

Report No. K-TRAN: KU-03-7  
FINAL REPORT

## **COLLECTION OF EMPIRICAL DATA FOR ASSESSING 800MHz COVERAGE MODELS**

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### **K-TRAN**

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KANSAS STATE UNIVERSITY  
THE UNIVERSITY OF KANSAS

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| <b>16 Abstract</b><br><p>Wireless communications plays an important role in KDOT operations. Currently, decisions pertaining to KDOT's 800MHz radio system are made on the basis of coverage models that rely on antenna and terrain characteristics to model the coverage. While this technique is well accepted, its effectiveness could be significantly improved if empirical data were available to better calibrate and validate the models. The University of Kansas was asked to develop and execute a plan for collecting the needed empirical data to better calibrate and validate coverage models. Eight towers were selected by KDOT based on antenna and terrain characteristics to represent a cross section of KDOT's tower array. A passenger car was outfitted with an integrated system to record a received signal strength index (RSSI) value every time period. For each data point, the computer would record the most recent position fix from the GPS receiver (updated about once per second) and would poll the spectrum analyzer for an RSSI value. A route was planned for each tower to provide the best pattern of data point locations. Once the data was collected, it was imported into a geographic information system (GIS). Thematic maps of each tower were generated, showing the RSSI values in graduated colors indicating the strength of the signal. Linear interpolation was used to generate an RSSI surface plot for each tower. Over 6,500 miles were driven, collecting more than 33,000 RSSI values for the 8 towers considered in this effort. The resulting data provides a wealth of drive test data, useful for calibrating the ComStudy propagation model, and is sufficient to show the general size and shape of the coverage area for each tower. Surface plots generated by linearly interpolating the data over a geographic area show the coverage area and potential dead spots. By using this data to improve the existing propagation models, KDOT can obtain a more precise picture of the coverage of their radio system across the entire state, and as a result be able to use these and associated resources more efficiently and effectively.</p> |                                                                  |                                   |                                                                                                                                                                               |                                                                                       |  |
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# **COLLECTION OF EMPIRICAL DATA FOR ASSESSING 800MHz COVERAGE MODELS**

Final Report

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THE KANSAS DEPARTMENT OF TRANSPORTATION  
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## **PREFACE**

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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## **ABSTRACT**

Wireless communications plays an important role in KDOT operations. Currently, decisions pertaining to KDOT's 800MHz radio system are made on the basis of coverage models that rely on antenna and terrain characteristics to model the coverage. While this technique is well accepted, its effectiveness could be significantly improved if empirical data were available to better calibrate and validate the models.

The University of Kansas was asked to develop and execute a plan for collecting the needed empirical data to better calibrate and validate coverage models. Eight towers were selected by KDOT based on antenna and terrain characteristics to represent a cross section of KDOT's tower array. A passenger car was outfitted with an integrated system to record a received signal strength index (RSSI) value every time period. For each data point, the computer would record the most recent position fix from the GPS receiver (updated about once per second) and would poll the spectrum analyzer for an RSSI value. A route was planned for each tower to provide the best pattern of data point locations.

Once the data was collected, it was imported into a geographic information system (GIS). Thematic maps of each tower were generated, showing the RSSI values in graduated colors indicating the strength of the signal. Linear interpolation was used to generate an RSSI surface plot for each tower. Over 6,500 miles were driven, collecting more than 33,000 RSSI values for the eight towers considered in this effort.

The resulting data provides a wealth of drive test data, useful for calibrating the ComStudy propagation model, and is sufficient to show the general size and shape of the coverage area for each tower. Surface plots generated by linearly interpolating the data over a

geographic area show the coverage area and potential dead spots. By using this data to improve the existing propagation models, KDOT can obtain a more precise picture of the coverage of their radio system across the entire state, and as a result be able to use these and associated resources more efficiently and effectively.

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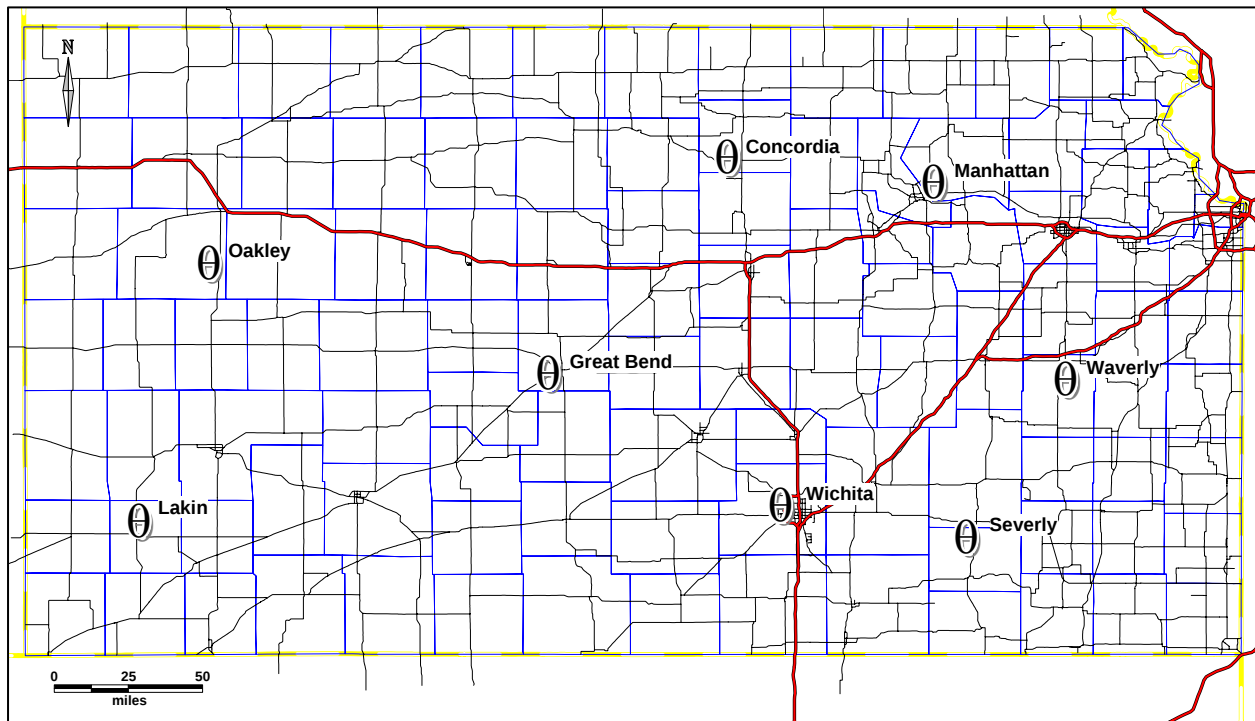
## **INTRODUCTION**

Wireless communications plays an important role in KDOT operations. Currently used primarily for voice communications, the importance of wireless systems will increase as more systems and devices are deployed that depend on wireless communications. For example, K-TRAN 01-05, "Development Plan for Automatic Vehicle Location (AVL) in Maintenance Vehicles," studied the use of wireless communications (both cellular and 800 MHz) for implementing a system for tracking the location of maintenance vehicles, monitoring material usage rates, and performing certain inventory functions such as tracking roadway striping.

In making decisions related to systems such as these, knowledge of the footprint of the wireless communications coverage is important. Currently, decisions pertaining to KDOT's 800MHz radio system are made on the basis of coverage models that rely on antenna and terrain characteristics to model the coverage. While this technique is well accepted, its effectiveness could be significantly improved if empirical data were available to better calibrate and validate the models. Toward that end, The University of Kansas was asked to develop and execute a plan for collecting the needed data.

## APPROACH

Eight towers were selected by KDOT based on antenna and terrain characteristics to represent a cross section of KDOT's tower array. Figure 1 shows the approximate location of the eight towers.

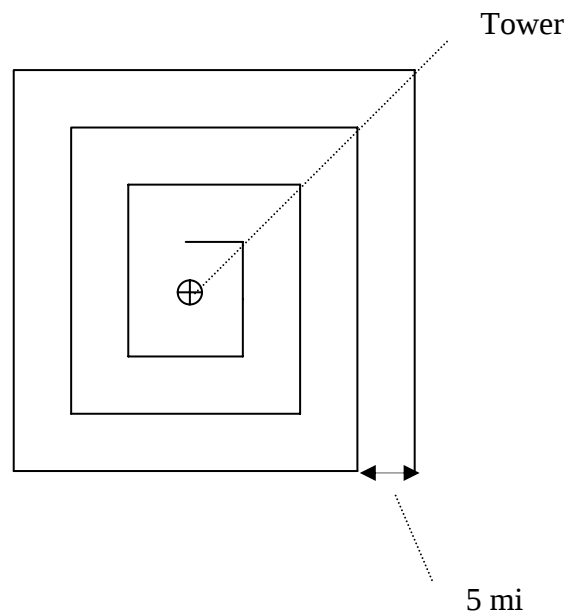


**Figure 1. Tower sites selected for data collection.**

A passenger car was outfitted with an integrated system to record a received signal strength index (RSSI) value every time period. The system included a ruggedized laptop computer mounted in the center of the front seat, a GPS receiver magnetically mounted to the roof of the vehicle and connected to the computer's serial (RS232) port, and a spectrum analyzer set in the center of the rear seat and connected to the computer's parallel port. The *Field Test 4* software package from Survey Technologies, Inc. (STI) was used to control the equipment and

collect the data. While the vehicle was moving, one data point was collected every 15 seconds. For each data point, the computer would record the most recent position fix from the GPS receiver (updated about once per second) and would poll the spectrum analyzer for an RSSI value.

A route was planned for each tower to provide the best pattern of data point locations while minimizing the route length. Route planning began by superimposing a square spiral over the tower sight and surrounding road network, as shown in Figure 2. A preliminary route was then chosen to approximate the spiral to the extent possible. Deviations were necessitated by terrain in some cases and were chosen to allow travel on better roads (reducing travel time) in other cases.



**Figure 2. Square spiral route.**

## Data Formats

The data output by Field Test 4 included the location at which the data was measured in geodetic coordinates and RSSI values for five different frequencies measured in decibels relative to 1 mv (dBm), as shown in Figure 3. Each tower was equipped with a transceiver tuned to one of the five frequencies. In Figure 3, the tower under study was tuned to 867.9125 MHz.

| Ndx                                                                                                                                                                | Lat         | Lon          | 866_1250 | 867_3625 | 867_9125 | 868_4250 | 868_6500 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|--------------|----------|----------|----------|----------|----------|
| 1                                                                                                                                                                  | 37.79716379 | -97.32727918 | -115.2   | -115.2   | -68.2    | -115.3   | -115.8   |
| 2                                                                                                                                                                  | 37.79699304 | -97.32749775 | -114.8   | -115.7   | -66.3    | -115.5   | -115.7   |
| 3                                                                                                                                                                  | 37.79674715 | -97.32661665 | -115.7   | -115.2   | -67.8    | -115.8   | -115.3   |
| 4                                                                                                                                                                  | 37.79671641 | -97.3263093  | -115.7   | -115.7   | -76.5    | -115.2   | -115.2   |
| 5                                                                                                                                                                  | 37.79604364 | -97.32627514 | -116.2   | -115.8   | -64.8    | -116.2   | -116.7   |
| 6                                                                                                                                                                  | 37.79604023 | -97.32627514 | -114.8   | -115.5   | -70.5    | -115.8   | -116.3   |
| 7                                                                                                                                                                  | 37.79595143 | -97.32764118 | -116.3   | -116.5   | -66.7    | -116     | -115.3   |
| ...                                                                                                                                                                |             |              |          |          |          |          |          |
| (Note: columns not used in processing have been omitted, including (as referenced in the data files) TOD, TmpLat, TmpLon, SystemID, Flags, Alt, NumSats, and dop.) |             |              |          |          |          |          |          |

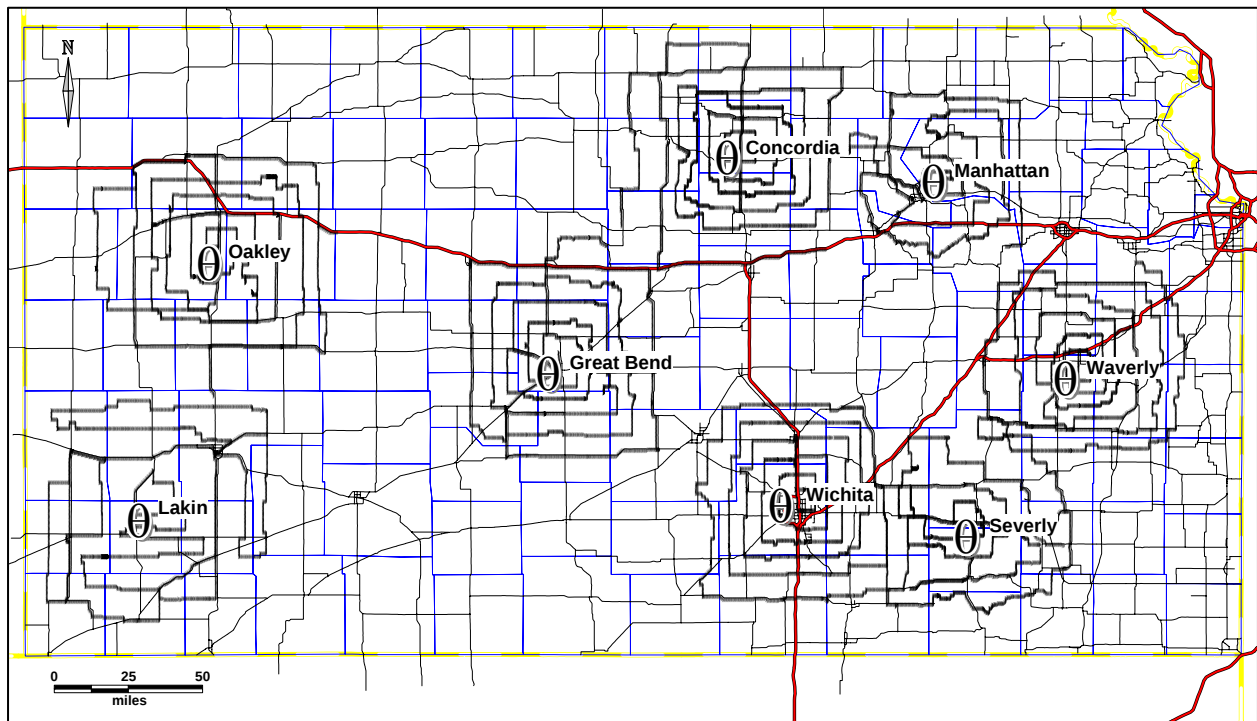
**Figure 3. Excerpt of Field Test 4 Ouput Data**

In order to use the data in the ComStudy propagation modeling software, the data must be converted to the specific format importable by ComStudy. A utility was developed (PreProcessDT.exe) to help facilitate the data conversion. Once the format of the data files output by the Survey Technologies software has been converted to the drive test data format required by ComStudy, they can be imported directly into ComStudy. Instructions for using PreProcessDT are provided in Appendix A.

## DATA SUMMARY

The goal was to obtain the most well-distributed data set that could be feasibly collected within the project constraints. Though deviations from the ideal route were necessary and further deviations had to be made in the field due to errors in the maps used for route planning, a well-distributed data set was obtained at each of the tower sights.

The extent of the data collection was to exceed the extent of the tower's coverage area. To accomplish this, the spiral was driven outward from the tower until signal strengths showed that the signal from the tower was sufficiently weak to indicate the edge of the coverage area. The actual routes driven can be seen in Figure 4, which is a plot of all data points recorded.



**Figure 4. Data points collected for all towers.**

Each tower required approximately one week for the data collection. Data was then reviewed for completeness, and additional data was collected where needed. Over the course of

the study, a total of 33,736 data points were collected, distributed amongst the sites as shown in Table 1.

The geodetic coordinates provided by the GPS receiver have an approximate accuracy of 30 ft<sup>1</sup>, based on typical characteristics of GPS data. The nature of the application did not require the application of differential corrections, and the equipment was not Wide Area Augmentation System (WAAS<sup>2</sup>) compatible.

**Table 1. Number of data points collected.**

| Site       | Data Points |
|------------|-------------|
| Concordia  | 5,124       |
| Great Bend | 4,411       |
| Lakin      | 3,741       |
| Manhattan  | 2,754       |
| Oakley     | 4,807       |
| Severy     | 4,072       |
| Waverly    | 4,212       |
| Wichita    | 4,615       |
| Total      | 33,736      |

The positional accuracy of the data was more than adequate for this application. For all tower sites, less than 1% of the data points used less than six satellites or showed a dilution of precision (DOP) greater than 4. The average DOP values were around 2.0, which suggests sufficient accuracy for this application. Satellite counts and DOP values are summarized by tower site in Table 2.

---

<sup>1</sup> I.e., the reported latitude and longitude are generally within 30 ft of the true latitude and longitude.

<sup>2</sup> The Wide Area Augmentation System (WAAS) is a product of the Federal Aviation Administration intended to improve GPS accuracy for aviation use. Certain GPS receivers can receive and apply WAAS corrections in real time. WAAS corrections are often categorized as differential corrections, though some argue that there are  
(continued on next page)

**Table 2. Satellite Count and DOP Characteristics by Tower Site**

| <b>NumSat</b>     | <b>Concordia</b> | <b>Great Bend</b> | <b>Lakin</b> | <b>Manhattan</b> | <b>Oakley</b> | <b>Severly</b> | <b>Waverly</b> | <b>Wichita</b> |
|-------------------|------------------|-------------------|--------------|------------------|---------------|----------------|----------------|----------------|
| <b>count</b>      | 5124             | 4411              | 3741         | 2754             | 4807          | 4072           | 4212           | 4615           |
| <b>avg</b>        | 7.8              | 7.5               | 7.8          | 7.9              | 7.7           | 7.8            | 7.7            | 7.7            |
| <b>x1</b>         | 4                | 4                 | 4            | 4                | 4             | 4              | 4              | 4              |
| <b>% &lt;= x1</b> | 0.1%             | 0.4%              | 0.0%         | 0.0%             | 0.9%          | 0.2%           | 0.1%           | 0.2%           |
| <b>x2</b>         | 6                | 6                 | 6            | 6                | 6             | 6              | 6              | 6              |
| <b>% &gt;= x2</b> | 99.9%            | 99.6%             | 100.0%       | 100.0%           | 99.1%         | 99.8%          | 99.9%          | 99.8%          |
|                   |                  |                   |              |                  |               |                |                |                |
| <b>dop</b>        | <b>Concordia</b> | <b>Great Bend</b> | <b>Lakin</b> | <b>Manhattan</b> | <b>Oakley</b> | <b>Severly</b> | <b>Waverly</b> | <b>Wichita</b> |
| <b>count</b>      | 5124             | 4411              | 3741         | 2754             | 4807          | 4072           | 4212           | 4615           |
| <b>avg</b>        | 2.1              | 2.2               | 2.1          | 2.2              | 2.0           | 2.2            | 2.1            | 2.0            |
| <b>x1</b>         | 2.5              | 2.5               | 2.5          | 2.5              | 2.5           | 2.5            | 2.5            | 2.5            |
| <b>% &lt;= x1</b> | 85.6%            | 81.0%             | 87.9%        | 79.2%            | 94.6%         | 82.7%          | 82.2%          | 91.3%          |
| <b>x2</b>         | 4                | 4                 | 4            | 4                | 4             | 4              | 4              | 4              |
| <b>% &gt;= x2</b> | 0.5%             | 0.2%              | 0.4%         | 0.5%             | 0.2%          | 0.3%           | 0.3%           | 0.2%           |

An average of about 800 miles were driven for each tower, not including miles driven from the home site (i.e., Lawrence, Kansas) to each tower site. For most sites, drivers stayed in local hotels to minimize the commute needed.

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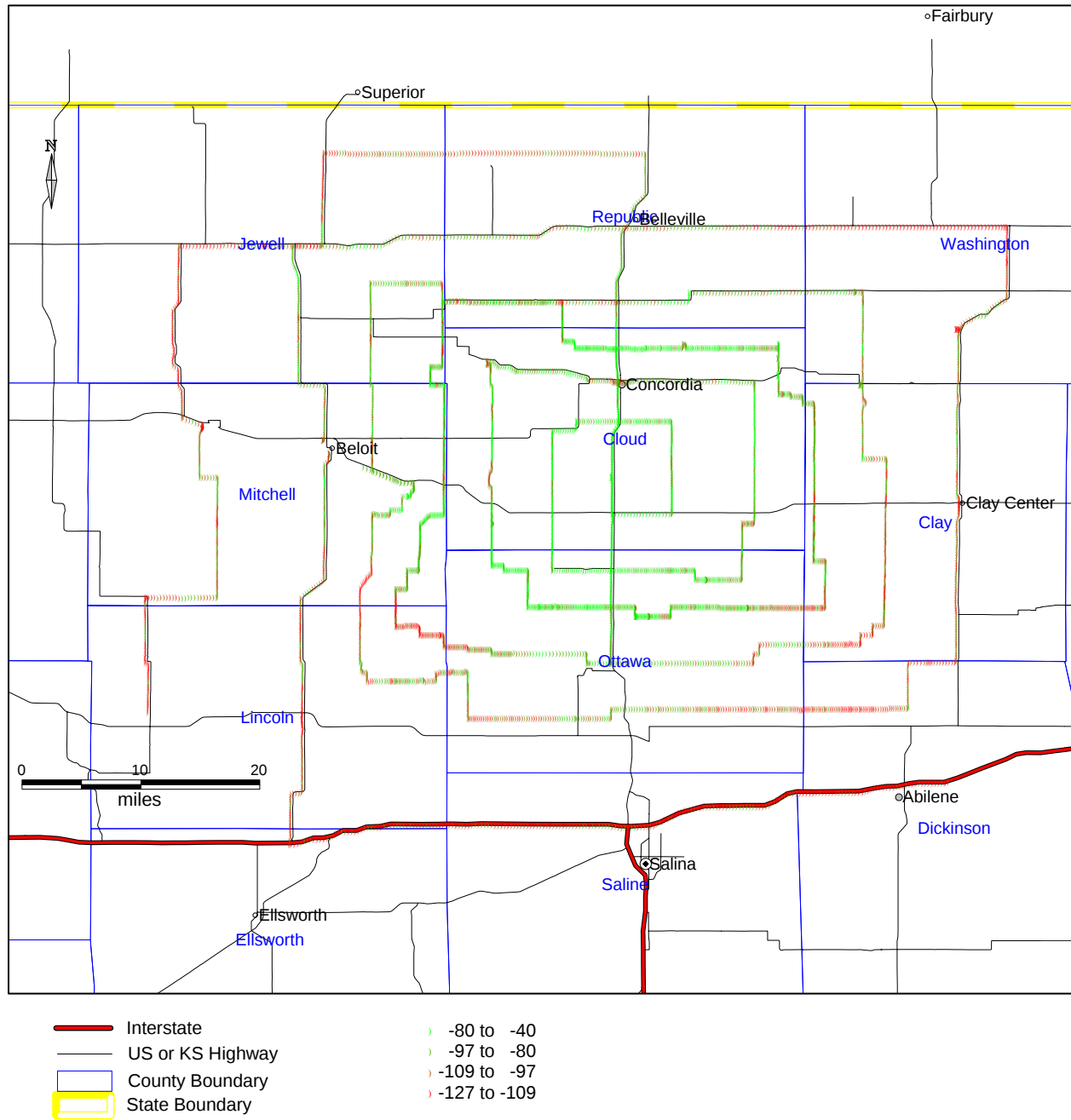
technical distinctions between the two.

## **DATA ANALYSIS**

Once the data was collected, it was imported into a geographic information system (GIS). Thematic maps of each tower were generated, showing the RSSI values in graduated colors indicating the strength of the signal. Red is used to indicate low RSSI values and green is used to indicate high RSSI values. Colors between red and green are used to indicate moderately low and moderately high values.

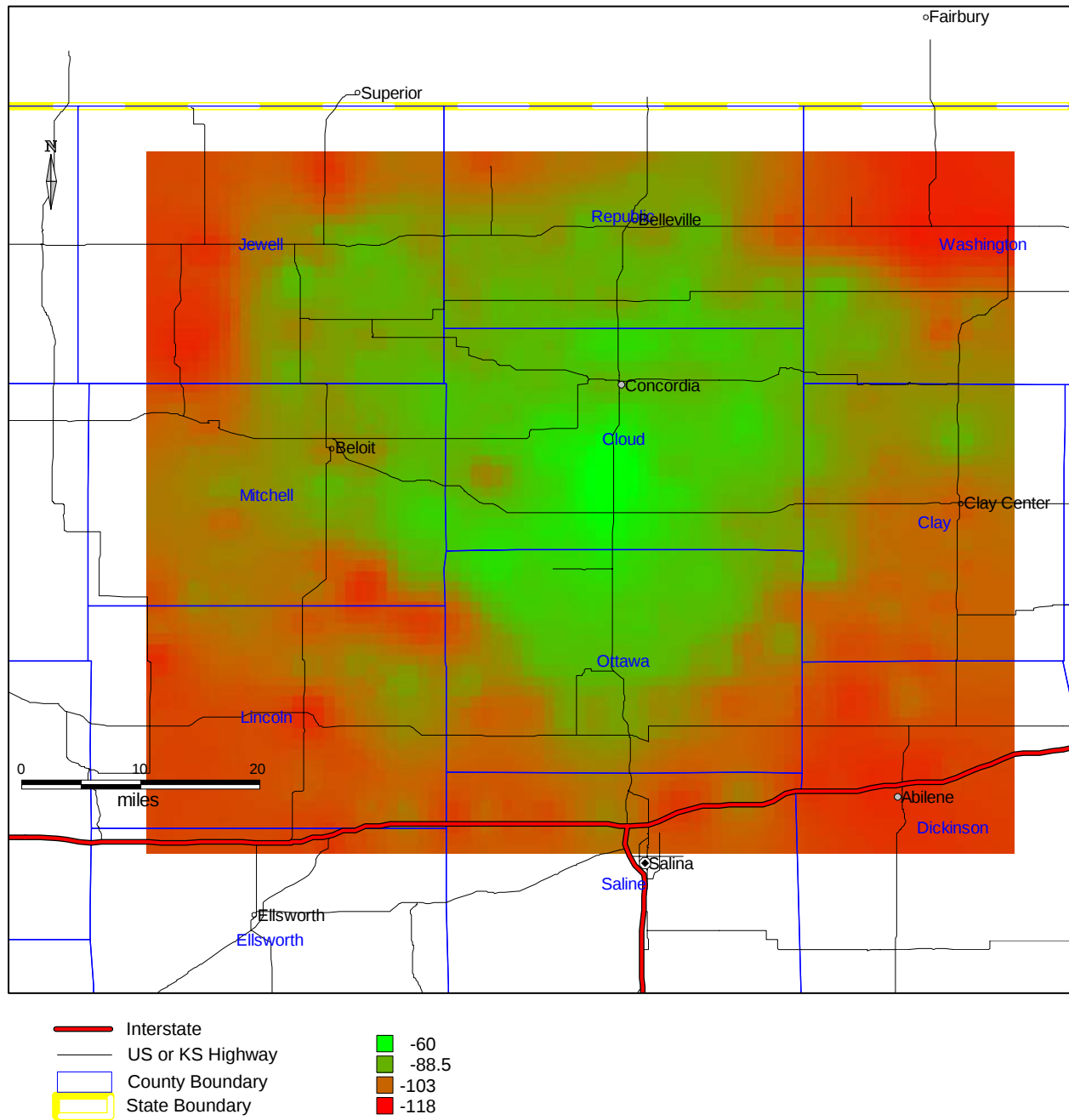
Linear interpolation was used to generate an RSSI surface plot for each tower. The color scheme used to illustrate the surfaces is identical to that used in the data plots mentioned above. Figure 5 through Figure 20 show the data plots and surface plots by tower site. It should be noted that the legends for the surface plots show the midpoint value for each range whereas the legends for the data point plots show the high and low values for each range. It should also be noted that these colors are optimized for color output, and coverage areas may not be clearly defined in grayscale printouts.

# Concordia

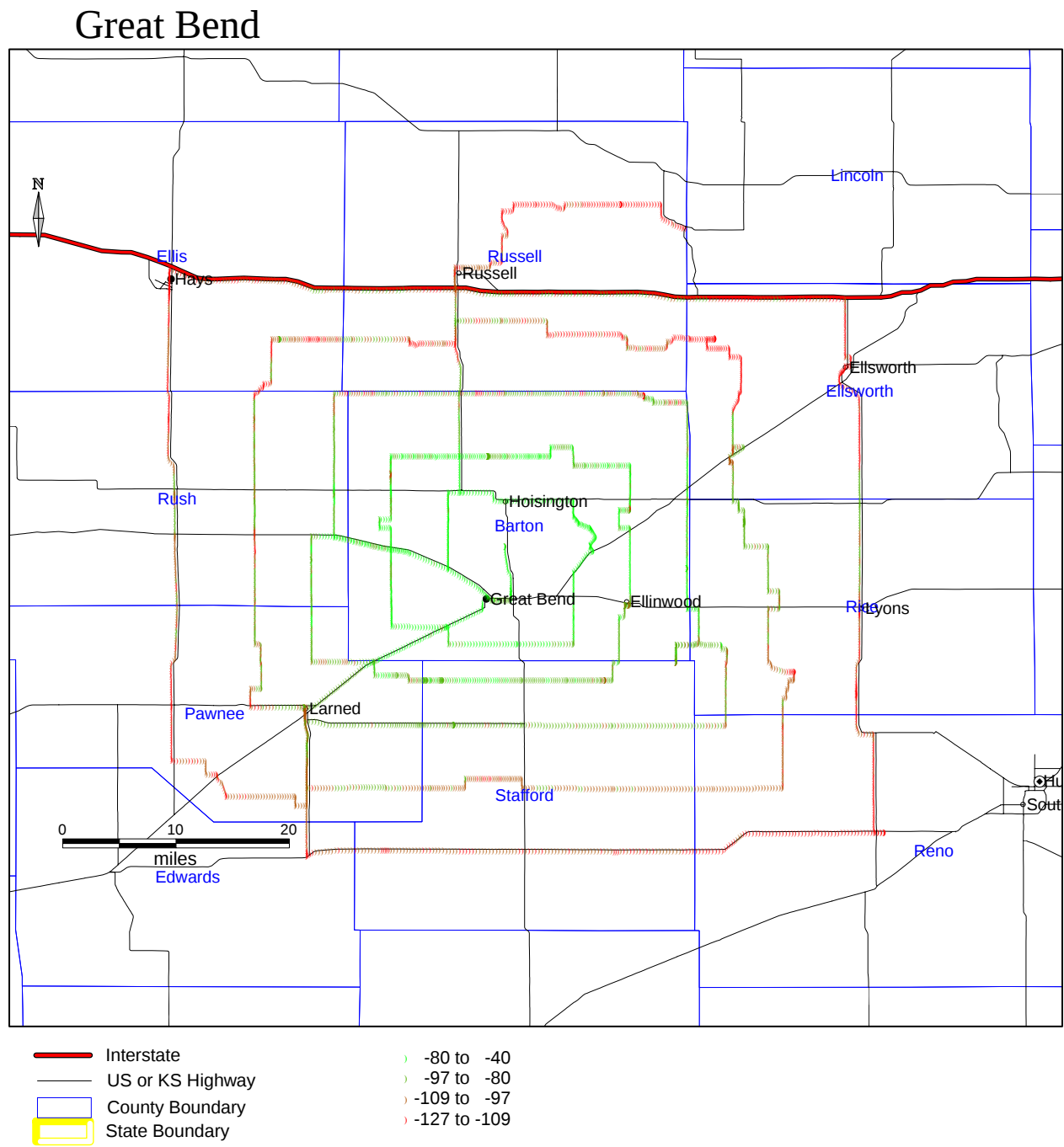


**Figure 5. RSSI Values for Concordia.**

# Concordia

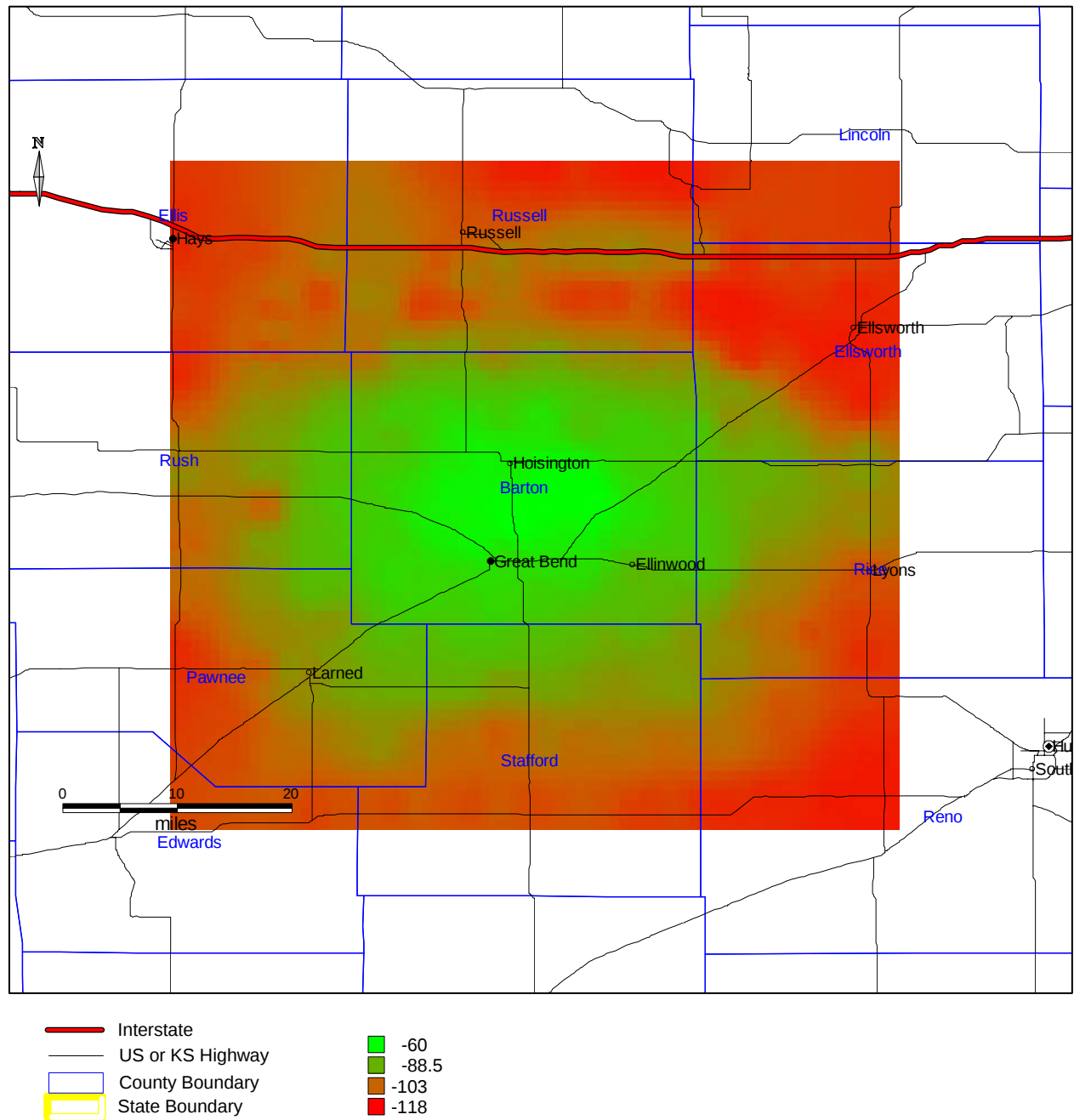


**Figure 6. Interpolated RSSI Values for Concordia.**

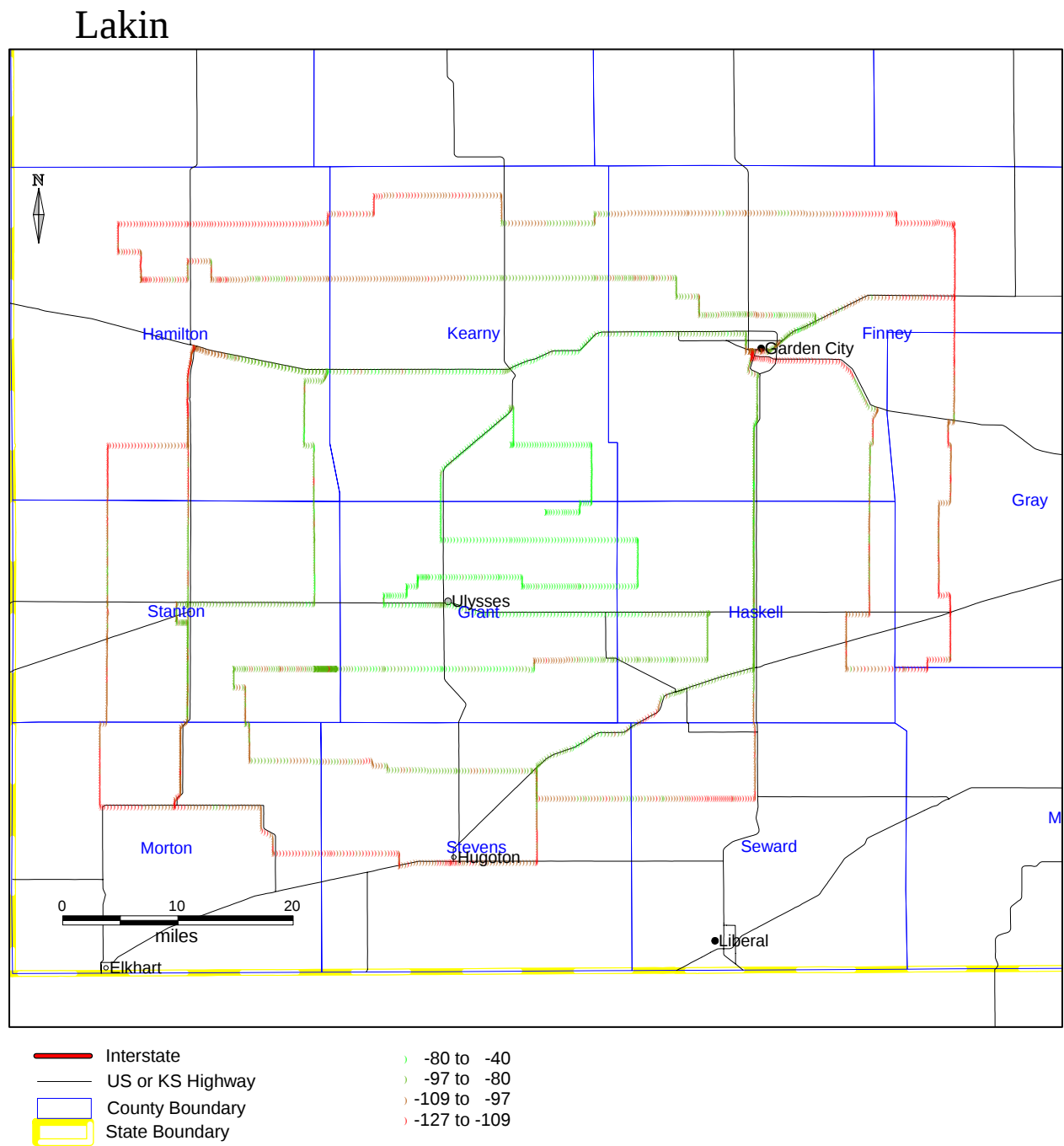


**Figure 7. RSSI Values for Great Bend.**

# Great Bend

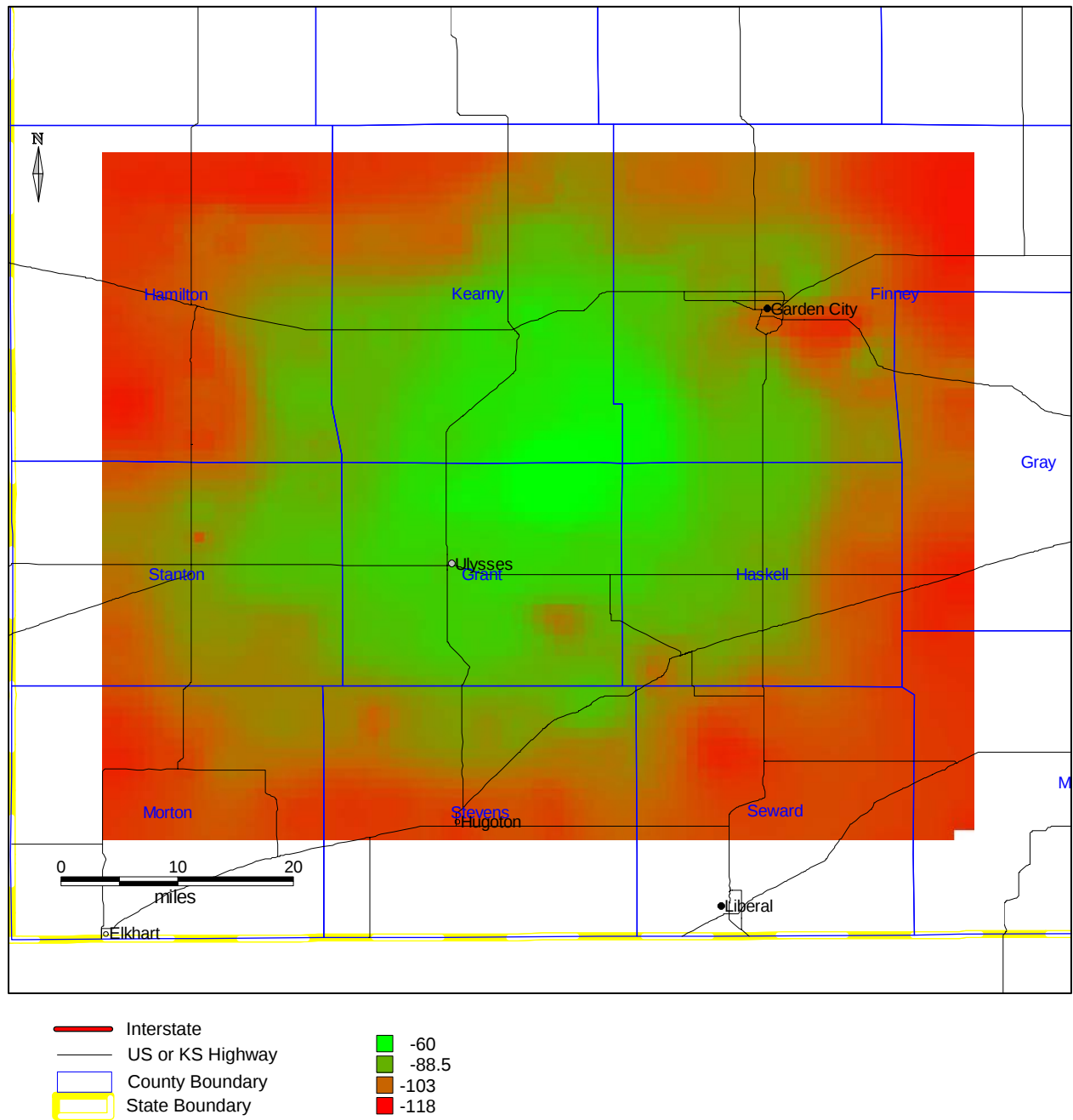


**Figure 8. Interpolated RSSI Values for Great Bend.**

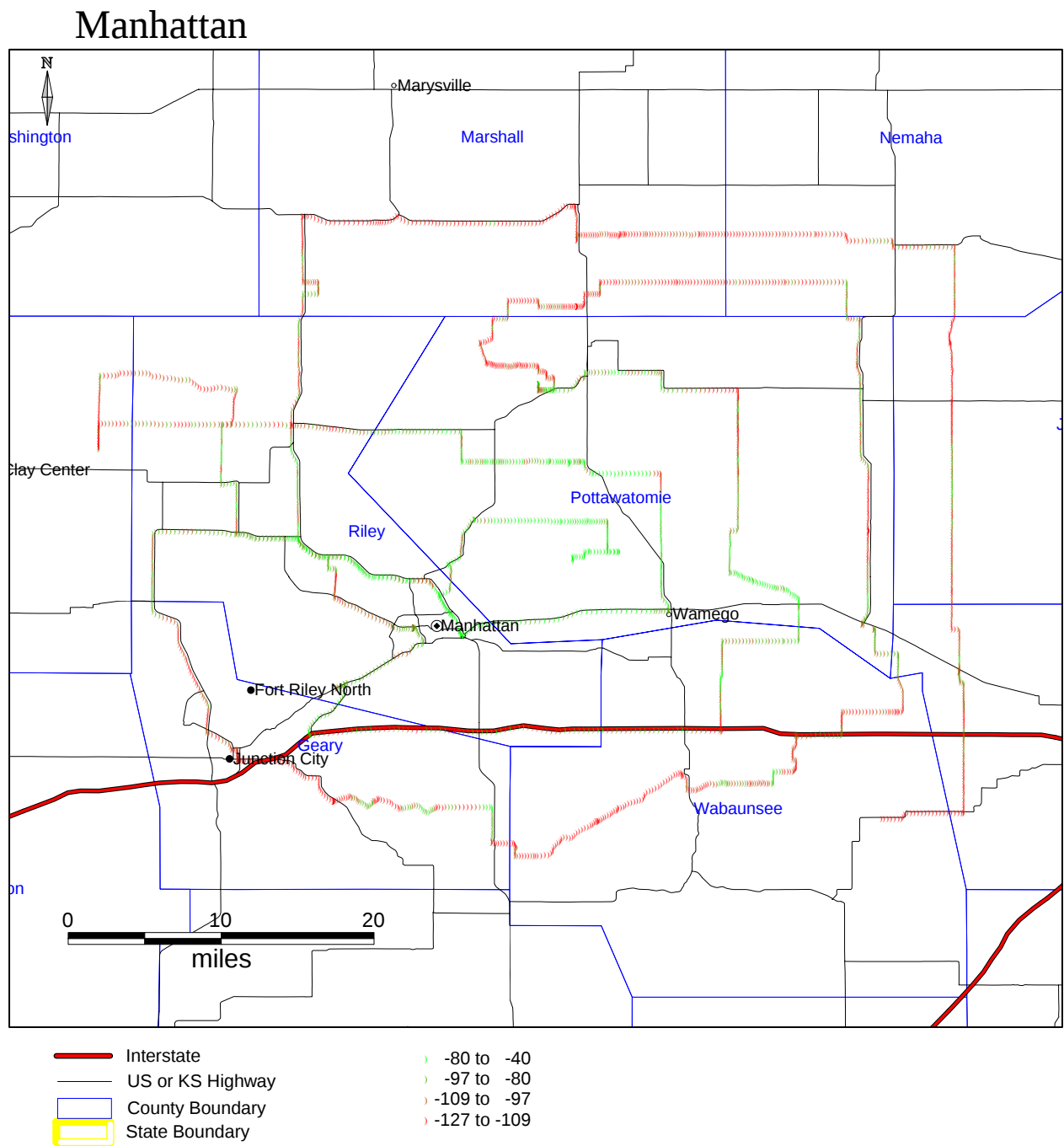


**Figure 9. RSSI Values for Lakin.**

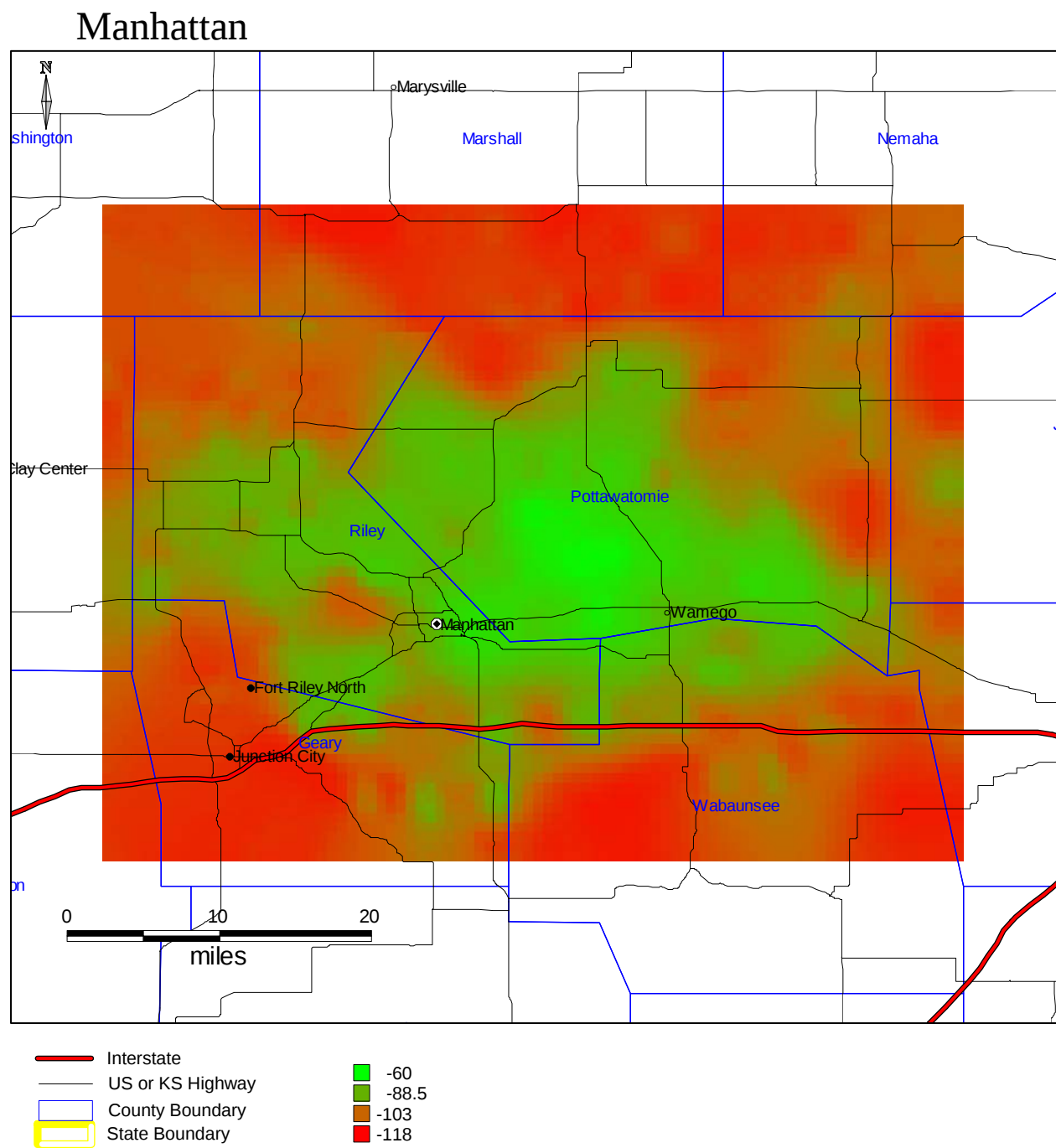
# Lakin



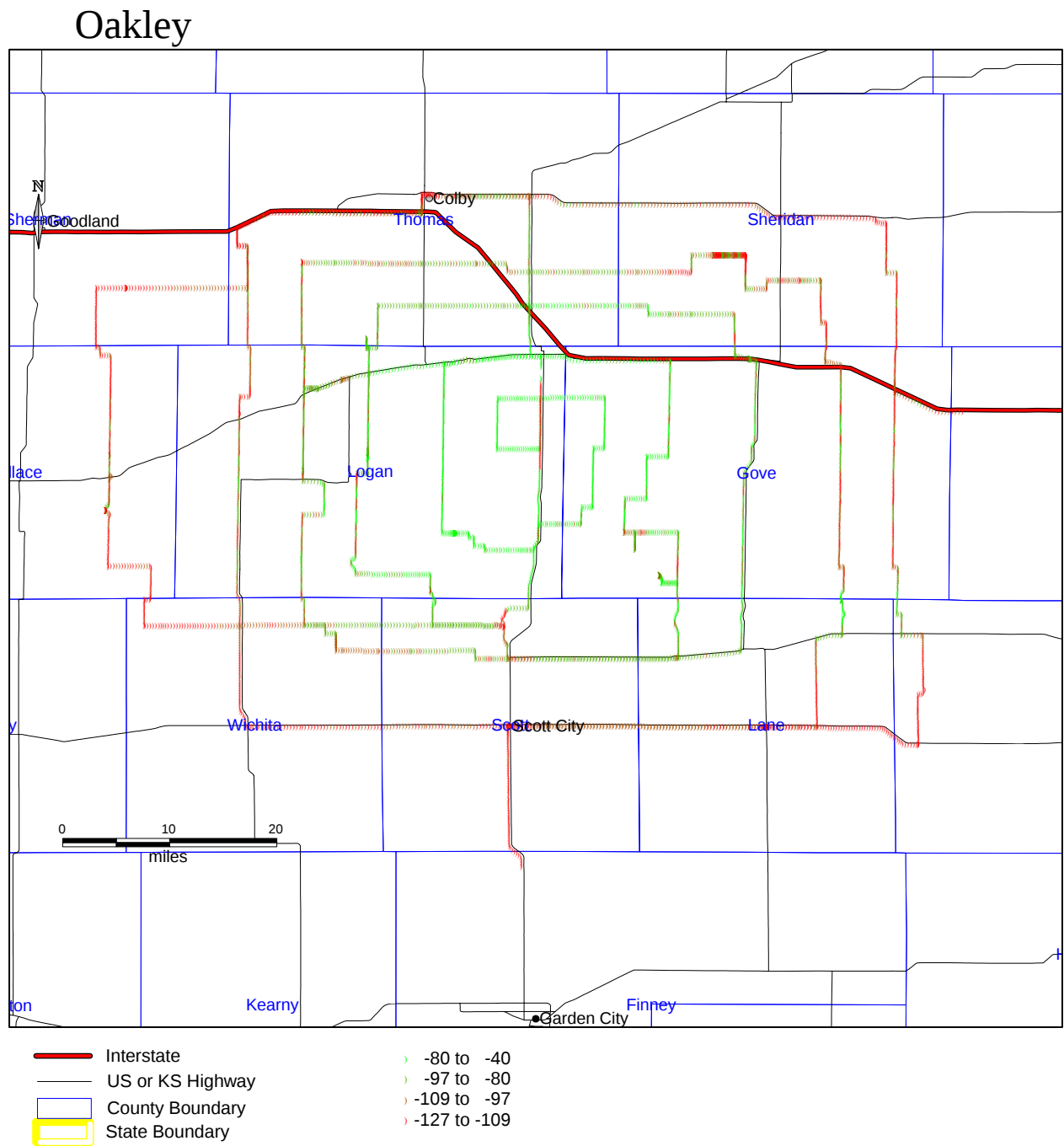
**Figure 10. Interpolated RSSI Values for Lakin.**



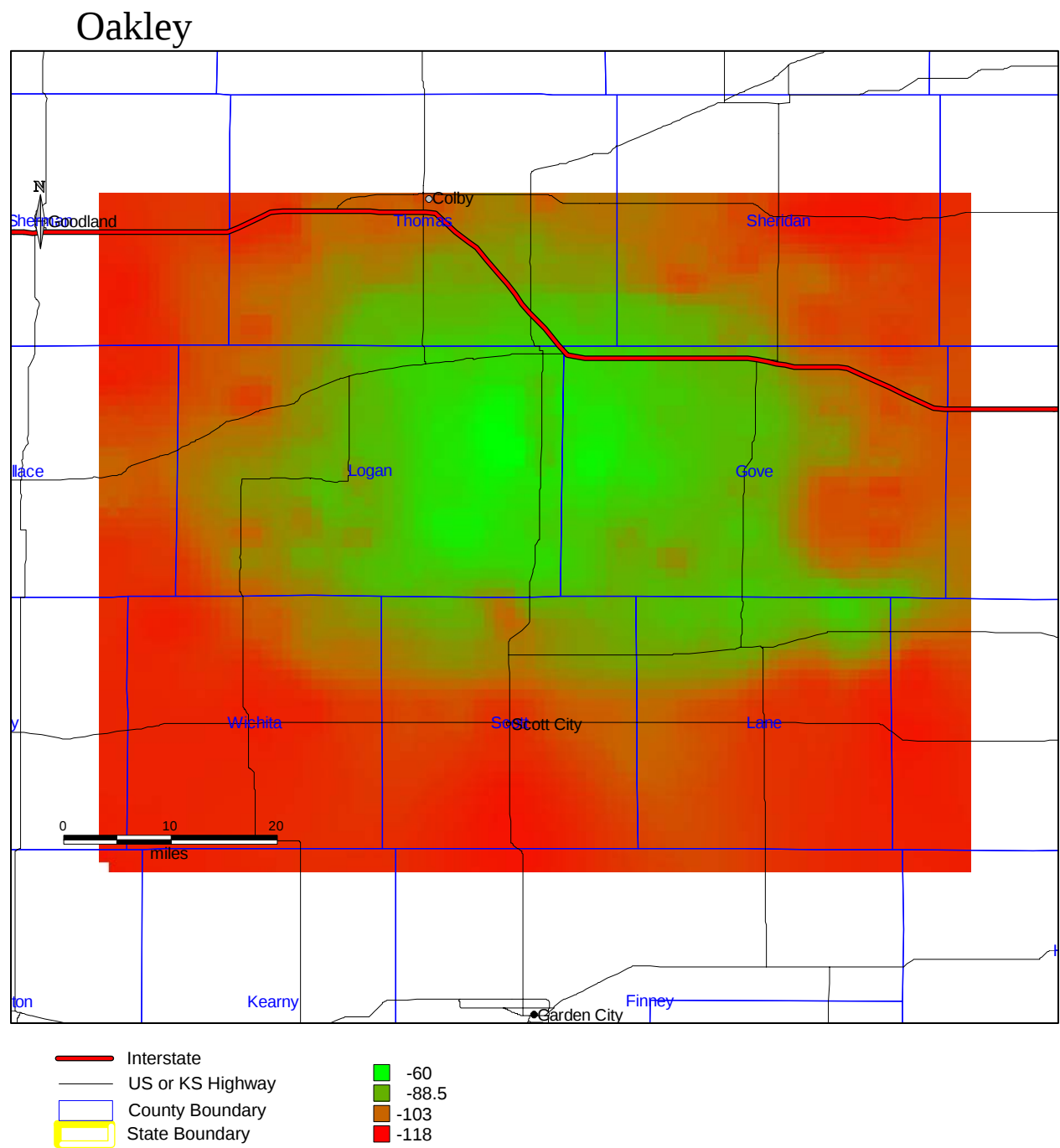
**Figure 11. RSSI Values for Manhattan.**



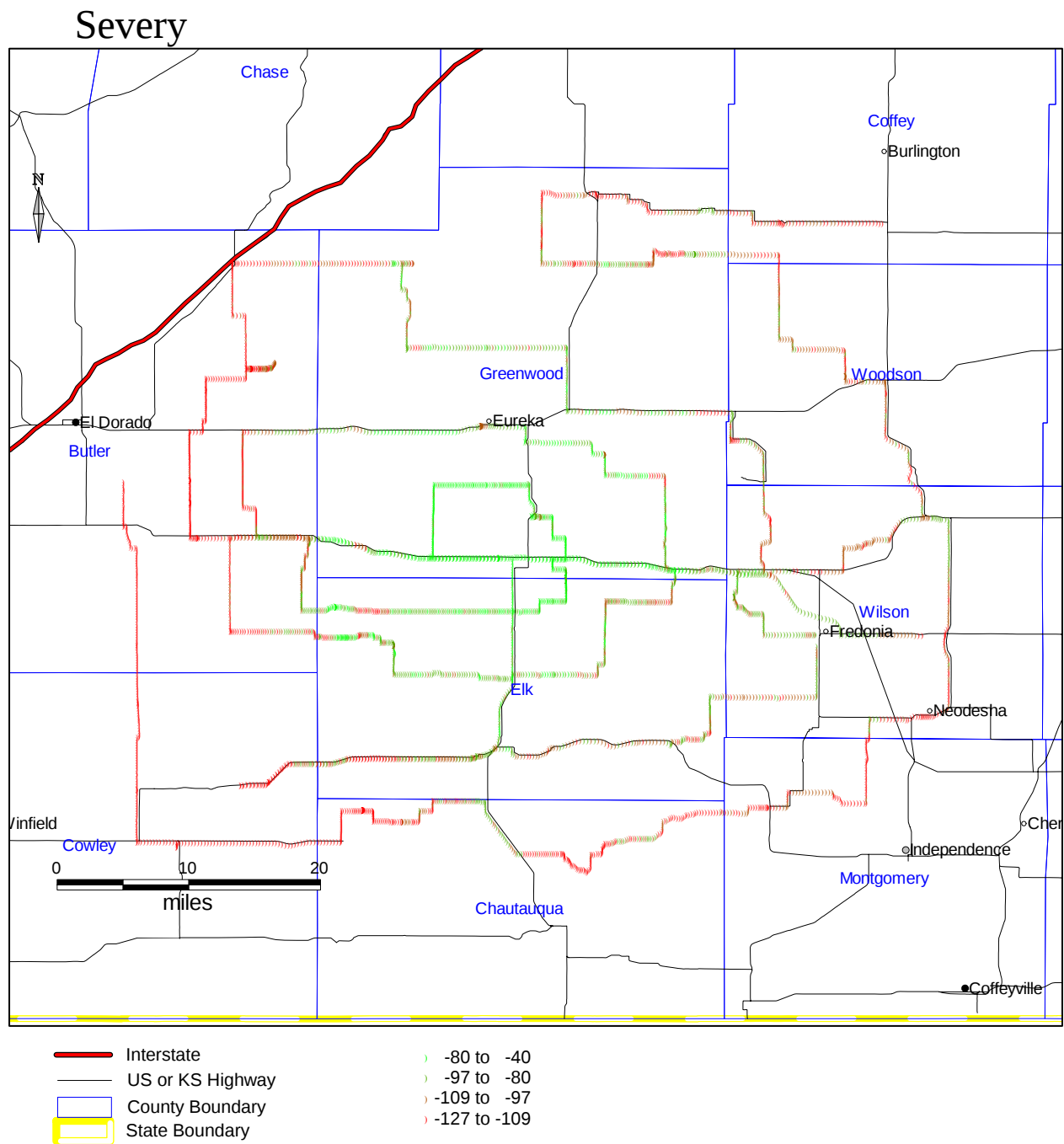
**Figure 12. Interpolated RSSI Values for Manhattan.**



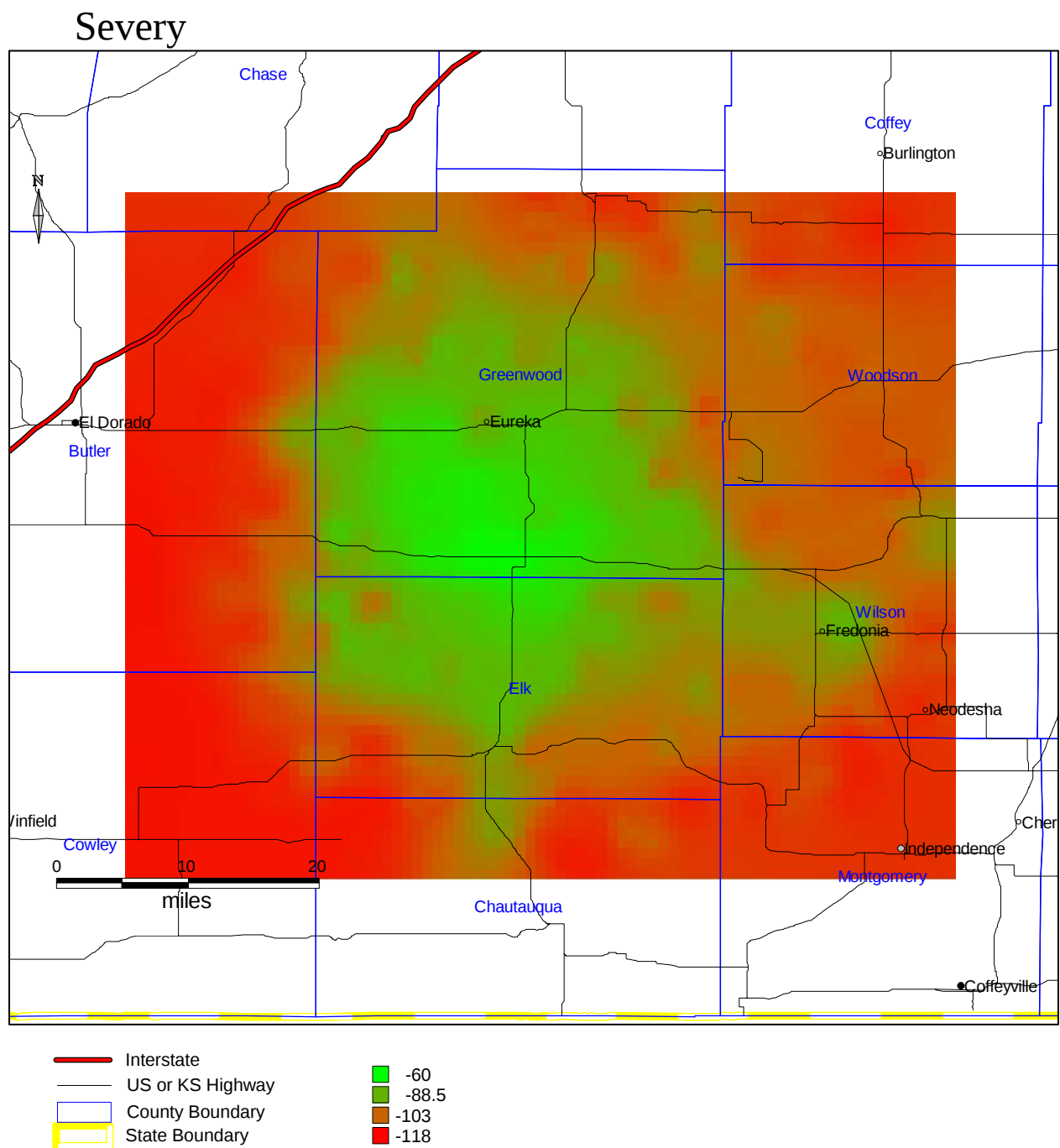
**Figure 13. RSSI Values for Oakley.**



**Figure 14. Interpolated RSSI Values for Oakley.**

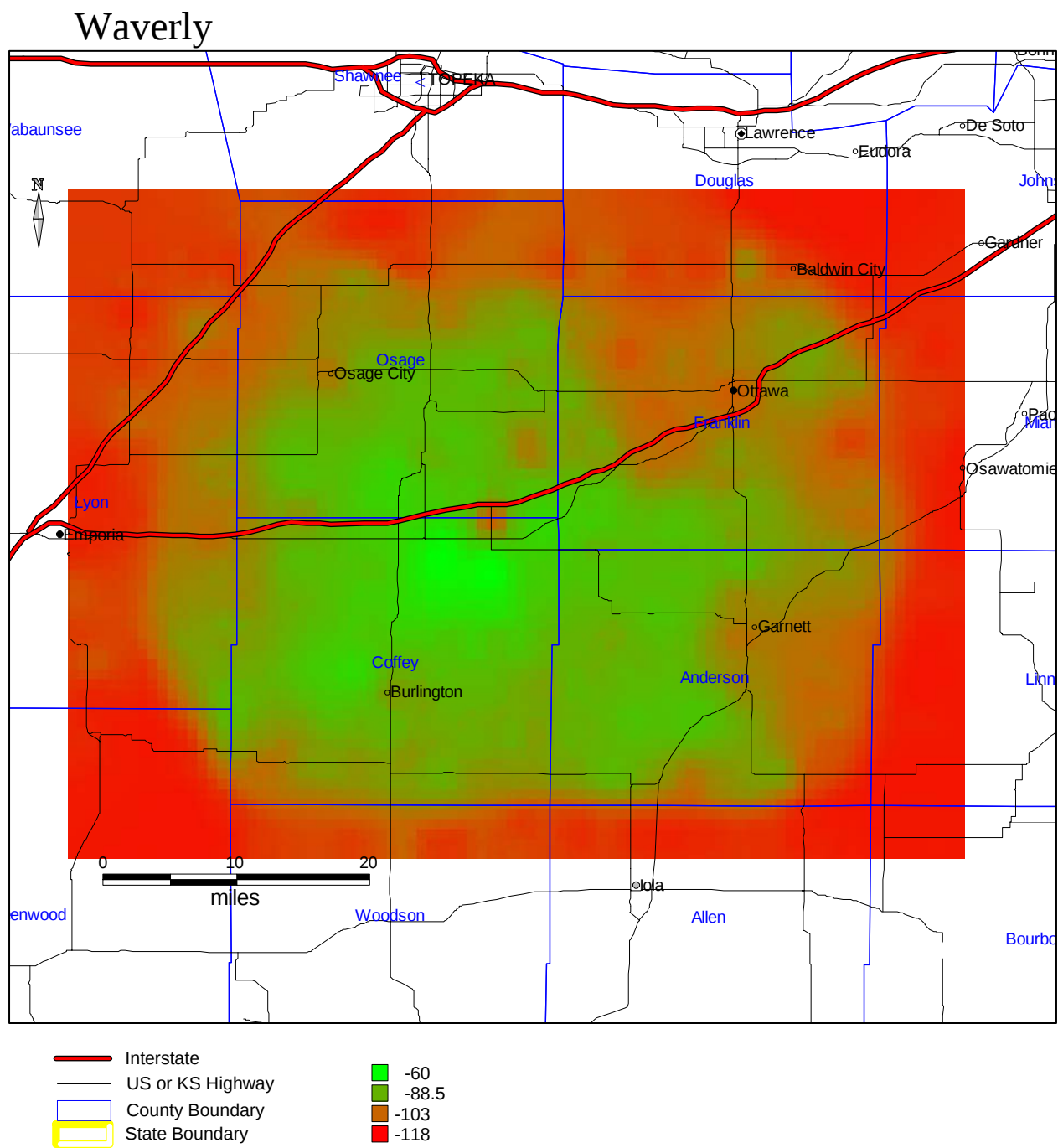


**Figure 15. RSSI Values for Severy.**

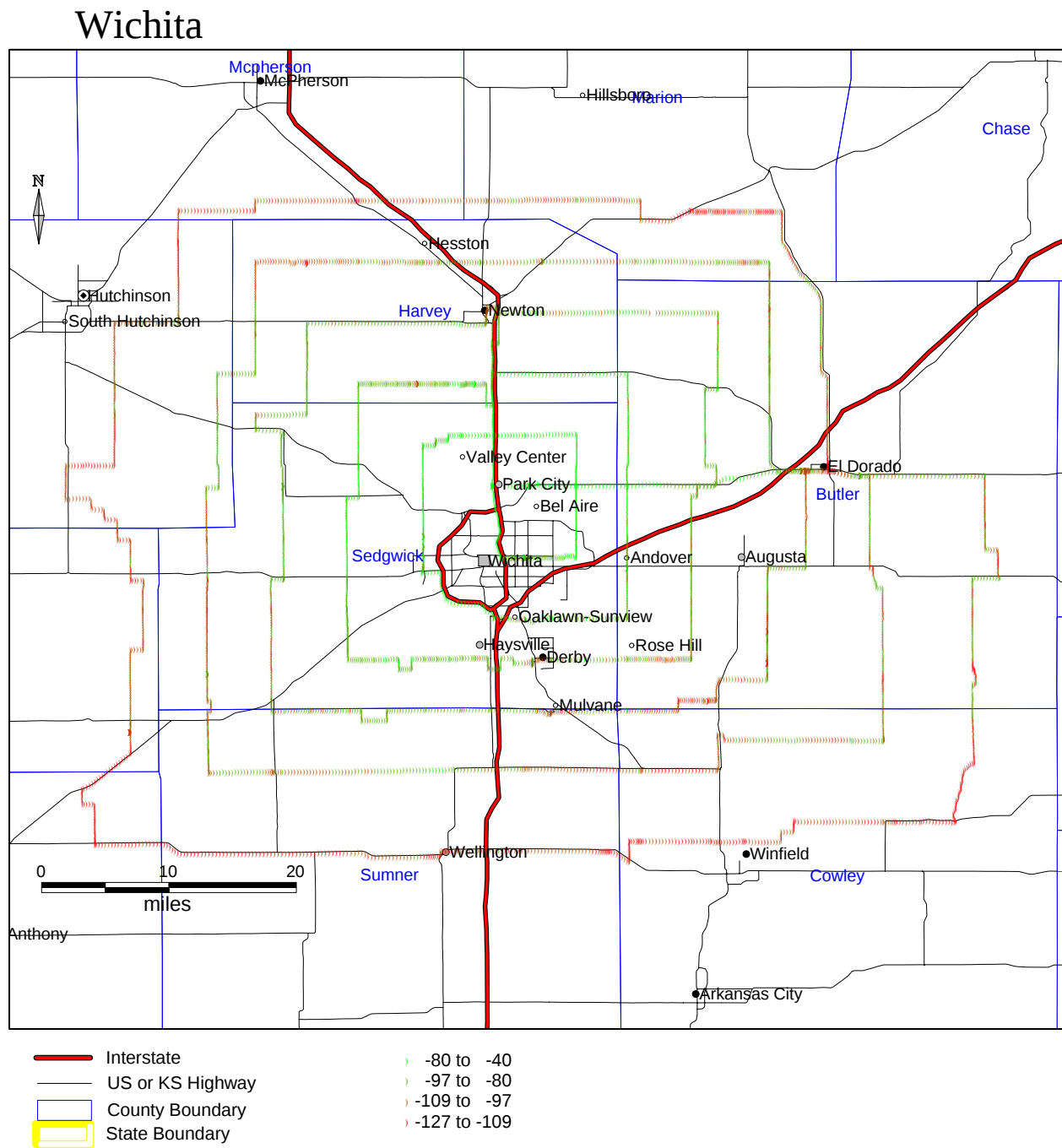


**Figure 16. Interpolated RSSI Values for Severy.**

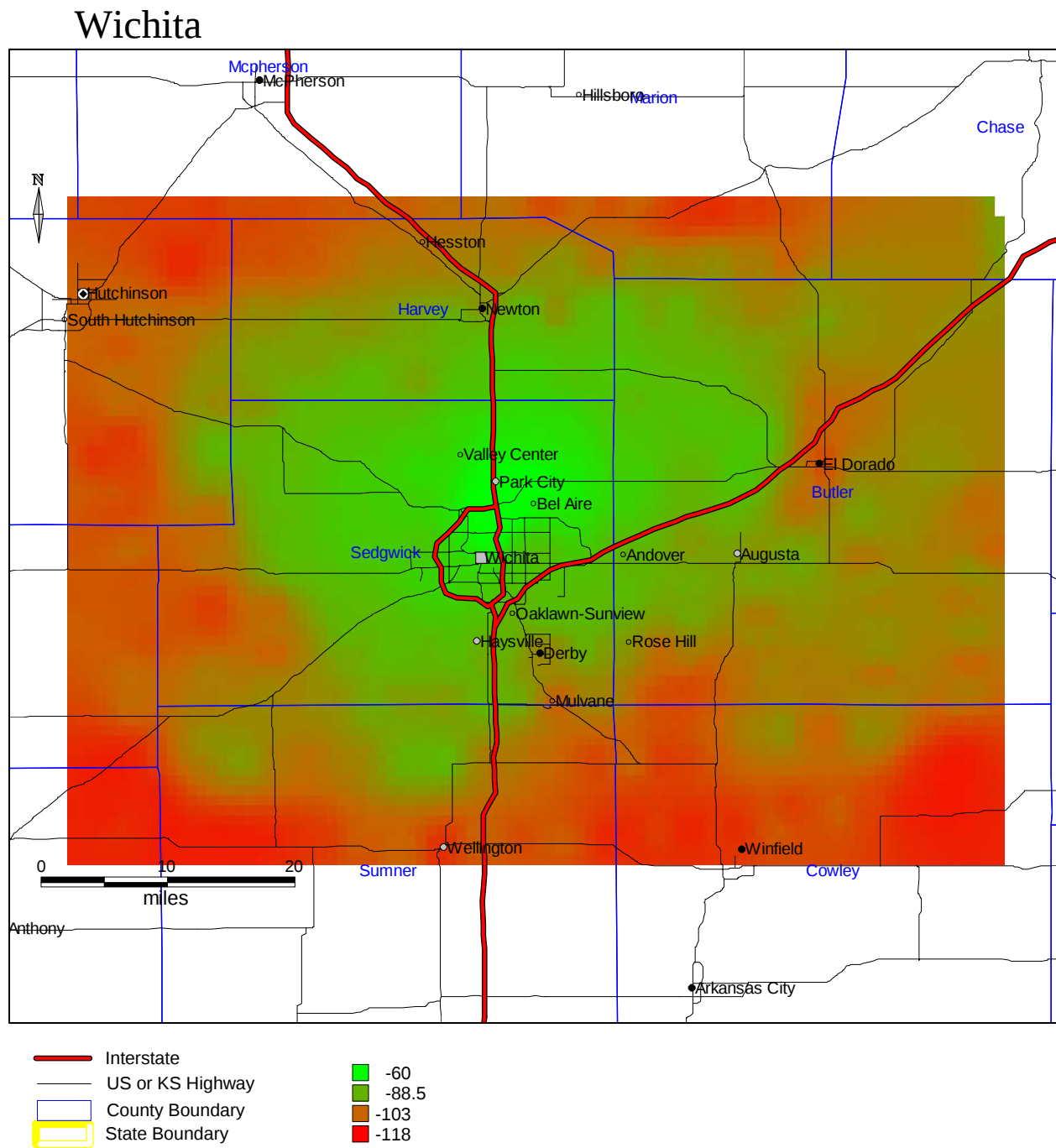




**Figure 18. Interpolated RSSI Values for Waverly.**



**Figure 19. RSSI Values for Wichita.**



**Figure 20. Interpolated RSSI Values for Wichita.**

The sites were deliberately selected to represent a diverse set of terrain and transceiver characteristics, and the patterns observed in the coverage data were correspondingly diverse from site to site. Consequently, it is difficult to characterize the coverage across all sites. If coverage area is defined as moderately low RSSI values or better, the coverage areas have an average radius of about 20 miles. Because the approach was designed to provide drive test data for propagation model calibration, the surface plots generated from the data should be used with caution. The data points along each highway segment driven are reliable and collected with an approximate linear resolution of about 500 ft to 1500 ft. In the areas between the highway segments driven, many locations are 5 miles or more from the nearest measured data point. Given those distances, the interpolated data must be interpreted as only a rough estimate of the actual coverage. The surface plots provide a picture of the general size and shape of the coverage area, but a more sophisticated propagation model (such as the ComStudy package) should be used if more minute detail is needed.

## **SUMMARY**

Over 6,500 miles were driven, collecting more than 33,000 RSSI values for the 8 towers considered in this effort. The use of a spiral route around the tower appears to be an effective technique for collecting a well-distributed data set while allowing flexibility in the size of the driving burden. The resulting data provides a wealth of drive test data, useful for calibrating the ComStudy propagation model, and is sufficient to show the general size and shape of the coverage area for each tower. Surface plots generated by linearly interpolating the data over a geographic area show the coverage area and potential dead spots. By using this data to improve the existing propagation models, KDOT can obtain a more precise picture of the coverage of their radio system across the entire state, and as a result be able to use these and associated resources more efficiently and effectively.

## **APPENDIX A: PREPROCESSDT USAGE**

To convert a file from the Survey Technologies output format to the ComStudy Drive Test import format, open Windows Explorer, then click on the Survey Technologies data file and drag it over "PreProcessDT.exe" and drop it. The new file will have the same name as the old except that " (DT)" will be added. Thus, "Reno Tower--July 02.txt" would be converted and saved to "Reno Tower--July 02 (DT).txt" . The new file will be saved in the same directory as the original. If another drive test file exists with the same name, you'll be asked whether the older file should be overwritten or not.

There is one caveat pertaining to the operating system's filename conventions. If you are running Windows NT, you should use filenames that are no more than 8 characters long. "KDOT Test Severly Tower (DT).txt" and "KDOT Test Conc Tower (DT).txt" will actually be saved as "KDOT\_T~1.txt" and "KDOT\_T~2.txt" (or something similar), making it difficult to remember which contains the data in ComStudy drive test format. This isn't a problem in Windows 2000, which handles the long filenames correctly.