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Chemical and ecological effects of contaminated tunnel wash water runoff to a small Norwegian stream

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ABSTRACT

Cleaning and washing of road tunnels are routinely performed and large volumes of contaminated wash water are often discharged into nearby recipients. In the present study, traffic related contaminants were quantified in tunnel wash water (the Nordby tunnel, Norway) discharged from a sedimentation pond to a nearby small stream, Årungselva. *In situ* size and charge fractionation techniques were applied to quantify traffic related metal species, while PAHs were quantified in total samples. All metals and several PAHs appeared at elevated concentrations in the discharged wash water compared with concentrations measured in Årungselva upstream the pond outlet, and to concentrations measured in the pond outlet before the tunnel wash event. In addition, several contaminants (e.g. Cu, Pb, Zn, fluoranthene, pyrene) exceeded their corresponding EQS. PAH and metals like Al, Cd, Cr, Cu, Fe and Pb were associated with particles and colloids, while As, Ca, K, Mg, Mo, Ni, Sb and Zn were more associated with low molecular mass species (<10 kDa). Calculated enrichment factors revealed that many of the metals were derived from anthropogenic sources, originating most likely from wear of tires (Zn), brakes (Cu and Sb), and from road salt (Na and Cl). The enrichment factors for Al, Ba, Ca, Cr, Fe, K, Mg and Ni were low, suggesting a crustal origin, e.g. asphalt wear. Based on calculated PAH ratios, PAH seemed to originate from a mixture of sources such as wear from tires, asphalt and combustion. Finally, historical fish length measurement data indicates that the fish population in the receiving stream Årungselva may have been adversely influenced by the chemical perturbations in runoffs originating from the nearby roads and tunnels during the years, as the growth in summer old sea trout (*Salmo trutta L.*) in downstream sections of the stream is significantly reduced compared to the upstream sections.

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1. Introduction

In Norway, more than 1000 road tunnels having a combined length close to 800 km have been built because of the challenging landscape with fjords and mountains, and additionally, in order to protect citizens in urban areas from noise and air pollution.

Although the discharge of highly polluted wash water during cleaning of tunnels has recently gained increased awareness (Paruch and Roseth, 2008a, b), the environmental concern related to road tunnels has traditionally been on air pollution (e.g. Sternbeck et al., 2002).

Many Norwegian tunnels are frequently washed (2–12 times/year) to prevent dusty conditions and poor visibility, and additionally, to increase their life span. In brief, a washing event includes removal of dust, debris and coarse material with a road sweeping machine before detergent is applied on the tunnel surfaces and other technical infrastructure. This is followed by high pressure cleaning before a road sweeping machine makes a last run removing both dirt and undrained wash water. According to the contractors, 60–100 L/m of wash water (0.5–1% detergent) is utilised in a two tube tunnel with four driving lanes.

Metals are often found in elevated concentrations in highway runoff as well as in tunnel wash water (e.g. Sansalone and Buchberger, 1997; Paruch and Roseth, 2008b), and can be present in different physico-chemical forms (i.e. metal species), varying in size (nominal molecular mass), charge properties and valence, oxidation state, structure and morphology, density, ligands etc. (Salbu and Oughton, 1995). Compared with high molecular mass (HMM) species such as

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colloids, polymers, pseudocolloids and particles, low molecular mass (LMM) species are believed to be more mobile and potentially more bioavailable. The aquatic system is highly dynamic and alterations in water quality variables such as pH, ionic strength, redox potential, temperature, suspended solids and the availability of inorganic and organic ligands (e.g. carbonates and organic matter) may change the speciation of metals and metalloids (Salbu and Oughton, 1995; Teien et al., 2004). A series of fractionation techniques have been utilised in the laboratories for metal speciation purposes, although *in situ* fractionation techniques should be applied to avoid storage effects affecting the species distribution. Utilising size exclusion techniques such as filtration and ultrafiltration, LMM species can be differentiated from colloids and particles. Combining size exclusion with charge separation techniques such as ion chromatography, information on positively-, negatively- and neutrally-charged LMM species can be attained (Teien et al., 2004). Therefore, the application of *in situ* size and charge fractionation techniques, as applied in the present work, is judged to be the most useful technique for characterizing fluctuating tunnel wash runoff, as well as the water quality which aquatic organisms are exposed to.

Metal toxicity towards aquatic organisms is well documented, and effects have been observed at different biotic levels represented by effects at a molecular and cellular level (e.g. protein damages, lipid peroxidation, chemosensory impairments and osmoregulatory failures) (e.g. Golovanova, 2008), effects at an individual level (e.g. changed behavior, reduced growth and condition factor) (e.g. Scott and Sloman, 2004; Golovanova, 2008), and finally, effects at a population level (e.g. alterations of the social hierarchies among fish) (e.g. Scott and Sloman, 2004). Hence, in the context of environmental management it is crucial to obtain data concerning metal speciation to better understand and predict the fate of metal contamination, as well as for the implementation of treatment by best management practices (BMPs).

Along with several metals, polycyclic aromatic hydrocarbons (PAHs) often appear at elevated concentrations in highway runoff, and their main sources are combustion, wear from tires, bitumen from the asphalt and leakage and spill of petroleum products (Kose et al., 2008; Napier et al., 2008). According to a recent review by Napier et al. (2008), the release of automobile derived PAHs in the environment shows an upward trend. This is of major concern since PAHs can cause serious harm to aquatic organisms, like mortality in all life stages, decrease in growth, reduced condition factor, edema, cardiac dysfunction, deformities, lesions and tumors, cataracts, immune system dysfunctions and estrogenic effects (Logan, 2007).

In Norway, harsh winter conditions requires the use of significant amounts of de-icing chemicals (normally NaCl) on the roads to enhance good friction and traffic safety for the road users. Road pavements inside tunnels are normally not de-iced, but deposition of salt may occur as a consequence of the vehicles passing through the tunnels. In addition, $MgCl_2$ is occasionally applied as a dust suppressor. High salt concentrations in highway runoff are frequently reported to affect freshwater ecosystems and may cause increased drift of lotic macroinvertebrates (Crowther and Hynes, 1977), alteration in fish blood physiology (Vosyliene et al., 2006) and alterations on amphibian community structures by excluding salt intolerant species (Collins and Russell, 2009). In addition, application of road salt may mobilize trace metals through ion exchange processes, thus potentially increasing their bioavailability (Amrhein et al., 1992).

The objective of the present study was to *in situ* characterize and quantify traffic related contaminants in runoff from a tunnel wash event discharged from a sedimentation pond into the stream Årungselva, and identify if any impact from these discharges could be identified for the downstream fish population, such as long-term changes in growth and density of juvenile sea trout (*Salmo trutta L.*).

2. Materials and methods

2.1. Study site

The water sampling survey was conducted April 20–21, 2006 during the last night of washing of the Nordby tunnel on the motorway E6. The 3.84 km long tunnel, with two separate tubes (each tube 10 m wide with two lanes) is situated 30 km south east of the City of Oslo, Norway (Fig. 1). The walls and the roof of the tunnel are covered with concrete. It was opened for traffic in 1993 and the annual average daily traffic (AADT) is approximately 25 000 vehicles (11% heavy duty vehicles >3500 kg) with an average vehicle speed of 89 km/h.

The tunnel is cleaned typically 4 to 6 times per year, one being a full wash. Before year 2000 the tunnel wash waters were diluted and discharged together with clean drainage water from the surrounding rock, while after year 2000 they were discharged separately. A significant fraction of coarse material and debris are removed from the runoff as it flows through several gully pots. Finally, the runoff is pumped to a sedimentation pond outside the tunnel before it is discharged into the stream Årungselva (Fig. 1). The sedimentation pond was established in spring 2000 as part of a larger extension of the motorway E6, which also included the construction of two additional new tunnels, the Smiehagen tunnel (0.95 km) and the Vassum tunnel (0.85 km). Hence, the sedimentation pond also receives runoff from these two tunnels and from 17 000 m^2 (1.7 ha) of open road areas between these tunnels.

Årungselva has a length of 2.5 km, from the eutrophic Lake Årungen to the Oslofjord. The discharge from the Lake Årungen, which mainly occurs during the spring and autumn floods, varies between nearly 0 m^3/s to at least 25 m^3/s. However, during the summer drought, long sections of the stream may be dry, except in the lower part where groundwater supply gives a wetted area even in such periods (Borgstrøm and Heggenes, 1988).

2.2. Water quality assessment

The tunnel wash water volume was estimated by recording the run time (hours) of the two drainage pumps and by multiplying the run time with their corresponding pump capacity (m^3/h). An automatic data logger (CR200 Campbell Scientific Ltd., recording every 10 min) was installed in a manhole in the outlet of the sedimentation pond and equipped with a multi water quality sensor (HORIBA W21SDI: temperature, pH, conductivity, dissolved oxygen and redox potential) and a turbidity sensor (WQ710 Global Water). All wash water samples from four sampling rounds during the washing event were collected from the manhole by using a peristaltic pump. In addition, one sampling round in the manhole and one upstream the pond outlet in Årungselva were performed prior to the washing event, and used as references in the data interpretation.

PAHs were analysed at the Bioforsk laboratory according to the USEPA analytic technique (EPA 8100). The limits of quantification (LOQ) were 0.01 µg/L for acenaphthylene, anthracene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenzo(ah)anthracene, benzo(ghi)perylene, 0.05 µg/L for fluorene, phenanthrene, fluoranthene, pyrene and chrycene and 0.1 µg/L for naphthalene and acenaphthene.

2.2.1. Metal partitioning by in situ fractionation of water

Ultrafiltration and ion exchange chromatography (IEC) were applied *in situ* to characterize the water with respect to size and charge distribution of the elements, as described by Salbu and Oughton (1995) and Teien et al. (2004). Ultrafiltration was performed using an Amicon H1P1-20 hollow-fibre cartridge with a nominal molecular cut-off mass of 10 kDa. IEC was performed on ultrafiltered water by cation exchange chromatography (Chelex-100 resin, Biorad)

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