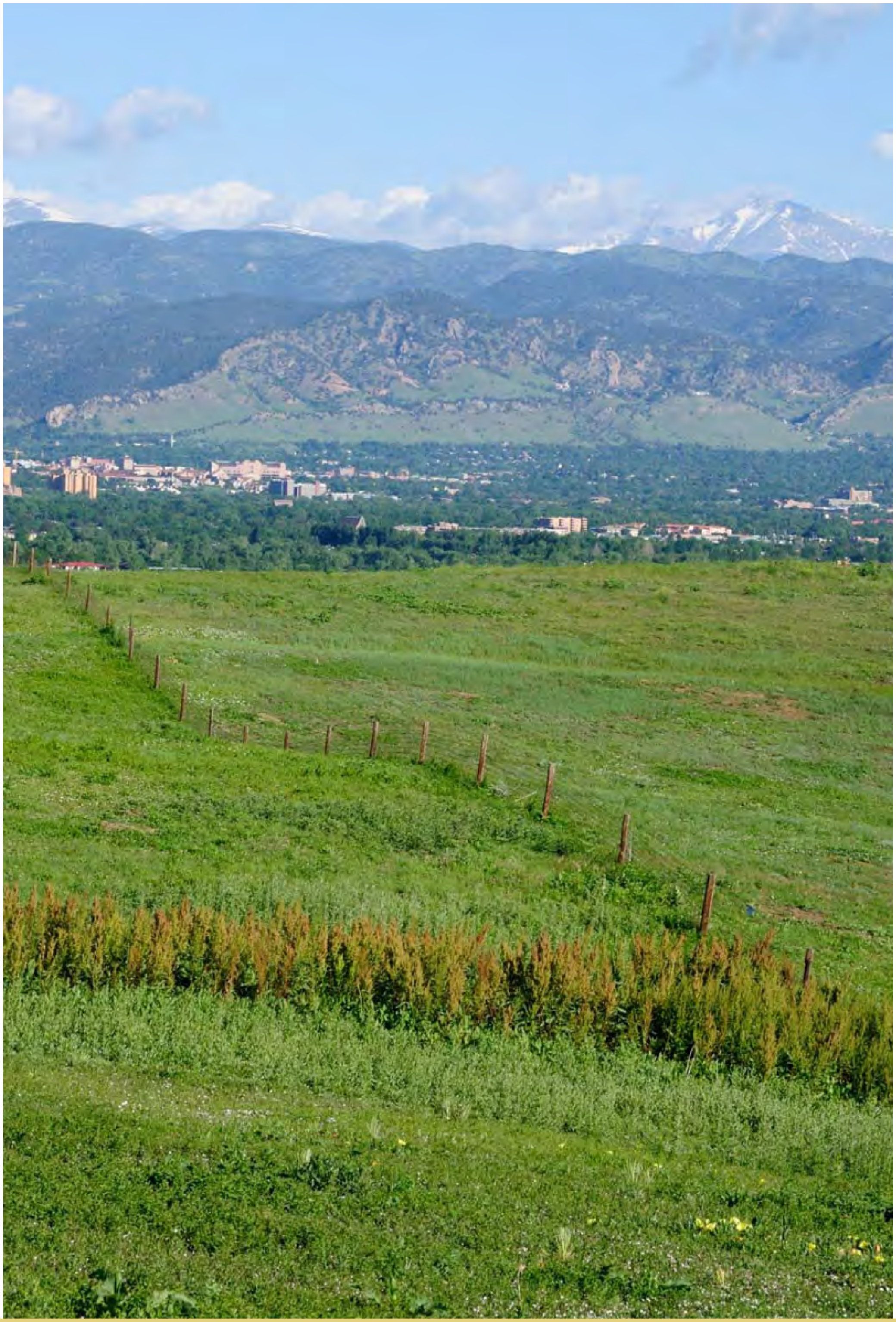
boulder county oil and gas roadway impact study

Final Draft

January 2013



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BBC RESEARCH & CONSULTING

Boulder County

boulder county oil and gas roadway impact study

FINAL DRAFT

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I. INTRODUCTION

Colorado is one of the nation's leading energy producing states. In 2011, Colorado was the 7th largest in total energy production, 10th in crude oil production and 5th in natural gas production. Oil and gas energy, in particular, is a growing sector in the region and ten of the nation's 100 largest natural gas fields and three of its 100 largest oil fields are found in Colorado (source: U.S. Energy Information Administration). One of the state's largest oil and gas producing areas is the Wattenberg Field and the Niobrara shale formation, including eastern Boulder County.

In 1901, oil was discovered in Boulder County and there are now hundreds of wells in the county. Because of Boulder County's close proximity to Weld County and the Wattenberg Oil Field, there has recently been a marked increase in the number of Boulder County oil and gas drilling permit applications.

The center of the Boulder Oil Field, 1902.
Source: Art Source International

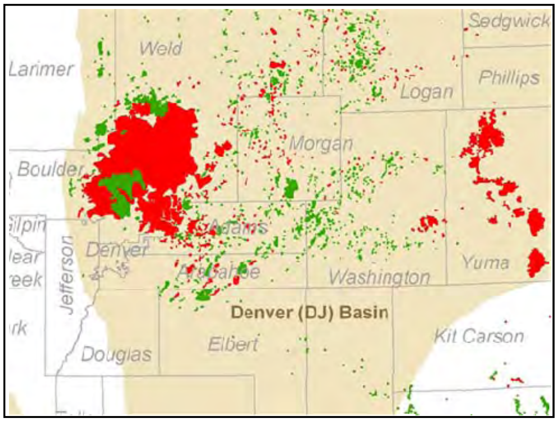
In February of 2012, the Boulder County Board of County Commissioners approved a temporary moratorium on local oil and gas permits. In April of 2012, the moratorium was extended to February 4, 2013 in order to study the potential impacts of significantly expanded oil and gas drilling in the region. During the moratorium the Planning Commission, Board of County Commissioners and Land Use Staff are working to study and update new oil and gas land use code regulations last updated in 1993. In November and December of 2012, the Planning Commission, Land Use staff and Board of County Commissioners entered into the review and public hearings stage to discuss the draft regulations.

Oil and gas drilling and production can impact local road systems, as well as other public infrastructure and services. Boulder County has commissioned this study to understand the potential impacts of oil and gas development and production on the County's road system and to design a road deterioration and safety fee to offset increased transportation maintenance, rehabilitation, and safety costs associated with heavy truck traffic and road damage.

Background

The Niobrara Shale

The Niobrara shale formation is a large geologic zone located in the central plains of North America. Remnants of ancient microorganisms that lived in the ancient inland sea about 85 million years ago comprise the shale formation. The geological zone spans portions of four states, including eastern Colorado, southeast Wyoming, western Nebraska and a small portion of northwest Kansas. The area is also referred to as the Denver-Julesburg Basin.



Oil and gas well locations in the Niobrara Shale in Colorado. Red indicates gas wells and green indicates petroleum wells.
Source: Buffalo Royalties, an energy management and investment company, 2011.

In 1901, the discovery of petroleum in Boulder County introduced energy production to the region. Because of advancements in technology and growing demand, oil and natural gas development began to dominate resource extraction activity in the basin. The production of natural gas in the Niobrara occurs predominately in the Colorado counties of Weld, Yuma and Washington and in southwestern Nebraska. Oil production is scattered throughout the region with higher concentrations in the north central and southwest part of the shale formation. As of December 2012, there were 49,993 producing oil or gas wells in Colorado, over 25,000 (approximately one-half) of which were in Niobrara Shale counties. A majority (about 19,700) of these wells is located in Weld County.

Colorado Front Range resource development over the past decade has been concentrated in Weld County. In the first 11 months of 2012, over 1,680 drilling permits were issued in Weld County while only a total of 103 drilling permits were issued in Adams, Arapahoe, Boulder, Morgan and Washington counties combined.

Boulder County Energy Development

Due to Boulder County's location along the western edge of the Wattenberg Field, energy companies are in the early stages of a new wave of exploration and drilling in Boulder County. Many national and international factors will shape future levels of drilling activity, including oil and gas prices, national economic growth prospects, and the merit of the Niobrara Shale relative to other production areas. Locally, a host of additional factors will influence how quickly efforts are made to determine a new field's prospects. Boulder County is one of several counties that lie above the Niobrara Shale. Depending on the geology of the shale, drilling could occur in any of the counties.

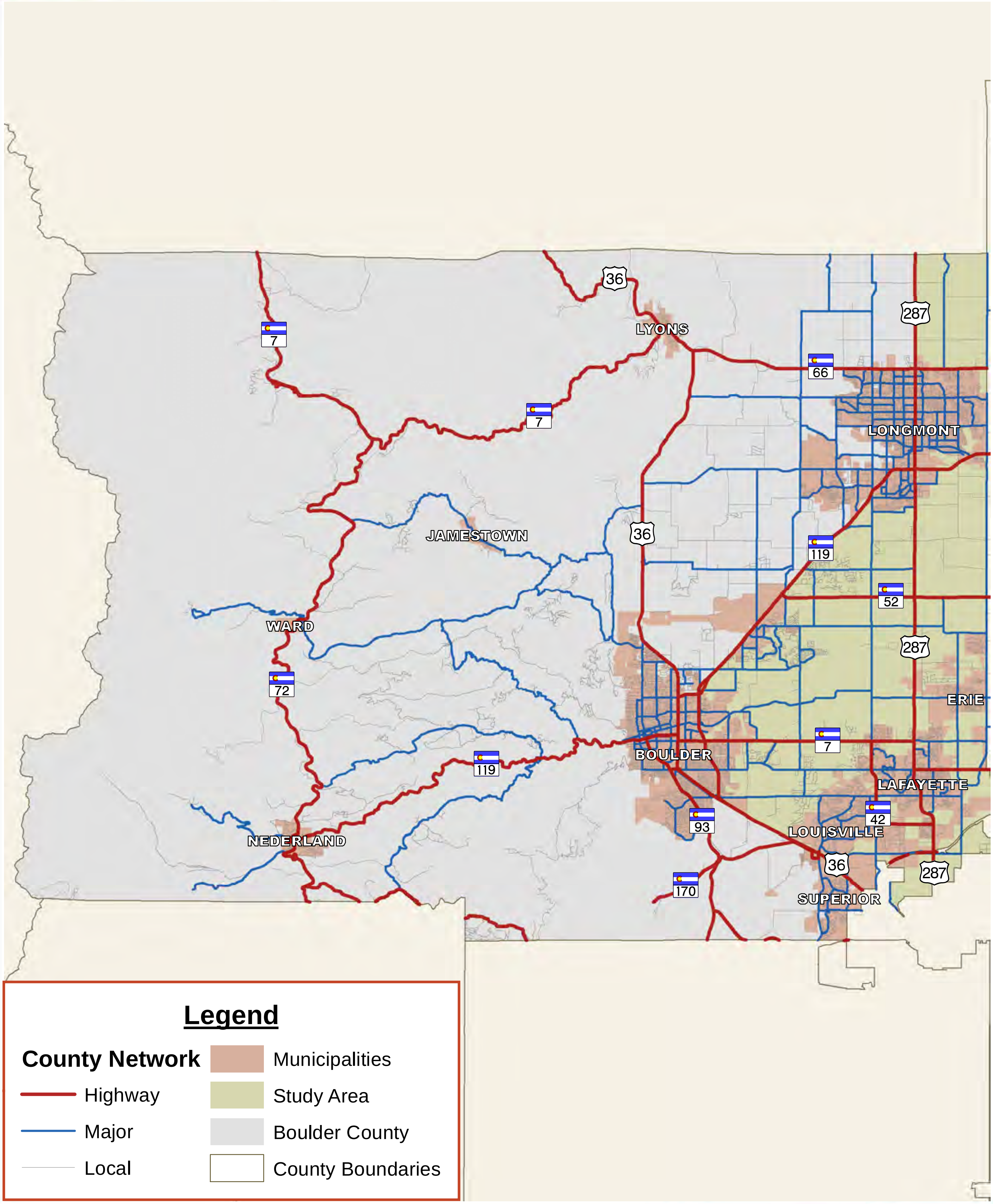
As of December 2012, there were 323 active oil and gas wells in Boulder County. In the first 11 months of 2012, the state (COGCC) approved 22 drilling permits in Boulder County. These permits await local approval after the moratorium is lifted in 2013.

Figure 1 on the following page shows the study area that includes the eastern portion of Boulder County. This area is home to the highest concentration of currently producing wells in the county and is likely to be the target area of new development. The oil and gas study area is defined as the unincorporated county land bordered by US 36 to the south, SH 119 and US 287 to the west and the eastern county line. All municipalities within the boundaries are excluded from the study area.

Based on producing wells in neighboring counties, energy companies will likely be primarily drilling for natural gas, and well depths will likely be between 6,000 and 8,000 feet.

boulder county oil and gas roadway impact study

Figure 1
Study Area



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Study Purpose

With the heightened interest in future oil and gas activity in and around Boulder County, the County issued a moratorium on drilling in February 2012. Since then, the County has worked to research and characterize many facets of oil and gas land use. This study is part of the broader update of the proposed oil and gas land use regulations. The study seeks to understand the potential impacts of oil and gas development to the county roadway system and to design fees as a prospective method to recover incremental costs associated with road deterioration and safety.

Because of the uncertainties associated with renewed oil and gas development in Boulder County, this study looks at three potential development scenarios (accelerated, steady, and low) in order to provide a range of potential road deterioration and safety costs. This study is not intended to predict oil and gas development location or intensity, rather to provide County officials with information about the potential impacts to the transportation system and associated county costs using an informed set of development scenarios based on the best available data.

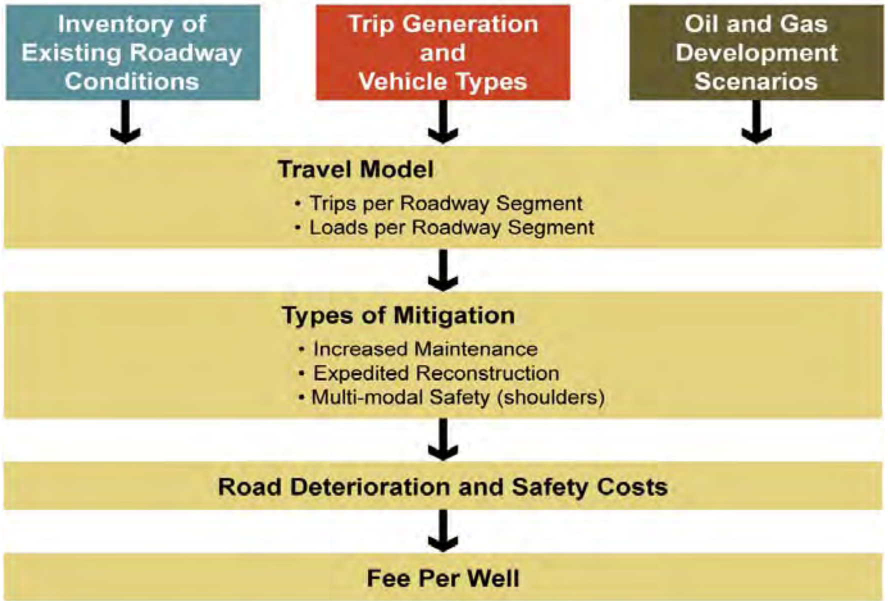
This study includes the design and calculation of road deterioration and safety fees that could offset the transportation-related damage of oil and gas development. Boulder County has broad power derived from state statutes to regulate public roads over which it has jurisdiction. The oil and gas road deterioration and safety fees are designed and structured within these parameters in cooperation with the Boulder County Transportation Department and County Attorney's office.

Process

To achieve the study purpose of assessing the potential impacts to the transportation system, quantifying maintenance, rehabilitation, and safety needs and calculating an appropriate road deterioration and safety fee, a series of analytical techniques have been used. The three primary inputs to the study process are shown on the top row of **Figure 2**. The inventory of existing roadway conditions provides a baseline for identifying investment needs that might result from oil and gas truck impacts. The trip generation and vehicle types provide the foundation for assigning trips and vehicle loads to the county roadway network. Finally, the oil and gas development scenarios serve to bracket the potential levels of impact.

All three primary inputs have been used in the development of a travel model, which assigns both oil and gas trips and loads to individual county road segments. Using the results of the travel model, mitigation strategies can be identified based on roadway maintenance needs, roadway rehabilitation and roadway safety improvements, resulting in incremental roadway deterioration and safety costs associated with each development scenario. After the incremental costs of road deterioration and road safety costs are calculated, a fee is designed to recover these costs during the oil and gas land use application process.

Figure 2. Study Process Diagram



Each box in **Figure 2** represents a set of calculations, many of which require assumptions because of the uncertainties of oil and gas development in general (e.g., the intensity of development), as well as the development potential of the field in Boulder County. The study team has relied heavily on input from previous studies pertaining to the impacts of oil and gas development from the Marcellus Shale in Pennsylvania, Barnett Shale in Texas and Uinta Basin in Utah. Likewise, the study team conducted a series of interviews with key industry representatives and COGCC staff for insight in establishing the development scenarios and understanding how and where oil and gas trucks could potentially impact the county roads. A list of references and a summary of the interviews are provided in **Appendix A** and **Appendix B**, respectively.

II. RESOURCE DEVELOPMENT

Well Development Overview

There are five stages in the development and operation of an oil or gas well:

- **Leasing and exploration** – Obtaining mineral rights and developing a well drilling program.
- **Pad construction** – Preparing the site, including building the access road and the well pad.
- **Drilling** – The process of drilling the well to the desired depth and completing the requisite number of horizontal bores.
- **Completion** – Converting the well system to a producing well, typically by fracturing the shale and completing the production well requirements. Removing flowback water from the well pad.
- **Production** – Extracting, storing and distributing the resource.

This process, as it is likely to occur within Boulder County, is described in greater detail in the following sections.

Leasing and Exploration

Drilling requires acquisition of subsurface mineral rights, which are often, but not exclusively, owned apart from a property's surface rights. Energy companies that have an interest in exploring an area for energy prospects, or extracting resources from a known reserve, must first buy or lease the appropriate subsurface ownership rights. Companies often negotiate mineral right acquisition on speculation, before the presence of productive resource is certain. In many instances, there can be aggressive leasing activity, which is followed by very little immediate development activity, or an area can be determined to be an unproductive source after a few test wells. Active mineral leasing efforts do not ensure future energy extraction.

Geologists and petroleum engineers will target an area for exploration, typically based on nearby well development patterns, and then company representatives will seek out property owners to acquire leases. Companies often try to maintain secrecy in this process in order to reduce speculation and keep lease costs down. Most companies will try to control a large area so that multiple wells can be drilled and the economic benefits of expensive exploration, leasing and well field development can be efficiently recovered. Often multiple companies will share in an individual well's, or a field's, financial returns.

With mineral rights secured, energy companies will approach the Colorado Oil and Gas Conservation Commission (COGCC) for confirmation of a drilling and spacing plan, which suggests the area in which initial drilling will occur. Companies may approach drilling operations slowly, spending time researching and surveying to determine the best locations for individual well development. If mineral rights are secure, companies sometimes allow other operators to proceed, modifying their own plans based on their competitors' success or failures. Many factors can influence how quickly efforts are made to determine a new field's prospects. Geological surveys, seismic exploration, core sampling and exploratory wells are common tools used to gauge the potential productivity of a region.

Exploratory wells are placed in order to obtain core samples and determine the likely productivity of the target shale. Results from the exploratory wells and the geography of an individual company's mineral rights holdings will dictate the larger field development strategy.

Pad Construction

The first stage of development is the construction phase. In the construction phase, crews build a road to the drilling site and construct a well pad. This process requires building a gravel road and grading a pad site generally 3 to 5 acres in area. Some pad sites contain multiple wells that may range from one to twenty, however the road and the pad require roughly the same amount of construction equipment, materials and truck trips.

Constructed well pad in Pennsylvania.
Source: Linde Corporation

Drilling

The next stage of development is the drilling stage. This stage requires one drilling rig to drill the well bore into the earth and continue horizontally in the direction of the intended extraction locations. In the Niobrara Shale, typical wells reach depths of between 6,000 to 8,000 feet and can extend a mile horizontally into the shale formation. If the site is a multi-well pad, the same single rig generally drills all wells on the pad. While the drilling rig transport is sensitive to the number of pads constructed, transportation of other materials including drilling fluid and materials, drilling equipment, casing and drill pipe are all "well sensitive", meaning each well will require additional materials. The number of trips required to transport the drilling materials will increase with each well on the pad. A well requires about 15-25 days to be drilled depending on the desired depth and lateral extension of the well.

Horizontal Drilling Rig in Pennsylvania.
Source: Matthew Burns, Go Marcellus Shale

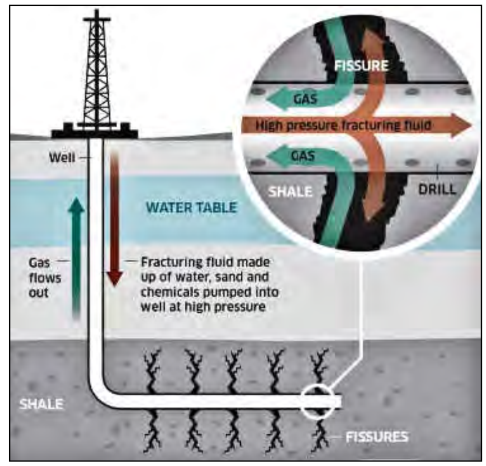
Completion

Once drilling is complete, the drilling rig is replaced with a multitude of hydraulic fracturing equipment including blender trucks, pump trucks, water tanks, flowback water trucks and fracture sand. Most of the completion equipment is well sensitive, meaning the number of trips will increase depending on the number of wells

Completion rig and trucks on a well pad.
Source: MIT Technology Review, Les Stone/Corbis

on each pad. Well completion requires significant truck trips primarily because of the water required in fracking the wells and the disposal of flowback water. On average, well completion requires between two and four million gallons of water. A typical water truck has capacity of between 5,000 and 6,000 gallons. Thus, on average, hauling water to the site and flowback water away from the site requires about 700 water round trips or about 1,400 one-way trips.

The workers first use a fracking gun to penetrate through the well casing and fracture the shale at the furthest depths of the well. Once the well has been penetrated by the fracking gun in the appropriate areas, a highly pressurized mixture of water is pumped into the fractures starting at the deepest end of the well. The fracking fluid flows through the fractures and begins to crack the shale along natural weaknesses in the rock. Proppant, usually a sand mixture, is introduced into the fractures to keep the cracks open and help oil and gas escape into the well. The workers use a series of plugs to maintain the pressure of a fracked segment and continue to frack the shale along the horizontal well. During this stage, between three and five million gallons of water are pumped at high pressures into the shale and then subsequently retrieved. Under the state's Oil and Gas Commission guidelines, all water used in this process is either recycled or properly disposed of under Commission regulations. The importation of water to the well and the subsequent removal to an approved disposal site is the most truck intensive element of a well's development.



Drilling and completion stage technology: hydraulic fracking and horizontal drilling.
Source: Sustainable Online Magazine, 2010

Once each of the arms of a well is sufficiently fractured, the plugs are removed and the well is ready for production, or the extraction of oil and gas. The completion stage takes between 15-20 days, depending on the depth and horizontal extension of the well.

Production

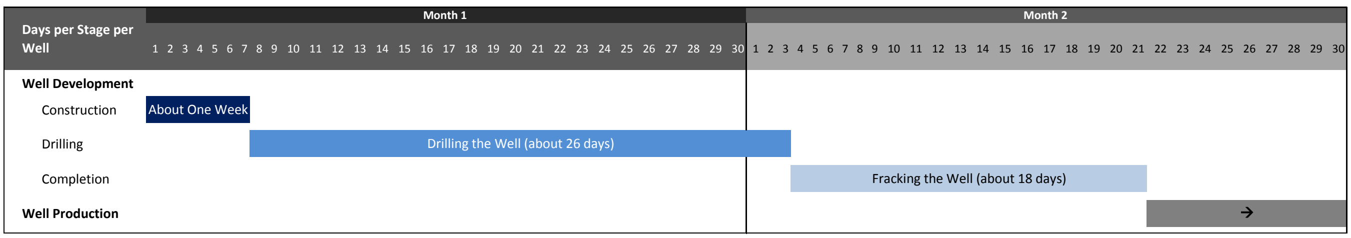
Once the well is complete, the well pad transitions to the production phase of pumping oil or gas and produced water from the well for storage, disposal or distribution. This requires the removal of completion machinery and the installation of production machinery including a wellhead, machines that separate the oil, gas and water, resource storage tanks and other well monitoring equipment. As oil and gas is pumped from the well, the contents are sent to machines that separate the oil, gas, water, and other gases. The produced water is either released into evaporative ponds or injected into underground injection wells, which often requires transport by pipeline or truck. The well maintains optimal pressure to continue the production of energy resources and is monitored by pressure gauges. If any abnormality is indicated, the well maintenance crew, located off-site, is automatically notified.

During the production phase, the number of truck trips required for each well drops significantly to about two truck trips per day or 730 trips annually. These trucks are necessary for minor well maintenance while larger vehicles are required for resource collection and any other major tasks supporting production. Production trips continue throughout the life of the well, possibly 15 to 25 years. In areas of highly clustered energy development, pipelines transport energy and waterlines transport produced water away from the site to common holding or distribution facilities.

Duration of Well Development

The approximate timing of constructing, drilling and completing a traditional single-well oil and gas well in a shale formation is between 45 and 60 days. **Figure 3** shows the schedule of developing one well on one pad site. Constructing the access road and pad takes about a week to complete. The drilling phase, including horizontal drilling, takes about 20-30 days to complete. The completion stage, including hydraulic fracturing, takes roughly 15-20 days to complete. Finally, the production phase lasts for the remaining life of the well, possibly 15-25 years. Multi-well pads have an extended development schedule.

Figure 3. Approximate Time Schedule to Develop One Well on One Pad Site



Sources: Capita Wells/Stagecoach Area Final Environmental Impact Statement, 2005; Tribal Energy and Environmental Information Clearinghouse, 2010.

Transportation Demands of Oil and Gas Development

Trip Generation

Oil and gas development requires the transport of heavy equipment to the well site to build access roads, construct a well pad and transport a drilling rig. Heavy trucks are also required to bring fresh water to the well site and often to transport produced water and extracted resources off site. There are three independent studies that inform a model of approximate truck trip generation in Boulder County. These studies were conducted by the National Parks Service, NTC Consultants and the Utah Department of Transportation (UDOT). Multiple studies focused in the Marcellus Shale formation in Pennsylvania, New York and Ohio refer to the truck trip data of the National Park Service study. In addition, other Marcellus Shale development studies use NTC truck trip data. The UDOT study quantifies potential truck trips of oil and gas development in the Utah's Uinta Basin.

The study team also conducted a literature review to determine if new research has been published related to energy development and transportation effects. The team interviewed knowledgeable persons that are connected to oil and gas development in the Niobrara Basin, including extensive discussions with well permitting staff at the COGCC.

National Data Sources on Single Well Trip Generation

Table 1 shows data extracted from multiple national and regional studies examining vehicle trip production by well development phase. The trips of each study are averaged across each phase of development and then summed to calculate trip generation figures.

Table 1. National Data on Trip Generation per Well

Phase		NPS 2008 1 pad, 1 well	NTC 2011 1 pad, 1 well	NTC 2009 1 pad, 1 well	UDOT 2006 1 pad, 1 well	Average 1 pad, 1 well
Construction	Pad and Road Construction	55	180	56	55	87
Drilling	Drilling Rig	60	190	60	60	93
	Drilling Fluid and Materials	75	90	75	30	68
	Drilling Equipment (casing, drill pipe, etc.)	75	190	75	-	113
Completion	Completion Rig	30	-	30	65	42
	Completion Fluid and Materials	30	40	30	70	43
	Completion Equipment (pipe, wellhead, etc.)	10	10	10	-	10
	Fracturing Equipment (pump trucks, tanks, etc.)	250	350	350	-	317
	Fracture Water	1,052	1,000	1,000	1,100	1,038
	Fracture Sand	48	46	45	52	48
	Flowback Water Disposal	-	200	500	-	350
Total Development Trips						**2,206**

Sources:

"Potential Development of the Natural Gas Resources in the Marcellus Shale", National Park Service, December 2008

"MIT Study on the Future of Natural Gas", NTC Consultants, 2010

"Impacts on Community Character of Horizontal Drilling and High Volume Hydraulic Fracturing in Marcellus Shale and Other Low-Permeability Gas Reservoirs", NTC Consultants, September 2009.

"Impacts on Community Character of Horizontal Drilling and High Volume Hydraulic Fracturing in Marcellus Shale and Other Low-Permeability Gas Reservoirs", NTC Consultants, February 2011.

"Highway Freight Traffic Associated with the Development of Oil and Gas Wells", Utah Department of Transportation, October 2006.

All trip estimates in **Table 1** include both inbound and outbound trips (Example: NTC 2011 identified 180 construction trips or 90 inbound and 90 outbound trips). The average trips per well data are for a specified development period of roughly 1.5 to 2 months, while the production related trips are expressed as annual trips and will continue for the duration of the well's production.

These data suggest that a typical well will generate about 2,206 trips during its two month development period or an average of 36 trips per day, largely related to water delivery and removal.

Production Phase Trip Generation

There are a number of factors that determine trip generation during the production stage including the nature of the field, success of wells and storage capacity for produced water and resource at the well pad. Based on a number of studies including a report by the Texas Department of Transportation (TXDOT) on the Barnett Shale, we expect an annual trip count of 730, based on 2 trips per day per well pad.

According to the TXDOT study, about 706 total trips are required per year to maintain a well pad (353 trucks per year). In addition, every five years another 1,994 trips (997 loaded trucks) are needed to "re-frack" a well. This brings the annual total trips to about 1.93 trips per day and an additional 5.5 daily trips every 5th year. However, the frequency and extent of re-fracking is uncertain. Because of this, an estimate two trips per day over the life of a well has been used.

Multi-Well Pad Site Trip Generation

As new horizontal drilling and fracturing techniques come into Boulder County, the regional standard practice is likely to become multiple wells on a single pad.

In order to make a reasoned and informed estimate on truck trip generation, the project team used the data from the four studies outlined in **Table 1**. The studies contain essentially the same stages of well development and are in one rig, one well format. However, based on industry trends, recent well permits and regional well-per-pad ratio intensities, Boulder County well development is expected to consist of a one rig, four well design. This change in development intensity and pattern will affect traffic generation and the traffic profile associated with drilling activity.

Table 2 shows the trip sensitivity by development stage from the 2009 NTC study. The project team used the underlying relationships in the study to adapt trip generation figures in all studies from one pad, single well pads to one pad, four well pads. The process involves increasing well-sensitive trips, such as fracking water and drilling fluid hauling, while holding pad-sensitive trips, such as pad construction trips and drilling rig transport, constant.

Table 2. Trip Generation Sensitivity for Single to Multi-Well Pad Conversion

Activity	Trip sensitivity
Construction Stage	
Pad and Road Construction	Pad sensitive
Drilling Stage	
Drilling Rig	Pad sensitive
Drilling Fluid and Materials	Well sensitive
Drilling Equipment (casing, drill pipe, etc.)	Well sensitive
Completion Stage	
Completion Rig	Pad sensitive
Completion Fluid and Materials	Well sensitive
Completion Equipment (pipe, wellhead, etc.)	Pad sensitive
Fracturing Equipment (pump trucks, tanks, etc.)	Pad sensitive
Fracture Water	Well sensitive
Fracture Sand	Well sensitive
Flowback Water Disposal	Well sensitive

Source: NTC Consulting, 2009

III. OIL AND GAS DEVELOPMENT SCENARIOS

This chapter provides potential future oil and gas development scenarios in Boulder County based on a blended methodology using expected well spacing and historic drilling rig counts. The study team also examined historic well development in active counties in Colorado to validate the development scenario estimates.

Due to its location in the Niobrara region along the western edge of the Wattenberg Field, energy companies are in the early stages of a new wave of exploration and drilling in Boulder County. Many national and international factors will shape future levels of drilling activity, including oil and gas prices, national economic growth prospects, and the merit of the Niobrara Shale relative to other production areas. Locally, a host of additional factors will influence how quickly efforts are made to determine a new field's prospects. Boulder County is one of several counties that lie above the Niobrara Shale. Depending on the geology of the shale, drilling could occur in any of the counties.

The study team developed a set of three future development scenarios based on expected well spacing and historic rig counts. The following exercise is not an attempt to predict the future, but rather an effort to develop an informed set of development scenarios based on the best available data.

Scenario Development Methodology

As part of the background research effort, the study team reviewed information from multiple sources, including local news outlets, energy company investor literature and the Colorado Oil and Gas Conservation Commission (COGCC). The goal of the literature review was to document current statewide and Front Range well drilling activity and field spacing patterns.

Future development scenarios were derived by mapping Boulder and neighboring counties and determining potential well development given expected well spacing patterns. The study team used historic drilling rig utilization rates to derive an estimate of the potential pace of well development over a 16-year period.

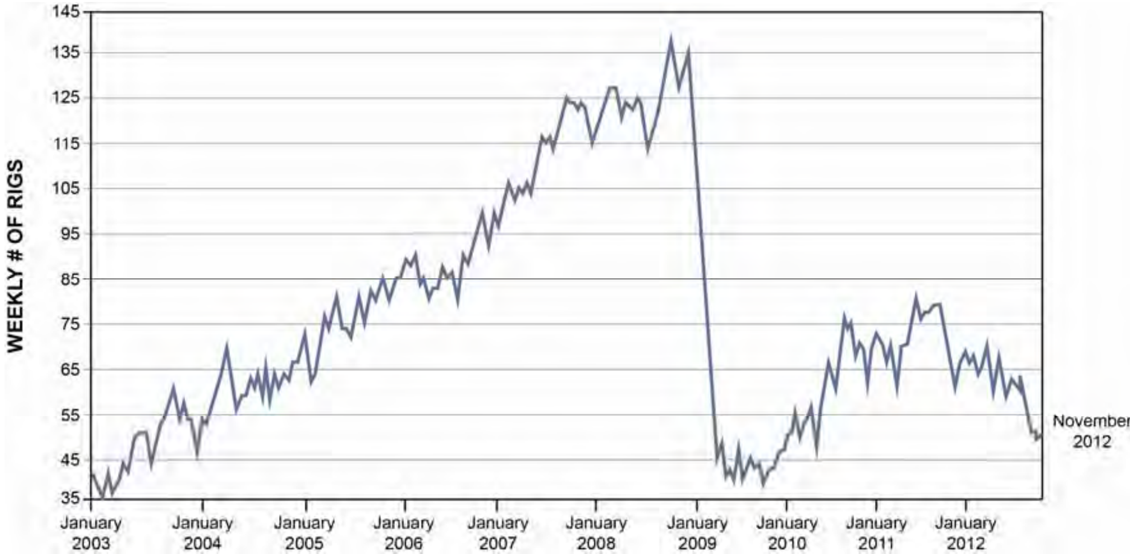
Rig Utilization

Drilling rigs are a large capital investment for any oil and gas development company. Drilling rig purchase or rental costs represent a significant barrier to entry into the industry. According to Baker Hughes, an oil field service company that tracks drilling rigs, there were 1,800 drilling rigs operating in the U.S. on December 7, 2012. Of those rigs, about 53 were operating in Colorado according to the COGCC.

Figure 4 shows the number of drilling rigs in operation in Colorado by week from 2003 to the present. The graph above shows operating drilling rigs peaked in fall 2008, before dropping precipitously. In fall 2008, there were nearly 140 drilling rigs in operation in Colorado. According to the most current estimate, there is less than half of the historic peak rig activity currently in operation in the state.

As of December 10, the COGCC reports that about 33 rigs are operating in Weld County, 9 rigs in Garfield County and 11 rigs spread among other counties in the state. Rig allocation has not topped 40 rigs in any one county in Colorado since the beginning of 2011.

Figure 4. Total Drilling Rigs Running in Colorado (2003-November 2012)



Source: COGCC Colorado Weekly & Monthly Oil & Gas Statistics, November 27, 2012.

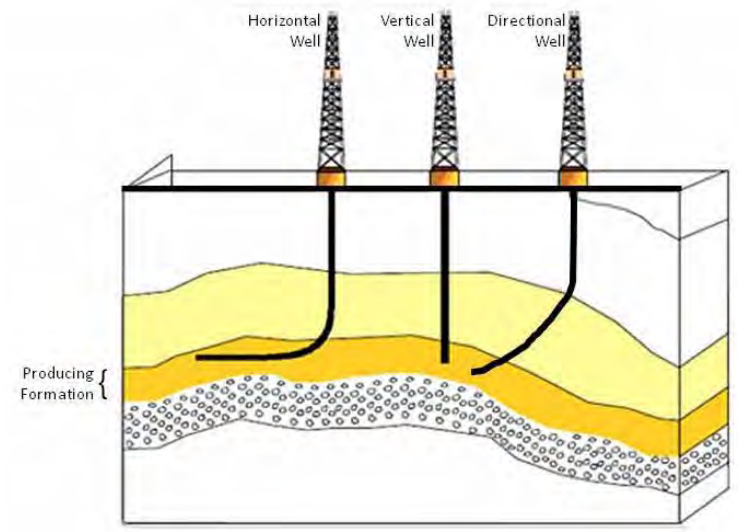
The study team contacted COGCC staff to discuss drilling scenario development. COGCC staff described a favored methodology, where drilling rigs and the well drilling period can be used to calculate the total amount of annual wells drilled per year. The information presented in Chapter II indicates that, in general, a typical well would take approximately 30 days to drill. Therefore, one rig can drill about 12 wells per year. Oil and gas companies have a finite amount of capital resources and operating a drilling rig is expensive and requires a significant capital commitment.

Oil and gas operators will allocate drilling rigs to areas that show the most promise in developing a productive well. Depending on their land holdings, oil and gas companies will consider other counties along the Front Range, Western Slope and across the nation, when deciding where to drill.

Boulder County Well Types and Spacing

The Wattenberg Field is one of the oldest oil and gas fields in Colorado and has seen a variety of drilling techniques to reach the resource rich formations. Past well development techniques in the area include directional and vertical wells to reach targeted resource deposits. **Figure 5** illustrates the types of drilling techniques in the Wattenberg Field.

Figure 5. Well drilling techniques

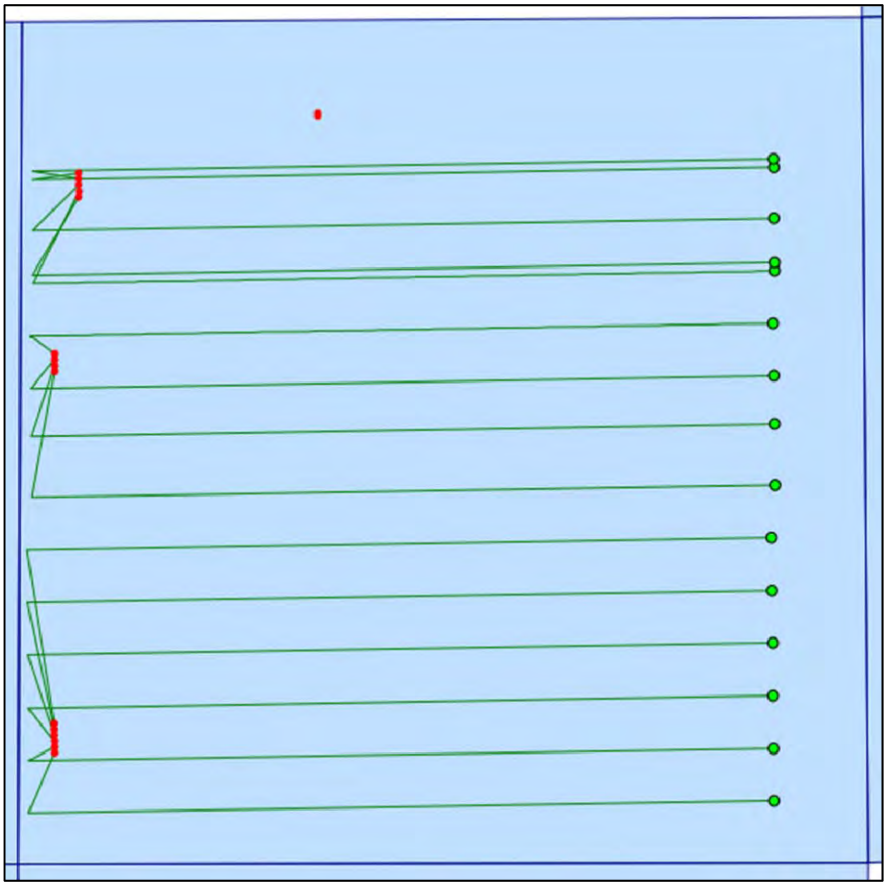


Source: Energy Information Administration, Office of Oil and Gas, BBC Research & Consulting.

Energy companies have learned over time that the most effective method to extract the hydrocarbons from shale formations is to drill horizontal wells and frack the shale to release the resource.

The study team met with COGCC well permitting staff to discuss current trends in the Wattenberg Field and possible future well development scenarios in Boulder County. The identified development study area lies within the boundaries of the Greater Wattenberg Area (GWA) and is subject to Rule 318A to guide the spacing parameters of new wells based on setbacks from lease lines, other well heads and frack lines. The most current spacing guidelines and setbacks for the Wattenberg allow generally for a maximum number of 16 horizontal wells in one square mile section. This rare and high-intensity development pattern is found primarily in Weld County above the Wattenberg Field “sweetspot.” **Figure 6** shows a sample square-mile section in Weld County obtained from the COGCC online GIS tool.

Figure 6. Horizontal Wells in Square-Mile Section, Weld County, December 2012



Source: COGCC GIS Online.

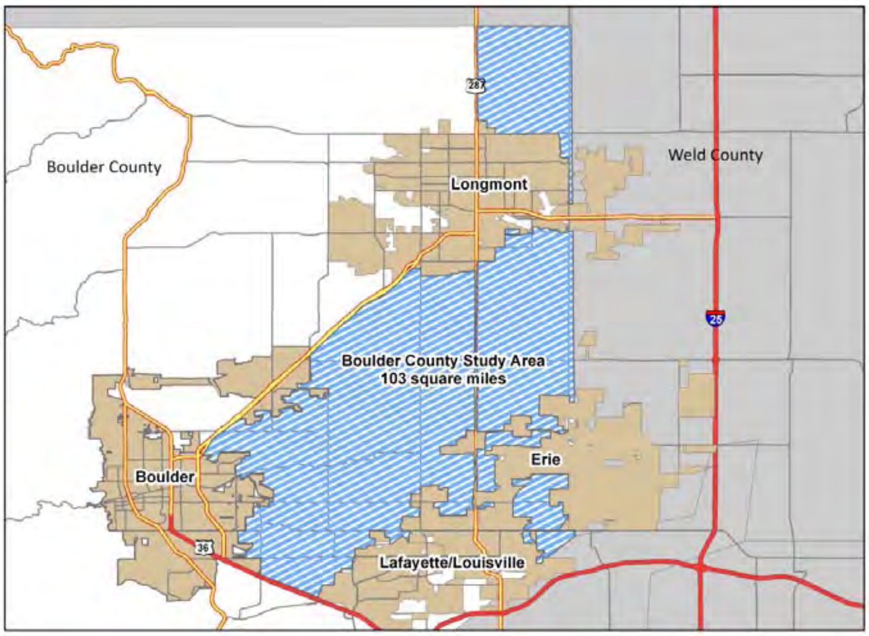
The Weld County square-mile section (**Figure 6**) shows a three pad development pattern with four, five, and six horizontal wells on the pads. The three clusters of red dots indicate the well pad and the well entry point of each well at the surface. The green lines represent the direction of the vertical and horizontal well bores. The angled green lines of the vertical wells spread to the desired depth and bend to the horizontal straight lines to show the extent of the horizontal drilling pattern. The green dots at the end of each horizontal line represent the "bottom holes" or the end of each well bore. Given this particular section, there are 15 horizontal wells in one square mile section.

The study team used well density in Weld County as a guide to future oil and gas scenario development. According to recent permits observed in the region, energy companies are mainly receiving permission to develop two pads and between four and 12 horizontal wells on each pad. Given this precedent, a typical development pattern of two well pads with four horizontal wells per 640-acre spacing unit (or one square mile) can be expected in unincorporated portions of Boulder County.

Boulder County Development Scenarios

The study team used the historic drilling rig activity and COGCC regulated spacing units to derive three hypothetical future well development scenarios. **Figure 7** shows the 103 square-miles study area in eastern Boulder County. The map also illustrates the study area's location and proximity to major roads in and outside of the county.

Figure 7. Boulder County oil and gas development region



Source: BBC Research & Consulting

Based on the 103 square-mile size of the study area and the expected pad spacing, the capacity in the area is 206 pads, or two pads per square-mile section. Given the expected four wells per pad drilling method, there is a capacity of 824 wells in the study area. **Table 3** presents the Boulder County baseline development assumptions for the oil and gas study area.

Table 3. Boulder County Baseline Capacity Assumptions

Category	Value
Baseline Assumptions	
Boulder County Area (Sq. Mi.)	751
Study Area (Sq. Mi.)	103
Pads per Square Mile	2
Wells per Pad	4
Boulder County Development Capacity (Pads)	206
Boulder County Development Capacity (Wells)	824

Note: The underlying assumptions are a calculation of development capacities in Boulder County, given the standard COGCC spacing.

Source: BBC Research & Consulting

Table 4 shows three hypothetical development scenarios during a 16-year development period. In the accelerated scenario, 10 rigs operate within the county, which is about one-third of current Weld County rigs. This would allow for a maximum of 120 new wells per year. There are five rigs operating in the county in the steady scenario, which is about one-sixth of current Weld County rigs. This would allow for a maximum of 60 new wells per year. While the accelerated and steady scenarios result in the same number of wells at the end of the analysis period, the drilling would occur over a much shorter duration in the accelerated scenario compared to the steady scenario. Lastly, the low scenario expects a single rig allocation allowing for a maximum of 12 new wells per year. In the low scenario, the study area would reach capacity in 69 years. All well development scenarios are assumed to involve a clustered four well per pad development pattern and horizontal drilling techniques. Each of the scenarios show the rig allocation, maximum pads constructed per year, the number of years required to reach capacity and the number of wells at the end of the 16-year analysis period.

Table 4. Hypothetical Development Scenarios

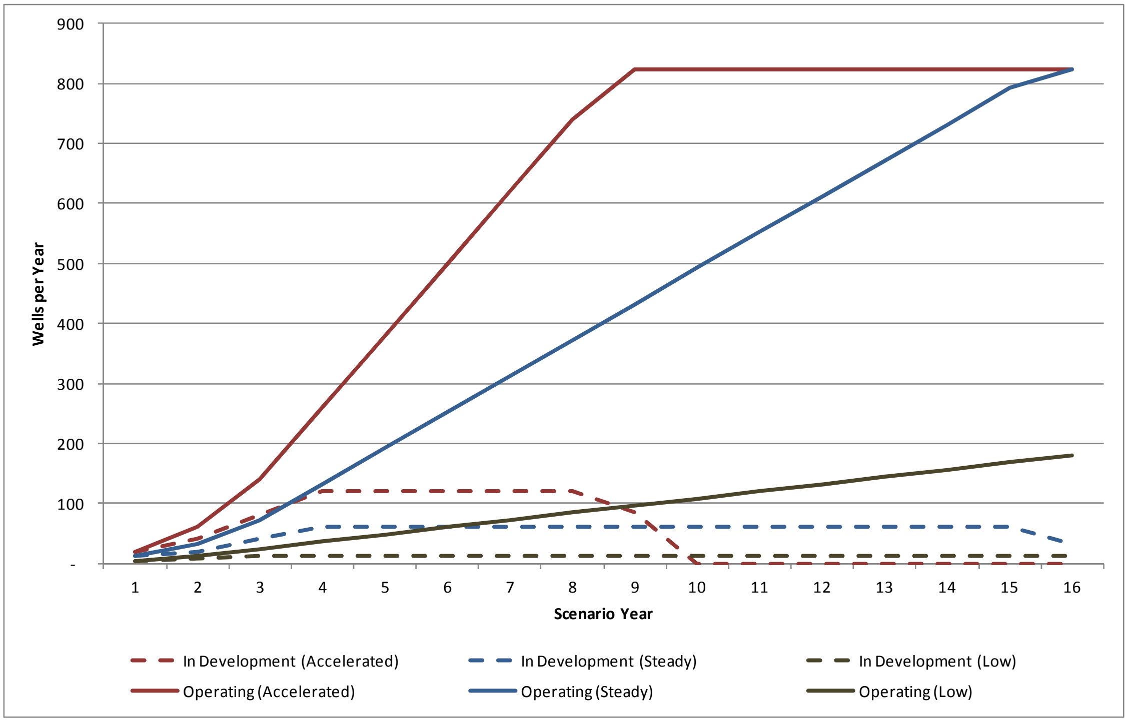
Category	Value
Accelerated Scenario	
Maximum wells per year (10 rigs)	120
Maximum pads per year	30
Years of development	9
Wells at end of analysis period	824
Steady Scenario	
Maximum wells per year (5 rigs)	60
Maximum pads per year	15
Years of development	16
Wells at end of analysis period	824
Low Scenario	
Maximum wells per year (1 rig)	12
Maximum pads per year	3
Years of development	16
Wells at end of analysis period	180

Note: Details on three hypothetical development scenarios include: drilling rig utilization; number of pads and wells developed per year; years required to reach development capacity; and wells developed at the end of the analysis period.

Source: BBC Research & Consulting.

The year-by-year profile of each of the development scenarios is shown in **Figure 8.** Each scenario assumes that oil and gas development would begin in year 1 in the figure with leasing and exploration occurring in the years leading up to year 1.

Figure 8. Boulder County Development Scenarios



Source: BBC Research and Consulting.

Figure 8 shows the addition of new wells in each scenario begins at a slow rate and increases to the annual development rate shown on **Table 4**. For the purpose of this study, a well's development is assigned to a single year, and that well will be in production in all subsequent years for the remainder of the 16-year study period. As seen in the **Figure 8**, the accelerated scenario reaches the study area capacity limit in year 9. The steady and low scenarios show constant operating well growth throughout the analysis period. A detailed breakdown of the development scenarios is included in **Appendix D**.

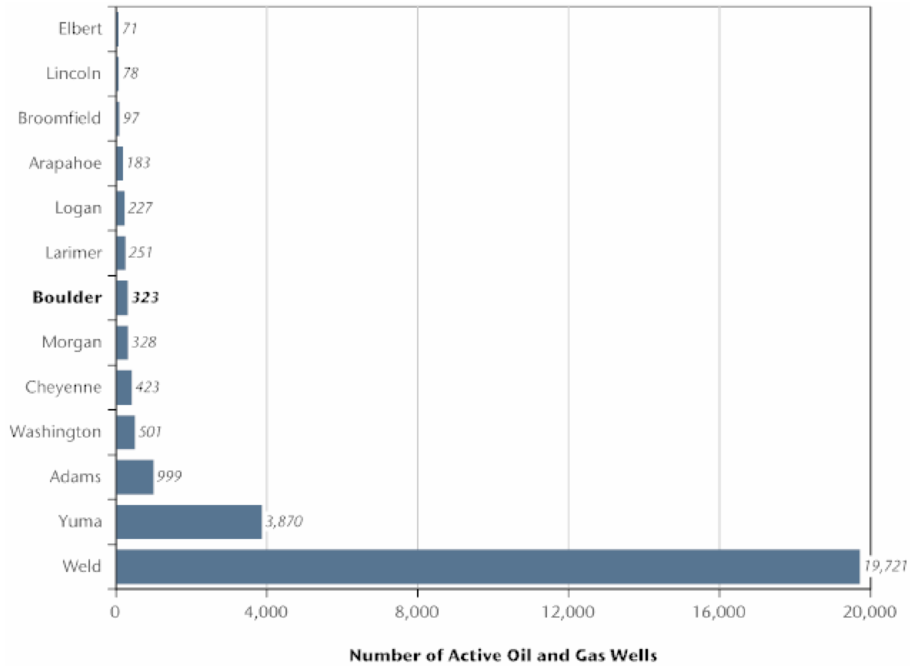
Recent Oil and Gas Development in Colorado

The following provides a discussion of recent oil and gas development in active counties in the Niobrara Shale area and elsewhere across the state to provide context for the drilling scenarios.

Existing Colorado Oil and Gas Wells

As of December 2012, Colorado has about 50,000 active wells, Boulder County has 323 active wells and neighboring Adams County has nearly 1,000 active wells. Most Boulder County wells were drilled decades ago and do not employ horizontal drilling or multi-well pads. Over the past five years, Boulder County's active well count has increased by 93 wells. The majority of Colorado's Front Range oil and gas wells are located in Weld County, which currently has over 19,700 active wells or nearly 40 percent of all active wells within the state. **Figure 9** shows COGCC data on active oil and gas wells in Weld County and other producing Front Range Counties.

Figure 9. Active Oil and Gas Wells in Colorado's Front Range (December 2012)



Source: COGCC, December 2012

Figure 9 shows most production occurring in Weld County, Yuma County and Adams County. Most other counties that lie above the Niobrara Shale currently have about 500 active oil and gas wells or fewer. Historically, most drilling and production activity has occurred in the northern Front Range and in counties in the northeastern portion of the state.

Well Development

The study team obtained data on active wells by county for the five most active producing counties from the COGCC for each of the last seven years and calculated the year-over-year change in active wells to examine well development activity in Colorado. **Table 5** shows the annual change in active wells for the five most active resource producing counties.

Table 5. Change in Active Wells per Year Colorado's Top 5 Producing Counties (2006-2012)

	2006	2007	2008	2009	2010	2011	2012	Average
Weld	566	546	548	1,286	1,262	1,424	1,314	992
Garfield	575	641	845	1,042	1,272	1,337	1,029	963
Yuma	245	468	580	331	186	189	133	305
Las Animas	272	274	412	324	113	38	26	208
La Plata	143	37	132	147	100	120	64	106
Annual Average Growth per County								**514**

Source: COGCC; BBC Research & Consulting.

Between 2006 and 2012, active wells have increased by over 18,000 in the five most active counties in the state. Weld County had the largest increase in active wells—an annual average increase of nearly 1,000. Garfield County had an annual average increase of over 960 wells over the same period. Active wells in Las Animas County and Yuma County increased by between 200 and 300 wells per year, respectively, in the last seven years. Active wells in La Plata County increased by about 100 per year over the same period. The average annual increase in active wells in the top five producing counties in the last seven years is just over 510 new wells per year. This figure is used in establishing context for the accelerated development scenario, which includes 120 wells drilled per year.

Table 6 shows the three well development scenarios, the number of drilling rigs required for each scenario and the percentage of historic peak and current statewide drilling rigs allocated to Boulder County in each scenario.

Table 6. Rig Utilization by Scenario

Scenario	Wells Drilled per Year	Required Drill Rigs	Percent of Historical Peak Rig Count	Percent of Current Rig Count
Accelerated	120	10	7%	19%
Steady	60	5	4%	9%
Low	12	1	0.7%	1.8%

Source: COGCC, BBC Research and Consulting

The accelerated scenario also requires a significant allocation of statewide drilling rigs (about 19% of current) to Boulder County. Based on this information, the study team believes the accelerated scenario to be a plausible upper limit. Again, it is important to note that this exercise is not intended to assign a probability to any of the scenarios occurring, but to appropriately define potential high and low levels of well development activity.

IV. Travel Model

Travel Model Methodology

A travel model has been developed using TRAFFIX software to assign the trips and vehicle-loads associated with the accelerated, steady and low development scenarios to the Boulder County roadway system. TRAFFIX is a GIS-based interactive computer program that assigns traffic to a network based on trip generation, trip distribution, and roadway network characteristics. Although the travel model includes roadways outside the jurisdiction of Boulder County (US and State Highways, and municipal roads), the transportation impacts (and associated improvement needs and costs) have been assessed only on roads under the jurisdiction of Boulder County.

The most intense transportation impacts of oil and gas development occur during the well pad construction, drilling, and completion activities. For a single pad site, these three activities are estimated to occur over a nearly six month period. Because oil and gas development occurs year-round, it has been assumed that the cumulative impacts of well pad development will be evenly distributed over the course of a calendar year. Therefore, all outputs from the travel model are on an annual basis. To assess the potential transportation impacts over time, the study team has evaluated four time periods in five year increments: Year 1, Year 6, Year 11, and Year 16.

Oil and gas development will result in increased traffic on the roadway network (vehicle-trips), as well as increased loads on the County's roads from the many heavy vehicle trips associated with the industry. For this reason, the TRAFFIX model has been used to estimate not only vehicle trips, but also loads as measured in equivalent single-axle loads (ESALs). The impact of heavy vehicles is dependent on a roadway's surface type (flexible pavement [gravel or asphalt] versus rigid pavement [concrete]). To properly calculate the ESAL impacts on Boulder County's roads, two ESAL model iterations are required; one for flexible pavement and one for rigid pavement.

The trip generation characteristics for oil and gas development phase are substantially different from the trip generation characteristics during the on-going well production phase. Therefore, for each evaluation year, the travel model has been run separately for the two phases.

The assignment process was conducted for a combination of each development scenario (low, steady, and accelerated), each analysis year (Years 1, 6, 11, and 16), for trips by phase (development and production), and for ESALs by surface type (flexible and rigid), resulting in a total of 57 iterations of the travel model (the accelerated scenario has no development in Years 11 or 16).

A summary of assumptions used to develop the travel model is provided in **Appendix E**.

Inventory of Study Area Roadways

The first step in modeling the oil and gas travel in Boulder County was to understand the existing conditions of the study area roadways. The following data were collected for study area roadways under the jurisdiction of Boulder County, which are highlighted in **Figure 10**.

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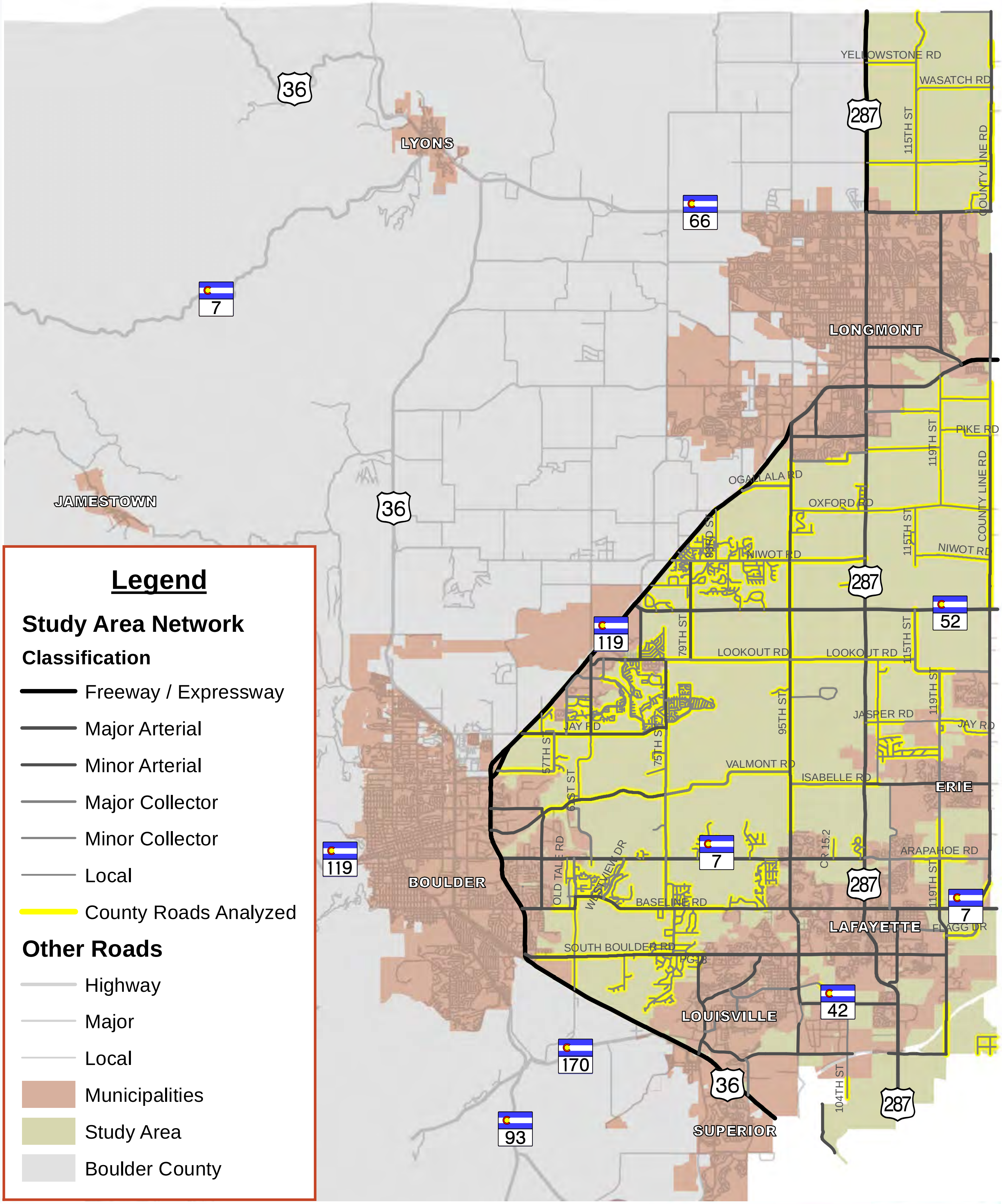
Figure 10

Study Area Road Network



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Traffic Counts

One of the primary goals of the modeling process is to estimate traffic volumes on the County roads as a result of oil and gas activity. It is useful to compare these estimates to existing and future background traffic to provide perspective and determine if the travel demand on any roadway segments might exceed the existing capacity. Daily traffic counts, including classification of vehicles at locations where available, were gathered from Boulder County's database. **Figure 11** illustrates current traffic volumes for a typical weekday.

Surface Conditions

Of the study area roads, approximately 88 percent (by centerline mileage) are asphalt, 10 percent are gravel, and two percent are concrete. **Figure 12** shows the surface type for each of the travel shed roadways. The surface condition, including the surface type, and the remaining service life, significantly affect how well a particular roadway segment can accommodate heavy truck traffic. The addition of numerous heavy trucks will, over time, cause a roadway to age at a greater rate than may have been originally anticipated. In order to estimate the degree to which the schedule for improvements on these roads would be accelerated, and to provide time-based costs of these improvements, the pavement quality index (PQI) of each road segment paved road was obtained. The PQI of each road segment was used to appy a rating of either Good, Fair, or Poor condition. **Figure 13** displays ratings for each paved roadway segment within the study area maintained by Boulder County.

Shoulders

Varying geometric configurations affect how well a roadway could accommodate the heavy truck traffic associated with the oil and gas industry. Wider shoulders provide space for bicyclists separate from the travel lanes. Shoulders also provide safety benefits for all roadway users: they serve as a countermeasure to run-off-road crashes and provide a stopping area for breakdowns or other emergencies. Boulder County's roadway design standards include a five foot shoulder for arterial roads and a four foot shoulder for collector roads. The shoulder widths of the study area roads in Boulder County area are shown on **Figure 14**. Approximately 32 percent (by centerline mileage) of paved roadways maintained by Boulder County have some kind of shoulder facility. Of those segments, 40 percent have a shoulder that is four feet or wider and 54 percent have a shoulder that is 3-4 feet wide. The remaining six percent are within a municipality's bike system and have some kind of bike facility (shoulder, bike lane, etc.).

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Figure 11

Existing Daily Traffic Volumes

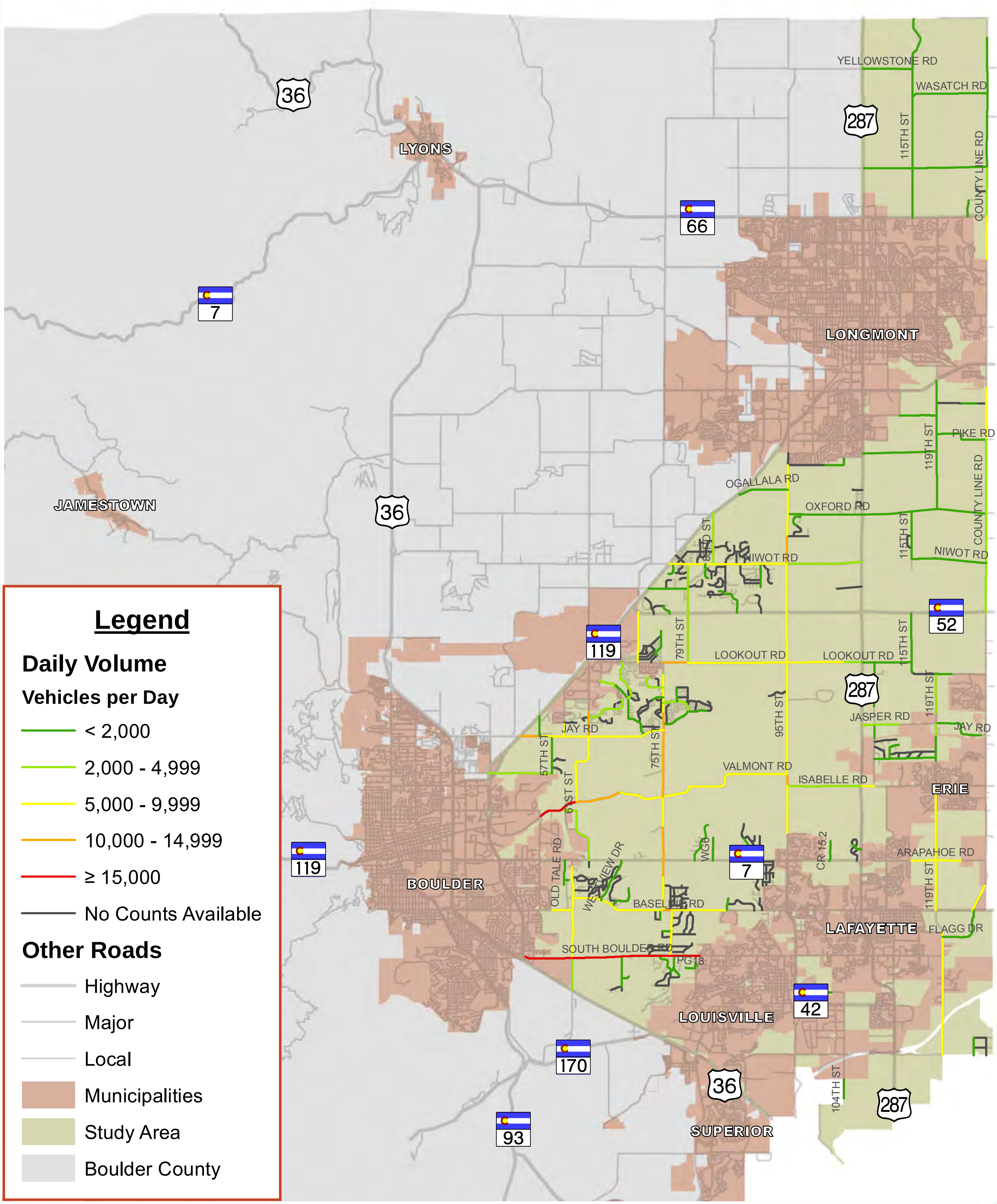

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Figure 12
Surface Types

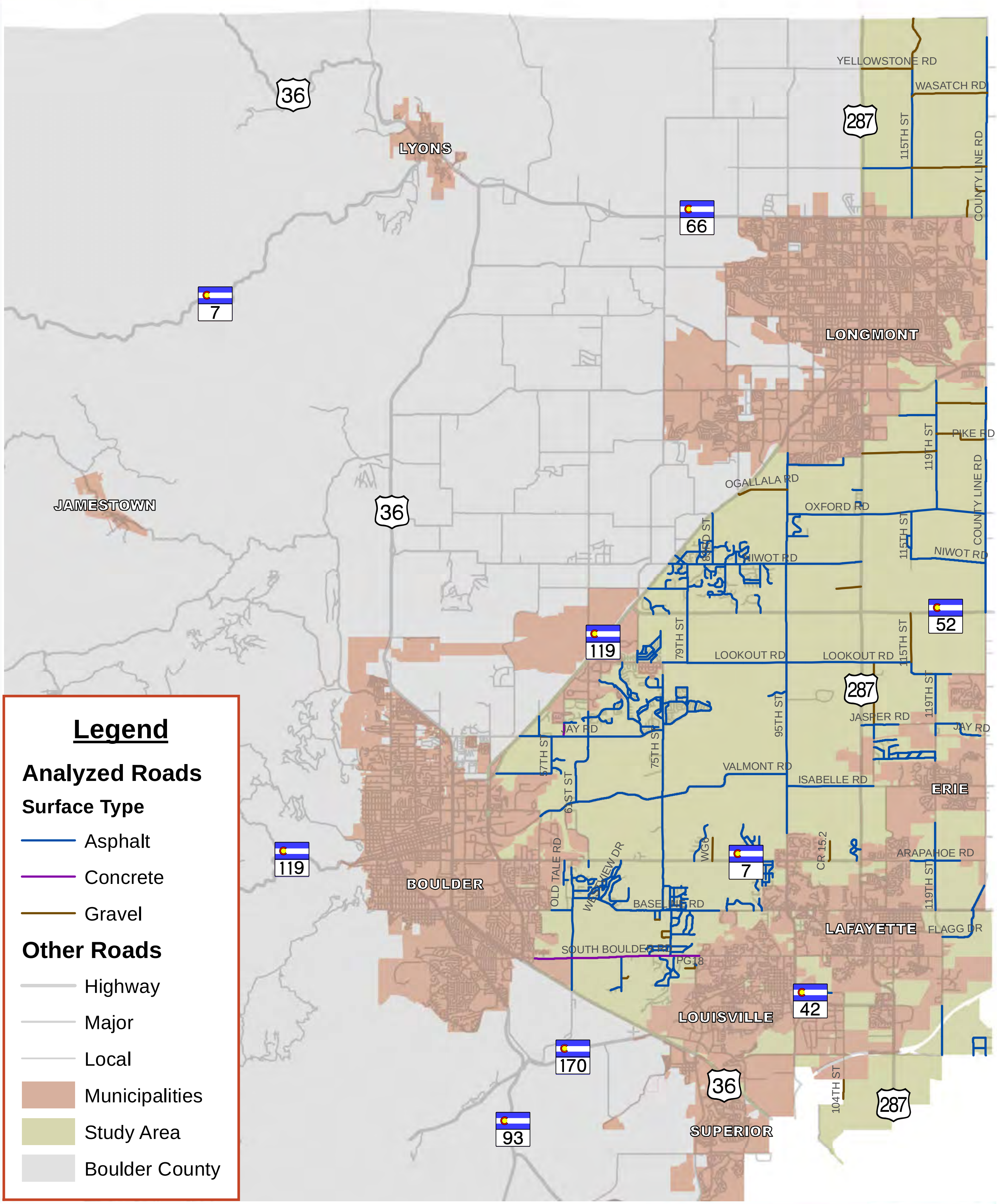

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Figure 13
Pavement Conditions

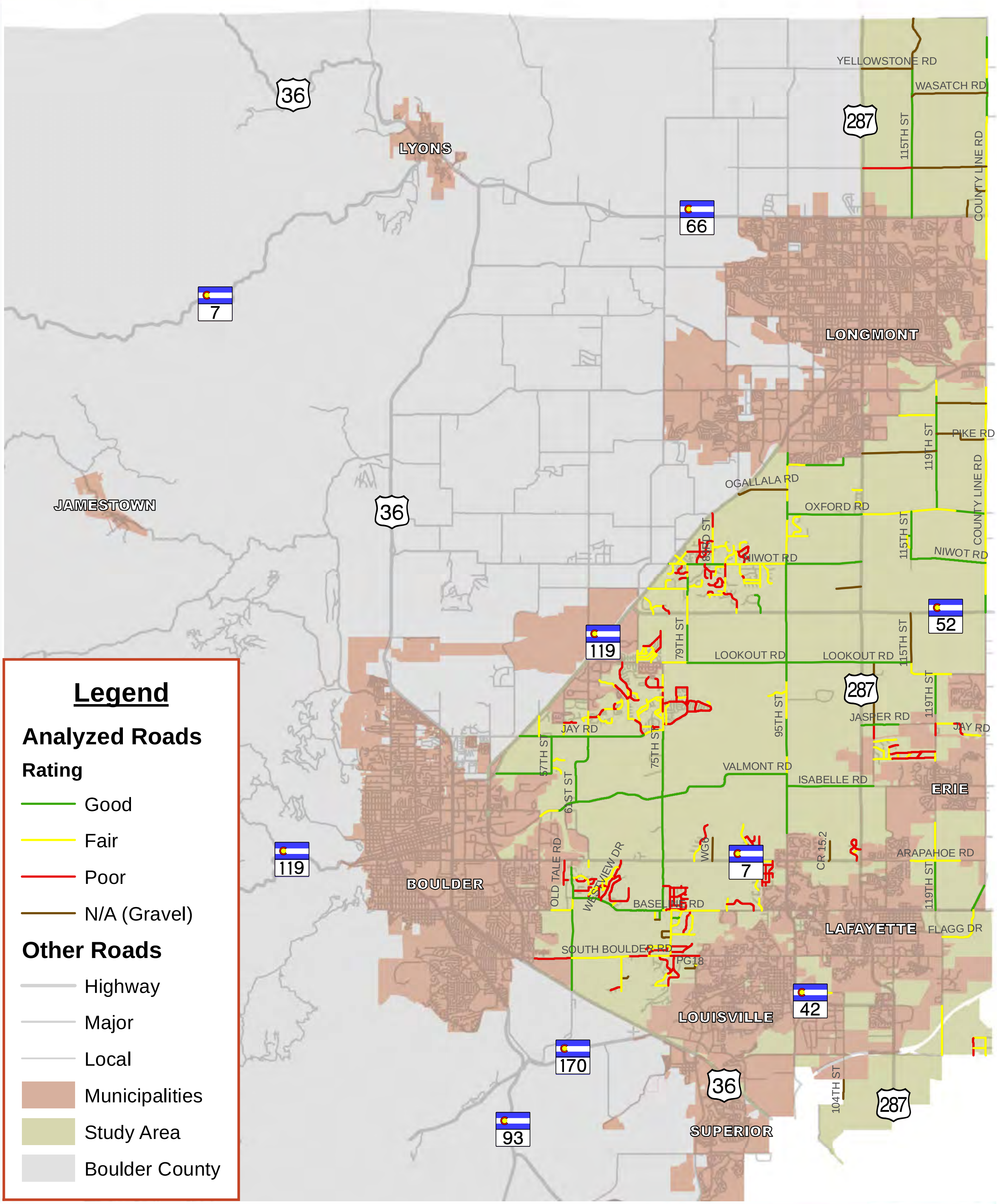

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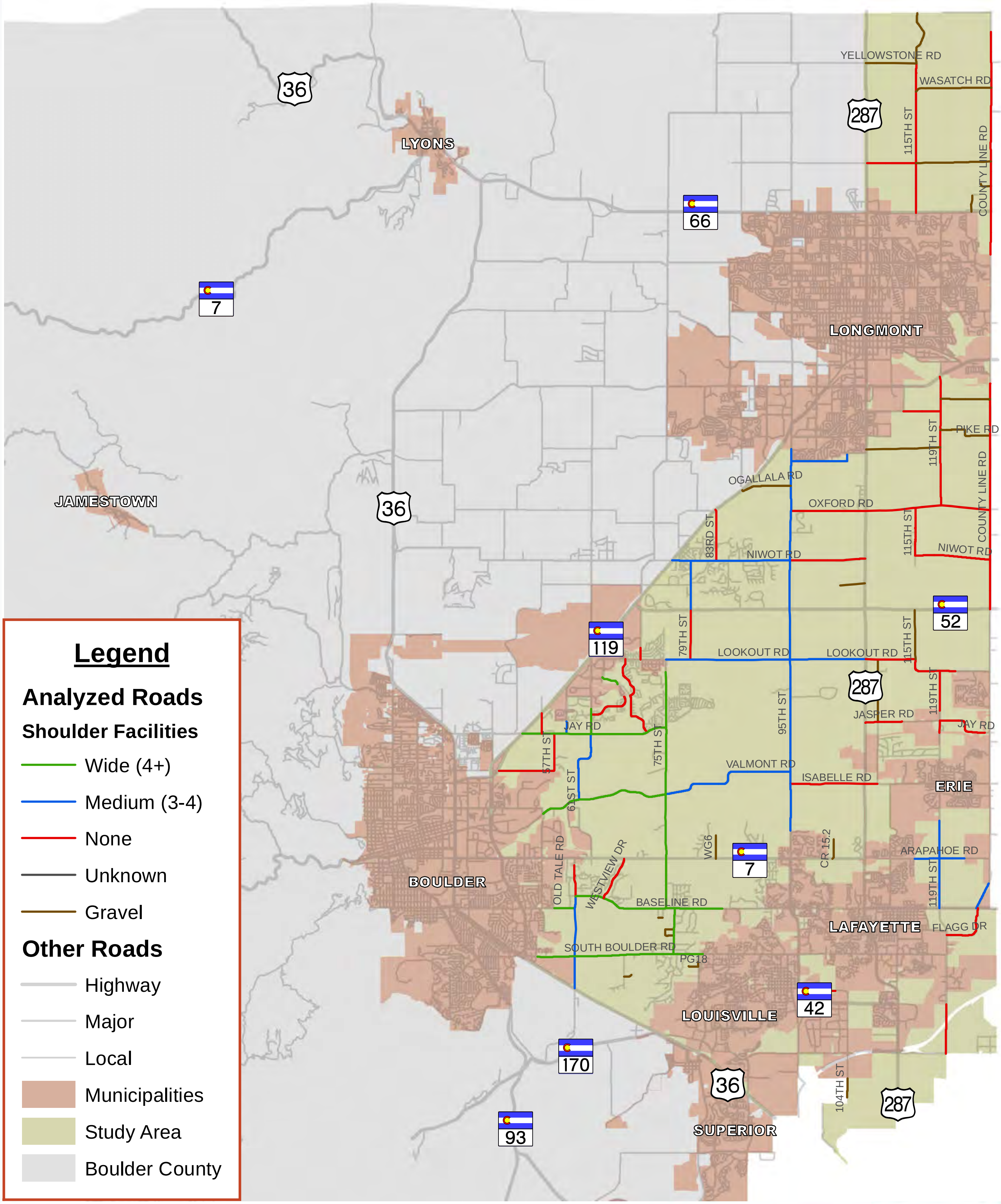
Figure 14
Shoulder Widths



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Bridge Postings

Data from the 2011 Federal Highway Administration's (FHWA) National Bridge Inventory (NBI) for bridges on the potential travel shed was also obtained in order to determine if there would be any weight or height restrictions that would limit use by oil and gas trucks. None of the bridges on the study area roads were identified to potentially have a weight concern (less than 5 out of 5 posting rating). However, bridges also have operational ratings that are specific to truck configurations (axle spacing, axle width, etc.). The County and the oil and gas industry should work together to ensure that actual truck types, weights, and configurations used during development and production can safely cross any bridge on a planned travel route. No bridges were found to have a height restriction or concern. (Federal Highway Administration, 2011). The bridge postings for County maintained bridges within the study area are shown on **Figure 15**. A listing of smaller structures not documented in the NBI was provided, but no height or posting information was available at the time of this study.

Trip Origins/Destinations

Trip origins and destinations were identified by determining where oil and gas development trips will likely be traveling to and from. For all trips, the pad site serves as either the point of origin or the destination. Trips will either involve a loaded truck delivering items to the site, removing elements to an off-site location, or transporting workers and machinery to and from the pad. Based on the geological formation and discussions with Boulder County staff, all wells are assumed to be located within the study area boundary shown on **Figure 1**. Given the uncertainty of where oil and gas pads may be developed within the study area, the area has been divided into one-mile sections, and the pads are assumed to be located near the center of each section.

In order to model where trucks would likely travel, pad sites had to be selected for each analysis year of each scenario. This selection allows the trips to be distributed across the County at locations where oil and gas could occur (within the study area); at the accelerated, steady, and low development scenarios; and at a frequency depending on the year of observation. Because there is no certainty as to when pad sites would be developed and where, pad locations were randomly selected from the one-mile sections within the study area. This selection was based on how many sites were estimated to be developed within the specific analysis year of each development scenario. The selection also ensured that each higher development scenario retained the same pads being developed as the previous scenario, and within the same year. Within each scenario, pads developed in one year were carried forward as producing pads from that point forward in order to maintain the reality of the oil and gas development and production process.

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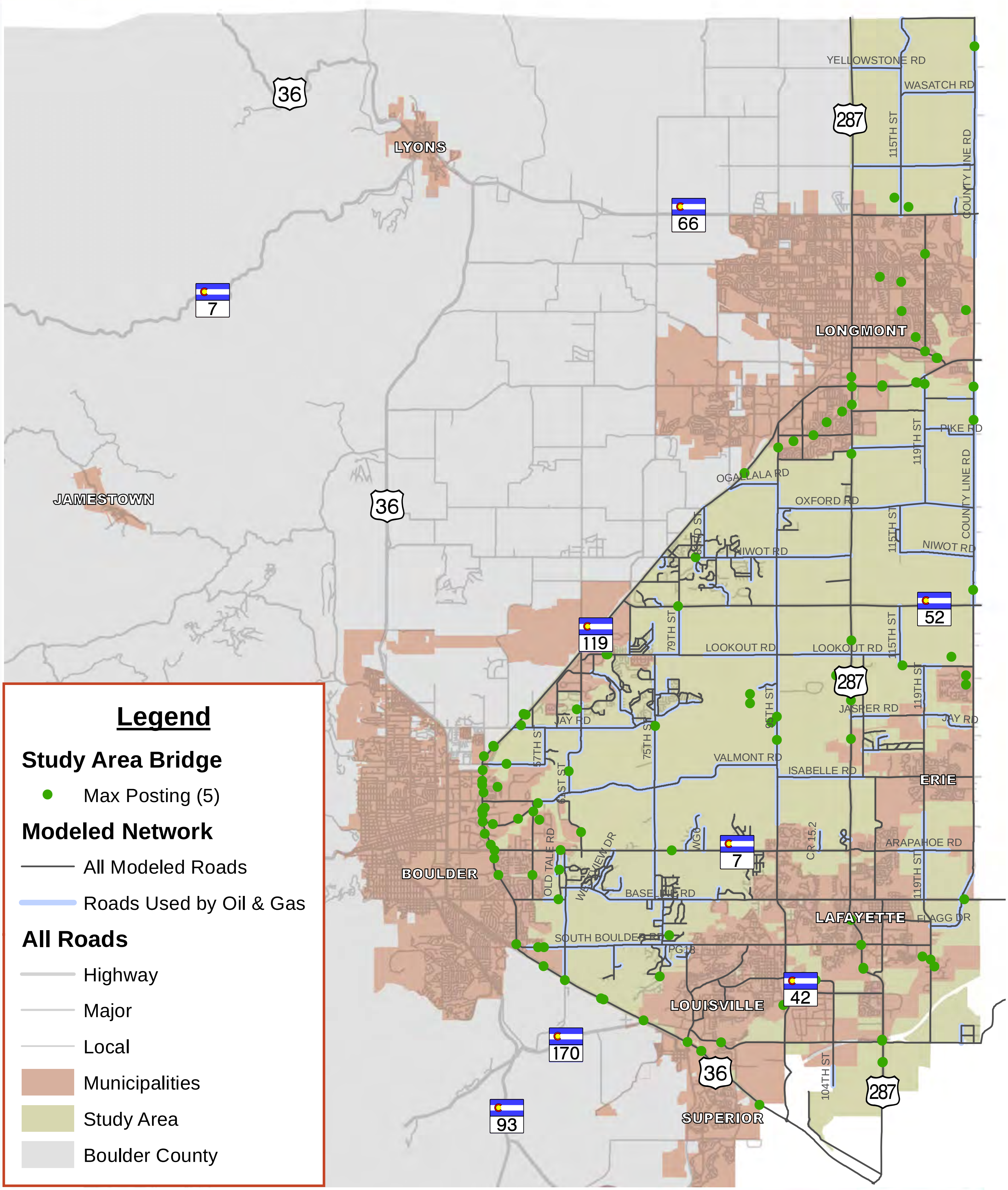
Figure 15

Major Bridge Postings



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With active pads for the development and production phases identified for each analysis year of each scenario, the trips and ESALs for those pads could be applied and totaled. This step was necessary due to some scenario years needing more pads in development and/or production than the number of one-mile sections, requiring more than one pad being developed and/or in production at a given section in a given year. Again, the centers of the sections are representative of pad development within that particular section. Each section could include up to two pads given spacing requirements, although a small number of sections in the model have three pads since the one-mile sections do not perfectly cover the study area.

Locations of the other end of oil and gas trips were estimated by categorizing and researching the reasons for travel (trip purposes). There are four primary trip purposes associated with oil and gas development, each of which uniquely impact where oil and gas trucks will travel:

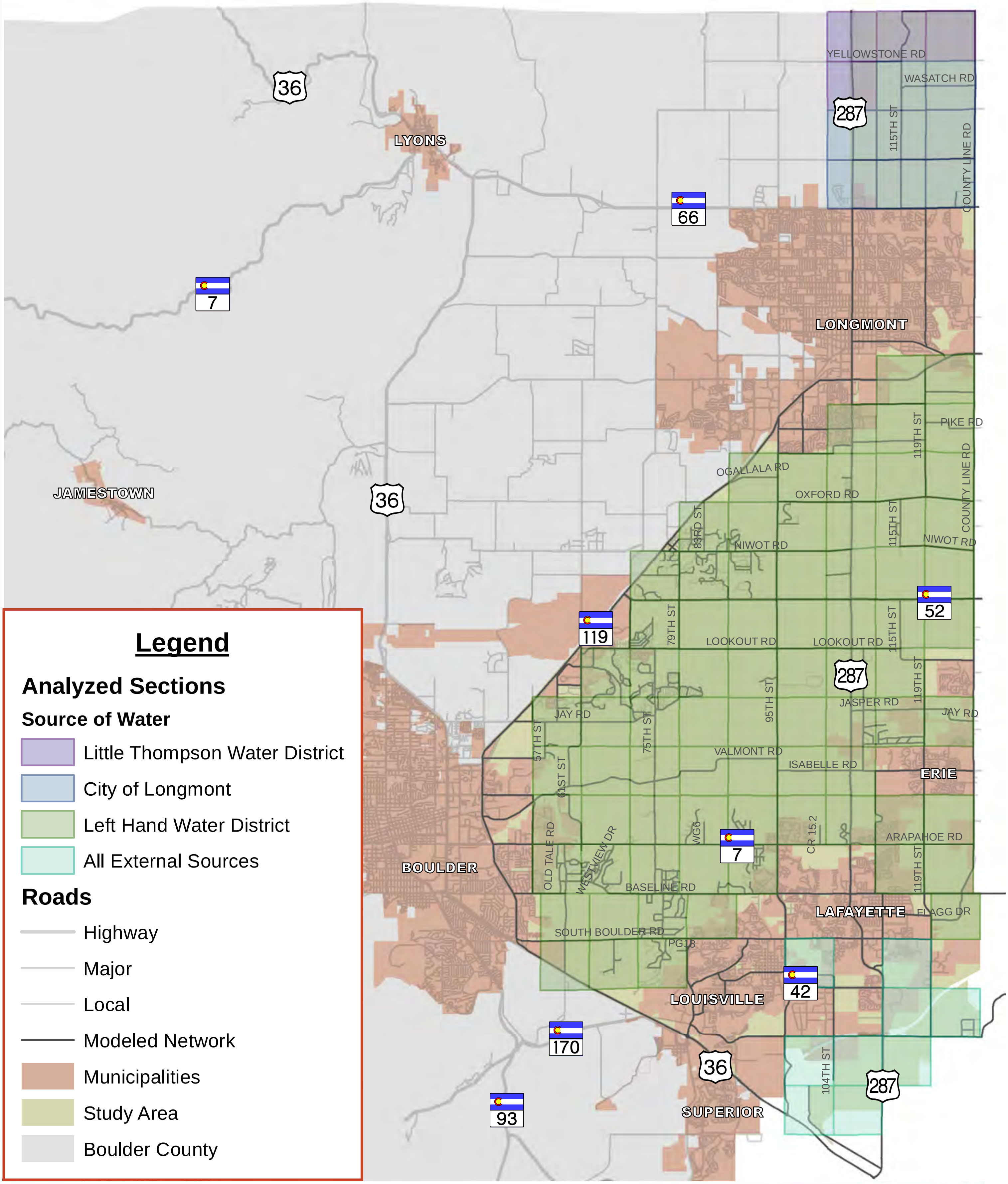
- Bringing fresh water to the site
- Removing produced water from the site
- Transporting equipment
- Transporting other materials

Fresh Water

Water is a key resource in the well drilling process as well as during the high pressure fracturing stage, where water is mixed with sand and chemicals. For oil and gas development in Boulder County, fresh water would likely be purchased from local water providers. Most of the study area is within the Left Hand Water District. The portion of the study area north of Longmont is covered by the Longs Peak and Little Thompson water districts, but only the Little Thompson Water District provides water for the oil and gas industry. Based on conversations with water providers in Boulder County, Left Hand Water is the most likely water provider within the County (summaries of phone interviews with water providers are included in **Appendix B**). Left Hand Water currently provides water to the oil and gas industry in Weld County through water hydrants. Depending on pricing and transport costs, it is conceivable that fresh water could be purchased from further outside of Boulder County. Given the uncertainty of these factors, it was assumed that oil and gas developers would acquire water from the nearest resources (90 percent), and the remaining 10 percent would transport water from areas outside of the County. Aurora Water, as an example, has established a pricing agreement with the industry. Sections in the extreme southeast corner of the county were assumed to acquire all of their water from external supply, as a confirmed local water source was not identified. **Figure 16** illustrates which water source each developable section is assumed to acquire its water from.

Figure 16

Water Source Assumptions



Legend

Analyzed Sections

Source of Water

- Little Thompson Water District
- City of Longmont
- Left Hand Water District
- All External Sources

Roads

- Highway
- Major
- Local
- Modeled Network
- Municipalities
- Study Area
- Boulder County

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Produced Water

Water is also a major byproduct of both the development and production phases. Produced water from the fracturing process and from the extraction of oil and/or gas is generated and must be appropriately treated. Based on an interview with the head of COGCC's Underground Injection Well Unit , for most fields in Colorado's Front Range, roughly 20 percent of the produced water is put into onsite evaporation ponds, another 20 percent is typically either discharged to local water bodies (if it meets quality standards) or used as dust abatement on dirt roads. The remaining 60 percent is usually injected into underground injection control (UIC) wells. No Class II UIC wells (which are associated with oil and gas production) currently exist in Boulder County and they would not likely be drilled until the field is proven with numerous producing oil or gas wells. Colorado has roughly 800 UIC wells, with the nearest UIC wells located in Weld County. Thus it was assumed that produced water that needs to be removed from the site would be trucked to Weld County via the nearest state highway to the pad site with access to I-25.

Equipment

An oil derrick being hauled.
Source: Colorado Motor Carriers Association

The equipment required for oil and gas development, including the drilling rig, the well structure, pumps, and well casings, could come from any location where oil and gas companies have operations, or where contractors providing such services are located. This equipment is ever moving from site to site or between storage locations and new sites. With this in mind, two sources were identified as likely suppliers of oil and gas equipment. The first is other oil and gas producing counties in Colorado that likely have equipment in use or in storage. Most of the relevant equipment within Colorado was identified to exist primarily in the Weld County-Denver area or in western Colorado. Trips to/from the study area were assumed to use the nearest state highway to access I-25, both northbound and southbound.

Transport of well equipment.
Source: Colorado Motor Carriers Association

Equipment could also come from the Gulf of Mexico region. Some specialty equipment is scarce in Colorado and may be brought in from other regions with a greater supply. Places such as Louisiana and Texas have previously been identified as possible source locations for such equipment for oil and gas operations in Utah, so such travel patterns could exist for operations in Colorado as well (Kuhn, 2006). State highways accessing I-25 were again used as the points of entry/exit.

Materials

Oil and gas development requires a variety of other materials in addition to water. Gravel, sand, piping, cement, chemicals, and other construction materials must be trucked to the site at different stages of the development phase. These resources would likely come from where supply is the greatest, trucking distance is shortest, and prices are the cheapest. Because these factors create a great deal of uncertainty as to where a resource may arrive from, it has been assumed that materials would arrive via I-25 from the north and south, with some preference towards trips to the south given the greater Denver area's capacity to provide a wide array of materials or to receive materials via rail from locations outside of Colorado.

Trip Generation and Vehicle Classification

The development and production phases have different stages and activities that use a variety of truck types to complete each activity. Each activity also generates a unique number of trips and may have varying origins/destinations for those trips. To best estimate where oil and gas traffic would travel and the impacts those trips would have, the trips and typical configurations for each activity have been estimated. **Appendix C** provides greater detail into truck types, configurations, and impacts.

Trip Generation by Activity

In anticipation of horizontal drilling and multiple wells per pad site in Boulder County, the trip generation rates used for this study have been developed using the resources and methodology described in Chapter II. **Table 7** documents the results of adapting trip generation rates from other studies to a four well per pad development pattern. Once the sources are averaged across each well development activity, the averages were adjusted according to pad and well sensitive trips. Average trip figures were then summed to derive the average truck traffic required to develop a typical clustered four-well pad. This calculation amounts to 7,184 total truck trips for the development of a well pad with four wells. After development, the activities during the production phase generate about 730 trips annually per operating well pad. The four wells per pad trip generation estimates shown in **Table 7** have been used as the basis the travel model.

Vehicle Classification

There are a variety of vehicle types used in oil and gas development and operations, with varying levels of impact. The load impact of oil and gas trucks can be as much as 6,000 to 30,000 times that of a passenger car. To account for the load impacts, equivalent single axle loads (ESALs) of each truck trip has been estimated and modeled. Some truck types are used in multiple stages and activities, while others are used only once. And for those trucks operating within more than one activity, their number of trips varies by activity. This variation requires each activity to have a vehicle classification profile where truck types, trip shares, and impacts are identified for input into the travel model.

Table 7. Trip Generation Estimates

Activity	1 Pad, 4 Wells
Construction Stage	
Pad and Road Construction	90
Drilling Stage	
Drilling Rig	90
Drilling Fluid and Materials	270
Drilling Equipment (casing, drill pipe, etc.)	450
Completion Stage	
Completion Rig	40
Completion Fluid and Materials	170
Completion Equipment (pipe, wellhead, etc.)	10
Fracturing Equipment (pump trucks, tanks, etc.)	320
Fracture Water	4,200
Fracture Sand	190
Flowback Water Disposal	1,400
Total Development Trips	**7,230**
Production Stage	
Oil & Water Removal	580
Operations and Maintenance	150
Total Production Trips (per year)	**730**

The most frequent heavy-truck activity during the development of a well comes from the transportation of water to and from the well during the drilling and hydraulic fracturing process (completion stage). According to Chesapeake Energy, between three and five million gallons of water are used during the drilling and completion stages of developing a well. This water is used to assist with cutting through rock and cooling the drill. This demand for water translates into about 4,200 trips (2,100 inbound and 2,100 outbound). Workers transport produced water and flowback water, extracted during the production phase, to a separate wastewater site, resulting in about 1,400 additional trips (700 inbound and 700 outbound).

A variety of resources including environmental impact studies of oil and gas development within the Rocky Mountain and Great Plains regions were used to identify truck types and their configurations. An initial list of specific trucks used was compiled by stages/activities of development and production. Where available, the percentage makeup of different truck types by activity was noted. Likewise a list of typical truck configurations for oil and gas operations was compiled, which documented the following characteristics:

- Axle configurations
- Weight configurations (total empty and full, and per axle)
- Level of impact expressed in equivalent single-axle load (ESAL) factors

Some of the resources consulted provided all three of these characteristics, but most provided only one or a combination of two. In order to best estimate the impact on roads, any configuration that could have a unique ESAL value was recorded. Once all unique configurations were identified, any holes in information for configuration were estimated based on other similar configurations. For configurations without a documented ESAL factor, the factor has been estimated based on the Pavement Tools Consortium's ESAL equations for flexible and rigid surfaces, which produce ESAL factors consistent with the American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* that defines ESALs for different truck configurations. Because these equations take roadway characteristics into account that were not obtained during this study (such as the serviceability index and structural number), values were generalized.

The specific truck types and their respective characteristics were assigned to the truck configurations identified based on the truck's purpose and observed descriptions within the various reports and studies consulted. This simplified the impact estimation process by grouping similar truck types and their uses into one configuration, thus assigning an ESAL value to a truck type.

Merging Trip Generation and Vehicle Classifications

The truck configuration profiles were linked with their respective activity within each stage of the development and production phases. Because descriptions were not available as to exactly which trucks are used for each activity, the reports and studies consulted were used to produce a best estimate as to how trucks are used. These resources were also referenced to estimate the average share of an activity's trips that each truck configuration would account for, and if the truck is loaded for inbound, outbound, or both trip directions. With trips and loads estimated for each truck per activity, their ESAL factors were calculated for a round-trip to be run through the travel model in order to estimate the trucks' impacts on the County roadways.

Table 8 documents the stages and activities for the development phase, along with each activity's number of generated one-way trips, most common truck types, estimated average ESAL factors for flexible and rigid surfaces, and origins/destinations. **Table 9** documents the same information for the production phase.

Table 8. Development Phase Trip Summary

Stage	Activity	1-Way Truck Trips (1 Pad, 4 Wells)	Duration (Days)	Average Truck Trips per Day (by Stage)	Average Truck Trips per Day (by Activity)	Typical Truck Types	ESAL Factors (Average for 1-Way Trip)	Origin (or Destination) of Trucks
Construction	Pad and Road Construction	90	7	12.9	12.9	3-axle & 5-axle haulers	Flex: 1.009 Rigid: 1.537	I-25 N/S
Drilling	Drilling Rig	90	103	7.9	0.9	Heavy 5-axle, other 3-axle	Flex: 0.888 Rigid: 1.047	I-25 N/S
	Drilling Fluid and Materials	270			2.6	3-axle & 5-axle tankers	Flex: 1.362 Rigid: 1.988	I-25 N/S
	Drilling Equipment (casing, drill pipe, etc)	450			4.4	5-axle haulers	Flex: 0.405 Rigid: 0.621	I-25 N/S
Completion	Completion Rig	40	70	90.4	0.6	Heavy 5-axle, other 3-axle	Flex: 0.979 Rigid: 1.203	I-25 N/S
	Completion Fluid and Materials	170			2.4	3-axle & 5-axle tankers	Flex: 1.362 Rigid: 1.988	I-25 N/S
	Completion Equipment (pipe, wellhead, etc)	10			0.1	5-axle haulers	Flex: 0.405 Rigid: 0.621	I-25 N/S
	Fracturing Equipment (pump trucks, tanks, etc)	320			4.6	Specialty, 3-5 axles	Flex: 0.724 Rigid: 0.782	I-25 N/S
	Fracture Water	4,200			60.0	5-axle tankers	Flex: 1.363 Rigid: 2.260	Local, I-25 N/S
	Fracture Sand	190			2.7	5-axle haulers	Flex: 1.363 Rigid: 2.260	I-25 S
	Flowback Water Disposal	1,400			20.0	5-axle tankers	Flex: 1.363 Rigid: 2.260	I-25 N
Total		**7,230**	**180**	**40.2**	**40.2**			

Table 9. Production Phase Trip Summary

Stage	Activity	1-Way Truck Trips (1 Pad, 4 Wells)	Duration (Days)	Average Truck Trips per Day (by Stage)	Average Truck Trips per Day (by Activity)	Typical Truck Types	ESAL Factors (Average for 1-Way Trip)	Origin (or Destination) of Trucks
Production	Oil & Water Removal	500	Daily	2.0	1.4	5-axle tankers	Flex: 1.363 Rigid: 2.260	I-25 N/S
	Operations & Maintenance	230	Daily		0.6	Work Trucks	Flex: 0.143 Rigid: 0.174	I-25 N/S
Total		**730**	**365**	**2.0**	**2.0**			

Trip Distribution and Assignment

With trips per pad site and their vehicular makeup established, the accelerated, steady, and low development and production scenarios could be modeled. To model where trips would go and the impacts they would generate, trips and ESALs were loaded (separately) in the TRAFFIX model. This process consists of two primary steps: distributing the trips and ESALs, and assigning them to the network.

Trip Distribution

Once the trips and ESALs per pad were calculated, they were entered into the TRAFFIX travel model at each pad, distributing trips and ESALs to origins and destinations based on activities as described previously. **Table 10** outlines how trips were allocated to/from each pad site.

Table 10. Trip Distribution Assumptions

Trip Profile	Trip Origin or Destination		
	I-25 to the North	I-25 to the South	Nearby Local Water District
North Access	via US 287, SH 66, SH 119, SH 52, or SH 7	--	--
South Access	--	via SH 66, SH 119, SH 52, SH 7, or US 36	--
North or South Access	50%	50%	--
Fresh Water Access	5%	5%	90%

Trip Assignment

With trips and ESALs distributed and linked, the TRAFFIX travel model was used to assign the trips and ESALs to the network based on which path would provide the shortest travel time. Because oil and gas trips take place at all hours of the day and every day of the week, background traffic and congestion were not factored into the modeling process to impact assignment.

The assignment process was conducted for a combination of each scenario level (low, steady, and accelerated), each analysis year (2016, 2021, 2026, and 2031), for trips by phase (development and production), and for ESALs by surface type (flexible and rigid), resulting in a total of 57 iterations of the travel model (the accelerated scenario has no development in 2026 and 2031).

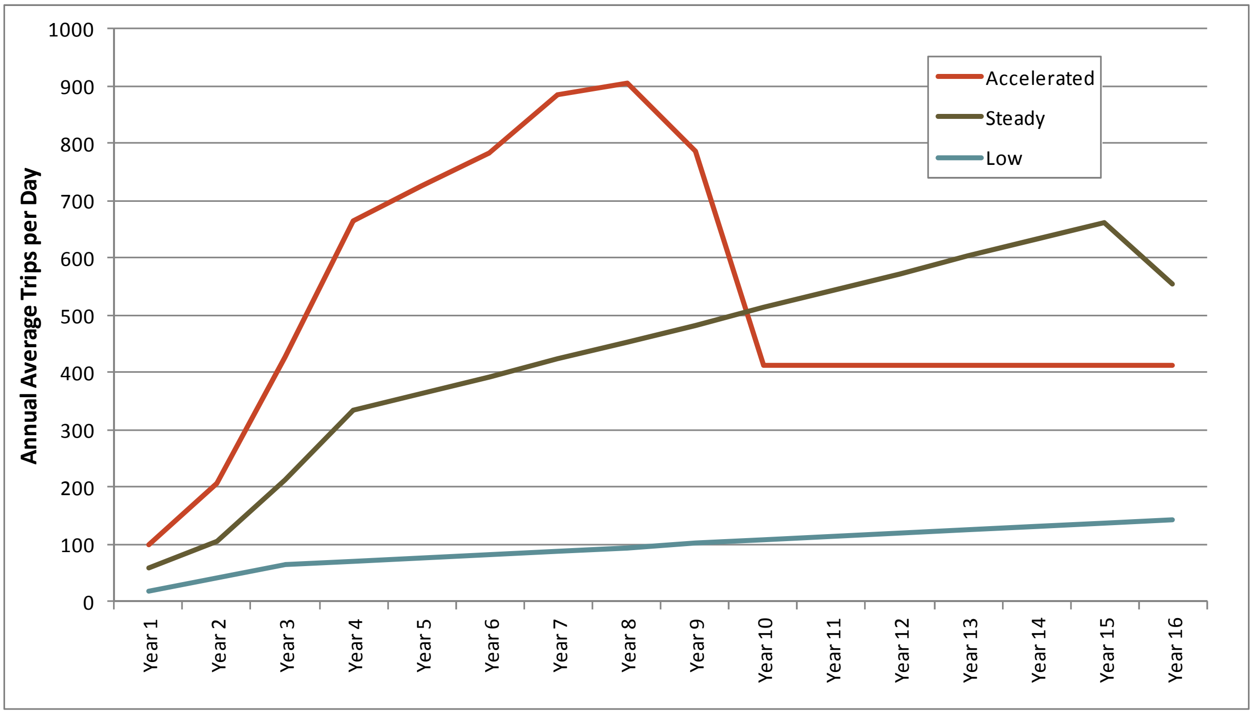
Model Results

As described previously, the TRAFFIX travel model output the number of trips and ESALs on each road segment. Based on these model runs and exported data, the following sections summarize the results.

Trips

The trips were modeled on an annual basis; in order to present trips in more manageable fashion, trips from both phases (development and production) were aggregated and converted to average annual daily trips by simply dividing the annual trips by 365. **Figure 17** illustrates the average number of oil and gas trips per day for each scenario over the 16 year study period. This figure depicts the cumulative trips of all pads being developed and producing wells. By dividing the annual trips evenly over the year, it is assumed that well development will be distributed over time resulting in a relatively even distribution of trips in total. It is important to note that trip generation will peak during the development phase at a particular pad site, resulting in a more profound local impact.

Figure 17. Estimated Oil & Gas Annual Average Trips per Day



Based on the travel model results, these trips are expected to occur over a large portion of the County roads within the study area. Some corridors handle a large portion of these trips, while others handle only one pad's worth or less. The highest concentration of trips on any one roadway segment was found to be approximately 40 trips per day (annual average) in the steady scenario. No County roads are expected to exceed the existing traffic volume capacity threshold due to the added oil and gas trips.

Although the total number of trips generated in the three scenarios is not particularly high, the impact that a Boulder County resident might experience if a well pad were developed in close proximity to their home could be significant, particularly during the development phase. **Figure 18** provides a graphical depiction of the number and types of trucks that are estimated per day for a pad with four wells during each stage of development and production. The duration of each stage is approximate; if a development stage occurs over a shorter duration of time, the number of daily truck trips would be intensified.

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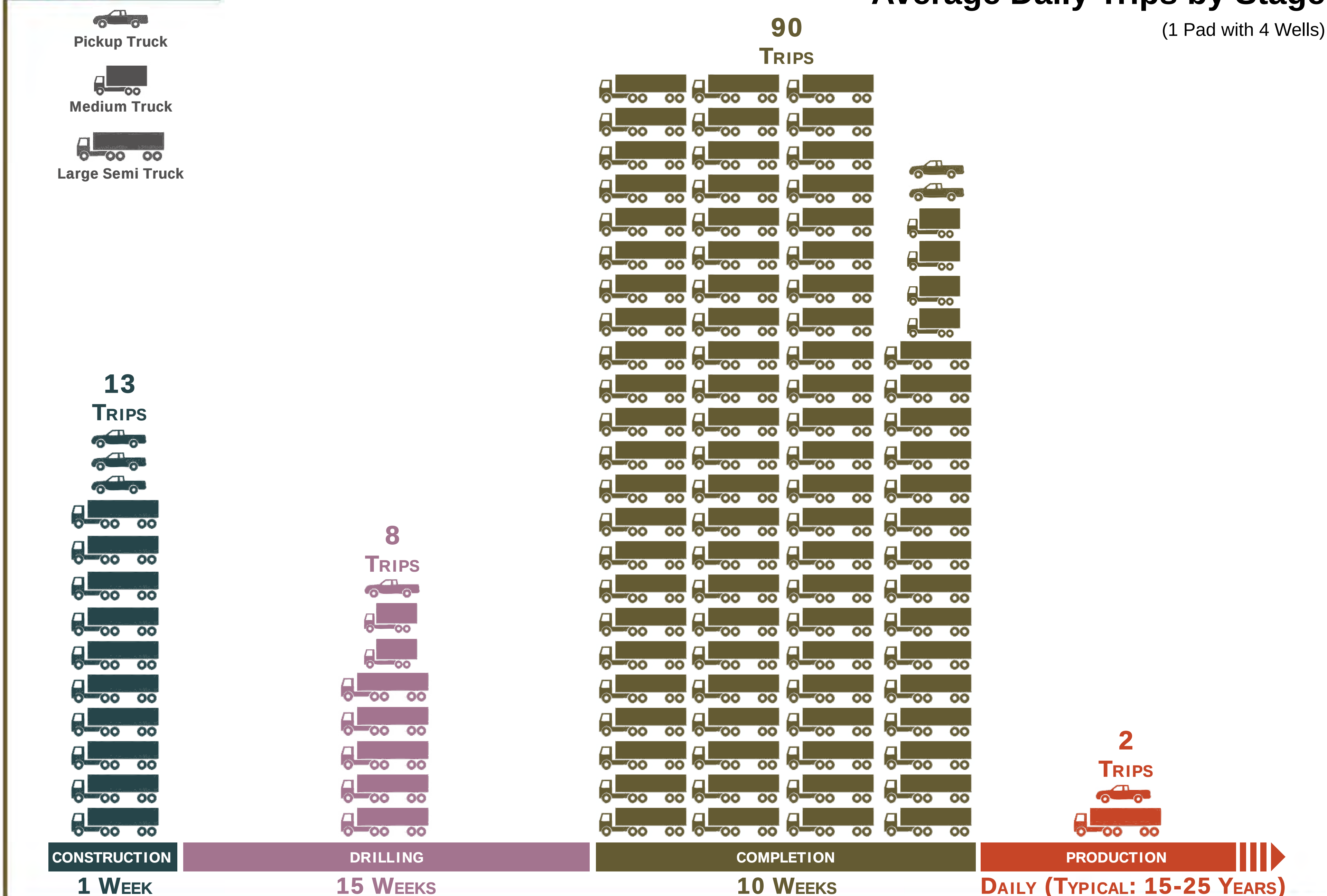
Figure 18
Average Daily Trips by Stage
(1 Pad with 4 Wells)



*Approximate Durations

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Figure 19 illustrates the magnitude of development trips on the study area County roads for the accelerated scenario in Year 6 (the peak development year modeled), while **Figure 20** illustrates the same information for production trips in Year 16 (the highest level of production trips. These maps illustrate how many oil and gas trips each road segment is expected to carry relative to the other oil and gas travel routes. Note that earlier analysis years and other scenarios (low and steady) have fewer pads in operation, meaning not all lease sites may have an active pad. Given the random selection of active pads, paths could change if active pads were rearranged. However, the arrangement tested with the TRAFFIX travel model is as likely as any other potential arrangement of active pads given the information obtained for this study. Furthermore, routes with high volumes in these scenarios and years are major routes regardless of how pad sites are arranged, as they provide essential links that eventually must be used.

Vehicle Miles Traveled

The trips assigned by TRAFFIX were also converted into vehicle miles traveled (VMT) to compare the increase in VMT caused by oil and gas operations with existing VMT on the study area County roads and predicted VMT growth based on the *Boulder County Transportation Master Plan*. All VMT values were calculated for roads maintained only by Boulder County and were shown to be used by in the travel model for oil and gas trips. At the highest level of oil and gas development assumed in the three scenarios, the additional VMT resulting from oil and gas trips would be less than one percent of the existing plus background VMT.

Although the number of the trips generated by the oil and gas industry in the three scenarios is relatively small in comparison to the existing traffic, the much greater transportation impact associated with industry is due to the weight of the vehicles. As described in the following section, the load impact of oil and gas trucks can be several magnitudes greater than that of a passenger car.

Equivalent Single-Axle Loads

Due to the high impact of heavy vehicles on roads, ESALs are essential in calculating potential improvements needed and the costs associated with those improvements.

To translate ESALs into a useable format from TRAFFIX, ESALs from the flexible ESAL model runs were used for gravel and asphalt roads, while ESALs from the rigid ESAL model runs were used for concrete roads. ESALs from each phase were aggregated for each road segment. These final ESAL aggregations were then used in calculating reductions in the remaining service life of each analyzed road segment, forming the basis for estimating needed improvements and costs.

To put ESAL factors for oil and gas vehicles into perspective, an average 4,000 pound passenger vehicle (2,000 pounds per axle) has an estimated ESAL factor of 0.0004 when using the Pavement Tools Consortium's equations for both flexible and rigid pavements. In comparison, the largest and heaviest oil and gas truck used in this study has an estimated full-load ESAL factor of 7.7 on flexible pavement and 12.6 on rigid pavement (Source: Upper Great Plains Transportation Institute, 2010). That is, the load impact to a road is 20,000 – 30,000 times that of a passenger car. A loaded water truck (the vehicle with the highest frequency of trips to and from an oil and gas well) has an estimated ESAL factor of 2.6 on flexible pavement and 4.4 on rigid pavement, 6,500 – 11,000 times the load impact of a passenger car.

Figure 19
Peak Annual Development Trips
(Accelerated Scenario Year 6)

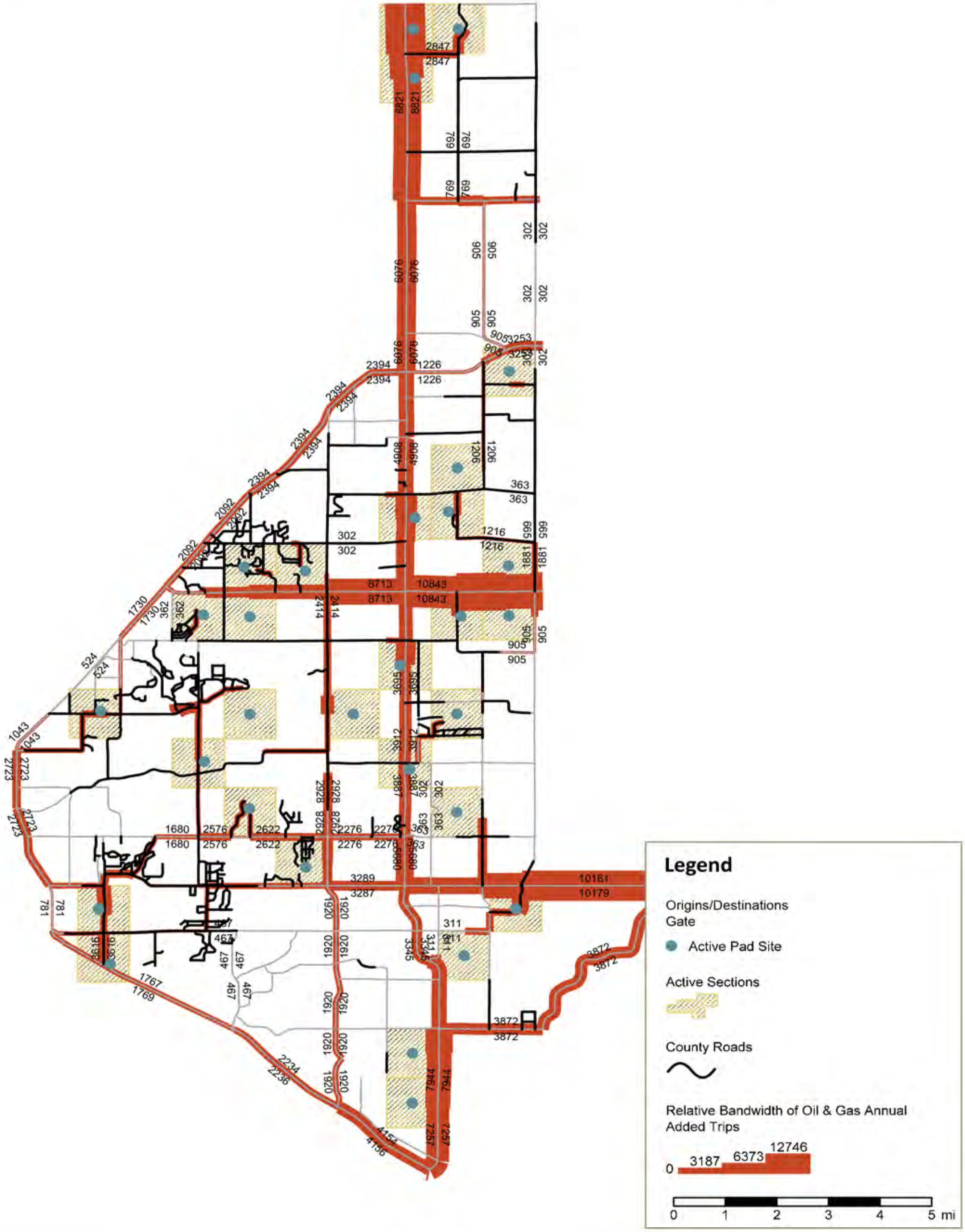

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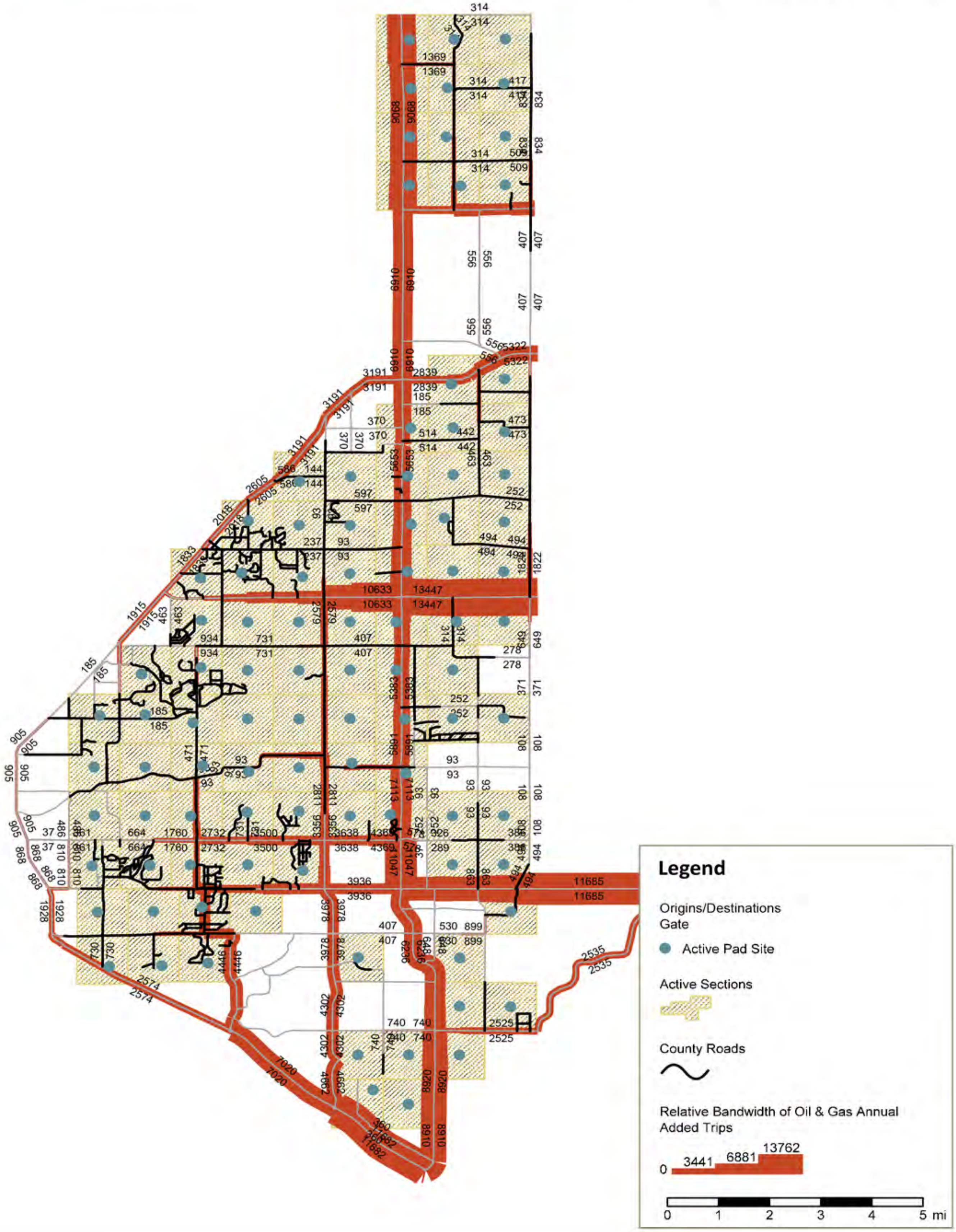
Figure 20
Peak Annual Production Trips
(Accelerated Scenario Year 16)



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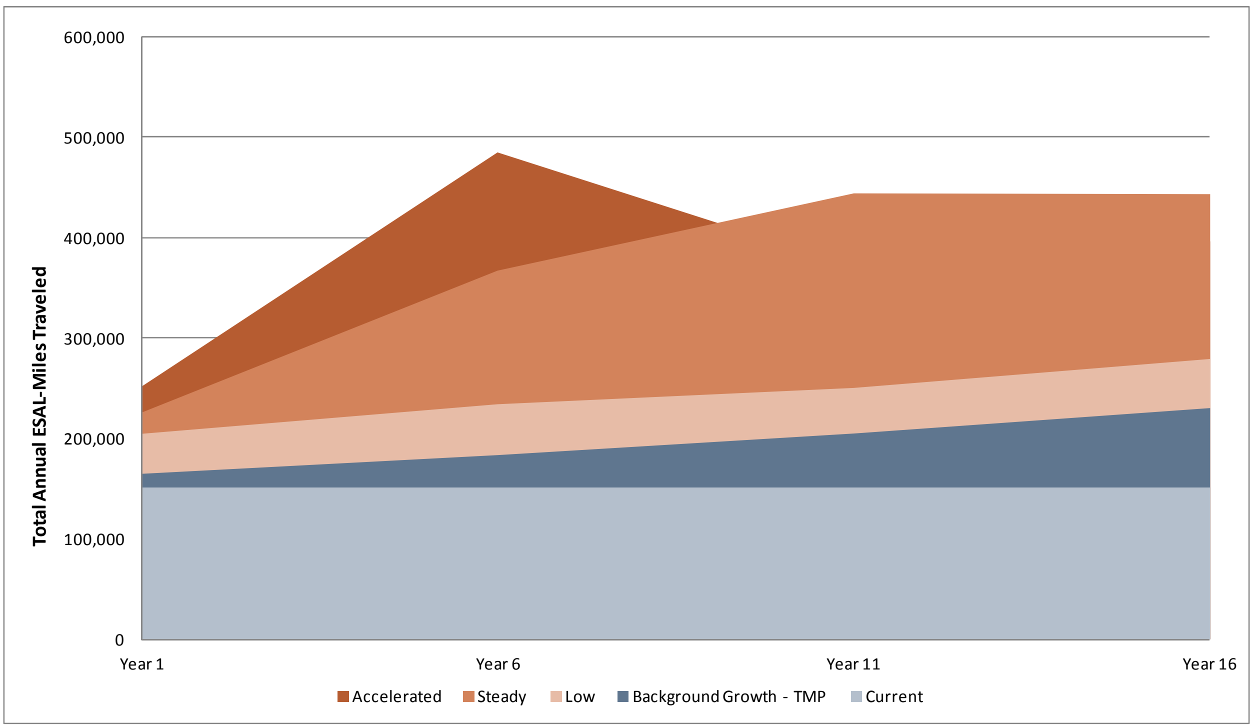
The ESALs assigned by TRAFFIX were also converted into ESAL-miles traveled (a concept similar to VMT) to compare the increase in ESAL-miles caused by oil and gas operations with existing ESAL-miles on the study area County roads and predicted ESAL-mile growth based on the *Boulder County Transportation Master Plan*. All ESAL-mile values were calculated for roads maintained only by Boulder County and were shown to be used by in the travel model for oil and gas trips. The ESAL loads for existing and future background traffic on the study area roads are based on existing vehicle classification counts from across the study area and typical ESAL values for medium and large truck classifications. As shown on **Figure 21**, the load (ESAL-mile) increase associated with the oil and gas trucks is significant. In the low scenario, the load increase is approximately 20 – 25 percent over the background. The load increase in the steady and accelerated scenarios ranges from 35 to nearly 165 percent over the background.

Figure 21. Loads on Roadway Network



V. Mitigation Needs

The mitigation measures and associated costs presented herein represent the additional costs or funding needs attributable to oil and gas traffic. They do not include baseline maintenance and/or improvement costs incurred by the County prior to substantial growth of oil and gas traffic.

For this study, oil and gas traffic was distributed to the County's network of roads, and an Equivalent Single Axle Load (ESAL) was applied to the associated traffic. The ESALs were determined at 5-year increments over the 16 year study period. Road mitigation measures and costs were then defined for the paved and unpaved roads impacted by oil and gas traffic based on the accelerated, steady, and low development scenarios.

Unpaved Road Analysis

The unpaved roads analyzed in this study were classified by the estimated additional truck traffic due to oil and gas development. The categories include:

- Low (0-25 average daily traffic [ADT])
- Elevated (25-50 ADT)
- Moderate (50-100 ADT)
- High (100+ ADT)

The following methodology describes how costs were attributed to each category.

Methodology

The increase in maintenance and rehabilitation costs are a key element in determining the improvement cost for unpaved roads. On gravel surfaces, as the ADT increases, the frequency of grading and gravel applications must increase to preserve the surface quality.

Maintenance and Rehabilitation Costs

The County's average cost of a grading operation is approximately $224 per mile each time the road is graded. The grading cycle within the County is dependent on the traffic volume of the road as well as if a dust suppressant can be applied. Some low volume, non-impacted gravel roads need to be graded only once every two months. However, if the road cannot be treated with a dust suppressant material (e.g., because of vertical grade, sensitive vegetation, etc.), the non-impacted, unpaved road may be graded up to two to three times per month.

The County's average cost per mile for gravelling is $44,200 per mile. This cost includes material, labor and equipment. Similar to the grading cycle, the graveling cycle within the County is dependent on the traffic volume of the road. For this study, the gravelling cycle time is six years for non-impacted unpaved roads. For purposes of this analysis, all graveling intervals were converted to a base yearly interval. That is, since the County provides a six-year cycle, the costs were converted to a yearly graveling cost that corresponds to the traffic projections.

If oil and gas trucks use an unpaved road as a transportation route, the road will have to be treated with a dust suppressant material to satisfy the State's Regulation 1 requirements. For this study, the impacted unpaved roads will have to be treated once each year. The County's average cost utilized for applying a dust suppressant material to a non-impacted gravel road is $2,100 per mile.

The maintenance and rehabilitation costs described above are based on the capacity that County resources can be utilized for these services. These costs may be increased if the County has to utilize outside resources to provide these additional services.

Low Category – Unpaved Roads

For the low-impact category, it is assumed that little additional work will be done to the road surface. Therefore, the only improvement costs attributed to low impact roads are increased maintenance costs for additional grading. For this study, the grading cycle would be increased to once per month instead of once every two months. The graveling cycle and application of dust suppressant would still occur as described above.

Elevated, Moderate and High Categories – Unpaved Roads

There were no segments of unpaved road sections that were categorized as elevated, moderate or high impacts for this study. As a reference, elevated and moderate impact categories would include maintenance and rehabilitation improvements that shorten the gravel application cycle, increase the application of dust suppressant as well as the grading cycle. For the high impact category, paving the gravel road becomes a lower cost option when life-cycle cost is considered. These categories can be further defined if the County encounters actual oil and gas traffic conditions for unpaved road segments that would fall into these categories.

Paved Road Analysis

Two factors are critical in analyzing the capabilities of paved roads to accommodate additional truck traffic: the current condition of the pavement and the structural rating, which is measured through the structural number (SN). The structural number is a function of the thickness of the surface and base layers and the materials of these layers.

The County provided a weighted average for the Pavement Quality Index (PQI) for all of the paved roads within this study. Surface treatments were not included in the improvement cost because these treatments do not have an impact on the structural ability of the pavement. However, it is noted that surface treatments aid in the prevention of oxidation of the pavement, which in turn, prolongs the life of the pavement. The following sections describe the methodology that was utilized to quantify the rehabilitation needs for Hot Mix Asphalt (HMA) Pavement and Concrete Pavement.

Hot Mix Asphalt Pavement Methodology

The approach to determine the rehabilitation needs to offset the impacts of oil and gas traffic on hot mix asphalt pavement roads requires the determination of the pavement structural number (SN) for existing traffic as well as existing traffic plus oil and gas traffic.

In order to determine the existing SN, the existing serviceability, initial serviceability, terminal serviceability, background ESAL, reliability level and standard deviation have to be defined. The existing serviceability is based on the weighted average PQI, as provided by the County, for each travel shed roadway. The existing serviceability is interpolated based on the PQI and values shown in **Figure 22**. The values shown in **Table 11** are based on industry standards for the different roadway classifications.

Figure 22. Pavement Condition Rating

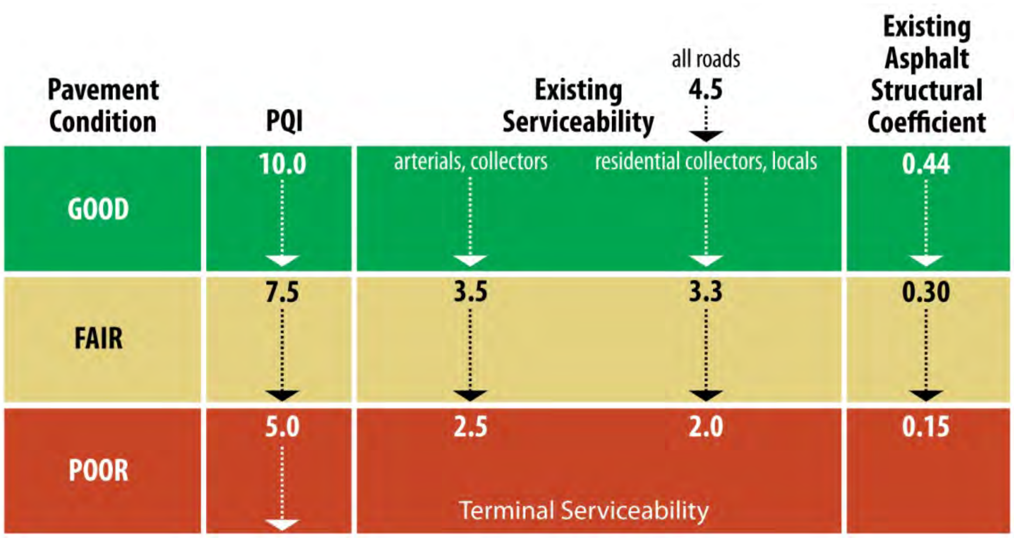


Table 11. Assumptions for Existing Pavement Sections

Roadway Classification	Design EDLA	Design ESAL	Reliability (%)	Standard Normal Deviate (Z_R)	Initial Serviceability	Terminal Serviceability	Standard Deviation	Structural Number[1] (SN) (New)
Principal Arterial	250	1,825,000	95	-1.645	4.5	2.5	0.44	5.02
Minor Arterial	200	1,460,000	90	-1.282	4.5	2.5	0.44	4.62
Collector	100	730,000	85	-1.037	4.5	2.5	0.44	4.03
Res. Collector	50	365,000	85	-1.037	4.5	2.0	0.44	3.49
Local	10	73,000	80	-0.841	4.5	2.0	0.44	2.68

[1] A subgrade resilient modulus (M_R) of 3,500 psi was used for all roadway classifications.

These values are then utilized to solve for SN within the following 1993 AASHTO Guide equation for flexible pavement:

$$\log W_{18} = Z_R \times S_0 + 9.36\log(SN+1) - 0.20 + \frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\log(M_R) - 8.07$$

W_{18} = predicted number of 18,000 lbs. (ESALs)
Z_R = Standard Normal Deviate
S_0 = Standard Deviation
SN = Structural Number
ΔPSI = Existing Serviceability – Terminal Serviceability
M_R = Subgrade Resilient Modulus (in psi)

After the SN is calculated for the existing conditions, the SN is calculated for the existing traffic plus the oil and gas traffic. The SN Deficiency is then calculated ($SN_{COMBINED}$ - $SN_{EXISTING}$). The required pavement overlay for the oil and gas traffic is then calculated by dividing the SN Deficiency by the Standard Deviation. A cost for the required overlay was then calculated for each respective section of hot mix asphalt road. An example of this process follows.

Poor Condition Asphalt Methodology

Heavy truck traffic such as the oil and gas traffic will expedite the need to reconstruct HMA roadways especially if the roadways have a poor current pavement condition. In order to program a portion of this impact into this study, the replacement cost of the pavement is calculated with the unit prices shown in **Table 12** for the poor segments of pavement as oil and gas traffic utilize these sections of roadway. After the roadway is reconstructed, the pavement is analyzed as a new pavement condition in subsequent years and utilizes the same methodology as described above. The segments that did not have poor pavement conditions were still considered with the same methodology as previously described.

Table 12. Assumptions for Poor PQI HMA Replacement

Roadway Classification	Standard Pavement Thickness	Unit Price per Mile per 1-Foot of Roadway Width
Principal Arterial	12”	$25,600
Minor Arterial	10”	$21,800
Collector	8”	$17,900
Res. Collector	8”	$17,900
Local	6”	$14,000

Hot Mix Asphalt Pavement Example

76th Street (Watonga Way to Wewoka Drive)

Roadway Classification – Collector

PQI Rating Score = 6.4

Pavement Condition = Fair

Design ESAL = 730,000 (from Table 2)

2016 Design ESAL = EDLA x Design Period = 100 x 365 = 36,500

Existing Serviceability = 3.06 (Interpolate from **Figure 22**)

Terminal Serviceability = 2.5 (from **Table 11**)

Reliability Level = 85% (from **Table 11**)

Standard Normal Deviate (Z_R) = -1.037 (from **Table 11**)

Existing SN = Solving AASHTO Equation = 2.98

2016 Oil & Gas ESAL = 8,090

Combined ESAL = 36,500 + 8,090 = 44,590

Combined SN = Solving AASHTO Equation = 3.15

SN Deficiency = $SN_{COMBINED}$ - $SN_{EXISTING}$ = 3.15 – 2.98 = 0.17

Required Overlay to achieve the Same Remaining Life = SN Deficiency/Standard Deviation = 0.17/0.44 = 0.39”

Associated Costs = Inches of HMA x Length of Road x Roadway Width x HMA Unit Costs ($60/Ton)

Associated Costs = 0.39” x (0.055 Tons/SY/1” Thickness) x 0.166 Miles x (5280 Feet/Mile) x 36 Feet x (1 Sq Yard/9 Sq Feet) x $60/Ton = $4,512 (Rounded to $4,600)

Concrete Pavement Methodology

The approach to determine the rehabilitation needs to offset the impacts of oil and gas traffic on concrete pavement roads requires the determination of the pavement service life. Standard design for pavement service life is a span of 20 years. The associated ESAL for the 20 year pavement service life are shown in **Table 13**.

Table 13. Standard Design ESALs for Concrete

Roadway Classification	Design ESAL
Principal Arterial	1,825,000
Minor Arterial	1,460,000
Collector	730,000
Res. Collector	365,000
Local	73,000

Oil and gas traffic will decrease the overall pavement service life for concrete roads. The amount of this decrease is calculated as a percentage and based on the calculated ESAL amount for oil and gas traffic divided by the overall Design ESAL. This percentage is then multiplied by the improvement costs per mile to reconstruct a concrete pavement road in its entirety. In the analysis, a reconstruction cost of $572,725 per lane per mile is utilized for reconstruction. This cost was derived from the Colorado Department of Transportation (CDOT) Transportation Facts for 2011 publication.

Concrete Pavement Example

South Boulder Road

Roadway Classification – Principal Arterial

Weight of Average PQI = 5.2

Pavement Condition = Fair

Design ESAL = 1,825,000

2016 ESAL = 14,764 (Oil & Gas Traffic)

Pavement Service Life Impact = 2016 ESAL/Design ESAL = 14,764/1,825,000 = 0.0081 or 0.81%

Associated Costs = Impact x Length of Road x Lanes x Reconstruction Cost

Associated Costs = 0.81% x 0.216 Miles x 4 Lanes x $572,725/Lane/Mile = $4,008 (Rounded to $4,100)

Safety Mitigation

In addition to the mitigation measures needed to offset the road deterioration, the study team identified measures to address the safety of the study area roads. The safety mitigation is based on the need for shoulder widening to maintain safe multi-modal roads with the increased truck traffic associated with the oil and gas traffic. Wider shoulders provide space for bicyclists separate from the travel lanes. Shoulders also provide safety benefits for all roadway users: they serve as a countermeasure to run-off-road crashes and provide a stopping area for breakdowns or other emergencies. Using the County's inventory of shoulder widths and their roadway design standards, the study team identified those roadways in the study area with sub-standard shoulders. If oil and gas trucks were assigned to those roadways in any of the three development scenarios in the travel model, it has been assumed that expedited shoulder widening would be needed to improve the multi-modal safety. The costs to widen the shoulders are based on the information presented in **Table 14** .Some of the shoulders would require only partial widening (that is, a narrow shoulder exists) which is reflected in the two foot width unit prices for minor arterials and collectors.

Table 14. Shoulder Widening Unit Costs

Road Classification	Shoulder Width	Unit Price/Mile
Principal Arterial	6' (Full Width - Both Sides)	$140,000
Minor Arterial	5' (Full Width - Both Sides)	$100,000
	2' (Partial Width - Both Sides)	$40,000
Collector	4' (Full Width - Both Sides)	$80,000
	2' (Partial Width - Both Sides)	$20,000

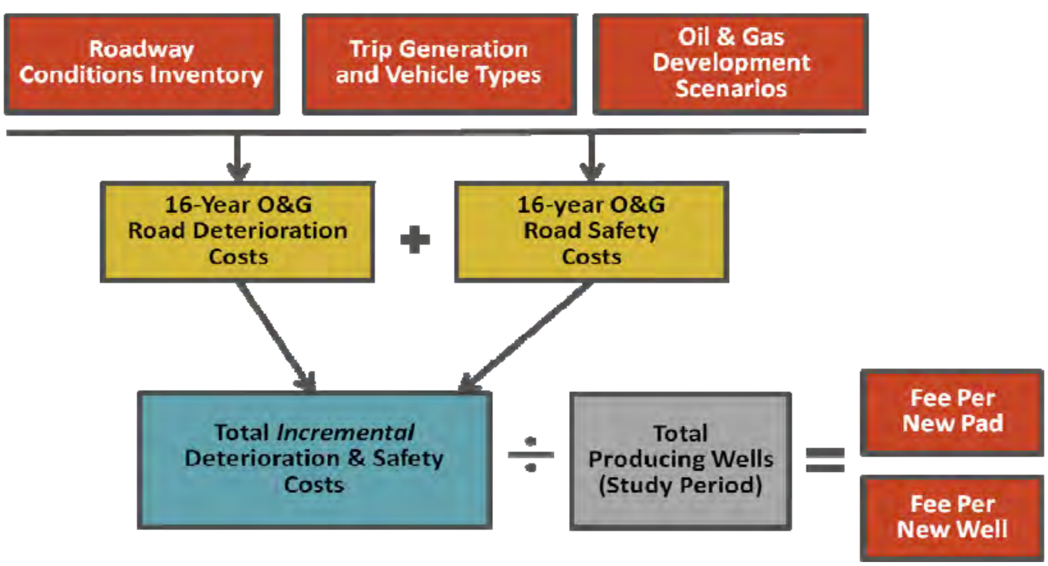
VI. Oil and Gas Road Deterioration and Safety Fee Design

The purpose of designing oil and gas road deterioration and safety fees is to recover the incremental costs associated with the energy industry's impact on the county road network. Because of the nature of oil and gas development, the most intense impact occurs during the first few months of a well's life. After the development stage, the well enters the less trip-intensive production stage for the remainder of the well's lifetime (15 to 25 years). The capital required to recover the costs of the development stage is ideally recovered before development begins or during the permitting process. This is accomplished through oil and gas road deterioration and safety fees.

In designing oil and gas road deterioration and safety fees, it is critical to isolate the oil and gas damage on the county roads. The fees are designed to recoup the *incremental* county cost associated with road deterioration and safety. The fees are based on a blend of the costs per well of the three scenarios and expected average trip lengths. The fees are also designed to be integrated into the oil and gas land use application process in the County's newly adopted regulations.

The methodology for calculating the oil and gas road deterioration and safety fees is shown in **Figure 23**. The process requires the combination of the inventory of roadway conditions, trip generation and vehicle types and development scenarios to find the 16-year incremental oil and gas road deterioration and road safety costs. The road deterioration costs are based on the unpaved and paved road methodologies described in Chapter V, and the safety costs are based on the shoulder widening methodology, also described in Chapter V. In the final step of the process, the incremental road deterioration and safety costs are divided by the expected total number of producing wells at the end of the study period. The fee is then separated into pad-specific and well-specific components according to the relative impact of pad construction compared to well development and production.

Figure 23. Fee Calculation Methodology



Fee Calculation

The oil and gas road deterioration and safety fees are calculated by finding total road deterioration and safety costs incurred by the oil and gas scenarios and dividing that total cost by the number of producing wells at the end of the study period. **Table 15** shows the deterioration and safety costs for each of the scenarios for a four-well pad and a single well.

Table 15. Calculation of Road Deterioration and Safety Fees

	Road Deterioration Cost	Safety Cost	Total Cost
Accelerated Scenario			
Total Cost (16-year period)	$24,393,296	$2,843,980	$27,237,276
Average Cost per 4-Well Pad	$118,414	$13,806	$132,220
Average Cost per Well	$29,604	$3,451	$33,055
Steady Scenario			
Total Cost (16-year period)	$24,661,955	$2,843,220	$27,496,175
Average Cost per 4-Well Pad	$119,718	$13,758	$133,476
Average Cost per Well	$29,929	$3,440	$33,369
Low Scenario			
Total Cost (16-year period)	$5,965,501	$2,105,360	$8,070,861
Average Cost per 4-Well Pad	$132,567	$46,786	$179,353
Average Cost per Well	$33,142	$11,696	$44,838
Scenario Average			
Average Cost per 4-Well Pad	$123,566	$24,783	$148,350
Average Cost per Well	$30,583	$6,196	$36,779
Average Cost per Pad Construction (1% of total cost)	$1,236	-	$1,236
Fee per Pad (rounded)			**$1200**
Fee per Well (rounded)			**$36,800**

The average cost per four-well pad is derived by dividing the total costs over the 16-year period by the number of four-well pads developed in each scenario. Then the average cost per well is found by dividing the average cost per four-well pad by four. This process is repeated for each scenario.

To calculate a separate fee for pad construction and well development, the project team averaged the costs for each scenario per four-well pad. Pad construction accounts for one percent of the average deterioration cost associated with a four-well pad ($1,236). This percentage is derived based on the construction phase's share of ESAL impact on the road network. Once the share of pad construction cost is taken out of the four-well pad average, the remainder is divided by four to calculate the average road deterioration cost per well ($30,583).

The average safety cost per four-well pad across the three scenarios is $24,783. These costs are only applicable to well development costs because there are no safety related expenditures incurred during the pad construction phase. Per well safety fees are calculated by dividing the average cost per four-well pad by four. The process produces a $6,196 safety fee per well.

The costs have been rounded to simplify the fee payments on a pad and well basis. For each new pad, there is a road deterioration fee of $1,200 to cover road maintenance and rehabilitation costs. For each new well there is a fee of $30,600 to cover road deterioration costs and a fee of $6,200 to cover safety costs. **Table 16** shows the fees for each new pad and new well.

Table 16. Oil and Gas Roadway Fees

	Road Deterioration Fee	Safety Fee	Total Fee
Pad	$1,200	-	**$1,200**
Well	$30,600	$6,200	**$36,800**

Note: Fees are in current year dollars.

Based on the fees above, a new four-well pad would be imposed a $148,800 deterioration and safety fee. The fees in **Table 16** are designed to recover the incremental costs associated with the energy industry's impact on the county road network and are expressed in current year dollars. To account for changing unit costs of roadway construction, rehabilitation, and maintenance, it may be appropriate to apply a cost index annually, such as the *Engineering News Record* or CDOT construction cost index.

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