IMPACTS TO MONTANA STATE HIGHWAYS DUE TO BAKKEN OIL DEVELOPMENT

FHWA/MT-13-002/8219

Final Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

February 2013

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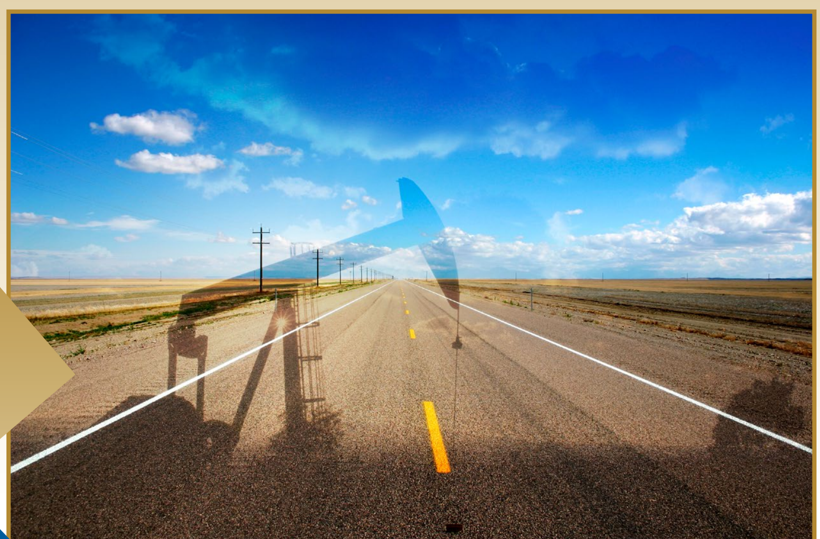

RESEARCH PROGRAMS

MDT

NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE

Impacts to Montana State Highways Due to Bakken Oil Development

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<tr><td colspan="4">16. Abstract
This study developed a detailed truck traffic forecasting model with specific attention to truck movements related to oil development in the Bakken formation in eastern Montana and western North Dakota.

Oil forecast scenarios as specified by MDT were analyzed to assess the differences in impacts under differing development scenarios. Locations of input sources were identified through industry websites, Departments of Transportation, and other regulatory bodies. Routes between aggregate well locations and input and output sources were estimated utilizing ESRI Network Analyst©. A series of capacity constrained optimization models were used to select the least cost set of routes for oil distribution in the region, and results were aggregated to the highway segment level.

Traffic data provided by MDT was used to calibrate and validate the traffic forecasting model. Traffic forecasting results are presented in shapefile format, which allows the user to retrieve segment specific forecasts and display changes in traffic volumes over the analysis period.</td></tr>
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EXECUTIVE SUMMARY

Recent oil development in western North Dakota and eastern Montana has resulted in large-scale highway needs which suggest the possibility that substantial investment will be required in the near future. This report outlines the development of a regional traffic model to predict and assess traffic increases in northeastern Montana as a result of oil development. The analysis included a significant data collection effort to identify: existing and potential locations of inputs to the drilling and horizontal fracturing processes, existing and potential saltwater disposal and oil collection facilities, forecasts of future production and exploration, and detailed geographic information system (GIS) network development. A mathematical optimization model was estimated to predict impacted highway segments, and traffic volumes were calibrated using observed traffic counts. Four rig count scenarios were analyzed: 20, 40, 80 and 160 rigs. Results of the analysis show significant traffic increases in the Richland, Roosevelt, and Sheridan county area with additional traffic increases in the surrounding areas.

The study developed traffic forecasts for all state-maintained roadways within the study area for the next 20 years. These results are presented visually as well as in supplementary GIS shapefiles. Traffic forecasts presented in this report are subject to assumptions made in terms of production and extraction technology as well as the underlying forecast scenarios. It is expected that the forecast information outlined in this report is to be used in conjunction with traditional traffic forecasting techniques and classification count observations for use in highway planning and design.

1. OVERVIEW

Recent improvements in oil extraction technology have increased the economic viability of production from oil shale formations. Because of these technological innovations and continued interests in fostering energy independence, the Bakken formation in western North Dakota and eastern Montana has become a major focus of current and future energy development plans.

Rapid oil development in western North Dakota and eastern Montana has resulted in large-scale highway needs which suggest that substantial investment will be required in the near future. Given the recent history of western North Dakota and escalating activity levels in Montana, the Montana Department of Transportation (MDT) has undertaken development of a traffic model to further understand the future demands and traffic patterns that will result from origins and destinations of fracking materials, as well as the transportation infrastructure needed to move both inbound materials and outbound products to transfer locations or market. This information is essential to forecasting the highway impacts of future oil development and production in the state as well as for identifying potential infrastructure funding gaps and solutions that will be critically important to the development and implementation of a comprehensive highway transportation plan to sustain Montana's needs.

This document outlines the data collection efforts and methodology used to develop a truck trip forecasting model for eastern Montana. The report is organized by individual tasks as specified in the study contract. However, because of the progression of the tasks, they are not presented in the same order as in the study contract. Chapter 2 outlines the locations for inputs to oil production and outbound destinations for crude and saltwater movements. Chapter 3 discusses the rationale behind analyzed scenarios. Chapter 4 describes efforts to construct a routable GIS model. Chapters 5 and 6 discuss additional data elements used to estimate ESAL factors and the evaluation of existing traffic data. Chapters 7, 8 and 9 describe the processes and methodology used to forecast and assign traffic to individual highway segments. Sample results are presented in Chapter 10. As specified in the contract, the deliverable form for traffic forecasts results is in GIS shapefiles. Chapter 11 describes the steps necessary to join and view the traffic forecasts within ESRI ArcMap.

2. DEVELOP GIS PRODUCTION DATABASE

2.1. Township as production locations

Township polygons are used in this analysis as the basis of the traffic analysis zones (TAZ). The township data was obtained from the TIGER® website (U.S. Census Bureau 2011). To represent the activity location in the township polygons, the centroid of the township was used to approximate locations of oil drilling activities and production (i.e. oil production sites). This designation provides more detailed results than aggregation to the county subdivision or zip code level. Moreover, this level of aggregation is appropriate as permit information is unavailable. (Figure 2-1).

In addition to truck trips generated as a result of oil development in Montana, many cross border movements result due to oil production in North Dakota. Due to capacity constraints on crude oil transload facilities in North Dakota, outbound oil may move to transload facilities in Montana. Aside from capacity limitations, the geographic proximity of North Dakota production to Montana transload facilities may generate additional crude oil truck trips. Well drilling inputs for North Dakota wells are often sourced from Montana for the reasons mentioned above. Therefore, North Dakota oil development areas are included in the analysis to account for cross-border movements. A total of 363 and 206 township centroids are considered in Montana and North Dakota respectively.

Figure 2-1: Township centroids as production sources.

2.2. Freshwater sites

Freshwater sources are critical to the traffic flow model because the locations generate a significant amount of traffic for the hydraulic fracturing process. However, because of limited data availability, the freshwater locations were difficult to obtain. The following are names and departments that were contacted to determine if there were any valid geographic coordinates of freshwater locations and possible capacities.

- "Water Source" in the Oil & Gas Data shapefile provided by Jim Halvorson (Halvorson 2012)
- GWIC dataset- shapefile, but no information on capacities or distinction of use for hydraulic fracturing (Montana Groundwater Information Center 2012)
- Division of Natural Resources Conservation (DNRC) Water Rights Query System contains capacity data, but no distinction of whether the water is available for use in

hydraulic fracturing at present (Montana Department of Natural Resources and Conservation 2012a).

The ground water wells data provide completion date, purpose for water, and the drilling company. Based on these sources and information, ground water wells that yield 300 gallons per minute or more are used in the analysis. This yield corresponds to a capacity of 1.094 million barrels of freshwater per year. By applying this threshold a total of 272 fresh water locations were selected for inclusion in the analysis.

- Water from Montana cannot be sold to other states (Montana Department of Natural Resources and Conservation 2012b). The guidance for municipalities report from April 19, 2012 says:
    - Municipalities may utilize their existing water rights to sell water for oil development <u>as long as the volume and flow of the water rights are not exceeded</u>.
    - Municipalities may also expand their water rights under the following conditions:
        - If a municipality wishes to increase its usage, including either the flow rate and/or the volume of its water right, then it must apply for and receive a Beneficial Water Use Permit (Form 600) for the additional <u>flow rate and/or volume</u> before actually increasing its usage. If the municipality expands its service area outside the historic place of use and needs to increase its flow rate and/or volume to service that growth then that also requires a new permit.
        - If the municipality expands its service area outside the historic place of use in order to sell water, but is not increasing its flow rate or volume, an Application to Change a Water Right (Form 606) ("Change") will need to be filed to add the new place of use. For example, if a municipality wants to set up a new water depot a mile outside of its municipal boundary then it needs to file a Change application and receive authorization before putting the water depot to use.

The potential to haul water from North Dakota to Montana is feasible as long as the company has been issued a "point of diversion" permit for using the water, according to state regulatory officials. The potential to haul water from Montana to North Dakota is not feasible, unless the company or individual meets the "Montana Code Annotated 2011, 85-2-311 sub-section (4)" criteria (Montana Legislature 2011).

The MDT has indicated that freshwater movements cross the border between Montana and North Dakota are possible despite the stated regulations. This study includes 42 freshwater locations from North Dakota, which will allow for cross-border movements (Figure 2-2). This model includes two scenarios: water procurement crossing borders and water consumption within state boundaries.

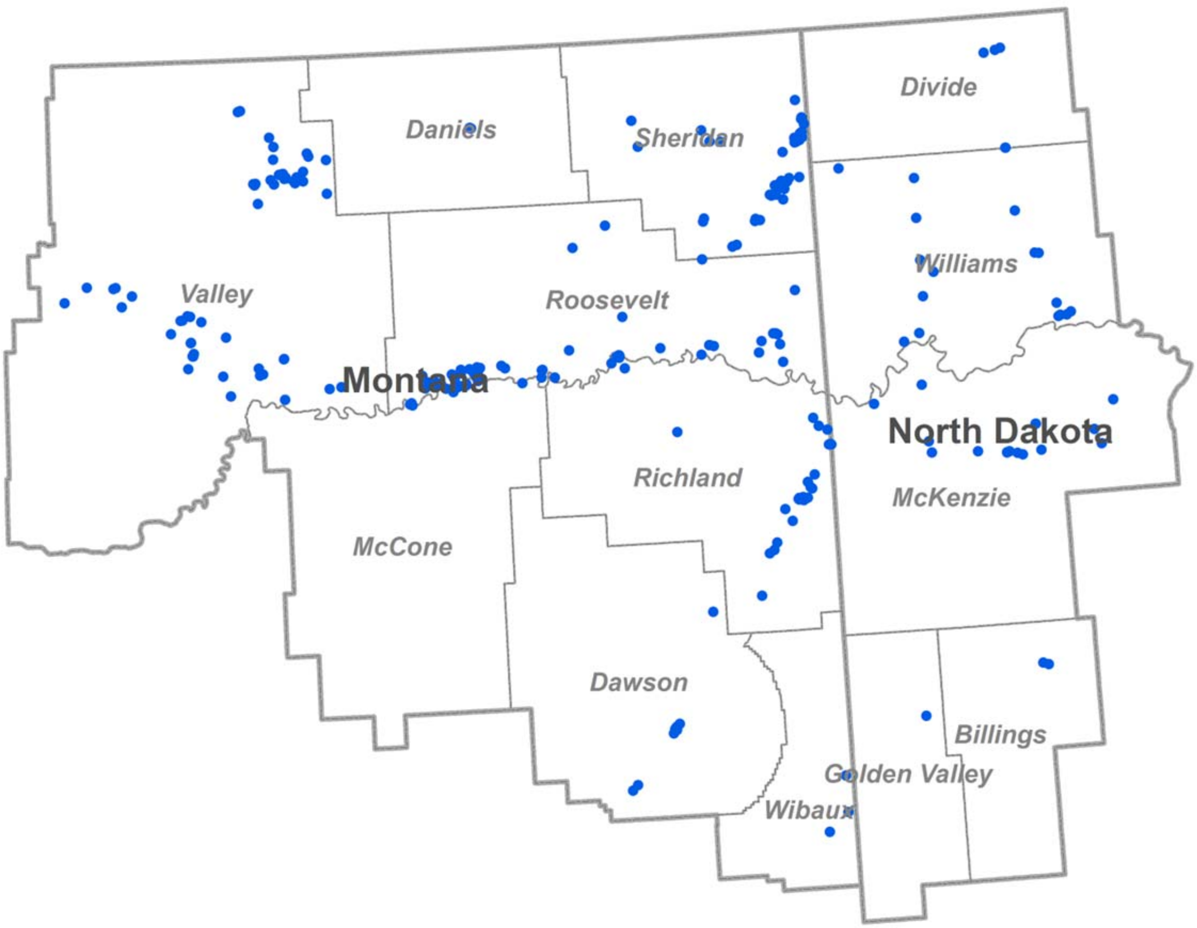


Figure 2-2: Selected freshwater locations.

2.3. Salt water disposal (SWD) sites

The Montana Oil and Gas Division provided oil well GIS shapefiles, including multiple well type designations. Among the types of wells, 272 active and drilling disposal sites are identified in Figure 2-3. There are 169 SWD sites in North Dakota and 103 sites in Montana. The SWD sites in North Dakota were obtained from the North Dakota oil and gas GIS map viewer (North Dakota Department of Mineral Resources 2012).

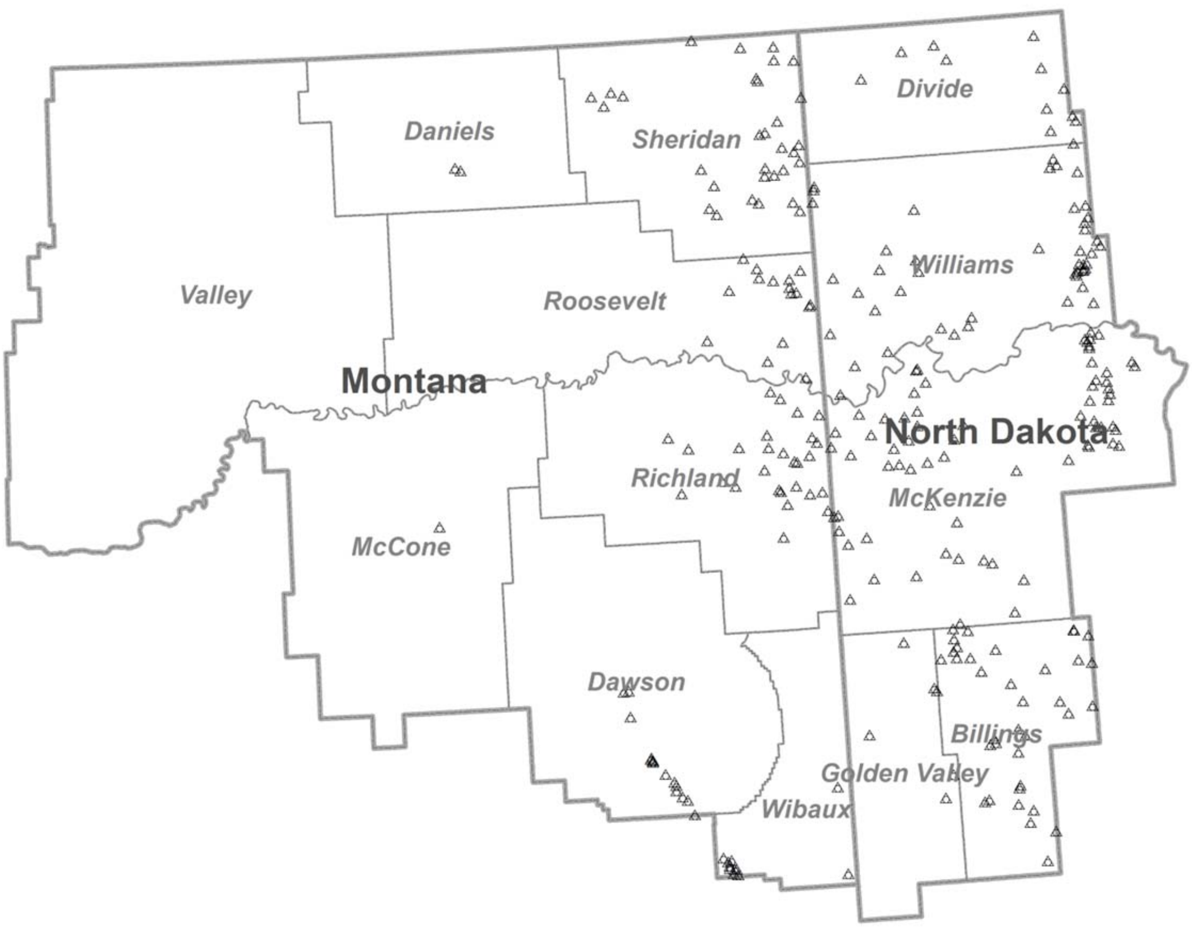


Figure 2-3: SWD locations.

2.4. Railroad transloading facilities

Rail transload facilities were identified and geocoded in the GIS network throughout the study region. Sources of the locations included railroad websites, private firm websites, NDDOT data, and visual identification from satellite imaging. Google Earth® was used to locate and verify facilities located on the rail network. Grain elevator terminals were excluded. The rail terminals were crosschecked with BNSF and local railroad companies' websites to determine whether they met the criteria for inclusion in the analysis.

Procore Inc. operates a facility in Bainville, MT, to serve the Bakken oil play (Procore Group Inc. 2002). Pioneer operates a BNSF spur located in Culbertson, MT, for off-loading super sacks of ceramic proppants. A transload facility in Dore, ND, is served by the BNSF railroad through the Yellowstone Valley Railroad (Pioneer Oil, LLC 2011). The crude-by-rail facility in Dore can handle 60,000 barrels per day (Progressive Railroading 2012) Specific facility locations are shown in Table 2-1.

Table 2-1: Railroad transloading facilities in Montana.

Latitude	Longitude	Place	Company
48.1432	-104.5160	Culbertson, MT	Pioneer oil Transloading
48.1468	-104.2325	Bainville, MT	Procore
46.1058	-105.1860	Poplar, MT	BNSF (Future)

Three rail transloading facilities in Montana and five rail transloading facilities in North Dakota are geocoded based on the data collected in Montana as well as locations identified in previous research efforts in North Dakota (Figure 2-4).

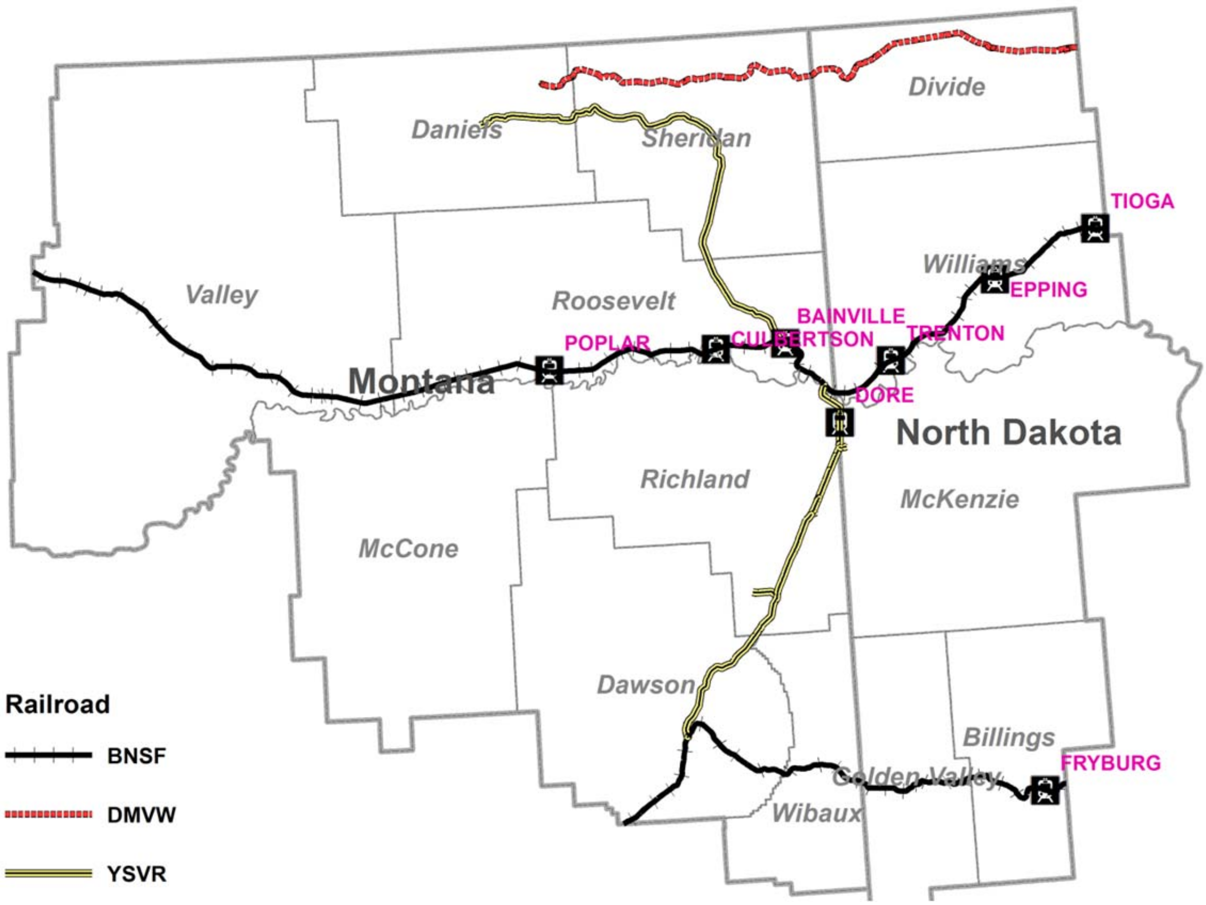


Figure 2-4: Railroad oil transloading facilities (Poplar station in the near future).

The four crude-by-rail sites in operation in North Dakota were included in the analysis and shown in Table 2-2: Trenton, Dore, Epping, and Tioga. Those facilities handle 70,000-90,000 barrels of oil per day (bbls/day). Trenton, Epping, and Tioga are located in Williams County, Dore in McKenzie County, and Fryburg in Billings County. The crude oil from these locations is transported via BNSF.

Table 2-2: Rail transloading sites in North Dakota (Dakota Plains Holdings Inc. 2012).

Location	**Company**	**Capacity** (bpd)	**Storage** (bpd)	**Pipeline Connection**
Trenton	Savage	90,000	300,000	Tesoro-Anacortes
Dore	Musket Corp.	70,000	90,000	Banner Pipeline
Epping	Rangeland COLT	80,000	600,000	Texon-East Coast
Tioga	Hess	70,000	180,000	Oil in via Gathering
Fryburg	Great Northern	70,000	300,000	Bakken Link Pipeline

Note: bpd means barrels per day.

2.5. Pipeline transloading facilities

Enbridge operates North Dakota Systems starting from Plentywood, MT, to Clearbrook, MN. The pipeline network is shown in Figure 2-5.

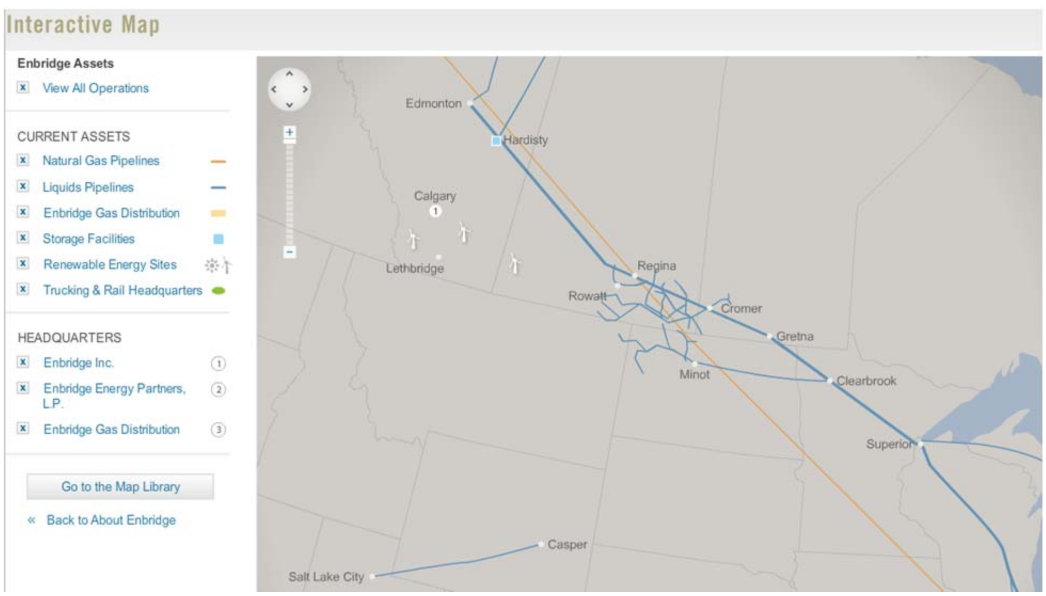


Figure 2-5: Interactive map of the Enbridge pipelines (Enbridge Inc. 2011).

Bridger Pipeline LLC owns and operates the Poplar System in eastern Montana (Figure 2-6). The Poplar system uses 10-inch and 12-inch lines for crude oil from the Williston Basin south to Baker, MT. The receipt points are Poplar in Roosevelt County, Fisher and Richey in Richland County, and Glendive in Dawson County. The stations have a capacity of 42,000 barrels per day (bpd) (Bridger Pipeline LLC 2011).

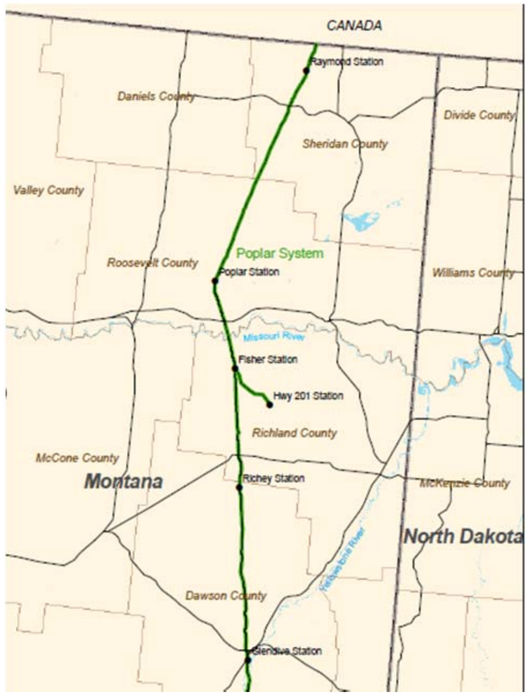


Figure 2-6: Poplar system in Montana (Bridger Pipeline LLC 2011).

Seven pipeline transloading locations are in Montana and 15 locations are within the study area in North Dakota (Figure 2-7).

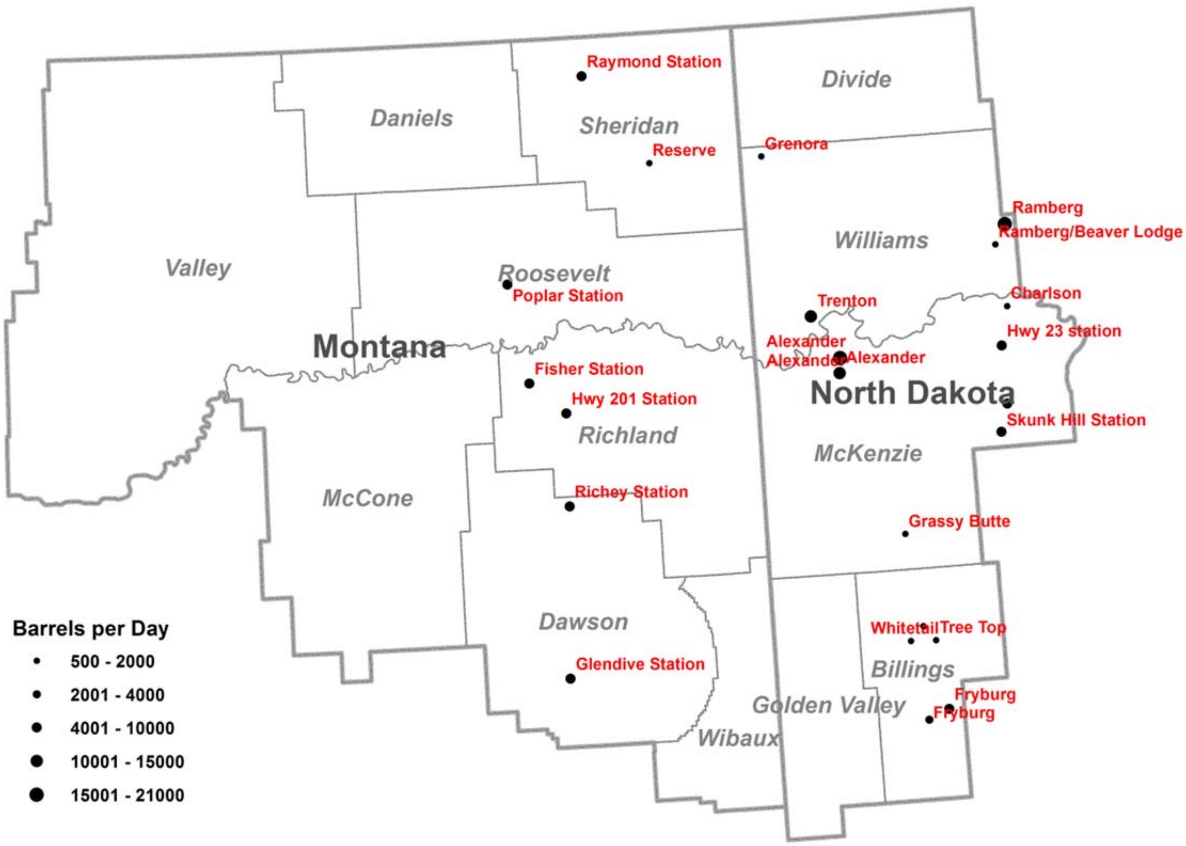


Figure 2-7: Pipeline transloading facilities.

2.6. Oil towns

Supplies and materials originate in larger towns and cities including Williston, ND, and Glendive and Sidney, MT. Though the city of Williston is located in North Dakota, there are no cross-border restrictions on material movements. Cities with populations greater than 4,000 are utilized as supply points in this study (Figure 2-8). In 2010, the populations of the three cities in the study region as reported by the US Census Bureau were:

- Sydney, MT : 5,191
- Glendive, MT : 4,935
- Williston, ND : 14,716

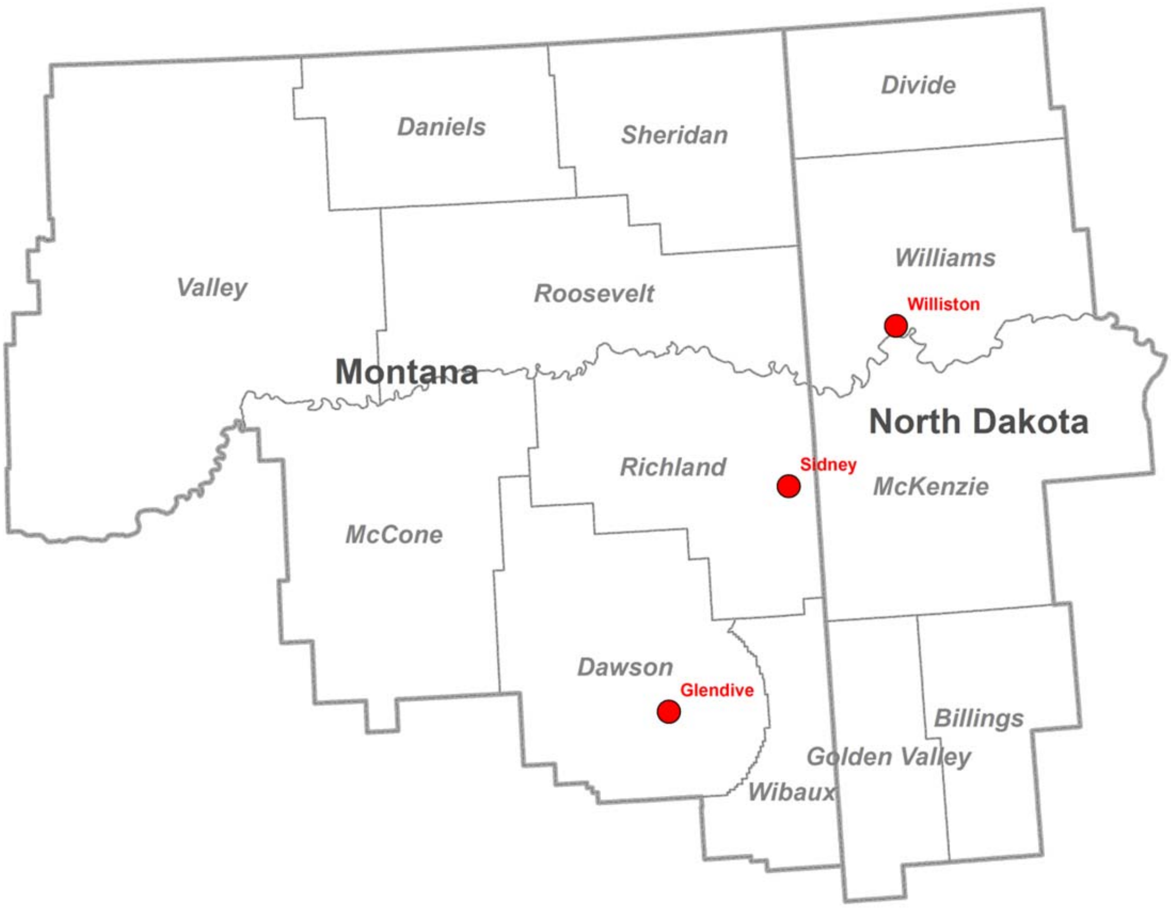


Figure 2-8: Oil Towns as supply locations in Montana and North Dakota.

2.7. Sand

BNSF Railway and U.S. Silica plan to supply frac sand on 100-car BNSF trains moving from a sand mine in Ottawa, IL, and a new facility in Rochelle, IL, in 2013 (Progressive Railroading 2012). Frac sand also will be supplied by Chippewa Sands in Chippewa Falls, WI, and Superior Silica Sands near New Auburn, WI, using the BNSF Railway to transport the sand to the Bakken formation (MineralWeb 2011). In addition, ceramic proppant and frac sand from China is currently being transported to the Bakken production region via rail. (Heartland Institute 2012) Canadian Pacific (CP) Railway is expected to transport dry sands supplied by U.S. Silica Holdings Inc. to the region from Sparta, WI, beginning in 2013 (Reuters 2012). Canadian Pacific Railway is expanding the capacity of its terminals in New Town and Portal, ND, while BNSF Railway operates North Dakota terminals in Minot, Stampede, Donnybrook, Ross, Zap and Dore, and a terminal in Sidney, MT (Schramm 2011).

This study uses four rail terminal locations for sand supply sources: Culbertson, Glendive and Sidney in Montana, and Williston in North Dakota as shown in Figure 2-9.

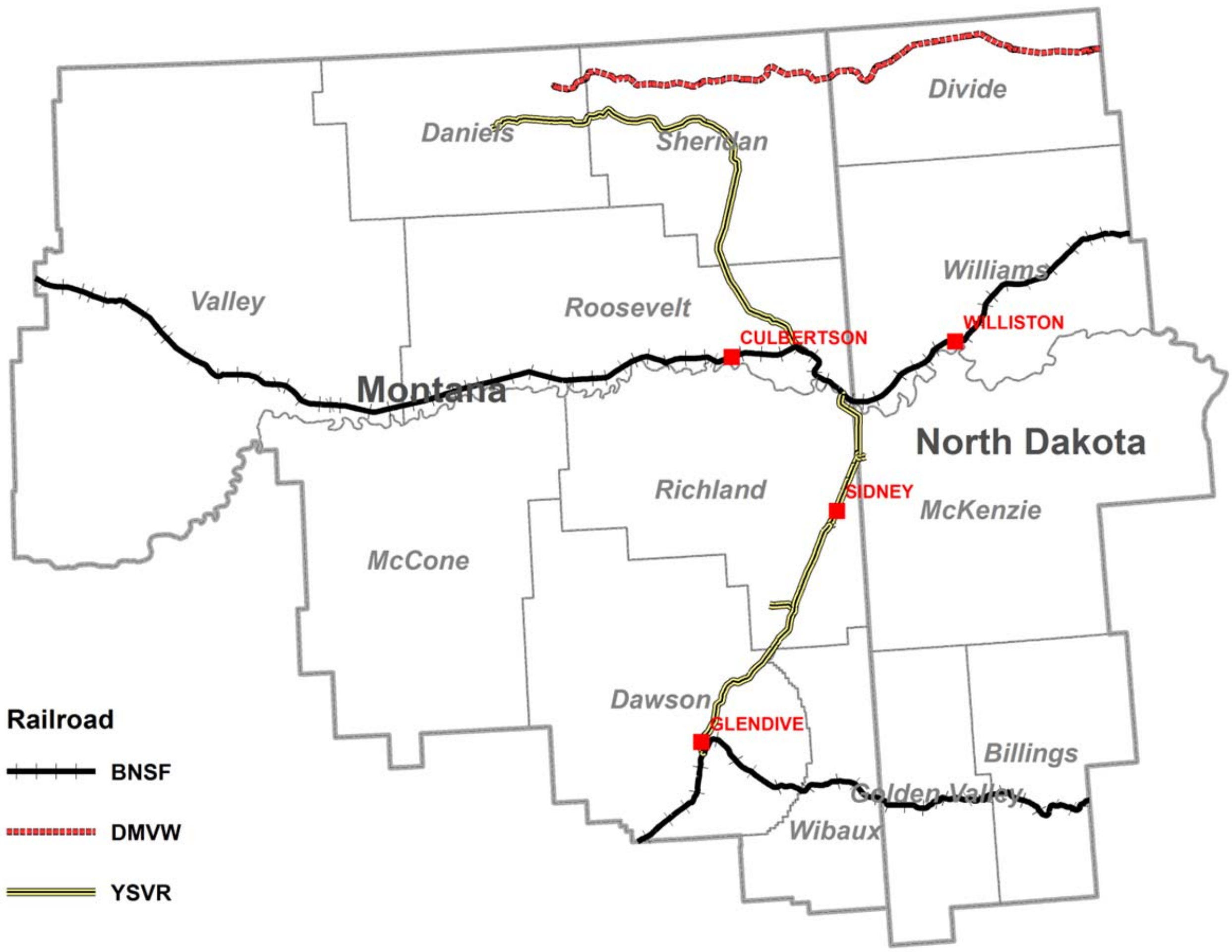


Figure 2-9: Frac sand rail supply locations.

2.8. Gravel/scoria

Gravel is a major trip generator for the construction of access roads and drilling pads. Scoria locations were provided by the Montana Department of Environmental Quality (DEQ) for the study. In the provided data, the study includes 113 active, private gravel locations (Figure 2-10). A database of gravel and scoria sites is not maintained for the state of North Dakota. Cross border movements of gravel and scoria from Montana to North Dakota are likely, but due to data limitations, could not be quantified in this analysis.

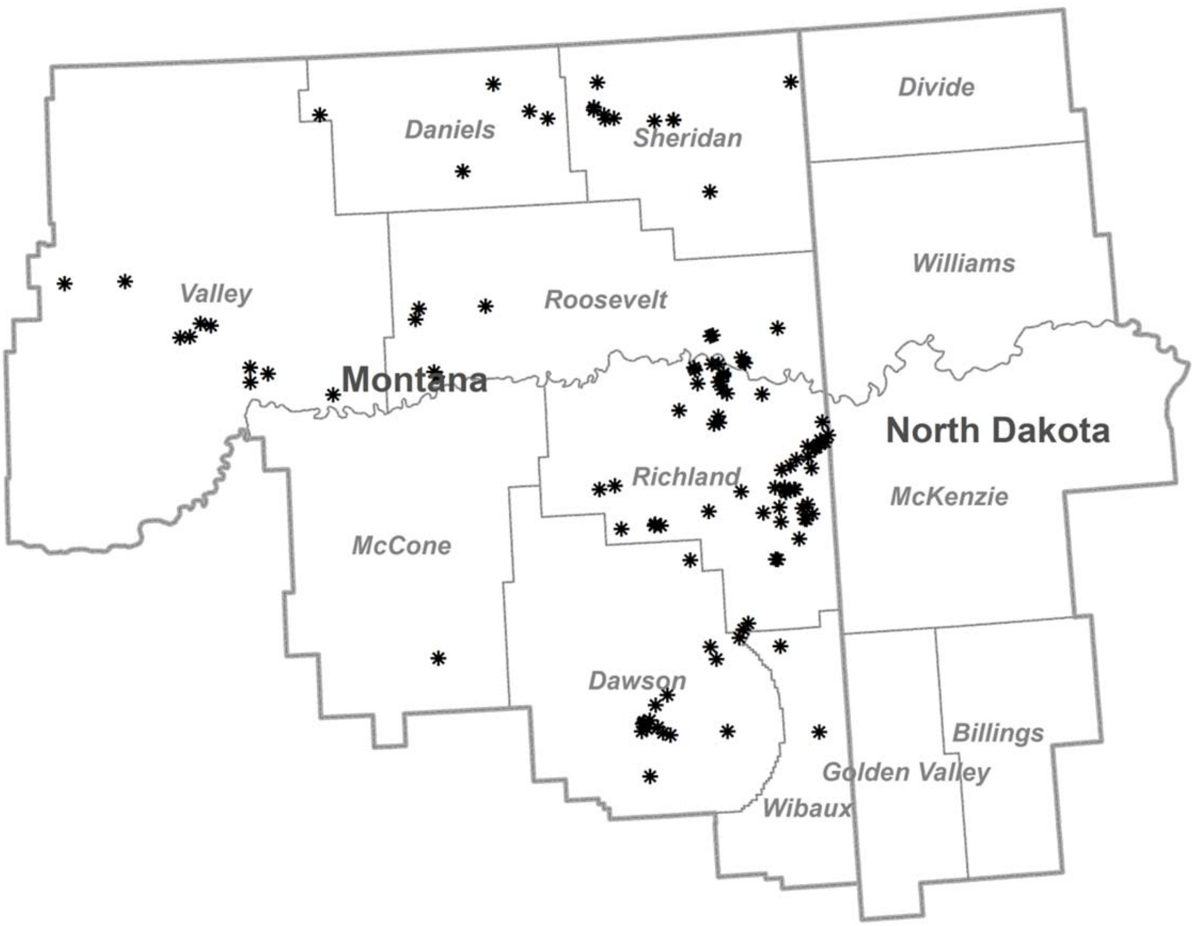


Figure 2-10: Gravel/scoria geographical locations in Montana.

3. SYNTHESIZE FORECASTS OF OIL DEVELOPMENT

A key driver of truck trip generation is the process of drilling and hydraulically fracturing a well. The number of new wells and duration of oil exploration must be estimated for placement of future wells. The North Dakota Oil and Gas Division produces rig forecasts and estimates the total number of wells by county during a 30-year time period. Forecast data by county was obtained for North Dakota development.

Acquisition of similar data from the Montana Oil and Gas Board (OGB) was attempted, but similar forecasts are not produced by the OGB. An interview with the OGB indicated that future development will occur in Richland, Roosevelt, and Sheridan counties. Recent historical rig counts have fluctuated between 10 and 17 rigs, with 20 expected in the near future. During a May 31, 2012, meeting with MDT, it was decided that scenarios of oil development using 20, 40, 80 and 160 rigs as the break points would be constructed. This will allow MDT to select the appropriate scenario based upon observed development and to model future impact.

4. DEVELOP A DETAILED GIS NETWORK OF STATE HIGHWAYS

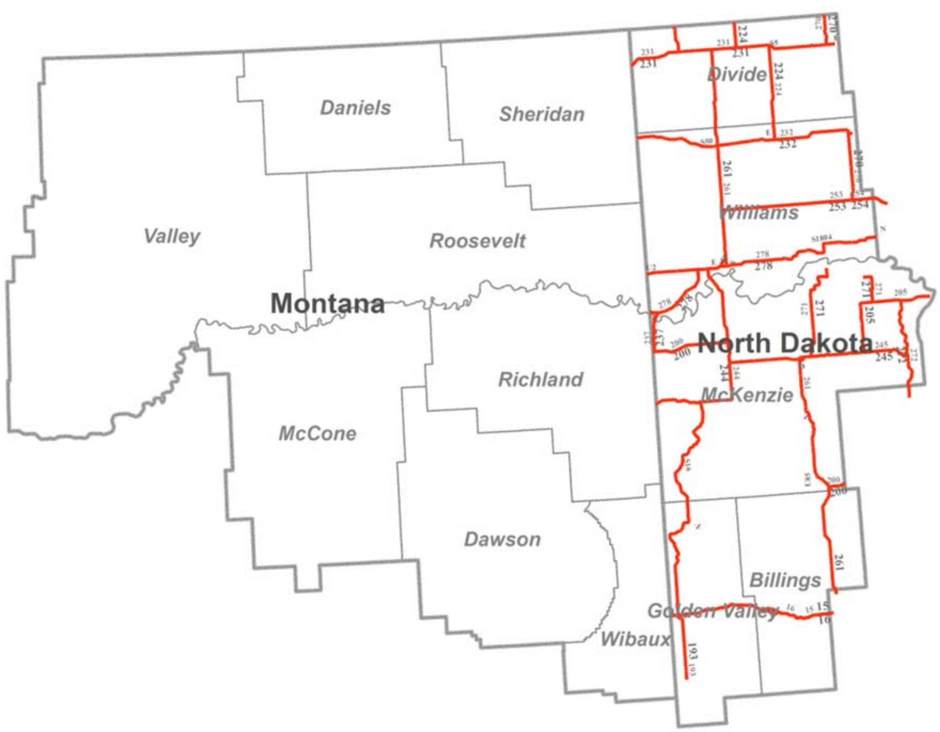
4.1. Road networks

Road networks were provided by MDT for northeast Montana. Oil activities in this area are closely related to the oil activities in northwest North Dakota because they are encompassed in the same oil seismic region. Therefore the network was expanded to include the road networks from North Dakota provided by the North Dakota GIS Hub portal so that extended road networks could be used for this comprehensive study (North Dakota GIS 2012). Thirteen counties were considered for the study: eight in Montana and five border counties in North Dakota (Figure 4-1).

Figure 4-1: Oil Counties in Montana and North Dakota.

Montana and North Dakota maintain road inventories using different methods such as functional classification and linear referencing system measures (kilometers in Montana and miles in North Dakota) (see Figure 4-2). This study converts segment length to miles and travel speed to miles per hour (mph) in order to calculate travel time on a consistent basis from state to state.

(a) Interstate and Non-Interstate Highways and Primary Roads in Montana



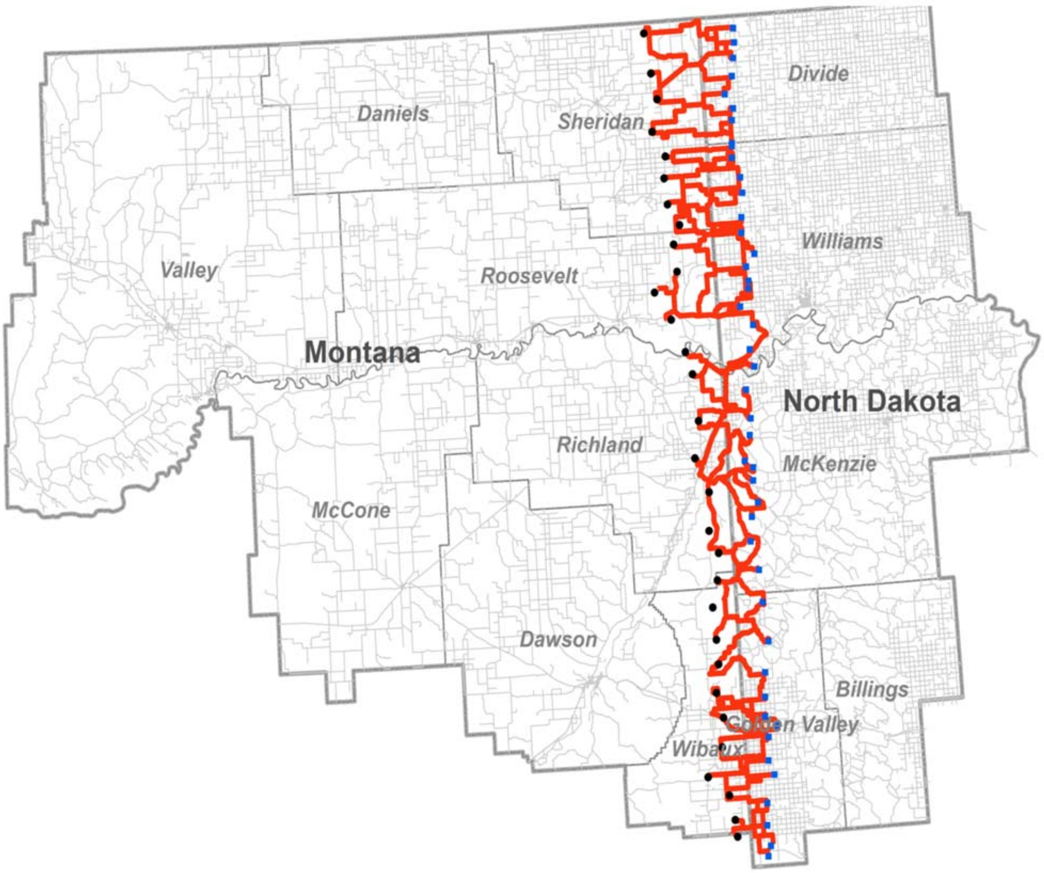
(b) Interstate, U.S. and State Highways in North Dakota

Figure 4-2: Roads in Montana and North Dakota Showing Different Classifications.

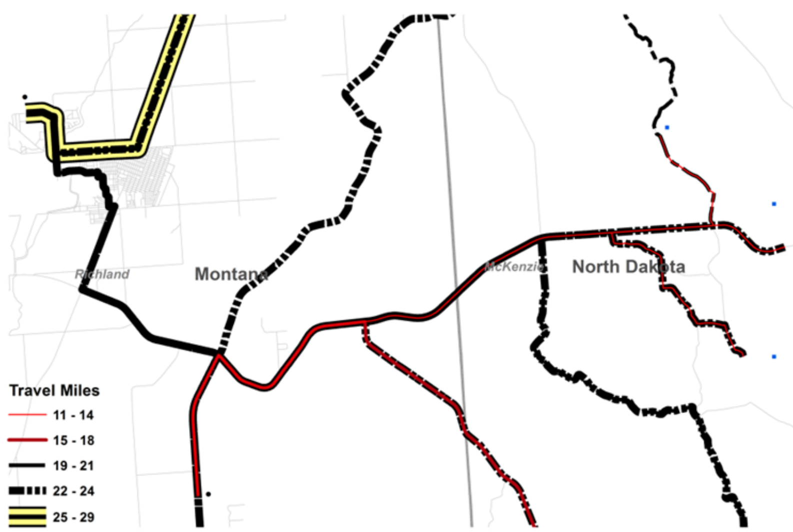
4.2. Border crossings

For the border crossing between Montana and North Dakota, the two road network data sets were merged into one. Because of differences in data sources, manual connection of Montana and North Dakota roads was required to ensure cross-border connectivity. To connect the border crossing points, the segments in the North Dakota road network were elongated or shortened. In other words, the Montana road segments are considered as base information to extend the oil study into North Dakota. In addition, the overlapped segments between Montana and North Dakota were removed from the North Dakota shapefile. The connecting points are based on TIGER® national road network 2011, which contains nationwide comprehensive road networks for the U.S. Census Bureau and provides connectivity between states.

For quality assurance purposes, dummy locations near the state border were generated: 30 origins in Montana and 36 destinations in North Dakota (Figure 4-3a). Using the Network Analyst tool in ArcMap 10.0, each origin point in Montana was connected to the three closest destinations in North Dakota. All shortest routes found were reasonable and appropriate within 30 miles for further analysis (Figure 4-3b).



(a) Three shortest paths from each origin



(b) Enlarged inspection for verification of appropriate routing

Figure 4-3: Quality assurance for connectivity through border crossings.

5. INTERSECTIONS AND JUNCTIONS

Connectivity between road segments to connect facilities and economic activity locations are essential for network analysis. For the multi-state analysis, the border crossing points between the states were manually connected. In addition, connectivity between multiple road classifications was ensured by creating new vertices as connecting points and removing unnecessary connections. The check points of the process:

- Confirm that routes follow logical paths based on the roads considered.
- Confirm that the connectivity observed conforms to expected criteria as assigned while building the network data set from existing roads.
- Determine that the closest facility is indeed the closest facility by a visual comparison of length of routes considered.
- Visual referencing is conducted to crosscheck the existence of actual connections in the network in order to verify the routes created.

5.1. Attribute settings

The model finds the fastest paths from origin to destination. Travel time was calculated for each segment with travel time as a function of travel speed and length of a segment, *travel time* = *f* (*travel speed*, *distance*).

5.1.1. Segment length

For the network analysis, the length of the segments and speed through the segments were used to calculate travel time for use as route impedance for this study. The road networks provided by MDT do not contain the true lengths of the road links. To quantify the discrepancy, the lengths of the segments in Montana and North Dakota were generated by using the embedded geometric calculator in ESRI ArcMap®. Following segment length estimation, comparison of the total length of all segments in the provided network and estimated lengths resulted in minimal error.

5.1.2. Travel speed through networks

General speed limit in Montana was obtained from the MDT website (Montana Department of Transportation 2010). To calibrate the speed information, speed data from the MDT highway economic model was used, where available. It was assumed that the speed limit was representative of the actual travel speed on on-system highways. The highway economic model data set was limited to the on-system routes and included the national highway system, all primary routes and some secondary routes (Figure 5-1). The missing speed information of the other off-system links was assumed.

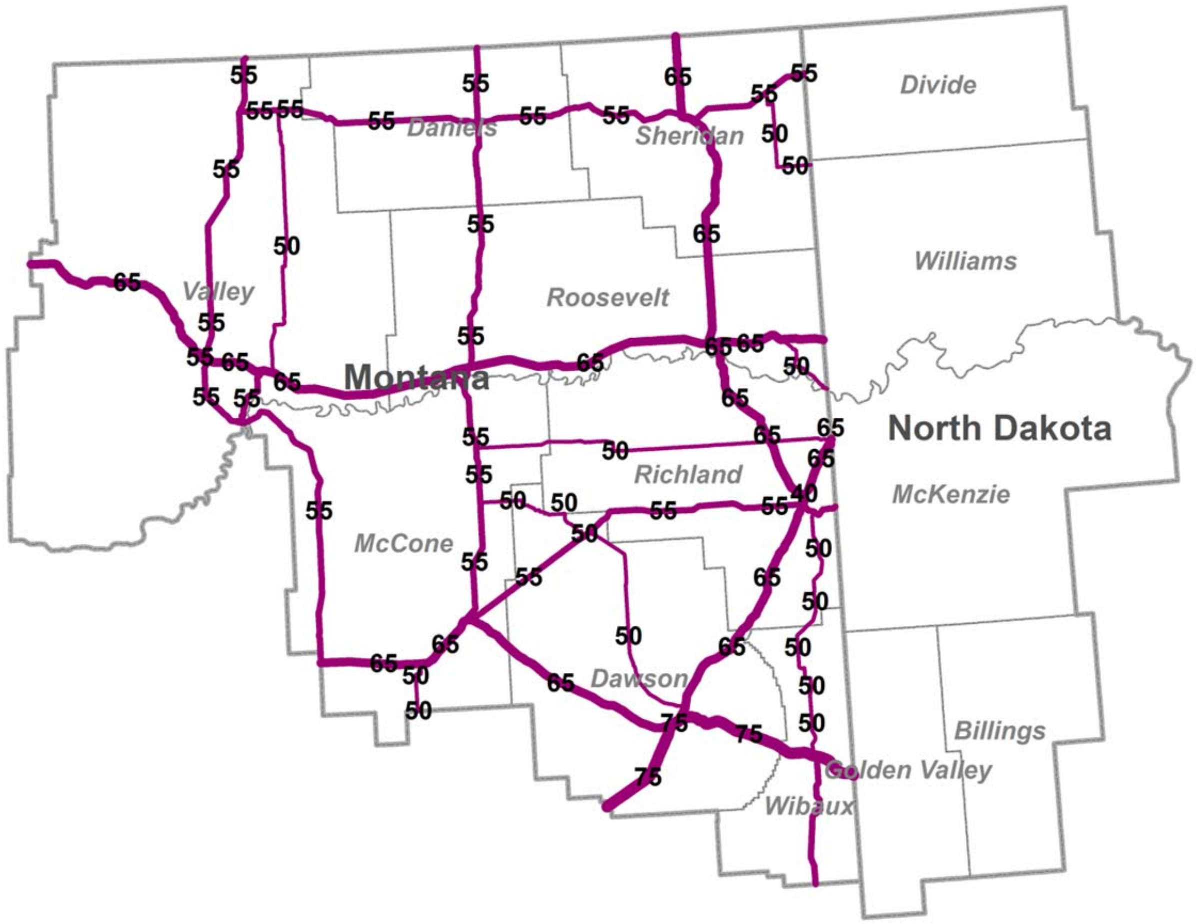


Figure 5-1: Travel speed through Highway Performance Maintenance Systems (HPMS) in Montana.

The assumed speed limits for other county and city road speed are shown in Table 5-1. As the table outlines, roadway speed limits vary by number of lanes, whether the highway is divided, jurisdiction, and surface type. Not all of these types of roadways are included in the analysis, but the decision rules were designed to consider every possible roadway combination.

Table 5-1: Estimation of the traveling speed of trucks during a daytime in Montana (miles per hour).

	Number of Lanes	**1**	**2**	**2**	**2**	**3**	**3**	**4**	**4**
	Divided	**no**	**no**	**no**	**yes**	**no**	**yes**	**no**	**Yes**
Type	***One way***	**no**	**no**	**yes**	**no**	**no**	**no**	**no**	**No**
Local	bladed	35	35	35	35	35	35	35	35
Local	graded	35	35	35	35	35	35	35	35
Local	gravel	35	35	35	35	35	35	35	35
Local	paved	45	45	45	45	45	45	45	45
Ramp	paved	35	35	35	35	35	35	35	35
Secondary	gravel	50	50	50	50	50	50	50	50
Secondary	paved	50	50	50	50	50	50	50	50

5.2. Sample routing verification

For the purpose of network and routing verification, seven random incidents (origins) in Montana and a single destination (Williston, ND), were located. The shortest paths were based on the shortest distance for verification purposes. Each segment was connected from any vertex to any other segments having connectivity to generate paths.

A total of 533 townships were used in this study. The centroid of each township was connected to the road network to ensure connectivity suitable for routing purposes (Figure 5-2). This process requires specification of the search tolerance for ArcMap© to connect the centroid to the road network. The greatest distance between township centroid and the road network was 9,753 meters (Figure 5-3), therefore the search tolerance was increased to 10,000 meters to ensure maximum connectivity. All other townships were connected to the closest segment point, and the increase in tolerance did not impact connectivity. Township centroids that were not connected are shown in Figure 4-7b. “A” locations (township-range number T035NR038E) in Figure 5-2b are candidate origins for oil production, while “B” locations may not be production centroids because they are outside of the road network provided by MDT and the study area. In this case, the “B” locations were removed.

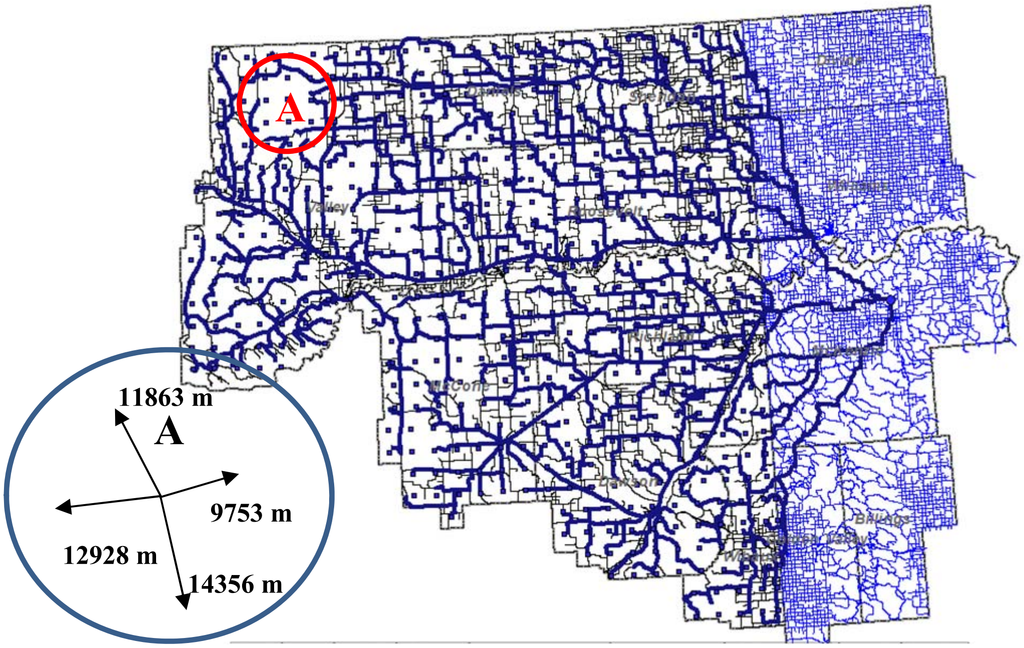


Figure 5-2: Locating township centroid to the road networks.

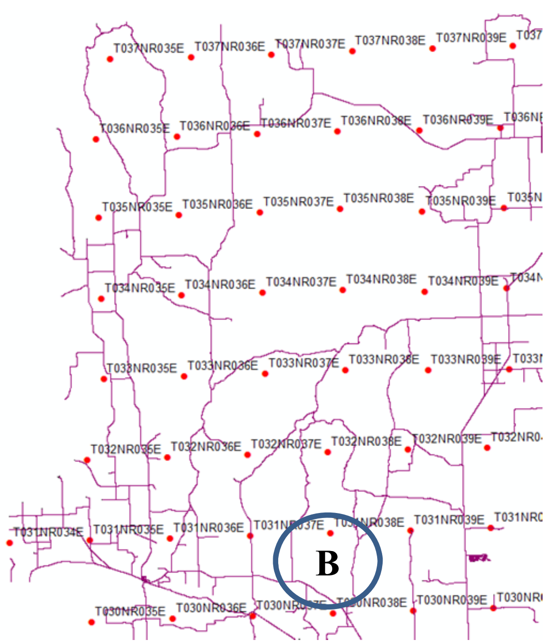


Figure 5-3: Unlocated centroid further than 5,000 meters from the closest road links.

Next, Network Analyst was used to select the closest facility in North Dakota for all incidents in Montana (i.e. township centroids). This process resulted in four different route categories as shown in Figure 5-4.

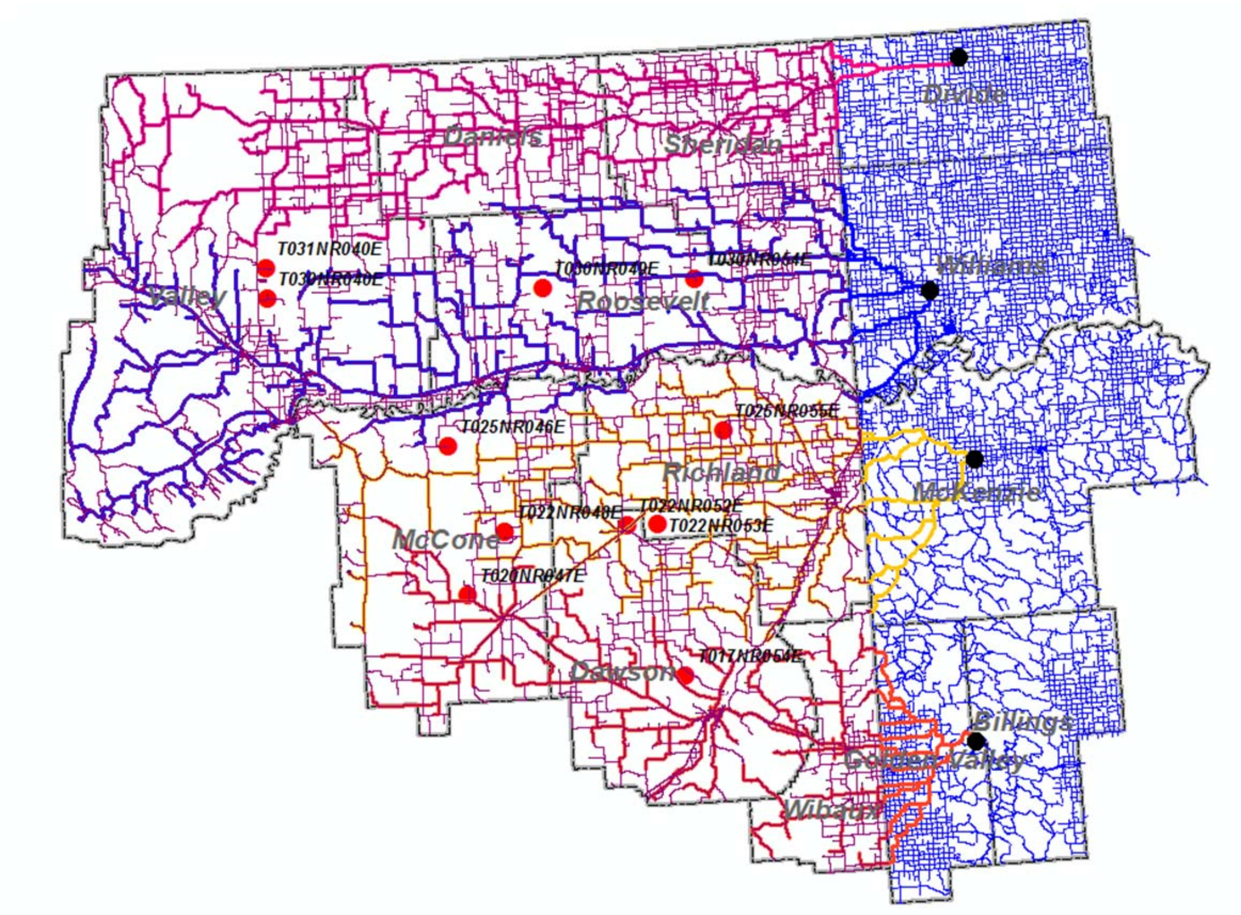


Figure 5-4: Shortest paths from township centroid to the closet facilities in North Dakota.

Where potential connection errors were identified, manual visual verification of the errors was conducted. Figure 5-5 provides an example of the identification of this type of error.

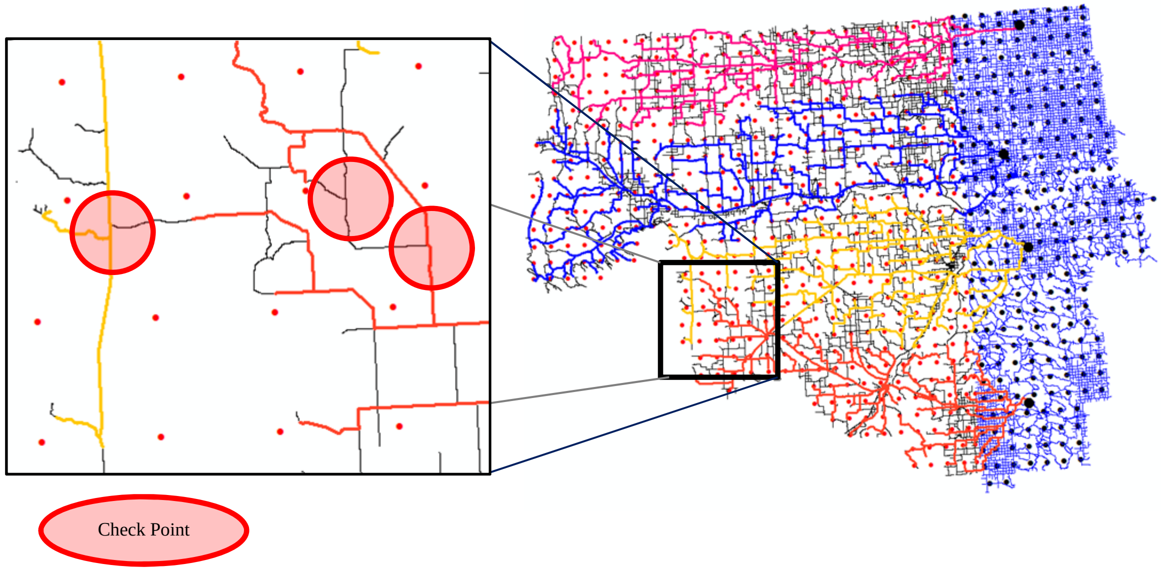


Figure 5-5: Potential connection errors identified.

The incident connects to the facility via the closest road link. In this case, the road link is isolated from the main road network. The model removed the isolated road segments and the centroid in this study. The isolated segments resulted from the clipping process of the Montana road network based on the county polygons. It is safe to remove the isolated segment and keep the centroid in the study. Results are shown in Figure 5-6 after updating the road networks and the township centroids.

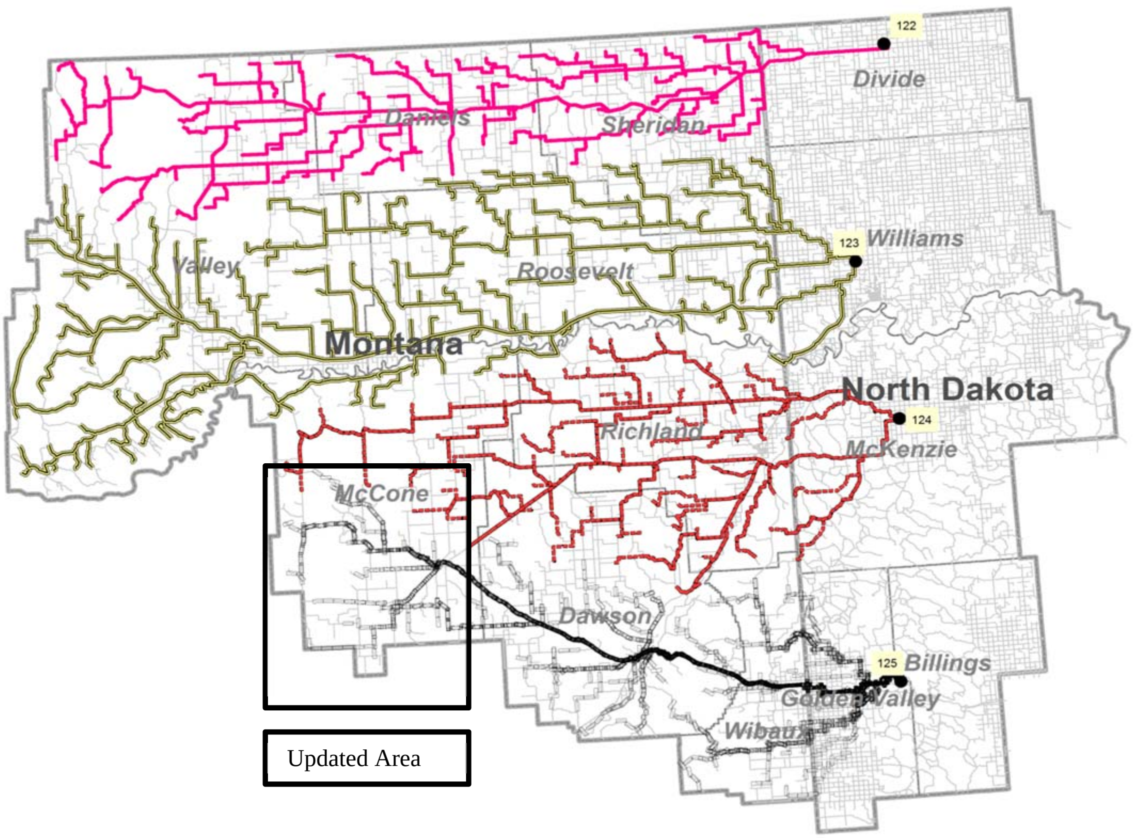


Figure 5-6: Updated road networks and the output of the closest facility module without error messages.

6. ESAL ESTIMATES

Before estimating the traffic generated due to oil development, estimates of equivalent single axle loads (ESALs) for individual truck types were compiled. The estimates presented below were initially developed by the NDDOT, and are periodically updated to reflect changes in technology and extraction practices.

ESAL estimates for the heavy drilling related equipment are presented in Table 6-1. The first column lists the equipment type by name, and the second column presents the total number of loads for a typical well. The second group of columns under the heading “Type Totals/Well” describes the number of axles, total weight and flexible and rigid ESALs for each group. The final column group under the heading “2011 ND Data” present the estimated flexible and rigid ESALs by individual truck type, which is used in the estimation process.

Note that for rig-related movements, all movements inbound and outbound are loaded and the loaded ESAL estimates are used to represent the highway impacts of these movements. The movements presented in Table 6-1 are generally indivisible, overweight or oversized loads which require special permits to travel over the highway system.

Table 6-1: ESAL Estimates for Rig Related Movements, Drilling Phase

Load Type	Number of Loads per Well	Type Totals/Well				2011 ND DATA	
		Axles	Weight (kips)	Group Flex ESALs	Group Rigid ESALs	Flex ESALs per Truck	Rigid ESALs per Truck
Generator House	6	60	961.2	56.9	56.4	9.5	9.4
Crown Section	2	14	280.0	18.4	32.2	9.2	16.1
Shaker Tank/Pit	2	20	285.4	12.8	12.3	6.4	6.1
Derrick	2	16	318.0	17.6	34.7	8.8	17.3
Suction Tank	2	16	241.2	6.5	11.1	3.3	5.6
VFD House	2	20	309.8	8.3	16.5	4.2	8.3
Mud Pump	4	40	663.6	24.7	50.6	6.2	12.6
Mud Boat	2	12	232.0	10.4	20.8	5.2	10.4
Shaker Skid	2	12	223.6	11.4	22.7	5.7	11.3
Substructure, Centerpiece, BOP Setting Machine, BOP Skid	10	90	1606.0	101.8	152.0	10.2	15.2
Draw Works	2	18	334.8	12.9	28.9	6.4	14.4
Hydraulic Unit	2	16	260.0	8.2	16.3	4.1	8.2
Choke Manifold	2	14	238.2	12.9	20.4	6.4	10.2
MCC House	2	18	348.0	16.0	33.8	8.0	16.9
Tool Room, Junk Box, Top Dog House	2	12	234.0	12.6	25.6	6.3	12.8
Screen House	2	22	317.0	22.9	12.7	11.5	6.4
Light Plant	2	22	340.0	32.4	15.9	16.2	8.0
Mud Tank	2	18	277.6	18.1	13.8	9.0	6.9
Workover Rigs	5	25	525.0	30.3	63.1	6.1	12.6

Freshwater truck movements are presented in Table 6-2. The movements are broken into three categories: overloads, legal loads, and empty return loads. The organization of the table is similar to Table 6-1 with the first group describing the type and number of loads. The second group describes number of axles, weight and ESAL estimates for the entire group. The third group breaks down ESAL estimates by individual truck. Overload estimates were obtained through discussions with NDDOT, North Dakota Highway Patrol and MDT. It is estimated that 25% of freshwater loads are overloaded, with a magnitude of 10,000 lbs. overloaded.

Table 6-2: ESAL Estimates Freshwater Movements, Drilling Phase

Load Type	Number of Loads per Well	Type Totals/Well				2011 ND DATA	
		Axles	Weight (kips)	Group Flex ESALs	Group Rigid ESALs	Flex ESALs per Truck	Rigid ESALs per Truck
Fresh Water Unpermitted Overloads (25% of Divisibles @ 90k - legal is 80k)	187	1496	16830.0	221.4	318.1	1.2	1.7
Fresh Water Legal Loads (76 kips) (75% of Divisibles)	562	4496	42712.0	361.9	530.5	0.6	0.9
Fresh Water Empty Return Loads (38 kips)	748	5984	28424.0	36.7	39.6	0.0	0.1

Sand truck movements are presented in Table 6-3. The movements are broken into three categories: overloads, legal loads, and empty return loads. The organization of the table is similar to Table 6-1 with the first group describing the type and number of loads. The second group describes number of axles, weight and ESAL estimates for the entire group. The third group breaks down ESAL estimates by individual truck. Overload estimates were obtained through discussions with NDDOT, North Dakota Highway Patrol and MDT. It is estimated that 25% of sand loads are overloaded, with a magnitude of 10,000 lbs. overloaded.

Table 6-3: ESAL Estimates Sand Movements, Drilling Phase

Load Type	Number of Loads per Well	Type Totals/Well				2011 ND DATA	
		Axles	Weight (kips)	Group Flex ESALs	Group Rigid ESALs	Flex ESALs per Truck	Rigid ESALs per Truck
Sand Unpermitted Overloads (25% of Divisibles @ 90k - legal is 80k)	93	465	8370.0	351.4	595.3	3.8	6.4
Sand Legal Loads (76 kips) (75% of Divisibles)	281	1405	21356.0	628.6	1102.1	2.2	3.9
Sand Empty Return Loads (38 kips)	374	1870	14212.0	53.9	65.1	0.1	0.2

7. ANALYSIS OF EXISTING TRAFFIC DATA

This section provides an overview of the analysis of 2011 traffic data provide by MDT. At the outset of this study, the most recent, complete traffic data available was the 2011 traffic classification counts, and the analysis presented reflects actual observed traffic conditions. The traffic counts data provides important statistics about average annual daily traffic (AADT). A statistical analysis of this data was performed to gain insights about the traffic patterns on major highways and other roads.

7.1. Distribution of AADT on major highways:

The AADT distribution for the truck traffic was studied in detail for highways 2, 5, 16, 200 and I-94. Figure 7-1 shows the average annual trucks per day (Truck AADT) on US Highway 2. It shows three different traffic zones. There are higher truck traffic volumes near the North Dakota border. Figure 7-2 explains this change with respect to the mile points. Near the North Dakota border, after mile point 647, there is higher truck AADT. In addition, the data shows increases in traffic near Glasgow, MT in Valley County, which are outside the primary oil development area.

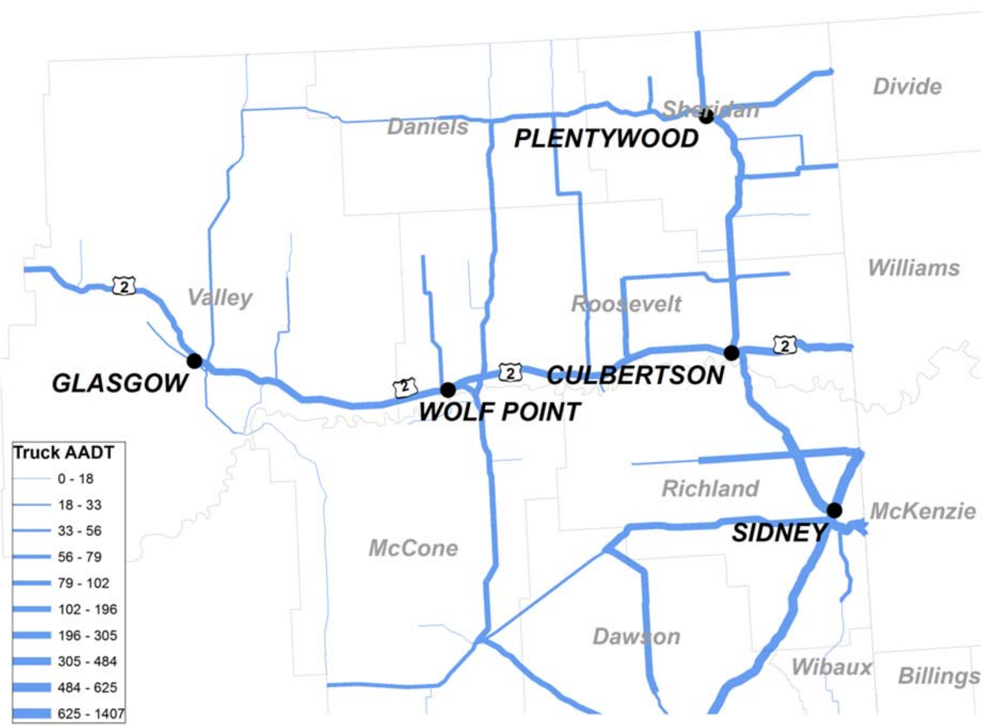


Figure 7-1: Average annual trucks per day: U.S. Highway 2.

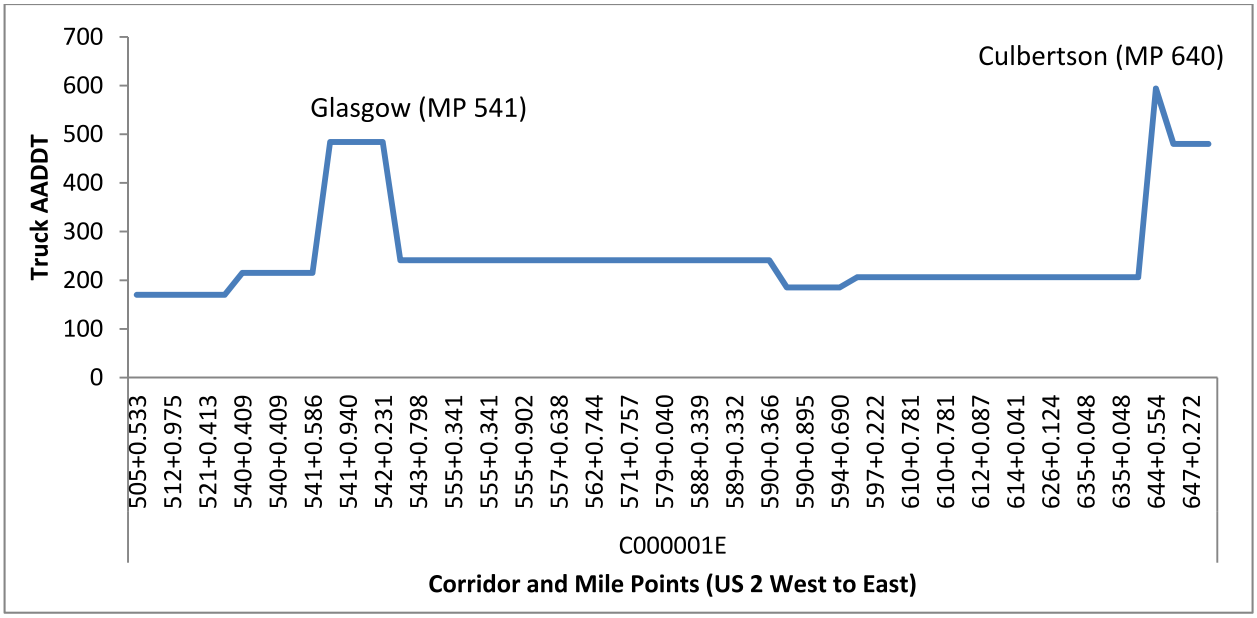


Figure 7-2: Truck AADT vs. milepoints: U.S. Highway 2.

Figure 7-3 shows distribution of truck AADT on Montana Highway 5. This highway also has higher levels of traffic near North Dakota border. Though Figure 7-4 shows there are some peaks, the average truck traffic on this highway is less. Montana highway 5 has two corridors. In the corridor near North Dakota border it shows high levels of truck traffic as depicted in Figure 7-3 and Figure 7-4.

Figure 7-3: Average annual trucks per day: Montana Highway 5

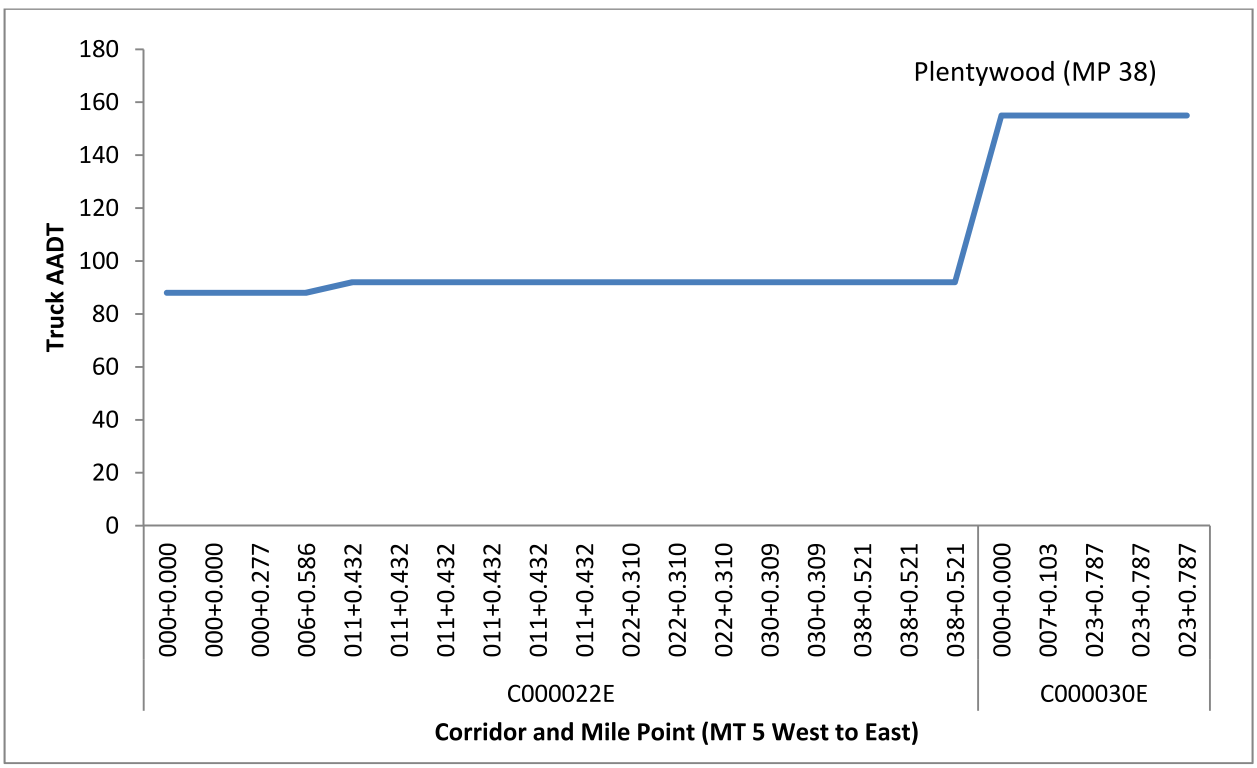


Figure 7-4: Truck AADT vs. mile points: Montana Highway 5

The truck AADT for Montana Highway 16 is depicted in Figure 7-5. It also distinct traffic levels over different segments of the route, primarily changing at intersections with other major routes. Montana Highway 16 shows the lowest traffic levels in the north and increases gradually to the south with highest traffic levels between Sidney and Glendive. Figure 7-6 shows similar characteristics, with more traffic near the start of the mile points and less traffic at the end near the Canadian border.

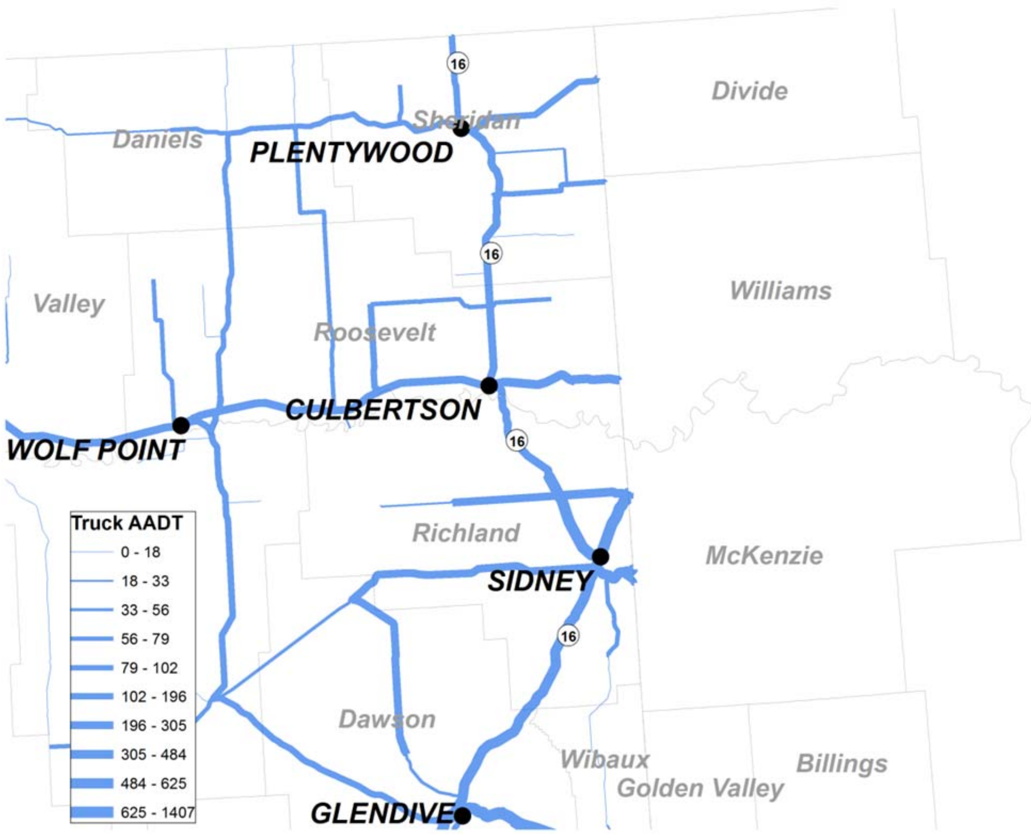


Figure 7-5: Average annual trucks per day: Montana Highway 16

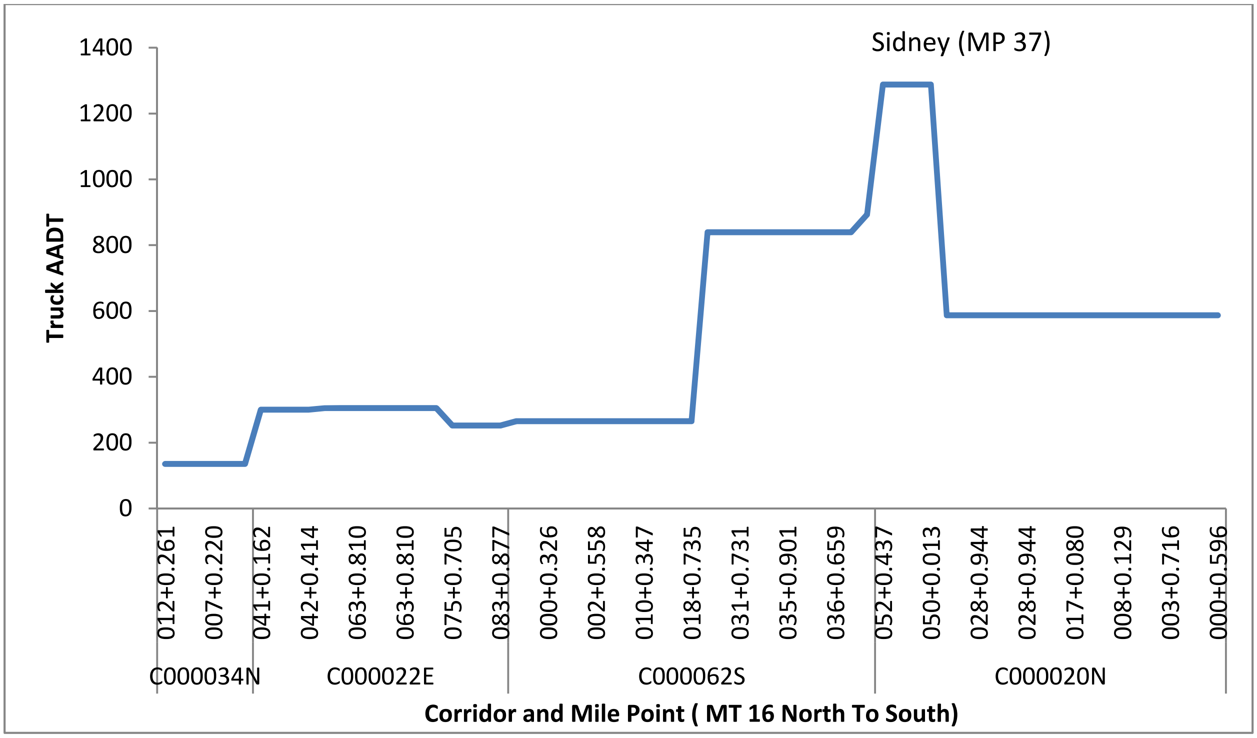


Figure 7-6: Truck AADT vs. mile points: Montana Highway 16

Figure 7-7 shows truck AADT on I-94. There is consistent truck traffic on I-94 over the milepoint range. Figure 7-8 supports this observation. It shows a flat trend of truck traffic without any major peaks or valleys.

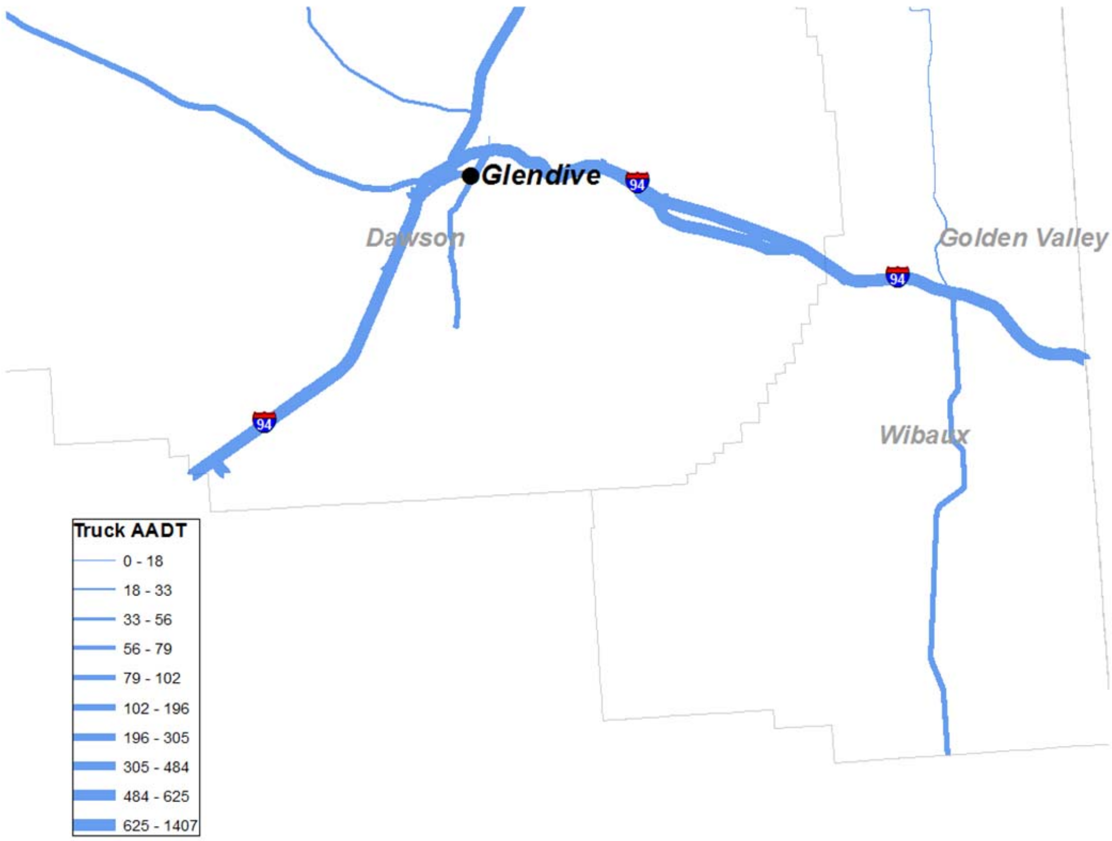


Figure 7-7: Average annual trucks per day: I-94

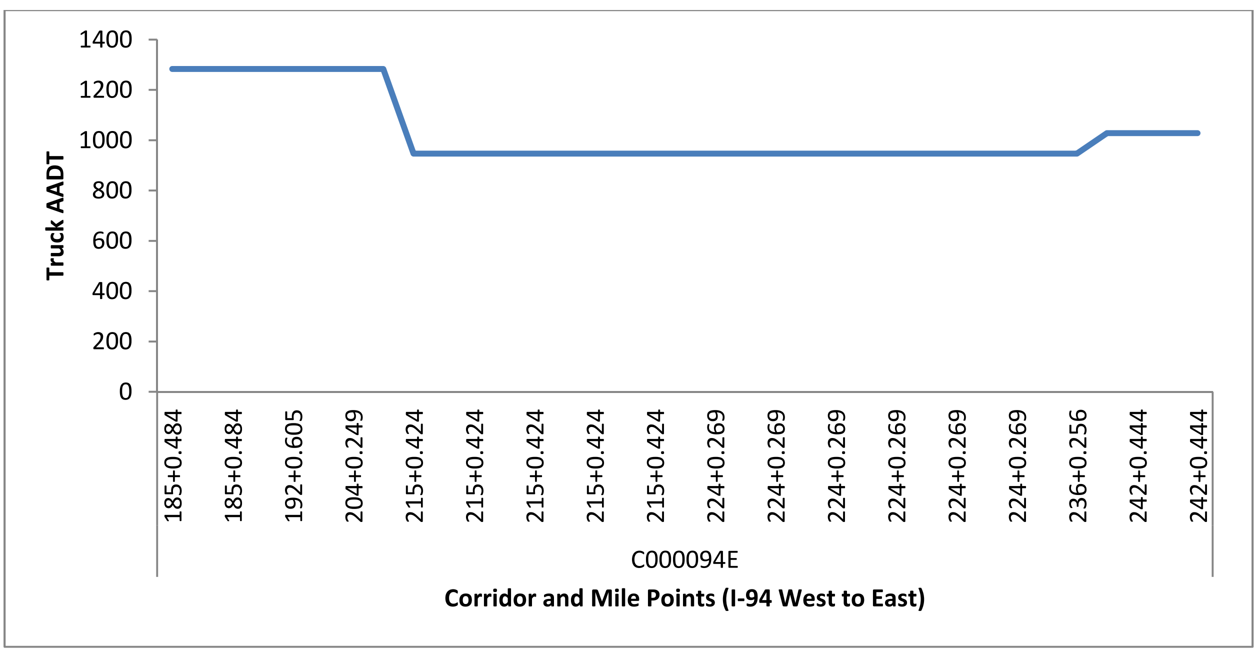


Figure 7-8: Truck AADT vs. mile points: I 94

Truck AADT on Montana Highway 200 is shown in Figure 7-9. Truck traffic on Montana Highway 200 shows a distinctive trend. It shows high levels of truck traffic from near the North Dakota border to Sidney, MT. West of Sidney the traffic level decreases dramatically. A similar trend can be seen in Figure 7-10. It shows lower traffic levels near the western part of the study region (first two corridors) and higher traffic levels near Sidney (Corridor C000020N).

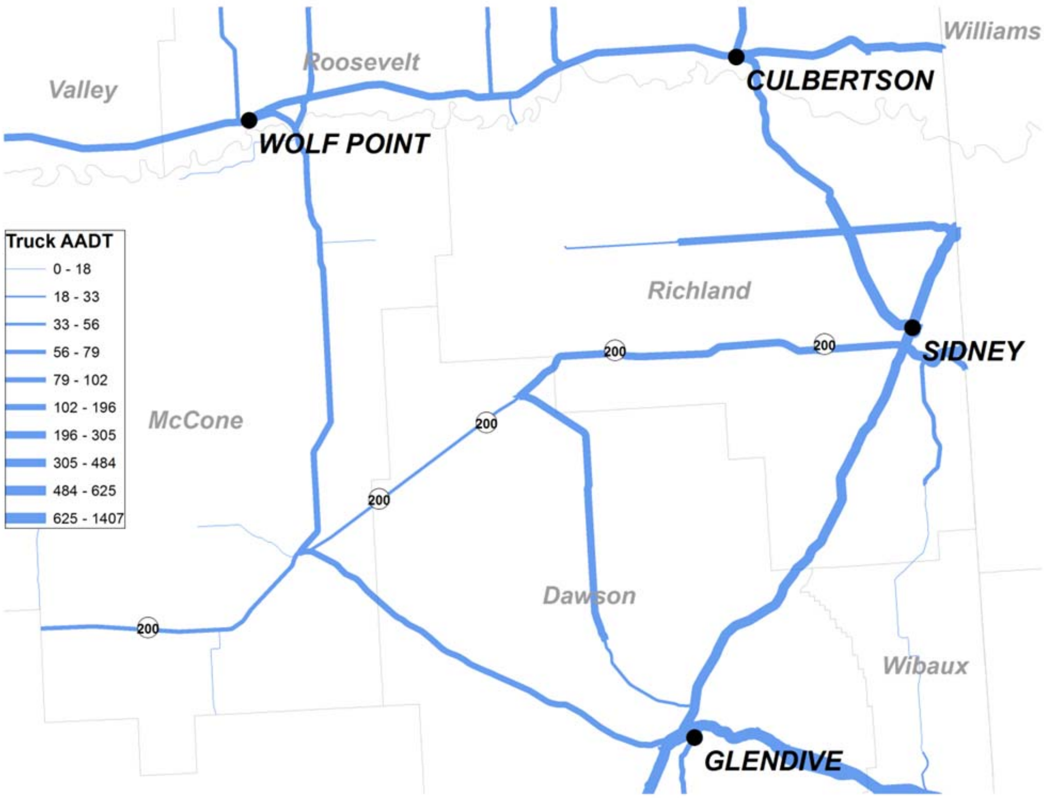


Figure 7-9: Average annual trucks per day: Montana Highway 200

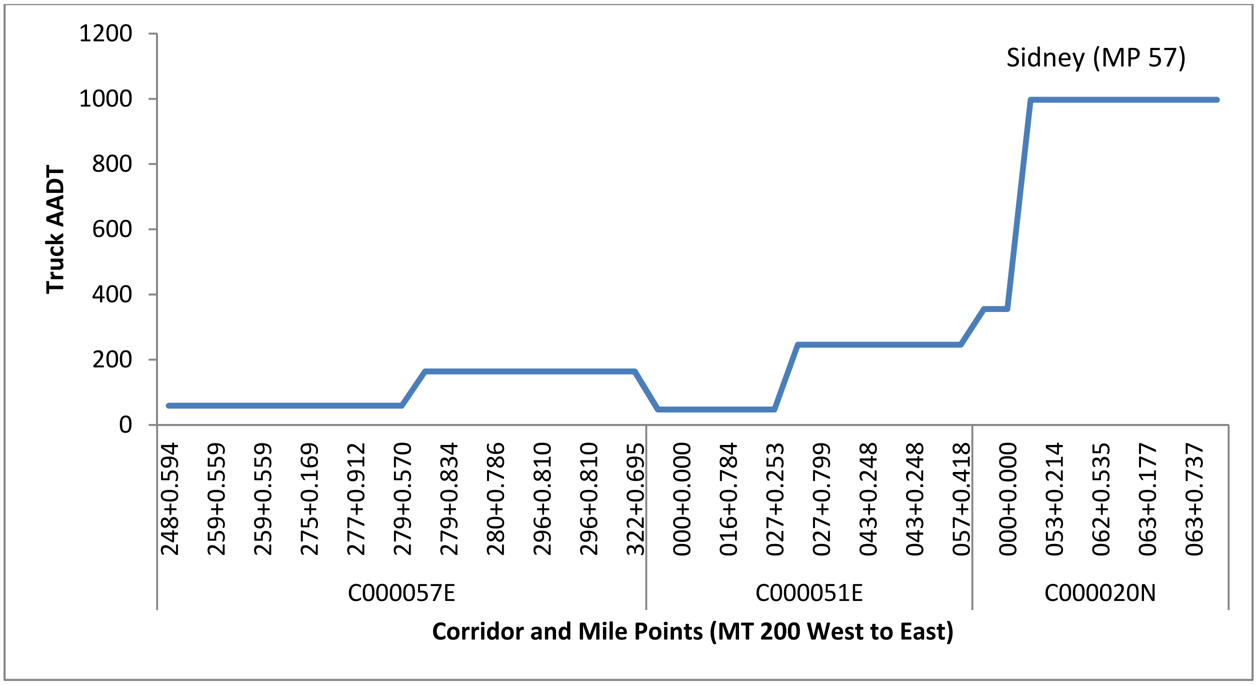


Figure 7-10: Truck AADT vs. mile points: Montana Highway 200

8. TRAFFIC MODELING

The traffic routing procedure generates the origin-destination (OD) matrix for all feasible routes from origins to destinations for oil transportation activities (see Figure 8-1). The OD matrices for all pairs of oil transportation activities include sources of sand, gravel, fresh water, and supplies as origins for supporting drilling activities and drilling sites as destinations. Saltwater is transported from drilling sites to saltwater disposal sites (SWD) as byproducts. Following drilling site completion, outbound oil is transported to rail or pipeline transloading sites.

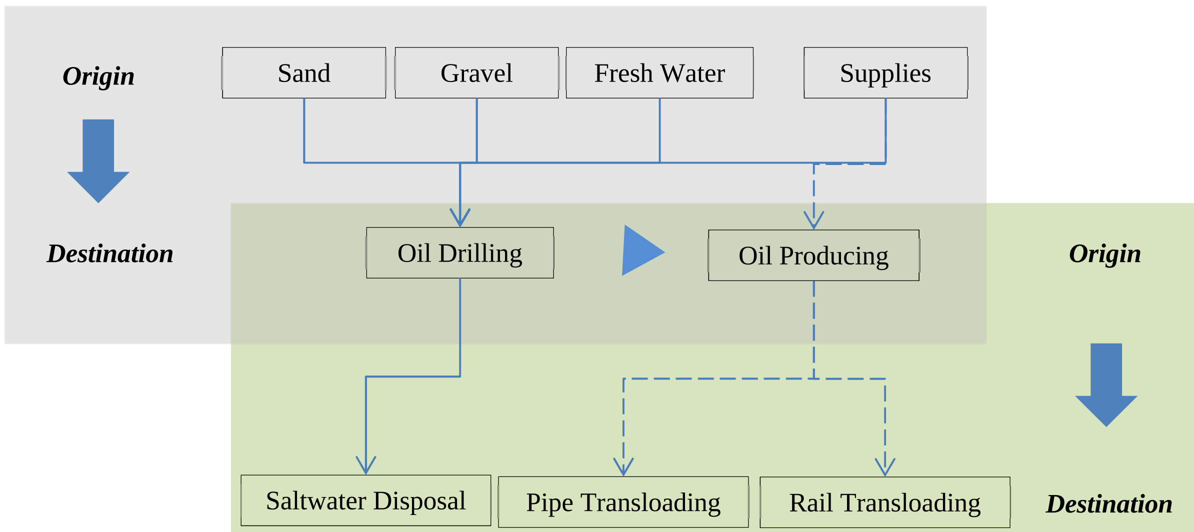


Figure 8-1: Oil-related transportation activities

The OD matrices were generated based on the Dijkstra's shortest path algorithm embedded in ArcMap® Ver. 10.0's specialized module of Network Analyst®. The module requires impedance information such as cost, distance, or time. This study used travel time to minimize the impedance. These low-impedance routes are called the fastest paths in this study.

In the process of generating OD matrices, the capacity of the locations and links were not considered. The constraint of capacity is considered in the optimization process, which finds the optimal routes among all the feasible routes in the OD matrices in light of system optimization.

9. ROUTE ASSIGNMENT/DISTRIBUTION MODEL

Assignment of routes for individual truck movements was done through a constrained optimization model. Each township has multiple origins from which inputs could be sourced, yet only one was chosen. Assignment of origin-destination pairs assumes that the source movement is an all-or-nothing assignment, as the route costs of alternative sources remain the same for all truck trips (Dybing 2012).

The objective of the oil development distribution model was to minimize the total cost of moving six inputs and two outputs from input origins and output destinations (Equation 1), subject to the following constraints: the demands at the township well sites (Equation 2), the supply capacities at input origin locations (Equation 3), handling capacities at destination locations (Equation 4), and the number of trucks on a route must be greater than or equal to zero. The model was estimated 21 times to optimize distribution from years 2011 through 2032.

$$Min \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{o} c_{ijk} * x_{ijk} + \sum_{j=1}^{m} \sum_{l=1}^{p} \sum_{k=1}^{o} c_{jlk} * x_{jlk}$$ **Equation 1**

$$\sum_{i=1}^{n} \sum_{k=1}^{o} x_{ijk} = D_{jk} \quad \forall jk$$ **Equation 2**

$$\sum_{j=1}^{m} \sum_{k=1}^{o} x_{ijk} \leq S_{ik} \quad \forall ik$$ **Equation 3**

$$\sum_{j=1}^{m} \sum_{k=1}^{o} x_{jlk} \leq U_{lk} \ \forall lk$$ **Equation 4**

$$x_{ijk} \ are\ non-negative\ integers\ for\ all\ i, j, k$$

Where:
i=Index for input origin
j=Index for township
k=Index for freight class
l=Index for outbound destination
c_{ijk}=Cost of carrying freight k between i and j
x_{ijk}=Truckloads of freight k between i and j
c_{jlk}=Cost of carrying freight k between j and l
x_{jlk}=Truckloads of freight k between j and l
D_{jk}=Demand at township j for freight k
S_{ik}=Supply at origin i for freight k
U_{lk}=Capacity at destination l for freight k

9.1. Route disaggregation and segment assignment

The distribution model assigns truck movements to individual routes. An individual segment of the state highway system may theoretically be included in each route that was chosen. For this reason, the selected routes must be disaggregated to component highway segments in order to assign the traffic flows to individual segments (Dybing 2012).

10. RESULTS

This section presents the results of the traffic model graphically via a series of traffic volume maps. As described in Chapter 3, four scenarios were analyzed: 20, 40, 80 and 160 rigs to account for the level of uncertainty surrounding oil development within the region. Included in this section are the results for the 20 and 40 rig scenarios. Results of the 80 and 160 rig analysis may be found in the appendix to this document. For each of the scenarios, results are visualized by year from 2012-2016, and in five-year increments through the remainder of the analysis period.

10.1. Scenario: 20 Rigs

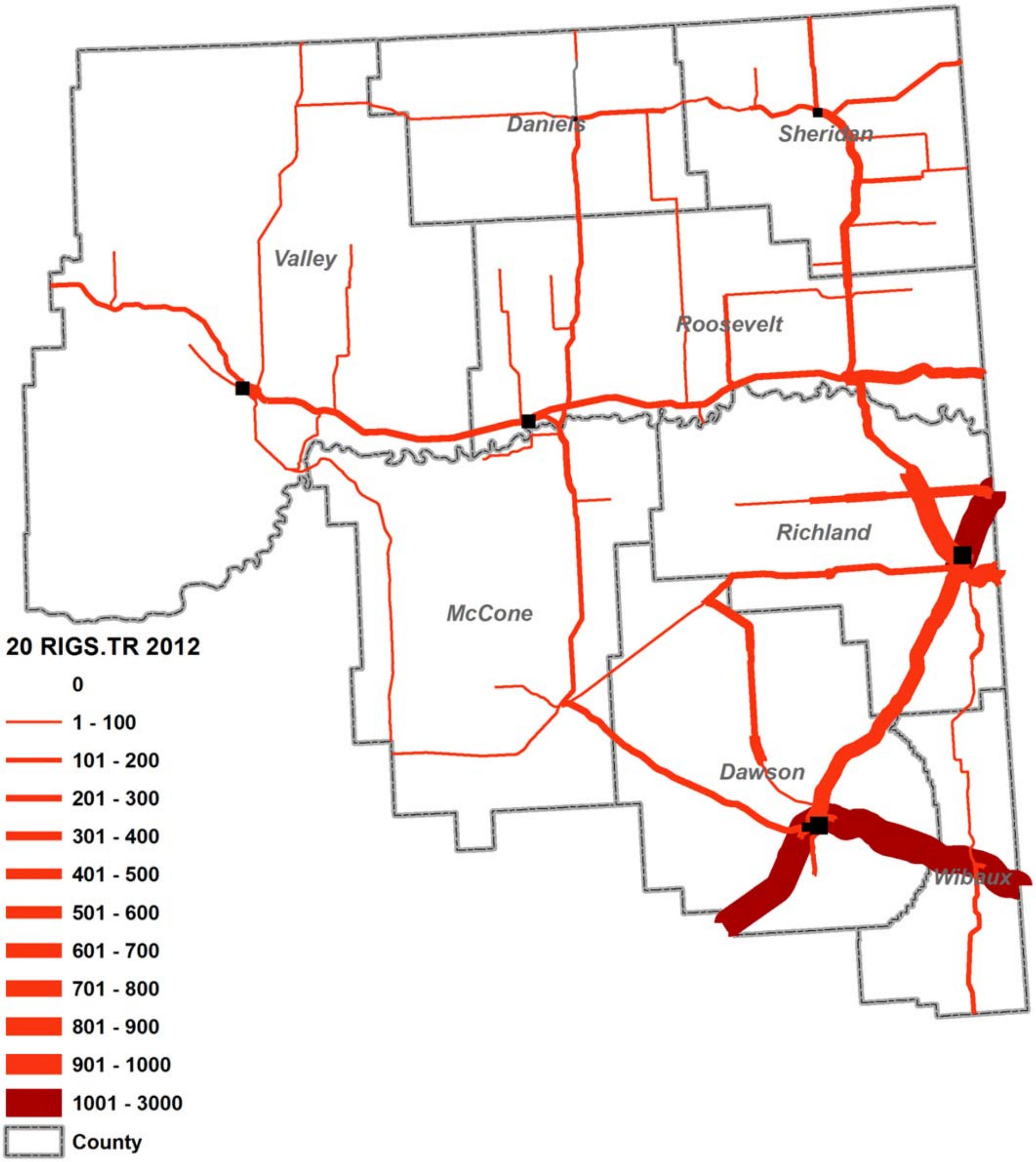


Figure 10-1: Truck traffic in 2012 for the 20 rig scenario.

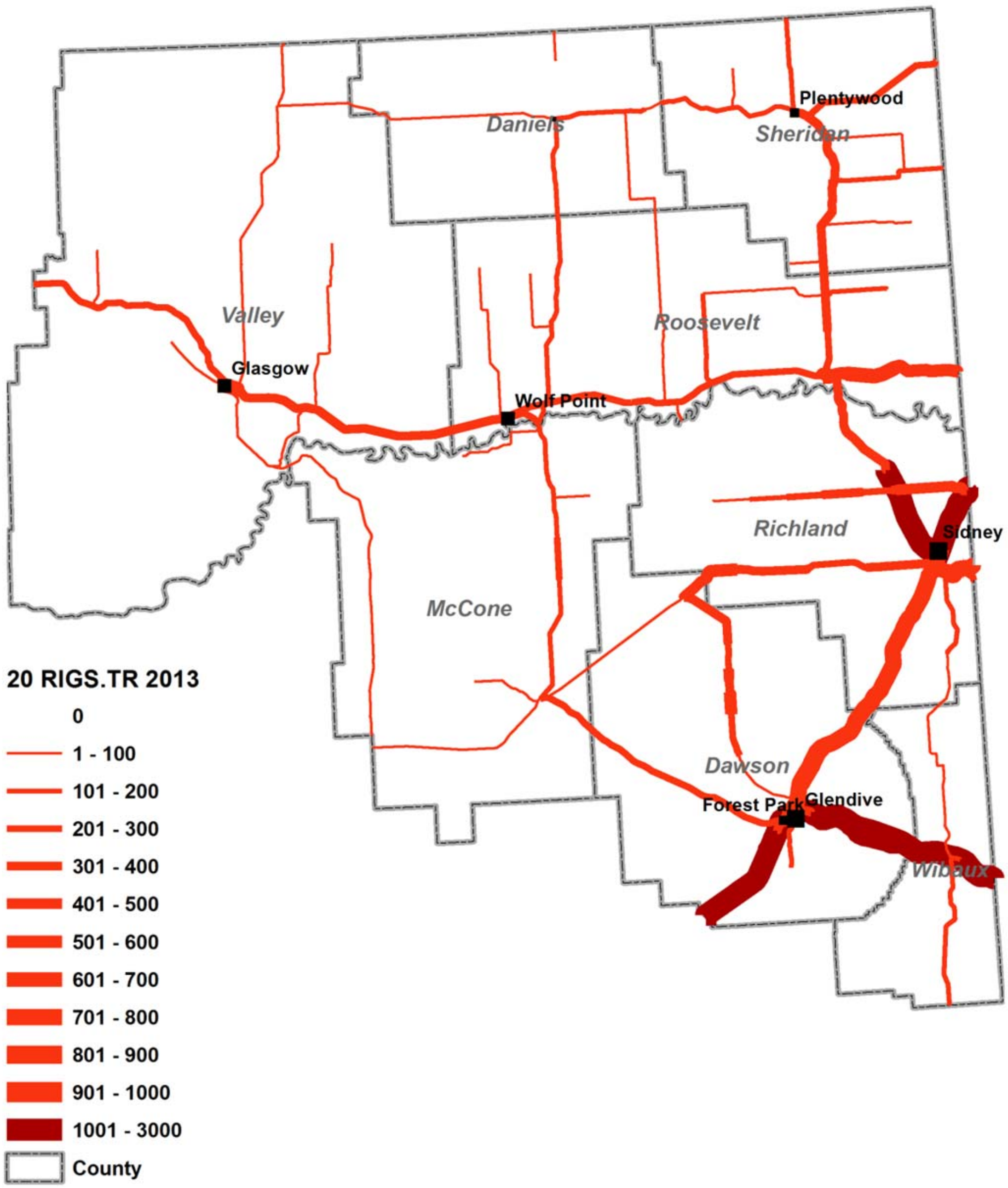


Figure 10-2: Truck traffic in 2013 for the 20 rig scenario.

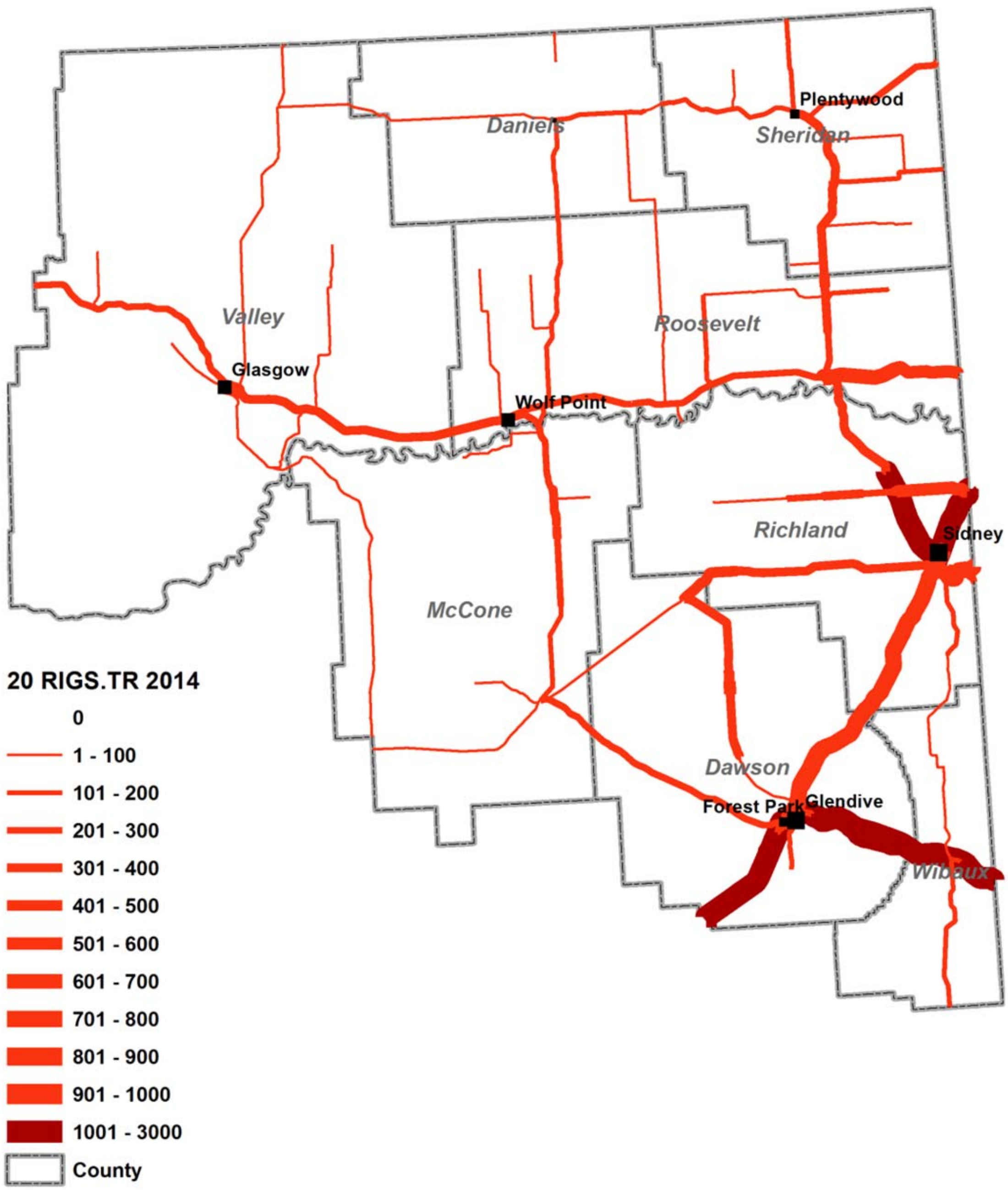


Figure 10-3: Truck traffic in 2014 for the 20 rig scenario.

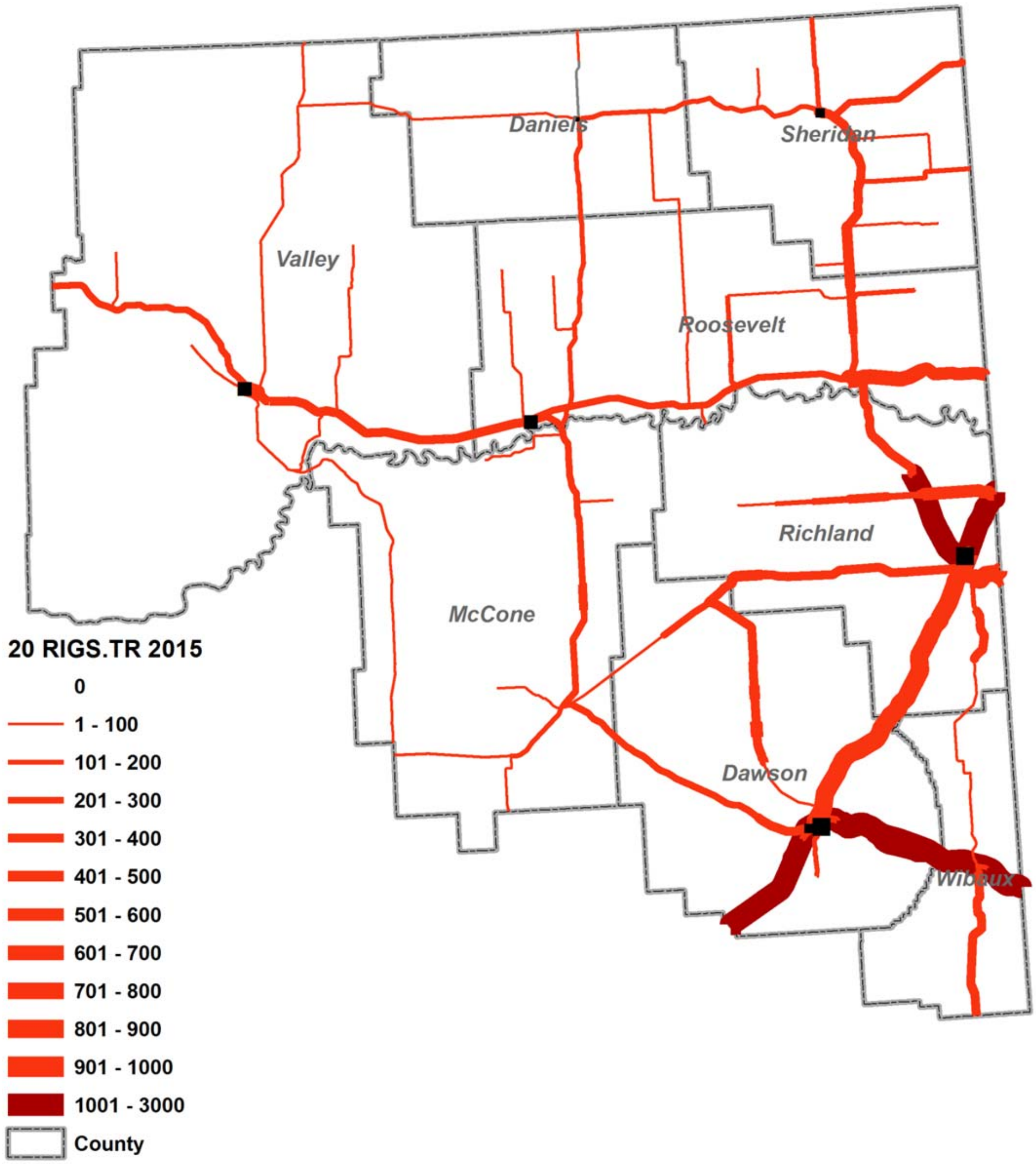


Figure 10-4: Truck traffic in 2015 for the 20 rig scenario.

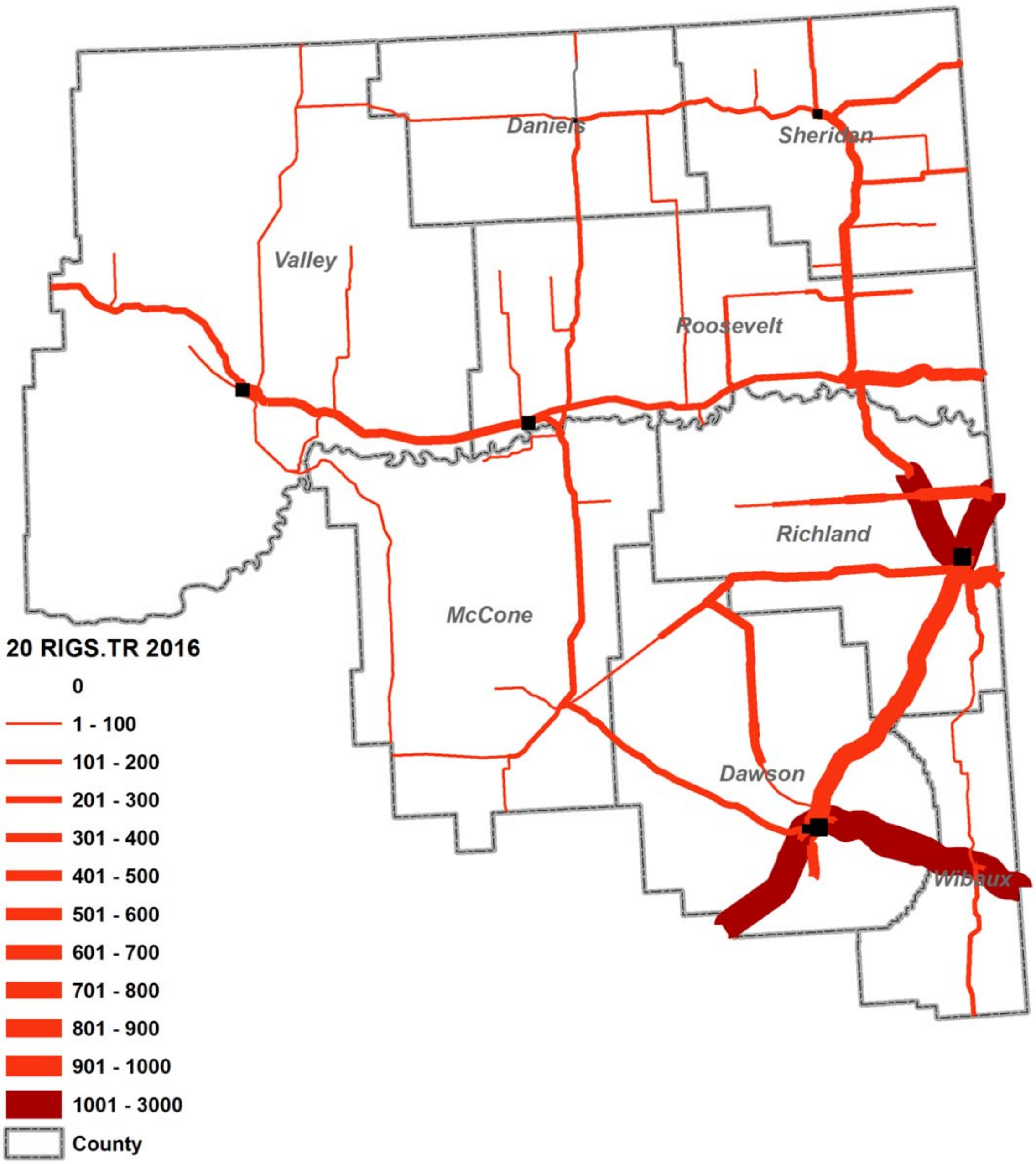


Figure 10-5: Truck traffic in 2016 for the 20 rig scenario.

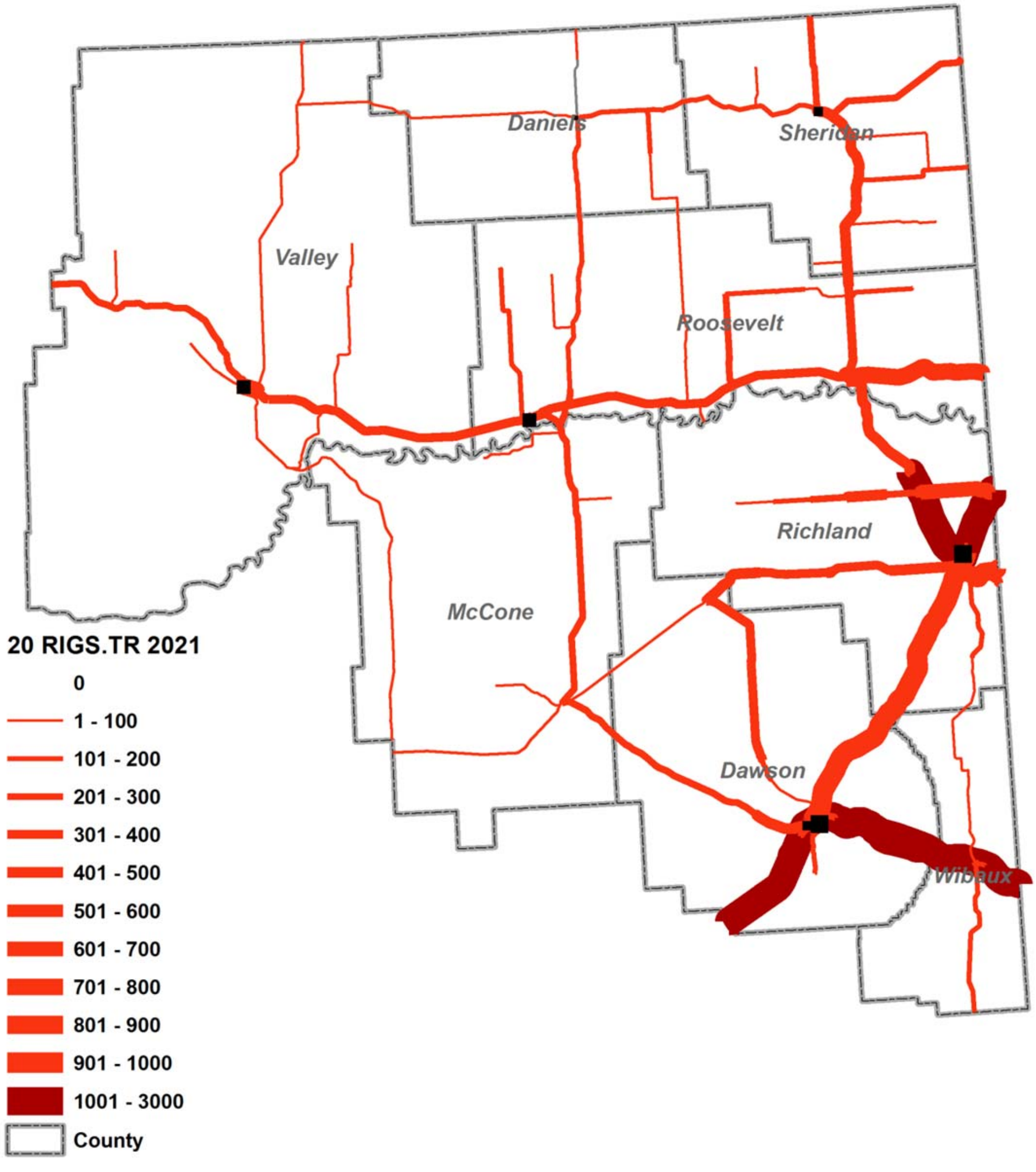


Figure 10-6: Truck traffic in 2021 for the 20 rig scenario.

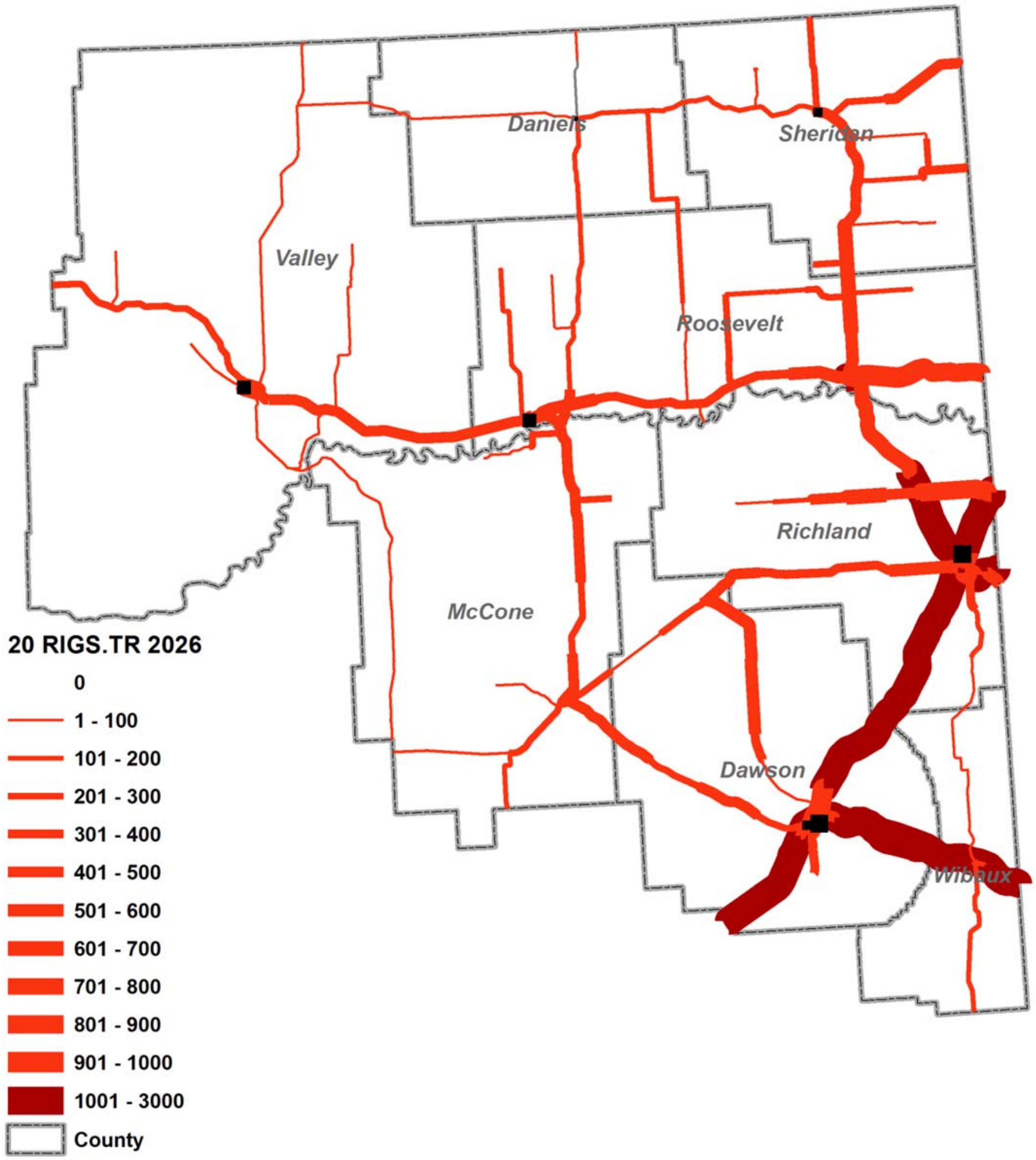


Figure 10-7: Truck traffic in 2026 for the 20 rig scenario.

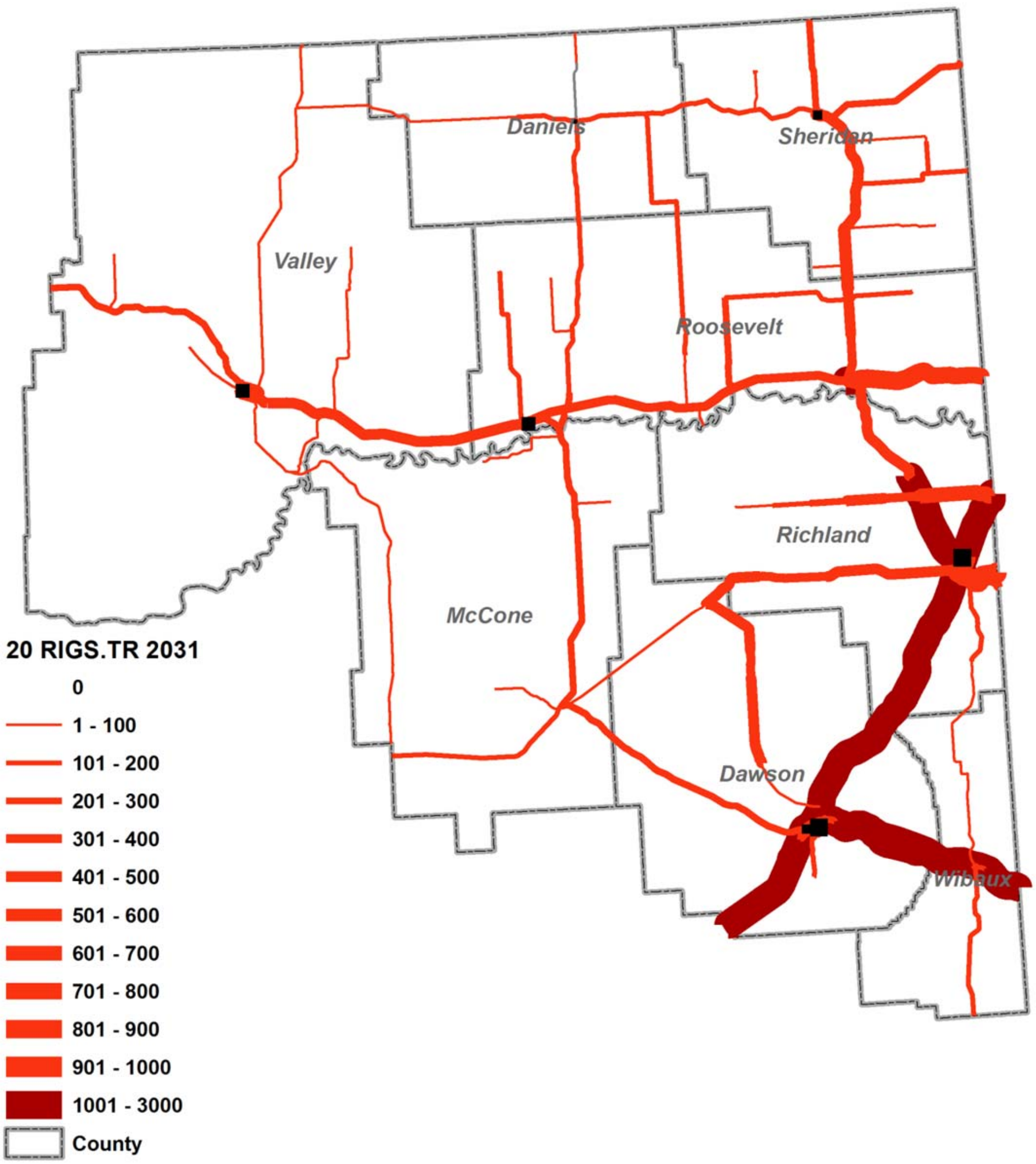


Figure 10-8: Truck traffic in 2031 for the 20 rig scenario.

10.2. Scenario: 40 Rigs

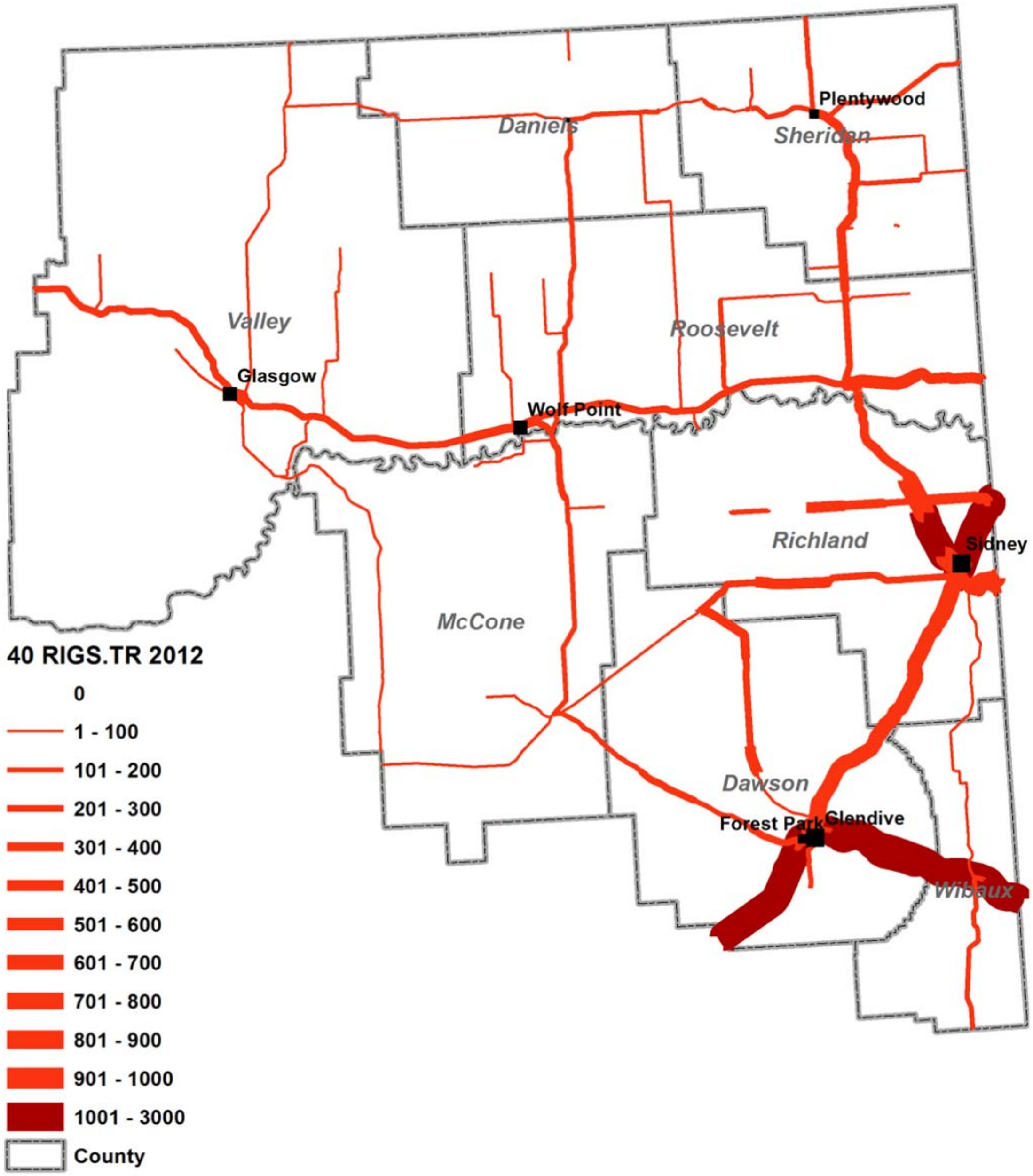


Figure 10-9: Truck traffic in 2012 for the 40 rig scenario.

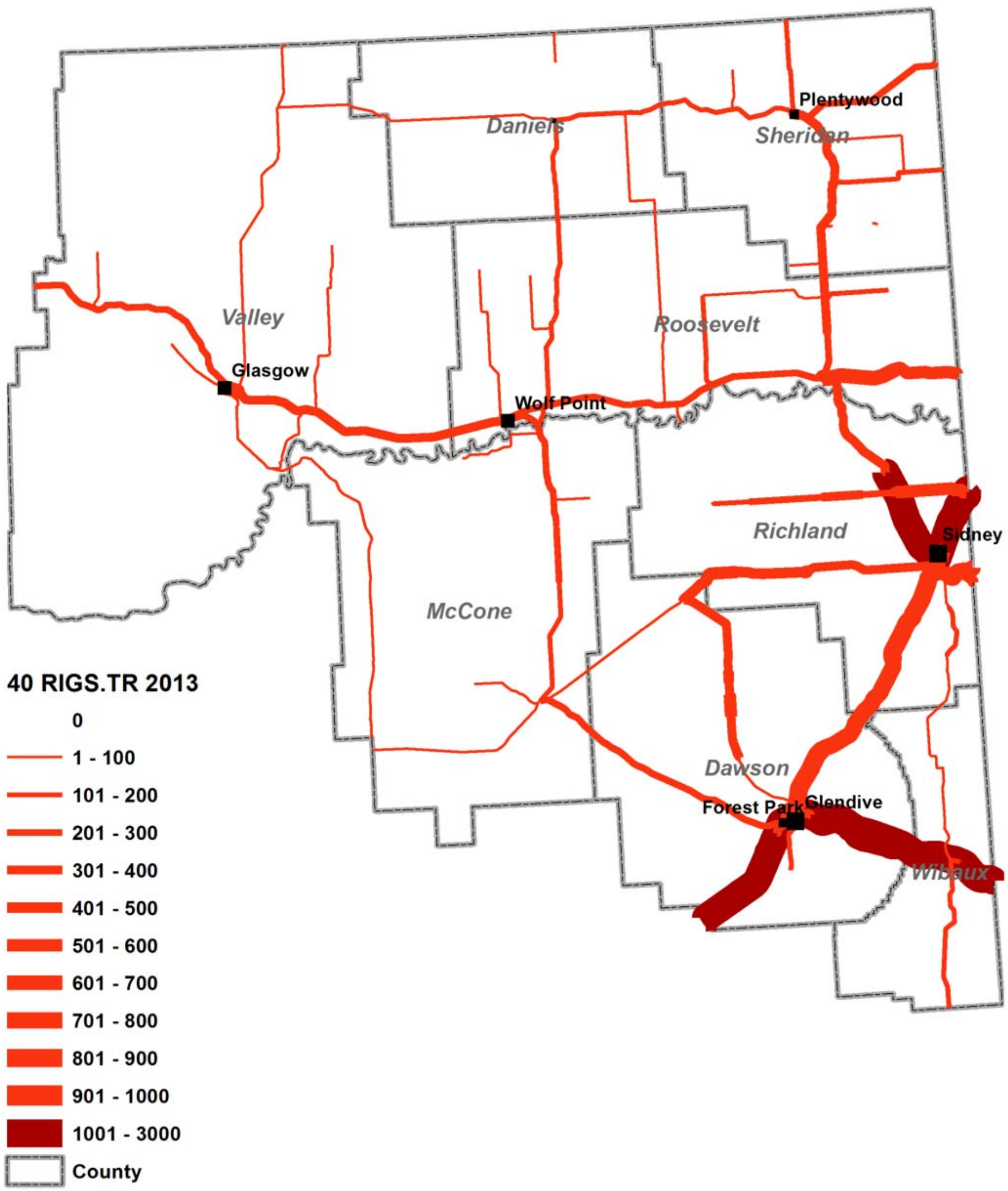


Figure 10-10: Truck traffic in 2013 for the 40 rig scenario.

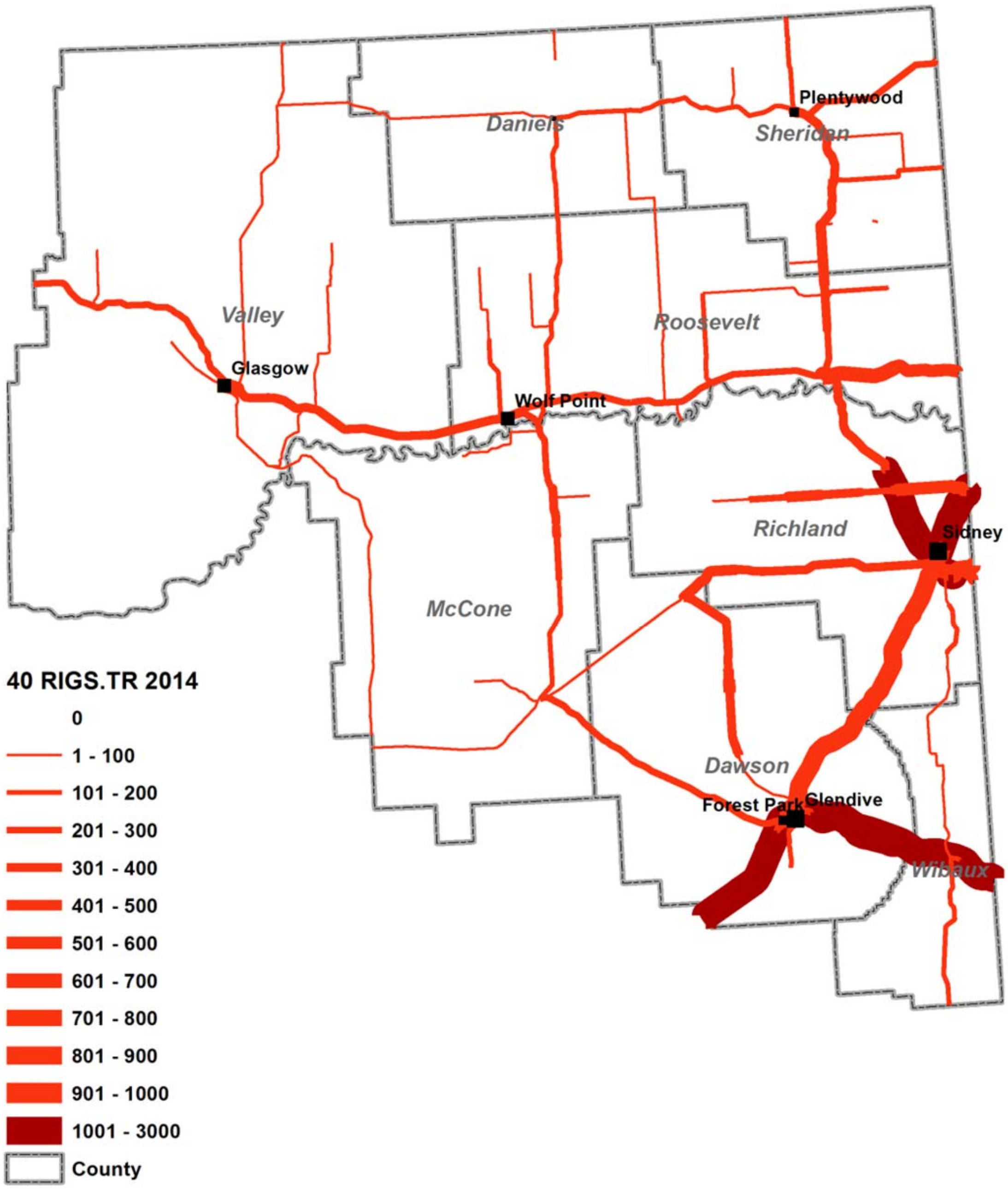


Figure 10-11: Truck traffic in 2014 for the 40 rig scenario.

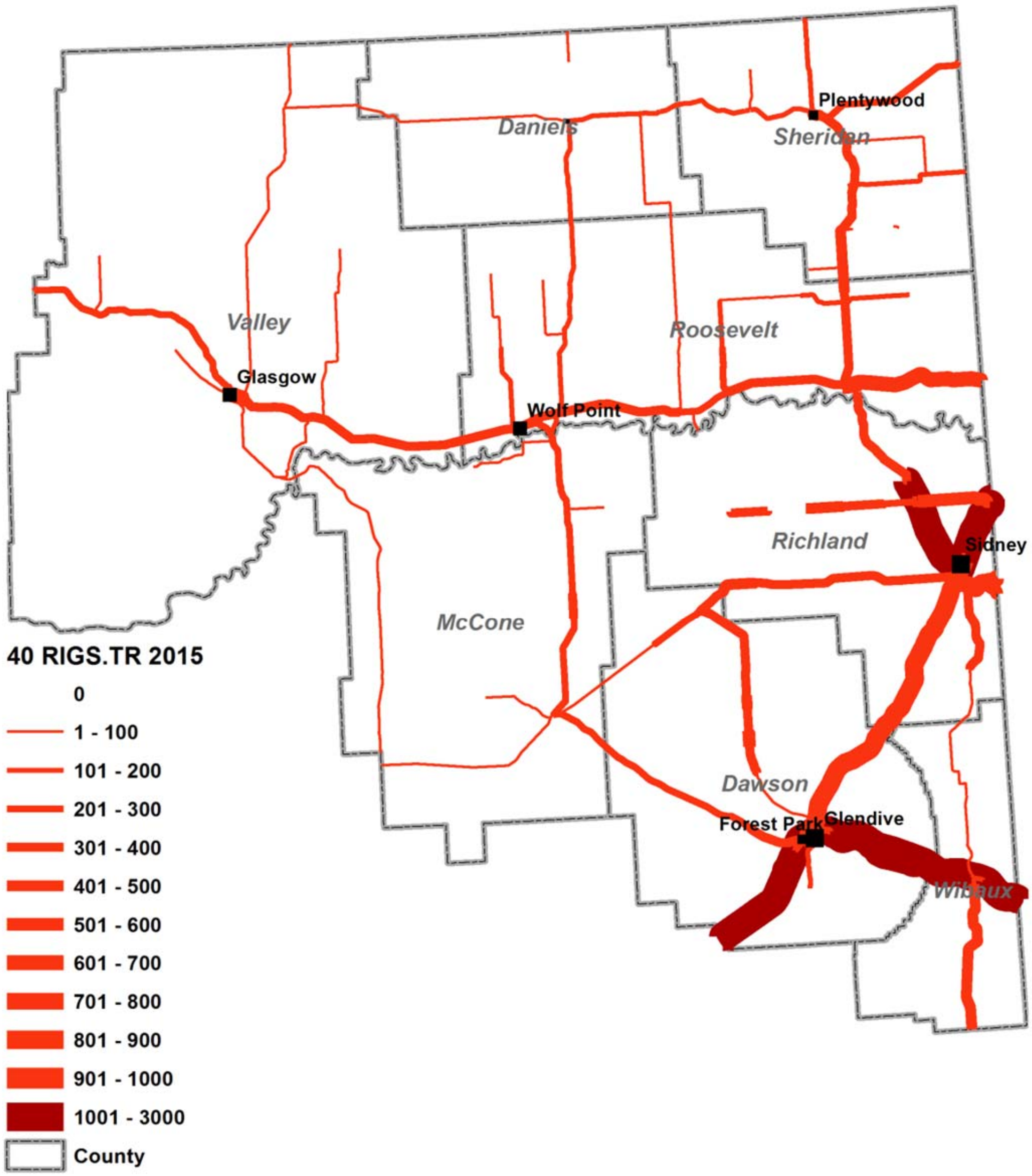


Figure 10-12: Truck traffic in 2015 for the 40 rig scenario.

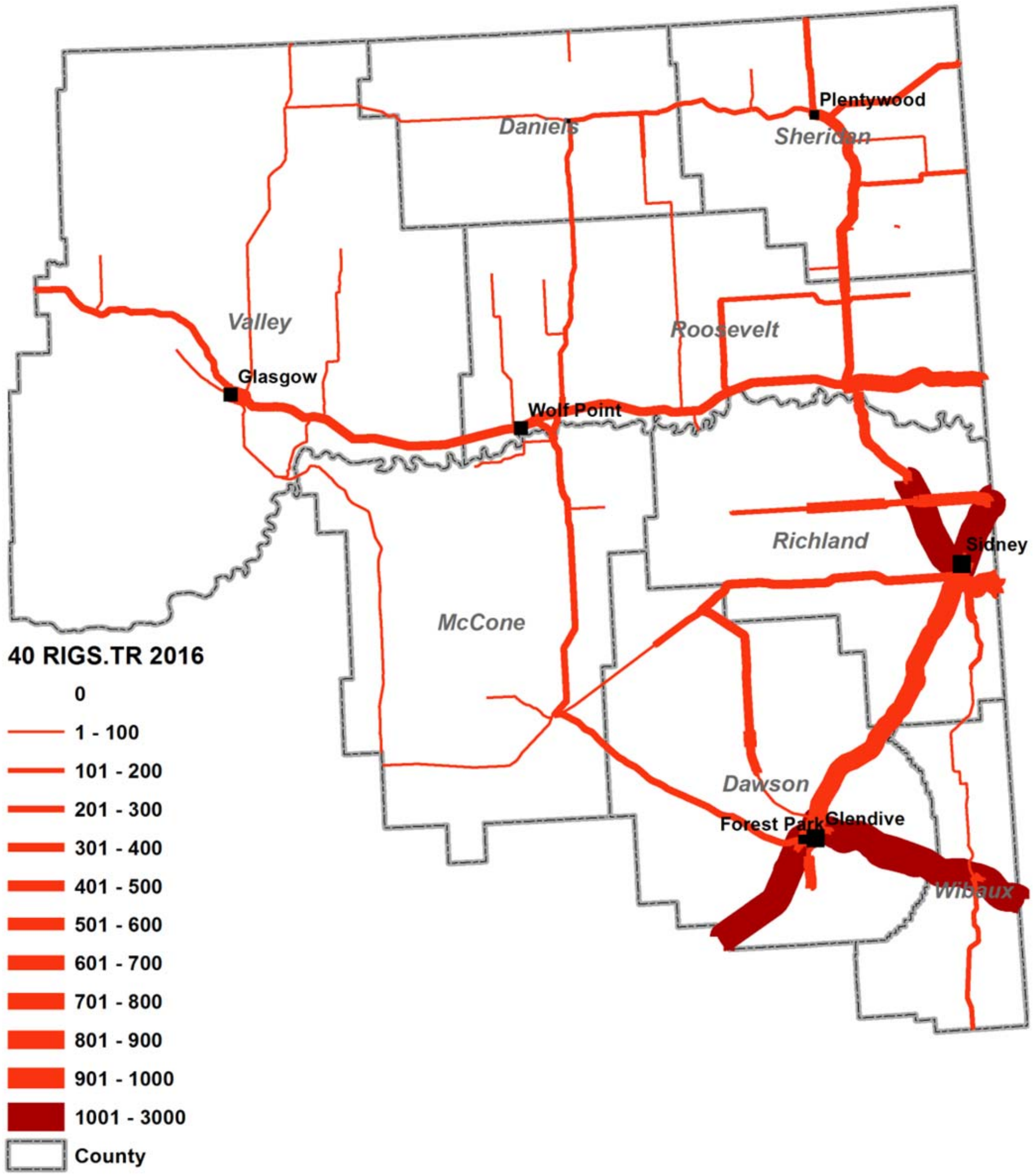


Figure 10-13: Truck traffic in 2016 for the 40 rig scenario.

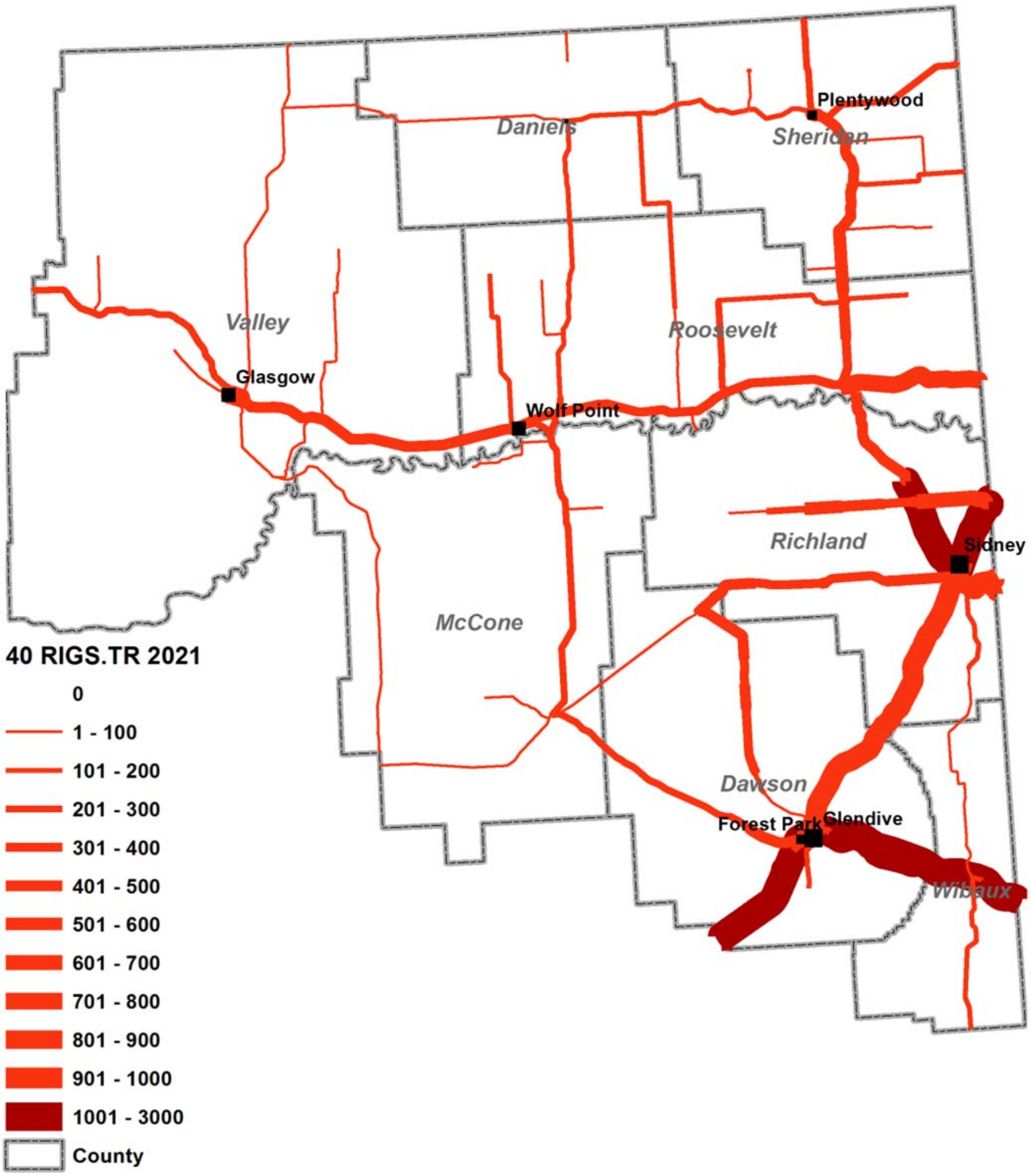


Figure 10-14: Truck traffic in 2021 for the 40 rig scenario.

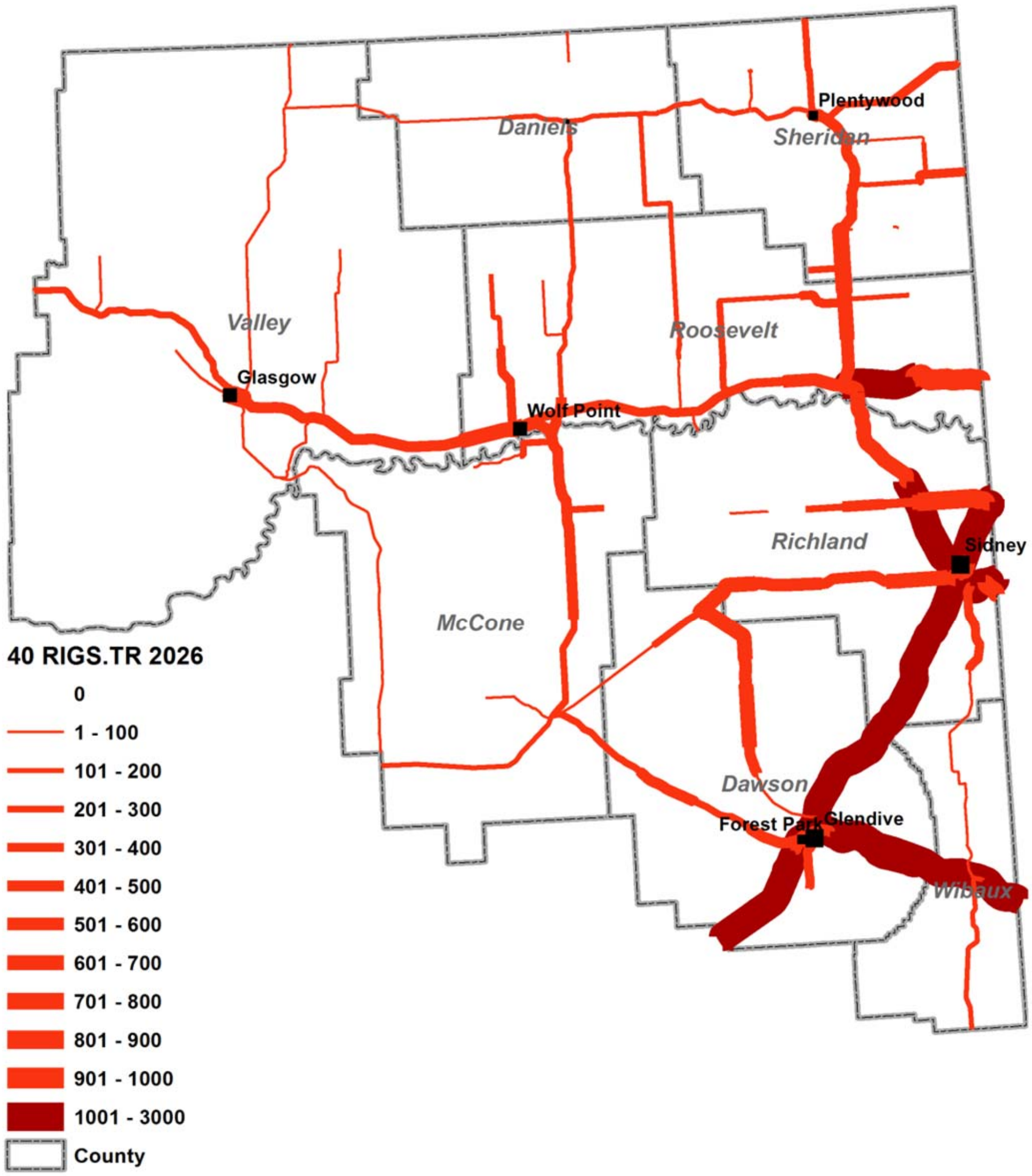


Figure 10-15: Truck traffic in 2026 for the 40 rig scenario.

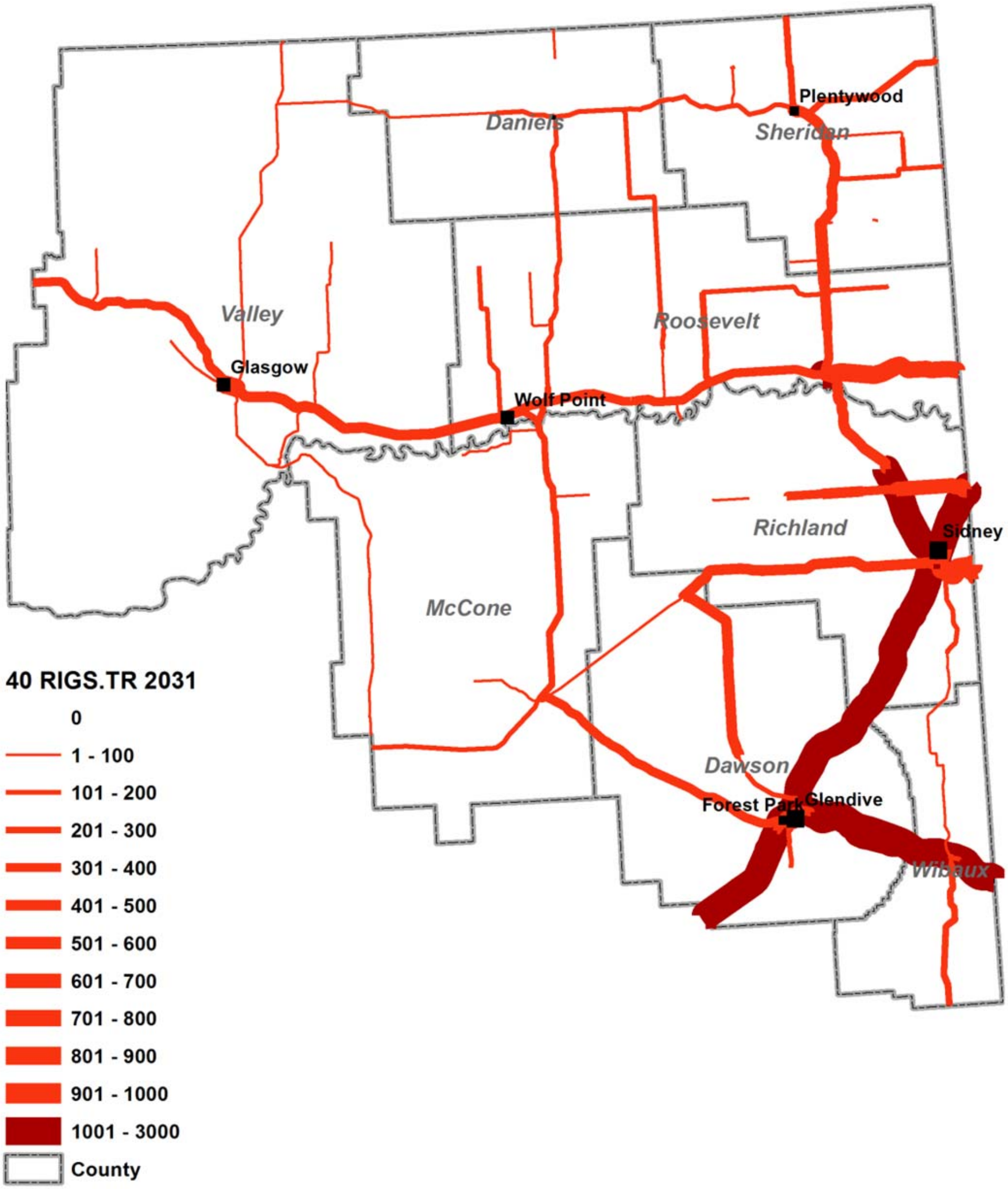


Figure 10-16: Truck traffic in 2031 for the 40 rig scenario.

11. IMPLEMENTATION

Chapter 10 provided an overview of the model results, with a focus on annual results for the first five years of the analysis period, and traffic estimates at five year intervals for the remainder of the analysis period. The primary deliverable from this study is a GIS shapefile and corresponding traffic estimate files stored in dBase format. The combination of these files allows for retrieval of traffic forecast estimates by individual subsegment by year. This chapter provides information on the use of the deliverables as well as instructions for segment-specific data retrieval.

The subsegment is a redefinition of segment length, delineated at the intersection of state highways and county roads. This process creates smaller roadway segments to more accurately assess the impact of trucks entering or departing a state highway because of highly localized oil development. Since the subsegment does not possess all the attributes of the full segment, a unique identifier is added to each subsegment for future use in connecting the dBase traffic forecasts to the GIS shapefile.

11.1. Base GIS Shapefile

The base GIS shapefile for use in the traffic analysis is discussed in Chapter 4. The attributes of the data in the base shapefile are shown in Table 11-1. Each of these data elements are as provided by MDT with the exception of SUBSEGID. As mentioned above, this variable represents a unique identifier generated by UGPTI for use in future data merge activities.

The base shapefile delivered to MDT is titled “Montana_Roads_OilCounty_StateResponsible.” This shapefile includes lines representing the highway network that the State of Montana is responsible maintaining and improving as indicated by the STATE_RESP attribute in the corresponding attribute file.

Table 11-1: Data elements of MDT highway shapefile

Variable Name	Meaning
DEPT_ROUTE	MDT Route Identifier
CORRIDOR	MDT Corridor Identifier
ROUTE_NAME	Route Name (where available)
ROUTE_TYPE	Road
SYSTEM	Route Classification (text)
FC	Route Classification (numeric)
SURF_TYPE	Surface Type
SURF_WIDTH	Surface Width
LANES	Number of Lanes
DIVIDED	If Highway = YES
ONEWAY	If One Way Highway = YES
STATE_RESP	If State Responsible = YES
STATE_MAIN	If State Maintained = YES
MAINT_SEC	Maintenance Jurisdiction
RECON_ID	MDT Internal Construction Identifier
IMPRV_ID	MDT Internal Construction Identifier
IMPRV_YEAR	MDT Internal Construction Year
CITY	City
COUNTY	County
MILES_3D	Miles
SUBSEGID	Unique Identifier Specified by UGPTI

11.2. Traffic forecast dBase files

The remaining deliverables are in the form of dBase files with filenames corresponding to the rig scenarios outlined in Chapter 3. Specific filenames and scenarios are found in Table 11-2.

Table 11-2: dBase filename and corresponding scenario

Filename	Scenario
20 Rigs.dbf	20 Rig Scenario
40 Rigs.dbf	40 Rig Scenario
80 Rigs.dbf	80 Rig Scenario
160 Rigs.dbf	160 Rig Scenario

The data elements in each of these dBase files are shown in Table 11-3. The first variable is SUBSEGID, which is common with the MDT shapefile definition above. This is the common unique identifier used to merge the shapefile with the forecast files. The remaining variables correspond to daily truck estimates and flexible and rigid ESAL estimates.

Table 11-3: Data elements in scenario data files

Variable Name	Meaning
SUBSEGID	Unique Identifier Specified by UGPTI
TR_11-TR_32	Daily Trucks in 2011-Daily Trucks in 2032
FLEX_11-FLEX_32	Flexible ESALS in 2011-Flexible ESALS in 2032
RIGID_11-RIGID_32	Rigid ESALS in 2011-Rigid ESALS in 2032

11.3. Joining the traffic forecasts to the MDT shapefile, and viewing forecasts

Note: These instructions are tailored to ESRI ArcMap version 10.0. If running a different version of ArcMap, please refer to the software documentation for the data join process.

Viewing the traffic forecasts in the shapefile is a two-step process. The first step is to load the shapefile into ESRI ArcMap. The state-maintained roadways will display in the viewing pane. Next, import the dBase file into ArcMap. The process is the same, although the data will not initially display. Right-clicking the line layer file will display an action menu. Selecting "Joins and Relates" reveals an additional menu. Click "Join" and a new window will appear.

The Join Data window provides a number of options to join the highway network line file with the corresponding dBase file. From the top drop-down menu, select "Join Attributes from a Table." Under step 1, select "SUBSEGID" as the attribute to join. In step 2, select the appropriate dBase file. In step 3, select "SUBSEGID" as the common attribute. Next select "OK." After ArcMap has finished processing, each traffic forecast is joined to the original shapefile provided by MDT. At this point, the identify feature can be used to view traffic forecasts for individual roadway segments. Additionally the display may be changed to categorize roadways by traffic levels.

11.4. Utilization of Data

It is expected that MDT would use these traffic forecasts in conjunction with existing traffic forecasting methods for planning decisions and pavement design. The model presented in this document is based upon assumptions and traffic data provided in 2011. As time progresses, current traffic data should be considered when making comparisons between model results and existing traffic forecasting methods.

12. CONCLUSION

Exploration of the Bakken formation has resulted in significant traffic increases on highways in northeastern Montana, both as a result of exploration and production within the state, and from spillover traffic from exploration and production activities in North Dakota. This study indicates that the increased traffic levels will continue so long as drilling rig counts remain constant or increase. The duration and scope of these activities is highly dependent on many exogenous factors, so forecasts of development provided by the Montana Oil and Gas Board and the North Dakota Oil and Gas Division of the Industrial Council are critical to the accuracy of traffic forecasts presented in this document.

The underlying production and exploration forecasts predict significant activity in coming years, with decreases in these activities toward the end of the analysis period. Because this study explicitly considers origin-destination movements resulting from oil exploration activities such as drilling and hydraulic fracturing as well as outbound saltwater and crude oil movements, it is expected that the forecasts provided by this study will provide additional information which will improve upon traditional traffic forecasting methods. For example, trendline forecasting is likely to underestimate or, in certain cases, overestimate traffic increases, depending on the timing of collected traffic observations.

As suggested earlier in this document, the traffic forecasts resulting from this study should be used in conjunction with traditional traffic forecasting methods, and validated against observed traffic classification counts in the future. In addition, continued monitoring of oil exploration and development forecasts from the Montana and North Dakota regulatory bodies is necessary to assess the validity of the underlying assumptions of this study and the potential need to modify the forecasts based upon fundamental changes in production and exploration.

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APPENDIX A: 80 Rig Scenario

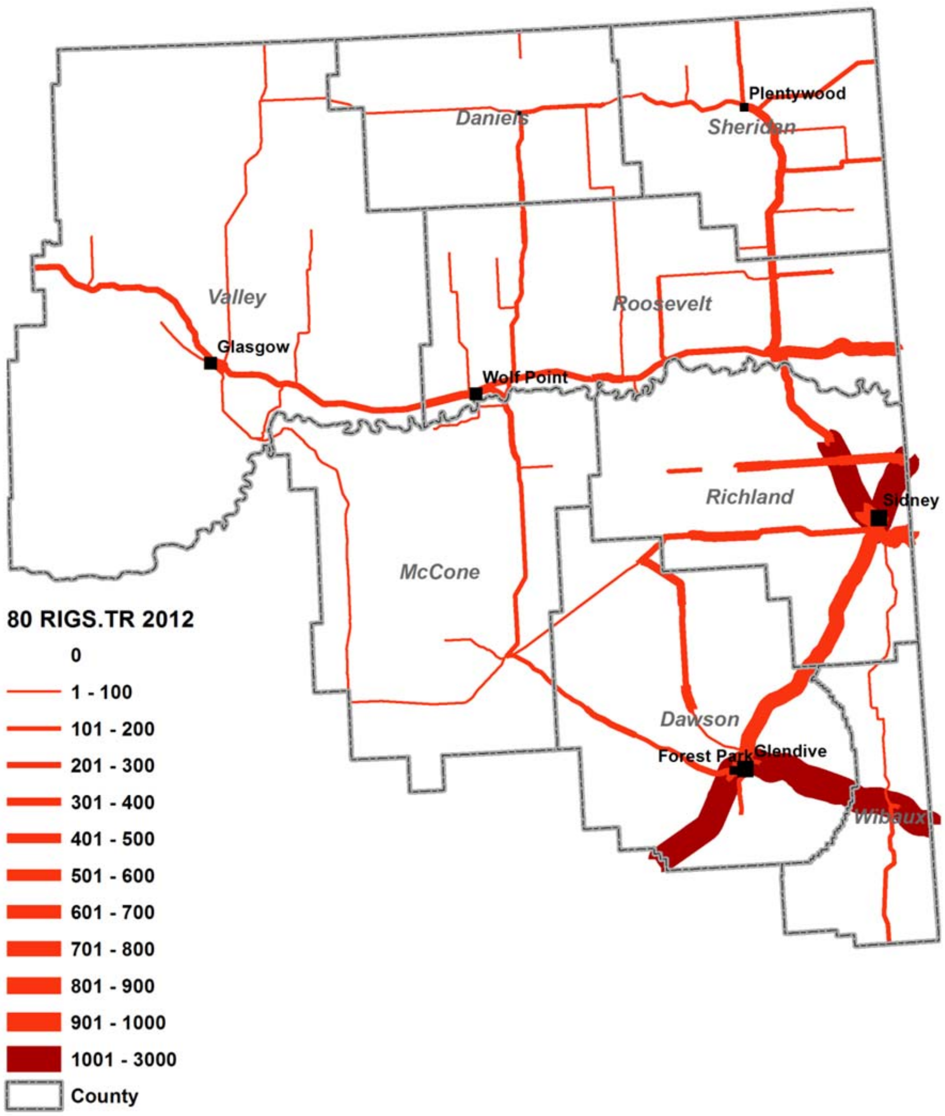

Figure A-1: Truck traffic in 2012 for the 80 rig scenario

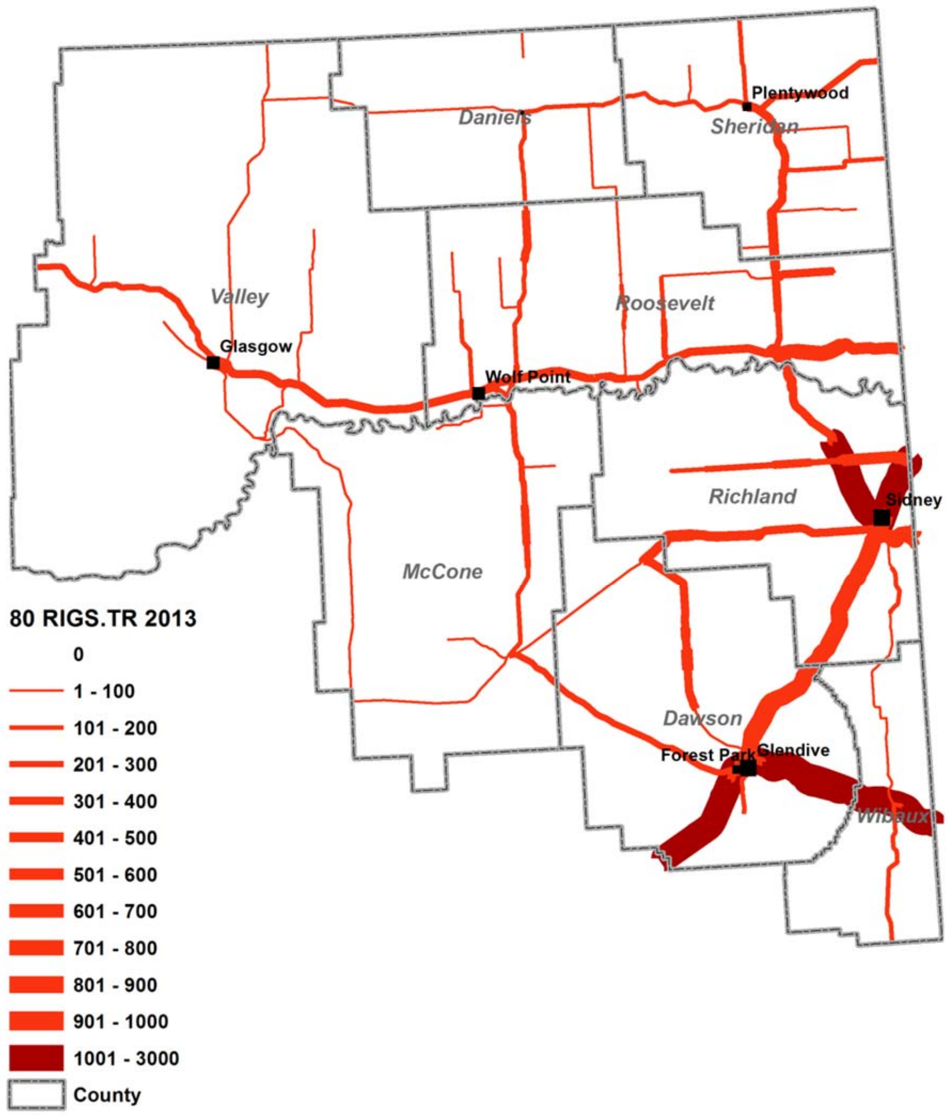

Figure A-2: Truck traffic in 2013 for the 80 rig scenario.

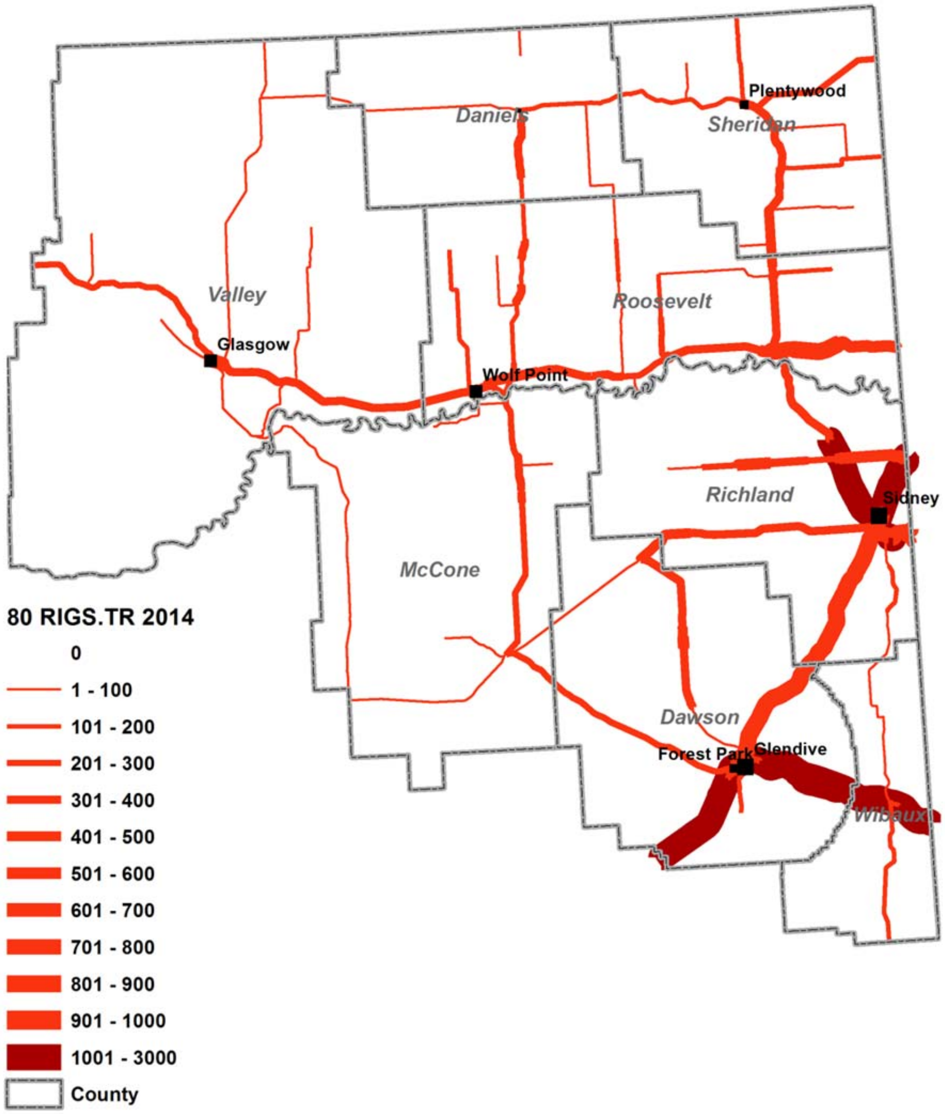

Figure A-3: Truck traffic in 2014 for the 80 rig scenario.

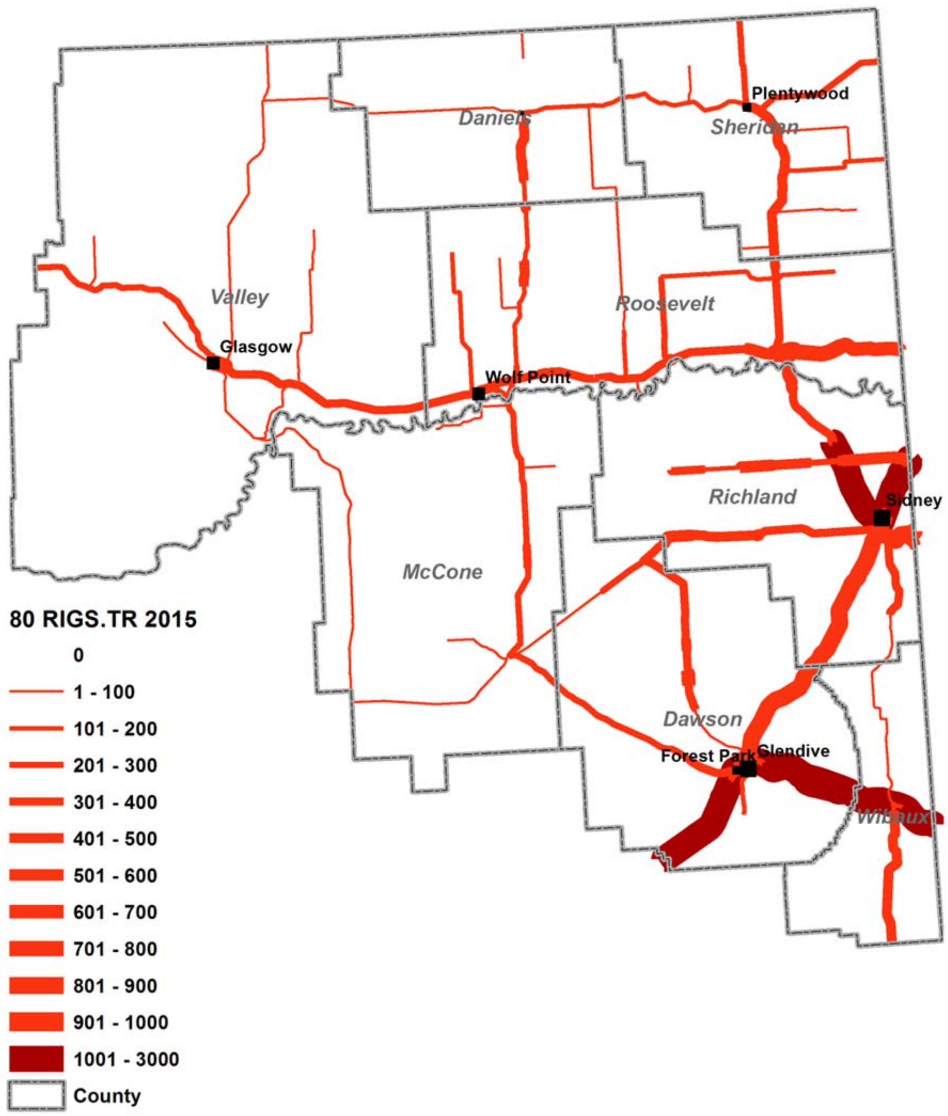

Figure A-4: Truck traffic in 2015 for the 80 rig scenario.

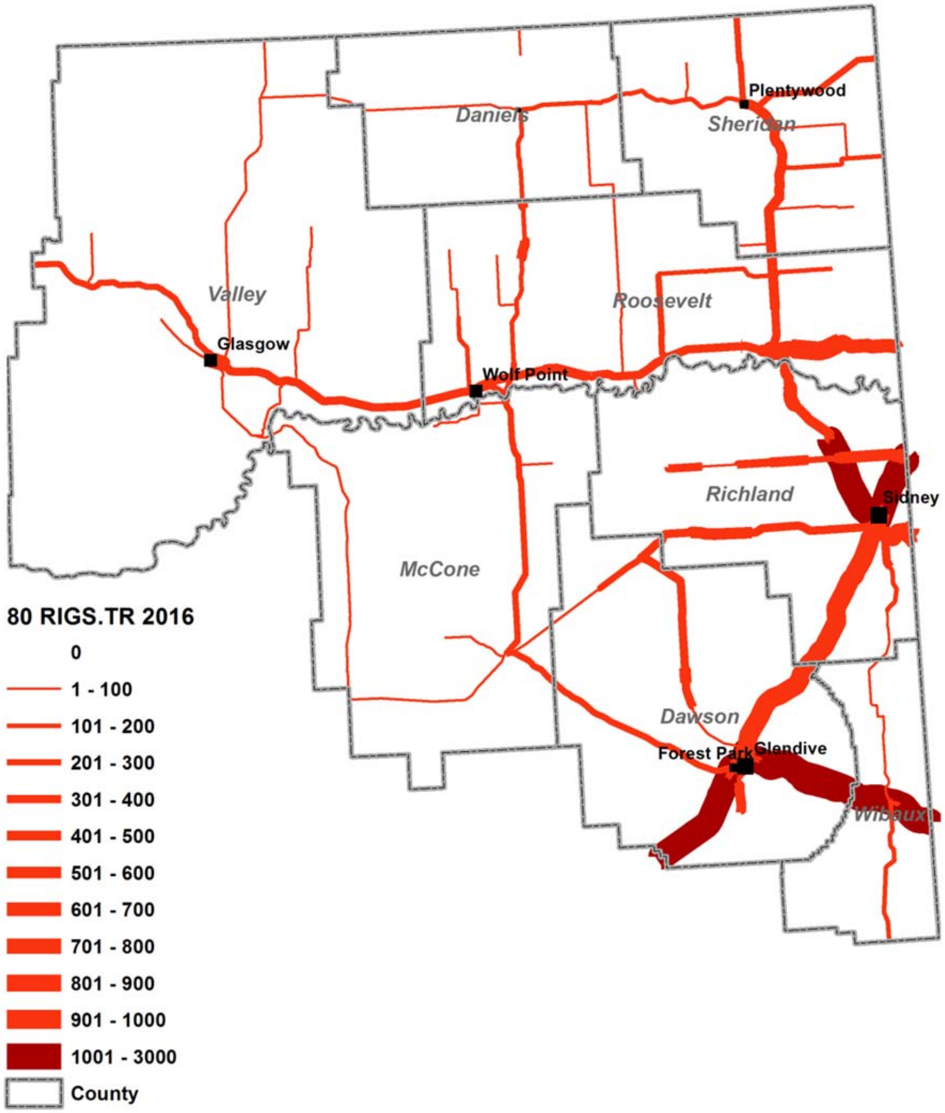

Figure A-5: Truck traffic in 2016 for the 80 rig scenario.

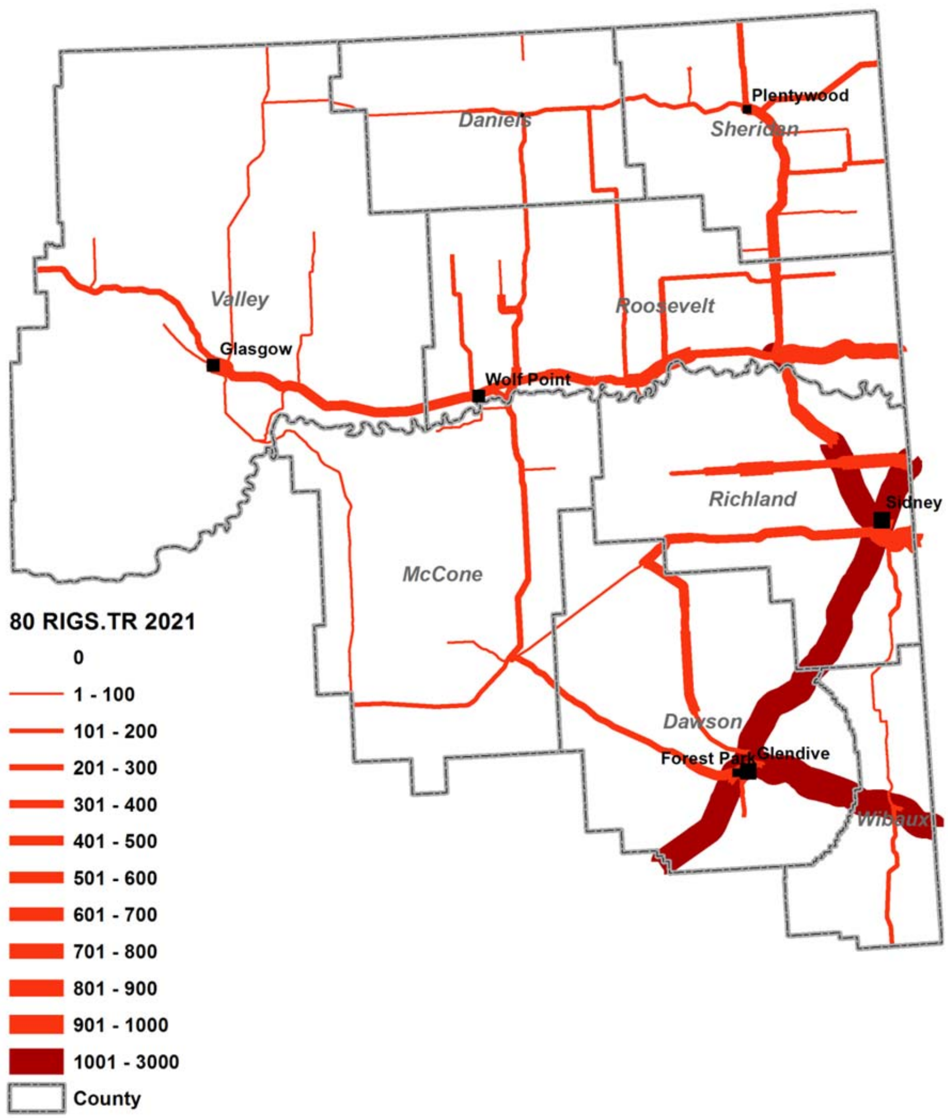

Figure A-6: Truck traffic in 2021 for the 80 rig scenario.

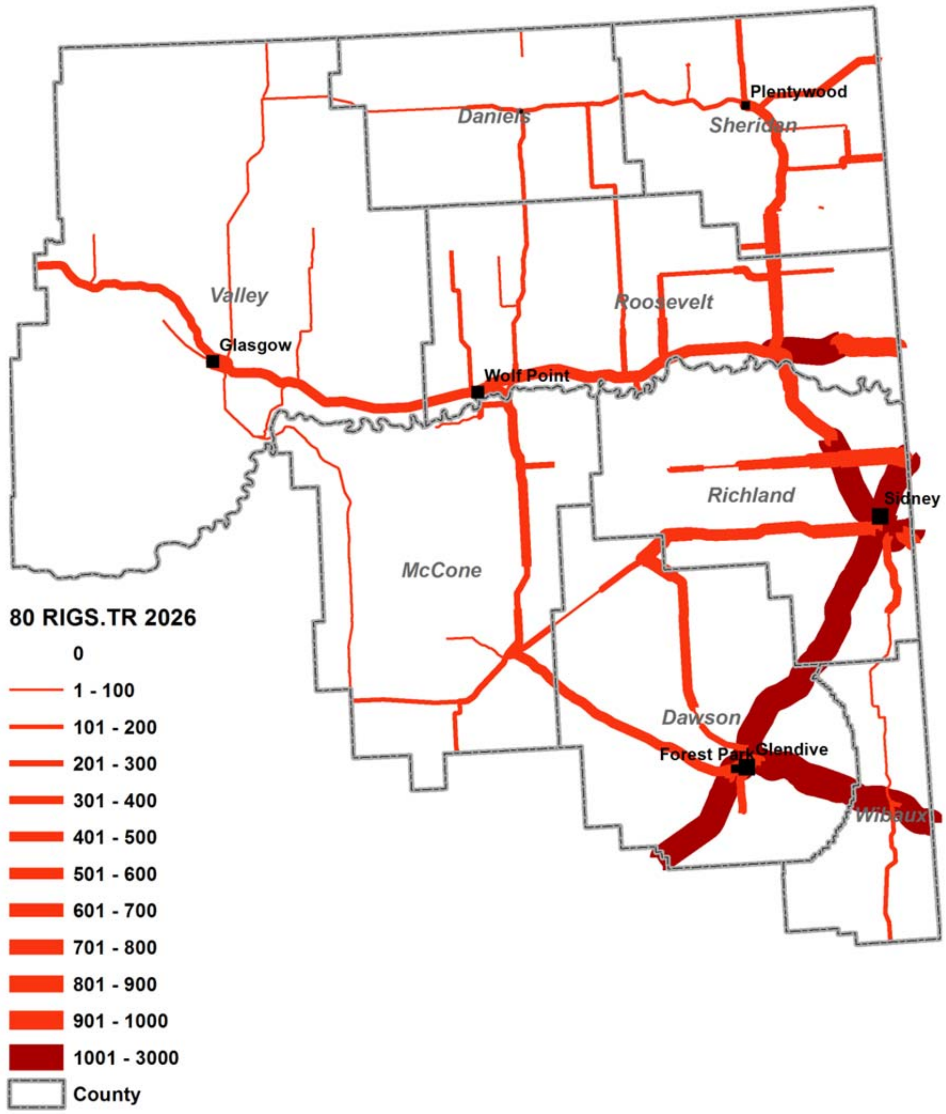

Figure A-7: Truck traffic in 2026 for the 80 rig scenario.

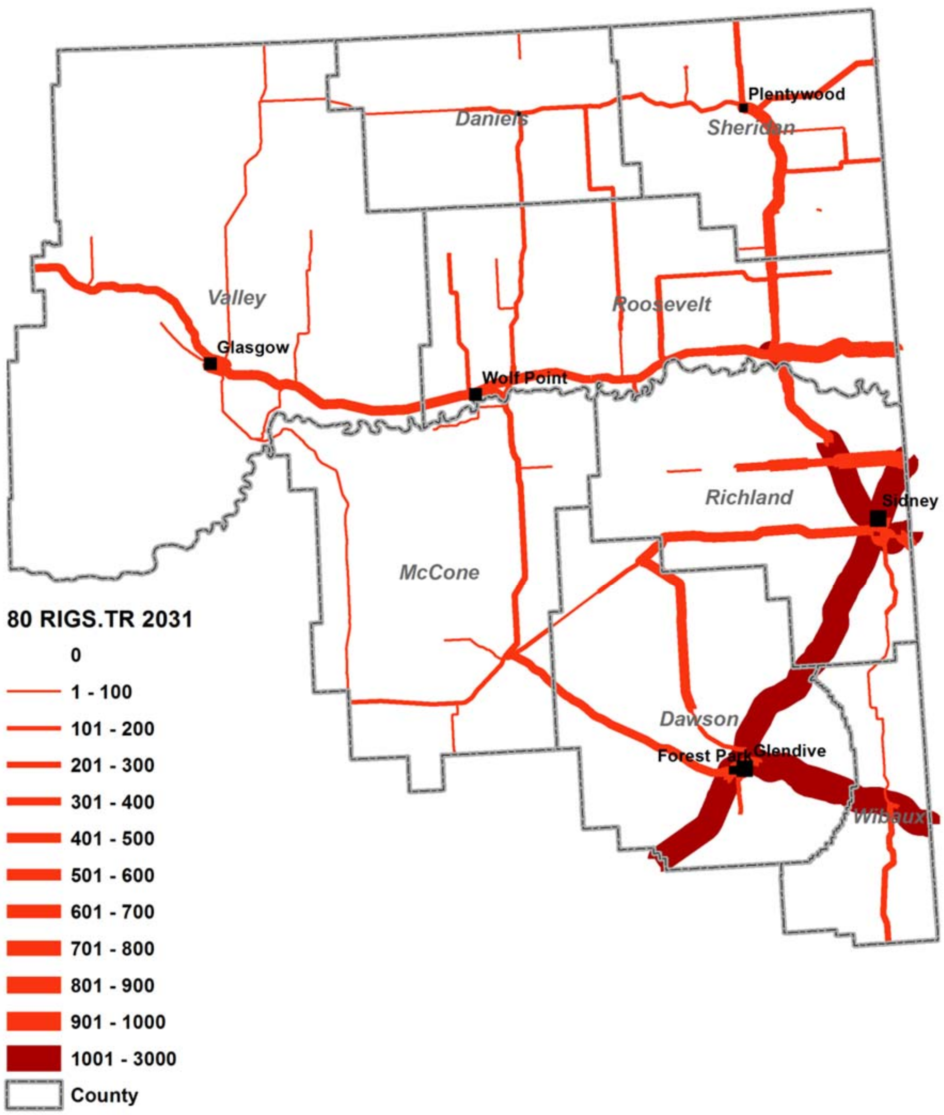

Figure A-8: Truck traffic in 2031 for the 80 rig scenario.

APPENDIX B: 160 Rig Scenario

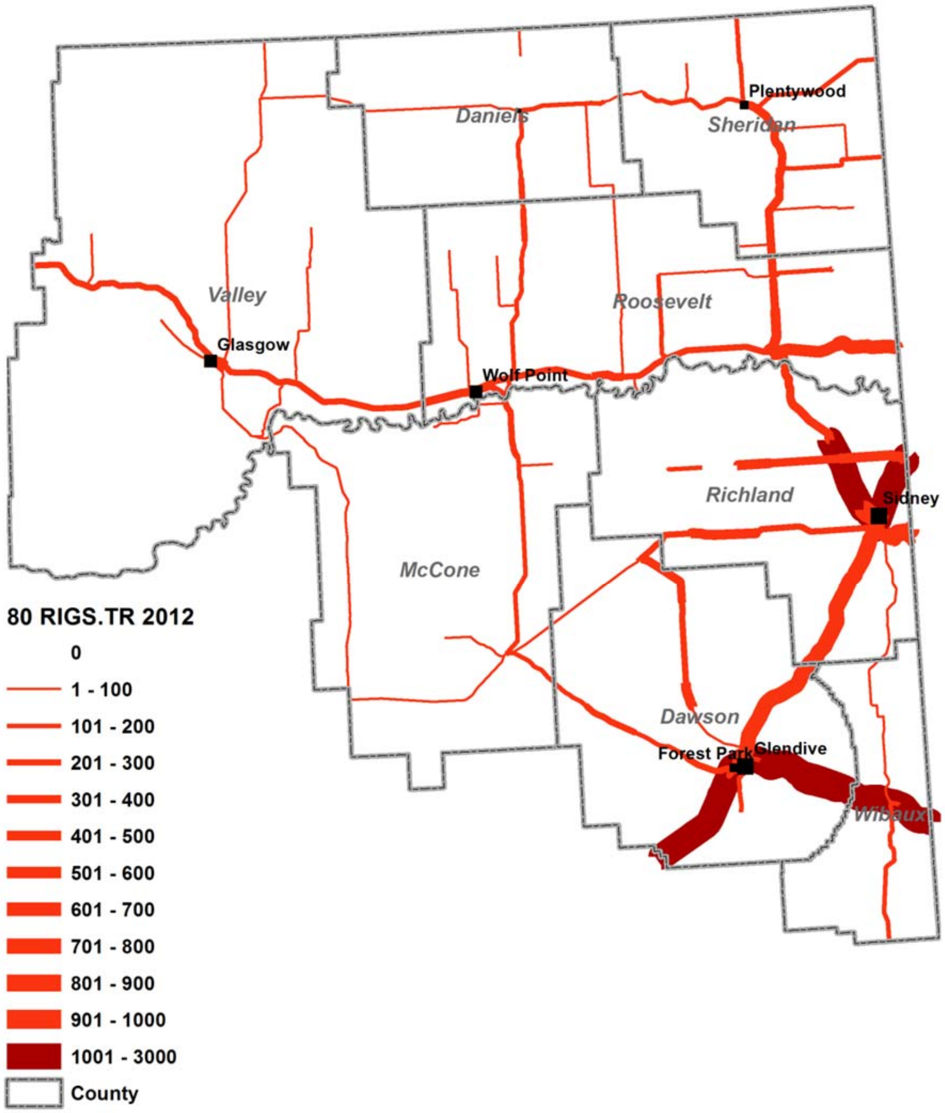

Figure B-1: Truck traffic in 2012 for the 160 rig scenario

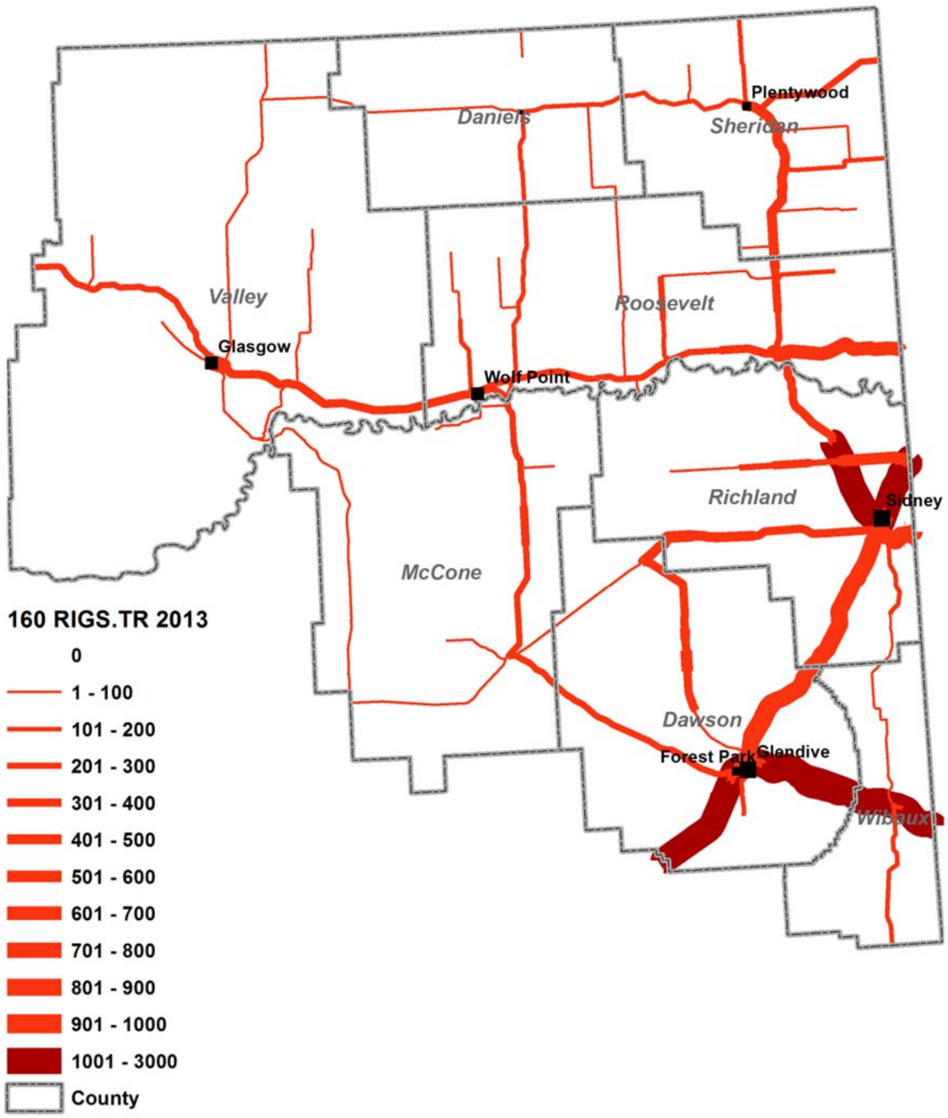

Figure B-2: Truck traffic in 2013 for the 160 rig scenario.

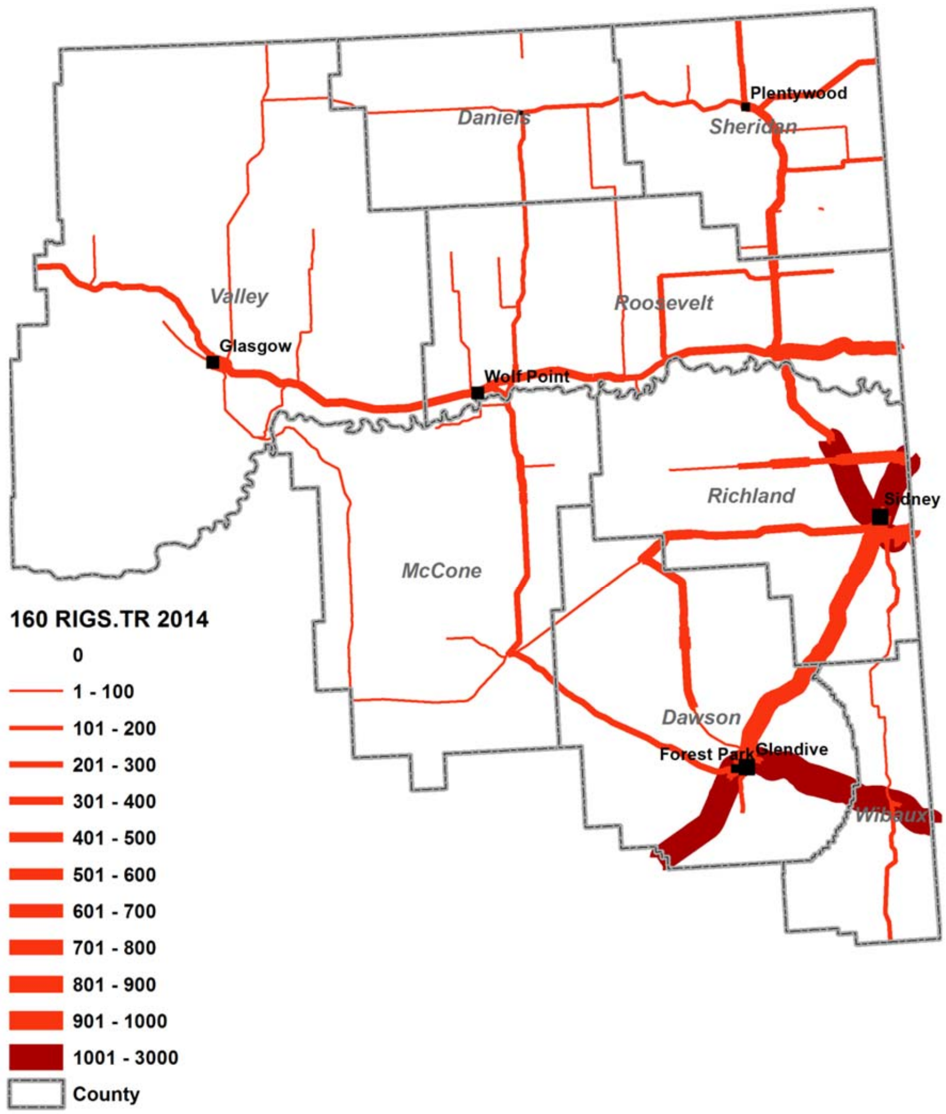

Figure B-3: Truck traffic in 2014 for the 160 rig scenario.

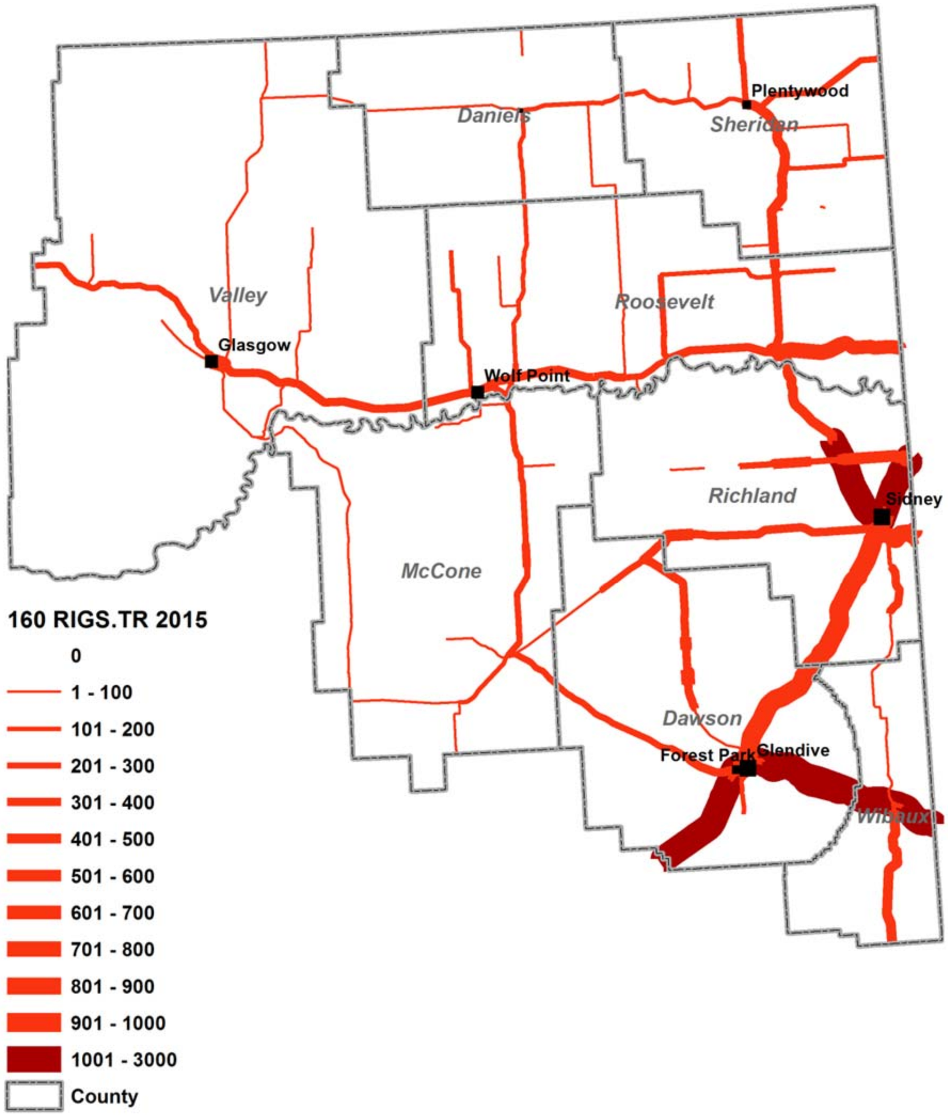

Figure B-4: Truck traffic in 2015 for the 160 rig scenario.

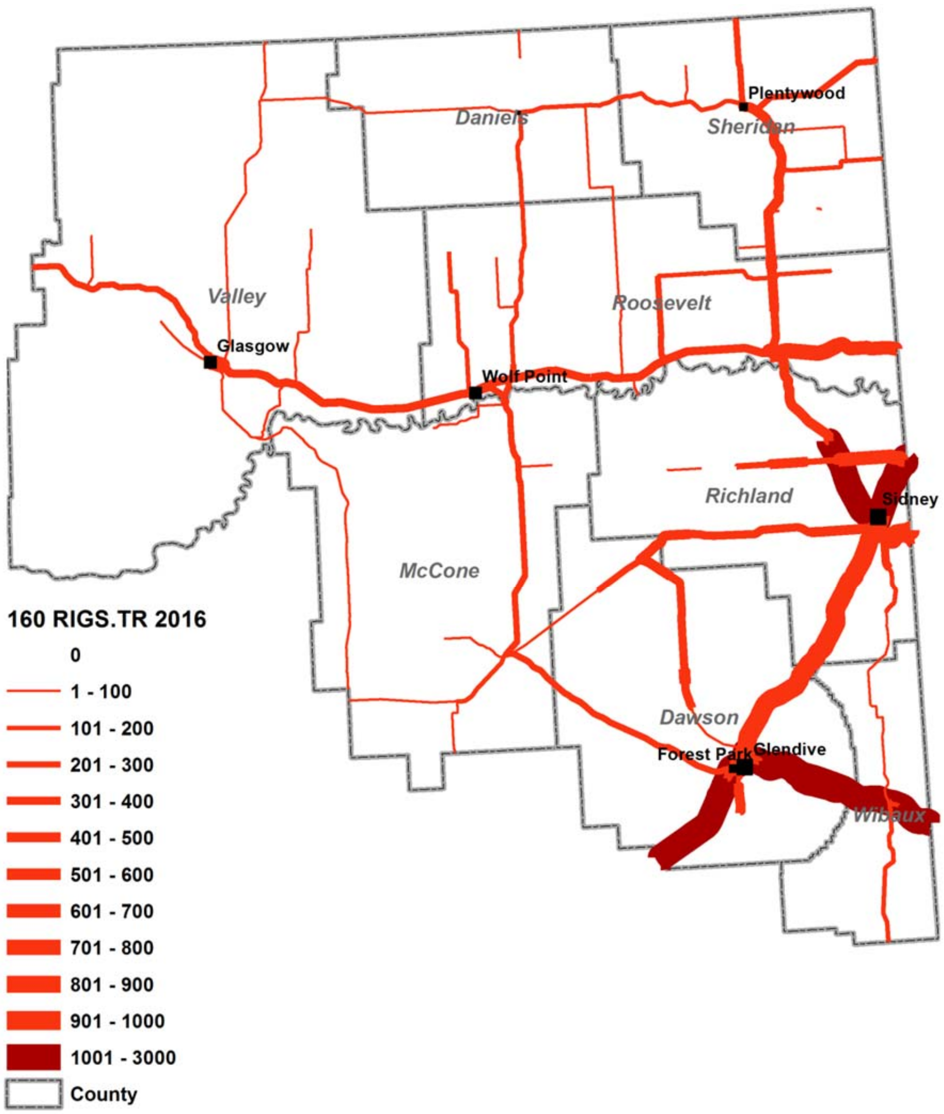

Figure B-5: Truck traffic in 2016 for the 160 rig scenario.

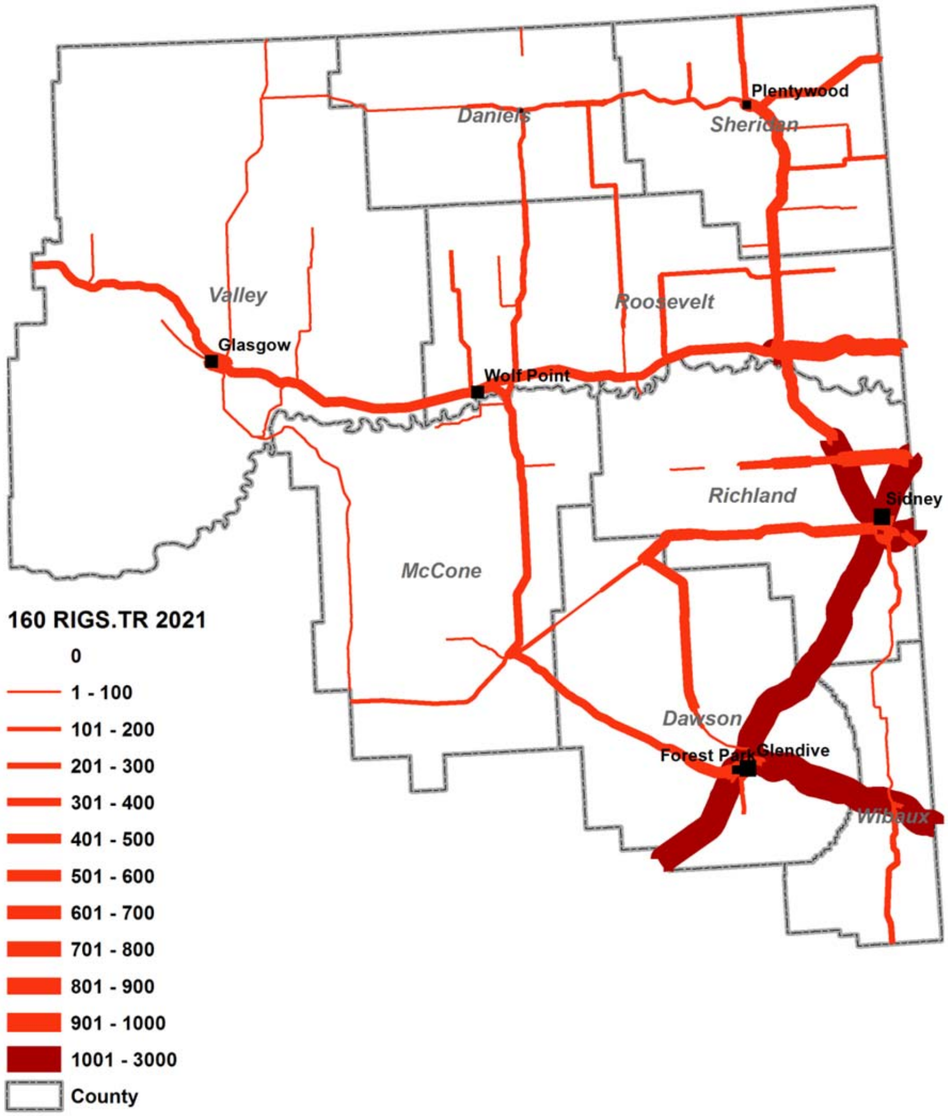

Figure B-6: Truck traffic in 2021 for the 160 rig scenario.

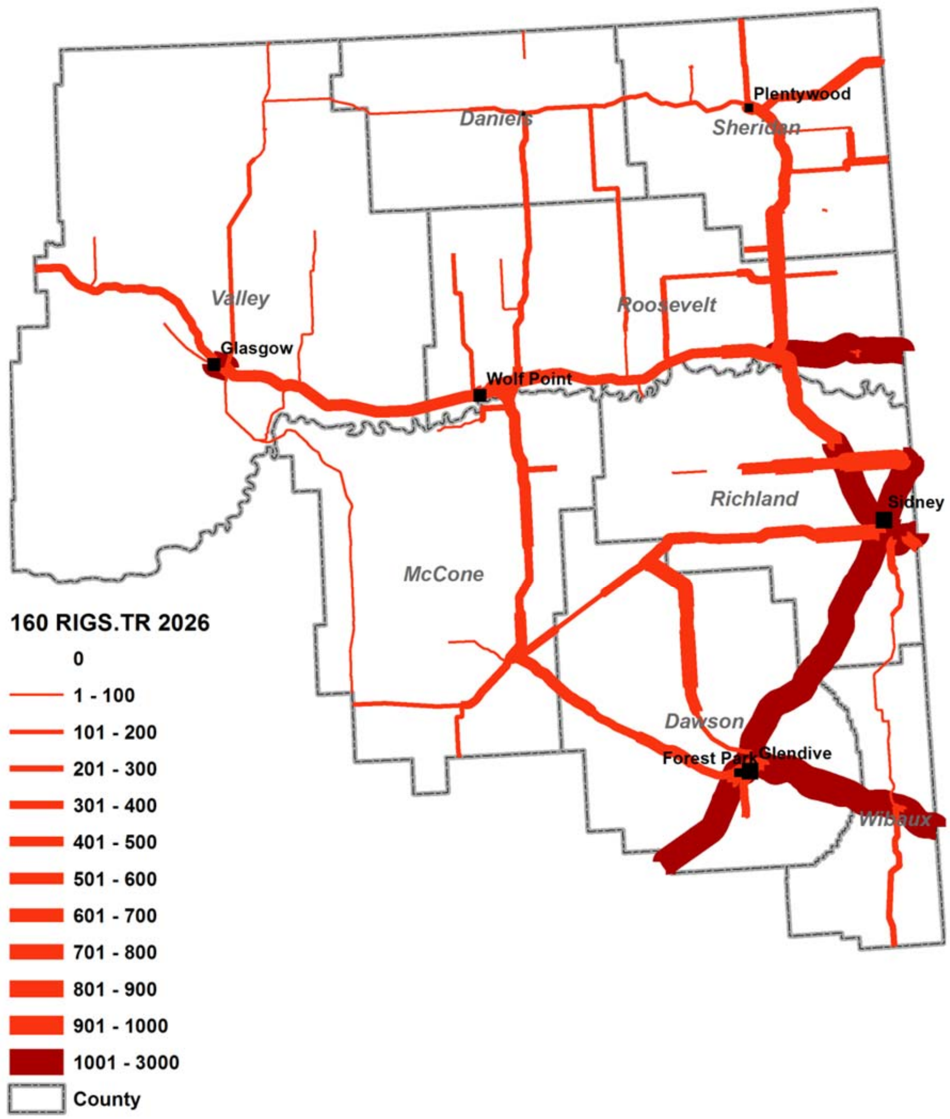

Figure B-7: Truck traffic in 2026 for the 160 Rig scenario.

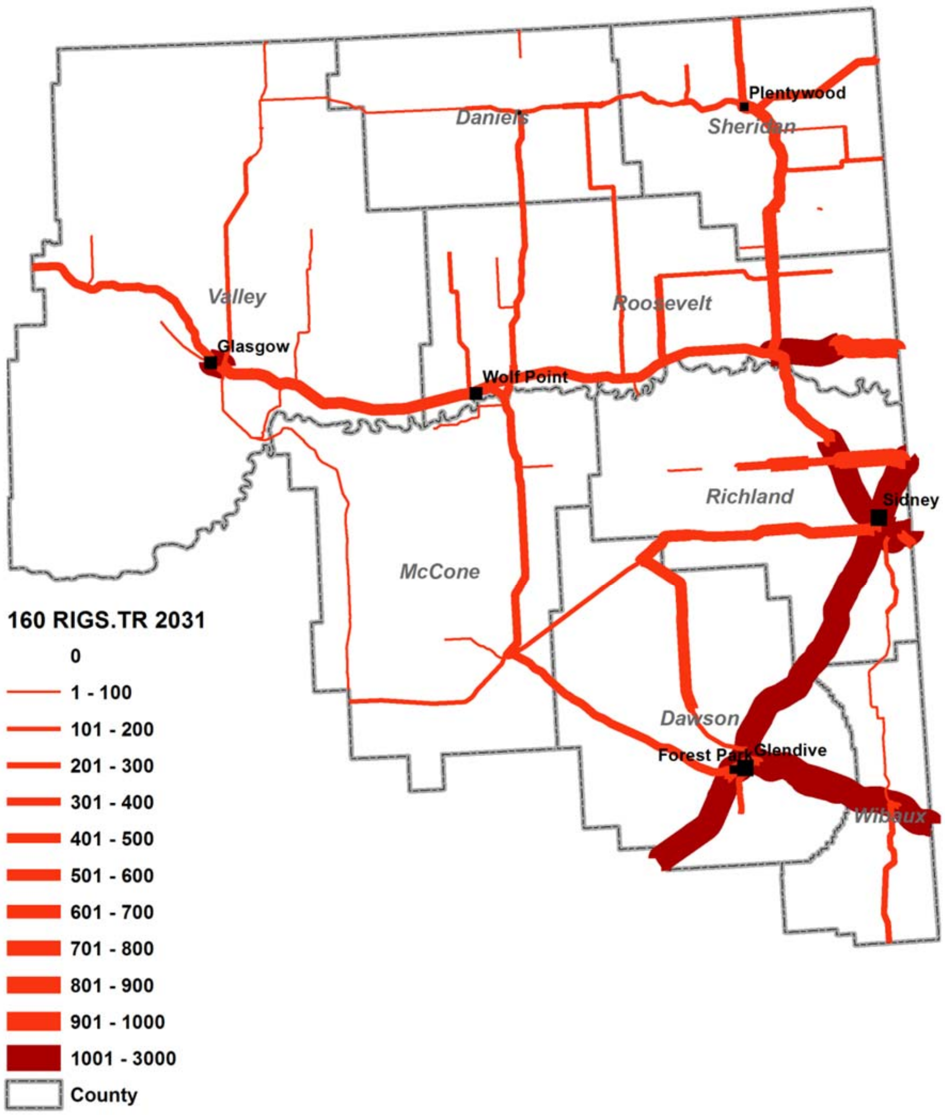

Figure B-8: Truck traffic in 2031 for the 160 Rig scenario.