TESTING AND EVALUATION OF RECOVERED TRACTION SANDING MATERIAL

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April 2013

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RESEARCH PROGRAMS

MDT

Testing and Evaluation of Recovered Traction Sanding Material

Project Report

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16. Abstract
The Montana Department of Transportation (MDT) is searching for a solution to the accumulation of traction sand that is applied to Montana highways every winter. An analysis of reuse and recycle options for salvaged traction sand was conducted using results of mechanical and chemical tests conducted on samples collected along the Bozeman Pass and the Lookout Pass areas. The results indicate there are viable alternatives to landfilling or roadside dumping of collected traction sand. The most appealing and cost-effective option is to reuse the collected material as traction sand in subsequent winters. A potential secondary option would be to process and mix (co-mingle) collected sand with gravel to produce a material that meets MDT gradation specifications for imported aggregate. The most promising co-mingling options are those that only necessitate the addition of finer aggregate and do not require additional coarse particles. MDT materials including plant mix surfacing, cement treated base, shoulder gravel, and crushed top surfacing could be economically produced by co-mingling collected traction sand with additional aggregate.

Based on laboratory tests conducted to measure chemical and metals concentrations, it appears that the samples tested in this study have chemical and metal concentrations that are generally characteristic of naturally occurring background levels. Nonetheless, a quality assurance process is recommended before reusing recovered traction sanding material to confirm that unhealthy levels of contaminants are not present. An implementation plan outlining best practices for separating, collecting, testing and processing salvaged traction sand is described. The results of this study indicate that the practice of recycling and reusing traction sand could potentially save money by eliminating landfill costs and by reducing the amount of new abrasives and aggregates that are purchased every year.

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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
APHA-AWWA-WPCF	American Public Health Association – American Water Works Association – Water Pollution Control Federation
CBC	Crushed Base Course
CDOT	Colorado Department of Transportation
CTB	Cement Treated Base
CTS	Crushed Top Surfacing
DEQ	Department of Environmental Quality
EPA	Environmental Protection Agency
LL	Liquid Limit
LQAS	Lot Quality Assurance Sampling
MDT	Montana Department of Transportation
MSU	Montana State University
NCHRP	National Cooperative Highway Research Program
O&G	Oil & Gas
QA	Quality Assurance
PAH	Polyaromatic Hydrocarbons
RCRA	Resource Conservation and Recovery Act
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
USGS	United States Geological Survey
WTI	Western Transportation Institute

EXECUTIVE SUMMARY

Large amounts of abrasive traction sanding material (traction sand) are applied to roadways in northern climates every winter season to increase tire-road friction and improve traction control. The deployed traction sand is typically collected from roadways in the spring as part of roadway maintenance operations, which include: sweeping and vacuuming roadway surfaces, shoveling accumulated material from between guardrail posts, and cleaning and collecting material from road shoulders and borrow ditches. While removing accumulations of material helps to alleviate problems alongside highways, it can create storage/disposal problems unless cost-effective alternatives are identified and implemented.

The recovery and reuse of this material represents a potentially desirable option to reduce the quantity of landfilled materials and to conserve natural resources. However, when used without any further treatment, recovered traction sand may create problems, including sedimentation in streams, clogging of culverts, and environmental contamination from chemicals, heavy metals, and volatile organic compounds.

The practical suitability and cost effectiveness of a statewide program for recycling and reusing traction sand on Montana roadways was evaluated in this study. This study included the sampling and testing of traction materials used in Montana to investigate viable options for their reuse. The research included the development of a protocol for sampling stockpiled traction material, a focused synthesis of current literature on the topic, material sampling at Lookout Pass and Bozeman Pass, geotechnical and chemical testing, evaluation of alternatives, and a cost–benefit analysis that compares the recycling option to current practices that primarily utilize virgin materials. These two locations were selected because they experience relatively large quantities of snowfall and prolonged periods of sub-freezing temperatures during the winter months, especially in the higher elevations. Consequently, large amounts of traction sand are used in these areas as part of winter maintenance operations.

A cost-benefit analysis of reuse and recycle options of salvaged traction sand was conducted using results of mechanical and chemical tests conducted on samples collected along the Bozeman Pass and the Lookout Pass areas. The results indicate there are viable alternatives to landfilling or roadside dumping of collected traction sand. The most appealing and cost-effective option is to reuse the collected material as traction sand in subsequent winters. Research conducted during this study indicates a potential secondary option would be to process and mix (co-mingle) collected sand with gravel to produce a material that meets MDT gradation specifications for imported aggregate. The most promising co-mingling options are those that only necessitate the addition of finer aggregate and do not require extra coarse particles. It was determined in this study that MDT materials including plant mix surfacing, cement treated base, shoulder gravel, and crushed top surfacing could be economically produced by co-mingling collected traction sand with additional aggregate.

The amount of screening and processing could be minimized by separating collected materials during spring maintenance. For example, material cleaned from side ditches is likely to contain excessively large coarse material and other debris. This material could be isolated (stockpiled

separately) and evaluated apart from the other collected sand because it will likely require a higher level of processing in comparison to material that is swept or vacuumed off of the roadway surface. Likewise, depending on the topography, material cleaned from the roadway shoulder and from between guardrail posts may have different characteristics than sweepings and ditch material. Separating these materials will result in a more efficient reuse process and could minimize the amount of screening and washing required before the material is suitable for reapplication. The gradation curves obtained during this study indicate that a significant percentage (90 to 95%) of collected material from the shoulders could be re-used with only basic processing to remove trash and debris, and a small percentage of oversize soil particles.

For project use, multiple gradations of the salvaged traction sand should be conducted and an average value used to develop a mix design by processing with a dry coarse aggregate. This will yield a mix design that serves as a reasonable starting point that should be verified by testing smaller trial batches prior to processing large quantities. It is expected that minor adjustments to the mix design may be necessary after examining gradation results from the trial batches.

Based on chemical lab tests conducted in this study and compared to background chemical and metal concentrations, it appears that the samples collected and tested from the Lookout Pass and Bozeman Pass sites have chemical and metal concentrations that are generally characteristic of naturally occurring background soil levels at the sites. Nevertheless, a Quality Assurance process may be necessary before reusing recovered traction sanding material, which may entail a standardized process of random sampling of previously applied sand and subsequent testing to confirm that it does not contain unreasonably high levels of contaminants.

This study indicates that collected traction sand can be considered a viable product for reuse and recycling, rather than categorizing it as a waste product. By recycling and reusing traction sand, MDT could potentially save money by eliminating landfill costs and by reducing the amount of new abrasives and aggregates that are purchased every year.

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INTRODUCTION

In North America, large amounts of abrasive traction sanding material (traction sand) are applied to roadways during winter season to improve traction. The Montana Department of Transportation (MDT) reportedly purchases and applies over one billion pounds (500,000 tons) of traction sand to state roads in an average winter season (Williams, 2003). Many local governments and transportation agencies, including MDT, collect traction sand from roadways following winter maintenance operations. The traction sand is collected in the spring as part of roadway maintenance operations, which include: sweeping and vacuuming roadway surfaces, shoveling accumulated material from between guardrail posts, and cleaning and collecting material from road shoulders and borrow ditches. While removing accumulations of material helps to alleviate problems alongside highways, it can create storage/disposal challenges unless cost-effective alternatives are identified and implemented.

The recovery and reuse of this material represents a potentially desirable option to reduce the quantity of landfilled materials and to conserve natural resources. However, when used without any further treatment, recovered traction sand may create new problems, including sedimentation in streams, clogging of culverts, and environmental contamination from chemicals, heavy metals, and volatile organic compounds.

Traction sand and miscellaneous debris collected from roadways is heterogeneous in composition and particulate structure. The engineering properties of this material are largely unknown and the suitability of reuse options is mostly anecdotal. A sampling and testing program was conducted as part of this study to better quantify mechanical and chemical properties of traction sanding material that had been deployed on the roadway surface the previous winter. Only after the material properties are better understood can a reliable evaluation of cost-effective and implementable reuse options be identified.

The overall goals of this study included the evaluation of material characteristics of traction sand collected from Montana highways and the investigation of reuse options for the collected material. Classification of both physical and chemical characteristics of the traction sand were important components for evaluating the feasibility and potential effectiveness of any reuse or recycling options. The options presented herein were evaluated based on their cost-effectiveness and their applicability to the state of Montana.

BACKGROUND AND OBJECTIVES

Background

Sand and other abrasive materials are widely used in winter maintenance as a means of increasing the level of friction for vehicular traffic on icy roadways. Traction sand is often applied after a stretch of highway has been plowed and a layer of ice or snow has bonded to the driving surface, or there is a potential for ice or snow accumulation in the upcoming hours. Because of high volumes of traffic, high traveling speeds, and large vehicles such as trucks and tractors, the traction sand is gradually pushed to the side of the highway. Eventually, the traction sand accumulates on the shoulder of the highway or on the surrounding land into deposits of scattered piles and drifts. Between winter storms or in the spring, this sand is collected in order to minimize environmental issues and to keep the roadway travel surface clear for safety. Typically, the sand is collected and placed in low spots along the roadway. There are two primary problems with the disposal of the collected, used sand. The first is the large amount of space that is required in order to store the material. Presently, this is one of MDT's issues near Lookout Pass in Northern Montana. The other issue is the cost that is associated with dumping the traction sand into local landfills.

A survey of 25 states and provinces in the United States and Canada revealed that approximately 74 percent of transportation agencies routinely apply sand as part of winter maintenance operations (Ye et al., 2009). These materials are typically applied to a plowed or scraped roadway surface that may have a layer of bonded snow or ice, thus providing a measure of traction between vehicle tires and the traveling surface (NCHRP, 2007).

Without proper treatment, reuse of expended sanding materials may create environmental and maintenance problems. State and local agencies often collect traction sand after the winter season to reduce potential impacts to the environment and infrastructure, as well as for reasons of driver safety. The collected materials are usually hauled away and stored in designated areas or disposed of in landfills. The Center for Watershed Protection recommends street sweeping during the spring snowmelt as a means of pollution prevention. The Minnesota Pollution Control Agency also recommends street sweeping twice a year for pollution prevention, once after the spring snowmelt (presumably to collect sanding material) and again after leaves fall in the autumn (Caraco and Claytor, 1997). It is common practice in northern U.S. and Canadian cities to remove traction sand after the winter maintenance season for public health and environmental reasons. In Auburn, Maine, for example, removal and disposal of winter sand is carried out by the highway maintenance program of the Public Works Department (City of Auburn, 2009).

Current Practices

The two obvious and most commonly used options for disposing of collected traction sand are to stockpile the material near the location it was collected or to haul the material to a landfill. Both options can be problematic, especially in the long term because stockpiled traction material collected from roadways occupies valuable space. For example, maintenance personnel from the

Bozeman Pass and the Lookout Pass areas of Montana report they are running out of low spots and other available areas within the highway right-of-way, which traditionally have been used to stockpile collected traction sand and other debris collected off the roadway surface and cleaned from ditches and shoulders. The same problems exist in more urban areas. For example, maintenance personnel from different Minnesota metropolitan councils reported they were running out of space for materials storage and the cost for storage continues to escalate (Metropolitan Council, 1994).

If local storage is not an option, then the material is hauled away and disposed of at a remote location such as a municipal landfill. The hauling and disposal costs of this option are often significant. A report issued in 1994 by the Minnesota Metropolitan Council found cities that had run out of storage space paid from $6 to $11 per ton to dispose of collected traction material, not including the hauling cost (Metropolitan Council, 1994).

For these reasons, some northern cities and states have begun recycling recovered sanding materials. A literature review identified several sanding material recycling practices. In 1993, the City of Bloomington, Minnesota, was reported to utilize a screed/shredder conveyer system to reclaim and reuse maintenance materials to reduce the amount requiring landfill disposal (Metropolitan Council, 1994). A demonstration project indicated there were potential savings to be realized in recycling winter ice control aggregate. The Minnesota study concluded that recycling street sweepings would be a cost-effective activity for maintenance agencies.

The Canadian city of Edmonton, Alberta, places approximately 165,000 tons of winter street sand on its roadways annually for winter maintenance, and about 70 percent (115,500 tons) of these materials are collected each spring. Before a recycling program was started in 2003, only about 25 percent of the recovered street sand was reused and 75 percent of the sweepings were landfilled. The Edmonton recycling program implemented a wet processing method with four phases: waste removal, material washing, fines processing, and clean sand dewatering and drying. The results of the demonstration project showed that 80 percent of the collected materials could be recovered. About 2 percent of the larger-sized aggregate material was diverted to the City of Edmonton aggregate recycling operation; about 6 percent of the small fine sand was washed during the process and used for fillcrete applications. This study, however, did not present a benefit–cost analysis for the two-year pilot project. Presently, a private firm is contracted by the city to recycle the sanding material (City of Edmonton, 2007).

The Public Works Department in the City of Olympia, Washington uses two sweepers to collect sand from streets, with a focus on main arterials that have the highest sand accumulation (City of Olympia, 2009). A screening process is used to separate sand from debris (e.g., leaves, branches, trash, car parts, etc.). The sand is then returned to stockpiles for reuse. The department has a preventive maintenance program to minimize the occurrence of blocked storm drains caused by accumulations of traction sanding material. The Massachusetts Executive Office of Transportation is sponsoring a study to address solid waste problems caused by street sweeping operations (Massachusetts Executive Office of Transportation, 2009). The objective of the project is to evaluate the barriers, economics, and opportunities for a variety of reuse options. A demonstration project may be conducted to further evaluate the reuse options.

Most of the programs identified in the literature review were urban-based and city-specific, rather than statewide. Further study and evaluation is necessary to determine if practices conducted within geographically confined urban areas can be extrapolated over larger geographic extents, and whether highway and interstate conditions in rural areas across varied terrain pose different environmental and maintenance issues or other logistical concerns. In some mountainous areas (e.g., Lookout Pass), MDT is not just recovering finer particulate sweepings but also rock, miscellaneous debris, organic soil, saturated organic plastic clay and vegetation that may require special processing and separation to make the material suitable for recycling. In summary, our review indicates most of the available information and literature regarding methods for recycling traction sanding materials and the costs and benefits of these recycling options are primarily oriented toward urban areas. In addition, the methods used in these recycling approaches are often based on specific resources and equipment available to local contractors, which can be proprietorial in nature. None of the approaches identified in the literature fully represent or replicate MDT's winter maintenance practices or Montana's rural transportation system and unique geographic and climatic conditions.

MDT Winter Maintenance Practices

The majority of DOTs in the United States use either salt or an aggregate-salt mixture to deice highways after compacted snow or ice begins to form on the roadway surface. Salt is useful in minimizing ice formation at temperatures near freezing; however, the effectiveness of salt rapidly decreases as temperatures drop toward the eutectic temperature for a sodium chloride salt solution, which is about -6^{o} F. Based on practical experience, salt is relatively ineffective when pavement temperatures drop below about 10^{o} F. Winter temperatures in the northern states can range from +20^{o} F to well below zero. States that experience below zero temperatures frequently add a liquid form of salt (magnesium chloride) to the solid sodium chloride granular salt. Liquid calcium chloride has shown to increase the performance of salt because of its lower eutectic temperature; i.e., calcium chloride is more effective at lowering the freezing temperature of water at low temperatures (Williams, 2003). Although salt additives to traction sand are known to improve the safety of driving surfaces during some winter conditions, there can be negative consequences to using salt, including: 1) increased winter maintenance expenses, 2) vehicle corrosion issues, and 3) environmental impacts from runoff.

The Montana Department of Transportation mobilizes a significant staff of operators and equipment every winter to keep the highways open and navigable even during the severe winter conditions that Montana experiences. Hazardous road conditions are addressed using multiple strategies.

1. Snowplows, trucks, and other equipment are used to remove accumulated snowfall from the roadway surface after a storm with a goal of keeping as much of the interstate driving lane surface as snow free as possible.
2. An abrasive consisting of traction sand is applied to the road surface to increase frictional resistance. MDT typically adds about 10% salt by weight to help keep sand stockpiles from freezing and to assist roadway surface deicing efforts.

3. When deemed necessary, liquid and solid chemicals are used to limit or reduce the bond that forms between snow/ice and the road surface to improve the efficacy of mechanical measures for removing snow.

Traction sanding material provides a temporary increase in frictional resistance for vehicles passing over compacted snow and ice. Two important considerations regarding the use of traction sand without de-icing additives are listed below.

1. The abrasive only aids in the increase of traction on the road, it does not eliminate or prevent the formation of ice or densely compacted snow.
2. Localized high velocity air currents can be created near the roadway surface by fast moving traffic, which have a tendency to blow the abrasives off of the roadway surface. Consequently, the majority of the sand is pre-wet with magnesium chloride or sodium chloride ($MgCl_2$ or NaCl) brine to enhance the placement and retention of traction sand on the road. Even with pre-wetting, traction sand is frequently blown off the road and duplicate applications are needed.

The required gradation for traction sand in Montana is shown in Table 1.

Table 1. MDT Specification for Traction Sand

Sieve (U.S. standard)	Size (mm)	Specified Range Low	High
5/16 in	7.94		100
#10	2.00	20	60
#40	0.425	0	30
#200	0.075	0	10

Montana does not generally apply salt directly to state highways; although salt is used when necessary in a few urban areas. However, rock salt is used for another, supporting application. Large stockpiles of traction abrasives typically are stored outside where they are subject to sub-freezing temperatures and moisture. Rock salt is added to these stockpiles at relatively low percentages to prevent them from freezing into large conglomerate masses, which can be difficult to breakup and load into sanding trucks. About 10% salt by weight is used to ensure that loaders can readily break into the stockpiles with a bucket or scoop; for the most part, this helps keep the stockpiles free of frozen clods during the winter season. Small amounts of salt brine can be created when melted snow and rain mix with salt that has been added to the stockpiles. This is an added benefit because the brine helps traction sand stick to compacted snow and ice on the highways for a longer period of time before it is blown off by wind and vehicular traffic (Williams, 2003). A dry sand application is not typically used in the western region of the state of Montana, because the winter conditions, particularly in mountain passes, regularly have significantly larger snow accumulation.

Project Objectives

State residents, along with tourists, desire a road surface that they can drive on safely during the winter months. Yearly studies conducted by MDT's Maintenance Division and Montana State University-Billings show that state residents believe the number one MDT responsibility should be winter maintenance of roads (Williams, 2003). Highway users consistently want safe highways to drive on, particularly when the weather is severe. With an increase of population, there is an increase of traffic across the state. The recycling of traction sand can provide a cost-effective method using less natural resources while at the same time provide Montana winter travelers the safe driving surface they desire.

The goal of this study is to evaluate the practical suitability and cost effectiveness of a statewide program for recycling and reusing traction sand on Montana roadways. Study results are anticipated to help MDT identify best options for recycling traction sanding materials and thus reducing problems associated with storage and disposal of these materials. The study results are expected to be of interest to other transportation agencies seeking methods to optimize reuse of traction sanding materials.

By recycling traction sand, MDT could potentially save money by eliminating landfill costs and by reducing the amount of new abrasives that need to be purchased every year. Currently, processed sand that meets the aggregate size standards for traction sand must be transported and stockpiled at district maintenance and storage yards every winter from distant locations. The cost of purchasing and transporting the aggregate continues to increase with increasing fuel costs. By recycling portions of collected traction sand, MDT may be able to reduce the annual recurring costs of producing or purchasing new aggregate.

This study included the sampling and testing of traction materials used in Montana to investigate viable options for their reuse. The research included the development of a protocol for sampling stockpiled traction material, a focused synthesis of current literature on the topic, material sampling at Lookout Pass and Bozeman Pass, geotechnical and chemical testing, evaluation of alternatives, and a cost–benefit analysis that compares the recycling option to current practices that primarily utilize virgin materials.

CURRENT APPLICATIONS

Currently, there are not many states or cities in North America that implement a recycling program for collected traction sand. A review of available literature indicates the primary application of used, collected traction sand is the reuse option in which previously deployed sand is collected off the roadway surface or shoulders and later reapplied on roads for traction purposes the following winter. Examples are provided in the following subsections of two cities in North America that currently employ this practice: Edmonton, Canada and Olympia, Washington. Other options such as collecting the deployed traction sand and processing it for use in another application such as structural backfill or asphalt base course have not been utilized by other cities because of the high cost of processing and handling the used sand.

Edmonton, Alberta – Sand Recycling Ltd.

The City of Edmonton, Alberta has used a traction sand recycling program for several years. The program reportedly has saved Edmonton money and decreased costs involved with the transportation of used sand to landfills and the purchasing of new sand from sources that can be as much as 100 km (60 miles) away. The City is able to reuse approximately 80 percent of the sand that is deployed during the winter months by collecting and reapplying the sand on city streets the following winter. Only a small percentage of the sand (about 5 percent) is shipped to landfills because of inadequate or undesirable material properties.

The City of Edmonton contracts the entire operation of collecting, processing, and recycling the winter traction sand with a private company; most recently, Sand Recycling Ltd. The operation used in Edmonton involves a collection process that is primarily suited for urban areas in which previously deployed traction sand is collected from city streets where drainage control features such as sidewalks and gutters help contain the material, simplifying the collection process. Because of environmental regulations pertaining to chloride contamination, the city does not use recycled sand for fill or backfill applications on construction projects; consequently, the city's recycling process for traction sand focuses on collection and reuse the following winter (Haug, 2011).

According to Sand Recycling Ltd., recycling costs are nearly equivalent to the cost of bringing in new material from off site because of the high disposal costs of collected traction sand. As a result of dwindling landfill space near Edmonton, the cost of landfill disposal has skyrocketed. Landfill tipping fees have risen to an average of 70 dollars per ton, which is a considerable expense that does not include the costs of trucking the material from the collection area to the landfill (Haug, 2011).

Sand Recycling Ltd. uses a washing procedure to process collected traction sand, rather than dry screening. Dry screening is not used for several reasons. Washing procedures tend to be more efficient and effective than dry screening at separating out fine-grained particles from sand-size particles. Prior to deployment, traction sand is comprised mostly of sand-sized particle between the No. 200 and No. 40 sieve sizes. After deployment, sand particles are mechanically pulverized and broken down over the winter months by vehicular traffic. This results in significant quantities of fines (particles smaller than the No. 200 sieve) in the collected sand. This is because the fines have a tendency to cling to the larger sand particles, which makes it difficult for the two to be separated. Fines also hold moisture, which increases the overall moisture content of the collected sand. The adhesion of the fines and the increase of moisture content necessitate washing procedures over dry screening (Haug, 2011).

Cycles of washing will reduce the chemical contaminant concentrations in the sand. These contaminants consist of sodium chloride, hydrocarbons, and metals (Haug, 2011). During winter months, sand stockpiles are “pickled” with sodium chloride to reduce the likelihood of the sand freezing and clumping together into large masses that can be difficult to excavate and load into sand deployment trucks. The sand is also pre-wetted before it is applied to the roads with a liquid calcium chloride, which helps the sand stick to the ice. These processes increase salt concentrations in the sand. Washing the collected sand helps decrease the salt concentrations. Nevertheless, the wash water must be disposed of properly through a remediation process.

Sand Recycling Ltd. has found that hydrocarbon contaminants originating from traveling vehicles can be found in collected traction sand. The wet washing process also aids in the removal of some hydrocarbons.

Olympia, Washington

The City of Olympia, Washington reuses traction sand, but at a much smaller scale than Edmonton. Snow events in Olympia are relatively short; consequently, the city’s transportation department does not experience the same scale of snow and ice demands that Montana and most other northern Rocky Mountain states typically experience. Because of this, the City of Olympia’s sand recycling program is on a smaller scale and is only applied on streets within the city.

The City purchases traction sand (they call this chip sand) from a local gravel pit. The City’s chip sand consists of quarter-inch-minus fractured rock. At the end of a snowfall event, the city streets are swept and the previously deployed traction sand is collected. The collected traction sand is passed through a screening process to remove garbage and debris that may have been collected during street sweeping. The sand that passes through the screening process is then placed back into traction sand stockpiles for the next snowfall event. The City of Olympia has not performed any materials, chemical, or mechanical testing on the sand that is recycled from the city streets (Krall, 2011).

Colorado Research

The Colorado Department of Transportation (CDOT) supported a detailed study on the uses of recycled traction sand and the results were published in a report by Pulley and Baird (2010). This report indicates that CDOT uses about 24,000 tons of traction sand annually. Similar to Montana, CDOT collects residual sand from the roadway surface and shoulders as part of their routine spring maintenance. The amount of collected materials varies widely from year to year and also geographically. For example, it was reported by Pulley and Baird (2010) that CDOT collected 100,000 tons of used sand during the 2004-2005 winter season as part of a sediment and watershed control/cleanup project. Over the long term, this represents a tremendous quantity of material that ultimately becomes either an opportunity or a liability. The research study by Pulley and Baird (2010) was initiated because the disposal of collected traction sand was becoming increasingly expensive due to limited landfill space and the cost of importing new materials. At the time of the Pulley and Baird (2010) study, Colorado disposed of a significant portion of collected traction sand in landfills. Similar to Montana, Colorado desires to explore alternative approaches for reusing or recycling collected traction sand.

Colorado typically uses a sand-salt mixture in mountainous areas and a magnesium chloride liquid anti-icing compound in metropolitan areas. The liquid compound is used in lieu of traction sand in urban areas to reduce the amount of airborne dust that can be created when traction sand is broken down into fine particulates by large volumes of vehicular traffic. (Montana follows a similar practice.)

The CDOT grain size specifications for Class 7 "Aggregate Base Course" requires 100 percent passing at 0.75" sieve, 20 to 85 percent passing a No. 8 sieve, and 5 to 15 percent passing a No. 200 sieve. According to the CDOT tests, Class 7 is the only soil classification that is appropriate for any reuse options. Class 7 requires a Liquid Limit (LL) of less than 30, which is met by the sampled traction sand since only a very small portion of the samples is clay (the Liquid Limit is the water content measurement of a soil when it starts changing from a plastic to liquid behavior).

A variety of lab tests were conducted on samples collected by CDOT. The lab tests consisted of: chemical and organic compound testing, heavy metal testing, and material classification tests. Sieve analyses were performed on the samples in order to classify the aggregate size. Ten sieve sizes were used in the aggregate testing, ranging from 0.75 inches to the No. 200 sieve (0.0029 inches). A review of the CDOT data indicates a majority of sand samples tested by CDOT passed greater than fifty percent of their particles through the No. 16 sieve (0.047 inches). All but one sample passed 100 percent through the 0.75-inch sieve and the mean percent passing the No. 200 sieve was about 8.7 percent. These observations show that the collected traction sand is a fine aggregate, with a minor amount of silt/clay and very few coarse particles.

Data provided by CDOT shows that more than 50 percent of the used traction sand meets the minimum size requirements for reuse; however, excessive fines would have to be removed from the collected material prior to reusing the material as traction sand. According to CDOT requirements, the minimum grain size for traction sand reuse is the No. 20 sieve size, which is about 0.033 inches. The Pulley and Baird (2010) study indicated that about 52.2 percent of sand recovered from roadway surfaces contained particles finer than the No. 20 sieve and would be unsuitable for reuse as traction sand and about 39.5 percent of the material recovered from basin areas contained particles finer than the No. 20 sieve and would be unsuitable for reuse as traction sand.

Identified Challenges

The majority of other recycling programs currently being implemented in other states are applied in urban areas only. According to Sand Recycling Ltd., there are two main reasons for this.

1. The trucks and equipment that are used for collection do not have to travel far distances in order to collect the material.
2. In cities, the curbs and gutters on along streets contain the traction sand that migrates off the roadway surface as a result of traffic.

In an interstate or highway application, the equipment and vehicles used to collect the sand will be required to travel greater distances and there is no type of curb or gutter system that helps contain sand that is thrown from the roadway surface by fast moving vehicles. A large amount of sand can potentially end up in ditches and surrounding area, making appropriate collection more difficult and expensive. In addition, material collected from highway shoulders and ditches is likely to contain higher percentages of rocks, debris, organic matter, plastic clays, and vegetation, which will need to be specially processed.

Another issue with sand reuse is the potential accumulation of excessive amounts of fines. Sand particles on the roadway surface are crushed by the heavy repeated dynamic loads from traveling vehicles, resulting in a larger amount of fines than were present in the initial application. To control airborne particulates (dust), it is important that limitations are placed on the initial quantity of fines in the traction sand. Consequently, a material screening and washing process may be necessary to separate and remove excessive fines from collected sand prior to pursuing any reuse options. It will be necessary to evaluate on a case by case basis whether this is most efficiently accomplished by a mobile operation or if it is more efficient to haul collected material to a centralize location for processing and redistribution. The screening and processing could be accomplished in-house or the work could be outsourced to a subcontractor. The decision will depend on the availability of equipment and cost. Factors including mobilization, travel distances, current workload, equipment availability, material quantities, and specification requirements will need to be considered on a case by case basis to evaluate the economic aspect of this effort and to determine the most cost-effective processing option.

OVERVIEW OF PROJECT RESEARCH TASKS

The sampling and testing conducted for this project focused on two high elevation mountain passes in Montana:

1. Lookout Pass – located in Mineral County, in northwestern Montana, and
2. Bozeman Pass – located in Gallatin County, in the southwestern part of the state.

These locations were selected because they experience relatively large quantities of snowfall and prolonged periods of sub-freezing temperatures during the winter months, especially in the higher elevations. Consequently, large amounts of traction sand are used in these areas as part of winter maintenance operations. Alternative solutions are desired by MDT because both areas are running short of space to store the used sand that is collected from the roadway surface and shoulders.

Lookout Pass

One of the two locations sampled during this study was the segment of Interstate 90 (I-90) that crosses a high elevation pass, known as Lookout Pass, in Mineral County. This location was selected for sampling because:

- the interstate has moderately high traffic volumes in this area,
- the winter season is long and the pass experiences large accumulations of snow, and
- the MDT District is running out of locations for disposing and storing collected traction sand.

Twelve individual sites were sampled on this stretch of I-90 to examine the stockpiles of material that were previously cleared from the roadway surface and in some cases included material excavated from the roadside ditches. Geographically, the sampling area extended, east to west, from the MDT Maintenance Facility in St. Regis to near the border of Idaho and Montana. Sample site locations are shown in Figure 1. Lookout Pass samples were collected from a range of locations along the highway, including: shoulder deposits, stockpiles from roadway sweeping operations, ditch material, and a background sand sample from a stockpile of unused traction sand at the St. Regis Maintenance Facility.

Figure 1. Lookout Pass sample sites.

Bozeman Pass

Interstate 90 was also the primary focus in Gallatin County. The stretch of highway that was examined began at Belgrade, MT and extended approximately midway between Bozeman and Livingston, MT. The majority of the samples taken from this area were located near Bozeman Pass, which also experiences high volumes of traffic and severe winter conditions. Figure 2 shows the sample locations for the Bozeman Pass samples in Gallatin County. Similar to the Lookout Pass samples, the Bozeman Pass samples were taken from a range of locations, including shoulder deposits, stockpiles from roadway sweeping operations, ditch material, and background sand samples obtained from stockpiles of traction sand that has not been applied to the highway.

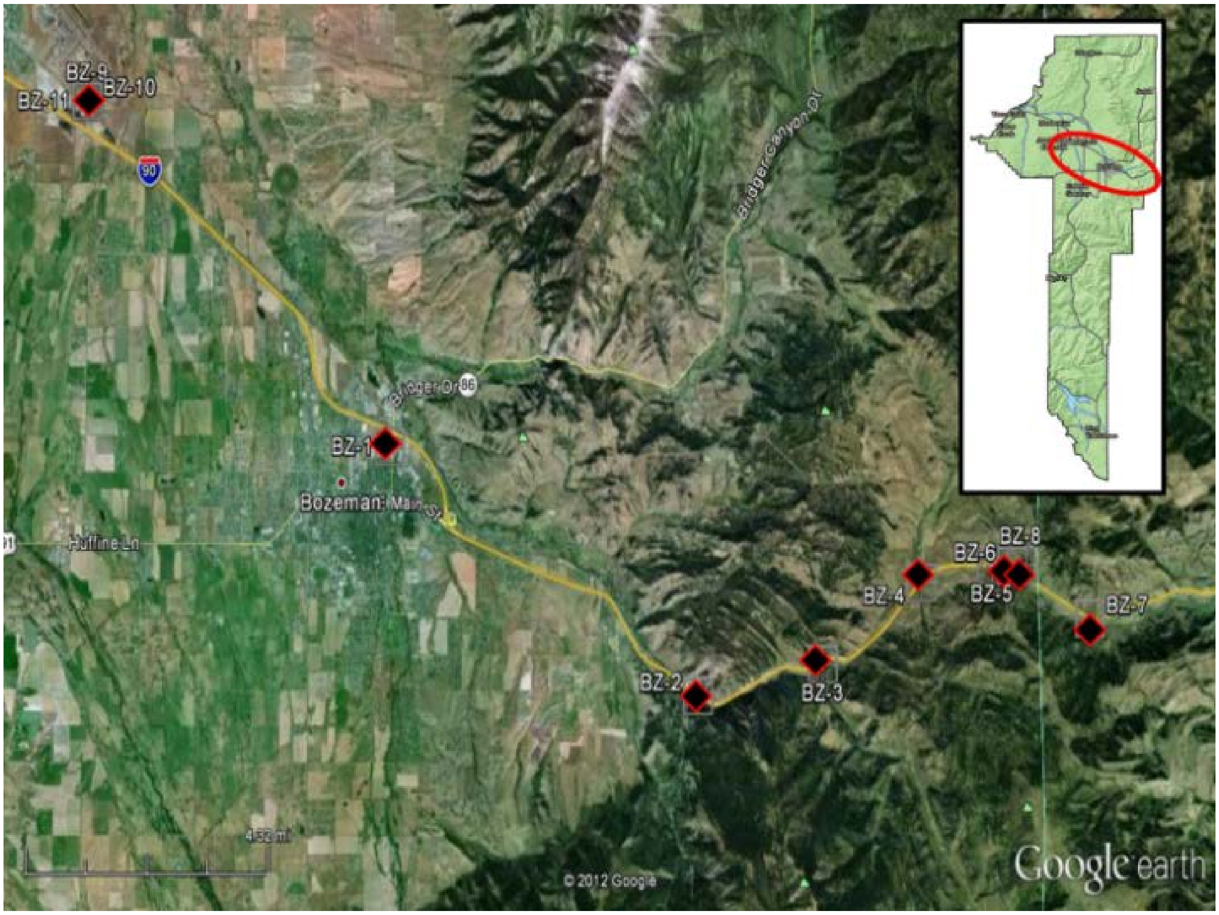

Figure 2. Bozeman Pass sample sites.

Traction Sand Quantities

The amount of traction sand that is provided to state counties by MDT is tracked and monitored every year. The amount that is provided fluctuates every year, based upon previous winter demands. The amount of traction sand that has been supplied to the two regions evaluated in this study, for the previous ten years, is provided in Table 2.

Table 2. Traction Sand Supply

Year	Lookout Pass (yd^3)	Bozeman Pass (yd^3)	Montana Totals (yd^3)
2002	22,460	11,221	641,221
2003	10,390	5,738	279,092
2004	16,256	5,670	300,947
2005	10,926	7,613	222,232
2006	17,624	6,151	262,465
2007	14,517	2,988	239,180
2008	17,666	5,193	252,790
2009	8,034	7,958	231,681
2010	6,479	7,733	167,383
2011	13,868	10,369	246,325
Average	**13,822**	**7,063**	**284,332**
Std. Dev.	**4,920**	**2,459**	**130,356**
10-year Total	**138,220**	**70,634**	**2,843,316**

The volumes of delivered traction sand shown in Table 2 fluctuate based on the length and severity of the previous winter seasons. That is, if the season is relatively mild, the stockpiles will not be depleted and consequently less material will be supplied for the upcoming winter season. If the previous winter was more severe, then a larger amount of traction sand will be brought in to replenish the stockpiles for the next season. Over a ten year period, Lookout Pass has been supplied an average of 13,822 cubic yards of traction sand per year and Bozeman Pass has received an average of 7,063 cubic yards per year. Over the past 10 years, statewide traction sand usage for Montana is on average about 284,332 yd^3 per year with a standard deviation of 130,356 yd^3.

The quantity of previously-deployed traction sand that is collected at the end of a winter season depends on many variables and historically has not been measured. It is difficult to track the quantity of collected material because of the different maintenance methods that are used to keep the roadway surface, shoulders and ditches clean. For instance:

- material can be spread into low spots in areas within the state right-of-way that have room for fill, or
- material can be temporarily stored in small stockpiles near the sides of the highway and later collected into dump trucks and hauled away, or
- material can be collected during cleaning and transported to more remote stockpile areas.

Because of these reasons, the average values shown in Table 2 represent reasonable estimates of the quantity of traction sand that is used on the roadways in these two locations. The volume of sand available for collection at the end of the season will be less than these average delivered values because some material will be lost and unrecoverable. The difference between the quantity of material delivered prior to the start of the season and the quantity collected at the end of the season has not been evaluated; however, we expect that a loss of anywhere from 20 to 50 percent is possible depending on many variables including topography, traffic volumes, weather and moisture conditions, wind, etc.

Site Sampling Plan

A primary goal of this study was to evaluate the practical suitability and the cost effectiveness of a statewide program for recycling and reusing traction sanding materials captured from Montana roadways. The material sampling and testing plan developed as part of this study, includes the following two primary components.

1. The **sampling plan** describes field procedures and protocols for characterizing the disposal areas, obtaining representative samples from each disposal/stockpile area, and documenting field sampling activities at the field sites.
2. The **testing plan** describes laboratory tests that will be specified for measuring geotechnical and chemical properties of samples obtained during the sampling events.

Material from two locations were sampled and tested by personnel from MDT. The areas are located at two different high elevation mountain passes on I-90, identified as: 1) **Bozeman Pass**, located about 10 miles east of Bozeman, at approximately 5720 ft elevation and 2) **Lookout Pass**, located about 100 miles northwest of Missoula, at approximately 4700 ft elevation. Both areas consisted of multiple separate disposal sites along or adjacent to I-90. Although this document was written specifically for the Bozeman Pass and Lookout Pass sampling locations, it is believed the protocols described in the sampling and testing plans could be used at other locations in Montana with appropriate site-specific modifications.

The Site Sampling Plan presented in Appendix A is nearly the same plan that was submitted by the MSU/WTI researchers and subsequently used as a guidance document during the sampling events at Lookout Pass and Bozeman Pass. For this reason, the verb tenses and temporal references to future events were left unchanged and are thus in the same form as the original document.

FIELD SAMPLING

Lookout Pass Samples

Twelve subsite locations within a 22-mile stretch of I-90 were sampled at the Lookout Pass area on August 24, 2011. At each subsite, the following three types of samples were collected:

- Large bulk samples (40 to 60 pound samples retained in double-lined sacks),
- Jar samples (16-ounce glass jar samples for chemical testing, stored on ice), and
- Ziploc bag samples (double-bagged, 1-gallon sample containers).
- The sample labeling scheme and subsite location descriptions are provided in Table 3.

Table 3. Lookout Pass Sample Identification

Sample No.	Subsite Name	Description	Coordinates
LP-1	Wylie stockpile #011117	virgin sand crushed at Wylie location (background sand), crushed circa 2008	N47.39555 W115.42223
LP-2	Taft sample #1, near MP 5.7, eastbound side of I-90	shoulder material	N47.42124 W115.60902
LP-3	Taft sample #2	sweeping material	N47.42040 W115.61205
LP-4	Taft sample #3	ditch material (wet)	N47.42040 W115.61205
LP-5	Taft sample #4	ditch material (dry)	N47.42040 W115.61205
LP-6	Brimstone cut, near MP 1.5, westbound side of I-90	shoulder material	N47.43616 W115.65587
LP-7	Milepost 8.5, eastbound side of I-90	shoulder material	N47.41674 W115.54660
LP-8	Saltese, near milepost 10.5, westbound side of I-90	shoulder material	N47.40975 W115.50950
LP-9	Henderson cut, near MP 22.8, eastbound side of I-90	sweeping material	N47.34421 W115.28430
LP-10	St. Regis Maintenance Facility	ditch material	N47.29844 W115.08361
LP-11	St. Regis Maintenance Facility	virgin sand crushed at Tricon Lumbermill pit (background sand), crushed circa 2007	N47.29844 W115.08361
LP-12	St. Regis Maintenance Facility	sweeping material	N47.29844 W115.08361

The chemical testing protocol that was used for the 16-ounce glass jar samples obtained from the Lookout Pass subsite is summarized in Table 4. Chemical analyses were conducted by Energy Laboratories in Helena, Montana.

Table 4. Lookout Pass Chemical Testing Protocol

Chemical Test	**Sample Name**
pH	all samples (LP-1 thru LP-12)
Chlorides	all samples (LP-1 thru LP-12)
RCRA Metals[1]	all samples (LP-1 thru LP-12)
TPH[2]	LP-1, LP-2, LP-3, LP-4, LP-5, LP-8, LP-9
PAH[3]	LP-1, LP-2, LP-3, LP-4, LP-5, LP-8, LP-9
TOC[4]	LP-1, LP-2, LP-3, LP-4, LP-5, LP-8, LP-9
Total Mercury[5]	LP-1, LP-2, LP-3, LP-4, LP-5, LP-8, LP-9
Total Cyanide[6]	LP-1, LP-2, LP-3, LP-4, LP-5, LP-8, LP-9

[1]RCRA metals (8 count): arsenic, barium, cadmium, chromium, copper, lead, selenium, and zinc in accordance with APHA-AWWA-WPCF.
[2]Total Petroleum Hydrocarbons in accordance with EPA test method 8015.
[3]Polyaromatic Hydrocarbons in accordance with EPA test method 8270C.
[4]Total Organic Carbon in accordance with EPA 415.3.
[5]Total Mercury in accordance with APHA-AWWA-WPCF.
[6]Total Cyanide in accordance with APHA-AWWA-WPCF.

The geotechnical testing protocol that was used for the samples obtained from the Lookout Pass subsites is summarized in Table 5. Geotechnical tests were conducted at the MDT Materials Lab in Helena, Montana. Atterberg Limits were determined from liquid limit and plastic limit tests that were conducted on material passing the No. 40 sieve size in compliance with Montana standard specifications. Water content tests were conducted on designated samples using a soil drying oven in compliance with Montana standard specifications. Particle size (sieve) analyses were conducted using a range of sieve sizes from the maximum particle size down to the No. 200, including the following sieve sizes: 1/2-inch, 5/16-inch, No. 4, No. 10, No. 20, No. 40, No. 60, No. 100, and No. 200. The percent passing the No. 200 sieve was determined using the sieve washing approach. Proctor moisture-density compaction tests were conducted on designated samples using standard Proctor energies in compliance with Montana standard specifications.

Table 5. Lookout Pass Geotechnical Testing Protocol

Geotechnical Test	Sample Name
Water content	all Ziploc samples (LP-1 thru LP-12)
Atterberg limits	all Ziploc samples (LP-1 thru LP-12)
Sieve analysis	all large bulk samples (LP-1 thru LP-12)
Proctor moisture-density compaction	large bulk samples: LP-1, LP-2, LP-3, LP-6, LP-8, LP-9

Bozeman Pass Samples

On September 29, 2011, eight locations within an approximately 8 mile stretch of I-90 near the Bozeman Pass area were sampled and three additional sample sets were obtained at the MDT Belgrade stockpile site located off of the Frontage Road, east of the Bozeman Airport. At each location, the following three types of samples were collected:

- Large bulk samples (40 to 60 pound samples retained in double-lined sacks),
- Jar samples (16-ounce glass jar samples for chemical testing, stored on ice), and
- Ziploc bag samples (double-bagged 1-gallon sample containers).

The sample labeling scheme and subsite location descriptions are provided in Table 6.

Table 6. Bozeman Pass Sample Identification

Sample No.	Subsite Name	Description	Coordinates
BZ-1	MDT Maintenance Facility stockpile off of Rouse Avenue	virgin sand mixed with 10% salt (background sand sample)	N45.69069 W111.03265
BZ-2	MP-315, south side of eastbound shoulder of I-90	shoulder material	N45.64099 W110.91941
BZ-3	MP-317.3, south side of eastbound shoulder of I-90	shoulder material	N45.64737 W110.87393
BZ-4	MP-319.6, south side of eastbound shoulder of I-90	shoulder material	N45.66367 W110.83810
BZ-5	MP-320.7, south side of eastbound shoulder of I-90	shoulder material	N45.66715 W110.81241
BZ-6	MP-321.3, median between traffic lanes, near top of pass	shoulder material	N45.66689 W110.80486
BZ-7	MP-322.8, south side of westbound shoulder of I-90	shoulder material	N45.65631 W110.77603
BZ-8	MP-321.2, Bozeman Hill stockpile, near top of pass	virgin sand mixed with 10% salt (background sand sample)	N45.66715 W110.80189
BZ-9	Belgrade stockpile site	Sweeping sample from top of north end of disposal area	N45.76017 W111.14514
BZ-10	Belgrade stockpile facility on Frontage Road	Sweeping sample from side slope of disposal area	N45.76017 W111.14514
BZ-11	Belgrade stockpile facility on Frontage Road	Sweeping sample from top of disposal area, near the southeast side of the facility	N45.76017 W111.14514

The chemical testing protocol for 16-ounce glass jar samples obtained from the Bozeman Pass subsites is summarized in Table 7. Chemical analyses were conducted by Energy Laboratories in Helena, Montana.

Table 7. Bozeman Pass Chemical Testing Protocol

Chemical Test	Sample Name
pH	all samples (BZ-1 thru BZ-11)
Chlorides	all samples (BZ-1 thru BZ-11)
RCRA Metals[1]	all samples (BZ-1 thru BZ-11)
TPH[2]	BZ-1, BZ-2,BZP-3, BZ-4, BZ-5, BZ-6, BZ-7, BZ-9, BZ-11
PAH[3]	BZ-1, BZ-2,BZP-3, BZ-4, BZ-5, BZ-6, BZ-7, BZ-9, BZ-11
TOC[4]	BZ-1, BZ-2,BZP-3, BZ-4, BZ-5, BZ-6, BZ-7, BZ-9, BZ-11
Total Mercury[5]	BZ-1, BZ-2,BZP-3, BZ-4, BZ-5, BZ-6, BZ-7, BZ-9, BZ-11
Total Cyanide[6]	BZ-1, BZ-2,BZP-3, BZ-4, BZ-5, BZ-6, BZ-7, BZ-9, BZ-11

[1]RCRA metals (8 count): arsenic, barium, cadmium, chromium, copper, lead, selenium, and zinc in accordance with APHA-AWWA-WPCF.
[2]Total Petroleum Hydrocarbons in accordance with EPA test method 8015.
[3]Polyaromatic Hydrocarbons in accordance with EPA test method 8270C.
[4]Total Organic Carbon in accordance with EPA 415.3.
[5]Total Mercury in accordance with APHA-AWWA-WPCF.
[6]Total Cyanide in accordance with APHA-AWWA-WPCF.

The geotechnical testing protocol for samples obtained from the Bozeman Pass subsites is summarized in Table 8. Geotechnical tests were conducted at the MDT Materials Lab in Helena, Montana, and conducted using the same protocols as the Lookout Pass samples, as previously outlined.

Table 8. Bozeman Pass Geotechnical Testing Protocol

Geotechnical Test	Sample Name
Water content	all Ziploc samples (BZ-1 thru BZ-11)
Atterberg limits	all Ziploc samples (BZ-1 thru BZ-11)
Sieve analysis	all large bulk samples (BZ-1 thru BZ-11)
Proctor moisture-density compaction	large bulk samples: BZ-1, BZ-2, BZ-3, BZ-6, BZ-7, BZ-9

MATERIAL CHARACTERISTICS

Physical and chemical testing was performed on the samples to provide a basis for the investigation of reuse options. Physical or mechanical tests consisted of sieve analyses and material characterization including Atterberg Limits and moisture contents. Chemical analyses included laboratory tests to measure concentration levels of metals and other harmful chemicals.

Physical Characteristics

Sieve analyses were performed on the samples obtained from Lookout Pass and Bozeman Pass using traditional AASHTO testing specifications to measure grain size distributions. The average percent passing values for a range of sieves, from 2 inches to 0.075 inches, are summarized in Table 9 for the twelve Lookout Pass samples and the eleven Bozeman Pass samples. As shown in Table 9, about half of the collected material ranges from a No.4 sieve to a No. 40 sieve. On average, 34 to 38 percent of the particles were finer than the No. 20 sieve (0.033 in). There was not a significant difference between the two sampling areas in terms of the upper and lower ranges of particle size (i.e., greater than 1-inch or less than the No. 200 sieve).

Table 9. Lookout Pass and Bozeman Pass Average Gradations

Sieve Size (U.S. standard)	Size (mm)	Lookout Pass % Passing	Bozeman Pass % Passing
2”	50.80	100	100
1”	25.40	99	100
3/4”	19.05	99	99
1/2”	12.70	98	98
3/8”	9.52	97	97
5/16”	7.94	95	95
#4	4.75	79	79
#10	2.00	52	53
#20	0.85	34	38
#40	0.42	24	27
#60	0.25	20	19
#100	0.15	16	13
#200	0.075	12	8

Grain size distribution plots for Lookout Pass and Bozeman Pass are shown in Figure 3 and Figure 4, respectively. The plots indicate that the particle gradation curves for the recovered traction sand samples follow a relatively smooth, narrow band between the 1-inch sieve and the No. 200 sieve. Gradation plots for all the samples obtained at Lookout Pass and Bozeman Pass are provided in Appendix B.

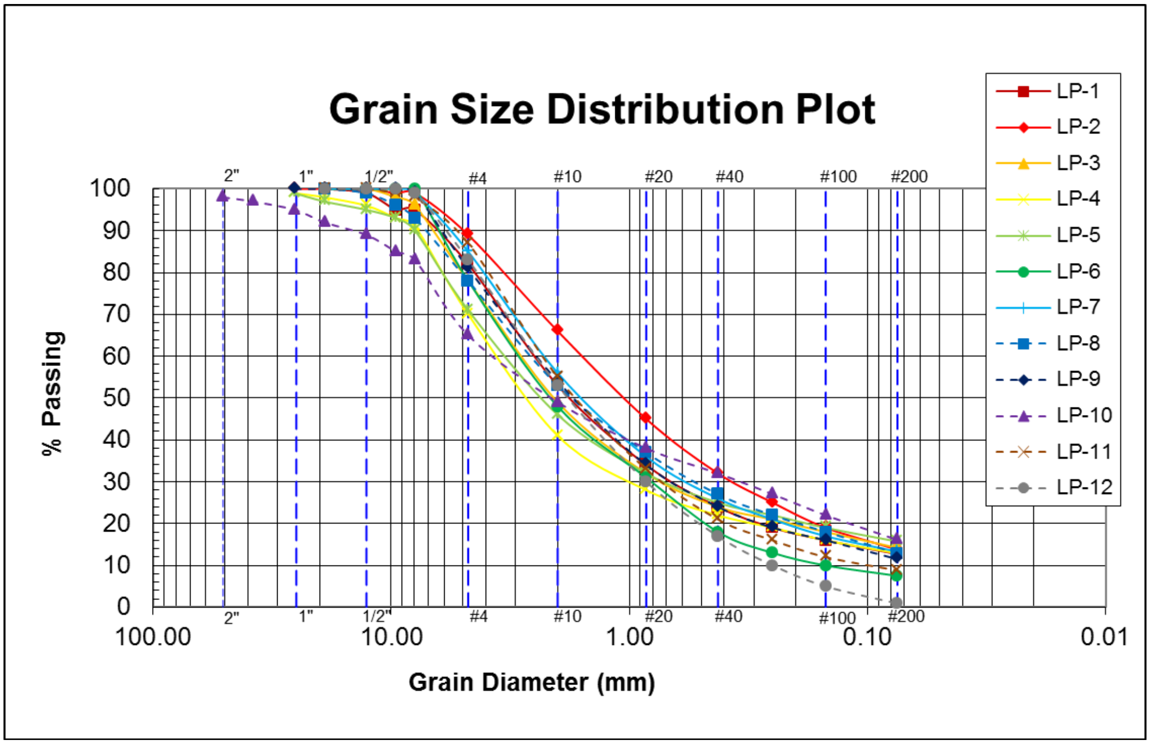

Figure 3. Lookout Pass gradation results.

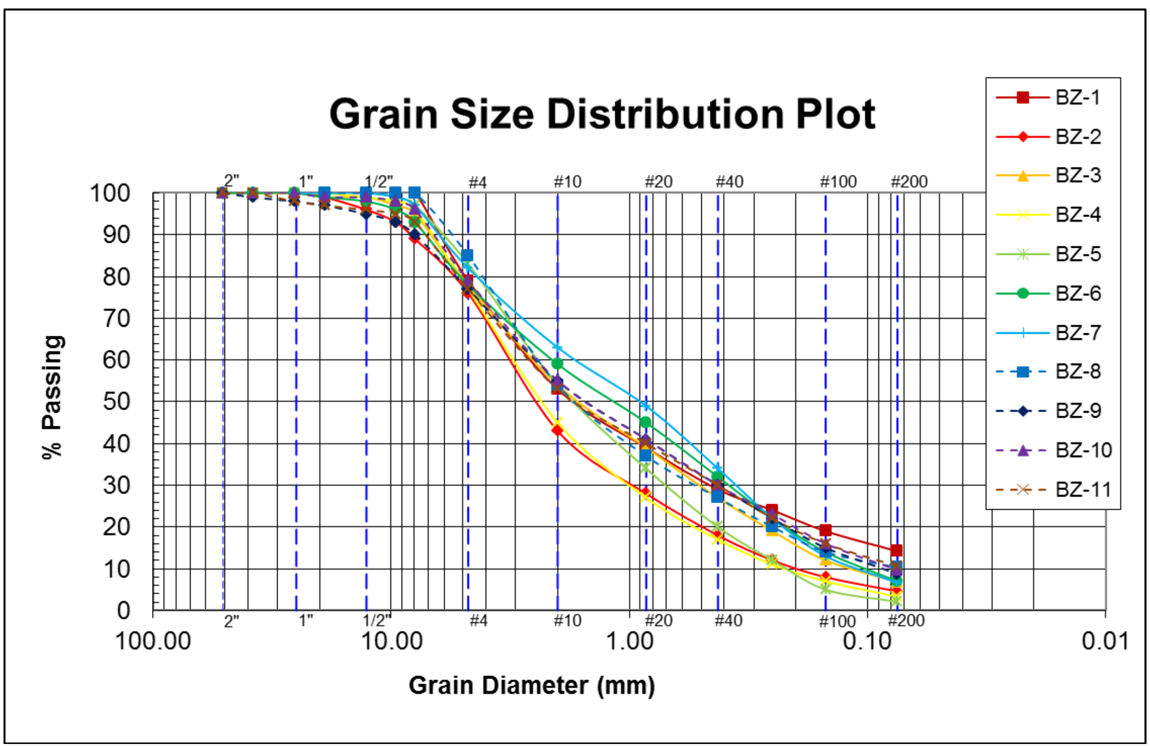

Figure 4. Bozeman Pass gradation results.

Based on Atterberg limit tests, the traction sand samples were found to be non-plastic and cohesionless; there was little to no clay in the collected samples.

Chemical Characteristics

Chemical concentration levels were measured in the recovered sanding material to determine the presence of any harmful contaminants. Three primary groups of contaminants were examined to identify any potentially harmful aspects of the collected sand. These included Total Petroleum Hydrocarbons (TPH), Oil and Gas (O&G), and metals, for which elevated concentrations above certain levels are known to pose a risk to the environment and to people.

The roadway surface and consequently any deployed traction sand can be exposed to elevated concentrations of TPH and O&G through common highway operations and incidents such as vehicle leaks, spills and accidents. For the applications studied in this project, risk-based levels of TPH and O&G are currently not well defined for highway material reuse options in the state of Montana, or in other neighboring states. However, even in this context, testing for TPH and O&G levels should still be considered prior to pursuing any reuse option. Measurements could be compared to background levels measured in control samples obtained from stockpiles of virgin traction sand. Further discussions with Montana Department of Environmental Quality (DEQ) may be warranted to help establish a reasonable ceiling limit of TPH and O&G for this application.

Increased levels of metals can result from vehicle parts being present in the sand or gathered with the sand during roadway and ditch cleaning and maintenance operations. In addition, miscellaneous items such as trash and debris can contain metals that will affect measured metal concentration levels. As a consequence, measured concentrations of metals found in traction sand collected from the roadway surface and burrow ditches are influenced by vehicle operations, accidents, malfunctions and other occurrences that for the most part are unpredictable and cannot be controlled or significantly influenced by transportation departments. A total of 23 samples randomly collected at different representative locations adjacent to the roadway were tested in the lab for metal concentrations: 12 at Lookout Pass and 11 at Bozeman Pass. Metal concentrations measured for samples collected at Lookout Pass and Bozeman Pass are summarized in Table 10 and Table 11, respectively.

Table 10. Lookout Pass Metal Concentration Summary

Metal	Element	Number of Samples	Detection Frequency (%)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Arsenic	As	12	50	8	5	10
Barium	Ba	12	100	67	43	84
Cadmium	Cd	12	N/D	N/A	N/A	N/A
Chromium	Cr	12	100	10	6	25
Copper	Cu	12	100	18	10	29
Lead	Pb	12	100	23	5	117
Mercury	Hg	12	N/D	N/A	N/A	N/A
Selenium	Se	12	N/D	N/A	N/A	N/A
Silver	Ag	12	N/D	N/A	N/A	N/A
Zinc	Zn	12	100	65	12	207

N/D = not detected
N/A = not applicable

Table 11. Bozeman Pass Metal Concentration Summary

Metal	Element	Number of Samples	Detection Frequency (%)	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Arsenic	As	11	9	6	6	6
Barium	Ba	11	100	111	78	157
Cadmium	Cd	11	N/D	N/A	N/A	N/A
Chromium	Cr	11	100	19	14	28
Copper	Cu	11	N/D	N/A	N/A	N/A
Lead	Pb	11	91	14	7	27
Mercury	Hg	11	N/D	N/A	N/A	N/A
Selenium	Se	11	N/D	N/A	N/A	N/A
Silver	Ag	11	N/D	N/A	N/A	N/A
Zinc	Zn	11	N/D	N/A	N/A	N/A

N/D = not detected
N/A = not applicable

As shown in Table 10 and Table 11 the presence of six metals were detected in the Lookout Pass samples, and four metals were detected in the Bozeman Pass samples. For the Lookout Pass samples, 50 percent of the samples contained arsenic. For Bozeman Pass, less than 10 percent of the samples contained arsenic, and 91 percent contained lead. Appendix C provides numerical concentration levels for chemical constituents identified in the soil samples from this study. Appendix D shows fluctuations of each metal concentration using bar charts.

The relevance of these measured metal concentration values is best appreciated by comparing measured values in the traction sand samples to background concentration levels, which are levels that occur naturally in the environment. A relevant comparison to background levels is useful in evaluating whether any of the metal concentrations are excessively high, which would indicate a need for more detailed testing and evaluation of additional samples. One source of comparison for background levels can be found in concentration values measured in the original stockpile samples. The stockpile concentration values would be considered below risk based levels, because this sand has not yet been applied to the roadway and consequently has not been exposed to vehicle or anthropogenic sources of potential contaminants.

A total of four samples were obtained from stockpiles of unused traction sand located near the two test areas: samples LP-1 and LP-11 were obtained during the Lookout Pass sampling event and samples BZ-1 and BZ-8 were obtained during the Bozeman Pass sampling event. Detailed metal concentrations measured at these sites are tabulated in Appendix C. This limited suite of tests indicates that in general, metal concentrations measured in the collected samples are greater than the concentrations measured in the virgin stockpile sand samples, which could be considered as background levels because the sand in the sampled stockpiles was obtained and processed from gravel borrow pits; i.e., this sand has not ever been applied on the highway. Consequently, there is a measureable increase in metal concentrations after traction sand is dispersed onto the roadway and subsequently collected from sweepings and shoulder/ditch cleaning operations.

Another comparison to background values was made using published hysteretic values obtained from a USGS Mineral Resources Program (Boerngen and Shacklette, 1981 and USGS, 2003). This program uses measured values collected during the 1960s and 1970s, which were later assimilated into a database that theoretically represents background concentrations of metals and other trace elements that were measured in surficial deposits of geomaterials sampled at a variety of different locations scattered across the United States. The data collection effort was sponsored by the U.S. Geological Survey and led by H.T. Shacklette. This data, now known as the “Shacklette Data”, consists of measurements taken on 1,323 samples that were collected from a depth of one foot below ground surface at locations described as non-cultivated fields that contained native vegetation (USGS, 2003). Starting with the dataset constructed by Shacklette (Boerngen and Shacklette, 1981), the USGS Mineral Resources Program was created initially using the Shacklette Data. Over time, the data set has been enhanced with additional measurements to provide an expanded database that can be used for estimating background concentrations of metals at sites across the U.S. Thousands of samples have been included in the database for the state of Montana, as shown graphically in Figure 5. Each dot on the map of Montana represents a sample site included in the Shacklette data set.

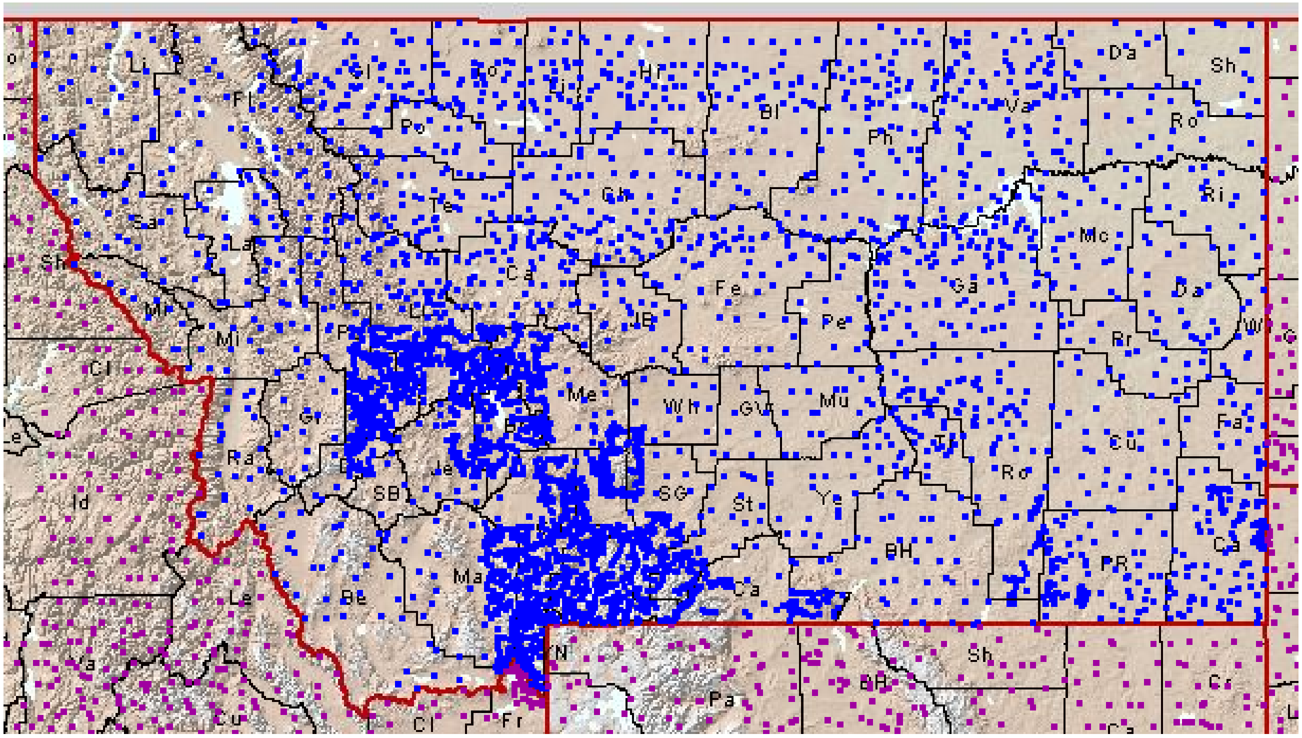

Figure 5. Location of USGS sample sites in Montana used to populate the Shacklette data set (Shacklette and Boerngen, 1984).

The Shacklette Data can be grouped various ways, such as by state or by a specific county. The data can also be grouped to include measurements for adjacent or neighboring counties. For the two sites evaluated in this study, background values by county and by adjacent county are shown in Table 12 for the Lookout Pass site and Table 13 for the Bozeman Pass site. The maximum, minimum and average metal concentration values measured at the Lookout Pass and Bozeman Pass sites were compared to USGS background values in Mineral County (Lookout Pass) and Gallatin County (Bozeman Pass). Data collected from the adjacent neighboring counties was also included in the comparison. In Table 12, the Lookout Pass data is compared to 84 background samples obtained in Mineral County and the counties immediately adjacent to Mineral County. In Table 13, the Bozeman Pass data is compared to 1,162 background samples obtained in Gallatin County and the counties immediately adjacent to Gallatin County.

Table 12. Lookout Pass Metal Concentration Comparison

Metal	Collected Lookout Pass Traction Sand Data			Mineral County (Lookout) Background Values[1]			Mineral + Adjacent Counties Background Values[1,2]		
	Mean (mg/kg)	Max (mg/kg)	# of Samples	Mean (mg/kg)	Max (mg/kg)	# of Samples	Mean (mg/kg)	Max (mg/kg)	# of Samples
As	8	10	12	9.33	18	12	8.36	31	84
Ba	67	84	12	768.42	1684	12	754.47	3481	84
Cd	N/D	N/D	12	5.00	5	12	4.84	5	84
Cr	10	25[†]	12	41.5	61	12	38.47	101	84
Cu	18	29[†]	12	21.42	35	12	29.53	168	84
Pb*	23	117[†]	12	11.17	27	12	16.17	111	84
Hg	N/D	N/D	12	0.00	0	12	0.00	0	84
Se	N/D	N/D	12	5.00	5	12	4.64	5	84
Ag	N/D	N/D	12	5.00	5	12	4.89	5	84
Zn**	65	207[†]	12	74.58	199	12	87.47	381	84

[1]County background concentrations found from USGS National Geochemical Survey Database (Boerngen and Shacklette 1981)

[2]Adjacent Counties include Missoula, Sanders, and Lake

[†]Maximum value found at LP-8

*Ignoring 117 mg/kg value, mean Lead = 14 mg/kg and max Lead 32 mg/kg - Both Below the Adjacent County Background Values

**Ignoring 207 mg/kg value, mean Zinc = 52 mg/kg and max Zinc = 76 mg/kg - Both Below the Adjacent County Background Values

N/D = not detected

As shown in Table 12, the average metal concentrations measured at Lookout Pass were below USGS background metal concentrations except for lead. The mean and maximum values for lead at lookout Pass were relatively high because of high lead concentrations measured in one sample, LP-8. Sample LP-8 had a lead concentration of 117 mg/kg, which is considerably higher than the next highest value at Lookout Pass, which was 32 mg/kg. If the concentration at LP-8 is not considered in this analysis, the mean value would decrease to 14 mg/kg, which is lower than the adjacent county background value. Nothing visually different was noted between the LP-8 sample site and the other sample sites, nor between individual samples; consequently, a specific reason for the high value of lead measured in sample LP-8 can only be speculated. One possible source of the increased concentration could be from a vehicle part that may have fallen off or ejected during a crash.

Table 13. Bozeman Pass Metal Concentration Comparison

Metal	Collected Bozeman Pass Traction Sand Data			Gallatin County (Bozeman) Background Values[1]			Gallatin + Adjacent Counties Background Values[1,2]		
	Mean (mg/kg)	Max (mg/kg)	# of Samples	Mean (mg/kg)	Max (mg/kg)	# of Samples	Mean (mg/kg)	Max (mg/kg)	# of Samples
As*	6	6	11	3.03	22	411	15.42	2600	1162
Ba	111	157	11	742.1	1694	411	649.54	3455	1162
Cd	N/D	N/D	11	4.98	6	411	5.18	75	1162
Cr	19	28[†]	11	156.75	982	411	109.71	2289	1162
Cu	N/D	N/D	11	29.45	222	411	40.67	949	1162
Pb*	14	27[†]	11	10.84	42	411	32.51	2488	1162
Hg	N/D	N/D	11	0.00	0	411	0.00	0	1162
Se	N/D	N/D	11	1.58	5	411	2.85	5	1162
Ag	N/D	N/D	11	5.04	14	411	5.18	64	1162
Zn	N/D	N/D	11	84.68	657	411	130.86	9536	1162

[1]County background concentrations found from USGS National Geochemical Survey Database (Boerngen and Shacklette 1981)

[2]Adjacent Counties include Meagher, Park, Broadwater, Madison and Jefferson

[†]Maximum value found at BZ-2

*Arsenic and Lead both below the adjacent county background values

N/D = not detected

As shown in Table 13, the average metal concentrations measured at Bozeman Pass were below USGS background metal concentrations for the adjacent counties except for arsenic. The average sample arsenic level is higher than the mean Gallatin County background level; however, the average Bozeman Pass value is considerably below average background values when neighboring counties are included in the comparison. Spikes in arsenic concentrations in surficial soils are relatively common in western U.S. Welch et al. (2000) reported that relatively higher levels of arsenic are oftentimes measured in soils and minerals in western states because of the preponderance of heavy metal mining sites and the wide distribution of large agricultural areas, which use pesticides that often contain higher levels of arsenic.

In summary, based on the lab tests conducted in this study and the comparison to background chemical and metal concentrations, it appears that the samples collected and tested from the Lookout Pass and Bozeman Pass sites have chemical and metal concentrations that are generally characteristic of naturally occurring background soil levels at the sites. Nonetheless, a Quality Assurance process may be necessary before reusing recovered traction sanding material, which may entail a standardized process of random sampling of previously deployed sand and subsequent testing to confirm that it does not contain unreasonably high levels of contaminants.

REUSE AND RECYCLE OPTIONS

Fine aggregate applications used in the state of Montana were examined as potential recycling options for the collected traction sand. After a preliminary examination, eight of the finer aggregates used by MDT were chosen for further investigation. These options are shown in Table 14.

Table 14. Potential Aggregate Materials Recycle Options

Material	Description	MDT Specification	Top Size (100% passing)	% Passing No. 200 Sieve
Cover Type I	Median cover aggregate	701.02.8 Grade 4A (crushed cover aggregate)	3/8 in	0-2
Cover Type II	Median cover aggregate	701.02.8 Grade 2A (crushed cover aggregate)	½ in	0-1
Plant Mix Surfacing ¾" – Grade A	Used to make asphalt concrete for road surface	701.03.2	¾ in	6-8
Crushed Base Course	Sublayer beneath asphalt concrete surfacing	701.02.4 (CBC Type A)	2 in or 1.5 in	3-5
Traffic Gravel	Used as temporary driving surface during construction	301.03.7 (CBC 701.02.4)	2 in	3-5
Traffic Gravel	Used as temporary driving surface during construction	301.03.7 (CTS 701.02.6)	1 in	2-8
CTB- Cement Treated Base	Used in Portland cement mixture as a sublayer beneath riding surface	701.02.9	¾ in	4-12
Shoulder Gravel	Used to surface shoulder adjacent to driving lanes.	301.03.6	¾ in	5-20
Crushed Top Surfacing GR 2B, 3B	Used on the top layer of roadway	701.02.7	1 or ¾ in	5-20
Crushed Top Surfacing GR 2A	Used on the top layer of roadway	701.02.6	¾ in	2-8
Traction Sand	Used for friction control on icy and snow covered roads		5/15	0-10

MDT Specifications

MDT material specifications describe required mechanical and physical characteristics for different aggregates that are used in a range of highway construction applications. The most common metric for specifying aggregates is the permissible range of aggregate sizes (gradation). Specified aggregate gradation ranges were compared with the recovered traction sand sieve analyses. By comparing specified aggregate gradation ranges to measured recovered traction sand sieve results, practical recycle options could be explored further if the collected traction sand gradations were approximately compatible to the gradation range in the specification. It was determined that for all the cases reviewed in this study, some processing and mixing with additional aggregate would be necessary for any of the recycle options. Even if the recovered traction sand was to be reused as traction material, some screening to remove excessive fines may be necessary. In some cases, it was determined that either the processing or mixing would be so extensive that the recycle option would not be economical or practical. For example, it was determined that recovered traction sand would require extensive processing with additional aggregate additives to meet the gradation requirement for concrete fine aggregate; and consequently, concrete aggregate was considered a nonviable option for recycling previously deployed traction sand. Therefore, it was determined that the most economical recycle option would be the reuse approach, summarized below.

1. Used traction sand is collected at the end of the winter or when conditions allow.
2. Random samples of the collected material are obtained for contaminant testing (metals, TPH, and O&G) and sieve analyses.
3. Collected material is screened and washed to remove excessive fines (providing the collected material does not contain contaminant levels excessively higher than measured in background virgin sand samples). If necessary, the collected material may be blended with virgin material.
4. Processed material is stockpiled for reuse on state highways the following winter.

The average sieve results for Lookout Pass and Bozeman Pass samples are plotted with the traction sand specification range in Figure 6 and Figure 7, respectively. The thick, black, dashed lines indicate the upper and the lower specification limits for traction sand based on current MDT specifications.

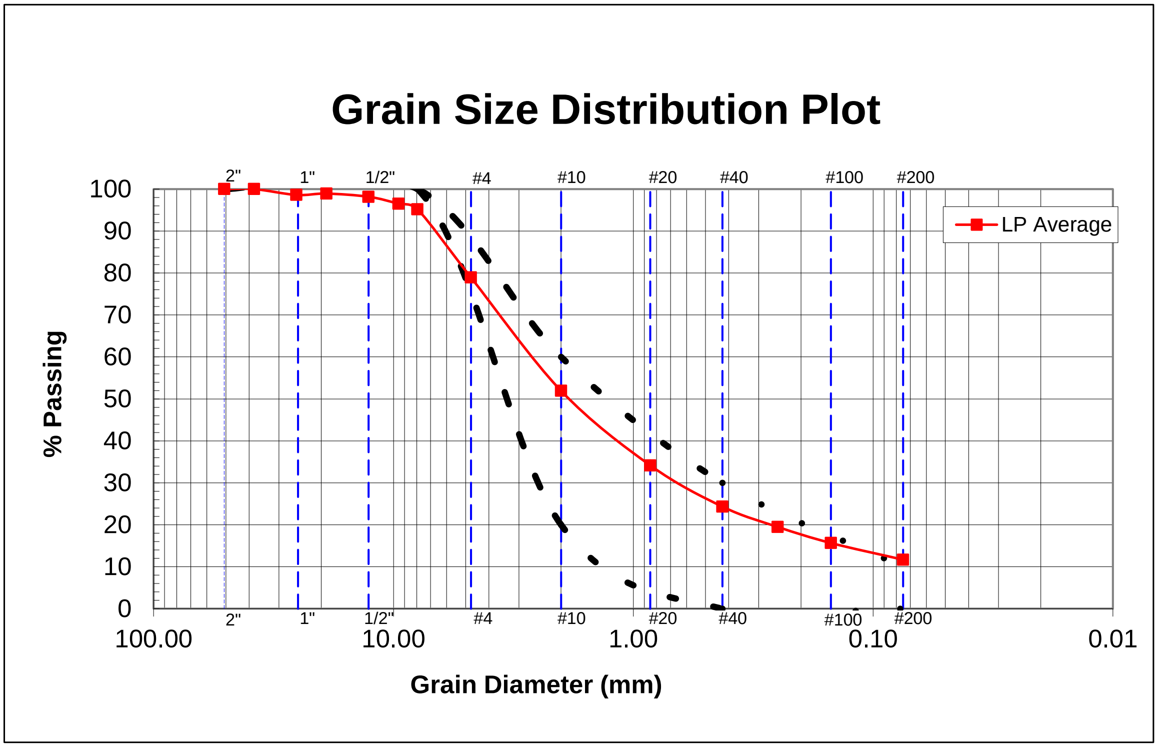

Figure 6. Average gradation results for recovered traction sand at Lookout Pass.

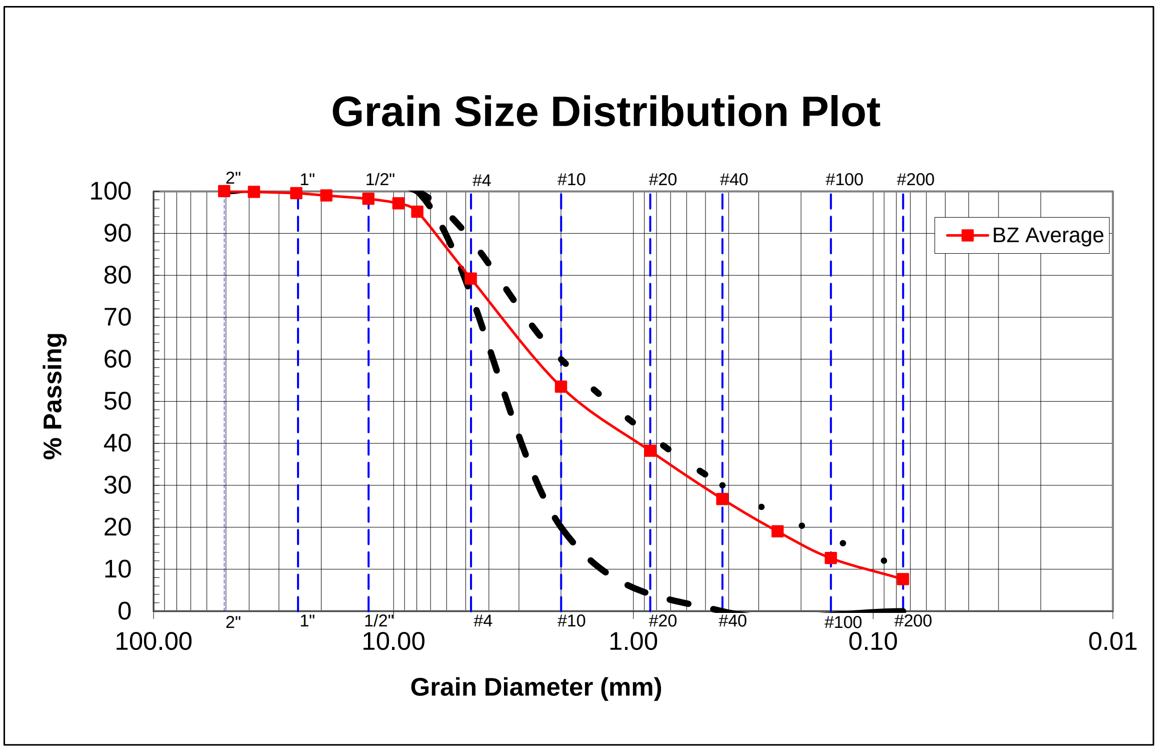

Figure 7. Average gradation results for recovered traction sand at Bozeman Pass.

These gradation plots indicate the majority of samples tested in this study are generally within the specification gradation range for traction sand, except at the outer sizes of the gradation range. Generally, less than 10 percent of the material was coarser than the specified gradation limits. The small quantity of coarse material is probably a result of extraneous debris and gravel collected during maintenance cleaning operations at the end of the winter season. On the small end of the gradation range, a few of the samples exhibited excessive fine contents. The excessive fines are likely a result of particle breakdown caused by vehicular traffic. A screening and washing process can be used to remove excessive fines prior to reuse. Excessively coarse particles can be removed by a screening process during the material processing stage.

The amount of screening and processing could be minimized by separating collected materials during spring maintenance. For example, material cleaned from side ditches is likely to contain excessively large coarse material and other debris. This material could be isolated (stockpiled separately) and evaluated apart from the other collected sand because it will likely require a higher level of processing in comparison to material that is swept or vacuumed off of the roadway surface. Likewise, depending on the topography, material cleaned from the roadway shoulder and from between guardrail posts may have different characteristics than sweepings and ditch material. Separating these materials will result in a more efficient reuse process and could minimize the amount of screening and washing required before the material is suitable for reapplication.

MARKET COST ANALYSIS

The reuse of traction sand will result in costs associated with collection and stockpiling, transportation, processing, and storage of the material. The potential costs are needed in order to complete a cost/benefit analysis for the reuse applications.

Mobilization

Costs associated with transporting or mobilizing the collected sand will vary depending on the location and distance from the collection site to the storage facility or processing location. Some of the parameters for the cost analysis include: travel distance from sweeping stockpiles to storage facility, equipment to load and haul, crew size, and completion time. Travel permits, stockpile site preparation, screen plant set-up, and site clean-up also need to be taken into account. This work could be conducted in-house by MDT or it could be contracted. If contracted, the work could be divided into separate contracts based on location, or the work could be bid as one larger statewide contract. Because of all these variables and unknowns, an average value of $4/ton was selected for the mobilization cost, which is consistent with the value used by (Pulley and Baird, 2010) in the Colorado study. Based on conversations with contractors, this appears to be a reasonable estimate; however, it should be recognized there could be a significant variation in the actual value depending on specific circumstances.

Screening

Screening of the collected material will occur after it is mobilized to a processing or storage facility. The sieve analyses conducted as part of this study reveal that some of the collected material will contain aggregate that is larger than specified limits. Consequently, screening will be necessary to remove unwanted larger particles. Screening will also remove any trash and/or debris that may be gathered during collection. Estimated cost parameters for screening include: screening machinery, loading and hauling equipment, crew size, and completion time. An average cost for re-screening of $6.50/ton was selected in this economic analysis. Similar to the transportation unit cost estimate, the variability of this unit cost could be large depending on many variables including material quantities and availability of equipment. The estimate of $6.50/ton is consistent with the value use by Pulley and Baird (2010) in the Colorado study.

Coarse Aggregate Addition

Coarse aggregate can be mixed with reclaimed or salvaged traction sand to modify the gradation of the aggregate for recycle applications. In other words, blending coarse aggregate with collected material (sometimes called co-mingling) could be conducted to create a higher-valued aggregate that meets the specification for material types other than traction sand. MDT uses a variety of aggregate types for the many different transportation-related applications. In order to explore any potential benefits of reuse or recycling traction sand, it is necessary to examine costs and quantities of aggregates commonly used by MDT. Table 15 provides a summary of some of the more frequently used aggregates in Montana. The data was compiled from bid files of MDT projects that were awarded to contractors over a 4-year period from March 2008 to March 2012.

Cover material and crushed base course represent the largest quantity of aggregate types used by MDT. More cover material was used over the 4-year period from 2008 to 2012 then all the other aggregate types combined. For the seven materials included in this assessment, the average bid prices were all greater than the average awarded price. The standard deviations (shown parenthetically and in blue font in Table 15) are notably high for the materials and yield coefficient of variations greater than 50 percent, which indicates a relatively large dispersion of the variable, or in other words, a high inconsistency in the award prices and bid prices data sets.

Table 15. Aggregates Used on MDT Projects from March 2008 to March 2012

Material	Avg. Award Price[1] ($/ton)	Avg. Bid Price[1] ($/ton)	Number of Projects	Total Material Placed[2] (ton)	Annualized Quantity (ton/yr)
Cover Material[3]	13.77 (*16.48*)	15.14 (*18.38*)	370	30,586,008	7,646,502
Plant Mix Surfacing[4]	26.35 (*6.24*)	28.42 (*5.58*)	99	2,933,041	733,260
Crushed Base Course	16.52 (*9.49*)	18.29 (*9.55*)	238	2,221,674	555,418
Traffic Gravel[5]	9.38 (*3.57*)	10.81 (*4.28*)	87	201,920	50,480
Cement Treated Base	15.86 (*12.38*)	18.29 (*14.44*)	8	135,473	33,868
Shoulder Gravel	13.87 (*7.68*)	16.53 (*8.89*)	39	25,514	6,378
Crushed Top Surfacing 3B	23.94 (*13.44*)	26.49 (*12.13*)	19	16,132	4,033
Crushed Top Surfacing 2A	20.63 (*12.73*)	21.54 (*11.58*)	5	5,048	1,262

[1]Average values for all the projects are included in this assessment. The values shown parenthetically and italicized are standard deviations for award and bid prices.
[2]Represents the total material placed over the 4-year period from 2008 to 2012 based on contracted amounts.
[3]Prices shown are averages for Cover Type I and II. Assumed material is placed 1-ft-thick. Total Material Placed and Annualized Quantity represent the sum of both Type I and Type II.
[4]The data did not distinguish between Type A and Type B.
[5]Traffic Gravel is required to meet the gradation specification of either Crushed Base Course or Crushed Top Surfacing.

A number of different aggregate gradation options were evaluated as potential additives to the traction sand. The granular aggregate additive provides a means of achieving a specified gradation by mixing, processing, and screening the additive with collected traction sand to arrive at a gradation that matches the gradation specification for the different aggregates shown in Table 15.

To increase the potential applicability of this approach, aggregate gradations specified by AASHTO (AASHTO M-43-05, 2009) were used to develop suitable mix designs. Based on an examination of different potential mix options, it was determined that the AASHTO #67 and the

AASHTO #8 were best suited for examining the feasibility of this process. As shown in Table 16, the #67 particle size ranges predominately from 3/4-in to No. 4 sieve size, and the #8 aggregate ranges predominately from 3/8-in to No. 10 sieve size.

Table 16. Gradations for Aggregates Examined as Potential Processing Additives

Sieve (U.S. standard)	Size (mm)	AASHTO M-43 #8		AASHTO M-43 #67	
		Low	High	Low	High
1”	25.40	---	---	100	100
3/4”	19.05	---	---	90	100
1/2”	12.70	100	100	---	---
3/8”	9.52	85	100	20	55
#4	4.75	10	30	0	10
#10	2.00	0	10	0	5
#100	0.15	---	---	---	---
#200	0.075	0	2	0	2

“---” indicates there is no specified value for the sieve size indicated.

A spreadsheet program was developed to evaluate potential recycle options by manipulating gradation combinations of salvaged traction sand and AASHTO aggregates. Table 17 shows a summary of the coarse aggregate addition analysis and the resulting percentages. To simplify the number of combinations, only multiples of 25 percent were considered as potential additives. This was considered a reasonable approximation considering the variability in the base material (traction sand samples).

For project use, multiple sieve analyses should be conducted on the salvaged traction sand and an average value used to develop a mix design by processing with limited amounts of dry coarse aggregate. This will yield a design mix that serves as a reasonable starting point that should be further verified by testing small trial batches prior to processing large quantities. It is expected that minor adjustments to the mix design may be necessary after examining gradation results from the trial batches.

Table 17. Potential Co-mingling Options to Match MDT Material Specifications

MDT Material Specification	Lookout Pass (%)	Bozeman Pass (%)	Coarse Aggregate Addition[a] (%)
Cover Material	25[b]	25[b]	75 (#8)
Plant Mix Surfacing Grade A	75[b]	75[b]	25 (#67)
Plant Mix Surfacing Grade B	75[b]	75[b]	25 (#67)
Crushed Base Course Type A	25	25	75 (#67)
Crushed Base Course Type B	50	50	50 (#8)
Traffic Gravel	refer to either Crushed Base Course or Crushed Top Surfacing		
Cement Treated Base	75[b]	75[b]	25 (#8)
Shoulder Gravel	75	75	25 (#67)
Crushed Top Surfacing 3B	100[b]	100[b]	0
Crushed Top Surfacing 2A	75[b]	75[b]	25 (#8)
Traction Sand	100	100	0

[a]Parenthetical reference refers to AASHTO M-43 #8 aggregate or AASHTO M-43 #67 aggregate.
[b]Indicates screening is necessary in addition to an aggregate additive to achieve desired mix design.

Salvaged traction sand would require prescreening to eliminate finer material prior to mixing with aggregate to develop the following material types: cover material, plant mix surfacing, cement treated base, and crushed top surfacing. These materials have a coarser gradation and have few to no fines; they are identified with a superscript "b" in the second and third columns of Table 17. This additional processing step of screening was accounted for in the cost analysis described in the next section. The traction sand reuse option requires no coarse aggregate addition in order to satisfy the MDT specification.

Cost/Benefit Analysis

A cost/benefit analysis was conducted to examine relative cost differentials when comparing recycle and reuse options versus importing virgin materials. The following input information was considered in the analyses:

- measured gradation data from the collected traction sand,
- recycle material options summarized in Table 17,
- relevant costs for processing the collected traction sand, and
- coarse aggregate additive material costs.

A summary of the cost/benefit analysis is shown in Table 18. The percentages of collected sand and coarse aggregate (from Table 17) are shown in the first two sections. The coarse aggregate unit costs in Table 18 were obtained from the Kenyon Noble Batch Plant near Belgrade, MT (Miller, 2012).

Table 18. Cost-Benefit Analysis Summary

MDT Material	Mat'l Cost[1] ($/ton)	Traction Sand (%)	Aggregate Additive #8 ($21/ton) or #67 ($9/ton)			Total Cost[4] ($/ton)	Relative Cost Savings[5]
			Add. (%)	Cost[2] ($/ton)	Prorated[3] ($/ton)		
Cover Material	13.77	25	75	9.00	6.75	17.25	(25.3%)
Plant Mix Surfacing Grade A & B	28.42	75	25	9.00	2.25	12.75	55.1%
Crushed Base Course Type A	16.52	25	75	9.00	6.75	17.25	(4.4%)
Crushed Base Course Type B	16.52	50	50	21.00	10.50	21.00	(27.1%)
Cement Treated Base	15.86	75	25	21.00	5.25	15.75	0.7%
Shoulder Gravel	13.87	75	25	9.00	2.25	12.75	8.1%
Crushed Top Surfacing 3B	26.49	100	0	0	0	10.50	152%
Crushed Top Surfacing 2A	21.54	75	25	21.00	5.25	15.75	26.9%
Traction Sand	15.77	100	0	0	0	4.00	74.6%

[1]Aggregate costs based on MDT project data – see Table 15. The cost shown represents either the average contract award price or the average bid price, whichever had the lowest standard deviation.
[2]Costs obtained from Kenyon Noble Batch Plant: $21/ton for AASHTO #8 and $9/ton for AASHTO #67.
[3]Prorated cost = (Aggregate additive cost) x (% Additive)
[4]Total cost = Prorated aggregate cost + Processing cost
Processing cost = Mobilization/Transportation (4.00 $/ton) + Screening (6.50 $/ton) = 10.50 $/ton
[5]Compared to costs shown in Column 2. Values in parenthesis indicate the recycle option will cost more than the virgin aggregate.

Cost estimates for the AASHTO aggregate additives were obtained from the Kenyon Noble batch plant. The "Total Aggregate Costs" in Table 18 include the aggregate additive cost, which was prorated based on the percentage of aggregate needed plus processing, which includes mobilization, transportation, and screening costs. The total reclaimed costs in this section combine the costs for mobilization, rescreening, and the prorated unit costs for the coarse aggregate. The last column in Table 18 compares the estimated recycled aggregate costs to the material cost from MDT project data that is summarized in Table 17. The cost for virgin traction sand (15.77 USD/ton) is an average cost incurred by MDT for supplying the seven Montana cities that stockpile and distribute traction sand. The highest reported cost was for the city of Great Falls (17.74 USD/ton) and the lowest reported cost was Bozeman (14.00 USD/ton). The standard deviation for the seven city average is 1.36 USD/ton.

The relative cost savings shown in Table 18 represent potential savings in aggregate costs for the different recycle options (on a relative scale). Positive values represent potential cost savings that may be recognized through recycling, while negative values (shown in parentheses) represent recycling applications that would not save money and would be more expensive than importing virgin materials from a supplier.

The most significant cost saving option involves the collection and reuse of previously deployed sand. Reuse of salvaged sand is the preferred and recommended option because the logistics involved with collecting and re-processing the material are less involved than the other options and this option has the highest potential for realizing a net cost savings. To maximize the benefits of this option, efficient procedures need to be developed for collecting and sorting disposed sand, as described in the Implementation Section of this report.

The cost evaluation indicates that options other than direct reuse are also feasible and could result in potential cost savings. The analyses reveal that recycling options that only necessitate the addition of finer aggregate and do not require extra coarse particles represent the next greatest probability of savings. The most cost efficient options can be realized when reclaimed traction sand is combined with additional aggregate to create a transportation material that is relatively fine and has a target specification gradation that requires less than about 40 percent material retained on the No. 40 sieve. These options include processing (screening) collected traction sand to meet the requirements of plant mix surfacing, cement treated base, shoulder gravel, and crushed top surfacing. In other words, the coarser the desired target material, the more expensive the recycling of collected traction sand. Materials that contain a greater percentage of coarse particles, such as crushed base course or cover material, require co-mingling of traction sand with a coarse additive (e.g., AASHTO #8 gravel), which can be significantly more expensive than finer-graded additives (e.g., AASHTO #67 gravel).

The costs shown in this section are approximate estimates and should only be used for these recycling relative comparisons. There are many variables that affect the actual cost of aggregates and construction materials, and costs can vary significantly over time and from project to project, as exhibited by the high standard of deviations in the MDT project data.

Implementation

With the exception of traction sand, any new aggregate produced by blending salvaged sand with a granular aggregate additive will incur additional transportation costs because the material will need to be loaded and hauled to an MDT construction project for deployment. Additional storage space will also be necessary until a project need is identified. The added costs of temporary storage near the point of collection followed by transportation to the end user (highway job site) were not included in the cost estimate described in the previous section because the two primary variables, time and distance, are unknown. These additional costs further support the conclusion that the most economical option is to collect, test, sort, and process previously deployed sand for reuse as traction sand the next winter season. Consequently, as described in the previous section, the most practical and economical option involves the collection and reuse of previously deployed sand. Information is provided in this section for the initiation of implementation procedures for this option.

Traction sand reuse procedures will need to be specially catered to mesh with routine procedures and practices already in place, and currently used for spring cleaning and maintenance. Initially, the procedures should utilize to the maximum extent possible specific equipment that is currently available at the local district maintenance shops. It is anticipated that over time, procedures and equipment will be modified to improve the efficiency of the process and the consistency of the results.

In general, implementation of a reuse options will involve some minor changes to MDT's current spring maintenance operations. These include:

1. To the extent possible and practical, salvaged material collected from the shoulders, from between the guardrails, and from roadway surface sweepings should be kept separate from material cleaned from borrow ditches.
2. Salvaged sand should be collected and removed from the right-of-way as quickly as practical. It is anticipated this will be accomplished by loading the material into trucks and hauling to a nearby designated stockpile location that is convenient in terms of both spring maintenance activities and winter snow fighting purposes.
3. The designated location should be selected such that it has sufficient size and convenience for the minor processing that will be necessary to remove debris and oversized material. Ideally, this location also will have sufficient area to store the stockpile until the next winter season.

The gradation curves obtained during this study indicate that a significant percentage (90 to 95%) of collected material from the shoulders could be re-used with only basic processing to remove trash and debris, and a small percentage of oversize soil particles. However, material cleaned from ditches contains random and sometimes excessive amounts of rock, oversized material, debris, etc. and would incur substantially greater processing to develop a material that is suitable for reuse.

Gradation data from samples collected in this study indicate the salvaged sand will likely have particle size distributions that are on the finer border of the specified gradation range for traction sand. This indicates that over time, as the sand is reused and recollected over multiple seasons, the gradation will continue to drift into the finer range and consequently the amount of necessary processing is expected to increase over time. This additional processing will involve either screening and removing (discarding) undersize material or blending in additional course material. It is anticipated, that the most cost efficient option would involve the blending of salvaged sand with newly imported virgin traction sand.

Because there will be some variability in the recovered material, both spatially and temporally, it will be necessary to periodically collect random samples of salvaged sand to help establish the amount of processing that will be necessary and to conduct chemical tests, because the data from this study occasionally showed numbers exceeding the levels in the background soil.

At each primary traction sand deployment location (e.g., Bozeman Pass or Lookout Pass), we recommend that samples be randomly collected from two areas each spring during collection of the deployed sand. The samples should be sufficiently large enough to conduct a sieve analysis and chemical tests as recommended in the following paragraph. Gradation curves developed from the sieve results should be compared to the specified gradation band for traction sand. If the gradation is too fine, then additional coarse sand should incrementally be added to the lab sample, as necessary, to achieve the target gradation. In the field, an equivalent percentage of coarse sand or fine aggregate should be processed with the stockpiled salvaged sand and an additional sieve analysis conducted after blending to verify the modified gradation. It is anticipated that 40 pounds of sample will be sufficient for conducting the sieve analyses and blending experiments. The addition of coarse sand would only be necessary if sieve results indicate the recovered material no longer meets the gradation specification for traction sand.

Conduct a minimum suite of chemical and metals concentration tests on randomly collected samples to identify potential environmental issues associated with reuse or disposal options. The suite of chemical and metals tests are not all-encompassing, but rather are structured after the testing protocols that have been used in the past and based on guidelines set forth in the Pacific Northwest Snowfighters Snow and Ice Control Chemical Products Specifications and Test Protocols (2009).

MDT will outsource the chemical and metals analyses to a contract lab. The laboratory should be contacted prior to sampling. MDT can provide the lab with the following list of tests and the lab will provide the appropriate size and quantity of sample jars, and a cooler for temporary storage of the samples until they are transported back to the lab. It is anticipated that a 16-ounce jar full of material will provide a sufficient sample size for each test. The following suite of tests is recommended:

- RCRA 8 Metals — Total: arsenic, barium, cadmium, chromium, copper, lead, selenium, and zinc in accordance with APHA-AWWA-WPCF.
- Total Petroleum Hydrocarbons (TPH) in accordance with EPA test method 8015
- Polyaromatic Hydrocarbons (PAH) in accordance with EPA test method 8270C
- Total Organic Carbon (TOC) in accordance with EPA 415.3
- Total Mercury in accordance with APHA-AWWA-WPCF
- Total Cyanide in accordance with APHA-AWWA-WPCF

These chemical and metals laboratory tests are conducted on relatively small samples, which consequently represent only a small percentage of the total material. For that reason, it is important to obtain representative samples. Material in the stockpile or load should be thoroughly mixed in the field (manually) with clean hand scoops prior to filling the sample jars. If an elevated reading is obtained in any of these tests, it will be necessary to obtain additional samples and conduct re-tests to determine if the high reading is symptomatic of a potentially contaminated load or if the high reading was more of an outlier caused by a small isolated particle in the sample jar. It may be more efficient to obtain extra samples during the initial sampling event and store these at the MDT Helena lab until results from the chemical tests are reviewed. The extra samples can then be discarded if re-testing is unnecessary.

DEQ has not established risk-based levels of TPH, O&G or heavy metals for highway reuse options. We suggest the following three sets of criteria be considered as benchmarks when evaluating results from the chemical tests:

1. Limits set forth by the Pacific Northwest Snowfighters (PNS, 2009).

The following total concentration limits are established by PNS (2009) in parts per million (ppm) for roadway deicers: Arsenic 5.0, Barium 100.0, Cadmium 0.20, Chromium 1.0, Copper 1.0, Lead 1.0, Mercury 0.05, Selenium 5.0, Zinc 10.00, Phosphorus 2500, and Cyanide 0.20.

The PNS (2009) specifications provide the following note: "Liquid products shall be tested as received. Solid Salts are to be diluted to a 25% (Weight/Volume) concentration and then tested as if the material was a liquid sample. Report only the values determined from the 25% solution for all of the parameters as compared to the specification limits. Do not back calculate the concentration of the parameters to the dry weight of the material."

2. Limits established by EPA for fertilizers.

EPA published a report in 1999 that established ceiling concentrations and monthly average concentrations of inorganic pollutants in sewage sludge associated with the application of fertilizers. Values for heavy metal limitations are summarized in Table 4-5, page 75 of the report (EPA, 1999).

3. Background sand samples.

The chemical and metals test results should also be compared to the results of tests conducted on samples that were obtained from virgin stockpile sources. It should be considered common procedure to obtain and test samples of virgin traction sand anytime samples of salvaged sand are analyzed.

CONCLUSIONS

A practical evaluation and cost-benefit analysis of reuse and recycle options for salvaged traction sand was performed using results of mechanical and chemical tests conducted on samples collected along the Bozeman Pass and the Lookout Pass areas. The results indicate there are viable alternatives to landfilling or roadside dumping of collected traction sand. The most appealing and cost-effective option is to reuse the collected material as traction sand in subsequent winters. Research conducted during this study indicates a potential secondary option would be to process and mix (co-mingle) collected sand with fine gravel to produce a material that meets MDT gradation specifications for imported aggregate. The most promising co-mingling options are those that only necessitate the addition of finer aggregate and do not require the addition of coarse gravel-size particles. MDT materials including plant mix surfacing, cement treated base, shoulder gravel, and crushed top surfacing could be produced by co-mingling collected traction sand with additional aggregate such as AASHTO #67.

It was determined that the most economical recycle option would be the reuse approach, summarized below.

1. Previously deployed traction sand is collected at the end of the winter or when conditions allow.
2. Random samples of the collected material are obtained for contaminant testing (metals, TPH, and O&G) and sieve analyses.
3. Based on the measured particle size gradations, collected material is screened and washed to remove excessive fines (providing the collected material does not contain contaminant levels excessively higher than measured in background virgin sand samples). If necessary, the collected material may be blended with virgin material.
4. Processed material is stockpiled for re-use on state highways the following winter.

The amount of screening and processing could be minimized by separating collected materials during spring maintenance. For example, material cleaned from side ditches is likely to contain excessively large coarse material and other debris. This material could be isolated (stockpiled separately) and evaluated apart from the other collected sand because it will likely require a higher level of processing in comparison to material that is swept or vacuumed off of the roadway surface. Likewise, depending on the topography, material cleaned from the roadway shoulder and from between guardrail posts may have different characteristics than sweepings and ditch material. Separating these materials will result in a more efficient reuse process and could minimize the amount of screening and washing required before the material is suitable for reapplication.

For project use, multiple gradations of the salvaged traction sand should be conducted and an average value used to develop a mix design by processing with a dry coarse aggregate. This will yield a particle size distribution that serves as a reasonable starting point that should be verified by testing smaller trial batches prior to processing large quantities. It is expected that minor adjustments to the mix design may be necessary after examining gradation results from the trial batches.

The samples collected and tested from the Lookout Pass and Bozeman Pass sites have chemical and metal concentrations that are generally characteristic of naturally occurring background soil levels at the sites, based on the chemical and metals analyses conducted in this study. Nevertheless, a quality assurance process may be necessary before reusing recovered traction sanding material, which may entail a standardized process of random sampling of previously deployed sand and subsequent testing to confirm that it does not contain unreasonably high levels of contaminants. DEQ has not established risk-based levels of TPH, O&G or heavy metals for highway reuse options. We suggest using criteria from the Pacific Northwest Snowfighters (PNS, 2009) manual and EPA (1999) sewage sludge fertilizer criteria as benchmarks when evaluating results from the chemical tests conducted on samples of salvaged sand. The chemical and metals analyses should also be compared to the results of tests conducted on samples that were obtained from virgin stockpile sources.

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APPENDIX A – SITE SAMPLING PLAN

A primary goal of this study was to evaluate the practical suitability and the cost-effectiveness of a statewide program for recycling and reusing traction sanding materials captured from Montana roadways. The material sampling and testing plan described in this document represents the first phase of the study, which included the following two primary components.

1. The **sampling plan** describes field procedures and protocols for characterizing the disposal areas, obtaining representative samples from each disposal/stockpile area, and documenting field sampling activities at the field sites.
2. The **testing plan** describes laboratory tests that will be specified for measuring geotechnical and chemical properties of samples obtained during the sampling events.

Material from two locations were sampled and tested by personnel from the Montana Department of Transportation (MDT). The areas are located at two different high elevation mountain passes on Interstate 90 (I-90), identified as: 1) **Bozeman Pass**, located about 10 miles east of Bozeman, at approximately 5,720 ft elevation and 2) **Lookout Pass**, located about 100 miles northwest of Missoula, at approximately 4,700 ft elevation. Both areas consisted of multiple separate disposal sites along or adjacent to I-90. Although this document was written specifically for the Bozeman Pass and Lookout Pass sampling locations, it is believed the protocols described in the sampling and testing plans could be used at other locations in Montana with appropriate site-specific modifications.

The Site Sampling Plan described herein is nearly the same plan that was submitted by the MSU/WTI researchers and subsequently used as a guidance document during the sampling events at Lookout Pass and Bozeman Pass. For this reason, the verb tenses and temporal references to future events were left unchanged and are thus in the same form as the original document.

Overview

Samples will be obtained from the disposal sites in early summer, after the materials thaw and when the weather conditions are agreeable for obtaining samples and visually classifying and documenting the primary constituents and the heterogeneity of the stockpiles. The sampling events are anticipated to occur in July 2011; the actual date will be determined based on the schedules and availability of MDT maintenance personnel for assisting with sample excavation and hauling.

MDT's involvement with the sampling task includes: 1) provide excavation equipment (most likely a truck loader or front-end loader), an operator, and a laborer to work with the researchers in obtaining samples at different locations within the stockpiles; and 2) provide a suitable truck and driver to haul the samples to the MDT materials lab in Helena. The geotechnical tests will be conducted by MDT personnel in the Helena materials lab. The chemical tests will be conducted by an outside laboratory subcontracted to MDT.

We anticipate obtaining about 1,500 to 2,000 pounds of samples from each of the two primary locations. Sampling buckets or burlap sacks, glass jars, and Ziploc freezer bags will be used to contain the samples. A representative from WTI/MSU will be on site to help coordinate the field work, label the sample containers, visually classify materials, and document and photograph the disposal sites and sampling events.

Multiple samples will be collected at different locations within each stockpile. Every effort should be made to ensure that representative samples are obtained.

Note – safety of field personnel is of primary importance. Only sampling locations that are a safe distance from oncoming traffic and flying debris should be considered. Safety vests and appropriate traffic warning devices should be utilized as necessary in conformance with MDT standard highway safety practices.

Stockpile Characterization

Every effort should be made to provide an overall characterization of the primary constituents or components of the disposal areas. This is especially important because there will likely be large natural (e.g., tree branches, stumps) and man-made materials (e.g., tires, car parts) in the stockpiles that cannot be practically included in the relatively small lab samples.

The disposal site at Lookout Pass consists of four (or possibly more) separate areas. The locations of the separate disposal areas will be identified and each area will be considered as a separate sub-site during this sampling event. The exact configuration of the disposal area at Bozeman Pass will be evaluated during the site visit. If necessary, sub-sites also will be established at this location. The disposal locations and separate sub-sites will be identified on a map and assigned a name that will be used for labeling samples and tracking lab test results.

The following list of activities should be conducted at each sub-site.

- Mark the location of each site on a topographic map and/or Google Earth map.
- Take digital photos of each sub-site.
- Estimate the volume (in cubic ft) of material in each sub-site. This will be an approximate estimate based upon the length, width, and height of the stockpiles measured with a cloth tape or by pacing.
- Use the loader to excavate pits or trenches into the stockpiles at each sub-site. Create a written log of these explorations with photographs, as appropriate.
- Provide a field estimate of the percentages of major constituents at each location. It is expected the constituents will consist of a varied range of items such as: sand, gravel, boulders, vegetation, wood, trash, automobile parts, etc. If practical, estimate the volume of the loader bucket and use the bucket as a measuring tool to help characterize the stockpile constituents.

Material Sampling Protocol

At each sub-site, collect representative samples for laboratory testing and analysis by subdividing the volume of stockpiled material into approximately equal zones. Obtain samples, clearly label sampling containers, and secure containers for transportation to the MDT Helena lab. Document activities in the field log using sketches as necessary to supplement written notes.

The sampling effort should focus on two objectives: 1) obtain a cross-section of random samples that are representative of the heterogeneous composition of the stockpiles, and 2) obtain separate samples that are representative of the two primary winter maintenance material removal activities, which are i) sweepings from the road surface and ii) debris cleaned from the ditches. Sampling details are provided in this section as a guideline. Field personnel will apply judgment and make modifications to the guidelines as necessary to achieve the sampling objectives. It is imperative that comprehensive notes and documentation of activities and observations are recorded in the field and that all samples are clearly labeled and cross-referenced in the field notes. This will be the primary on-site activity and responsibility of the MSU/WTI researcher.

A variety of sample sizes will be obtained. The method of storage will depend on the purpose of the sample (i.e., geotechnical test or chemical analysis). Samples that will be used for water content and Atterberg limits will be stored in plastic sample containers consisting of 1-gallon freezer bags that are doubled or nested together. Samples for chemical analyses will be stored in 16-ounce glass jars and kept cool in large coolers with ice packets. Large burlap sacks will be used for the remaining test samples, which are anticipated to weigh about 40 lb. each.

Following are specific details and guidelines to consider during sampling.

Within each sub-site, collect evenly spaced samples by subdividing the volume of stockpiled material into approximately 6 to 8 equal zones. Use the sample plan shown in Table 19 as a guideline for the size and type of samples that should be gathered from each zone.

Table 19. Sampling Guidelines

Location	Large Burlap Bag Samples (~ 40 lb.)	Small Ziploc Geotechnical Samples	16 oz. Glass Jars Chemical Samples (store in cold cooler)
Lookout Pass			
-Sub-site 1	7	10	4
-Sub-site 2	7	10	4
-Sub-site 3	7	10	4
-Sub-site 4	7	10	4
Bozeman Pass	8	10	4

From each sub-site location, collect separate samples of roadway sweepings and ditch debris, as practical.

Samples typically should not be collected from the outer surface of a stockpile. Soil from the outer skin of the stockpile may not be representative because of segregation and weathering. Samples should be taken 1 to 2 ft below the surface or preferably from the sidewalls or bottom of an excavated trench, or directly from a scoop of material in the loader bucket.

Use a shovel or metal hand scoop to fill the sample containers. Include anything in the sample container that fits into the shovel or scoop. This could include gravels, chunks of asphalt, bits of tire, cigarette butts, etc. Make a notation in the field notebook of any material that will not fit in the shovel, such as large tree branches. Make note of the depth of the sample below the surface of the stockpile.

Sample bags and jars should be clearly labeled with the following information:

- "Sand Recycling Project No. 8213"
- Sample ID Number (will be determined on-site)
- Sample Location (sub-site number and any other distinguishing characteristics)
- Date Sampled
- Indicate if the sample is one of a number of companion samples; for example, 1 of 3.

Place small geotechnical samples (4 – 6 lb.) in plastic 1-gallon Ziploc freezer bags. Double bag each sample. Mark the inner bag with the complete sample information (described in the previous bulleted item) and mark the outer bag with the sample ID number. Seal both the inner and outer bags and further secure the outer bag with a piece of duct tape.

Place samples for chemical analysis in 16 ounce glass jars and store in a cooler containing ice packets to maintain a relatively constant, cool temperature. (Samples for geotechnical testing do not need to be kept in a cooler.)

Place large samples (~ 40 lb.) in heavy-duty burlap/plastic sample bags. Write the sample ID number on the inner plastic bag and write the complete sample information on the outer bag. Secure the inner plastic bag and outer burlap bag securely with duct tape. The bags should not be completely filled. Limit the weight of each bag to about 40 lb. Two 40 lb. bags are preferable to one 80 lb. bag for ease in handling and transporting. Heavy or over-filled bags get dropped and break open and are not easy to move around.

An alternate approach for the burlap bag samples is to first shovel the material into a 5 gallon bucket, which can then be carried and handled easier than the burlap sample bags. After moving the buckets to a convenient location, fill the burlap sacks with material from the buckets and label appropriately.

Record a visual description and classification of the material surrounding each sample. This classification will consist of a qualitative description of the material, including items such as: estimated aggregate size distribution, moisture content, plasticity, and presence of organic matter or non-natural material (trash, debris, etc.).

If the sampling site has debris, small bits of chain, or tires parts, they should be included in the large sample containers.

Take pictures at each sampling location.

Draw a plan-view sketch of each sub-site and show the sample locations. Use a cloth tape or calibrated step/pace to measure the distances between sampling locations.

Laboratory Testing Plan

Geotechnical laboratory tests will be conducted in the MDT materials lab in Helena. A written testing schedule that associates specific samples with required laboratory tests will be provided by the MSU/WTI principal investigator after completion of the field sampling events. As tests are completed, the lab will provide written results to a representative of the project technical panel and this will be forwarded to the principal investigator (PI). If possible, data and results will be transmitted as electronic computer files. The lab is encouraged to provide intermediate results rather than waiting until all testing is complete.

Reports from the materials lab will document the standard specification (i.e., MT, AASHTO, or ASTM) that was used as a guideline for conducting each test. Any deviation or modification to the standard specifications should be clearly described in the lab reports. Chemical analyses of selected soil samples will be subcontracted to a specialty lab selected by the project technical panel.

Geotechnical Tests

Conduct geotechnical tests to quantify physical and mechanical properties of the stockpiled material. The project PI will submit a lab work order (post-sampling lab testing schedule) that specifies the tests that will be conducted on each sample. The quantity of tests provided in this section is for planning purposes. It should be recognized that test quantities may be modified or adjusted slightly based on information obtained during the field sampling event. Significant modifications to the test schedule will be considered only after consultation with the project technical panel.

In summary, samples obtained from the two I-90 passes will be delivered to the MDT materials lab in Helena and tested in accordance with the testing plan that will be developed after the field sampling event. It is expected that the post-sampling lab testing schedule will include the following tests and approximate quantities: particle size (sieve) analyses (20 tests); Atterberg liquid limits and plastic limits (20 tests); natural (as-sampled) water contents (40 tests); and Proctor moisture-density (10 tests). The numbers in parentheses indicate the approximate quantity of laboratory tests that are anticipated.

Following are additional details of the tests.

Particle Size (Sieve) Analysis: Conduct particle size analyses using a range of sieve sizes from the maximum particle size down to the No. 200 sieve. The percent passing the No. 200 sieve should be determined using the sieve washing approach. At a minimum, include the following sieve sizes: 1/2-inch. 5/16-inch, No. 4, No. 10, No. 20, No. 40, No. 60, No. 100, and No. 200. Include additional sieve sizes as necessary to obtain a complete particle size distribution curve.

Atterberg Limits: Conduct liquid limit and plastic limit tests on material passing the No. 40 sieve size in compliance with standard specifications.

Water Content: Measure the water content of designated samples using a soil drying oven in compliance with standard specifications.

Proctor Moisture-Density Tests: Conduct Standard Proctor moisture-density tests on designated samples in compliance with standard specifications.

It is likely that some of the samples will contain miscellaneous non-geomaterial debris, such as tire parts, litter, organics, etc. The post-sampling lab testing schedule will specify whether non-geomaterials should be left in the sample or if miscellaneous debris should be screened and removed prior to conducting a test. It is anticipated that some of the tests will be conducted on both screened and unscreened samples. The post-sampling lab testing schedule will provide specifics on combining and splitting certain samples.

Chemical Tests

Conduct a minimum suite of chemical tests to identify potential environmental issues associated with reuse or disposal options. The suite of chemical tests are not all-encompassing, but rather are structured after the testing protocols that have been used in the past and based on guidelines set forth in the Pacific Northwest Snowfighters Snow and Ice Control Chemical Products Specifications and Test Protocols (2009).

MDT will outsource the chemical analyses to a contract lab. Specific samples will be identified in the post-sampling lab testing schedule. It is expected that the following suite of tests will be conducted on 15 samples:

RCRA 8 Metals — Total: arsenic, barium, cadmium, chromium, copper, lead, selenium, and zinc in accordance with APHA-AWWA-WPCF.

- Total Petroleum Hydrocarbons (TPH) in accordance with EPA test method 8015
- Polyaromatic Hydrocarbons (PAH) in accordance with EPA test method 8270C
- Total Organic Carbon (TOC) in accordance with EPA 415.3
- Total Mercury in accordance with APHA-AWWA-WPCF
- Total Cyanide in accordance with APHA-AWWA-WPCF

A 16-ounce jar full of material will provide a sufficient sample size to conduct the full suite of tests listed above. A second phase of additional chemical testing may be ordered depending on results from the initial suite of tests. Extra samples will be obtained during the field investigation and stored at the MDT Helena lab until results from the chemical tests are reviewed by the project principal investigator and technical panel. Approval from the project technical panel would be obtained before requesting any additional chemical tests.

Equipment

Following is a checklist of items that should be brought to the field. Responsibilities for bringing equipment are divided between MSU/WTI and MDT based on resources available to each group. Field personnel should communicate prior to the investigation and make adjustments as necessary to ensure that all the items are available and ready.

MSU/WTI Responsibility

- personnel: principal investigator to coordinate and document sampling activities
- 50 ft or 100 ft cloth tape and 25-ft retractable tape measure

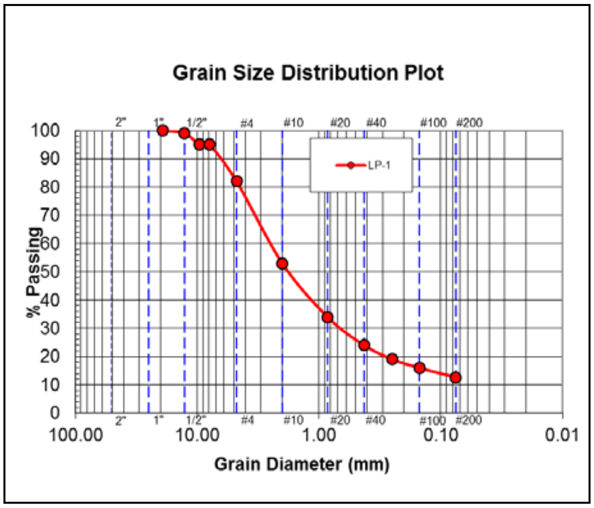
- safety vest
- two digital cameras (one for backup) and extra batteries
- field notebook, markers, writing paraphernalia
- shovel
- large metal hand scoops (3)
- gallon-size plastic Ziploc freezer bags (100)
- duct tape, masking tape

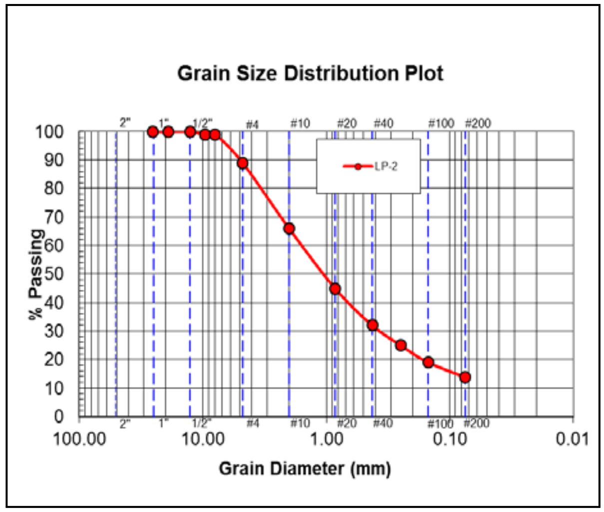
MDT Responsibility

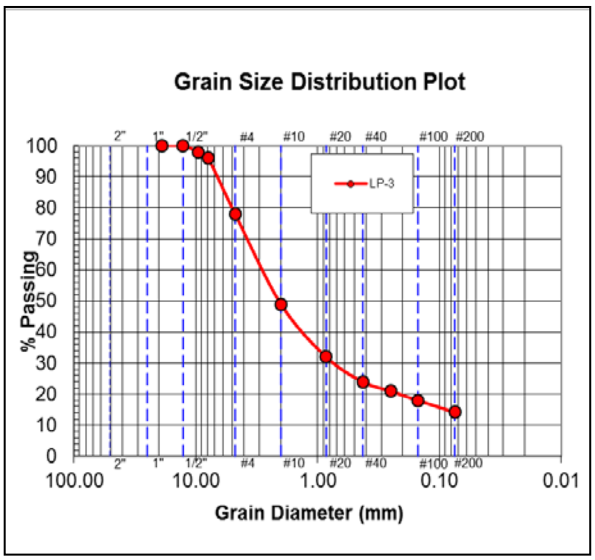
- personnel: equipment operator, truck driver, laborer to help with sampling and loading
- safety vests and traffic warning devices — in accordance with MDT standard practices
- excavation equipment (loader or excavator with mechanical bucket)
- 16-ounce glass sample jars with lids and coolers with frozen blue ice packets for cold storage of chemical samples (these are often furnished by the testing lab)
- shovel
- plastic-lined burlap sample bags with approximately 80 lb capacity (60)

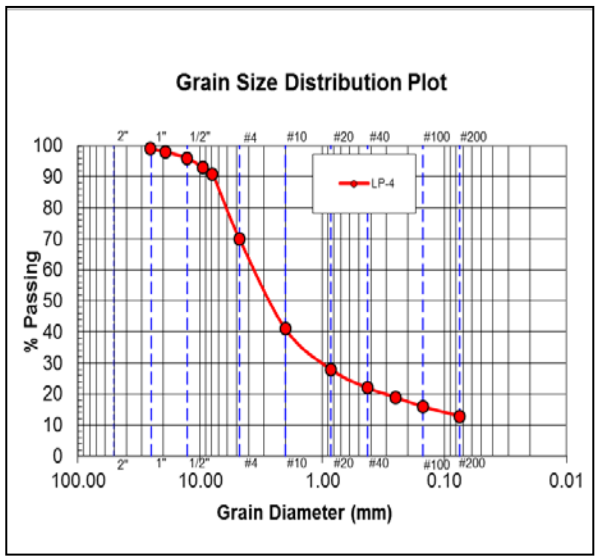
APPENDIX B – SIEVE ANALYSIS RESULTS

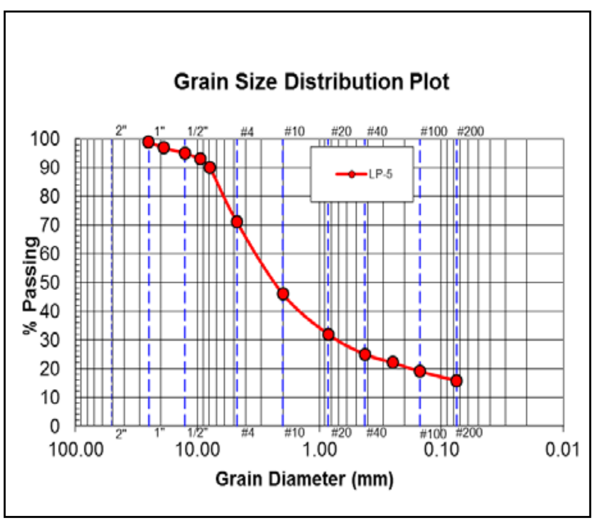
Lookout Pass

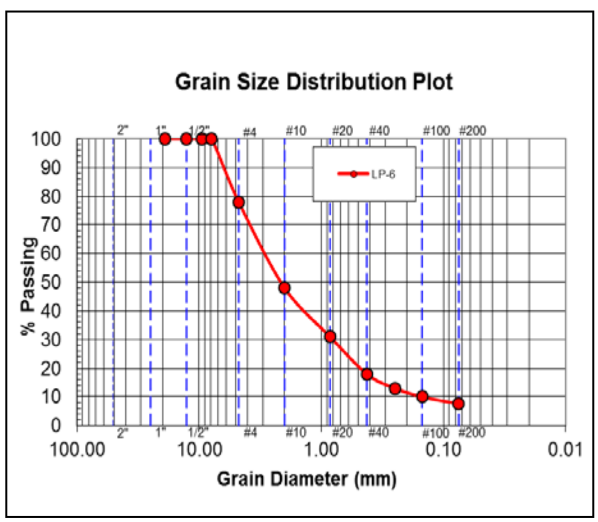




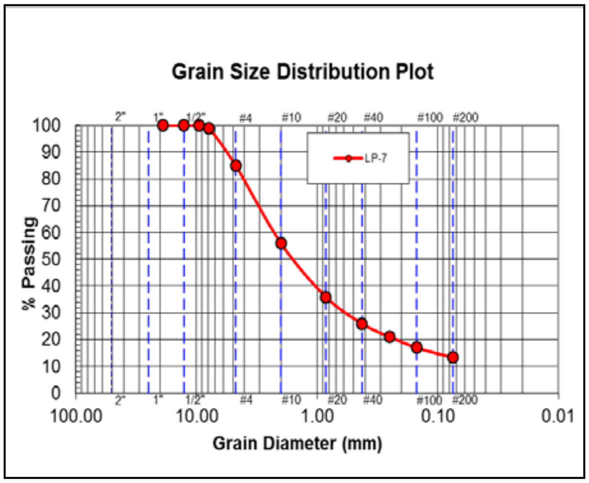


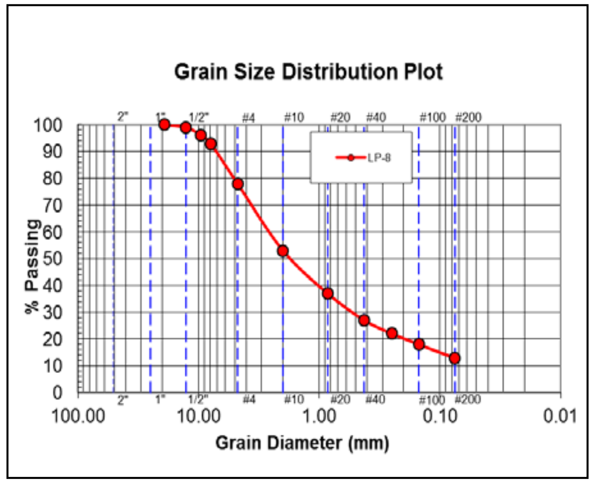


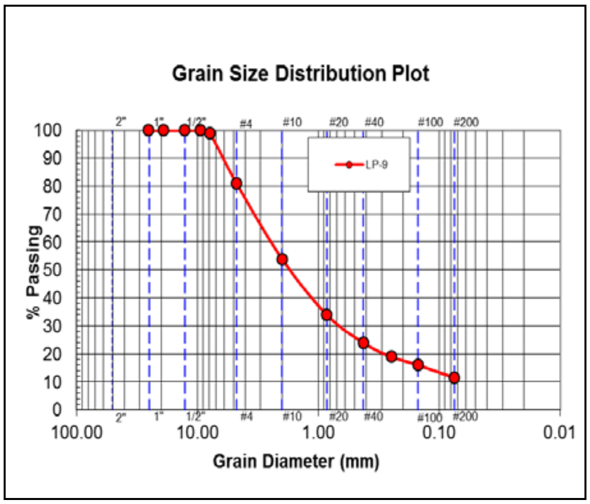


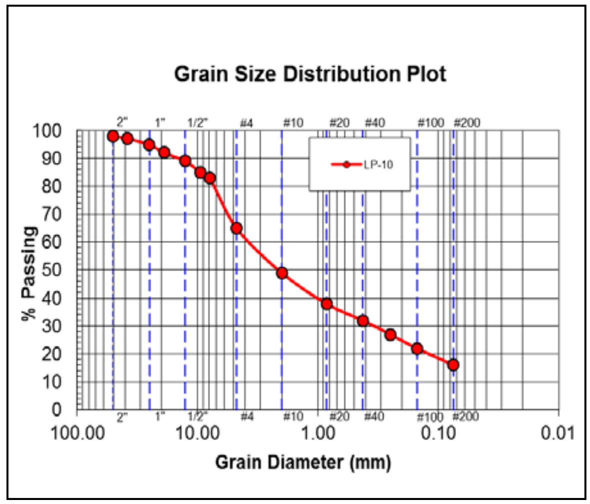


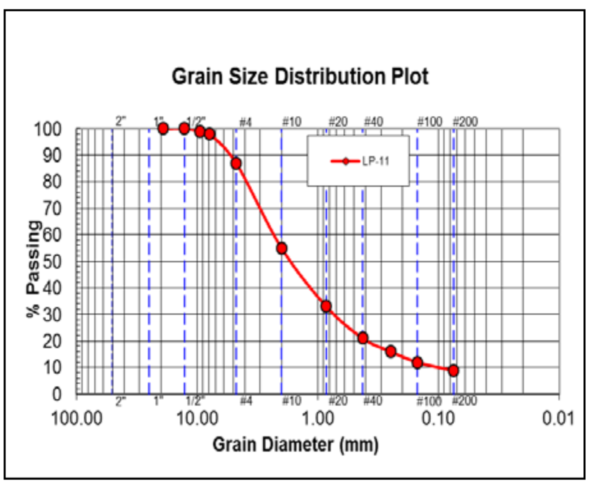
Lookout Pass – continued

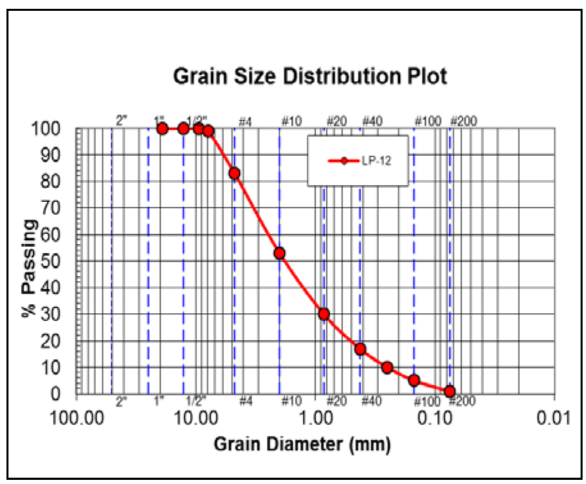




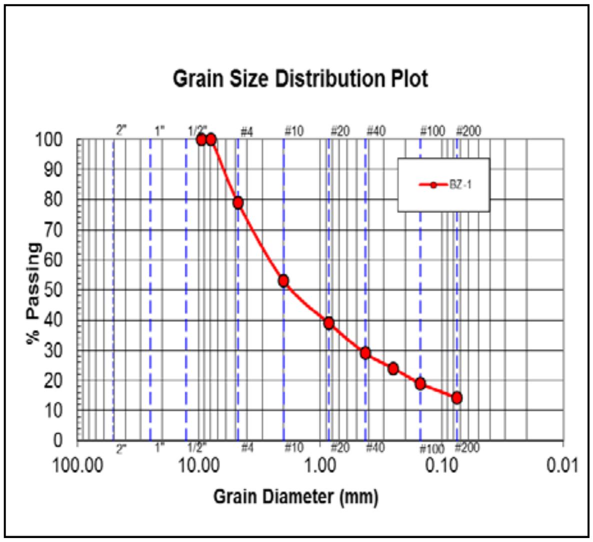


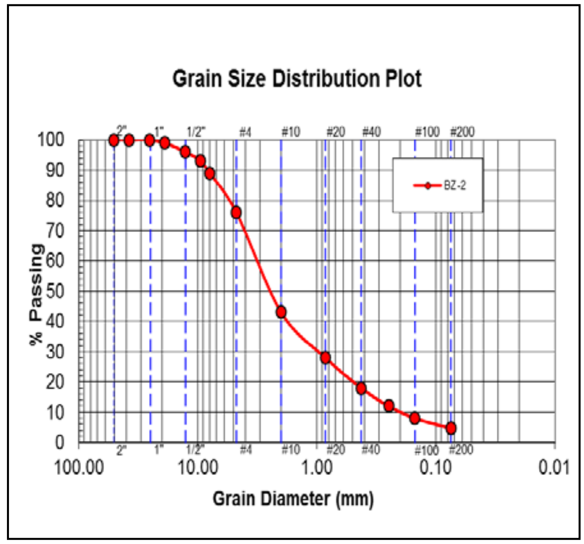


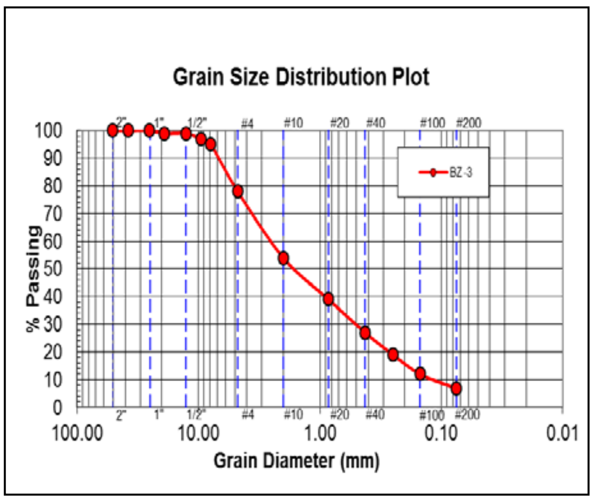


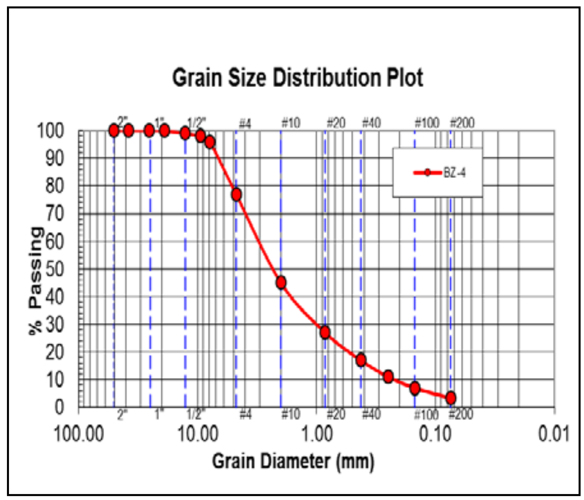


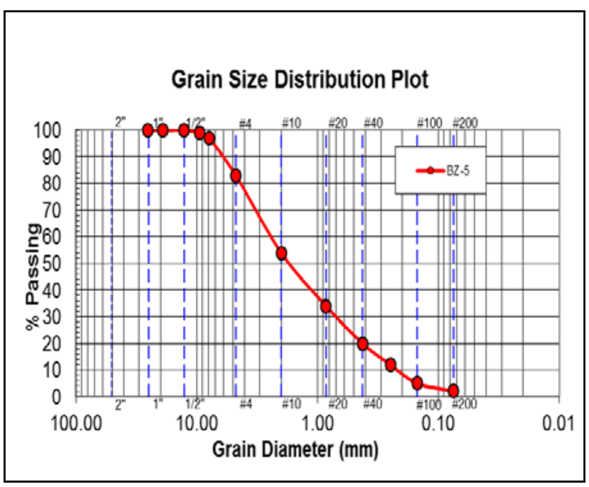
Bozeman Pass

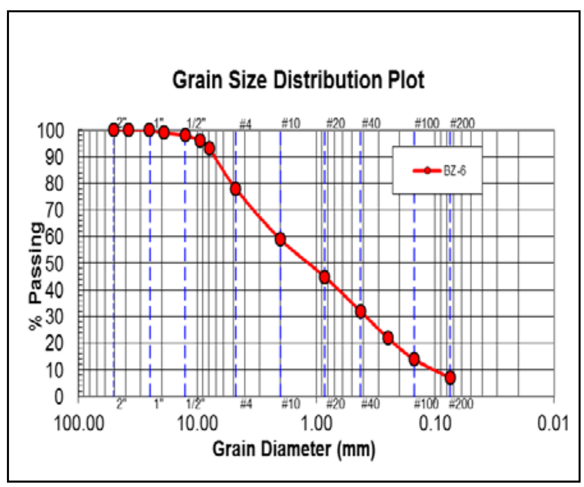












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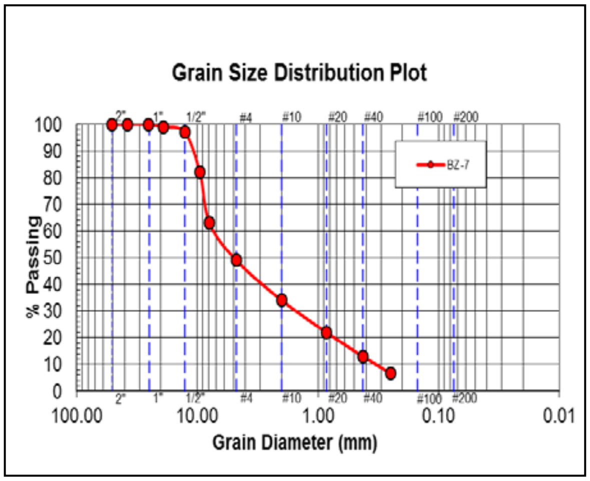
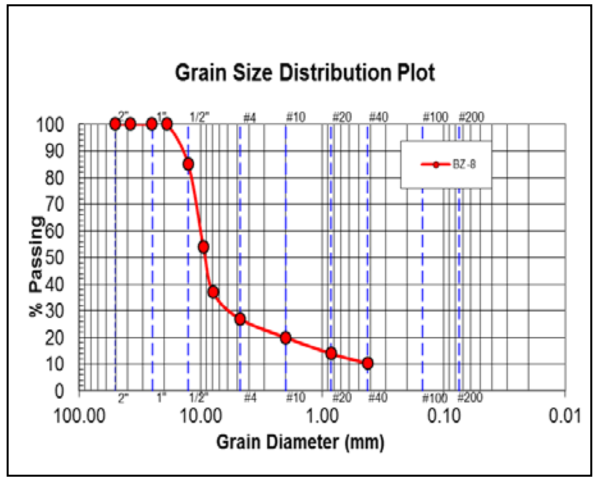
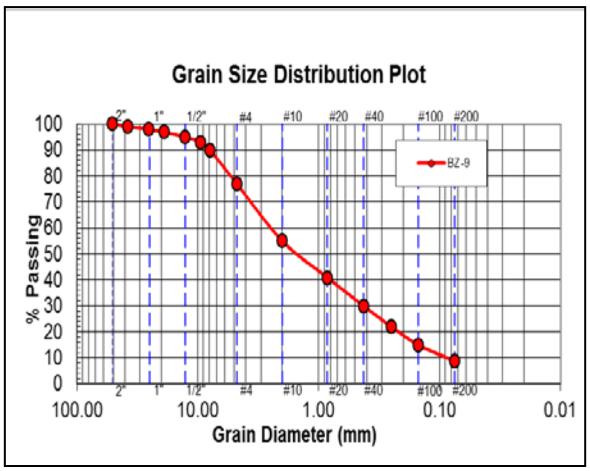
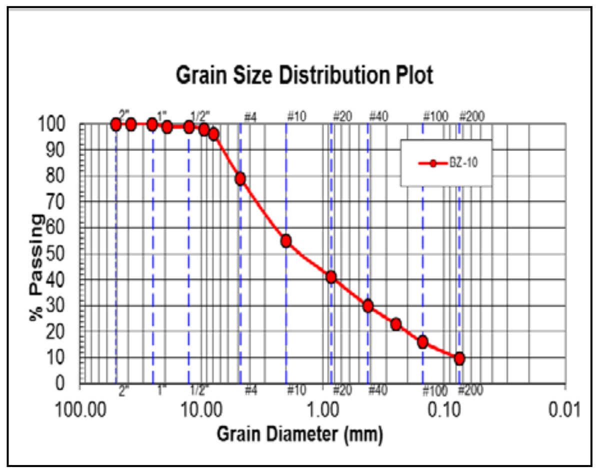
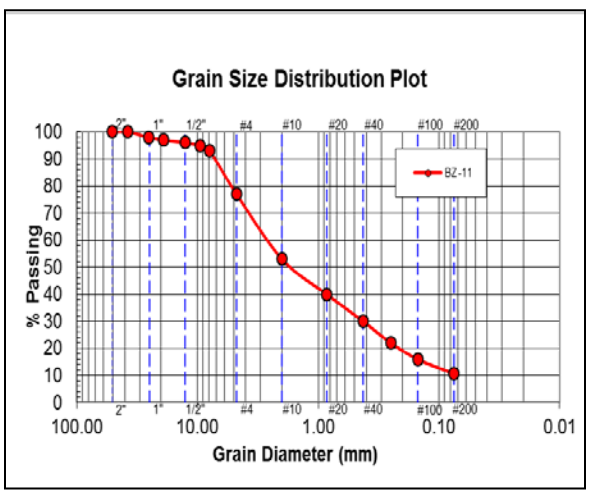










APPENDIX C – CHEMICAL TEST RESULTS

Lookout Pass

Sample ID	LP-1*	LP-2	LP-3	LP-4	LP-5	LP-6	LP-7	LP-8	LP-9	LP-10	LP-11*	LP-12
Lab Test (units)												
TOC (%)	0.07	0.80	1.52	1.63	1.34	-	-	0.60	0.55	-	-	-
pH (saturated paste)	8.0	8.2	7.3	6.3	6.6	7.7	8.3	8.2	7.9	7.6	8.9	7.9
Chloride (meq/L)	0.3	2.5	0.2	ND	0.2	0.2	1.2	0.7	2.5	1.1	ND	11.6
Extractable Metals												
Arsenic (mg/kg)	6	9	10	ND	5	8	ND	ND	8	ND	ND	ND
Barium (mg/kg)	46	84	81	43	70	67	64	82	78	67	58	68
Cadmium (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium (mg/kg)	6	9	10	7	8	8	8	25	8	9	8	9
Copper (mg/kg)	17	16	19	14	23	20	21	29	16	14	10	17
Lead (mg/kg)	11	14	32	17	23	12	11	117	10	10	5	12
Selenium (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc (mg/kg)	47	50	63	44	68	60	76	207	61	31	12	60
Mercury (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Petro-Hydrocarbons - volatile												
GRO (mg/kg)	0.95	0.57	1.20	0.94	0.54	-	-	0.48	ND	-	-	-
TP Hydrocarbons (mg/kg)	0.98	0.59	1.20	0.96	0.61	-	-	ND	ND	-	-	-
Trifluorotoluene (% Rec)	79.0	78.0	87.0	103.0	81.0	-	-	89.0	93.0	-	-	-
S-V Organic Compounds												
2-Methylnaphthalene (mg/kg)	ND	ND	ND	ND	ND	-	-	ND	ND	-	-	-
Acenaphthylene (mg/kg)	ND	ND	ND	ND	ND	-	-	ND	ND	-	-	-
Anthracene (mg/kg)	ND	ND	ND	ND	ND	-	-	ND	ND	-	-	-
Benzo(a)anthracene (mg/kg)	ND	ND	ND	ND	ND	-	-	0.98	ND	-	-	-
Benzo(a)pyrene (mg/kg)	ND	ND	ND	ND	ND	-	-	0.56	ND			
Benzo(b)fluoranthene (mg/kg)	ND	ND	ND	ND	ND	-	-	1.70	ND	-	-	-
Benzo(g, h, i)perylene (mg/kg)	ND	ND	ND	ND	ND	-	-	ND	ND			
Benzo(k)fluoranthene (mg/kg)	ND	ND	ND	ND	ND	-	-	1.20	ND	-	-	-
Chrysene (mg/kg)	ND	ND	ND	ND	ND	-	-	1.30	ND	-	-	-
Dibenzo(a,h)anthracene (mg/kg)	ND	ND	ND	ND	ND	-	-	ND	ND	-	-	-
Fluoranthene (mg/kg)	ND	ND	ND	ND	ND	-	-	2.20	ND	-	-	-
Fluorene	ND	ND	ND	ND	ND	-	-	ND	ND			
Indeno(1,2,3-cd)pyrene (mg/kg)	ND	ND	ND	ND	ND	-	-	ND	ND	-	-	-
Naphthalene (mg/kg)	ND	ND	ND	ND	ND	-	-	ND	ND	-	-	-
Phenanthrene (mg/kg)	ND	ND	ND	ND	ND	-	-	5.20	ND	-	-	-
Pyrene (mg/kg)	ND	ND	ND	ND	ND	-	-	4.70	ND	-	-	-
2-Fluorobiphenyl (% Rec)	84.0	73.0	84.0	80.0	77.0	-	-	77.0	81.0	-	-	-
Nitrobenzene-d5 (% Rec)	76.0	49.0	62.0	67.0	58.0	-	-	51.0	75.0	-	-	-
Terphenyl-d14 (% Rec)	106.0	77.0	122.0	101.0	85.0	-	-	89.0	94.0	-	-	-
Cyanide, total (mg/eq)	ND	ND	ND	ND	ND	-	-	ND	ND	-	-	-

* = Background sand sample from stockpile at yard

ND = Not Detected

Bozeman Pass

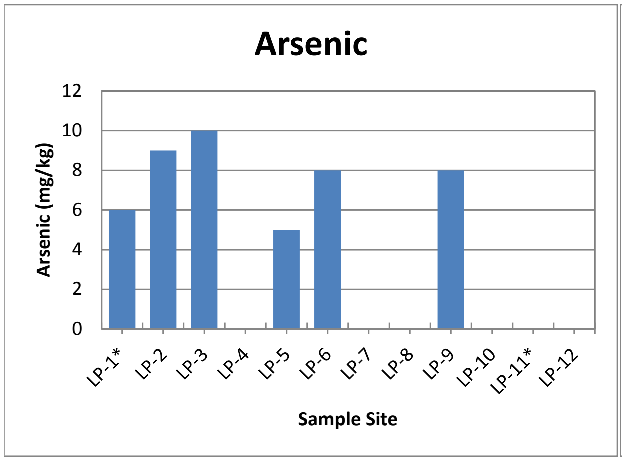
Sample ID	BZ-1*	BZ-2	BZ-3	BZ-4	BZ-5	BZ-6	BZ-7	BZ-8*	BZ-9	BZ-10	BZ-11
Lab Test (units)											
TOC (%)	0.02	2.44	0.82	1.05	0.25	0.61	0.61	0.04	1.24	0.95	0.89
pH (saturated paste)	7.0	8.3	8.3	8.0	8.6	8.4	8.7	7.7	7.5	7.6	7.4
Chloride (meq/L)	4,330.0	8.4	0.5	1.0	0.3	0.6	1.0	1,540.0	230.0	2.6	5.5
Extractable Metals											
Arsenic (mg/kg)	ND	6	ND	ND	ND	ND	ND	ND	ND	ND	ND
Barium (mg/kg)	88	87	95	139	78	112	108	132	100	123	157
Cadmium (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium (mg/kg)	14	28	21	14	16	16	21	16	22	19	18
Lead (mg/kg)	ND	27	10	8	7	11	14	8	20	18	16
Selenium (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mercury (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Petro-Hydrocarbons - volatile											
GRO (mg/kg)	1.40	1.20	1.20	1.40	1.10	1.20	1.10	1.10	1.20	1.10	1.10
TP Hydrocarbons (mg/kg)	1.40	1.20	1.20	1.50	1.10	1.20	1.10	1.10	1.20	1.10	1.10
Trifluorotoluene (% Rec)	77.0	72.0	74.0	73.0	74.0	73.0	72.0	73.0	71.0	70.0	70.0
S-V Organic Compounds											
2-Methylnaphthalene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthylene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Anthracene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(a)anthracene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(a)pyrene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(b)fluoranthene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(g, h, i)perylene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(k)fluoranthene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chrysene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenzo(a,h)anthracene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Naphthalene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pyrene (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Fluorobiphenyl (% Rec)	74.0	78.0	90.0	68.0	77.0	95.0	77.0	77.0	83.0	84.0	76.0
Nitrobenzene-d5 (% Rec)	76.0	73.0	103.0	61.0	70.0	96.0	76.0	81.0	85.0	72.0	63.0
Terphenyl-d14 (% Rec)	94.0	90.0	107.0	85.0	87.0	118.0	84.0	94.0	98.0	108.0	86.0
Cyanide, total (mg/eq)	1.1	ND	ND	ND	ND	ND	ND	3.3	ND	ND	ND

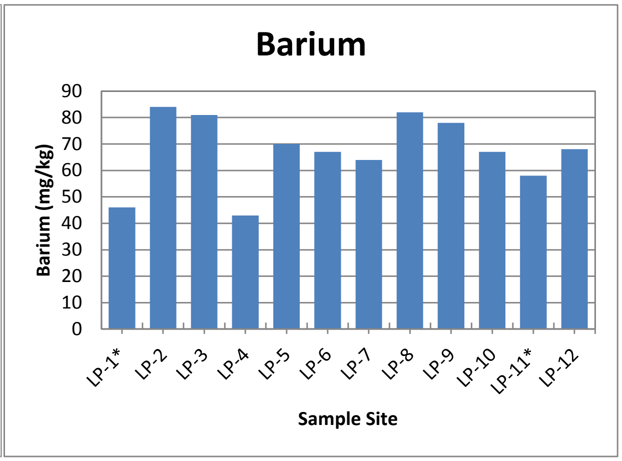
* = Background sand sample from stockpile at yard

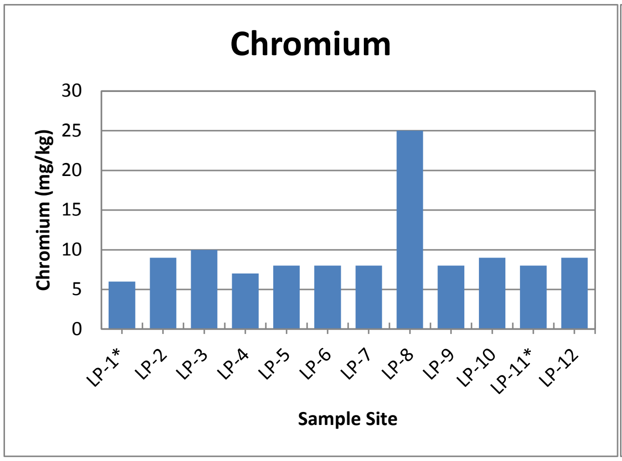
ND = Not Detected

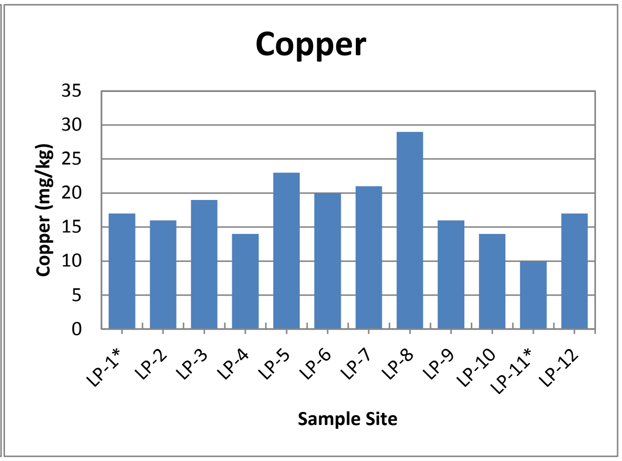
APPENDIX D – PLOTS OF CHEMICAL TEST RESULTS

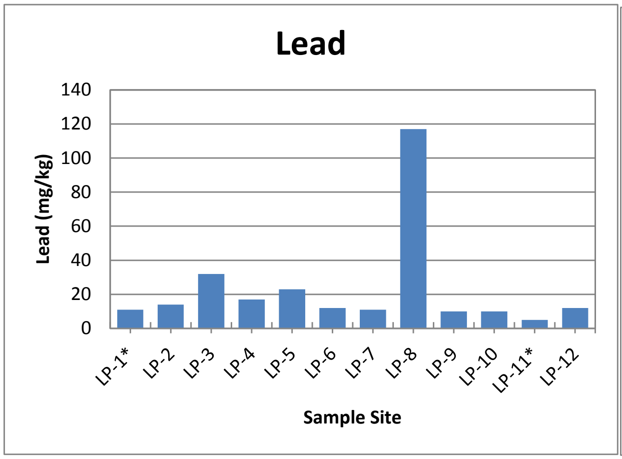
Lookout Pass

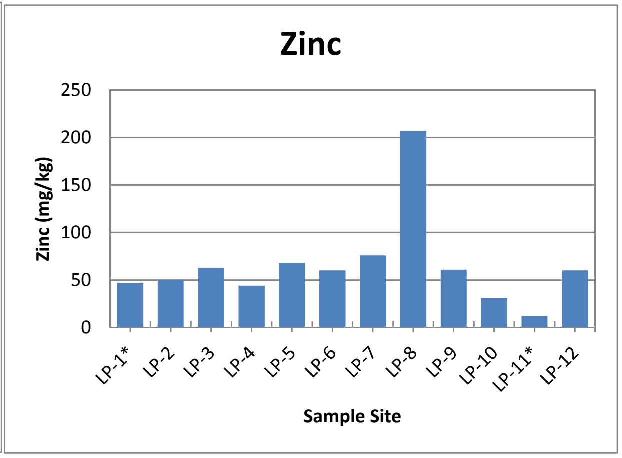












Bozeman Pass