Holistic Approach to Reed Bed Management on UK Coal Mine Water Treatment Schemes

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Abstract

As part of its UK mine water treatment portfolio, the Coal Authority operates sixty treatment schemes with surface flow wetlands for the treatment of ferruginous mine waters. Typically, these reed beds are planted with either a monoculture of Phragmites australis (common reed) or mixed planting with *Phragmites sp.* and *Typha latifolia* (Bulrush). Initially, many of these reed beds were operated as self-managing systems receiving minimal maintenance, however, this led to a range of operational issues, which reduced treatment efficiency. Over time, the Coal Authority has developed a holistic approach to the management of these reed beds that recognises their need to be actively managed in order to perform effectively, alongside protecting the biodiversity value of these systems and identifying sustainable methods of reed bed waste disposal.

Keywords: Mine water; passive treatment; reed beds; operational experience

Introduction

Aerobic wetlands have been used for passive mine water treatment for over thirty years, having been first proposed in the late 1980's and early 1990's e.g. Girts *et al*. (1987) and Wieder (1989). Key papers such as Hedin *et al*. (1994) and Tarutis *et al*. (1999), which focus on wetland treatment systems, are often cited in the literature, along with the slightly later Piramid Design Guidelines (2003). Today, aerobic wetlands are a mainstay of the passive mine water treatment toolbox, with countless examples used across the globe. In the UK, the Coal Authority alone currently operates sixty schemes, which include surface flow reed beds for the treatment of ferruginous mine waters. Some of these schemes have been in operation since the mid 1990's, whereas others are more recent, having been constructed in the past five years. The current scheme portfolio manages approximately 37 hectares (370,000 m2) of reed bed, operating at various altitudes (400 m to sea level) and with a range of mine water qualities (fresh to saline). Typically, these reed beds are planted with either a monoculture of *Phragmites australis* (common reed) or mixed planting with *Phragmites sp.* and *Typha latifolia* (Bulrush) (fig. 1); *Iris pseudacorus* (yellow flag iris) has also been planted at some sites. Reed beds are not only very effective treatment systems if maintained appropriately, they also have the added benefit of providing priority wetland habitat for a range of small mammals, invertebrates and birds when managed well.

A common misconception in the early days of reed bed management was that these natural systems could be operated with a "minimum amount of attention and money" if they were "properly designed and constructed" (Hedin *et al*., 1994). This statement has been taken somewhat literally at many sites in the past, with often little, to sometimes even no maintenance taking place. Operational experience in the UK has shown that this lack of intervention inevitably results in a reduction in treatment efficiency of a reed bed. Ochre and organic debris accumulation increases over time, reducing the freeboard of water. This can result in water over topping the reed bed bunds, which can cause localised flooding with part treated mine water if not promptly rectified. Furthermore, the accumulation of detritus in the reed bed combined with a reduction in water depth, allows natural plant succession to take place, with invasive trees (e.g. alder and birch) and shrubs (e.g. gorse and hawthorn) often colonising reed beds and, over time, out competing the reeds (fig.

Figure 1 *Overgrown reed bed with trees and scrub at Whitworth A&B, South Wales (left), vs. mixed plant (Typha sp. and Phragmites sp.) maintained reed bed at Allerdean Mill, Northumberland (right)*

1). These larger terrestrial plants not only have the potential to damage the infrastructure of the reed bed itself if left unchecked, with the roots breaching liners (clay or plastic), but also cause preferential flow pathways to develop, reducing treatment performance further.

If left unattended for ten years or more, the reed beds eventually become redundant as they become so congested with ochre and organic detritus that mine water can no longer effectively flow through them. Insufficient maintenance of reed bed treatment systems therefore not only results in inefficient treatment systems, which increases the risk of breaching environmental permit conditions and causing an environmental incident, but ultimately, also cost much more to rectify. Over the past seven years, the Coal Authority has moved away from the minimal intervention model, to one where the aim is for routine maintenance to take place every 2 – 3 years in each individual reed bed unit. A number of key operational learning points have been identified over this transitional period that are discussed in more detail in this paper.

Controlling Water Levels

Controlling water levels, and having the ability to increase water levels in a reed bed during maintenance works, is one the most important factors when maintaining reed beds. The majority of material that builds up in a reed bed over time originates from the plants themselves due to the annual cycle of reed growth and die-back. To reduce the build-up of this organic debris, it is important to cut the reeds back regularly. The principal equipment used for reed cutting by the Coal Authority is an amphibious vehicle called a 'Truxor'™. This machine floats out into the reed bed, minimising any damage occurring to the rhizomes. In order for a Truxor to be deployed however, water levels in the reed bed need to be increased so that there is sufficient distance between the cut reed height, the rhizomes, and the normal operating water level; this is not always achievable if the reed bed is full of detritus.

When the Truxor was first deployed at Coal Authority sites, the blades were set at the lowest level, water levels were increased, where possible, so that the machine would float, and the reeds were cut at the water level. This procedure had the disadvantage that when the reed beds were full of detritus, the rhizomes were at risk of being pulled out of the substrate. Furthermore, any surviving reed stems were often drowned as the water level was too high. Both of these outcomes resulted in the reeds failing to recover, with either a few plants surviving around the edges of the reed bed, or the reed beds becoming devoid of plants altogether, examples include the reed beds at Sheephouse Wood and Old Meadows, Lancashire (fig. 2).

Following a number of failed attempts at a variety of sites, a different strategy is now deployed. Where reed beds have become so full of detritus that it is no longer possible to increase water levels, a full reed bed refurbishment is now planned, as the wetland has gone beyond the point of recovery. Where

Figure 2 *Old Meadows, Lancashire, where the reeds failed to recover following a reed cut (left), and Chell Heath, Stoke-on-Trent, where grasses and thistles have out competed the reeds (right)*

water levels are being successfully controlled however, they are increased to allow the Truxor to float freely (600 mm minimum water depth is required), and the reeds are cut 300 mm above the water level. This activity is repeated on a 2 – 3 year cycle depending on how vigorous the reed growth is at site, with the organic reed waste currently composted. It is worth noting that new trials commenced in 2023 to investigate the suitability of this material to be turned into a biochar product for use in land reclamation.

In addition to controlling water levels during routine maintenance activity, another key consideration for managing water levels is to minimise invasive plant species (e.g. grasses) from colonising reed beds. If water levels are kept too shallow, common grasses can get a foothold in a reed bed and in some circumstances, out compete the reeds e.g. Chell Heath, Staffordshire (fig. 2). Freshly planted reed beds are most at risk of this, however, if reed cuts are too brutal, the plants can be weakened, allowing other plant species to establish. Water depths in Coal Authority reed beds are generally maintained at a minimum depth of 300 mm to help mitigate this risk.

Reed Selection for Planting

When planting a new or refurbished reed bed, the choice of plants is the second most important consideration. As discussed above, reeds beds operated by the Coal Authority are typically planted with Phragmites sp. reeds, with some sites also including mixed planting with *Typha sp*. When the reed bed refurbishment programme commenced around seven years ago, small young plants, ≈100 mm in height were purchased due to the lower expenditure. However, these plants took longer to establish and were more prone to failure. In the last three years, older plants (1 – 2 years old) have been purchased, that are allowed to mature in the nursery and reach a height of 300 – 450 mm. Despite the higher initial outlay, these more mature plants settle into their new positions more quickly, and establish faster than the younger plants, thereby allowing the reed beds to be recommissioned sooner. In addition, wherever possible, local nurseries are also used to supply the reeds; this helps to reduce the reed mortality rate, as the plants are acclimatised to the local conditions.

At some sites, where sufficient reeds are present and it is possible to extract them from the existing substrate without damaging the rhizomes, it has proved feasible to use the existing reeds that are already acclimatised to a particular site. Preventing damage to the rhizomes is key to the success of this activity, as if the rhizomes are damaged, the reeds will fail to recover leaving areas of open water (e.g. Acomb, Northumberland). This procedure has been important at sites where conditions are more challenging due to either the climate (i.e. wind exposure) or elevation of the location (e.g. Deerplay, Lancashire), or at sites where the mine water is more saline (e.g. Horden, North East Coast). This technique has the added advantage that the reeds are mature and therefore more tolerant of being moved, thereby allowing the reed bed to re-establish more quickly. This process is done in a phased approach, starting at one end of the reed bed and gradually working forwards. The reeds are extracted in 'sods' at least 200 mm deep (or deeper depending on the depth of the rhizomes in the substrate) so they can be temporarily stored on site between being extracted and re-planted, minimising the time they are out of water. Any excess or damaged reeds are disposed of at the end of the works, although the numbers are generally small. This more sustainable practice has the added advantage of minimising waste, which is either spread to land (in England and Scotland) or used in anaerobic digesters.

Reeds used to be planted individually and evenly spaced (3–4 plants per m^2) across the reed bed (fig. 3), however, this offered limited protection to plants from the prevailing weather conditions, and exposed them to greater risk of predation from birds (as happened at Summersales, Lancashire and Kimblesworth, County Durham). This methodology has been replaced by planting reeds together in rows (fig. 3), with the tops of the plants kept above the minimum water outlet level of the reed bed. Planting the reeds close together affords the plants greater protection from the weather, and reduces the risk of the tender plants being eaten by geese in the winter months, before they become fully established. Where predation from birds is a known risk, young reeds are planted into hessian mats and grown to ≈50 cm in height before being taken to site. This minimises the risk of the rhizomes being pulled directly from the growing media by the grazing birds.

Growing Media

In order for reeds to flourish, whether they be new or transplanted plants, it is essential to ensure that the correct growing media is placed in the reed bed. At sites where young reeds are planted, fresh growing substrate (BS3882:2015 British Standard Multi-Purpose Grade Top Soil) is imported to site. It is important to import fresh growing media when fully refurbishing a reed bed, as testing has indicated that the existing substrate is generally depleted in nutrients, and no longer

Figure 3 *Individual planting of young plants at Pool Farm, Scotland (left), which failed to establish vs. acclimatised reeds replanted in rows at Deerplay, Lancashire (right)*

fit for purpose (e.g. Deerplay, Lancashire). Generally a clay-rich loam is preferred, which has been found to have the correct nutrient balance for reeds. Where reeds are being transplanted however, the original substrate is typically used to minimise disturbance to the reeds, with fresh soil only added if required.

In areas where reeds are to be planted (at least 2 m wide open water zones are left at both the inlet and outlet ends of the reed bed in order to prevent the reeds choking the inlet and outlet channels over time), a layer of growing media (thickness ≈200 mm) is evenly placed across the reed bed; 200 mm provides sufficient depth of growing media for the rhizomes to take root. Once in place, it is important that the soil is wetted (generally with treated mine water), to stabilise it ready for the reeds to be planted; this prevents the soil from being blown away and helps maintain an even depth across the reed bed. This activity has to be done with care however, as if too much water is introduced, the growing media becomes too wet, and no longer holds its form, resulting in the reeds failing to establish properly (e.g. Silverdale, Staffordshire).

Where transplanted reeds are being re-planted, it is important to ensure that the growing media is evenly spread between the rows so that the reeds can colonise the full reed bed. When the Coal Authority first attempted transplanting reeds, insufficient growing media was placed between the rows, primarily due to logistical issues at site. It was assumed that over time, the build-up of ochre and some organic detritus material would provide sufficient substrate for subsequent new plants to spread out across the gaps between the rows (e.g. Deerplay, Lancashire and Silverdale Staffordshire). However, this has not proved to be the case, and no further reed colonisation has taken place. Where substrate has been spread across the reed bed however, be that for young (e.g. Gwenffrwd, South Wales) or transplanted reeds (e.g. Caphouse, Yorkshire), the reeds have successfully recolonised the entire reed bed quickly.

Reed Bed Establishment and After Care

Once reed beds have been refurbished, it is important that the plants are given time to fully establish prior to the reed bed being brought back online. If reed beds are recommissioned too quickly, the reeds often die back, resulting in sparse reed coverage at best, or at worst, the complete loss of a reed bed (e.g. Blenkinsopp, Northumberland). Initially, mine water was used to keep the freshly planted reed bed wet, however, this led to undesirable ochre deposition, which limited reed uptake and stunted their growth, particularly at sites where the mine water is more brackish. In preference to mine water, rainwater is now allowed to accumulate in the reeds beds to a depth of at least ≈50 mm, which has resulted in a much higher success rate; in periods of dry weather, freshwater is either obtained from the local receiving waterbody, subject to the necessary consents and approvals, or transported to site from an appropriate source. Water levels need to be kept at a minimum of 50 mm, in order to prevent other plant species (e.g. grasses), from colonising the reed bed and out competing the reeds. Once at least one third of new reed growth is above the water level, mine water is gradually re-introduced to the reed bed, with the level increased incrementally until the water depth is ≈300 mm deep. Generally, a minimum of at least six months is required before a reed bed is brought back online.

Maintenance Activity Window

Although generally small in area compared to natural wetlands, mine water treatment reed beds still provide key nesting habitat for a variety of bird species, including some red and amber listed species in the UK (Jaques *et al.*, 2021), often in areas where wetland habitats are rare. Consequently, any operational activity at these sites has to be restricted to prevent any accidental damage to nesting birds. Reed bed cuts and reed bed refurbishment works in the UK therefore only take place between the months of September and early March. Ideally reed bed cuts are undertaken earlier in the maintenance window, as reed beds can be brought online relatively quickly (three weeks) after the works have been completed. Reed bed refurbishments are however far more invasive. These works are best done later in the operational season, nearer to spring, to minimise the time new plants remain dormant in the colder winter months. By planting early in the calendar year, the young or transplanted plants establish more quickly and are at less risk of predation from winter migratory birds, thereby having a higher success rate.

Prioritisation Model

Currently, the Coal Authority manage ≈160 individual reed beds, many of which are now in need of refurbishment, or for those that have been refurbished, require a reed cut every 2–3 years. In order to prioritise the programme of works, a new model has been established that assess the condition of the reed bed (i.e. reed height (used as a proxy for health); reed coverage; infestation of other plants; flow distribution; and available freeboard) and how well the reed bed is performing in terms of iron removal and permitted limits. Each item has a weighted score and is divided into five different scoring categories ranging from 1 (excellent) to 5 (bad). A reed bed that is performing well and is in good condition would gain a priority score of 20 (Grade 1), whereas a reed bed in poor condition would have a priority score of 100 (Grade 5). Data for each reed bed are collected at the end of each financial year by the Coal Authority's operational contractor, and the data are then uploaded into the model. Although it will vary from year to year due to budget constraints, the top ten reed beds are generally taken forward to the reed bed refurbishment programme for the following financial year (in the UK the financial year starts every April). With thirty-three reed beds successfully refurbished to date, it will take approximately fifteen years before all the reed beds in the current portfolio are brought back into good working order.

Conclusions

Based on nearly thirty years of operational experience, it has become clear that the original assumption that well designed reed beds required minimal maintenance was incorrect. When reed beds are left unattended, they eventually cease to work as intended and not only cost significant sums to refurbish (the average spend in 2022 for refurbishing a reed bed in the UK was £236,000), there is also a risk to permit compliance and associated reputational damage. In order to keep reed beds working effectively for longer, they need to be cut regularly (every 2–3 years), with a suitable avenue found for the waste material (currently composting). It is imperative that water levels are controlled to not only maintain even flow distribution but also facilitate regular reed cuts. When reed beds do need refurbishing, it is important to use reeds of an appropriate size when replanting (or transplant the existing reeds if possible), plant the reeds in rows in suitable substrate, and gradually introduce mine water after allowing the reeds to establish for at least six months. By following the approach described herein, the risk of the reed bed failing, and requiring replacement within two years is minimised. With such a large number of reed beds to manage, a prioritisation model has been created to help identify the reed beds most in need of refurbishment, which can then be moved across to the rolling reed bed cut programme once the works are successfully completed. It is however estimated that it will take around fifteen years and cost ≈£53 million, to rectify the damage caused by the low maintenance operational model.

Acknowledgements

The authors would like to thank the organisers and hosts of the IMWA 2023 and all the operatives at Severn Trent Services who help us deliver the reed bed refurbishment programme and manage our mine water treatment schemes. This paper is dedicated to the memory of Adam D.

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