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Synergistic wetland treatment of sewage and mine water: Pollutant removal performance of the first full-scale system

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ABSTRACT

Wetland systems are now well-established unit processes in the treatment of diverse wastewater streams. However, the development of wetland technology for sewage treatment followed an entirely separate trajectory from that for polluted mine waters. In recent years, increased networking has led to recognition of possible synergies which might be obtained by hybridising approaches to achieve co-treatment of otherwise distinct sewage and mine-derived wastewaters. As polluted discharges from abandoned mines often occur in or near the large conurbations to which the former mining activities gave rise, there is ample scope for such co-treatment in many places worldwide. The first full-scale co-treatment wetland anywhere in the world receiving large inflows of both partially-treated sewage ($\sim$100 L s^{-1}) and mine water ($\sim$300 L s^{-1}) was commissioned in Gateshead, England in 2005, and a performance evaluation has now been made. The evaluation is based entirely on routinely-collected water quality data, which the operators gather in fulfillment of their regulatory obligations. The principal parameters of concern in the sewage effluent are suspended solids, BOD_5, ammoniacal nitrogen (NH_4–N) and phosphate (P); in the mine water the only parameter of particular concern is total iron (Fe). Aerobic treatment processes are appropriate for removal of BOD_5, NH_4–N and Fe; for the removal of P, reaction with iron to form ferric phosphate solids is a likely pathway. With these considerations in mind, the treatment wetland was designed as a surface-flow aerobic system. Sample concentration level and daily flow rate date from April 2007 until March 2011 have been analyzed using nonparametric statistical methods. This has revealed sustained, high rates of absolute removal of all pollutants from the combined wastewater flow, quantified in terms of differences between influent and effluent loadings (i.e. mass per unit time). In terms of annual mass retention rates, for instance, the wetland system sequesters the following percentages of the key pollutants: BOD_5: 41%; Fe 89%; NH_4–N: 66%; dissolved P: 59%; total P: 46%; suspended solids: 66%. For similar wastewater chemistries, application of this type of co-treatment elsewhere could reasonably be based on the observed areally-normalized mass removal rates for the various pollutants found in this investigation.

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1. Introduction

Wetland systems are now well-established unit processes in the treatment of diverse wastewater streams (e.g. Kadlec and Wallace, 2009). The adoption of wetlands as unit processes in wastewater treatment is a natural development from numerous informal observations that pollutants tend to be sequestered when wastewaters flow through natural wetlands (e.g. Cooke, 1994). Sewage treatment wetlands have developed substantially from modest beginnings in the mid-20th Century (Vymazal, 2011). Wetland treatment was subsequently extended to landfill leachates (Mulamoottil et al. 1999), which often contain similar pollutants to sewage, albeit usually at higher concentrations. In the late 1980s and 1990s, independent developments in the mining industry led to the emergence of distinctive types of wetlands for ferruginous and/or acidic mine drainage (e.g. Wieder, 1989; Younger et al. 2002), with similar systems being proposed subsequently for neutralization of extreme alkalinity in leachates arising in the steel and cement industries (Mayes et al. 2006).

These various types of wetland were developed by different communities of scientists and engineers, working largely in isolation from each other. Hence the system design traditions evolved essentially in parallel, with very little communication between the sewage and mine water treatment communities until the first decade of the new Millennium (Rose, 2013). Even today, contact between the two communities remains sporadic, as they tend to be dealing with quite distinct pollutants: for instance, the principal parameters of concern in the sewage effluent are usually suspended solids, BOD_5, ammoniacal nitrogen (NH_4–N) and, increasingly, phosphate (P) (e.g. Vymazal, 2011). In the majority of abandoned mine water discharges, the principal contaminant concern is usually iron (Fe), though pH, Al, Mn and other metals can also be of concern in the more acidic mine waters (Younger et al. 2002).

The limited communication between the two communities may well be leading to many missed opportunities, since polluted discharges from abandoned mines often occur in or near the large conurbations to which the former mining activities gave rise (Younger et al. 2002), from which large flows of sewage emanate. Furthermore, the contrasting characteristics of sewage and mine water can be expected to give rise to synergies if the two are mixed and co-treated: for instance, removal of Fe from the mine water and P from the sewage can be expected to occur by rapid precipitation of ferric phosphate solids (Dobbie et al. 2009). Removal of suspended solids from the sewage can be expected due to flocculation with the ubiquitous ferric sulfate complexes that develop in aerated mine waters. Removal of dissolved ferrous iron from the mine water (Batty and Younger, 2002), and BOD_5 and NH_4–N from the sewage (Cooke, 1994; Demin et al. 2002) are all favored by oxidation reactions in an aerobic system. Testing of these concepts at pilot scale by a team led by the first author gave encouraging results (Johnson and Younger, 2006), and this encouraged laboratory testing by a USA-based team of the feasibility of extending the approach to co-treat very acidic mine waters with sewage (e.g. Strosnider and Nairn, 2010; Strosnider et al. 2011a,b), with a view to implementing this approach at Potosí, Bolivia (Strosnider and Nairn, 2010). That work revealed that co-treatment with strongly acidic mine waters enhances the disinfection of sewage effluent (Winfrey et al. 2010), and results in impressive removal rates for BOD and phosphorous (Strosnider et al. 2011b), and zinc (Strosnider et al. 2013), albeit denitrification is apparently inhibited under the conditions studied (Strosnider et al. 2011b). Several laboratory-based studies have examined alternative co-treatment options for mine water and sewage, including activated sludge techniques (Hughes and Gray, 2012, 2013), and anaerobic digestion (Deng and Lin, 2013). Conceptually similar investigations have included field trials of addition of sewage to acidic mine pit lake water (McCullough et al. 2008). In the meantime, full-scale co-treatment of mine water and sewage has now been undertaken at the Lamesley site in the UK for more than 7 years. This paper presents a first analysis of how this, the first full-scale mine water/sewage co-treatment constructed wetland system in the world, has performed, drawing lessons for further applications of this environmental technology elsewhere in the world.

2. Study system: Lamesley co-treatment wetland system, UK

The hamlet of Lamesley is located on the edge of the Tyneside conurbation, at Gateshead, in north-eastern England (Latitude 54°54′19.3″N, Longitude 1°35′57.8″W). The site itself is in a low-lying valley floor area, underlain by more than 150 m of laminated glacio-lacustrine clays of Quaternary age. Beneath the adjoining valley flanks, however, multiple seams of coal occur (Mills and Holliday, 1998), and these have been extensively mined by surface and underground methods since the late 16th Century, with the last deep mines closing in the 1960s and the last opencast site closing in the 1990s Since the last mines closed, pumping has been maintained from one of the deep mine shafts of Kibblesworth Colliery, in order to prevent uncontrolled flooding of mine-workings in the densely populated urban area of Gateshead, which would be highly likely to lead to multiple uncontrolled mine water discharges and elevated rates of hazardous mine gas emissions posing a risk to health and safety (Younger, 1998). The water pumped from the shaft is of neutral pH (7.0) and brackish (conductivity ~ 4400 $\mu S\ cm^{-1}$), with elevated sodium (780 $mg\ L^{-1}$), calcium (162 $mg\ L^{-1}$), sulfate (395 $mg\ L^{-1}$), chloride (900 $mg\ L^{-1}$) and alkalinity (755 $mg\ L^{-1}$ as $CaCO_3$ equivalent) (Younger, 1998). Until about the year 2000, the Kibblesworth mine water contained very little dissolved ferrous iron (<0.9 $mg\ L^{-1}$), but changing patterns of groundwater movement in other flooded workings in the region resulted in this increasing to as much as 20 $mg\ L^{-1}$. As the quantity of water pumped at Kibblesworth is very high (mean 276 $L\ s^{-1}$; $\sigma = 85$; $n = 1422$), the total loadings of iron entering the River Team (into which the mine water was hitherto discharged without treatment) were also very high, averaging some 120 $Kg\ d^{-1}$. In-channel oxidation of this ferrous iron led to extensive cloaking of the benthos with unsightly ochre (ferric hydroxide). This resulted in pressure from the environmental regulator (the Environment Agency) for treatment of the mine water.