Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3
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doi: 10.32075/17ECSMGE-2019-0249

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

An innovative framework for selecting sustainable options to reduce the risk of soil erosion and environmental pollution incidents on road construction sites

Développer un cadre innovant pour sélectionner des options durables afin de réduire les risques d'érosion des sols et de pollution environnementale

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ABSTRACT: It is widely accepted that silt pollution originating from disturbed exposed ground associated with construction sites is a contributing factor in the degradation of the water environment. A recent major highways construction project in Scotland resulted in releases of silt-rich water into ecologically sensitive watercourses which was followed by enforcement action by the Environmental Regulator. The review of current literature revealed a lack of clearly defined best-practice guidance as one of the contributing factors faced by contractors in terms of minimising the risk of pollution to the water environment during large scale construction projects. Without suitable, relevant and readily available reference material, contractors or their representatives are faced with the ongoing challenge of selecting appropriate control and treatment options targeted to site-specific characteristics. For this study, we collaborated with stakeholders involved in major highways construction projects, to identify the sources of best-practice guidance and ascertain any perceived limitations within them. The results comprise the identification of necessary key parameters required for successful and efficient runoff control and treatment of sediment contaminated water during earthwork construction. Based on the results of this study, an innovative framework is proposed which will aid in the selection of sustainable options best suited for local environmental variables and specific construction activities.

RÉSUMÉ: Il est largement admis que la pollution par le limon provenant des sols exposés perturbés, associée aux chantiers de construction, est un facteur contribuant à la dégradation du milieu aquatique. Un récent projet majeur de construction d'autoroutes en Écosse a entraîné des rejets d'eau riche en limon dans des cours d'eau écologiquement sensibles, qui ont été suivis par une action en justice de la part du régulateur de la protection de l'environnement. L'examen de la littérature actuelle a révélé un manque d'orientations clairement définies sur les pratiques optimales, l'un des facteurs contributifs auxquels les entrepreneurs sont confrontés pour

réduire au minimum le risque de pollution de l'eau lors de projets de construction à grande échelle. Sans matériel de référence approprié, pertinent et facilement disponible, les contractants ou leurs représentants sont confrontés au défi constant de sélectionner des options de contrôle et de traitement appropriées, adaptées aux caractéristiques spécifiques du site. Pour cette étude, nous avons collaboré avec les parties prenantes impliquées dans les grands projets de construction d'autoroutes afin d'identifier les sources d'orientation en matière de pratiques optimales et de déterminer les limites perçues. Les résultats comprennent l'identification des paramètres clés nécessaires pour un contrôle efficace du ruissellement et le traitement de l'eau contaminée par les sédiments pendant la construction du terrassement. Sur la base des résultats de cette étude, un cadre innovant est proposé qui facilitera la sélection des options durables les mieux adaptées aux variables environnementales locales et aux activités de construction spécifiques.

Keywords: soil erosion; environmental pollution; highway construction; drainage; slope stability

1 INTRODUCTION

During the construction of a large-scale highways project in north-east Scotland, multiple silt pollution incidents affected ecologically sensitive water courses. In response, the Scottish Environment Protection Agency (SEPA) imposed a financial penalty (£280,000) on the Construction Joint Venture (CJV), which was distributed to provide community and environmental benefits in the areas affected by the incidents. Following the pollution incidents, a concern raised by the CJV was the lack of concise guidance material which would allow them to effectively select the most appropriate control and/or treatment options to mitigate specific on-site activities and meet site-specific conditions.

The construction industry is widely accepted to be a major contributor to silt pollution arising from silt-polluted runoff affecting the water environment in Scotland (SEPA, 2018). During large-scale construction activities, large areas of bare ground are left exposed, which, during precipitation events, are at risk of water erosion and the subsequent loss of erodible material following site clearance and earthworks. Once this eroded material enters watercourses it can prove to be detrimental to ecologically sensitive species, including Freshwater Pearl Mussel (*Margaritifera margaritifera*) and Atlantic Salmon (*Salmo salar*). The need to reduce the risk of pollution during large-scale construction activities in Scotland is now at the forefront, as construction activities are not permitted to commence before a Construction Site Licence (CSL) is granted by SEPA under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (Scottish Government, 2013).

With the introduction of the CSL, Contractors are required to consider soil type and characteristics to better inform the selection of efficient temporary drainage control and treatment options for use on a site-specific basis. Given the linear nature of highways construction projects, it is possible that contractors will encounter a diverse array of ground conditions and soil types (CIRIA, 2006), which add a degree of complexity to ensuring that runoff control and treatment of polluted water are effective from the out-set of a project to reduce the risk to the water environment.

For temporary drainage control and treatment options to be sustainable, any negative environmental impacts should be minimised whilst maximising the environmental benefits provided (CIRIA, 2015; Li and Wang, 2016) whilst providing social and economic benefits (Goulden et al, 2018). To maximise environmental benefits, control and treatment options should be selected which afford the maximum

performance efficiency based on site-specific conditions.

The aim of this study is to propose an innovative framework to drive the selection of site-specific sustainable control and treatment options. The proposed framework has been developed following a critical review of literature on the subject of drainage from earthworks and stakeholder experience.

2 MATERIALS AND METHODS

2.1 Literature Review

The literature review focussed on the guidance stipulated by SEPA (2018) to critically assess the content and ascertain where limitations in the information that practitioners responsible for temporary drainage are expected to follow. This guidance includes a range of Pollution Prevention Guidelines (PPG), Guidance for Pollution Prevention (GPP) and Construction Industry Research Information Association (CIRIA) publications.

Additionally, the review was used to assess the efficiencies of commonly deployed sediment control and treatment options used on major highways construction projects.

The key parameters required for successful and efficient runoff control have been identified following a literature review and stakeholder engagement exercise. The parameters include site-specific characteristics including soil properties, local hydrology, receptors and the geomorphology of the site location. Furthermore, parameters associated with the works undertaken on site (activity type, phasing and timing of works, and the presence of materials, plant and chemical storage and batching areas) are included as these need to be considered for successful and efficient runoff control.

2.2 Stakeholder Engagement

An anonymised survey was carried out to elicit opinions from respondents directly involved in major highway construction projects in Scotland. The structured questionnaire, which, included open and closed questions was designed to capture a range of information relevant to this study, including the awareness of and usage/implementation of current best practice guidance (SEPA, 2018) when considering site-specific control and mitigation options for protecting the water environment.

Semi-formal in-depth interviews were also conducted to clarify and further explore the themes emerging from the survey. The interviewees included employees from different stakeholders involved in the planning, design, and construction processes for highway infrastructure, giving them the opportunity to state the benefits and weaknesses that exist in the current approach to ensure successful and efficient runoff control and treatment of sediment contaminated water during earthwork construction and where future improvements can be made. Thematic analysis was carried out after the interviews in order to identify the parameters for inclusion in the innovative framework.

3 RESULTS

3.1 Literature Review

The literature review has highlighted that there is a lack of concise reference material that stakeholders are expected to follow for the effective selection of temporary options to meet the minimum requirements for the CSL with source material bridging multiple industries.

The PPGs and GPPs provide good-practice and environmental regulatory guidance in Scotland, covering a range of construction-related activities, which without adopting good-practice or meeting regulatory requirements could result in environmental pollution and/or penalties for non-compliance. However, there is a lack of concise guidance that would allow designers to adequately design temporary drainage methods based on site-specific conditions. Many of the

guidance documents place an emphasis on the treatment of polluted water which, as reported in the literature, can be a costlier approach compared to the control of sediment and erosion risk as a preventative measure. Furthermore, relying on treatment of polluted water prior to discharge places added reliance on the expected performance of treatment options. However, without a full appreciation of site-specific conditions, and adequate monitoring and maintenance the actual performance of treatment options, can be poorer than expected, increasing the risk of environmental non-compliance (CIRIA, 2006).

A review into the efficiency of silt fences (Anonymous, 1997) found the trapping efficiency ranged between 30 - 86% with soil type and slope gradient affecting performance. The poor performance of silt fences has been associated with inadequate installation, monitoring and maintenance (Barrett et al, 1998; Gogo-Abite & Chopra, 2013). Sedimentation basins have been found to underperform (Kalainesan et al, 2009) when used in a highway construction setting, with 15 % removal of Total Suspended Solids (TSS) which was attributed to the re-suspension of material within the basin. Anonymous (1997b), reported that sedimentation basin TSS removal was between 18-98.7% with poor performance attributed to factors including soil particle size and erosion at the inlet. Applying compost and mulch mix as a temporary erosion control measure can reduce erosion by up to 95% (CIRIA, 2006) with the most efficient run-off and soil control delivered by applying the mulch on an untilled surface (Bakr et al, 2012).

A recurring theme within the reviewed literature (DEFRA, 2011; DEFRA, 2009; CIRIA, 2006) is the importance of developing a site-specific plan providing information on soil type, topography, land-use and water features to guide the successful selection of control and treatment options for efficient performance.

3.2 Questionnaire

Potential respondents were invited to complete the survey via the Environmental Forum hosted by Civil Engineering Contractors Association Scotland (CECA Scotland) and was promoted across their multiple social media outlets to maximise interest. Additional questionnaires were also issued to highway maintenance, environmental regulatory and within a consulting engineering organisation. Themes identified from the responses included: ensuring temporary control and treatment is best-suited to site-specific conditions and local hydrology and the activity being undertaken. Weaknesses in contract documentation, communication and on-site management have also been highlighted as areas where improvements need to be made.

3.3 Stakeholder Engagement

Stakeholders which included representatives from a client, environmental regulator and consulting engineers were asked to provide details on the current approach to managing surface water on highway construction projects. Respondents reported a need for a concise source of information that can be used to steer the design of site-specific approaches to manage surface water. Additionally, several respondents reported that improved modes of communication between all interested parties would be beneficial as this can permit the transfer of local knowledge surrounding weather and potentially problematic soil likely to be encountered during construction.

Preventing water from becoming polluted in the first place, was also highlighted as an area for improvement along with ensuring that site management practices including minimising exposed ground are practiced on site.

Several respondents commented on the need for adequate sizing of treatment options to prevent failures attributed to capacity exceedance. Additionally, it was highlighted that more emphasis is required to ascertain the foot-print for control and treatment options. This approach en-

sures contractors have adequate space within Land Made Available (LMA) to effectively control and treat water, which is a constraint on highway construction sites (CIRIA, 2006).

The identification of the likely presence of fine soil at an early stage of a project is an area that respondents felt required attention, as this will aid the identification of suitable control and treatment options tailored to mitigate the specific pollutant types.

The key factors influencing good choices of water and treatment management, which are built into the framework are: understanding site-specific characteristics and on-site construction activities as this will guide the suitable selection of control and treatment options best suited to meet specific site requirements. Continued communication with environmental regulators is also recommended as this will minimise the risk of failing to meet the requirements of the CSL.

4 DISCUSSION

Based on the findings from the study, an innovative framework is proposed that will aid in the selection of sustainable options best suited for on-site activities and local environmental variables to reduce the risk of further soil erosion and environmental pollution incidents (Figure 1).

The framework begins with the collection of site-specific data collection which will be informed by desk-based and field observations as this, in conjunction with details on the construction activity will help identify the source of pollutants and their pathways to receptors. The collection of site-specific soil and hydrological data informs the sizing of control and treatment options which will be used to assess the required land to accommodate the options. The framework then allows for the selection of sustainable control and treatment options by assessing the cost-benefit and carbon-footprint of potential options to determine the most sustainable option. Continued liaison with environmental regulators ensures that the requirements for the CSL will be met whilst the inclusion of continued monitoring and maintenance will reduce the risk of environmental pollution because of poor maintenance which reduces the performance of control and treatment options and increases the risk of environmental pollution.

The framework incorporates site-specific characteristics (soil properties, hydrology/hydrogeology, water quality and geomorphology) which have been identified following a review of literature and stakeholder engagement (CIRIA, 2006; DEFRA, 2009; DEFRA, 2011) as localised contributory factors which must be considered when designing site-specific efficient runoff control and treatment options.

The need to consider soil properties (soil texture, structure and consistency) is now more pertinent as it is a requirement to demonstrate to SEPA that there is an understanding of soil properties on site as this will determine the settlement rate of eroded material and guide the sizing of the drainage solutions (SEPA, 2018).

Understanding soil on site is not a new concept. Published literature from the agricultural (DEFRA, 2009) and forestry (Forestry Commission, 2017) sectors highlight the importance of protecting soil as a valuable resource but also to reduce the risk of soil erosion. Furthermore, protecting soil resources is a key consideration for protecting water quality (DEFRA, 2011).

Based on available data including historic borehole logs (British Geological Survey, 2018) and Ground Investigations carried out to inform the route selection and design of major highways projects, it is possible to identify soil composition. Not only does this permit the identification of earthworks that will potentially contribute to silt pollution, it also gives designers the ability to identify variations in soil properties along the extent of the linear development.

Complimenting existing available soil property data with in-situ and laboratory analysis to determine soil organic matter content, soil texture, soil structure and permeability, would permit the application of a soil loss equation such as RUSLE (Renard et al, 2007).

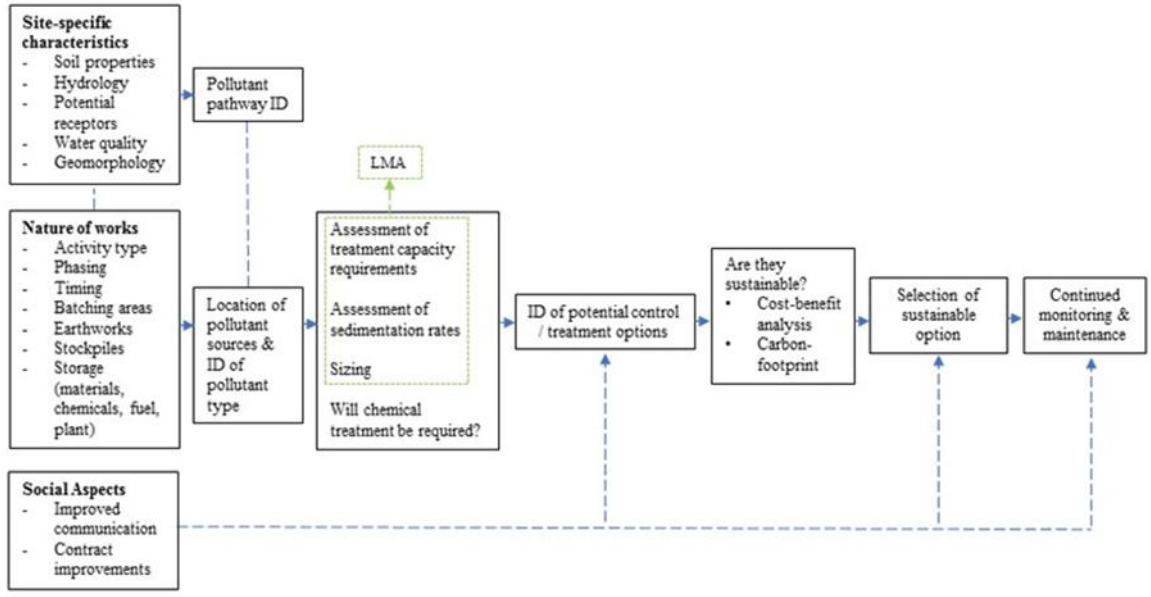


Figure 1 Innovative Framework

Incorporating soil loss estimation into the framework has multiple advantages for selecting the most appropriate control and treatment options. Calculating the estimated soil loss will allow the designer to assess the likely sediment loading, which is important for ensuring that water treatment options are sized accordingly to provide continuous effective treatment. Additional site-specific characteristics, including hydrology (precipitation event frequency and intensity) and geomorphology (slope character) are also required for RUSLE, which will provide designers with relatively accurate data for sizing requirements. Effective sizing provides designers with the ability to ensure that sufficient land provisions are included in the Compulsory Purchase Orders to accommodate surface water management options on site, which was a concern raised by stakeholders. Additionally, contractors will have an indication on the likely maintenance regime required to prevent excessive build-up of sediment in the system which can reduce treatment efficiencies and increase the risk of capacity exceedance.

Although the hydrological receptors are usually identified during the Environmental Impact Assessment (EIA) process, there are instances where features are not always identified (e.g. dry ditches, field drains). Following precipitation events, these features can convey polluted water discharging from a construction site directly to a sensitive watercourse. Additionally, unidentified features can introduce sources of pollution to site from surrounding areas, which, depending on the surrounding land use can result in Contractors being held accountable for pollution incidents which are often assumed to be a result of on-site activities by the general public, increasing the risk of Environmental Regulator's enforcement action against Contractors.

Identifying the nature of works is also fundamental for ensuring sustainable options are selected on a site-specific basis. The nature of works includes:

- Activity type;
- Phasing;
- Timing;
- Batching;
- Earthworks;
- Haul routes
- Stockpiles and material storage, and
- Plant washing.

Knowing the nature of works will allow designers to effectively select and design options which are best-suited to the specific construction activity.

When site-specific characteristics and nature of works are known, the framework follows a source-pathway-receptor approach (SEPA, 2003) which will guide the selection of the most suitable options based on site-specific conditions and pollutant sources. The availability of site-specific and nature of works information will allow designers to assess the sizing and treatment capacity requirements and sedimentation rates thus allowing designers to assess at an early stage the foot-print required to accommodate control and treatment options. This approach has added benefits by ensuring that adequate Land Made Available is included in Compulsory Purchase Orders (CPOs) to facilitate control and treatment, reducing the risk to contractors and potential programme delays if additional land is required following the publication of CPOs.

In situations where soil has a high fines content, this framework facilitates the identification of the need for chemical additions (coagulants and flocculants) required to promote sedimentation. This ability will reduce the risk of project delays and pollution of receptors whilst permission to use chemical additions is sought from the Environmental Regulator.

Potential control and treatment options can be identified once there is a clear understanding of site-specific characteristics and nature of works. To ensure that options are sustainable, cost-benefit analysis and carbon-footprint analysis can be applied to determine the most suitable sustainable option which will be assessed during further research.

The framework will be initially deployed on an upcoming major highways project in Scotland. In-situ and laboratory monitoring and parameter analysis will be carried out to further inform the framework parameterisation and application. As the framework has not yet been applied, it is anticipated that subsequent improvements will be made after weaknesses in the framework become apparent following initial deployment.

5 CONCLUSIONS

An innovative framework has been developed to select sustainable options best suited for on-site activities and local environmental variables to reduce the risk of further soil erosion and environmental pollution incidents. The inclusion of key parameters focused on site-specific characteristics and the nature of works ensures that sustainable options are selected which are best-suited to the local environment, which can be variable along the extent of liner construction projects.

The robustness of the framework will be assessed at an upcoming highways construction project, which will provide an opportunity to monitor and observe construction activities in a ‘live’ setting. Refinements will then be made before re-applying the framework.

6 ACKNOWLEDGEMENTS

The authors wish to thank the generous support of KTP Innovate UK grant (KTP010752) and Jacobs UK Ltd and Dr Meldrum at Glasgow Caledonian University for their continued support and assistance.

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