ESTABLISHING RIPARIAN WOODY VEGETATION FOR CONSTRUCTED STREAMS ON MINED LANDS USING THE FORESTRY RECLAMATION APPROACH

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INTRODUCTION

Construction and renovation of streams and riparian corridors on mined lands have become common activities in Appalachia. Surface mining for coal can disturb ephemeral and intermittent streams, and may disturb permanent streams in some cases. Under the Clean Water Act, operations that fill or otherwise disturb streams must perform compensatory mitigation.

Scientific studies have identified beneficial effects of woody vegetation (trees and shrubs) in riparian areas of streams on mined areas and elsewhere. This advisory describes the reasons for establishing woody vegetation in constructed streams' riparian areas, and describes proper methods for mine sites.

Riparian Trees and Shrubs

The riparian zone of a river or stream is the adjacent land, including the stream's banks, the overflow zone, and a transitional zone. These areas may be vegetated in forests, or contain large boulders and coarse woody debris (Figure 1). The size of the riparian zone may be narrow in steep mountain forests or wide in flatter regions. The benefits of streamside trees and shrubs in naturally forested regions are well known and have been well documented for natural streams. Specifically, riparian woody vegetation helps control erosion and mitigate stream temperatures and flow, which sustains aquatic life within the streams and the ecosystem functions they provide.

Riparian woody vegetation stabilizes streamside soils, protects the stream channel, and enhances watershed processes that support healthy stream life. Establishing riparian forest helps to buffer excessive runoff, sedimentation, and pollutant movement from watershed areas into streams. Forest vegetation aids water infiltration processes that support streamflow, and helps to prevent extreme streamflow that can damage channel features (Booth et al. 2004; Price et al. 2006). Dense plantings of a diversity of riparian trees foster those functions (Rowntree and Dollar 1999; Berendse et al. 2015).

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Riparian trees and shrubs also support aquatic life and associated stream functions. Streamside woody vegetation deposits leaves and woody debris into the stream. These organic materials serve as energy sources for aquatic insects and other biota that consume plant matter directly; these organisms, in turn, process the raw organic materials, transforming and reducing them into smaller pieces that support other aquatic organisms. The plant-matter consuming organisms themselves are food sources for higher trophic-level species such as fish, salamanders and birds (Cummins 1975). The leaves and branches that fall into streams also form stream features, such as pools, riffles, runs and glides, which create habitat for aquatic life (Webster et al. 2012). Riparian woody vegetation also shades both the stream's banks and its waters during the warm weather season, helping to maintain water temperatures that are favorable to native aquatic life (Webster et al. 2012), and provides nesting habitat for birds.

FIGURE 1. Forested riparian zone along a mountain stream.

These riparian-vegetation functions are especially important for maintaining aquatic life in small headwater streams, such as those that are often disturbed by Appalachian surface mining.

Regulatory requirements emphasize restoration of aquatic life and stream processes in streams that are constructed as compensatory mitigation. Results from recent studies suggest that re-establishing riparian woody vegetation can aid in restoring stream life and stream processes, thus aiding satisfaction of those legal requirements.

Krenz (2015) and Krenz et al. (2016) compared in-stream organic-matter processes in streams constructed as compensatory mitigation on mine sites to those in streams draining unmined forested areas ("reference streams"). Although all constructed streams were performing these functions to some degree, most were not functioning at the same level as the reference streams at the time of the study. Some individual constructed streams did, however, exhibit organic matter functions similar to reference streams. Dense canopy cover and presence of riparian forest-like vegetation—with high levels of stream shading and low stream temperatures—characterized the constructed streams that functioned most similar to reference streams. Therefore, the authors concluded that establishing woody riparian vegetation contributes to restoration of organic matter processes as well as temperature regimes in constructed streams.

Riparian forest cover can be important for larger organisms also. Sweeten (2015) and Sweeten and Ford (2016) collected stream salamanders from 70 stream segments with a variety of riparian conditions and land uses including surface coal mining. They found that greater canopy cover of the riparian zone had higher abundance and occupancy rate of dusky salamanders (*Desmognathus* spp.) than riparian zones without trees and shrubs. Additionally, mature forest-like conditions such as a high diversity of native tree species, large woody debris, and detritus cover, were found to greatly influence the presence and abundance of dusky salamanders. Wood and Williams (2013) also found lower abundances of dusky salamanders in reclaimed grassland and shrubland where there was less detritus, lower stem densities, less large woody debris, less canopy cover, and an increase in invasive herbaceous species, such as Sericea lespedeza, as compared to forested or partially forested sites. Invasive herbaceous species may not produce the necessary forest-like microhabitat (i.e., leaf litter, cover, and large woody debris) to provide the cool, moist habitat needed for salamanders and birds in Appalachian riparian zones (Lemke et al. 2013; Murray and Stauffer 1995).

Given the above information, establishing riparian buffers for constructed streams on mine sites is critical to re-establish aquatic life and essential stream processes.

Establishing Forested Riparian Buffers for Mine-Site Streams

During reclamation, surface mine operators endeavor to establish riparian woody vegetation when constructing and repairing disturbed streams on mine sites. The Forestry Reclamation Approach (FRA) (Burger et al. 2005; Forest Reclamation Advisory #2) is often used to establish native trees in mined areas. Agouridis et al. (2010) describe methods for establishing riparian buffers for streams in urban and agricultural areas; these methods can also be adapted and integrated with FRA practices to establish effective riparian woody vegetation on mine sites. Considering the above, the following sequence is recommended for establishing riparian woody vegetation along streams constructed on surface mines:

1. Ensure Suitable Riparian Soils

Stream construction designs should ensure that streamside soils are suitable for establishing shrubs and trees.

When soil material is being manipulated and moved to construct stream channels, suitability of soil chemical properties for shrubs and trees should be considered. The ARRI guidelines for soil-material selection (Skousen et al. 2011; FR Advisory #8) can be followed when constructing riparian areas and stream channels. When natural soils can be used, these will generally be more favorable for trees and shrubs than mine spoils to support native vegetation and good growth. Natural soils can be used alone, if quantities are sufficient, or mixed with mine spoils—preferably weathered spoils. When natural soils are not available, weathered mine spoils will be more favorable for trees and shrubs than unweathered spoils.

Survey the mine soils and vegetation in the areas intended for tree planting, using assessment methods recommended by Skousen et al. (2011; FR Advisory #8) and Burger et al. (2013; FR Advisory #11). For soil assessment, consider both chemical properties such as soil pH and conductivity and physical properties, such as density and compaction. Take soil samples, and submit those samples for soil analysis as described by Burger et al. (2013; FR Advisory #11). Use the results of those soil assessments to plan soil amendments, soil loosening, and tree species selection (as described by Davis et al. 2012; FR Advisory #9 and Rathfon et al. 2015; FR Advisory #13).

Soil physical properties must also be suitable if planted trees are to survive and grow. Stream construction often uses heavy equipment that compacts soil adjacent to the stream channel. Compacted soils should be loosened before planting trees. Soil loosening procedures are described by Sweigard et al. (2007; FR Advisory #4) and by Burger et al. (2013; FR Advisory #11). Soil ripping, as described by these advisories, can be applied in areas away from the stream.

When soils directly adjacent to the stream become compacted, different loosening procedures should be applied. For example, an excavator with a ripping tooth can be used to loosen soils (Burger et al. 2013; FR Advisory #11). Care should be used during this operation—compaction of soils near the stream bank should be loosened while assuring that the stream banks themselves remain stable. An area surrounding each planting hole should also be loosened, to enable root growth, soil drainage, and soil aeration. Loosening soils along the contour, when possible, is likely to produce better results than if loosening is only applied to the planting hole. It is important to note that such activities within the streambank are utilized only during re-establishment of the riparian forest.

Finally, where feasible, include large rocks and large woody debris within the riparian zone to provide habitat for wildlife. These materials can be placed along and even in the stream channel.

2. Develop a Planting Plan; Select Tree Species

Planning to re-establish shrubs and trees in a large segment or all of the constructed stream's watershed, when possible, will be beneficial, because the entire watershed influences water quality and flow—consequently influencing stream biota and processes. Where only the streambank is to be reforested, at least 25 feet on both sides of the stream is recommended (Agouridis et al. 2010); but reforesting larger areas will be more advantageous over the long run.

Follow the guidance of Agouridis et al. (2010) and Davis et al. (2012; FR Advisory #9), and consider soil and site properties when designing the planting area. As general guidance, we recommend *at least* two rows of trees and shrubs identified as suitable for "wet sites" by Davis et al. (2012; FR Advisory #9) and Rathfon et al. (2015; FR Advisory 13) be planted at 8x8-foot spacing along each side of the stream. If moist riparian soils extend further back from the stream, additional rows of moist-site species can be established. Only native species of trees and shrubs should be planted (Table 1).

Similarly, on drier upland areas further back from the stream, select species that are recommended for those site types. Matching tree species with their appropriate moisture/site type is critical for successful riparian reforestation.

3. Re-establish Trees, Shrubs, and Other Vegetation.

Most active and legacy mine sites are planted using bare-root seedlings, as described by Davis et al. (2010; FR Advisory #8). These same methods can be applied to establish trees and shrubs in riparian areas.

TABLE 1. Tree species recommended for planting in riparian zones.

Species	Latin name
CROP TREES	
river birch	*Betula nigra*
shellbark hickory	*Carya laciniosa*
sweetgum	*Liquidambar styraciflua*
American sycamore	*Platanus occidentalis*
swamp white oak	*Quercus bicolor*
bur oak	*Quercus macrocarpa*
swamp chestnut oak	*Quercus michauxii*
cherrybark oak	*Quecus pagoda*
pin oak	*Quercus palustris*
shumard oak	*Quercus shumardii*
NITROGEN FIXING	
smooth alder	*Alnus serrulata*
Honeylocust	*Gleditsia triacanthos*
WILDLIFE TREES AND SHRUBS	
chokeberry	*Aronia melanocarpa*
common buttonbush	*Cephalanthus occidentalis*
silky dogwood	*Cornus amomum*
flowering dogwood	*Cornus florida*
American hazelnut	*Corylus americana*
red osier dogwood	*Cornus stolonifera*
deciduous holly	*Ilex decidua*
ninebark	*Physocarpus opulifolius*
black willow	*Salix nigra*

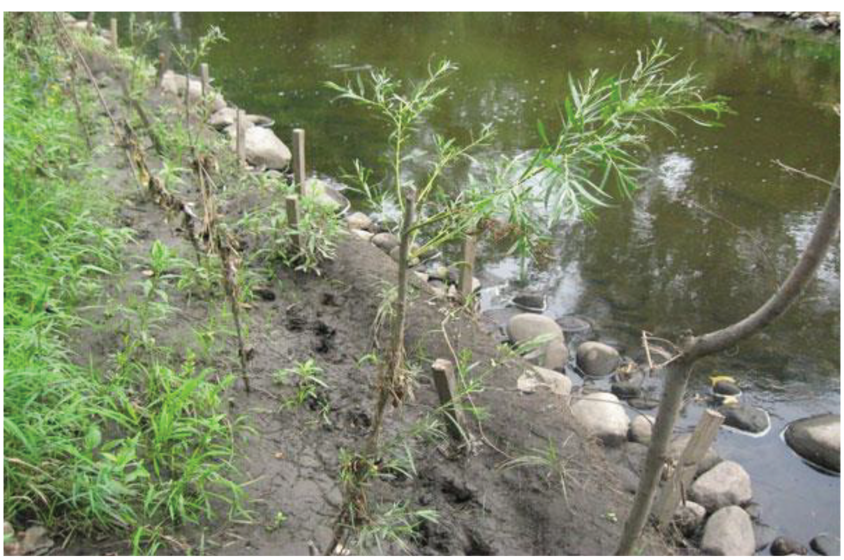
Rapid re-establishment of streamside woody canopy is important to aquatic life and in-stream ecosystem functions. Therefore, tree-establishment methods intended to accelerate woody vegetation growth are sometimes used in the near-stream riparian areas. As described by Agouridis et al. (2010), live-stakes and cuttings can be used to re-establish willow species (Figure 2) and other species such as silky dogwood, Virginia sweetspire, alder, elderberry, ninebark and buttonbush. Also, container seedlings are available for a wide range of tree species. Both of these methods enable establishment of larger-sized seedlings than the bare-root plantings that are typical on surface mines.

Container seedlings, grown in pots ranging from very small (16 cubic inches) to as big as 5 gallons, can be planted with a mass of roots and the soil-like growth media. These container seedlings will be more costly than bare-root seedlings but, if planted correctly and protected, they will grow more rapidly, and establishment under harsh conditions is usually much higher. Given the likelihood that more rapid streamside tree establishment will encourage more rapid return of stream life and function, use of containerized seedlings can be advantageous despite the increased cost.

Herbaceous vegetation should also be established on non-vegetated soils in the constructed stream corridor. Herbaceous vegetation should be selected while understanding requirements of shrubs and trees. Burger et al. (2009; FR Advisory #6) describe herbaceous vegetation that is compatible with newly-planted trees on mine reclamation areas. The tree-compatible seed mix described by these authors can be seeded on stream banks in association with newly planted trees, although other revegetation practices are also possible. For example, Agouridis et al. (2010) recommend selecting native grass and forb plant species for riparian plantings. Numerous reference sources are available to aid plant-species selection, such as Virginia DCR (2011) and UK CES (2013).

Other erosion control methods such a coir mats, brush layer and wattles may also be acceptable and may be used with or without herbaceous seeding treatments. Native vegetation often colonizes rapidly, especially when there is an intact riparian system upstream.

FIGURE 2. Live willow stakes planted in a riparian zone.



Although sometimes recommended for riparian areas because they provide rapid and dense vegetative cover, fast- and tall-growing grass species such as tall fescue should be avoided when establishing riparian shrubs and trees. Such grasses will compete aggressively with growing trees for nutrients and water, may threaten their survival, and will often slow their growth. Also, tall fescue is known to be allelopathic to several species including some trees (Hensen 2001), meaning that it releases biochemical substances into the soil that can inhibit desired vegetation including planted trees.

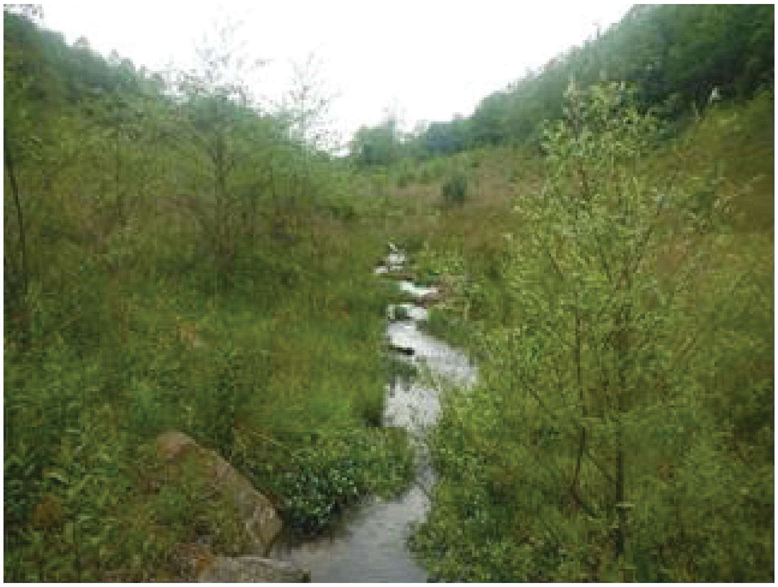
Trees are often planted in riparian areas using protective devices such as shelters and weed mats (Figure 3; Agouridis et al. 2010). Tree shelters are plastic or mesh tubes, large enough to accommodate early growth, that protect young seedlings in areas where browsing by white-tailed deer, eastern cottontail rabbits or rodents (such as pine voles), or destruction by beavers might otherwise occur. Tree shelters can be especially helpful for riparian plantings given the likelihood that browsing animals (such as white-tailed deer) will frequent such areas to access water. Weed mats are made from weather-resistant fabric that, when placed on the ground at the base of a young tree, transmits air and water but inhibit growth of competing plants directly adjacent to the planted seedling's base. Use of weed mats on sites with high populations of small mammals should be carefully considered however, as the weed mats may add to increased seedling mortality by providing winter refuge/habitat for the small mammals.

4. Protect and Maintain the Plantings

Re-establishing trees as bare-root seedlings on areas with pre-existing vegetation requires that such vegetation be controlled, as described by Burger et al. (2013; FR Advisory #11). Container seedlings are larger than bare-root seedlings and, hence, better able to survive competition by

FIGURE 3. Using a tree shelter and fabric mat provides protection from both animal browsing and competing vegetation.

FIGURE 4. Reconstructed stream channel and riparian zone, with a variety of woody vegetation and stream habitat. Note the presence of large boulders and woody debris in and along the stream channel. Cranes Nest Gob Pile, Wise Co. VA.



herbaceous plants. Regardless, tree seedling growth will be more rapid if they are not subjected to vigorous competition from other plants.

Riparian plantings should be inspected on a regular basis for undesirable invasive plants. Certain invasive plants are fast-growing and, if established while planted trees are still young, may proliferate, overtop the planted trees, and become dominant within the riparian area. Two species with significant potential to cause such effects are autumn olive and Japanese knotweed; other invasive plant species known to be problematic for reforestation plantings on mine sites are listed by Burger et al. (2013; FR Advisory #11). If problematic invasive trees or shrubs become established on a newly planted riparian area, they should be eliminated immediately.

SUMMARY

Stream construction on surface coal mines occurs commonly as a means of replacing stream resources that have been disturbed by mining. Restoration of aquatic life and processes in such streams can be encouraged by establishing woody vegetation—trees and shrubs—in these streams' riparian areas and elsewhere in their watersheds. This can be accomplished by combining practices recommended by the FRA for establishing forest trees on surface coal mines with those used commonly for riparian reforestation in non-mining areas. Successful riparian reforestation is a positive outcome for aquatic life, wildlife, and people, and can greatly enhance the overall reclaimed ecosystem (Figure 4).

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All Forest Reclamation Advisories are available on the Appalachian Regional Reforestation Initiative's web page (www.arri.osmre.gov). In addition, a compilation of Advisories 1–12 can be found in *The Forestry Reclamation Approach: Guide to successful reforestation of mined lands*, published by the USDA Forest Service, Northern Research Station, available from https://www.nrs.fs.fed.us/pubs/54344.