D4.1 Literature review on treatment of runoff from highway construction sites

CEDR PROPER PROJECT

Lian Lundy, Mike Revitt and Bryan Ellis
Middlesex University, UK

Conference of European Directors of Roads (CEDR)

Executive summary

This report is the first deliverable of WP4 (Sustainable assessment of measures and treatment systems for highway runoffs during construction work) of the CEDR PROPER project. This deliverable compliments PROPER Deliverable 3.1 (A review of blue-green treatment solutions) which focuses on the management of surface runoff during the operational phase of highways. In addition to addressing treatment options, this report describes the sources of pollution within a highway construction site, the pathways to receiving water bodies and the subsequent environmental impacts. It identifies suspended solids as the key pollutant of concern within highway construction surface runoff, both directly (as a pollutant in its own right) and indirectly (as a carrier of a range of other pollutant types), which can lead to a range of on-site and off-site impacts. The challenges posed by and the opportunities for the management of surface runoff within a space- and time-limited linear environment are addressed. With little, if any, data available on the performance of sustainable treatment technologies to mitigate the impact of highway construction runoff within the peer-review literature, this report draws together information from the grey literature and collates information from various sets of national guidelines on treatment approaches to mitigating surface runoff from a variety of linear construction projects. The report concludes that, whilst there appears to be a high level of awareness on the need for measures to manage highway construction runoff, at the current time there is insufficient, data freely available to inform treatment technology selection on the basis of pollutant removal. The need to urgently address this identified lack of data on an issue pertaining to the sustainability of national and European transport infrastructure strategies is highlighted.

Acknowledgements

We gratefully acknowledge the financial and technical support of the CEDR transnational road programme call 2016: Environmentally Sustainable Roads: Surface- and Groundwater Quality (funded by Austria, Finland, Germany, Ireland, Netherlands, Norway and Sweden) and the CEDR Programme Advisory Board.

Table of contents

Table of tables

1. Introduction

Construction projects inevitably alter their environment. The construction of highways has been identified as one of the most widespread forms of landscape modification over the last century, impacting on surface and subsurface soil physical conditions (Trombulak and Frissell, 2000; Chen et al., 2009). Construction sites can be a source of pollution both as a result of the associated activities (e.g. vegetation clearance) as well by virtue of their presence which, for example, requires the use and storage of fuel and building materials. Sources of pollution on construction sites include disturbed soils (from land clearing activities and earth works), runoff from exposed ground, materials stockpiled on-site and highway-related haulage routes, the washing of plant equipment, fuel and chemical storage areas, refuelling sites and the leaking from and/or damage of the above (Dong et al., 2012; SEPA, 2009). Whilst at a catchment scale, the land take associated with any particular project may be small and the construction phase relatively short lived in comparison to the life span of the permanent works being built, the impact of construction activities can be disproportionately large (Barret et al., 1995). For example, in the UK, construction sites are responsible for more water pollution incidents than any other activity sector (CIRIA, 2006). Levels of erosion associated with construction activities have been reported to be up to 100 times greater than that associated with agricultural land (Brady and Weil, 1999), particularly during the initial 'rough grading phase' when constructions sites are cleared and levelled (Line et al., 2002). SEPA (2009) identify the risk from construction sites to receiving waters as 'very high', with the risks associated with the construction of linear projects (i.e. highways, tunnels and bridges) receiving particular attention due to the number of different environments and catchments they may pass through (including crossing water bodies), cumulative impacts (several discharges to the same water body) and the extended distances which require management. Whilst these effects are usually temporary, the elevated levels of pollution (particularly suspended solids) can reduce the diversity of fauna in the impact area as a function of the direct smothering of fish/macroinvertebrates or their migration as a result of drift (Barret et al., 1995; Trombulak and Frissell, 2000). Several post-construction studies have reported a return to pre-construction levels of species abundance/diversity approximately one year after construction project completion (Barret et al., 1995). However, other studies have identified longer recovery time periods of decades (Hindar and Nordstrom, 2015; McNeill, 1996). The economic burden (often to tax payers) of clearing construction erosion debris from highways, culverts and streams has also been highlighted (USDA NRCS, 2000).

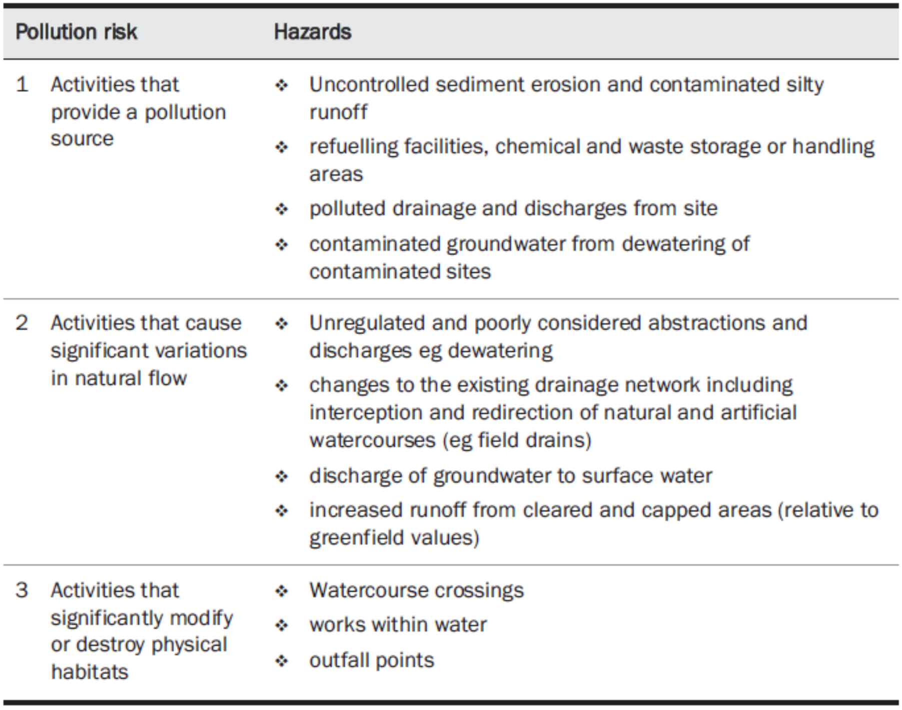
The quality of surface runoff (in terms of both pollutant composition and loads) varies in relation to land use activities (Lundy et al., 2011). As activities undertaken during the construction of highways differ notably from those undertaken during routine highway operation, the quality of runoff derived during highway construction is also expected to differ significantly between these two phases i.e. highway construction and operation (Kayhanian et al., 2001). However, whilst there is a considerable published literature on the quality of (and options to mitigate runoff from) construction sites *per se* (i.e. a generic category covering the development and installation of a range of infrastructure types), specific studies addressing the mitigation of runoff from highway construction sites are scarce (Barret et al., 1995; Bruen et al., 2006; Chen et al., 2009). Where highway construction runoff studies have been undertaken and reported, these typically refer to the construction of unpaved roads (Dong et al., 2012). However, it is noted that the construction of many roads require development of an environmental impact study (EIS) which sets out a series of measures and recommendations to mitigate environmental impacts. For example, the Environmental Impact Assessment Directive (85/337/EEC) applies to all motorways and express roads (see its Annex I) considered to have significant effects on the environment. Therefore, it is likely there is considerable expertise on highway construction runoff mitigation within an EIA context but that this information is held ‘in house’ and therefore not currently accessible. This current PROPER review hence draws on data and knowledge from studies on the treatment of runoff from a variety of construction projects and considers their relevance within the specific context of the need for and opportunities to treat highway construction runoff. It also directly builds on the findings of several earlier PROPER Deliverables including those pertaining to the impact of highway runoff on receiving waters (e.g. PROPER D2.1, 2.2 and 2.4) and highway runoff treatment using SUDS/BMPs (PROPER D3.1). To avoid repetition the reader is referred to these documents to supplement the current report which includes new information on highway construction runoff behaviour/treatment technologies not addressed

2. Highway construction activities as sources of pollution to receiving waters

2.1 Linear construction site characteristics

The construction of a highway is typically a large scale project which may span several river basins with a variety of geologies, habitats and topographies. In their guidance to the UK construction sector, the Construction Industry and Research Information Association (unexpect) identify highway construction as part of a broader ‘linear construction’ category which poses similar challenges to those associated with the construction of, for example, railway lines, cables and pipelines. CIRIA (2006) have developed specific UK guidance for the control of water pollution from such linear construction sites, including the development of classification systems for linear construction activities (and associated hazards) that may pose a risk to surface waters (see Table 1) and groundwaters (see Table 2) respectively.

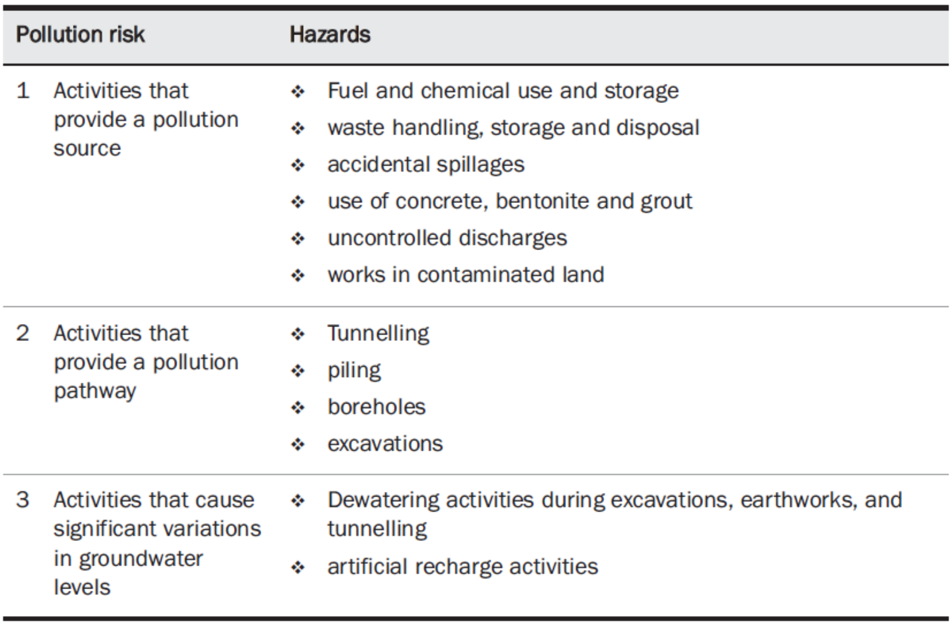
Table 1 Construction activities that pose a risk to surface water (CIRIA, 2006)



Pollution risk	Hazards
1 Activities that provide a pollution source	❖ Uncontrolled sediment erosion and contaminated silty runoff ❖ refuelling facilities, chemical and waste storage or handling areas ❖ polluted drainage and discharges from site ❖ contaminated groundwater from dewatering of contaminated sites
2 Activities that cause significant variations in natural flow	❖ Unregulated and poorly considered abstractions and discharges eg dewatering ❖ changes to the existing drainage network including interception and redirection of natural and artificial watercourses (eg field drains) ❖ discharge of groundwater to surface water ❖ increased runoff from cleared and capped areas (relative to greenfield values)
3 Activities that significantly modify or destroy physical habitats	❖ Watercourse crossings ❖ works within water ❖ outfall points

Groundwater is generally considered more vulnerable to pollution than surface water as particulates (that may otherwise adsorb pollutants) are removed on infiltration, and the costs of mitigating groundwater pollution are reported to exceed those associated with prevention by a factor of 10. Contamination of groundwater is a major concern in karstic areas where highway construction activities may expose openings within the rock allowing the rapid transfer of sediments and associated pollutants into underlying groundwater bodies (CEDR PROPER D2.1 and D2.2).

Table 2 Construction activities that pose a risk to groundwaters (CIRIA, 2006)



Pollution risk	Hazards
1 Activities that provide a pollution source	❖ Fuel and chemical use and storage ❖ waste handling, storage and disposal ❖ accidental spillages ❖ use of concrete, bentonite and grout ❖ uncontrolled discharges ❖ works in contaminated land
2 Activities that provide a pollution pathway	❖ Tunnelling ❖ piling ❖ boreholes ❖ excavations
3 Activities that cause significant variations in groundwater levels	❖ Dewatering activities during excavations, earthworks, and tunnelling ❖ artificial recharge activities

As well as surface water runoff generated as a result of rainfall, other sources of water on construction sites can include dewatering from excavations, washing operations, road sweepers, cooling water used during drilling and works involving cofferdams. Types of pollutants reported as discharging from highway construction sites can include suspended solids (mobilised soils, silts and sediments), hydrocarbons (mobilised from contaminated land or leaks/spills from fuel storage and use), metals (from contaminated land / traffic), salts (use of winter de-icing materials) and other chemical substances (leaching from highway construction materials) (SEPA, 2009). A typical recommendation from EIS, applicable to countries with seasonal variations in rainfall, is to concentrate the most impacting activities during the dry season, in order to minimise erosion and transport of solids to surface water. Highway construction runoff can mobilise a range of organic and inorganic pollutants used in construction activities. The concentrations of these pollutants is dependent on several factors including the types of work being carried out as well as the meteorological conditions. A key pollutant within runoff from all types of construction activities is suspended solids (Han and Bai, 2009), with research from Lohnes and Coree (2002) estimating that – by mass - 25% of mobilised particles have a diameter <5µm. Whilst studies on the mass of soils mobilized by runoff during highway construction activities is limited, a study by Dong et al. (2012) reported that volume of construction spoils (often used a surrogate for potential soil losses in a construction context) ranged from 2-5 million m^3 per 100 kilometres of highway constructed in China. These data are site specific, since they depend on the geological context, soil characteristics, surrounding land use, and topography, among others.

Whilst various researchers (e.g. Kalainesan et al., 2009; USDA NRCS, 2000) recommend the use of the Revised Universal Soil Loss Equation (RUSLE) to predict soil losses from highway construction sites, Dong et al. (2012) suggest that, due to differences in factors affecting soil erosion by environment type, the use of process-based models e.g. SIBERIA or empirical models e.g. RUSLE to predict erosion in farmland environments, require re-calibrating to enable their use in predicting soil loss from highway construction sites. Whilst there are no quantitative standards for the concentration of total suspended solids (TSS) discharging from highway construction sites, the US EPA's National Pollution Discharge Elimination System (NPDES; regulates discharge of pollutants to receiving waters in the US) sets the following standards for TSS in stormwater discharging from industrial sites (see Table 3).

Table 3 Effluent TSS limits (mg/L) for stormwater discharge from industrial sites

Instantaneous maximum	Daily Maximum	Weekly average	Monthly average	Annual average
60-100	45-100	45	30	50

Data on the concentration of sediments discharging from a highway construction site is scarce and - where available – is reported in a variety of formats which makes direct comparisons between studies difficult. Table 4 (below) gives an overview of the highway construction runoff data available in the literature.

Table 4. Overview of studies reporting data on the levels of sediments mobilised by highway construction runoff

Parameter	Concentration	Authors	Country
Suspended solids	1390 mg/l (returned to pre-construction levels of <5mg/l after construction)	Barton (1977)	In stream (Canada)
	60 and 130 mg/L (from a preconstruction maximum of 30mg/l)	Embler and Fletcher (1983)	In stream (USA)
Sediment yield	Increased by 2 orders of magnitude	Hainly (1980)	USA
	x20 times the sediment during the 2 month highway construction phase than during the previous 12-months	Duck 1985	UK
Suspended solids	x450 the background level of TSS recorded	SEPA (2001)	UK
	Maximum concentration: 91-1442 mg/l	Kalainesan et al., 2009	Data from 4 sites, USA
Total solids	Six-fold increase in total solids leaving the site during construction.	Cleveland and Fashokun (2006)	USA
Total suspended solids	Higher concentrations reported D/S of highway construction site in comparison to U/S	Chen et al., (2009)	USA
Suspended solids	No significant difference between U/S and D/S sites during highway construction (except when control measures failed).	Huang, and Ehrlich, (2003)	USA
	Catchment 1: 326-20,340 mg/l	McNeill (1996)	Suspended solids in highway construction site discharges (UK)
	Catchment 2: 103 – 46,800 mg/l		
	Catchment 1: U/S of construction site: 2-8 mg/l D/S of construction site: 35 – 1854 mg/l		Suspended solids in receiving waters U/S and D/S of construction sites (UK)
	Catchment 2: U/S of construction site: 4-11 mg/l; D/S of construction site: 350 – 3660 mg/l		

Key: U/S = upstream; D/S = downstream

Whilst it is not possible to draw specific conclusions from this data set (low number of studies; variety of formats) all (bar one) studies report that highway construction activities generated a notable increase in the levels of suspended solids discharging from a site in comparison to respective pre-construction levels.

2.2 Unexpected ground conditions

With regard to sources of pollution, unknown ground conditions can be a major source of both unanticipated construction costs and environmental impacts. For example, a study by Yew and Makowski (1989) reported a case where a highway construction project led to the exposure of pyritic shale materials which, in turn, resulted in the leaching of sulphuric acid into nearby watercourses and fish kills. Analysis of receiving watercourse pH values reported pH levels of 4.0-4.4 which, in combination with naturally low levels of alkalinity, enhanced the bioavailability of metals. More recently Hindar and Norstram (2015) reported on the impact of the construction of a major road in Norway which cut through sulphur-bearing rocks. Negative impacts are also reported in relation to sulphate clays which occur in countries adjacent to the Baltic Sea, leading to the development of guidelines for the identification, risk management and treatment of sulphate soils in transport construction projects by the Finnish Transport Agency (Vertanen, 2016). Exposure of sulphur-rich bed rock to air and moisture resulted in their oxidation and the production of sulphuric acid which discharged into a nearby water course. Whilst the use of shell sand and limestone gravel mitigated reduced pH levels at one rock waste deposit site, insufficient amounts of these materials were added at two further sites. The pH of resulting effluents ranged from pH 4.0-4.6 and concentrations of Al (particularly toxic to fish) increased by over a factor of 10. Generically referred to as acid rock drainage (ARD), this phenomenon is well understood within the mining industry with a few examples of similar issues occurring in relation to highway construction projects having been reported (e.g. Hammarstrom et al., 2003). Similar concerns have also been expressed over the potential for uranium to be released from uranium-rich shale bed rock as a result of a tunnel construction project in Norway where such shales naturally occur (Telmers, 2013), with initial laboratory leaching tests indicating that up to 36% of total uranium may be mobilised under certain low pH conditions. Knowledge of the impact of the exposure of such suplphr- rich materials have led to recommendations that sulphide hazard analysis (presumable to check for the occurrence of pyritic shales) should be undertaken as part of the pre-design phase of all highway construction projects (Orndorff and Daniels, 2004). Another natural phenomenon to consider during construction works is the occurrence of naturally elevated arsenic concentrations in bedrock and/or soil. More common in Central and Southern European countries, the distribution and concentration of arsenic within European subsoils has been mapped (see Salminen et al., 2005). Whilst not specific to highway construction projects, guidelines for the sustainable use and reuse of aggregate resources in areas with elevated arsenic concentrations have been developed as part of an EU LIFE project (ASROCKs, undated).

2.3 On-site impacts

Depending on the climate, season, topography, soil composition and type of construction project, environmental impacts can occur both on- and off- site. On-site impacts can include elevated levels of erosion (due to the exposure of soil surfaces, construction of earthworks and/or generation of spoil piles), hydrocarbons, substances associated with building materials and other chemicals (from routine construction activities – including the use of explosives in rock blasting / tunnelling – Fsources or accidental spills), and their subsequent mobilisation by wind, gravity and/or rain (SEPA 2009; Johnson, 2003). Exposure of the top layer of soil as a result of land clearing can lead to changes of *in situ* soil composition and structure, such as the loss of organic matter and nutrients which, in turn, can increase soil compaction and reduce infiltration capacity (USDA NRCS, 2000). Increased on-site soil compaction can also lead to increases in the volume of surface runoff generated at a site-scale (a function of reduced infiltration capacity). Pollution from fuels, building materials / other chemicals stored and used on site may also have an on-site negative impact on receiving water systems if mobilised and infiltrated into underlying groundwaters by, for example, rainfall or wash waters. Specific impacts will vary as a function of the materials / chemicals present on-site (see PROPER Deliverables 2.1, 2.2 and 2.4). There is a particular risk of pollution of water bodies by construction activities that involve crossing a water course or water body, or take place above a groundwater body. This is often the case with highway construction projects which, due to their length, are likely to cross several surface and subsurface water bodies. Whilst discharges to surface water bodies are often visible (and therefore traceable and site managers subject to prosecution), the pollution of groundwater is less readily identified (CIRIA, 2006). The types of pollutants arriving at groundwater bodies may also differ, with surface waters receiving pollution dominated by the particulate associated fraction. In contrast, overlying soils may act to filter out particles infiltrating towards groundwater, with the result that the pollution load is dominated by soluble pollutants such as chlorides. Both surface water and groundwater bodies can demonstrate hydrologic seasonality e.g. seasonal fluctuations in groundwater depth and low summer flows in surface water which can also have an impact on receiving water vulnerability (see PROPER Deliverable 2.2).

2.4 Off-site impacts

Off-site impacts include the discharge of exposed soils (once mobilised by runoff, soils are referred to as sediments) and associated pollutants deposited on-site as result of construction activities to receiving water bodies. Sediments are commonly identified as one of the main sources of environmental impacts associated with any given construction project (CWS, 2008; CIRIA, 2006; Johnson, 2003; Bruen et al., 2006; USDA NRCS, 2000; Barret et al., 1995). Impacts can be both direct (e.g. increased levels of turbidity, reduced penetration of sunlight, damage of fish gills and blanketing of basal substrates reducing habitat quality and smothering fauna) as well as indirect (sediments acting as carriers for hydrocarbons, metals and microbial pollutants which – as a results of changes in physicochemical conditions - can be released into solution with associated impacts on receiving water ecologies) (see PROPER Deliverables 2.1 and 2.4). A study by McNeill (1996) of the impacts of six highway construction sites in Scotland (the UK) reported the uncontrolled discharge of runoff led to the development of sediment layers in receiving waters varying from 20 mm – 300 mm in depth. It was reported that such layers where unlikely to be displaced (even by flood flows) and instead become compacted, forming a crust which can permanently alter the habitat – and thus ecology – of the receiving water. Particular attention was drawn to the inability of salmonids to penetrate such crusts in order to lay eggs, and subsequent loss of spawning grounds. A study of the impact of three highway construction projects on receiving water quality reported that all short-term effects were a result of soil erosion mobilised by runoff (Barret et al., 1995). Further impacts on receiving water habitats may occur as result of the use of temporary barriers within construction works e.g. if a river is temporarily halted at fish migratory time then populations could be prevented from reaching spawning grounds. Likewise, movement of construction equipment from site to site may also provide a pathway for the spread of invasive species (SEPA, 2009).

3. Approaches for the management of highway construction runoff

Highway construction sites may not always be amenable to the use of conventional treatment systems as they can generate large volumes of water which – due to the linear nature of the site – can be difficult to divert within or around a site. In all construction projects, a key priority is to manage surface water runoff (which erodes exposed areas) leaving the site. Sediment (defined here to include soils, mud, clay, silt and sand etc.), is widely identified as the single main pollutant directly generated by construction site activities (CIRIA, 2006; USDA NRCS, 2000). Unless mitigation steps are taken, highly accelerated levels of erosion are often the most visible and detrimental factor impacting on environmental quality of any given construction project (USDA NRCS, 2000). As well as having direct effects on receiving water ecologies (see PROPER D2.1 for a comprehensive review), sediment particles also act as carrier for a range of pollutants (see Section 2.4).

In reducing sediment loads mobilised by runoff, there are two key approaches: firstly, prevention i.e. prevent runoff flowing across exposed soils and secondly, treatment (detention/retention of runoff to allow mobilised sediment to settle out). Erosion prevention (e.g. minimisation of exposed areas and the prompt establishment of vegetation) is considered to be more effective and cheaper than sediment control and its incorporation within the early stages of any programme of work is recommended (CWS, 2008). Where runoff controls (e.g. silt fences, retention ponds etc.) are likely to be required, these should be installed before site clearance commences. Proactively reducing the risk of erosion / early installation of sediment controls offers a range of benefits, ranging from reduced land-take for settlement ponds to the potential for quicker land reinstatement / reduced compensation complaints for heavily damaged land from adjoining landowners. Such approaches underpin the three principles identified by SEPA (2009) in their guidance to minimise the volume of contaminated run-off being generated from temporary construction works:

- divert (clean water away from sites),
- minimise erosion (from exposed soils)
- prevent (contaminated runoff from entering water courses)

Whilst a range of factors will influence the selection of erosion and sediment controls, site conditions (including the location of specific construction activities) are the most important drivers. Likewise, the performance of any treatment measures are a function of the rainfall event (intensity and duration), site characteristics (amount of cleared/exposed areas), soil type (particle size and cohesive characteristics) as well as the types of control measure and their operation and maintenance regime. Access and haulage roads in particular may generate significant quantities of sediment which can be transported in surface runoff flows. Linked to this, vehicle wash-down on leaving a construction site is a common and important mitigation strategy which is almost mandatory on all highway construction sites. Whilst not providing much receiving waterbody protection, the practice does help to minimise local environmental concerns.

3.1 Highway construction erosion control measures

The following sections describe a range of commonly used temporary on-site control approaches for reducing sediment loads mobilised by highway construction runoff.

Utilise existing vegetation

In contrast to new planting, existing vegetation may have extensive root systems which stabilise soils and prevent soil dry out, further reducing the amount of soil mobilised by runoff (CWS, 2008). CIRIA (2006) recommend leaving mature vegetation around the perimeter of the site and along water courses (at least 5 m wide) to act as a buffer against sediments leaving the site/entering a water course. Also recommended – particularly on linear construction projects – is that the work is undertaken in phases, with ground cleared immediately prior to construction/its recovering. SEPA (2009) recommend leaving vegetative buffer strips at least 5–10 m wide along site boundaries/water courses to act as sediment filters.

Establish new vegetation

Promptly seed/plant exposed areas with local species following completion of construction areas. Johnson (2003) states that such activities can reduce erosion by 90%. If outside the growing season, alternative slope covering materials such as woodchips, mulch, geotextiles or hydraulic binders can be used. Irrigation of vegetation should be considered to maintain plant health, with the use of fertilisers avoided.

Diversion drains

These are simple ditches for transporting water to a desired location. They are used either to direct off-site runoff around a construction area or to prevent on-site runoff leaving a site untreated, and should be lined with non-erodible materials such as turf or geotextiles (SEPA, 2009). Diversion drains may also be used as a ‘containment measure’ around areas of contaminated soils or other materials. The outflow of the drainage ditch should be directed to a settlement pond or level spreader (a vegetated (stabilised) area where a concentrated flow is converted to a sheet flow).

Bunds

These are temporary walls/embankments made from straw bales/geotextiles to prevent runoff crossing areas of exposed soils and /or to prevent contaminated runoff leaving a site untreated.

Check dams

These are small temporary dams installed across a drainage ditch or swale. The primary aim is to reduce runoff flow velocity and create a small temporary pool behind each dam to encourage sedimentation. Check dams can be constructed using a range of materials including wood, straw bales or rock-filled gabions. Check dams require regular inspection and it is recommended that accumulated sediments are removed when they reach 50% of the check dam height.

Silt fence

Typically consisting of a geotextile or a row of straw bales, a silt fence is installed at right angles to a sheet flow to filter out larger sediments, with removal efficiency decreasing with decreasing particle size. For example, performance data reported in the CIRIA (2006) guidance states anticipated removal of 80-90% for sands, reducing to 0-20% for silt-clay-loam. Silt fences require firm anchorage as if not properly secured (e.g. with stakes) they provide only minimal sedimentation control.

Sustainable drainage systems (SUDS)

A range of green infrastructure systems (e.g. swales, filter drains, retention ponds). The use of SUDS for the mitigation of runoff during highway construction (when sediment loads can be many times in excess of those transported during routine highway operation) needs to be carefully considered. Whilst a range of SUDS have been successfully used as temporary treatment systems, regular maintenance is required to remove accumulated sediments. This is essential if the intention is that construction runoff SUDS are to become permanent systems treating runoff from the same highway during its operational phase (SEPA, 2009). If SUDS are not intended to be part of the construction runoff treatment system, they should be installed in the final construction phase to reduce the opportunities for elevated sediment loads clogging e.g. infiltration systems (Johnson, 2003).

3.2 Highway construction runoff treatment systems

Treating the runoff from linear construction sites such as highways can be challenging, as large runoff volumes are generated with limited space to divert flows and/or install treatment systems. Hence the use of onsite erosion control measures should be prioritised. However, if following their use, treatment is still required, there are several possible treatment approaches for removing sediments (and associated pollutants) from highway construction site runoff. The US Federal Highways Administration (FHA) identifies the following principles when considering treatment measures for reducing loads of suspended solids in surface runoff (Johnson, 2003) as follows:

- reduce water velocity e.g. front-end sedimentation ponds/silt traps/ gross pollutant traps etc
- divide runoff into smaller volumes e.g. use of multiple cellular systems
- promote infiltration
- provide mechanical or structural retention methods

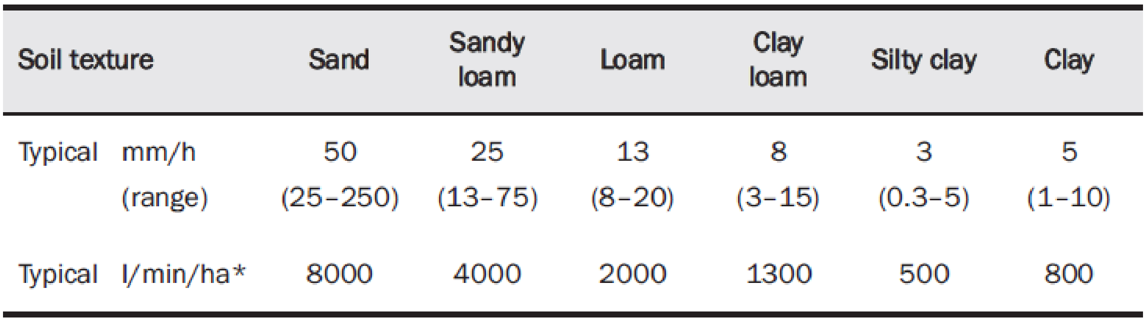
The optimal type of treatment will depend on local conditions e.g. volume of water generated, types of pollutants (particularly suspended solids load) and the amount of space available to install a system (SEPA, 2009). Depending on the site circumstances, one or more systems may be required in combination.

Passive infiltration

Depending on the volume and quality of surface runoff generated and local soil conditions, runoff can be directed to a grassed area and allowed to infiltrate into the ground. This approach is only an option for treatment and disposal if:

- a short-term solution for relatively low volumes is required
- transported sediments are not a carrier of other biological or chemical pollutants
- the infiltration characteristics of local soils match required needs (see Table 5)
- groundwater is not shallow / of a sensitive status
- land drains are sealed/diverted

Table 5. Typical infiltration rates for various soils (CIRIA, 2006)



Soil texture		Sand	Sandy loam	Loam	Clay loam	Silty clay	Clay
Typical	mm/h (range)	50 (25–250)	25 (13–75)	13 (8–20)	8 (3–15)	3 (0.3–5)	5 (1–10)
Typical	l/min/ha*	8000	4000	2000	1300	500	800

Active infiltration

If there is a need to treat larger volumes or manage runoff over an extended period of time, installation of a soakaway or an infiltration basin should be considered. Soakaways are rock-filled underground chambers or voids which enable surface runoff to infiltrate into the ground via the base and sides of the system (PROPER D3.2). Infiltration basins are typically larger storage systems without an outlet to a watercourse, effectively detaining surface runoff above ground until it infiltrates into the ground through vegetated or rock basal substrates (PROPER D3.2). Again the infiltration characteristics of local soils are of paramount consideration (see Table 5) when identifying if this treatment option is feasible, together with the presence of land drains (which can channel surface runoff directly to a receiving water course). Robust planning is required to ensure the basin is appropriately sized (see e.g. CIRIA, 2006 for design details)

Settlement pond

These are ponds designed to promote the settlement of suspended solids under quiescent conditions and are an effective, low maintenance and relatively simple treatment technology to install. Surface runoff is typically channelled to a pond where it is retained for treatment prior to discharge to a receiving watercourse. It is more or less mandatory in many EU Member States and internationally for highway construction companies to install lined retention ponds to capture surface runoff. This requirement is considered to be a necessary control for particulate settlement and in most cases must be installed prior to commencement of any construction activity. Other management approaches e.g. silt fences, vegetation etc. are considered as being supplementary measures. A disadvantage of the technology is the required space i.e. depending on volumes of surface runoff generated, it may not be possible to fit a settlement pond of the required capacity within the site confines. In its design guidance for linear projects, CIRIA (2006) recommend that, given the temporary nature of construction works, settlement ponds be designed to capture the 1 in 10 year event, with an emergency spillway in case of larger events. However, there is an increasing realisation that a 1:10 year event design is likely to be exceeded within a 2-3 year constructional period. This has led to use of a 1:100 year design for construction site retention ponds in Australia and 1: 50 year design for treatment systems in Canada. Settlement ponds are not intended to act as infiltration systems and therefore, depending on local soil types, the pond may require lining e.g. with bentonite or geotextile. Factors informing the required detention time (the length of time water must be held to enable particulate settlement to occur) is a function of particle size and density, water disturbance, depth and temperature (Masters-Williams et al, 2001). As a rule of thumb, a retention time of 2-3 hours is recommended for most particulate materials, but finer particulate matter may require several days. Sedimentation efficiency generally increases with increasing pond surface area. However, very fine particulate material (e.g. with a particle diameter <2µm such as clays) may never settle out without the addition of a flocculation agent. Alternatively a different treatment technology may be required e.g. use of a dynamic separator. In a study of the performance of four sedimentation basins to mitigate highway construction runoff loads, Kalainesan et al. (2009) reported low TSS removal efficiencies of 15-20% concluding that the basins were poorly designed. Quite frequently regulatory authorities specify a follow-on tertiary polishing treatment or further cellular settlement treatment in addition to front-end sedimentation.

Settlement tank

These operate on a similar basis to settlement ponds, but are smaller, portable systems which promote the settlement of suspended solids. Tanks often include a series of baffles to control inflow turbulence and hence promote sedimentation. As with all systems, design capacity and inflow pump rates (where applicable) need to be carefully considered e.g. if in-tank turbulence is not controlled then the settlement tank will not operate efficiently. Settlement tanks need to be maintained on a daily basis and sediments removed on a regular basis to maintain performance.

Sustainable drainage systems (SUDS)

As noted in Section 3.1, the term SUDS refers to a wide range of green infrastructure systems (e.g. filter strips, filter drains, and detention basins; see Table 6).

Table 6. Descriptions of different sustainable drainage systems (Scholes et al., 2007)

System type	Description
Filter drains	Gravelled trench systems where stormwater can drain through the gravel to be collected in a pipe; unplanted but host to algal growth.
Porous asphalt	Open graded powdered/crushed stone with binder: high void ratio; no geotextile liner present (may or may not include subsurface storage)
Porous paving	Continuous surface with high void content, porous blocks or solid blocks with adjoining infiltration spaces; an associated reservoir structure provides storage; no geotextile liner present; host to algal growth.
Filter strip	Grassed or vegetated strip of ground that stormwater flows across.
Swales	Vegetated broad shallow channels for transporting stormwater.
Soakaways	Underground chamber or rock-filled volume: stormwater soaks into the ground via the base and sides; unplanted but host to algal growth.
Infiltration trench	A long thin soakaway; unplanted but host to algal growth.
Infiltration basin	Detains stormwater above ground which then soaks away into the ground through a vegetated or rock base.
Retention ponds	Contain some water at all times and retains incoming stormwater; vegetated margins.
Detention basins	Dry most of the time and able to store rainwater during wet conditions; often possess a grassed surface e.g. settlement ponds
Extended detention basin	Dry most of the time and able to store rainwater during wet conditions for up to 24 hours; grassed surface and may have a low basal marsh.
Settlement pond	Pond designed for the settlement of suspended solids
Constructed wetlands	Vegetated system with extended retention time

In contrast to piped drainage systems (which remove runoff as quickly as possible from a location) SUDS aim to mitigate runoff as close as possible to its source using infiltration and, where this is not possible, detention until the rain event has passed. Whilst settlement ponds (see above) are a type of SUDS, they are commonly identified separately to other types of SUDS in guidance documents (e.g. CIRIA, 2006) and hence the same approach has been used here.

Performance data

Kayhanian et al., (2001) reports the results of a study monitoring the quality of runoff from 15 highway construction sites. A range of types of highway construction sites (e.g. new constructions, highway widening schemes etc.) were included in the 15 sites and samples were collected downstream of any treatment systems which included, for example, silt fences, vegetated berms and straw bales. Whilst the type of SUDS are identified per site, the results are presented as a single data set and therefore it is not possible to draw any conclusions regarding the level of treatment offered by a particular SUDS. However, the study concluded that, following SUDS treatment, concentrations of a range of pollutants in highway construction site runoff were less than that those typically identified for operational highway runoff. The exceptions to this conclusion were chromium, nickel, phosphorus and TSS. While the source of the elevated metals was not clear, mean concentrations of TSS in highway construction runoff (499mg/l) were associated with exposed grounds and exceeded mean concentrations reported for operational highway runoff by a factor of 3 (160mg/l). Similarly, a study of the performance of a range of highway construction runoff treatment devices (identified to include detention basins, gross pollutant traps and sand filters) was reported to reduce transported metal loads transported by 80%, but removal efficiency per system type was not reported (Ball et al., 2000). In their impact assessment of highway drainage on surface water quality, Bruen et al. (2006) recommend the early installation filter drains on highway construction sites to treat surface runoff prior to discharge, but do not report any specific highway construction runoff performance data. The same study reports the common use of retention ponds, silt traps and open drains during highway construction projects in Ireland to prevent the pollution of receiving waters. Their role is to ensure that construction activities do not increase the suspended solids content of receiving waters but, again, not specific performance data is reported (Bruen et al., 2006)

4. Conclusions

The construction of highways often involves the manipulation of extended corridors of land which typically pass thorough a number of different environments / geologies/catchments including the need to cross water bodies and excavate in depth, potentially affecting aquifers . Managing surface runoff generated during highway construction can hence be extremely challenging, with the clearing of land exposing soils which are readily mobilised by rainfall. Thus there is increasing opportunity for multiple discharge points to local water courses (leading to cumulative impacts). There is also often limited availability of space /opportunity within a linear construction site to divert / treat surface runoff prior to discharge. Whilst the time period for construction may represent only a fraction of the total life span of a highway and its catchment footprint may be relatively low, the impact of runoff derived during this phase can be disproportionally large. The key pollutant of concern in highway construction is suspended solids, with the range of reported impacts varying from fish kills to reduced macroinvertebrate counts. Whilst the effects of highway construction runoff are usually temporary (studies show a return to pre-construction SS levels one year after construction is completed), more serious and long-term effects have been reported when highway construction projects have cut through sulphur-rich shales. Exposure of such rocks to water and moisture generates sulphuric acid which, on discharge to receiving waters, can lead to major fish kills and habitat recovery periods of decades.

Guidelines are available in several European Member States outlining the sources of construction site pollution, the pathways via which they can impact on surface water bodies and approaches to mitigate these impacts (see PROPER D4.2). However, empirical research on the role of highway construction sites as pollutant sources, the loads generated and the performance of treatment technologies to mitigate potential impacts, has received scarce attention in the peer-review research literature. Within the grey literature (i.e. national guidelines), approaches to managing highway construction sites are broadly divided into two categories: firstly, the use of onsite erosion control measures (e.g. existing / new vegetation, silt fences and check dams). Secondly, if following the use of erosion controls treatment is still required, several possible treatment approaches to remove sediments (and associated pollutants) exist. These include settlement ponds, different approaches to active and /or passive infiltration systems, as well as the opportunities to use a range of sustainable drainage systems. However, irrespective of the treatment approach identified, empirical data on pollutant removal performance is rarely – if ever – provided. Hence, whilst the need to address surface runoff derived from highway construction sites appears to be well recognised (using the amount of guidance for its control as an indicator), it is a relatively poorly characterised type of surface runoff in comparison to the knowledge base associated with the quality of runoff from other land use activities. Further, the limited database on the performance of treatment technologies for mitigation of highway construction site runoff means that it is not possible to select treatment technologies on the basis of pollutant loadings alone. Given that highway construction is identified as one of the major sources of landscape modification over the last century, this lack of attention to-date is surprising and highlighted as an important area requiring further research.

5. References

ASROCKS (undated) Guidelines for sustainable exploitation of aggregate resources in areas with elevated arsenic concentrations. LIFE10 ENV/FI/000062 ASROCKS. Available at: http://projects.gtk.fi/ASROCKS_ENG/index.html

Ball JE, Wojcik A and Tilley J (2000) Stormwater quality from roads surfaces – monitoring of the Hume Highway at South Strathfield. WRL research report: No. 204 ISBN: 0 85824 039 4.

Barrett ME, Zuber RD, Collins ER, Malina, JF, Charbeneau, RJ and Ward, GH (1995) A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction. Center for Research in Water Resources report 95-5. Available at: http://www.ce.utexas.edu/centers/crwr/reports/online.html

Barton BA (1977) cited in Barrett ME, Zuber RD, Collins ER, Malina, JF, Charbeneau, RJ and Ward, GH (1995) A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction. Center for Research in Water Resources report 95-5. Available at: http://www.ce.utexas.edu/centers/crwr/reports/online.html

Brady NC and RR Weil (1999) *The Nature and Properties of Soils*. 12th ed. Prentice Hall. Upper Saddle River, NJ.

Bruen M, Johnston P, Quinn MK, Desta M, Higgins N, Bradley C and Burns S (2006) Impact Assessment of Highway Drainage on Surface Water Quality 2000-MS-13-M2. Main Report. Available at: https://www.epa.ie/pubs/reports/research/water/

Chen Y, Viadero RC, Wei X, Fortney R, Hedrick LB, Welsh SA, Anderson JT and Lin LS (2009) Effects of Highway Construction on Stream Water Quality and Macroinvertebrate Condition in a Mid-Atlantic Highlands Watershed, USA. J. Environ. Qual. 38:1672–1682

CIRIA (2006) Control of water pollution from linear construction projects: Technical guidance. CIRIA; London. ISBN-13: 978-0-86017-648-0.

Cleveland TG and Fashokun A (2006) Construction-associated solids loads with a temporary control BMP. Journal of Construction Engineering and Management 132(10) DOI: 10.1061/(ASCE)0733-9364(2006)132:10(1122)

CWS (2008) Erosion Prevention and Sediment Control: Planning and Design Manual. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwiq-JnI-e7kAhVR0aYKHSjcCp4QFjAAegQIAxAC&url=https%3A%2F%2Fwww.cleanwaterservices.org%2Fmedia%2F1464%2Ferosion-prevention-and-sediment-control-manual.pdf&usg=AOvVaw32kNU0bwZzdc5CrH7uo6tI

Dong J, Zhang K and Guo Z (2012) Runoff and soil erosion from highway construction spoil deposits: A rainfall simulation study. Transportation Research Part D 17 (2012) 8–14.

Duck RW (1985) cited in Barrett ME, Zuber RD, Collins ER, Malina, JF, Charbeneau, RJ and Ward, GH (1995) A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction. Center for Research in Water Resources report 95-5. Available at: http://www.ce.utexas.edu/centers/crwr/reports/online.html

Embler PF and Fletcher MO (1983) cited in Barrett ME, Zuber RD, Collins ER, Malina, JF, Charbeneau, RJ and Ward, GH (1995) A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction. Center for Research in Water Resources report 95-5. Available at: http://www.ce.utexas.edu/centers/crwr/reports/online.html

Hainly RA (1980) cited in Barrett ME, Zuber RD, Collins ER, Malina, JF, Charbeneau, RJ and Ward, GH (1995) A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction. Center for Research in Water Resources report 95-5. Available at: http://www.ce.utexas.edu/centers/crwr/reports/online.html

Han, B., Z. Bai, et al. (2009). "Chemical characterizations of PM10 fraction of paved road dust in Anshan, China." Transportation research Part D(14): 599-603.

Hammarstrom JM, Seal RR, Meier AL and Jackson JC (2003) Weathering of sulfidic shale and copper mine waste: secondary minerals and metal cycling in Great Smoky Mountains National Park, Tennessee, and North Caroline, USA. Environmental Geology 45, 35–57.

Hindar A and Norstram DK (2015 Effects and quantification of acid runoff from sulfide-bearing rock deposited during construction of Highway E18, Norway. Applied Geochemistry 62 (2015) 150–163

Huang, C.-P., and Ehrlich, R.S. (2003) cited in Clark S, Pitt R, Burian S, Field R, Fan E, Heaney J and Wright L (2007) Annotated Bibliography of Urban Wet Weather Flow Literature from 1996 through 2006. University of Alabama; Tuscaloosa,

Johnson A (2003) Erosion Control Handbook for Local Roads. US Department of Transport; Federal Highways Authority. Available at: https://www.scribd.com/

Kalainesan S, Neufeld RD, Quimpo R and Yodnane P (2009) Sedimentation basin performance at highway construction sites. Journal of Environmental Management 90, 838-849.

Kayhanian M, Murphy K, Regenmorter L and Haller R (2001) Characteristics of Stormwater Runoff From Highway Construction Sites in California. Transportation Research Record 1743, Paper No. 01-3181, National Academy Press; Sacramento.

Line DE, White NM, Osmond DL, Jennings GD and Mojonnier CB (2002) Pollutant export from various land uses in the upper Neuse River Basin. Water Environment Research 74, 100-108.

Lohnes, R. A. and B. J. Coree (2002). Determination and evaluation of alternate methods for managing and controlling highway-related dust Iowa City, Department of Transportation or the Highway Research Board**:** 32.

Masters-Williams H, Heap H, Kitts S, Greenshaw L, Davies S, Fisher P, Hendrie M and Owens D (2001) Control of water pollution from constriction sites. CIRIA 352; London. Available at www.ciria.og

McNeill A (1996) Road Construction and River Pollution in South-West Scotland. Journal of the Chartered Institute of Water and Environmental Management 10, 175-182.

Orndorff, Z.W., Daniels, W.L., (2004) Evaluation of acid-producing sulfidic materials in Virginia highway corridors. Environ. Geol. 46, 209–216.

Salminen, R. (chief ed.) et al. 2005. Geochemical Atlas of Europe. Part 1 - Background Information, Methodology and Maps. Geological Survey of Finland, Otamedia Oy, Espoo, 525pp.

Scholes L, Revitt DM and Ellis JB (2007) A systematic approach for the comparative assessment of stormwater pollutant removal potentials. Journal of Environmental Management, 88 (3), pp 467-478.

SEPA, (2009) Engineering in the Water Environment Good Practice Guide: Temporary Construction Methods. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwj3vcOEnO_kAhXBKVAKHQy5AFwQFjAAegQIBhAC&url=https%3A%2F%2Fwww.sepa.org.uk%2Fmedia%2F150997%2Fwat_sg_29.pdf&usg=AOvVaw3RKlUM_TyuMg8Qo1ysRmef

Telmers, TA (2013), The mobility of uranium from U-containing bedrock materials as a function of pH: Implications for tunnel construction. Norwegian University of Sciences. MSc thesis. Available at: https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/189613

Trombulak SC and Frissell CA (2000) Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14, 18-30.

USDA NRCS (2000) soil quality – urban technical note No. 1. Erosion and Sedimentation on Construction Sites.

US EPA National Pollution Discharge Elimination System (1984) Standards for TSS in stormwater discharging from industrial sites

Vertanen E (2016) Identification, risk management and treatment of sulphate soils in transport infrastructure construction. Finnish Transport Agency, Technology and Environment. Helsinki 2016. ISSN 2343-1741, ISBN 978-952-317-259-3.

Yew CP and Makowski BP (1989) cited in Barrett ME, Zuber RD, Collins ER, Malina, JF, Charbeneau, RJ and Ward, GH (1995) A review and evaluation of literature pertaining to the quantity and control of pollution from highway runoff and construction. Center for Research in Water Resources report 95-5. Available at: http://www.ce.utexas.edu/centers/crwr/reports/online.html