MOUNTAIN-PLAINS CONSORTIUM

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Assessing the Cost-Effectiveness of Wyoming's CMAQ Unpaved Road Dust Suppression Program, Year 2

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Disclaimer

ABSTRACT

This study is part of a multiple year study conducted at the University of Wyoming to assess the effectiveness of dust suppressant treatments on gravel roads. The multiple year study was conducted to assist the Wyoming Department of Transportation (WYDOT) and the Federal Highway Administration optimize the use of the congestion mitigation and air quality (CMAQ) funds. The federal CMAQ program is implemented to fund projects that contribute to air quality improvements. For a number of years, Wyoming counties have used CMAQ funds to apply chemical dust suppressant treatment to gravel roads. The state of Wyoming owns a large inventory of low-volume gravel roads that connect rural Wyoming areas. The main objectives of this study were to assess the effectiveness of the CMAQ program in Wyoming, develop long-term gravel roads performance models, and conduct a life-cycle cost analysis to compare the costs of treating and maintaining gravel roads. The study utilizes field data and exploratory and statistical analysis to assess and evaluate the performance of chemical treatment on gravel roads. The results of this study will be used in developing cost-effective maintenance strategies that will aid in optimizing the Wyoming asset management program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

The following table describes the abbreviations and acronyms used in this document:

Abbreviation	Description
AASHTO	American Association of state highway and transportation officials
ADT	Average daily traffic
ADTT	Average daily truck traffic
ASTM	American society of testing and material
CMAQ	Congestion mitigation and air quality
EPA	Environmental Protection Agency
FHWA	Federal highway administration
GIS	Geographic Information System
NAAQS	National Ambient Air Quality Standards
PASER	Pavement Surface evaluation rating
PMS	Pavement Management system
PM	Particulate Matter
STP	Surface Transportation Program
USACR	United States Army Corps of Engineers
WYDOT	Wyoming Department of transportation
WYT2/LTAP	Wyoming Technology Transfer Center/Local Technical Assistance program

1. INTRODUCTION

1.1 Introduction

This study is part of a multiple year study conducted by the Wyoming Technology Transfer Center (WYT2) at the University of Wyoming to assess the effectiveness of chemical dust suppressant treatment on gravel roads. The federal congestion mitigation and air quality (CMAQ) program funds projects aimed at improving air quality in the United States. For a number of years, Wyoming counties have used CMAQ funds to apply chemical dust suppressant treatment on gravel roads. The state of Wyoming owns a large inventory of gravel roads spread around the state. Most of these roads serve low-traffic volumes and connects rural Wyoming areas. With the significant increase of oil and gas drilling operations in recent years, local authorities witnessed a substantial increase in traffic volumes, resulting in higher maintenance costs that are out of their reach. This has led to higher demands from counties and local jurisdictions to apply for and receive CMAQ funds. WYDOT and the Federal Highway Administration are facing a significant increase in CMAQ funding applications and are looking for more cost-effective ways to allocate these funds.

Gravel roads are considered one of the main sources of particulate matter (PM) in the atmosphere. Dust generated from gravel roads is classified as PM_{10}, particulate matter less than 10 micrometers in diameter. Figure 1.1 illustrates fugitive dust emissions generated from a gravel road in Converse County, Wyoming. Fugitive dust generated from Wyoming's gravel roads poses air pollution issues that can increase the risk of health and environmental problems.

Figure 1.1 Dust emission from a gravel road in Converse County, Wyoming

With 12,000 miles of gravel roads in Wyoming, and the influx of oil and gas drilling operations in the state, heavy truck traffic volumes have resulted in higher dust emissions and higher deterioration rates of gravel roads. Counties are left incapable of maintaining their roads due to budget constraints. Considering these issues, it is important to research and investigate more effective strategies in treating and maintaining gravel roads in Wyoming and developing cost-effective strategies to use CMAQ funds where they are most needed.

1.2 Research Objectives

The objectives of this research study are to evaluate the effectiveness of the CMAQ program in Wyoming and develop cost-effective strategies to implement with CMAQ funds. The study is looking to investigate the issues mentioned earlier by undertaking the following objectives:

1. Assess the effectiveness of the CMAQ program in Wyoming by assessing dust suppressant treatment efforts on gravel roads. This study aims to evaluate the efficiency of these efforts to develop a better understanding of gravel road dust emission behaviors and ultimately improve dust mitigations and air quality on gravel roads.
2. Develop long-term performance models to predict the service life and behavior of chemically treated gravel roads. Such models can be used in assessing the effectiveness of chemical dust suppressant treatments and help quantify the benefits of applying chemical treatment.
3. It has been proven that chemical dust treatment is effective in reducing dust generation and improving roadway safety and visibility. The third objective of this study is to conduct a life-cycle cost analysis to compare the cost of maintaining chemically treated roads with the cost of maintaining untreated roads. Such a comparison aims to compare the cost and benefits of each option, and will help aid agencies and decision makers in making cost effective asset management decisions.

1.3 Expected Outcomes

This study will provide valuable information to state legislatures and decision makers, such as WYDOT and the Federal Highway Administration, which will aid in practical and more efficient allocation of CMAQ funds. This study included the testing of CMAQ-funded roads before and after applying chemical treatment. The results of this testing can help evaluate current practices and recommend improvements in the future. In addition, the analysis will clearly justify the expenditures of the CMAQ program.

Another expected outcome of this study is the development of long-term performance models that predict the service life of chemical dust suppressant treatment on gravel roads. Such models can calculate the amounts of dust reductions achieved by applying chemical treatments and helping to quantify the benefits of using dust mitigation products. This will also assist in conducting cost benefit analyses to evaluate the different alternatives available to decision makers in maintaining their gravel road network asset. The ultimate goal of this study is to develop a more rigorous understanding of dust emission behaviors from gravel roads and to recommend the most efficient dust mitigation practices.

1.4 Report Organization

This report is organized into seven chapters as follows:

Chapter 1 of this report provides an introduction of the research topic and objectives, the expected outcomes of the study, and why cost-effective strategies are needed in the implementation of the CMAQ program in Wyoming.

Chapter 2 discusses the various literature pertaining to the generation of particulate matter from gravel roads, factors affecting PM generation, the maintenance and management of unsealed road networks, and different dust suppressant products available on today’s market.

Chapter 3 provides a summary of the experimental methodologies developed and followed in this research study. It discusses the different data collection steps followed to conduct this experimental study. A flow chart of the overall report organization is included in this chapter.

Chapter 4 discusses the continuation of the CMAQ study initiated in summer 2014. The chapter explains the continuing data collection conducted in the following years, and illustrates the new counties and road sections included in the study. Chapter 4 also describes the analysis conducted and the results obtained from analyzing the collected data.

Chapter 5 includes detailed discussions of the methodologies and results of the long-term chemical dust treatment performance study. This includes a discussion of the road sections tested, testing procedures, and two types of data analyses conducted.

Chapter 6 discusses the life-cycle cost analysis study conducted to compare the cost of maintaining treated roads with the cost of maintaining untreated roads. This chapter describes data sources and organizations, and concludes with a discussion of data analysis, results, and conclusions.

Chapter 7 concludes this study by summarizing and highlighting the results and conclusions reached in the study. Chapter 7 also includes recommendations developed based on the findings, and provides insights for future research work to be done to better understand dust behavior on gravel roads.

2. LITERATURE REVIEW

2.1 Introduction

The state of Wyoming owns a large inventory of gravel (or unsealed or unpaved) roads spread all around the state. Gravel roads are cheaper to build and maintain than paved roads, but one of their major detriments is dust generation. The Clean Air Act amendments passed by congress in 1990 required reduction of air pollution caused by transporting vehicles. The Congestion Mitigation and Air Quality Improvement (CMAQ) program was initiated under this act to support surface transportation projects and other related efforts that contribute to air quality improvements. For a number of years, Wyoming counties have benefited from CMAQ funds to apply dust suppressants to gravel roads and help reduce dust generation and contribute to the attainment of national ambient air quality standards (NAAQS) for ozone, carbon monoxide, and particulate matter. In this chapter, a literature review is conducted to determine key topics related to the management and maintenance of gravel roads.

2.2 Background

The U.S. Environmental Protection Agency (EPA) specifies gravel rural roads as a source of pollution. When gravel roads erode, soil particles are loosened and carried away from the road by traffic, wind, water runoff, or other transport means (U.S. Environmental Protection Agency, 2016). In recent years, Wyoming has experienced an increase in oil drilling operations, which have led to heavy truck traffic on the state's rural road network. Increased traffic has deteriorating effects on road conditions which lead to more dust generation. The Wyoming Department of Transportation (WYDOT) provides around $2 million each year for local governments to support CMAQ projects. An application must be submitted to WYDOT in order to receive the funds. WYDOT CMAQ funding provides for an 80% federal portion; and a minimum of a 20% local match is required. Typically, WYDOT receives far more requests for funding than the program allocation, and preference is given to projects in energy and industrial areas where heavy truck traffic exists. The goal of the CMAQ funds, as stated by WYDOT, is to mitigate airborne particulate matter by controlling dust generation on gravel roads. For the years 2013-2014, a number of Wyoming counties received the CMAQ funds. Table 2.1 lists Wyoming counties that sponsored CMAQ funded projects and the total amount of spending in each county. Figure 2.1 shows the awarded counties and their locations.

Table 2.1 2013/2014 CMAQ Sponsored Projects in Certain Wyoming Counties

Project Sponsor	Total Spending (Including CMAQ)
Campbell County	$436,000
Carbon County	$241,000
City of Sheridan	$40,000
Converse County	$550,000
Crook County	$280,000
Johnson County	$600,000
Lincoln County	$607,000
Sheridan County	$336,000
Sublette County	$250,000
Sweetwater County	$400,000
Teton County	$50,000
Uinta County	$50,000
Weston County	$160,000
Total	$4,000,000

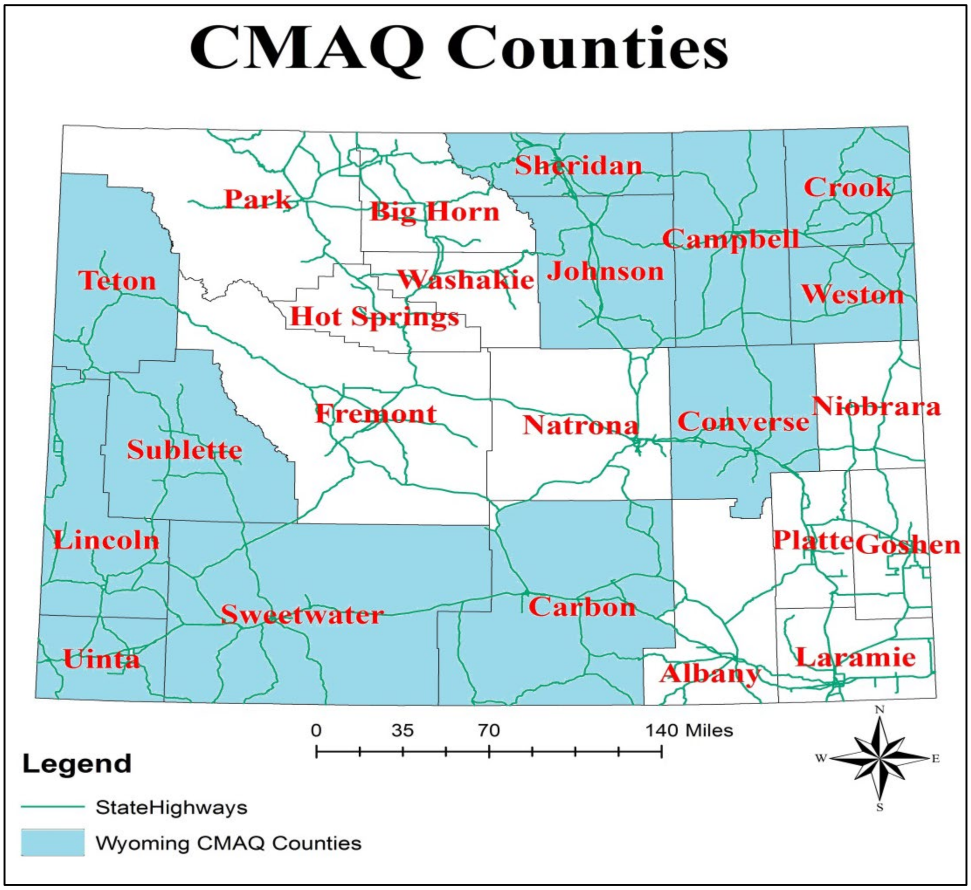


Figure 2.1 Wyoming counties awarded CMAQ funds in 2013/2014

2.3 Dust Generation

All gravel roads will generate dust under traffic. There are several variables that influence how much dust is generated. The variables that impact the amount of dust generated by a vehicle driving on gravel roads can be classified into four major factors (Thenoux, Bellolio, & Halles, 2007):

- Factors specific to the road: The amount of dust generated on a gravel road is directly proportional and related to the amount of fines contained in the wearing coarse material, the construction quality of the gravel road (compaction and homogeneity), and the physiochemical characteristics of the fine material (plasticity, liquidity, particle size, moisture content, fine percentage, etc.).
- Factors specific to the geographic area and climate
- Factors specific to the operational conditions of the vehicle
- Factors specific to the vehicle type and weight

2.3.1 Road Dust Generation

Dust generated from gravel roads is technically defined as solid particulate matter released in the atmosphere. These solid particles range from smaller to medium sized soil particles, ranging between approximately 0.5 to more than 100 μm in particle diameter (Barnes, 2014). Dust from gravel roads can be generated from multiple sources. Mechanical breakdown of the surfacing soil and aggregate in gravel roads results in the creation of dust. As vehicles pass over the road, the shearing force created at the interface between the vehicle tires and the road surface causes dust generation. The weight of the vehicle is also a key factor in dust generation, as it will make soil particles lose cohesion and generate dust. Dust can also be generated from open space fields and gravel lots surrounding gravel roads. As airborne dust particles settling on the road will be suspended by vehicle tire pressure, dust will regenerate into the atmosphere. Another source of dust on roads (both paved and gravel) is the deposition of dust attached to vehicles when driving on dirt roads, which can then be transferred into the air to become fugitive dust (Barnes, 2014). Figure 2.2 illustrates each of these processes of road dust generation.

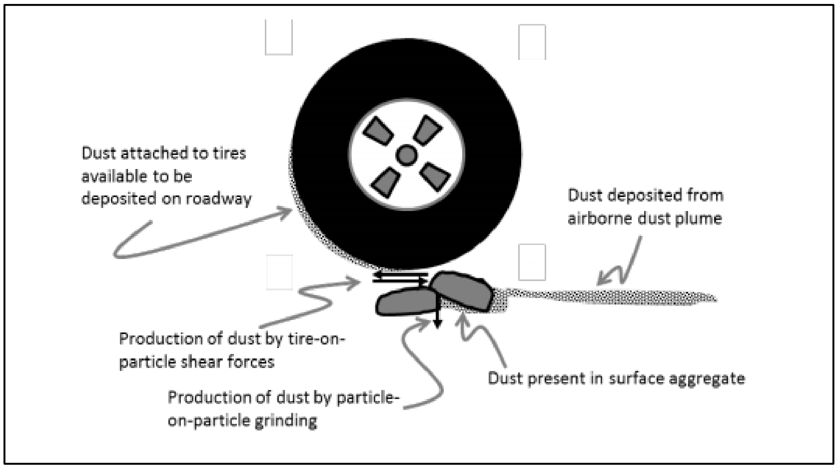


Figure 2.2 Sources of dust on gravel roads (Barnes, 2014)

Climate is also considered to have a big effect on dust generation. Areas with higher precipitation rates and wetter climates tend to have less dust particles in the air compared with dry climate areas.

2.3.1.1 Traffic Effect

Traffic is the main generator of dust on gravel roads. The heavier the vehicle the more road damage it will cause and the more dust the road will generate. In recent years, Wyoming has witnessed a boom in the oil and gas operations driven by newly discovered oil extraction technologies such as fracking. This oil industrial boom has caused truck traffic to heavily increase on some of Wyoming county gravel roads, causing them to deteriorate faster and generate extensive amounts of dust. There is a need to have an effective system in place to treat and maintain county gravel roads and ensure they remain in serviceable conditions for the public to use. A study conducted by the Wyoming Technology Transfer Center found that the cost of maintenance for a Wyoming county road affected by the oil and gas influx was approximately $11,500/miles more per year than that of a road not affected (Stroud, Ksaibati, & Shinstine, 2015).

2.3.1.2 Road Material Composition

Gravel roads are composed of several soil materials. There are three basic types of soil materials used for building gravel roads: gravel, sand, and fines (from largest to smallest particle size) (Maine Department of Environmental Protection, 2010). Coarse materials, gravel, and sand are all visible to the naked eye. Fines, particles passing through the 75µm (#200) sieve, however, are made of small sized particles that cannot be seen by the bare eye (Bolander, 1999).

Fines (silts and clays), sand, and coarse materials each have specific properties that make it useful for different aspects of road building. Coarse materials provide strength, but have large air voids between the particles that make them prone to failure due to displacement. That is why fines are used to fill up the voids and provide interlock cohesive forces that will hold the coarse material together. Fines also provide protection to the road surface by preventing water from infiltrating into the road base (Maine Department of Environmental Protection, 2010).

2.3.1.3 Climate Effect

Climate is considered an important factor in dust generation. A study conducted by the United States Geological Survey center in collaboration with the Institute of Arctic and Alpine Research at the University of Colorado, Boulder, looked at the relationship between dust deposition and climate. The study found that climatic factors make a major contribution to dust flux. It was found that average dust concentrations increase with the increase in mean annual temperature, suggesting that higher dust concentrations exist in higher temperature areas. It was also found that dust flux reflects changes in annual precipitation, where more dust was generated during dry climates and less dust was generated during wet climates. Hydrologic conditions are considered a major factor in dust generation. Another study found that in arid United States climates, dust concentrations are higher in the atmosphere than in wetter climates (Reheis, 2006).

2.4 Dust Measurement Tools

There are different tools and devices used to measure dust concentrations in buildings, work sites, and open spaces. Each of these tools has a unique technique to measure dust concentrations. Two different devices are used in data collection for this study, each with a different measuring technique and different measuring units. These two devices are the Haz-Dust EPAM 5000, developed by Environmental Devices Corporation, and the Dustometer, developed by Colorado State University.

2.4.1 HAZ-DUST EPAM-5000

The HAZ DUST EPAM 5000 is a stationary environmental particulate air monitoring device. It is designed to measure existing levels of ambient air pollution. The main purpose of the device is to measure lung damaging airborne particles (PM_{10} and $PM_{2.5}$). According to the manufacturer, "EPAM-5000 is an innovative light scattering nephelometer and filter gravimetric air sampler combined in one portable compact and lightweight design. The unique design allows the air quality investigator to collect size selective particulate matter using two proven techniques: light scattering and filter gravimetric. Size selective sampling is achieved by a single jet impactor for PM-10, PM-2.5, PM-1.0um, TSP, or 4.5 um with OSHA approved respirable cyclone" (Environmental Devices Corporation, 2014). Figure 2.3 shows the EPAM-5000 components.

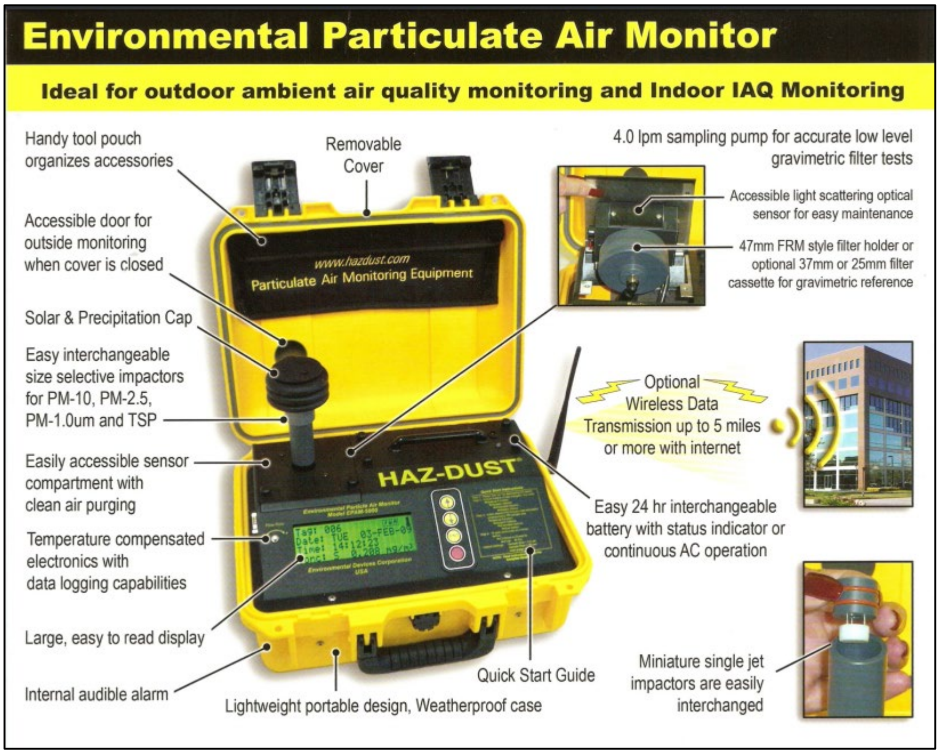


Figure 2.3 EPAM-5000 components

2.4.2 CSU Dustometer

The Colorado State University Dustometer is a dust measuring device developed during a research study conducted by Colorado State University to assess the relative effectiveness of gravel road dust suppressants. The goal of developing the Dustometer was to create a device that is cheap, easy to use, and moderately accurate in measuring dust generated from gravel roads. The biggest advantage of the CSU Dustometer is its intent to measure dust generated from gravel roads. The CSU Dustometer enables the measurement of dust concentrations from a roadway section instead of a single point on the road; this results in more accurate dust concentration measurements that represent the conditions of the entire roadway section (Sanders T. G., 1997).

2.5 Dust Pollution

2.5.1 Environmental Protection Agency (EPA)

The U.S. Environmental Protection Agency (EPA) was created to serve as a governing organization that protects human health and the environment. Its main duty is to write and enforce laws and regulations to ensure all Americans are protected from significant risks to human health and the surrounding environment. Another mission of the EPA is to ensure that the public has access to accurate information regarding existing environmental conditions and other information that helps communities manage human and environmental risks (US Environmental Protection Agency, 2015). The EPA has a set of standards and regulations pertaining to particulate matter generated from fugitive dust emissions in the atmosphere. The EPA classifies gravel roads as the main source or the main generator of PM_{10} in the environment. The EPA recommends that dust mitigation applications be implemented on gravel roads, especially on roads connecting populated areas (Environmental Protection Agency, 2003)

2.5.2 Particulate Matter

Particulate matter (PM) is defined by the EPA as "a mixture of solid particles and liquid droplets found in the air, some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope." (U.S. Environmental Protection Agency, 2016).

Particulate matter (PM) is classified into two:
- PM_{10}, or particulate matter less than 10 micro meters (Also referred to as inhalable particles)
- $PM_{2.5}$, or particulate matter less than 2.5 micro meters (Also referred to as fine inhalable particles)

Figure 2.4 shows a size scheme to help compare the size of PM particles with the size of a human hair or fine beach sand. This demonstration is included to help visualize how small particulate matter is.

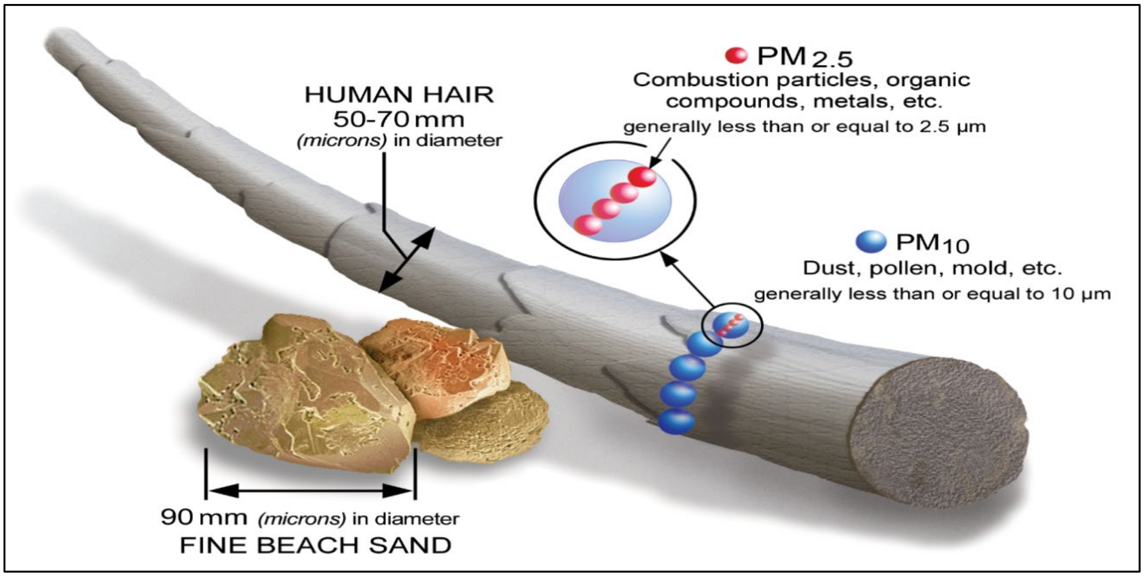


Figure 2.4 Size comparison for PM particles (U.S. Environmental Protection Agency, 2016)

2.5.3 Sources of Particulate Matter

Particulate matter particles generate from different sources. Construction sites, gravel roads, and open fields are some of the main generators of particulate matter in the atmosphere. However, PM particles can also form in the atmosphere as a result of complex chemical reactions, such as nitrogen oxides and sulfur dioxide, which are air pollutants usually generated in the atmosphere from automobiles and industrial power plants (U.S. Environmental Protection Agency, 2016).

Examples of PM particles in the air include fine solids or liquids such as smoke, fly ash, flumes, mists, aerosols, and condensing vapors that can be suspended in the air for extended periods of time. These particles can generate from a variety of stationary and mobile sources; these sources can be divided into two categories: human-caused and nature-caused. Human-caused activities include agricultural and industrial operations, construction and demolition activities, combustion of wood and fossil fuels, and the generation of dust from gravel roads. Natural sources can include non-anthropogenic or biogenic sources, which include dust generated from wildfires and windblown dust (San Joaquin Valley Air Pollution Control District, 2012).

2.5.4 Clean Air Act

The Clean Air Act was passed by the EPA to control air pollution on a national level. The Clean Air Act is a federal law considered to be one of the most influential environmental laws in the 20th century. Internationally, the Clean Air Act is considered to be one of the most comprehensive air quality laws in the world, and is followed by other countries as a model to implement.

2.5.4.1 CMAQ Program

With congressional passage of the Clean Air Act amendments in 1990, the congestion mitigation and air quality (CMAQ) program was initiated to attain national ambient air quality standards (NAAQS) and fund surface transportation projects that contribute to air quality improvements and provide traffic congestion relief (U.S. Department of Transportation, 2016). The CMAQ program provides funding to state and local government agencies to implement air transportation projects that will improve air quality for areas that do not meet the NAAQS standards for ozone, carbon monoxide (CO), and particulate matter ($PM_{2.5}$ and PM_{10}) (Federal Register, 2014). In 2015, under the CMAQ program the Federal Highway Administration (FHWA) awarded more than $30 billion to fund over 30,000 transportation-related environmental projects related to improving air quality to state DOTs, metropolitan planning organizations (MPOs), and other agencies throughout the United States (U.S. Department of Transportation, 2016).

2.5.4.2 CMAQ Program in Wyoming

For several years, the state of Wyoming has received and benefited from federal aid funds authorized under the CMAQ program. WYDOT has specified three main objectives to use with CMAQ funds (Wyoming Department of Transportation, 2013):

- Ensuring, maintaining, and/or bringing areas into attainment with the NAAQS for carbon monoxide, ozone, and particulate matter
- Helping local government agencies alleviate air quality problems caused by oil and gas operations, energy developments, and other heavy industrial-related activities in their vicinities.
- Supplement the Surface Transportation Program (STP) throughout the state as determined by the Wyoming Transportation Commission

WYDOT awards approximately $2 million each year for counties and local governments to use for CMAQ-related projects. WYDOT requires local agencies seeking CMAQ funding to submit an application that clearly identifies the project boundaries and expected benefits. WYDOT also requests that project applications address existing air quality conditions and how the proposed project will improve these conditions. WYDOT also required applicants to provide plans on pre- and post-project air quality monitoring to evaluate the effectiveness of the CMAQ-funded projects (Wyoming Department of Transportation, 2013). CMAQ funding in Wyoming provides for an 80% federal portion, and a 20% local match is required. WYDOT emphasized that the applications requesting CMAQ funding far exceeds the available program allocations, and overmatch by the project sponsor is highly encouraged. Because of the high demand on CMAQ funding that far exceeds available allocations, WYDOT only awards these funds to projects in industrial and energy impacted areas. The preference is given to projects that aim to mitigate airborne particulate matter generations caused by energy or industrial-related activities (Wyoming Department of Transportation, 2013).

2.6 Dust Treatment and Stabilization

2.6.1 Types of Stabilizers

A recent study conducted in 2014 found there are nearly 200 products being sold and marketed for dust control and soil stabilization in North America. Many of these products are proprietary, and their exact mechanism is not declared (Federal Highway Administration, 2015). However, this chapter includes the best known and commonly used products that states, counties, agencies, factories, plants, farmers, and ranch owners use to treat and mitigate dust generated from gravel roads.

2.6.1.1 Chlorides

Chlorides are the most commonly used products as dust control agents in the United States and Canada. Chlorides are usually classified into three categories: magnesium chloride, calcium chloride, and sodium chloride (road salt). Magnesium chloride is often used in the liquid form; calcium chloride can be used in both dry and liquid forms. Sodium chloride is rarely used as it is the least effective. If used properly, calcium chloride and magnesium chloride can be very effective in reducing dust generation and stabilizing road soil. Magnesium and calcium chlorides are hygroscopic products in that they absorb moisture from the air and keep the road surface consistently moist. Another advantage is the simplicity and ease of application. The chlorides can be used in two ways to control dust: sprayed on the road or mixed with the gravel (Federal Highway Administration, 2015).

2.6.1.2 Resins

Resins main component is lignin sulfonate, a naturally occurring polymer found in wood. Lignin sulfonate acts like glue by holding the cellulose fibers of pulp together (Pacific Dust Control, 2016). Lignin sulfonate is a high-viscosity, naturally sticky material; it works by providing cohesion to bind soil particles together. It has the advantage of being an environmentally friendly and safe material. It is also non-corrosive and non-toxic. Lignin sulfonate treatments can be more effective than chlorides on gravel roads with higher amounts of sand (Federal Highway Administration, 2015).

2.6.1.3 Natural Clays

Some regions around North America have excellent deposits of natural clay, which is highly plastic and provide strong cohesion to soil particles when added to gravel. Clay can only be used in one way to reduce dust emissions from gravel roads and provide stabilization; it must be mixed into a portion of the gravel layer. This way it will provide some cohesion to bind soil particles together and enhance the stability of the road (Federal Highway Administration, 2015). By binding soil particles together, less fine particles will be loosened and released into the atmosphere as fugitive dust.

2.6.1.4 Asphalts

Recycled asphalt products were once a popular option among local governments to use as a dust mitigation product. However, due to the existence of environmentally hazardous materials, such as kerosene and fuel oil in recycled asphalts, its use was banned in many places. The EPA has specific regulations regarding the use of recycled asphalt as an emulsifying agent, and a special permission is needed before use. In addition to EPA regulations, the application procedures require special equipment, which can increase the cost of using recycled asphalts (Federal Highway Administration, 2015).

2.6.1.5 Soil Cement

Portland cement can also be used as a soil stabilizer. Portland cement works by increasing the strength and stability of the soil. It is often used to stabilize base and sub-base materials underlying pavement structures. The use of Portland cement as a soil stabilizer is proven as an effective alternative for improving soil properties, strength, and stability. However, it is not an effective dust mitigation solution due to its high cost and poor performance as a dust suppressant. Using Portland cement on gravel roads also requires careful analysis and design to determine the optimal amount of cement mixture needed and what depth it must be applied to achieve the desired strength and stability (Federal Highway Administration, 2015).

2.6.1.6 Other Commercial Binders

Many commercial products exist in the U.S. market. They are marked under different names and sold by different commercial companies. Companies almost always provide detailed supplemental information on how to prepare the road surface and apply the product. Counties usually test a new product on a small section first before investing in large quantities. This ensures that the performance of the product is well examined before being applied to more miles of road (Federal Highway Administration, 2015).

2.6.2 Benefits of Stabilization

There are many benefits to applying chemical dust treatment to gravel roads. These benefits include significantly reducing dust generations, and minimizing soil aggregate loss. On high-volume roads, these benefits significantly justify the cost, and treatment can be proven as very cost effective. A major benefit of applying soil stabilizers is to reduce the loss of fines, which are an important component of the road surface structure. Fines work as a binding agent to keep the soil component held together. When fines are lost from a gravel road surface, the sand and aggregate that remain will tend to lose their interlock binding force; this will lead to distresses, such as corrugation (washboarding) and reduced skid resistance, forming on the road surface. Lost fines are also expensive to replace (Environmental Protection Agency, 2003).

Another major benefit of stabilization is the reduction of aggregate loss. When dust control products are applied and are working well, the fine materials in the soil are well bonded and will not loosen and become dust. This also means that the granular components of the soil will experience strong interlock binding forces and will not be lost or whipped off the road by moving traffic (Environmental Protection Agency, 2003). Many studies have found that as much as one ton of aggregate per mile is lost each year for each vehicle driving over a gravel road daily. This means that if a gravel road has average daily traffic (ADT) of 200 vehicles per day, more than 200 tons of aggregate can be lost per mile each year (Federal Highway Administration, 2015).

Reduction in maintenance cost is also a major benefit of applying dust treatment to gravel roads. When dust control treatment is applied correctly, its benefits can outweigh the cost. A well stabilized road surface that is firmly bonded will require less blading and maintenance over time than a poorly bonded road. Although blading and shaping are usually needed to prepare the road for dust control treatment application, chemical treatment will significantly reduce the need for such operations. This can be a great economic advantage for dust control treatment and can be result in major savings in equipment and labor cost. A county road official once commented on the benefit of dust treatment by saying, "I don't react to dust complaints. All gravel roads have dust. But I do react to high maintenance costs. When we have to re-gravel a road frequently and perform blade maintenance frequently, then it's time to look at stabilizing the surface. Reduced maintenance is what we're after. Dust control is just a bonus!" (Federal Highway Administration, 2015)

In addition, dust has many polluting side effects on nearby animals, water sources, and plants. By applying dust suppressants, dust pollution is significantly reduced and its harmful effects are minimized. Dust treatment can prevent water wells and ground water sources from getting polluted with fine dust particles generated from gravel roads. Dust treatment can also save nearby cattle and wildlife from inhaling dust particles, which can possibly result in their suffocation.

One of the major benefits of applying dust treatment and soil stabilization to gravel roads is the potential to save lives and reduce fatal crashes on gravel roads. Reducing dust generated from the road will significantly enhance visibility and reduce the risk of crashes. Finally, reducing dust generation from gravel roads will minimize human exposure to air polluted by particulate matter. As the literature review suggested, dust particles can cause serious health issues, such as asthma and lung cancer, when inhaled, and dust treatment will significantly reduce this risk. Overall, applying dust treatment to gravel roads has many advantages and benefits that justify its cost.

2.6.3 Application Methods

Each dust chemical treatment product has its own appropriate application instructions, rate, and frequency. Manufacturers usually provide agencies with comprehensive guidelines that can be used to optimize the use of the product. According to the United States Department of Agriculture Technology and Development Program, higher application rates or increased frequency is required when the following conditions are present (Bolander, 1999):

- High traffic volumes with high speeds and a larger percentage of truck traffic
- Low humidity conditions, especially when using calcium chloride
- Low fines content in road surface, typically when there is less than 10% passing through the 75 μm (No. 200) sieve
- Poorly bladed surface and/or loose wearing surface

Optimized use of chemical treatments can also be achieved by ensuring full penetration of the liquid dust suppressant into the soil. Proper penetration mitigates loss of the palliative resulting from surface wear (Langdon, Hicks, & Williamson, 1980).

Although each treatment product has its own application procedures, there are general application guidelines that can be applied to all dust suppressant products (Bolander, 1999). These tips include:

- Apply treatment in the spring, immediately after the wet season.
- If possible, apply treatment after rain so road components are wet and in good workable conditions.
- Do not apply treatment right before rain, this will cause treatment to wash away and be wasted.
- Follow manufacturer's recommendations and instructions on application rates, mixing procedures, and soil compaction, and allowing curing time before opening the road for traffic.

- Moisten road surface if it was dry, except when using recycled asphalt products.
- If a hard crust is present, break up and loosen the surface.
- Use adequate machinery to ensure uniform distribution of the dust suppressant.

2.6.4 Treatment Frequency

Chemical dust suppression treatment is not permanent. Treatment will have to be applied periodically. Depending on the product type, how long a dust palliative is effective varies. Other factors also affect how long dust treatments last; these factors include the treatment type, soil characteristics, climate, application rate, and traffic conditions (Office of Environmental Assistance, 2014).

2.7 Gravel Roads Management System

2.7.1 Existing International Management Systems

A gravel road is defined as a road made of gravel. Gravel roads are more popular in less developed nations, but are also considered a major part of a developed nation's infrastructure (Skorseth & Selim, 2000). There have been continuous efforts to better manage unsealed roads (Huntington & Ksaibati, Implementation Guide for the Management, 2011). Multiple international organizations have developed manual guides and tools to help local governments manage and maintain their gravel road assets. The World Bank developed multiple software programs related to the maintenance and management of gravel roads. These tools include the deterioration of gravel roads model (DETOUR), the Roads Economic Decisions Model, and the Highway Development and Management software (HDM-4) (World Bank, 2009).

Several countries in different regions of the world have also invested in considerable efforts in order to develop effective management systems for their gravel roads network. A pilot study was conducted in South Africa's Western Cape Province to develop algorithms for routine gravel roads maintenance schedules. The study resulted in the development of a blading optimization module to supplement the gravel management system of the Western Cape Provincial Administration in South Africa (Burger, Henderson, & van Rooyen, 2007).

2.7.2 National Management Systems

The United States has few to no asset management systems in place to manage gravel road networks. This is due to the low traffic volumes on gravel roads, as well as the limited funds counties have to spend on their infrastructure. Counties usually allocate most of their budgets to roads and infrastructure with higher traffic volumes and higher usage rates. Wyoming is the least populated U.S. state, and with more than 12,000 miles of gravel roads, there is a need to implement effective processes for the management of unsealed roads in rural counties.

Several factors are associated with the management of gravel roads. In basic terms, these factors include inventory information, performance evaluations, and tracking of maintenance and costs. There are different strategies that can be implemented to address these factors. Many counties have already adapted these strategies to improve their asset management practices. The use of a GIS-based asset management and department cost tracking tool is an example of such strategies (Huntington & Ksaibati, Management of Unsealed Gravel Roads, 2011).

2.8 Gravel Roads Maintenance and Treatments

2.8.1 Types of Maintenance

Counties are often required to routinely rehabilitate and maintain gravel roads. Several types of maintenance are required to keep gravel roads in serviceable conditions. These maintenance work types are usually divided into two types: routine work and major work. The ultimate goal of maintenance work on gravel roads is to ensure three basic elements of the gravel road's cross section are met. These elements, as highlighted by the FHWA, are (Federal Highway Administration, 2015):

- Crowned driving surface
- Shoulders with slopes that lead away from the middle of the road
- Clean ditch for drainage

Figure 2.5 illustrates a basic gravel road cross section, as recommended by the FHWA.

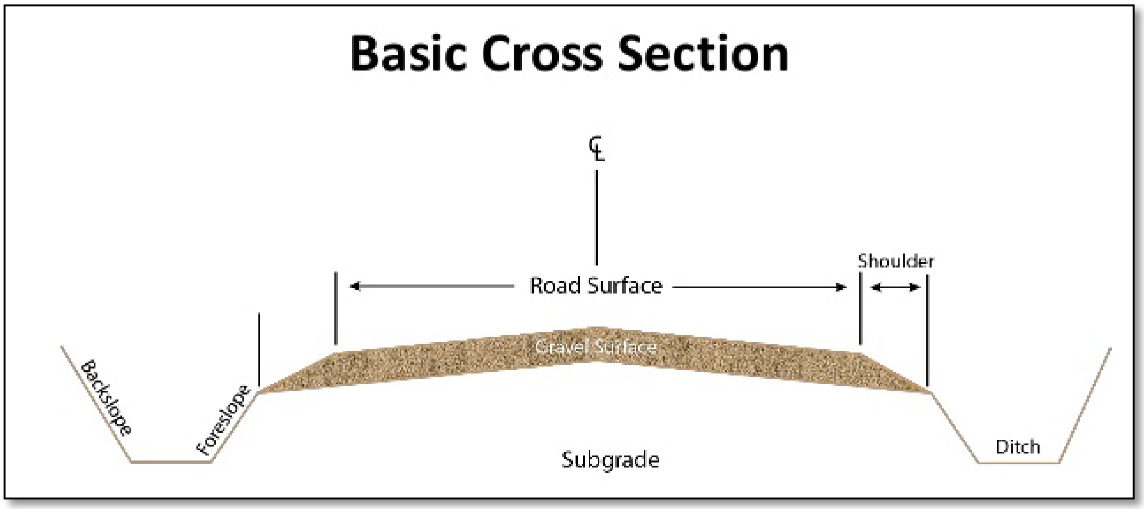


Figure 2.5 Roadway cross section

2.8.1.1 Routine Maintenance Work

This includes work done periodically to keep and maintain gravel roads in serviceable condition. Routine work can include different types of periodic work done on gravel roads. Routine maintenance work makes sure the roadway shape and drainage are in good conditions. Routine maintenance work can include the following:

- Shaping. Shaping work is usually conducted to ensure the road's crown is well sloped. The FHWA recommends that county operators use motor graders with the angle of the moldboard fixed between 30 and 45 degrees. This will ensure the recovery of loose aggregate from the shoulder of the roadway without spilling roadway material to the edges (Federal Highway Administration, 2015).
- Fixing high shoulders. Sometimes the road surface is not compacted well enough, and a condition known as high shoulders can occur. High shoulders are also referred to as secondary ditches, as they cause water to be trapped away from draining into the designed ditch. This can cause several issues, including potholes that affect the quality of the road (Federal Highway Administration, 2015). Figure 2.6 illustrates some road issues that can be caused by high shoulders.

Figure 2.6 High Shoulders on road surface causing drainage issues
(Federal Highway Administration, 2015)

Re-shaping or blading is usually required to fix the issue of high shoulders. Blading will ensure the sloped crown of the road is maintained and no drainage issues exist.

- Mowing. Depending on the climate characteristics of the region, grass and vegetation can grow quickly or slowly on the ditches and the road shoulders, causing some drainage problems. Mowing operations can have many benefits in enhancing road conditions and improving the overall safety of the road. The benefits of mowing usually offset the cost by reducing the need for other maintenance needs resulting from bad drainage (Federal Highway Administration, 2015).

2.8.1.2 Major Rehabilitation Work

Over time, any gravel road will start to deteriorate and experience distresses that require more than just routine maintenance work. Major road deterioration can also result from heavy rainstorms or heavy traffic operations. Figure 2.7 shows a road with major deteriorations due to extensive heavy traffic and wet conditions.

Figure 2.7 Major road deterioration (Federal Highway Administration, 2015)

Major road issues will require major rehabilitation work to be done to the road. This involves the following (Federal Highway Administration, 2015):

- Complete cross section re-shaping
  This involves the reshaping of the road surface, as well as the shoulder and the ditch areas. Motor graders are usually used to conduct this work. Compaction is also recommended, as this will enhance the strength and stability of the road.
- Re-graveling
  Heavy rainstorms can lead to the loss of aggregate from the road soil content. Re-graveling is needed to replace the lost surfacing aggregate. Heavy trucks might be required to haul the new surfacing aggregate to the road.

2.9 Gravel Road Condition Assessment

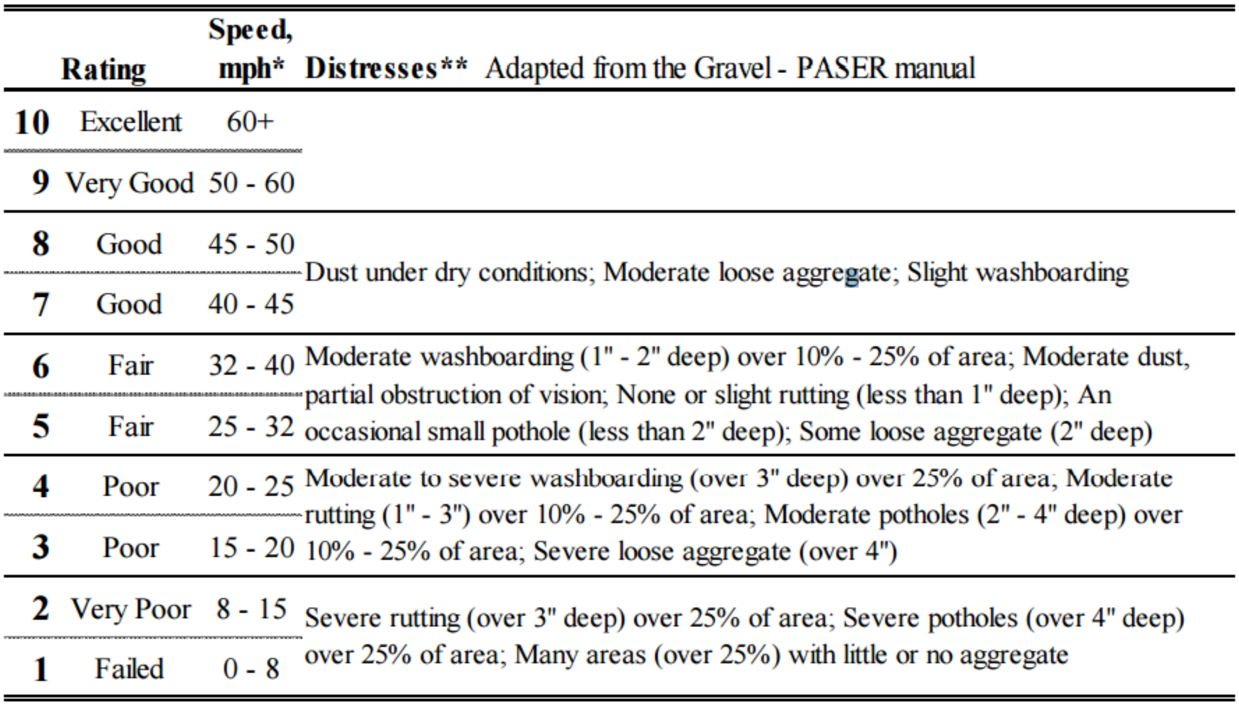
Gravel roads make up more than 39% of U.S. roads. A critical aspect of gravel road asset management is to periodically rate and monitor road conditions. In order to do so, a system based on experimental and scientific background is needed. There are very few rating manuals that address condition ratings of gravel roads (Huntington & Ksaibati, Implementation Guide for the Management, 2011).

Two types of road surface assessment methods exist: manual and automated. Automated systems usually consist of sensors mounted to a moving vehicle. Automated systems can lead to decreased maintenance costs, but because unsealed road conditions change quickly, the use of automated systems might not be the most practical. Manual methods are usually divided into measurement methods and visual evaluations. Visual evaluations are easier to conduct since raters usually do not need to leave their vehicles. Measurement methods are more accurate but more time consuming (Huntington & Ksaibati, Management of Unsealed Gravel Roads, 2011). Included is a discussion of few rating manuals designated to measure gravel roads conditions.

2.9.1 WYT^2/LTAP Modified PASER Rating

Developed by the Wyoming Technology Transfer Center, the modified pavement surface evaluation and rating (PASER) manual is a rating guide that combines two complementary guides for visually assessing unsealed roads. The modified PASER manual rating guide combines the Ride Quality Rating Guide (RQRG), which assesses the quality of an unsealed road's ride as perceived by the traveling public, and the Gravel Roads Rating System (GRRS), which evaluates seven distresses: potholes, rutting, washboards, loose aggregate, dust, crow, and roadside drainage (Huntington & Ksaibati, Implementation Guide for the Management, 2011).

The modified PASER rating manual uses a rating scale of 1 to 10 (a rating of >= 9 is an excellent road; a road of <= 2 is a failing road). The modified PASER manual is adapted from the PASER manual produced by the Wisconsin Transportation Information Center. Figure 2.8 illustrates the adapted gravel road-PASER rating manual. The WYT2/LTAP modified PASER rating manual is intended to be used on a network-based level. Its fast, low-cost nature makes it a practical option for agencies to use for network level assessments. However, for a more detailed project level assessment, other measurement-based manuals should be used to ensure accurate assessment of existing road conditions. Figure 2.9 shows a gravel road with excellent conditions.



Rating		Speed, mph*	Distresses** Adapted from the Gravel - PASER manual
10	Excellent	60+	
9	Very Good	50 - 60	
8	Good	45 - 50	Dust under dry conditions; Moderate loose aggregate; Slight washboarding
7	Good	40 - 45	
6	Fair	32 - 40	Moderate washboarding (1" - 2" deep) over 10% - 25% of area; Moderate dust, partial obstruction of vision; None or slight rutting (less than 1" deep); An occasional small pothole (less than 2" deep); Some loose aggregate (2" deep)
5	Fair	25 - 32	
4	Poor	20 - 25	Moderate to severe washboarding (over 3" deep) over 25% of area; Moderate rutting (1" - 3") over 10% - 25% of area; Moderate potholes (2" - 4" deep) over 10% - 25% of area; Severe loose aggregate (over 4")
3	Poor	15 - 20	
2	Very Poor	8 - 15	Severe rutting (over 3" deep) over 25% of area; Severe potholes (over 4" deep) over 25% of area; Many areas (over 25%) with little or no aggregate
1	Failed	0 - 8	

Figure 2.8 Adapted gravel road-PASER rating (Wyoming Technology Transfer Center, 2014)

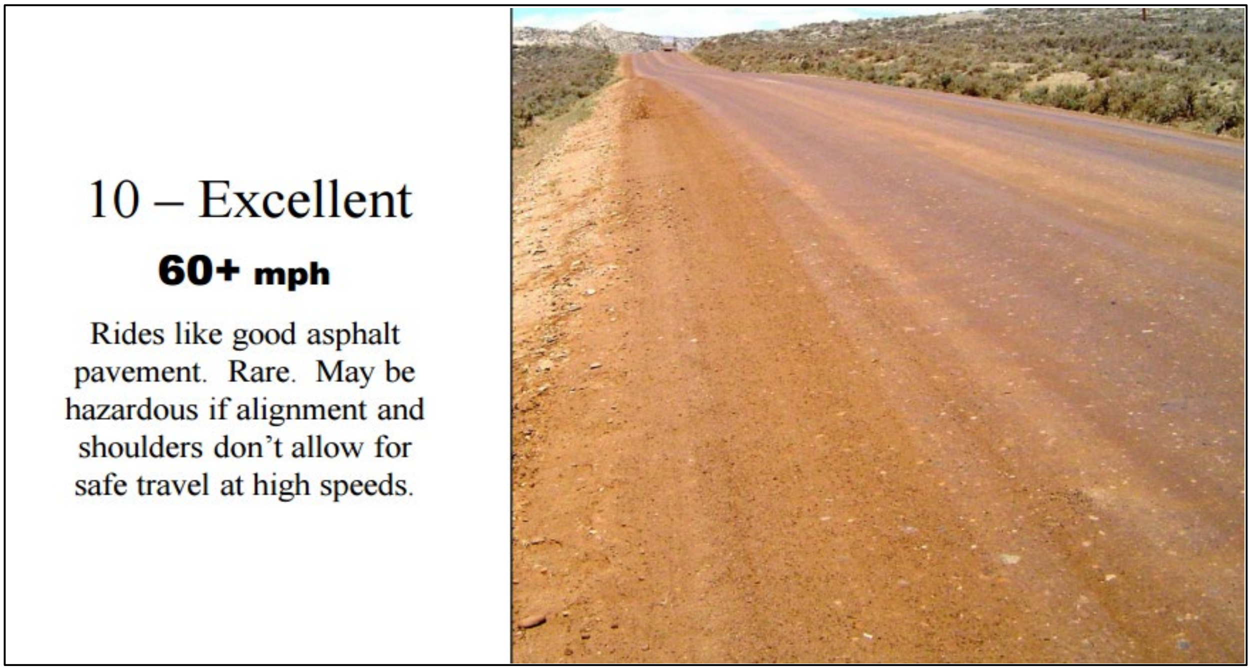


Figure 2.9 Gravel road with excellent conditions (Wyoming Technology Transfer Center, 2014)

2.9.2 USACE Rating System

A well-established gravel road assessment procedure was developed by the United States Army Corps of Engineers (USACE). The measurement-based USACE manual requires actual detailed measurements of distresses on the road (Eaton, Gened, & Dernn, 1987). These measurements are added up to generate a gravel road conditions index (GRCI). The measurement of the distresses includes measuring the extent of each distress in specific units and specifying its severity level. Dust is the only exception to this, as it is visually evaluated. Table 2.2 shows the distresses evaluated under the USACE rating system.

Table 2.2 Distress Types for the USACE Rating System

Distress	Units
• **Improper Cross Section**	• Linear feet
• **Corrugation**	• Square feet
• **Roadside Drainage**	• Linear feet
• **Dust**	• Visual
• **Potholes**	• Number
• **Rutting**	• Square feet
• **Loose Aggregate**	• Linear feet

The severity levels of these distresses are classified as low, medium, and high. Specified breakout values help the rater determine the severity. The USACE system assigns deduct values to each distress; the deduct values determine the overall URCI of the road on a scale of 1 to 100.

2.10 Dust Treatment Cost Effectiveness

The main goal of this study is to assess the effectiveness of chemical dust treatments on gravel roads. Cost is the main factor in determining whether chemical treatment is an effective solution to dust generated from gravel roads or whether other options need to be considered. A study was conducted by Thomas G. Sanders where treatment was applied to selected gravel road test sections to evaluate the relative effectiveness of commercially available road dust suppressants in abating fugitive dust emission and loss of fines from gravel road surfaces (Sanders T. G., 1997). The study found that the dust suppressants studied reduced fugitive dust emission from the gravel roadways by 50% to 70%. The treated test sections also retained 42% to 61% more aggregate than the untreated control test section. The study concluded that the cost savings of retaining aggregate on the treated test sections more than offset the costs of applying dust suppressants (Sanders T. G., 1997). This study is still used as a reference and as a marketing tool for companies to advertise their chemical dust treatment products to counties and local governments.

2.11 Chapter Summary

This chapter included a literature review of existing knowledge and common practices related to gravel roads. A review of dust generation on gravel roads suggested that traffic is the main generator of dust from gravel roads. Traffic impact generates loose fine particles from the road and leads to the emission of dust. Heavier vehicle types result in more dust generation than smaller vehicles. The literature also suggested that traffic speeds, road material composition, and climate play major roles in dust concentration emissions from gravel roads. In addition, this chapter also discussed different measurement tools used to measure dust emission rates.

This chapter also discussed dust pollution sources and regulations. The EPA is taking the lead in issuing and regulating air quality standards. This chapter included a review of literature related to dust suppressant products and the benefits of applying chemical dust suppressant treatment on gravel roads, as well as the different types of products on the market today. Finally, this chapter included the discussion of literature pertaining to existing gravel road management systems, on both the national and the international levels. Additionally, different gravel road condition assessment manuals were discussed. The chapter concluded with a discussion of dust treatment effectiveness in reducing dust emissions and improving overall road conditions.

3. METHODOLOGY

3.1 Introduction

This chapter summarizes the research methods and techniques used to conduct this research study. Figure 3.1 outlines the report organization. This research focused on collecting real field data and analyzing these data using different techniques. Actual field data were collected from several counties around Wyoming. Descriptive and exploratory analyses were conducted to examine trends and behaviors of gravel roads. Statistical analysis was also conducted to estimate relationships between dust emissions and other variables related to gravel roads. The goal of this research is to develop a more comprehensive understanding of gravel road performance. This study was divided into three objectives, which are organized as follows:

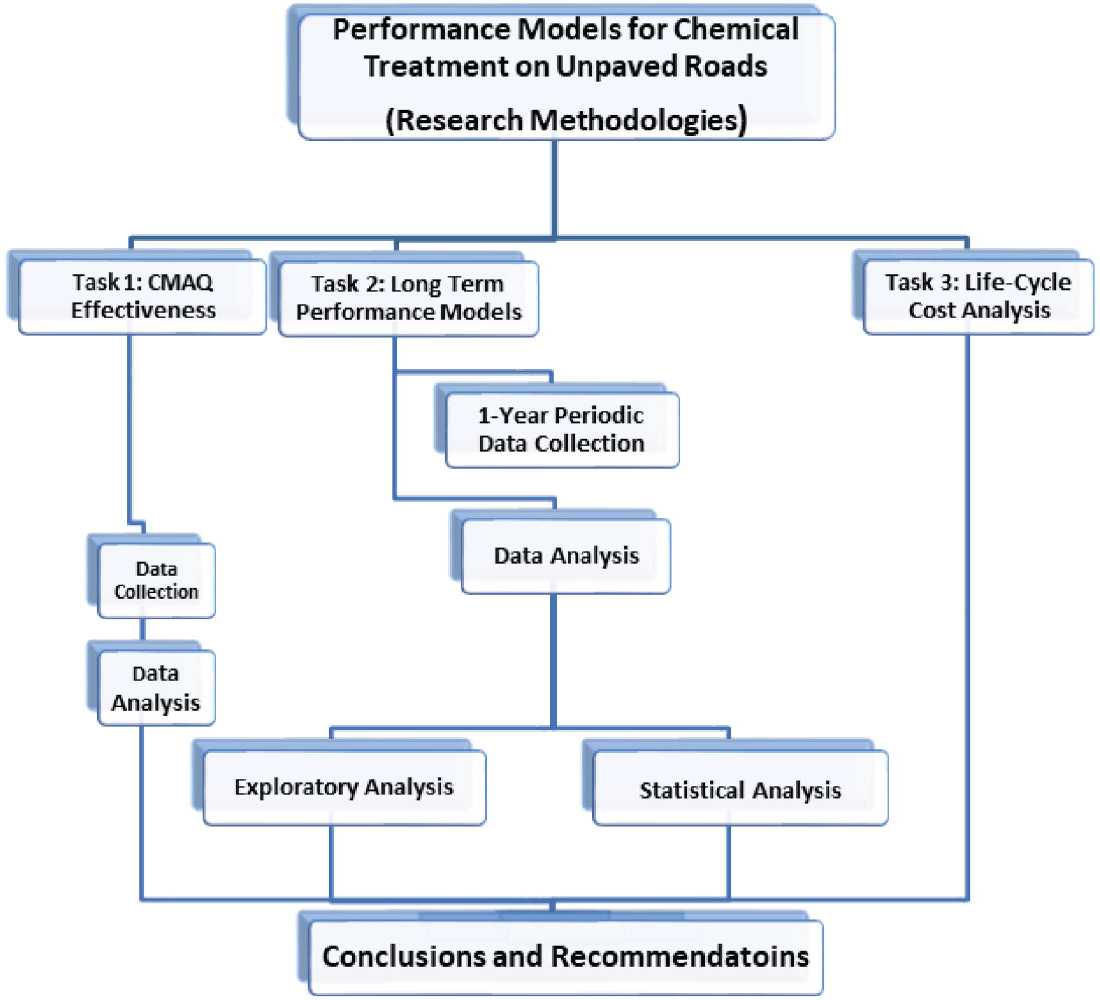


Figure 3.1 Schematic diagram for research methodology

3.2 Objective 1: CMAQ Program Effectiveness Study

Objective 1 was to continue the study conducted by the WYT2/LTAP office to assess the effectiveness of the CMAQ program implementation in Wyoming. This included the continuation of the data collection process, where gravel roads from various counties around Wyoming were tested before and after treatment using two testing methods. Testing, as described in Chapter 4, included measuring dust concentrations before and after treatment; it also included the collection of aggregate and moisture samples from the road surface, the collection of temperature and wind speeds, as well as traffic counts. A descriptive analysis was conducted to explore dust generation trends from gravel roads.

3.3 Objective 2: Developing Performance Models for Gravel roads

Objective 2 was to conduct a long-term performance study to model the performance of chemical dust treatment over a period of time. This objective's goal was to develop performance models for chemical treatment on gravel roads and evaluate the life-cycle of treatment. Another goal was to determine what factors affect treatment performance. For this objective, dust emissions were measured on each of the tested road sections. Traffic data were also obtained for each of the study sections. Aggregate and moisture samples and wind and temperature reading were collected as well. Road conditions were evaluated over the period of the study using the modified PASER gravel manual to rate the ride quality of the road and periodically assess road conditions. Data were collected from 11 recently treated county roads in Wyoming. Data were collected periodically to monitor the performance of treatment over time. Monitoring included testing the studied roads before and right after treatment, and after one month, three months, six months, and one year of treatment. Chapter 5 describes the testing procedures and equipment used for data collection. Analysis was conducted to determine what factors contribute to gravel road deterioration. Different types of analyses were conducted to carefully evaluate the performance of treatment over time. Both exploratory and statistical analyses were conducted; the goal was to model treatment behavior and to examine which variables contribute to treatment degradations. Chapter 5 includes comprehensive explanations of the analysis conducted and the results obtained.

3.4 Objective 3: Life-cycle Cost Benefit Analysis

Objective 3 was to conduct a life-cycle cost analysis to compare the cost of maintaining untreated gravel roads with the cost of maintaining treated gravel roads. This objective's goal was to quantify the benefit of applying chemical dust treatment to gravel roads and evaluate the cost effectiveness of the treatment option. Actual detailed data were obtained from Johnson County in Wyoming. The data included cost information related to maintaining untreated gravel roads, as well as cost data related to the application of chemical dust treatment and any other related maintenance work. The obtained cost data were organized and analyzed to determine which alternative is more cost effective. Chapter 6 describes the procedures followed in obtaining and organizing the data. The chapter also discusses the analysis conducted to determine the most cost-effective maintenance options for counties. Finally, based on the results obtained from the analysis conducted for each of the three objectives, conclusions were reached and recommendations were developed with lessons drawn from this study. The conclusions and recommendations developed in this study are included in Chapter 7, which also includes suggestions on what can be done in future related work.

3.5 Chapter Summary

This chapter described the organization followed throughout this report. The first objective of this study was to assess the effectiveness of the CMAQ program in Wyoming. The second objective was to develop long-term performance models to predict the service life of chemical treatment on gravel roads. The third objective examined the life-cycle costs of different gravel road maintenance alternatives.

4. CMAQ PROGRAM EFFECTIVENESS STUDY

4.1 Introduction

This chapter discusses the continuation of the Congestion Mitigation and Air Quality (CMAQ) program assessment study conducted at the University of Wyoming. This study started in the summer of 2014 and is projected to continue until July 2017. The study's main objective is to assess dust suppressant effectiveness and ensure that air quality improvement efforts funded by the CMAQ program in Wyoming are effective. The congestion mitigation and air quality program is funded by the federal government to ensure states, cities, and counties comply with federal air quality regulations. Each year Wyoming receives federal funding allocated to the CMAQ program. The state of Wyoming then awards these funds to counties in an effort to mitigate dust pollution generated from gravel roads.

Because CMAQ funds are limited, counties have to compete to receive funding for their projects. The state of Wyoming is looking to investigate the effectiveness of CMAQ funds used in Wyoming. For this reason, the state hired the Wyoming Technology Transfer Center to conduct a research study that will examine the effectiveness of Wyoming's CMAQ gravel road dust suppression program. This chapter includes a thorough discussion of the data collection and analysis conducted to assess the effectiveness of the CMAQ program in Wyoming.

4.2 Data Collection

Data collection methodologies were developed to ensure a comprehensive dataset is collected that includes all different parameters affecting dust generation on gravel roads. Data collection included the measurement of dust concentrations on gravel roads, as well as soil properties, traffic characteristics, and in-situ climate conditions for each CMAQ road included in this study.

4.2.1 Dust Data Collection

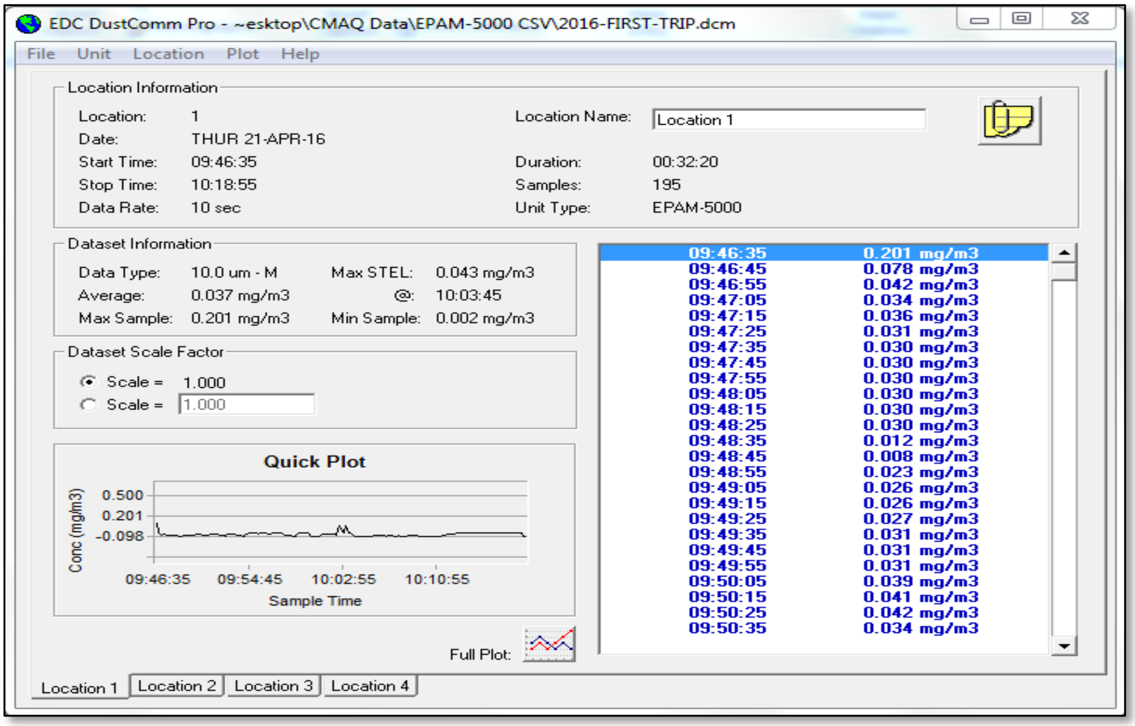
Two methods were used to collect dust concentration data from gravel roads. The first method used a stationary device placed on the side of the road. The stationary device used was the HAZ-Dust EPAM 5000, which is a boxed device that continuously monitors and measures surrounding dust concentrations. The device can be used to measure both particulate matter with diameters smaller than 2.5 micrometers ($PM_{2.5}$), and particulate matter with diameters smaller than 10 micrometers (PM_{10}). For this study, only PM_{10} concentrations were measured. The device utilizes infrared technology to sensor inhalable coarse particles in the air. According to the device user manual:

> The Haz-Dust uses the principle of near-forward light scattering of an infrared radiation to immediately and continuously measure the concentration in mg/m3 of airborne dust particles. This principle utilizes an infrared light source positioned at a 90-degree angle from a photo detector. As the airborne particles enter the infrared beam, they scatter the light. The amount of light received by the photo detector is directly proportional to the aerosol concentration. A unique signal processes internally and compensates for noise and drift. This allows high resolution, low detection limits and excellent base line stability (HAZ-DUST User Guide).

The unit continuously measures air quality every second. The data are recorded in units of milligrams per meter cubed. The data are then imported to a computer using software that comes with the device. Appendix A-1 includes the imported dust concentration data from the EPAM-5000 device. Data are imported in the format of a spreadsheet. Figure 4.1 shows the HAZ-DUST EPAM 5000 stationary dust measuring device unit.

Figure 4.1 HAZ-DUST EPAM 5000 Stationary Dust Measuring Device

EDC Dust Comm Pro is software used to import dust concentration data from the EPAM unit. The software is convenient and easy to use. It imports periodically measured dust concentration data as spreadsheets, and can generate plots and basic descriptive analysis of the data. Figure 4.2 demonstrates an example of imported data.



Location Information

Location: 1
Date: THUR 21-APR-16
Start Time: 09:46:35
Stop Time: 10:18:55
Data Rate: 10 sec
Location Name: Location 1
Duration: 00:32:20
Samples: 195
Unit Type: EPAM-5000

Dataset Information

Data Type: 10.0 um - M
Average: 0.037 mg/m3
Max Sample: 0.201 mg/m3
Max STEL: 0.043 mg/m3
@: 10:03:45
Min Sample: 0.002 mg/m3

Dataset Scale Factor

● Scale = 1.000
○ Scale = 1.000

09:46:35	0.201 mg/m3
09:46:45	0.078 mg/m3
09:46:55	0.042 mg/m3
09:47:05	0.034 mg/m3
09:47:15	0.036 mg/m3
09:47:25	0.031 mg/m3
09:47:35	0.030 mg/m3
09:47:45	0.030 mg/m3
09:47:55	0.030 mg/m3
09:48:05	0.030 mg/m3
09:48:15	0.030 mg/m3
09:48:25	0.030 mg/m3
09:48:35	0.012 mg/m3
09:48:45	0.008 mg/m3
09:48:55	0.023 mg/m3
09:49:05	0.026 mg/m3
09:49:15	0.026 mg/m3
09:49:25	0.027 mg/m3
09:49:35	0.031 mg/m3
09:49:45	0.031 mg/m3
09:49:55	0.031 mg/m3
09:50:05	0.039 mg/m3
09:50:15	0.041 mg/m3
09:50:25	0.042 mg/m3
09:50:35	0.034 mg/m3

Figure 4.2 EDC DustComm Pro importing data

The second device used to measure dust generated from gravel roads is the Colorado State University Dustometer, a moving device developed by researchers from Colorado State University (CSU). As described in Chapter 2, the CSU Dustometer is a moving device placed behind a moving vehicle. Using glass microfiber filters weighted before and after placement in the Dustometer, dust concentration is measured by taking the difference between the weight of the filters before and after being placed in the Dustometer. Dust is measured in units of grams per mile. A total of six measurements per road were taken. Each set of measurement is done using a different sieve size (#38 and #200). The average of the three is then recorded as the dust measurement for the tested gravel road. Figure 4.3 shows the device being used to measure dust concentrations on a gravel road in Wyoming.

Figure 4.3 CSU-DUSTOMETER

4.2.2 Traffic Data Collection

Traffic is considered an important factor in dust generation. Data collection included collecting the existing characteristics of traffic on the studied gravel roads. The traffic characteristic data collected included vehicle composition, speed, and volume on the road. The study used Centurion two tube traffic counters installed on the road when data collection occurred. Figure 4.4 shows the traffic counter used in this study. A previous study conducted by the Wyoming Technology Transfer Center determined that three hours was an optimal data collection time. Traffic counters were installed on the tested road and traffic characteristics were measured for three hours. Appendix A-3 includes the imported traffic volumes. Both the traffic counter and the HAZ-DUST EPAM 5000 were installed together and left to run for the entire three-hour testing period. Figure 4.5 shows the data collection setup on a gravel road in Sweetwater County, Wyoming.

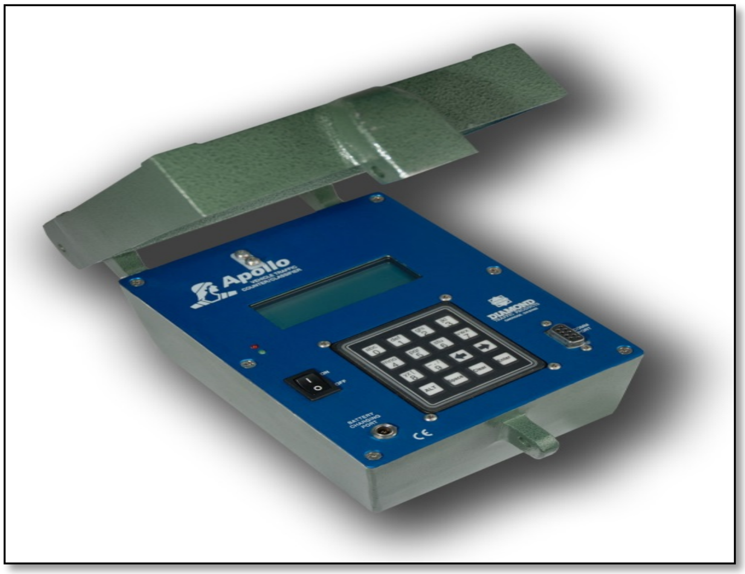


Figure 4.4 Centurion traffic counter

Figure 4.5 Data collection equipment setup

4.2.3 Climate Data Collection

The literature review suggested that climate is one of the major factors in dust generation. Dry weather and low precipitation rates can result in more dust being generated when compared with wet areas. Existing climate data were measured and monitored during the data collection process. Collected data included measuring wind speeds and temperature. Precipitation data for the different counties included in the data collection were obtained from the United States National Oceanic and Atmospheric Administration (NOAA). A WindMate handheld measuring device was used to measure wind speed and temperature during data collection. Figure 4.6 shows the device used for the measurements.

Figure 4.6 WindMate wind and temperature measuring device

Wyoming is the 10th-largest U.S. state, with a total area of almost 98 million square miles (The ipl2 Consortium, 2012). A great variation in precipitation rates can be found throughout the states. Counties included in this study each experience different weather and climate conditions. Figure 4.7 illustrates average annual precipitation in Wyoming, which has a dry, continental climate, with warm summers and cold winters. The significant variation in elevations throughout the state contributes to wide temperature ranges and varying precipitation rates (Western Regional Climate Center, 2016). To illustrate some of these variations, Teton County, in the northwest side of the state, annually receives the highest amount of rainfall (22.29 inches) compared with Big Horn County, the driest county in Wyoming with only 6.8 inches of rain annually. Table 4.1 shows Wyoming counties ranked based on annual precipitation rates.

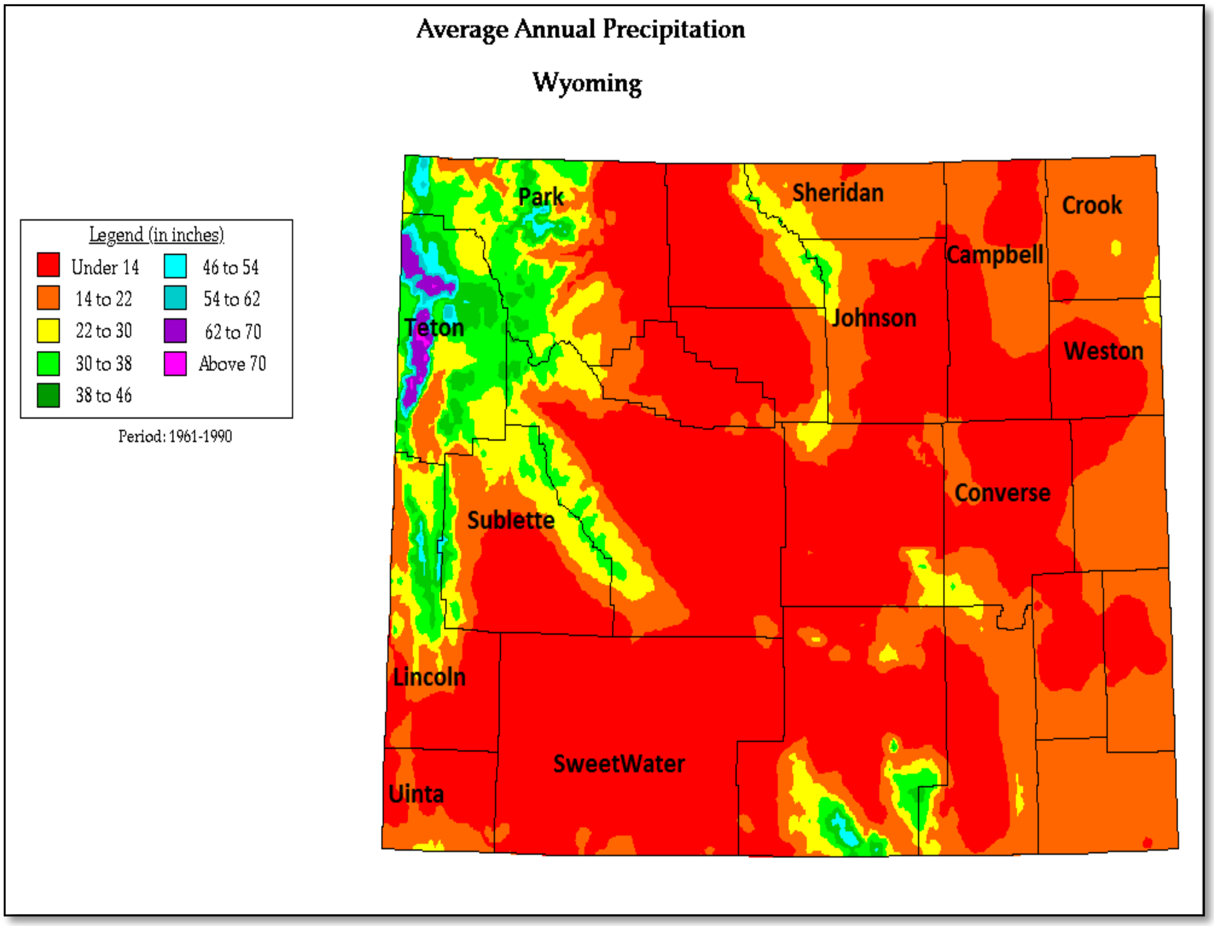


Figure 4.7 Wyoming average annual precipitation
(National Oceanic and Atmospheric Administration, 2015)

Table 4.2 Wyoming Counties Ranked Based on Average Precipitation

Rank	Average Precipitation ▼	County / Population
1	22.29 inches	Teton, WY / 21,294
2	18.09 inches	Crook, WY / 7,083
3	15.68 inches	Laramie, WY / 91,738
4	15.33 inches	Sheridan, WY / 29,116
5	15.26 inches	Lincoln, WY / 18,106
6	14.86 inches	Weston, WY / 7,208
7	14.60 inches	Campbell, WY / 46,133
8	14.33 inches	Goshen, WY / 13,249
9	14.21 inches	Johnson, WY / 8,569
10	14.16 inches	Platte, WY / 8,667
11	14.13 inches	Niobrara, WY / 2,484
12	12.95 inches	Converse, WY / 13,833
13	12.86 inches	Sublette, WY / 10,247
14	12.62 inches	Albany, WY / 36,299
15	11.61 inches	Hot Springs, WY / 4,812
16	11.59 inches	Natrona, WY / 75,450
17	11.15 inches	Park, WY / 28,205
18	10.55 inches	Carbon, WY / 15,885
19	10.17 inches	Uinta, WY / 21,118
20	8.67 inches	Fremont, WY / 40,123
21	8.46 inches	Sweetwater, WY / 43,806
22	7.85 inches	Washakie, WY / 8,533
23	6.84 inches	Big Horn, WY / 11,668

4.2.4 Soil Aggregate and Moisture Samples

Aggregate samples were collected for all the tested roads from three spots considered most representative of the road. A bag was filled with aggregate for each road and sent to the University of Wyoming soils lab to conduct the required testing. Figure 4.8 demonstrates how aggregate samples were collected from each tested gravel road.

Figure 4.8 Aggregate sampling

Three moisture samples were also collected for each tested road before and after treatment. Moisture tins similar to the one illustrated in Figure 4.9 were used to collect three moisture content samples from three locations considered representative of the road. The three samples were taken to the University of Wyoming soils lab, weighted, and placed in an oven at 217°F, as specified by ASTM D4442, for 24 hours. Each sample was weighted and the average of three recorded as the moisture content for the tested road. Appendix A-4 includes the soil properties testing information.

Figure 4.9 Moisture sampling

4.3 Study Sections

Data were collected from 11 Wyoming counties, all of which received CMAQ funding to apply chemical dust suppressant treatment on their gravel roads. A total of 63 roads were tested before chemical treatment was applied. Of the 63 roads tested before treatment, samples of 28 roads were tested after treatment to evaluate the effectiveness of the dust suppressants. Table 4.2 summarizes the CMAQ roads tested and their properties.

4.4 Descriptive Analysis

The collected data were summarized and organized in order to explore trends and assess the different characteristics of the studied gravel roads before and after treatment. This section includes a descriptive analysis of the collected data, which include traffic characteristics, soil and aggregate properties, weather conditions, and dust emission rates before and after treatment for the gravel CMAQ roads included in this study.

Table 4.2 Tested CMAQ Roads

County	Road	Year Tested	(Precip. Rates)	Suppressant Type
Lincoln	Muddy Creek	2014	15-20 Wet	MgCl
	Gomer	2015	15-20 Wet	MgCl
	Sublett-Pomeroy Basin	2015/2016	15-20 Wet	MgCl
	Lupine	2015/2016	15-20 Wet	MgCl
	Kemmerer Landfill	2016	15-20 Wet	MgCl
	Fontenelle-North	2015/2016	15-20 Wet	MgCl
Converse	Jenne Trail	2014/2015	10-15 Moist	CaCl
	Ross Road	2015	10-15 Moist	CaCl
Crook	D-Road	2014	15-20 Wet	MgCl
Campbell	Cosner	2014	10-15 Moist	MgCl
	Moore	2014	10-15 Moist	MgCl
	Turnercrest	2015	10-15 Moist	MgCl
	Todd	2015	10-15 Moist	MgCl
	Christensen	2015	10-15 Moist	MgCl
	Hayden	2015/2016	10-15 Moist	MgCl
	Black & Yellow	2015	10-15 Moist	MgCl
	Iberlin	2015/2016	10-15 Moist	MgCl
Johnson	TTT Road	2015	10-15 Moist	CaCl
	Irrigary Rd	2015/2016	10-15 Moist	CaCl
	Lower Sussex Rd	2015/2016	10-15 Moist	CaCl
	Schoonover Rd	2015/2016	10-15 Moist	CaCl
	Upper Powder River	2015/2016	10-15 Moist	CaCl
Sweetwater	Wamsutter S	2015	<10 Dry	MgCl
	WamsutterNorth	2015	<10 Dry	MgCl
	Patrick Draw	2015/2016	<10 Dry	MgCl
	Eden Ryepatch	2015	<10 Dry	MgCl
	Eden Reservoir	2015	<10 Dry	MgCl
	Eighteen mile Rd	2015	<10 Dry	MgCl
	County line Rd	2015	<10 Dry	MgCl
	Lower Farson Cut off	2015/2016	<10 Dry	MgCl
Uinta	Piedmont Rd 173	2015	<10 Dry	MgCl
	Piedmont Aspen Rd 171	2015	<10 Dry	MgCl
Weston	Grieves	2015	10-15 Moist	CaCl
	Bruce	2015	10-15 Moist	CaCl
	Mush Creek	2015	10-15 Moist	CaCl
Teton	Spring Gulch Rd	2015	>20 Very Wet	MgCl
Sheridan	Murphy Gulch	2015/2016	15-20 Wet	CaCl
	Lower Prairie Dog	2015/2016	15-20 Wet	CaCl
	North Park Rd	2015/2016	15-20 Wet	CaCl
	Wolf Creek Rd	2015/2016	15-20 Wet	CaCl
	Higby Rd	2015/2016	15-20 Wet	CaCl
	Dayton East	2015/2016	15-20 Wet	CaCl
	Beckton Hall	2016	15-20 Wet	CaCl
	Halfway Ln	2016	15-20 Wet	CaCl
Carbon	CR 608	2016	<10 Dry	MgCl

4.4.1 Traffic Characteristics

In this study, an exploratory investigation was conducted to explore the traffic characteristics that exist on the studied roads. Tube traffic counters were used in the data collection, as explained earlier. The average daily traffic (ADT), average daily truck traffic (ADTT), and 85th percentile traffic speed data were obtained from the counters. The results revealed that the average daily traffic on the analyzed roads ranged from as low as 24 vehicles per day to as high as 2,574 vehicles per day. Table 4.3 shows a descriptive analysis for the collected average daily traffic data. It is apparent from this table that the average daily traffic for the studied roads was around 269 vehicles per day. This is within the range classified for gravel roads. However, the literature review suggests that gravel roads with traffic volumes more than 500 vehicles per day should be paved (Edvardsson & Magnusson, 2009). Several roads were found to have ADTs higher than 500. It is recommended that counties should consider the feasibility of paving these roads. Figure 4.10 shows the variations in ADT reported for the 63 monitored roads.

Table 4.3 ADT Descriptive Analysis

Average Daily Traffic Descriptive Analysis	
Mean	269
Standard Error	42
Median	184
Mode	72
Standard Deviation	337
Minimum	24
Maximum	2574
Sum	16951
Count	63

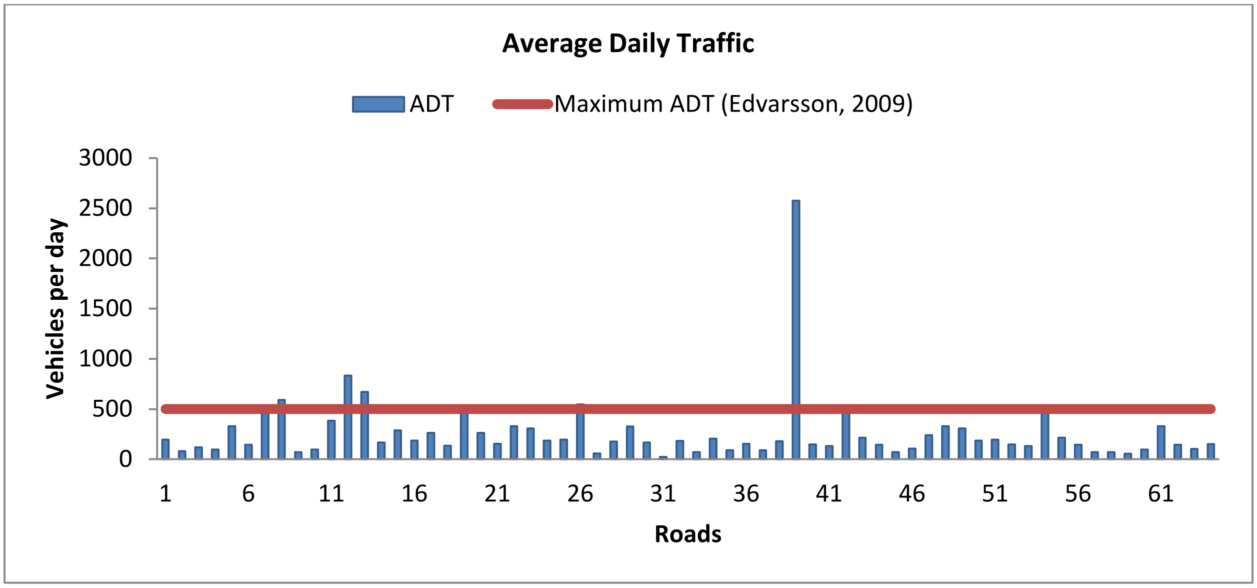


Figure 4.10 ADT variations

Truck traffic also ranged from as low as zero trucks per day on some roads to as high as 420, or 71% of the total traffic on the road. This reveals the impact of the recent oil and gas operations happening in some parts of Wyoming where most of the traffic on some roads is truck traffic. Table 4.4 shows a descriptive analysis of the truck traffic data collected. The table indicates that the ADTT on all the studied roads was around 63 trucks per day. Figure 4.11 shows the variations in the ADTT for the studied CMAQ roads.

Table 4.4 ADTT Descriptive Analysis

ADTT Descriptive Analysis	
Mean	63
Standard Error	9
Median	37
Mode	0
Standard Deviation	77
Minimum	0
Maximum	420
Sum	4379
Count	62

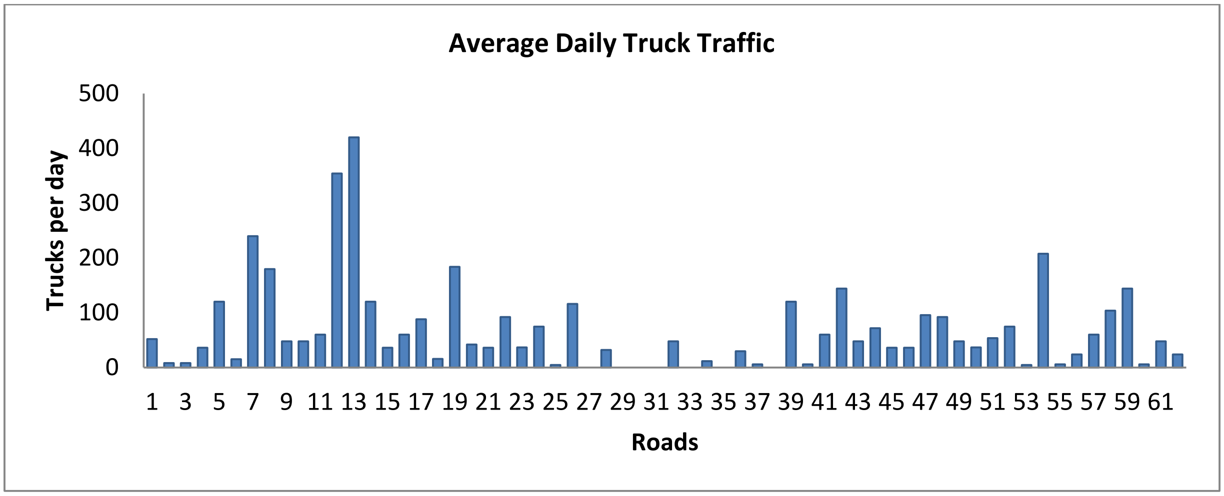


Figure 4.11 ADTT Variations

Traffic speed data were also collected and downloaded from the traffic counters. It is apparent from Table 4.5 that traffic speeds ranged from 10 mph to 74 mph. The average speed was found to be equal to 45 mph. Knowing that most gravel roads have speed limits between 30 and 40 mph, the actual driving speeds are above the speed limit, and more law enforcement might be needed on gravel roads.

Table 4.5 Traffic Speed Data Descriptive Analysis

Traffic Speed Descriptive Analysis	
Mean	45
Standard Error	2
Median	45
Mode	53
Standard Deviation	12
Minimum	10
Maximum	74
Count	62

4.4.2 Soil and Aggregate Characteristics

Aggregate samples collected from the studied roads were tested at the University of Wyoming soils lab in accordance with AASHTO testing standards. A sieve analysis was performed in accordance with AASHTO T27 and T11 to determine the gradations of the tested soils. Atterberg limit tests were also performed in accordance with AASHTO T89 and T90 for the tested soils to determine their liquid limit, plastic limit, and plasticity index. Table 4.6 shows the results of the gradation analysis. It was found that most of the tested roads had granular materials (less than 35% of total sample passing the #200 sieve). This indicates that CMAQ-funded roads have a good mixture of granular materials and are not made up of clay or silty materials.

Table 4.6 AASHTO Soil Classifications of Tested Roads

AASHTO Soil Classification	# of Roads
A-1-a	21
A-1-b	26
A-2-4	7
A-2-6	11

4.4.3 Weather Conditions

For this research study, an effort was made to test and include counties with varying precipitation rates and varying weather and climate characteristics. Using the annual average rainfall rates for each county, counties were ranked into four climate categories: dry, moist, wet, and very wet. Table 4.7 shows the counties studied and their corresponding precipitation. By including counties with different weather conditions, a more comprehensive dataset, with a better representation of road performance under different climate conditions in Wyoming, is collected.

Table 4.7 Counties Included in the Research Study

County	**Annual Precipitation**			
	<10	**10-15**	**15-20**	**>20**
	Dry	**Moist**	**Wet**	**Very Wet**
Lincoln			x	
Converse		x		
Crook			x	
Campbell		x		
Johnson		x		
Uinta	x			
Sweetwater	x			
Weston		x		
Sheridan			x	
Laramie			x	
Teton				x

4.4.4 Dust Emission Rates

Counties with various weather, traffic, and road soil characteristics were included in the study. As illustrated in Figure 4.12, varying dust emission rates were reported. The lowest dust concentration reported from untreated roads was 0.267 mg/m3, and the highest reported dust concentration was around 5.2 mg/m3. This great variation in dust concentrations illustrates the difference in dust generation from roads with different traffic volumes, soil properties, and weather conditions.

Table 4.8 Descriptive Analysis for Tested Dust Concentrations

Dust Emissions Descriptive Analysis (mg/m^3)	
Mean	1.438
Standard Error	0.114
Median	1.263
Mode	0.914
Standard Deviation	0.918
Minimum	0.267
Maximum	5.190
Count	63

The federal ambient air quality standard for particulate matter PM_{10} concentration for a 24-hour average is 150 µg/m3 (Smith, 2015). This is equal to 0.15 mg/m3 when comparing this value to the mean dust PM_{10} recorded concentration value reported in Table 4.8 (PM_{10} concentration=1.438 mg/m3). It may be observed that before treatment, dust generation levels are high and exceed federal limits. This may also indicate that dust suppressant treatment is needed to reduce fugitive dust emission rates and abide with federal air quality standards and regulations.

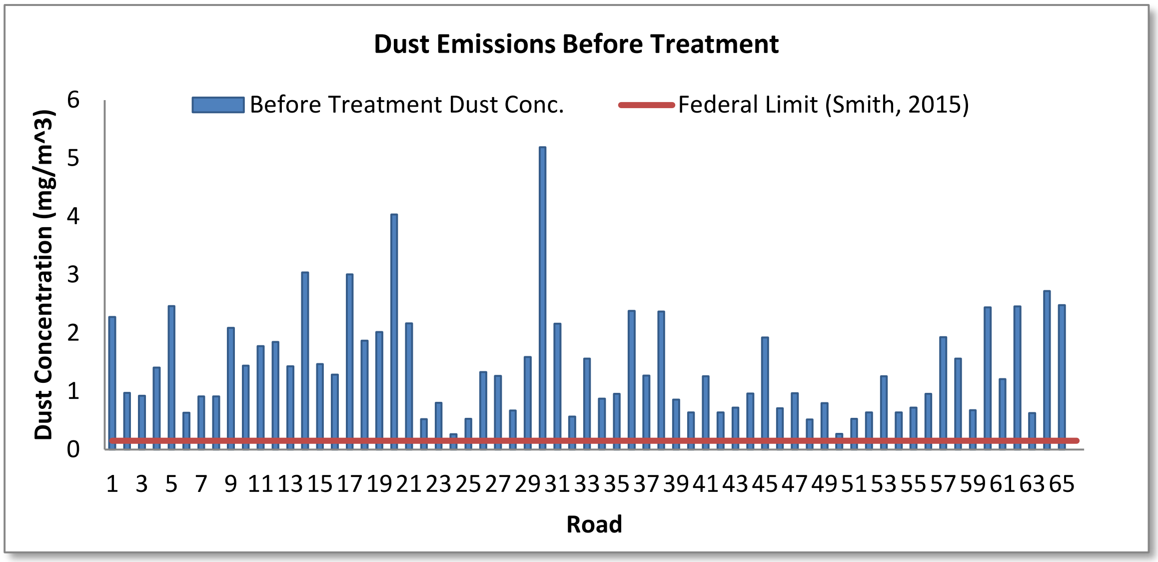


Figure 4.12 Recorded dust concentrations

Dust emission rates after treatment were collected from 25 roads. Table 4.9 highlights descriptive statistical values for recorded dust concentrations. It can be noted that the mean dust concentration value for gravel roads after treatment was found to be equal to 0.08 mg/m3. This value is below the federal limit specified for PM_{10}. It can be concluded that dust treatment is very effective in reducing dust generations from gravel roads. A mean reduction value of 1.358 mg/m3 of dust was achieved by applying chemical treatment. This is equal to almost 95% of the total dust generated from these roads before treatment. Figure 4.13 illustrates the recorded dust concentrations from tested roads after treatment. It can be noted that most roads are below or within the federal limit. Figure 4.14 compares the concentrations of dust on the roads before and after treatment. The comparison confirms the effectiveness of chemical treatment in significantly reducing dust and improving overall air quality conditions.

Table 4.9 Descriptive Statistics for After Treatment Dust

After Treatment Dust Emissions Descriptive Statistics	
Mean	0.08
Standard Error	0.01
Median	0.05
Standard Deviation	0.07
Minimum	0.02
Maximum	0.29
Count	25

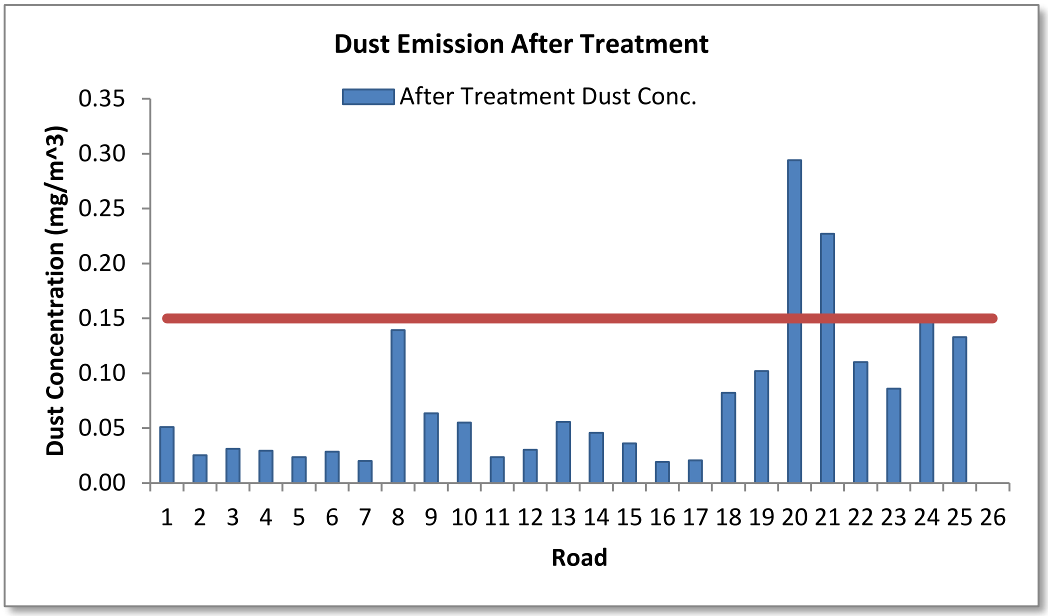


Figure 4.13 After treatment dust emissions

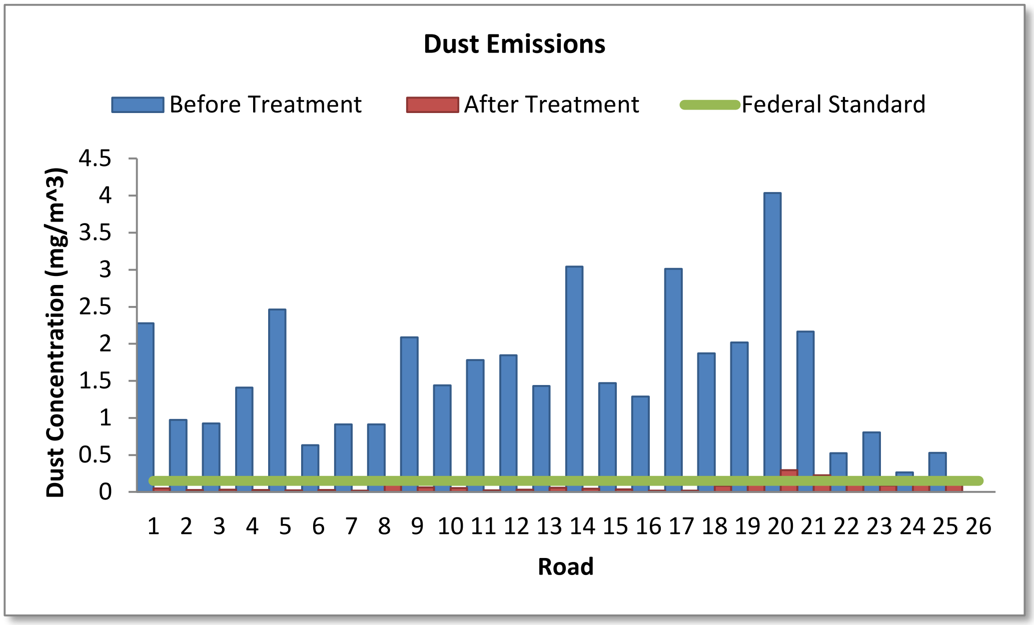


Figure 4.14 Comparing dust emissions before and after treatment

4.5 Chapter Summary

This chapter summarized data collection methods used to study and evaluate the effectiveness of the CMAQ program in Wyoming. It described the data collection process followed to collect data related to dust generation from gravel roads. This included evaluating all factors believed to contribute to dust generation and mitigation from gravel roads. These factors included traffic characteristics, soil and aggregate parameters, weather conditions, and dust concentrations. This chapter also provided exploratory and statistical analyses of the collected data. Exploratory analysis was conducted to examine trends and values of traffic characteristics, dust concentrations, soil properties, and climate and weather conditions. Traffic speeds and volumes were examined to determine their variations and effect on CMAQ-funded roads. Dust concentrations were the most important factor, as measuring dust generations before and after the applications of CMAQ-funded chemical dust suppressant treatment determined the effectiveness of the treatment. The analysis indicated that dust concentrations before treatment were in violation of EPA standards. However, dust treatment efforts paid by CMAQ funds proved to be effective in reducing dust concentrations to nearly zero values.

5. PERFORMANCE MODELS FOR CHEMICAL DUST TREATMENT

5.1 Introduction

As part of the multiple year study conducted by the Wyoming Technology Transfer Center, a secondary objective was to measure and evaluate the performance of chemical dust suppressant treatment on gravel roads. Dust emission rates were measured, and road surface condition deteriorations were assessed to develop performance models that predict performance of the chemical treatment over time. Such models can aid counties and local agencies in better understanding the life-cycle of chemical treatment on gravel roads over time, and can result in the implementation of more cost-effective treatment strategies. Another goal of the study was to quantify the benefit of applying chemical dust suppressant treatment to gravel roads. By quantifying the benefit in terms of dust reduction achieved by the application of the chemical treatment, counties can quantitatively justify the use of CMAQ and other funds to purchase and apply dust suppressant treatment to their gravel roads.

5.2 Experimental Study

Fugitive dust emissions from 11 recently treated gravel roads located in five different counties in Wyoming were measured periodically for one year. Visual survey ratings of the 11 roads were taken each time. Surfacing moisture samples were collected, and traffic speeds and volumes by class were collected using a two-tube traffic counting system. Surfacing aggregate samples were also collected, and their gradations were determined.

Figure 5.1 illustrates the location of the five counties chosen for this study. Table 5.1 highlights the county road sections tested and some of their properties. The table includes dust concentrations right after treatment, and after one month, three months, six months, and one year of treatment.

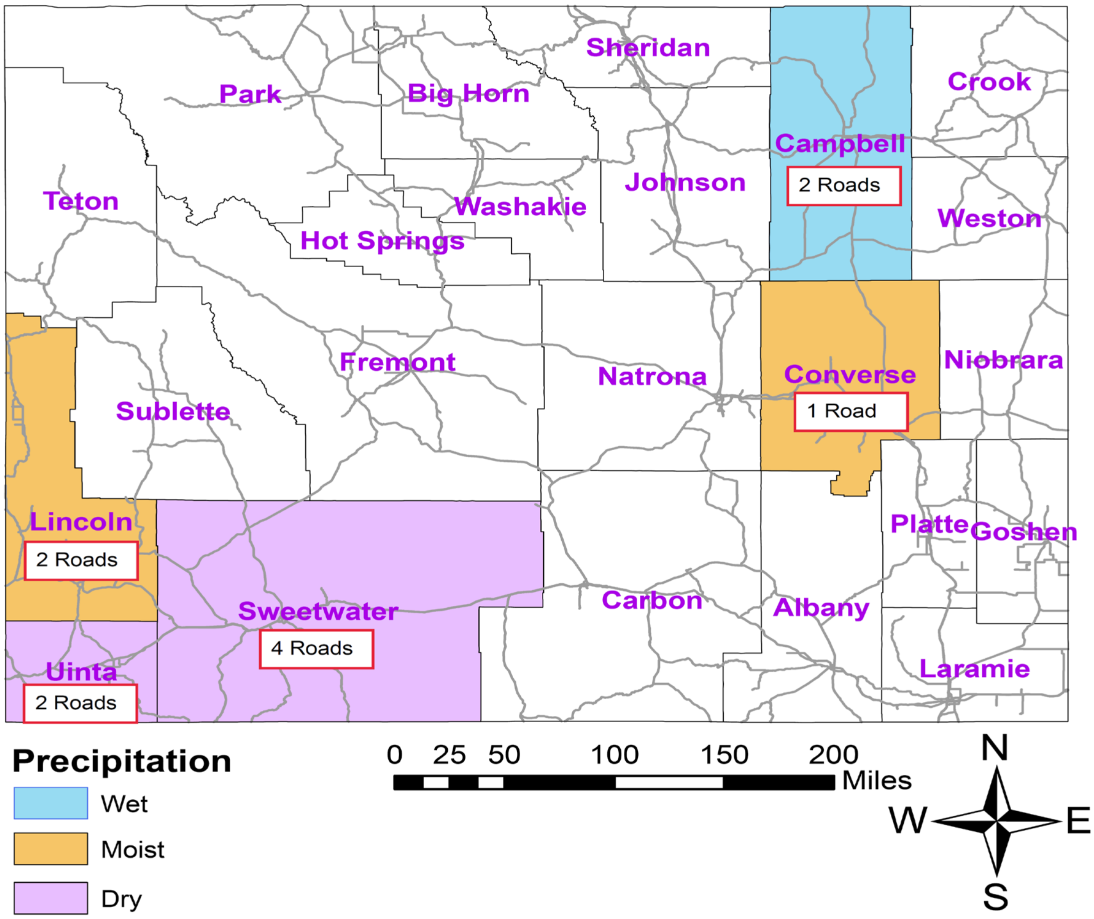


Figure 5.1 Wyoming counties included in the study

Table 5.1 Summary of Studied Roads Properties

County	Road	ADT	85th Traffic speed (mph)	AASHTO	%Passing #200
Sweetwater	1. Wamsutter	546	48	A-2-4	10.5%
	2. Eden Ryepatch	328	39	A-1-a	8.4%
	3. Eden Reservoir	168	37	A-1-b	14.9%
	4. County line Rd	184	50	A-1-b	2.9%
Uinta	5. Piedmont Rd 173	204	39	A-2-6	6.0%
	6. Piedmont Aspen Rd 171	90	35	A-1-a	6.0%
Lincoln	7. Gomer	80	44	A-2-6	12.5%
	8. Sublet-Pomery	120	47	A-1-a	8.9%
Converse	9. Jenne Trail	536	43	A-1-b	14.1%
Campbell	10. Black and Yellow	504	45	A-2-6	11.1%
	11. Turner Crest	288	41	A-2-6	8.1%

5.2.1 Data Collection

Data collection was performed on each selected road after it was treated with a suppressant. Data collection for each road consisted of setting up a stationary dust concentration measurement device and a traffic counter, and allowing these to run for three hours. During this three-hour period, aggregate and moisture samples, wind and temperature readings, and dust concentrations from a mobile dust monitoring unit were collected. An aggregate sample was collected from three locations and considered as a representative of the overall aggregate composition of the road section. Laboratory analysis of the aggregate sample determined aggregate gradation and clay content. In order to determine the water content of the soil, three moisture samples were taken during data collection and were averaged to get a representative value for each road. Wind and temperature readings were taken throughout the data collection period to determine the in-situ weather conditions. A handheld weather gauge was used to collect these readings. Readings were taken every half hour during the three-hour data collection period. To determine traffic characteristics, an Apollo Traffic Counter/Classifier was used. The Apollo system consisted of the traffic counter box and two pneumatic tubes, which were stretched across the roadway and connected to the box. The counter collected information on vehicle type, volume, and speed. The traffic counter was set up at the beginning of data collection and allowed to run for the entire three-hour collection period.

In order to determine dust concentrations from the road, two devices were used. The first of these was the HAZ-DUST EPAM-5000, which is a stationary dust monitoring device. This unit is a high sensitivity real-time particulate air monitor. The unit operates by drawing dust particles into a sensor head and detecting particles once every second. Dust concentrations are instantaneously calculated and all data points are stored in the unit memory for later analysis (Environmental Devices Corporation, 1999). In order to determine the PM_{10} pollution from a road, the unit was fitted with a 10µm inlet sleeve. An EPAM-5000 was placed on each side of the road being tested approximately one to two feet from the edge of the traveled way. To begin a data collection period, the device was turned on and set to run. Once a data collection period was complete, the device was turned off. The device could later be connected to a personal computer and the data collected could be downloaded. The unit was set up at the beginning of data collection and allowed to run for the entire three-hour collection period. The second device used to determine dust concentrations was the Colorado State University (CSU) Dustometer. This device is attached behind a vehicle and used while traveling. The mobility of the device, as well as the short duration of each test, means that many data points can be recorded in one day (Sanders, Quayenortey, & Jorgensen, 2015). The Dustometer system includes a 2000W generator, a 1/3 hp high volumetric suction pump, and a fabricated steel box that holds an 8-inch x 10-inch microfiber glass filter. The setup also includes a two-inch flexible hose that connects the vacuum pump to the filter box. The filter box is attached to the vehicle via a steel plate bolted to the vehicles bumper. The generator and the suction pump are attached via a hitch mounted cargo carrier. The on/off switch for the device is located next to the driver's seat. This means the entire setup can be operated by one person.

A Chevrolet Suburban was used to perform the dust measurements. A one-mile test section was marked out before any measurements were taken. To perform a measurement, a pre-weighed filter paper was inserted into the filter box. The generator mounted on the cargo carrier was started and the device was readied for a data collection run. The vehicle was started and brought to a speed of 40 mph. At the start of the one-mile section, the suction pump was turned on. At the end of the one-mile section, the suction pump was turned off, and the vehicle was brought to a stop. The pre-weighed filter, which had collected dust throughout the measurement, was carefully inserted into a sealed bag to be re-weighed at the laboratory. For each test section, three replicate dust measurements were made. The average of these three measurements was used to determine the concentration of dust on the road in grams per mile before and after treatment.

The modified PASER WYT2/LTAP rating guide, which uses visual surveys to rate the road on a scale of 1 to 10, was used to assess tconditions of the tested roads. (Wyoming Technology Transfer Center, 2014). Figure 2.8 in Chapter 2 shows an overview of the modified PASER rating guide.

5.3 Data Analysis

Data were collected periodically from the studied roads. Data collection took place at several stages. These stages included before the chemical treatment was applied and right after treatment, and after one month, three months, nine months, and one year of treatment. Data collected included dust concentrations, moisture samples, road conditions, traffic characteristics, temperature, and wind speeds. Collected data were organized and analyzed. Analysis was divided into three sections. Exploratory analysis was conducted to examine trends in dust generation and road condition deterioration over time. Statistical analysis was conducted to examine factors that contribute to dust generation, mitigation, and road deterioration. Finally, a life-cycle cost analysis was conducted in Chapter 6 to compare the cost of maintaining untreated gravel roads with the cost of maintaining treated gravel roads over a two-year period. The purpose was to evaluate the economic worth of each option to help counties make economically sound capital investment decisions.

5.3.1 Exploratory Analysis

Collected periodic dust concentrations were plotted in Figure 5.2 to examine how dust generation on gravel roads performs over time. A performance curve was developed to predict dust concentration values over one year. Equation 1 presents the developed model to estimate dust concentrations as a function of time. Figure 5.2 illustrates chemical treatment performance over time with roads with the highest, lowest, and average dust production rates highlighted. Equation 2 shows a formulation developed to predict dust production rates over time.

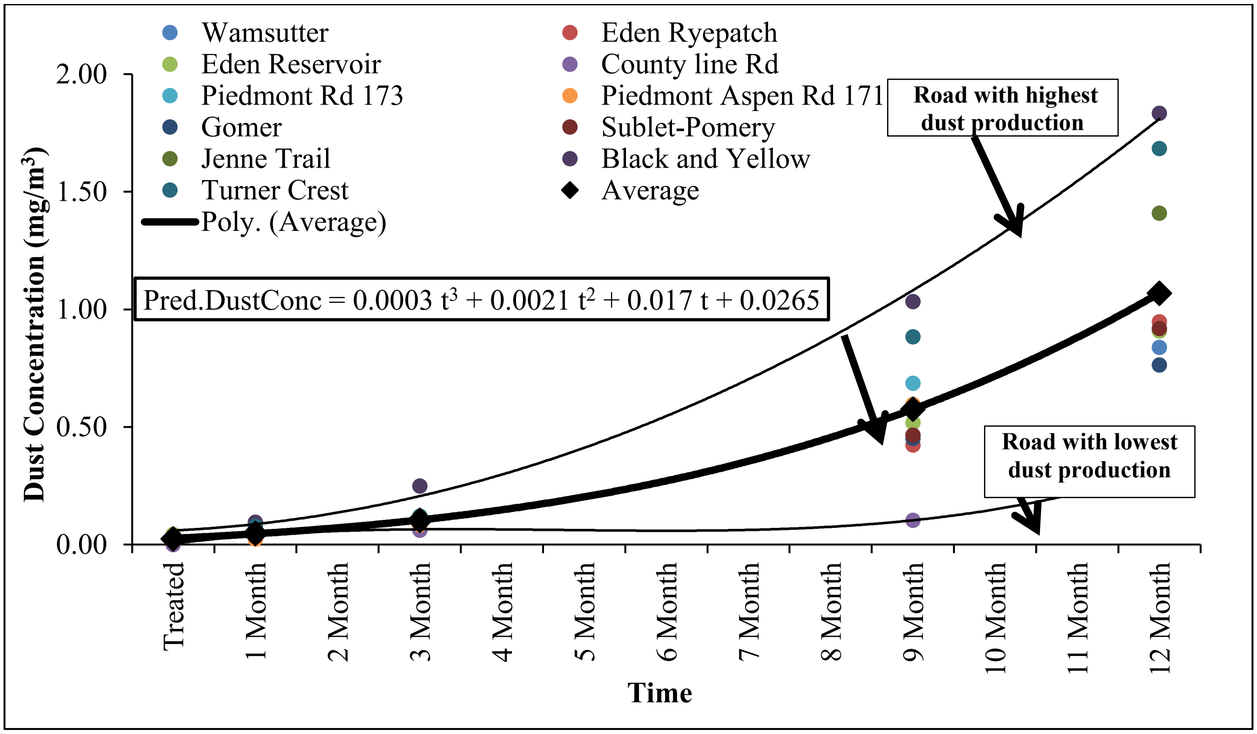


Figure 5.2 Chemical treatment performance over time

Note: For Piedmont Rd 173 and Piedmont Aspen Rd 171, after one year, data were not collected due to the road being chemically re-treated again before the proposed testing date.

Data were collected for Jenne Trail Rd in Converse County before and right after treatment and after one year of treatment.

Predicted Dust Concentration (mg/m^3)= $f(t) = 0.0003 * t^3 + 0.0021 * t^2 + 0.017 * t + 0.0265$ (1)

Dust Production Rate (mg/m^3/month) $= \frac{d}{dt} f(t)$ (2)

Where: t = time in months

PASER windshield road condition ratings were also plotted in Figure 5.3 to examine road condition performance over time. From the data in Figure 5.3, it is apparent that applying chemical treatment improves road conditions. Equation 3 highlights a model developed to predict the PASER condition rating of a gravel road over time.

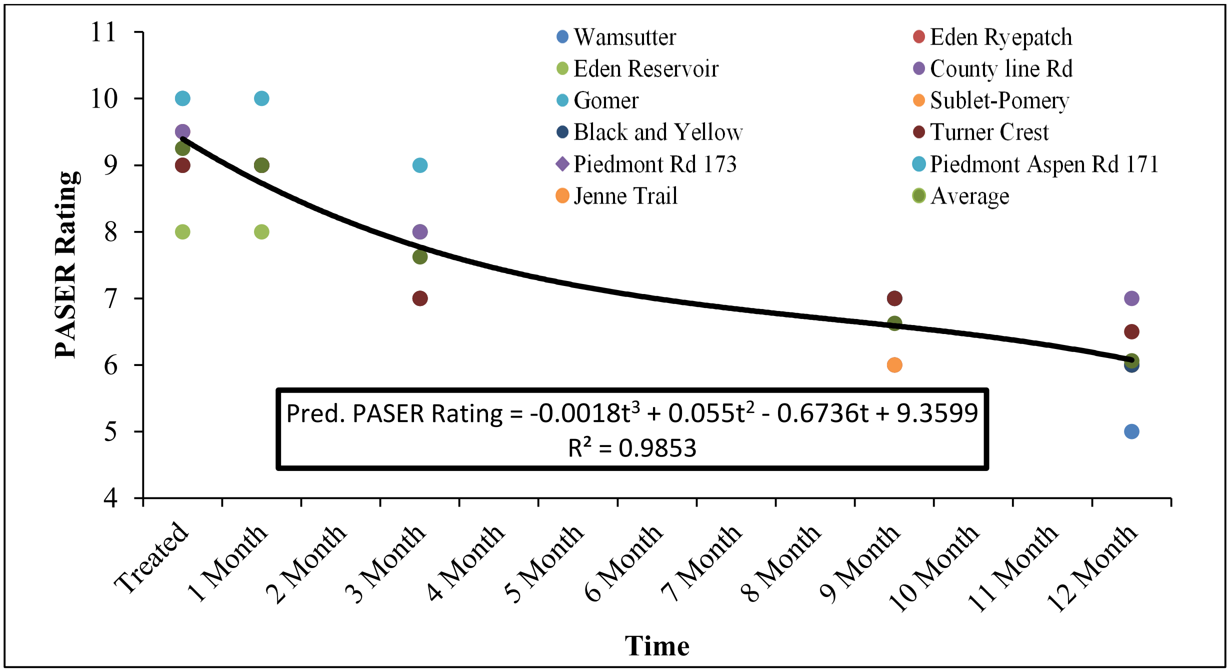


Figure 5.3 PASER windshield road surface condition ratings over time

Predicted PASER Rating = $-0.0018t^3 + 0.055t^2 - 0.6736t + 9.3599$ (3)

Where: t = time in months

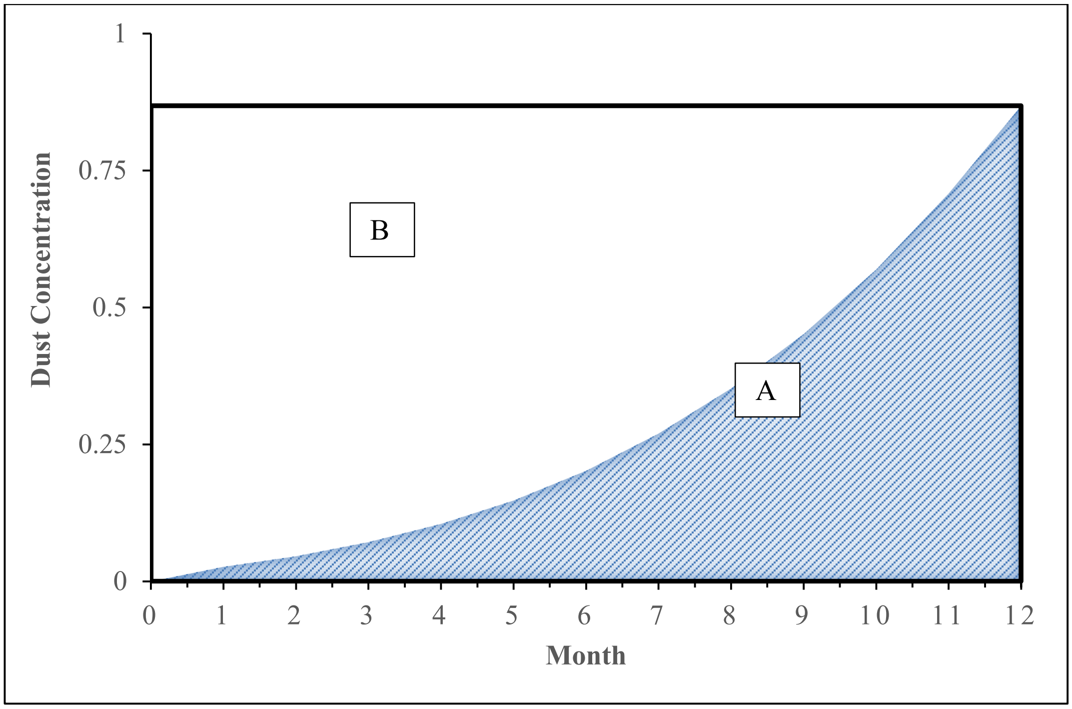
5.3.2 Estimate of Dust Reduction

To quantify the benefit of dust treatment over time, annual dust reduction values were calculated. This was done by taking the difference between dust generated from the treated roads over one year and dust generated when no treatment was applied, with a conservative assumption that the same before treatment dust levels will be generated throughout the year. The reduction percentages calculated are highlighted in Table 5.2. Reduction percentage values were calculated based on equation 4 and Figure 5.4. Using this method of analysis, an average reduction value of 269 mg/m3/year, or 69%, is achieved annually by applying chemical dust suppressants on gravel roads. It is apparent that one year after treatment, dust concentrations and PASER condition ratings went back to before treatment levels, as shown in Table 5.3.

$$\% \text{ Dust Reduction } = \frac{D_t * T_t - \int_{t_0}^{t_f} f(t)dt}{D_t * T_t} * 100 \quad (4)$$

Where: D_t = Dust concentration at time *t*,

T_t = Time period



Note: Area A: Dust with treatment; Area B: Dust reduction; Area, (A+B): Potential dust without treatment.

Figure 5.4 Potential dust production and reduction after applying treatment

Table 5.2 Annual Dust Reduction Values Resulting from Applying Dust Treatment

County	Road	T-Dust per year (mg/m^3/year)	U-Dust per year (mg/m^3/year)	Reduction %
Sweetwater	1. Wamsutter	132	486	73%
	2. Eden Ryepatch	114	236	52%
	3. Eden Reservoir	127	388	67%
	4. County line Rd	39	208	81%
Uinta	5. Piedmont Rd 173	78	321	76%
	6. Piedmont Aspen Rd 171	65	350	81%
Lincoln	7. Gomer	111	355	69%
	8. Sublet-Pomery	120	338	64%
Campbell	9. Black and Yellow	264	736	64%
	10. Turner Crest	220	537	59%

T-Dust: Annual amount of dust generated from treated gravel roads
U-Dust: Annual amount of dust that would have been generated if roads were not treated

Table 5.3 Comparison of Dust Reduction and PASER Condition Rating After a Year

Roads	Dust Concentration			PASER Condition Rating		
	1 Month before treatment	**1 Year after treatment**	**Reduction after 1 Year**	**1 Month before treatment**	**1 Year after treatment**	**Reduction after 1 Year**
Wamsutter	1.33	0.84	0.49	6	5	1
Eden Ryepatch	0.65	0.95	-0.30	7	6	1
Eden Reservoir	1.06	0.91	0.16	6	6	0
County line Rd	0.57	0.32	0.26	7	7	0
Gomer	0.97	0.76	0.21	8	6	2
Sublet-Pomery	0.93	0.92	0.01	8	6	2
Jenne Trail	0.91	1.41	-0.50	-		
Black and Yellow	2.02	1.83	0.18	6	6	0
Turner Crest	1.47	1.68	-0.21	6	6.5	-0.5
Average	**1.10**	**1.07**	**0.03**	**6.75**	**6.06**	**0.69**

5.3.3 Statistical Analysis

A paired t-test with a 95% confidence level was conducted to compare the population means of dust concentration data before treatment was applied and dust concentrations after nine months, and one year of treatment applications on each of the 11 monitored roads. As highlighted in Table 5.4, one tailed P-value was found to be significant, indicating the population means for dust concentration observations before and after nine months of treatment are different. This indicates that dust generation levels after nine months of treatment did not reach pre-treatment levels. For the paired t-test comparing dust concentration levels before treatment and after one year of treatment, the P-value was found to be not significant, indicating that dust concentration levels after one year are back to before-treatment levels. A conclusion can be drawn that matches existing knowledge where chemical dust treatments on gravel roads have a lifetime period of approximately one year.

Table 5.4 One Tail Paired T-Test

	Untreated	*After 1 year*
Mean	1.101488438	1.06890162
Variance	0.199883151	0.23199143
Observations	9	9
Pearson Correlation	0.776422014	
Hypothesized Mean Difference	0	
df	8	
t Stat	0.313107066	
P(T<=t) one-tail	0.38110327	
t Critical one-tail	1.859548038	

To assess what variables contribute to dust generation and reduction, a regression analysis was run to evaluate the relationships between the amount of annual dust generated from treated roads (mg/m^3/year) and traffic features, soil characteristics, and climate conditions on each of the studied roads. Using the SAS statistical analysis software, a multiple regression analysis was performed with the annual amount of dust generated from treated roads as the dependent variable, and the ADT, ADTT, 85th percentile traffic speed in mph, the moisture content in the road soil before treatment, the average moisture content of the road soil after treatment, the soil plasticity index (PI), the annual rainfall in inches, and the amount of fines in the soil passing the #200 sieve as the independent variables. The SAS code script used in the analysis is attached in Appendix B.

As shown in Table 5.5, the results reveal that significant statistical evidence exists to conclude that ADT, ADTT, plasticity index, and the soil moisture content before treatment are not significant predictors of dust generated from treated roads and can thus be dropped from the model. Using the Bayesian Information Criterion (BIC) tool in SAS for model selection, it was found that the most significant prediction model is one that includes the 85th percentile traffic speed, the amount of fines in the soil passing the #200 sieve, and the average moisture content of the soil after treatment as independent variables to predict the annual dust generated from chemically treated roads. The results indicate that the model coefficient of determination is equal to 82%, indicating that 82% of the variation in annual dust levels is explained by the predictors.

Table 5.5 Parameter Estimation Results for Predicting Dust

Variables	Parameter Estimates from OLS Model	
	Initial Model	Final Model
Intercept	-222.0	-144.0
ADT	0.00889	-
ADTT	-0.07114	-
Traffic Speed (mph)	11.62	8.999*
%Fines passing #200 sieve	12.16	9.988**
Moisture Content Before Treatment	13.91	-
Average Moisture Content After Treatment	-106.7	-75.48**
Soil Plasticity Index PI	-1.123	-
Number of Observations	10	10
Goodness of Fit		
BIC	**112.7**	84.72
R-Square	**0.8736**	0.8176
Adj R-Square	**0.4311**	0.7264

Note: $^{*}P<0.05$, $^{**}P<0.01$

Equation 5 is a linear equation developed to predict the annual amount of dust to be generated by chemically treated roads.

$$\hat{Y} = -144.0 + 8.999\,X_1 + 9.988\,X_2 - 75.48\,X_3 \qquad (5)$$

Where:

$\hat{Y}$: Predicted annual amount of dust generated from chemically treated roads (mg/m^3/year)
X_1: 85th percentile traffic speed (mph)

X_2: Amount of fines in the soil passing the #200 sieve (%)

X_3: Average moisture content of soil after treatment

Equation 5 suggests that an increase in traffic speed on a gravel road would increase the predicted annual amount of dust generated from a treated road. Another observation from equation 5 is that as the amount of fines in the soil passing the #200 sieve increases by 1%, and the traffic speed on the road increases by one mph, the predicted annual amount of dust generated would increase by 18.99 mg/m^3/year when the post-treatment soil moisture content is held constant. This shows that both traffic speed and the amount fines in the road soil contribute to an increase in dust generation. A conclusion can be drawn that chemical dust treatment will have a better performance on roads with less fines in their soil content and slower traffic speeds.

5.4 Chapter Summary

This chapter discussed the methodologies, data collection, data analysis, and results of this research study's second objective. The chapter explained the methodologies and the data collection procedures conducted to evaluate the performance of chemically treated roads over time. Eleven recently treated roads were periodically monitored for one year. Monitoring included the measurement of dust emissions, traffic volumes, soil aggregate properties, soil moisture content, and road surface conditions. Collected data were then explored and analyzed, and several results were reached. A performance model was developed that predicts the amount of dust to be generated from chemically treated gravel roads over time. Another model was developed that depicts the performance of road surface conditions and predicts their deterioration over time. An exploratory analysis also helped quantify the benefits of using dust chemical treatment on gravel roads. A 70% reduction of dust generation is achieved annually by applying chemical dust suppressant treatment to gravel roads. Statistical analyses confirmed the observed results that the service life of chemical treatment on gravel roads is about one year.

In addition, the chapter described statistical regression analysis conducted on the collected data. Statistical regression analysis established relationships between annual amount of dust generated from chemically treated roads and different roadway characteristics. A linear regression model was developed to predict annual dust emission rates from chemically treated gravel roads. The results found in this chapter contribute to a growing body of literature about the behavior and performance of chemical treatment on gravel roads. Such knowledge can aid agencies and decision makers in implementing more cost-effective strategies to manage and maintain their gravel road asset network.

6. LIFE-CYCLE COST ANALYSIS

6.1 Introduction

Transportation agencies and local governments are always faced with the dilemma of making decisions to allocate limited available funding to projects. The decision-making process is always complex and involves a mixture of scientific, political, institutional, social, environmental, human, and economic factors. Engineers are tasked with making economic decisions when selecting projects, evaluating alternatives, and dealing with operational and maintenance costs (Rugani, 2016). As part of the comprehensive study conducted by the Wyoming Technology Transfer Center to assess the effectiveness of applying dust treatment on gravel roads, a life-cycle cost analysis was conducted to compare the cost of maintaining untreated gravel roads with the cost of maintaining treated gravel roads. Life-cycle cost analysis is defined as a "process for evaluating the total economic worth of a usable project segment by analysing initial costs and discounted future cost, such as maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment" (Kane, 1996). This chapter describes the methods followed to obtain the cost data and conduct the cost analysis.

Maintenance of gravel roads depends on many different road parameters. These include the road soil characteristics, traffic composition (including vehicle and truck traffic volumes), and the environment (including climate, temperature, and precipitation rates). Due to limited funding available to counties and local agencies in Wyoming, local jurisdictions are finding it challenging to provide adequate care and maintenance to their roads. The state of Wyoming only awards CMAQ funding to counties impacted by industrial and energy operations. The available CMAQ funding is very limited, and counties must submit an application and provide a 20% local match to be awarded CMAQ funds.

6.2 Cost Data

Johnson County, located in the north-central part of Wyoming, was chosen for the analysis. Detailed cost data, which included maintenance and treatment works of eight gravel roads in the county for fiscal years 2013/2014 and 2014/2015, were obtained from Johnson County. Five of these roads were annually treated using a chloride dust suppressant. The other three roads were only maintained throughout the two years with no chemical treatment applications. Appendix C includes the cost data obtained

6.3 Data Organization

The data obtained was summarized to calculate the costs per mile for each treatment work and maintenance type. Cost data pertaining to untreated roads maintenance costs are highlighted in Table 6.1. The table shows the amount of funds Johnson County had to invest to maintain the three roads in serviceable conditions. Buffalo Sussex road cost Johnson County more than $9,000 per mile to maintain in two consecutive years. Irrigary and Lower Sussex roads, however, cost around $2,500 per mile to maintain in two years. This variation highlights the complexity and the differences in maintenance needs among gravel roads even when located in the same county.

Table 6.1 Summary of Untreated Roads Maintenance Costs

Year	Road	Cost	Miles	Cost/Mile
2014	Buffalo sussex	$18,675	28	$667
2015		$234,246		$8,366
2014	Irrigary	$4,260	16.5	$258
2015		$36,066		$2,186
2014	Lower sussex	$11,484	11.86	$968
2015		$22,394		$1,888

Table 6.2 highlights the costs per mile associated with applying chemical treatment on five gravel roads. It was found that for 2014, the average cost per mile for applying chemical dust treatment in Johnson County was around $4,405. For 2015, the average cost was around $4,845. The relatively similar cost per mile for the two years indicates that Johnson County used similar operations in applying chemical dust suppressant treatment to its gravel roads.

Table 6.2 Chemical Treatment Cost/Mile

Cost per mile of annual chemical treatment				
Year	Project	Avg cost/mile		
2014	Chemical	$4,213		
2015	Treatment	$4,650		
		Average:	$4,431	Per Mile

Johnson County had two classifications for maintenance work done on gravel roads: general maintenance (GM) and major work. Table 6.3 shows the costs associated with the work types. Major work includes efforts like purchasing, hauling, blading and patching gravel, loading trucks, and laying gravel on the road. Table 6.3 also highlights that Johnson County spent more money on maintenance in 2015 than in 2014. The average maintenance cost per mile in 2014 was $631. For 2015, the average cost was calculated to be around $4,150. The significant difference highlights the high spending by Johnson County on rehabilitation projects on the studied gravel roads.

Table 6.3 Maintenance Cost/Mile

Cost per mile for maintenance of untreated roads				
Year	Project Type	Average cost/mile	Yearly average	
2014	GM	$295	$341	
2015	GM	$387		
2014	Major Work	$336	$2,048	
2015	Major Work	$3,759		
		Total:	$2,389	Per Mile

6.4 Preliminary Analysis

Analyzing summarized data indicated that major work projects are done once every two years, with an average cost of $3,760/mile/year. When no major work is done, general maintenance and minimum road work cost around $340/mile/year on average. Figure 6.1 highlights projected spending per mile for the untreated roads for the two fiscal years of 2014 and 2015. It can be noted that major rehabilitation work was conducted in the second year, costing approximately $7,800 per mile.

Analysis of the cost data for the chemically treated roads revealed that once treatment is applied and completed, no maintenance work is conducted for the life-cycle of the treatment. It was found that, on average, Johnson County spends $4,665 per mile annually on applying chemical treatment to gravel roads, with the dust suppression agent costing the most. It was also found that chemical dust treatment is only applied once per year. Table 6.4 illustrates the average annual costs per mile of chemical treatment applications and maintenance work done by Johnson County for the consecutive fiscal years of 2014 and 2015.

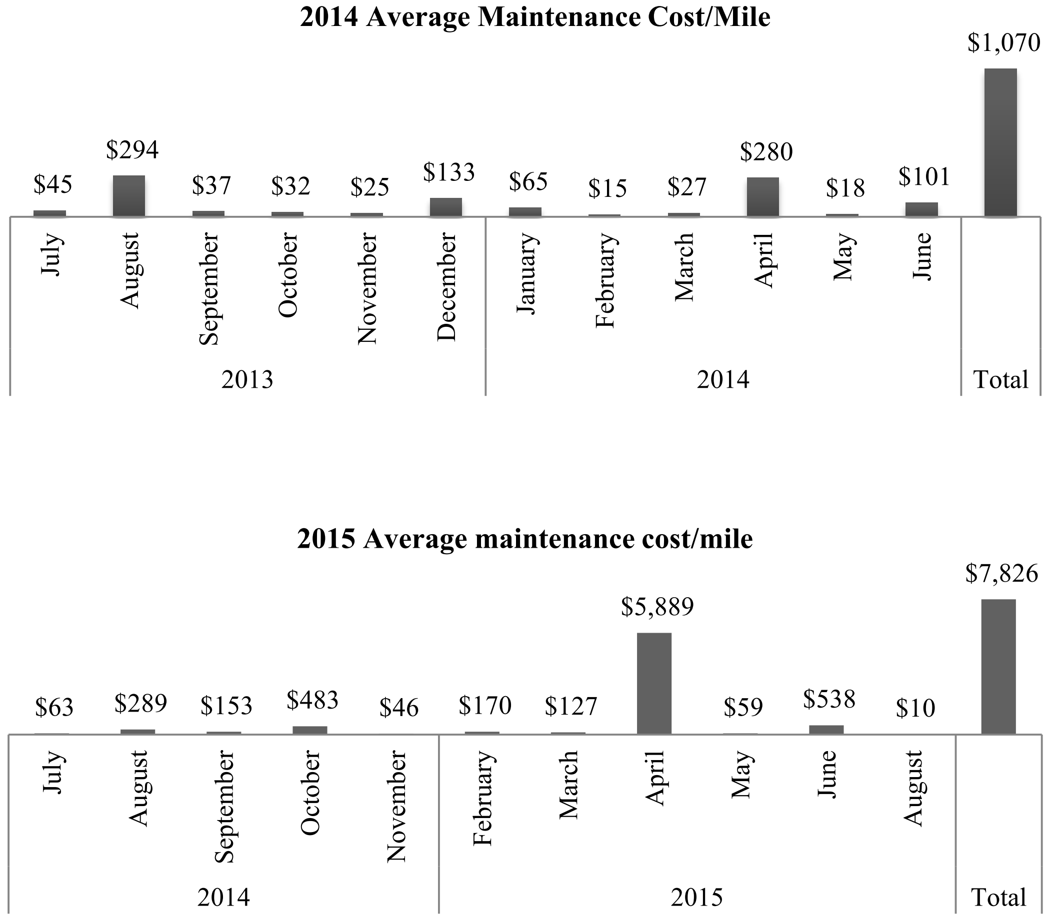


Figure 6.1 Average maintenance cost/mile for untreated roads

Table 6.4 Average Annual Cost of Chemical Treatment and Maintenance Work per Mile

Year	Average Annual Cost of Treatment / mile (Std. Deviation) for Treated Roads	Average Annual Cost of Maintenance / mile (Std. Deviation) for untreated Roads
2014	$4,845 ($466)	General Maintenance: $295 ($30) Major Work: $336 ($261)
2015	$4,406 ($281)	General Maintenance: $387 ($194) Major Work: $3,759 ($2,794)

6.5 Life-cycle Cost Analysis

6.5.1 Life-cycle Assessment Assumptions

The following assumptions were made and followed throughout the analysis process:

- For both treatment and maintenance operations, for a median traffic speed of 40 mph, assuming it will cost 28¢ per mile to operate a passenger car* at 40 mph on pavement, it will cost 39¢ per mile to operate it on a gravel road at the same speed (Kentucky Transportation Center, 2003).
  * 1984 Federal Highway Administration statistics quote an operating cost of 28¢ per mile for an intermediate size passenger car traveling on average suburban pavement.
- Costs included in the analysis are the average costs per mile.
- As found earlier, the life-cycle of chemical treatment is one year, and the life-cycle of major rehabilitation work on gravel roads is two years.
- Once a road is treated, no maintenance or work is needed for the lifetime of the treatment.
- Once major maintenance work is done to a gravel road, no maintenance is needed during the same year, but general maintenance costing $1,070/mile is needed for the second year.
- The analyzed roads all had an ADT > 150.

6.5.2 LCC Analysis

Life-cycle cost analysis was conducted to compare the life-cycle cost of maintaining chemically treated roads with the life-cycle cost of maintaining untreated roads. The analysis is highlighted in Table 6.5, with the cost of both alternatives analyzed and compared over two years. As the data from Johnson County indicated, major maintenance work is applied to untreated gravel roads once every two years, whereas for treated roads, treatment is applied annually.

Table 6.5 Life-cycle Cost Analysis

	Untreated Gravel roads	Chemically treated Gravel Roads
Capital Cost		
Initial cost	$ 7,826	$ 4,665
Life time	2 Years	1 Year
User cost during construction	$ 4	-
Recurring cost	-	$ 4,665
Operation and maintenance cost		
Cost in Year 1	-	-
Cost in Year 2	$1,070	-
Total:	$ 8,900	$9,329

Data from Table 6.5 indicate that when evaluated over two years, maintaining chemically treated gravel roads is $429 more expensive than maintaining untreated gravel roads. Initial examination suggests that maintenance of untreated gravel roads is more cost-effective than maintenance of chemically treated roads due to the high initial cost of applying chemical treatments. However, it is critical to include the user cost associated with air pollution caused by dust generated from untreated roads. As the literature review suggested, dust is an air pollutant harmful to nearby humans, animals, plants, and water sources and can undermine safety on gravel roads due to dust caused impaired visibility. It was difficult to come up with a monetary value to assign a cost to air pollution caused by dust particles generated from untreated gravel roads. However, knowing that a difference of only $429 was calculated between the costs of maintaining chemically treated gravel roads and the cost of maintaining untreated roads, it may be concluded that applying chemical treatment is more cost efficient and will result in significant reductions of dust.

6.6 Chapter Summary

In this chapter, a life-cycle cost analysis was conducted to compare the cost of maintaining chemically treated roads with the cost of maintaining untreated roads. Cost data were obtained from Johnson County, Wyoming, and analyzed to compare the average cost per mile for each alternative. Obtained data included detailed two years' data of maintenance costs associated with maintaining three untreated roads in Johnson County. Data also included two years of detailed costs associated with applying chemical dust suppressant treatment on five roads located in different parts of the county. Data were summarized to enable a clear comparison of the cost per mile associated with applying chemical dust treatment on gravel roads and the cost per mile associated with maintenance work on untreated roads. A life-cycle cost analysis was conducted to compare the two alternatives. The results suggest that applying chemical dust treatment is more cost efficient when considering the air quality improvement benefits achieved by applying the dust suppressant.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This study was part of a multiple year study conducted by the Wyoming Technology Transfer Center to assess the effectiveness of using chemical dust suppressant treatment on gravel roads. The research was divided into three objectives and included the use of field collected data and comprehensive statistical analysis to measure and evaluate chemical treatment effectiveness. The conclusions summarized in this chapter add valuable knowledge to a growing body of literature regarding the maintenance and management of low-volume gravel roads. The recommendations discussed in this chapter should help local agencies and decision makers better understand the performance of chemical treatment on gravel roads and develop cost-effective strategies to manage and maintain their gravel road networks.

Objective 1 of this study included the continuation of the CMAQ effectiveness study started in the summer of 2014. This involved including more counties and testing more CMAQ-funded roads. Testing included measuring dust emission rates, surfacing aggregate type, soil moisture content, road traffic characteristics, and weather conditions before and after chemical treatment was applied. Field data were collected from CMAQ-funded roads in Campbell, Carbon, Converse, Crook, Johnson, Lincoln, Sheridan, Sweetwater, Teton, Uinta, and Weston counties in Wyoming.

Objective 2 of this research study developed performance models for treated gravel roads to assess the effectiveness of using chemical dust treatment. This objective included periodically collecting field data from several chemically treated roads. The collected data were then analyzed to model the performance of fugitive dust generations and road surface conditions. Models were developed to predict dust emissions and road surface condition deterioration over time. The annual amount of dust reduction achieved by applying chemical dust treatment was also determined by analyzing the collected data. Statistical analysis was also utilized to determine the service life of chemical treatment on gravel roads, as well as assess the relationship between the different factors contributing to dust generation from treated gravel roads over time.

Objective 3 of this research was a life-cycle cost analysis study that looked at comparing the cost of maintaining untreated roads with the cost of maintaining treated roads. Actual field data were obtained from Johnson County and analyzed to conduct the comparison study. The data obtained included detailed monthly cost data for different work activities for three roads in Johnson County that were maintained periodically, but without the use of chemical treatment. In addition, detailed cost data for five roads in Johnson County chemically treated on a yearly basis were collected. The life-cycle cost analysis conducted compared the two options as alternatives for counties to use when deciding on their asset preservation strategies.

7.2 Conclusions

The data collected for each of the three objectives were summarized and analyzed. Analysis included the use of descriptive, comparison, and statistical analyses. Conclusions reached from the conducted analysis for each of the three objectives are addressed as the following:

7.2.1 Objective 1:

- Traffic volumes reported on CMAQ county roads ranged from 24 vehicles per day to 2,574 vehicles per day. The literature review suggests that roads with traffic volumes higher than 500 should be paved. The average traffic volume for all the roads was around 270 vehicles per day.
- Truck traffic on CMAQ roads also ranged from 0 trucks per day to 420 trucks per day, or 71% of the overall traffic on the road. The high truck traffic shows the increase of oil and gas activities in some Wyoming counties and highlights its impact on local county roads.
- Traffic speeds on CMAQ roads ranged from 10 mph to 74 mph. The average recorded speed was 45 mph, which is higher than the 30 mph posted speed limit on most county gravel roads. Traffic speed has been linked to higher dust generation and faster deterioration rates. This indicates that more law enforcement is needed on gravel roads to ensure drivers follow the speed limit.
- Almost all CMAQ-funded roads were composed of granular materials, with less than 35% of fines passing the #200 sieve. The roads tested were AASHTO classified as:
    - 21 roads classified as A-1-a
    - 26 roads classified as A-1-b
    - 7 roads classified as A-2-4
    - 11 roads classified as A-2-6
- Most CMAQ tested roads were found to have high dust emission rates that violate the Environmental Protection Agency requirements before treatment. The reported high concentrations highlight the need for dust suppressant treatment.
- Variable dust emission rates were also recorded from the tested CMAQ roads, indicating that CMAQ roads in various Wyoming locations generate varying dust emissions.
- Chemical dust treatment significantly reduced dust emissions to values below the federal PM_{10} concentration limits.
- Dust Mitigation efforts paid by CMAQ funds are effective in significantly reducing dust generation and improving air quality.

7.2.2 Objective 2:

This study was set out to assess the performance of chemical dust treatments on gravel roads and evaluate their effectiveness. The aim was to develop an understanding of the deterioration behavior of roads treated with dust suppressants and predict the service life of the treatment. The findings suggest the following:

- In general, the service life of chemical dust suppressant treatments on gravel roads ranges from 10-12 months before dust generation levels and road surface conditions return to before-treatment levels.
- An average of 269 mg/m3/year of dust reduction was achieved over a year by applying chemical dust treatment to gravel roads.
- This is equal to almost 70% reduction percentage of the total dust that could have been generated over one year.
- The statistical investigation also proved there is no difference between dust emission rates before treatment and after one year of treatment. This indicates that the service life of chemical treatment on gravel roads is around one year. This finding adds to a growing body of literature on dust control treatment service life and its behavior over time.
- The second major finding of the statistical analysis was that traffic speeds, the amount of fines in the soil passing the #200 sieve, and average soil moisture content after treatment are all significant factors that contribute to annual dust generation from chemically treated roads.

- These findings can indicate that gravel roads with granular soil-aggregate mixtures (35% or less of total sample passing No. 200 sieve) contribute to better annual dust reduction and more effective chemical treatment.
- The findings also indicate that slower traffic speeds on gravel roads contribute to better annual dust reduction and more effective long-term chemical treatment.

7.2.3 Objective 3:

Life-cycle cost analysis was conducted to compare the cost of maintaining treated roads with the cost of maintaining untreated roads. The main findings are highlighted as the following:

- The findings of the life-cycle cost analysis initially suggested that maintaining untreated gravel roads is slightly cheaper than maintaining treated gravel roads. This is due to the high initial cost of applying chemical dust treatment to gravel roads.
- A difference of only $430 was calculated between the two maintenance programs.
- It is concluded that applying chemical dust treatment is more cost effective when considering the environmental and safety benefits achieved by the significant reduction in dust emission.
- On average, chemical treatments cost around $4,450 per mile to apply on gravel roads.
- Once chemical treatment is applied, no maintenance work of the treated road is needed for almost one year.
- Untreated roads needed regular maintenance on a monthly basis.
- Average maintenance cost of untreated roads was around $340 in 2014 and $2,000 in 2015. The significant difference indicates that counties conduct major rehabilitation work once every two years.

7.3 Recommendations

This research has thoroughly investigated the use of chemical dust treatment as part of the CMAQ program in Wyoming. The findings conclude that chemical dust treatment is effective in reducing dust generation and improving gravel road serviceability. CMAQ dollars to fund dust treatment projects are being used efficiently. For Wyoming agencies responsible for allocating CMAQ funds, the following are recommendations based on findings of the study:

- Dust mitigation has proven to be very effective in improving air quality. It is recommended that CMAQ funds be used to finance dust mitigation projects.
- Gravel roads experiencing higher traffic volumes will generate more dust and should be prioritized when scheduling chemical treatment.
- Gravel roads in drier climate areas will generate more dust and should also be prioritized when scheduling chemical treatment.
- Performance models developed in Chapter 5 can be used to estimate future dust generations from chemically treated roads.
- The performance models developed provide useful tools for decision makers to better decide where to allocate CMAQ funds.

7.4 Future Studies

In the course of this investigation, numerous learned lessons suggest more research is needed to better quantify and assess the long-term effectiveness of chemical treatment on gravel roads. Future research should therefore concentrate on investigating the following:

- Continue the data collection process to include more CMAQ-funded roads in the analysis.
- Measure the amount of gravel lost over time as roads deteriorate.
- Monitor the performance and cost of different unpaved road chemical treatment products and maintenance practices over several years.
- Document long-term gravel loss, road performance, and user cost to develop predicting performance models.

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APPENDIX A: CMAQ ROADS DATA

APPENDIX A-1: EPAM 5000

EPAM Data: Untreated Roads

County:	**Lincoln**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Muddy Creek**	Above 0.5	Average	2.277
Date:	TUE 15-JUL-14	(Threshold)	Std. Dev.	0.628
Road Condition:	Untreated			
Start:	15:59:44			
End:	17:47:04			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Lincoln**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Gomer**	Above 0.5	Average	0.973
Date:	FRI 05-JUN-15	(Threshold)	Std. Dev.	0.477
Road Condition:	Untreated			
Start:	7:08:04			
End:	10:47:54			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Lincoln**			
Location Name:	**Sublett-Pomeroy**	**PM_{10} Concentration (mg/m^3)**		
Date:	FRI 05-JUN-15		Average	0.927
Road Condition:	Untreated	Above 0.5		
Start:	6:31:43	(Threshold)	Std. Dev.	0.456
End:	9:28:53			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Converse**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Jenne Trail**	Above 0.5	Average	2.674
Date:	WED 02-JUL-14	(Threshold)	Std. Dev.	2.962
Road Condition:	Untreated			
Start:	9:50:19			
End:	13:46:49			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Converse**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Ross**	Above 0.5	Average	0.914
Date:	MON 01-JUN-15	(Threshold)	Std. Dev.	0.438
Road Condition:	Untreated			
Start:	14:52:57			
End:	17:48:37			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Crook**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**D-Road**	Above 0.5	Average	1.779
Date:	TUE 08-JUL-14	(Threshold)	Std. Dev.	1.277
Road Condition:	Untreated			
Start:	10:47:28			
End:	14:43:38			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Cosner**	Above 0.5	Average	1.846
Date:	MON 25-AUG-14	(Threshold)	Std. Dev.	1.359
Road Condition:	Untreated			
Start:	11:50:44			
End:	15:35:14			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	Clarkelen	Above 0.5	Average	1.433
Date:	WED 09-JUL-14	(Threshold)	Std. Dev.	0.898
Road Condition:	Untreated			
Start:	13:34:40			
End:	17:40:00			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	Moore Road	Above 0.5	Average	3.043
Date:	WED 09-JUL-14	(Threshold)	Std. Dev.	3.481
Road Condition:	Untreated			
Start:	9:03:35			
End:	12:54:35			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Turnercrest**	Above 0.5	Average	2.017
Date:	WED 17-JUN-15	(Threshold)	Std. Dev.	1.440
Road Condition:	Untreated			
Start:	16:19:29			
End:	19:16:39			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Todd**	Above 0.5	Average	1.287
Date:	FRI 19-JUN-15	(Threshold)	Std. Dev.	0.862
Road Condition:	Untreated			
Start:	6:32:48			
End:	9:21:18			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Christensen**	Above 0.5	Average	3.010
Date:	THUR 18-JUN-15	(Threshold)	Std. Dev.	2.638
Road Condition:	Untreated			
Start:	8:08:44			
End:	10:57:34			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Hayden**	Above 0.5	Average	1.870
Date:	TUE 02-JUN-15	(Threshold)	Std. Dev.	1.285
Road Condition:	Untreated			
Start:	6:42:54			
End:	9:36:24			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Black & Yellow Road**	Above 0.5	Average	1.471
Date:	TUE 02-JUN-15	(Threshold)	Std. Dev.	1.227
Road Condition:	Untreated			
Start:	9:59:55			
End:	12:52:45			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Iberlin**	Above 0.5	Average	4.036
Date:	TUE 02-JUN-15	(Threshold)	Std. Dev.	3.668
Road Condition:	Untreated			
Start:	13:11:40			
End:	16:12:10			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Johnson**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**TTT Road**	Above 0.5	Average	2.166
Date:	THUR 18-JUN-15	(Threshold)	Std. Dev.	2.065
Road Condition:	Untreated			
Start:	12:35:41			
End:	15:43:21			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Sweetwater**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Wamsutter**	Above 0.5	Average	1.330
Date:	TUE 26-MAY-15	(Threshold)	Std. Dev.	0.837
Road Condition:	Untreated			
Start:	13:08:40			
End:	16:09:30			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Sweetwater**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Patrick Draw**	Above 0.5	Average	1.673
Date:	THUR 28-MAY-15	(Threshold)	Std. Dev.	0.196
Road Condition:	Untreated			
Start:	10:52:53			
End:	13:40:03			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Weston**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Grieves**	Above 0.5	Average	2.383
Date:	WED 01-JUL-15	(Threshold)	Std. Dev.	3.450
Road Condition:	Untreated			
Start:	10:45:00			
End:	13:58:40			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Weston**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Bruce**	Above 0.5	Average	1.270
Date:	WED 01-JUL-15	(Threshold)	Std. Dev.	0.650
Road Condition:	Untreated			
Start:	7:27:08			
End:	10:16:18			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Weston**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Mush Creek**	Above 0.5	Average	2.371
Date:	WED 01-JUL-15	(Threshold)	Std. Dev.	2.085
Road Condition:	Untreated			
Start:	17:32:40			
End:	19:58:20			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

EPAM Data: Treated Roads

County:	**Lincoln**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Muddy Creek**	Above	Average	0.051
Date:	TUE 30-SEP-14	0.01	Std. Dev.	0.062
Road Condition:	Treated			
Start:	8:37:51			
End:	9:05:48			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Lincoln**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Gomer**	Above	Average	0.023
Date:	WED 24-JUN-15	0.01	Std. Dev.	0.039
Road Condition:	Treated			
Start:	10:33:55			
End:	13:39:05			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Lincoln**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Sublette-Pomeroy**	Above	Average	0.032
Date:	WED 24-JUN-15	0.01	Std. Dev.	0.045
Road Condition:	Treated			
Start:	7:01:59			
End:	10:14:09			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Converse**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Jenne Trail**	Above	Average	0.029
Date:	THUR 14-AUG-14	0.01	Std. Dev.	0.018
Road Condition:	Treated			
Start:	9:41:51			
End:	12:05:31			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Crook County**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**D-Road**	Above	Average	0.024
Date:	THUR 21-AUG-14	0.01	Std. Dev.	0.022
Road Condition:	Treated			
Start:	14:41:08			
End:	18:42:58			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Cosner**	Above	Average	0.028
Date:	WED 24-SEP-14	0.01	Std. Dev.	0.019
Road Condition:	Treated			
Start:	13:43:53			
End:	17:24:23			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Campbell**	**PM$_{10}$ Concentration (mg/m^3)**		
Location Name:	**Clarkelen**	Above	Average	0.020
Date:	FRI 22-AUG-14	0.01	Std. Dev.	0.012
Road Condition:	Treated			
Start:	9:50:24			
End:	13:25:14			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Campbell**	**PM$_{10}$ Concentration (mg/m^{3})**		
Location Name:	**Moore**	Above	Average	0.141
Date:	FRI 22-AUG-14	0.01	Std. Dev.	0.254
Road Condition:	Treated			
Start:	7:45:25			
End:	9:24:05			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Carbon**				
Location Name:	**CR 608**				
Date:	TUE 24-MAY-16		Threshold	0.5	mg/m3
Start:	8:38:28		Average =	0.9674	mg/m3
End:	9:27:08		Std Dev =	0.174547	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				

Location Number:	**Converse**			
Location Name:	**Bill Hall Rd**			
Date:	THUR 16-JUN-16	Threshold	0.5	mg/m3
Start:	10:40:40	Average =	2.089479	mg/m3
End:	13:53:30	Std Dev =	2.075779	mg/m3
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Sheridan**			
Location Name:	**Wolf Creek Rd**			
Date:	TUE 17-MAY-16	Threshold	0.5	mg/m3
Start:	19:05:07	Average =	0.7215	mg/m3
End:	20:45:47	Std Dev =	0.1025	mg/m3
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Sheridan**			
Location Name:	**North Park Rd**			
Date:	TUE 17-MAY-16	Threshold	0.5	mg/m3
Start:	16:28:13	Average =	0.641	mg/m3
End:	19:22:03	Std Dev =	0	mg/m3
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Sheridan**				
Location Name:	**Murphy Gulch Rd**				
Date:	TUE 17-MAY-16		Threshold	0.5	mg/m3
Start:	10:01:54		Average =	0.6405	mg/m3
End:	12:39:34		Std Dev =	0.097702	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				
Location Number:	**Sheridan**				
Location Name:	**Lower Praire**				
Date:	TUE 17-MAY-16		Threshold	0.5	mg/m3
Start:	13:37:52		Average =	0.867333	mg/m3
End:	16:39:12		Std Dev =	0.058574	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				
Location Number:	**Sheridan**				
Location Name:	**Higby Rd**				
Date:	WED 18-MAY-16		Threshold	0.5	mg/m3
Start:	10:54:17		Average =	1.927167	mg/m3
End:	13:42:37		Std Dev =	0.927581	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				
Location Number:	**Sheridan**				
Location Name:	**Halfway Ln**				
Date:	WED 18-MAY-16		Threshold	0.5	mg/m3
Start:	8:04:33		Average =	0.7124	mg/m3
End:	10:52:23		Std Dev =	0.26787	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				
Location Number:	**Sheridan**				
Location Name:	**East Dayton**				
Date:	WED 18-MAY-16		Threshold	0.5	mg/m3
Start:	7:08:47		Average =	0.963571	mg/m3
End:	9:54:07		Std Dev =	0.333655	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				

Location Number:	**Lincoln**				
Location Name:	**Lupine Rd**				
Date:	WED 25-MAY-16		Threshold	0.5	mg/m3
Start:	13:44:46		Average =	1.408833	mg/m3
End:	15:56:26		Std Dev =	0.724854	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				

Location Number:	**Lincoln**				
Location Name:	**Kemmerer Landfill**				
Date:	WED 25-MAY-16		Threshold	0.5	mg/m3
Start:	10:56:55		Average =	2.464	mg/m3
End:	14:00:25		Std Dev =	2.099444	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				

Location Number:	**Lincoln**				
Location Name:	**Fontennelle**				
Date:	TUE 24-MAY-16		Threshold	0.5	mg/m3
Start:	16:23:28		Average =	0.632333	mg/m3
End:	19:30:28		Std Dev =	0.110424	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				

Location Number:	**Johnson**				
Location Name:	**Irrigary**				
Date:	THUR 21-APR-16		Threshold	0.5	mg/m3
Start:	9:47:47		Average =	0.523	mg/m3
End:	12:20:17		Std Dev =	0	mg/m3
Data Type:	10.0 um - M				
Unit Type:	EPAM-5000				
Data Scale:	1				

APPENDIX A-2: CSU-DUSTOMETER

CSU Dustometer Data: Untreated Roads

County: Lincoln
Road: Muddy Creek
Condition: Untreated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.6	16.05	2.45
		Average	2.45

County: Lincoln
Road: Gomer
Condition: Untreated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	16.2	1.5
1	14.6	15.5	0.9
1	14.7	16.4	1.7
		Average	1.37
		std dev	0.34

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.6	1
1	14.7	15.4	0.7
1	14.6	16.5	1.9
		Average	1.20
		std dev	0.51

County: Lincoln
Road: Sublette-Pomeroy
Condition: Untreated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	17.2	2.5
1	14.6	15.8	1.2
1	15.5	16.6	1.1
		Average	1.60
		std dev	0.64

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	17.8	3.1
1	14.7	16.9	2.2
1	14.7	16.6	1.9
		Average	2.40
		std dev	0.51

County: Converse
Road: Jenne Trail
Condition: Untreated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.56	14.35	0.79
1	13.61	14.4	0.79
1	13.58	17.4	3.82
		Average	1.8
		std dev	1.428355698

County: Converse
Road: Ross
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	15.1	0.4
1	14.6	15.3	0.7
1	14.5	15.4	0.9
		Average	0.67
		std dev	0.21

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.1	0.5
1	14.5	15	0.5
1	14.5	15.4	0.9
		Average	0.63
		std dev	0.19

County: Campbell
Road: Cosner
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.97	15.78	2.81
1	12.88	18.02	5.14
		Average	3.975
		std dev	1.165

County: Campbell
Road: Turnercrest
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.4	0.8
1	14.6	15.9	1.3
1	14.7	15.2	0.5
		Average	0.87
		std dev	0.33

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.3	1.7
1	14.7	15.8	1.1
1	14.7	15.4	0.7
		Average	1.17
		std dev	0.41

County: Campbell
Road: Todd
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	15.2	0.5
1	14.6	15.8	1.2
1	14.6	15.3	0.7
		Average	0.80
		std dev	0.29

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.5	1.9
1	14.7	16.2	1.5
1	14.7	16.9	2.2
		Average	1.87
		std dev	0.29

County: Campbell
Road: Christensen
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.9	2.3
1	14.6	16	1.4
1	14.7	16.2	1.5
		Average	1.73
		std dev	0.40

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	16.9	2.2
1	14.6	18	3.4
1	14.7	16.6	1.9
		Average	2.50
		std dev	0.65

County: Campbell
Road: Hayden
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.9	2.3
1	14.6	16.4	1.8
1	14.6	17.1	2.5
		Average	2.20
		std dev	0.29

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.4	1.8
1	14.8	16.4	1.6
1	14.6	16.3	1.7
		Average	1.70
		std dev	0.08

County: Campbell
Road: Black & Yellow
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.7	1.1
1	14.6	15.5	0.9
1	14.6	15.7	1.1
		Average	1.03
		std dev	0.09

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.5	1.9
1	14.6	15.8	1.2
1	14.5	15.8	1.3
		Average	1.47
		std dev	0.31

County: Campbell
Road: Iberlin
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.5	15.4	0.9
1	14.5	15.4	0.9
1	14.6	15.2	0.6
		Average	0.80
		std dev	0.14

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.5	15.2	0.7
1	14.7	15	0.3
1	14.7	15.4	0.7
		Average	0.57
		std dev	0.19

County: Johnson
Road: TTT
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.6	1
1	14.7	16	1.3
1	14.7	17.2	2.5
		Average	1.60
		std dev	0.65

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.4	15.7	1.3
1	14.6	15.6	1
1	14.5	16.1	1.6
		Average	1.30
		std dev	0.24

County: Sweetwater
Road: Wamsutter
Condition: Untreated

Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13	17.93	4.93
1	12.67	15.21	2.54
1	12.7	17.16	4.46
		Average	3.98
		std dev	1.03

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.97	15.29	2.32
1	13.02	15.45	2.43
1	13.07	15.34	2.27
		Average	2.34
		std dev	0.07

County: Sweetwater
Road: Patrick Draw
Condition: Untreated

Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13	16.73	3.73		1	12.94	15.09	2.15
1	12.67	15.61	2.94		1	12.96	15.27	2.31
1	12.7	16.35	3.65		1	12.89	15.18	2.29
		Average	3.44				Average	2.25
		std dev	0.36				std dev	0.07

County: Weston
Road: Grieves
Condition: Untreated

Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.5	17.2	2.7		1	14.6	17.4	2.8
1	14.5	16.7	2.2		1	14.5	16.3	1.8
1	14.6	17	2.4		1	14.5	16.7	2.2
		Average	2.43				Average	2.27
		std dev	0.21				std dev	0.41

County: Weston
Road: Bruce
Condition: Untreated

Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	17.2	2.6		1	14.6	17.3	2.7
1	14.6	16.4	1.8		1	14.5	16.9	2.4
1	14.6	17.6	3		1	14.5	17	2.5
		Average	2.47				Average	2.53
		std dev	0.50				std dev	0.12

County: Weston
Road: Mush Creek
Condition: Untreated

Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	17.4	2.7		1	12.84	17.1	4.26
1	14.5	17.3	2.8		1	14.6	18.3	3.7
1	14.6	16.5	1.9		1	12.82	17.6	4.78
		Average	2.47				Average	4.25
		std dev	0.40				std dev	0.44

CSU Dustometer Data: Treated Roads

County: Lincoln
Road: Muddy Creek
Condition: Treated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
0.5	12.9	13.28	0.38
0.5	12.92	13.17	0.25
0.5	12.9	13.24	0.34
		Average	0.65
		Std Dev	0.11

County: Lincoln
Road: Gomer
Condition: Treated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.79	13	0.21
1	12.82	13.2	0.38
1	12.8	13	0.2
		Average	0.26
		std dev	0.08

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.79	12.9	0.11
1	12.96	13.2	0.24
1	12.8	13	0.2
		Average	0.18
		std dev	0.05

County: Lincoln
Road: Sublette-Pomeroy
Condition: Treated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	15.3	0.6
1	14.6	15.1	0.5
1	14.6	15	0.4
		Average	0.50
		std dev	0.08

Screen Size: #200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	14.8	0.2
1	14.7	14.8	0.1
1	14.6	14.8	0.2
		Average	0.17
		std dev	0.05

County: Converse
Road: Jenne Trail
Condition: Treated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.85	13.7	0.85
1	12.82	14.22	1.4
1	12.91	13.12	0.21
		Average	0.82
		std dev	0.49

County: Campbell
Road: Cosner
Condition: Treated
Screen Size: #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.6	13.62	0.02
1	13.54	13.58	0.04
1	13.62	13.62	0
		Average	0.02
		Std Dev	0.016329932

Appendix A-3: Traffic Volumes

Per-Vehicle Summary Report: LINCOLN, GOMER

```
Station ID :    LIN-GOM-U                                               Last Connected Device Type Apollo

          Info Line 1 :                                                         Version Number :       1.66
          Info Line 2 :                                                         Serial Number :       11297
GPS Lat/Lon :                                                                   Number of Lanes :         2
          DB File :         LIN-GOM-U.DB                                        Posted Speed Limi 0.0 mph

                                                           Lane Configuration
#         Dir.      Information          Vehicle Sensors   Sensor Spacing      Loop Length

   1.00                                  Axle-Axle         4.0 ft
   3.00                                  Axle-Axle         4.0 ft
Average Daily Traffic (ADT)

                    Weekday                                Weekend                  Total ADT
                    Cars :            80   100%            Cars :                   Cars :            80    100%
          Trucks :                     0          0%       Trucks :                 Trucks :           0      0%

                    Total :           80                   Total :                  Total :           80

Speed Totals
          50 % :    39.5 mph                 Top Speed :   40.8 mph                 Average Truck Speed :
          85 % :    40.5 mph                 Low Speed :   21.6 mph                 Average Car Speed :      37.7 mph
          Avg :     37.7 mph        10mph Pace Speed:      36.5 - 46.4     90.00%

Peak Hour Totals

          AM Peak Hour (Volume)                            AM Peak Hour (Speed)
          Weekday :     10:00 - 11:00    (Avg 14)          07:30 - 08:30      ( 40.3 mph)
          Weekend :
          PM Peak Hour (Volume)                            PM Peak Hour (Speed)

          Weekday :
          Weekend :
Grand Totals

          Total Cars :                 10 (        80 ADT)  Average Length :   11.4 ft  Average Headway :      756.1 sec
          Total Trucks :                0 (         0 ADT)  Average Axles :      2.00            Average (755.9 sec
          Total Volume :               10 (        80 ADT)
```

Per-Vehicle Summary Report: LINCOLN, SUBLETTE-POMEROY

```
Station ID :    LIN-SUB-U                                               Last Connected Device Type Apollo

          Info Line 1 :                                                         Version Number :       1.66
          Info Line 2 :                                                         Serial Number :       11166
GPS Lat/Lon :                                                                   Number of Lanes :         2
          DB File :         LIN-SUB-U.DB                                        Posted Speed Limi 0.0 mph

                                                           Lane Configuration
#         Dir.      Information          Vehicle Sensors   Sensor Spacing      Loop Length

   1.00                                  Axle-Axle         4.0 ft
   3.00                                  Axle-Axle         4.0 ft
Average Daily Traffic (ADT)

                    Weekday                                Weekend                  Total ADT
                    Cars :           112    93%            Cars :                   Cars :           112     93%
          Trucks :                     8          7%       Trucks :                 Trucks :           8      7%

                    Total :          120                   Total :                  Total :          120

Speed Totals
          50 % :    36.0 mph                 Top Speed :   51.1 mph                 Average Truck Speed :    15.5 mph
          85 % :    38.8 mph                 Low Speed :   15.5 mph                 Average Car Speed :      35.4 mph
          Avg :     34.1 mph        10mph Pace Speed:      35.9 - 45.8     53.30%

Peak Hour Totals

          AM Peak Hour (Volume)                            AM Peak Hour (Speed)
          Weekday :     08:30 - 09:30    (Avg 10)          08:15 - 09:15      ( 37.1 mph)
          Weekend :
          PM Peak Hour (Volume)                            PM Peak Hour (Speed)

          Weekday :
          Weekend :
Grand Totals

          Total Cars :                 14 (       112 ADT)  Average Length :   17.9 ft  Average Headway :      474.6 sec
          Total Trucks :                1 (         8 ADT)  Average Axles :      2.40            Average (474.2 sec
          Total Volume :               15 (       120 ADT)
```

Per-Vehicle Summary Report: CONVERSE, JENNE TRAIL

Station ID : CON-JEN-T

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CON-JEN-T.DB

Version Number : 1.51
Serial Number : 11194
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spaci	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
	Cars :	296	55%	Cars :		Cars :	**296**	55%
Trucks :		240	45%	Trucks :		Trucks :	**240**	45%
	Total :	536		Total :		Total :	**536**	

Speed Totals

50 % : 34.9 mph
85 % : 43.5 mph
Avg : 33.8 mph

Top Speed : 56.0 mph
Low Speed : 6.3 mph
10mph Pace Speed: 34.5 - 44.4 38.80%

Average Truck Speed : 30.1 mph
Average Car Speed : 36.8 mph

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)
Weekday :	10:00 - 11:00	(Avg 33)	11:00 - 12:00 (34.7 mph)
Weekend :			
PM Peak Hour (Volume)			PM Peak Hour (Speed)
Weekday :	12:00 - 13:00	(Avg 20)	12:00 - 13:00 (33.5 mph)
Weekend :			

Grand Totals

Total Cars :	37 (	296 ADT)	Average Leng	31.9 ft	Average Headway :	122.7 sec
Total Trucks :	30 (	240 ADT)	Average Axle	3.40	Average Gap :	122.0 sec
Total Volume :	67 (	536 ADT)				

Per-Vehicle Summary Report: CONVERSE, ROSS

Station ID : CON-ROS-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CON-ROS-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
	Cars :	376	63%	Cars :		Cars :	**376**	63%
Trucks :		216	37%	Trucks :		Trucks :	**216**	37%
	Total :	592		Total :		Total :	**592**	

Speed Totals

50 % : 32.3 mph
85 % : 38.2 mph
Avg : 31.4 mph

Top Speed : 47.7 mph
Low Speed : 10.7 mph
10mph Pace Speed: 30.2 - 40.1 55.40%

Average Truck Speed : 29.6 mph
Average Car Speed : 32.5 mph

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)
Weekday :			
Weekend :			
PM Peak Hour (Volume)			PM Peak Hour (Speed)
Weekday :	17:30 - 18:30	(Avg 36)	16:00 - 17:00 (35.6 mph)
Weekend :			

Grand Totals

Total Cars :	47 (	376 ADT)	Average Length :	26.1 ft	Average Headway :	125.7 sec
Total Trucks :	27 (	216 ADT)	Average Axles :	3.00	Average (	125.1 sec
Total Volume :	74 (	592 ADT)				

Per-Vehicle Summary Report: CAMPBELL, TURNERCREST

Station ID : **CAM-TUR-U**

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-TUR-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

Weekday			Weekend		**Total ADT**		
Cars :	252	87%	Cars :		Cars :	**252**	87%
Trucks :	36	13%	Trucks :		Trucks :	**36**	13%
Total :	288		Total :		Total :	**288**	

Speed Totals

50 % :	38.2 mph	Top Speed :	51.6 mph		Average Truck Speed :	35.9 mph
85 % :	43.6 mph	Low Speed :	18.1 mph		Average Car Speed :	37.7 mph
Avg :	37.4 mph	10mph Pace Speed:	34.9 - 44.8	70.80%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday :
Weekend :
PM Peak Hour (Volume)

AM Peak Hour (Speed)

PM Peak Hour (Speed)

Weekday : 16:30 - 17:30 (Avg 30) 16:15 - 17:15 (38.6 mph)
Weekend :

Grand Totals

Total Cars :	42	(252 ADT)	Average Length :	16.2 ft	Average Headway :	186.9 sec
Total Trucks :	6	(36 ADT)	Average Axles :	2.30	Average Gap :	186.6 sec
Total Volume :	48	(288 ADT)				

Per-Vehicle Summary Report: CROOK, D-ROAD

Station ID : **CRO-D-T**

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CRO-D-T.DB

Version Number : 1.51
Serial Number : 11194
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

Weekday			Weekend		**Total ADT**		
Cars :	324	84%	Cars :		Cars :	**324**	84%
Trucks :	60	16%	Trucks :		Trucks :	**60**	16%
Total :	384		Total :		Total :	**384**	

Speed Totals

50 % :	52.6 mph	Top Speed :	82.1 mph		Average Truck Speed :	43.6 mph
85 % :	62.1 mph	Low Speed :	9.9 mph		Average Car Speed :	54.9 mph
Avg :	53.1 mph	10mph Pace Speed:	49.8 - 59.7	48.40%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday :
Weekend :
PM Peak Hour (Volume)

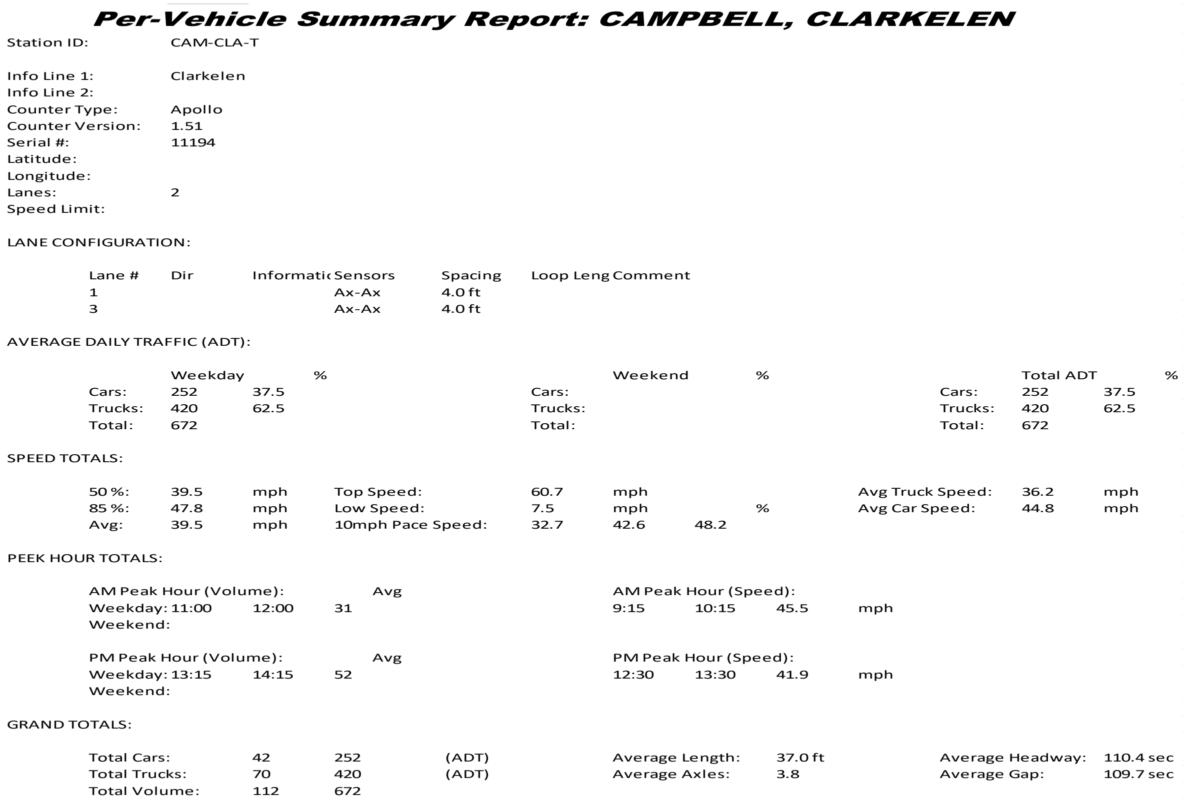
AM Peak Hour (Speed)

PM Peak Hour (Speed)

Weekday : 18:30 - 19:30 (Avg 28) 14:15 - 1(57.0 mph)
Weekend :

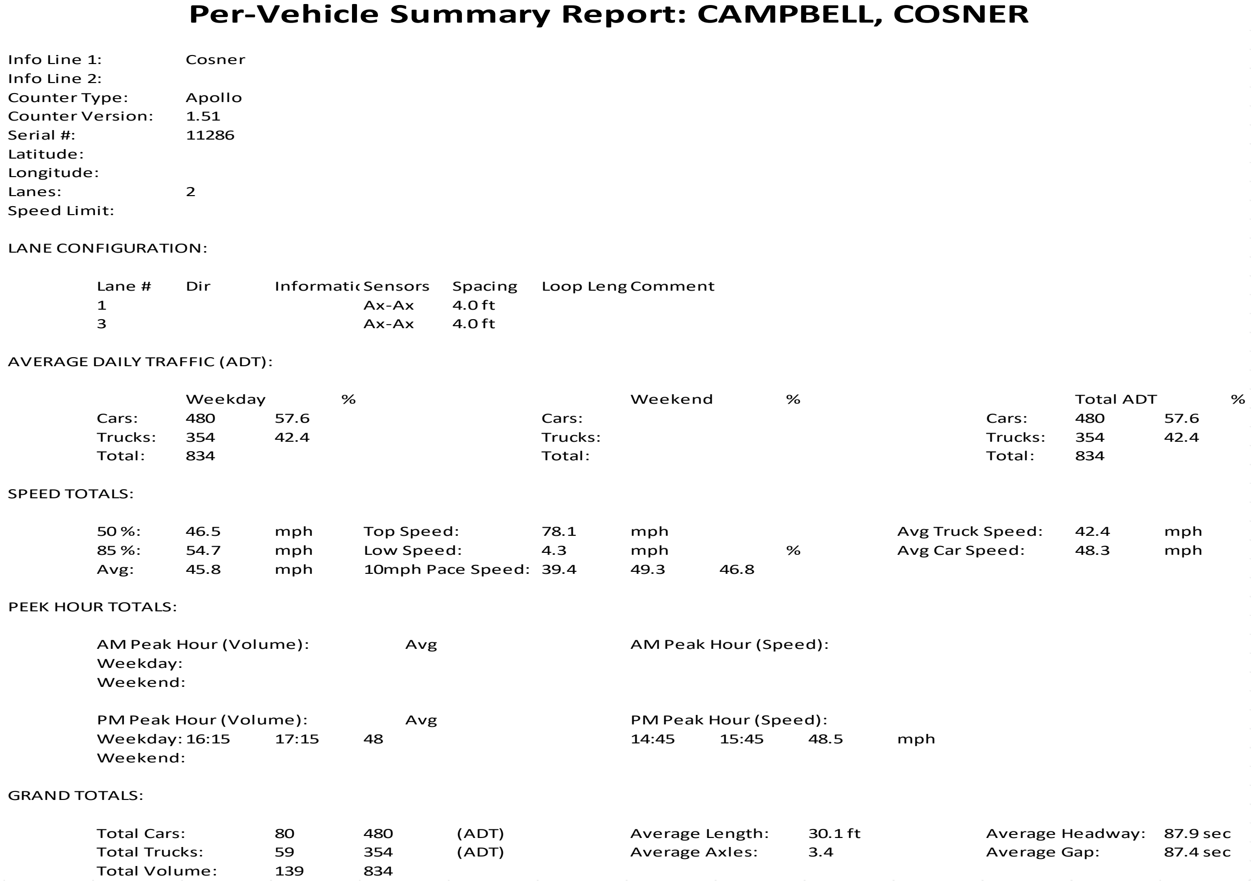
Grand Totals

Total Cars :	54	(324 ADT)	Average Length :	18.4 ft	Average Headway :	203.4 sec
Total Trucks :	10	(60 ADT)	Average Axles :	2.60	Average Gap :	203.2 sec
Total Volume :	64	(384 ADT)				



Per-Vehicle Summary Report: CAMPBELL, CLARKELEN

```
Station ID:          CAM-CLA-T

Info Line 1:         Clarkelen
Info Line 2:
Counter Type:        Apollo
Counter Version:     1.51
Serial #:            11194
Latitude:
Longitude:
Lanes:               2
Speed Limit:

LANE CONFIGURATION:

     Lane #   Dir     Informatic Sensors   Spacing   Loop Leng Comment
     1                           Ax-Ax     4.0 ft
     3                           Ax-Ax     4.0 ft

AVERAGE DAILY TRAFFIC (ADT):

              Weekday        %                          Weekend        %                         Total ADT        %
     Cars:    252     37.5                   Cars:                                    Cars:    252       37.5
     Trucks:  420     62.5                   Trucks:                                  Trucks:  420       62.5
     Total:   672                            Total:                                   Total:   672

SPEED TOTALS:

     50 %:    39.5    mph     Top Speed:          60.7    mph                   Avg Truck Speed:   36.2    mph
     85 %:    47.8    mph     Low Speed:          7.5     mph          %        Avg Car Speed:     44.8    mph
     Avg:     39.5    mph     10mph Pace Speed:   32.7    42.6    48.2

PEEK HOUR TOTALS:

     AM Peak Hour (Volume):          Avg                     AM Peak Hour (Speed):
     Weekday: 11:00   12:00   31                             9:15     10:15    45.5     mph
     Weekend:

     PM Peak Hour (Volume):          Avg                     PM Peak Hour (Speed):
     Weekday: 13:15   14:15   52                             12:30    13:30    41.9     mph
     Weekend:

GRAND TOTALS:

     Total Cars:      42      252     (ADT)          Average Length:  37.0 ft        Average Headway:  110.4 sec
     Total Trucks:    70      420     (ADT)          Average Axles:   3.8            Average Gap:      109.7 sec
     Total Volume:    112     672
```



Per-Vehicle Summary Report: CAMPBELL, COSNER

```
Info Line 1:         Cosner
Info Line 2:
Counter Type:        Apollo
Counter Version:     1.51
Serial #:            11286
Latitude:
Longitude:
Lanes:               2
Speed Limit:

LANE CONFIGURATION:

     Lane #   Dir     Informatic Sensors   Spacing   Loop Leng Comment
     1                           Ax-Ax     4.0 ft
     3                           Ax-Ax     4.0 ft

AVERAGE DAILY TRAFFIC (ADT):

              Weekday        %                          Weekend        %                         Total ADT        %
     Cars:    480     57.6                   Cars:                                    Cars:    480       57.6
     Trucks:  354     42.4                   Trucks:                                  Trucks:  354       42.4
     Total:   834                            Total:                                   Total:   834

SPEED TOTALS:

     50 %:    46.5    mph     Top Speed:          78.1    mph                   Avg Truck Speed:   42.4    mph
     85 %:    54.7    mph     Low Speed:          4.3     mph          %        Avg Car Speed:     48.3    mph
     Avg:     45.8    mph     10mph Pace Speed:   39.4    49.3    46.8

PEEK HOUR TOTALS:

     AM Peak Hour (Volume):          Avg                     AM Peak Hour (Speed):
     Weekday:
     Weekend:

     PM Peak Hour (Volume):          Avg                     PM Peak Hour (Speed):
     Weekday: 16:15   17:15   48                             14:45    15:45    48.5     mph
     Weekend:

GRAND TOTALS:

     Total Cars:      80      480     (ADT)          Average Length:  30.1 ft        Average Headway:  87.9 sec
     Total Trucks:    59      354     (ADT)          Average Axles:   3.4            Average Gap:      87.4 sec
     Total Volume:    139     834
```

Per-Vehicle Summary Report: CAMPBELL, MOORE

	CAM-MOO-T
Info Line 1:	Moore
Info Line 2:	
Counter Type:	Apollo
Counter Version:	1.51
Serial #:	11194
Latitude:	
Longitude:	
Lanes:	2
Speed Limit:	

LANE CONFIGURATION:

Lane #	Dir	Informatic	Sensors	Spacing	Loop Leng	Comment
1			Ax-Ax	4.0 ft		
3			Ax-Ax	4.0 ft		

AVERAGE DAILY TRAFFIC (ADT):

	Weekday	%		Weekend	%		Total ADT	%
Cars:	48	28.6	Cars:			Cars:	48	28.6
Trucks:	120	71.4	Trucks:			Trucks:	120	71.4
Total:	168		Total:			Total:	168	

SPEED TOTALS:

50 %:	32.6	mph	Top Speed:	39.5	mph			Avg Truck Speed:	33.1	mph
85 %:	37.3	mph	Low Speed:	9.6	mph		%	Avg Car Speed:	30.1	mph
Avg:	32.2	mph	10mph Pace Speed:	30	39.9	81				

PEEK HOUR TOTALS:

AM Peak Hour (Volume):			Avg	AM Peak Hour (Speed):			
Weekday: 8:00	9:00	14		8:15	9:15	33.4	mph
Weekend:							
PM Peak Hour (Volume):			Avg	PM Peak Hour (Speed):			
Weekday:							
Weekend:							

GRAND TOTALS:

Total Cars:	6	48	(ADT)	Average Length:	45.9 ft	Average Headway:	247.3 sec
Total Trucks:	15	120	(ADT)	Average Axles:	4.5	Average Gap:	246.3 sec

---

Per-Vehicle Summary Report: CAMPBELL, TODD

Station ID :	**CAM-TOD-U**	Last Connected Device Type :	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	CAM-TOD-U.DB	Posted Speed Limit :	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spac*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend	**Total ADT**		
	Cars :	126	67%	Cars :	Cars :	**126**	67%
Trucks :		60	33%	Trucks :	Trucks :	**60**	33%
	Total :	186		Total :	Total :	**186**	

Speed Totals

50 % :	33.1 mph	Top Speed :	100.5 mph		Average Truck Speed :	25.7 mph
85 % :	43.0 mph	Low Speed :	6.0 mph		Average Car Speed :	37.5 mph
Avg :	33.7 mph	10mph Pace Speed:	33.0 - 42.9	37.50%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)
Weekday :	07:00 - 08:00	(Avg 15)	09:30 - 10:30 (100.5 mph)
Weekend :			
PM Peak Hour (Volume)			PM Peak Hour (Speed)
Weekday :			
Weekend :			

Grand Totals

Total Cars :	22	(	126	ADT)	Average Len	27.9 ft	Average Headway :	294.1 sec
Total Trucks :	10	(	60	ADT)	Average Axl	3.30	Average (	293.3 sec
Total Volume :	32	(	186	ADT)				

Per-Vehicle Summary Report: CAMPBELL, CHRISTENSEN

Station ID :	**CAM-CHR-U**	Last Connected Device Type :	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11297
GPS Lat/Lon :		Number of Lanes :	2
DB File :	CAM-CHR-U.DB	Posted Speed Limit :	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**	
Cars :	176	66%	Cars :		Cars :	**176**	66%
Trucks :	88	34%	Trucks :		Trucks :	**88**	34%
Total :	264		Total :		Total :	**264**	

Speed Totals

50 % :	39.5 mph	Top Speed :	48.5 mph		Average Truck Speed :	38.0 mph
85 % :	46.9 mph	Low Speed :	24.5 mph		Average Car Speed :	40.1 mph
Avg :	39.4 mph	10mph Pace Speed:	37.4 - 47.3	66.70%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	08:15 - 09:15	(Avg 16)	09:45 - 10:45	(42.5 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	22	(	176	ADT)	Average Length :	19.3 ft	Average Headway :		286.0 sec
Total Trucks :	11	(	88	ADT)	Average Axles :	2.60		Average Gap :	285.7 sec
Total Volume :	33	(	264	ADT)					

Per-Vehicle Summary Report: CAMPBELL, HAYDEN

Station ID :	**CAM-HAY-U**	Last Connected Device Type :	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	CAM-HAY-U.DB	Posted Speed Limit :	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spac*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**	
Cars :	120	88%	Cars :		Cars :	**120**	88%
Trucks :	16	12%	Trucks :		Trucks :	**16**	12%
Total :	136		Total :		Total :	**136**	

Speed Totals

50 % :	40.2 mph	Top Speed :	43.2 mph		Average Truck Speed :	36.3 mph
85 % :	42.3 mph	Low Speed :	6.3 mph		Average Car Speed :	34.4 mph
Avg :	34.7 mph	10mph Pace Speed:	34.5 - 44.4	76.50%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	07:00 - 08:00	(Avg 12)	07:15 - 08:	(40.3 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	15	(	120	ADT)	Average Len	14.7 ft	Average Headway :		551.8 sec
Total Trucks :	2	(	16	ADT)	Average Axl	2.40		Average (	551.4 sec
Total Volume :	17	(	136	ADT)					

Per-Vehicle Summary Report: CAMPBELL, BLACK & YELLOW

Station ID : CAM-BLA-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-BLA-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
	Cars :	320	63%	Cars :		Cars :	**320**	63%
	Trucks :	184	37%	Trucks :		Trucks :	**184**	37%
	Total :	504		Total :		Total :	**504**	

Speed Totals

50 % : 28.0 mph
85 % : 42.9 mph
Avg : 28.0 mph

Top Speed : 66.7 mph
Low Speed : 3.4 mph
10mph Pace Speed: 23.7 - 33.6 39.10%

Average Truck Speed : 25.2 mph
Average Car Speed : 29.5 mph

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 10:30 - 11:30 (Avg 26)
Weekend :
PM Peak Hour (Volume)

Weekday : 12:00 - 13:00 (Avg 24)
Weekend :

AM Peak Hour (Speed)
10:30 - 11:30 (32.4 mph)

PM Peak Hour (Speed)

12:00 - 13:00 (25.0 mph)

Grand Totals

Total Cars :	41	(	320	ADT)	Average Length	22.7 ft	Average Headway :	145.9 sec
Total Trucks :	23	(	184	ADT)	Average Axles :	3.10	Average Gap :	145.1 sec
Total Volume :	64	(	504	ADT)				

Per-Vehicle Summary Report: CAMPBELL, IBERLIN

Station ID : CAM-IBE-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-IBE-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spaci*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
	Cars :	222	84%	Cars :		Cars :	**222**	84%
Trucks :		42	16%	Trucks :		Trucks :	**42**	16%
	Total :	264		Total :		Total :	**264**	

Speed Totals

50 % : 28.2 mph
85 % : 40.6 mph
Avg : 29.5 mph

Top Speed : 43.9 mph
Low Speed : 6.0 mph
10mph Pace Speed: 24.6 - 34.5 47.70%

Average Truck Speed : 18.6 mph
Average Car Speed : 31.5 mph

Peak Hour Totals

AM Peak Hour (Volume)
Weekday :
Weekend :
PM Peak Hour (Volume)

Weekday : 13:30 - 14:30 (Avg 20)
Weekend :

AM Peak Hour (Speed)

PM Peak Hour (Speed)

12:30 - 1:(33.6 mph)

Grand Totals

Total Cars :	37	(	222	ADT)	Average Leng	16.1 ft	Average Headway :	230.4 sec
Total Trucks :	7	(	42	ADT)	Average Axle	2.30	Average (	230.0 sec

Per-Vehicle Summary Report: JOHNSON, TTT

Station ID : JOH-TTT-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : JOH-TTT-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
	Cars :	120	76%	Cars :		Cars :	**120**	76%
Trucks :		36	24%	Trucks :		Trucks :	**36**	24%
	Total :	156		Total :		Total :	**156**	

Speed Totals

50 % :	25.1 mph	Top Speed :	36.4 mph	Average Truck Speed :	23.8 mph
85 % :	34.4 mph	Low Speed :	10.7 mph	Average Car Speed :	24.5 mph
Avg :	24.4 mph	10mph Pace Speed:	26.9 - 36.8 48.10%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday :
Weekend :
PM Peak Hour (Volume)

AM Peak Hour (Speed)

PM Peak Hour (Speed)

Weekday : 13:00 - 14:00 (Avg 14) 12:30 - 13:30 (31.2 mph)
Weekend :

Grand Totals

Total Cars :	21 (120 ADT)	Average Length : 32.3 ft	Average Headway :	346.3 sec
Total Trucks :	6 (36 ADT)	Average Axles : 3.40	Average Gap :	345.3 sec
Total Volume :	27 (156 ADT)			

Per-Vehicle Summary Report: SWEETWATER, WAMSUTTER

Station ID : SWE-WAM-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : SWE-WAM-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
	Cars :	432	79%	Cars :		Cars :	**432**	79%
Trucks :		114	21%	Trucks :		Trucks :	**114**	21%
	Total :	546		Total :		Total :	**546**	

Speed Totals

50 % :	39.5 mph	Top Speed :	55.3 mph	Average Truck Speed :	32.0 mph
85 % :	45.5 mph	Low Speed :	9.9 mph	Average Car Speed :	40.0 mph
Avg :	38.3 mph	10mph Pace Speed:	34.6 - 44.5 60.40%		

Peak Hour Totals

AM Peak Hour (Volume) AM Peak Hour (Speed)
Weekday : 01:30 - 02:30 (Avg 39) 04:00 - 05:00 (40.8 mph)
Weekend :
PM Peak Hour (Volume) PM Peak Hour (Speed)

Weekday :
Weekend :

Grand Totals

Total Cars :	72 (432 ADT)	Average Length : 21.4 ft	Average Headway :	108.5 sec
Total Trucks :	19 (114 ADT)	Average Axles : 2.70	Average (	108.0 sec
Total Volume :	91 (546 ADT)			

Per-Vehicle Summary Report: SWEETWATER, PATRICK DRAW

Station ID : SWE-PAT-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : SWE-PAT-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend	**Total ADT**		
Cars :		144	81%	Cars :	Cars :	**144**	81%
Trucks :		32	19%	Trucks :	Trucks :	**32**	19%
Total :		176		Total :	Total :	**176**	

Speed Totals

50 % : 28.1 mph
85 % : 38.0 mph
Avg : 27.5 mph

Top Speed : 43.2 mph
Low Speed : 12.2 mph
10mph Pace Speed: 24.6 - 34.5 47.80%

Average Truck Speed : 22.3 mph
Average Car Speed : 28.6 mph

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 11:00 - 12:00 (Avg 6)
Weekend :
PM Peak Hour (Volume)
Weekday : 12:15 - 13:15 (Avg 15)
Weekend :

AM Peak Hour (Speed)
10:45 - 11:45 (36.8 mph)
PM Peak Hour (Speed)
12:30 - 13:30 (31.0 mph)

Grand Totals

Total Cars : 19 (144 ADT)
Total Trucks : 4 (32 ADT)
Total Volume : 23 (176 ADT)

Average Length : 14.6 ft
Average Axles : 2.10

Average Headway : 291.4 sec
Average Gap : 291.0 sec

Per-Vehicle Summary Report: WESTON, GRIEVES

Station ID : WES-GRI-U

Last Connected Device Type Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : WES-GRI-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend	**Total ADT**		
Cars :		126	80%	Cars :	Cars :	**126**	80%
Trucks :		30	20%	Trucks :	Trucks :	**30**	20%
Total :		156		Total :	Total :	**156**	

Speed Totals

50 % : 39.0 mph
85 % : 45.7 mph
Avg : 37.9 mph

Top Speed : 55.9 mph
Low Speed : 13.7 mph
10mph Pace Speed: 35.8 - 45.7 61.50%

Average Truck Speed : 41.4 mph
Average Car Speed : 37.0 mph

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 11:00 - 12:00 (Avg 12)
Weekend :
PM Peak Hour (Volume)
Weekday : 13:45 - 14:45 (Avg 12)
Weekend :

AM Peak Hour (Speed)
10:45 - 11:45 (38.4 mph)
PM Peak Hour (Speed)
12:15 - 13:15 (47.5 mph)

Grand Totals

Total Cars : 21 (126 ADT)
Total Trucks : 5 (30 ADT)
Total Volume : 26 (156 ADT)

Average Length 18.6 ft
Average Axles 2.50

Average Headway : 402.3 sec
Average Gap : 402.0 sec

Per-Vehicle Summary Report: WESTON, BRUCE

Station ID :	**WES-BRU-U**	Last Connected Device Type :	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11297
GPS Lat/Lon :		Number of Lanes :	2
DB File :	WES-BRU-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

Weekday			Weekend		**Total ADT**		
Cars :	84	93%	Cars :		Cars :	**84**	93%
Trucks :	6	7%	Trucks :		Trucks :	**6**	7%
Total :	90		Total :		Total :	**90**	

Speed Totals

50 % :	36.0 mph	Top Speed :	51.3 mph	Average Truck Speed :	8.6 mph
85 % :	41.8 mph	Low Speed :	8.6 mph	Average Car Speed :	34.0 mph
Avg :	32.3 mph	10mph Pace Speed:	35.9 - 45.8	60.00%	

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	07:45 - 08:45	(Avg 8)	07:00 - 08:00	(42.8 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	14 (	84 ADT)	Average Length :	13.2 ft	Average Headway :	568.9 sec
Total Trucks :	1 (	6 ADT)	Average Axles :	2.20	Average Gap :	568.5 sec
Total Volume :	15 (	90 ADT)				

Per-Vehicle Summary Report: WESTON, MUSH CREEK

Station ID :	**WES-MUS-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	WES-MUS-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

Weekday			Weekend		**Total ADT**		
Cars :	180	99%	Cars :		Cars :	**180**	99%
Trucks :	0	1%	Trucks :		Trucks :	**0**	1%
Total :	180		Total :		Total :	**180**	

Speed Totals

50 % :	22.1 mph	Top Speed :	32.2 mph	Average Truck Speed :	
85 % :	25.7 mph	Low Speed :	11.7 mph	Average Car Speed :	22.9 mph
Avg :	22.9 mph	10mph Pace Speed:	19.7 - 29.6	73.30%	

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	19:30 - 20:30	(Avg 14)	17:15 - 18:15	(27.5 mph)
Weekend :				

Grand Totals

Total Cars :	15 (	180 ADT)	Average Length :	13.6 ft	Average Headway :	456.3 sec
Total Trucks :	0 (	0 ADT)	Average Axles :	2.30	Average Gap	456.0 sec
Total Volume :	15 (	180 ADT)				

Per-Vehicle Summary Report: SWEETWATER, WAMSUTTER NORTH

Station ID :	**SWE-WAMN-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11297
GPS Lat/Lon :		Number of Lanes :	2
DB File :	SWE-WAMN-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
Cars :	60	100%		Cars :		Cars :	**60**	100%
Trucks :	0		0%	Trucks :		Trucks :	**0**	0%
Total :	60			Total :		Total :	**60**	

Speed Totals

50 % :	25.0 mph	Top Speed :	28.7 mph			Average Truck Speed :	
85 % :	28.7 mph	Low Speed :		6.0 mph		Average Car Speed :	20.4 mph
Avg :	20.4 mph	10mph Pace Speed:	18.9 - 28.8		72.70%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	11:00 - 12:00	(Avg 4)	11:00 - 1	(17.7 mph)
Weekend :				
PM Peak Hour (Volume)			**PM Peak Hour (Speed)**	
Weekday :	12:00 - 13:00	(Avg 5)	12:00 - 1	(26.8 mph)
Weekend :				

Grand Totals

Total Cars :	11	(	60	ADT)	Average Length : 9.3 ft	Average Headway :	555.5 sec
Total Trucks :	0	(	0	ADT)	Average	2.00	Average Gap : 555.1 sec
Total Volume :	11	(	60	ADT)			

Per-Vehicle Summary Report: UINTA, CR 171

Station ID :	**UIN-171-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	UIN-171-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
Cars :	90	99%		Cars :		Cars :	**90**	99%
Trucks :	0		1%	Trucks :		Trucks :	**0**	1%
Total :	90			Total :		Total :	**90**	

Speed Totals

50 % :	22.9 mph	Top Speed :	39.5 mph			Average Truck Speed :	
85 % :	35.2 mph	Low Speed :		6.3 mph		Average Car Speed :	23.2 mph
Avg :	23.2 mph	10mph Pace Speed:	31.3 - 41.2		40.00%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			**PM Peak Hour (Speed)**	
Weekday :	15:45 - 16:45	(Avg 12)	16:30 - 1	(39.1 mph)
Weekend :				

Grand Totals

Total Cars :	15	(	90	ADT)	Average Length : 12.9 ft	Average Headway :	574.3 sec
Total Trucks :	0	(	0	ADT)	Average	2.10	Average Gap : 573.8 sec
Total Volume :	15	(	90	ADT)			

Per-Vehicle Summary Report: UINTA, CR 173

Station ID : **UIN-173-U**

Last Connected Device Type Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : UIN-173-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday				Weekend	**Total ADT**		
	Cars :	192	94%		Cars :	Cars :	**192**	94%
Trucks :		12		6%	Trucks :	Trucks :	**12**	6%
	Total :	204			Total :	Total :	**204**	

Speed Totals

50 % :	32.8 mph	Top Speed :	39.8 mph		Average Truck Speed :	14.0 mph
85 % :	38.8 mph	Low Speed :	11.6 mph		Average Car Speed :	31.8 mph
Avg :	30.8 mph	10mph Pace Speed:	30.1 - 40.0	70.60%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	19:15 - 20:15	(Avg 17)	18:15 - 19:15	(37.9 mph)
Weekend :				

Grand Totals

Total Cars :	16	(	192	ADT)	Average Length :	14.6 ft	Average Headway :	195.5 sec
Total Trucks :	1	(	12	ADT)	Average Axles :	2.40	Average (	195.1 sec
Total Volume :	17	(	204	ADT)				

Per-Vehicle Summary Report: TETTON, SPRING GULCH RD

Station ID : **TET-SPR-U**

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : TET-SPR-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor S*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday					Weekend	**Total ADT**		
	Cars :	2454	95%			Cars :	Cars :	**2454**	95%
Trucks :		120		5%	Trucks :		Trucks :	**120**	5%
	Total :	2574				Total :	Total :	**2574**	

Speed Totals

50 % :	34.5 mph	Top Spee	64.2 mph		Average Truck Speed :	37.2 mph
85 % :	40.4 mph	Low Spee	7.8 mph		Average Car Speed :	34.4 mph
Avg :	34.5 mph	10mph Pace Speed:	30.3 - 40.	63.90%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	10:00 - 11:00	(Avg 139)	08:30 - 0	(37.0 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	12:00 - 13:00	(Avg 132)	12:00 - 1	(34.4 mph)
Weekend :				

Grand Totals

Total Cars :	409		(	2454	ADT)	Average l	12.4 ft	Average Headway :	27.4 sec
Total Trucks :		20	(	120	ADT)	Average /	2.10	Average (	27.1 sec
Total Volume :	429		(	2574	ADT)				

Per-Vehicle Summary Report: SWEETWATER, EDEN RESERVOIR RD

Station ID :	**SWE-EDE-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11297
GPS Lat/Lon :		Number of Lanes :	2
DB File :	SWE-EDE-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday		Weekend		**Total ADT**		
Cars :	168	100%	Cars :		Cars :	**168**	100%
Trucks :	0	0%	Trucks :		Trucks :	**0**	0%
Total :	168		Total :		Total :	**168**	

Speed Totals

50 % :	35.9 mph	Top Speed :	39.5 mph		Average Truck Speed :	
85 % :	36.6 mph	Low Speed :	14.9 mph		Average Car Speed :	31.9 mph
Avg :	31.9 mph	10mph Pace Speed:	35.9 - 45.8	71.40%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	16:00 - 17:00	(Avg 7)	15:15 - 16:15	(38.0 mph)
Weekend :				

Grand Totals

Total Cars :	7	(	168	ADT)	Average Length :	11.0 ft	Average Headway :	422.7 sec
Total Trucks :	0	(	0	ADT)	Average Axles :	2.60	Average (	422.5 sec
Total Volume :	7	(	168	ADT)				

Per-Vehicle Summary Report: SWEETWATER, EDEN RYEPATCH

Station ID :	**SWE-EDR-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11297
GPS Lat/Lon :		Number of Lanes :	2
DB File :	SWE-EDR-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday		Weekend		**Total ADT**		
Cars :	328	100%	Cars :		Cars :	**328**	100%
Trucks :	0	0%	Trucks :		Trucks :	**0**	0%
Total :	328		Total :		Total :	**328**	

Speed Totals

50 % :	33.5 mph	Top Speed :	46.8 mph		Average Truck Speed :	
85 % :	39.1 mph	Low Speed :	13.9 mph		Average Car Speed :	32.6 mph
Avg :	32.6 mph	10mph Pace Speed:	32.4 - 42.3	56.10%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	18:15 - 19:15	(Avg 27)	17:45 - 18:45	(37.7 mph)
Weekend :				

Grand Totals

Total Cars :	41	(	328	ADT)	Average Length :	11.3 ft	Average Headway :	183.1 sec
Total Trucks :	0	(	0	ADT)	Average Axles :	2.00	Average (	182.8 sec
Total Volume :	41	(	328	ADT)				

Per-Vehicle Summary Report: SWEETWATER, LOWER FARSON RD

Station ID :	**SWE-LOW-U**		Last Connected Device Type	Apollo
Info Line 1 :			Version Number :	1.66
Info Line 2 :			Serial Number :	11166
GPS Lat/Lon :			Number of Lanes :	2
DB File :	SWE-LOW-U.DB		Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday		Weekend		**Total ADT**		
Cars :	72	100%	Cars :		Cars :	**72**	100%
Trucks :	0	0%	Trucks :		Trucks :	**0**	0%
Total :	72		Total :		Total :	**72**	

Speed Totals

50 % :	41.4 mph	Top Speed :	43.1 mph		Average Truck Speed :	
85 % :	41.8 mph	Low Speed :	17.8 mph		Average Car Speed :	35.7 mph
Avg :	35.7 mph	10mph Pace Speed:	41.4 - 51.3	66.70%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	17:30 - 18:30	(Avg 8)	17:15 - 18:15	(39.7 mph)
Weekend :				

Grand Totals

Total Cars :	9	(	72	ADT)	Average Length :	11.6 ft	Average Headway :	578.0 sec
Total Trucks :	0	(	0	ADT)	Average Axles :	2.00	Average (	577.8 sec
Total Volume :	9	(	72	ADT)				

Per-Vehicle Summary Report: SWEETWATER, COUNTY LINE RD

Station ID :	**SWE-COU-U**		Last Connected Device Type	Apollo
Info Line 1 :			Version Number :	1.66
Info Line 2 :			Serial Number :	11166
GPS Lat/Lon :			Number of Lanes :	2
DB File :	SWE-COU-U.DB		Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Sp*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday		Weekend		**Total ADT**		
Cars :	136	73%	Cars :		Cars :	**136**	73%
Trucks :	48	27%	Trucks :		Trucks :	**48**	27%
Total :	184		Total :		Total :	**184**	

Speed Totals

50 % :	40.6 mph	Top Speed :	66.1 mph		Average Truck Speed :	40.4 mph
85 % :	50.1 mph	Low Speed :	15.7 mph		Average Car Speed :	42.9 mph
Avg :	42.3 mph	10mph Pace Speed:	34.7 - 44.	56.50%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	08:30 - 09:30	(Avg 12)	07:30 - 0	(51.2 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	17	(	136	ADT)	Average L	16.2 ft	Average Headway :	320.4 sec
Total Trucks :	6	(	48	ADT)	Average A	2.40	Average (	320.1 sec
Total Volume :	23	(	184	ADT)				

Per-Vehicle Summary Report: SWEETWATER, EIGHTEEN MILE R

	Station ID :		**SWE-EIG-U**						Last Connected Device Type			Apollo	
	Info Line 1 :									Version Number :		1.66	
	Info Line 2 :									Serial Number :		11166	
	GPS Lat/Lon :									Number of Lanes :		1	
	DB File :		SWE-EIG-U.DB							Posted Speed Limi		0.0 mph	
								Lane Configuration					
#	*Dir.*	*Information*			*Vehicle Sensors*			*Sensor Sp*	*Loop Length*				
3.00					Axle-Axle			4.0 ft					
Average Daily Traffic (ADT)													
		Weekday						Weekend		**Total ADT**			
		Cars :	24	100%				Cars :		Cars :		**24**	100%
	Trucks :			0	0%		Trucks :			Trucks :		**0**	0%
		Total :	24					Total :		Total :		**24**	
Speed Totals													
	50 % :		0.0 mph			Top Speed :		29.8 mph		Average Truck Speed :			
	85 % :		0.0 mph			Low Speed :		29.8 mph		Average Car Speed :			29.8 mph
	Avg :		29.8 mph		10mph Pace Speed:			29.8 - 39.	100.00%				
Peak Hour Totals													
	AM Peak Hour (Volume)							AM Peak Hour (Speed)					
	Weekday :		07:30 - 08:30		(Avg 4)			06:45 - 0	(29.8 mph)				
	Weekend :												
	PM Peak Hour (Volume)							PM Peak Hour (Speed)					
	Weekday :												
	Weekend :												
Grand Totals													
	Total Cars :			1	(	24	ADT)	Average	13.5 ft	Average Headway :			0.0 sec
	Total Trucks :			0	(	0	ADT)	Average	2.00			Average	0.0 sec
	Total Volume :			1	(	24	ADT)						

Per-Vehicle Summary Report: SHERIDAN, WOLF CREEK RD

Station ID :		**SHE-WOL-U**								Last Connected Device Type			Apollo		
	Info Line 1 :										Version Number :		1.66		
	Info Line 2 :										Serial Number :		11166		
GPS Lat/Lon :											Number of Lanes :		2		
	DB File :		SHE-WOL-U.DB								Posted Speed Limi		0.0 mph		
									Lane Configuration						
#	*Dir.*	*Information*				*Vehicle Sensors*			*Sensor Sp*	*Loop Length*					
1.00						Axle-Axle			4.0 ft						
3.00						Axle-Axle			4.0 ft						
Average Daily Traffic (ADT)															
		Weekday							Weekend		**Total ADT**				
		Cars :		168	77%				Cars :		Cars :		**168**	77%	
	Trucks :			48	23%			Trucks :			Trucks :		**48**	23%	
		Total :		216					Total :		Total :		**216**		
Speed Totals															
	50 % :	28.1 mph					Top Speed :		55.7 mph		Average Truck Speed :			55.5 mph	
	85 % :	52.6 mph					Low Speed :		17.4 mph		Average Car Speed :			28.3 mph	
	Avg :	34.3 mph				10mph Pace Speed:			20.3 - 30.	55.60%					
Peak Hour Totals															
	AM Peak Hour (Volume)								AM Peak Hour (Speed)						
	Weekday :		11:00 - 12:00		(Avg 18)				10:15 - 1	(38.6 mph)					
	Weekend :														
	PM Peak Hour (Volume)								PM Peak Hour (Speed)						
	Weekday :														
	Weekend :														
Grand Totals															
	Total Cars :				7	(	168	ADT)	Average	11.9 ft	Average Headway :			114.9 sec	
	Total Trucks :				2	(	48	ADT)	Average	2.30			Average	114.7 sec	
	Total Volume :				9	(	216	ADT)							

Per-Vehicle Summary Report: SHERIDAN, NORTH RD

Station ID :		**SHE-NOR-U**								Last Connected Device Type :				Apollo	
	Info Line 1 :											Version Number :		1.66	
	Info Line 2 :											Serial Number :		11166	
GPS Lat/Lon :												Number of Lanes :		2	
	DB File :		SHE-NOR-U.DB									Posted Speed Limi		0.0 mph	
									Lane Configuration						
#	*Dir.*	*Information*				*Vehicle Sensors*			*Sensor Sp*	*Loop Length*					
1.00						Axle-Axle				4.0 ft					
3.00						Axle-Axle				4.0 ft					
Average Daily Traffic (ADT)															
		Weekday							Weekend			**Total ADT**			
		Cars :		360	71%				Cars :			Cars :		**360**	71%
	Trucks :			144	29%			Trucks :				Trucks :		**144**	29%
		Total :		504					Total :			Total :		**504**	
Speed Totals															
	50 % :	30.1 mph					Top Speed :		66.1 mph			Average Truck Speed :			56.2 mph
	85 % :	57.6 mph					Low Speed :		9.9 mph			Average Car Speed :			28.6 mph
	Avg :	36.5 mph				10mph Pace Speed:			25.3 - 35.	33.30%					
Peak Hour Totals															
	AM Peak Hour (Volume)									AM Peak Hour (Speed)					
	Weekday :		08:45 - 09:45		(Avg 36)					07:45 - 0	(43.5 mph)				
	Weekend :														
	PM Peak Hour (Volume)									PM Peak Hour (Speed)					
	Weekday :														
	Weekend :														
Grand Totals															
	Total Cars :				15	(	360	ADT)	Average	11.6 ft		Average Headway :			98.4 sec
	Total Trucks :				6	(	144	ADT)	Average	2.00				Average	98.2 sec
	Total Volume :				21	(	504	ADT)							

Per-Vehicle Summary Report: SHERIDAN, LOWER PRAIRE RD

Station ID :	**SHE-LOW-U**	Last Connected Device Type :	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	SHE-LOW-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Sp	Loop Length
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
Cars :		72	54%	Cars :		Cars :	**72**	54%
Trucks :		60	46%	Trucks :		Trucks :	**60**	46%
Total :		132		Total :		Total :	**132**	

Speed Totals

50 % :	26.2 mph	Top Speed :	60.5 mph		Average Truck Speed :	39.2 mph
85 % :	49.8 mph	Low Speed :	7.9 mph		Average Car Speed :	28.4 mph
Avg :	33.3 mph	10mph Pace Speed:	26.1 - 36.	36.40%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	05:30 - 06:30	(Avg 13)	04:45 - 0	(37.2 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	6	(	72	ADT)	Average	14.7 ft	Average Headway :	259.3 sec
Total Trucks :	5	(	60	ADT)	Average	2.20	Average	259.0 sec
Total Volume :	11	(	132	ADT)				

Per-Vehicle Summary Report: SHERIDAN, HIGBY RD

Station ID :	**SHE-HIG-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	SHE-HIG-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Sp	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		**Total ADT**		
Cars :		72	66%	Cars :		Cars :	**72**	66%
Trucks :		36	34%	Trucks :		Trucks :	**36**	34%
Total :		108		Total :		Total :	**108**	

Speed Totals

50 % :	27.7 mph	Top Speed :	67.8 mph		Average Truck Speed :	50.5 mph
85 % :	36.9 mph	Low Speed :	12.4 mph		Average Car Speed :	26.0 mph
Avg :	34.2 mph	10mph Pace Speed:	22.9 - 32.	55.60%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	02:45 - 03:45	(Avg 18)	02:00 - 0	(38.1 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	6	(	72	ADT)	Average	11.9 ft	Average Headway :	147.0 sec
Total Trucks :	3	(	36	ADT)	Average	2.00	Average	146.8 sec
Total Volume :	9	(	108	ADT)				

Per-Vehicle Summary Report: SHERIDAN, HALFWAY LN

Station ID :	**SHE-HAL-U**	Last Connected Device Type :	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	SHE-HAL-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Sp*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday				Weekend		**Total ADT**		
	Cars :	72	66%		Cars :		Cars :	**72**	66%
Trucks :		36	34%	Trucks :			Trucks :	**36**	34%
	Total :	108			Total :		Total :	**108**	

Speed Totals

50 % :	29.0 mph	Top Speed :	55.2 mph	Average Truck Speed :	54.2 mph
85 % :	52.6 mph	Low Speed :	9.9 mph	Average Car Speed :	23.7 mph
Avg :	33.9 mph	10mph Pace Speed:	52.6 - 62. 33.30%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	00:00 - 01:00	(Avg 4)	00:00 - 0	(31.4 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	23:00 - 24:00	(Avg 2)	23:00 - 2	(42.6 mph)
Weekend :				

Grand Totals

Total Cars :	6	(72	ADT)	Average I	13.5 ft	Average Headway :	171.4 sec
Total Trucks :	3	(36	ADT)	Average /	2.10	Average (	171.2 sec
Total Volume :	9	(108	ADT)				

Per-Vehicle Summary Report: SHERIDAN, DAYTON EAST RI

Station ID :	**SHE-EAS-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	SHE-EAS-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Sp*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday				Weekend	**Total ADT**		
	Cars :	72	50%		Cars :	Cars :	**72**	50%
Trucks :		72	50%	Trucks :		Trucks :	**72**	50%
	Total :	144			Total :	Total :	**144**	

Speed Totals

50 % :	28.8 mph	Top Speed :	61.5 mph	Average Truck Speed :	59.1 mph
85 % :	59.3 mph	Low Speed :	18.3 mph	Average Car Speed :	24.9 mph
Avg :	42.0 mph	10mph Pace Speed:	56.6 - 66. 50.00%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	23:00 - 24:00	(Avg 12)	22:15 - 2	(48.9 mph)
Weekend :				

Grand Totals

Total Cars :	3	(72	ADT)	Average I	12.3 ft	Average Headway :	215.8 sec
Total Trucks :	3	(72	ADT)	Average /	2.00	Average (	215.7 sec
Total Volume :	6	(144	ADT)				

Per-Vehicle Summary Report: LINCOLN, LUPINE RD

Station ID :		**LIN-LUP-U**								Last Connected Device Type			Apollo	
	Info Line 1 :										Version Number :		1.66	
	Info Line 2 :										Serial Number :		11166	
GPS Lat/Lon :											Number of Lanes :		2	
	DB File :		LIN-LUP-U.DB								Posted Speed Limi		0.0 mph	
									Lane Configuration					
#	*Dir.*	*Information*				*Vehicle Sensors*			*Sensor Sp*	*Loop Length*				
1.00						Axle-Axle			4.0 ft					
3.00						Axle-Axle			4.0 ft					
Average Daily Traffic (ADT)														
		Weekday							Weekend		**Total ADT**			
		Cars :		60	62%				Cars :		Cars :		**60**	62%
	Trucks :			36	38%			Trucks :			Trucks :		**36**	38%
		Total :		96					Total :		Total :		**96**	
Speed Totals														
	50 % :	30.6 mph					Top Speed :		67.9 mph		Average Truck Speed :			63.7 mph
	85 % :	59.8 mph					Low Speed :		20.0 mph		Average Car Speed :			27.8 mph
	Avg :	41.3 mph				10mph Pace Speed:			27.2 - 37.	50.00%				
Peak Hour Totals														
	AM Peak Hour (Volume)								AM Peak Hour (Speed)					
	Weekday :		06:15 - 07:15		(Avg 16)				05:15 - 0	(46.3 mph)				
	Weekend :													
	PM Peak Hour (Volume)								PM Peak Hour (Speed)					
	Weekday :													
	Weekend :													
Grand Totals														
	Total Cars :				5	(	60	ADT)	Average l	12.1 ft	Average Headway :			353.7 sec
	Total Trucks :				3	(	36	ADT)	Average /	2.00			Average (	353.6 sec
	Total Volume :				8	(	96	ADT)						

Per-Vehicle Summary Report: CONVERSE, BILL HALL RD

Station ID :		**CON-BIL-U**								Last Connected Device Type :				Apollo	
	Info Line 1 :											Version Number :		1.66	
	Info Line 2 :											Serial Number :		11166	
GPS Lat/Lon :												Number of Lanes :		2	
	DB File :		CON-BIL-U.DB									Posted Speed Limi		0.0 mph	
									Lane Configuration						
#	*Dir.*	*Information*				*Vehicle Sensors*			*Sensor Sp*	*Loop Length*					
1.00						Axle-Axle				4.0 ft					
3.00						Axle-Axle				4.0 ft					
Average Daily Traffic (ADT)															
		Weekday							Weekend			**Total ADT**			
		Cars :		24	33%				Cars :			Cars :		**24**	33%
	Trucks :			48	67%			Trucks :				Trucks :		**48**	67%
		Total :		72					Total :			Total :		**72**	
Speed Totals															
	50 % :	186.4 mph					Top Speed :		100.5 mph			Average Truck Speed :			36.8 mph
	85 % :	186.4 mph					Low Speed :		6.3 mph			Average Car Speed :			2.2 mph
	Avg :		8.6 mph			10mph Pace Speed:			16.5 - 26.	9.30%					
Peak Hour Totals															
	AM Peak Hour (Volume)									AM Peak Hour (Speed)					
	Weekday :		05:15 - 06:15		(Avg 16)					04:45 - 0	(48.2 mph)				
	Weekend :														
	PM Peak Hour (Volume)									PM Peak Hour (Speed)					
	Weekday :														
	Weekend :														
Grand Totals															
	Total Cars :				35	(	24	ADT)	Average l	13.7 ft		Average Headway :			249.3 sec
	Total Trucks :				8	(	48	ADT)	Average /	2.70				Average (	248.9 sec
	Total Volume :				43	(	72	ADT)							

Per-Vehicle Summary Report: CONVERSE, COMBS RD

Station ID :	**CON-COM-U**	Last Connected Device Type :	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	CON-COM-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Sp*	*Loop Length*
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

Weekday			Weekend		**Total ADT**		
Cars :	48	50%	Cars :		Cars :	**48**	50%
Trucks :	48	50%	Trucks :		Trucks :	**48**	50%
Total :	96		Total :		Total :	**96**	

Speed Totals

50 % :	43.2 mph	Top Speed :	68.0 mph		Average Truck Speed :	51.9 mph
85 % :	186.4 mph	Low Speed :	7.6 mph		Average Car Speed :	9.6 mph
Avg :	23.7 mph	10mph Pace Speed:	64.2 - 74.	16.70%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	07:30 - 08:30	(Avg 8)	05:15 - 0	(68.0 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	8	(	48	ADT)	Average	8.3 ft	Average Headway :		466.9 sec
Total Trucks :	4	(	48	ADT)	Average	2.00		Average	466.8 sec
Total Volume :	12	(	96	ADT)					

Per-Vehicle Summary Report: CARBON, CR 608

Station ID :	**CAR-608-U**	Last Connected Device Type	Apollo
Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	CAR-608-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Sp*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

Weekday			Weekend		**Total ADT**		
Cars :	144	60%	Cars :		Cars :	**144**	60%
Trucks :	96	40%	Trucks :		Trucks :	**96**	40%
Total :	240		Total :		Total :	**240**	

Speed Totals

50 % :	25.7 mph	Top Speed :	60.3 mph		Average Truck Speed :	46.9 mph
85 % :	53.9 mph	Low Speed :	12.1 mph		Average Car Speed :	23.5 mph
Avg :	32.8 mph	10mph Pace Speed:	22.9 - 32.	50.00%		

Peak Hour Totals

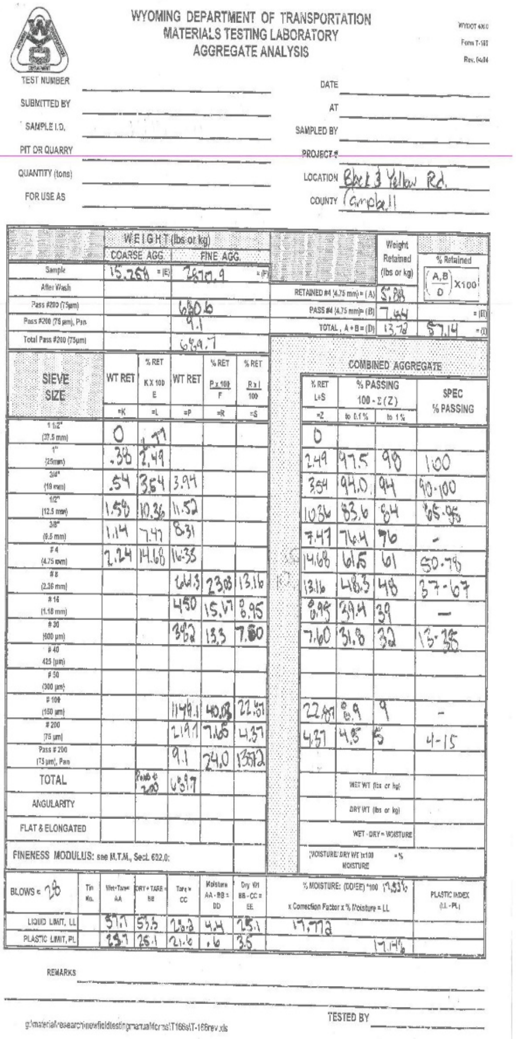
AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	00:30 - 01:30	(Avg 16)	00:00 - 0	(32.8 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :				
Weekend :				

Grand Totals

Total Cars :	6	(	144	ADT)	Average	15.1 ft	Average Headway :		186.6 sec
Total Trucks :	4	(	96	ADT)	Average	2.30		Average	186.2 sec
Total Volume :	10	(	240	ADT)					

APPENDIX A-4: SOIL PROPERTIES

Aggregate Analysis



WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

WYDOT 406.0
Form T-166
Rev. 04/04

TEST NUMBER
SUBMITTED BY
SAMPLE I.D.
PIT OR QUARRY
QUANTITY (tons)
FOR USE AS
DATE
AT
SAMPLED BY
PROJECT #
LOCATION Block 3 Yellow Rd.
COUNTY Campbell

WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.
Sample	15.258 =(E)	2870.9 =(F)
After Wash		
Pass #200 (75µm)		680.6
Pass #200 (75 µm), Pan		9.1
Total Pass #200 (75µm)		689.7

	Weight Retained (lbs or kg)	% Retained (A,B / D) X100
RETAINED #4 (4.75 mm) = (A)	5.88	
PASS #4 (4.75 mm) = (B)	7.44	=(H)
TOTAL, A + B = (D)	13.72	57.14 =(I)

COMBINED AGGREGATE

SIEVE SIZE	WT RET =K	% RET K X 100 / E =L	WT RET =P	% RET P x 100 / F =R	% RET R x I / 100 =S	% RET L+S =Z	% PASSING 100 - Σ(Z) to 0.1 %	% PASSING to 1 %	SPEC % PASSING
1 1/2" (37.5 mm)	0	.77				0			
1" (25mm)	.38	2.49				2.49	97.5	98	100
3/4" (19 mm)	.54	3.54	3.94			3.54	94.0	94	90-100
1/2" (12.5 mm)	1.58	10.36	11.52			10.36	83.6	84	65-95
3/8" (9.5 mm)	1.14	7.47	8.31			7.47	76.4	76	-
# 4 (4.75 mm)	2.24	14.68	16.33			14.68	61.5	61	50-78
# 8 (2.36 mm)			661.3	23.03	13.16	13.16	48.3	48	37-67
# 16 (1.18 mm)			450	15.67	8.95	8.95	39.4	39	—
# 30 (600 µm)			382	13.3	7.60	7.60	31.8	32	13-35
# 40 425 (µm)									
# 50 (300 µm)									
# 100 (150 µm)			1149.1	40.03	22.87	22.87	8.9	9	-
# 200 (75 µm)			219.1	7.65	4.37	4.37	4.5	5	4-15
Pass # 200 (75 µm), Pan			9.1	24.0	13.72				
TOTAL		Pass # 200	689.7				WET WT (lbs or kg)		
ANGULARITY							DRY WT (lbs or kg)		
FLAT & ELONGATED							WET - DRY = MOISTURE		

FINENESS MODULUS: see M.T.M., Sect. 602.0:

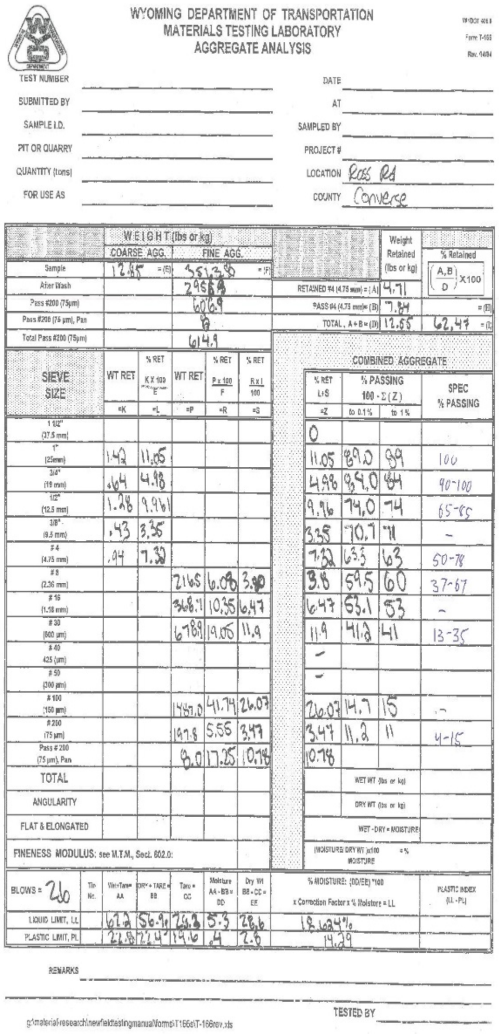
(MOISTURE/ DRY WT)x100 = % MOISTURE

BLOWS = 28	Tin No.	Wet+Tare= AA	DRY + TARE = BB	Tare = CC	Moisture AA - BB = DD	Dry Wt BB - CC = EE	% MOISTURE: (DD/EE) *100 17.53% x Correction Factor x % Moisture = LL	PLASTIC INDEX (LL - PL)
LIQUID LIMIT, LL		57.1	53.5	28.2	4.4	25.1	17.772	
PLASTIC LIMIT, PL		25.7	25.1	21.6	.6	3.5	17.14%	

REMARKS

TESTED BY

g:\material\research\newfieldtestingmanual\forms\T166s\T-166rev.xls



WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

WYDOT 406.0
Form T-166
Rev. 04/04

TEST NUMBER
SUBMITTED BY
SAMPLE I.D.
PIT OR QUARRY
QUANTITY (tons)
FOR USE AS
DATE
AT
SAMPLED BY
PROJECT #
LOCATION Ross Rd
COUNTY Converse

WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.
Sample	12.85 =(E)	3513.8 =(F)
After Wash		2956.9
Pass #200 (75µm)		606.9
Pass #200 (75 µm), Pan		8
Total Pass #200 (75µm)		614.9

	Weight Retained (lbs or kg)	% Retained (A,B / D) X100
RETAINED #4 (4.75 mm) = (A)	4.71	
PASS #4 (4.75 mm) = (B)	7.84	=(H)
TOTAL, A + B = (D)	12.55	62.47 =(I)

COMBINED AGGREGATE

SIEVE SIZE	WT RET =K	% RET K X 100 / E =L	WT RET =P	% RET P x 100 / F =R	% RET R x I / 100 =S	% RET L+S =Z	% PASSING 100 - Σ(Z) to 0.1 %	% PASSING to 1 %	SPEC % PASSING
1 1/2" (37.5 mm)						0			
1" (25mm)	1.42	11.05				11.05	89.0	89	100
3/4" (19 mm)	.64	4.98				4.98	84.0	84	90-100
1/2" (12.5 mm)	1.28	9.961				9.96	74.0	74	65-85
3/8" (9.5 mm)	.43	3.35				3.35	70.7	71	–
# 4 (4.75 mm)	.94	7.32				7.32	63.3	63	50-78
# 8 (2.36 mm)			216.5	6.08	3.80	3.8	59.5	60	37-67
# 16 (1.18 mm)			368.1	10.35	6.47	6.47	53.1	53	–
# 30 (600 µm)			678.9	19.06	11.9	11.9	41.2	41	13-35
# 40 425 (µm)						–			
# 50 (300 µm)						–			
# 100 (150 µm)			1487.0	41.74	26.07	26.07	14.7	15	–
# 200 (75 µm)			197.8	5.55	3.47	3.47	11.2	11	4-15
Pass # 200 (75 µm), Pan			8.0	17.25	10.78	10.78			
TOTAL							WET WT (lbs or kg)		
ANGULARITY							DRY WT (lbs or kg)		
FLAT & ELONGATED							WET - DRY = MOISTURE		

FINENESS MODULUS: see M.T.M., Sect. 602.0:

(MOISTURE/ DRY WT)x100 = % MOISTURE

BLOWS = 26	Tin No.	Wet+Tare= AA	DRY + TARE = BB	Tare = CC	Moisture AA - BB = DD	Dry Wt BB - CC = EE	% MOISTURE: (DD/EE) *100 x Correction Factor x % Moisture = LL	PLASTIC INDEX (LL - PL)
LIQUID LIMIT, LL		62.2	56.9	28.3	5.3	28.6	18.624%	
PLASTIC LIMIT, PL		22.8	22.4	19.6	.4	2.8	14.29	

REMARKS

TESTED BY

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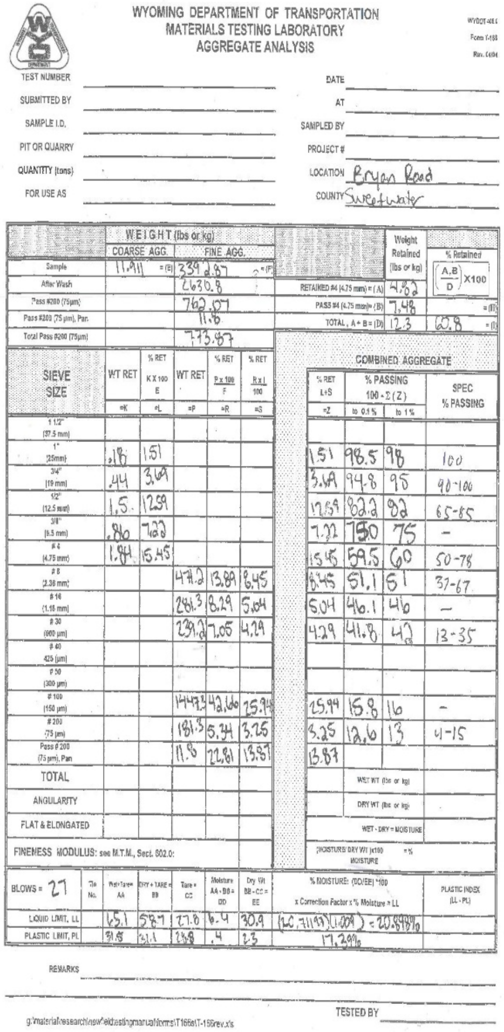

WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

WYDOT 406.0
Form T-166
Rev. 04/04

TEST NUMBER
SUBMITTED BY
SAMPLE I.D.
PIT OR QUARRY
QUANTITY (tons)
FOR USE AS
DATE
AT
SAMPLED BY
PROJECT #
LOCATION Bryan Road
COUNTY Sweetwater

WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.
Sample	11.911 =(E)	3392.87 =(F)
After Wash		2630.8
Pass #200 (75µm)		762.07
Pass #200 (75 µm), Pan		11.8
Total Pass #200 (75µm)		773.87

	Weight Retained (lbs or kg)	% Retained (A,B / D) X100
RETAINED #4 (4.75 mm) = (A)	4.82	
PASS #4 (4.75 mm) = (B)	7.48	=(H)
TOTAL, A + B = (D)	12.3	60.8 =(I)

COMBINED AGGREGATE

SIEVE SIZE	WT RET =K	% RET K X 100 / E =L	WT RET =P	% RET P x 100 / F =R	% RET R x I / 100 =S	% RET L+S =Z	% PASSING 100 - Σ(Z) to 0.1 %	% PASSING to 1 %	SPEC % PASSING
1 1/2" (37.5 mm)									
1" (25mm)	.18	1.51				1.51	98.5	98	100
3/4" (19 mm)	.44	3.69				3.69	94.8	95	90-100
1/2" (12.5 mm)	1.5	12.59				12.59	82.2	82	65-85
3/8" (9.5 mm)	.86	7.22				7.22	75.0	75	–
# 4 (4.75 mm)	1.84	15.45				15.45	59.5	60	50-78
# 8 (2.36 mm)			471.2	13.89	8.45	8.45	51.1	51	37-67
# 16 (1.18 mm)			281.3	8.29	5.04	5.04	46.1	46	–
# 30 (600 µm)			239.2	7.05	4.29	4.29	41.8	42	13-35
# 40 425 (µm)									
# 50 (300 µm)									
# 100 (150 µm)			1447.3	42.66	25.94	25.94	15.8	16	–
# 200 (75 µm)			181.3	5.34	3.25	3.25	12.6	13	4-15
Pass # 200 (75 µm), Pan			11.8	22.81	13.87	13.87			
TOTAL							WET WT (lbs or kg)		
ANGULARITY							DRY WT (lbs or kg)		
FLAT & ELONGATED							WET - DRY = MOISTURE		

FINENESS MODULUS: see M.T.M., Sect. 602.0:

(MOISTURE/ DRY WT)x100 = % MOISTURE

BLOWS = 27	Tin No.	Wet+Tare= AA	DRY + TARE = BB	Tare = CC	Moisture AA - BB = DD	Dry Wt BB - CC = EE	% MOISTURE: (DD/EE) *100 x Correction Factor x % Moisture = LL	PLASTIC INDEX (LL - PL)
LIQUID LIMIT, LL		65.1	58.7	27.8	6.4	30.9	(20.71197)(1.009) = 20.898%	
PLASTIC LIMIT, PL		31.5	31.1	28.8	.4	2.3	17.39%	

REMARKS

TESTED BY

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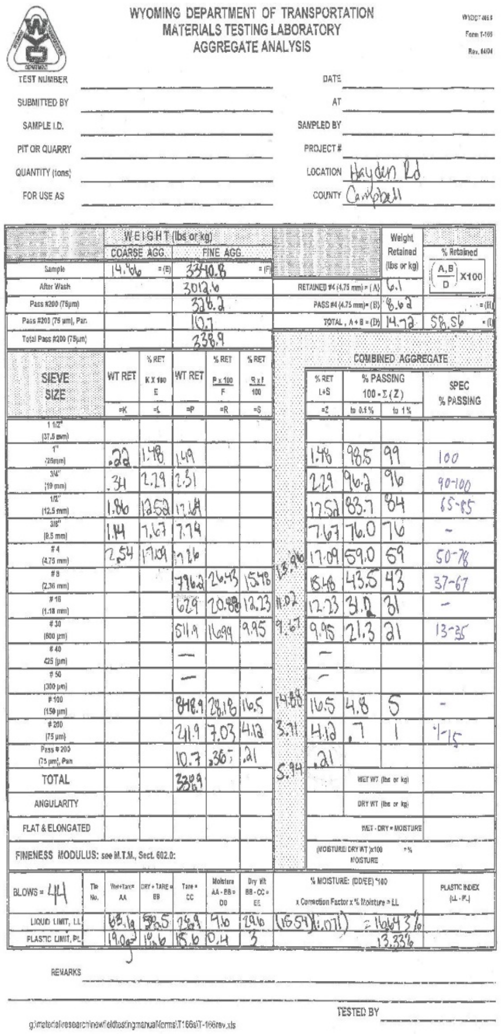

WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

WYDOT 465
Form T-166
Rev. 04/04

TEST NUMBER
SUBMITTED BY
SAMPLE I.D.
PIT OR QUARRY
QUANTITY (tons)
FOR USE AS
DATE
AT
SAMPLED BY
PROJECT #
LOCATION Hayden Rd
COUNTY Campbell

WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.		Weight Retained (lbs or kg)	% Retained (A,B / D) X100
Sample	14.66 =(E)	3340.8 =(F)			
After Wash		3012.6	RETAINED #4 (4.75 mm) = (A)	6.1	=(H)
Pass #200 (75µm)		328.2	PASS #4 (4.75 mm) = (B)	8.62	
Pass #200 (75 µm), Pan		10.7	TOTAL, A + B = (D)	14.72	58.56 =(I)
Total Pass #200 (75µm)		338.9			

SIEVE SIZE	WT RET =K	% RET K X 100 / E =L	WT RET =P	% RET P x 100 / F =R	% RET R x I / 100 =S		COMBINED AGGREGATE % RET L+S =Z	% PASSING 100 - Σ(Z) to 0.1 %	% PASSING 100 - Σ(Z) to 1 %	SPEC % PASSING
1 1/2" (37.5 mm)										
1" (25mm)	.22	1.48	1.49				1.48	98.5	99	100
3/4" (19 mm)	.34	2.29	2.31				2.29	96.2	96	90-100
1/2" (12.5 mm)	1.86	12.52	12.69				12.52	83.7	84	65-85
3/8" (9.5 mm)	1.14	7.67	7.79				7.67	76.0	76	-
# 4 (4.75 mm)	2.54	17.09	17.26				17.09	59.0	59	50-78
# 8 (2.36 mm)			796.2	26.43	15.48	13.96	15.48	43.5	43	37-67
# 16 (1.18 mm)			629	20.88	12.23	11.02	12.23	31.2	31	-
# 30 (600 µm)			511.9	16.99	9.95	9.67	9.95	21.3	21	13-35
# 40 425 (µm)			—				—			
# 50 (300 µm)			—				—			
# 100 (150 µm)			848.9	28.18	16.5	14.88	16.5	4.8	5	-
# 200 (75 µm)			211.9	7.03	4.12	3.71	4.12	.7	1	1-15
Pass # 200 (75 µm), Pan			10.7	.365	.21	5.94	.21			
TOTAL			338.9				WET WT (lbs or kg)			
ANGULARITY							DRY WT (lbs or kg)			
FLAT & ELONGATED							WET - DRY = MOISTURE			
FINENESS MODULUS: see M.T.M., Sect. 602.0:							(MOISTURE/ DRY WT)x100 = % MOISTURE			

BLOWS = 44	Tin No.	Wet+Tare= AA	DRY + TARE = BB	Tare = CC	Moisture AA - BB = DD	Dry Wt BB - CC = EE	% MOISTURE: (DD/EE) *100 x Correction Factor x % Moisture = LL	PLASTIC INDEX (LL - P.L)
LIQUID LIMIT, LL		63.19	58.5	28.9	4.6	29.6	(15.54)(1.071) = 16.643%	
PLASTIC LIMIT, PL		19.02	18.6	15.6	0.4	3	13.33%	

REMARKS

TESTED BY

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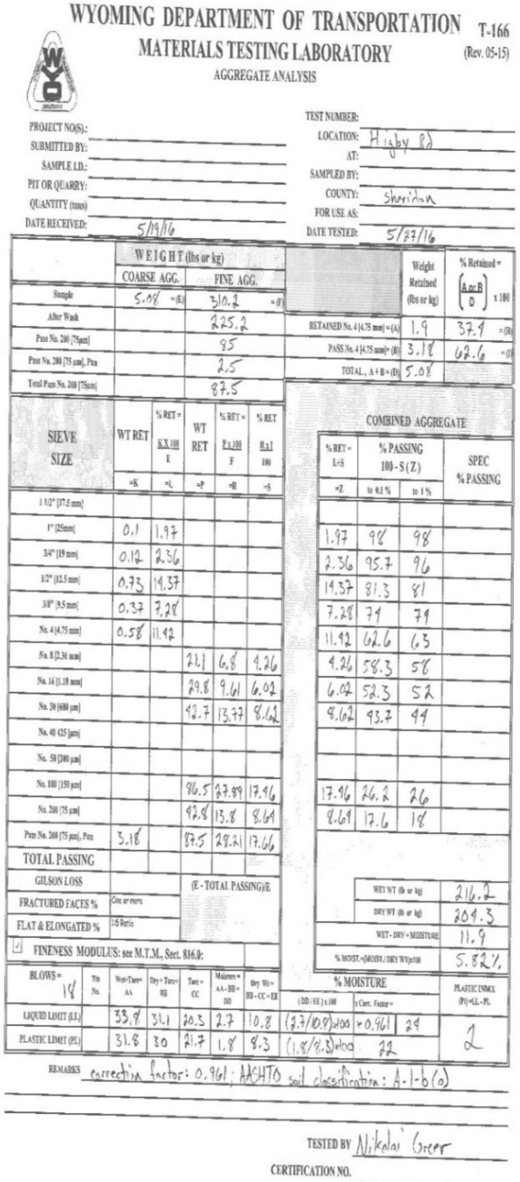


WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

T-166
(Rev. 05-15)

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/19/16
TEST NUMBER:
LOCATION: Higby Rd
AT:
SAMPLED BY:
COUNTY: Sheridan
FOR USE AS:
DATE TESTED: 5/27/16

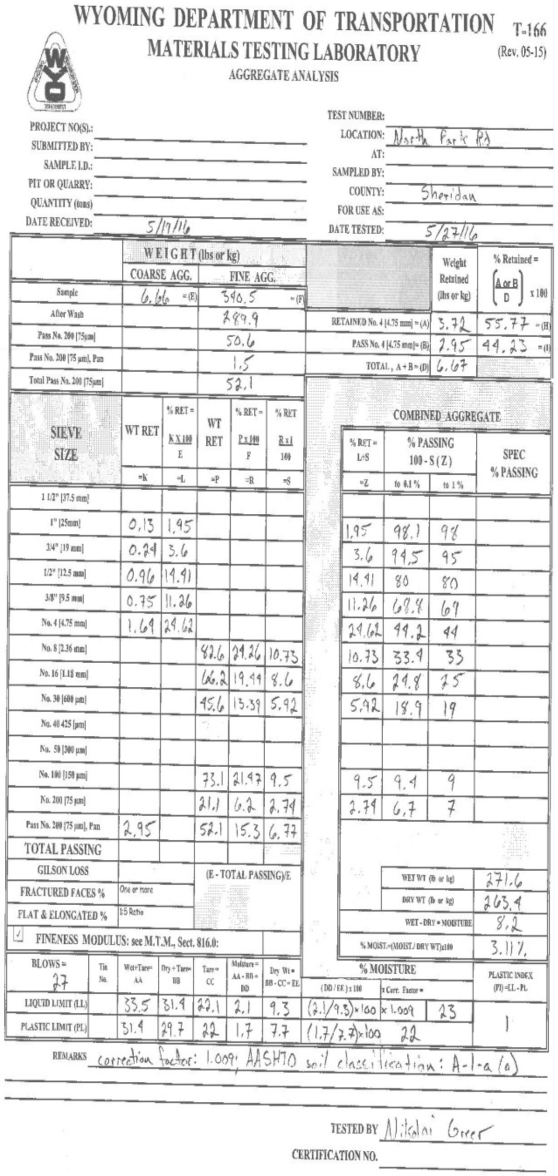
WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.		Weight Retained (lbs or kg)	% Retained = (A or B / D) x 100
Sample	5.08 =(E)	310.2 =(F)			
After Wash		225.2	RETAINED No. 4 [4.75 mm] = (A)	1.9	37.4 =(H)
Pass No. 200 [75µm]		85	PASS No. 4 [4.75 mm] = (B)	3.18	62.6 =(I)
Pass No. 200 [75 µm], Pan		2.5	TOTAL, A + B = (D)	5.08	
Total Pass No. 200 [75µm]		87.5			

SIEVE SIZE	WT RET =K	% RET = K X 100 / E =L	WT RET =P	% RET = P x 100 / F =R	% RET R x I / 100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100 - S(Z) to 0.1 %	% PASSING 100 - S(Z) to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.1	1.97				1.97	98	98	
3/4" [19 mm]	0.12	2.36				2.36	95.7	96	
1/2" [12.5 mm]	0.73	14.37				14.37	81.3	81	
3/8" [9.5 mm]	0.37	7.28				7.28	74	74	
No. 4 [4.75 mm]	0.58	11.42				11.42	62.6	63	
No. 8 [2.36 mm]			21.1	6.8	4.26	4.26	58.3	58	
No. 16 [1.18 mm]			29.8	9.61	6.02	6.02	52.3	52	
No. 30 [600 µm]			42.7	13.77	8.62	8.62	43.7	44	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			86.5	27.89	17.46	17.46	26.2	26	
No. 200 [75 µm]			42.8	13.8	8.64	8.64	17.6	18	
Pass No. 200 [75 µm], Pan	3.18		87.5	28.21	17.66				
TOTAL PASSING									
GILSON LOSS			(E - TOTAL PASSING)/E				WET WT (lb or kg)		216.2
FRACTURED FACES %	One or more						DRY WT (lb or kg)		204.3
FLAT & ELONGATED %	1:5 Ratio						WET - DRY = MOISTURE		11.9
☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:							% MOIST.=(MOIST./ DRY WT)x100		5.82%

BLOWS = 18	Tin No.	Wet+Tare= AA	Dry + Tare= BB	Tare = CC	Moisture = AA - BB = DD	Dry Wt = BB - CC = EE	% MOISTURE (DD / EE) x 100	x Corr. Factor =		PLASTIC INDEX (PI) =LL - PL
LIQUID LIMIT (LL)		33.8	31.1	20.3	2.7	10.8	(2.7/10.8)x100	x0.961	24	2
PLASTIC LIMIT (PL)		31.8	30	21.7	1.8	8.3	(1.8/8.3)x100	22		

REMARKS correction factor: 0.961; AASHTO soil classification: A-1-b(0)

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

T-166
(Rev. 05-15)

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/17/16
TEST NUMBER:
LOCATION: North Park Rd
AT:
SAMPLED BY:
COUNTY: Sheridan
FOR USE AS:
DATE TESTED: 5/27/16

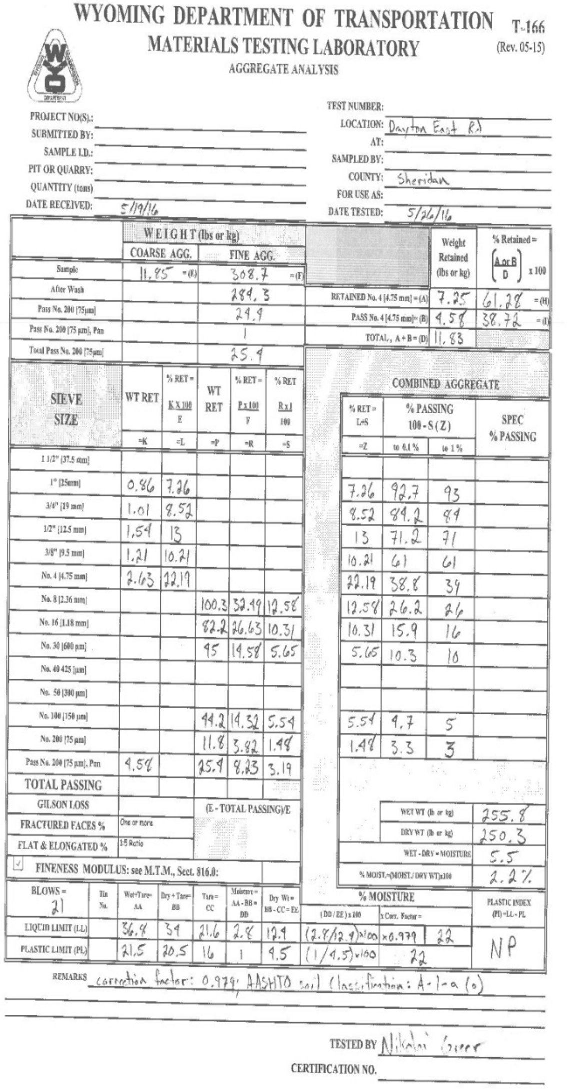
WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.		Weight Retained (lbs or kg)	% Retained = (A or B / D) x 100
Sample	6.66 =(E)	340.5 =(F)			
After Wash		289.9	RETAINED No. 4 [4.75 mm] = (A)	3.72	55.77 =(H)
Pass No. 200 [75µm]		50.6	PASS No. 4 [4.75 mm] = (B)	2.95	44.23 =(I)
Pass No. 200 [75 µm], Pan		1.5	TOTAL, A + B = (D)	6.67	
Total Pass No. 200 [75µm]		52.1			

SIEVE SIZE	WT RET =K	% RET = K X 100 / E =L	WT RET =P	% RET = P x 100 / F =R	% RET R x I / 100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100 - S(Z) to 0.1 %	% PASSING 100 - S(Z) to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.13	1.95				1.95	98.1	98	
3/4" [19 mm]	0.24	3.6				3.6	94.5	95	
1/2" [12.5 mm]	0.96	14.41				14.41	80	80	
3/8" [9.5 mm]	0.75	11.26				11.26	68.8	69	
No. 4 [4.75 mm]	1.64	24.62				24.62	44.2	44	
No. 8 [2.36 mm]			82.6	24.26	10.73	10.73	33.4	33	
No. 16 [1.18 mm]			66.2	19.44	8.6	8.6	24.8	25	
No. 30 [600 µm]			45.6	13.39	5.92	5.92	18.9	19	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			73.1	21.47	9.5	9.5	9.4	9	
No. 200 [75 µm]			21.1	6.2	2.74	2.74	6.7	7	
Pass No. 200 [75 µm], Pan	2.95		52.1	15.3	6.77				
TOTAL PASSING									
GILSON LOSS			(E - TOTAL PASSING)/E				WET WT (lb or kg)		271.6
FRACTURED FACES %	One or more						DRY WT (lb or kg)		263.4
FLAT & ELONGATED %	1:5 Ratio						WET - DRY = MOISTURE		8.2
☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:							% MOIST.=(MOIST./ DRY WT)x100		3.11%

BLOWS = 27	Tin No.	Wet+Tare= AA	Dry + Tare= BB	Tare = CC	Moisture = AA - BB = DD	Dry Wt = BB - CC = EE	% MOISTURE (DD / EE) x 100	x Corr. Factor =		PLASTIC INDEX (PI) =LL - PL
LIQUID LIMIT (LL)		33.5	31.4	22.1	2.1	9.3	(2.1/9.3)x100	x1.009	23	1
PLASTIC LIMIT (PL)		31.4	29.7	22	1.7	7.7	(1.7/7.7)x100	22		

REMARKS correction factor: 1.009; AASHTO soil classification: A-1-a(0)

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION T-166
MATERIALS TESTING LABORATORY (Rev. 05-15)
AGGREGATE ANALYSIS

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/19/16
TEST NUMBER:
LOCATION: Dayton East Rd
AT:
SAMPLED BY:
COUNTY: Sheridan
FOR USE AS:
DATE TESTED: 5/26/16

	WEIGHT (lbs or kg) COARSE AGG.	WEIGHT (lbs or kg) FINE AGG.		Weight Retained (lbs or kg)	% Retained = (A or B / D) x 100
Sample	11.85 =(E)	308.7 =(F)			
After Wash		284.3	RETAINED No. 4 [4.75 mm] = (A)	7.25	61.28 =(H)
Pass No. 200 [75µm]		24.9	PASS No. 4 [4.75 mm] = (B)	4.58	38.72 =(I)
Pass No. 200 [75 µm], Pan		1	TOTAL, A + B = (D)	11.83	
Total Pass No. 200 [75µm]		25.4			

SIEVE SIZE	WT RET =K	% RET = K X 100 / E =L	WT RET =P	% RET = P x 100 / F =R	% RET R x 1 / 100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100 - S (Z) to 0.1 %	to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.86	7.26				7.26	92.7	93	
3/4" [19 mm]	1.01	8.52				8.52	84.2	84	
1/2" [12.5 mm]	1.54	13				13	71.2	71	
3/8" [9.5 mm]	1.21	10.21				10.21	61	61	
No. 4 [4.75 mm]	2.63	22.19				22.19	38.8	39	
No. 8 [2.36 mm]			100.3	32.49	12.58	12.58	26.2	26	
No. 16 [1.18 mm]			82.2	26.63	10.31	10.31	15.9	16	
No. 30 [600 µm]			45	14.58	5.65	5.65	10.3	10	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			44.2	14.32	5.54	5.54	4.7	5	
No. 200 [75 µm]			11.8	3.82	1.48	1.48	3.3	3	
Pass No. 200 [75 µm], Pan	4.58		25.4	8.23	3.19				
TOTAL PASSING									
GILSON LOSS			(E - TOTAL PASSING)/E						
FRACTURED FACES %	One or more								
FLAT & ELONGATED %	1:5 Ratio								

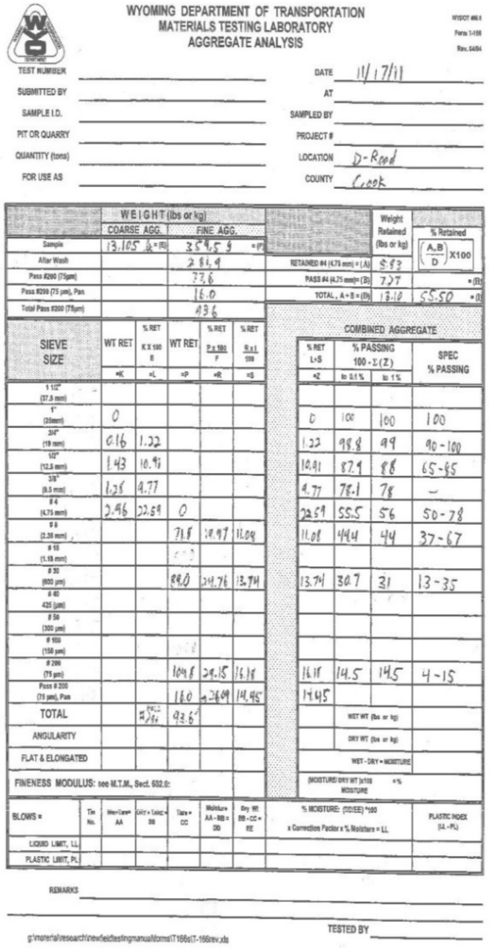
WET WT (lb or kg)	255.8
DRY WT (lb or kg)	250.3
WET - DRY = MOISTURE	5.5
% MOIST.=(MOIST./DRY WT)x100	2.2%

☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:

BLOWS = 21	Tin No.	Wet+Tare= AA	Dry + Tare= BB	Tare = CC	Moisture = AA - BB = DD	Dry Wt = BB - CC = EE	% MOISTURE (DD / EE) x 100	x Corr. Factor =		PLASTIC INDEX (PI) = LL - PL
LIQUID LIMIT (LL)		36.4	34	21.6	2.8	12.4	(2.8/12.4)x100	x0.979	22	NP
PLASTIC LIMIT (PL)		21.5	20.5	16	1	4.5	(1/4.5)x100	22		

REMARKS correction factor: 0.979; AASHTO soil classification: A-1-a (0)

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS
WYDOT 466.1
Form T-166
Rev. 04/04

TEST NUMBER
SUBMITTED BY
SAMPLE I.D.
PIT OR QUARRY
QUANTITY (tons)
FOR USE AS
DATE 11/17/11
AT
SAMPLED BY
PROJECT #
LOCATION D-Road
COUNTY Crook

	WEIGHT (lbs or kg) COARSE AGG.	WEIGHT (lbs or kg) FINE AGG.		Weight Retained (lbs or kg)	% Retained (A,B / D) X100
Sample	13.105 =(E)	359.59 =(F)			
After Wash		281.9	RETAINED #4 (4.75 mm) = (A)	5.83	
Pass #200 (75µm)		77.6	PASS #4 (4.75 mm) = (B)	7.27	=(H)
Pass #200 (75 µm), Pan		16.0	TOTAL, A + B = (D)	13.10	55.50 =(I)
Total Pass #200 (75µm)		93.6			

SIEVE SIZE	WT RET =K	% RET K X 100 / E =L	WT RET =P	% RET P x 100 / F =R	% RET R x 1 / 100 =S	COMBINED AGGREGATE % RET L+S =Z	% PASSING 100 - Σ (Z) to 0.1 %	to 1 %	SPEC % PASSING
1 1/2" (37.5 mm)									
1" (25mm)	0					0	100	100	100
3/4" (19 mm)	0.16	1.22				1.22	98.8	99	90 - 100
1/2" (12.5 mm)	1.43	10.91				10.91	87.9	88	65 - 85
3/8" (9.5 mm)	1.28	9.77				9.77	78.1	78	–
#4 (4.75 mm)	2.96	22.59	0			22.59	55.5	56	50 - 78
#8 (2.36 mm)			71.8	19.97	11.08	11.08	44.4	44	37 - 67
#16 (1.18 mm)									
#30 (600 µm)			89.0	24.76	13.74	13.74	30.7	31	13 - 35
#40 425 (µm)									
#50 (300 µm)									
#100 (150 µm)									
#200 (75 µm)			104.8	29.15	16.18	16.18	14.5	14.5	4 - 15
Pass #200 (75 µm), Pan			16.0	26.09	14.45	14.45			
TOTAL		[illegible]	93.6						
ANGULARITY									
FLAT & ELONGATED									

WET WT (lbs or kg)	
DRY WT (lbs or kg)	
WET - DRY = MOISTURE	
(MOISTURE/ DRY WT)x100 = % MOISTURE	

FINENESS MODULUS: see M.T.M., Sect. 602.0:

BLOWS =	Tin No.	Wet+Tare= AA	DRY + TARE = BB	Tare = CC	Moisture AA - BB = DD	Dry Wt BB - CC = EE	% MOISTURE: (DD/EE) *100 x Correction Factor x % Moisture = LL	PLASTIC INDEX (LL - PL)
LIQUID LIMIT, LL								
PLASTIC LIMIT, PL								

REMARKS

TESTED BY

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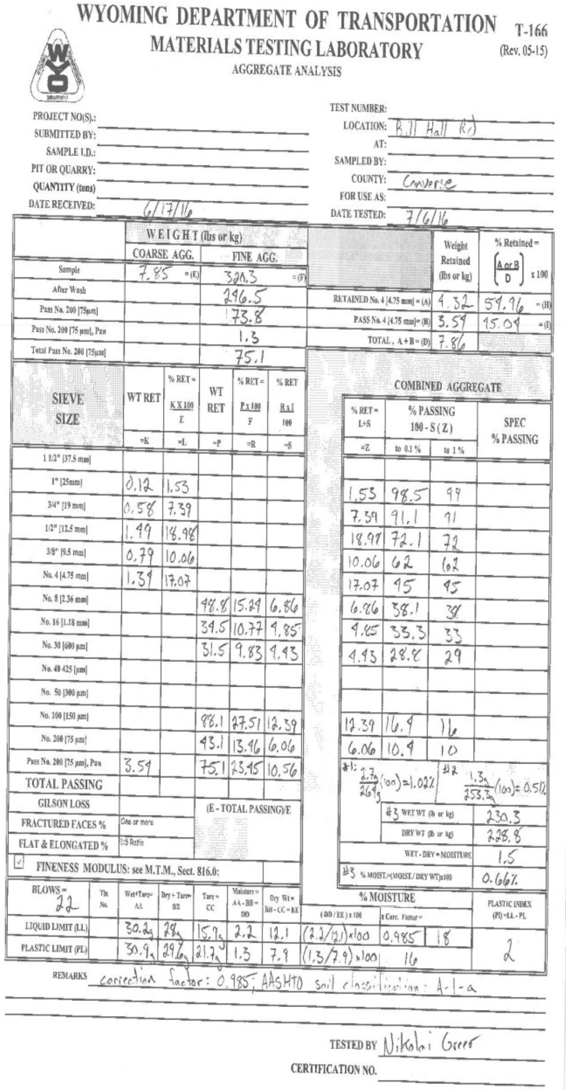


WYOMING DEPARTMENT OF TRANSPORTATION T-166
MATERIALS TESTING LABORATORY (Rev. 05-15)
AGGREGATE ANALYSIS

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 6/17/16
TEST NUMBER:
LOCATION: Bill Hall Rd
AT:
SAMPLED BY:
COUNTY: Converse
FOR USE AS:
DATE TESTED: 7/6/16

	WEIGHT (lbs or kg) COARSE AGG.	WEIGHT (lbs or kg) FINE AGG.		Weight Retained (lbs or kg)	% Retained = (A or B / D) x 100
Sample	7.85 =(E)	320.3 =(F)			
After Wash		246.5	RETAINED No. 4 [4.75 mm] = (A)	4.32	54.96 =(H)
Pass No. 200 [75µm]		73.8	PASS No. 4 [4.75 mm] = (B)	3.54	15.04 =(I)
Pass No. 200 [75 µm], Pan		1.3	TOTAL, A + B = (D)	7.86	
Total Pass No. 200 [75µm]		75.1			

SIEVE SIZE	WT RET =K	% RET = K X 100 / E =L	WT RET =P	% RET = P x 100 / F =R	% RET R x 1 / 100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100 - S (Z) to 0.1 %	to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.12	1.53				1.53	98.5	99	
3/4" [19 mm]	0.58	7.39				7.39	91.1	91	
1/2" [12.5 mm]	1.49	18.98				18.98	72.1	72	
3/8" [9.5 mm]	0.79	10.06				10.06	62	62	
No. 4 [4.75 mm]	1.34	17.07				17.07	45	45	
No. 8 [2.36 mm]			48.8	15.24	6.86	6.86	38.1	38	
No. 16 [1.18 mm]			34.5	10.77	4.85	4.85	33.3	33	
No. 30 [600 µm]			31.5	9.83	4.43	4.43	28.8	29	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			88.1	27.51	12.39	12.39	16.4	16	
No. 200 [75 µm]			43.1	13.46	6.06	6.06	10.4	10	
Pass No. 200 [75 µm], Pan	3.54		75.1	23.45	10.56				
TOTAL PASSING									
GILSON LOSS			(E - TOTAL PASSING)/E						
FRACTURED FACES %	One or more								
FLAT & ELONGATED %	1:5 Ratio								

#1: $\frac{2.7g}{264g}(100)=1.02\%$ #2 $\frac{1.3g}{253.3g}(100)=0.51\%$

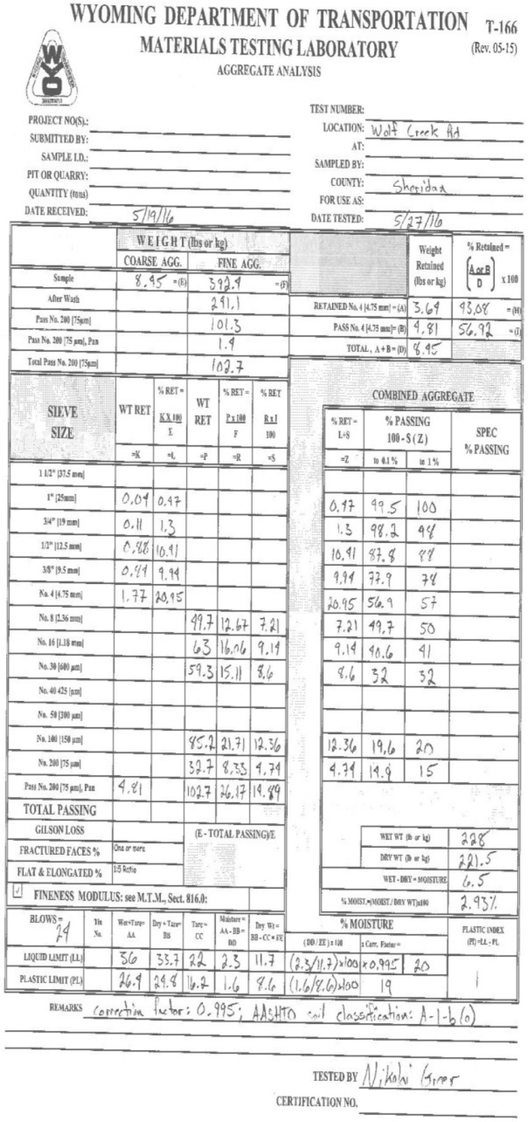
#3 WET WT (lb or kg)	230.3
DRY WT (lb or kg)	228.8
WET - DRY = MOISTURE	1.5
#3 % MOIST.=(MOIST./DRY WT)x100	0.66%

☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:

BLOWS = 22	Tin No.	Wet+Tare= AA	Dry + Tare= BB	Tare = CC	Moisture = AA - BB = DD	Dry Wt = BB - CC = EE	% MOISTURE (DD / EE) x 100	x Corr. Factor =		PLASTIC INDEX (PI) = LL - PL
LIQUID LIMIT (LL)		30.2g	28g	15.9g	2.2	12.1	(2.2/12.1)x100	0.985	18	2
PLASTIC LIMIT (PL)		30.9g	29.6g	21.7g	1.3	7.9	(1.3/7.9)x100	16		

REMARKS correction factor: 0.985; AASHTO soil classification: A-1-a

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION T-166
MATERIALS TESTING LABORATORY (Rev. 05-15)
AGGREGATE ANALYSIS

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/19/16
TEST NUMBER:
LOCATION: Wolf Creek Rd
AT:
SAMPLED BY:
COUNTY: Sheridan
FOR USE AS:
DATE TESTED: 5/27/16

WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.
Sample	8.95 =(E)	392.4 =(F)
After Wash		291.1
Pass No. 200 [75µm]		101.3
Pass No. 200 [75 µm], Pan		1.4
Total Pass No. 200 [75µm]		102.7

	Weight Retained (lbs or kg)	% Retained = (A or B / D) x 100
RETAINED No. 4 [4.75 mm] = (A)	3.64	43.08 =(H)
PASS No. 4 [4.75 mm] = (B)	4.81	56.92 =(I)
TOTAL, A + B = (D)	8.45	

SIEVE SIZE	WT RET =K	% RET = KX100/E =L	WT RET =P	% RET = Px100/F =R	% RET = RxI/100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100-S(Z) to 0.1 %	% PASSING 100-S(Z) to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.04	0.47				0.47	99.5	100	
3/4" [19 mm]	0.11	1.3				1.3	98.2	98	
1/2" [12.5 mm]	0.88	10.41				10.41	87.8	88	
3/8" [9.5 mm]	0.84	9.94				9.94	77.9	78	
No. 4 [4.75 mm]	1.77	20.95				20.95	56.9	57	
No. 8 [2.36 mm]			49.7	12.67	7.21	7.21	49.7	50	
No. 16 [1.18 mm]			63	16.06	9.14	9.14	40.6	41	
No. 30 [600 µm]			59.3	15.11	8.6	8.6	32	32	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			85.2	21.71	12.36	12.36	19.6	20	
No. 200 [75 µm]			32.7	8.33	4.74	4.74	14.9	15	
Pass No. 200 [75 µm], Pan	4.81		102.7	26.17	14.89				
TOTAL PASSING									

GILSON LOSS		(E - TOTAL PASSING)/E
FRACTURED FACES %	One or more	
FLAT & ELONGATED %	1:5 Ratio	

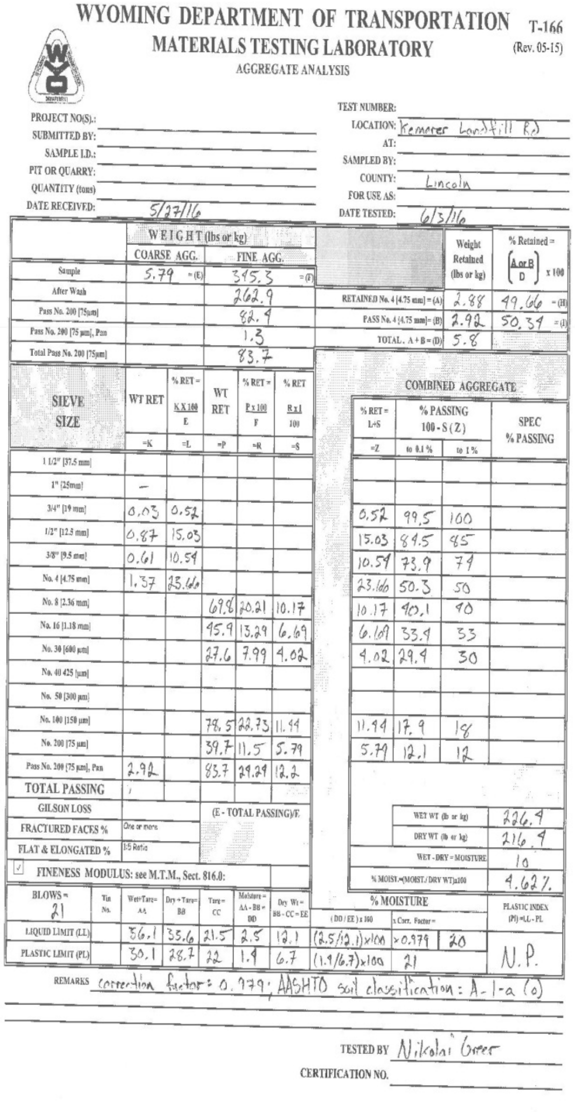
☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:

WET WT (lb or kg)	228
DRY WT (lb or kg)	221.5
WET - DRY = MOISTURE	6.5
% MOIST.=(MOIST./DRY WT)x100	2.93%

BLOWS = 24	Tin No.	Wet+Tare= AA	Dry+Tare= BB	Tare= CC	Moisture= AA-BB= DD	Dry Wt= BB-CC=EE	% MOISTURE (DD/EE)x100	x Corr. Factor=		PLASTIC INDEX (PI)=LL-PL
LIQUID LIMIT (LL)		36	33.7	22	2.3	11.7	(2.3/11.7)x100	x0.995	20	1
PLASTIC LIMIT (PL)		26.4	24.8	16.2	1.6	8.6	(1.6/8.6)x100	19		

REMARKS correction factor: 0.995; AASHTO soil classification: A-1-b (0)

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION T-166
MATERIALS TESTING LABORATORY (Rev. 05-15)
AGGREGATE ANALYSIS

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/27/16
TEST NUMBER:
LOCATION: Kemmerer Landfill Rd
AT:
SAMPLED BY:
COUNTY: Lincoln
FOR USE AS:
DATE TESTED: 6/3/16

WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.
Sample	5.79 =(E)	345.3 =(F)
After Wash		262.9
Pass No. 200 [75µm]		82.4
Pass No. 200 [75 µm], Pan		1.3
Total Pass No. 200 [75µm]		83.7

	Weight Retained (lbs or kg)	% Retained = (A or B / D) x 100
RETAINED No. 4 [4.75 mm] = (A)	2.88	49.66 =(H)
PASS No. 4 [4.75 mm] = (B)	2.92	50.34 =(I)
TOTAL, A + B = (D)	5.8	

SIEVE SIZE	WT RET =K	% RET = KX100/E =L	WT RET =P	% RET = Px100/F =R	% RET = RxI/100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100-S(Z) to 0.1 %	% PASSING 100-S(Z) to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	–								
3/4" [19 mm]	0.03	0.52				0.52	99.5	100	
1/2" [12.5 mm]	0.87	15.03				15.03	84.5	85	
3/8" [9.5 mm]	0.61	10.54				10.54	73.9	74	
No. 4 [4.75 mm]	1.37	23.66				23.66	50.3	50	
No. 8 [2.36 mm]			69.8	20.21	10.17	10.17	40.1	40	
No. 16 [1.18 mm]			45.9	13.29	6.69	6.69	33.4	33	
No. 30 [600 µm]			27.6	7.99	4.02	4.02	29.4	30	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			78.5	22.73	11.44	11.44	17.9	18	
No. 200 [75 µm]			39.7	11.5	5.79	5.79	12.1	12	
Pass No. 200 [75 µm], Pan	2.92		83.7	24.24	12.2				
TOTAL PASSING									

GILSON LOSS		(E - TOTAL PASSING)/E
FRACTURED FACES %	One or more	
FLAT & ELONGATED %	1:5 Ratio	

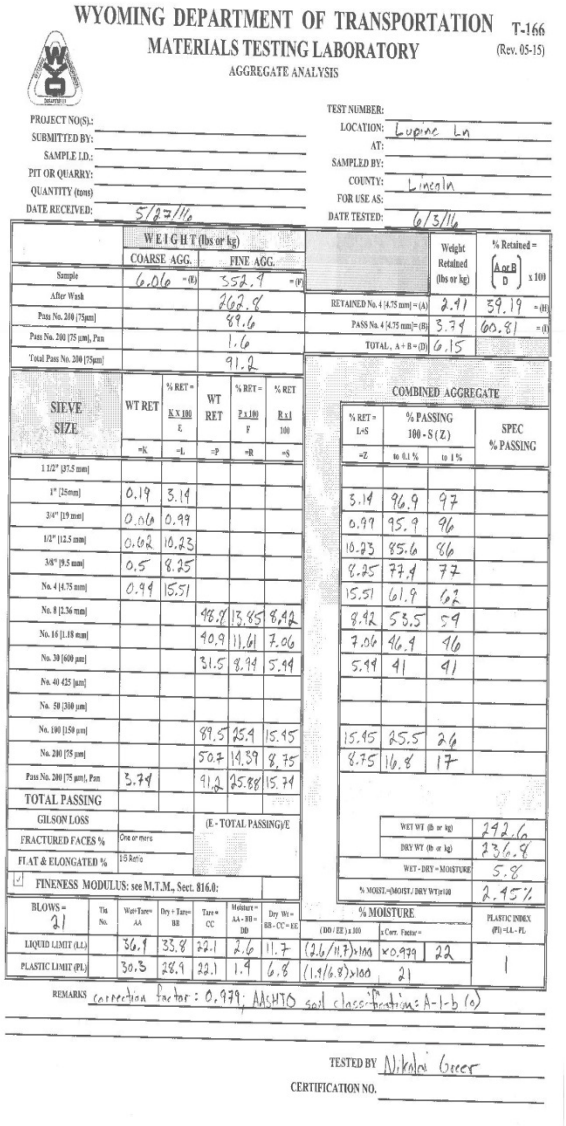
☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:

WET WT (lb or kg)	226.4
DRY WT (lb or kg)	216.4
WET - DRY = MOISTURE	10
% MOIST.=(MOIST./DRY WT)x100	4.62%

BLOWS = 21	Tin No.	Wet+Tare= AA	Dry+Tare= BB	Tare= CC	Moisture= AA-BB= DD	Dry Wt= BB-CC=EE	% MOISTURE (DD/EE)x100	x Corr. Factor=		PLASTIC INDEX (PI)=LL-PL
LIQUID LIMIT (LL)		36.1	33.6	21.5	2.5	12.1	(2.5/12.1)x100	x0.979	20	N.P.
PLASTIC LIMIT (PL)		30.1	28.7	22	1.4	6.7	(1.4/6.7)x100	21		

REMARKS correction factor = 0.979; AASHTO soil classification: A-1-a (0)

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION T-166
MATERIALS TESTING LABORATORY (Rev. 05-15)
AGGREGATE ANALYSIS

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/27/16
TEST NUMBER:
LOCATION: Lupine Ln
AT:
SAMPLED BY:
COUNTY: Lincoln
FOR USE AS:
DATE TESTED: 6/3/16

WEIGHT (lbs or kg)	COARSE AGG.	FINE AGG.
Sample	6.06 =(E)	352.4 =(F)
After Wash		262.8
Pass No. 200 [75µm]		89.6
Pass No. 200 [75 µm], Pan		1.6
Total Pass No. 200 [75µm]		91.2

	Weight Retained (lbs or kg)	% Retained = (A or B / D) x 100
RETAINED No. 4 [4.75 mm] = (A)	2.41	39.19 =(H)
PASS No. 4 [4.75 mm] = (B)	3.74	60.81 =(I)
TOTAL, A + B = (D)	6.15	

SIEVE SIZE	WT RET =K	% RET = KX100/E =L	WT RET =P	% RET = Px100/F =R	% RET = RxI/100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100-S(Z) to 0.1 %	% PASSING 100-S(Z) to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.19	3.14				3.14	96.9	97	
3/4" [19 mm]	0.06	0.99				0.99	95.9	96	
1/2" [12.5 mm]	0.62	10.23				10.23	85.6	86	
3/8" [9.5 mm]	0.5	8.25				8.25	77.4	77	
No. 4 [4.75 mm]	0.94	15.51				15.51	61.9	62	
No. 8 [2.36 mm]			48.8	13.85	8.42	8.42	53.5	54	
No. 16 [1.18 mm]			40.9	11.61	7.06	7.06	46.4	46	
No. 30 [600 µm]			31.5	8.94	5.44	5.44	41	41	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			89.5	25.4	15.45	15.45	25.5	26	
No. 200 [75 µm]			50.7	14.39	8.75	8.75	16.8	17	
Pass No. 200 [75 µm], Pan	3.74		91.2	25.88	15.74				
TOTAL PASSING									

GILSON LOSS		(E - TOTAL PASSING)/E
FRACTURED FACES %	One or more	
FLAT & ELONGATED %	1:5 Ratio	

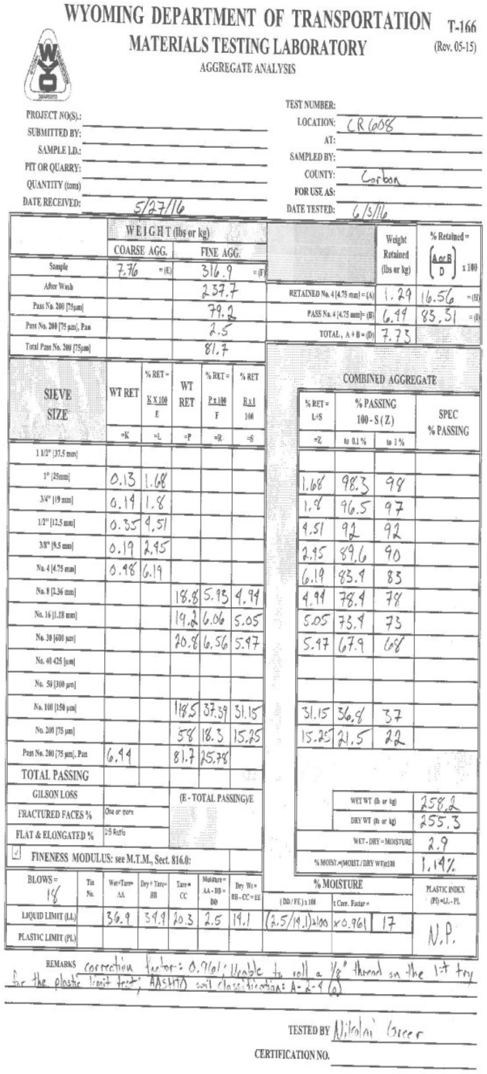
☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:

WET WT (lb or kg)	242.6
DRY WT (lb or kg)	236.8
WET - DRY = MOISTURE	5.8
% MOIST.=(MOIST./DRY WT)x100	2.45%

BLOWS = 21	Tin No.	Wet+Tare= AA	Dry+Tare= BB	Tare= CC	Moisture= AA-BB= DD	Dry Wt= BB-CC=EE	% MOISTURE (DD/EE)x100	x Corr. Factor=		PLASTIC INDEX (PI)=LL-PL
LIQUID LIMIT (LL)		36.4	33.8	22.1	2.6	11.7	(2.6/11.7)x100	x0.979	22	1
PLASTIC LIMIT (PL)		30.3	28.9	22.1	1.4	6.8	(1.4/6.8)x100	21		

REMARKS correction factor: 0.979; AASHTO soil classification: A-1-b (0)

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

T-166
(Rev. 05-15)

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/27/16

TEST NUMBER:
LOCATION: CR 608
AT:
SAMPLED BY:
COUNTY: Carbon
FOR USE AS:
DATE TESTED: 6/3/16

	WEIGHT (lbs or kg) COARSE AGG.	FINE AGG.
Sample	7.76 =(E)	316.9 =(F)
After Wash		237.7
Pass No. 200 [75µm]		79.2
Pass No. 200 [75 µm], Pan		2.5
Total Pass No. 200 [75µm]		81.7

	Weight Retained (lbs or kg)	% Retained = $\left(\frac{A \text{ or } B}{D}\right) \times 100$
RETAINED No. 4 [4.75 mm] = (A)	1.29	16.56 =(H)
PASS No. 4 [4.75 mm]= (B)	6.44	85.31 =(I)
TOTAL, A + B = (D)	7.73	

SIEVE SIZE	WT RET =K	% RET = KX100/E =L	WT RET =P	% RET = Px100/F =R	% RET RxI/100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100 - S (Z) to 0.1 %	to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.13	1.68				1.68	98.3	98	
3/4" [19 mm]	0.14	1.8				1.8	96.5	97	
1/2" [12.5 mm]	0.35	4.51				4.51	92	92	
3/8" [9.5 mm]	0.19	2.45				2.45	89.6	90	
No. 4 [4.75 mm]	0.48	6.19				6.19	83.4	83	
No. 8 [2.36 mm]			18.8	5.93	4.94	4.94	78.4	78	
No. 16 [1.18 mm]			19.2	6.06	5.05	5.05	73.4	73	
No. 30 [600 µm]			20.8	6.56	5.47	5.47	67.9	68	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			118.5	37.39	31.15	31.15	36.8	37	
No. 200 [75 µm]			58	18.3	15.25	15.25	21.5	22	
Pass No. 200 [75 µm], Pan	6.44		81.7	25.78					
TOTAL PASSING									

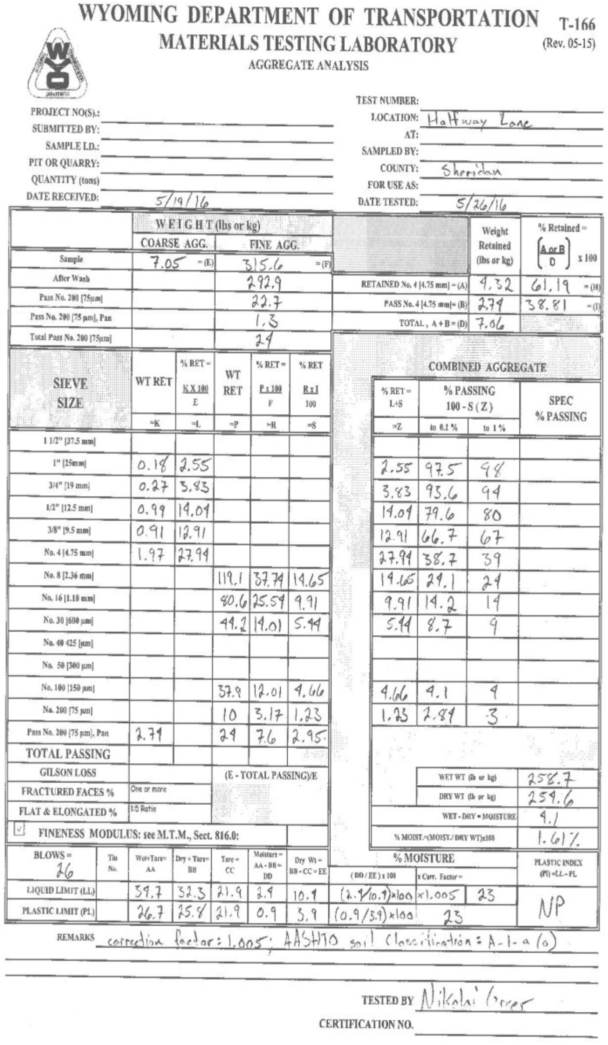
GILSON LOSS
FRACTURED FACES % One or more
FLAT & ELONGATED % 1:5 Ratio
(E - TOTAL PASSING)/E
☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:

WET WT (lb or kg)	258.2
DRY WT (lb or kg)	255.3
WET - DRY = MOISTURE	2.9
% MOIST.=(MOIST./DRY WT)x100	1.14%

BLOWS = 18	Tin No.	Wet+Tare= AA	Dry + Tare= BB	Tare = CC	Moisture = AA - BB = DD	Dry Wt = BB - CC = EE	% MOISTURE (DD / EE) x 100	x Corr. Factor =		PLASTIC INDEX (PI) = LL - PL
LIQUID LIMIT (LL)		36.9	34.4	20.3	2.5	14.1	(2.5/14.1)x100	x0.961	17	N.P.
PLASTIC LIMIT (PL)										

REMARKS correction factor: 0.961; Unable to roll a 1/8" thread on the 1st try for the plastic limit test; AASHTO soil classification: A-2-4 (0)

TESTED BY Nikolai Greer
CERTIFICATION NO.



WYOMING DEPARTMENT OF TRANSPORTATION
MATERIALS TESTING LABORATORY
AGGREGATE ANALYSIS

T-166
(Rev. 05-15)

PROJECT NO(S).:
SUBMITTED BY:
SAMPLE I.D.:
PIT OR QUARRY:
QUANTITY (tons)
DATE RECEIVED: 5/19/16

TEST NUMBER:
LOCATION: Halfway Lane
AT:
SAMPLED BY:
COUNTY: Sheridan
FOR USE AS:
DATE TESTED: 5/26/16

	WEIGHT (lbs or kg) COARSE AGG.	FINE AGG.
Sample	7.05 =(E)	315.6 =(F)
After Wash		292.9
Pass No. 200 [75µm]		22.7
Pass No. 200 [75 µm], Pan		1.3
Total Pass No. 200 [75µm]		24

	Weight Retained (lbs or kg)	% Retained = $\left(\frac{A \text{ or } B}{D}\right) \times 100$
RETAINED No. 4 [4.75 mm] = (A)	4.32	61.19 =(H)
PASS No. 4 [4.75 mm]= (B)	2.74	38.81 =(I)
TOTAL, A + B = (D)	7.06	

SIEVE SIZE	WT RET =K	% RET = KX100/E =L	WT RET =P	% RET = Px100/F =R	% RET RxI/100 =S	COMBINED AGGREGATE % RET = L+S =Z	% PASSING 100 - S (Z) to 0.1 %	to 1 %	SPEC % PASSING
1 1/2" [37.5 mm]									
1" [25mm]	0.18	2.55				2.55	97.5	98	
3/4" [19 mm]	0.27	3.83				3.83	93.6	94	
1/2" [12.5 mm]	0.99	14.04				14.04	79.6	80	
3/8" [9.5 mm]	0.91	12.91				12.91	66.7	67	
No. 4 [4.75 mm]	1.97	27.94				27.94	38.7	39	
No. 8 [2.36 mm]			119.1	37.74	14.65	14.65	24.1	24	
No. 16 [1.18 mm]			80.6	25.54	9.91	9.91	14.2	14	
No. 30 [600 µm]			44.2	14.01	5.44	5.44	8.7	9	
No. 40 425 [µm]									
No. 50 [300 µm]									
No. 100 [150 µm]			37.9	12.01	4.66	4.66	4.1	4	
No. 200 [75 µm]			10	3.17	1.23	1.23	2.84	3	
Pass No. 200 [75 µm], Pan	2.74		24	7.6	2.95				
TOTAL PASSING									

GILSON LOSS
FRACTURED FACES % One or more
FLAT & ELONGATED % 1:5 Ratio
(E - TOTAL PASSING)/E
☑ FINENESS MODULUS: see M.T.M., Sect. 816.0:

WET WT (lb or kg)	258.7
DRY WT (lb or kg)	254.6
WET - DRY = MOISTURE	4.1
% MOIST.=(MOIST./DRY WT)x100	1.61%

BLOWS = 26	Tin No.	Wet+Tare= AA	Dry + Tare= BB	Tare = CC	Moisture = AA - BB = DD	Dry Wt = BB - CC = EE	% MOISTURE (DD / EE) x 100	x Corr. Factor =		PLASTIC INDEX (PI) = LL - PL
LIQUID LIMIT (LL)		34.7	32.3	21.9	2.4	10.4	(2.4/10.4)x100	x1.005	23	NP
PLASTIC LIMIT (PL)		26.7	25.8	21.9	0.9	3.9	(0.9/3.9)x100	23		

REMARKS correction factor: 1.005; AASHTO soil classification: A-1-a (0)

TESTED BY Nikolai Greer
CERTIFICATION NO.

APPENDIX B: SAS REGRESSION ANALYSIS CODE SCRIPT

```
* reg2.sas - Task 2 Regression Analsyis (Okak) 09/04/16;

options nocenter;

data dat;
      * [Report, p 147];
input dusta adt adtt speed fines umoist amoist pi rain; datalines;
131.5868 546 116 48 10.5 3.18 3.1590  7.17  6.94
114.1887 328   0 39  8.4 6.40 3.0833 12.00  9.66
127.0873 168   0 37 14.9 2.85 2.6965  0.00  8.56
 38.7090 184  48 50  2.9 5.60 3.9140  0.00  9.11
 78.2859 204  12 39  6.0 2.07 1.9400 17.19 12.13
 65.0319  90   0 35  6.0 2.21 2.0675  5.94 12.13
111.0800  80   8 44     12.5 2.83 3.1392 18.76 11.00
120.5311 120   8 47  8.9 1.41 3.4370  4.52 11.00
263.9503 504 184 45     11.1 1.91 1.8282 14.06 13.60
220.1124 288  36 41      8.1 1.49 1.3116 17.20 13.60
;

proc print data=dat; run;

* Model Selection;

            * AIC = [ n*log(SSE/n)+2p ] + n+2;
proc glmselect data=dat;
      * selection by aic, bic, adjrsq;
  *model dusta = adt adtt speed fines umoist amoist pi / selection=none
stats=(adjrsq aic bic sbc);
  *model dusta = adt fines / selection=none stats=(adjrsq aic bic sbc);
  model dusta = adt adtt speed fines umoist amoist pi / selection=stepwise
choose=bic;
run;

proc reg data=dat;
      * p-values;
   *model dusta = adt adtt speed fines umoist amoist pi / selection=adjrsq
sbc bic ;
  *model dusta = adt adtt speed fines umoist amoist pi  / selection=backward
sle=0.4 sls=0.1 aic bic;
   *model dusta = adt adtt speed fines umoist amoist pi  / selection=adjrsq
aic bic;
  * model dusta = adt fines rain;                                        *
final reduced model ?;
  * output out=resid p = pred r = rresid student=rstudent;
*model dusta =adt adtt speed fines umoist amoist pi;
model dusta = speed fines amoist;
run;

* Diagnostics;

goptions reset=global ftitle=swissb ftext=swiss htitle=2 htext=3 hsize=8
vsize=6;
symbol1 value=dot height=4;
proc univariate data=resid normal plot;
```

```
  var rstudent;
  qqplot rstudent / normal(mu=est sigma=est);
run;


*** time.sas - Evaluation of Concentration over Time 09/06/16;
* objective 2;

options nocenter;

data dat; input conc red paser t road $; datalines;
1.33028  0.0      6.0 -1    wam
0.02755      1.30273 10.0  0    wam
0.03118      1.29910  9.0  1  wam
0.06812      1.26216  8.0  3  wam
0.59450      0.73578  6.0  9  wam
0.83900      0.49128  5.0 12  wam
0.64750  0.0      7.0 -1    edenry
0.02741      0.62009  9.5  0  edenry
0.03124      0.61626  9.0  1  edenry
0.07560      0.57190  7.0  3  edenry
0.42378      0.22372  6.0  9  edenry
0.94800     -0.30050  6.0 12  edenry
1.06400  0.0      6.0 -1    edenre
0.04380      1.02020  8.0  0  edenre
0.05552      1.00848  8.0  1  edenre
0.07890      0.98510  8.0  3  edenre
0.51879      0.54521  7.0  9  edenre
0.90800      0.15600  6.0 12  edenre
 0.5700  0.0      7.0 -1    county
0.00000      0.57000  9.5  0  county
0.04577      0.52423  9.0  1  county
0.06123      0.50877  8.0  3  county
0.10429      0.46571  7.0  9  county
0.31500      0.25500  7.0 12  county
0.87807  0.0      6.0 -1    pied173
0.02129      0.85677  9.0  0  pied173
0.05092      0.82714  8.0  1  pied173
0.11581      0.76226  8.0  3  pied173
0.68642      0.19165  6.0  9  pied173
0.95933  0.0      6.0 -1    pied171
0.01425      0.94508  9.0  0  pied171
0.02392      0.93541  9.0  1  pied171
0.08388      0.87545  8.0  3  pied171
0.59640      0.36293  6.0  9  pied171
0.97335  0.0      8.0 -1    gomer
0.01994      0.95341 10.0  0  gomer
0.03594      0.93741 10.0  1  gomer
0.08951      0.88384  9.0  3  gomer
0.45193      0.52142  7.0  9  gomer
0.76383      0.20952  6.0 12  gomer
0.92659  0.0      8.0 -1    sublet
0.03172      0.89487  9.0  0  sublet
0.03473      0.89186  9.0  1  sublet
0.09020      0.83640  7.0  3  sublet
0.46540      0.46119  6.0  9  sublet
```

```
0.91950      0.00709  6.0 12  sublet
0.91366  0.0      7.0 -1     jenne
0.02924   .      10.0  0     jenne
1.40928   .       7.0 12     jenne
2.01675  0.0      6.0 -1     bl-yell
0.03095      1.98580  9.0  0  bl-yell
0.09584      1.92091  9.0  1  bl-yell
0.24980      1.76695  7.0  3  bl-yell
1.03350      0.98325  7.0  9  bl-yell
1.83350      0.18325  6.0 12  bl-yell
1.47127  0.0      6.0 -1     turner
0.03144      1.43983  9.0  0  turner
0.07837      1.39290  9.0  1  turner
0.12145      1.34982  7.0  3  turner
0.88400      0.58727  7.0  9  turner
1.68400     -0.21273  6.5 12    turner
;


proc print data=dat; run;

* polynomial trends;

proc glm data=dat;                                          * individual
road;
  where t>-1 & road='bl-yell';
  model conc = t t*t t*t*t;
run;

proc sort data=dat; by t; run;                        * average of roads;
proc means data=dat noprint;
  by t; var conc paser;
output out=mdat mean=mconc mpaser;
proc print data=mdat;
run;

proc glm data=mdat;
  where t>-1;
  * model mconc = t t*t t*t*t;
  model mpaser = t t*t t*t*t;
run;

symbol value=dot height=2;
proc gplot data=dat;
  plot conc*t = road;
run;

* paired t-tests;

data dat2; set dat; where t=-1 | t=9; keep conc road;
proc sort data=dat2; by road;                         * 1 year;
data mdat2; array yy(2) y1-y2;
do t=1 to 2;
  set dat2; by road;
  yy(t)=conc; drop conc;
  if last.road then return; end;
```

```
run;

proc print data=mdat2;
run;

proc ttest data=mdat2 side=u;
  paired y1*y2;
```

APPENDIX C: JOHNSON COUNTY COST DATA

2014 Johsnon County

Road Name	Project	Cost	Total Cost	Miles	CaCl cost/Mile	Cost/Mile
135 / Streeter Gravel	000 / Travel Time	$871	$53,924	12.2	**$3,548**	**$4,420**
	001 / Transport Equipment	$695				
	015 / Dust Supression	$43,284				
	201 / Dust Control - Prepare Surface	$1,178				
	202 / Dust Control - Prewater	$7,200				
	205 / Dust Control- other unspecified Objectives	$696				
195 / Upper Powder River Gravel	000 / Travel Time	$1,490	$124,186	29	**$3,393**	**$4,282**
	001 / Transport Equipment	$1,338				
	015 / Dust Supression	$98,399				
	201 / Dust Control - Prepare Surface	$9,006				
	202 / Dust Control - Prewater	$12,356				
	205 / Dust Control- other unspecified Objectives	$1,596				
14 / Crazy Woman Canyon Gravel	000 / Travel Time	$367	$19,279	4	**$3,883**	**$4,820**
	001 / Transport Equipment	$507				
	015 / Dust Supression	$15,532				
	201 / Dust Control - Prepare Surface	$834				
	202 / Dust Control - Prewater	$1,699				
	205 / Dust Control- other unspecified Objectives	$17,115				
204B / Schoonover Gravel	000 / Travel Time	$886	$97,229	24.5	**$3,295**	**$3,969**
	015 / Dust Supression	$80,723				
	201 / Dust Control - Prepare Surface	$3,475				
	202 / Dust Control - Prewater	$10,685				
	205 / Dust Control- other unspecified Objectives	$1,459				
8 / Stockyard Gravel	015 / Dust Supression	$5,709	$7,262	1.6	**$3,568**	**$4,538**
	201 / Dust Control - Prepare Surface	$653				
	202 / Dust Control - Prewater	$633				
	205 / Dust Control- other unspecified	$266				

2015 Johsnon County						
Road Name	**Project**	**Cost**	**Total Cost**	**Miles**	**CaCl cost/mile**	**Cost/Mile**
135 / Streeter Gravel	000 / Travel Time	$1,069	**$60,651**	**12.2**	**$3,934**	**$ 4,971**
	001 / Transport Equipment	$136				
	014 / Contracted Water Truck	$2,860				
	201 / Dust Control - Prepare Surface	$2,860				
	202 / Dust Control - Prewater	$5,552				
	204 / Dust Control-Apply Calcium Chloride	$47,994				
	205 / Dust Control- other unspecified Objectives	$180				
195 / Upper Powder River Gravel	000 / Travel Time	$950	**$135,424**	**30**	**$3,672**	**$ 4,514**
	014 / Contracted Water Truck	$4,565				
	201 / Dust Control - Prepare Surface	$5,964				
	202 / Dust Control - Prewater	$11,294				
	204 / Dust Control-Apply Calcium Chloride	$110,164				
	205 / Dust Control- other unspecified Objectives	$2,200				
	401 / Equipment Repair & Maint	$287				
14 / Crazy Woman Canyon Gravel	000 / Travel Time	$956	**$22,625**	**4**	**$4,279**	**$ 5,656**
	001 / Transport Equipment	$390				
	014 / Contracted Water Truck	$660				
	201 / Dust Control - Prepare Surface	$622				
	202 / Dust Control - Prewater	$2,670				
	204 / Dust Control-Apply Calcium Chloride	$17,115				
	401 / Equipment Repair & Maint	$212				
204B / Schoonover Gravel	000 / Travel Time	$560	**$105,373**	**24.5**	**$3,413**	**$ 4,301**
	001 / Transport Equipment	$462				
	014 / Contracted Water Truck	$4,345				
	020 / Construction oversight/Administration	$1,857				
	201 / Dust Control - Prepare Surface	$5,590				
	202 / Dust Control - Prewater	$8,298				
	204 / Dust Control-Apply Calcium Chloride	$83,618				
	401 / Equipment Repair & Maint	$644				
8 / Stockyard Gravel	201 / Dust Control - Prepare Surface	$526	**$7,650**	**1.6**	**$4,004**	**$ 4,781**
	202 / Dust Control - Prewater	$143				
	204 / Dust Control-Apply Calcium Chloride	$6,406				
	205 / Dust Control- other unspecified Objectives	$574				

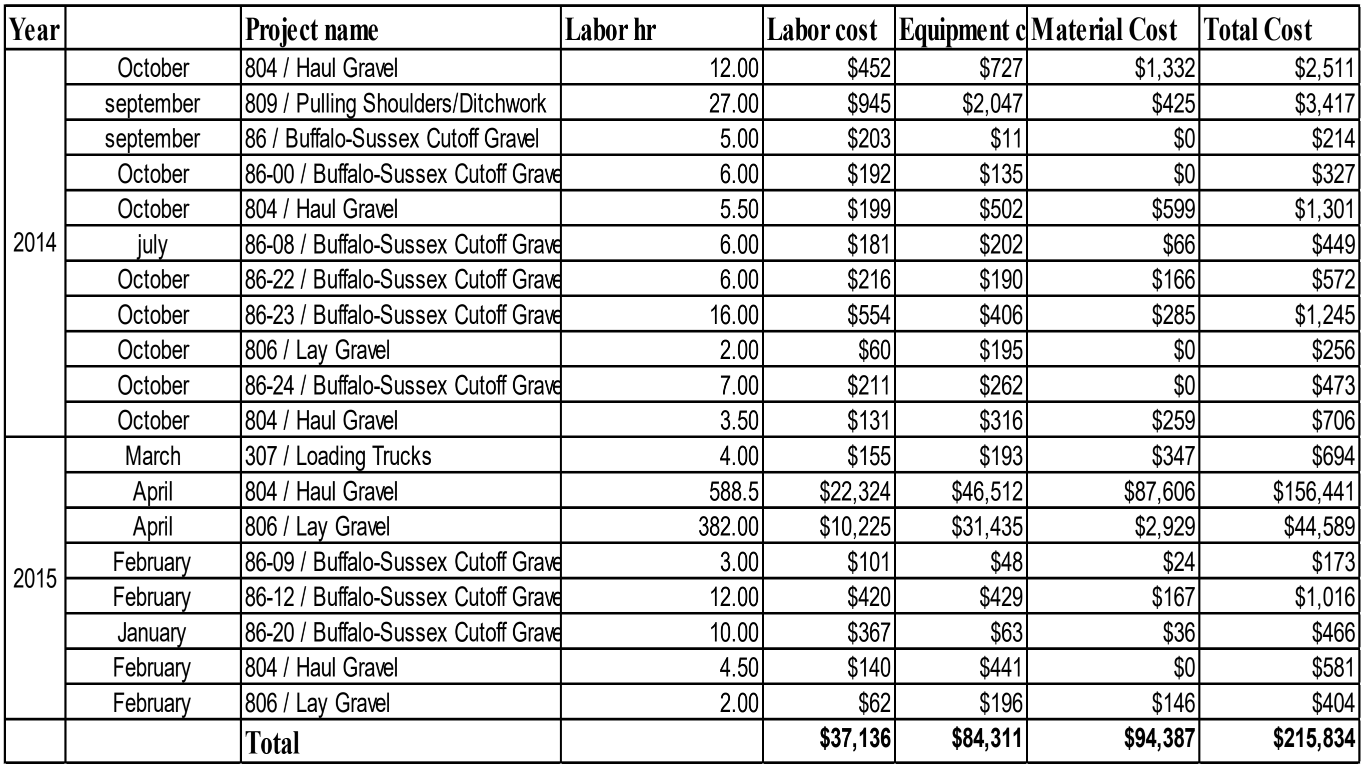
2014 Buffalo sussex maintainenace cost/mile

Year	Month	Project name	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2013	July	GM	14.5	$466.61	$413.10	$116.31	$996.02
	August	GM	4.5	$128.75	$89.73	$63.27	$281.75
	September	GM	15	$482.70	$282.08	$156.91	$921.69
	October	GM	6	$193.08	$201.52	$44.71	$439.31
	November	GM	7.5	$241.35	$113.33	$49.59	$404.27
	December	GM	26	$861.34	$503.92	$199.36	$1,564.62
2014	March	GM	11	$353.98	$165.52	$160.46	$679.96
	April	GM	22	$707.96	$332.42	$241.74	$1,282.12
	May	GM	2	$64.36	$30.22	$0.00	$94.58
	June	GM	27.5	$884.95	$484.81	$291.21	$1,660.98
	Total		136	$4,385.08	$2,616.64	$1,323.57	**$8,325.29**

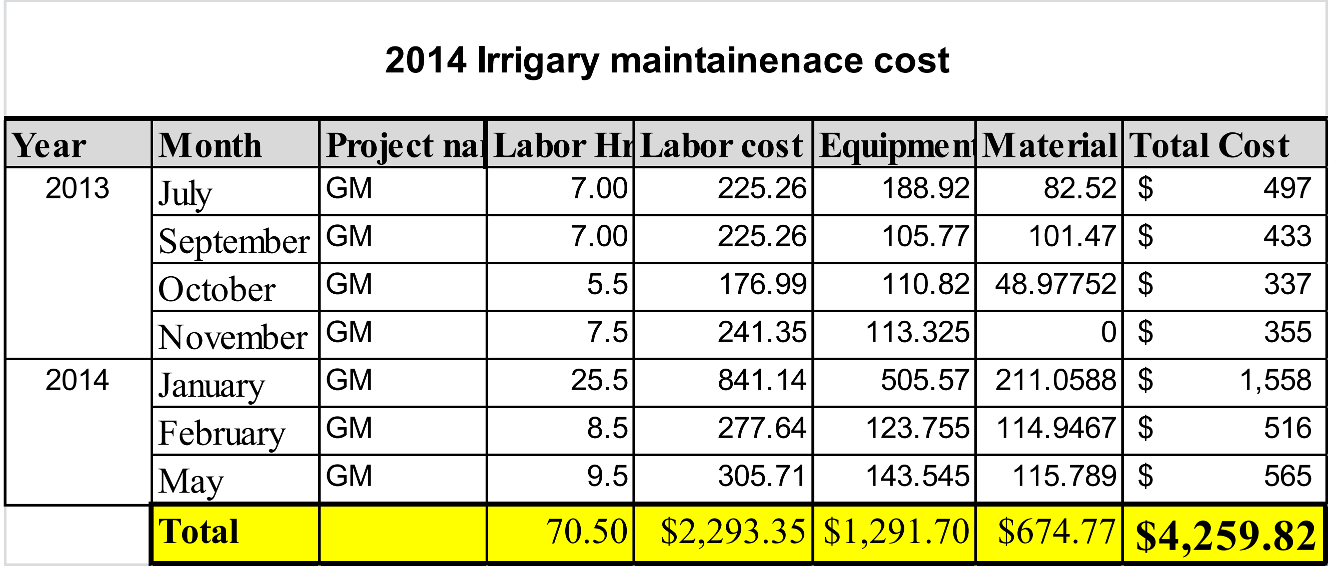
Year	Month	Project name	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2013	August	86 / Lay Gravel Buffalo-Sussex Cutoff Gravel	148	$4,708.69	$3,601.94	$1,412.32	$9,722.94
	August	86-19 / Lay Gravel Buffalo-Sussex Cutoff Gravel Segment 19	6.00	$ 139.17	$ 96.99	$ 22.72	$ 258.88
	October		4	$ 141.70	$ 64.66	$ -	$ 206.36
2014	May	86-22 / Lay Gravel Buffalo-Sussex Cutoff Gravel Segment 22	2.50	$80.45	$80.83	$ -	$161.28
	Total		158	$5,070.01	$3,844.41	$1,435.04	**$10,349.45**

2015 Buffalo sussex maintainenace cost/mile

Year	Month	Project name	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2014	July	GM	2.5	$80.45	$37.78	$33.68	$151.91
	September	GM	12.5	$393.44	$280.65	$85.06	$759.14
	October	GM	60.5	$1,938.18	$1,628.71	$435.70	$4,002.59
	November	GM	8	$196.16	$342.95	$0.00	$539.11
2015	February	GM	9	$314.83	$395.20	$47.94	$757.97
	March	GM	38	$1,047.48	$1,195.06	$281.99	$2,524.52
	April	GM	88.5	$2,486.09	$2,857.48	$843.19	$6,186.75
	May	GM	32.5	$863.46	$884.60	$310.66	$2,058.72
	June	GM	22.5	$721.07	$538.78	$172.21	$1,432.06
			274	$8,041.14	$8,161.20	$2,210.43	$18,412.76



Year		Project name	Labor hr	Labor cost	Equipment c	Material Cost	Total Cost
2014	October	804 / Haul Gravel	12.00	$452	$727	$1,332	$2,511
	september	809 / Pulling Shoulders/Ditchwork	27.00	$945	$2,047	$425	$3,417
	september	86 / Buffalo-Sussex Cutoff Gravel	5.00	$203	$11	$0	$214
	October	86-00 / Buffalo-Sussex Cutoff Grave	6.00	$192	$135	$0	$327
	October	804 / Haul Gravel	5.50	$199	$502	$599	$1,301
	july	86-08 / Buffalo-Sussex Cutoff Grave	6.00	$181	$202	$66	$449
	October	86-22 / Buffalo-Sussex Cutoff Grave	6.00	$216	$190	$166	$572
	October	86-23 / Buffalo-Sussex Cutoff Grave	16.00	$554	$406	$285	$1,245
	October	806 / Lay Gravel	2.00	$60	$195	$0	$256
	October	86-24 / Buffalo-Sussex Cutoff Grave	7.00	$211	$262	$0	$473
	October	804 / Haul Gravel	3.50	$131	$316	$259	$706
2015	March	307 / Loading Trucks	4.00	$155	$193	$347	$694
	April	804 / Haul Gravel	588.5	$22,324	$46,512	$87,606	$156,441
	April	806 / Lay Gravel	382.00	$10,225	$31,435	$2,929	$44,589
	February	86-09 / Buffalo-Sussex Cutoff Grave	3.00	$101	$48	$24	$173
	February	86-12 / Buffalo-Sussex Cutoff Grave	12.00	$420	$429	$167	$1,016
	January	86-20 / Buffalo-Sussex Cutoff Grave	10.00	$367	$63	$36	$466
	February	804 / Haul Gravel	4.50	$140	$441	$0	$581
	February	806 / Lay Gravel	2.00	$62	$196	$146	$404
		Total		**$37,136**	**$84,311**	**$94,387**	**$215,834**



2014 Irrigary maintainenace cost

Year	Month	Project na	Labor Hr	Labor cost	Equipment	Material	Total Cost
2013	July	GM	7.00	225.26	188.92	82.52	$ 497
	September	GM	7.00	225.26	105.77	101.47	$ 433
	October	GM	5.5	176.99	110.82	48.97752	$ 337
	November	GM	7.5	241.35	113.325	0	$ 355
2014	January	GM	25.5	841.14	505.57	211.0588	$ 1,558
	February	GM	8.5	277.64	123.755	114.9467	$ 516
	May	GM	9.5	305.71	143.545	115.789	$ 565
	Total		70.50	$2,293.35	$1,291.70	$674.77	**$4,259.82**

2015 Irrigaray maintenance cost

Year	Month	Project name	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2014	July	GM	24	$593.52	$517.55	$423.81	$1,534.88
	August	GM	10	$213.90	$73.01	$58.08	$344.99
	September	GM	$5.00	$180.12	$167.16	$0.00	$347.28
2015	February	GM	15.5	$481.24	$385.05	$69.43	$935.72
	April	GM	20.5	$744.45	$645.74	$56.63	$1,446.82
	June	GM	4	$136.78	$51.08	$55.70	$243.56
	Total		79	$2,350.01	$1,839.59	$663.65	**$4,853.24**

Year	Month	Project name	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2015	June	010 / Haul Gravel Contractor	40	$0.00	$6,894.30	$7,040.00	$13,934.30
2014	August	802 / Blade Patching Gravel	3.00	$ 90.42	$ 215.64	$ -	$ 306.06
2015	June		8	$ 241.12	$ 781.20	$ 119.03	$ 1,141.35
2014	August	804 / Haul Gravel	36.00	$ 1,404.65	$ 2,218.31	$ 1,935.49	$ 5,558.45
2015	June		28.00	$ 1,139.05	$ 1,933.53	$ 3,402.65	$ 6,475.23
2014	July	806 / Lay Gravel	14.00	$ 176.96	$ 1,050.00	$ 104.26	$ 1,331.22
	August		8.00	$ 101.12	$ 600.00	$ 34.75	$ 735.87
2015	June		3.00	$ 137.19	$ -	$ -	$ 137.19
2014	September	809 / Pulling Shoulders/Ditchwork	3.00	$113.07	$215.64	$11.10	$ 339.81
2015	February		8.00	$248.00	$784.00	$ 220.93	$ 1,252.93
	Total		190	$14,708.24	$22,896.14	$12,879.32	**$31,212.41**

2014 Lower Sussex cost

Year	Month	Project n	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2013	July	GM	0.5	$16.50	$48.83	$0.00	$65.32
	August	GM	2	$62.68	$99.78	$63.76	$226.22
	Septembe	GM	4	$128.72	$143.59	$0.00	$272.31
	October	GM	8.5	$273.53	$156.15	$66.57	$496.25
2014	February	GM	2.5	$80.45	$37.78	$31.85	$150.08
	March	GM	9.00	$ 284.31	$103.15	$28.48	$415.94
	April	GM	17.00	$ 588.67	$387.58	$86.57	$1,062.82
	May	GM	2.5	$80.45	$26.08	$28.55	$135.08
	June	GM	13	$409.31	$621.96	$67.59	$1,098.86
	Total		59	$1,924.61	$1,624.87	$373.37	**$3,922.85**

Year	Month	Project n	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2014	April	804 / Haul Gravel	18.50	$658.63	$1,413.89	$1,559.43	$3,631.94
2013	July	809 / Pulling Shoulders /Ditchwor	3.50	$115.47	$341.78	0	$ 457.24
2014	April	804 / Haul Gravel Lower Sussex	7.50	$247.77	$454.25	$403.62	$1,105.63
2014	April	804 / Haul Gravel Lower Sussex	5.50	$185.73	$357.56	$313.90	$857.19
2014	April	000 / Travel	18.00	$619.90	$388.97	$53.40	$1,062.27
2014	April	804 / Haul Gravel	3.00	$94.02	$181.71	$171.41	$447.14
	Total		169.5	$5,787.62	$10,360.74	$8,459.83	**$7,561.40**

2015 Lower Sussex maintenance cost

Year	Month	Project name	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2014	July	GM	5.00	160.90	75.55	$99.01	$335.46
	September	GM	2	$66.34	$99.78	$0.00	$166.12
2015	March	GM	10	$390.10	$443.16	$39.10	$872.36
	April	GM	13	$507.13	$255.60	$42.11	$804.84
	May						
	June	GM	7	$295.39	$15.84	$0.00	$311.23
	August						
	Total		37	$1,419.86	$889.93	$180.21	**$2,490.00**

Year	Month	Project name	Labor hr	Labor cost	Equipment cost	Material Cost	Total Cost
2015	March	809 / Pulling Shoulders/Ditchwork	8.00	$312.08	$678.72	$70.96	$1,061.76
2015	August	76-07 / Lower Sussex Gravel Segment 7	3.5	123.59	242.38	0	365.97
2014	September	76-08 / Lower Sussex Gravel Segment 8	10.50	$375.89	$316.32	$206.30	$898.50
2015	June		2.50	$94.18	$3,478.80	$3,795.27	$ 7,368.25
2015	June	76-13 / Lower Sussex Gravel Segment 13	0	$0.00	$3,607.70	$3,410.00	$ 7,017.70
2015	May	76-14 / Lower Sussex Gravel Segment 14	1	$ 31.00	$ 15.11	$ 15.92	$ 62.03
2015	June	76-17 / Lower Sussex Gravel Segment 17	7.00	$764.54	$1,650.70	$715.00	$3,130.24
	Total		138.00	$3,915.65	$31,592.61	$24,304.45	**$19,904.44**