# Evaluation of Effectiveness and Cost-Benefits of Woolen Roadside Reclamation Products: Material Selection

## Task 2 Report

Prepared by:
Rob Ament
Road Ecology Program Manager
Western Transportation Institute
College of Engineering
Montana State University, Bozeman

Monica Pokorny and Stuart Jennings
Senior Ecologist and Principal Scientist
KC Harvey Environmental, LLC
Bozeman, Montana

Prepared for:
Montana Department of Transportation
2701 Prospect Avenue
P.O. Box 201001
Helena, MT 59620-1001

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# Glossary

| | |
|---|---|
| Batt | a piece of felted or carded wool material in rolls or sheets, such as wool |
| Carding | a mechanical process to disentangle unorganized clumps of wool fiber and align them to be parallel with one another |
| Felt | a textile that is produced by matting, condensing and pressing fibers, such as wool, together |
| Needle felt | "barbed" needles in machines enter wool and grab top layers and intertwine them with interior layers of fibers in a continuous repeated process to make wool fabric |
| Noil | short fiber removed by the combing of wool |
| Roving | a slightly twisted roll or strand of unspun wool fiber |
| Scour | the removal of wool wax (lanolin), suint (perspiration), dirt, excrement, dust and other matter from the fleece in water. |
| Wet felt | warm soapy water is applied to layers of wool and it is repeatedly agitated and compressed to make a single piece of fabric |
| Worsted | wool or yarns that have a long staple length (4 inch fibers and longer only), are carded *and* combed, are stronger, finer, smoother and harder than woolen yarns/wool |

# 1 INTRODUCTION

This document is the Task 2 Report for evaluating the effectiveness of woolen roadside reclamation products. The overall objective of the project is to evaluate wool products that can be used for roadside reclamation projects by the Montana Department of Transportation (MDT) and other transportation agencies. The project seeks to develop and test potential wool products that can be easily produced as complementary or replacement products to existing standard best management practices (BMPs). The project will laboratory test selected promising wool reclamation products to assure they meet specifications for MDT and Federal Highway Administration (FHWA) deployment. Field tests of the woolen products will evaluate their effectiveness compared to standard practices. The project will also conduct a cost benefit analyses of successful lab and field tested wool products and develop an implementation plan for the top performing wool products.

The subject of this report and the primary objective of Task 2 is to identify and develop wool products with the potential for roadside applications. Task 2 conducted a review of existing woolen reclamation materials, and woolen products with the potential to be further developed for roadside reclamation purposes. There were three product areas explored:

- Existing woolen products produced abroad (i.e. New Zealand) that are not available in the United States.
- Woolen products made in the U.S. for horticultural or residential purposes that could possibly be utilized in roadside reclamation efforts.
- New woolen reclamation materials that could be produced by Montana wool producers or other manufacturers.

Task 2 reviewed, explored, developed, and secured the most promising woolen materials for roadside reclamation. Task 2 also sought to assure that there is an adequate supply of the wool reclamation product to meet the needs of the transportation sector, assuming the product proves to be successful after its acquisition or development and its performance in lab, field, and cost-benefit evaluations.

# 2 BACKGROUND

Highway right-of-way management following construction on MDT lands requires creating conditions conducive to the establishment and survival of reclamation plantings while controlling soil erosion, and sedimentation into adjacent water bodies. Woolen reclamation products have many attributes that may make them superior to existing standard roadside reclamation materials. This project seeks to develop and test the effectiveness of woolen erosion control, soil retention and vegetation establishment products for roadside reclamation purposes. Wool products will be compared to existing BMPs that often use imported coconut fiber (coir) erosion control fabrics or synthetic non-biodegradable geotextile materials.

Erosion control fabrics generally meet the requirements established by the U.S. Department of Transportation, Federal Highway Administration's standard specifications for construction of roads and bridges on federal highway projects. These specifications for materials are incorporated into each state department of transportation's handbook. There are several types of erosion control blankets (ECB): temporary, extended, and semi-permanent. One of the most commonly used ECBs produced is comprised of a straw filler between two layers of coconut fiber (coir) mesh which is a Type 3.B extended term ECB. Extended term ECBs, particularly Type 3.B are the focus of this project's wool product development. They are designed to have a functional longevity up to 24 months, can be deployed on slopes with gradients up to 1 vertical to 5 horizontal (1V:5H) and used in channels (MDT 2014). Extended term ECBs are intended to reduce soil erosion, water run-off and improve the seedlings' environment for their establishment and growth.

Roadside reclamation products containing wool may perform similarly or better than standard straw/coconut ECBs. Scoured weed-seed free wool can store up to 400% of its weight in water (Upton 2003). Wool becomes saturated at 33% of its weight of moisture-free fibers (D'Arcy 1990). That is, when scoured wool absorbs water greater than 33% of its weight, the moisture is more readily available for plant growth and adsorption. This characteristic could make woolen erosion control blanket more advantageous in drier climates. In addition, sheep wool contains up to 17% nitrogen and can act as a slow release fertilizer for plant growth and development (Herfort 2010). Research from Europe testing the use of woolen fabrics for establishing vegetation on green roofs resulted in over three times more plant canopy cover when wool was used in mats compared to standard coconut fiber mats (Herfort 2010).

Two other potential woolen roadside reclamation materials explored for this project are silt fence and using wool as an additive to wood-based mulch. The standard silt fence normally deployed by transportation agencies is currently made of synthetic woven materials and must be removed after a highway project is concluded. There is potential for the development of a wool silt fence that could be 100 percent biodegradable and potentially left in place, leaving sediments and the reclamation site undisturbed at the conclusion of the project.

With wool's high nitrogen value and water holding capacity it may be a relatively inexpensive addition to wood mulch (compost) to boost revegetation establishment. Wood mulch is commonly used after seeding roadsides to protect and enhance seedling growth. In other countries, New Zealand for example, pelletized sheep wool (often mixed with sheep manure) is

commercially available and can be added to compost to speed up the decomposition process or is sold as a fertilizer (see Daltons at: http://www.daltons.co.nz/home-gardening/retail-products/organic/organic-sheep-pellets). Adding wool to standard wood compost on roadsides may serve to increase nitrogen availability for seedling establishment and growth and improve moisture retention of the compost blanket.

# 3 MATERIALS AND METHODS

Woolen products were identified for testing in roadside applications by searching for products on the internet, working with the Montana Wool Lab at Montana State University, and contacting and working with U.S. based wool producers and woolen mills. Woolen products were identified and placed into three broad categories: 1) wool products produced abroad, 2) wool products currently used for horticulture and landscaping in the U.S. that may have roadside applications, and, 3) U.S. wool mill products with the potential to develop for new roadside reclamation uses and/or products (Table 1).

**Table 1. Woolen products identified or developed for roadside reclamation from abroad, existing U.S. products for horticulture or potential U.S. products to be developed or used in a new way.**

| Product and Manufacturer | Produced Abroad | Existing U.S. Product | New Use or Product Development |
|---|---|---|---|
| BioWool 400, wool matting, Cirtex Industries, New Zealand | X | | |
| Biomac Woolmulch, Maccaferri, New Zealand | X | | |
| TerraMat Wool, GeoTech Systems Ltd, New Zealand | X | | |
| EcoWool Mulch Mats, Advance Landscape Systems, New Zealand | X | | |
| Wool Mulch Mat, Terra Lana, New Zealand | X | | |
| Twool, Twool Twine, England | X | | |
| Thermafleece, Eden Renewable Innovations, England | X | | |
| Woolch, Grazeland Farm, Minnesota, U.S. | | X | |
| Blow-in Wool Insulation, Brookside Woolen Mill, MT | | X | |
| Wet Felted Wool Batts, Sugar Loaf Wool Mill, MT | | | X |
| Needle Felted Wool Batts, Brookside Woolen Mill, MT | | | X |
| Carded Wool Batting, Sugar Loaf Wool Mill and Thirteen Mile Lamb and Wool Company, MT | | | X |
| Noils, Montana Wool Lab, MT | | | X |
| Loom Salvage, Faribault Woolen Mill, MN | | | X |
| Washed/Scoured Wool, Brookside Woolen Mill, MT | | | X |
| Wool / Straw ECB, Ramy Turf Products, Mankato, MN | | | X |

## 3.1 Existing Woolen Products Produced Abroad

The top four wool producing countries in the world are China, Australia, New Zealand, and the United Kingdom (United Nations 2012). A literature and internet search located woolen products produced abroad that are not available in the United States. For products with potential for use along roadsides, product samples were procured to review product integrity and qualities prior to purchasing. Product samples were also sent to Montana woolen producers to determine whether they could make a similar product.

### 3.1.1 Biowool, Cirtex Industries

Cirtex Industries in New Zealand manufacture BioWool, a non-woven, 100% pure wool matting using recycled and fleece wool. Cirtex BioWool 400 is a biodegradable wool matting used for protecting cut faces and exposed soil from wind and water erosion, and is used around horticultural plantings where it provides plants with nutrients as it degrades (Cirtex 2014; Figure

1). In addition, BioWool assists vegetation establishment while insulating the seed and root zones from extremes of heat and cold through moisture penetration. The BioWool 400 fabric also suppresses weeds while allowing establishment of plants, therefore reducing the need for chemical sprays (Cirtex 2014). Being a natural, recycled product also provides aesthetic advantages over synthetic products. BioWool 400 is available in 2 meter (m) x 50 m (6.6 feet (ft) x 164 ft) rolls.


**Figure 1: Biowool, BW 400, product sample from Cirtex Industries in New Zealand.**

### 3.1.2 Woolmulch, Geofabrics New Zealand, Ltd., formerly Maccaferri, Ltd.

Geofabrics New Zealand, Ltd. is a geosynthetics company specializing in providing products and engineering solutions for the preservation of the environment. Geofabrics® manufactures Biomac Woolmulch, 100% wool matt reinforced with a jute mesh. It is used for landscaping and plant establishment, along with protecting soils from erosion. Biomac Woolmulch has the following advantages over synthetic products (Geofabrics 2015):

- Wool provides insulation for improved plant growth
- The non-woven structure allows surface water penetration while reducing evaporation of moisture from the soil
- Better surface contact is achieved which improves erosion resistance to overland flow
- Its biodegradable material releases valuable nutrients for improved plant growth
- Thicker wool mats reduce sunlight for inhibiting weeds

Biomac wool matting is supplied in two densities: 500 grams (g)/$m^2$ and 300 g/$m^2$ (14.8 ounces (oz)/yard (yd)$^2$ and 8.9 oz/$yd^2$).

### 3.1.3 TerraMatt Wool System, Geotech Systems, Ltd.

Geotech Systems, Ltd. of New Zealand makes three different wool products for erosion control and to help vegetation establishment via its TerraMatt Wool system. The three wool products are: plain wool blanket, the wool blanket reinforced with jute, and wool plant collars. These short-term erosion control and revegetation blanket remains functional for 12 to 24 months. All three products are needle punched wool mats made from recycled sheep's wool fiber.

TerraMat Wool is designed to be an effective soil erosion protection system that also promotes the establishment vegetation on roadside slopes up to 1:1 slopes and can be applied to steeper slopes with additional staking (Geotech 2013). Thus, TerraMat products can be used for embankments, filled side slopes, drainage channels and stream banks, along with applicability for roadsides.

### 3.1.4 EcoWool Mulch Mats, Advance Landscape Systems

EcoWool Mulch Mats made by Advance Landscape Systems in New Zealand are 100% natural and manufactured from waste wool. EcoWool Mats are 500 g/m$^2$ (14.8 oz/yd$^2$) and sold in two sizes: 450 x 450 mm (17.7 inch (in) x 17.7 in) or 360 millimeter (mm) x 360 mm (14.2 in x 14.2 in) squares. Due to their pre-cut nature and easy placement around tree/shrub bases, EcoWool Mulch Mats are recommended in any size tree and shrub planting projects where soil conservation and weed suppression are required (Advance Landscape Systems 2011).

The EcoWool Mulch Mat allows for effective penetration of water and fertilizer, as it stays damp for hours after wetting while reducing evaporation and erosion. Because the product is made from wool, it contains nitrogen, sulfur, sodium, potassium, and magnesium that are released into the soil as it gradually degrades two to three years after installation (Advance Landscape Systems 2011). Eco-Wool also suppresses unwanted vegetation growth around establishing plants by blocking out sunlight (Advance Landscape Systems 2011).

### 3.1.5 Wool Mulchmat, Terra Lana

Terra Lana's Mulchmat produced in New Zealand is a fully biodegradable non-woven wool matting made from pure and recycled wool. Since it is a natural product made from wool, Mulchmat is biodegradable and releases nutrients giving growing plants a boost (Terra Lana 2014). Mulchmat suppresses weeds, prevents soil erosion and soil moisture loss while insulating plants from temperate extremes. The benefits of Mulchmat aid in the establishment of plant species when used in landscape plantings, horticulture, and native species re-revegetation. Terra Lana Mulchmat has a density of 500 g/m$^2$ (14.8 oz/yd$^2$).

Terra Lana also produces a reinforced version of the MulchMat that is strengthened with jute fiber (Terra Lane 2014). This product is ideal for stabilizing soil on slopes and is also 500 g/m$^2$ (14.8 oz/yd$^2$) consisting of 300 g/m$^2$ wool (8.9 oz/yd$^2$) and 200 g/m$^2$ jute (5.9 oz/yd$^2$). Both products are supplied in rolls or pre-cut mats for placing around trees (Terra Lane 2014).

### 3.1.6 Twool Twine, Provenance Company Ltd.

Twool® twine is a 100% wool, British alternative to imported jute twine. It is made from 'lustre' long wool from a rare breed of Whiteface Dartmoor sheep (Twool 2012). The long staple length makes the twool exceptionally strong and durable while maintaining wools soft and springy

attributes. Twool® is available in 100 m (328 ft) and 35 m (115 ft) spools, and in woven bags (Figure 2). Twool® is currently used as a garden product that is compostable, turning into a slow-release fertilizer as it degrades (Twool 2012).

**Figure 2: Wool bag made from woven Twool.**

### 3.1.7 Thermafleece, Eden Renewable Innovations

Thermafleece Original is an insulation product that combines natural and recycled fibers for an optimal density for thermal and acoustic performance. The product is 85% wool, 15% polyester binder for enhanced performance, durability and sustainability. Eden Renewable Innovations' research found that using 75% wool in combination with recycled fibers outperforms alternative products with a higher percentage of wool (Theremafleece 2014). The wool fiber is capable of absorbing more moisture (40% of its weight) than any other natural fiber due to its high fiber saturation point. The complex protein structure of wool fibers allows it to absorb indoor air pollutants creating a healthier indoor environment (Thermafleece 2014). Thermafleece Original is sold in 1,200 meter (3,937 ft) sections. It is available in 400 mm or 600 mm (15.7 in or 23.6 in) widths and 50 mm, 75 mm and 100 mm (2 in, 3 in, and 4 in) thicknesses.

## 3.2 Two Existing U.S. Woolen Products

Literature and internet searches were used to identify horticultural or landscaping woolen products made in the U.S. that could possibly be utilized in roadside reclamation efforts. One product, Woolch is used in gardening but may have roadside applicability. Another product is blow-in wool insulation that may be ideal for incorporating in to roadside hydromulching or blow-on compost applications.

### 3.2.1 Woolch, Grazeland Farm, Minnesota

Woolch™ is a blend of recycled wool and wood. The wool is waste fiber from the Faribault woolen mill in Minnesota and the wood slivers are a waste by-product from a sawmill. The wool

and wood fibers are blended, sprayed with a green vegetable-based dye, and then fused together via a roller and heat process (Figure 3). Woolch™ provides effective weed control for two years. Woolch allows for water and nutrients to move through the fibers and plant stolons can root through it from the top.

The wool mulch stabilizes soil temperature, retains moisture, and increases plant yields. As it degrades, it provides nutrients to the soil. It is used by preparing the soil for planting, installing Woolch™ on the soil surface, and cutting holes in the fabric for planting. The Woolch™ product is available in row strips 38 x 152 cm (15 x 60 in), tomato pad squares 51 x 51 cm (20 x 20 in), container mats 1.2 x 1.5 m (4 x 5 ft), and large rolls 1.5 x 24.4 m (5 x 80 ft).

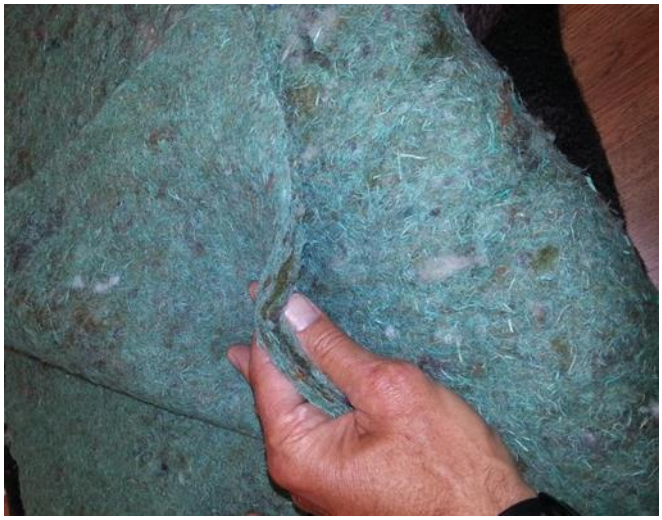

**Figure 3: Woolch™ product has wool and wood fibers.**

### 3.2.2 Blow-in Wool Insulation, Brookside Woolen Mill, Montana

Blow-in insulation is washed and scoured wool that is cut into 1.9 centimeter (cm) (¾ in) pieces (Montana Green Insulation 2011). The length and color of the wool fibers are not important. The cut wool fibers can easily pass through a blow-in insulation machine to residential attics. The loose pieces can be applied at various densities and is more useful for filling small, uneven spaces than standard bats. Brookside Woolen Mill markets this on the internet under the name Montana Green Insulation.

## 3.3 New Woolen Reclamation Materials

The last category of woolen products searched were products that are readily made in the U.S. but are made for non-roadside reclamation purposes. These are products produced by Montana wool producers or other manufactures where the roadside use could diversify the product usefulness and versatility, and expand market and income possibilities for producers. For example, a strong felted wool material could be used to replace non-biodegradable silt fence. The wool silt fence equivalent would not have to be removed at the end of the construction project and could add nitrogen to the area as it decomposes.

To identify potential wool products currently being manufactured by woolen mills in Montana, we visited and met with Brookside Woolen Mill of Malta, Montana (Brookside); Thirteen Mile Lamb and Wool Company of Belgrade, Montana (13 Mile); and, Sugar Loaf Wool Carding Mill in Hall, Montana (Sugar Loaf). We also worked with the manager of the Montana Wool Lab (Dr. Lisa Surber) at Montana State University to identify potential wool products and producers for this research project. Finally, we engaged producers of industry standard erosion control blanket (ECB) products made of coconut and straw to discuss the potential for substituting imported coconut fibers with locally developed wool.

### 3.3.1 Wet Felted Wool Blanket, Sugar Loaf Wool Carding Mill, Montana

Felt is a textile that is produced by matting, condensing and pressing fibers together. The wool is first washed and scoured. Wool can be transformed into felt using the techniques of needle felting and wet felting. Wool is manipulated during wet felting when hot soapy water is applied to layers of animal hairs placed at ninety-degree angles to one another. Repeated agitation and compression causes the fibers to hook together into a single piece of fabric. Felting can be used to make simple shapes or flat pieces. Felted material is used in a variety of industries including automotive, musical instruments, home construction, home décor, and clothing. For example, in the automotive industry, felted wool damps the vibrations between interior panels and prevents dirt from entering into joints.

Sugar Loaf produces wet felted wool mats. These mats are the same weight approximately 400 $g/m^2$ (12 $oz/yd^2$) as roadside reclamation materials produced in New Zealand (Figure 4). Sugar Loaf offers the options of producing the wet felted mats in a variety of weights in a three foot width. Sugar Loaf wet felted wool has the potential for making the following roadside reclamation products: ECB, weed mat, or silt fence.

**Figure 4: Wet felted wool samples from Sugar Loaf Wool Carding Mill.**

### 3.3.2 Needle Felted Wool Blanket, Brookside Woolen Mill, Montana

Needle felting is dry wool fibers tangled/matted together using a barbed felting needle. The wool is first washed and scoured. Needle felting can more easily control the final shape of the product. The needles used in industrial felting have notches along the shaft of the needle that grab the top layer of fibers and tangle them with the inner layers of fibers as the needle enters the wool. The tangled and compressed felt produces a strong material suitable for a variety of uses.

Brookside produces needle felted wool mats. This local Montana wool mill can produce the wool mats in a variety of felted weights, widths, and densities (made by manipulating the number and direction of needle passes). Brookside needle felted wool has a potential for roadside reclamation use as an ECB or weed mat.

### 3.3.3 Wool Batting, Sugar Loaf Wool Mill and Thirteen Mile Wool Company, Montana

Wool batting is a roll or sheet of wool fiber. The wool is washed and scoured then put through a carder. The carder can make batts that are a blend of multiple fiber types or a blend of fiber colors. Traditional uses are for mattresses, bedding, upholstered furniture, and insulation.

Two Montana wool mills, Sugar Loaf and 13 Mile make wool batts. The batts produced are approximately up to 1.2 meters wide and 0.9 meters long (4 ft x 3 ft). Both companies can produce the batts in a variety of weights and colors (Figure 5). The wool batting has a potential for roadside reclamation use as an ECB when used in conjunction with a natural (i.e., cotton) open mesh retention layer.

**Figure 5: Wool batting produced at Sugar Loaf Wool Carding Mill in Hall, Montana.**

### 3.3.4 Noils, Montana Wool Lab, Montana

The process of combing cleans plant matter, dirt, and other foreign substances from the wool. Combing also removes the short and immature fibers called noils. As noil is a relatively short fiber, the fabric made from noil is weaker and considered less valuable. In order to spin a uniform worsted yarn, the noil must be removed.

A sample of noils was received from the Montana Wool Lab at Montana State University. The coarse noils are of interest as a low quality wool product that may be able to be incorporated into ECB or blow-on compost material for roadside reclamation uses.

### 3.3.5 Loam Salvage, Faribault Woolen Mill, Minnesota

Founded in 1865 in Fairibault, Minnesota the Faribault Woolen Mill is an icon of American woolen craftsmanship. Faribault woolens are renowned for their quality woolen blankets. The mill weaves blankets on a loam and uses a polyester fiber to add strength to the woven wool fiber. The mill produces large quantities of loam salvage from the weaving machines. The salvage is woven pieces of wool fabric cut from loams. This loam salvage is a waste material that sells for low cost and has the potential to be used in an ECB.

### 3.3.6 Washed/Scoured Wool, Brookside Woolen Mill, Montana

Washed and scoured wool of 7.6 - 17.8 cm (3 - 7 in) fibers, or cut into shorter fibers, is available at the Brookside Woolen Mill (Figure 6). The color of the wool fibers or the contamination with hair is not important. The long wool fibers have the potential to be mixed with straw to make ECB. It could possibly be a substitute for imported coconut fibers while adding the water holding and nutrient benefits of wool. The loose pieces sell at a relatively low cost and could be added to ECB in a variety of straw/wool ratios. The washed and scoured wool pieces can also be shredded which may be beneficial for incorporation into an ECB (Figure 7).

**Figure 6: Washed and scoured wool sample from Brookside Woolen Mill.**

**Figure 7: Washed, scoured and shredded wool sample from Brookside Woolen Mill.**

### 3.3.7 Wool/Straw ECB, Ramy Turf Products, Mankato, Minnesota

Started in 1932 as part of Ramy Seed Company, Ramy Turf Products is a family owned and operated business specializing in the supply of premium quality grass seed mixtures and erosion control products. Many of their offerings are specific to erosion control including silt fence, wattles, erosion control blankets, and hydroseed mulches. Their ECB manufacturing facility allows them to produce and develop products with a variety of technical specifications. For example, they have produced approved materials for all Minnesota Department of Transportation (DOT) and most Wisconsin DOT categories and classes. Ramy Turf Products was approached for collaboration in developing a pure wool and wool/straw blends of ECB due to their long-term working relationship with KC Harvey Environmental, LLC, their ability to manufacture ECB and their interest in product research and development (Figure 8).

**Figure 8: Photo of demonstration site where two different wool:straw ratio erosion control blankets produced by Ramy Turf Products are staked next to each other on a slope being reclaimed after recent construction along Interstate Highway 90 near Belgrade, Montana.**

# 4 RESULTS

## 4.1 Existing Woolen Products Produced Abroad

The New Zealand and English wool products were promising for roadside reclamation uses in Montana. Unfortunately, shipping products to Montana was cost prohibitive. For example, the cost of one roll of 2 m x 50 m (6.6 ft x 164 ft) Cirtex Biowool BW 400 was NZD $400 with a shipping cost of $2,750 NZD. Acquiring adequate amounts of materials in a timely manner would have been cost prohibitive for the project. As a result, our research team elected to work with local wool mills and manufacturers in the U.S. to produce similar products.

## 4.2 Existing U.S. Woolen Products

The sample of Woolch™ received from Grazeland Farms easily separated fibers and pulled apart. While this product may be suitable for small-scale garden use, it would not be durable enough for large-scale roadside applications.

The 1.9 cm (¾ in) blow-in insulation produced at Brookside is composed of short wool fibers that could possibly enhance wood compost. Blower trucks apply wood-based mulch and this is a common practice for highway reclamation projects by MDT and other state highway agencies. The research team selected to test applications of adding wool fibers to standard compost used by MDT. To test wool as a compost additive, initially the research team will need to investigate the appropriate ratio of wool:compost suitable for roadside applications (Table 2).

## 4.3 New Woolen Reclamation Products

Wet felted wool from Sugar Loaf and needle felted wool from Brookside are to be tested for uses in roadside reclamation. A variety of weights/densities of these products will be tested as ECBs. Wool batting produced by 13 Mile will be tested in a variety of weights and colors to determine their usefulness as ECB. Washed/scoured and washed/scoured/shredded fibers of wool were selected for testing in a mixture with straw as filling in ECBs developed by Ramy Turf Products.

Two products were not selected for further testing as woolen reclamation products. The noils material appeared to become matted and unsuitable as a blow-on compost product. The loam salvage was also eliminated from further testing due to the presence of small amounts (<10%) of polyester fibers used in the weaving process that make the produce non-100% biodegradable (Table 2).

**Table 2: Summary of wool products reviewed for further testing in the project.**

| Product and Manufacturer | Selected for Preliminary Testing | Comments |
|---|---|---|
| BioWool 400, wool matting, Cirtex Industries, New Zealand | No | Cost prohibitive due to shipping |
| Biomac Woolmulch, Maccaferri, New Zealand | No | Cost prohibitive due to shipping |
| TerraMat Wool, GeoTech Systems Ltd, New Zealand | No | Cost prohibitive due to shipping |
| EcoWool Mulch Mats, Advance Landscape Systems, New Zealand | No | Cost prohibitive due to shipping |
| Wool Mulch Mat, Terra Lana, New Zealand | No | Cost prohibitive due to shipping |
| Twool, Twool Twine, England | No | Not a suitable product |
| Thermafleece, Eden Renewable Innovations, England | No | Not a suitable product |
| Woolch, Grazeland Farm, Minnesota, U.S. | No | Not durable enough for large-scale roadside applications |
| Blow-in Wool Insulation, Brookside Woolen Mill, MT | Yes | Selected as an addition for compost applications |
| Wet Felted Wool Batts, Sugar Loaf Wool Mill, MT | Yes | Selected for testing as ECB and silt fence |
| Needle Felted Wool Batts, Brookside Woolen Mill, MT | Yes | Selected for testing as ECB |
| Carded Wool Batting, Sugar Loaf Wool Mill and Thirteen Mile Lamb and Wool Company, MT | Yes | Selected for testing as ECB |
| Noils, Montana Wool Lab, MT | No | Material becomes matted and appears unsuitable for compost addition |
| Loom Salvage, Faribault Woolen Mill, MN | No | The woven pieces have a non-biodegradable fiber |
| Washed/Scoured Wool, Brookside Woolen Mill, MT | Yes | Selected for testing as a component of an ECB |
| Wool / Straw ECB, Ramy Turf Products, Mankato, MN | Yes | Selected for testing as ECB |

# 5 IMPLEMENTATION

## 5.1 Preliminary Field Trials

Based on the evaluation of the sixteen wool products from around the world, the research team worked with the three Montana wool mills to develop and manufacture a variety of select wool fabrics that were considered to be the most promising for roadside reclamation products – erosion control blankets, ditch liners, silt fences or wool as an additive to wood-derived compost (Table 3). Three different wool fabric manufacturing methods – carding, wet felting, and needle punch felting - were used to create 1 m x 1 m (3.3 ft x 3.3 ft) test batts of material for preliminary testing. In addition, after exploration of the appropriate amount of wool to add to wood compost was completed, two ratios of scoured wool:compost were created to test in 1 m by 1 m test plots.

**Table 3: Woolen products identified for preliminary field trials.**

| Woolen Product | Source |
|---|---|
| 407 g/m$^2$ (12 oz/yd$^2$) wet felted wool batt | Sugar Loaf Wool Mill |
| 203 g/m$^2$ (6 oz/yd$^2$) wet felted wool batt | Sugar Loaf Wool Mill |
| 68 g/m$^2$ (2 oz/yd$^2$) carded wool batt (dark and grey) | Thirteen Mile Lamb and Wool Company |
| 136 g/m$^2$ (4 oz/yd$^2$) carded wool batt (dark and grey) | Thirteen Mile Lamb and Wool Company |
| 203 g/m$^2$ (6 oz/yd$^2$) carded wool batt (dark and grey) | Thirteen Mile Lamb and Wool Company |
| 271 g/m$^2$ (8 oz/yd$^2$) carded wool batt (dark and grey) | Thirteen Mile Lamb and Wool Company |
| 40:1 compost:scoured & cut wool (1.9 cm (0.75 in)) | Brookside Woolen Mill |
| 20:1 compost:scoured & cut wool (1.9 cm (0.75 in)) | Brookside Woolen Mill |
| Single layer, single pass, needle felted wool batt | Brookside Woolen Mill |
| 2 crossed layers, double needle felted wool batt | Brookside Woolen Mill |
| ½ layer – 4 times needle felted wool batt | Brookside Woolen Mill |

Similar to the ECBs from New Zealand - BioMac Woolmulch and the Terramat Wool system - the research team was aware that wool fabric by itself would most likely not have the strength necessary to replace standard short-term ECB, ditch liner or plastic silt fence materials currently used by MDT. The Biomac Woolmulch and Terramat Wool system's manufacturers offered options to add fibers or mesh to the wool matts to give them the appropriate tensile strength to withstand steep slopes, endure for at least one to two years and control erosion.

The Montana wool mills did not have the appropriate equipment or machinery to add natural or synthetic fibers to their wool products, to enhance the woolen fabrics with various stitching patterns or to apply layers of natural or synthetic mesh to the wool product. Thus, our preliminary field trial focused on the amount of wool and the type of manufacture process of the wool matt that would be most successful for roadside applications. The manufacture of the ultimate wool reclamation product, its ability to meet FHWA specifications for the category of product it seeks to replace (i.e., ECB, silt fence), and the appropriate type of strengthener to use with the wool in the manufacturing process was not the focus of the preliminary field trials. Those concerns are to be addressed later after the different types of wool batts performance is evaluated. Laboratory tests are to be completed in Task 3 and the specifications for the type of reclamation product the wool batt is targeted for will be decided for this task.

The focus of the preliminary field tests was to determine if the weight, color or type of method to create the wool fabric would promote or impede seedling germination or growth through the material. A series of side-by-side plots were established in a private field south of Bozeman in the summer of 2014. Test plots, 1 m x 1 m (3.3 ft x 3.3 ft) in size, were established in rows and a typical MDT seed mix of perennial grasses (Table 4) was hand broadcast on each plot before the woolen batts or mulch was applied. The seed mix was given to the project by MDT and bought from Bruce Seed Farm, Inc., Townsend, Montana. Prior to installation, the area was cleared of vegetation using glyphosate (Roundup®) and raked to create good seed to soil contact.

**Table 4 : Typical MDT perennial grass seed mix and seeding rate used for preliminary test plots.**

| Common Name | Scientific Name (Cultivar) | Percent of Seed Mix | Seeds/lb | PLS/lb (Percent Live Seed) | Seeding Rate (lbs/acre) | PLS/ft$^2$ | Seeding Rate (kg/ha) | Seeding Rate (g/m$^2$) |
|---|---|---|---|---|---|---|---|---|
| Sheep Fescue | *Festuca ovina* | 29% | 680,000 | 675,648 | 2.5 | 39 | 2.8 | 0.28 |
| Thickspike wheatgrass | *Elymus lanceolatus spp lanceolatus* | 29% | 154,000 | 152,306 | 2.5 | 9 | 2.8 | 0.28 |
| Canada wildrye | *Elymus canadensis* | 29% | 115,000 | 108,008 | 2.5 | 6 | 2.8 | 0.28 |
| Canada Bluegrass | *Poa compressa* | 14% | 2,500,000 | 2,441,000 | 1.25 | 70 | 1.4 | 0.14 |
| | **TOTAL:** | **100%** | **3,449,000** | **3,376,962** | **8.75** | **124** | **9.8** | **0.98** |

All test plots were constructed near Bozeman, MT, on 10 June 2014, except for the needle felted products which were installed 8 September 2014. Each woolen product had one replication. In addition, the carded wool batting had a dark and light grey color version of each product (Figure 9). Wool products were secured on each test plot by covering with mesh netting and sod staples.

**Figure 9: Field trial set-up to identify the products for large-scale testing.**

**Figure 10: Seedlings are able to penetrate the 68 g/m$^2$ and 136 g/m$^2$ carded wool batting (left), but had difficulty penetrating the 203 g/m$^2$ and 271 g/m$^2$ carded wool batting (right).**

## 5.2 Results of Preliminary Field Trials

The test plots were visually assessed for their ability to provide ground cover and allow seedling establishment and penetration of the woolen material (Figure 10). In general, the color of the wool batting did not impact seedling establishment. Therefore, dark wool batts could be used for the project's two year field trials, which was beneficial because they more closely resembles soil colors and are less expensive than white wool. We found the denser wool products (203 g/ $m^2$ – 407 g/$m^2$ (6 oz/$yd^2$ - 12 oz/$yd^2$)) did not readily allow seedling penetration. Instead, the seedlings lifted these thicker wool products from the soil surface decreasing their ability to retain soil and moisture, nor prevent erosion. Therefore, the wet felted wool batt (407 g/$m^2$ (12 oz/$yd^2$)), and the 203 g/$m^2$ (6 oz/$yd^2$) and 271 g/$m^2$ (8 oz/$yd^2$) carded batts were eliminated from the subsequent two year field trials of Task 4 (Table 5).

## 5.3 Geotextile Manufacturing

In the fall of 2014 and winter of 2015, the research team explored the potential of engaging a manufacturer of rolled erosion control materials that also supported re-vegetation. We contacted Ramy Turf Products, LLC, (Ramy) of Mankato, Minnesota which makes many different standard ECB products that are deployed in Montana and other northern states (i.e., Minnesota, North Dakota, and Wisconsin). The research team was interested in Ramy because of their experience in making short-term (1-2 years) rolled ECBs, and sought their support in developing prototype woolen ECBs for the research project (Ramy Turf 2015).

As part of this exploration of potential wool ECBs, Brookside in Malta, Montana was the only large facility to scour (clean) wool for use by other businesses. For example, they currently scour wool for use as a natural, hypoallergenic blow in insulation and this is marketed and sold as Green Montana Wool Insulation (Montana Green Insulation 2011). The insulation is washed/scoured and then cut to lengths of approximately 1.9 cm (3/4 in). These short wool fibers are then shredded. Brookside also makes the precursor to this product which is washed/scoured 1.9 cm (3/4 in) wool fibers. These two types of fibers were the type of wool material that Ramy thought might be possible to use in its ECB roller machinery and could be mixed with straw.

Ninety-one kilograms (200 lbs) each of the two different scoured wool products were used for experimentation in the winter of 2015. Ramy investigated how each of the two wool products performed in their ECB roller and machinery (Figure 11). They also experimented with different proportional mixes of wool and straw. Ramy determined that the best wool product to use in the ECB roller was the 1.9 cm cut and shredded product from Brookside. Ramy made a variety of wool ECB prototypes including pure wool and 30:70 wool:straw ratios in the ECB fill. The fill material is approximately 542 g/$m^2$ (1 pound/$yd^2$) of material. Thus, pure wool short-term rolled ECB would contain approximately 542 g/$m^2$ (16 oz/$yd^2$) and 50:50 wool:straw would contain approximately 271 g/$m^2$ of wool and 271 g/$m^2$ of straw (8 oz/$yd^2$ of wool and 8 oz/$yd^2$ of straw).

**Figure 11: Screen capture from a video of Ramy experimenting with pure wool fill in the ECB roller to produce short-term ECB blankets for this research project.**

Ramy discovered that its machinery readily accepted wool in its hoppers and that they could mix straw and wool at different ratios (Figure 12), particularly if they had Brookside's cut and shredded wool product. They conducted a process of trial and error to become familiar with how the wool behaved in the roller machinery and how to get it into a mixture with the straw. A Ramy business partner stated that it only took one hour to convert the ECB roller operation from its standard manufacturing function to one that could use wool.

**Figure 12: Screen capture of a video of Ramy experimenting with a wool-straw combination for fill in the roller to produce short-term ECB blankets.**

The results of the experimentation were rolls of ECB of different wool and straw ratios. These rolls were sent to the WTI research team for their review. The research team and a representative of MDT found the products to be very similar in appearance and function to standard short-term ECB rolls. It was observed that there were a variety of mixes of wool and straw as fill, but it was the two external mesh layers that give the material its strength. Thus, pure wool and wool:straw of different ratios that filled the experimental ECBs could be installed and secured on roadside slopes exactly the same as standard rolled short-term straw fill ECB materials.

As a result of the success of Ramy's experimental production, the research team ordered an additional 363 kg (800 lb) of 1.9 cm (3/4 in) cut and shredded wool from Brookside and had it shipped to Ramy. Ramy made the following materials to be used for the two year field tests and laboratory tests (Table 5):

3 Rolls of pure wool ECB fill
3 Rolls 70:30 wool: straw ECB
3 Rolls 50:50 wool: straw ECB
3 Rolls 30:70 wool: straw ECB

Note: Rolls are 2.4 meters (8 feet) wide and ~ 18 meters (60 feet) long

**Table 5: Summary of wool materials developed for silt fence, rolled erosion control blanket or as an additive to wood compost and selected for 2-year field tests.**

| WEIGHT and PURPOSE | WOOL MANUFACTURE METHOD | PRODUCT MANUFACTURER | PRELIMINARY FIELD TEST CONDUCTED | SELECTED for FIELD TESTING | COMMENT |
|---|---|---|---|---|---|
| ***Silt Fence*** | | | | | |
| 407 g/m$^2$ (12 ounces (oz)/yard (yd)$^2$) batt | Wet Felt | Sugar Loaf Wool Mill | No | Yes | Highest tensile strength of all pure wool materials |
| 407 g/m$^2$ (12 oz/yd$^2$) batt (2-6 oz pieces combined) | Wet Felt | Sugar Loaf Wool Mill | No | Yes | Will require additional fibers/treatment to provide strength |
| ***Extended Term Erosion Control Blanket (ECB)*** | | | | | |
| 203 gram (g)/meter (m)$^2$ (6 oz/yd$^2$) batt | Wet Felt | Sugar Loaf Wool Mill | Yes | No | Suppresses seedlings |
| 407 g/m$^2$ (12 oz/yd$^2$) batt | Wet Felt | Sugar Loaf Wool Mill | Yes | No | Suppresses seedlings |
| 272 g/m$^2$ (8 oz/yd$^2$) batt | Card | Thirteen Mile Lamb and Wool Co. | Yes | No | Partially suppresses seedlings |
| 203 g/m$^2$ (6 oz/yd$^2$) batt | Card | Thirteen Mile Lamb and Wool Co. | Yes | No | Appears to slightly suppresses seedlings |
| 136 g/m$^2$ (4 oz/yd$^2$) batt | Card | Thirteen Mile Lamb and Wool Co. | Yes | Yes | Light weight allowed better seedling penetration |
| 68 g/m$^2$ (2 oz/yd$^2$) batt | Card | Thirteen Mile Lamb and Wool Co. | Yes | Yes | Light weight allowed better seedling penetration |
| Single layer wool carded batt, one pass thru needle punch | Needle Punch | Brookside Woolen Mill | Yes | Yes | Strong but light weight |
| Single layer carded wool batt, two crossed passes thru needle punch | Needle Punch | Brookside Woolen Mill | No | No | Little difference to one pass material |
| One half layer carded wool batt, four crossed passes thru needle punch | Needle Punch | Brookside Woolen Mill | No | Yes | Closest product to New Zealand's BioWool 400 sample |
| Pure wool filled ECB | Scour & Cut | Ramy Turf Products | No | No | Standard ECB machinery does not incorporate cut wool well |
| Pure wool filled ECB | Scour, Cut & Shred | Ramy Turf Products | No | Yes | Standard ECB machinery can use this wool product the best |
| 70% wool : 30% straw filled ECB | Scour, Cut & Shred | Ramy Turf Products | No | Yes | Not sure if pure wool needed, so trying different ratios |
| 50% wool : 50% straw filled ECB | Scour, Cut & Shred | Ramy Turf Products | No | Yes | Not sure if pure wool needed, so trying different ratios |
| 30% wool : 70% straw filled ECB | Scour, Cut & Shred | Ramy Turf Products | No | Yes | Not sure if pure wool needed, so trying different ratios |
| ***Wool Compost Enhancement*** | | | | | |
| 40:1 by weight, wood compost : scoured & cut wool, 1.9 centimeters (0.75 inch) | Scour & Cut | Glacier Gold Compost: Brookside Woolen Mill | Yes | Yes | Appears to be ideal ratio |
| 20:1 by weight, wood compost : scoured & cut wool, 1.9 centimeters (0.75 inch) | Scour & Cut | Glacier Gold Compost: Brookside Woolen Mill | Yes | No | Too much wool in mix |

# 6 RECOMMENDATIONS AND CONCLUSIONS

The product search and preliminary field trials during the summer of 2014 identified eight pure wool products with the highest potential to improve roadside reclamation efforts for MDT and other transportation agencies. These wool materials occur in three types of reclamation material: 1) erosion control blanket, 2) silt fence, or 3) as an additive to wood derived compost (Table 6).

The woolen products developed and selected for prototypes of woolen ECBs are the 68 g/m$^2$ and 136 g/m$^2$ (2 oz/yd$^2$ and 4 oz/yd$^2$) carded wool batts, and three different types of needle punch felted wool batts. The sixth potential wool product, to be used primarily for seedling establishment, is standard compost with a cut wool additive at a ratio of 40 (moist weight) compost: 1 (dry weight) scoured and cut wool. This same material can be used solely for seedling establishment, that is, on flat or low grade roadsides where erosion is not a concern (Table 6).

Lastly, wool silt fence prototypes will be developed and tested using wet felted wool at two densities: 203 g/m$^2$ and 407 g/m$^2$ (6 oz/yd$^2$ and 12 oz/yd$^2$) (Table 6). It is unclear if felted wool at either density is strong enough to withstand storm events and surface runoff as silt fence. These wool products have the least prospects of success of all the wool reclamation prototypes

developed by the project, without further development with the manufacturing sector to give them the required strength needed to withstand storm events.

**Table 6: Woolen silt fence and erosion control fabrics identified for Tasks 3 and 4.**

| Woolen Product | Source | Product Use |
|---|---|---|
| 407 grams (g)/meter $(m)^2$ (12 ounces (oz)/yard $(yd)^2$) | Sugar Loaf Wool Carding Mill | Silt Fence |
| 203 $g/m^2$ (6 $oz/yd^2$) wet felted wool batt | Sugar Loaf Wool Carding Mill | Silt Fence |
| 68 $g/m^2$ (2 $oz/yd^2$) carded wool batt (dark) | Thirteen Mile Lamb and Wool Company | ECB and seedling establishment |
| 136 $g/m^2$ (4 $oz/yd^2$) carded wool batt (dark) | Thirteen Mile Lamb and Wool Company | ECB and seedling establishment |
| 40:1 compost:scoured wool (cut 1.9 cm (3/4")) | Brookside Woolen Mill | Seedling establishment |
| Single layer, single pass, needle felted | Brookside Woolen Mill | ECB and seedling establishment |
| 2 crossed layers, double needle felted | Brookside Woolen Mill | ECB and seedling establishment |
| ½ layer – 4 times needle felted | Brookside Woolen Mill | ECB and seedling establishment |

The ECB product developed with a geotextile manufacturer in Minnesota using washed/scoured/shredded wool mixed at various ratios with straw produced five products for future field and laboratory tests (Table 7). Their wool-straw ratios are varied to determine if lower amounts of wool (and thus less expensive ECB to produce) perform equal to, or better than, ECBs with higher amounts of wool.

**Table 7: Rolled erosion control blankets manufactured for Tasks 3 and 4.**

| Woolen Product | Source | Product Use |
|---|---|---|
| 100% wool fill ECB | Ramy Turf Products | ECB and seedling establishment |
| 50:50 wool: straw fill ECB | Ramy Turf Products | ECB and seedling establishment |
| 30:70 wool: straw fill ECB | Ramy Turf Products | ECB and seedling establishment |
| 70:30 wool: straw fill ECB | Ramy Turf Products | ECB and seedling establishment |
| 60:40 wool: straw fill ECB | Ramy Turf Products | ECB and seedling establishment |

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