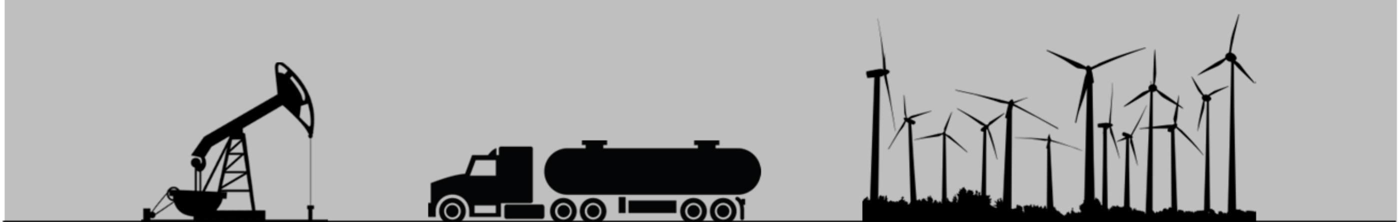
Traffic Loads for Segment and Corridor-Level Analyses

Implementation Report IR-16-04



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INTRODUCTION

Energy developments that rely on horizontal drilling and hydraulic fracturing (also called fracking) technologies generate enormous amounts of truck traffic on state, county, and local roads. Secondary roads, in particular, were never designed to carry such high truck traffic volumes and heavy loads. The result has been accelerated degradation of pavements and roadside infrastructure, as well as increases in congestion and crash and fatality rates.

Quantifying the number of truck trips and resulting 18-kip equivalent single axle loads (ESALs) associated with the development and operation of oil and gas wells is a critical requirement for designing and maintaining pavement structures on energy sector roads. However, this is not enough. In order to implement roadway design, construction, and maintenance plans in energy sector areas, it is necessary to document the location, number, and characteristics of existing and planned well developments. It is also important to map out the routes that trucks are likely to use during the development and operation of those wells.

This report describes a geographic information system (GIS)-based methodology to estimate truck volumes and ESALs at the individual roadway segment level for any number of oil or gas wells that are developed and operated in a geographic area. The methodology uses inputs such as, but not limited to, locations of anticipated wells; identification and location of equipment, materials, and other supplies needed to develop and operate the wells; number and type of trucks needed for each development and operation activity; evaluation of loaded and unloaded number of ESALs for each truck type, and length of the analysis period. Additional information about specific input data elements is available in other reports, including RR-15-01, RR-16-01, IR-16-01, IR-16-02, IR-16-03, ESB-16-06, ESB-16-07, and ESB-16-08.

The methodology described in this report uses four-step travel demand modeling principles that were adapted to take into account specific trip generation, trip distribution, and route assignment characteristics of typical unconventional energy developments in the state. Anticipated applications of the methodology include, but are not limited to, estimation of truck volumes and ESALs at the roadway segment and corridor levels, determination of roadway and roadside maintenance needs, prioritization of pavement maintenance and rehabilitation projects, evaluation of truck route plans, analysis of traffic operations and safety impacts, and analysis of congestion and access management requirements. The report documents the results of a case study in Karnes County using wells that were completed in 2013.

TRAVEL DEMAND MODELING APPROACH AND ASSUMPTIONS

Four-step travel demand modeling includes trip generation, trip distribution, mode choice, and route assignment components. Because the main goal of the modeling effort was to determine truck volumes and ESALs for pavement maintenance and design purposes, trips requiring non-truck vehicles (e.g., pickup trucks, utility trucks, and personal vehicles) were not included in the analysis. Although the number of non-truck trips needed to develop and operate oil and gas wells could be quite significant (some estimates place the number of these trips as being of the same of magnitude as the number of truck trips), the corresponding impact on the total number of ESALs would be very small. Further refinements of the modeling approach could include non-truck trips for applications such as emergency evacuations and traffic and congestion management.

Specific assumptions and modeling approach for the trip generation, trip distribution, and trip assignment components follow.

- **Trip Generation**. This step determines the number of trips associated with origins and destinations for each trip purpose. Wells are trip producers, making well locations the origin of all trips (whether trucks arrive at or leave well locations). Locations that provide or receive equipment, materials, and other supplies are trip attractors. For trip productions, the number of trips corresponds to the number of trucks needed for each well development or operation activity, making trip productions constrained. Implementation Report IR-16-03 provides information about the number of trucks needed for each activity. For trip attractions, individual supplier capacity can limit the number of attracted trips. For simplicity, suppliers are not assumed to be capacity-constrained, i.e., suppliers have sufficient materials and supplies to address the needs of the well developments they serve.
- **Trip Distribution**. This step determines the number of trips between each trip production (oil or gas well) and each trip attraction (i.e., each supplier). A number of methods are available to estimate trips between trip productions and attractions, including growth factor methods, gravity models, and destination choice models. Growth factor methods require an existing trip distribution matrix to be available. Gravity models rely on short path calculations and impedance measures between trip productions and attractions, such as travel time or travel cost. Commonly used impedance functions include exponential, inverse power, and gamma. Destination choice models are a generalization of gravity models, which use a wider range of explanatory variables and are, therefore, more data intensive. Because posted speed limit data and other roadway characteristics were available for all roadway segments, TTI researchers selected a gravity model to determine the number of trips between trip productions and trip attractions. The researchers also used an inverse power impedance function because this kind of function only required the estimation of one parameter.
- **Route Assignment**. This step assigns trips between trip productions and attractions to routes based on certain rules. Several methods are available to assign routes, e.g., all-or-nothing, user equilibrium, and system optimum. All-or-nothing assignment allocates trips to single, minimum-cost paths without considering roadway capacity or impact of traffic on travel cost. This method is frequently unrealistic in urban areas where congestion is common, but it may be more suitable for rural and relatively uncongested areas. Both user equilibrium assignment and system optimum assignment consider roadway capacity and impact of traffic on travel cost. User equilibrium assignment assumes that all travelers strive to find a path with minimum travel time. System optimum assignment assumes that travelers cooperate with each other to minimize total system travel time.

  For the analysis, TTI researchers used an all-or-nothing assignment because most energy developments occur in rural areas with sparse transportation networks and occasional congestion. With truck trips assigned to routes, the last step was to convert the assigned number of trips on each roadway segment to ESALs using the ESAL calculations for individual truck types as described in Implementation Report IR-16-03.

CASE STUDY

TTI researchers conducted a case study using wells completed in Karnes County in 2013 to evaluate the feasibility of the modeling approach. Table 1 provides a listing of the various datasets used for the analysis. Figure 1 shows the location of wells completed in Karnes County. Figure 2 shows the locations of the suppliers listed in Table 1. The analysis was conducted using TransCAD 7.0.

Table 1. Data Used in Case Study.

Dataset	Number of Records	Source of Information
Completed wells (2013)	493	Railroad Commission of Texas
Aggregate suppliers	14	TxDOT Corpus Christi District Office
Drilling rig and equipment suppliers	3	TxPROS oversize/overweight permit database
Water suppliers	9	TxDOT Karnes City Area Office
Pipe and casing suppliers	4	Google search
Fracking sand suppliers	2	TxDOT Karnes City Area Office
Chemical suppliers	9	Google search
Injection disposal wells (as of 2014)	615	Railroad Commission of Texas
Crude oil terminals	2	TxDOT Karnes City Area Office

For the modeling effort, the researchers used wellhead locations. As Figure 1 shows, most wells completed in Karnes County are horizontal wells in which the lateral component is approximately one mile long. Although Figure 1 suggests one wellhead location for several laterals, in reality each wellhead has its own lateral (with its own American Petroleum Institute [API] number). This characteristic facilitated modeling of the number of trucks and ESALs at the individual lateral level.

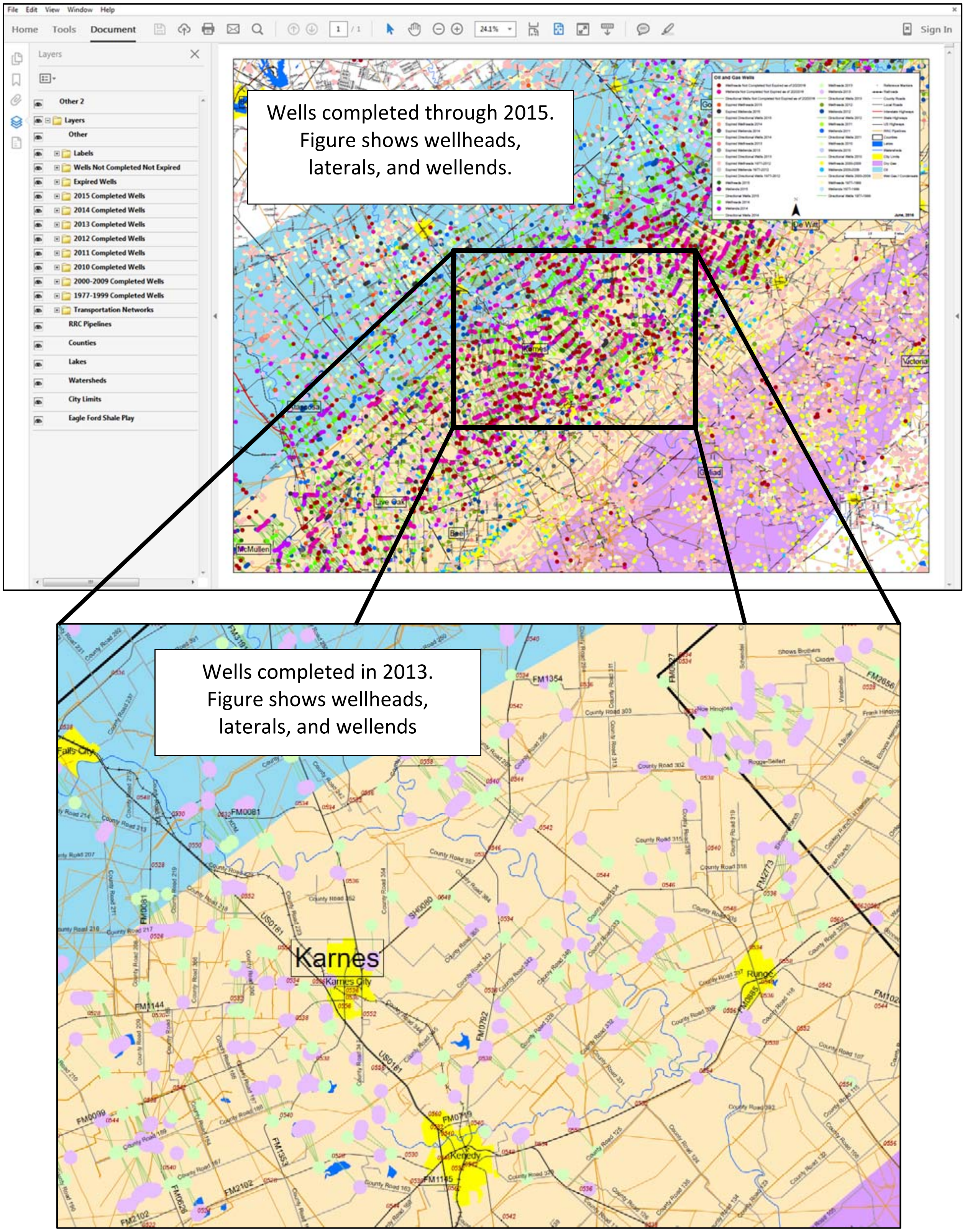

Figure 1. Wells Completed in Karnes County.

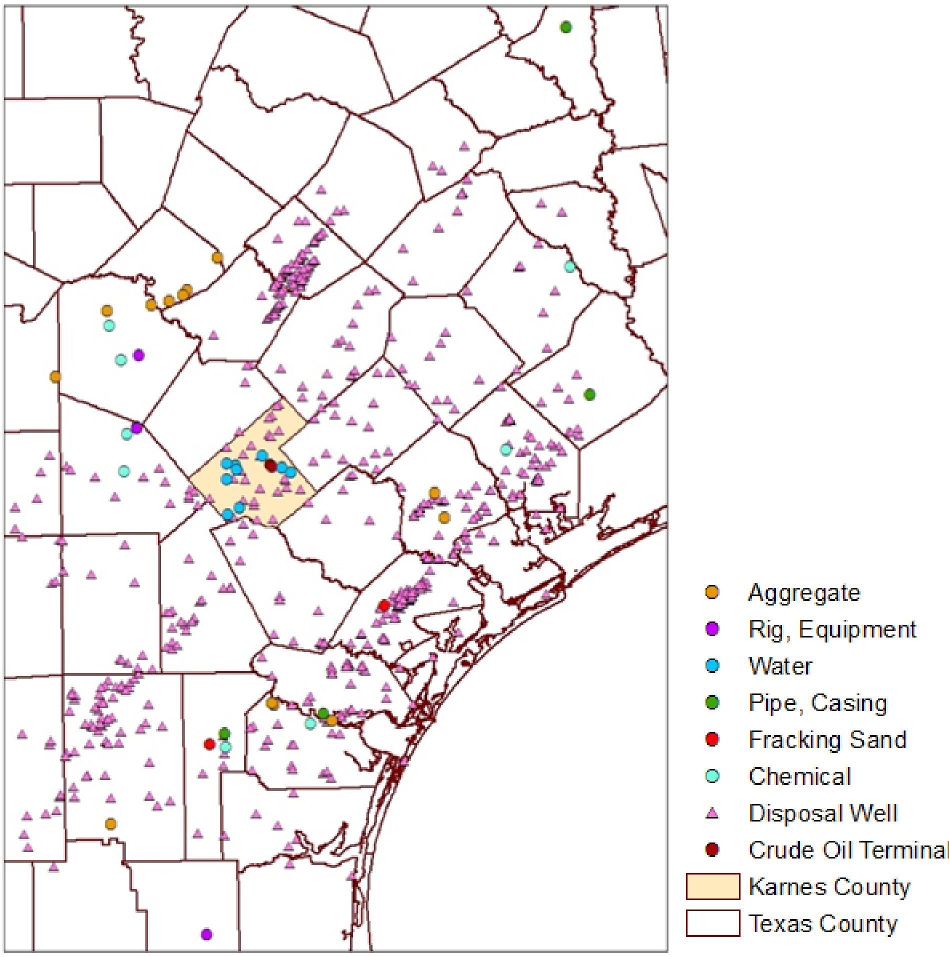

Figure 2. Location of Potential Suppliers Used for the Analysis.

Trip Generation

The researchers prepared a trip generation table showing the number of trips generated by trip productions and trip attractions. Trip generation calculations involved the following assumptions:

- Trips are loaded or unloaded depending on the trip purpose and direction. For example, for fracking water, the trip from a supplier to a well is loaded while the return trip is empty. For flowback or produced water disposal, the trip to the well is empty while the trip to the disposal facility is loaded.

- All wells need the same amount of resources and number of trucks regardless of operator or number of wellheads and laterals developed at the same pad location. Table 2 shows the number of trucks needed for each development, operation, and re-fracking activity. A sensitivity analysis is possible in order to examine the impact of variations in resources needed, e.g., in relation to the use of temporary water lines to decrease the number of trucks needed to carry fracking water, or in relation to the impact due to multiple wells developed at the same pad location within a short duration.

Table 2. Truckloads Needed for Individual Wells in the Eagle Ford Shale Region.

Well Development Activity	Truck Volume (per well)	Supplier
Drilling pad and construction equipment	70	Aggregate suppliers
Drilling rig	4	Drilling rig and equipment suppliers
Drilling fluid and materials	59	Water suppliers
Drilling equipment: casing, drilling pipe	54	Pipe and casing suppliers
Fracking equipment: pump trucks, tanks	74	Drilling rig and equipment suppliers
Fracking water (steel tank)	715	Water suppliers
Fracking water (aluminum tank)	306	Water suppliers
Fracking sand (steel tank)	103	Fracking sand suppliers
Fracking sand (aluminum tank)	44	Fracking sand suppliers
Other additives and fluids	24	Chemical suppliers
Flowback water removal	255	Injection disposal wells
Total	1,708	
Well Production Activity	**Truck Volume (per well and year)**	**Supplier**
Produced water (steel tank)	65	Injection disposal wells
Produced water (aluminum tank)	22	Injection disposal wells
Oil production (steel tank)	249	Crude oil terminals
Oil production (aluminum tank)	83	Crude oil terminals
Total	418	
Well Re-fracking Activity	**Truck Volume (per well and event)**	**Supplier**
Fracking equipment: pump trucks, tanks	74	Drilling rig and equipment suppliers
Fracking water (steel tank)	715	Water suppliers
Fracking water (aluminum tank)	306	Water suppliers
Fracking sand (steel tank)	103	Fracking sand suppliers
Fracking sand (aluminum tank)	44	Fracking sand suppliers
Other additives and fluids	24	Chemical suppliers
Flowback water removal	255	Injection disposal wells
Total	1,515	

- All suppliers have sufficient capacity to address the needs of individual wells. Because suppliers are capacity-constraint and information about pricing of materials and services from various suppliers was not available, the choice of suppliers for each well is only based on travel time. In some cases, there was information that suggested specific trip characteristics or trends. For example, many water trucks use steel tanks. However, weigh-in-motion (WIM) data records indicated a substantial number of aluminum tank trucks. Using the WIM data records as a guidance, the researchers assumed a 7/3 split between the number of steel tank trucks and aluminum tank trucks.

- Pavement impact is assumed to be linearly dependent on the amount of traffic, e.g., doubling the number of trucks of the same type would result in twice the number of ESALs. This characteristic made it possible to simplify the modeling effort considerably by only having to run TransCAD once for each trip purpose assuming a normalized number of trips per development or operation activity: 100. During the route assignment step, the researchers multiplied the resulting number of assigned trips per roadway segment by the corresponding number of trucks in Table 2 and then dividing by 100 to obtain the correct number of assigned trucks per roadway segment for each development or operation activity.

Trip Distribution

In the absence of any additional information about factors that contribute to the selection of material or service suppliers, this selection was only based on travel time considerations. More specifically, the researchers assumed that the impedance between a well and a supplier location was only a function of the shortest travel time between them. Posted speed limit data was used to provide a measure of travel time between origins and destinations. A literature review on the specific connection between pavement conditions and traveling speeds, which would have provided additional insight about travel times on energy sector corridors, particularly secondary roads such as farm-to-market (FM) roads, was inconclusive. Nevertheless, the modeling environment enables users to modify speed data either for entire groups of roadway segments or for individual roadway segments to conduct sensitivity analyses. With this approach, it is possible to evaluate, for instance, the conditions under which trucks would begin to drive more often on unpaved county roads instead of on-system state roads.

The production-constrained gravity model used to determine the number of trips between each well and each supplier location was as follows:

$$T_{ij} = P_i \frac{A_j \times f(d_{ij})}{\sum_{k=1}^{z} A_k \times f(d_{ik})}$$

where:

T_{ij} = Truck flow produced by trip production *i* and attracted to trip attraction *j*.
P_i = Number of trips produced by trip production *i*.
A_j = Number of trips attracted to trip attraction *j*.
$f(d_{ij})$ = Friction factor between trip production *i* and trip attraction *j*.
z = Number of trip attractions.

The output was an origin-destination matrix showing the choice of suppliers for each well and the associated number of trips for each choice of supplier.

The friction factor is calculated by using the following inverse power impedance function:

$$f(d_{ij}) = {d_{ij}}^{-b}$$

where:

d_{ij} = Impedance between trip production *i* and trip attraction *j*.
b = Model parameter.

In the absence of real-world data to calibrate the *b* parameter, the researchers tried several values and decided to use 0.5. In an effort to replicate the decreasing likelihood of a trip as a function of distance in rural areas, the default value of 0.02 in TransCAD was considered unrealistic because the likelihood of a trip would depend very little on the travel time between an origin and a destination. A *b* value of 0.5 would more likely represent the relationship between travel times and the corresponding likelihood of trips. Calibration based on field data would further reduce the level of uncertainty associated with *b*.

Route Assignment

As mentioned, the researchers used an all-or-nothing assignment method to complete the route assignment step. In essence, this method assigned all the trips between each origin-destination pair to the shortest path between that pair, regardless of roadway capacity or congestion. The output was segment-based truck flow for each direction of travel.

ESAL Calculations

For the conversion of truck volumes to ESALs, the researchers used the results of an analysis that estimated ESALs for each truck type based on axle weight distributions from weigh-in-motion (WIM) station readings. Details of this analysis are available in Implementation Report IR-16-03. Table 3 shows the number of ESALs for each truck type.

The researchers then calculated the total number of ESALs for each segment (in each direction) by multiplying the number of assigned trucks for each activity by the corresponding number of ESALs per truck, by adding the number of ESALs for each phase, and by aggregating the three phases of development, operation, and re-fracking. Assuming an analysis period of 20 years and four re-fracking events during this period, the cumulative number of ESALs for each direction of segment *i* was as follows:

$$Total\_ESAL_i = Dev\_ESAL_i + 20 \times Prod\_ESAL_i + 4 \times Refrc\_ESAL_i$$

where:

$Total\_ESAL_i$ = Total cumulative ESALs for one direction of segment *i*
Dev_ESAL_i = Cumulative ESALs from development activities for one direction of segment *i*
$Prod\_ESAL_i$ = Cumulative ESALs from production activities for one direction of segment *i*
$Refrc\_ESAL_i$ = Cumulative ESALs from re-fracking activities for one direction of segment *i*.

Table 3. ESALs per Truck Type in the Eagle Ford Shale Region.

Well Development Activity	Truck Type	ESALs per Truck (Trip to Well)	ESALs per Truck (Trip from Well)
Drilling pad and construction equipment	5-axle dump	1.177	0.092
Drilling rig	5-axle rig	8.676	8.676
Drilling fluid and materials	5-axle water	1.412	0.092
Drilling equipment: casing, drilling pipe	5-axle flatbed	1.709	0.066
Fracking equipment: pump trucks, tanks	5-axle equipment	2.606	2.606
Fracking water (steel tank)	5-axle water	1.412	0.092
Fracking water (aluminum tank)	5-axle water	1.412	0.023
Fracking sand (steel tank)	5-axle water	1.876	0.092
Fracking sand (aluminum tank)	5-axle sand	1.876	0.023
Other additives and fluids	5-axle sand	1.412	0.092
Flowback water removal	5-axle sand	0.092	1.412

Well Production Activity (per year)	Truck Type	ESALs per Truck (Trip to Well)	ESALs per Truck (Trip from Well)
Produced water (steel tank)	5-axle water	0.092	1.412
Produced water (aluminum tank)	5-axle water	0.023	1.412
Oil and condensate production (steel tank)	5-axle water	0.092	1.412
Oil and condensate production (aluminum tank)	5-axle water	0.023	1.412

Well Re-Fracking Activity (per event)	Truck Type	ESALs per Truck (Trip to Well)	ESALs per Truck (Trip from Well)
Fracking equipment: pump trucks, tanks	5-axle equipment	2.606	2.606
Fracking water (steel tank)	5-axle water	1.412	0.092
Fracking water (aluminum tank)	5-axle water	1.412	0.023
Fracking sand (steel tank)	5-axle sand	1.876	0.092
Fracking sand (aluminum tank)	5-axle sand	1.876	0.023
Other additives and fluids	5-axle water	1.412	0.092
Flowback water removal	5-axle water	0.092	1.412

Results

The first set of runs involved determining ESAL values due to the development and operation of one well over 20 years. Because the number of ESALs depends on the direction of travel (to the well or away from the well), the researchers prepared three sets of results for each roadway segment: ESALs for trips to the well, ESALs for trips from the well, and higher directional ESALs (i.e., the higher ESAL value between the two directions of travel). Figure 3 shows the total number of ESALs for trips to the well, Figure 4 shows the total number of ESALs for trips from the well, and Figure 5 shows higher directional ESALs. As expected, roadway segments near the well had a much higher number of ESALs than segments farther away from the well. In the immediate vicinity of the well, the total number of ESALs was 10,757 for trips to the well and 15,059 for trips from the well. The total number of ESALs decreased as the roadway segments were farther away from the well.

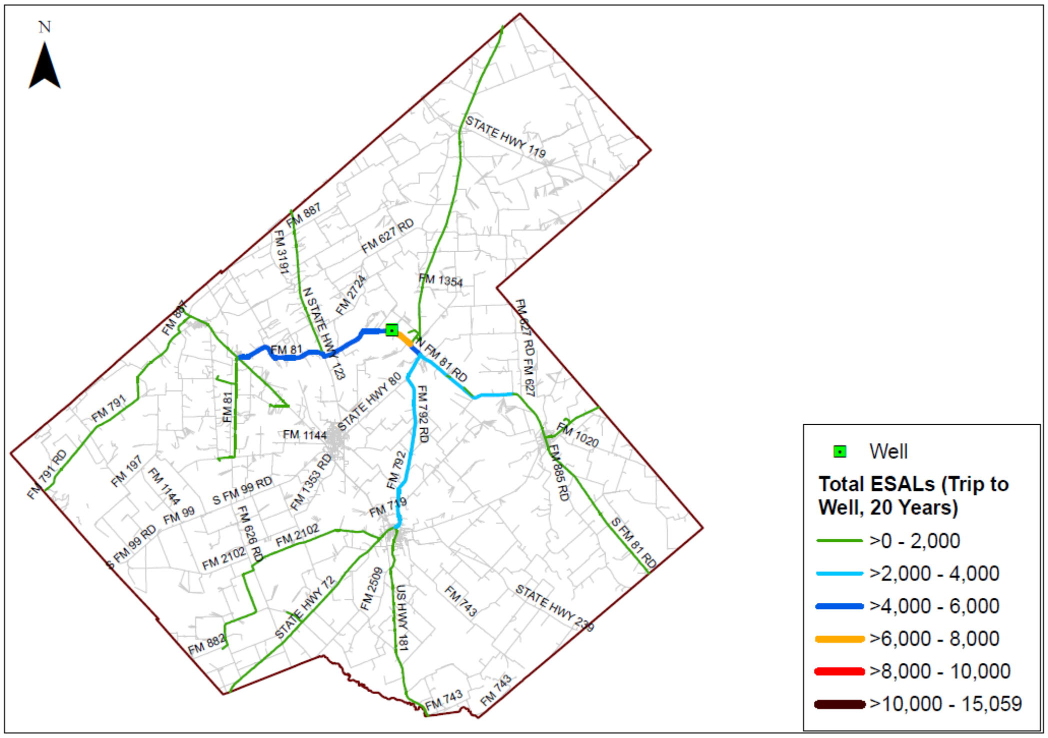

Figure 3. Total Number of ESALs (Trips *to* the Well) – One Well.

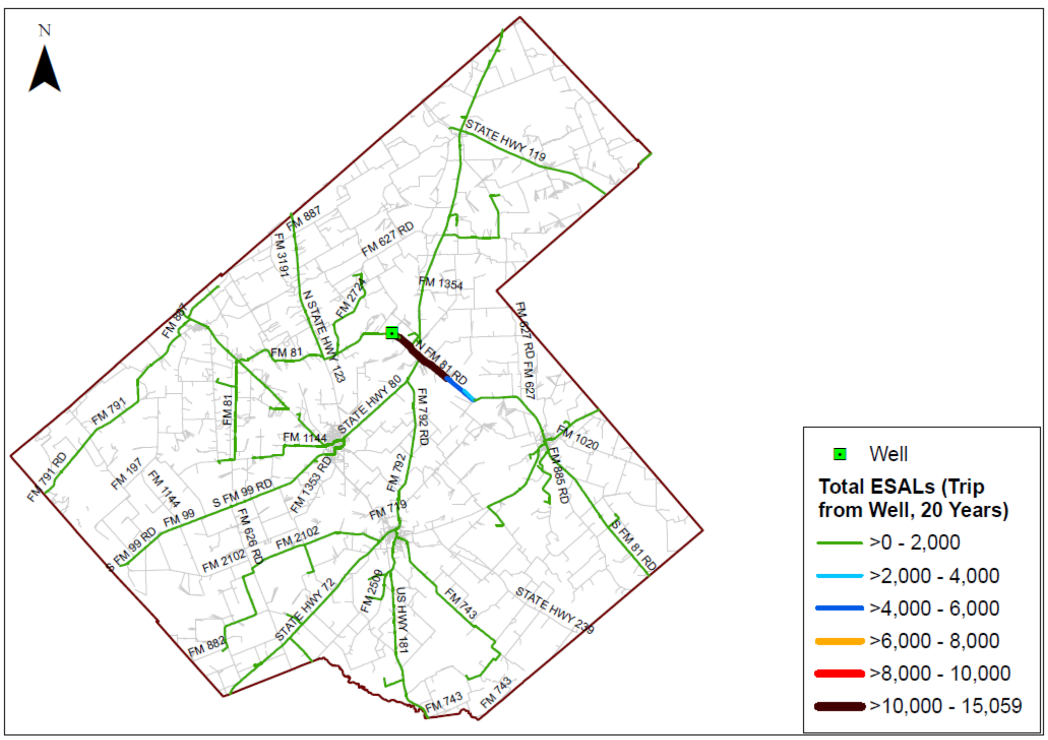

Figure 4. Total Number of ESALs (Trips *from* the Well) – One Well.

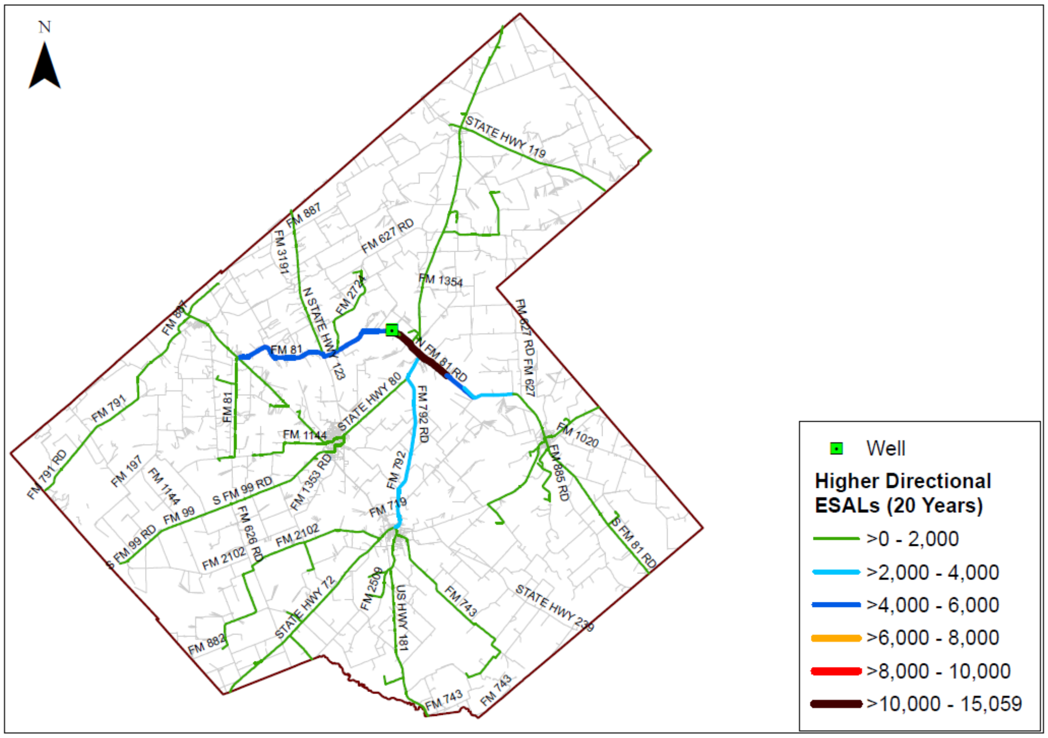

Figure 5. Total Number of ESALs (Higher Directional ESALs) – One Well.

Notice in Figure 4 that FM 81 southeast of the well would be expected to have over 10,000 ESALs for trips from the well during the 20-year analysis period. Part of the reason is the location of two crude oil truck off-load terminals on FM 81 approximately four miles southeast of the well.

The second set of runs involved increasing the numbers of wells. The following scenarios were completed: 10 wells, 100 wells, 200 wells, and 493 wells (i.e., the same number of wells completed in 2013). The 10-well, 100-well, and 200-well scenarios involved a random selection of wells from the total population of 493 wells completed in 2013.

Figure 6 through Figure 9 show the spatial distribution of higher directional ESALs for the four scenarios analyzed. The figures clearly show that the number and extent of roadway segments affected increase as the number of wells increases and their location is more widely spread out throughout Karnes County. FM 81 southeast of SH 80 had the highest number of ESALs. In the 493-well scenario (Figure 9), the number of directional ESALs on FM 81 southeast of SH 80 was higher than 4.4 million.

Table 4 provides a summary of the number of miles involved for each scenario and ESAL interval, as well as the corresponding percentage with respect to the total number of network miles. For example, for the 100-well scenario, approximately 37 miles (or 11% of the on-system network) would have 250,000-500,000 ESALs over 20 years. By comparison, for the 493-well scenario, approximately 67 miles (or 20% of the on-system network) would have 250,000-500,000 ESALs over 20 years.

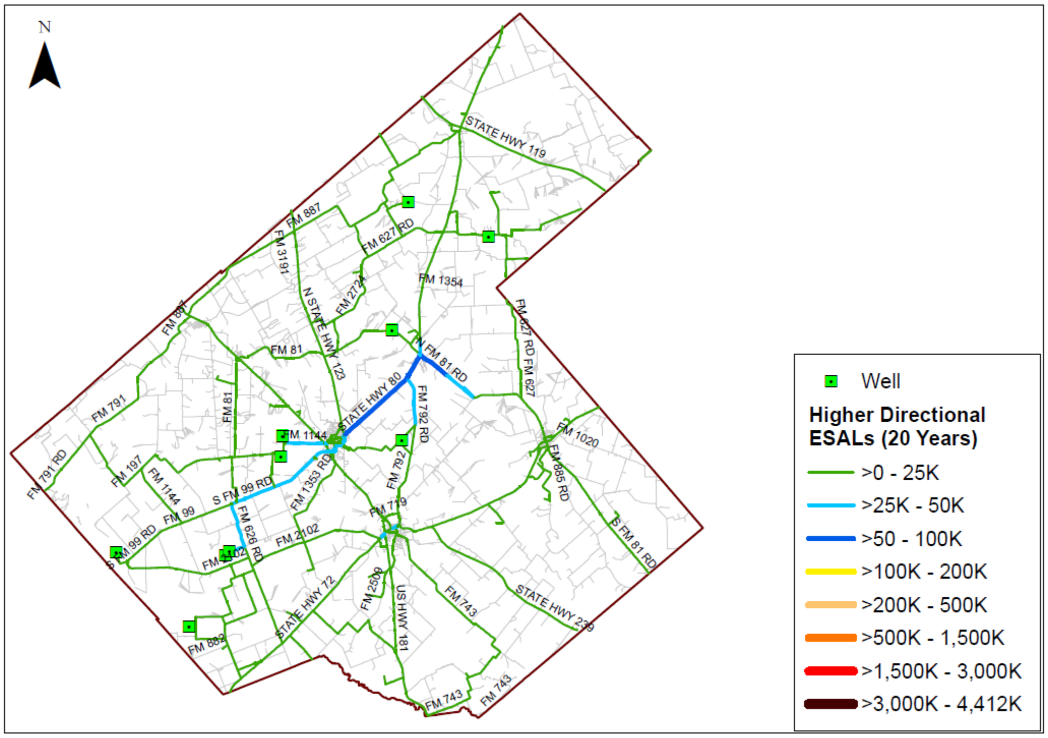

Figure 6. Total Number of ESALs (Higher Directional ESALs) – 10 Wells.

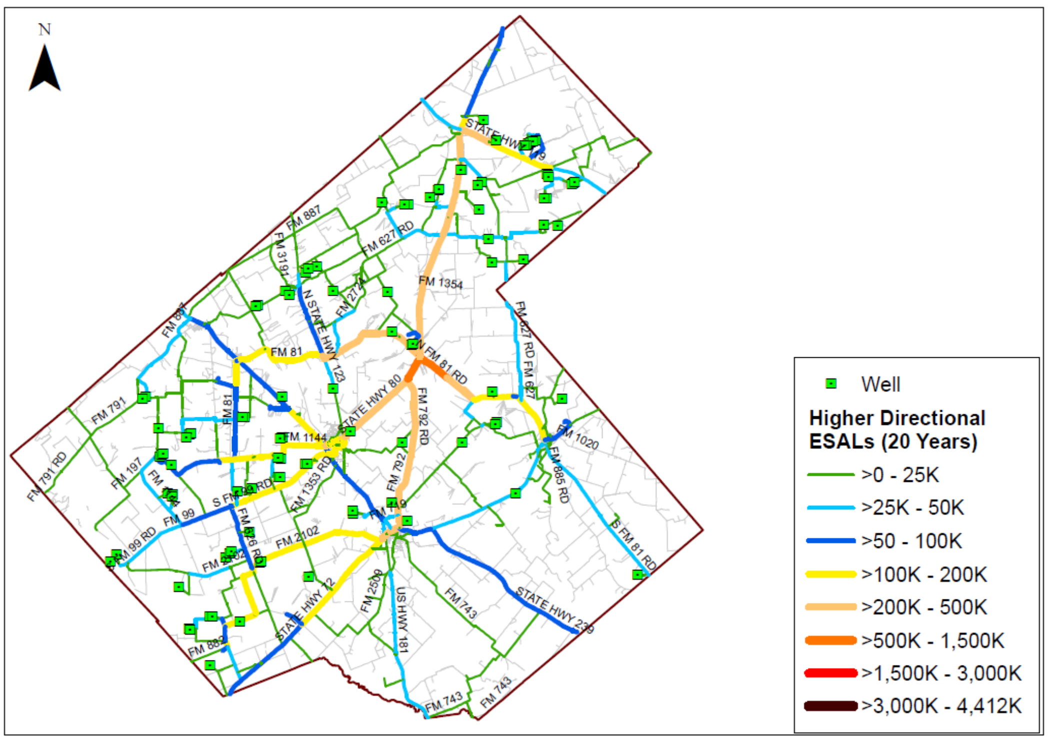

Figure 7. Total Number of ESALs (Higher Directional ESALs) – 100 Wells.

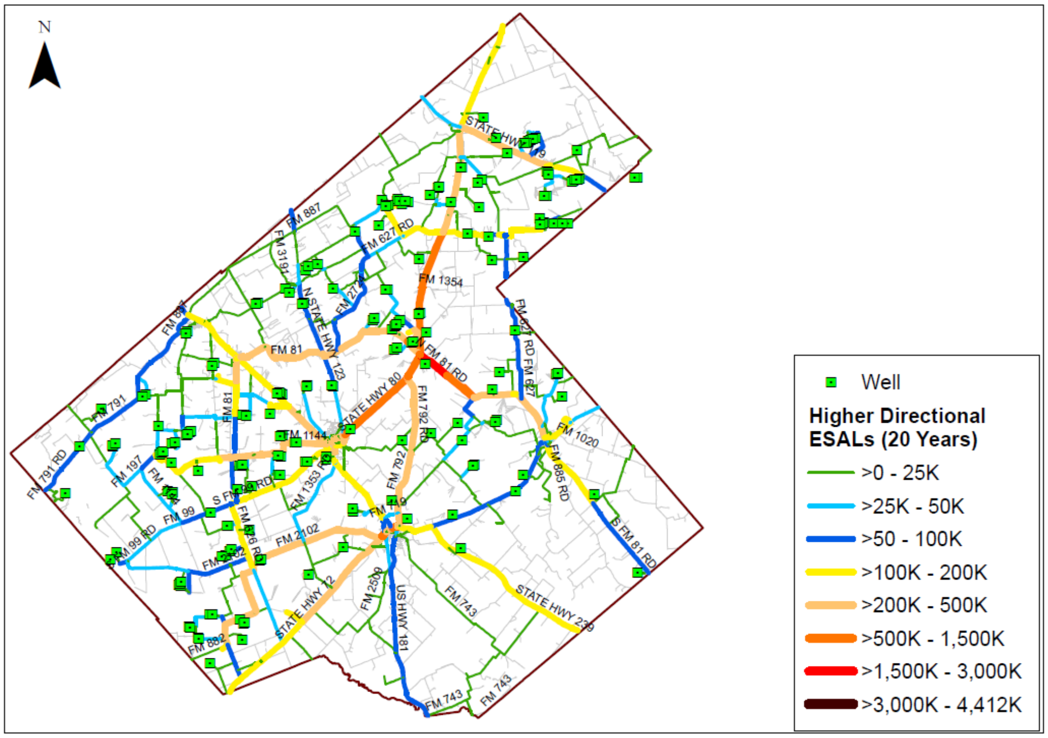

Figure 8. Total Number of ESALs (Higher Directional ESALs) – 200 Wells.

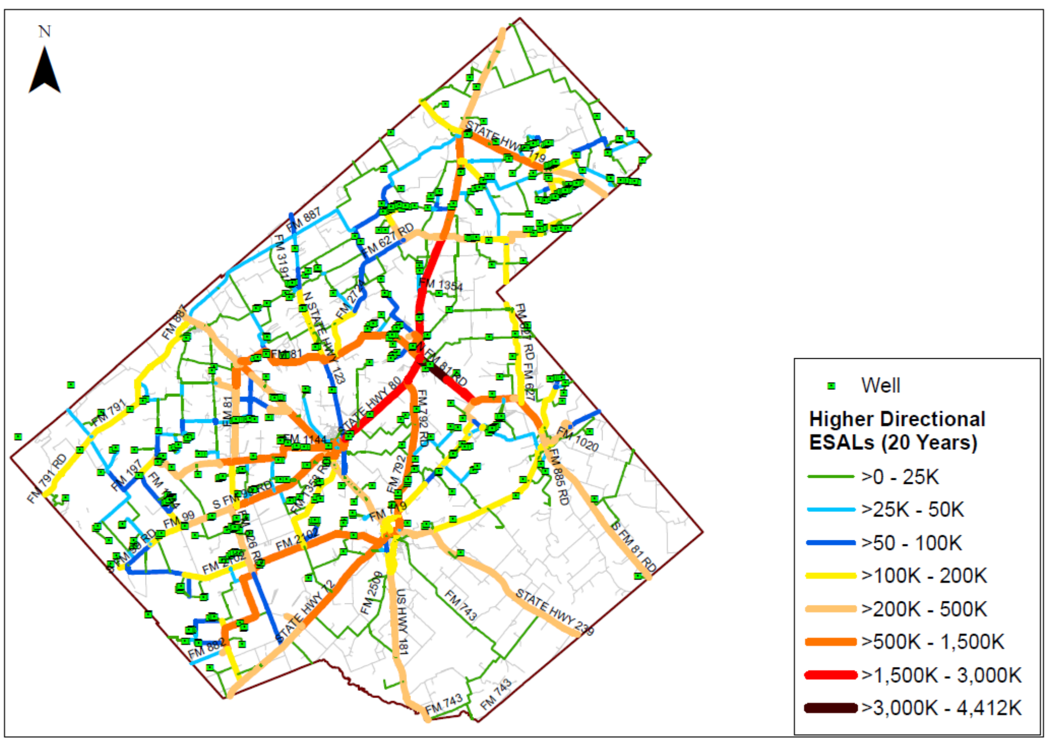

Figure 9. Total Number of ESALs (Higher Directional ESALs) – 493 Wells.

Table 4. Miles of On-System and Off-System Roads Used to Develop and Operate Wells.

Higher Direction ESALs (20 Years)	1 Well				10 Wells			
	On-System Roads Used		Off-System Roads Used		On-System Roads Used		Off-System Roads Used	
	Miles	Percent*	Miles	Percent**	Miles	Percent	Miles	Percent
>0 – 25,000	198	59%	31	2%	274	81%	88	7%
>25,000 – 50,000	-	-	-	-	18	5%	3	0.2%
>50,000 – 100,000	-	-	-	-	8	2%	-	-
>100,000 – 200,000	-	-	-	-	-	-	-	-
>200,000 – 500,000	-	-	-	-	-	-	-	-
>500,000 – 1,500,000	-	-	-	-	-	-	-	-
>1,500,000 – 3,000,000	-	-	-	-	-	-	-	-
>3,000,000 – 4,412,000	-	-	-	-	-	-	-	-
Total	**198**	**59%**	**31**	**2%**	**300**	**88%**	**91**	**7%**

Higher Direction ESALs (20 Years)	100 Wells				200 Wells			
	On-System Roads Used		Off-System Roads Used		On-System Roads Used		Off-System Roads Used	
	Miles	Percent*	Miles	Percent**	Miles	Percent	Miles	Percent
>0 – 25,000	104	31%	215	17%	61	18%	260	21%
>25,000 – 50,000	71	21%	26	2%	38	11%	45	4%
>50,000 – 100,000	54	16%	11	0.8%	75	22%	12	1%
>100,000 – 200,000	51	15%	3	0.2%	63	19%	14	1%
>200,000 – 500,000	37	11%	1	0.1%	67	20%	2	0.2%
>500,000 – 1,500,000	3	0.9%	-	-	16	5%	1	0.1%
>1,500,000 – 3,000,000	-	-	-	-	2	0.6%	-	-
>3,000,000 – 4,412,000	-	-	-	-	-	-	-	-
Total	**320**	**95%**	**255**	**21%**	**321**	**95%**	**333**	**27%**

Higher Direction ESALs (20 Years)	493 Wells			
	On-System Roads Used		Off-System Roads Used	
	Miles	Percent	Miles	Percent
>0 – 25,000	61	18%	260	21%
>25,000 – 50,000	38	11%	45	4%
>50,000 – 100,000	75	22%	12	1%
>100,000 – 200,000	63	19%	14	1%
>200,000 – 500,000	67	20%	2	0.2%
>500,000 – 1,500,000	16	5%	1	0.1%
>1,500,000 – 3,000,000	2	0.6%	-	-
>3,000,000 – 4,412,000	-	-	-	-
Total	**321**	**95%**	**333**	**27%**

* Percentage of the total of 337 miles of on-system roads in Karnes County.
** Percentage of the total of 1,243 miles of off-system roads in Karnes County.

For comparison purposes, Figure 10 shows the spatial distribution of ESALs listed in the TxDOT Road-Highway Inventory Network (RHiNo) database. Of particular interest are corridors where the cumulative ESALs in Figure 9 are higher than the corresponding ESALs listed in the RHiNo database. Examples include FM 81, SH 80 south of FM 627, FM 1144, FM 1353, and FM 2102.

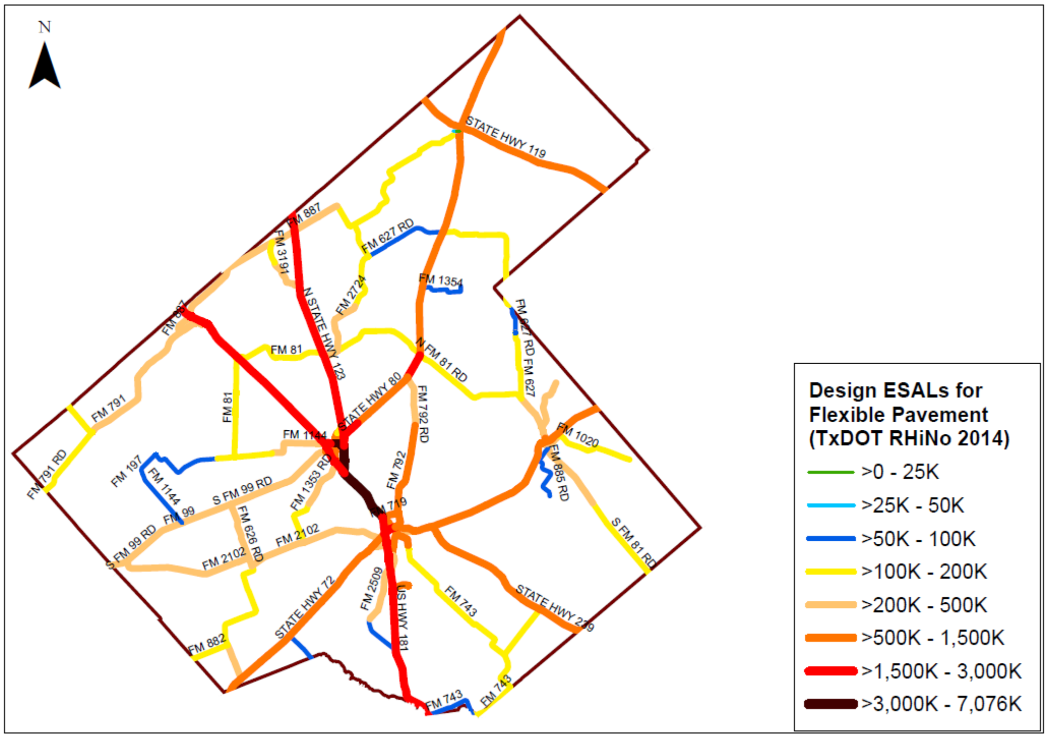

Figure 10. ESALs According to the TxDOT RHiNo Database.

APPLICABILITY OF THE METHODOLOGY

The methodology described in this report enables users to map truck traffic in connection with energy developments to the surface transportation network in the state. Examples of potential applications of the methodology include, but are not limited to, the following:

- Forecast the spatial distribution of ESALs due to the development and operation of any number of wells over a specified analysis period. For wells that are in the development stage, analysis can be conducted to evaluate the future impact due to well development, operation, and re-fracking on the transportation network. For wells that are in production, the analysis can focus on future impact due to well production and re-fracking activities

- Forecast the spatial-temporal distribution of ESALs due to the development and operation of any number of wells. For example, it may be of interest to determine how the spatial distribution of ESALs evolves over time during the development, production, and re-fracking phases of multiple wells. The methodology enables users to forecast spatial-temporal distributions of ESALs by aggregating ESALs associated with each well during the analysis period.

- Evaluate alternative scenarios by conducting sensitivity analyses. One potential application could be to evaluate the reduction in truck traffic impact on the transportation network resulting from various temporary water pipe implementations.

- Forecast the spatial distribution of ESALs in urban areas due to well developments that take place in rural areas. One potential application could be to determine the need and feasibility of alternative truck routes. As an illustration, Figure 11 provides a zoomed-in view of Figure 9 around Karnes City. With all 493 wells developed throughout the county, there would be a substantial amount of truck traffic with city limits. The results of the simulation could shed some light as to expected truck volumes and traffic patterns, which could be used to determine whether (and when) alternative truck routes may be warranted.

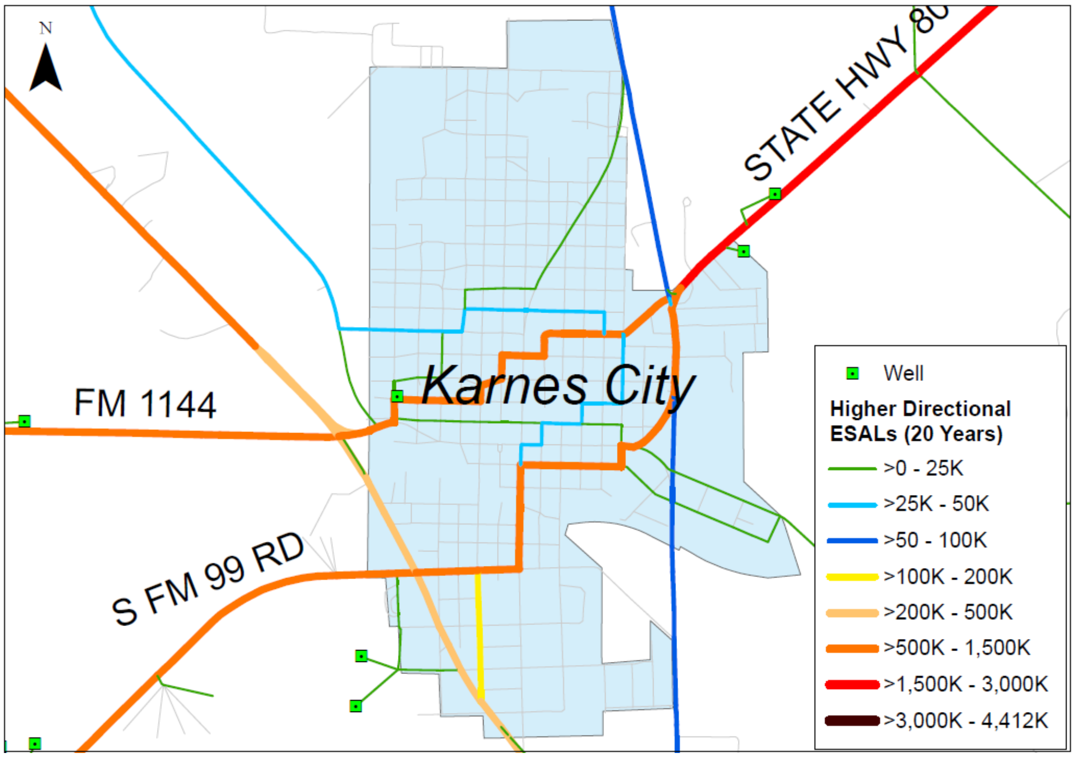

Figure 11.. ESAL Distributions in Karnes City Due to 493 Wells in Karnes County.

Anticipated enhancements of the methodology include the following:

- The methodology did not take into account economies of scale that operators implement when developing multiple wells within a short period, which would result in a lower number of trucks per well. Future enhancements would enable a variety of logistical assumptions, e.g., by combining trips involving multiple wells for a number of development or production activities. These wells could be located either on the same pad or on different pads.

- The methodology assumed that the water and sand needed for fracking operations were uniform throughout the region. Through a separate initiative, TTI researchers are currently conducting an analysis to determine spatial and temporal variations in the amount of water and sand used. These results could be used to fine tune the estimates, which could have an impact on trip modeling results.

- The methodology did not consider non-truck trips needed to develop and operate oil and gas wells because these trips would likely result in a very small number of ESALs. Future refinements could include non-truck trips for applications such as emergency response and congestion management.