# A METHODOLOGY FOR ASSESSING HEAVY TRAFFIC IMPACTS ON GRAVEL ROADS SERVING OIL AND GAS DRILLING OPERATIONS


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## ABSTRACT

The Wyoming Technology Transfer Center in cooperation with the Wyoming Department of Transportation and Sheridan, Johnson, and Carbon Counties undertook a three-year pilot asset management program. These counties were selected because of the significant impacts to their road networks arising from oil and natural gas drilling activities. One objective of this program was to assess the impacts to the counties' roads from drilling activities with the hope that decision makers will be given a better understanding of drilling activities' impacts. This paper describes that assessment.

Based on surface conditions, improvement recommendations were made for roads with inadequate surface conditions for their functional class. The cost of these recommended improvements was examined for both the roads serving predominantly drilling activities and for the rest of the counties' roads, along with the distresses driving these recommendations. By comparing the rate at which improvements were recommended on the drilling and non-drilling roads, conclusions about the impacts of drilling traffic are drawn.

The portion of drilling roads in sub-standard condition is much higher than that for the rest of the counties' roads. It is clearly demonstrated that heavy traffic associated with drilling activities has done significant damage to these three counties' roads, above and beyond what would be anticipated from typical traffic loads.

The methodology presented here could easily be adapted to other road systems experiencing a significant influx of heavy truck traffic to assess the additional traffic's impact.

# INTRODUCTION

Many parts of the State of Wyoming, along with other oil and natural gas producing regions, are experiencing a dramatic increase in exploratory and production drilling. Gravel county roads that once handled very low traffic volumes are now carrying in excess of a thousand vehicles per day with a high proportion of heavy trucks. A typical example is shown in Figure 1. These roads should by most reasonable standards be upgraded to paved roads, except for one factor: Soon the drilling will be completed and traffic volumes will fall off dramatically. Unfortunately, no one knows just how long the boom will last on a global scale or for any one road. This uncertainty about future traffic volumes combined with very limited capital improvement funds often keeps these roads from being upgraded.

During the last oil boom of the 1970's and early 1980's the Texas State Department of Highways and Public Transportation sponsored a research study that estimated that drilling a single well takes about 60 days, and that 1365 trucks larger than standard pickups travel to the well site during preparation and drilling. It also estimated that during production, lasting about three years, 150 large trucks per month serve each well. This study addressed the issues of oil field traffic on paved State highways where the additional drilling traffic had a substantial impact, summarizing the situation with the following statement:

"Low-volume rural roads in oil-producing areas were not initially constructed to endure the impact of intense oil field truck traffic. Thus, a condition of persistent rehabilitation was not anticipated under normal operating situations, and complete pavement restoration costs were not normally accounted for in the planning of maintenance. Since typical traffic characteristics and usual vehicle distributions are not applicable to roadways that carry oil field traffic, there is a need to determine the definitive elements of oil field traffic demand." *(1)*

The situation for lower volume gravel roads in Sheridan, Johnson, and Carbon Counties is certainly more acute. The population of these three counties combined is slightly under 50,000 with an area a bit larger than the State of Maryland (see Figure 2). The climate is semi-arid with cold winters. Cattle ranching is the primary form of agriculture. These counties' roads were not designed to carry the traffic volumes of the Texas State roads, so they are even less able to absorb an influx of drilling traffic.

With the recent escalation in oil and gas drilling activities, these three counties with small populations and tax bases are struggling to maintain their county roads. Once production begins in earnest, they will start to see significant revenues from oil and gas extraction, but while the wells are being drilled there are substantial impacts to the counties' roads without the funding, at least from public sources, to maintain these roads. Often, by necessity, drilling companies will provide financial and material support to the county forces trying to maintain the roads used to access drilling sites. Efforts to address this situation through the State legislature have not been successful, presenting both counties and drilling companies with a financial dilemma. Eventually the counties will receive revenue to compensate them for the impacts to their roads, but in the short term they must try to maintain their roads without adequate funds. The drilling companies must maintain access to their work sites while still fulfilling their fiduciary duty to the owners, all the while knowing that they will soon be expected to pay taxes on the resources they develop. It is difficult for both companies and counties to keep up with the rapidly expanding drilling activities using the county roads.

In 2004, the Wyoming Department of Transportation (WYDOT) and the Wyoming Technology Transfer Center ($T^2$/LTAP – part of the FHWA's Local Technical Assistance Program) began planning an asset management program to assist three counties with management of their road systems. In the spring of 2004, with approval from their county commissioners, Sheridan, Johnson, and Carbon Counties contracted with $T^2$/LTAP to implement asset management programs. Data collection took place during the summers of 2004, 2005, and 2006.

The asset management program was initiated to provide assistance to these counties whose road networks were experiencing considerable impacts from oil and gas drilling. One of the goals was to assess the impacts of drilling activities on county roads. This paper presents the results of that assessment. For more information on this project, see *(2)* and *(3)*.

A procedure was developed that generates recommended improvements on a segment-by-segment basis for gravel roads in each of the three counties. By comparing the recommended improvements on roads known to experience predominantly drilling traffic to the roads in the rest of the county, the relative impact of drilling activities on gravel county roads is assessed.

These assessments of oil and gas drilling activities' impacts only provided good results on the gravel and dirt portion of the county road networks; only about 10% of these counties' road mileage is paved or chip sealed, and most of that mileage is on a few roads (Johnson and Carbon Counties) or adjacent to an urban area (Sheridan County). Thus, from a statistical point of view there aren't enough oiled roads to make a reasonable assessment of drilling impacts on them. The analysis described in this paper applies only to the 90% of these counties' roads that are surfaced with gravel or dirt (see Table 1).

# METHODOLOGY

## Preliminary Methods and Analysis

### *Data Collection*

Data collectors observed the following surface distresses while slowly driving each road segment: rutting, washboards, potholes, loose aggregate, dust, gravel quality, gravel quantity, drainage, crown, and overall condition. At the end of each segment the distresses were rated and crown slope and top width were measured. Gravel road ratings were based on the Pavement Surface Evaluation and Rating (PASER) system developed by the Wisconsin Transportation Information Center *(4)*. This system rates roads from Excellent to Failed. These ratings are primarily driven by necessary maintenance activities. Table 2 shows a brief summary of the rating standards used with the PASER gravel road rating system. The PASER manual has an extensive list of visible distresses which aren't presented here. The training materials used at the $T^2$/LTAP Center are available elsewhere *(2)*.

### *Functional Class Assignment*

A functional class was assigned to each road segment by $T^2$/LTAP in conjunction with the counties. Road segments were assigned to one of four functional classes: Resource, Local, Minor Collector, or Major Collector. Functional classes are based primarily on traffic volumes (see Table 3). However, other factors, such as school bus routes, are also considered when assigning a road to a functional class. In addition, the functional classes are primarily assigned based on long-term usage due to typical road use, rather than on the short-term usage due to drilling activities.

### *Improvement Recommendations*

Establishing which unpaved roads are to be recommended for improvement and the type and cost of these improvements is a several step process. Surfacing and drainage conditions are rated. They are compared to the desired conditions for the road segment's functional class, with those with inadequate conditions being selected for improvement. Appropriate improvement treatments are selected based on the functional class and observed distresses using the improvement-type decision matrix shown in Table 4. Finally, the treatment with the highest cost is recommended. Some treatments, such as dust suppressant and regravel, are specific and well defined, while others such as spot maintenance, spot repair, and rehabilitation, are more general and should be considered to cover a wide range of treatments that could be performed at the cost levels shown in Table 5. A more detailed description of the improvement recommendation procedure is available elsewhere *(2)*.

## Primary Analytical Procedures

### *Drilling Roads Identification*

The counties' road and bridge forces generally know which roads are servicing the oil and gas fields. This knowledge combined with information available from the asset management system was used to identify those roads with predominantly drilling traffic. One piece of information collected was the approach type. Drilling approaches are those roads entering the county roads which predominantly carry traffic serving drilling operations. These are almost always either private roads or roads owned by the Bureau of Land Management (USBLM). By mapping the drilling approaches, many county roads with heavy drilling impacts are identified, as shown in Figure 3. This combined with local knowledge was used to generate a map of roads experiencing significant impact from drilling activities, also shown in Figure 3. Several roads with high drilling traffic do not have many drilling approaches. This happens when these roads are used to access drilling leases in other jurisdictions, such as the USBLM or adjacent counties. Conversely, some roads with quite a few drilling approaches are not listed as drilling roads. This generally occurs when the wells have been completed and are in the production phase when traffic is dramatically reduced. The best way to keep track of when and where drilling is impacting county roads is to ask those who maintain them.

*Drilling Impact Analysis*

To assess the degree of impact from drilling activities, the rate of recommended improvements on drilling and non-drilling roads was compared, both in terms of cost and mileage. These comparisons were performed both on each county individually and on the three counties combined.

# DRILLING IMPACTS ON RECOMMENDED IMPROVEMENTS

## Road-by-Road Impacts

The primary results of this assessment are lists of the drilling roads in each county and the improvements recommended for these roads. Table 6 shows all the drilling roads identified in each county along with the cost of recommended improvements on these roads. These roads carry a wide variety of traffic, as seen by the complete range of functional classes from Major Collector to Resource. The criterion for identifying roads as 'drilling roads' is that they carry 'predominantly' drilling traffic. Most of the roads identified as drilling roads have some sort of improvements recommended for them, as shown in Table 6.

## Functional Class Impacts

Table 7 contains the portion of recommended improvements that take place on drilling roads, along with the total fraction of drilling roads in each functional class. Roads in the Resource class have no improvements that may be attributed to drilling impacts. While only 5% of the Local roads carry predominantly drilling traffic, 21% of the recommended improvement costs on Local roads are on those identified as drilling roads. The greatest impact to the counties is on the Collector drilling roads with about $3.4M of recommended improvements. Clearly, it is on these higher volume roads, those that are the most expensive to maintain, that drilling activities have the greatest impact.

## Impacts by Distress Type

Once a road was identified as being in need of improvements, the treatment with the highest cost was selected using the improvement-type decision matrix (Table 4). Treatment selection is dictated by the distress type costing the most to repair. All improvement treatments identified using this procedure were selected to correct one of five distresses – drainage, rutting, dust, washboards, or potholes. With the exception of drainage, when a more expensive treatment is performed to correct the most severe distress, other distresses will usually be corrected by the same treatment. The more general improvement treatments – maintaining, spot maintenance, spot repair, rehabilitation, and reconstruction – are flexible and may be tailored to the observed distresses. The more specific treatments – regravel, dust suppressant, and ditch work – will usually correct other less severe distresses that cause less expensive work, such as blading, to be recommended. When this is not the case, it is assumed that some of the more expensive recommended improvement cost would be diverted from the recommended treatment to those needed to correct other distresses, and that the cost of these additional repairs would be relatively minor.

Figure 4 shows the cost of recommended improvements due to each of these five distresses on the counties' unpaved road systems as a whole and on the portion of these road networks serving predominantly drilling traffic. Clearly, potholes are the primary distress driving the improvement recommendations. Rutting also accounts for a significant portion of recommended improvements, with dust, washboards, and drainage making relatively minor contributions, both on the drilling roads and on the county systems as a whole.

Table 8 breaks out the costs in Figure 5 by functional class. The overall trends described above apply primarily to the Collector Roads, and most closely to the Minor Collectors. This isn't surprising since 84% of the recommended improvements on the entire system are on the Collectors. For drilling roads, 95% of the recommended improvements are on the Collectors. Further examination of the distresses driving improvements for the various functional classes yields interesting though predictable results as described in the following paragraphs.

### *Drainage*

As one would expect, drilling traffic had no adverse effects on drainage. Drilling roads had considerably fewer recommended drainage improvements than a random sample would predict. Since drilling companies can't afford to have their activities shut down by rain, it is not surprising that the roads they use regularly have adequate drainage.

### *Dust*

Nearly all – 96% – of the recommended dust suppressant was on drilling roads. An obvious explanation is that the heavy, and often higher speed, traffic on drilling roads breaks up the road surface's crust, allowing more dust to be dispersed into the air. As described in the following paragraph, dust suppressant application as driven by the dust ratings may also reduce problems associated with washboarding.

### *Washboards*

Washboards, though frequent, are relatively inexpensive to fix at least in the short-term. Often dust loss will lead to washboarding, so many roads recommended for maintenance to address the washboards will also have dust suppressant recommended to address dust loss. Since dust suppressant is more expensive, dust will generally be the controlling distress, thereby hiding some of the negative impacts of washboards using this analytical method. In a number of cases, dust suppressant will be used to minimize both dust and washboarding. Therefore, this analytical method may somewhat understate the washboarding problem.

### *Rutting*

Rutting, second only to potholes in terms of the cost of recommended improvements, is the cause of most of the distresses on Local roads, both for drilling roads and for the systems as a whole. Rutting's impact is a much smaller portion of the total impacts on Minor Collectors, and smaller still on Major Collectors. These aren't surprising results since rutting is primarily a structural failure. Roads in the higher functional classes are generally stronger and more able to withstand heavy traffic loads.

### *Potholes*

Potholes drive 66% of the improvements recommended for the county road systems as a whole and 69% of those on the drilling roads. These impacts are confined almost entirely to the Collectors. Several factors contribute to this: Local and Resource roads are more likely to suffer from rutting due to their lesser structural capacity. High traffic volumes, weights, and tire pressures greatly accelerate the formation of potholes on the higher volume roads. Finally these same traffic conditions tend to beat the crown out of the road surface, making it more prone to trapping water which leads to more potholes. None of these circumstances are unique to drilling traffic, but the volume of traffic accompanying drilling operations is significantly higher than those normally carried by these roads, causing potholes to be the primary form of distress on drilling roads as well as on the rest of the counties' unpaved roads.

## System-Wide Impacts

The bottom line is that half of the recommended improvements on the counties' roads are on 15% of their roads, those roads with drilling traffic. Figure 5 demonstrates the discrepancy between the portion of the mileage in each county that serves predominantly drilling activities and the portion of sub-standard roads within the counties on these drilling roads. Clearly, drilling roads represent a small fraction of the roads in each county but a large fraction of the roads that have deteriorated to unacceptable levels.

# IMPLEMENTATION

Several of the roads with the highest recommended improvement costs had already been upgraded by the time this analysis was completed. Most were regraveled, sometimes with the addition of dust suppressant, and in several instances other problems such as poor curve alignments were also corrected. Such improvements would be classified as Spot Repairs or Rehabilitation using the method described in this paper. This observation that the more subjective decisions made by county road and bridge departments agree with the predictions made using the improvement recommendation method described here lends confidence to this analysis.

## SUMMARY AND CONCLUSIONS

A multiple step process is used to assess the impacts of oil and gas drilling on gravel county roads in three Wyoming counties with significant drilling activity. The roads are rated using a 'windshield' survey method. Those with inadequate surface conditions for their functional class are recommended for improvement. Based on the distresses exhibited by these roads, appropriate treatments are recommended to upgrade individual road segments. Roads with predominantly drilling traffic are identified. Finally, the amount and type of improvements recommended for drilling roads is compared to the rest of the counties' unpaved roads.

The data garnered in this analysis provides interesting though not surprising results. The following conclusions can be drawn from the analysis performed in this study:

- The sudden influx of drilling traffic onto the unpaved roads of Sheridan, Johnson, and Carbon Counties, Wyoming, is having significant adverse effects on the surface conditions of those roads carrying this extra traffic. These adverse effects are indicated by a much higher incidence of roads serving drilling traffic not meeting the standards expected for their functional class which may be attributed to the large increase in both the number and size of the vehicles serving drilling operations, though the possible effects of higher speeds on these roads should not be overlooked.

- The analysis developed in this paper demonstrates that the roads serving drilling activities are lagging significantly behind the rest of the counties' roads. Drilling companies assist the counties with equipment, labor, and funding. Unfortunately no good data is available to quantify these contributions. Eventually, the counties should see revenue from taxes to be paid by the drilling companies. However, in the short term the counties' roads are deteriorating in spite of drilling companies' efforts to assist them. Hopefully once more wells go into production and the counties receive related revenue, they will have the resources to repair the damage done by oil and gas drilling activities.

- On unpaved roads of all classes, those serving drilling traffic are in considerably greater need of surface improvements than the rest of the counties' unpaved roads. These effects are most pronounced on Minor Collector roads. Major Collectors suffer less from the influx of drilling traffic since they are already capable of handling significant amounts of traffic. Local and Resource roads are easier for county road and bridge forces to keep up with since they carry less traffic, even when this traffic is serving oil and gas drilling operations.

- As one would expect, there is no tendency for drainage improvements to be more frequent on the drilling roads. Additional heavy traffic does not significantly affect a road's drainage.

- Improvement recommendations due to dust are almost exclusively on drilling roads. Heavier traffic and higher speeds damage the surface crust, allowing more dust to be driven off the road surface. This loss of dust may also contribute to other distresses.

- The predominant distresses necessitating improvements to drilling roads are rutting on the Local roads and potholes on the Collectors. These are not surprising results. Potholes may form as the surface's ability to shed water is reduced due to the increased permeability caused by the loss of fines in the form of dust. Rutting on Local roads is probably caused when heavy drilling traffic traverses these roads, exceeding their limited structural capacities. The Collectors, already possessing greater structural capacity, are less susceptible to structural failure manifested as rutting, but their surfaces are still damaged as the crown is flattened out by traffic and as heavy vehicles pound out potholes where the surface has been softened by moisture. These observations are consistent with those one would expect on roads subjected to an influx of heavy truck traffic.

The methods described here could be applied to other situations, such as logging roads or ethanol plant haul roads, where there has been a significant increase in truck traffic.

## DISCLAIMER

The procedures described in this paper do not constitute any policy or standard procedure of the Wyoming Department of Transportation, the University of Wyoming, the Wyoming Technology Transfer Center, Sheridan County, Johnson County, or Carbon County.

## ACKNOWLEDGMENTS

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# LIST OF TABLES AND FIGURES

**TABLE 1 County Road Network Mileages by Drilling and Surface Type**

| | Carbon | Johnson | Sheridan | TOTAL |
|---|---|---|---|---|
| *Gravel Drilling* | 116 | 97 | 54 | 267 |
| *Gravel Non-Drilling* | 764 | 361 | 433 | 1,558 |
| *Asphalt* | 74 | 105 | 32 | 211 |
| *Total* | 954 | 563 | 519 | 2,036 |

**TABLE 2 PASER Gravel Roads Rating System Standards *(4)***

| Rating | General Condition | Drainage | Maintenance |
|---|---|---|---|
| 10 - Excellent | New construction or total reconstruction | Excellent drainage | Little or no maintenance needed |
| 8 - Good | Recently regraded; Adequate gravel for traffic | Good crown and drainage throughout | Routine maintenance may be needed |
| 6 - Fair | Shows traffic | Needs some ditch improvement and culvert maintenance | Regrading (reworking) necessary to maintain; Some areas may need additional gravel |
| 4 - Poor | Travel at slow speeds (less than 25 mph) is required | Major ditch construction and culvert maintenance also required | Needs additional new aggregate |
| 2 - Failed | Travel is difficult and road may be closed at times | Needs complete rebuilding and/or new culverts | |

**TABLE 3 Functional Class Traffic Volumes**

| Functional Class | Approximate Traffic Volume, ADT |
|---|---|
| Resource | 0 - 30 |
| Local | 30 - 100 |
| Minor Collector | 100 - 300 |
| Major Collector | 300 - 1000 |

**TABLE 4 Recommended Improvement Treatments Based On Distress Condition and Functional Class**

| Distress & Condition | Resource | Local | Minor Collector | Major Collector |
|---|---|---|---|---|
| ***Overall*** | | | | |
| **Excellent** | None | None | None | None |
| **Good** | None | None | None | None |
| **Fair** | None | None | None | Blading |
| **Poor** | None | Blading | Spot Maintenance | Regravel |
| **Failed** | Blading | Regravel | Rehabilitation | Rehabilitation |
| ***Loose Aggregate*** | | | | |
| **Excellent** | None | None | None | None |
| **Good** | None | None | None | None |
| **Fair** | None | None | None | None |
| **Poor** | None | None | Blading | Blading |
| **Failed** | None | Blading | Spot Maintenance | Spot Maintenance |
| ***Potholes*** | | | | |
| **Excellent** | None | None | None | None |
| **Good** | None | None | None | None |
| **Fair** | None | Spot Maintenance | Regravel | Spot Repair |
| **Poor** | Blading | Spot Repair | Spot Repair | Rehabilitation |
| **Failed** | Spot Maintenance | Rehabilitation | Reconstruction | Reconstruction |
| ***Washboards*** | | | | |
| **Excellent** | None | None | None | None |
| **Good** | None | None | None | None |
| **Fair** | None | Blading | Blading | Blading |
| **Poor** | Blading | Spot Maintenance | Regravel | Regravel |
| **Failed** | Blading | Regravel | Regravel | Regravel |
| ***Rutting*** | | | | |
| **Excellent** | None | None | None | None |
| **Good** | None | None | None | None |
| **Fair** | None | Spot Maintenance | Spot Maintenance | Regravel |
| **Poor** | Spot Maintenance | Regravel | Regravel | Rehabilitation |
| **Failed** | Regravel | Rehabilitation | Rehabilitation | Reconstruction |
| ***Drainage*** | | | | |
| **Excellent** | None | None | None | None |
| **Good** | None | None | None | None |
| **Fair** | None | Clean Ditches | Clean Ditches | Clean Ditches |
| **Poor** | Clean Ditches | Reshape Ditches | Reshape Ditches | Reshape Ditches |
| **Failed** | Reshape Ditches | Reshape Ditches | Spot Repair | Spot Repair |
| ***Dust*** | | | | |
| **Excellent** | None | None | None | None |
| **Good** | None | None | None | None |
| **Fair** | None | None | None | None |
| **Poor** | None | Dust Suppressant | Dust Suppressant | Dust Suppressant |
| **Failed** | Dust Suppressant | Dust Suppressant | Dust Suppressant | Dust Suppressant |

**TABLE 5 Improvement Treatment Costs per Mile by Functional Class**

| | Cost/mile | | | |
|---|---|---|---|---|
| ***Treatment*** | **Resource** | **Local** | **Minor Collector** | **Major Collector** |
| *Maintaining* | $400 | $400 | $400 | $400 |
| *Spot Maintenance* | $1,350 | $1,350 | $1,350 | $1,350 |
| *Dust Suppressant* | $1,500 | $5,000 | $7,000 | $8,000 |
| *Regravel* | $10,000 | $12,000 | $15,000 | $18,000 |
| *Spot Repair* | $30,000 | $50,000 | $70,000 | $90,000 |
| *Rehabilitate* | $100,000 | $150,000 | $175,000 | $200,000 |
| *Reconstruct* | $400,000 | $800,000 | $1,000,000 | $1,200,000 |
| *Clean Ditches* | $500 | $500 | $500 | $500 |
| *Reshape Ditches* | $2,000 | $3,000 | $3,500 | $4,000 |

## TABLE 6 Recommended Improvements and Costs on Drilling Roads

| County | Road Number | Functional Class | Total Miles | Miles Rec. for Impr. | Primary Recommended Improvements * | Recommended Improvement Costs |
|---|---|---|---|---|---|---|
| Carbon | 701 | Major Collector | 18.8 | 8.0 | Spot Repair | $545,281 |
| | 605S | Minor Collector | 2.2 | 2.0 | Rehabilitate | $347,946 |
| | 605N | Major Collector | 23.1 | 4.2 | Spot Repair & Regravel | $209,491 |
| | 700 | Minor Collector | 17.9 | 3.0 | Spot Repair & Regravel | $103,251 |
| | 340 | Major Collector | 1.2 | 1.0 | Spot Repair | $86,528 |
| | 730 | Local | 6.0 | 2.0 | Regravel | $23,444 |
| | 294 | Local | 4.9 | 0.0 | None | $0 |
| | 1 | Minor Collector | 19.7 | 0.0 | None | $0 |
| | 100 | Resource | 14.4 | 0.0 | None | $0 |
| | 501 | Local | 7.5 | 0.0 | None | $0 |
| | | *Drilling Subtotals* | 116 | 20.1 | -- | $1,315,941 |
| | | *County Totals* | 880 | 48.9 | -- | $1,913,675 |
| | | *Drilling Percentage* | 13% | 41% | -- | 69% |
| Johnson | 204B | Major Collector | 24.2 | 24.2 | Dust Suppressant | $193,333 |
| | 190 | Local | 4.0 | 3.0 | Rehabilitate | $160,963 |
| | 195 | Minor Collector | 27.0 | 9.0 | Spot Repair & Regravel | $158,974 |
| | 259 | Major Collector | 6.1 | 6.1 | Spot Repair & Dust Suppressant | $131,791 |
| | 51 | Minor Collector | 14.0 | 5.5 | Regravel & Dust Suppressant | $67,811 |
| | 54 | Minor Collector | 21.8 | 4.0 | Regravel | $60,118 |
| | | *Drilling Subtotals* | 97 | 51.7 | -- | $772,989 |
| | | *County Totals* | 458 | 74.3 | -- | $1,378,118 |
| | | *Drilling Percentage* | 21% | 70% | -- | 56% |
| Sheridan | 1211 | Major Collector | 14.8 | 14.8 | Rehabilitate, Spot Repair & Regravel | $804,439 |
| | 273 | Minor Collector | 7.1 | 5.1 | Spot Repair | $302,576 |
| | 38 | Minor Collector | 6.5 | 3.9 | Spot Repair | $220,038 |
| | 114 | Minor Collector | 3.3 | 2.3 | Spot Repair & Regravel | $87,974 |
| | 1231 | Minor Collector | 12.3 | 3.0 | Spot Repair & Dust Suppressant | $82,936 |
| | 40 | Local | 10.0 | 0.0 | None | $0 |
| | | *Drilling Subtotals* | 54 | 29.1 | -- | $1,497,963 |
| | | *County Totals* | 487 | 80.7 | -- | $3,485,914 |
| | | *Drilling Percentage* | 11% | 36% | -- | 43% |
| Totals | | *Drilling Subtotals* | 267 | 101.0 | -- | $3,586,893 |
| | | *County Totals* | 1825 | 203.8 | -- | $6,777,707 |
| | | *Drilling Percentage* | **15%** | **50%** | -- | **53%** |

* *Improvements accounting for less than 10% of the total improvements on the road are not listed.*

### TABLE 7 Drilling Mileages and Recommended Improvements as a Percentage of System Totals

| | | Resource | Local | Minor Collector | Major Collector | TOTAL |
|---|---|---|---|---|---|---|
| ***Total Miles*** | *System* | 315 | 624 | 718 | 168 | 1,825 |
| | *Drilling* | 14 | 32 | 132 | 88 | 267 |
| | *Drilling Percent* | **4%** | **5%** | **18%** | **52%** | **15%** |
| ***Miles Recommended for Improvement*** | *System* | 24 | 22 | 86 | 72 | 204 |
| | *Drilling* | 0 | 5 | 38 | 58 | 101 |
| | *System Percent* | 8% | 4% | 12% | 43% | 11% |
| | *Drilling Percent* | **0%** | **15%** | **29%** | **66%** | **38%** |
| ***Costs of Recommended Improvements*** | *System* | $216,826 | $879,542 | $2,745,749 | $2,935,590 | $6,777,707 |
| | *Drilling* | $0 | $184,406 | $1,431,624 | $1,970,863 | $3,586,893 |
| | *Drilling Percent* | **0%** | **21%** | **52%** | **67%** | **53%** |

Table 8 Recommended Improvement Costs by Distress Type and Functional Class

| | | Drainage | Rutting | Dust | Washboards | Potholes | TOTAL |
|---|---|---|---|---|---|---|---|
| **Resource** | *All Roads* | $4,883 | $211,944 | $0 | $0 | $0 | $216,826 |
| | *Drilling Roads* | $0 | $0 | $0 | $0 | $0 | $0 |
| | ***Drilling Percent*** | 0% | 0% | -- | -- | -- | 0% |
| **Local** | *All Roads* | $8,848 | $800,462 | $8,081 | $12,250 | $49,900 | $879,542 |
| | *Drilling Roads* | $2,971 | $181,435 | $0 | $0 | $0 | $184,406 |
| | ***Drilling Percent*** | 34% | 23% | 0% | 0% | 0% | 21% |
| **Minor Collector** | *All Roads* | $145,401 | $465,487 | $41,402 | $151,296 | $1,942,163 | $2,745,749 |
| | *Drilling Roads* | $510 | $382,767 | $34,646 | $89,928 | $923,774 | $1,431,624 |
| | ***Drilling Percent*** | 0% | 82% | 84% | 59% | 48% | 52% |
| **Major Collector** | *All Roads* | $4,794 | $195,748 | $283,129 | $0 | $2,451,919 | $2,935,590 |
| | *Drilling Roads* | $0 | $147,476 | $283,129 | $0 | $1,540,259 | $1,970,863 |
| | ***Drilling Percent*** | 0% | 75% | 100% | -- | 63% | 67% |
| **All Classes** | *All Roads* | $163,925 | $1,673,642 | $332,612 | $163,546 | $4,443,982 | $6,777,707 |
| | *Drilling Roads* | $3,481 | $711,677 | $317,774 | $89,928 | $2,464,033 | $3,586,893 |
| | ***Drilling Percent*** | 2% | 43% | 96% | 55% | 55% | 53% |

**FIGURE 1  Dead Horse Road, Johnson County, Wyoming.**

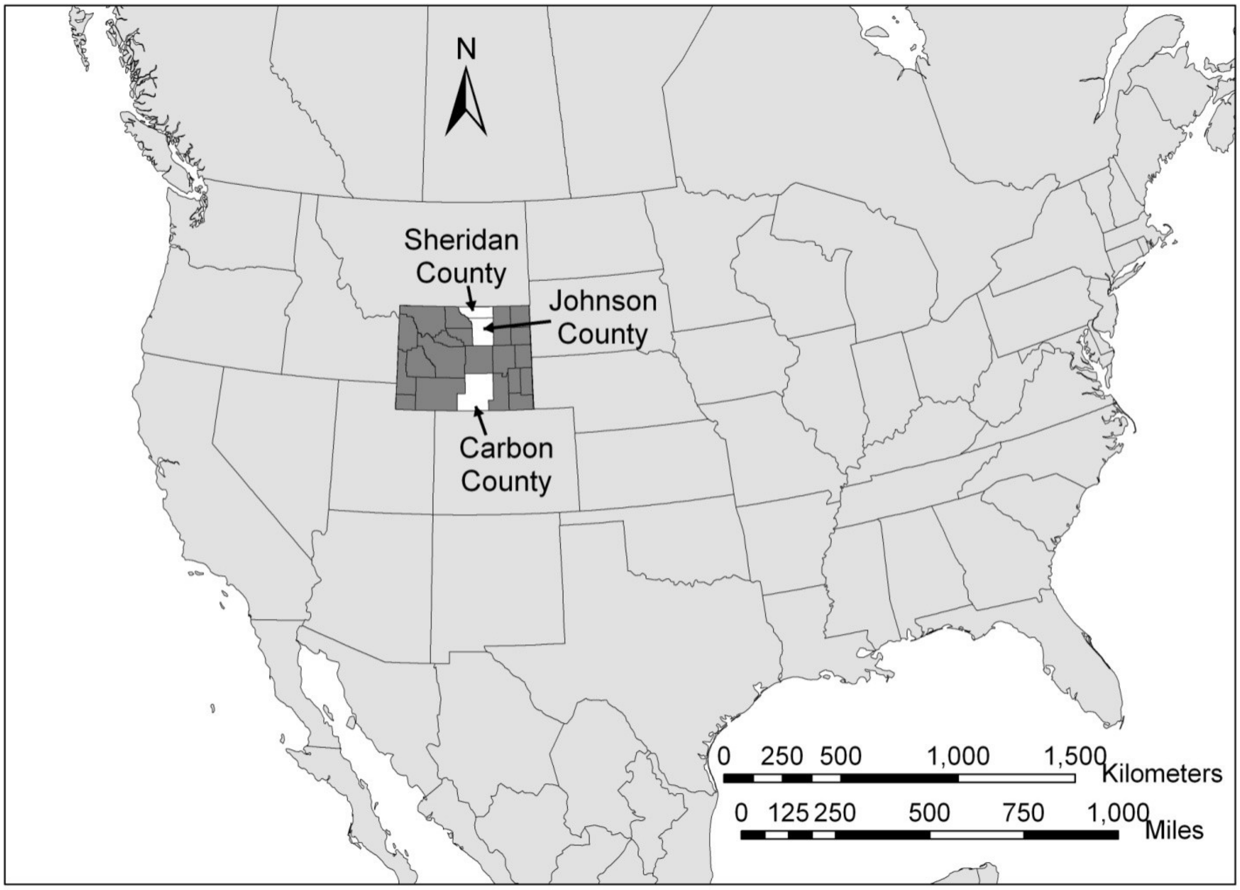



**FIGURE 2 Sheridan, Johnson, and Carbon Counties, Wyoming, USA.**

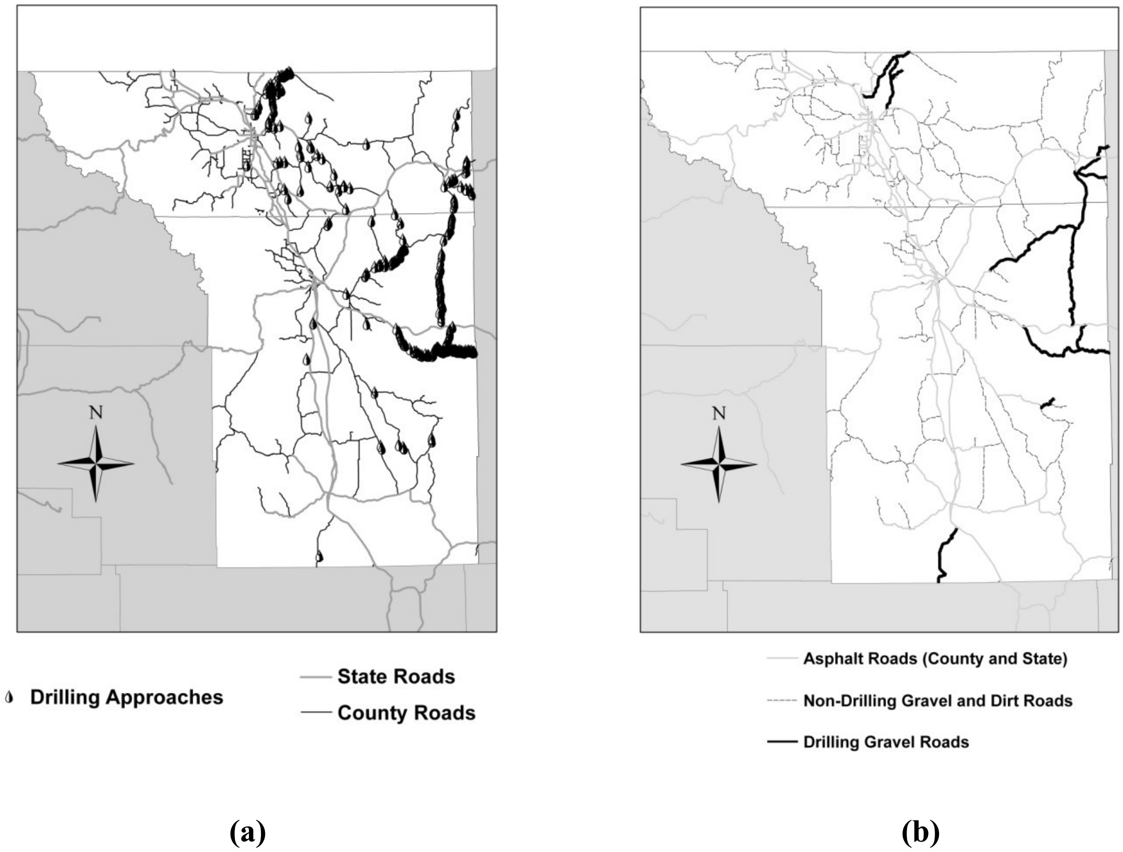



**FIGURE 3 Drilling approaches (a) and roads (b), Sheridan County (N) and Johnson County (S).**

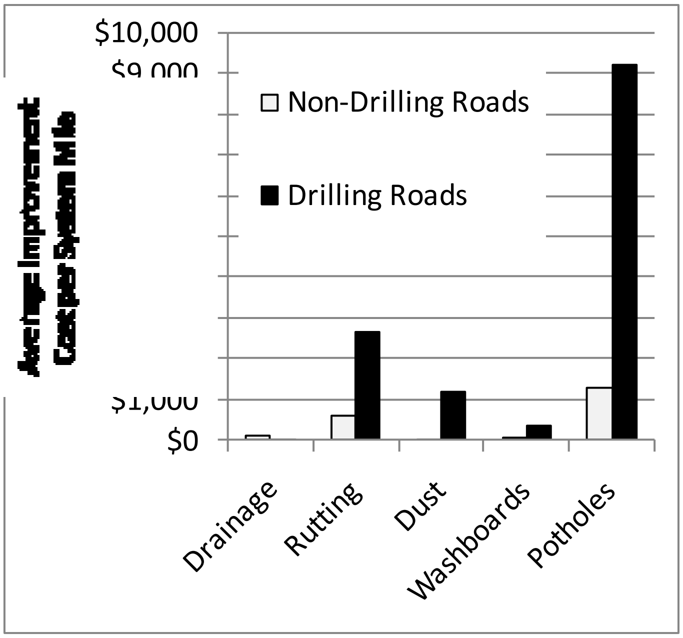
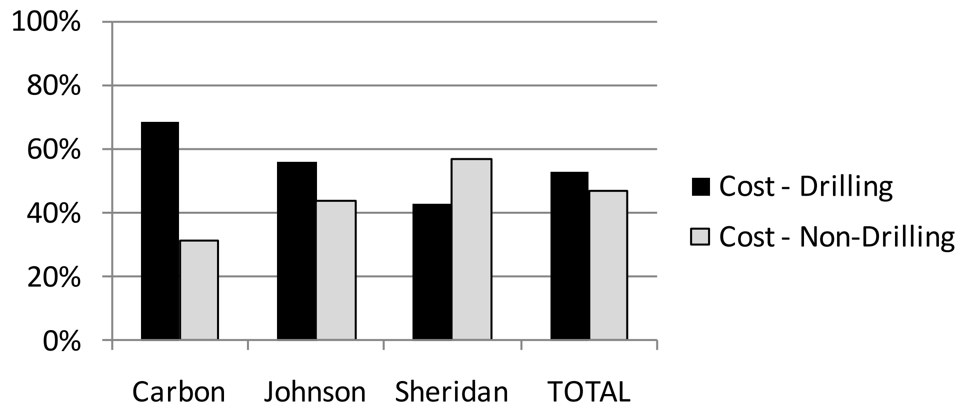
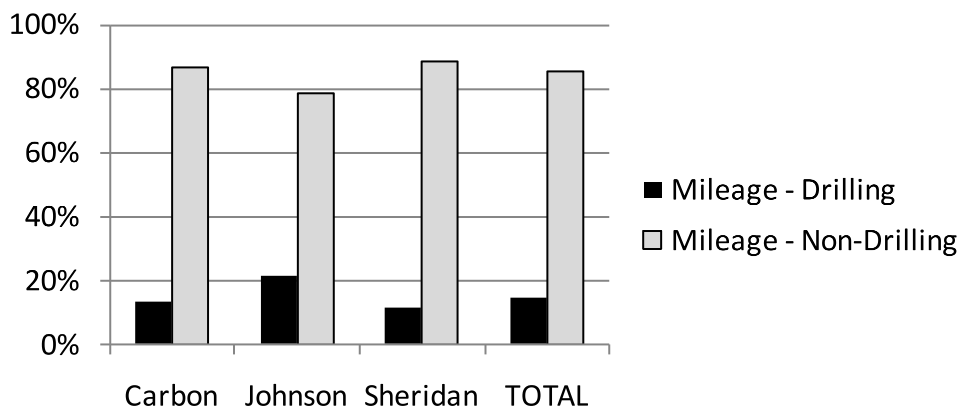



**FIGURE 4 Cost of recommended improvements due to distress type.**




(a)




**(b)**

**FIGURE 5 Costs of recommended improvements (a) and total gravel mileages (b) on drilling and non-drilling roads.**