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POWELL RIVER PROJECT

RECLAMATION GUIDELINES FOR SURFACE MINED LAND

Reforestation Guidelines for Unused Surface Mined Lands in the Eastern United States

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More than a million acres in the Appalachian region were surface mined for coal under the Surface Mining Control and Reclamation Act (SMCRA) (US OSM 2008). Much of this land was reclaimed using practices intended to stabilize the surface, prevent erosion, and establish herbaceous vegetation suitable for grazing livestock, but most is not used for grazing. Other areas were reclaimed to post-mining uses such as wildlife habitat or unmanaged forest using similar techniques, but with shrubs and trees able to survive heavy grass cover and compacted mine soils. Today, these lands are mostly covered with persistent herbaceous species, such as fescue and sericea lespedeza, and a mix of invasive and native woody species with little commercial or ecological value, and most are not used or managed. From an ecological standpoint, these lands are said to be in a state of "arrested succession," meaning that current conditions hinder recruitment of native forest trees. For these lands to become productive forests, intervention is needed to loosen compacted mine soils, correct chemical or nutrient deficiencies, and replace the current vegetation.

Re-establishing productive forests on otherwise unused and non-productive mined lands will generate economic value for landowners and communities, and will enhance environmental quality by accelerating restoration of ecosystem services – such as watershed protection, water quality enhancement, carbon storage and wildlife habitat – that are typically provided by native forests on non-mined landscapes.

This document describes practices that can be applied to restore native forests on *unused* mined lands that are unoccupied, unmanaged, and unproductive. Most unused mined land would be those acres mined since 1980, reclaimed to satisfy SMCRA guidelines, bond released, and now under landowner control. Land mined before 1980, some of which has been identified as "abandoned mined land" could also be reforested using these guidelines. Today, lands being actively mined in Virginia and in some other states are commonly reclaimed using the Forestry Reclamation Approach (FRA) (see Virginia Cooperative Extension publication 460-123 or Forest Reclamation Advisory No. 2), which establishes productive forest as a post-mining land use in accord with SMCRA. The guidelines in this publication are intended for lands mined and reclaimed without the FRA that are not forested and not under active management.

Forest restoration on these lands typically requires a sequence of steps or procedures over several years; we describe a series of such procedures, which can be reduced to "four Ps" – plan, prepare, plant, and protect:

1. Assess site conditions and develop a forest restoration PLAN.
2. PREPARE the site to make it more favorable for forest establishment.

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3. PLANT a combination of valuable, native trees or plantation species.
4. PROTECT the site and new planting with follow-up management, including weed control, fire prevention, and animal and human trespass.

Each of these major steps is described below as a series of procedures, in a format explaining "why" it is needed, "what to do," and "how" to do it. All four steps are needed to ensure reforestation success.

1. Assess the Site and Develop a Reforestation PLAN

The first step in a reforestation process is to develop a plan or strategy by assessing site conditions. Based on this assessment, a written plan can be developed and contractors sought for the needed reforestation operations. State reclamation extension specialists and state foresters may assist with this assessment and planning.

Survey Existing Vegetation

Why: Herbaceous plants and woody shrubs, many of them non-native and invasive, often dominate reclaimed post-SMCRA mine sites (Zipper et al. 2007, and Figure 1). Successful reforestation requires that existing vegetation be eliminated or controlled. Thus, the reforestation plan must include a strategy for control of competing vegetation.

What To Do: Visit the site, observe, and take notes on the types and amounts of grass, legume, and woody cover.

How:

- Develop a map of the area and delineate sections of the site that have different types and amounts of vegetation (Figures 1a – 1c). Determine the acreage of each area and the total for the site. A GIS map, or an aerial or satellite photo, would be especially useful to determine acreage and to record the assessment survey, as well as a record of the application of all reforestation procedures. Satellite imagery that is freely available on internet mapping sites can be used to prepare a base map and to estimate areas.

Figures 1a – 1c. Vegetation on unused post-SMCRA mine sites. Depending on reclamation method, site age, and soil conditions, vegetation may be predominantly herbaceous (a, upper left); predominantly low-value woody vegetation with invasive species (b, upper right); or mixed woody and herbaceous (c, lower left). In nearly all cases, the herbaceous and woody vegetation is dense and competitive. Successful reforestation will require that this vegetation be controlled or eliminated.

- Identify areas having 50% or more of the site covered with low-value woody plants such as autumn olive, multi-flora rose or other invasive trees or shrubs. For these areas, aerial spraying will be an efficient and effective control method.
- Identify areas having woody cover less than 50%. For these areas, aerial spraying may not be necessary and mechanical clearing may suffice.
- Identify areas having less than 10% of the site covered by woody vegetation, where a clearing operation will not be necessary.
- Determine the approximate density and amount of legume cover (e.g. sericea lespedeza). This information will be needed to formulate herbicide mixes, as grasses and legumes require different herbicides for their control.

The most troublesome competing plants are often vigorous grasses and legumes, including those sown after mining such as tall fescue and invasive species like sericea lespedeza that can occupy mine sites even when not sown. These species are tenacious and competitive; successful reforestation requires their control or elimination. About 5 years after reclamation, even if not planted, woody plants such as autumn olive and black locust invade the unmanaged mine sites. When allowed to mature, these invasive woody plants become a significant obstacle to any form of site management, including reforestation with more desirable timber species.

Test Mine Soil Physical Properties

Why: Soil physical properties on unused coal mine sites are often poorly suited for planting trees and will benefit from deep soil tillage. Surface soils on many sites have been compacted by mining equipment, and virtually all mine soils have become denser over time due to gravity-induced physical settling. A dense or compacted soil does not have enough open pore space for normal rooting and water and air infiltration.

Survey the site in advance of reforestation to determine where deep tillage will be needed and how it will be applied. Research demonstrates that loosening of older mine soils will significantly improve survival and growth of planted trees (Fields-Johnson et al. 2008; Skousen et al. 2009). Deep tillage of dense mine soils will produce a favorable soil condition where roots can extend easily and access needed water, nutrients and air.

What To Do: Survey the site to determine how soil physical properties vary, paying special attention to soil density and compaction. Identify areas where deep tillage will be applied.

How To:

- Walk over the site, and assess soil density on all major areas, Use a sharp, common hand spade to estimate the extent of compaction by putting a modest amount of foot pressure (~50 pounds) on the spade while rocking its tip to by-pass coarse fragments (if a rock big enough to block the spade is encountered, move

Table 1. The relationship among degree of compaction, spade penetration depth, and forest site quality on mine soils with good chemical properties (after Burger, Mitchem, and Scott 2002). Forest site quality is an indicator of the soil's ability to support growing trees.

	Soil Density Condition				
	Very Dense	**Dense**	**Moderately Compacted**	**Slightly Compacted**	**Loose**
Spade penetration	0-1 inches	1-3 inches	3-6 inches	6-9 inches	9-12 inches
Site Quality Class	V (poor)	IV (fair)	III (medium)	II (good)	I (excellent)
Oak site index [a]	40	50	60	70	80
Use for wood products	None	Firewood	Railroad ties	Saw timber	Veneer
$ /1000 board ft stumpage value[b]	-	< $100	$200	$500	$1,000

[a]Oak site index: Tree height at age 50.

[b]Typical or average prices over the past 10 years, cited to illustrate the relationship between site quality and the value of timber produced. Timber market prices change with time.

to another spot). The depth of spade penetration will be affected by the degree of compaction and is an indicator of forest site quality (Table 1).

- If the surface is loose enough to allow the spade or shovel to penetrate easily (6 to 12 inches) with moderate foot pressure, planted trees should do well without tillage.
- If the soil surface is so tight that it is difficult to penetrate the surface, the soil will need to be loosened to make the site productive. Even if surface soils are loose, subsurface compaction may be present; if it occurs within 4 feet of the surface, subsurface compaction will hinder the growth of planted trees.

In our experience, trees planted on post-SMCRA mined sites with slopes less than 15% will usually benefit from deep tillage. Even when not overly compacted, mine soils on broad, near-level surfaces often experience poor drainage conditions because they lack subsurface channels to enable water and air movement (Figure 2). The presence of plant species such as rushes and cattails is a clear indication of continually moist soil conditions that must be alleviated in order for planted trees to grow and thrive.

Figure 2. The vegetation in the lower-center of the photo is emerging from a poorly drained area on this reclaimed mine site. Dominant plant species are cattails and rushes in the poorly drained area, while grasses, sericea lespedeza and annual broadleaf weeds dominate other portions of the mine site. Poorly drained areas such as this are common on near-level areas of post-SMCRA mine sites.

Test Mine Soil Chemical Properties

Why: Most Appalachian mine sites have soil chemical properties that are adequate for tree establishment, but it is prudent to check soil chemical properties as part of the reforestation plan. Mine soil acidity, salinity, and fertility are essential soil chemical properties that need assessment and testing for possible corrective measures.

What To Do: Sample mine soils, complete necessary forms for each sample, and send the samples to a state or private testing lab; use the test results to determine if corrective measures are needed.

How:

- For each area with different amounts of vegetation, collect a soil sample for chemical testing. Even within an area with a given amount of cover (e.g. less than 10%) there may be places where strongly acidic, salty, or nutrient poor-soil occurs; for these areas, a separate soil sample should be taken (if larger than 10 acres). These areas can often be identified visually from patches of bare soil and sparse vegetation, which is sometimes discolored due to nutrient deficiencies.

Procedures for sampling mine soils and interpreting test results are described by VCE publication 460-121. Mine land owners or managers in Virginia can obtain proper forms, sample boxes, and instructions from local Cooperative Extension offices and send soil samples to the Virginia Tech Soil Testing Laboratory (*http://www.soiltest.vt.edu/*).

Complete required forms for each sample. Common soil testing procedures are intended for natural soils. Mine soils are quite different from natural soils; therefore, it is important to request that the testing lab provide a recommendation specifically for mine soils as well as the forest type to be planted (e.g. native hardwoods, pines, biomass species, or any other specialty crop).

Test results are normally mailed within two weeks. Essential soil test results are:

- Acidity: If soil pH is between 5.5 and 6.5, soil chemical properties are likely excellent for reforestation. If soil pH is less than 5.5, lime should be applied as recommended by the soil test report as needed to raise soil pH to the 5.5–6.5 range. If pH is 4.0 or less, and if the landowner suspects that acid materials are close to the surface, more detailed soil investigations should be conducted to ensure that soil tillage does not disturb acidic materials in the subsurface. If pH is 7.0 or higher, soil properties will not be favorable for most native forest trees. In that case, the tree-planting prescription should use species that can tolerate high-pH sites as recommended by VCE publication 460-123.

- Salinity: On the surfaces of mine soils that have been in place for at least five years, soluble salts should be within or only slightly above the range that is typical for natural soils in the area. If soluble salt levels at the surface remain significantly above the range that is typical for natural soils, a more detailed soil investigation is advised.
- Minor nutrients: If the soil test shows low levels of one or more micronutrients, we recommend that a micronutrient mix be included in the fertilizer application.

Nitrogen (N) and phosphorus (P) fertilizer should always be applied as fertilizer because most mine spoils carry little of these nutrients in plant available forms. Common reclamation procedures on older coal mine sites applied P fertilizers at levels that were adequate for establishing grasses, but were less than adequate for the long-term growth of forest trees. Mine soils do not retain the fertilizer N applied during reclamation unless it is converted into plant-biomass and soil-organic forms, so soil N available to trees in older mine soils will often be less than necessary to support the rapid early growth needed to overtop competing herbaceous vegetation.

Other essential macronutrients – calcium (Ca), magnesium (Mg), potassium (K), and sulfur (S) are usually present in adequate quantities because mine soils are made of freshly fractured rocks that are rich in these required nutrient elements; as the mine soils weather, these elements are released from the rock materials and become available to plants.

If the site is so highly acidic that very little vegetation is growing on it, despite the passage of several years time since reclamation, it is likely that the soils contain significant quantities of acid-forming minerals. For such lands, the guidelines of this publication are not an appropriate treatment.

Determine Forest Type and Species to Plant

The landowner should determine his or her objectives for the site as this affects which species and species mixes to plant. In most cases, mined land will be suitable for mixed native hardwoods. Professional tree planting contractors will plant a mix of silviculturally-compatible crop and wildlife tree species (see VCE publication 460-123). If the site is prepared correctly and protected from weeds and other pests, other desirable native species will volunteer.

In some cases a landowner may want a pine or woody biomass plantation instead of, or in addition to, native hardwoods. Plantation management and harvesting usually require specialized operations and equipment; therefore, plantations should be planned on areas of the site with slopes less than 10 to 15%. A relatively large contiguous area is usually needed in order for a pine or biomass plantation to be a profitable enterprise. Because deep tillage causes significant roughening and loosening of the surface, vehicle-access roadways needed for plantation management activities should be planned prior to the deep tillage operations and left untilled.

Obtain Bids from Contractors

Using the site assessment results, contractors can be sought who are capable of conducting the operations that will be necessary to reforest the site. Because site clearing, tillage, liming and fertilization, tree planting and herbicide application are all specialized operations, solicitation of separate bids for each are advised. Develop written bid requests that include a site description, map with listed acreage, a detailed description of the work to be done, and the date by which the work must be completed. State forestry and county extension offices can often provide lists of available contractors who operate in a given region.

2. PREPARE the Mined Site for Planting

Preparing the mined site for planting usually requires three steps: 1) removing and controlling existing undesirable vegetation; 2) improving the mine soil's chemical properties by adding lime and fertilizer; and 3) improving the mine soil's physical properties by deep tilling with a dozer to alleviate mine soil compaction and consolidation.

Remove and Control Existing Vegetation

Why: It is essential that the pre-existing vegetation be controlled because it will otherwise compete for sunlight, water, and nutrients needed by tree seedlings to survive and grow. Because the pre-existing vegetation has established rooting and physical stature, it has an advantage over newly planted seedlings. If pre-existing vegetation is not controlled, it will quickly overtop and out-compete planted tree seedlings, and those seedlings will not survive.

What To Do: Kill and remove woody stems that will interfere with reforestation operations prior to soil preparation. Apply herbicides to control herbaceous vegetation both before and after planting tree seedlings.

How to:

- If the woody vegetation covers more than 50% of the site, is at an advanced growth stage (stems > 2 inches in diameter), and consists of species that vigorously re-sprout or re-grow when cut down, consider an aerial application of an early- to mid-summer herbicide; this is the most efficient and effective way to kill the existing vegetation. Application of a broad spectrum herbicide over the entire site will kill both woody and herbaceous species. Spraying, as opposed to cutting/chipping stems without spraying, is desirable because the spray will kill the root systems as well as the stems and prevent re-growth and re-sprouting. Aerial spraying requires the site to be sufficiently large (at least 40 acres) and removed from housing and other land uses that could be negatively affected by an aerial spray.
- During late summer to early fall, clear the dead woody stems that were killed with the aerial spray with a root rake mounted on a dozer (Figure 3b). Grubbing with a straight blade on a dozer is not advised because it removes surface soil, litter, and organic matter important for good soil tilth and fertility. Unlike a straight blade, a root rake removes woody vegetation but the soil filters through the rake and creates less site disturbance.
- If aerial spraying is not an option on sites with dense woody vegetation, alternative strategies are possible. One is to shear woody stems at ground level using a shearing blade (Figure 3a) on a dozer and rake the stems into windrows or piles. A better alternative is to grind and chip all woody stems, leaving the chips on site (Figure 3c); these chips will be incorporated into the soil through tillage and will decompose over time, adding organic matter and nutrients to the soil. However, without aerial spraying to kill the root systems, stump and root sprouts will require post-planting control with herbicides.

Figures 3a - c. Equipment that can be used for site clearing operations: (a, upper left) a “KG-style” shearing blade, attached to a dozer, for shearing dense woody vegetation at ground level; (b, lower left) a brush-rake, also attached to a dozer, for grubbing roots and moving and piling sheared vegetation with low disturbance of surface soils; and (c, upper right) a tree shredder, attached to a skid-steer tractor, for grinding and shredding both above-ground and below-ground stumps and roots, an operation that can prevent much of the vigorous re-sprouting that will occur if only woody tops are removed.

- If woody cover is less than 50% and aerial spray is not an option, clear the woody vegetation with a chipper or tree-grinder (Figure 3c). Re-sprouting can be controlled with a subsequent herbicide application; a full-site herbicide application with tractors or ATVs is recommended when a dense sod covers most of the area. If no herbicides are used to control vegetation prior to planting, herbicide application shortly after planting will be critical to the planted seedlings' survival.
- If woody cover is less than 10% and the stems are less than 2 inches in diameter, no site clearing is needed; tillage dozers can drive over vegetation of this size and it will not interfere with other operations. If a dense sod is present, and depending on the make-up of the vegetation, spray with a mix of glyphosate and/or other herbicide products and at rates recommended by specialists, to kill the sod (Figure 4).

Figure 4. A tractor applying herbicide to a former mine site with little or no woody vegetation.

Improve the Mine Soil's Chemical Properties

Why: Soil fertility is essential to the planted trees' growth, and soil pH affects plant availability of soil P. In the short term, access to essential nutrients will enable quick early growth of planted seedlings; this is desirable because post-planting herbicide applications can cease once the planted seedlings overtop their competition. Over the longer term, adequate fertility is essential to forest productivity.

What To Do: Apply lime (if necessary) and fertilizer as needed to improve the mine soil's fertility and chemical properties. Lime is usually easy to apply with standard, commonly-available equipment. However, fertilizers must be applied strategically to restrict availability to the planted trees and to prevent the fertilizer application from stimulating competition by undesirable vegetation.

How To:

- Apply lime prior to tillage (if needed) so it is incorporated into the soil. Apply an amount recommended by soil test results to attain a soil pH range of 5.5 to 6.5, If lime is needed, it is essential that lime be applied prior to the tillage operation, as the rough surface created by the tillage will hinder or prevent application using standard wheeled equipment.
- Apply fertilizer in narrow bands over the tree-planting row that is established by the tillage operation. On most mined lands, application of 50 lbs. N and 100 lbs. P (230 lbs P2O5) per acre will improve tree survival and growth over the long term. If present in the fertilizer used, additional potassium (K) can also be applied to ensure that plant-available soil K is adequate for the trees' early growth. An efficient way to do this is to mount a ground-driven fertilizer dispenser on the front of the tillage dozer that will apply the fertilizer in a narrow band so it can be incorporated into the soil by the tillage device on the tractor's rear end.
- If fertilizer cannot be applied in the tree row as described above, apply it at the base of each tree seedling using fertilizer pellets (also called "fertilizer tablets" by some marketers). Apply the fertilizer pellets as the trees are being planted by placing the pellet below the surface in the "tree closing hole" that is created about 2 to 4 inches from the planted seedling (see Forest Reclamation Advisory No. 7 for a description of this procedure).

  If fertilizer is applied as pellets, apply additional fertilizer around each tree after the first growing season.

- If fertilizer is not applied prior to tree planting or applied only as pellets at planting, apply fertilizer to the soil surface after planting by distributing approximately one 16-ounce cup of di-ammonium phosphate fertilizer (18-46-0) per tree seedling in a 3-foot circle around the stem of each tree, keeping it about 12 inches from the stem and ensuring that the fertilizer is evenly spread. As well as being more laborious and time consuming than the other two recommended methods, this method will be less effective because the surface-applied fertilizer is not incorporated into the soil.

The most efficient and effective way to fertilize is to apply in a band, during tillage, over the tree-planting row. It is especially important to keep the N fertilizer in the tree row because it will stimulate growth by grasses and other herbaceous plants. Band application of fertilizer in the tree row using this procedure is commonly done in pine plantations in the Southeast. Restricting the fertilizer application to a narrow band will aid post-planting competition control, as herbicide application in the tree row only is easier than if stimulated growth occurs over the entire field. When fertilizer is applied in narrow bands as described above, post-planting weed control using herbicides sprayed in the same band is essential. Reclaimed mine sites usually have large herbaceous seed pools that will be especially competitive when fertilized, even during the first growing season after tillage and planting. Keeping fertilizer in the tree row also allows its incorporation into the soil by the tillage tool and places it where the young tree roots can access it easily. Subsurface incorporation is especially important for P because it is relatively immobile in soils.

Fertilizer pellets contain sufficient N to help the planted seedlings become established, but they do not contain enough P and other nutrients to support their long-term growth. Therefore, if pre-planting fertilizer is applied as pellets, it is essential to the planted trees' productivity that additional P fertilizer be applied.

The method of fertilizer application will influence post-establishment weed control. If the fertilizer is applied prior to planting over the tillage row as recommended, weed control can be applied as a band spray over that row. If fertilizer pellets and/or individual-tree applications are used, post-planting weed control can be accomplished by spot spraying a 3-foot circle around each tree. Less stimulation of competing vegetation will occur if fertilizer is applied in pellet form, and less herbicide damage of trees usually occurs with spot spraying compared to band spraying.

Improve the Mine Soil's Physical Properties

Why: When mine soils have become dense, soil loosening is needed to allow normal rooting, water infiltration, soil drainage, and movement of air into the soil surface, all of which are required for productive tree growth.

What To Do: Loosen compacted mine soils with a soil ripper, sub-soiler, or other specialized tillage device (Figure 5). Because forest trees require at least 4 feet

Figure 5. A standard single-shank ripper preparing a mine site for reforestation. The soil-ripping "tooth" being pulled by the dozer is intended to loosen soil material to a depth of 3 feet or more. The best results are achieved if this operation is performed in late summer and fall when the soil is dry.

of rooting depth for adequate growth, rip compacted mined sites to at least 3 feet of depth if possible. This deep tillage operation will typically require a dozer such as a Cat D-8 or larger. Application of deep tillage to active mines is described by Forest Reclamation Advisory No. 4; these practices can be adapted for use on older mined sites.

How To: Several approaches are possible:

- If the surface, and not the subsurface, has been compacted, use a shallow (less than 3 foot) ripper with two or more shanks to loosen the compacted surface. Till the entire surface of the mine site. However, unless the site manager has personal knowledge of the reclamation procedures, it is difficult to know that subsurface compaction is not an issue.
- When the mined site is deeply compacted, which is typical, rip the site with a long-shank ripper (36 inches) 10 feet between rips when planting hardwoods, or 8 feet between rips when planting biomass plantations.
- It is often necessary to loosen more land area than will occur with a single pass of a single-shank ripper. If a single-shank ripper is the only tool available, cross-rip the site in perpendicular directions with the first pass up and down the slope and the second pass parallel to the slope contour to minimize erosion.
- If available, use a multi-featured Savannah-type tool (Figures 6 and 7) with a deep shank to break up compacted subsoils, coulters to form a mound over the ripped trench, and additional smaller shanks on

either side of the deep shank to break up surface compaction. This treatment opens the subsoil for tap roots, loosens the surface for lateral feeder roots, and builds a small mound over the deep trench on which to plant the seedling. This type of tillage is most helpful on near-level areas with poor drainage,

Figure 6. An example of a soil ripping tool (Savannah-type plow) used to prepare several mine sites in Wise County, Virginia, for reforestation in late 2007. The ripping shank is 36" long and the large steel wheels on the end of the shaft behind the ripping shank ("coulters") are 30 inches in diameter. The coulters are intended to push a mound onto the top of the ripped channel, where trees can be planted.

Figure 7. An advanced tillage tool intended for use on mined lands. A center shank (not visible) rips a deep trench through the compacted mine soil while the coulters produce a mound of loose soil over the rip where the trees are planted. Smaller shanks (up to six) to the right and left break up the surface on either side of the planting location to a depth of 12-to-18 inches; the top of one such smaller shank is visible as it enters the soil on the right hand side of the tool bar.

as trees planted on the elevated mounds will be able to root in the loosened, aerated soil.

- Where herbaceous vegetation has formed a thick rooting mass over the land surface, disk the site to break up the soil surface and herbaceous vegetation root mat (Figures 8 and 9). This operation will help prevent sod or root clumps from getting caught up in ripping tool. Breaking up the surface prior to ripping will also increase the movement of air and water through the soil surface after trees have been planted. If the site was limed, surface tillage will help incorporate the lime in the soil surface.

Rip the site at specific spacings to accommodate the tree-planting plan; trees should be planted near or over the deep rips. A common practice is for the dozer to

Figure 8. A large disk being used to break up surface soil and herbaceous vegetation root mass prior to soil ripping. This operation is not always necessary, but it can increase the efficiency of the deep tillage operation on sites where dense vegetation is present.

Figure 9. Preparing an area for reforestation research at Powell River Project Research and Education Center. The large disk (left) is used first to break up the sod, then an advanced deep-tillage device (right), was used to prepare the land for planting.

progress across the site with each pass by tracking over one of the track marks from the previous pass; this practice will keep the rips parallel on an 8- to 10-foot spacing while limiting the area that is left compacted by the dozer tracks (Figure 10).

In all cases, tillage should be done when the mine soil is relatively dry, usually late summer and fall. When dry, compacted mine soils are loosened to a greater extent by the tillage tool. When soils are wet, traction is limited, the dozer will compact the soil where it tracks, and tillage is less effective. Completing tillage operations by October allows enough time for loosened soil to settle a bit prior to planting which improves tree survival.

Figure 10. An aerial view of a former mine site being prepared for reforestation. Woody vegetation was removed and herbaceous vegetation was herbicided prior to the deep-tillage operation shown by the photo. Photo by Richard Davis, Virginia Department of Mines, Minerals and Energy.

3. PLANT the Site with Selected Tree Species

Why: Over many decades, native hardwoods are likely to re-establish on unused Appalachian mined lands through natural processes, but natural processes are hindered by the vigorous, non-forest vegetation that occurs on most mine sites. Natural invasion by the heavy-seeded tree species – including oaks and hickories – will occur even more slowly, especially on larger mine sites, because these species' seeds are not carried by wind.

What To Do: Plant trees of species that are suited to reforestation goals. If the goal is to reestablish the native forest, plant a mix of native hardwoods, these trees should be commercially viable hardwoods that will provide multiple benefits including wood products, carbon sequestration, wildlife habitat, and watershed control.

How: A mix of native hardwoods or single-species stands of biomass trees can be planted depending on the landowners' objectives.

- To reforest with native hardwoods, plant white and red oaks, sugar maple, white ash, black cherry, tulip poplar, and/or hickory species at a combined rate of 600 trees per acre. We generally recommend a mix of 5 to 6 species. Additional tree species to attract birds and other wildlife such as dogwood, shagbark hickory, redbud, crab apple, white pine, and black locust should also be included in the planting mix at a combined rate of 100 trees per acre. If soil conditions are favorable, other wind and bird-disseminated native species enter the site as seed, creating a diverse and compatible native forest cover. When the site is prepared correctly and the planted trees are protected from weeds and other pests, planted native trees should out grow and over top invasive species. Species other than those listed could be included in the mix (e.g. American chestnut hybrids), and one or more may need to be avoided due to species-specific pests (e.g. emerald ash borer). See VCE publication 460-123 for further guidance on selection of trees for planting on mined lands.
- If the landowner intends to manage the restored site for the purpose of maximizing biomass production, faster growing species such as hybrid poplars or pines can be planted as single species plantations.
- Hand-plant the trees over the deep rips to enable tap roots to penetrate the soil easily. For mixed native hardwoods rows should be at 10-foot intervals, and for pine or biomass plantations rows should be at 8-foot intervals. Plant seedlings 6 to 8 feet apart within the row to achieve desired stocking rates.
- Plant trees on high ground, close to but beside the ripped channel, which will enable the roots to access the loosened soil within the rips easily. On sites prepared with a Savannah type-plow (Figures 6 and 7), plant the trees on the mound created by the coulter disks. Do not plant trees directly within the channel, where they can sink to below the optimal planting depth as the soil within the rip settles. On sites that are cross-ripped, plant trees where the rips cross to enable the lateral roots to extend easily in both directions. Tree planting procedures that are commonly applied on active surface mine can also be used on previously mined areas. See Forest Reclamation Advisory No.

7 for a detailed description of how to plant trees on mine sites.

Planting a mix of tree species correctly, and with the proper care that ensures survival, is both hard and specialized work. We recommend trained and/or professional tree planters be used to plant mined land; an experienced tree planter can properly plant 1000 to 1200 trees in an 8-hour day (about 2 acres).

4. PROTECT and Survey the Site and Trees After Planting

Protect the Planted Trees

Why: Young, planted trees are vulnerable to a variety of hazards, especially through their first year. The effort required to protect seedlings during the first few years after planting will be a small part of the overall reforestation project, but it is essential to a successful outcome.

A primary threat is competing vegetation, and there are several reasons for controlling it. Most obvious is that excessive competition will prevent seedlings from accessing the sunlight, water, and nutrients that they will need to survive. Perhaps not so obvious, rodents such as voles will use a heavy sod cover for winter shelter and de-bark the tree seedlings for a winter food source, killing the trees.

What To Do: Protect the site and planted trees from pests and hazards.

Common-sense protective measures should be applied. For example, uncontrolled ATV traffic can cause significant damage, while the presence of combustible matter – such as windrows of woody vegetation that were removed prior to planting, and dense, dry, stems of sericea lespedeza in the early spring – can present a fire hazard. Maintaining gates and fences at critical access points can help limit uncontrolled human access and guard against these hazards.

Most critical, however, is the control of competing vegetation, usually with herbicides, which is essential to reforestation success on virtually all reforested sites (Figure 11).

Figure 11. A young oak seedling growing on a post-SMCRA mine site that was prepared for reforestation using deep tillage. The soil loosening operation made the site more favorable for herbaceous vegetation, as well as for trees. Surrounding vegetation, mostly sericea lespedeza, is taller than the seedling; an opening for the seedling has been maintained with herbicide. When the seedling becomes taller than the surrounding vegetation, herbicide applications will no longer be needed.

How:

- Immediately after planting while the seedlings are still dormant, apply a pre-emergent herbicide in a band over the tree rows to reduce germination and emergence of herbaceous vegetation from seeds in the soil. This application will slow the herbaceous competition but will not prevent it.
- Band or spot-spray around the trees with a post-emergent herbicide in June or July. If sprayed, trees will be killed by most post-emergent herbicides. Careful, direct spraying with tree shields on spray wands is recommended.
- Repeat these herbicide applications for one or more additional years, as required, until the planted trees begin to overtop the herbaceous ground cover (see Figure 11).

Herbicide application is a specialized practice and service. Some professional tree-planting contractors also provide herbicide application services; herbicides should be applied by a contractor who is familiar with the tree planting arrangement. During the growing season, herbicides should be applied using tree-shields or other means and under calm atmospheric conditions to ensure that no herbicides contact leaves of planted trees. As the trees grow, develop canopy, and overtop the herbaceous ground cover, the competitive, sun-demanding grasses and legumes will yield to species that enter the site as seed, and herbicides will no longer be needed.

Some of the post-planting protections can be minimized when vegetation is controlled effectively prior to planting. For example: the dense sod covers that support bark-consuming voles and rodents, and the dense stands of sericea lespedeza that can be fire hazards when standing as dry stems in the early spring, can both be limited by an effective pre-planting weed-control herbicide application.

Browsing by deer, and possibly by elk, is another hazard, one that is difficult to predict and control. Occasional browse will slow the growth of young hardwood tree seedlings, but usually will not kill them.

Assess Survival of Planted Trees and Replant if Needed

Why: Stocking surveys are needed to determine success of the reforestation effort. To foresters, the term "stocking" means the number of living trees per unit area at a given point in time, and is usually expressed as trees/acre. If stocking is inadequate after the first growing season, additional planting can be done the following winter. If the reforestation steps were applied according to these guidelines, significant effort and money were spent to clear, till, and fertilize the area. A stocking survey followed by re-planting, if and where needed, will take advantage of the work already applied at significant expense.

What To Do: In September of the planted trees' first year, assess tree survival and stocking by determining the number of trees/acre still living. Mid-summer of the trees' first growing season is their most critical period; trees that survive the mid-summer heat and drought will generally make it through the fall and winter and into the next growing season. Assess site stocking (trees/acre) after the mid-summer heat has passed but while the trees still have their leaves so living trees are easy to identify.

How: Assess stocking by establishing circular 1/20 acre plots at various locations over the site; count surviving trees within those plots.

- To define a 1/20 acre circular plot, use a rope or tape measure with a radius of 26 feet 4 inches to define a circle around a fixed point. This circle is 1/20 of an acre in area.
- For small mine sites (10 acres or less), locate one plot per acre. For areas greater than 10 but less than 40 acres, locate one plot for every 2 acres. For areas greater than 40 acres, a total of 25 sample plots randomly located over the site will usually be adequate.
- Locate sample plots randomly across the planted acreage. One way to do this is to walk in a straight line across the planted area, locating sample points every 40 paces (80 steps).
- Count the number of planted trees within each 1/20 acre circular plot and multiply that number by 20 to estimate the number of trees per acre. Record this per-acre number for each plot.
- Repeat for all plots and add all plot values. Divide this total by the number of plots for an overall average trees/acre for the mined site.

Where weeds have been controlled successfully over the planted trees' first summer, one that has not been unusually hot and dry, site stocking of planted trees should be no less than 420 trees per acre, or 70% survival if 600 trees per acre were planted. If stocking is below this level, the site manager should work with the tree planter to determine the cause for poor survival. If the reason is poor seedling quality or improper planting, the manager can determine who is responsible and seek to engage that party in remedial re-planting. If first-year survival is not satisfactory, "holes" left by non-surviving trees should be re-planted during the next winter.

By the end of the third growing season, trees should be above the competing ground cover vegetation and free to grow. By this time, they should be established and beyond the point of imminent threat by competing weeds, rodents, and other pests. If all reforestation guidelines and procedures were executed properly, there will be little further tree mortality until self-thinning occurs after tree canopy closure at about age 12 to 15. A final stocking survey should be done after the third growing season using the same stocking survey procedures described above. At this time, a minimum of 400 well-distributed, healthy, trees/acre ensures reforestation success. This stocking could include desirable woody species that were not planted but volunteered on the site.

Summary: Step-by-Step Guidance

Table 2 is a step-by-step prescription and timeline for a full suite of site preparation treatments and forestry operations, as described above. Depending on site conditions, it is possible that not all of these treatments are necessary. For example, if the site assessment reveals little or no woody vegetation, no initial site clearing is needed.

Different combinations of these treatments may be needed depending on site conditions, cost, or availability of contractors. If sites are mostly covered by non-marketable native and non-native woody species, site clearing is needed and total reforestation costs could exceed $1000 per acre. When these procedures can be implemented prior to development of dense woody vegetation, reforestation costs can be significantly reduced.

Expected Outcome

Re-establishment of native Appalachian forests on reclaimed mine lands, that are not being used and managed for other purposes, can produce economic benefits in the form of marketable timber and environmental benefits such as watershed protection, carbon sequestration, and improved wildlife habitat. Until recently with the adoption of the Forestry Reclamation Approach (Forest Reclamation Advisory No. 2), common coal-mine reclamation practices under SMCRA were not adequate for establishing native, productive forests on mine sites, and often created conditions unfavorable to reforestation. When the guidelines described above are applied appropriately, productive Appalachian forests can be restored on these unused mined lands (Figure 12).

In addition to planting trees, necessary practices include site clearing to remove woody vegetation that interferes with tillage and planting operations; soil tillage ("ripping") with a dozer to mitigate soil compaction on the near-level and gently sloping sites where ripping can be conducted safely and where soil compaction is generally most intense; vegetation control to reduce competition by plants that would otherwise compete with tree seedlings for water, light, and nutrients; and fertilization to supply nutrients that are generally not available in sufficient quantities to support productive tree growth over the long term. Application of these practices will amount to a significant long-term investment. Where land managers are willing to make such investments, these practices can establish or restore forests and the products and services they provide (Figure 13).

Figure 12. Native hardwoods have been established successfully on a West Virginia mine site that was ripped to mitigate mine soil compaction. Hardwood seedlings can be seen growing on the mounds. The loose mine soil created by the ripping operation and the sparse nature of this tree-compatible ground cover have aided seedling survival.

Figure 13. This post-SMCRA mine site in Kentucky was reforested through application of techniques similar to those described in this publication, about eight years before this photograph was taken.

Table 2. Timeline and summary of recommended practices for restoring forest cover on lands that have been mined for coal and reclaimed using conventional practices. Cited costs are general estimates as of this writing. Herbicides are suggested as general guidance; site managers should obtain professional expertise, as needed, to ensure that herbicides are properly selected and applied for specific vegetation and site conditions.

Time	Task	Task Detail
PLAN		
Prior to July of Year 1	*Survey vegetation, test soil properties*	Survey the area as needed to assess vegetation, and test soil physical and chemical properties. Use the resulting information to develop a reforestation plan that is suited to site conditions.
PREPARE (Year 1)		
July	*Remove and control existing vegetation*	Broadcast spray a mix of glyphosate and triclopyr herbicides (e.g. Accord, Garlon) via ground or air for herbaceous and woody weed control, following label directions. Approximate cost is $100 per acre. Alternatively, employ a contractor to grind and chip all woody vegetation on site (approximate cost is $200 per acre) to be followed by broadcast spray of a herbicide such as glyphosate, glyphosate-2,4D, or glyphosate-triclopyr mix for herbaceous control, for approximately $100 per acre.
August - September	*Improve soil properties: Apply lime, if needed*	Apply lime as needed to raise pH to the 5.5 – 6.5 range. If soil test data are not available, apply lime at 4 tons/acre. Approximate cost is $15 per acre. If trees are to be fertilized using pellets, band- apply fertilizer P but not N.
October	*Improve soil properties: Deep-till and fertilize*	Till and mound (on the contour, if possible) with a deep-tillage tool with approximately 8 to10 ft spacing between center rows. Simultaneously band-apply in front of the plow, per acre, 250 pounds of diammonium phosphate and 75 pounds of potash with 20 pounds of pre-mixed micronutrients. Approximate cost is $400 per acre.
PLANT (Year 2)		
February-March	*Plant trees*	Plant a mix of commercially-valuable tree species at a rate of 600 trees per acre along with 100 mixed wildlife trees/shrubs. Approximate cost is $500 per acre. If banded fertilizer was not applied as part of the tillage operation, place a fertilizer pellet in the closing hole next to each tree seedling when planted. The fertilizer pellet should be a one-ounce, complete, slow-release fertilizer.

Table 2. **(cont.) Timeline and summary of recommended practices for restoring forest cover on lands that have been mined for coal and reclaimed using conventional practices. Cited costs are general estimates as of this writing. Herbicides are suggested as general guidance; site managers should obtain professional expertise, as needed, to ensure that herbicides are properly selected and applied for specific vegetation and site conditions.**

Time	Task	Task Detail
PROTECT		
		Year 1:
February-March	*Apply preemergent weed control*	Immediately after planting, band spray over the tree rows a pre-emergent herbicide following label directions. An oxyfluorfen product combined with pendimethalin product has proved effective. Approximate cost is $100 per acre.
May-June	*Apply postemergent weed control*	Band-apply or spot-apply herbicide around each tree seedling (*for example:* glyphosate plus 2,4-D or triclopyr) following label directions. Approximate cost is $100 per acre.
September	*Assess tree survival*	Survey tree stocking, determine if any re-planting is needed, and report on the success of the reforestation plan. Approximate cost is $30 per acre.
		Year 2:
January-March	*Replant if needed*	If the tree survival assessment reveals inadequate survival in any area, fill in between surviving trees as needed to assure adequate stocking.
February-March	*Repeat premergent weed control*	Repeat the preemergent herbicide treatment as necessary. Approximate cost is $100 per acre.
May-June	*Repeat postemergent weed control*	Repeat the spot-spray herbicide treatment as necessary. Approximate cost is $100 per acre.
		Year 3:
May-June	*Assess vegetation*	Walk the site to determine if the majority of planted trees have grown to the point where the uppermost leaves are above the herbaceous competition.
May-June	*Repeat postemergent weed control, if needed*	If/where planted trees are not above the herbaceous vegetation: Repeat the spot-spray herbicide treatment as necessary. Approximate cost is $100 per acre treated.
September	*Final stocking survey*	Survey tree stocking. Look for a minimum of 400 planted tress/acre.

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References

Powell River Project / Virginia Cooperative Extension (VCE) Publications: Available from Powell River Project (http://www.cses.vt.edu/PRP/) and Virginia Cooperative Extension.

Burger, J. A., and C. E. Zipper. *How to Restore Forests on Surface-Mined Lands*. VCE publication 460-123.

Burger, J. A., and C. E. Zipper. *Restoring the Value of Forests on Reclaimed Mined Land*. VCE publication 460-138.

Daniels, W. L., and C. E. Zipper. *Creation and Management of Productive Mine Soils*. VCE publication 460-121.

Appalachian Regional Reforestation Initiative (ARRI) Publications: Available from http://arri.osmre.gov/FRA.shtm

Forest Reclamation Advisory No. 1: *The Appalachian Regional Reforestation Initiative.*

Forest Reclamation Advisory No. 2: *The Forestry Reclamation Approach.*

Forest Reclamation Advisory No. 4: *Loosening Compacted Soils on Mine Sites.*

Forest Reclamation Advisory No. 5: *Mine Reclamation Practices to Enhance Forest Development Through Natural Succession.*

Forest Reclamation Advisory No. 7: *Planting Hardwood Tree Seedlings on Reclaimed Mine Land in Appalachia.*

Other References

Burger, J. A., D. Mitchem, and D. Scott. 2002. Field assessment of mine site quality for establishing hardwoods in the Appalachians. p. 226-240. In *Proceedings, American Society of Mining and Reclamation*, 226-240. Lexington, Ky.: ASMR.

Fields-Johnson, C., C. Zipper, D. Evans, T. Fox, and J. Burger. 2008. Fourth-year Tree Response to Three Levels of Silvicultural Input on Mined Land. In *Proceedings, 25th Annual Meeting, American Society of Mining and Reclamation*. Lexington, Ky.: ASMR.

Haering, K. C., W. Daniels, and J. Galbraith. 2004. The influence of overburden weathering and mining method on Appalachian mine soil morphology and properties. *Soil Science Society of America Journal* 68: 1315-1325.

Skousen, J., J. Gorman, E. Pena-Yewtukhiw, J. King, J. Stewart, P. Emerson, and C. DeLong. 2009. Hardwood tree survival in heavy ground cover on reclaimed land in West Virginia: Mowing and ripping effects. *Journal of Environmental Quality* 38:1400-1409.

U.S. Office of Surface Mining (US OSM). *2008 Annual Report*. Department of the Interior. Washington, D.C.

Zipper, C., J.A. Burger, J.M. McGrath, and B. Amichev. 2007. Carbon Accumulation Potentials of Post-SMCRA Coal-Mined Lands. In *Proceedings, 24th Annual Meeting, American Society of Mining and Reclamation*. Lexington, Ky.: ASMR.