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Fuel Breaks to Reduce Large Wildfire Impacts in Sagebrush Ecosystems

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Holloway Fire along the Oregon-Nevada border, 2012. Photo credit: InciWeb

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Purpose

This technical note provides a brief synopsis of proactive, linear fuel breaks as a tool for reducing negative impacts associated with large-scale wildfire in sagebrush ecosystems. The note summarizes what fuel breaks are designed to do, features of effective fuel breaks, specifications of common fuel break designs, and maintenance and management considerations based on a compilation of existing publications and practical lessons learned from past greenstrip and plant materials trials in the Great Basin. The purpose is primarily to provide practitioners with sufficient information to begin cooperative landscape planning efforts.

Background

Sagebrush ecosystems in the Great Basin are currently undergoing a period of significant transformation due to large-scale wildfires and accelerated fire frequency fueled by exotic annual grass invasion (Fig. 1; Balch et al. 2013, Brooks et al. 2015, Chambers et al. In Review). Longer, hotter and drier fire seasons (Westerley et al. 2006) have resulted in a dramatic rise in the number of *megafires* – fires that exhibit extreme behavior, exceed suppression capability, and grow exceptionally large (for our purposes, defined as 10s to 100s of thousands of acres). Due to the pace and scale of this landscape change, wildfire is now considered among the most urgent threats to sagebrush-obligate species, such as greater sage-grouse (Coates et al. 2015, USFWS 2015). The wholesale ecological state conversions from sagebrush steppe to exotic annual grasslands, as well as the loss of sagebrush cover over vast areas for extended periods of time, are of primary concern to conservationists. Large fires are also resulting in significant social and economic hardship for livestock producers forced to relocate animals and secure alternative forage.

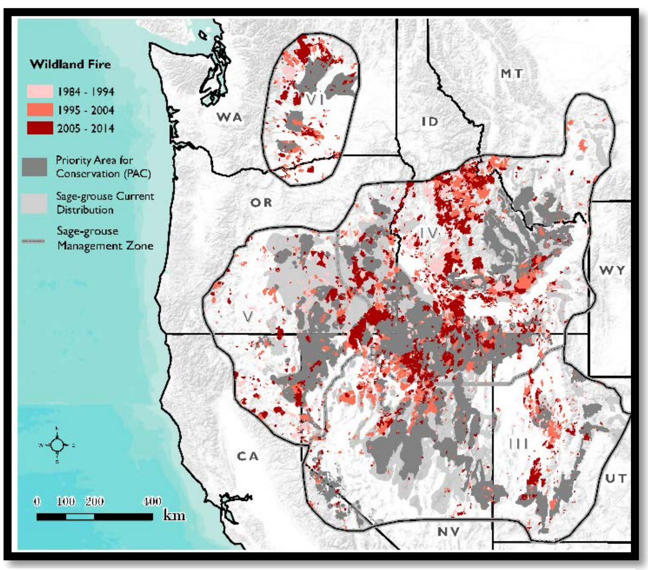


Figure 1. Wildfires (1984-2014) across the western range of sage-grouse (from Chambers et al. In Review)

Fire suppression efforts have been effective at stopping most fires during initial attack. Over 97% of all wildfires are kept to less than 1,000 acres and 99% less than 10,000 acres (Havlina et al. 2015, Murphy et al. 2013). However, the few fires (1-3%) that escape initial attack can grow exceptionally large. Since

2000, individual fires exceeding 100,000 acres in the sagebrush steppe – a phenomenon rarely seen over the past century – have become a near annual occurrence in the Great Basin. Fire managers describe these fires as occurring under a 'perfect storm' of conditions, such as, long-term drought, extreme fire hazard, high winds, low humidity, and multiple starts which make direct attack and control very difficult. Boosting suppression resources alone is often not sufficient to improve effectiveness under these conditions and only a change in weather permits containment. While predicting exactly where these events may occur is impossible, recent observations suggest many megafires are linked to cheatgrass-dominated areas which serve as primary ignition points and facilitate spread within large, contiguous stands of sagebrush (Baker 2011, Balch et al. 2013). Increased fuel continuity and loading, along with a longer burning period due to climate, has led to fire managers reporting that fires that no longer 'lay down' at night.

To improve firefighting capability, fire managers recommend more emphasis on presuppression activities, such as, the proactive installation of fuel breaks in strategic locations. The term "fuel break" is used broadly here to refer to a variety of activities ranging from vegetation manipulation and greenstrips to disking or roadbed manipulation.[1] Essentially, fuel breaks are a strip or block of land where the vegetation has been reduced, removed, or modified to reduce flame lengths and the rate of spread of oncoming wildfires. The National Wildfire Coordination Group defines fuel breaks as "a natural or manmade change in fuel characteristics which affects fire behavior so that fires burning into them can be more readily controlled." Well-placed fuel breaks can facilitate fire suppression efforts to reduce fire size and frequency by improving firefighter access and minimizing response times, providing safe and strategic anchor points for suppression, and compartmentalizing wildfires and constraining fire growth. Fuel breaks are not the solution to the wildfire problem in sagebrush ecosystems but are an important part of the presuppression toolbox to help reduce wildfire size.

What is the function of a fuel break?

Fuel breaks are designed to manipulate the fuels aspect of the fire behavior triangle (Fig. 2) – which is the only leg of the triangle management actions can control.

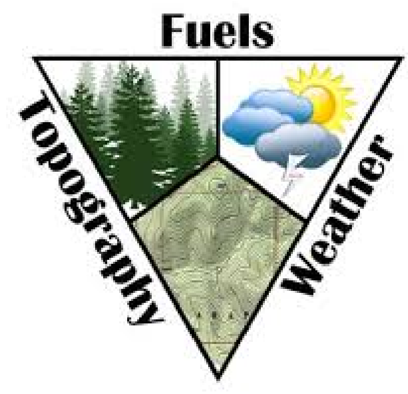


Figure 2. Components of the wildland fire triangle.

[1] Individual agencies may have specific criteria for fuel break related activities that should be adhered to when planning projects. For example, NRCS distinguishes between Fuel Break (383) and Firebreak (394) in their conservation practice standards.

Fuels management is directed toward modifying fuel properties to affect fire behavior.

Three key elements of fuels modification can be affected to improve fuel break function (Pellant 1994):

1. *Disrupt fuel continuity.* Fuel continuity can be disrupted by removing all or most of the vegetation (e.g., by mowing, disking, or applying herbicide) or replacing cheatgrass, which provides a continuous fine fuel, with discrete plants such as bunchgrasses or forage kochia, which have larger spaces between individual plants (Fig. 3). This treatment reduces the spread rate and intensity of surface fires since discontinuous fuels do not carry a fire as well as continuous fuels.

Figure 3. Creating separation between individual plants is a key aspect of disrupting fuel continuity as illustrated by the forage kochia greenstrip.

2. *Reduce fuel accumulations and/or volatility.* Stands of woody plants (e.g., shrubs, juniper) generates longer flame lengths and residence times compared to herbaceous vegetation and increases the probability of "spotting" ahead of wildfires in rangelands (Fig. 4). Big sagebrush and rabbitbrush have high volatile oil content, further promoting extreme fire behavior and intensity in shrublands. Also, replacing annual grasses with low-growing perennial bunchgrasses (e.g., Sandberg bluegrass) reduces fuel loading in most years which influences rate of spread and intensity.

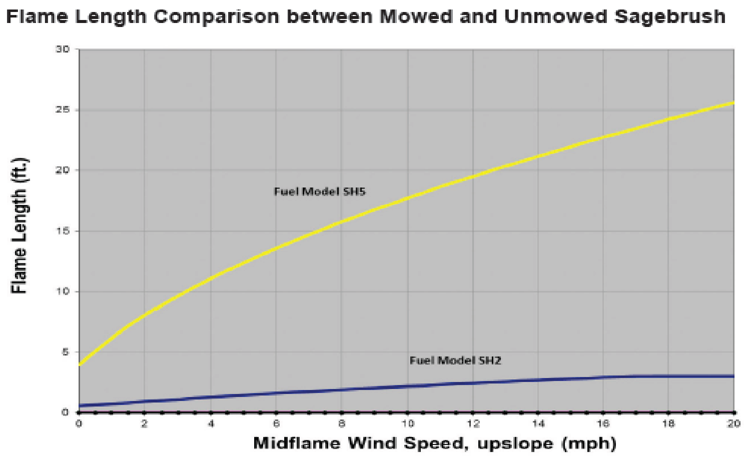


Figure 4. Generalized example of flame length comparison between the typical sagebrush fuel model (SH5) and a representative model (SH2) for mowed fuel. The graph shows the results of the BEHAVE+ fire behavior model in typical summer conditions with a 20 percent slope (from Moriarti et al. 2015).

3. *Increase the proportion of plants with a higher moisture content.* The moisture content of the various species in the plant community governs the length of time during the fire season when fuels and fire behavior are hazardous and ignition potential is high. Increasing the proportion of plants with high moisture and low volatile oil content can reduce both the potential for ignition and fire behavior.

Do fuel breaks work?

Fuel break effectiveness continues to be a subject of much debate yet relatively little research has been conducted evaluating their role in constraining wildfire size and frequency. In forested systems, some evidence suggests that fuel breaks play an important role in controlling large fires, but only when they facilitate fire management activities (Syphard et al. 2011a, b). In those studies, firefighter access to fuel breaks was found to be the most important determinant of effectiveness. Unfortunately, traditional fire behavior models do not capture the combined effects of fire suppression and fuel breaks. Despite the lack of scientific information, firefighters routinely say they use, and require, fuel breaks in wildfire operations (Moriarti et al. 2015).

According to a qualitative assessment based on interviews with BLM fire/fuels specialists in the Great Basin and information gleaned from the Fuel Treatment Effectiveness database (FTEM), fuel breaks are frequently observed affecting fire behavior and are considered important in controlling most wildfires (Moriarti et al. 2015). In that assessment, managers believed the primary purpose of fuel breaks is to allow firefighters to actively engage in fire suppression in a safe, strategic manner without committing an exhaustive amount of resources to contain the spread of wildfire (Moriarti et al. 2015).

While there are many instances of fuel breaks slowing or stopping fires on their own, they are typically not expected to operate in isolation. Fuel breaks are designed primarily to reduce the rate of spread, residence time, and intensity of wildfire and to be used in conjunction with firefighting resources (e.g., hand crews, dozers, air tankers, water tenders) to increase the odds of containment. Proactively established fuel breaks augment suppression efforts by providing firefighters better access and safe locations to establish anchor points and engage in wildfire suppression. While fuel breaks are less effective in slowing down head fires under extreme conditions, they can dramatically reduce the spread rate of a flaming front under normal conditions. In areas with pinion-juniper woodlands, fuel breaks are designed to move a high intensity crown fire onto the ground. Strategically placed fuel breaks can help contain flanking and backing fires using fewer resources, and provide safe anchor points to conduct burnout (backfire) operations for combating head fires.

Fuel breaks should not be expected to stop every fire even when combined with suppression resources. Syphard et al. (2011a, b) found only 22% to 47% of fires were stopped at fuel breaks even when firefighters could access them in forested systems, which emphasizes the importance of setting realistic expectations for effectiveness and ensuring fuel breaks are designed to be appropriate for the anticipated fire behavior. To borrow an engineering analogy, dams are designed to withstand certain events (100-, 500-year floods) and effectiveness of the structure is judged relative to the specified design event. In the sagebrush steppe, proactive fuel breaks are increasingly being considered to aid suppression of the 1-3% of fires escaping initial attack. However, fuel breaks must be designed within the bounds of other ecological, social, and economic considerations which influences potential options and effectiveness. Fundamentally, fuel breaks are about reducing risks, not eliminating them. What constitutes fuel break 'success' in an era of megafires increasingly beyond control may boil down to whether or not the practice alters fire behavior and allows suppression to reduce losses at a scale commensurate with the size of large fires. Land managers and owners must carefully plan fuel breaks to increase the odds that the practice will perform as intended for firefighters when needed.

Landscape Planning

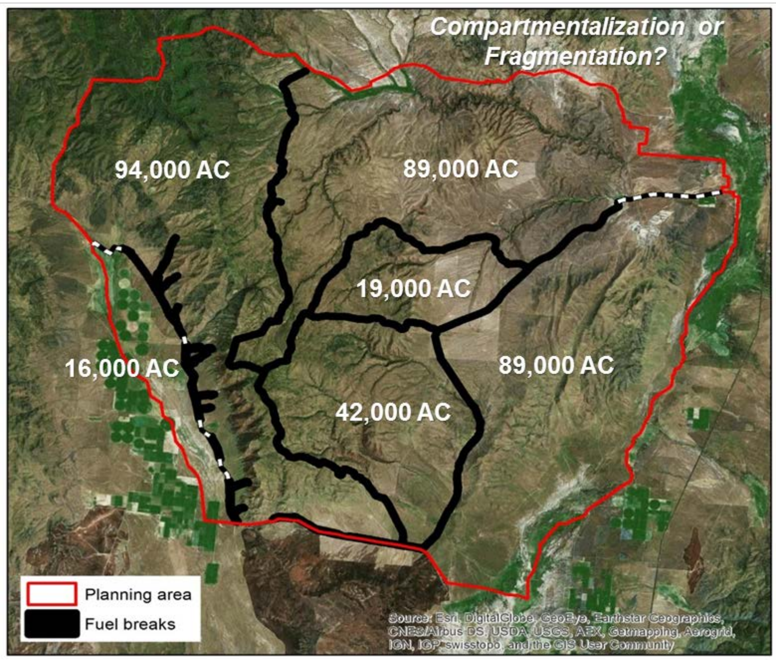
Understanding context and evaluating trade-offs

It is not uncommon for land managers to think 'too small,' such as an individual land ownership or specific location of high ecological value, when considering fuel breaks to reduce large wildfire risks in the sagebrush steppe. It is highly recommended that fuel break planning take a whole watershed/landscape view to match the scale of the wildfire threat. Working collaboratively with landowners, managers, and the fire and fuels community in the region to develop a strategic plan will help ensure fuel breaks are implemented in the right places and effectively utilized when fire occurs.

An important and early step in planning strategic fuel breaks is gathering information on the surrounding landscape context and scoping with interdisciplinary stakeholders and partners. While fuel breaks can be beneficial in reducing wildfire size and severity, there are many other environmental and social issues that must be considered. Key concerns include sage-grouse and other wildlife habitat fragmentation, risk of increasing invasive weeds, effects of non-native plant introductions on native plant communities, impacts to wilderness characteristics, and challenges with implementation across multiple jurisdictional boundaries. Ultimately, whether or not fuel breaks are appropriate for a particular landscape comes down to local stakeholders weighing risks against potential benefits and conducting appropriate assessments to evaluate social and environmental impacts.

In highly modified landscapes previously impacted by large fires, the benefits of fuel breaks can often outweigh potential risks. Fuel breaks in these landscapes can be used to reduce future fire frequency and allow for adequate recovery time for sagebrush and other perennial plants. In areas already converted to annual grassland, fuel breaks are an essential practice to help managers contain the problem from spreading to adjacent intact lands.

Fuel break implementation within relatively intact sagebrush-dominated landscapes requires much more careful consideration of trade-offs. While the goal is to maintain large and intact stands of sagebrush habitat, fuel breaks often involve manipulating or removing some sagebrush in order to reduce fuel continuity and loading. The potential reward of reducing future fire size needs to be weighed against negative side effects from intentional disturbance of the land today. Creating too much cumulative disturbance in the wrong locations can result in habitat fragmentation and other issues that work against conservation goals, such as, maintaining sage-grouse which are sensitive to very low levels of fragmentation on the landscape (Knick et al. 2013, Dahlgren et al. 2015). However, large fires are often occurring in these expanses of contiguous sagebrush, so planners must go through a risk management process with local stakeholders to determine the size of area they are willing to potentially see burned in one event (Box 1).



Box 1. By design, fuel breaks fragment the landscape into smaller compartments. Assessing trade-offs about whether or not this fragmentation is more likely to be detrimental or beneficial can be informed by considering the fuel break footprint relative to available sagebrush habitat in the project area and the size of the compartments being created. In this example, strategic fuel breaks are being implemented along roads to protect core sage-grouse habitat in about a 346,000-acre project area. Fuel break widths range from 200-800 ft (lines not to scale). Cumulatively, the fuel breaks were estimated to impact 1,466 acres or 0.4% of the total project area. Individual compartments still maintain relatively large blocks. In balancing potential risk with reward, local partners determined this fuel break system provided fire managers with options for limiting fire impacts if fire escaped initial attack without overly fragmenting important habitat.

Trade-offs between proactive fuels treatments and potential negative effects to sage-grouse underscore the importance of thoughtful planning and analysis involving interdisciplinary stakeholders. Detrimental impacts of disturbances involving sagebrush removal to sage-grouse populations are well established (Knick and Connelly 2011). Yet, if current wildfire trends continue, catastrophic sage-grouse population declines are forecast over the next 30 years without targeted intervention to reduce the cumulative area burned (Coates et al. 2015). Sage-grouse population increases normally seen during years of favorable weather are essentially negated when too much wildfire activity occurs near leks which, over time, steadily reduces population size (Blomberg et al. 2012, Coates et al. 2015). Few alternative solutions exist to curb current wildfire trends, but fire managers agree proactive fuel breaks give suppression resources the best chance to reduce large fire impacts to sage-grouse habitats and populations.

Incorporating available sage-grouse population information, such as lek locations and seasonal habitat use, is critical to designing fuel break networks that both minimize habitat impacts and maximize potential wildfire suppression benefits. A prudent first step would be to explore alternative locations for fuel breaks outside of, or adjacent to, priority habitats that would still reduce wildfire risks to acceptable levels. If this is not feasible, planners should seek to minimize the overall cumulative impact of fuel breaks to reduce unintended consequences.

Fuel break construction may also increase weeds in otherwise intact landscapes if not implemented and maintained properly. Merriam et al. (2006) found that nonnative plant abundance was considerably higher on fuel breaks than in adjacent wildland areas, especially when heavy ground disturbance was involved, providing a potential vector for weed invasion. However, fuel break construction and maintenance methods that retained perennial vegetation and minimized exposure of bare ground were much less likely to promote invasive plant species expansion. Even with minimal ground disturbance, weeds can increase with response varying along environmental gradients (e.g., warm-dry Wyoming big sagebrush to cool-moist mountain big sagebrush sites) and depends heavily upon existing plant communities (Davies et al. 2012, Pyke et al. 2014, Schupp et al. 2015).

Incorporating information on the relative ecosystem resilience to disturbance and resistance to invasive annual grasses can help managers evaluate trade-offs (Chambers et al. 2015). Soil temperature and moisture regimes can be used as a surrogate for potential sagebrush ecosystem resilience and resistance that can be readily depicted spatially using existing soil survey data (Maestas and Campbell 2014; Maestas et al. 2016). Relative resilience and resistance can also be assessed on-site using a combination of soils and vegetation information (Miller et al. 2014, 2015). Overlaying this information on project areas can help planners judge relative risks of detrimental impacts of wildfire at landscape scales. For example, lower elevation areas with warm and dry soils are less resilient to fire and more prone to conversion to cheatgrass than cooler and moister sites. Given the high risk of negative fire impacts and low success in rehabilitating these types of ecosystems, the need for strategically placed fuel breaks could be well justified to prevent catastrophic ecological state changes. Conversely, fuel breaks in cooler and moister areas are likely to be more heavily debated because favorable recovery after fire is much more likely with time. In these areas, fuel breaks would be installed primarily to reduce the potential for large fire to remove sagebrush from vast areas all at once.

Recently, the BLM engaged partners across the Great Basin in application of the Fire and Invasive Assessment Tool (FIAT) to identify priority landscapes where strategic fuel breaks should be considered to reduce wildfire and invasive annual grass impacts to important sage-grouse habitats (BLM 2014, USDI 2015; http://www.landscape.blm.gov/geoportal). The tool integrated key information, such as, sage-grouse distribution and abundance, existing land cover, and relative ecosystem resilience and resistance, to help partners regionally identify potential project areas where more detailed planning may need to be initiated. This exercise served as an important first step to gauge potential need across county and state boundaries, allowing agency decision makers to better understand context, weigh risks, and prioritize landscapes for accelerated stakeholder engagement and thorough planning to assess trade-offs and develop management alternatives.

Strategic placement

Since fuel breaks are a primarily a tool for fire managers to use, access is the number one priority for strategic fuel break placement. By utilizing known, existing road systems to access fuel breaks, habitat disturbance can be minimized and initial response time to wildfires can be reduced. Fuel breaks can be placed directly next to resource values at risk to provide point protection, or as compartments to minimize losses of landscape scale vegetation like sagebrush communities.

Fuel break planning should cross ownership boundaries in order to minimize risk of fire escaping containment lines. Gaps in fuel break lines across ownerships can significantly reduce the potential utility and effectiveness. Coordination with federal fire and fuels specialists, private landowners, Rangeland Fire Protection Associations (RFPAs), state agencies, and other land managers is critical when designing a network of strategic fuel breaks. Planning should ensure fuel breaks are contiguous, well known, and most importantly accessible, so fire managers can utilize fuel breaks effectively and safely during suppression activities.

Beyond improved accessibility during suppression, focusing fuel break implementation along existing road systems has additional advantages over dispersed fuel breaks. Placing fuel breaks along roads reduces negative ecological consequences of dispersed disturbance, such as, increasing weeds and wildlife habitat fragmentation. From a social standpoint, fuel breaks along roads are much more visible to the public and can create hazards of wildlife congregating along roads, however, restricting disturbance footprints to existing manipulated corridors may reduce controversy during NEPA scoping and increase buy-in needed to accelerate implementation. Keying in fuel breaks to existing roads increases effectiveness by taking advantage of mineral soil or paved surfaces to create a break in fuel continuity.

Finally, linear fuel breaks along roads are more easily and cost-effectively maintained over time allowing for proper weed control and retreatment if needed.

Additional information should also be used to inform decisions about fuel break placement. Topography, vegetation types (fuel loads), ignition density maps, estimated suppression response times, and location of existing presuppression resources can help stakeholders weigh risks of large fire and determine key locations for fuel breaks. It is frequently noted that large fires are fueled by atypical and erratic winds, so precise placement of fuel breaks based on prevailing weather or wind patterns may not be adequate.

From a fire manager's perspective, fuel breaks are most useful when:

- ***Implemented at the appropriate scale***
  - Think about whole landscapes not just postage stamps
- ***Strategically placed***
  - Firefighters need to know where they are and believe in them
- ***Proactively established***
  - Must be there when the fire breaks out
- ***Economical***
  - Must be practical to implement and maintain

Fuel Break Design Options

Summarized here are the primary linear fuel break techniques managers are using in the Great Basin today to reduce impacts of large fires. Exact specifications vary across the region and should be developed based upon site conditions and goals. Fuel break width in particular is contingent upon the fuel type and potential fire behavior. However, this list provides some common parameters used when implementing each alternative. It may be desirable to implement a combination of fuel break design options as part of a strategic landscape fuel break plan. Careful planning of each fuel break segment should be conducted to ensure the most appropriate option is implemented based on site conditions. Features such as streams, rock escarpments, or low fire risk plant communities (i.e. low/black sagebrush sites and meadows) can be effective fuel breaks and might reduce or eliminate the need for additional treatment (Davidson and Smith 1997). For a brief comparison of fuel break advantages, disadvantages, and costs see Appendix A.

A. Road Maintenance and Roadside Disking (Brown Strips)

Roads have been the primary form of control lines and in some cases provide the only source for a fuel break. Bladed roads and adjacent roadbeds can be very effective for controlling wildfires, and are the primary features firefighters use to help suppress wildfires. Road improvements alone, however, are not enough to suppress wildfires in heavy brush or during high wind events.

Creating "brown strips" using a disk or plow that completely remove strips of vegetation is the preferred treatment for reducing wildfire starts and spread along interstates and highways (Fig. 5). Disk lines generally range from 10 to 20 feet wide when implemented to catch fires initiated along roads. Brown strips would need to be considerably wider if implemented to stop or reduce spotting wildland fires. However, weedy plants often increase if not maintained annually. Also, soil erosion can be a concern on steeper slopes and highly erodible sites.

Figure 5. Roadside disking (Photo credit: Winnemucca District BLM).

Typical Design Features of Roadside Brown Strips:

- *10-20 ft wide along one or both sides of existing roads to catch road fire starts*
- *Plowed to mineral soil*
- *Implemented in late spring - early summer after last major precipitation*
- *Annual treatment at a minimum; re-plowed or chemically treated when plants reemerge*

B. Mowed Fuel Breaks

Mowed fuel breaks are the preferred treatment to limit wildfire size in or near intact sagebrush patches, especially where perennial herbaceous understory vegetation is adequate (Fig. 6). Fire managers recommend mowing strips of at least 100 to 300 feet immediately adjacent to roads, on both sides, depending on live fuel loading and resource objectives. Mowed strips must be wide enough to break large-scale, wind-driven fires that can produce 30- foot flame lengths. Fire managers typically suggest "the wider the fuel break, the better" but again this is a balance with other resource values and most state wildlife agencies have guidelines regarding fuel break widths in sage-grouse habitats. Vegetation should be mowed down to the lowest level feasible given the equipment being used and slope or rock limitations (generally at least 6 to 12 inches sagebrush height).

Reducing the shrub canopy through mowing can result in a release of herbaceous plants in the short-term (one to three-years), especially annual species (Davies et al 2012, Pyke et al. 2014). Additionally, mowing sites with limited perennial herbaceous vegetation should not be expected to recover without assistance. Follow-up chemical treatments and drill seeding should be planned as needed to prevent the spread of invasive plants and restore perennials (Davies et al. 2012, Pyke et al. 2014, Schupp et al. 2015).

Figure 6. Mowed fuel break along existing road.

Typical Design Features of Mowed Fuel Breaks:

- *100-300 ft wide from centerline of existing road (each side)*
- *Vegetation mowed as low as possible; retreatment when shrub re-growth >15 in average*
- *Implemented when fire risk is low*
- *Herbicide application as needed to reduce annual grasses and other weeds*
- *Seeding where herbaceous perennial plant density inadequate*

C. Vegetative Fuel Breaks (Greenstrips)

"Greenstripping" refers to the practice of establishing strips of perennial, fire-resistant vegetation in strategic locations to reduce the rate of spread and the intensity of wildfires. Individual plants growing in a greenstrip are normally widely spaced with areas of bare ground between which reduces the ability of fire to spread from one plant to the next. Decreased fuel, shorter plant height, reduced fuel continuity, and higher fuel moisture content of the plants growing in the greenstrip all help slow fire spread under normal conditions (Davidson and Smith 1997). A key advantage of greenstripping is that it requires relatively limited maintenance after establishment compared to other techniques. Another advantage is that properly timed livestock grazing can be used as a tool to reduce cheatgrass and lengthen the period that the greenstrip plants remain green. Greenstripping is a preferred method in areas that have undergone conversion to invasive annual grassland or areas highly susceptible to annual grass invasion. Strips 100 to 300 feet wide are recommended depending on slope, surface rock (which affects seeding success), and fuel break objectives.

Desirable plant materials for greenstrips should possess as many of the following attributes as possible (adapted from Monsen 1994, Pellant 1994, and Davidson and Smith 1997):

- Stay green (retain high moisture content) during a majority of the wildfire season
- Grow as widely separated individual plants (to reduce fuel continuity) or be relatively low height at maturity and produce relatively low amounts of fuel
- Be adapted to the site and able to persist through extended droughts
- Tolerate grazing
- Survive occasional burns
- Capable of establishing and persisting in competition with annual species

Few plant materials are able to meet all of these criteria, but suitable options are available across a variety of site conditions (Appendix B). Plant materials used in greenstrips should be selected primarily to meet the purpose of a functional fuel break. Well-intentioned efforts to satisfy multiple resource concerns with greenstrip plantings (e.g., wildlife habitat, livestock production) often result in the fuel break not performing as effectively as needed to meet fuels management objectives. For example, seeding productive forage grasses can result in too much biomass and litter if not consistently grazed at the appropriate time. Also, diverse mixes that include heavy component of short-lived forbs may give way to weeds if perennial grasses do not fill the gaps. While single species seedings of competitive plants are typically undesirable in rangeland seedings, they can be very effective in targeted fuel break applications especially in warmer and drier areas. Also, given the high likelihood of extended drought, it is critical to stick to plant materials that have a demonstrated ability to persist in the face of harsh conditions and heavy weed pressure. For example, since the 1980's, plant material trials at the Orchard Experimental Site near Boise, ID (3200 ft, 8-10" precip.), have revealed that some seeded species can establish and perform well for a decade or more but then completely disappear which emphasizes the need for long-term monitoring and careful selection of proven plants (Great Basin Fire Science Delivery Project 2011; Tilley et al. 2010).

Typical Design Features of Greenstrips:

- *100-300 ft wide from centerline of existing road (each side)*
- *Site preparation for seeding for 1-2 growing seasons*
- *Herbicide application as needed to reduce annual grasses and other weeds*
- *Seeding conducted in fall/winter*
- *Grazing deferment during establishment period needed*
- *Grazing used as a tool to maintain low fuel volume and seeded species*

Typical Greenstrip Scenarios

Scenario #1: Forage Kochia Only (synthesis below adapted from BLM 2011)

Forage kochia is the most preferred species for greenstrips because it possesses all of the attributes to create a functional fuel break (Fig. 7; Monsen 1994; Monsen and Memmott 1999; Harrison et al. 2002; St John and Ogle 2009; Waldron 2011). It has been effectively used in several fuel break projects across southern Idaho for almost thirty years (Harrison et al. 2002). Forage kochia re-sprouts from the base following fire (McArthur et al. 1990, Harrison et al. 2002), is highly competitive against invasive annual grasses and forbs (Tilley et al. 2012), which allows it to maintain bare ground between individual plants. Forage kochia has been shown to effectively reduce flame lengths and slow the spread of fires even in windy conditions (Harrison et al. 2002, Monsen and Memmott, 1999, Monsen 1994). In plant material trials, it has stood the test of time persisting on harsh, arid sites through extended periods of drought (Great Basin Fire Science Delivery Project 2011).

Despite the positive attributes of forage kochia for greenstrip purposes, the potential for it to spread into existing native rangelands with open and available niches may be a concern in some settings (Gray and Muir 2013). Reported recruitment or spread of forage kochia has been most strongly correlated with the level of soil disturbance in the surrounding area, lack of competition from other vegetation, and open spaces surrounding established kochia plants. Spread was also correlated with prevailing winds but this

Figure 7. Forage kochia greenstrip (Photo credit: BLM).

was determined to be of less significance (Harrison et al. 2000), likely because the seed for this plant has no mechanism for wind dispersal. Forage kochia seed does not persist in the digestive tract of ruminants, and therefore would not be spread by most grazing animals (Schauer et al. 2004). Forage kochia seed loses viability quickly, even under ideal processing and storage conditions (Tilley et al. 2012); therefore a soil seed bank is not likely to persist.

Multiple studies have found that forage kochia will spread into disturbed sites with abundant bare soil and few native perennials, but spreads very little into established shrub and perennial stands (McArthur et al. 1990, Clements et al. 1997, Harrison et al. 2000, Harrison et al. 2002, Sullivan et al. 2013). Monaco et al. (2003) found that ten years after seeding kochia, it had not moved into the adjacent cheatgrass stand. Similarly, 10 years after a greenstrip planting in Skull Valley, UT and 12 years after a greenstrip planting near Mountain Home, ID, forage kochia had spread very little into adjacent dense cheatgrass stands as reported in Harrison et al. (2002). Gray and Muir (2013) found that soil cover was a predictor of forage kochia spread, and suggested that this finding may indicate that bare soil is necessary for its establishment. Abundance of forage kochia was positively correlated with the number of fires since the kochia seeding occurred (Gray and Muir 2013), which may relate to the capability of kochia to resprout following fire.

Direct seeding is best accomplished in the fall or winter by broadcasting on top of the soil. Seed viability is generally limited to one year and use of fresh seed with a current germination analysis is highly recommended. If a drill is used for seeding, seed should not be placed deeper than 1/16-inch. Recommended full drill seeding rate for a pure stand is 2 lb/ac Pure Live Seed; double for broadcast seeding (Appendix B).

Scenario #2: Introduced Grass Single-Species Seedings and Mixes

Crested wheatgrass, seeded alone or in combination with other species, is a commonly used introduced grass in greenstrips (Fig. 8). Forage kochia and crested wheatgrass mixed seedings have also been applied extensively. Introduced forbs, such as, dryland alfalfa, blue flax, and small burnet have also been used in some mixes. Crested wheatgrass is often selected for greenstrip plantings because it establishes quickly and reliably, is competitive with invasive weeds, is palatable and can withstand livestock pressure, and is well adapted to persist in arid sagebrush systems. It also breaks up the continuity of cheatgrass by minimizing fine fuels in the interspaces during many years. However, if not actively mowed or grazed annually at the right time, it can produce a significant amount of fuel with low moisture content later in summer making it a less effective fuel break. If crested wheatgrass is used, preference should be given to less productive, shorter-statured varieties and a rigorous management plan followed to manage fuel loads. Siberian wheatgrass is an alternative to crested wheatgrass that has finer leaves, retains its greenness and palatability later into the summer, and yields less than most crested wheatgrass cultivars during average to better moisture years (St. John and Ogle 2009).

Figure 8. Crested wheatgrass greenstrips showing managed (left) and unmanaged (right). Unmanaged crested wheatgrass greenstrips can produce significant fine fuels and may be less effective. Crested wheatgrass may not preclude cheatgrass from occupying interspaces, as seen in photo on the right, which limits the ability to reduce fuel continuity (Photo credits: BLM).

Russian wildrye and sheep fescue are introduced grasses that have been less widely utilized but provide effective alternatives (Fig. 9). Russian wildrye is a long-lived very drought tolerant bunchgrass that produces abundant basal leaves that remain green and palatable late into the year as long as soil moisture is available. It can take up to 2-3 years to become well established, but it competes very effectively against undesirable plants and it withstands drought more effectively and is more palatable than crested wheatgrass and Siberian wheatgrass (Great Basin Fire Science Delivery Project 2011; St. John and Ogle 2009). Wide row spacing of ≥18 inches is recommended to create bare ground interspaces for greenstrip purposes (St. John and Ogle 2009). Sheep fescue is a long-lived short stature bunchgrass with low above-ground production, but poor palatability. The dense root system commonly excludes other species establishing in the interspaces between fescue plants, which works well for disrupting fuel continuity. Sheep fescue is best adapted to 14+ inch precipitation zones (St. John and Ogle 2009) which limits utility on warmer and drier sites where greenstrips are most commonly implemented. See Appendix B for additional plant material specifications.

Figure 9. Russian wildrye seeding 13 years after establishment in Idaho (middle). This species effectively excludes competition and produces less litter than many other species including Siberian wheatgrass (foreground and background).

Scenario #3: Low-Growing Native Species Mixes

Figure 10. Greenstrip consisting of low-growing natives (Photo credit: Winnemucca District BLM).

Recently, native plant materials have become more widely utilized for greenstrip purposes (Fig. 10). Sandberg bluegrass and bottlebrush squirreltail are the primary low-growing native grasses being seeded in parts of the Great Basin for this purpose. Western yarrow and Lewis flax (native plant similar to blue flax) are forbs commonly included in mixes. Traditionally, introduced species have been favored for greenstrips due for a variety of reason ranging from widely available, low-cost seed, to ease of establishment and competitiveness. With native species, preferred locally-sourced plant materials have become available in some areas making this an increasingly viable option.

These low-growing natives offer several advantages including significantly reduced fine fuel loads, superior drought tolerance, resilience to disturbance, reduced impacts to native habitats, and more social acceptance than introduced species. Once established and at full occupancy, Sandberg bluegrass and squirreltail can be highly competitive with cheatgrass as well, reducing biomass by 53-60% in one study (Goergen et al. 2011). Booth et al. (2003) showed that as little as 15-20% cover of squirreltail could eliminate cheatgrass completely (Booth et al. 2003). These species green up and cure early, but produce very little standing biomass thereby serving as effective fuel breaks during fire season.

Some concerns with the use of these species include longevity, establishment and persistence of full stands, availability of locally-adapted material, and lack of long-term data on performance for fuel break purposes. Sandberg bluegrass and squirreltail are generally considered early seral species and some stand thinning and plant composition transitions would be expected over time. Use of low-growing natives in greenstrips holds promise as viable technique as suitable seed sources become available but long-term monitoring must continue to better understand performance. See Appendix B for additional plant material specifications.

Establishing Greenstrips (adapted from St. John and Ogle 2009)

Site Preparation

Developing a new greenstrip requires the removal of the existing vegetation, preparation of a seedbed and the seeding of adapted plant material. Removing the existing vegetation reduces competition for water, nutrients and light, which allows new vegetation to become established. Seedbed preparation is often ignored in rangeland seedings (Davidson and Smith, 1997) and is a major reason for project failure. Seedbeds should be weed free, firm and moist prior to planting. The seedbed should be firm enough that a person’s heel-print does not go deeper than ¼ to ½ inch into the prepared seedbed. All weeds and the weed seedbank need to be controlled to reduce competition and to facilitate seedling establishment. Mechanical and/or chemical seedbed preparation strategies may be needed:

> *1) Conventional or Clean Tillage* – Seedbed is prepared with plows, discs, chisels, tool-bars using sweeps or other types of equipment. Mechanical seedbed preparation must bury cheatgrass seed at least 2½ inches deep to obtain effective cheatgrass control (Pellant, 1996). After the tillage operation is completed, the land should be given adequate time to settle and firm up on its own. The seed is then planted directly into the prepared seedbed using a disc or furrow type drill.

2) Chemical – On rangeland sites that are free of brush, seedbed is prepared with applications of a broad spectrum herbicide such as glyphosate and 2,4-D to control existing vegetation. Sites infested with annual grasses may require treatment with additional herbicides such as Imazapic (note: seeding may need to be delayed a year after Imazapic to reduce undesired residual impacts). Rangeland or no-till drills should be used if no mechanical seedbed preparation is used. If the weed competition cannot be controlled using chemicals alone, then conventional tillage and herbicide combinations are recommended.

Many land managers desiring instant results try to interseed without first controlling the existing vegetation, but this approach almost always fails on rangelands. This is because there is too much competition from existing established vegetation for limited water and nutrients. Therefore, interseeding is not recommended.

Seeding

Different plant materials generally feed through a seed drill at variable rates because of differences in seed size, seed shape and seed weight. Therefore, seed mixtures tend to separate with heavy seed migrating to the bottom and light seed migrating toward the top of the drill box as the drill bounces across the field during the seeding operation. When planting a mixture of different-sized seeds, it is recommended that a carrier such as rice hulls be used to facilitate the drilling operation (St. John et al. 2005).

Seeding is generally done during late fall or early spring dormant plantings. The rule-of-thumb for dormant fall plantings is to have the seed in the ground late enough so seed does not germinate until spring, and for spring plantings, get the seed in the ground as early as planting equipment allows. The advantage of an early spring seeding is that it allows one additional weed control operation (control of winter germinated species such as cheatgrass and medusahead) just prior to or during the planting process. However, if the soil is not moist to about a foot deep in the spring, the possibility of increased stand failure exists. Deferring the planting until fall is recommended given the uncertainty of the timing and amount of spring and summer precipitation.

In general, a rangeland drill equipped with an agitator, double disc openers, depth bands and packer wheels is ideal. No-till or depth band-equipped drills limit the surface disturbance reducing damage to existing biological crusts and perennial plants, reducing soil erosion, and limiting cheatgrass invasion. This type of equipment provides optimal seed placement at proper depths, with good seed-to-soil contact for moisture retention. Seeding difficulties can often arise when the drill is filled too full with seed. Never fill a drill more than half full. Filling the drill to the top frequently results in seed bridging on one or more of the openers. Other difficulties arise when the drill is not properly calibrated and/or in poor operating condition (see St. John et al. 2007 for calibration information). Always check the drill before filling it. Common issues that interfere with seed flow include: rusty gears, grease globs, mouse or wasp nests, and bag string collecting in slots of feed mechanism, as well as, cracked, plugged and kinked delivery tubes.

Many shortcomings of a drill can be overcome with a properly prepared seedbed. For example, a weed free and very firm seedbed will allow a drill without depth bands to place seed at the proper depth if the spring tension on the openers is reduced. If the drill is not equipped with press wheels, drag chains can be installed behind the openers and/or the field can be rolled or cultipacked following planting to ensure good seed-soil contact. Drills equipped with furrow openers can be modified by fastening delivery tubes behind the openers so the seed falls into the furrow and is properly firmed or pressed with the packer wheels. The Truax Roughrider drill provides an alternative to the standard rangeland drill with its ability to control seeding depth hydraulically and minimize surface disturbance with a minimum till mechanism (Shaw et al. 2011).

Post-Seeding Management

Plantings should be inspected at the end of the first growing season to evaluate seeding establishment. Care must be taken when evaluating rangeland seedings since first year results may be misleading unless closely examined. Often good seedling establishment is masked by heavy weed growth. Many such stands have been plowed up and reseeded, when another year of deferment and observation could have allowed the seeded perennials to become fully established and eliminate the weeds through competition. However if seeding failure is obvious upon careful inspection, assess the need for additional weed control in the upcoming fall or spring in order to maintain a well prepared site and plan for reseeding. If weeds are not an issue, reseeding can occur in the fall following the first growing season.

More established seedings fail for lack of post-seeding treatment and grazing management than for any other reason within management control. Early control of weeds eliminates competition and allow establishment of a vigorous stand. Weeds can be controlled using selective herbicides or by mowing above the desired seedlings and prior to seed set by the weeds. Seedlings must receive adequate protection until they become established plants. Not only are plants more easily overgrazed during the establishment period, they can sometimes be pulled out of the ground by grazing animals. As a general rule, grazing should be deferred until the first seed crop is mature, after which only light grazing during that season should be allowed. Grazing deferment may need to occur through the end of the second or third growing season. Establishment may take even longer for native species plantings. For this reason, it is critical that greenstrip planting be coordinated early with livestock permittees and landowners so they can incorporate rest needs into their grazing management plans.

Monitoring and Maintenance

Fuel breaks should be viewed as long-term infrastructure requiring periodic maintenance, rather than a one-time practice. Agencies and landowners implementing the practice should plan for an on-going commitment of resources upfront. Monitoring and maintenance needs will depend upon the fuel break technique used but all options will require regular inspection for weed problems and performance issues.

On mowed fuel breaks and greenstrips, herbicide treatment of weed infestations along with additional seeding in places may be needed to maintain perennial vegetation and prevent fuel breaks from becoming a weed vector. Also, regular applications of pre-emergent herbicides to control cheatgrass will help reduce fine fuels and promote desired perennials. As native shrubs recover and herbaceous litter accumulates, mowing may also be needed to maintain fuel break function by removing dead plant material and invigorating seeded species.

Grazing must also be closely managed to support proper fuel break function. Livestock and wildlife are often attracted to greenstrips, which can result in overuse and eventual loss of seeded species. If areas of unsustainable use occur, adjustments in livestock timing, intensity, or duration may be needed since few options exist for limiting wildlife use. Conversely, livestock should also be viewed as an important tool for reducing fine fuels and maintaining seeded species. Establishing a grazing strategy that is benign or beneficial to the predominant species in the fuel break can help extend the lifespan of the practice. Targeted grazing to remove current year's growth prior to onset of fire season can be an effective way of ensuring greenstrips are 'green' and fire resistant when it matters most. Reducing fuels outside of fuel breaks using targeted grazing is another option beyond linear fuel breaks that is currently being evaluated for application in reducing large fires (for more information on this technique, see: http://greatbasinfirescience.org/highlight/2015/10/26/science-resources-targeted-grazing-for-fuels-management).

Glossary of Key Fire/Fuels Terms (NWCG 2016: http://www.nwcg.gov/glossary/a-z)

Anchor Point: An advantageous location, usually a barrier to fire spread, from which to start constructing a fireline. The anchor point is used to minimize the chance of being flanked by the fire while the line is being constructed.

Backing Fire: 1) Fire spreading, or ignited to spread, into (against) the wind or downslope. A fire spreading on level ground in the absence of wind is a backing fire. 2) That portion of the fire with slower rates of fire spread and lower intensity normally moving into the wind and/or down slope. Also called: heel fire.

Burning Out: Setting fire inside a control line to consume fuel located between the edge of the fire and the control line.

Burning Period: That part of each 24-hour period when fires spread most rapidly; typically from 10:00 AM to sundown.

Direct Attack: Any treatment applied directly to burning fuel such as wetting, smothering, or chemically quenching the fire or by physically separating the burning from unburned fuel.

Extended Attack: Actions taken on a wildfire that has exceeded the initial response.

Extreme Fire Behavior: Extreme implies a level of fire behavior characteristics that ordinarily precludes methods of direct control action. One or more of the following is usually involved: high rate of spread, prolific crowning and/or spotting, presence of fire whirls, strong convection column. Predictability is difficult because such fires often exercise some degree of influence on their environment and behave erratically, sometimes dangerously.

Fine Fuels: Fast-drying dead or live fuels, generally characterized by a comparatively high surface area-to-volume ratio, which are less than 1/4-inch in diameter and have a time lag of one hour or less. These fuels (grass, leaves, needles, etc.) ignite readily and are consumed rapidly by fire when dry.

Fire Behavior: The manner in which a fire reacts to the influences of fuel, weather, and topography.

Fire Presuppression: Activities undertaken in advance of fire occurrence to help ensure more effective fire suppression. Activities includes overall planning, recruitment and training of fire personnel, procurement and maintenance of firefighting equipment and supplies, fuel treatment and creating, maintaining, and improving a system of fuel breaks, roads, water sources, and control lines.

Fire Season: 1) Period(s) of the year during which wildland fires are likely to occur, spread, and affect resources values sufficient to warrant organized fire management activities. 2) A legally enacted time during which burning activities are regulated by federal, state or local authority.

Fire Severity: Degree to which a site has been altered or disrupted by fire; loosely, a product of fire intensity and residence time.

Firebreak: A natural or constructed barrier used to stop or check fires that may occur, or to provide a control line from which to work.

Flame Length: The distance between the flame tip and the midpoint of the flame depth at the base of the flame (generally the ground surface), an indicator of fire intensity.

Flank Fire: A firing technique consisting of treating an area with lines of fire set into the wind which burn outward at right angles to the wind. (synonym: Lateral Fire)

Flanking Fire Suppression: Attacking a fire by working along the flanks either simultaneously or successively from a less active or anchor point and endeavoring to connect two lines at the head.

Fuel Break: A natural or manmade change in fuel characteristics which affects fire behavior so that fires burning into them can be more readily controlled.

Fuel Continuity: The degree or extent of continuous or uninterrupted distribution of fuel particles in a fuel bed thus affecting a fire's ability to sustain combustion and spread. This applies to aerial fuels as well as surface fuels.

Fuel Moisture Content: The quantity of moisture in fuel expressed as a percentage of the weight when thoroughly dried at 212 degrees F.

Head Fire: A fire spreading or set to spread with the wind. (synonym: Advancing Fire)

Indirect Attack: A method of suppression in which the control line is located some considerable distance away from the fire's active edge. Generally done in the case of a fast-spreading or high-intensity fire and to utilize natural or constructed firebreaks or fuel breaks and favorable breaks in the topography. The intervening fuel is usually backfired; but occasionally the main fire is allowed to burn to the line, depending on conditions.

Initial Attack (IA): A preplanned response to a wildfire given the wildfire's potential. Initial attack may include size up, patrolling, monitoring, holding action or suppression.

Rate of Spread: The relative activity of a fire in extending its horizontal dimensions. It is expressed as rate of increase of the total perimeter of the fire, as rate of forward spread of the fire front, or as rate of increase in area, depending on the intended use of the information. Usually it is expressed in chains or acres per hour for a specific period in the fire's history.

Residence Time: The time, in seconds, required for the flaming front of a fire to pass a stationary point at the surface of the fuel. The total length of time that the flaming front of the fire occupies one point.

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Appendix A. Comparison of typical fuel break alternatives.

Fuel Break	Typical Settings	Advantages	Disadvantages	Cost
Roadside Disking	-Along highly disturbed corridors with high likelihood of ignitions -Primary roads, interstates and highways	-Mineral soil with no fuels is the most effective fuel break	-Annual treatment required -High potential for wind and water erosion on erodible soils and steeper slopes -Disturbed areas serve as weed corridors, especially if not maintained annually -Road improvement on secondary dirt roads can increase human access and disturbance	$30-50/ac annually -Herbicide may be needed to control weeds
Mowed Fuel Breaks	-Relatively intact sagebrush communities with adequate perennial understory	-Minimizes ground disturbance -Maintains native perennial herbaceous vegetation if present	-Fuels reduced but not removed -Can increase herbaceous fuels on some sites -Can encourage rabbitbrush (highly volatile) over time -Regular re-treatment required as shrubs recover	$30-50/ac, recurring 5-10 years -Regular herbicide applications may be needed to control weeds
Greenstrips	-Areas highly susceptible to annual grass invasion (warm/dry sagebrush sites) or impacted by repeated fire	-Relatively limited maintenance -Ability to reduce continuity between plants and increase proportion of plants with higher moisture content	-Fuels reduced but not removed -Increased upfront cost -Visual impacts on landscape -Potential for introduced plants to spread	$100-500/ac -Depends upon plant materials cost at time of establishment and degree of site prep -May require reseeding if failure

Appendix B. Common plant material options for greenstrips.

Name	Origin[1]	Lifeform	Relative Height	Seedling vigor	Longevity	Precip. Zone (in)	Soil Texture Fine	Med	Coarse	Seeds/lb	Drill Seeding Rate PLS (lb/ac)[2]	Seeding depth (in)	Recommended releases
Sandberg Bluegrass ***(Poa secunda)***	N	Bunchgrass	Low	Low - Med.	Long	8-18	X	X	X	1,000,000	2	0-1/4	[3]High Plains, Reliable, Mountain Home
Bottlebrush Squirreltail ***(Elymus elymoides)***	N	Bunchgrass	Low	Med.	Long	8-18		X	X	220,000	7	1/4-1/2	[3]Fish Creek, Toe Jam Creek, Rattlesnake, Pueblo, Wapiti, Pleasant Valley, Antelope Creek
Thickspike Wheatgrass **(*Elymus lanceolatus*)**	N	Sod Forming Grass	Mid-Tall	Med.	Long	8-16	X	X		135,000	6	1/4-1/2	'Sodar', 'Critana', 'Bannock', 'Bannock II'
Russian Wildrye ***(Psathrostachys juncea)***	I	Bunchgrass	Tall	Low	Long	8-12	X	X		170,000	6	0-1/4	Bozoisky II, Bozoisky Select
Siberian Wheatgrass ***(Agropyron fragile)***	I	Bunchgrass	Tall	Med.	Long	8-16	X	X	X	160,000	6	1/4-1/2	Vavilov, Vavilov II
Crested Wheatgrass ***(Agropyron cristatum or desertorum)***	I	Bunchgrass	Mid - Tall	Rapid	Long	9-16	X	X	X	165,000	5	1/4-1/2	Hycrest, Hycrest II, Nordan, Summit
Sheep Fescue ***(Festuca ovina)***	I	Bunchgrass	Low	Low	Long	12-22	X	X		680,000	4	0-1/4	'Covar', 'Bighorn'
Forage Kochia ***(Kochia prostrata)***	I	Subshrub	Mid	Low	Long	8-16	X	X	X	395,000	2	0-1/16	Immigrant
Western Yarrow ***(Achillea millefolium)***	N	Forb	Low - Mid	Low	Med.	8-60		X	X	4,400,000	0.5	0-1/8	[3]Eagle, Yakima, Great Northern
Blue Flax ***(Linum perenne)***	I	Forb	Mid	Low-Med.	Short	10-20		X	X	278,000	4	0-1/8	Appar
Alfalfa ***(Medicago sativa)***	I	Forb	Tall	Med.	Med.	12-25	X	X		200,000	5	1/16-1/2	Ranger, Ladak
Small Burnet ***(Sanguisorba minor)***	I	Forb	Mid	Med.	Med.	15-25	X	X		42,000	26	1/4-1/2	Delar

[1]N=Native, I=Introduced

[2]Represents single species drill seeding rate; when seeding a mixture, adjust seeding rates to match the desired percentage of the mix. Plant spacing: Broadcast or 12-inch drill rows with the exception of Russian wildrye (18+ inch spacing); seed rates should be doubled for broadcast seeding

[3]For native species, it is preferable to use seed that comes from a population that nearest approximates the planting site; if not available, use the recommended release that is best adapted to site conditions (see TN 24)