ions compete with metal pollutants for membrane binding sites in aquatic organisms	Reduction in metal bioavailability and toxicity (+2)
	Receiving stream alkalinity	Removal of free metal ions due to carbonate complexation	Reduction in metal bioavailability and toxicity (+1)
	Presence of natural dissolved organic materials	Removal of free metal ions due to organic complexation; Mobilisation of hydrophobic PAHs	Reduction in metal bioavailability and toxicity; Potential increases in PAH bioavailability and toxicity (0)
	Receiving stream acidity	Promotes availability of free metal ions; some competition between metal and hydrogen ions for adsorption sites	Increase in metal toxicity balanced by some competitive uptake (-1)

Intrinsic receiving water characteristics which potentially reduce the vulnerability of receiving waters to highway discharges include the possibility of an increased dilution capacity (+3), the presence of elevated hardness in the receiving water (+2) and/or alkalinity (+1) and the provision of essential minerals and nutrients due to the natural weathering of rocks and soils (+1). In contrast, there are considerably more factors which can result in an increased risk being posed to the receiving water environment as a consequence of highway runoff discharges. Of particular consequence is the presence of elevated concentrations of chloride in highway runoff due to winter maintenance activities (-4) as this can directly affect aquatic biota resulting in drift behaviour as well as facilitating increased toxicity through the release of particulate associated metals and PAHs to the soluble phase. The existence of a first flush effect in which elevated loads of toxic pollutants are discharged to a receiving water during the early stages of a storm event also presents a high risk scenario (-3).

Table 3 Characterisation of ecological impacts on surface receiving waters

Type of impact	Influencing factor	Nature of receiving water impact	Examples of beneficial (+ve score) or non-beneficial (-ve score) effects
Ecological	Elevated temperatures in highway runoff	Influences physiological processes; reduces dissolved oxygen levels and possibly increases concentrations of dissolved substances	Affects the metabolic and reproductive rates of algae, benthic invertebrates and fish (-2)
	Physiological stresses	Species sensitivity	Different species and life stages show different responses (-2)
	Physical presence of roads	Provide movement corridors and changes to stream habitats; Separation of streams from flood plains	Changes in species e.g. removal of native species/invasion by non-native species; Limits on exchanges between stream and riparian zone leading to potential loss of ecosystem services (-1)
	Factors influencing food availability	Affects the distribution of different aquatic species	Possible reductions in biodiversity (-1)

Detrimental risk scores of -2 have been awarded to impacts related to increased flows which can result in both changes to the receiving water habitats associated with pool riffle sequences and the increased mobilisation and transport of sediments. Changes in the ecological status of receiving water flora and fauna due to physiological stresses induced by factors such as increases in water temperature and water quality variations are also considered to present a risk score of -2. Elevation of receiving water acidity could represent a similar risk score but the toxic impact of the subsequent release of free metal ions can be ameliorated to some extent by an increased competition for cell surface adsorption sites by hydrogen ions thereby meriting a risk score of -1. Similar risk scores are awarded to the ecological impacts created by the physical presence of roads (encouraging increases in non-native species and potential losses of ecosystem services) and reductions in biodiversity due to changes in food availability. The results of the application of this systematic approach to consider the impacts of extrinsic aspects (e.g. road and site characteristics and climate conditions) will be presented in the conference presentation.

CONCLUSIONS

As a contribution to supporting the implementation of research into practice, this paper presents the results of a synthesis of the research literature undertaken to identify and score criteria (and supporting indicators) to enable the systematic identification of surface waters vulnerable to highway traffic pollution. Results of the evaluation of intrinsic factors influencing surface water vulnerability (presented above) are complimented by a similar characterisation and scoring of the factors influencing highway runoff quality during road operation (see conference presentation). Together these criteria form a framework for the systematic identification of surface waters vulnerable to highway traffic pollution. The next stage of the research will involve the integration of environmental legal requirements and constraints relating to road activities into the above assessment to develop a decision support tool to enable stakeholders to identify receiving waters vulnerable to highway traffic pollution.

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