usRAP

UNITED STATES ROAD ASSESSMENT PROGRAM

A program of the AAA Foundation for Traffic Safety

Pilot Program Phase III

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May 2010

U.S. Road Assessment Program (usRAP) Pilot Program—Phase III

Final Report

For
AAA Foundation for Traffic Safety

MRI Project No. 310537.1.021

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DISCLAIMER

The conclusions and recommendations presented in this report are those of AAAFTS and its contractors and do not represent the official positions and policies of the participating highway agencies. The maps prepared in the pilot studies and presented in this report are illustrative examples that provide useful information concerning the safety performance of the roadway system and are presented here solely to demonstrate the potential utility of usRAP. The specific maps presented in this report do not, by themselves, provide sufficient information to determine which roadways should receive priority for improvement. In determining improvement priorities, highway agencies consider many factors beyond those depicted on the maps in this report. Decisions regarding any improvements are based on detailed engineering studies that consider the improvement types most appropriate for specific road sections and the cost and anticipated effectiveness of those improvements. In response to recently established Federal legislation contained in Section 1410 of SAFETEA-LU, each state highway agency will be establishing its own criteria and procedures necessary to satisfy the identification of 5 percent of their public road locations exhibiting the most severe safety needs. This report does not constitute a standard, specification, or regulation.

The information contained in this report has been compiled for the purpose of identifying, evaluating, or planning safety enhancements. The report identifies information used for the purpose of developing highway safety construction improvement projects which may be implemented, using federal-aid highway funds. Any document displaying this notice shall be used only for those purposes deemed appropriate by the participating state departments of transportation. See Title 23, United States Code, Section 409.

This report was funded by the AAA Foundation for Traffic Safety in Washington, D.C. Founded in 1947, the AAA Foundation is a not-for-profit, publicly supported charitable research and education organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from the American Automobile Association and its affiliated motor clubs, from individual members, from AAA-affiliated insurance companies, as well as from other organizations or sources.

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Section 1. Introduction

1.1 Background

The level of safety for motorists on U.S. roads varies widely. Controlled-access freeways, with no at-grade intersections or driveways, provide the highest level of safety among road types. Other safety enhancing features of roadways include medians, roadside clear zones, guardrails, median barriers, and intersection turn lanes. Highway agencies have limited funds for improving the safety features of roadways, so it is important that their investment decisions are made in a way that provides maximum benefits to motorists and to the public at large.

Roadway and roadside improvements will have a key role in improving the overall safety performance of the highway system. However, a key to understanding the nature of safety on the highway system is to recognize that, while every crash occurs on some road segment, this does *not* imply that the design or operational characteristics of that road segment are necessarily the *cause* of those crashes. While driver and vehicle factors contribute to the causation of many more crashes than road factors, risk maps of the road system can help to identify roadways where there are opportunities to improve safety.

Currently, there is no systematic road assessment program in North America to inform motorists of the level of safety on the roads they travel or to help auto clubs and others provide informed advice to highway agencies on needs for safety improvement. Systematic road assessment programs have begun in Europe and Australia. The European Road Assessment Program (EuroRAP) was started in 2000 and the Australian Road Assessment Program (AusRAP) was started in 2003 to develop and implement systematic road assessment protocols.

The AAA Foundation for Traffic Safety (AAAFTS) is completing a pilot program to test the technological and political feasibility of instituting a U.S. Road Assessment Program (usRAP). This work has been funded by AAAFTS, with support from FIA Foundation for the Automobile and Society and the International Road Assessment Program (iRAP), and the Midwest Transportation Consortium (MTC) at Iowa State University. The pilot program is examining the various technological barriers—are appropriate data available and how should those data be aggregated? The pilot test is also examining political barriers—will highway agencies cooperate with such a program and can liability concerns be overcome? This pilot program is focusing attention on the need for highway safety improvement and starting a national dialogue on the issue. There is concern that crash investigations and existing road safety data in many jurisdictions are not adequate to support comprehensive analyses of road safety features. It is envisioned that the national dialogue would help create public support for higher funding to upgrade data systems and make road safety improvements.

The usRAP pilot program began in 2004 and a report on the first phase of the work was published by AAAFTS in 2006. The Phase I work included pilot studies of usRAP concepts in two states: Iowa and Michigan. Two safety mapping protocols were tested: risk maps that present a synthesis of available crash statistics summarized by crash location and star rating maps that present an assessment of safety-related design features of specific roadway sections.

A second phase of the usRAP pilot program then further developed the risk mapping concepts tested in Phase I with pilot studies in two additional states: Florida and New Jersey. Phase II explored the development of supplementary risk maps that address safety issues of interest to the participating states, such as unbelted occupant, speed-related, alcohol-involved, roadway- and lane-departure, commercial-vehicle-involved, older-driver, and young driver crashes. Phase II has also developed a new road assessment protocol: performance tracking to monitor the changes in safety over time for specific roadway sections. A report on the Phase II work was published by AAAFTS in 2008.

This effort has been followed by a third phase of the usRAP pilot program where the risk mapping methodology from Phase II has been applied to four additional states: Illinois, Kentucky, New Mexico, and Utah. Supplementary risk maps for Michigan have also been developed as part of Phase III and Phase III has included a validation study of the star rating protocol utilizing data from Iowa and Washington.

usRAP is also participating in a Roadway Safety Foundation effort to improve safety risk communication strategies in cooperation with the Utah Department of Transportation and the Genesee County Road Commission in Michigan. Results of these efforts will be reported when they are completed.

When all of the ongoing efforts are complete, a final report on the three-phase usRAP pilot study effort will be prepared to summarize the overall pilot study results and present recommendations for national implementation of usRAP.

The usRAP pilot program is very timely given recent Federal highway safety program requirements in Section 1401 of the Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). A provision in Section 1401 requires that states, as a condition for obtaining Federal funds from the Highway Safety Improvement Program (HSIP), must submit an annual report to the U.S. Secretary of Transportation describing at least 5 percent of locations with the most severe safety needs, and an assessment of remedies, costs, and other impediments to solving the problems at each location. The Secretary is required to make these reports available to the public on the U.S. Department of Transportation web site and through other means. The risk maps prepared in the usRAP pilot program represent an effective tool that could be used to identify 5 percent of the roadway system with the greatest safety needs. usRAP maps may also be an effective tool for identifying roadway sections eligible for improvement as part of the SAFETEA-LU high-risk rural roads program.

iRAP has been created to coordinate the results of usRAP, EuroRAP, and AusRAP. iRAP has also launched a program to apply the RAP concepts to improving highway safety in low- and middle-income countries throughout the world.

Midwest Research Institute (MRI) has managed the pilot program for AAAFTS with assistance from the Center for Transportation Research and Education (CTRE) at Iowa State University (ISU) and the participation of an advisory panel of key stakeholders. This report supplements the Phase I report published in 2006 and the Phase II report published in 2008; the report presents the results of Phase III of the usRAP pilot program, including the results of pilot studies conducted in Illinois, Kentucky, and Utah and the results of further work in Michigan. This report also presents the results of research to validate the star rating concept using data from Iowa and Washington.

1.2 Objectives

The primary objectives of the potential usRAP program are to:

- reduce death and serious injury on U.S. roads rapidly through a program of systematic assessment of risk that identifies major safety shortcomings, which can be addressed by practical road improvement measures.
- ensure that assessment of risk lies at the heart of strategic decisions on route improvements, crash protection, and standards of route management.

The objectives are identical to the objectives of the ongoing EuroRAP and AusRAP programs.

As envisioned, usRAP would be implemented as a cooperative effort by highway agencies and auto clubs to accomplish the important objectives presented above. At the heart of the usRAP concept is that highway agencies need the support of auto clubs and the general public to make the case for investments to bring about a substantial reduction in highway crashes. Better information on the safety performance of the roads the motoring public travels should create additional dialogue and public debate on road safety, something that is sorely needed, which in turn can create support for greater investment in highway safety and can help to target those investments to the locations with the greatest need.

1.3 usRAP Advisory Panel

This pilot program has been conducted under the guidance of an advisory panel of key stakeholders representing highway agencies, auto clubs, and other interested organizations. The members of the advisory panel are:

- Hamid Bahadori, Automobile Club of Southern California, Los Angeles, California
- Kevin Bakewell, Auto Club South, Tampa, Florida
- Gregory Cohen, American Highway Users, Washington, DC
- John Daly, Genesee County Road Commission, Flint, Michigan (representing the National Association of County Engineers)
- Rolayne Fairclough, AAA Utah, Salt Lake City, Utah
- Michael Griffith, Federal Highway Administration, Washington, DC
- Robert Hull, Utah Department of Transportation, Salt Lake City, Utah
- Anthony Kane, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC
- Dale Lighthizer, Michigan Department of Transportation, Lansing, Michigan
- Lilla Mason, AAA Blue Grass/Kentucky, Lexington, Kentucky
- Michelle Mount, AAA New Jersey, Florham Park, New Jersey
- Patricia Oliver-Wright, New Mexico Department of Transportation, Santa Fe, New Mexico
- Patricia Ott, New Jersey Department of Transportation, Trenton, New Jersey
- Jack Peet, Auto Club Group/AAA Michigan, Dearborn, Michigan
- Joe Santos, Florida Department of Transportation, Tallahassee, Florida
- Ed Stoloff, Institute of Transportation Engineers, Washington, DC
- Priscilla Tobias, Illinois Department of Transportation, Springfield, Illinois
- Michael Trentacoste, Federal Highway Administration, McLean, Virginia
- Thomas Welch, Iowa Department of Transportation, Ames, Iowa
- Roger Wentz, American Traffic Safety Services Association, Fredericksburg, Virginia
- Jeff Wolfe, Kentucky Transportation Cabinet, Frankfort, Kentucky

1.4 Organization of This Report

The remainder of this report is organized as follows. Section 2 presents the results of the Phase III usRAP pilot studies conducted in Illinois, Kentucky, New Mexico, and Utah. Section 3 presents the results of further work conducted as part of Phase III in one of the previous pilot study states, Michigan. Section 4 presents the findings of a star rating validation study conducted with data from the states of Iowa and Washington. Section 5 summarizes the findings and recommendations of this report.

Section 2.
usRAP Phase III Pilot Studies

This section of the report presents an overview of the pilot studies conducted in Illinois, Kentucky, New Mexico, and Utah as part of Phase III of the usRAP pilot program.

2.1 Objective

The objective of the pilot studies was to further demonstrate and test potential usRAP concepts by application to roads in three additional states. In Phase I, initial usRAP concepts were derived from EuroRAP and from the discussions of the usRAP technical advisory panel and were applied in pilot studies in Iowa and Michigan. Additional pilot studies were conducted in Phase II in Florida and New Jersey. The Phase III studies provided further opportunities for application of the risk mapping protocols in Illinois, Kentucky, and Utah.

2.2 usRAP Protocols Tested

The usRAP concept involves three protocols for safety assessment and mapping of roadway systems. These are:

- *risk mapping* to document the risk of death and serious injury crashes and show where risk is high and low
- *star ratings* based on inspection of roads to examine how well they protect users from crashes and from deaths and serious injuries when crashes occur
- *performance tracking* to monitor changes in the safety performance of the road system over time and relate those changes to ongoing safety improvement programs

This section of the report focuses on risk mapping for the Phase III pilot studies in Illinois, Kentucky, New Mexico, and Utah. Supplementary mapping for one of the states that participated in the Phase I pilot studies, Michigan, is addressed in Section 3 of this report. In accordance with the recommendations in the Phase I report, further work to develop and validate the star rating protocol has been conducted and is presented in Section 4 of this report.

usRAP risk maps use four risk measures based on observed crash history. Each measure is computed for the road sections of appropriate length for each type of road that makes up the road network under consideration. Each measure is classified into five categories and displayed on maps using color coding for the five categories. The four maps and their corresponding risk measures are:

- Map 1—fatal and serious injury crashes per mile of road
- Map 2—fatal and serious injury crashes per hundred million vehicle-miles of travel
- Map 3—ratio of fatal and serious injury crash rate per hundred million vehicle-miles of travel to the average crash rate for similar roads
- Map 4—potential number of fatal and serious injury crashes saved per mile in a specified time period if crash rate per hundred million vehicle-miles were reduced to the average crash rate for similar roads

All four maps can be prepared from a database that contains just four pieces of information about each road section:

- number of fatal and serious injury crashes that occurred on the road section in a specified time period
- road type
- section length
- traffic volume (ADT)

Map 1 is considered useful because it presents the actual observed number of crashes per unit length (crash density).

Map 2 is considered the basic risk map because fatal and serious injury crashes per hundred million vehicle-miles of travel are proportional to the risk of a fatal or serious injury to an individual motorist traveling through the section in question.

Maps 3 and 4 are useful because they compare the crash experience for particular road segments to their group average. Map 4, in particular, is intended as indicative of the safety benefit that could be achieved if a road section were improved.

Additional map types are also being considered for use in usRAP because they are appropriate for North American conditions or because they address specific concerns of participating highway agencies. In Phase I, these supplementary maps types included intersection risk maps and maps that express risk in terms of the economic losses due to crashes. In Phases II and III, supplementary maps types have addressed specific crash types of interest to highway agencies, including crash types associated with emphasis areas in the state strategic highway safety plans.

2.3 Pilot Study Activities

The following activities have been conducted as part of the Phase III pilot studies:

- The research team met with the participating highway agencies to identify existing data files, and data elements within those files, that were available for testing of usRAP concepts and to discuss the quality of those data.
- Using the available data, and in consultation with the participating highway agencies, the research team developed procedures for preparing risk maps. These procedures were consistent with the procedures used in the usRAP Phase I and II pilot studies.
- The research team prepared risk maps for the highway systems of interest selected in each state. The risk maps included Maps 1 through 4, as well as other map types identified by the research team and the participating highway agencies as potentially relevant.

2.4 Results of the Illinois Pilot Study

The Illinois pilot study was conducted in cooperation with the Illinois Department of Transportation. This section presents the results of the Illinois pilot study. The section first discusses general issues concerning the roadway network included in the pilot study, the manner in which that road network was divided into road segments for analysis, and the data that were assembled for analysis. The results of risk mapping are then presented.

2.4.1 Roads Selected for Inclusion in Mapping

State primary roads in the rural areas were selected for the Illinois pilot study. These roads include Interstate, US, and state numbered routes. The Interstate routes in Illinois include toll roads. Rural roads were identified based on the rural/urban categories in the State's functional classification data.

2.4.2 Road Classification

Roads were classified into four road types: freeway, multilane divided, multilane undivided, and two-lane roads. The road type definition was based on access control, median type, and number of lanes. Unique combinations of these variables were assigned to one of the road-type categories. In some cases, particularly where the combination of these variables was atypical, sections were assessed based on the design type and extent of adjacent road sections. The appropriate category was then assigned based on this assessment.

2.4.3 Scope of Analysis and Mapping

Risk maps were developed for the selected road system throughout the entire state. The roads included in the Illinois pilot study are shown in Figure 1.

2.4.4 Segmentation

Segmentation for the study sections in Illinois was developed from available road inventory data. The objective of the segmentation process is to define continuous road segments that are as long as practical while remaining relatively homogeneous. The segments in most state road inventory data bases are relatively short. Therefore, the project team developed a procedure for aggregation of adjacent sections:

- with same county, route number, and road type
- with speed limits within 5 mph
- with ADTs within 20 percent, or within 2,000 veh/day
- with similar ADT, same road type, and speed limits less than or equal to 50 mph in towns or rural communities
- with very short sections with speed limits greater than or equal to 55 mph, with same road type and similar ADT
- of extremely short length
- with speed limits less than or equal to 50 mph just outside a town with similar sections within the town

In some cases, particularly where extremely short sections were not aggregated by the preceding rules, these rules were modified to eliminate unrealistically short analysis sections. Even with the aggregation of road sections described above, the roadway sections in the Illinois pilot study are shorter and experience fewer expected fatal and major injury crashes than the road sections used by EuroRAP. The EuroRAP sections averaged approximately 12 mi in length, while those for the Illinois pilot study averaged only 3 mi in length. However, if the EuroRAP criterion that road sections should average 20 fatal and major injury crashes in three years were applied in Illinois, road sections much longer than 12 mi would be needed. Such long sections would reduce the usefulness of the maps in defining risk in a way that would help in identifying future safety improvement projects. Therefore, a decision was reached to retain the shorter section lengths in the Illinois pilot study.

2.4.5 Crash Type, Selection, and Assignment

For all maps prepared in the Illinois pilot study, only fatal and A-injury crashes were analyzed. For the remainder of this section, presentation and discussion of crashes, and crash-based data, are limited to fatal and A-injury crashes on rural state roads. For consistency with previous pilot studies, the state’s crash severity level for A injuries is referred to on the maps as major injuries.

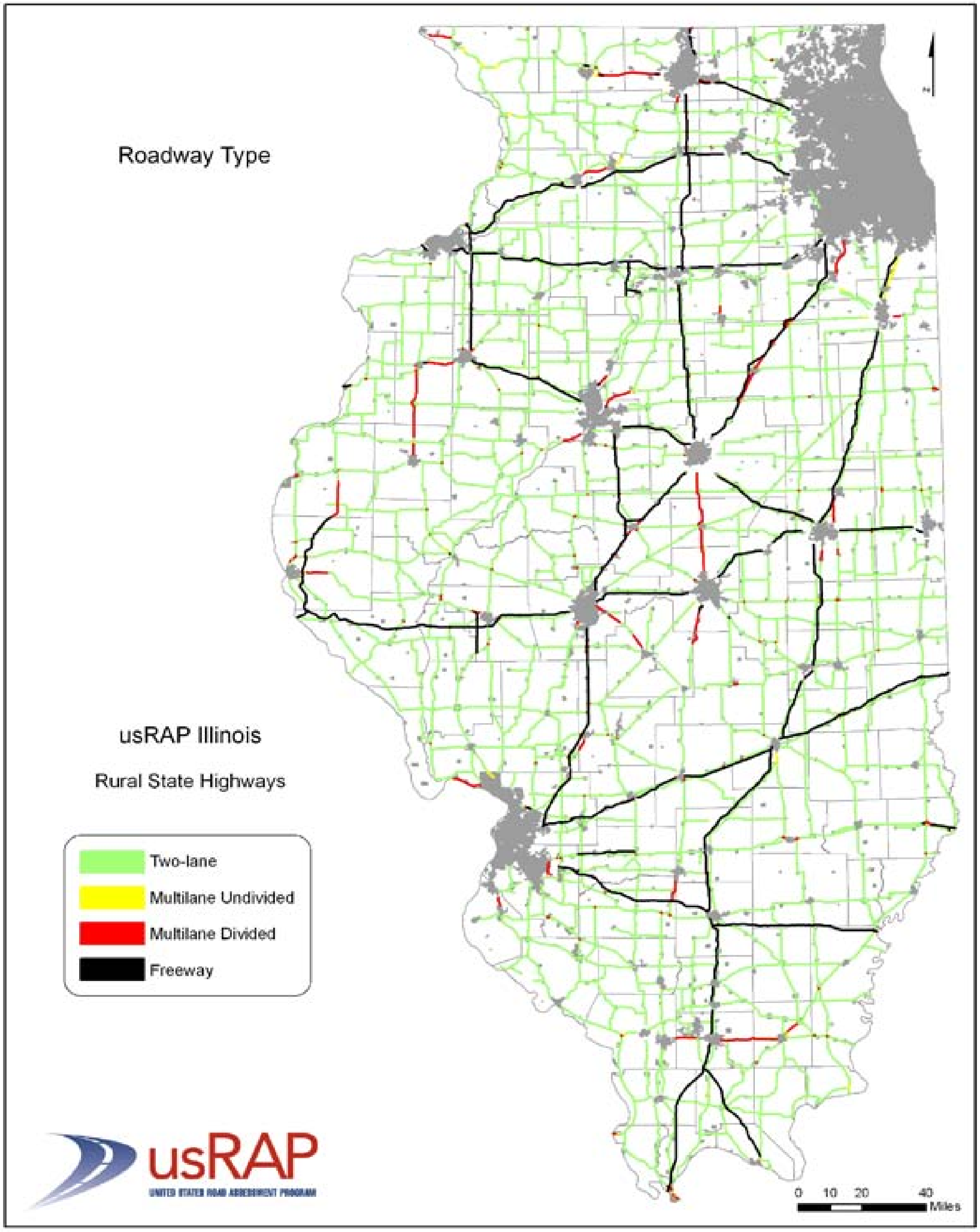


Figure 1. Roads Included in Illinois Pilot Study

Crashes were located, their coordinates were derived, and they were assigned to specific roadway segments using the best available GIS cartography.

2.4.6 Study Period and Data Summary

Based on previous usRAP experience, a five-year study period duration of crash data (2002-2006) were selected for analysis and presentation. Table 1 presents crash totals for 11,003 centerline miles of rural state highways for each year of the study period.

Table 1. Crash Data for Illinois Pilot Study

Year	Fatal crashes	Serious injury crashes	Total fatal and major injury crashes
2002	246	1,559	1,805
2003	286	1,613	1,899
2004	259	1,464	1,723
2005	281	1,552	1,833
2006	230	1,147	1,377
Total	**1,302**	**7,335**	**8,637**

2.4.7 Risk Maps

Following is a summary of the data used for risk mapping in the Illinois pilot study:

- Statewide totals for rural state highways
  - 3,762 segments
  - 11,003 mi of road
  - 21.5 billion annual veh-mi of travel (VMT)
  - 8,637 fatal and serious injury crashes
- Statewide averages for analysis sections on rural state highways
  - Average length = 2.9 mi
  - AADT = 5,342 veh/day
  - Fatal and serious injury crashes = 0.46 crashes/section/year
  - Fatal and serious injury crash density = 0.16 crashes/mi/year
  - Average crash rate = 8.05 per 100M VMT

Table 2 presents summary information by road type.

Table 2. Summary Risk Mapping Data for Illinois Pilot Study

						Fatal & major injury crashes			
Road type	Number of sections	Total length (mi)	Average length (mi)	AADT	Annual VMT (billion)	Total frequency	Annual frequency	Annual density (per mi)	Average rate (per 100M VMT)
Freeway	252	1,555	6.2	18,487	10.5	1,718	1.36	0.22	3.28
Multilane divided	430	357	0.8	7,954	1.0	496	0.23	0.28	9.58
Multilane undivided	92	50	0.5	7,020	0.1	64	0.14	0.26	10.15
Two-lane roads	2,988	9,042	3.0	2,969	9.8	6,358	0.43	0.14	12.98
Total	**3,762**	**11,003**	**2.9**	**5,342**	**21.5**	**8,637**	**0.46**	**0.16**	**8.05**

2.4.7.1 Selection of Risk Categories for Use on Risk Maps

A sequence of color codes was used to define categories on each map in ascending order of risk:

- dark green (lowest risk)
- light green
- yellow
- red
- black (highest risk)

Risk categories are defined so that each category in increasing order of risk contains a progressively smaller portion of the roadway system and so that the highest risk category on each map includes 5 percent of roadway length. The selected risk categories and their associated colors are as follows:

- dark green (lowest risk) 40 percent of roadway length
- light green 25 percent of roadway length
- yellow 20 percent of roadway length
- red 10 percent of roadway length
- black (highest risk) 5 percent of roadway length

This approach should serve to focus attention on the roadway sections with the greatest potential for safety improvement. The highest risk category (shown in black on the various maps) should assist in meeting the Federal mandate that states identify 5 percent of locations with the most severe safety needs. The roads in the highest risk category vary among the various types of maps, indicating that there are multiple considerations in deciding which road sections have the most severe safety needs. Each state has established its own criteria for generating its 5-percent reports; usRAP risk mapping could provide one method for accomplishing this in the future, but the final choice of approaches will be determined by individual state highway agencies.

Examples of risk maps for the Illinois pilot study are presented below. These risk maps have been developed using 5 years of data.

Because shorter section lengths were used in the Illinois pilot study than would be suggested by EuroRAP criteria (see discussion of segmentation above), some road sections in the Illinois pilot study experienced only a few fatal and major injury crashes in five years but were classified in a high risk category. It did not appear appropriate to classify sections with limited crash experience as high risk, since they generally had short lengths or very low traffic volumes, so a criterion was adopted that no road section would be considered for classification in the two highest risk categories (red and black on the various maps) unless it experienced more than two fatal or major injury crashes in five years; such low-crash-count segments with higher risk measures generally appear in the medium risk (yellow) category on the maps presented.

2.4.7.2 Road Section Crash Density Maps (Map 1)

The first type of risk map developed was the annual crash density map (Map 1). Figure 2 presents a crash density map for Illinois using categories with risk category boundaries using the criteria discussed above. The lowest risk category (dark green) on this map includes 40 percent of the total length of the Illinois state highway system; the highest risk category includes 5 percent of the total length. Because Map 1 is based on crashes per mile, some higher volume roads, including freeways, appear in the higher risk categories; on subsequent maps taking traffic volumes into account, freeways generally appear in the lower risk categories.

2.4.7.3 Road Section Crash Rate Maps (Map 2)

Risk maps based on crash rate per 100 million veh-mi of travel were also developed for Illinois roads. While five years of crash data were used, a single AADT value was used to compute exposure. Figure 3 presents a typical crash rate map for Illinois roads.

2.4.7.4 Ratio of Crash Rate Relative to Similar Road Types (Map 3)

Figure 4 presents a map based on the ratio of fatal- and major-injury crash rate for each road section to the average rate based on similar roads (Map 3).

2.4.7.5 Potential Crash Savings (Map 4)

Map 4 indicates the potential for reducing fatal- and major-injury crashes if road sections with above-average crash rates could be brought to the average crash rate for roads of similar type. Figure 5 presents a typical map of this type for rural state highways in Illinois.

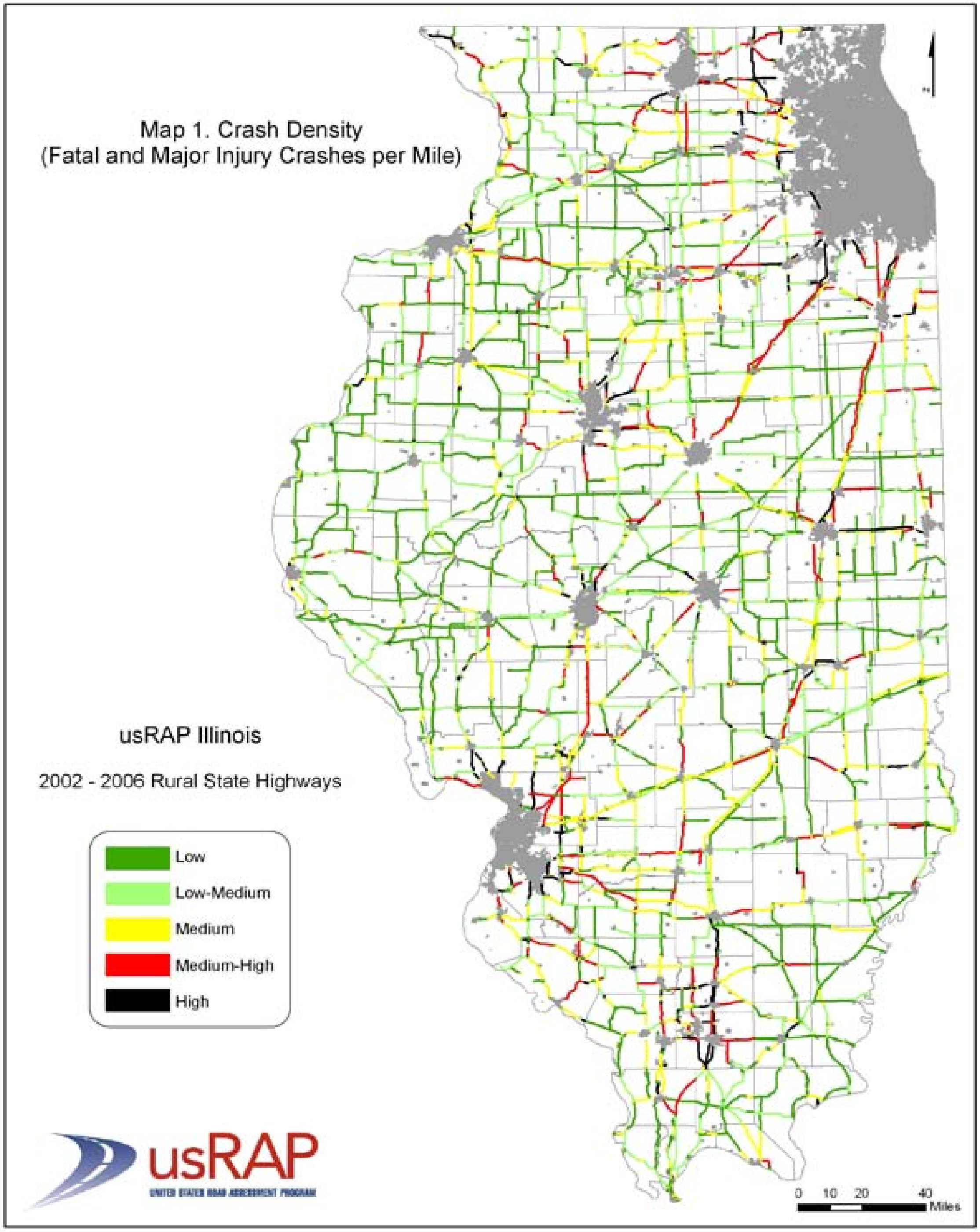


Figure 2. Example of Map 1 for Illinois

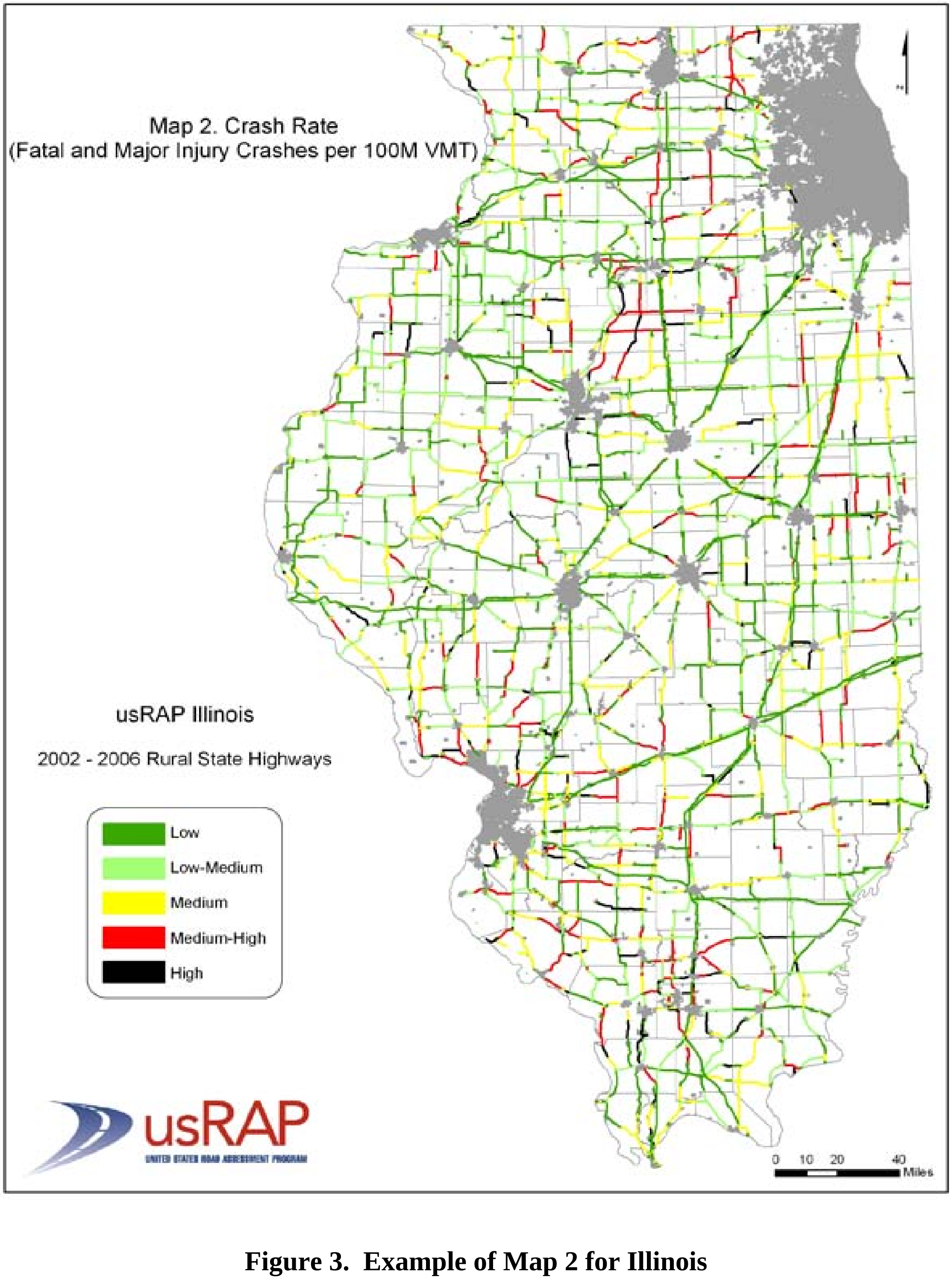


Figure 3. Example of Map 2 for Illinois

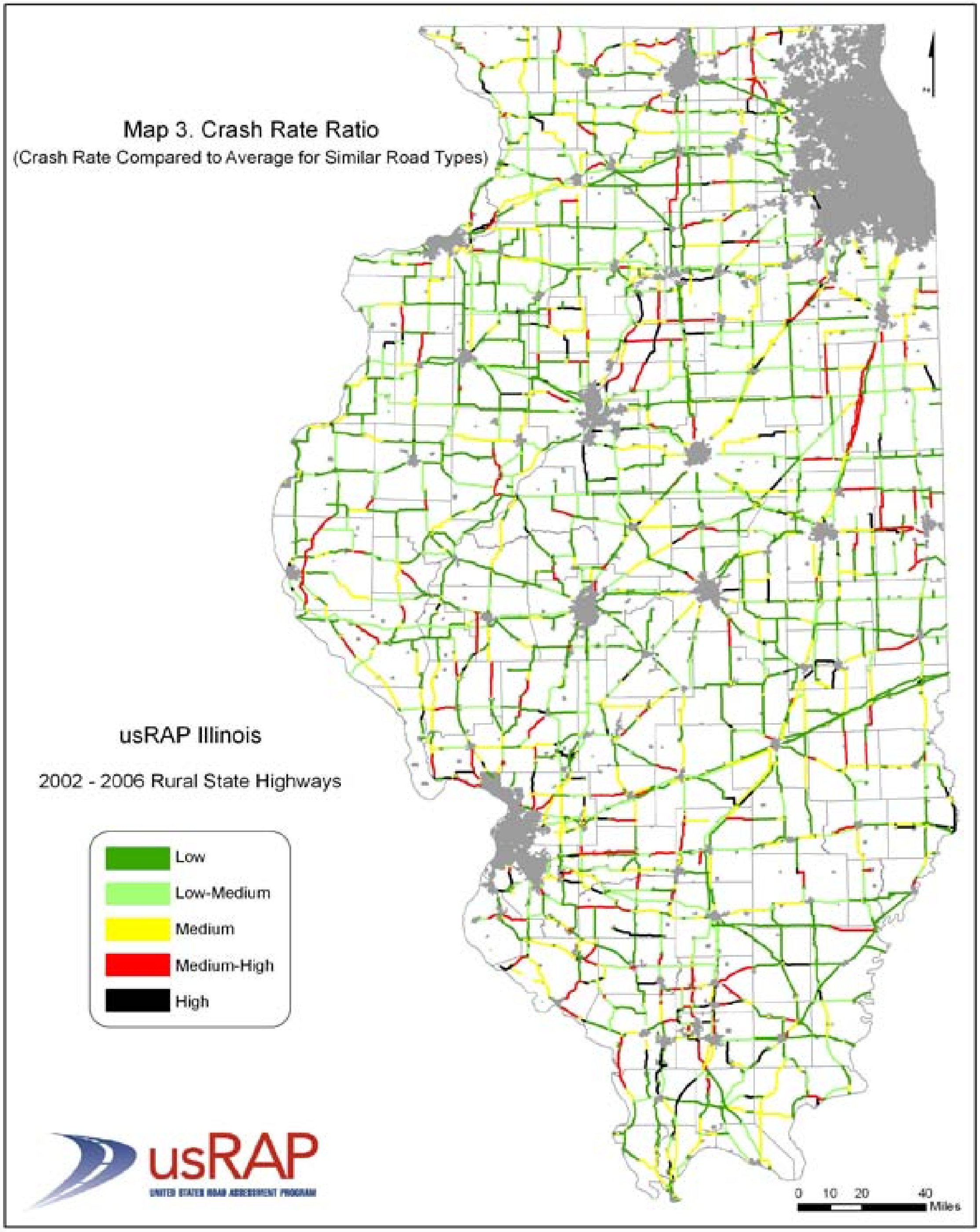


Figure 4. Example of Map 3 for Illinois

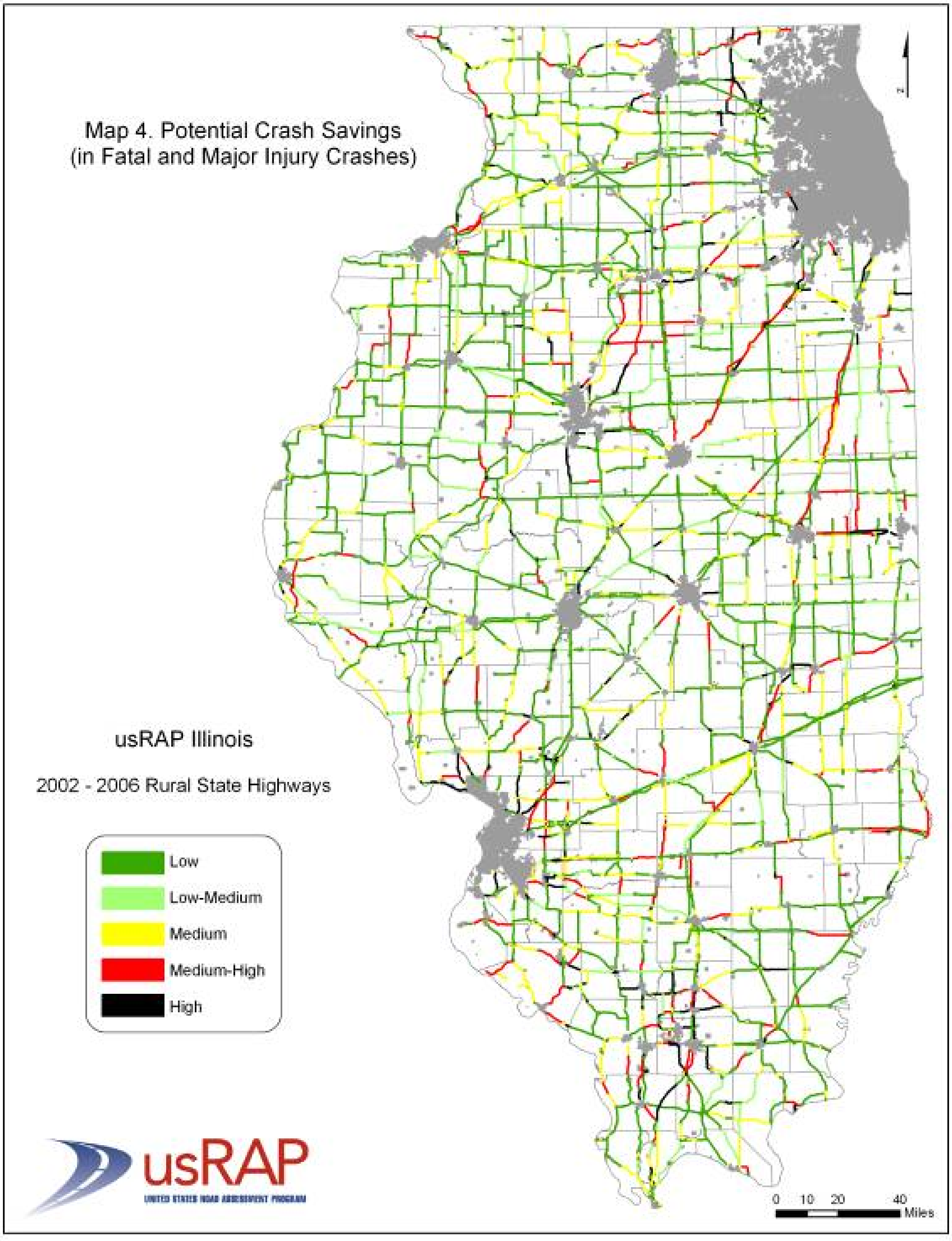


Figure 5. Example of Map 4 for Illinois

2.4.7.6 Supplementary Maps

usRAP pilot studies typically involve the development of supplementary risk maps, in addition to the basic Maps 1 through 4, that address issues of interest to the participating highway agencies. Additional map types were created for the Illinois pilot study to address two specific crash types of interest, including:

- alcohol- or drug-involved crashes
- roadway-departure crashes

Maps analogous to Maps 1 through 4 were prepared for alcohol- or drug-involved crashes in Illinois (see Figures 6 through 9). Alcohol- or drug-involved crashes are defined as those in which an officer reported alcohol/drug involvement using one of the following categories: alcohol, alcohol impaired, drinking, had been drinking, drugs, or drug impaired. Figures 6 through 9 present Maps 1 through 4, respectively, for alcohol- and drug-involved crashes in Illinois. For each of these maps, a minimum of two fatal- or major-injury alcohol- or drug-involved crashes were required for a road section to be considered medium-high or high risk.

Maps analogous to Maps 1 through 4 were prepared for roadway-departure crashes in Illinois (see Figures 10 through 13). Roadway-departure crashes are defined as those crashes for which the reported sequence of events includes running off the roadway, overturning, or striking a specific roadside object or for which the collision type is head-on or sideswipe-opposite direction. For each of these maps, a minimum of three fatal- or major-injury roadway-departure crashes was required for a section to be considered medium-high or high risk.

2.4.8 Use of the usRAP Maps in Illinois

The Illinois DOT has found the usRAP risk maps to be a useful tool and has found that they are generally consistent with the results of recent review of state highways in Illinois using Safety Performance Functions (SPFs). The usRAP supplementary maps for roadway-departure crashes should be of direct assistance to the Illinois DOT and the supplementary risk maps for alcohol-and-drug-related crashes should be of assistance to law-enforcement agencies. Appropriate next steps could involve risk mapping for county roads in selected counties in Illinois to involve local agencies in usRAP.

2.5 Results of the Kentucky Pilot Study

The Kentucky pilot study was conducted in cooperation with the Kentucky Transportation Cabinet. This section presents the results of the Kentucky pilot study. The section first discusses general issues concerning the roadway network included in the pilot study, the manner in which that roadway network was divided into road segments for analysis, and the data that were assembled for analysis. The results of risk mapping are then presented.

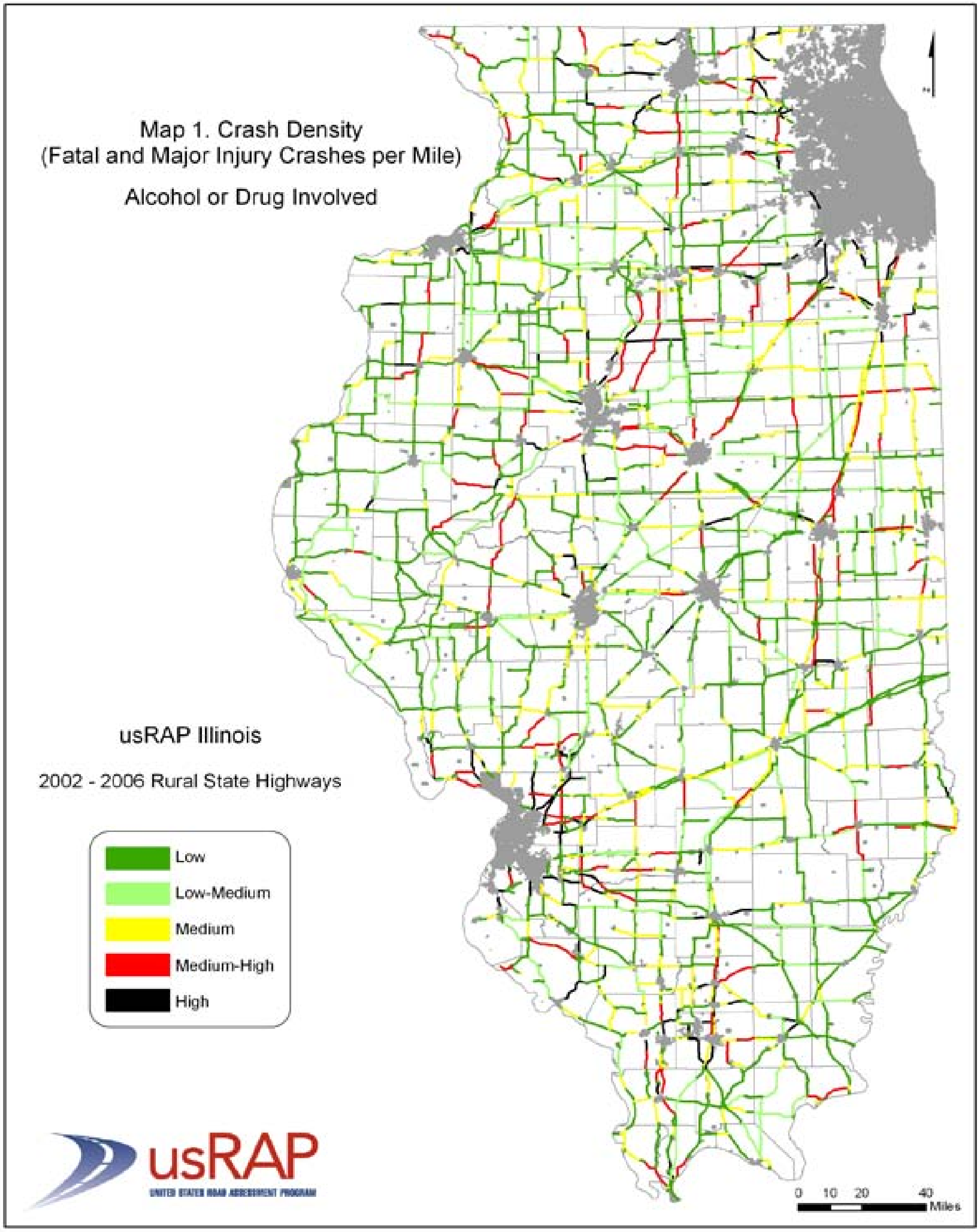


Figure 6. Illinois Map 1 for Alcohol- or Drug-Involved Crashes

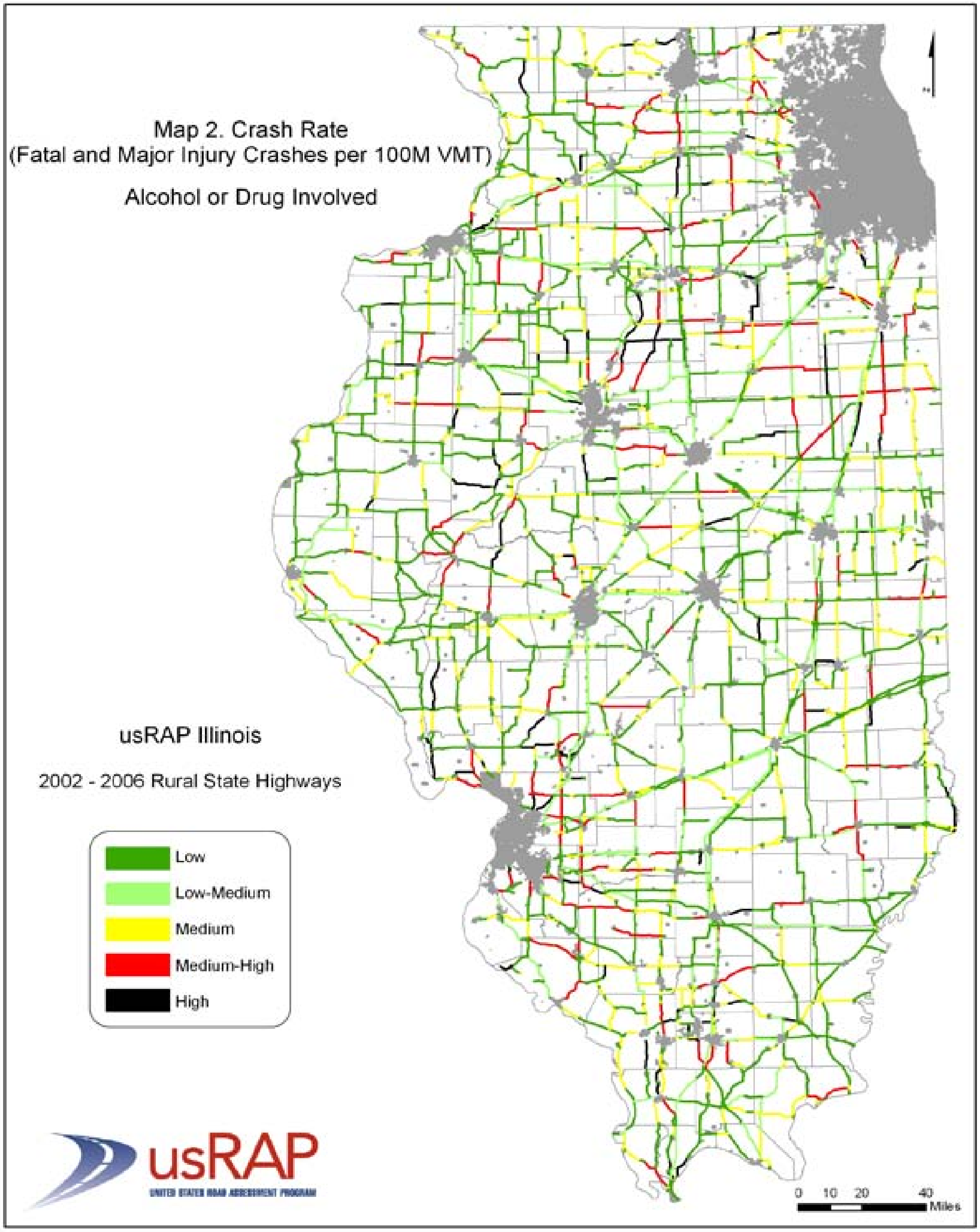


Figure 7. Illinois Map 2 for Alcohol- or Drug-Involved Crashes

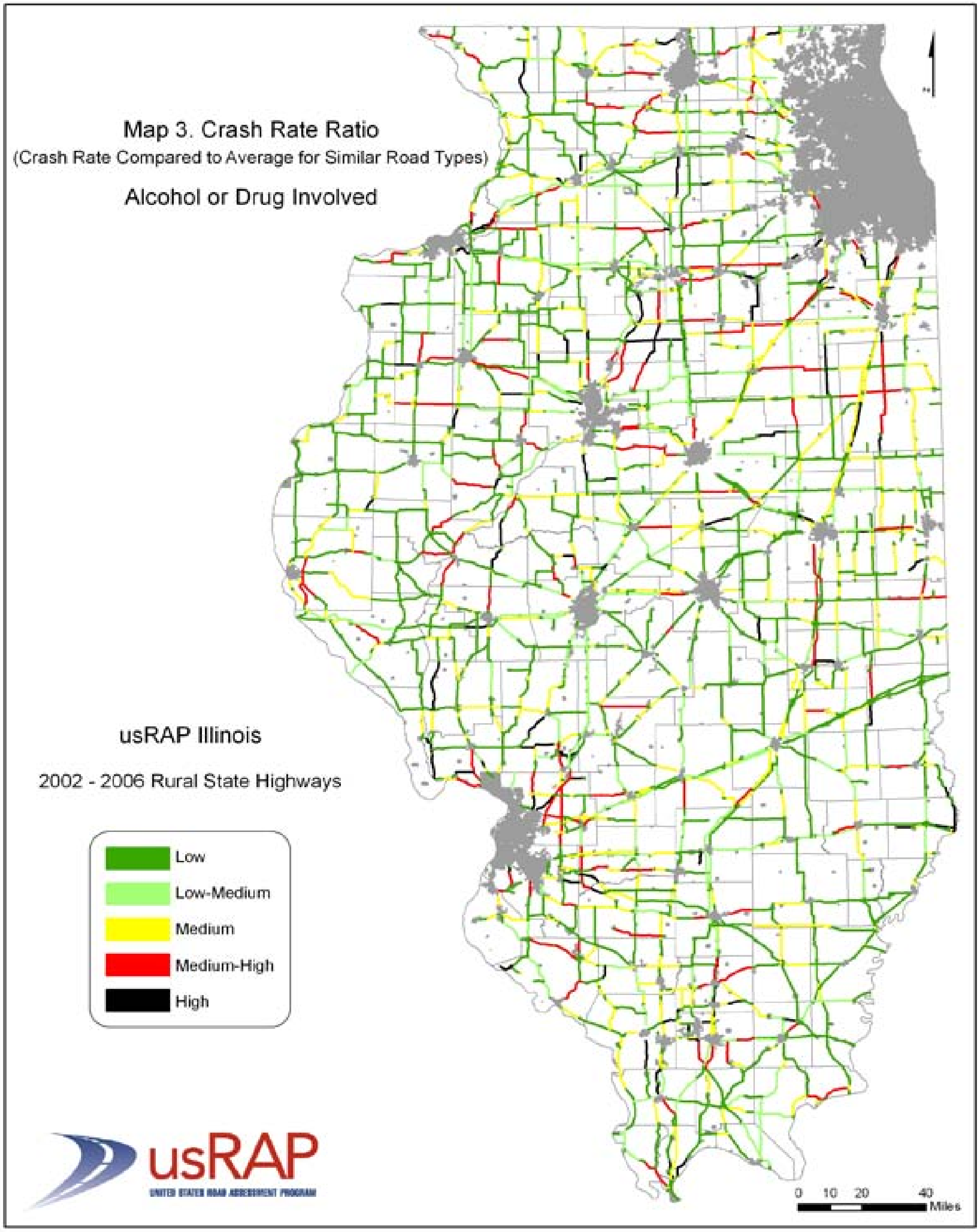


Figure 8. Illinois Map 3 for Alcohol- or Drug-Involved Crashes

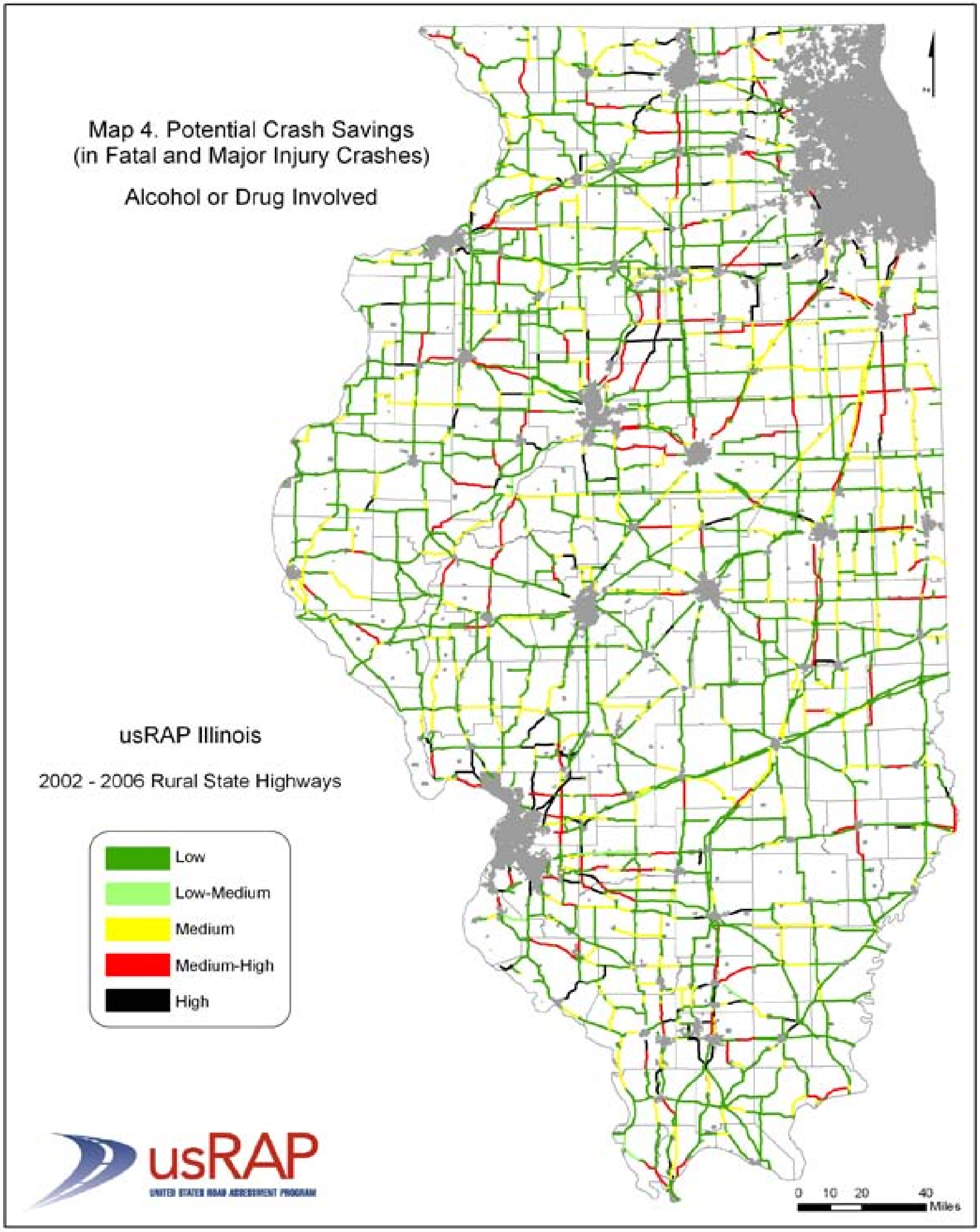


Figure 9. Illinois Map 4 for Alcohol- or Drug-Involved Crashes

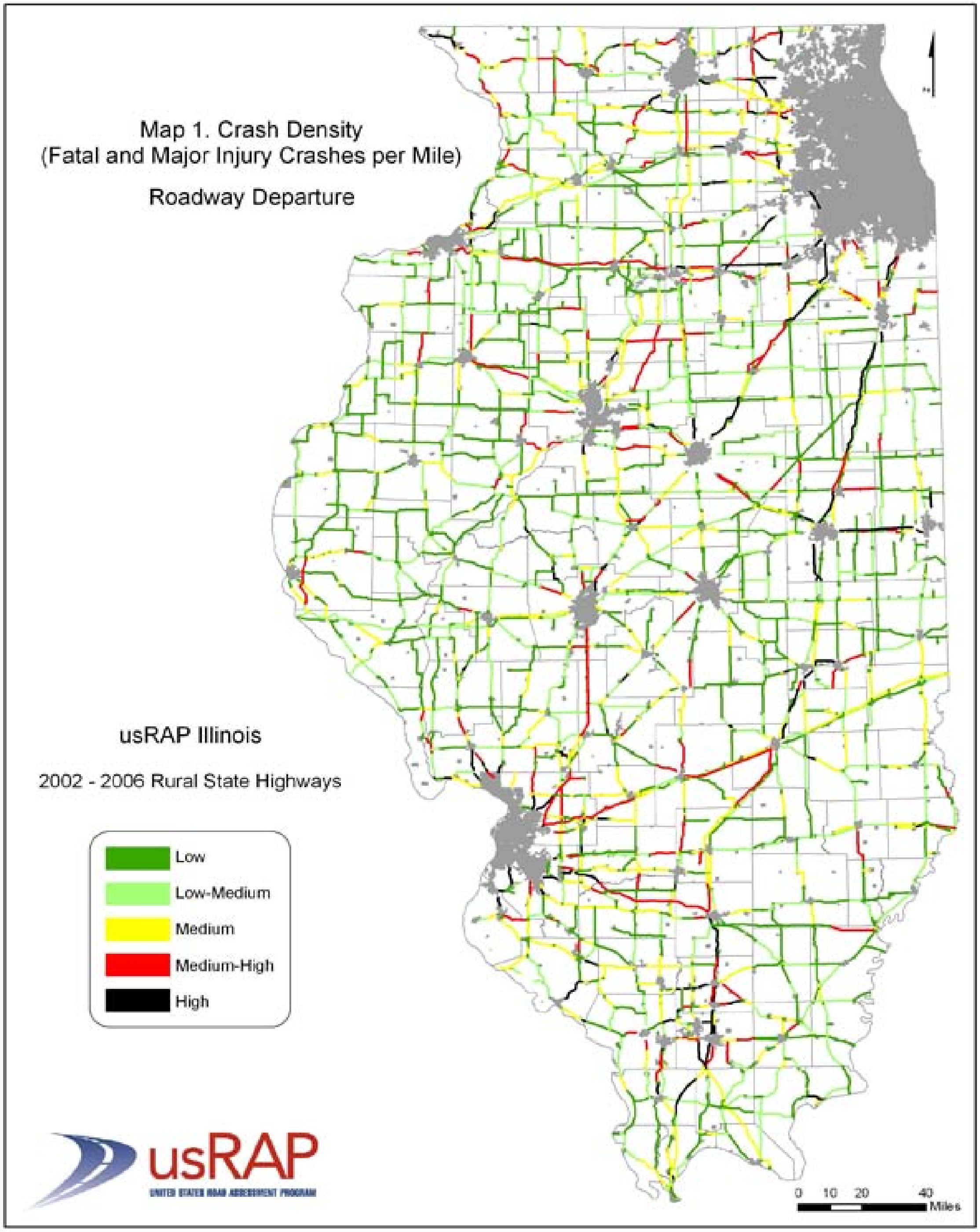


Figure 10. Illinois Map 1 for Roadway-Departure Crashes

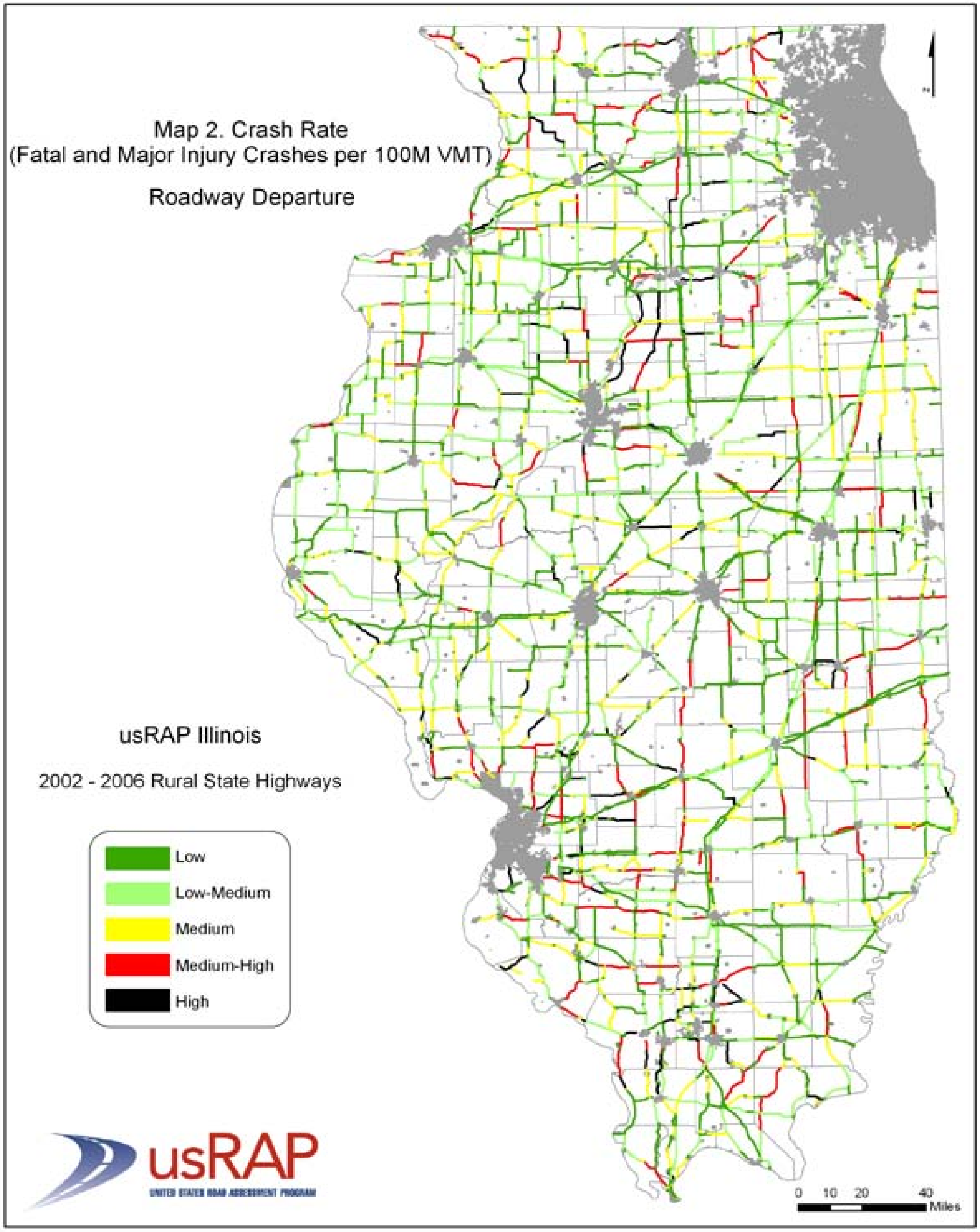


Figure 11. Illinois Map 2 for Roadway-Departure Crashes

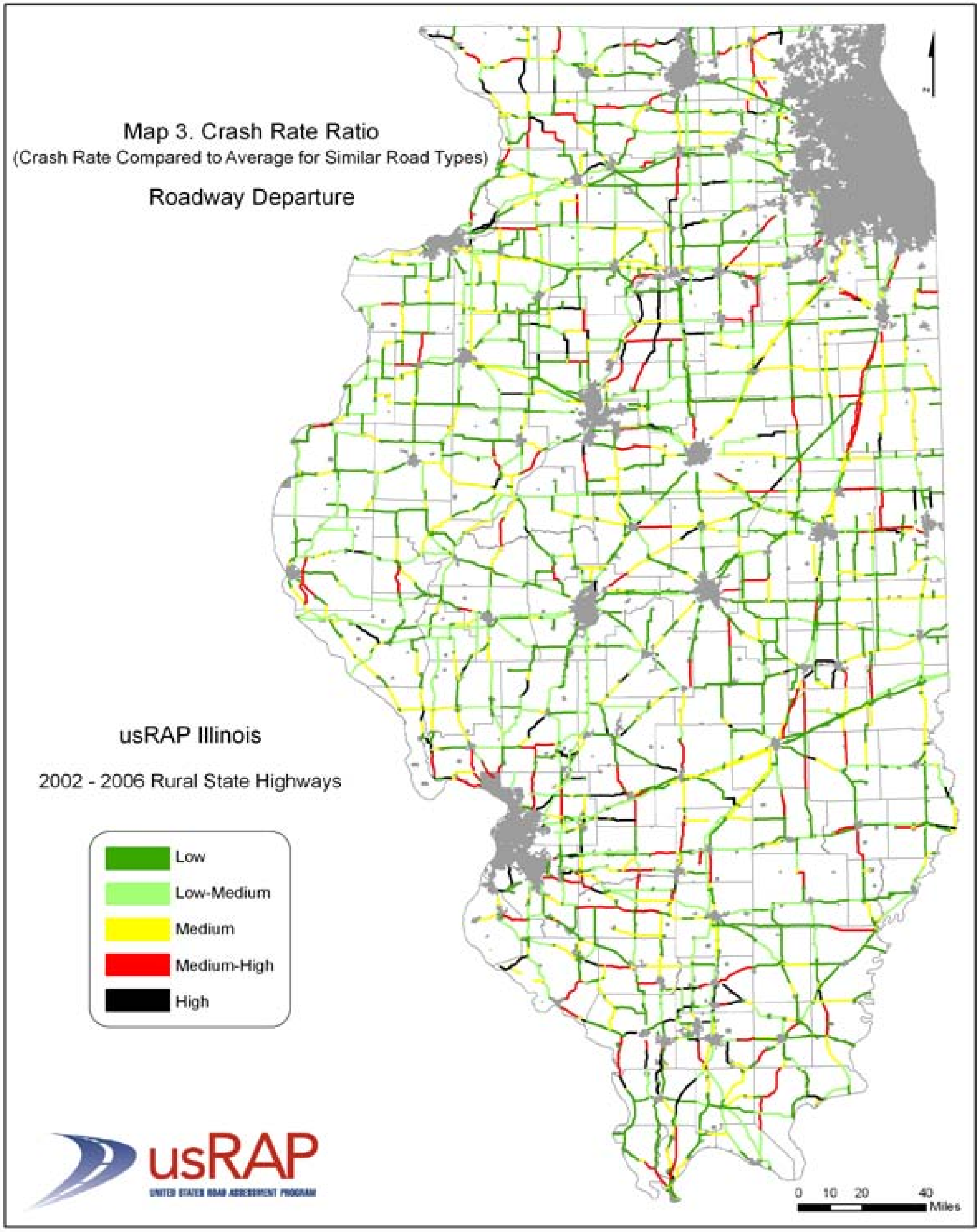


Figure 12. Illinois Map 3 for Roadway-Departure Crashes

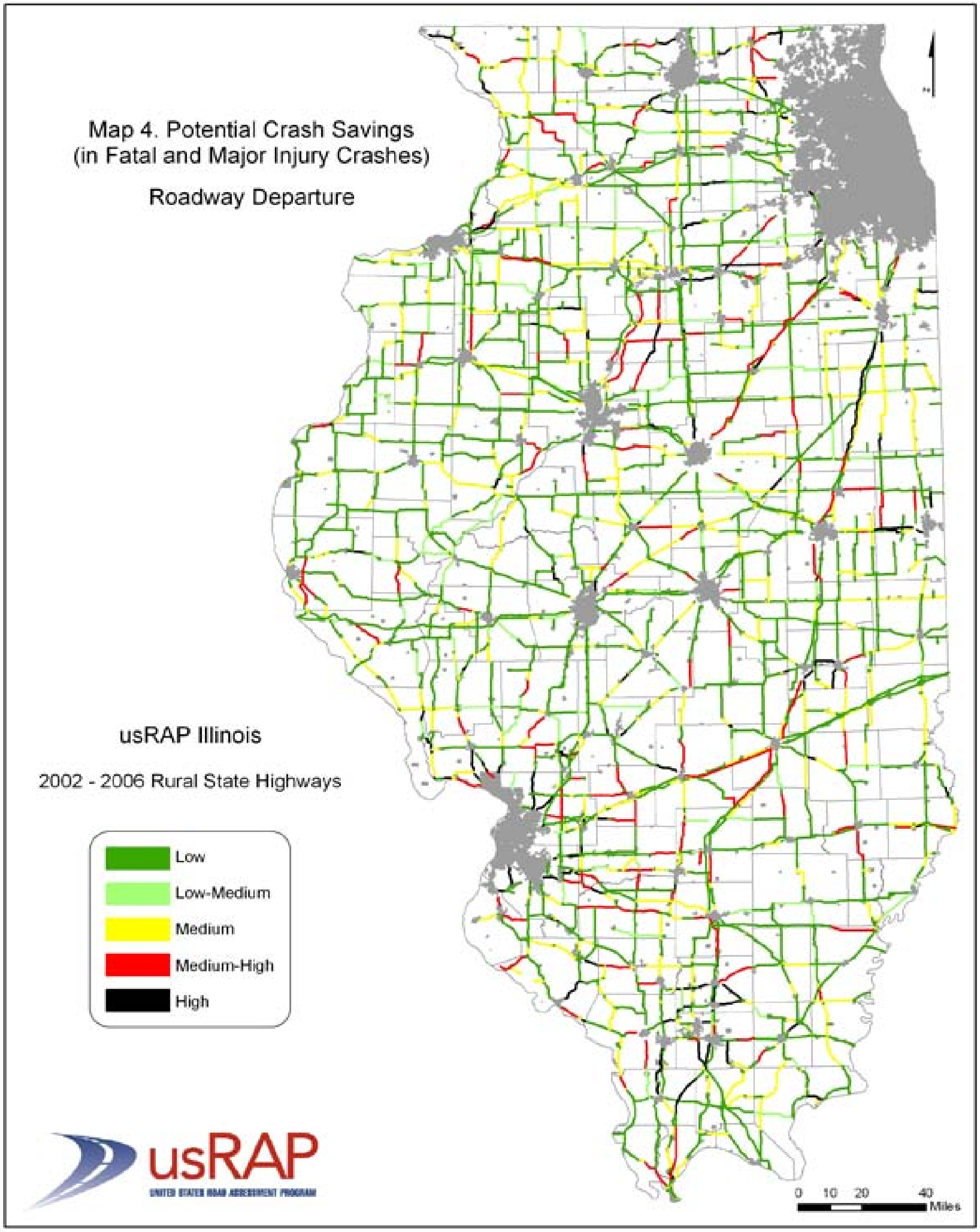


Figure 13. Illinois Map 4 for Roadway-Departure Crashes

2.5.1 Roads Selected for Inclusion in Mapping

State primary roads in rural areas were considered in the Kentucky pilot study. These roads include Interstate, parkway, US, and Kentucky numbered routes. Rural roads were identified based on the rural/urban categories in the state's functional classification data.

2.5.2 Road Classification

Roads included in this pilot study were classified into four road types: freeway, multilane divided highway, multilane undivided, and two-lane roads. The road type definition was based on access control, median type, and number of lanes. Unique combinations of these variables were assigned to one of the road-type categories. In some cases, particularly where the combination of these variables was atypical, sections were assessed based on the design type and extent of adjacent road sections. The appropriate category was then assigned based on this assessment.

2.5.3 Scope of Analysis and Mapping

Risk maps were developed for the selected road system throughout the entire state. The roads included in the Kentucky pilot study are shown in Figure 14.

2.5.4 Segmentation

Segmentation for the study sections in Kentucky was developed from available road inventory data. The objective of the segmentation process is to define continuous road segments that are as long as practical while remaining relatively homogeneous. The segments in most state road inventory data bases are relatively short. Therefore, the project team developed a procedure for aggregation of adjacent sections:

- with same county, route number, and road type
- with speed limits within 5 mph
- with ADTs within 20 percent, or within 2,000 veh/day
- with similar ADT, same road type, and speed limits less than or equal to 50 mph in towns or rural communities
- with very short sections with speed limits greater than or equal to 55 mph, with same road type and similar ADT
- of extremely short length
- with speed limits less than or equal to 50 mph just outside a town with similar sections within the town

In some cases, particularly where extremely short sections were not aggregated by the preceding rules, these rules were modified to eliminate unrealistically short analysis sections. Even with the aggregation of road sections described above, the roadway sections in the Kentucky pilot study are shorter and experience fewer expected fatal and

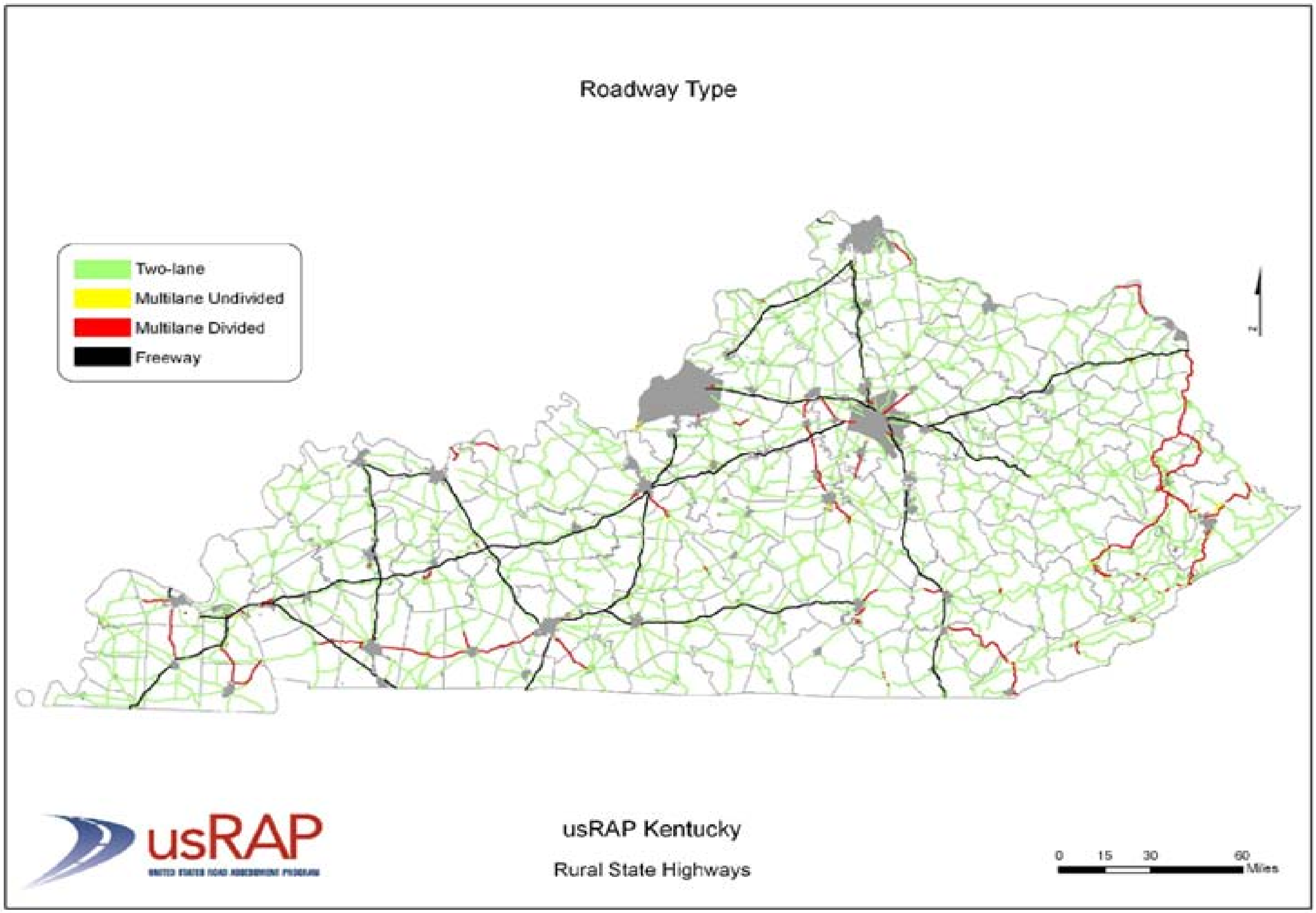


Figure 14. Roads Included in Kentucky Pilot Study

major injury crashes than the road sections used by EuroRAP. The EuroRAP sections averaged approximately 12 mi in length, while those for the Kentucky pilot study averaged only 3.5 mi in length. However, if the EuroRAP criterion that road sections should average 20 fatal and major injury crashes in three years were applied in Kentucky, road sections much longer than 12 mi would be needed. Such long sections would reduce the usefulness of the maps in defining risk in a way that would help in identifying future safety improvement projects. Therefore, a decision was reached to retain the shorter section lengths in the Kentucky pilot study.

2.5.5 Crash Type, Selection, and Assignment

For all maps prepared in the Kentucky pilot study, only fatal- and incapacitating-injury crashes were analyzed. For the remainder of this section, presentation and discussion of crashes, and crash-based data, are limited to fatal- and incapacitating-injury crashes on rural state roads. For consistency with previous pilot studies, the State's crash severity level for incapacitating injuries is referred to on the maps as major injuries.

Crashes were located, their coordinates were derived, and they were assigned to specific roadway segments using the best available GIS cartography.

2.5.6 Study Period and Data Summary

As in the other usRAP pilot studies completed to date, five years of data (2002-2006) were selected for analysis and presentation.

Table 3 presents crash totals for 10,784 centerline mi of rural state highways for each year of the study period.

Table 3. Crashes by Severity Level for Kentucky Pilot Study

Year	Fatal crashes	Incapacitating injury crashes	Total fatal and major injury crashes
2002	385	1,823	2,208
2003	463	1,672	2,135
2004	458	1,562	2,020
2005	431	1,569	2,000
2006	402	1,499	1,901
Total	**2,139**	**8,125**	**10,264**

2.5.7 Risk Maps

Following is a summary of the data used for risk mapping in the Kentucky pilot study:

- Statewide totals for rural state highways
  - 3,111 segments
  - 10,784 mi of road
  - 21.7 billion annual veh-mi of travel (VMT)
  - 10,264 fatal and incapacitating injury crashes
- Statewide averages for analysis sections on rural state highways
  - Average length = 3.5 mi
  - AADT = 5,524 veh/day
  - Fatal and incapacitating injury crashes = 0.66 crashes/section/year
  - Fatal and incapacitating injury crash density = 0.19 crashes/mi/year
  - Average crash rate = 9.44 per 100M VMT

Table 4 presents the summary information for rural state roads.

Table 4. Summary of Risk Mapping Data for Kentucky Pilot Study

						Fatal and major injury crashes			
Road type[a]	Number of sections	Total length (mi)	Average length (mi)	AADT (veh/day)	Annual VMT (billion)	Total frequency	Annual frequency	Annual density (per mi)	Average rate (per 100M VMT)
Freeway	129	1,082	8.4	22,065	8.7	1,332	2.07	0.25	3.06
Multilane divided	255	592	2.3	11,480	2.5	911	0.71	0.31	7.35
Multilane undivided	92	45	0.5	13,842	0.2	126	0.27	0.56	11.09
Two-lane roads	2,635	9,066	3.4	3,120	10.3	7,895	0.60	0.17	15.29
Total	**3,111**	**10,784**	**3.5**	**5,524**	**21.7**	**10,264**	**0.66**	**0.19**	**9.44**

[a] Parkways in Kentucky include both freeways and conventional road types and were assigned to these categories as appropriate.

2.5.7.1 Selection of Risk Categories for Use on Risk Maps

The statewide risk maps for the Kentucky pilot study use the same risk categories developed in the same manner as the risk categories in the other usRAP pilot studies. The risk categories and their associated colors are as follows:

- dark green (lowest risk) 40 percent of roadway length
- light green 25 percent of roadway length
- yellow 20 percent of roadway length
- red 10 percent of roadway length
- black (highest risk) 5 percent of roadway length

The highest risk category (shown in black on the various maps) should assist in meeting the Federal mandate that states identify 5 percent of locations with the most severe safety needs.

Examples of all risk maps for the Kentucky pilot study are presented in below. These risk maps have been developed using five years of data.

As in the other usRAP pilot studies, road sections with two or fewer fatal- or major-injury crashes in five years were not included in the two highest risk categories. It did not appear appropriate to classify sections with limited crash experience as high risk, since they generally had short lengths or very low traffic volumes, so a criterion was adopted that no road section would be considered for classification in the two highest risk categories (red and black on the various maps) unless it experienced more than two fatal- or major-injury crashes in five years; such low-crash-count segments with higher risk measures generally appear in the medium risk (yellow) category on the maps presented.

2.5.7.2 Road Section Crash Density Maps (Map 1)

The first type of risk map developed was the annual crash density map (Map 1). Figure 15 is a typical crash density map for all rural state highways in Kentucky.

2.5.7.3 Road Section Crash Rate Maps (Map 2)

Risk maps based on crash rate per 100 million veh-mi of travel were also developed for Kentucky roads. While five years of crash data were used, a single AADT value was used to compute exposure. Figure 16 presents a typical crash rate map for Kentucky roads.

2.5.7.4 Ratio of Crash Rate Relative to Similar Road Types (Map 3)

Figure 17 presents a map based on the ratio of fatal- and major-injury crash rate for each road section to the average rate of similar roads (Map 3).

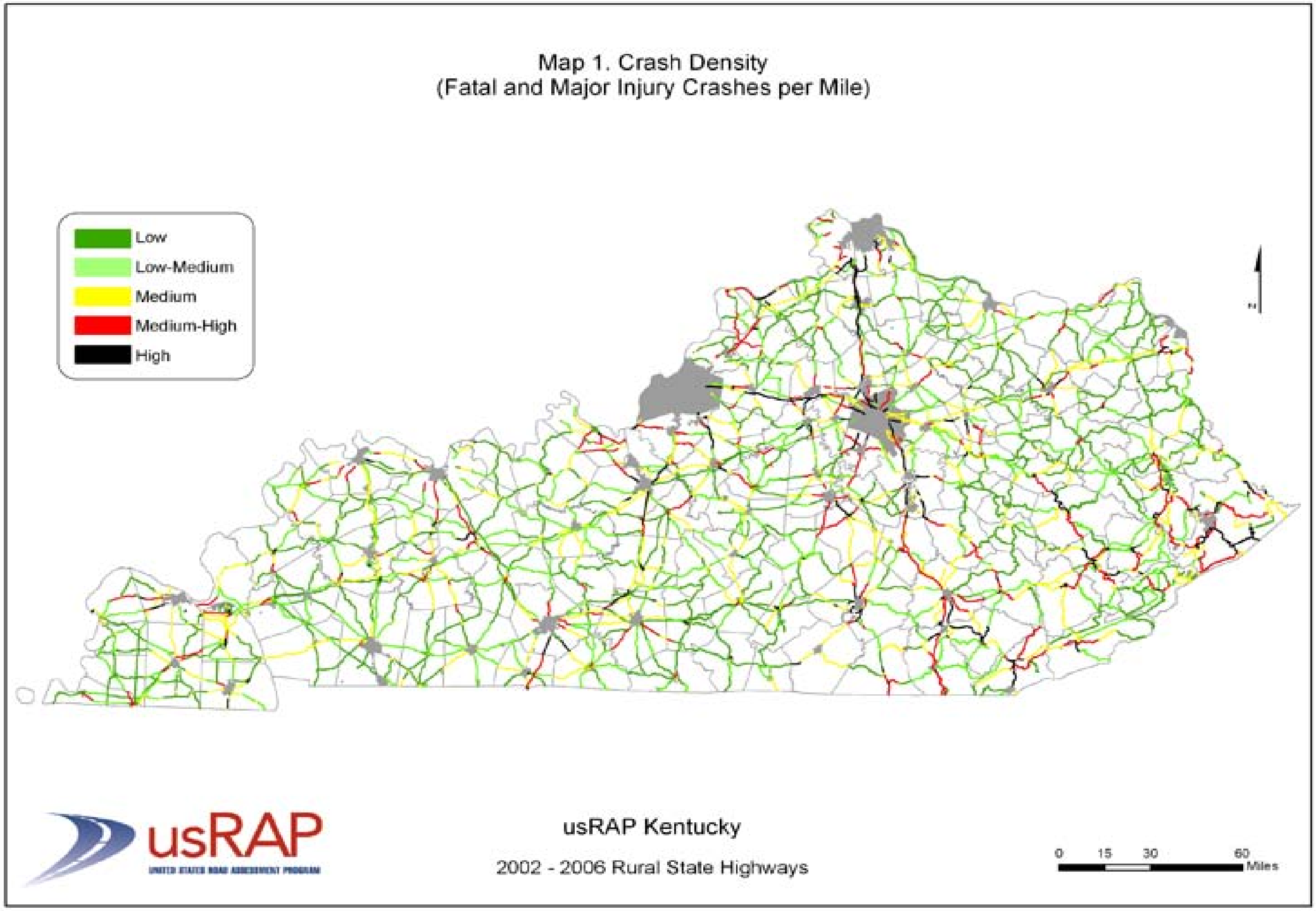
2.5.7.5 Potential Crash Savings (Map 4)

Map 4 indicates the potential for reducing fatal- and major-injury crashes if road sections with above-average crash rates could be brought to the average crash rate for roads of similar type. Figure 18 presents a typical map of potential crash savings for state highways in Kentucky.

2.5.7.6 Supplementary Maps

Supplementary risk maps have been prepared as part of the Kentucky pilot studies in a manner similar to those prepared for previous pilot studies. The supplementary map types prepared for Kentucky include:

- speed-involved crashes
- alcohol-involved crashes
- aggressive driving crashes
- lane-departure crashes



15. Example of Map 1 for Kentucky

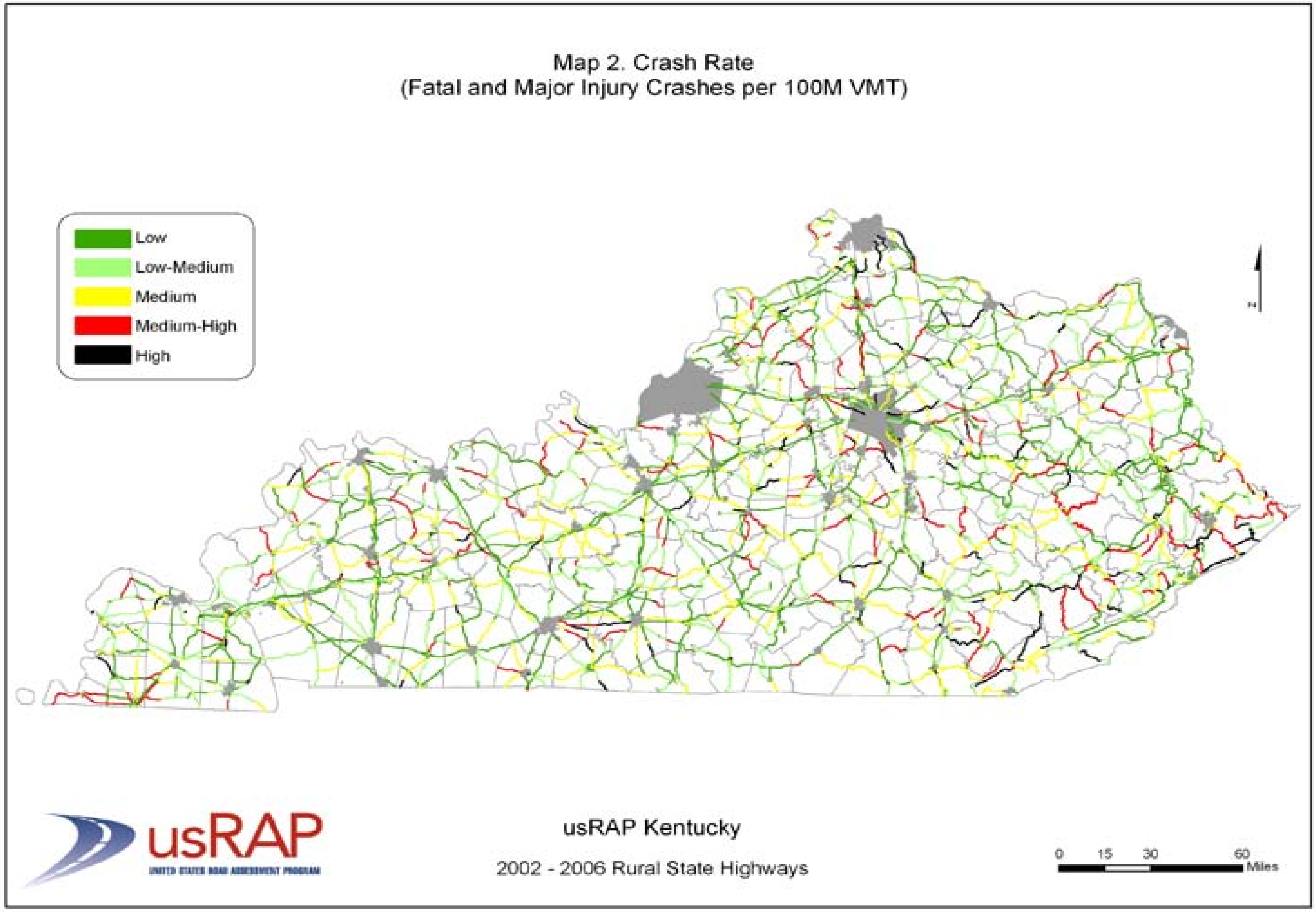


Figure 16. Example of Map 2 for Kentucky

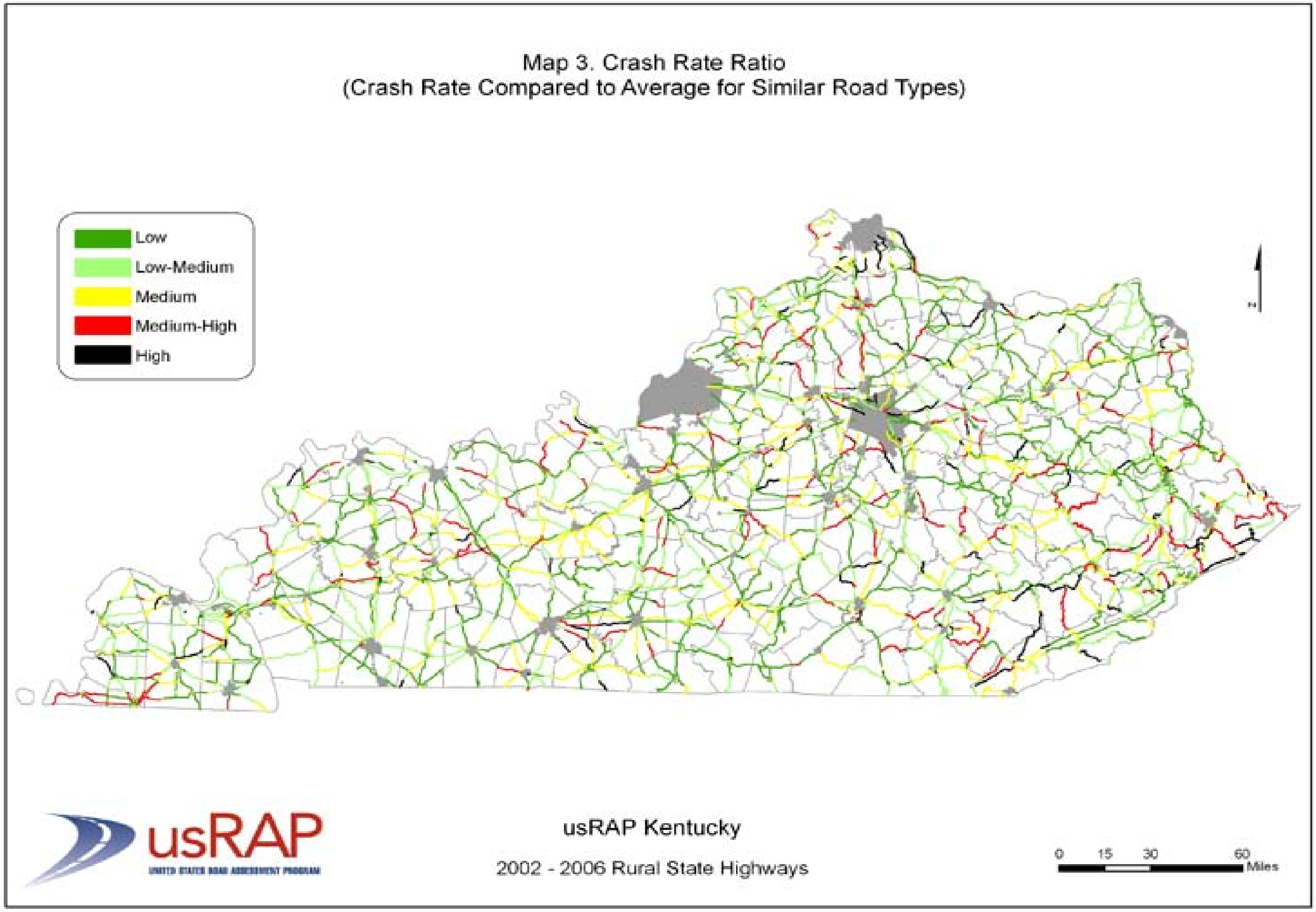


Figure 17. Example of Map 3 for Kentucky

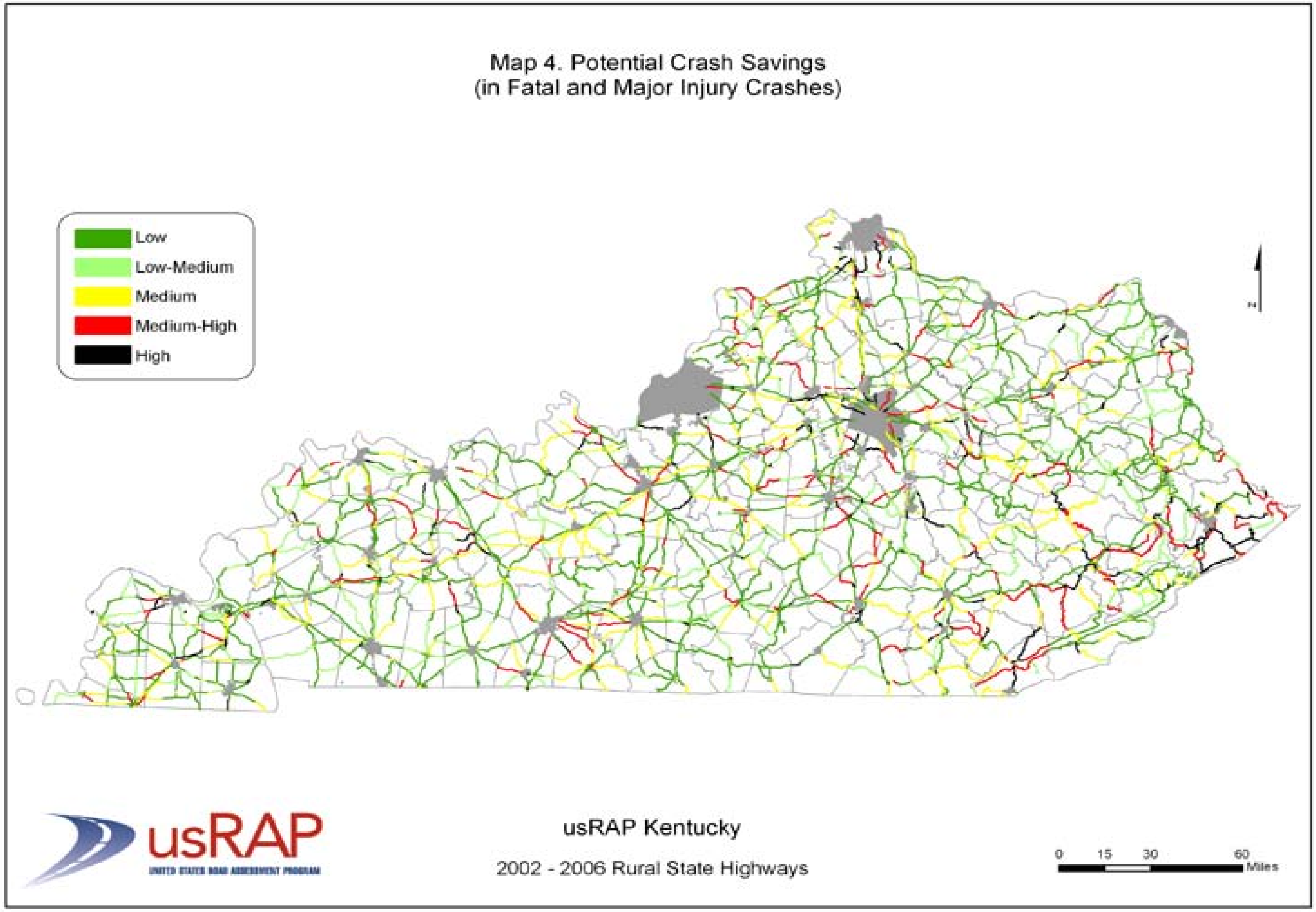


Figure 18. Example of Map 4 for Kentucky

Maps analogous to Maps 1 through 4 were prepared for speed-involved crashes in Kentucky (see Figures 19 through 22). Speed-involved crashes in Kentucky were identified from a state-defined speed-involved crash code. For each of these maps, a minimum of two fatal- and major-injury speed-involved crashes were required for a road section to be considered medium-high or high risk.

Maps analogous to Maps 1 through 4 were prepared for alcohol-involved crashes in Kentucky (see Figures 23 through 26). Alcohol-involved crashes in Kentucky were identified if one of two codes was used in the state crash data:

- one of the drivers is suspected of drinking
- the human factor of alcohol is involved

For each of these maps, a minimum of two fatal and major injury alcohol-involved crashes were required for a road section to be considered medium-high or high risk.

Maps analogous to Maps 1 through 4 were prepared for aggressive-driving crashes in Kentucky (see Figures 27 through 30). Aggressive-driving crashes in Kentucky were identified from a state-defined aggressive-driving crash code. For each of these maps, a minimum of two fatal- or major-injury lane-departure crashes were required for a road section to be considered medium-high or high risk.

Maps analogous to Maps 1 through 4 were prepared for lane-departure crashes in Kentucky (see Figures 31 through 34). Lane-departure crashes in Kentucky were identified from a state-defined lane-departure crash code. Lane-departure crashes in Kentucky are defined in a manner similar to roadway-departure crashes in other states. For each of these maps, a minimum of three fatal- or major-injury lane-departure crashes were required for a road section to be considered medium-high or high risk.

2.5.8 Use of the usRAP Maps in Kentucky

The usRAP maps will be used to supplement other data sources that support the Kentucky Transportation Cabinet’s Highway Safety Improvement Program, which may lead to safety projects to address infrastructure needs.

2.6 Results of the New Mexico Pilot Study

The New Mexico pilot study was conducted in cooperation with the New Mexico Department of Transportation. This section presents the results of the New Mexico pilot study. The section first discusses general issues concerning the roadway network included in the pilot study, the manner in which that roadway network was divided into road segments for analysis, and the data that were assembled for analysis. The results of risk mapping are then presented.

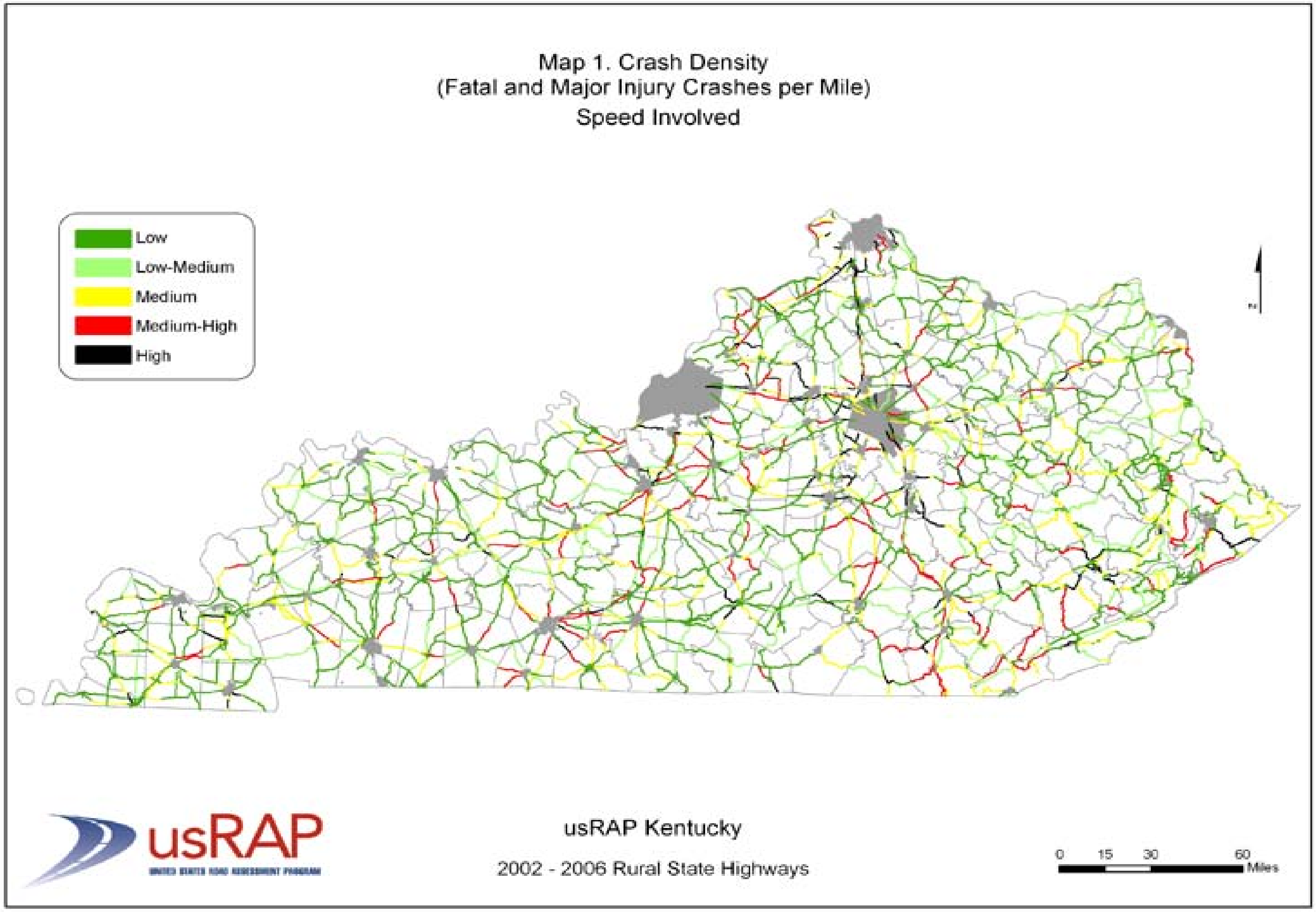


Figure 19. Kentucky Map 1 for Speed-Involved Crashes

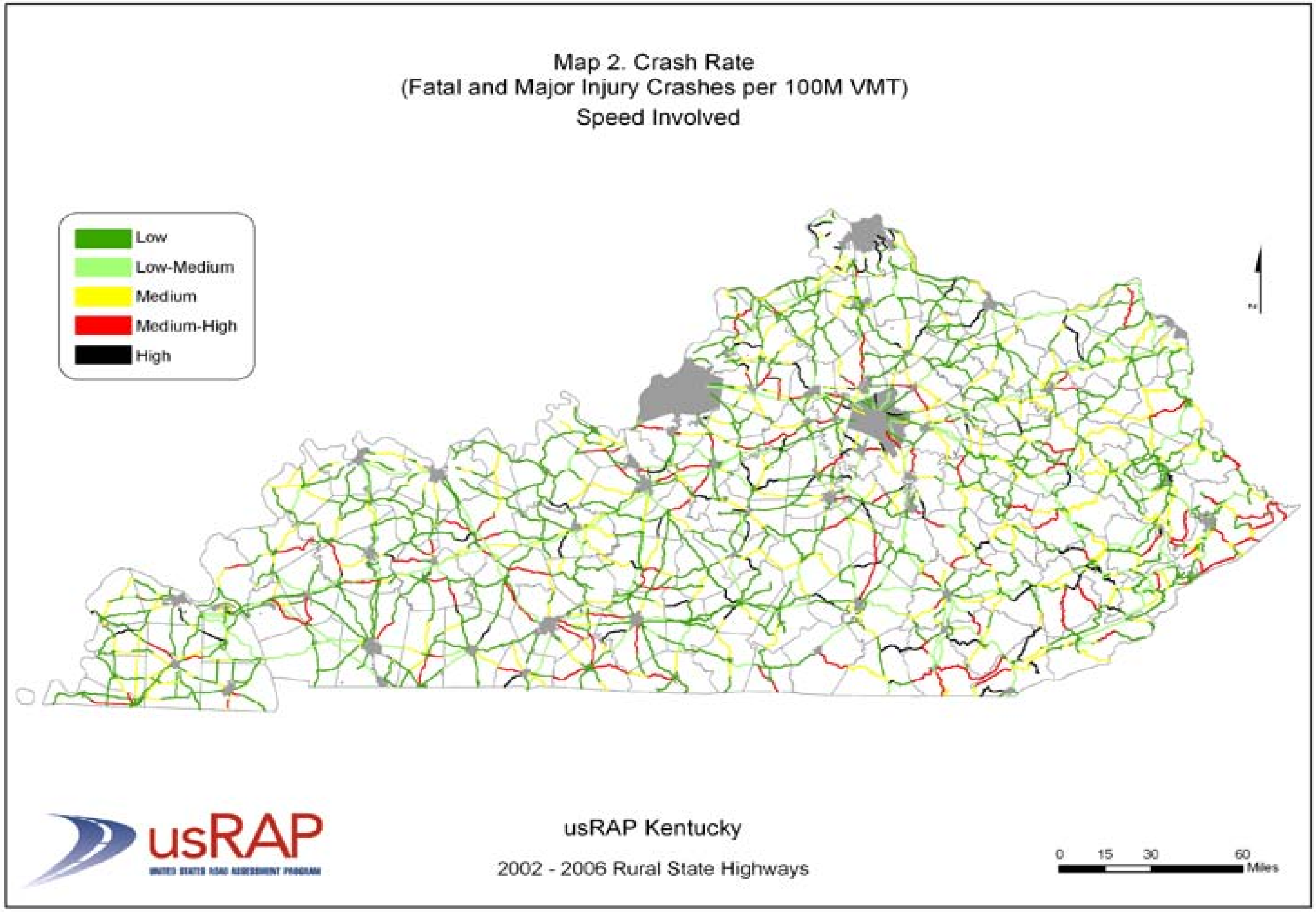


Figure 20. Kentucky Map 2 for Speed-Involved Crashes

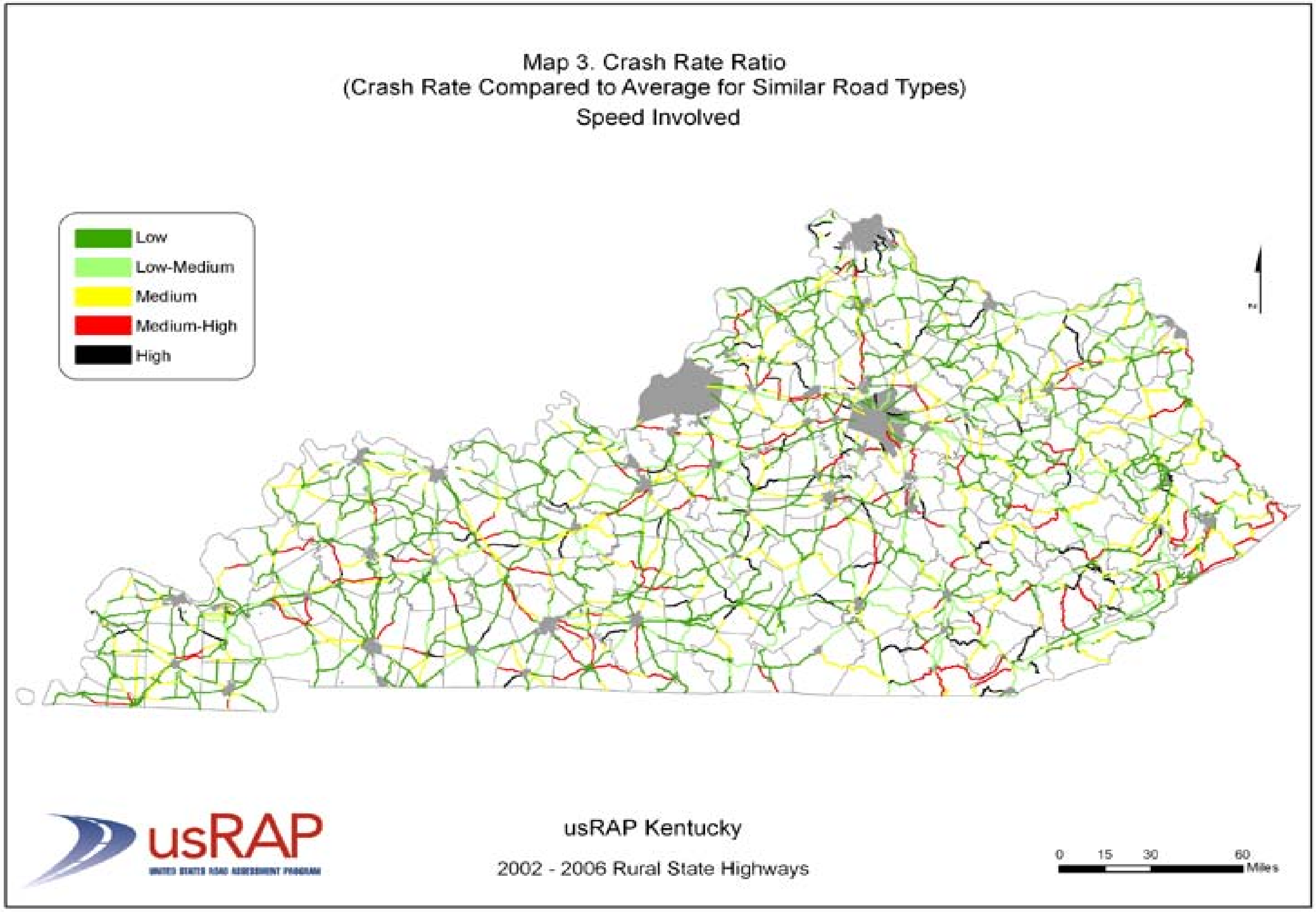


Figure 21. Kentucky Map 3 for Speed-Involved Crashes

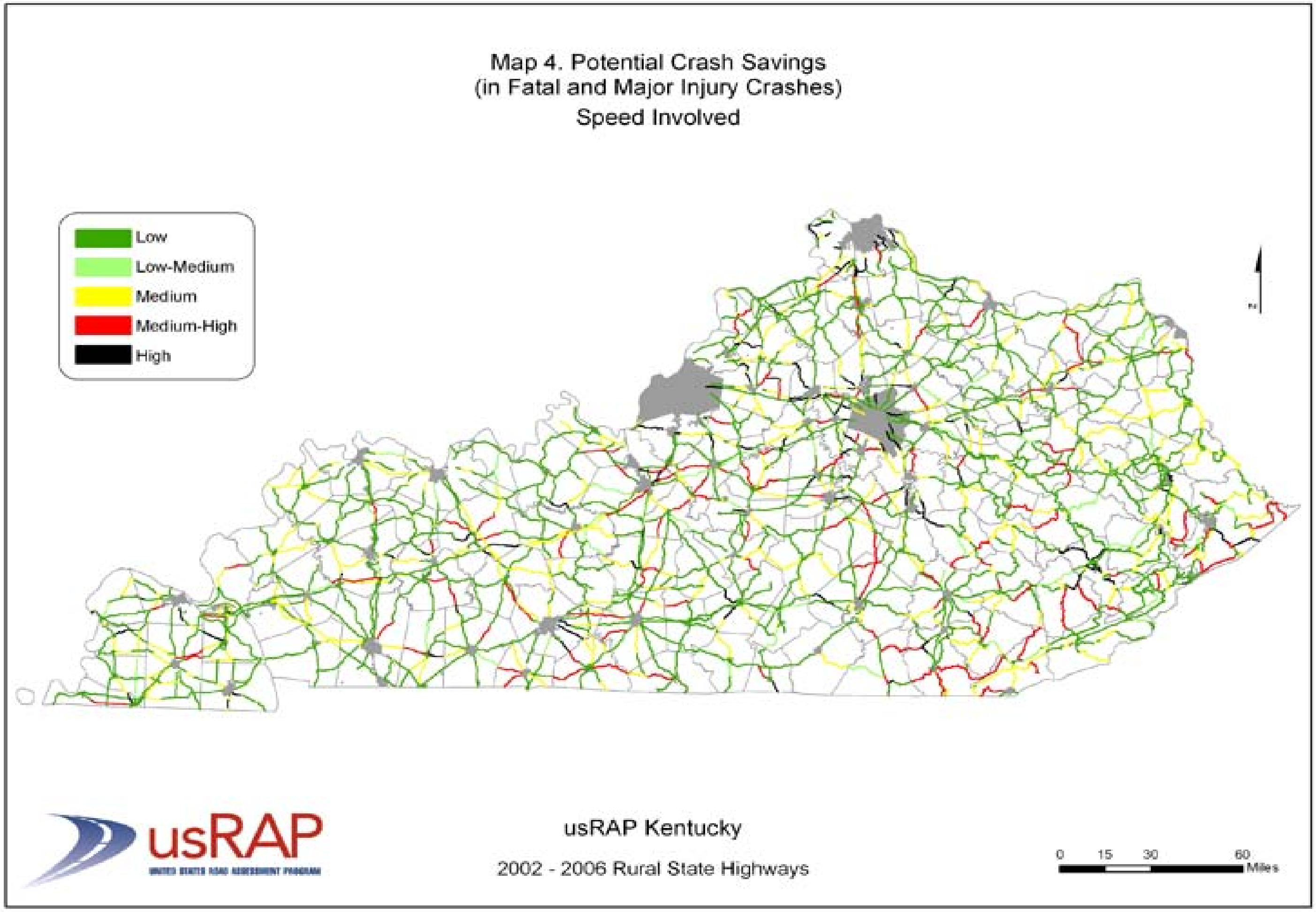


Figure 22. Kentucky Map 4 for Speed-Involved Crashes

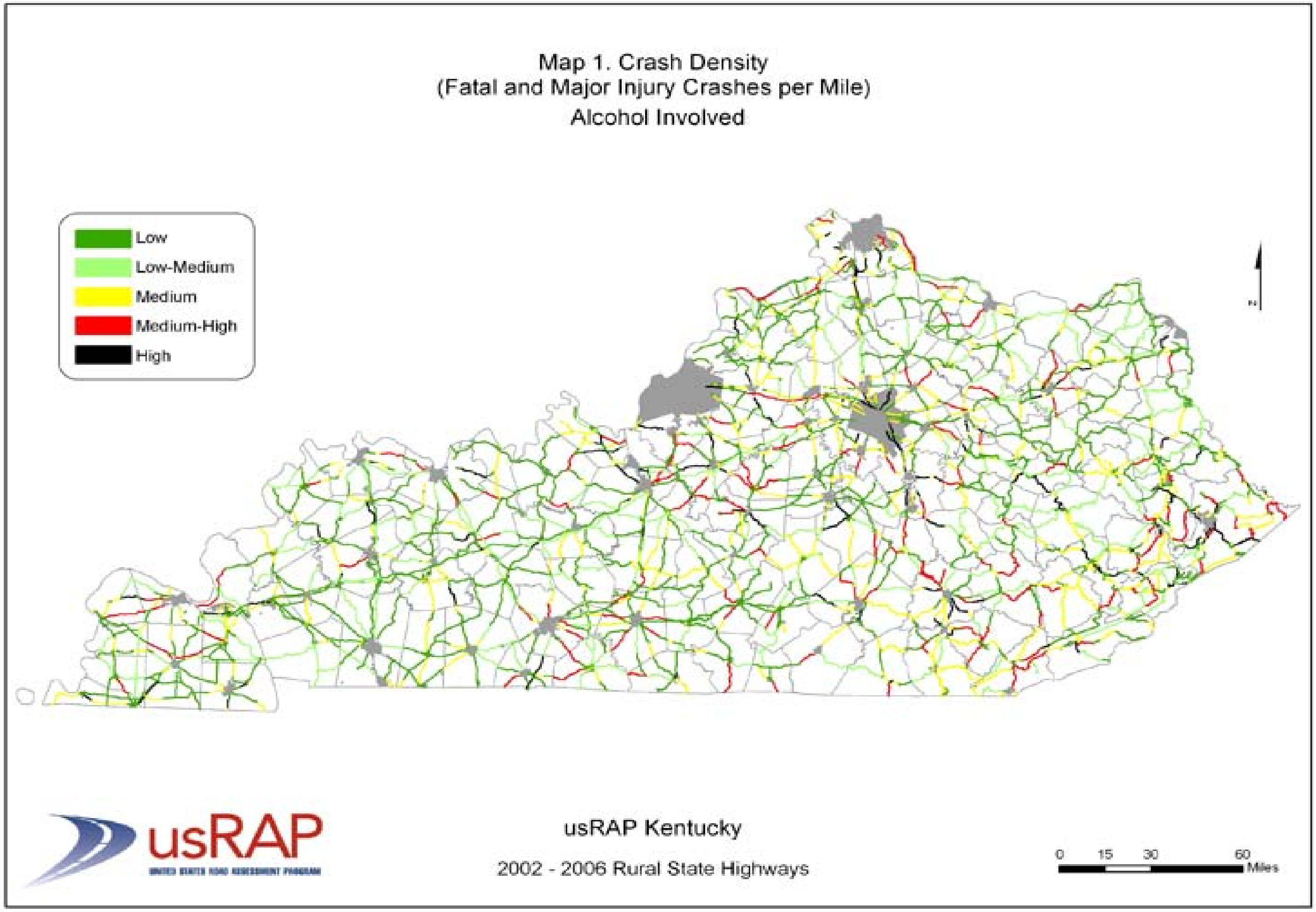


Figure 23. Kentucky Map 1 for Alcohol-Involved Crashes

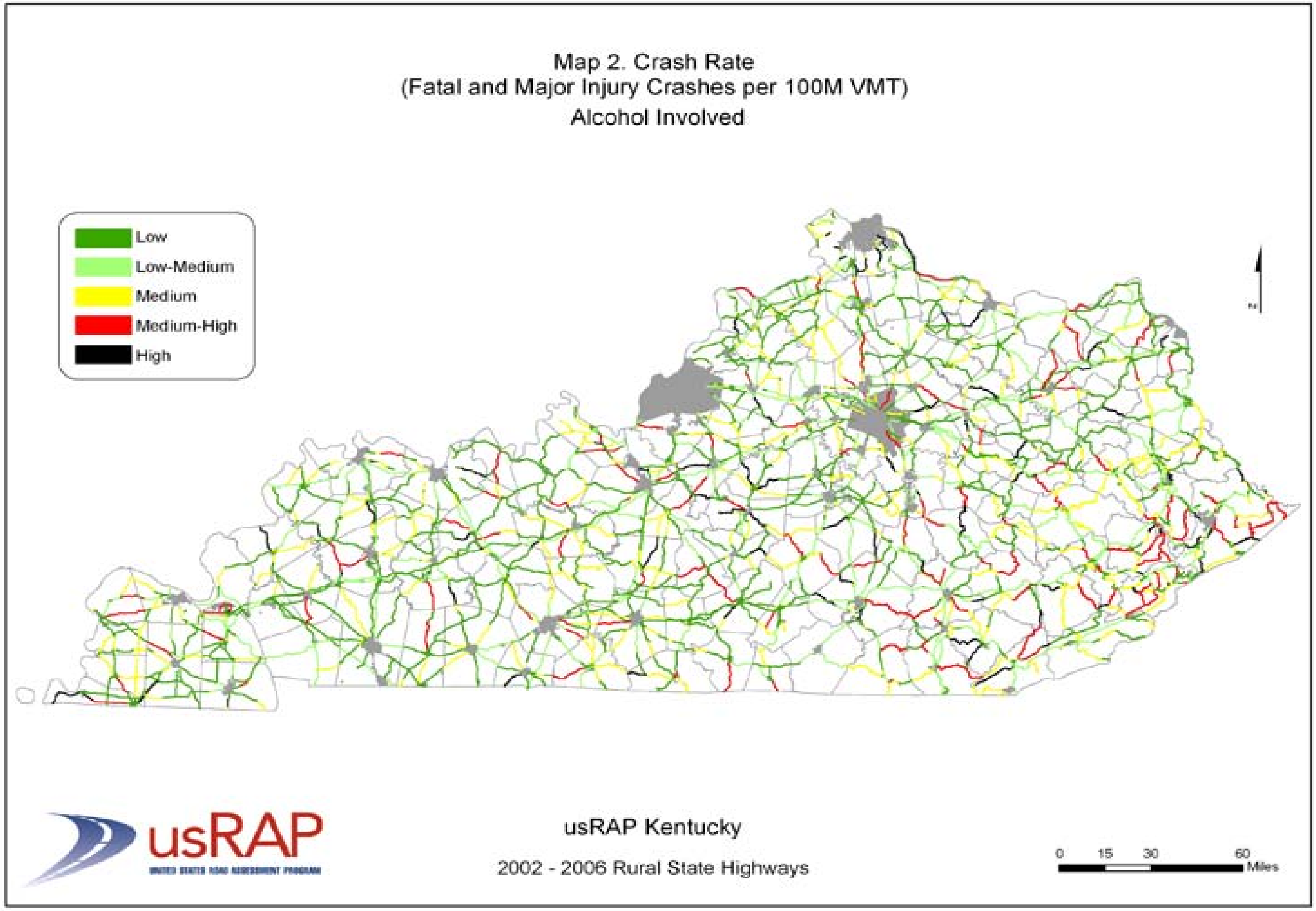


Figure 24. Kentucky Map 2 for Alcohol-Involved Crashes

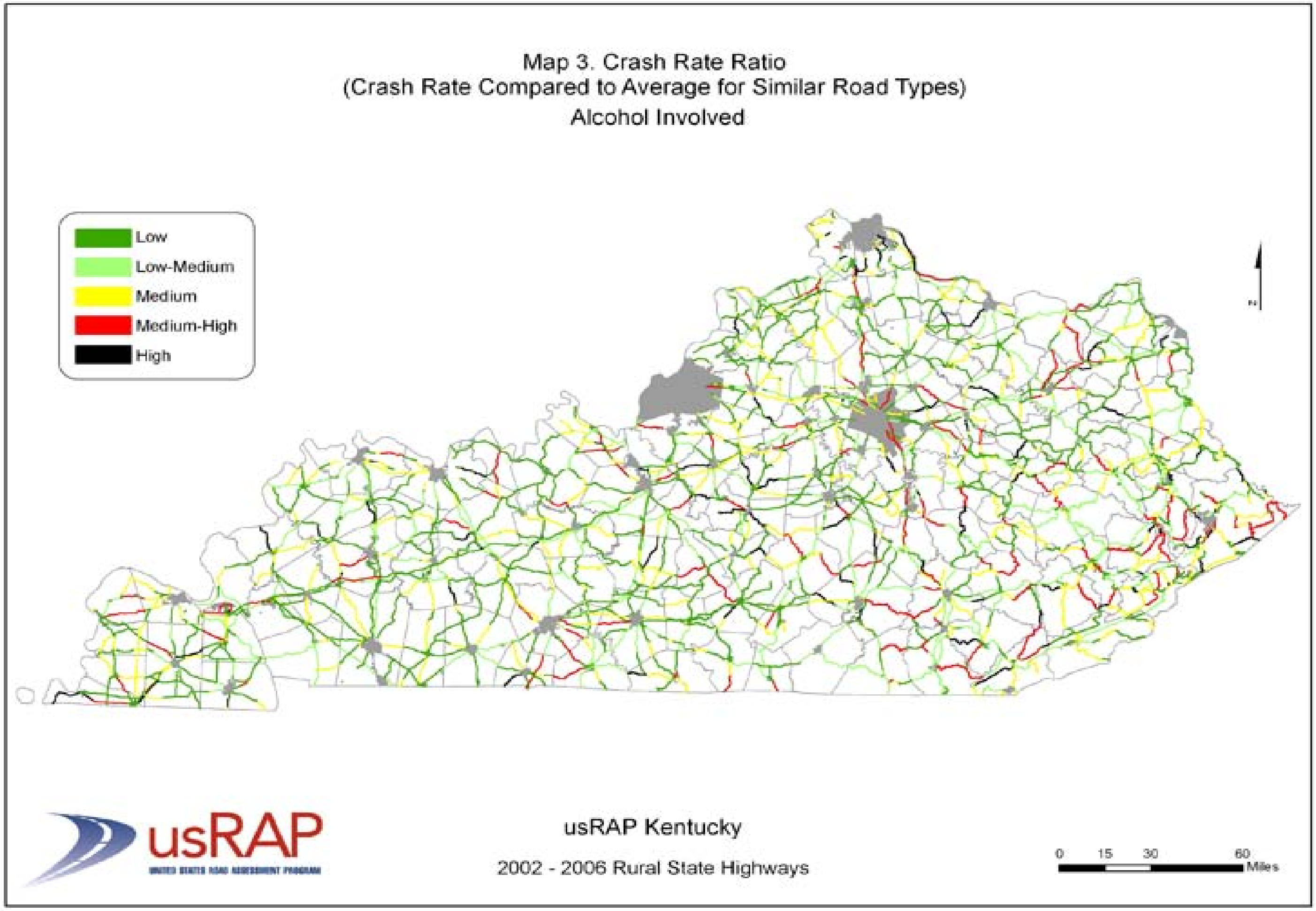


Figure 25. Kentucky Map 3 for Alcohol-Involved Crashes

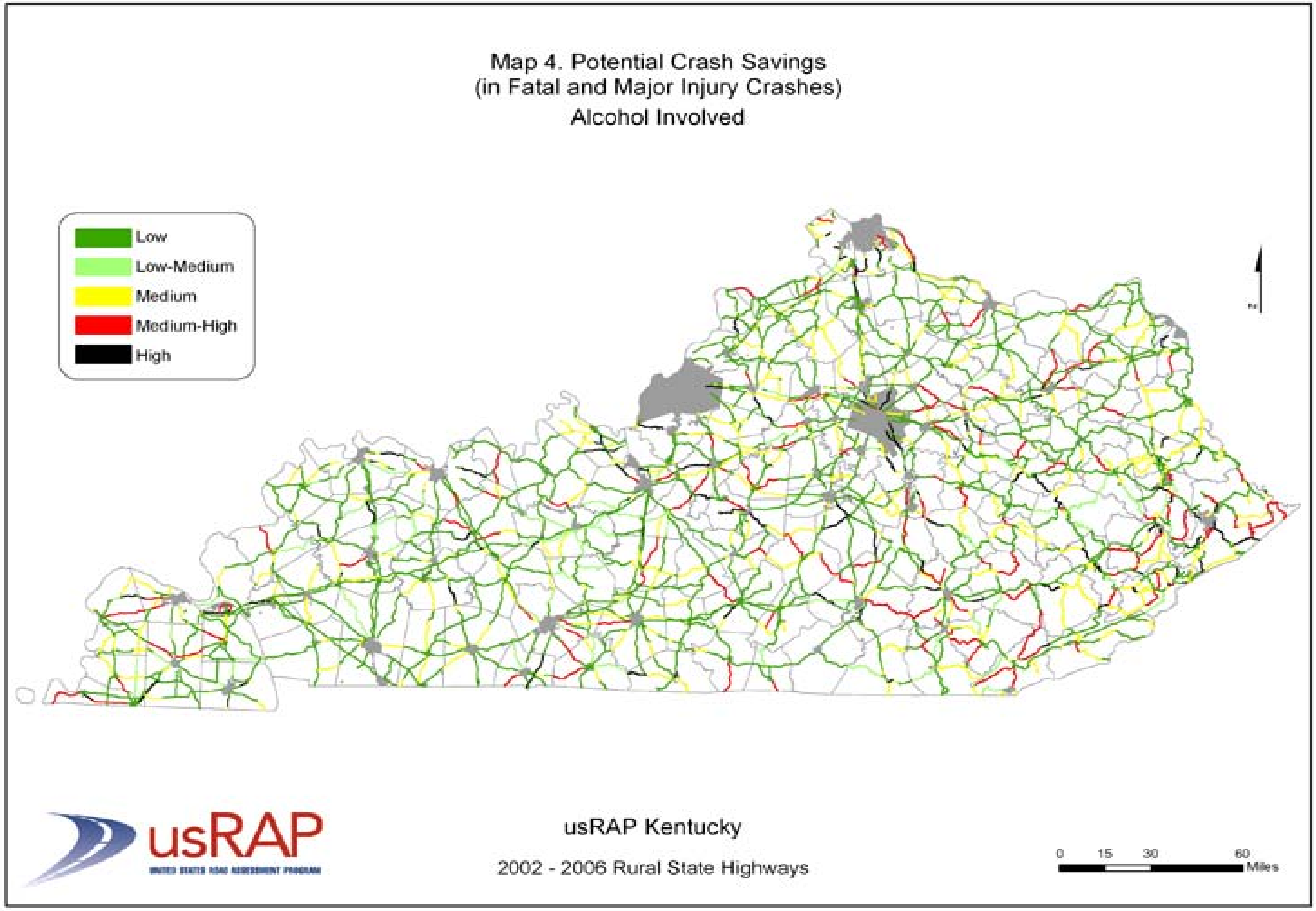


Figure 26. Kentucky Map 4 for Alcohol-Involved Crashes

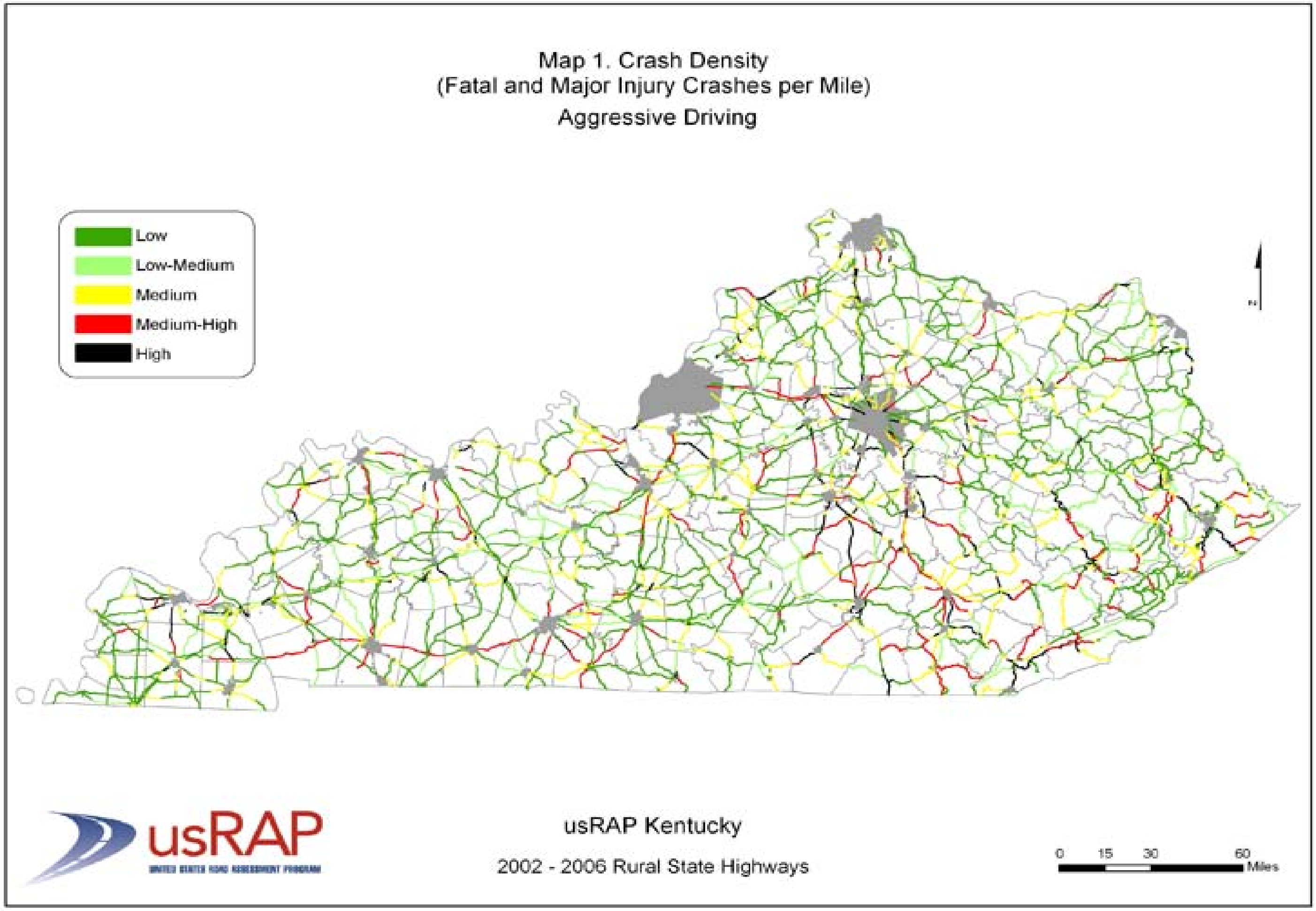


Figure 27. Kentucky Map 1 for Aggressive-Driving Crashes

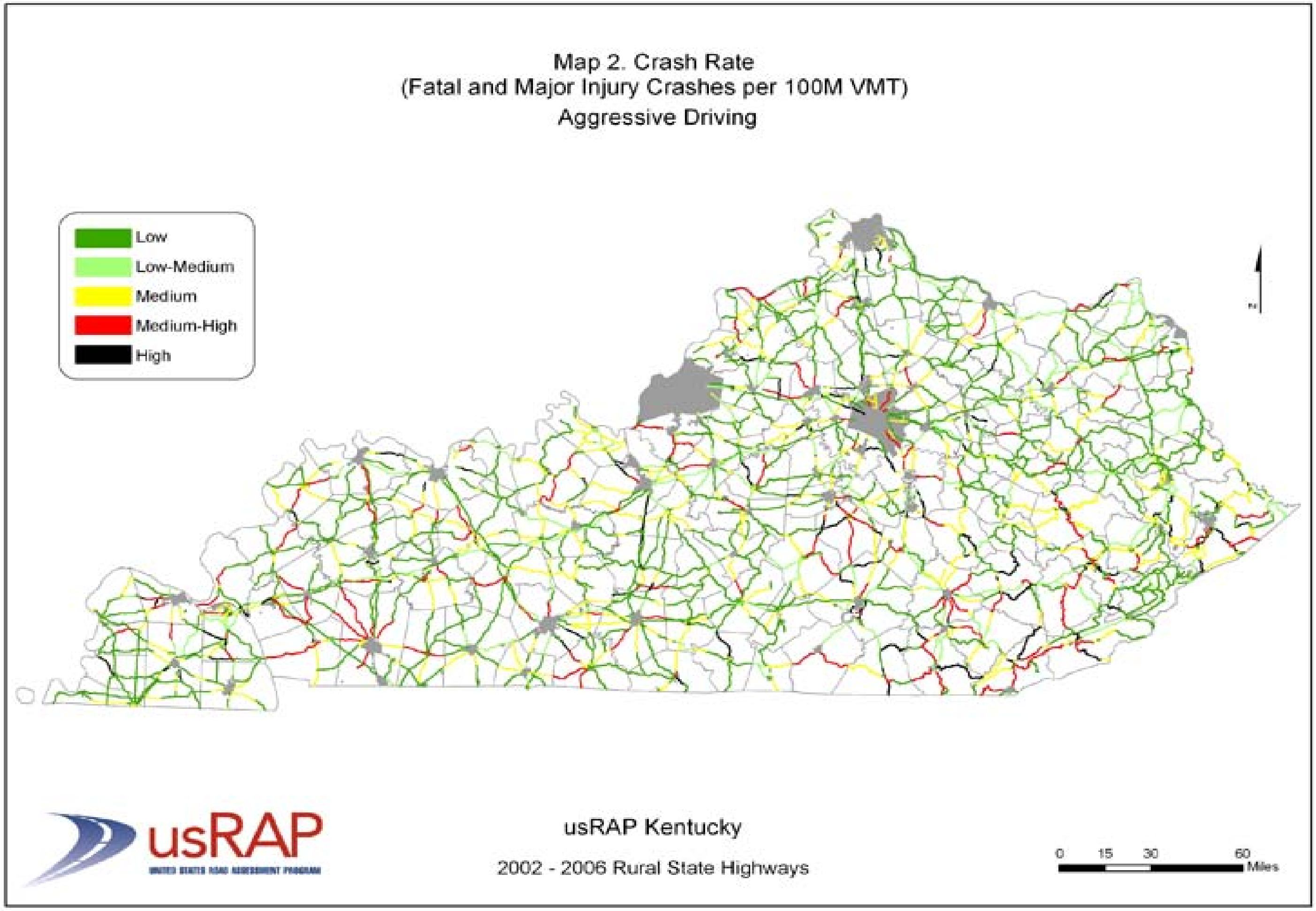


Figure 28. Kentucky Map 2 for Aggressive-Driving Crashes

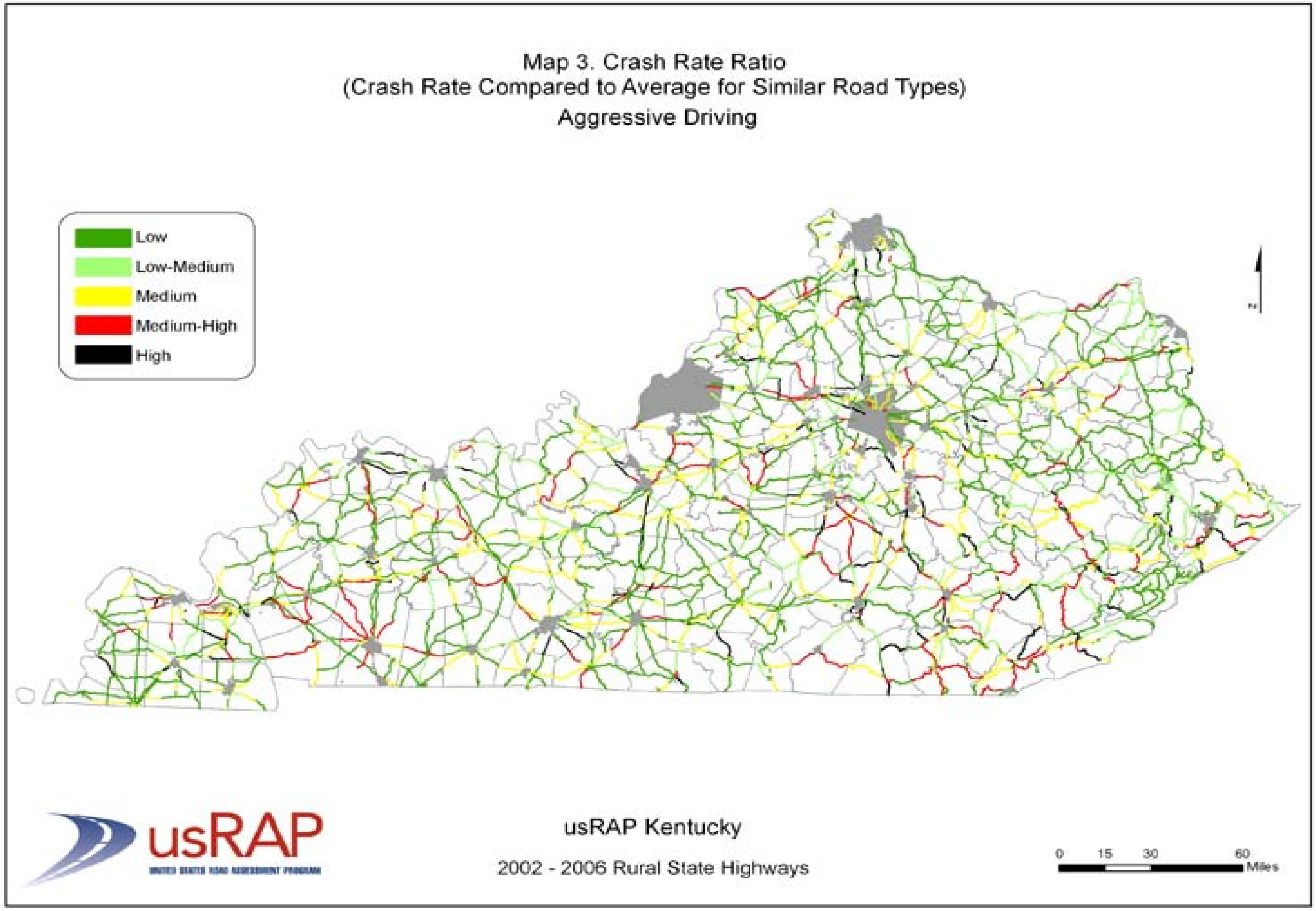


Figure 29. Kentucky Map 3 for Aggressive-Driving Crashes

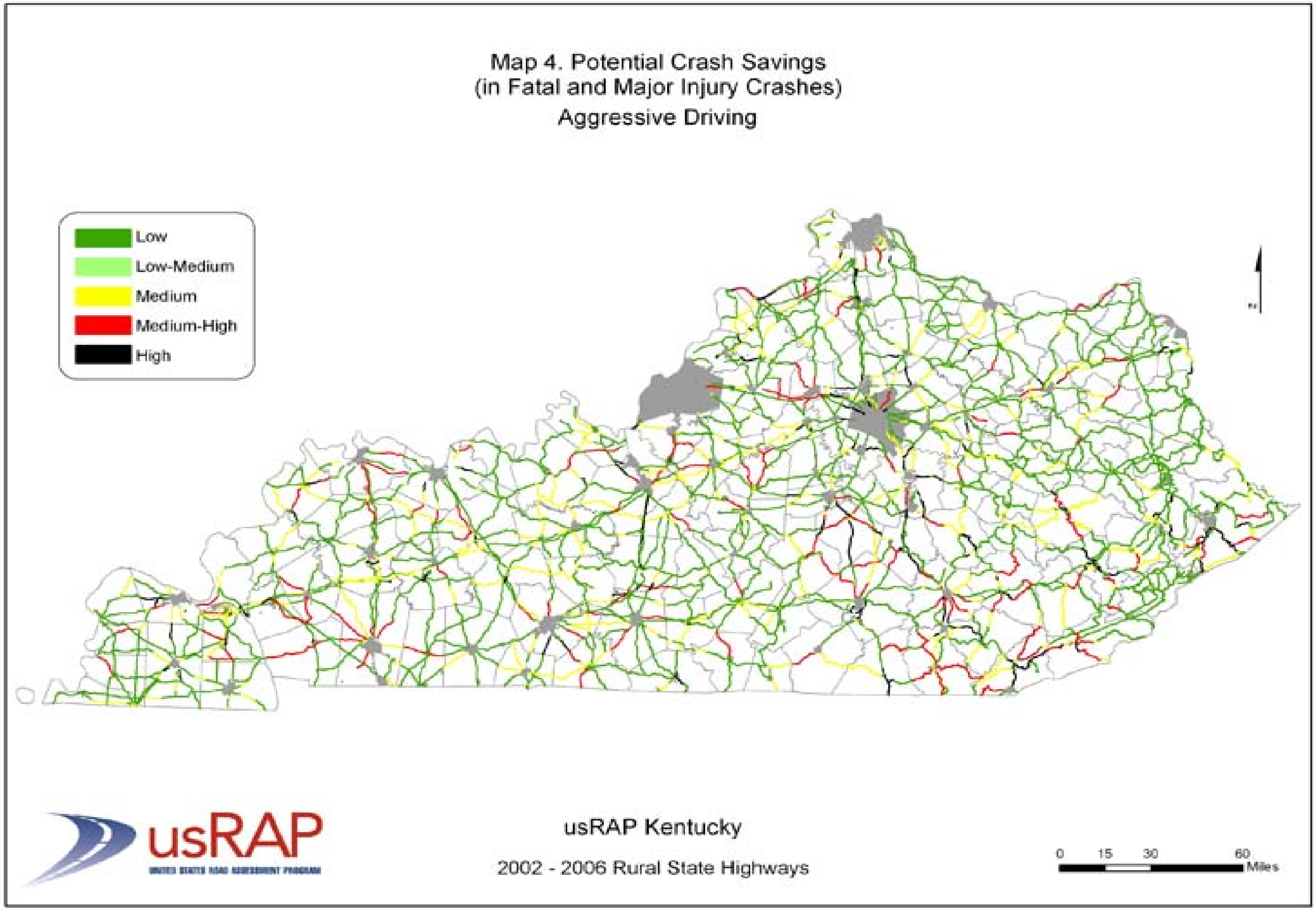


Figure 30. Kentucky Map 4 for Aggressive-Driving Crashes

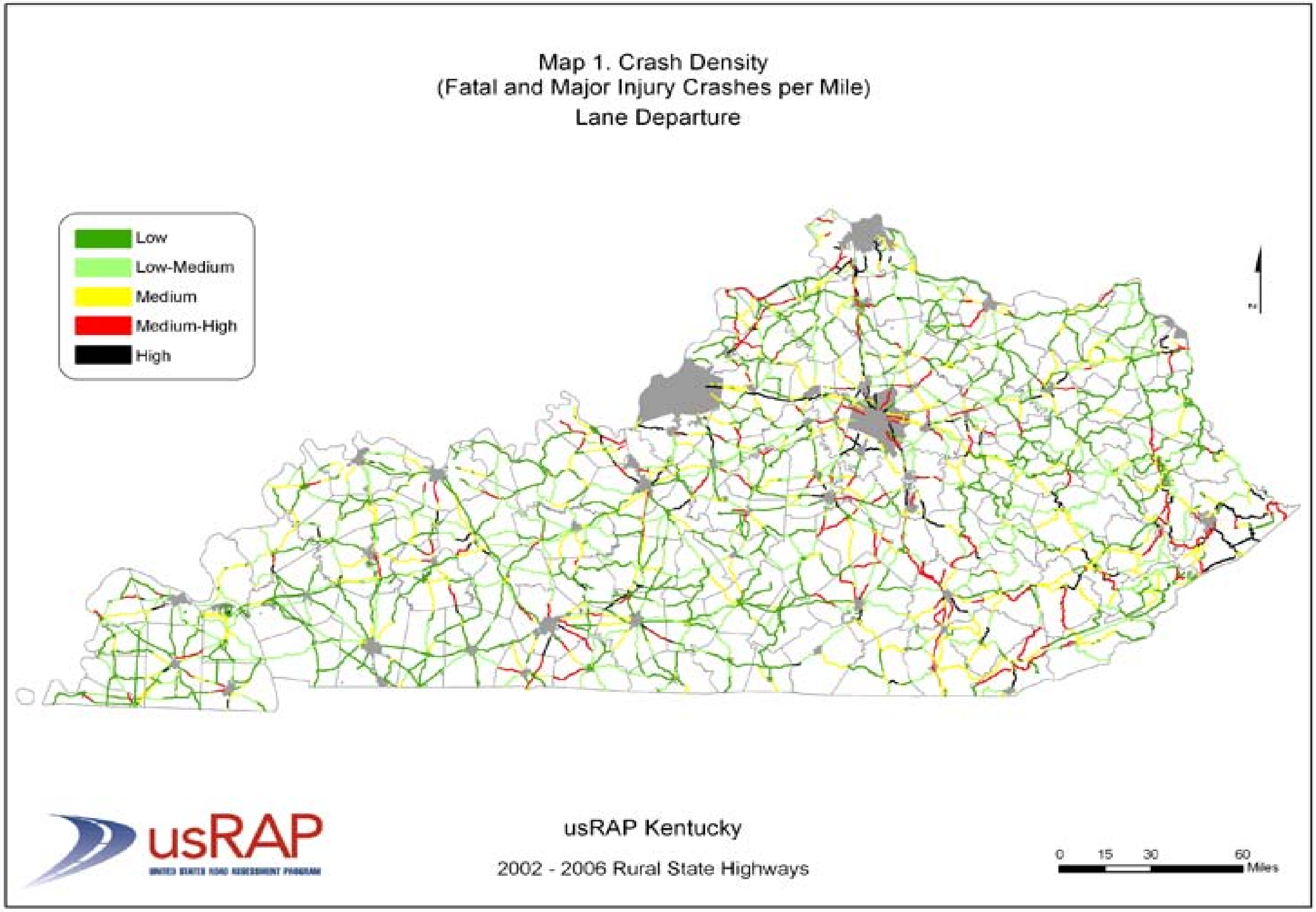


Figure 31. Kentucky Map 1 for Lane-Departure Crashes

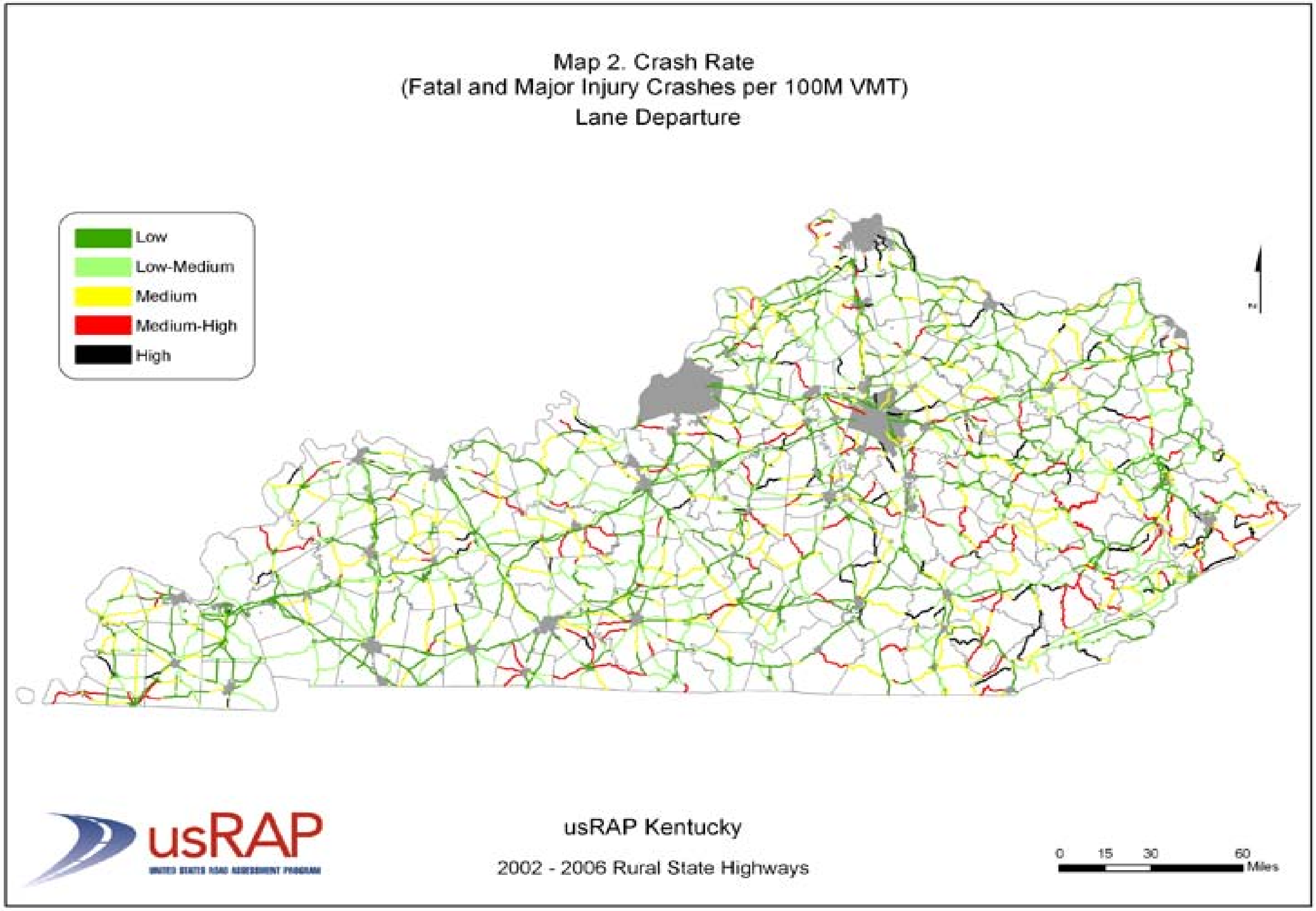


Figure 32. Kentucky Map 2 for Lane-Departure Crashes

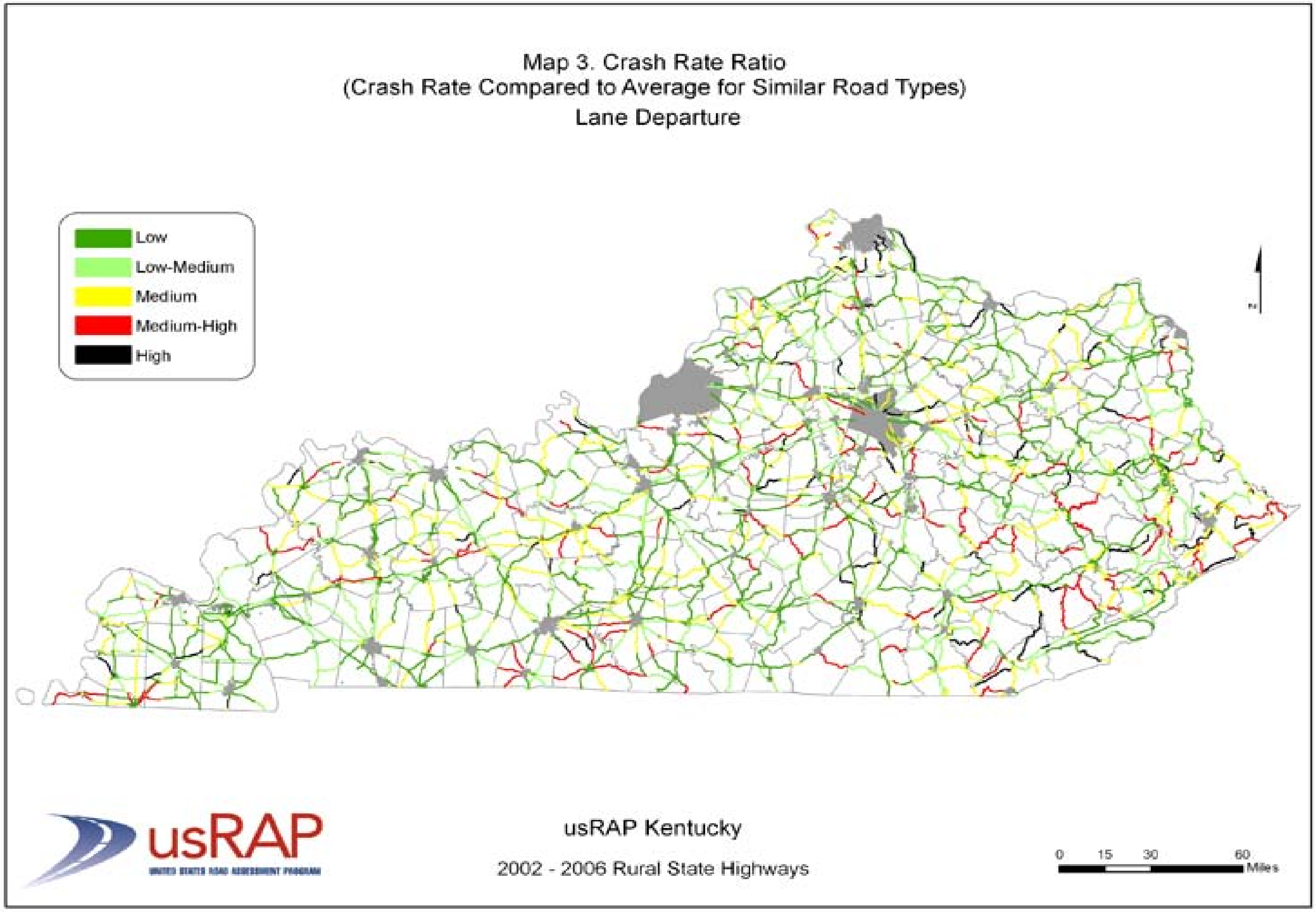


Figure 33. Kentucky Map 3 for Lane-Departure Crashes

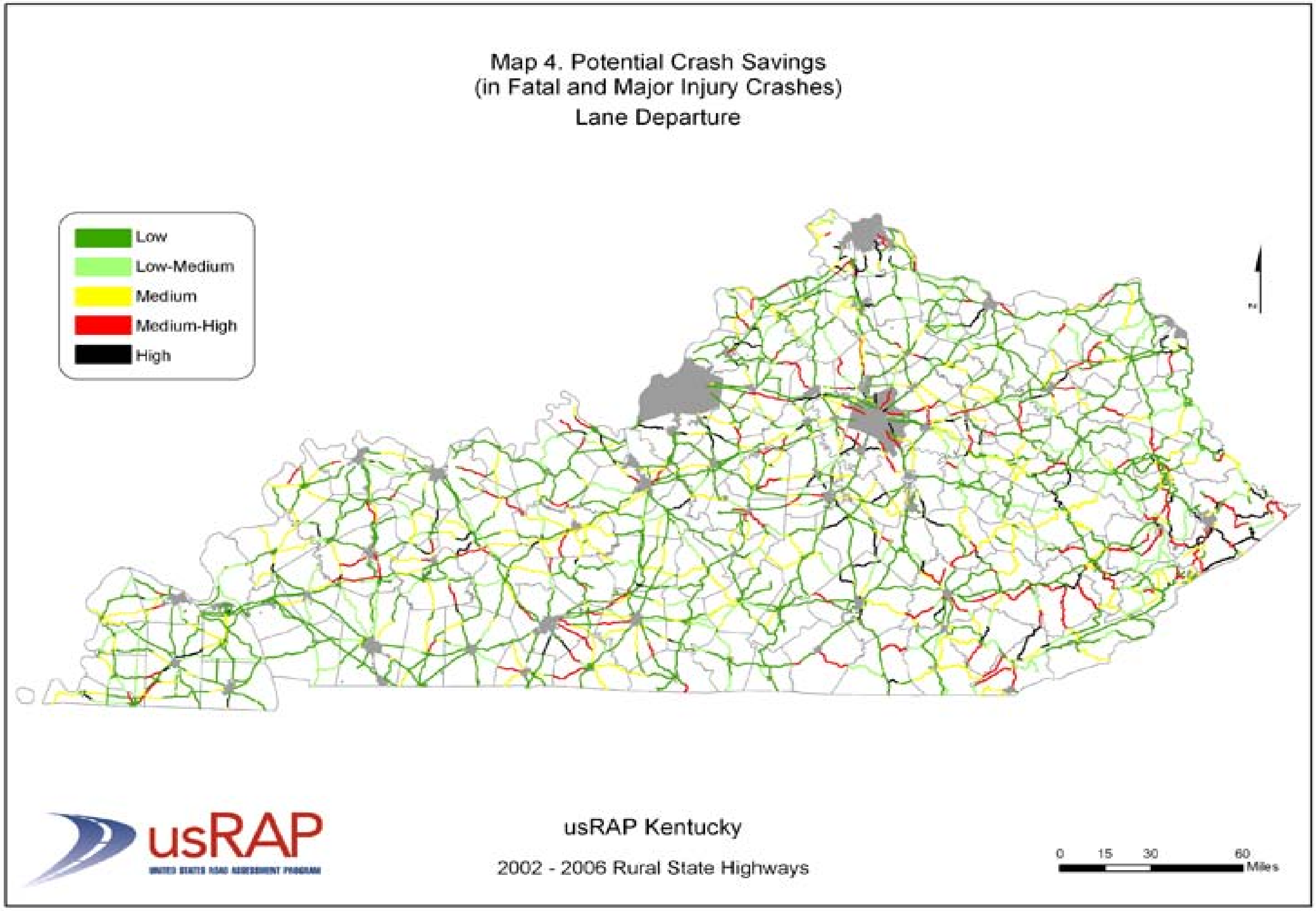


Figure 34. Kentucky Map 4 for Lane-Departure Crashes

2.6.1 Roads Selected for Inclusion in Mapping

State primary roads were considered in the New Mexico pilot study. These roads include Interstate, US, and state-numbered routes. Both rural and urban roads were included in the New Mexico pilot study.

2.6.2 Road Classification

Roads included in this pilot study were classified into eight road types: rural freeway, rural multilane divided highway, rural multilane undivided, rural two-lane roads, urban freeway, urban multilane divided highway, urban multilane undivided, and urban two-lane roads. The road type definition was based on access control, median type, and number of lanes. The distinction between rural and urban area types was based on the State's functional classification data. Unique combinations of these variables were assigned to one of the road-type categories. In some cases, particularly where the combination of these variables was atypical, sections were assessed based on the design type and extent of adjacent road sections. The appropriate category was then assigned based on this assessment.

2.6.3 Scope of Analysis and Mapping

Risk maps were developed for the selected road system throughout the entire state, including both urban and rural roadways. The roads included in the pilot study are shown in Figure 35.

2.6.4 Segmentation

Segmentation for the study sections in New Mexico was developed from available road inventory data. The objective of the segmentation process is to define continuous road segments that are as long as practical while remaining relatively homogeneous. The segments in most state road inventory data bases are relatively short. Therefore, the project team developed a procedure for aggregation of adjacent sections:

- with same county, route number, and road type
- with speed limits within 5 mph
- with ADTs within 20 percent, or within 2,000 veh/day
- with similar ADT, same road type, and speed limits less than or equal to 50 mph in urban areas, towns, or rural communities
- with very short sections with speed limits greater than or equal to 55 mph, with same road type and similar ADT
- of extremely short length
- with speed limits less than or equal to 50 mph just outside a town with similar sections within the town

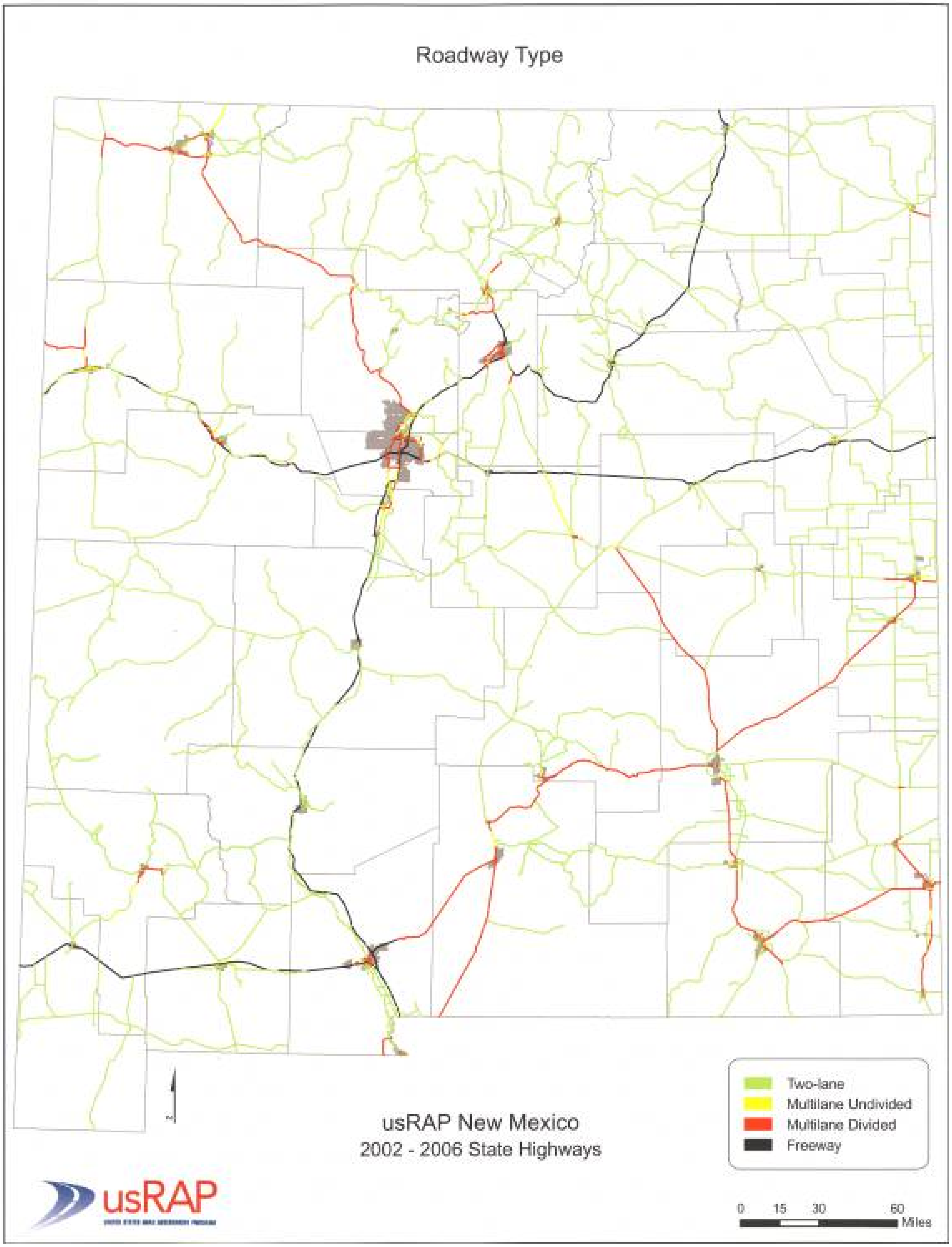


Figure 35. Roads Included in New Mexico Pilot Study

In some cases, particularly where extremely short sections were not aggregated by the preceding rules, these rules were modified to eliminate unrealistically short analysis sections. Even with the aggregation of road sections described above, the roadway sections in the New Mexico pilot study are shorter and experience fewer expected fatal and major injury crashes than the road sections used by EuroRAP. The EuroRAP sections averaged approximately 12 mi in length, while those for the New Mexico pilot study averaged only 6 mi in length. However, if the EuroRAP criterion that road sections should average 20 fatal and major injury crashes in three years were applied in New Mexico, road sections much longer than 12 mi would be needed. Such long sections would reduce the usefulness of the maps in defining risk in a way that would help in identifying future safety improvement projects. Therefore, a decision was reached to retain the shorter section lengths in the New Mexico pilot study.

2.6.5 Crash Type, Selection, and Assignment

For all maps prepared in the New Mexico pilot study, only fatal- and incapacitating-injury crashes were analyzed. For the remainder of this section, presentation and discussion of crashes, and crash-based data, are limited to fatal- and incapacitating-injury crashes on rural state roads. For consistency with previous pilot studies, the State's crash severity level for incapacitating injuries is referred to on the maps as major injuries.

Crashes were located, their coordinates were derived, and they were assigned to specific roadway segments using the best available GIS cartography.

2.6.6 Study Period and Data Summary

As in the other usRAP pilot studies completed to date, five years of data (2002-2006) were selected for analysis and presentation. Tables 5 and 6 present crash totals for rural and urban state highways, respectively, for each year of the study period.

Table 5. Crashes by Severity Level for Rural State Routes in New Mexico

Year	Fatal crashes	Incapacitating injury crashes	Total fatal and incapacitating injury crashes
2002	197	651	848
2003	160	608	768
2004	222	568	790
2005	194	441	635
2006	185	331	516
Total	**958**	**2,599**	**3,557**

Table 6. Crashes by Severity Level for Urban State Routes in New Mexico

Year	Fatal crashes	Incapacitating injury crashes	Total fatal and incapacitating injury crashes
2002	59	385	444
2003	46	376	422
2004	54	392	446
2005	55	347	402
2006	46	268	314
Total	**260**	**1,768**	**2,028**

2.6.7 Risk Maps

Following is a summary of the data used for risk mapping in the New Mexico pilot study:

- Statewide totals for rural state highways
  - 1,133 segments
  - 10,285 mi of road
  - 10.8 billion annual veh-mi of travel (VMT)
  - 3,557 fatal and incapacitating injury crashes
- Statewide averages for analysis sections on rural state highways
  - Average length = 9.1 mi
  - AADT = 2,877 veh/day
  - Fatal and incapacitating injury crashes = 0.63 crashes/section/year
  - Fatal and incapacitating injury crash density = 0.07 crashes/mi/year
  - Average crash rate = 6.59 per 100M VMT
- Statewide totals for urban state highways
  - 873 segments
  - 1,025 mi of road
  - 5.8 billion annual veh-mi of travel (VMT)
  - 2,028 fatal and incapacitating injury crashes
- Statewide averages for analysis sections on urban state highways
  - Average length = 1.2 mi
  - AADT = 15,462 veh/day
  - Fatal and incapacitating injury crashes = 0.46 crashes/section/year
  - Fatal and incapacitating injury crash density = 0.40 crashes/mi/year
  - Average crash rate = 7.01 per 100M VMT

Tables 7 and 8 present the summary information by road type for rural and urban state roads, respectively.

Table 7. Summary of Rural State Route Risk Mapping Data for New Mexico

Road type	Number of sections	Total length (mi)	Average length (mi)	AADT (veh/day)	Annual VMT (billion)	Fatal & incapacitating injury crashes: Total frequency	Average annual frequency	Annual density (per mi)	Average rate (per 100M VMT)
Freeway	104	851	8.2	15,237	4.7	1,306	2.51	0.31	5.52
Multilane divided	144	850	5.9	6,334	2.0	553	0.77	0.13	5.63
Multilane undivided	65	105	1.6	6,246	0.2	80	0.25	0.15	6.66
Two-lane roads	820	8,479	10.3	1,249	3.9	1,618	0.39	0.04	8.37
Total	**1,133**	**10,285**	**9.1**	**2,877**	**10.8**	**3,557**	**0.63**	**0.07**	**6.59**

Table 8. Summary of Urban State Route Risk Mapping Data for New Mexico

Road type	Number of sections	Total length (mi)	Average length (mi)	AADT (veh/day)	Annual VMT (billion)	Fatal & incapacitating injury crashes: Total frequency	Annual frequency	Annual density (per mi)	Average rate (per 100M VMT)
Freeway	80	178	2.2	44,714	2.9	530	1.33	0.59	3.64
Multilane divided	266	269	1.0	16,156	1.6	833	0.63	0.62	10.52
Multilane undivided	192	146	0.8	13,324	0.7	370	0.39	0.51	10.45
Two-lane roads	335	432	1.3	3,617	0.6	295	0.18	0.14	10.16
Total	**873**	**1,025**	**1.2**	**15,462**	**5.8**	**2,028**	**0.46**	**0.40**	**7.01**

2.6.7.1 Selection of Risk Categories for Use on Risk Maps

The statewide risk maps for the New Mexico pilot study use the same risk categories developed in the same manner as the risk categories in the other usRAP pilot studies. The risk categories and their associated colors are as follows:

- dark green (lowest risk) — 40 percent of roadway length
- light green — 25 percent of roadway length
- yellow — 20 percent of roadway length
- red — 10 percent of roadway length
- black (highest risk) — 5 percent of roadway length

The highest risk category (shown in black on the various maps) should assist in meeting the new Federal mandate that states identify 5 percent of locations with the most severe safety needs (see Section 4.2 of the Phase I report).

Examples of all statewide maps for the New Mexico pilot study are presented in below. All maps for the New Mexico pilot study have been developed using five years of data.

As in the other usRAP pilot studies, road sections with two or fewer fatal- or major-injury crashes in five years were not included in the two highest risk categories. It did not appear appropriate to classify sections with limited crash experience as high risk, since they generally had short lengths or very low traffic volumes, so a criterion was adopted that no road section would be considered for classification in the two highest risk categories (red and black on the various maps) unless it experienced more than two fatal- or major-injury crashes in five years; such low-crash-count segments with higher risk measures generally appear in the medium risk (yellow) category on the maps presented.

2.6.7.2 Road Section Crash Density Maps (Map 1)

The first type of risk map developed was the annual crash density map (Map 1). Figure 36 is a typical crash density map for all state highways in New Mexico.

2.6.7.3 Road Section Crash Rate Maps (Map 2)

Risk maps based on the fatal- and major-injury crash rate were also developed for New Mexico roads. While 5 years of crash data were used, a single AADT value was used to compute exposure. Figure 37 presents a typical crash rate map for New Mexico roads.

2.6.7.4 Ratio of Crash Rate Relative to Similar Road Types (Map 3)

Figure 38 presents a typical maps for New Mexico based on the ratio of fatal- and major-injury crash rate for each road section to the average rate of similar roads (Map 3).

2.6.7.5 Potential Crash Savings (Map 4)

Map 4 indicates the potential for reducing fatal- and incapacitating-injury crashes if road sections with above-average crash rates could be brought to the average crash rate for roads of similar type. Figure 39 presents a typical map of the potential crash savings for state highways in New Mexico.

2.6.7.6 Supplementary Maps

Supplementary risk maps for New Mexico will be developed at a later date.

2.6.8 Use of the usRAP Maps in New Mexico

The New Mexico DOT believes that the analysis for New Mexico from usRAP provides an excellent overview of fatal and major injury crashes at the statewide level. The usRAP pilot study helped to point out areas with concentrations of crashes that will

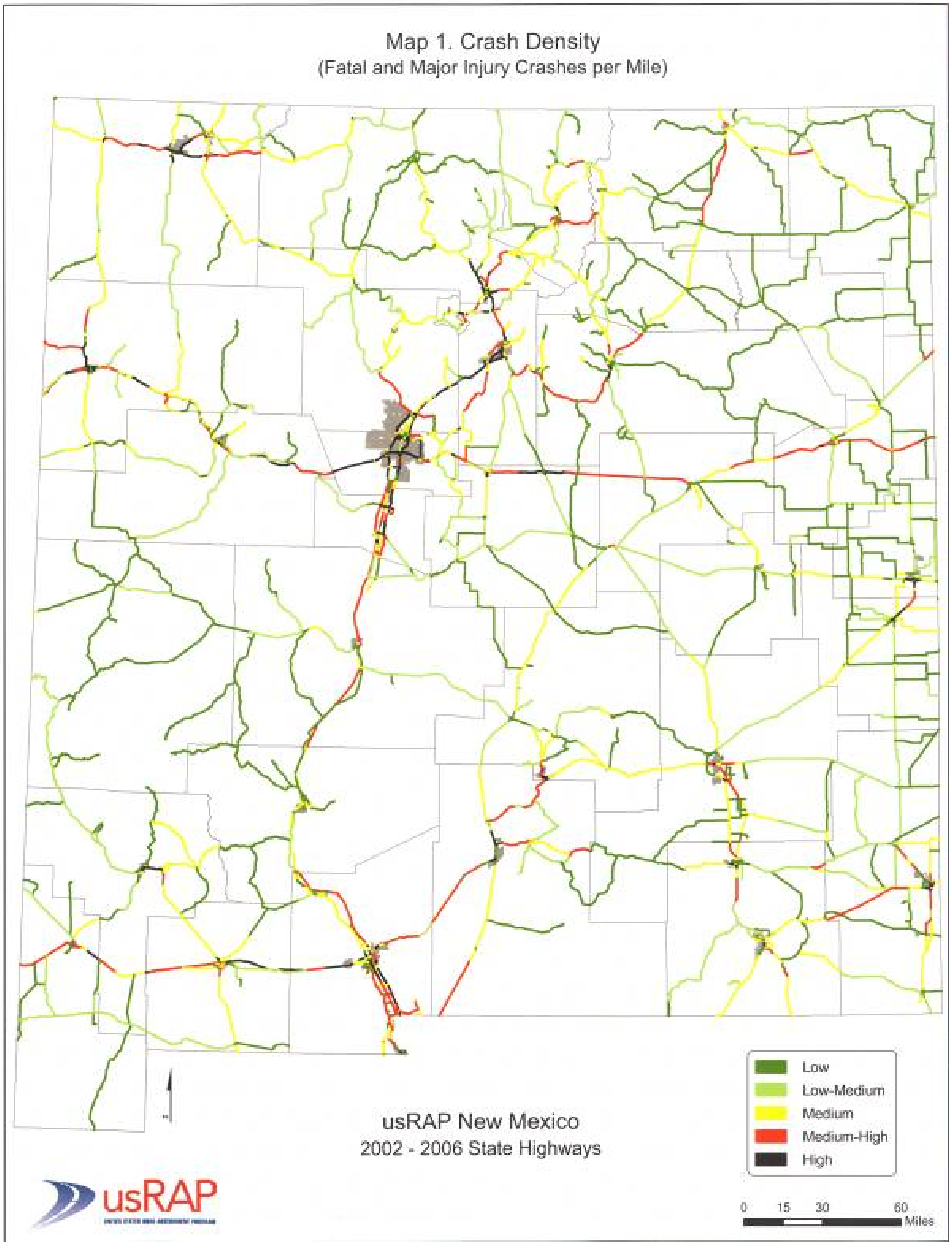


Figure 36. Example of Map 1 for New Mexico

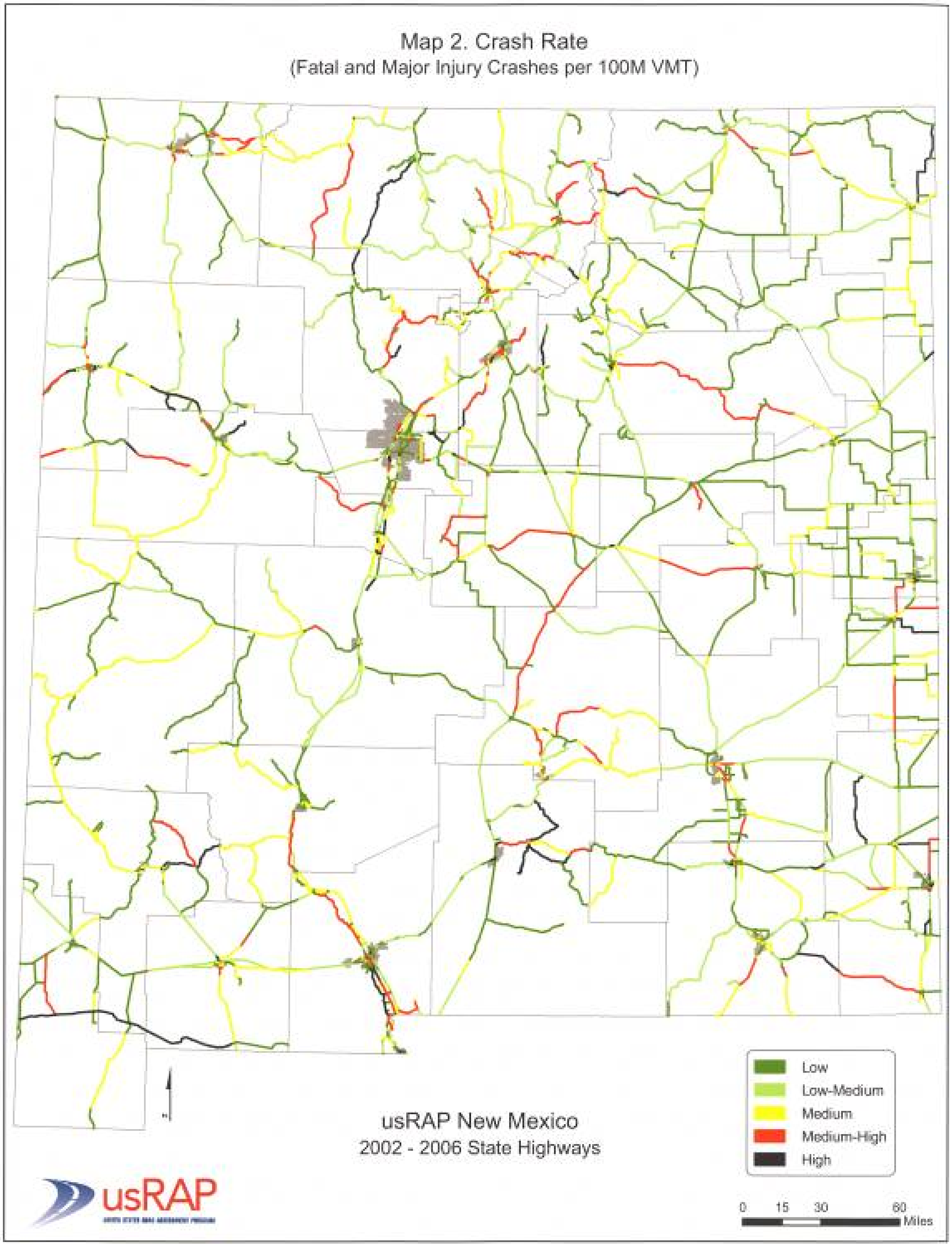


Figure 37. Example of Map 2 for New Mexico

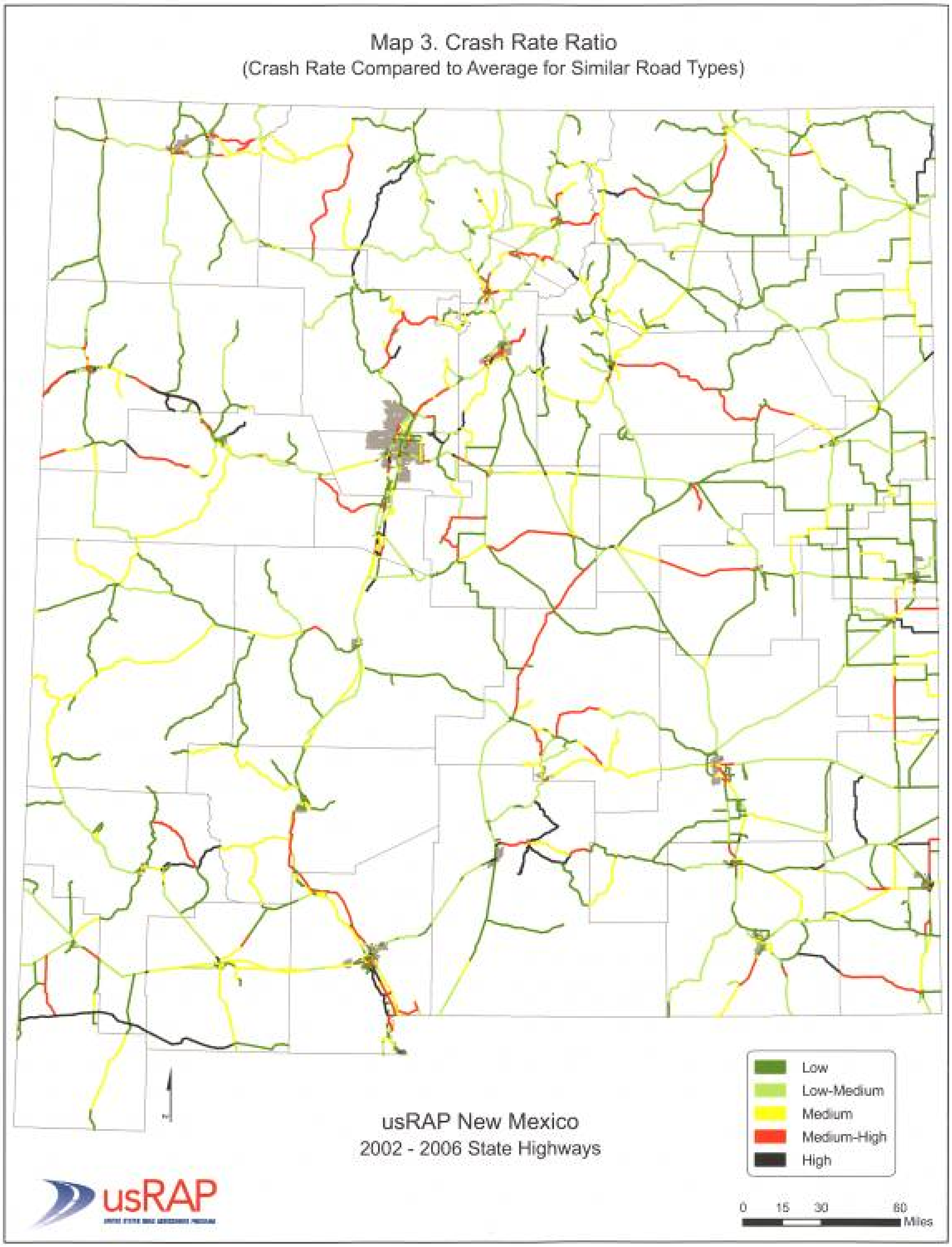


Figure 38. Example of Map 3 for New Mexico

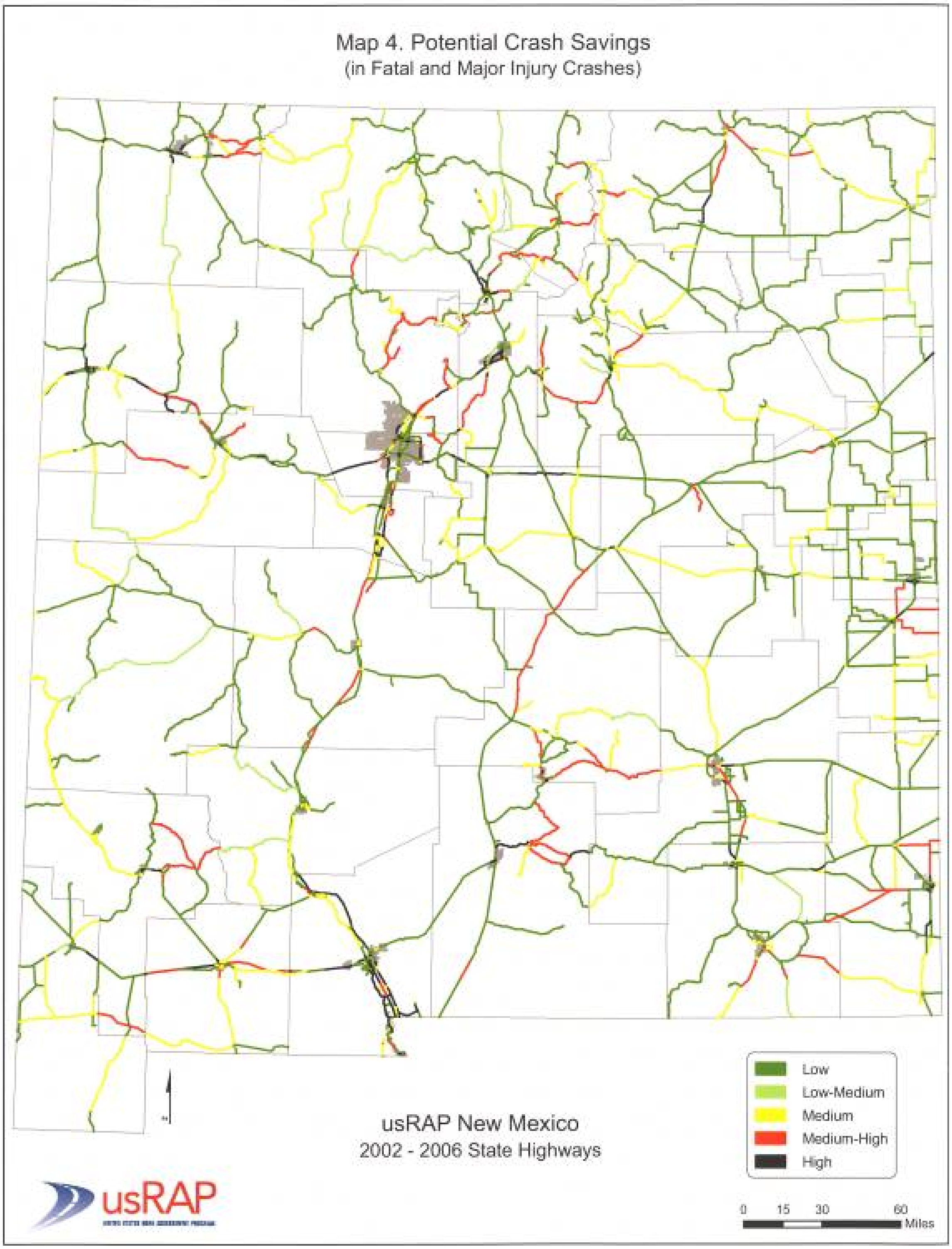


Figure 39. Example of Map 4 for New Mexico

receive further review and planning. Through the risk maps, critical corridors were identified. These maps are a valuable resource for New Mexico.

The usRAP pilot program gave the New Mexico DOT a good opportunity to have the crash data reviewed by an outside agency and it helped us make improvements to the crash locations for multiple years of data. Given the opportunity, the New Mexico DOT would like to concentrate on statewide analysis of intersection crashes outside of the major urban areas. The usRAP project would provide a great service to the New Mexico DOT and other state DOTs if the states could receive federal aid to perform more sophisticated analyses. This would be particularly beneficial in the areas of rural intersection and rural lane-departure crashes.

2.7 Results of the Utah Pilot Study

The Utah pilot study was conducted in cooperation with the Utah Department of Transportation. This section presents the results of the Utah pilot study. The section first discusses general issues concerning the roadway network included in the pilot study, the manner in which that roadway network was divided into road segments for analysis, and the data that were assembled for analysis. The results of risk mapping are then presented.

2.7.1 Roads Selected for Inclusion in Mapping

State primary roads were considered in the Utah pilot study. These roads include Interstate, US, and state-numbered routes. Both rural and urban roads were included in the Utah pilot study.

2.7.2 Road Classification

Roads included in this pilot study were classified into eight road types: rural freeway, rural multilane divided highway, rural multilane undivided, rural two-lane roads, urban freeway, urban multilane divided highway, urban multilane undivided, and urban two-lane roads. The road type definition was based on access control, median type, and number of lanes. The distinction between rural and urban area types was based on the State's functional classification data. Unique combinations of these variables were assigned to one of the road-type categories. In some cases, particularly where the combination of these variables was atypical, sections were assessed based on the design type and extent of adjacent road sections. The appropriate category was then assigned based on this assessment.

2.7.3 Scope of Analysis and Mapping

Risk maps were developed for the selected road system throughout the entire state, including both urban and rural roadways. The roads included in the pilot study are shown in Figure 40 for the state as a whole and, in an enlargement in Figure 41 for the Provo-

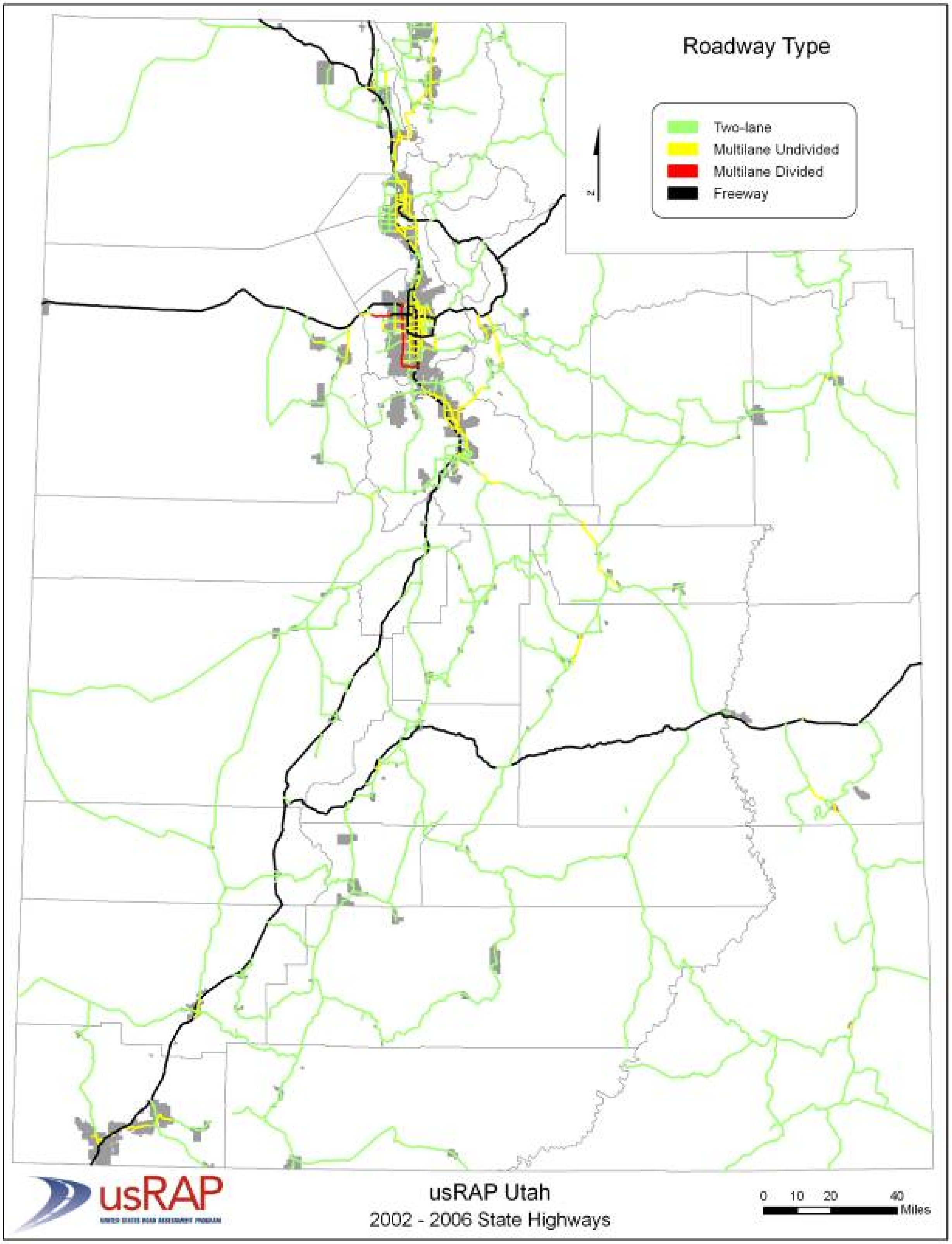


Figure 40. Roads Included in Utah Pilot Study

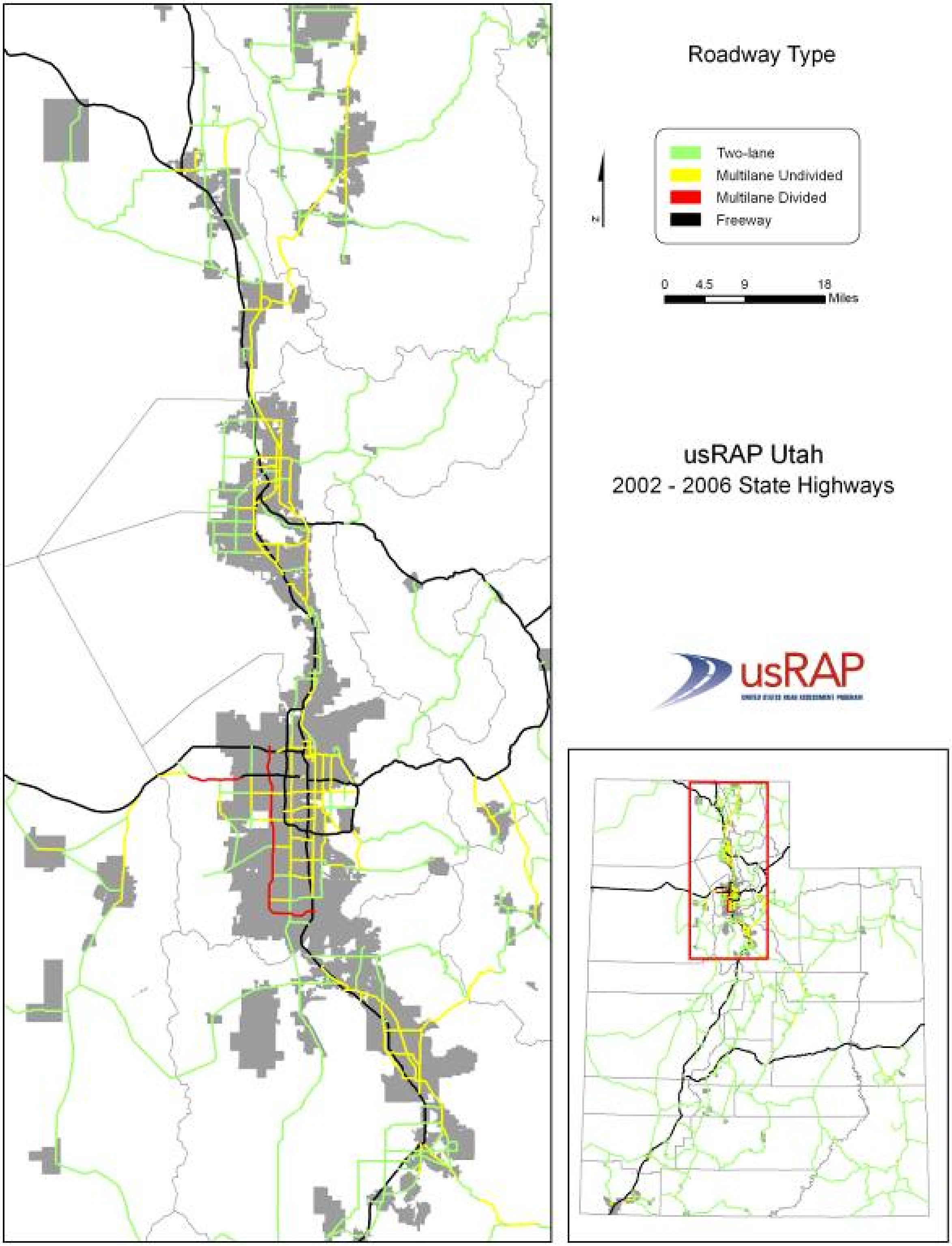


Figure 41. Roads Included in Utah Pilot Study (Provo-Salt Lake City-Ogden Metropolitan Area

Salt Lake City-Ogden metropolitan area. This enlargement makes the individual road sections in this densely populated area more easily distinguishable.

2.7.4 Segmentation

Segmentation for the study sections in Utah was developed from available road inventory data. The objective of the segmentation process is to define continuous road segments that are as long as practical while remaining relatively homogeneous. The segments in most state road inventory data bases are relatively short. Therefore, the project team developed a procedure for aggregation of adjacent sections:

- with same county, route number, and road type
- with speed limits within 5 mph
- with ADTs within 20 percent, or within 2,000 veh/day
- with similar ADT, same road type, and speed limits less than or equal to 50 mph in urban areas, towns, or rural communities
- with very short sections with speed limits greater than or equal to 55 mph, with same road type and similar ADT
- of extremely short length
- with speed limits less than or equal to 50 mph just outside a town with similar sections within the town

In some cases, particularly where extremely short sections were not aggregated by the preceding rules, these rules were modified to eliminate unrealistically short analysis sections. Even with the aggregation of road sections described above, the roadway sections in the Utah pilot study are shorter and experience fewer expected fatal and major injury crashes than the road sections used by EuroRAP. The EuroRAP sections averaged approximately 12 mi in length, while those for the Utah pilot study averaged only 5 mi in length. However, if the EuroRAP criterion that road sections should average 20 fatal and major injury crashes in three years were applied in Utah, road sections much longer than 12 mi would be needed. Such long sections would reduce the usefulness of the maps in defining risk in a way that would help in identifying future safety improvement projects. Therefore, a decision was reached to retain the shorter section lengths in the Utah pilot study.

2.7.5 Crash Type, Selection, and Assignment

For all maps prepared in the Utah pilot study, only fatal- and incapacitating-injury crashes were analyzed. For the remainder of this section, presentation and discussion of crashes, and crash-based data, are limited to fatal- and incapacitating-injury crashes on rural state roads. For consistency with previous pilot studies, the State’s crash severity level for incapacitating injuries is referred to on the maps as major injuries.

Crashes were located, their coordinates were derived, and they were assigned to specific roadway segments using the best available GIS cartography.

2.7.6 Study Period and Data Summary

As in the other usRAP pilot studies completed to date, five years of data (2002-2006) were selected for analysis and presentation. Tables 9 and 10 present crash totals for rural and urban state highways, respectively, for each year of the study period.

Table 9. Crashes by Severity Level for Rural State Routes in Utah

Year	Fatal crashes	Incapacitating injury crashes	Total fatal and incapacitating injury crashes
2002	143	966	1,109
2003	150	821	971
2004	132	847	979
2005	137	797	934
2006	127	459	586
Total	**689**	**3,890**	**4,579**

Table 10. Crashes by Severity Level for Urban State Routes in Utah

Year	Fatal crashes	Incapacitating injury crashes	Total fatal and incapacitating injury crashes
2002	74	1,230	1,304
2003	72	1,093	1,165
2004	71	1,019	1,090
2005	45	1,120	1,165
2006	68	657	725
Total	**330**	**5,119**	**5,449**

2.7.7 Risk Maps

Following is a summary of the data used for risk mapping in the Utah pilot study:

- Statewide totals for rural state highways
  - 886 segments
  - 5,137 mi of road
  - 7.7 billion annual veh-mi of travel (VMT)
  - 4,579 fatal and incapacitating injury crashes
- Statewide averages for analysis sections on rural state highways
  - Average length = 5.8 mi
  - AADT = 4,114 veh/day
  - Fatal and incapacitating injury crashes = 1.03 crashes/section/year
  - Fatal and incapacitating injury crash density = 0.18 crashes/mi/year

- Average crash rate = 11.87 per 100M VMT

- Statewide totals for urban state highways
  - 299 segments
  - 706 mi of road
  - 9.7 billion annual veh-mi of travel (VMT)
  - 5,449 fatal and incapacitating injury crashes

- Statewide averages for analysis sections on urban state highways
  - Average length = 2.4 mi
  - AADT = 37,803 veh/day
  - Fatal and incapacitating injury crashes = 3.64 crashes/section/year
  - Fatal and incapacitating injury crash density = 1.54 crashes/mi/year
  - Average crash rate = 11.18 per 100M VMT

Tables 11 and 12 present the summary information by road type for rural and urban state roads, respectively.

Table 11. Summary of Rural State Route Risk Mapping Data for Utah

						Fatal & incapacitating injury crashes			
Road type	Number of sections	Total length (mi)	Average length (mi)	AADT (veh/day)	Annual VMT (billion)	Total frequency	Annual frequency	Annual density (per mi)	Average rate (per 100M VMT)
Freeway	57	784	13.8	13,107	3.8	1,852	6.50	0.47	9.87
Multilane divided	1	3	3.0	12,767	0.0	9	1.80	0.60	12.90
Multilane undivided	67	191	2.8	13,324	0.9	504	1.50	0.53	10.86
Two-lane roads	761	4,159	5.5	1,989	3.0	2,214	0.58	0.11	14.67
Total	**886**	**5,137**	**5.8**	**4,114**	**7.7**	**4,579**	**1.03**	**0.18**	**11.87**

Table 12. Summary of Urban State Route Risk Mapping Data for Utah

						Fatal & incapacitating injury crashes			
Road type	Number of sections	Total length (mi)	Average length (mi)	AADT (veh/day)	Annual VMT (billion)	Total frequency	Annual frequency	Annual density (per mi)	Average rate (per 100M VMT)
Freeway	41	158	3.9	91,815	5.3	1,275	6.22	1.61	4.80
Multilane divided	8	28	3.5	34,961	0.4	161	4.03	1.16	9.07
Multilane undivided	159	328	2.1	26,970	3.2	3,325	4.18	2.03	20.60
Two-lane roads	91	192	2.1	12,181	0.9	688	1.51	0.72	16.09
Total	**299**	**706**	**2.4**	**37,803**	**9.7**	**5,449**	**3.64**	**1.54**	**11.18**

2.7.7.1 Selection of Risk Categories for Use on Risk Maps

The statewide risk maps for the Utah pilot study use the same risk categories developed in the same manner as the risk categories in the other usRAP pilot studies. The risk categories and their associated colors are as follows:

- dark green (lowest risk) 40 percent of roadway length

- light green 25 percent of roadway length
- yellow 20 percent of roadway length
- red 10 percent of roadway length
- black (highest risk) 5 percent of roadway length

The highest risk category (shown in black on the various maps) should assist in meeting the new Federal mandate that states identify 5 percent of locations with the most severe safety needs (see Section 4.2 of the Phase I report).

Examples of all statewide maps for the Utah pilot study are presented in below. All maps for the Utah pilot study have been developed using five years of data.

As in the other usRAP pilot studies, road sections with two or fewer fatal- or major-injury crashes in five years were not included in the two highest risk categories. It did not appear appropriate to classify sections with limited crash experience as high risk, since they generally had short lengths or very low traffic volumes, so a criterion was adopted that no road section would be considered for classification in the two highest risk categories (red and black on the various maps) unless it experienced more than two fatal- or major-injury crashes in five years; such low-crash-count segments with higher risk measures generally appear in the medium risk (yellow) category on the maps presented.

2.7.7.2 Road Section Crash Density Maps (Map 1)

The first type of risk map developed was the annual crash density map (Map 1). Figure 42 is a typical crash density map for all state highways in Utah. Figure 43 shows an enlargement of the same map for the Provo-Salt lake City-Ogden metropolitan area.

2.7.7.3 Road Section Crash Rate Maps (Map 2)

Risk maps based on the fatal- and major-injury crash rate were also developed for Utah roads. While five years of crash data were used, a single AADT value was used to compute exposure. Figures 44 and 45 present typical crash rate maps for Utah roads.

2.7.7.4 Ratio of Crash Rate Relative to Similar Road Types (Map 3)

Figures 46 and 47 present typical maps for Utah based on the ratio of fatal- and major-injury crash rate for each road section to the average rate of similar roads (Map 3).

2.7.7.5 Potential Crash Savings (Map 4)

Map 4 indicates the potential for reducing fatal- and incapacitating-injury crashes if road sections with above-average crash rates could be brought to the average crash rate for roads of similar type. Figures 48 and 49 present typical maps of the potential crash savings for state highways in Utah.

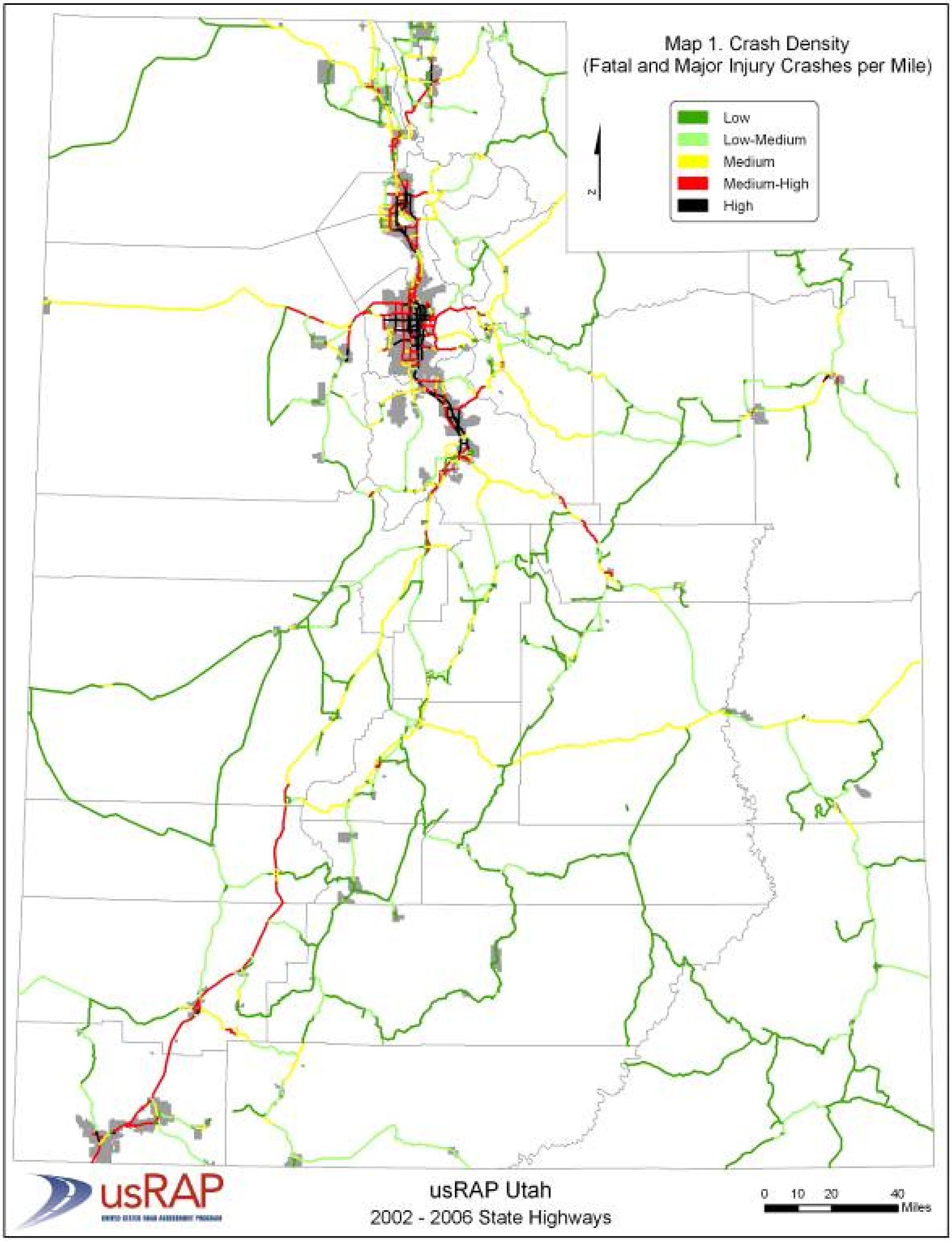


Figure 42. Example of Map 1 for Utah

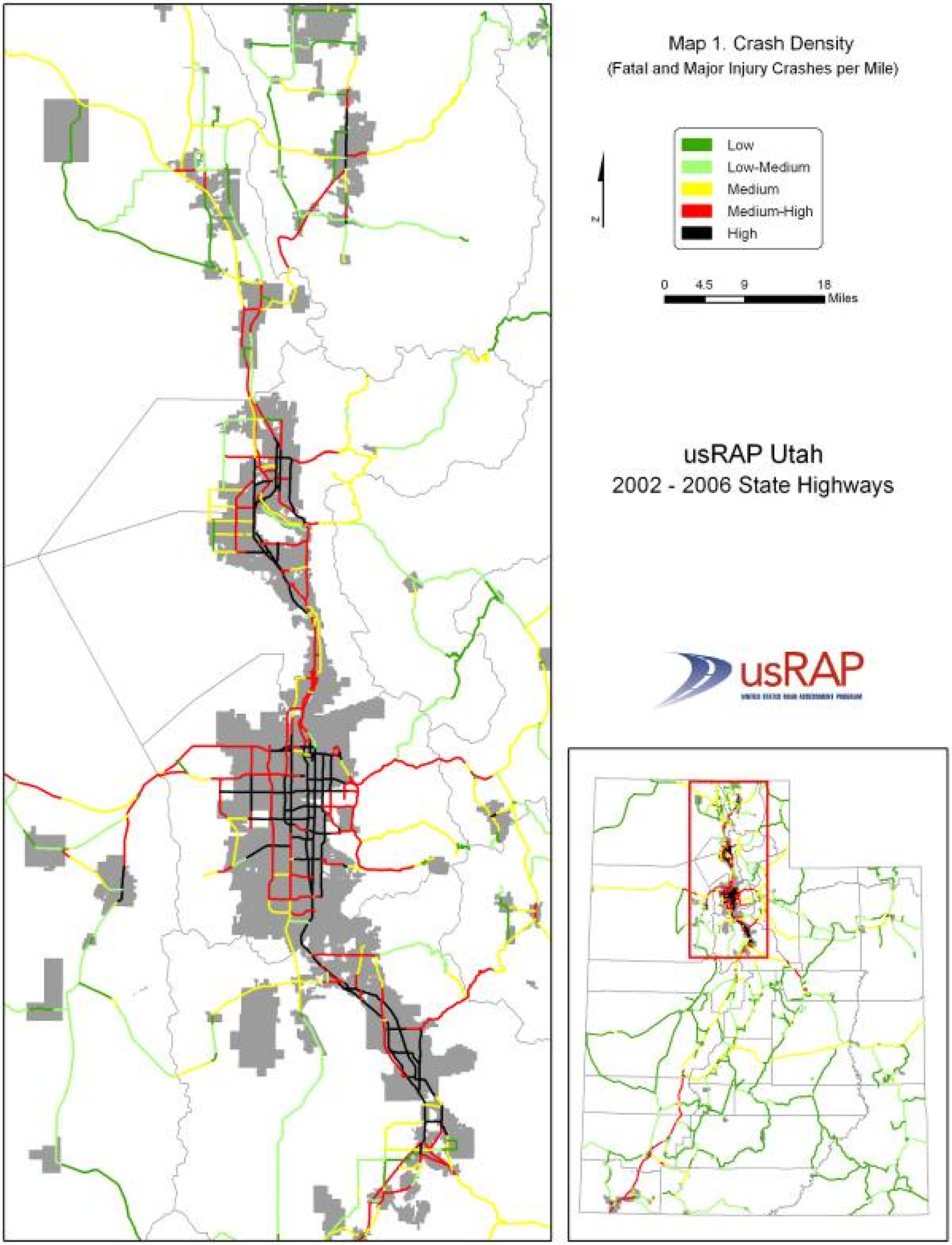


Figure 43. Example of Map 1 for Utah (Provo-Salt Lake City-Ogden Metropolitan Area)

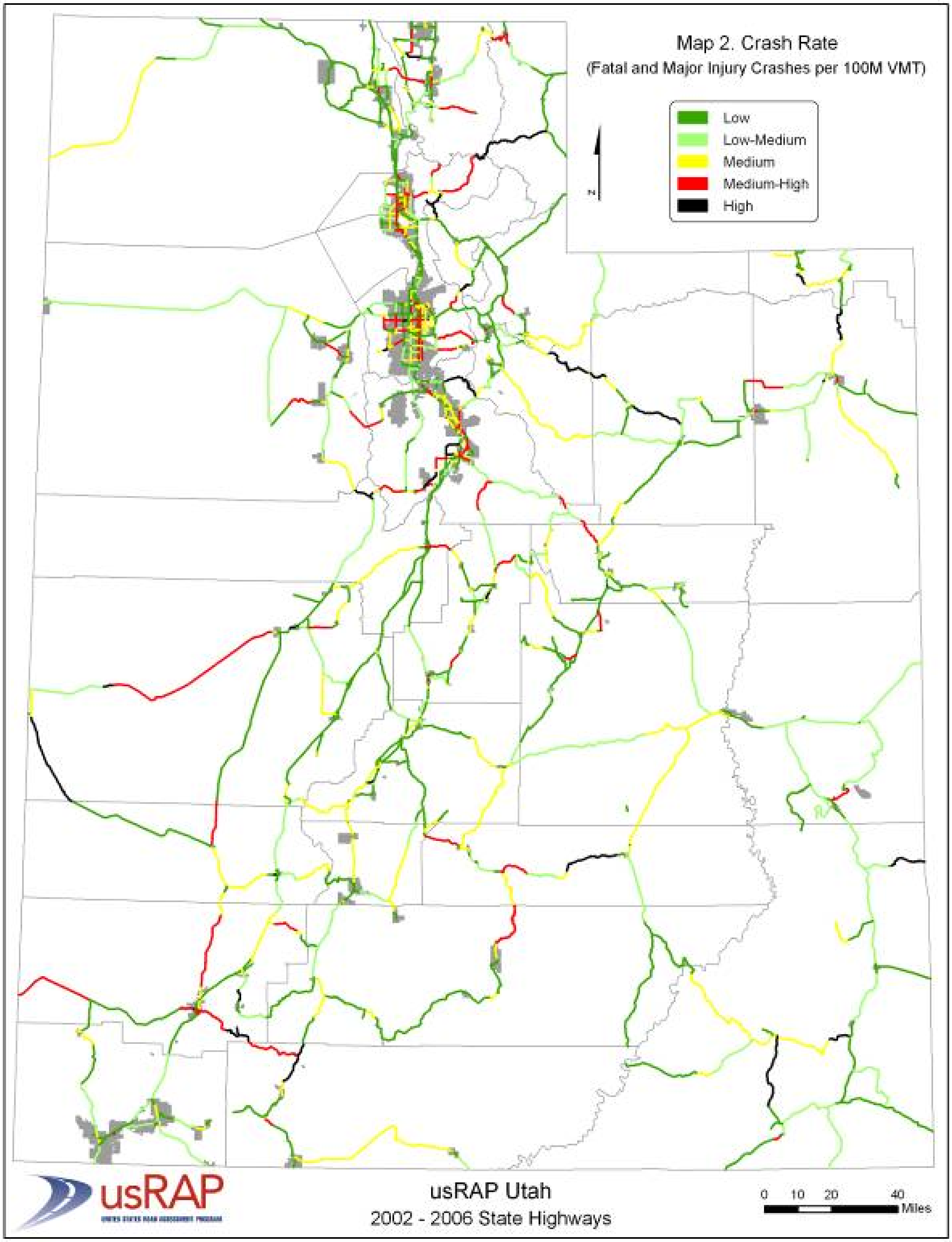


Figure 44. Example of Map 2 for Utah

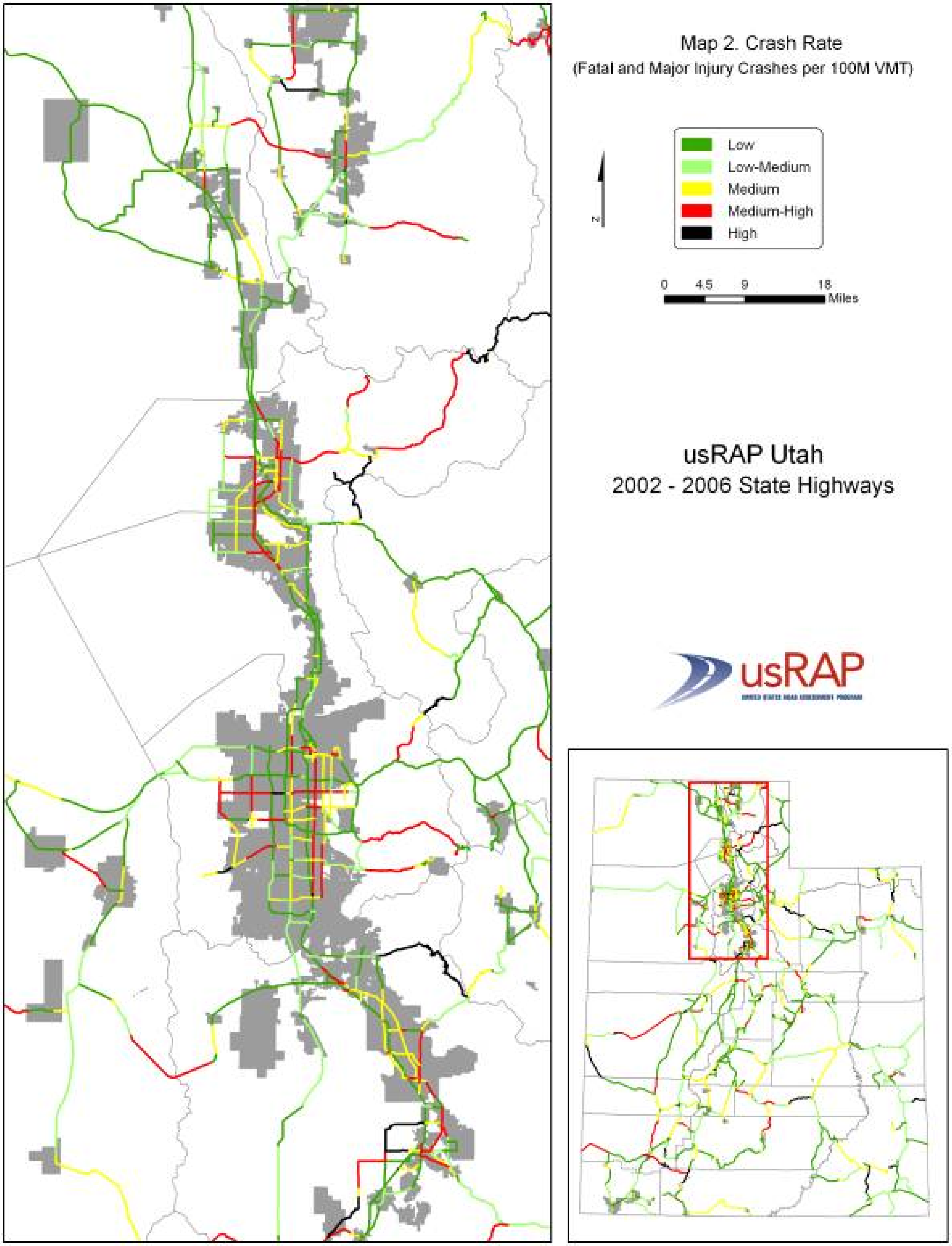


Figure 45. Example of Map 2 for Utah (Provo-Salt Lake City-Ogden Metropolitan Area)

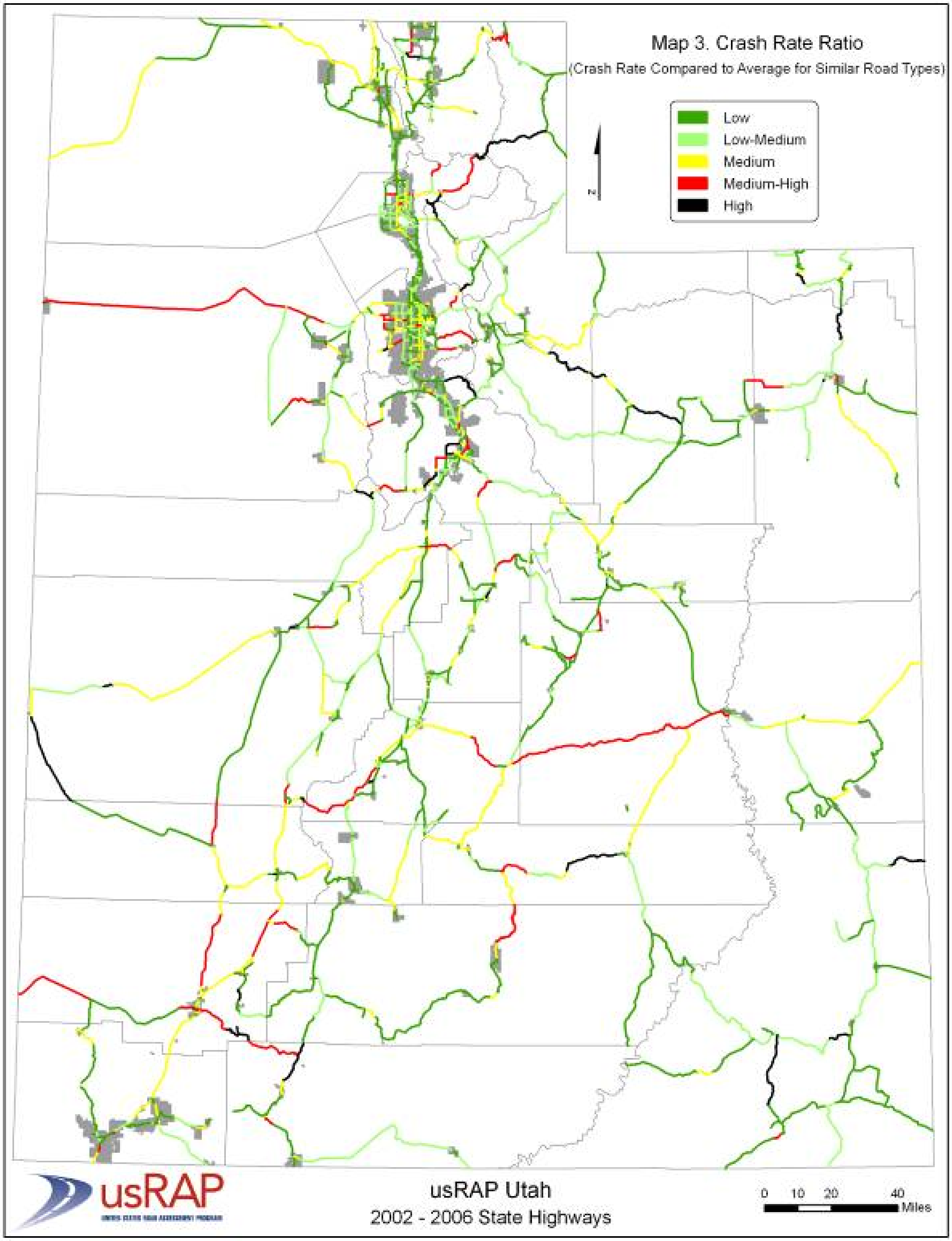


Figure 46. Example of Map 3 for Utah

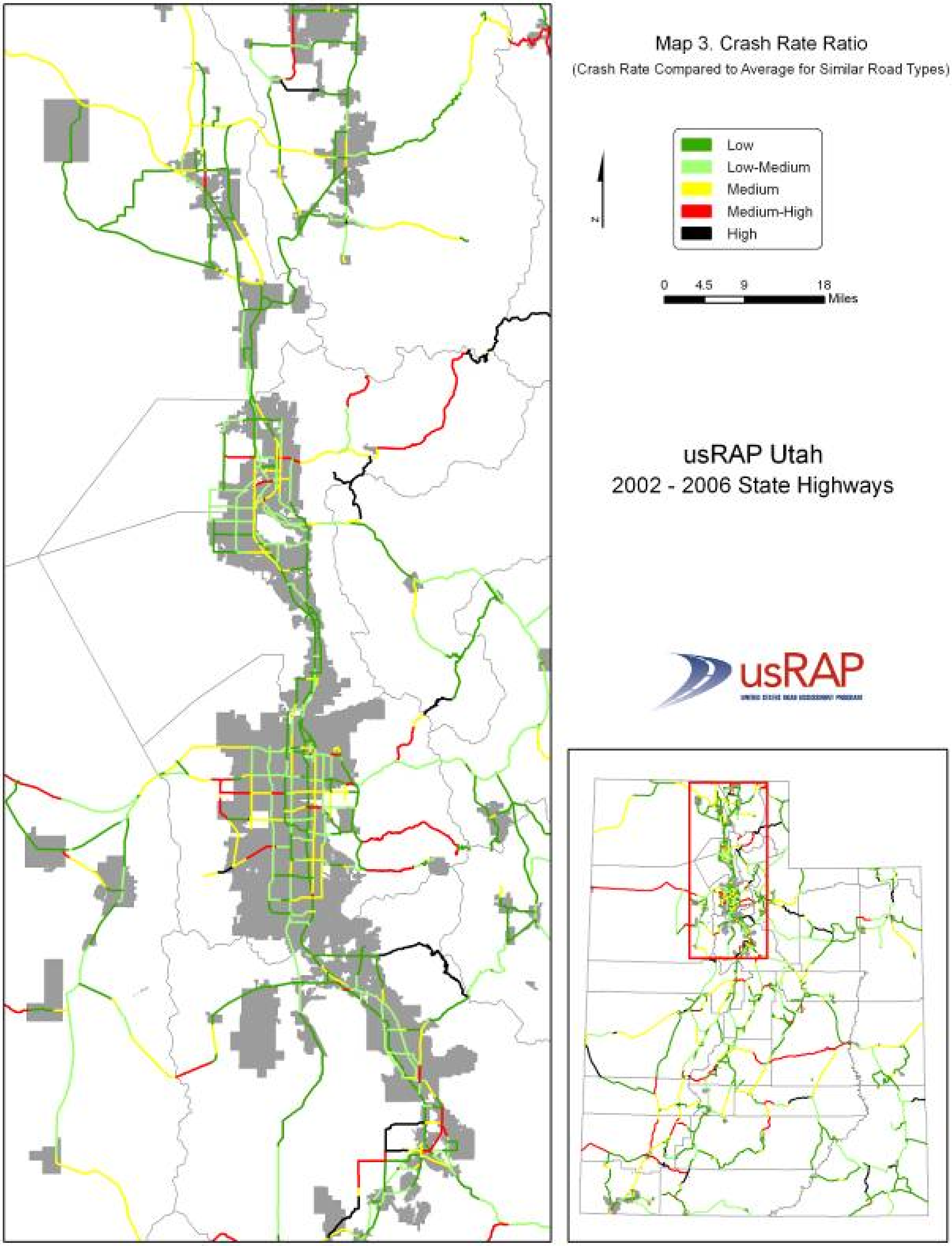


Figure 47. Example of Map 3 for Utah (Provo-Salt Lake City-Ogden Metropolitan Area)

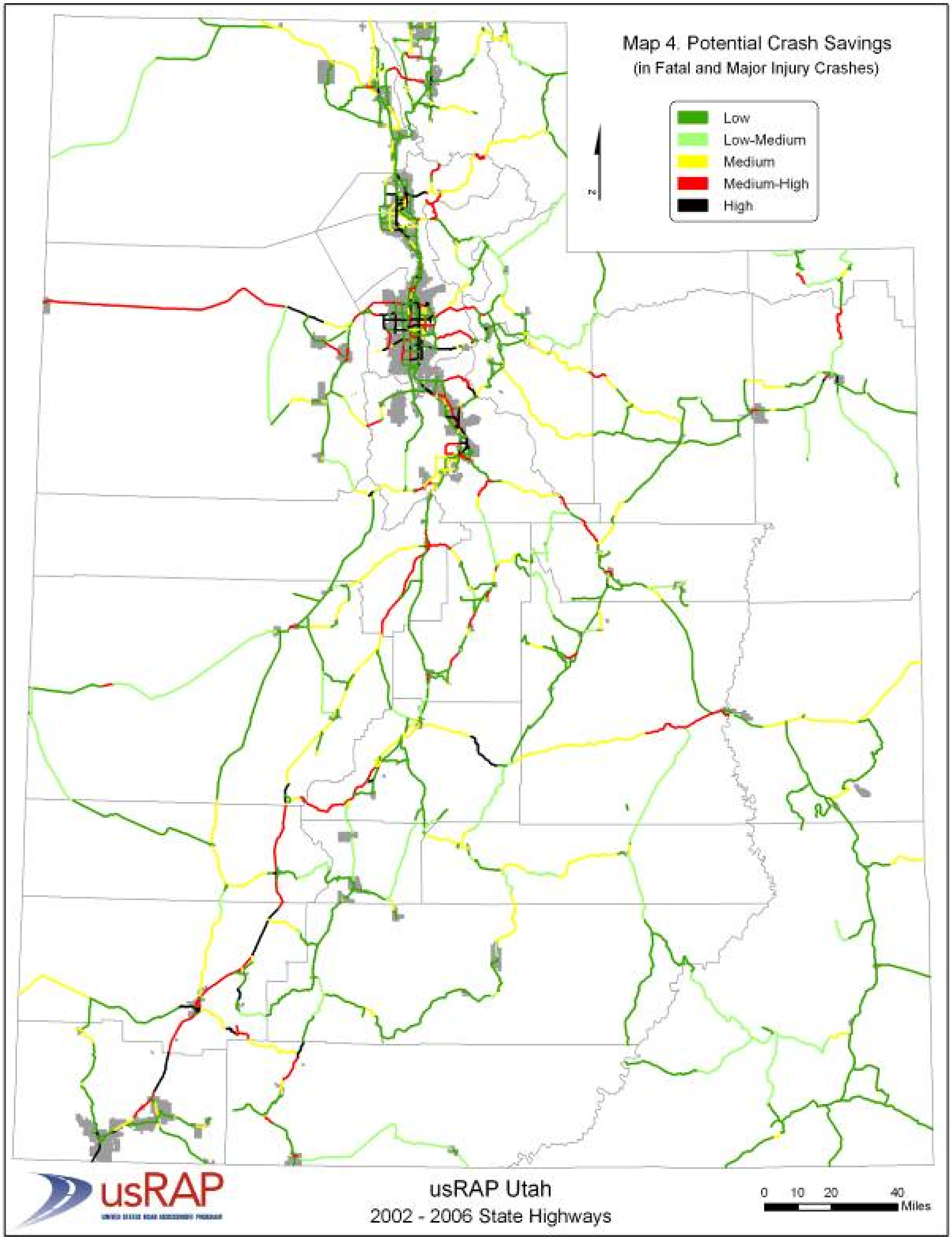


Figure 48. Example of Map 4 for Utah

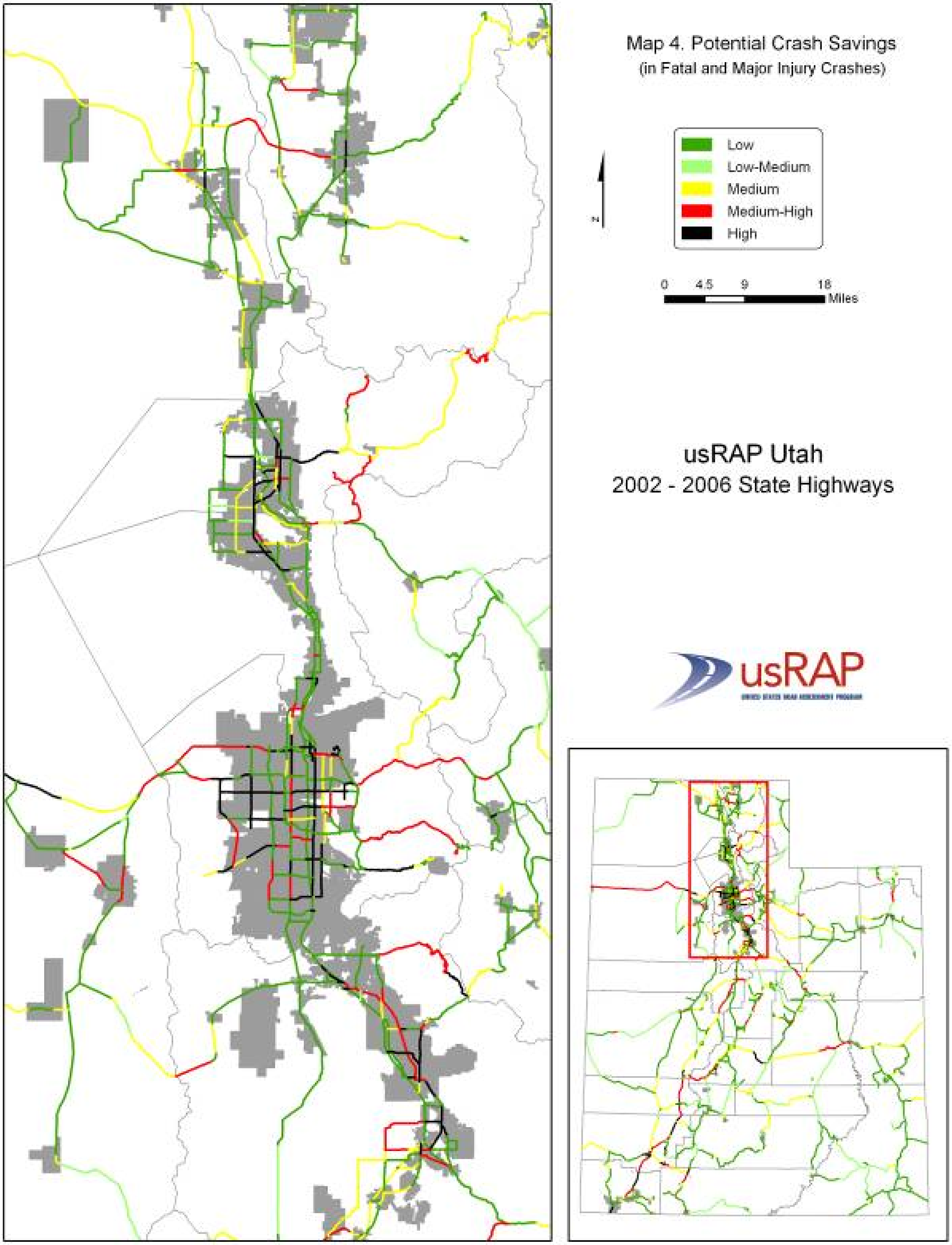


Figure 49. Example of Map 4 for Utah (Provo-Salt Lake City-Ogden Metropolitan Area)

2.7.7.6 Supplementary Maps

Supplementary risk maps have been prepared as part of the Utah pilot studies in a manner similar to those prepared for previous pilot studies. The supplementary map types prepared for Utah include:

- aggressive-driving crashes
- roadway-departure crashes
- unrestrained-occupant crashes
- younger driver crashes

For all of the Utah supplementary maps, a minimum of three or more fatal- or major-injury crashes in five years were required for a road section to be considered medium-high or high risk.

Maps analogous to Maps 1 through 4 were prepared for aggressive-driving crashes in Utah (see Figures 50 through 53). Aggressive-driving crashes in Utah were identified as crashes that included at least one of the following driver contributing circumstances:

- exceeding posted speed limit
- speed too fast for conditions
- following too closely
- reckless/aggressive

Maps analogous to Maps 1 through 4 were prepared for roadway-departure crashes in Utah (see Figures 54 through 57). Roadway-departure crashes for Utah were identified as crashes that included one of the following categories as either the first harmful event for the crash or as any part of the sequence of events for any vehicle involved in the crash:

- ran-off-road right
- ran-off-road left
- crossed median/centerline

Maps analogous to Maps 1 through 4 were prepared for unrestrained-occupant crashes in Utah (see Figures 58 through 61). Unrestrained-occupant crashes in Utah were identified as crashes, for vehicle types other than two-wheel vehicles, off-road vehicles, school buses, or other buses, for which safety equipment was indicated as none or not properly used. Such crashes primarily involved vehicle occupants not using available safety belts.

A map analogous to Map 1 was prepared for younger driver crashes in Utah (see Figure 62). Younger driver crashes were identified as crashes in which any of the involved drivers was less than 20 years of age.

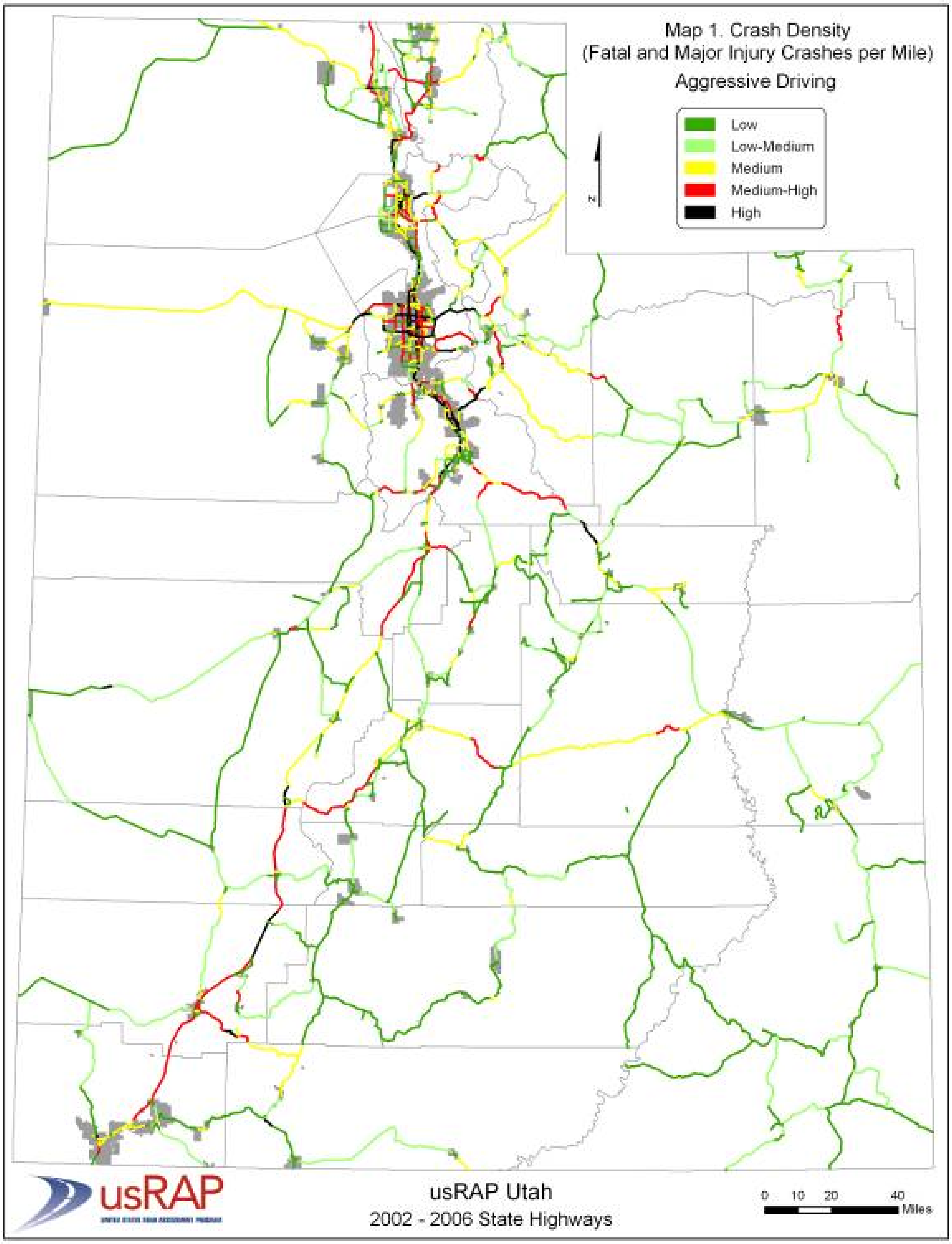


Figure 50. Utah Map 1 for Aggressive-Driving Crashes

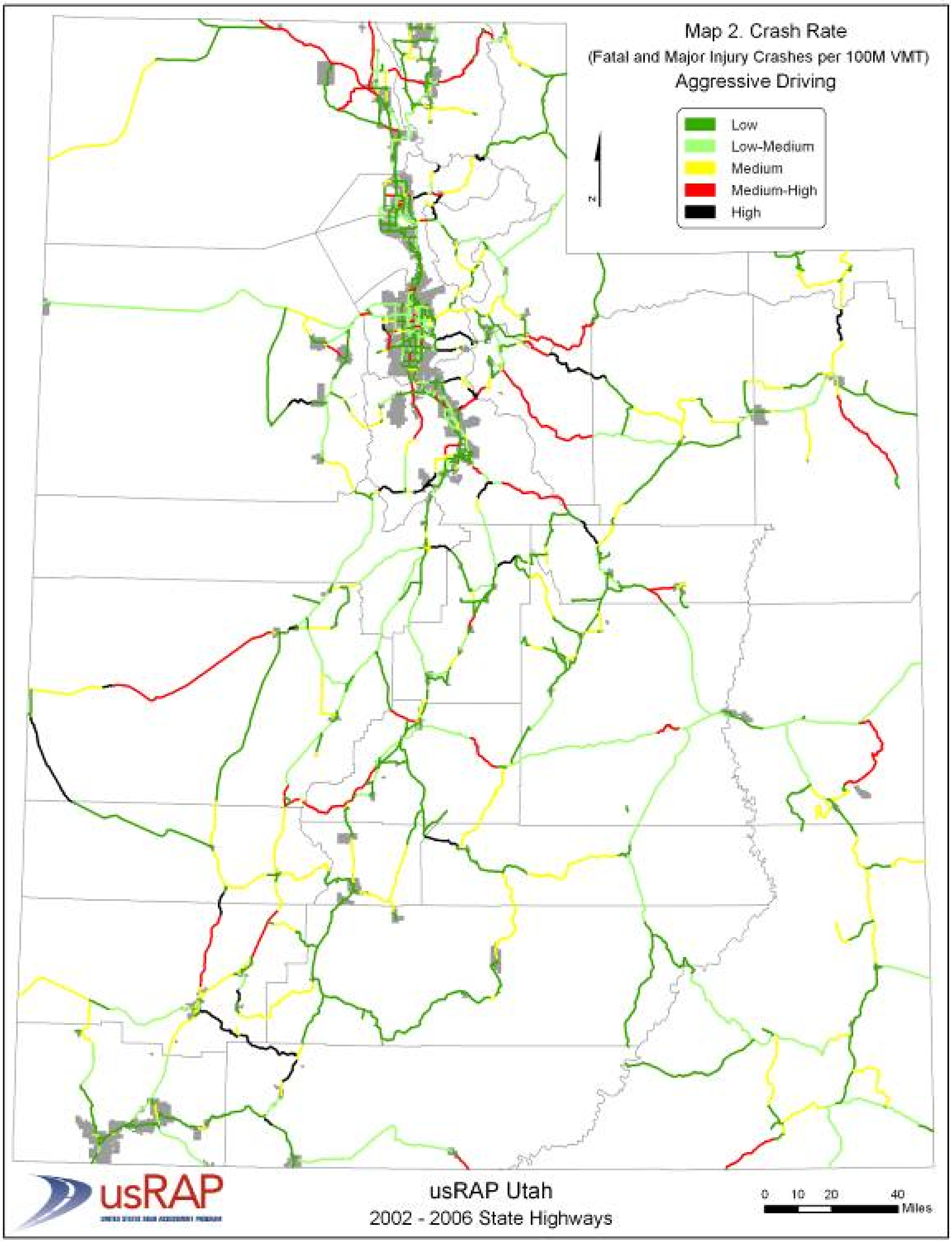


Figure 51. Utah Map 2 for Aggressive-Driving Crashes

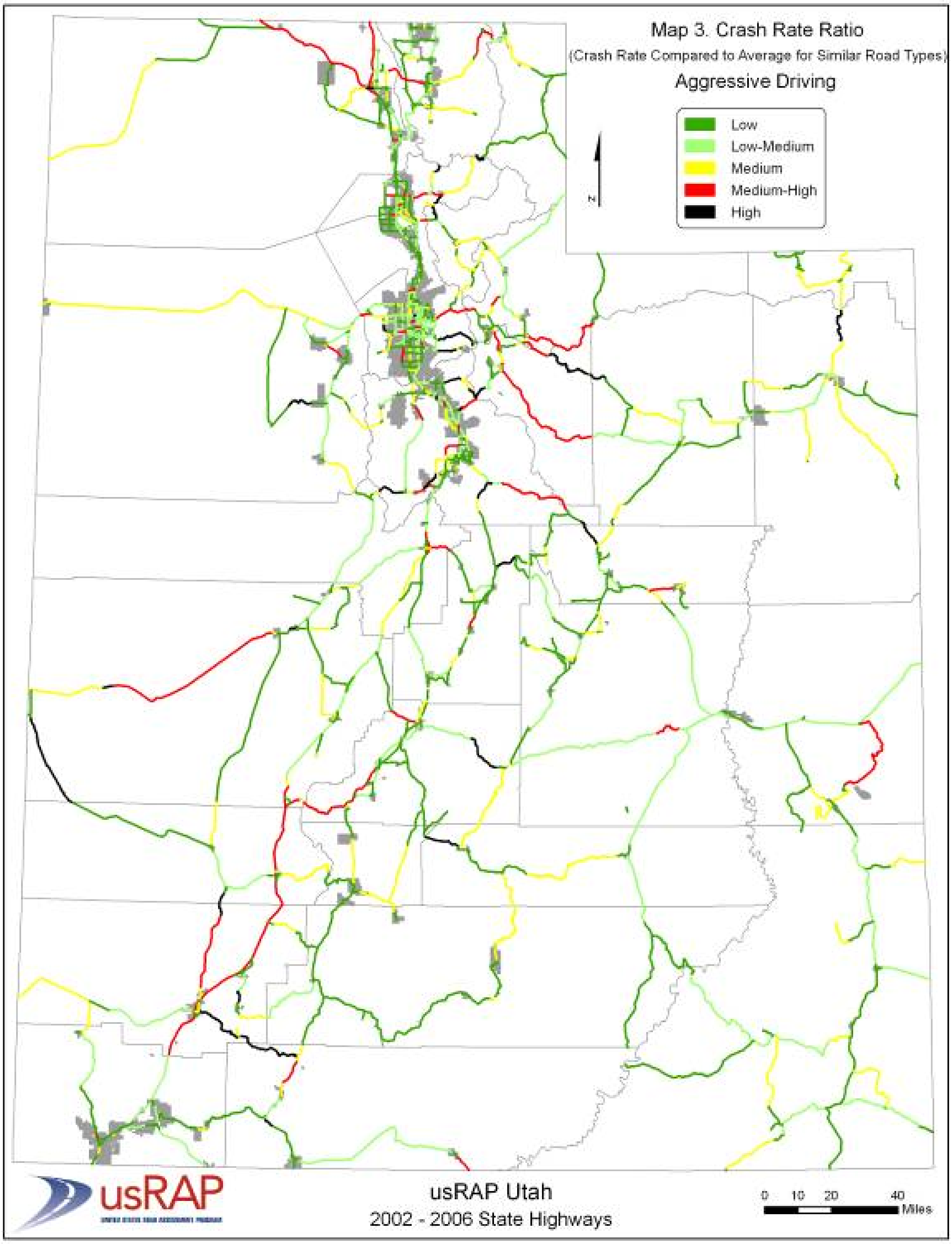


Figure 52. Utah Map 3 for Aggressive-Driving Crashes

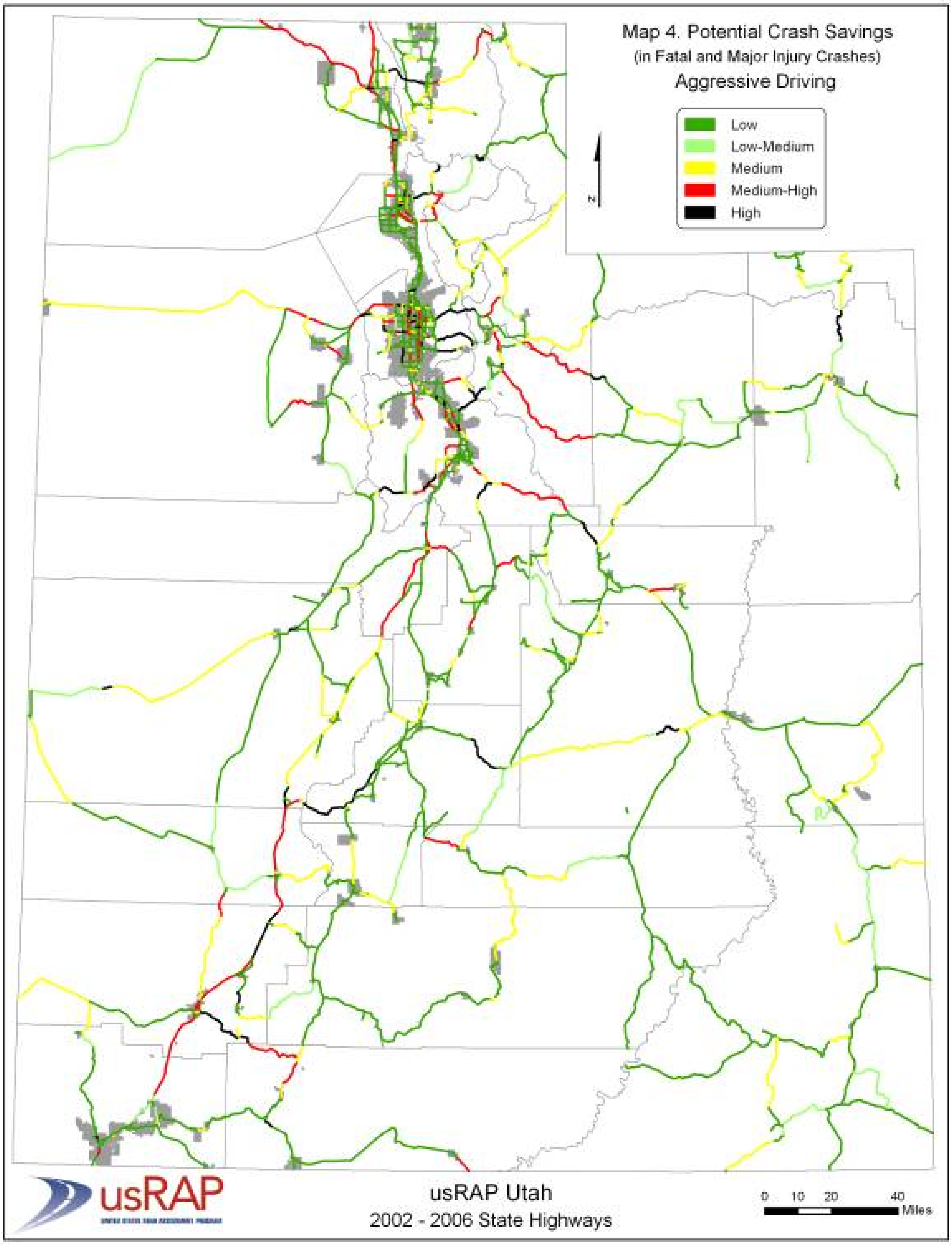


Figure 53. Utah Map 4 for Aggressive-Driving Crashes

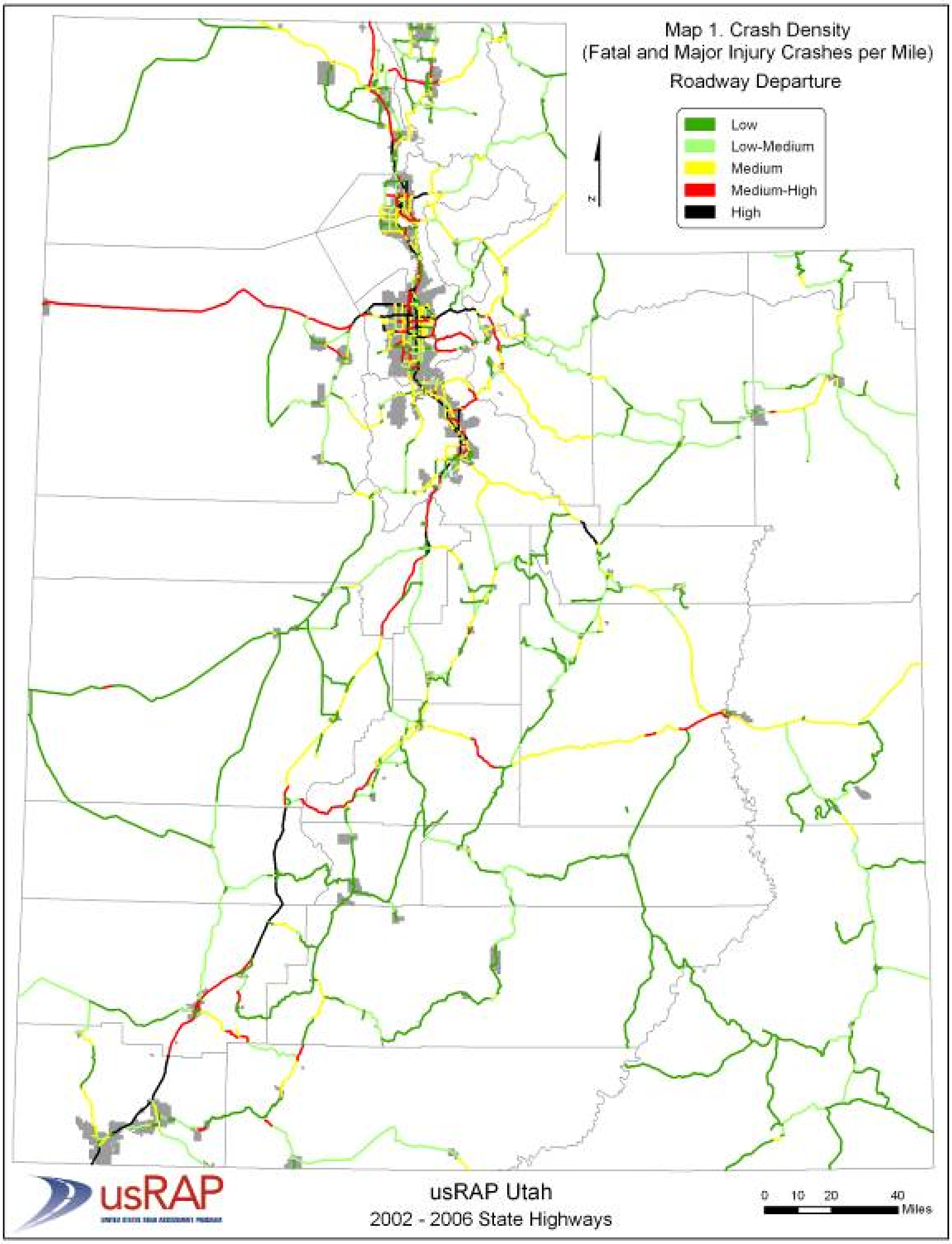


Figure 54. Utah Map 1 for Roadway-Departure Crashes

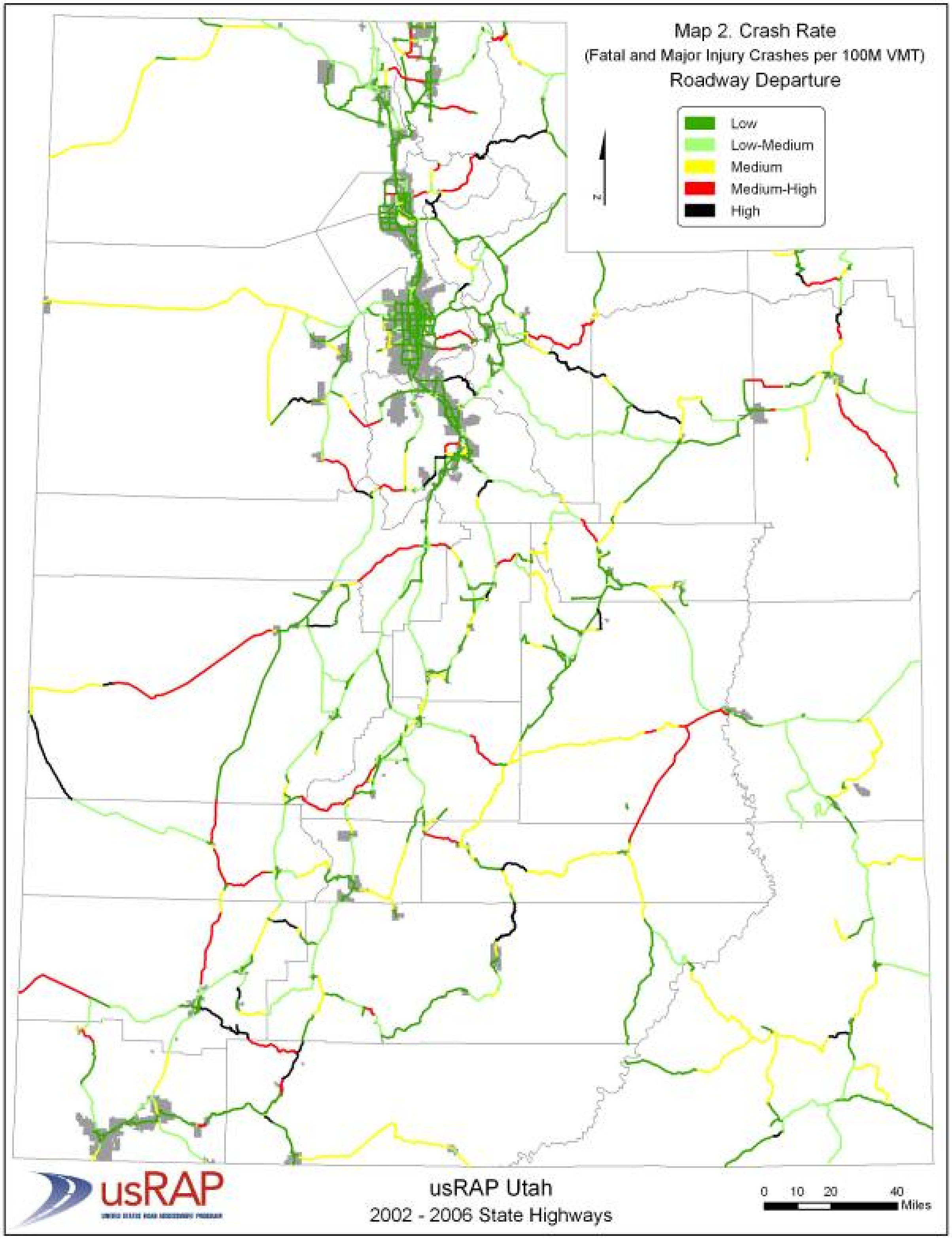


Figure 55. Utah Map 2 for Roadway-Departure Crashes

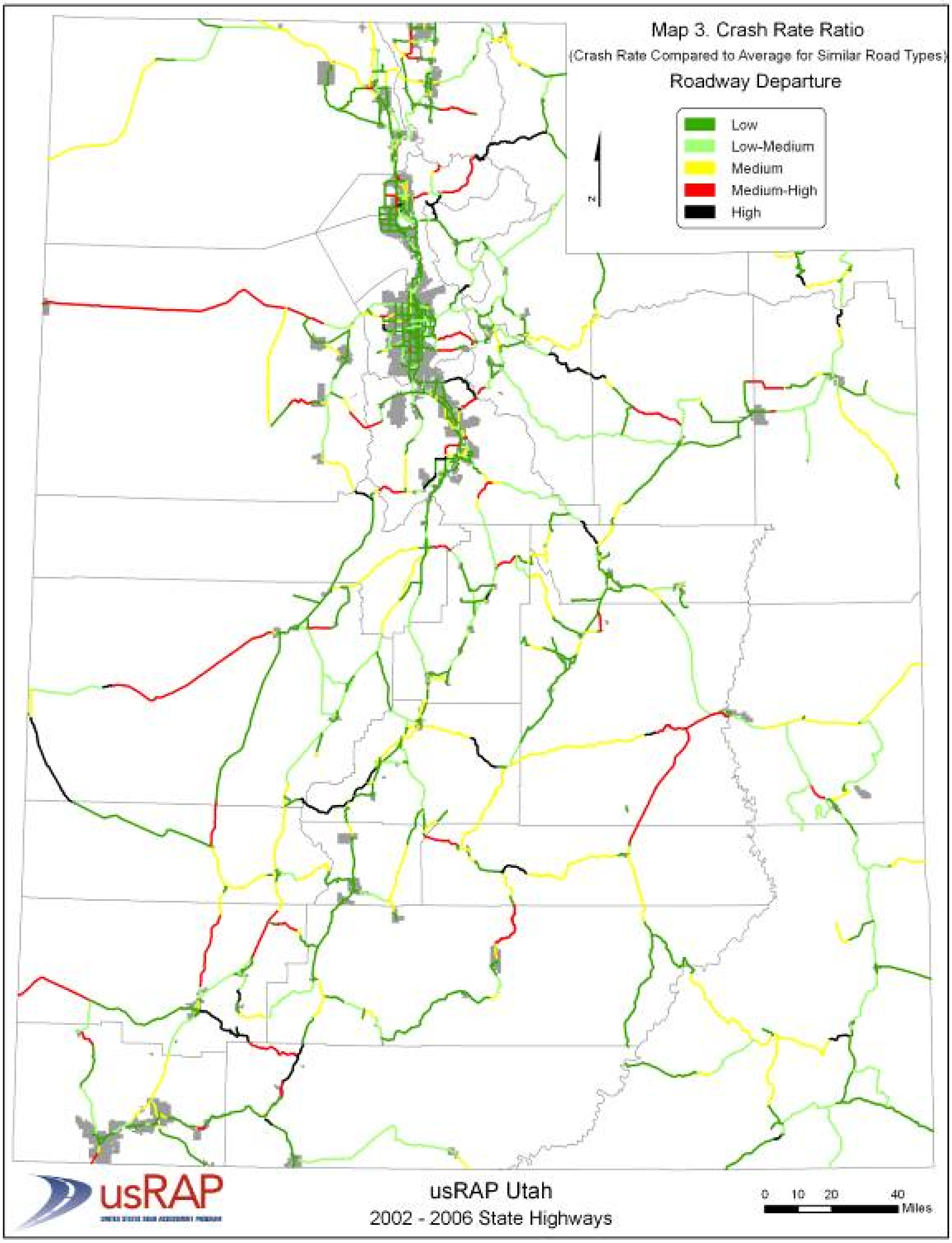


Figure 56. Utah Map 3 for Roadway-Departure Crashes

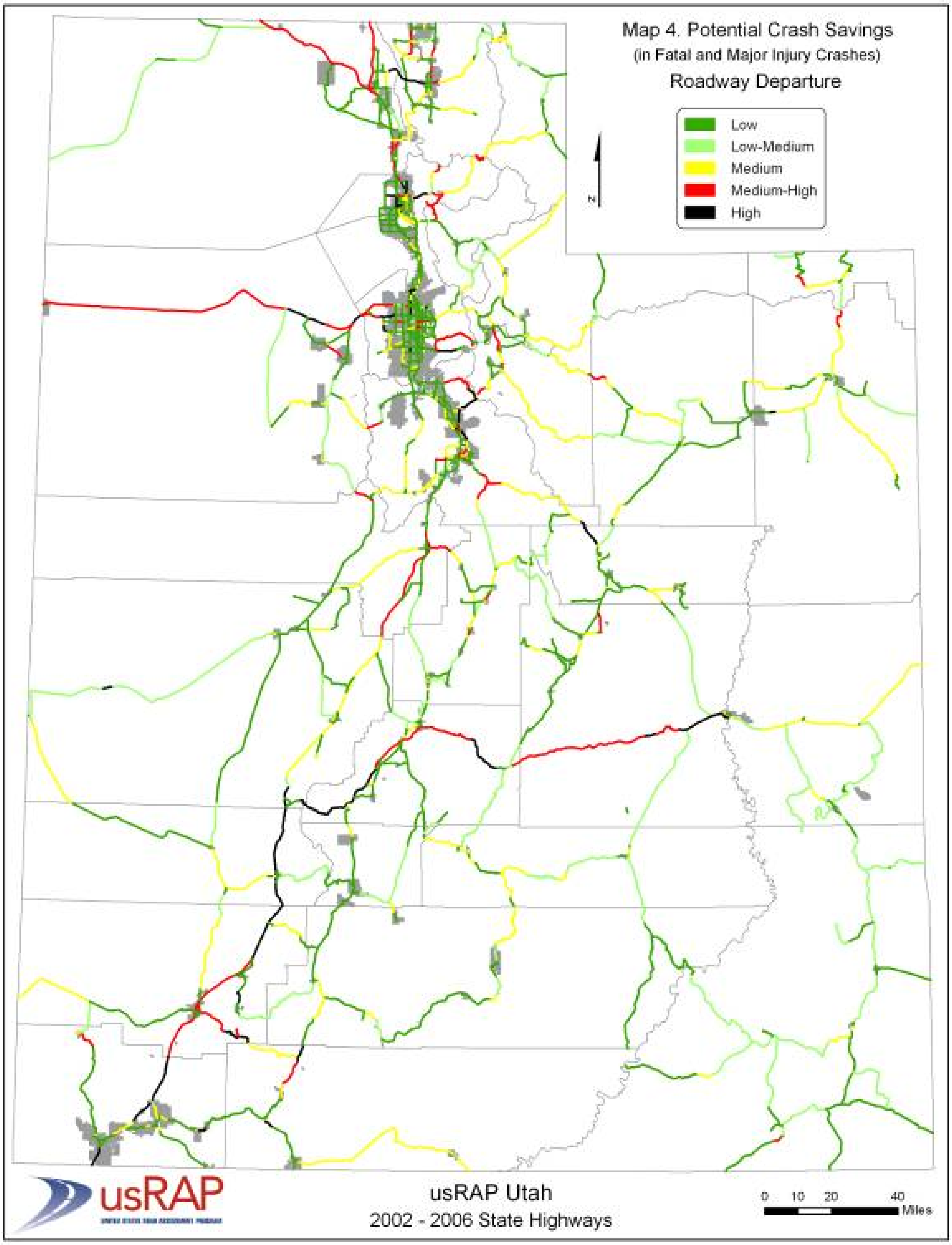


Figure 57. Utah Map 4 for Roadway-Departure Crashes

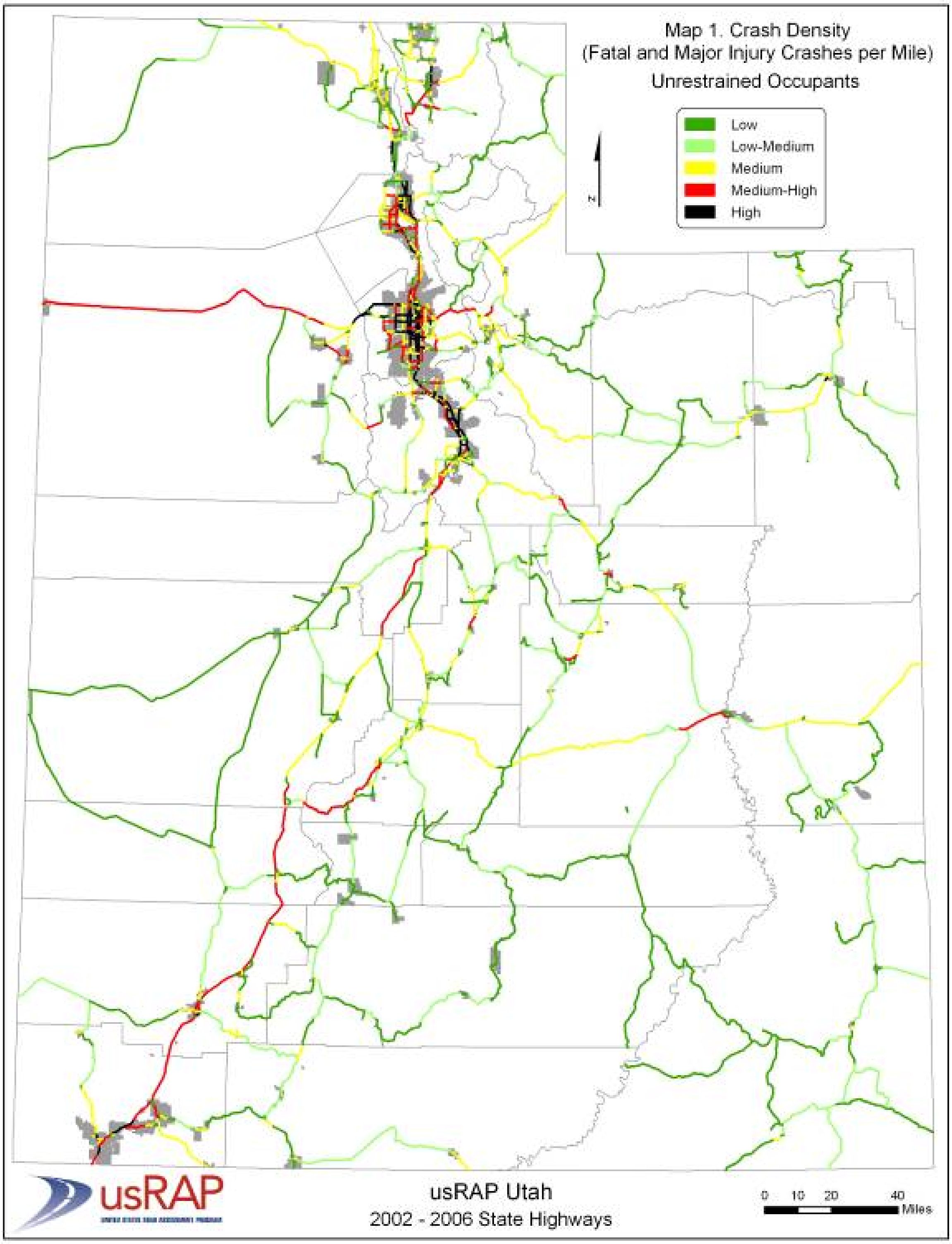


Figure 58. Utah Map 1 for Unrestrained-Occupant Crashes

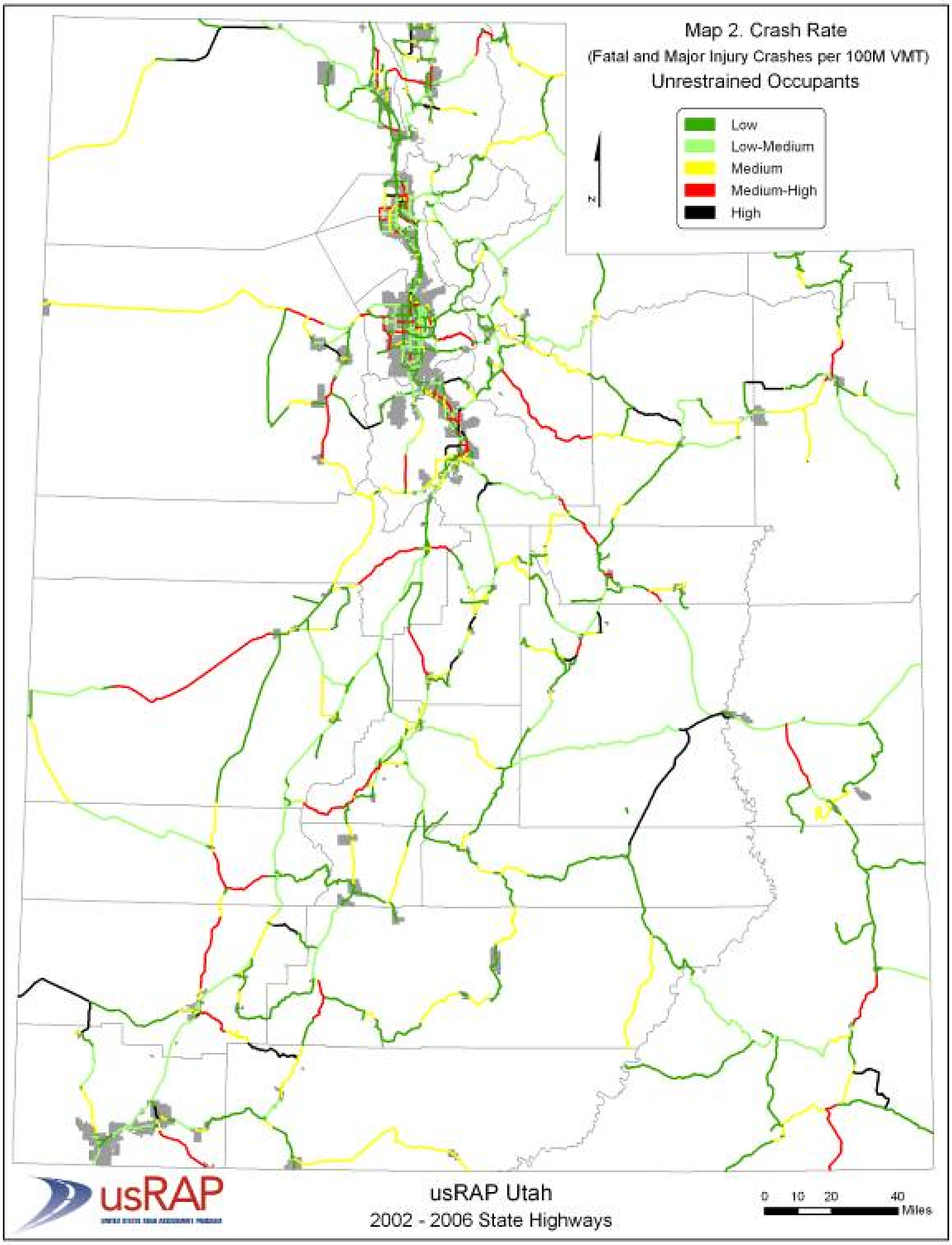


Figure 59. Utah Map 2 for Unrestrained-Occupant Crashes

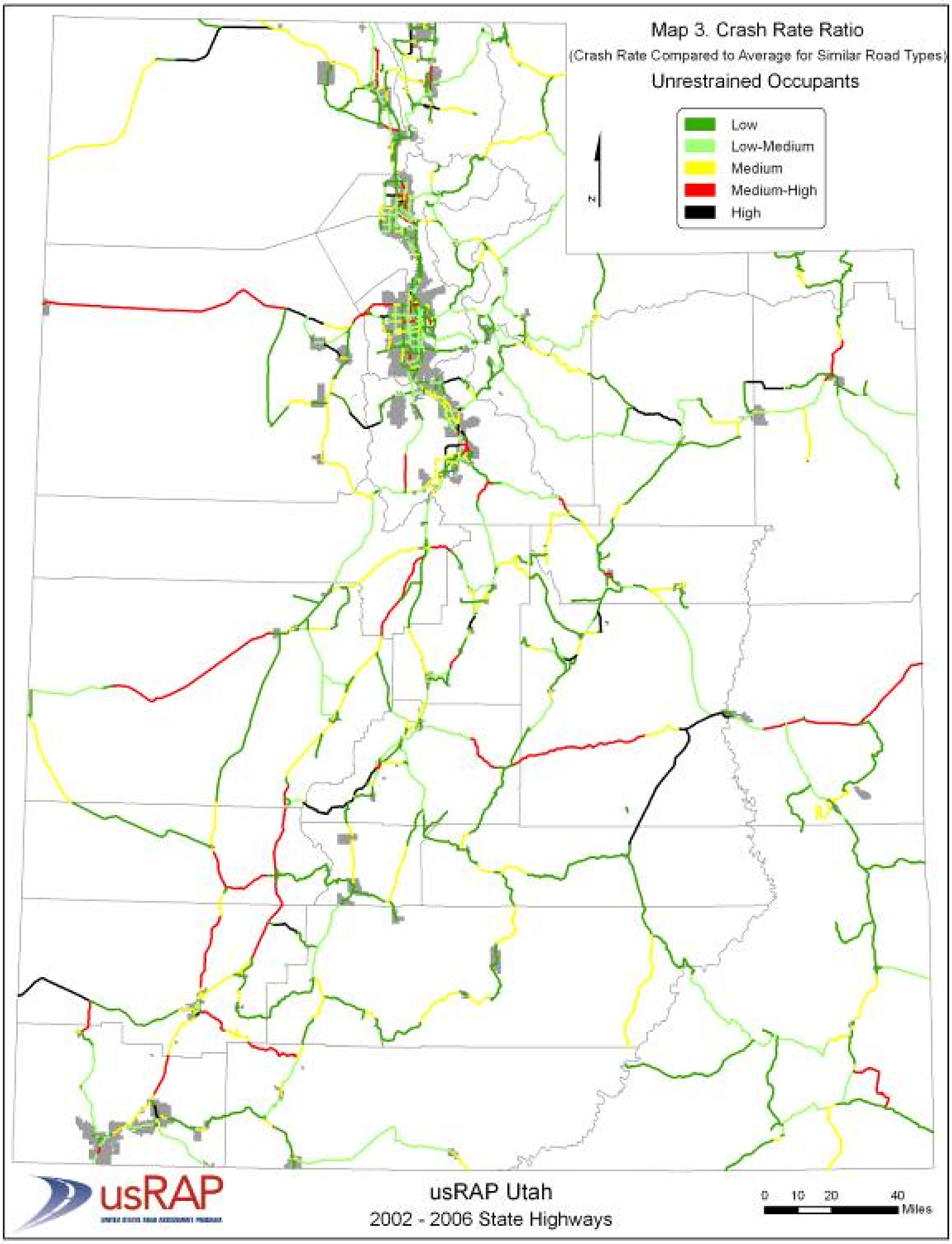


Figure 60. Utah Map 3 for Unrestrained-Occupant Crashes

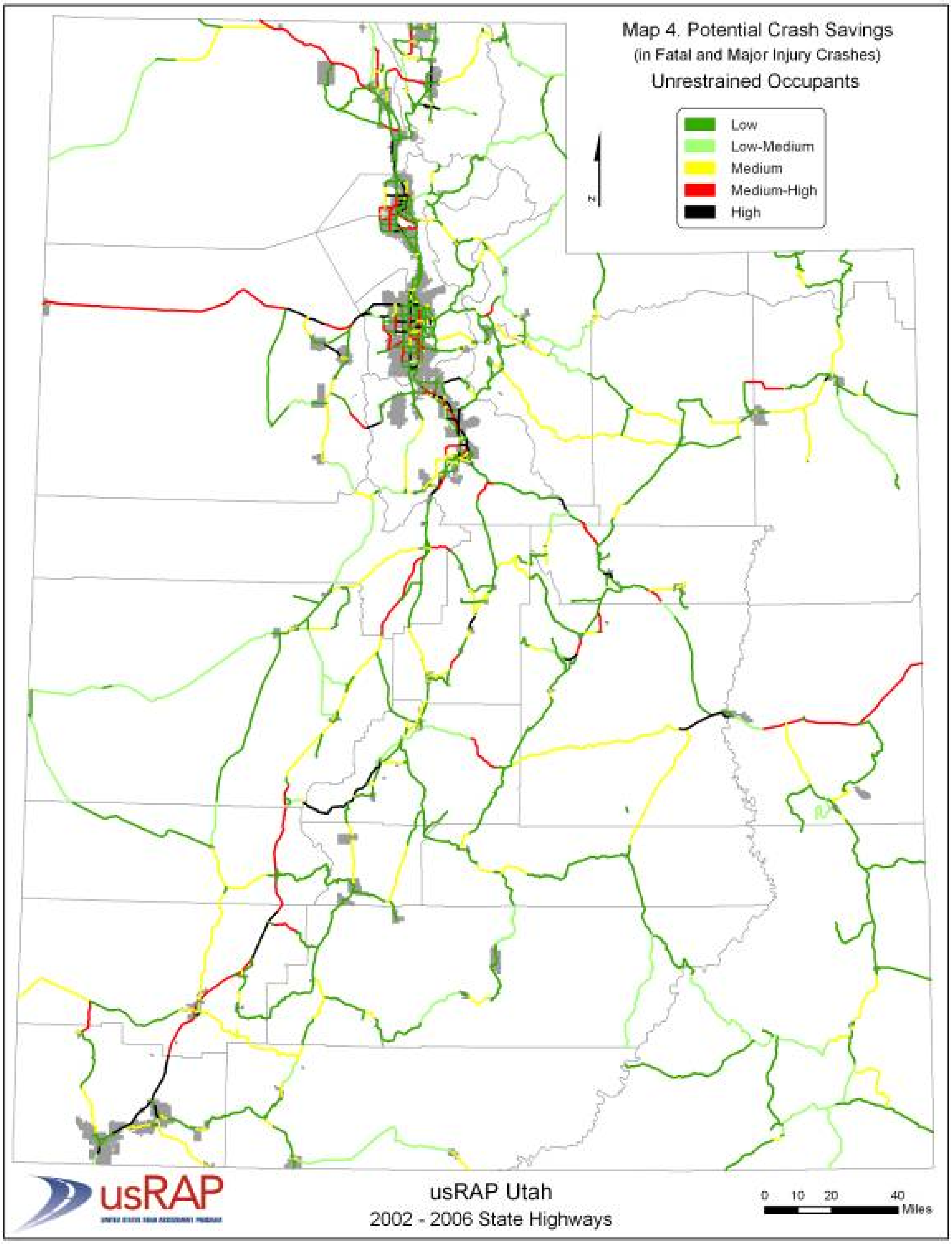


Figure 61. Utah Map 4 for Unrestrained-Occupant Crashes

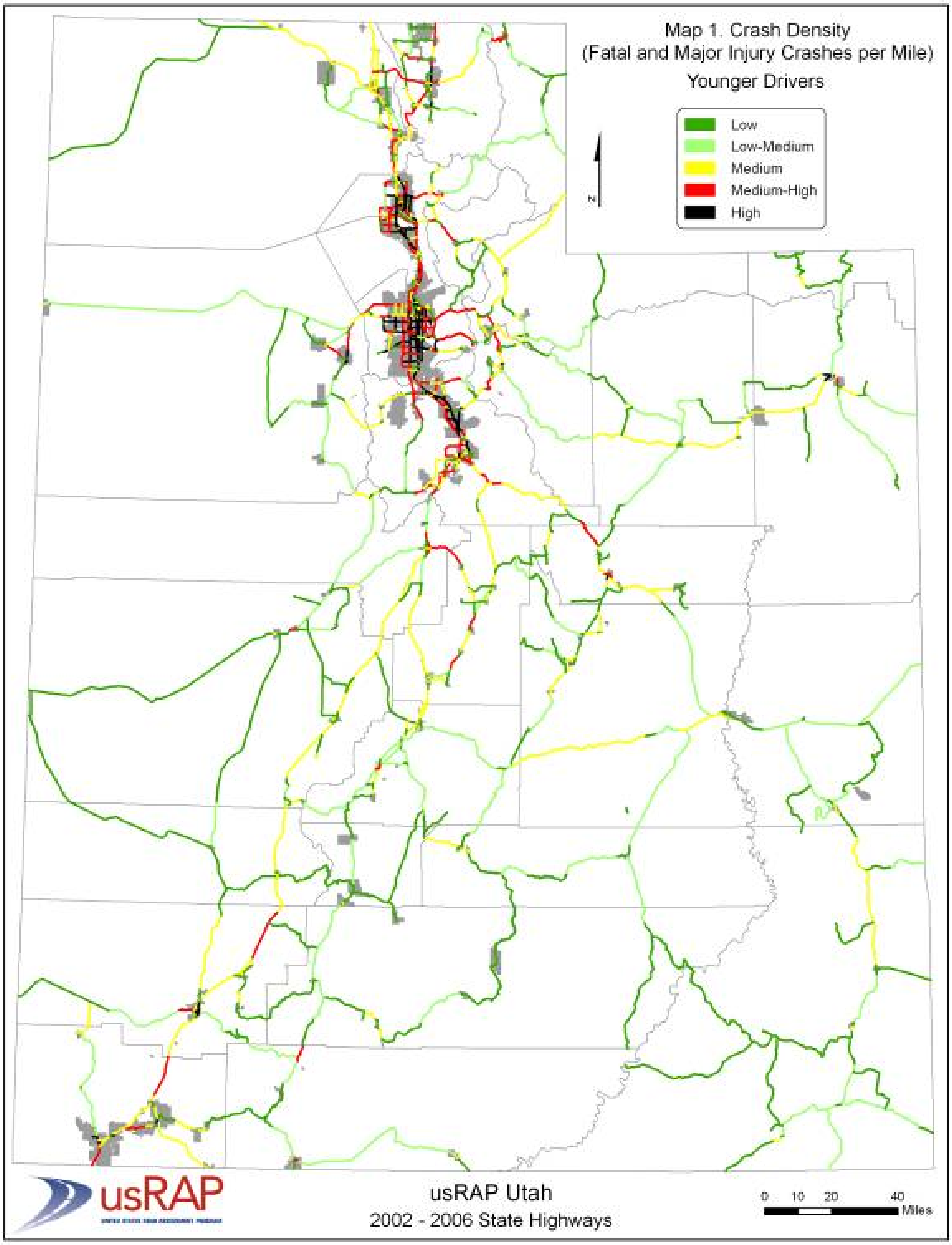


Figure 62. Utah Map 1 for Younger Driver Crashes

2.7.8 Use of the usRAP Maps in Utah

The Utah DOT believes that the usRAP risk maps can provide an important contribution to highway safety management in Utah. The risk maps will be of assistance in managing safety on state highways in both rural and urban areas; risk mapping of county roads should also be considered. The Utah DOT is using the usRAP maps as a public communication tool to document safety improvement needs in two specific areas of the state around Tooele Valley. A phone survey of the Tooele County residents was conducted to find out about what makes them feel unsafe driving on State Route 112 and how often they participate in certain unsafe driving behaviors. Based on the survey, full-page color newspaper ads were developed and a press release was developed and distributed for the newspapers that serve both communities. The key messages about the safety improvements to the roadway were that usRAP maps and crash data analyses were used to support the safety project and that the Utah DOT had listened to the communities' roadway safety concerns and developed a road improvement project to meet the identified needs. A usRAP map specifically focused on the Toole Valley project location that was developed and was used in the press and advertising materials.

The American Traffic Safety Services Association (ATTSA) is using reprints of the Utah advertisements as part of its package to legislators and staffers as they go to Capitol Hill to advocate for roadway safety funding in April 2010. ATTSA has found the ads to provide an excellent example of the kinds of clear communications that can help both the public and decision makers to be more aware of importance of highway safety and the steps that can be taken to make roadway improvements. In particular, usRAP highlighted a roadway situation that needed immediate attention, and it speaks to the process of involving numerous groups, agencies, and members of the public coming together to solve a roadway situation in need of improvement.

Another use of the usRAP maps was in the safety project development process. Utah DOT regional traffic engineering staff used the usRAP maps for initial screening and identification of locations to be considered for safety projects. The maps enabled Utah DOT staff to quickly identify locations for additional analysis and review. One region specifically used the maps as a public information tool to demonstrate the prioritization of safety projects based on the risk categories.

Section 3.
Further Work With Phase I and II Pilot States

This section of the report presents an overview of further work conducted with the Phase I and II pilot states. In particular, supplementary risk maps for Michigan were developed to correspond to the updated risk maps that were prepared during Phase II.

3.1 usRAP Activities in Michigan

This section describes additional risk mapping activities in Michigan.

3.1.1 Updated Michigan Risk Maps

The risk maps in the Phase I report were prepared using crash data for the years from 2000 to 2004, inclusive. Updated risk maps were prepared during Phase II with crash data for the years from 2002 to 2006, inclusive. Thus, these updated risk maps are based on three years of crash data (2002 to 2004) that were not available at the time the Phase I maps were developed. The updated Michigan risk maps were developed using the same procedures and criteria as the Phase I risk maps. Thus, the colors shown on the maps represent the same percentages of the road system as the other pilot studies. Figures 63 through 66 present the updated Michigan risk maps for the years 2002 through 2006, inclusive, for Maps 1 through 4, respectively. While these maps were included in the usRAP Phase II report, they are also shown here to provide context for the new supplementary maps, presented below. Table 13 summarizes the Michigan risk mapping data for the years 2002 through 2006.

3.1.2 Supplementary Risk Maps for Michigan

Supplementary risk maps have been prepared for Michigan as part of the usRAP Phase II effort in a manner similar to those prepared for the previous pilot studies. The supplementary map types prepared for Michigan include:

- alcohol-involved crashes
- roadway-departure crashes
- nonintersection crashes

Maps analogous to Maps 1 through 4 were prepared for alcohol-involved crashes in Michigan (see Figures 67 through 70). Alcohol-involved crashes were identified as any crash for which drinking was indicated as being involved or for which any driver, pedestrian, or bicyclist was indicated as having been drinking. For each of these maps, a minimum of two fatal- or major-injury alcohol-involved crashes were required for a road section to be considered medium-high or high risk.

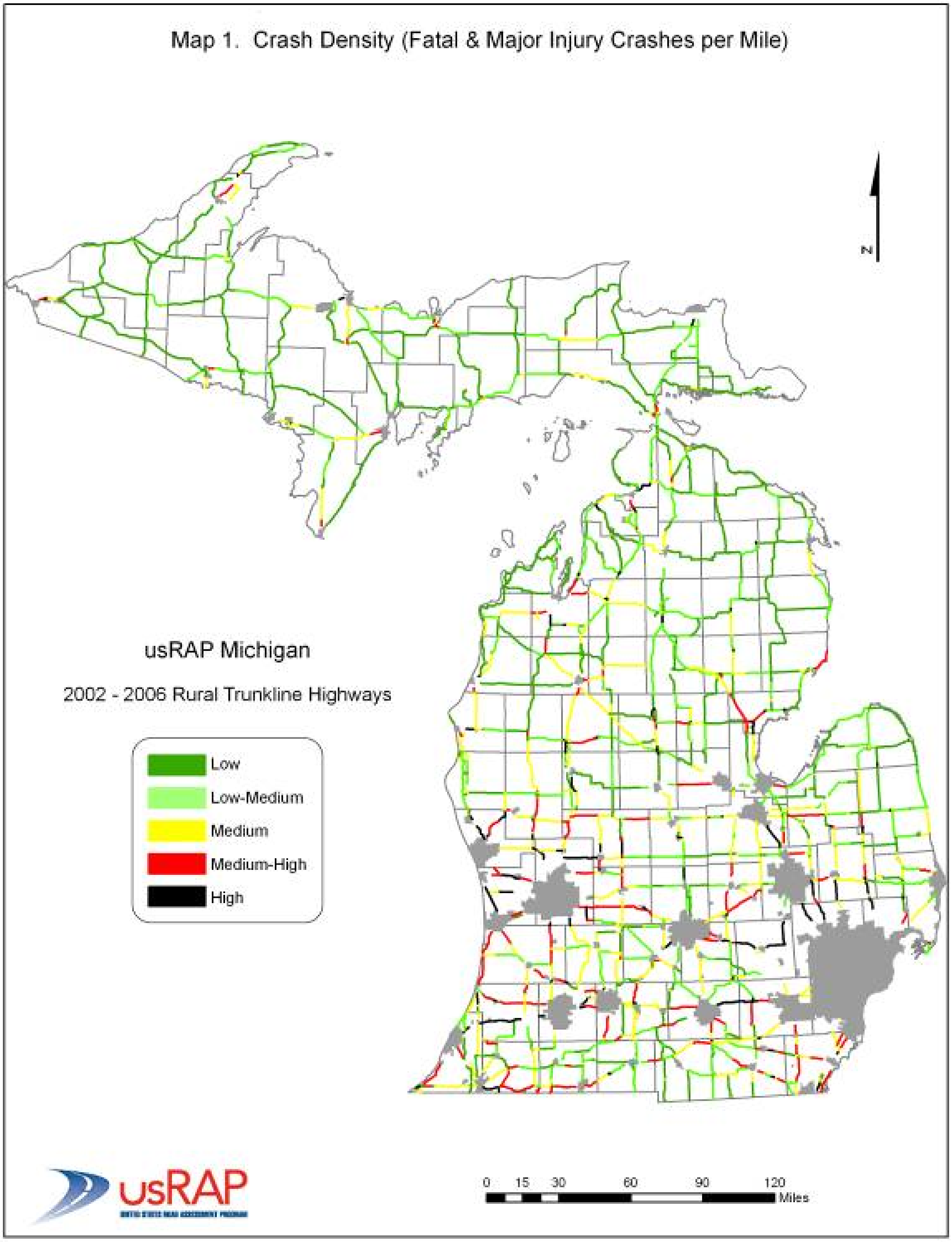


Figure 63. Updated Version of Map 1 for Michigan (2002 to 2006)

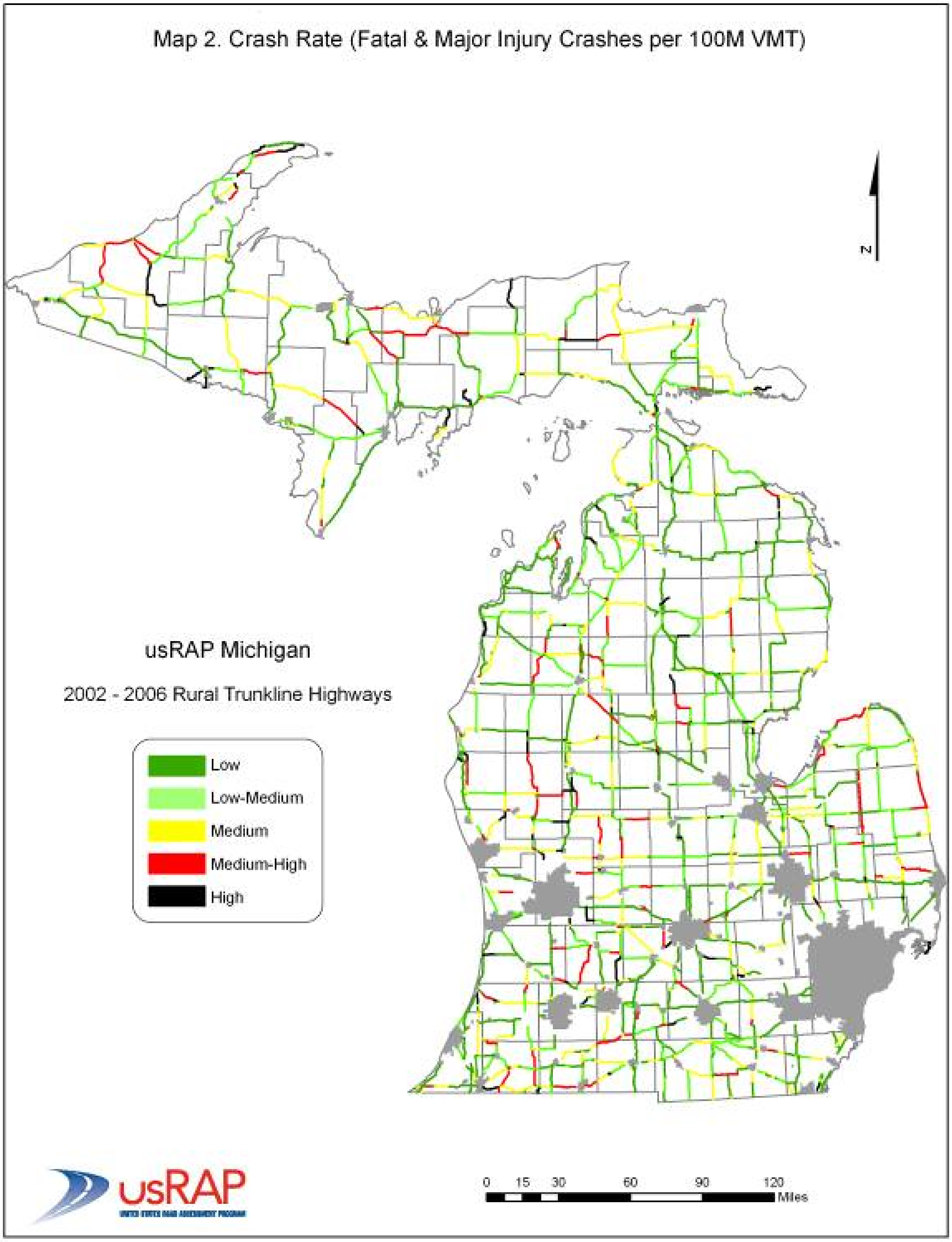


Figure 64. Updated Version of Map 2 for Michigan (2002 to 2006)

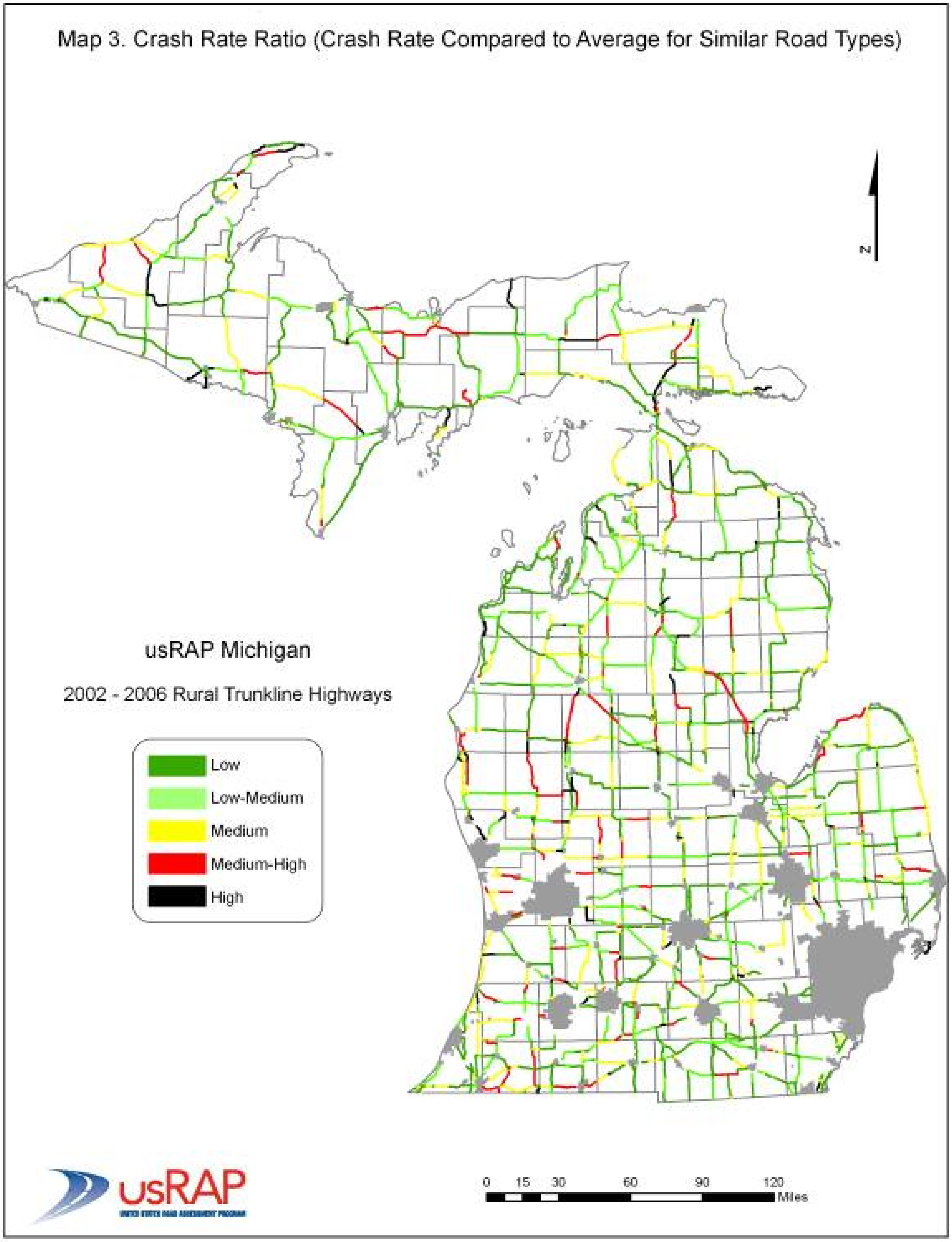


Figure 65. Updated Version of Map 3 for Michigan (2002 to 2006)

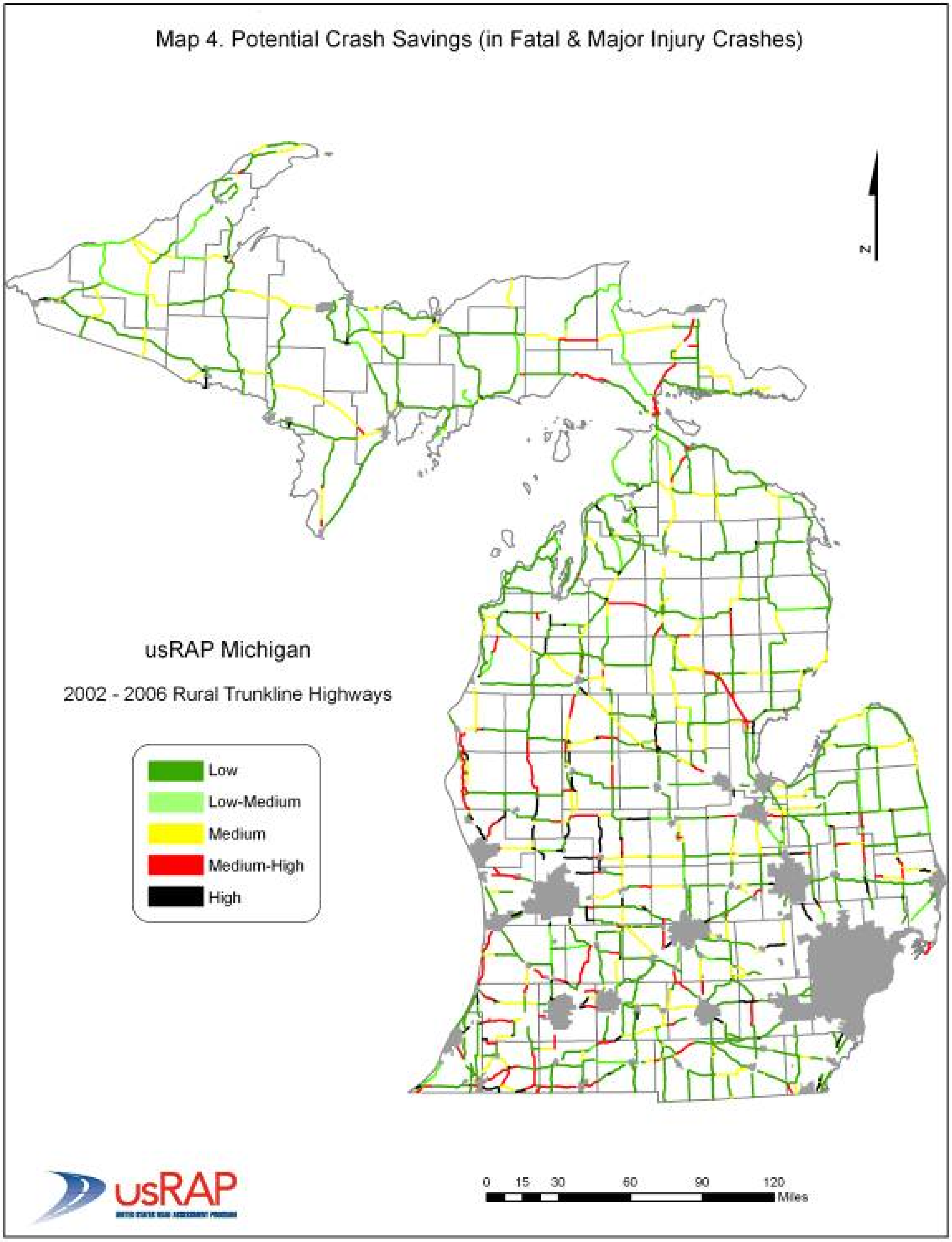


Figure 66. Updated Version of Map 4 for Michigan (2002 to 2006)

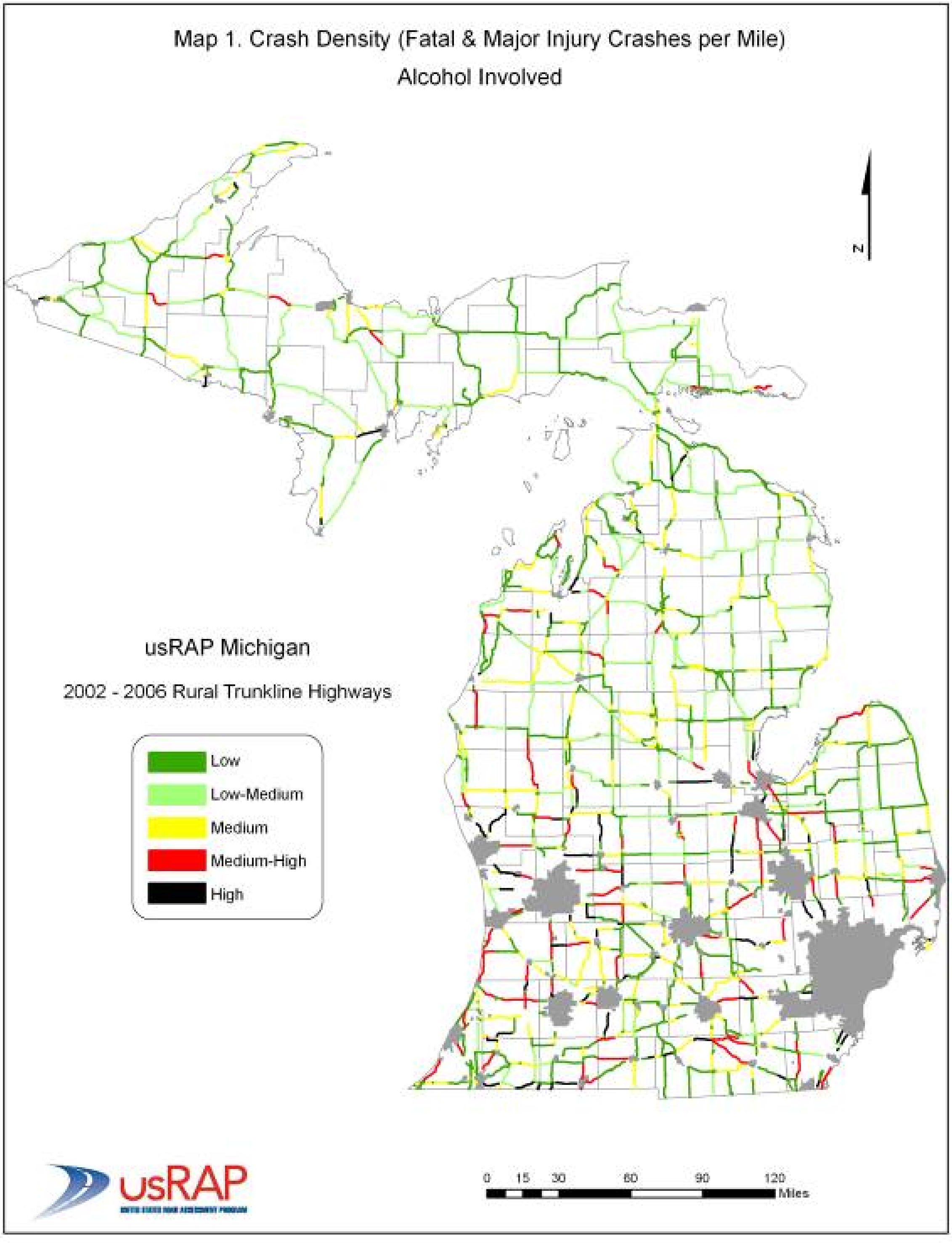


Figure 67. Michigan Map 1 for Alcohol-Involved Crashes

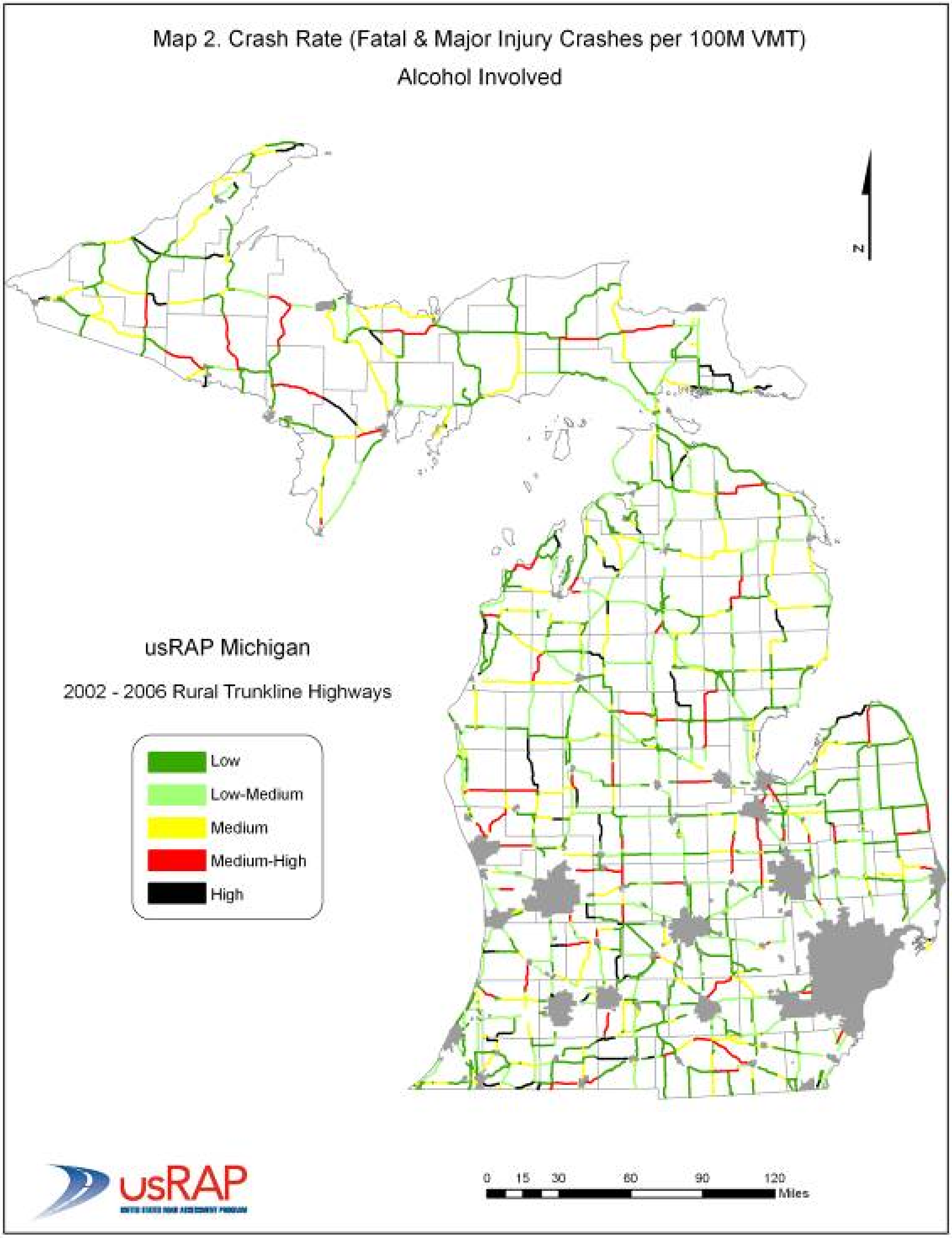


Figure 68. Michigan Map 2 for Alcohol-Involved Crashes

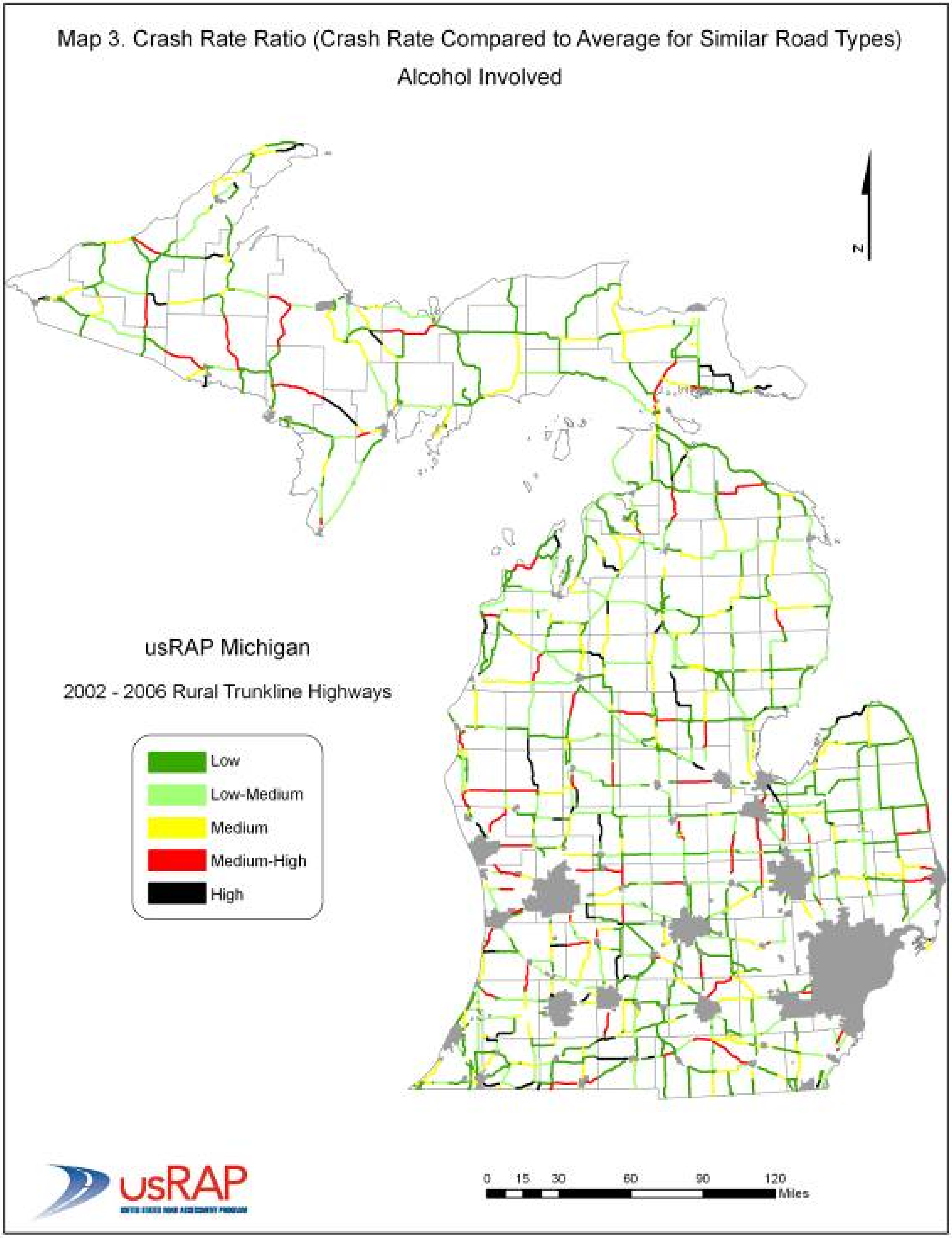


Figure 69. Michigan Map 3 for Alcohol-Involved Crashes

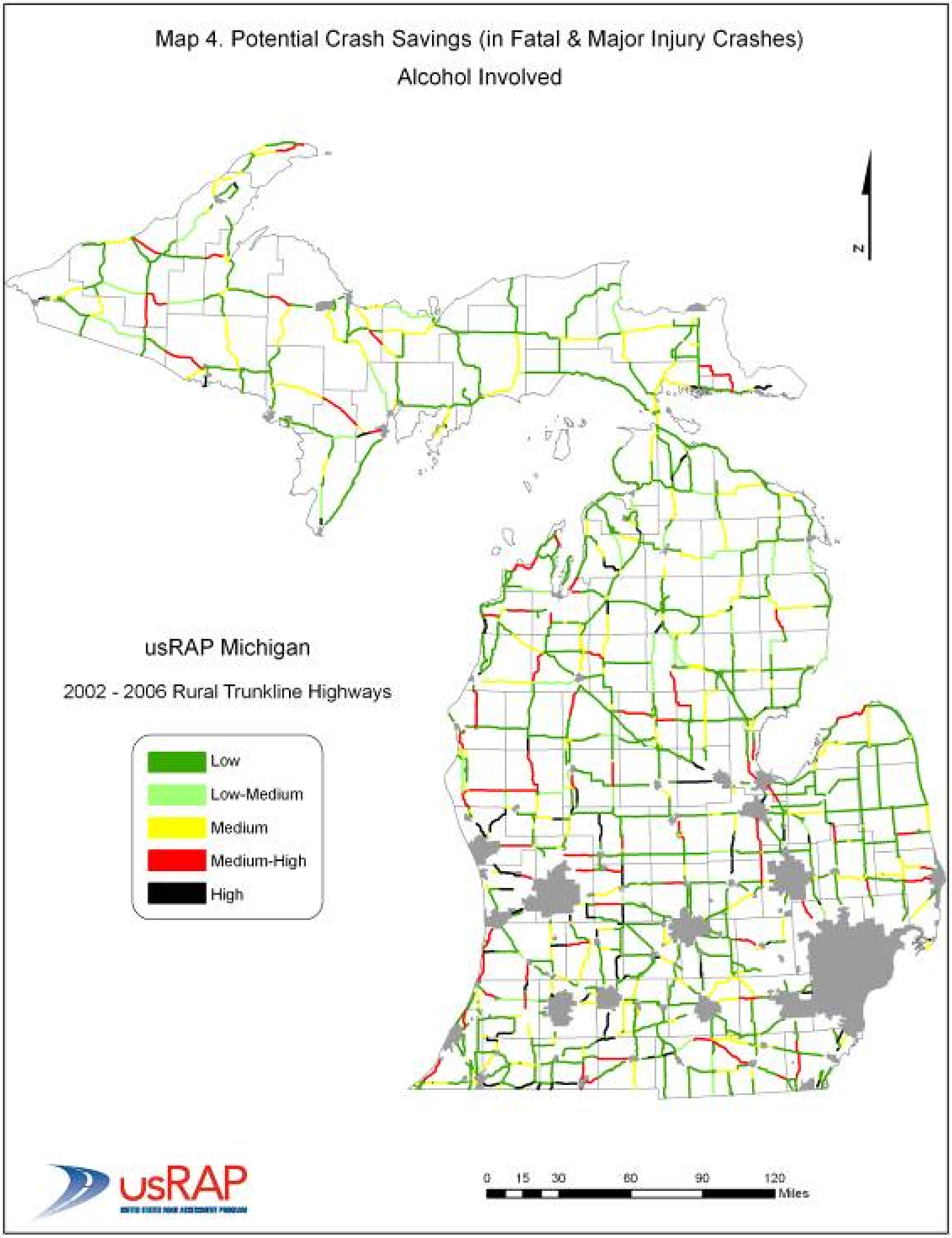


Figure 70. Michigan Map 4 for Alcohol-Involved Crashes

Table 13. Michigan Risk Mapping Data (2002-2006)

Road type	Number of sections	Road miles	Average length (mi)	AADT (veh/day)	Annual VMT (billion)	Fatal & major injury crashes: Total frequency	Annual frequency	Annual density (per mi)	Average rate (per 100M VMT)
Freeway	160	1,001	6.3	23,922	8.7	1,297	1.62	0.26	2.97
Multilane divided	33	85	2.6	13,937	0.4	104	0.63	0.25	4.84
Multilane undivided	38	78	2.1	11,259	0.3	153	0.80	0.39	9.46
Two-lane roads	1,126	5,970	5.3	4,492	9.8	4,320	0.77	0.14	8.83
Total	**1,357**	**7,134**	**5.3**	**7,405**	**19.3**	**5,874**	**0.87**	**0.27**	**6.09**

Maps analogous to Maps 1 through 4 were prepared for roadway-departure crashes in Michigan (see Figures 71 through 74). Roadway-departure crashes were identified as nonintersection and noninterchange crashes in which there was a harmful event indicating that any involved vehicle:

- crossed the centerline or median
- ran-off-road left
- ran-off-road right
- collided with any fixed object

For each of these maps, a minimum of two fatal- or major-injury roadway-departure crashes were required for a road section to be considered medium-high or high risk.

Maps analogous to Maps 1 through 4 were prepared for nonintersection crashes in Michigan (see Figures 75 through 78). Nonintersection crashes were identified as all crashes that did not occur at an intersection or interchange and were not related to the presence of an intersection or interchange. For each of these maps, a minimum of three fatal- or major-injury nonintersection crashes were required for a road section to be considered medium-high or high risk.

3.1.3 Use of the usRAP Maps in Michigan

The Michigan DOT has, to date, made only limited use of the usRAP risk maps, but believes they can serve as another tool in Safety Management of the road system to supplement other tools in current use. The challenge in using the risk maps will be deciding how to prioritize investigations of high-risk segments to determine whether safety improvement projects are needed or whether education or enforcement strategies are more appropriate. The supplementary risk maps should help in this regard. In particular, the Michigan DOT thinks that the supplementary maps in this report that separated roadway segment crashes from intersection crashes (see Figures 75 through 78) will be helpful. It would also be helpful to have the risk mapping results in spreadsheet form so that the locations of specific segments can be easily identified. The Michigan DOT encourages usRAP to add urban areas to the RAP risk mapping protocol.

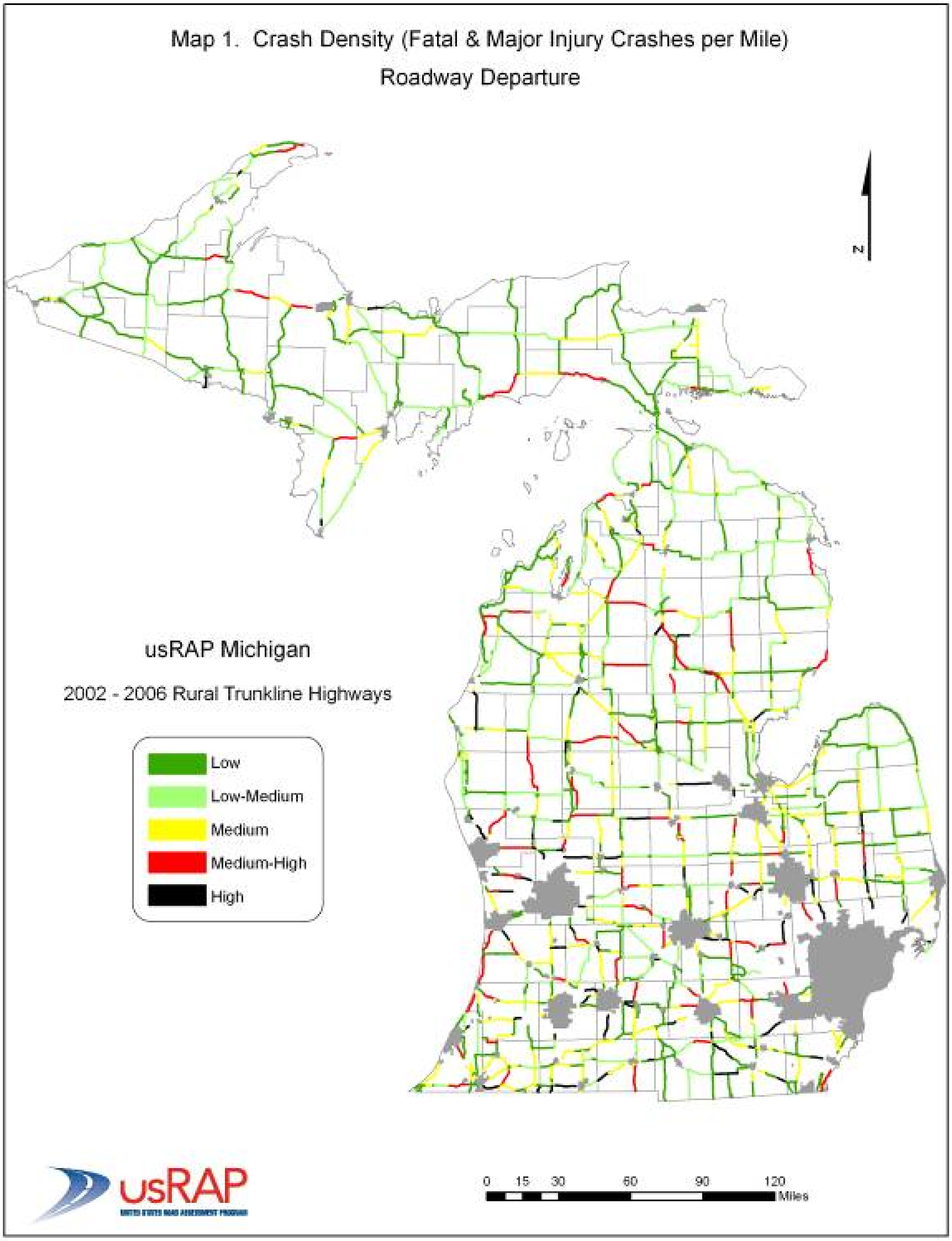


Figure 71. Michigan Map 1 for Roadway-Departure Crashes

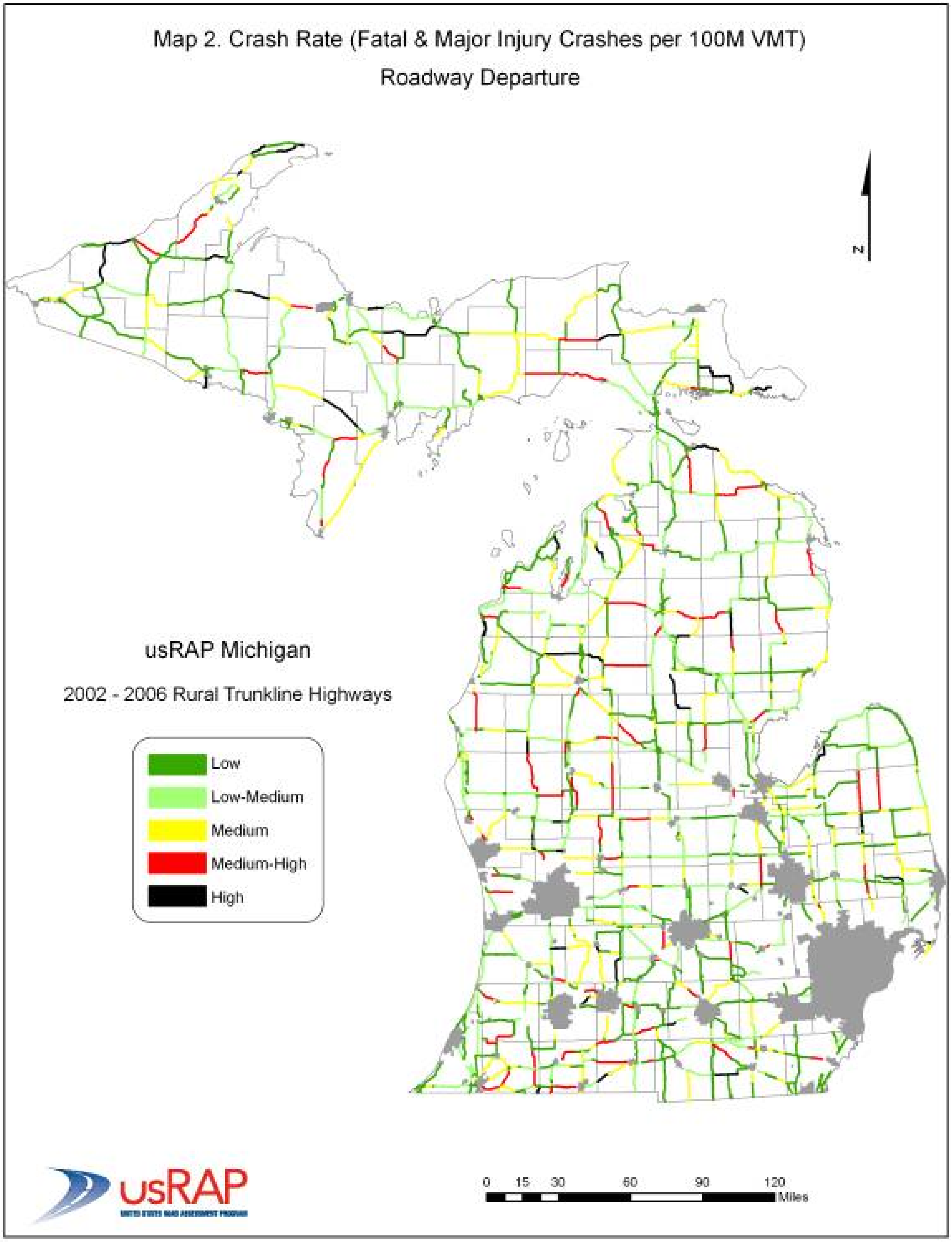


Figure 72. Michigan Map 2 for Roadway-Departure Crashes

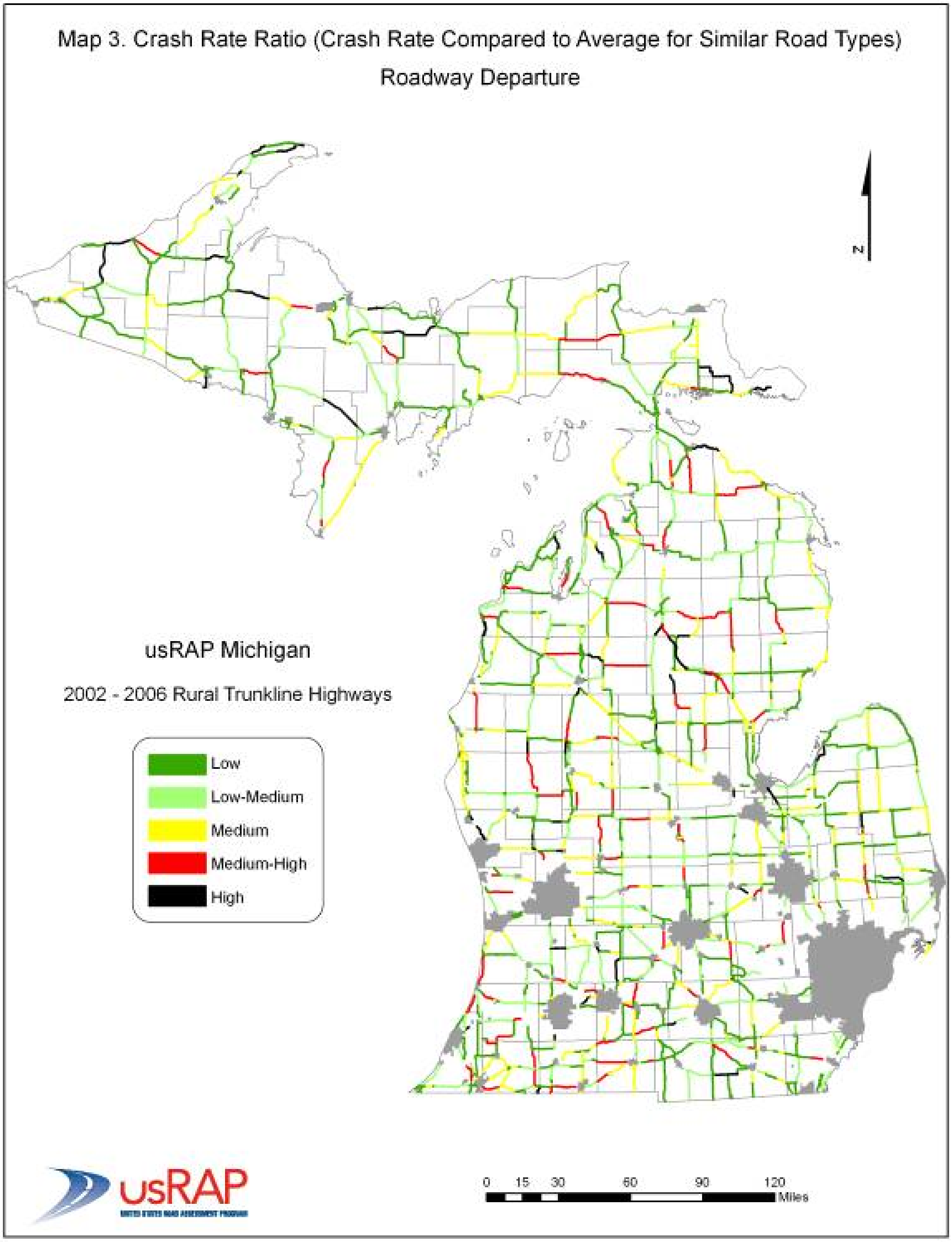


Figure 73. Michigan Map 3 for Roadway-Departure Crashes

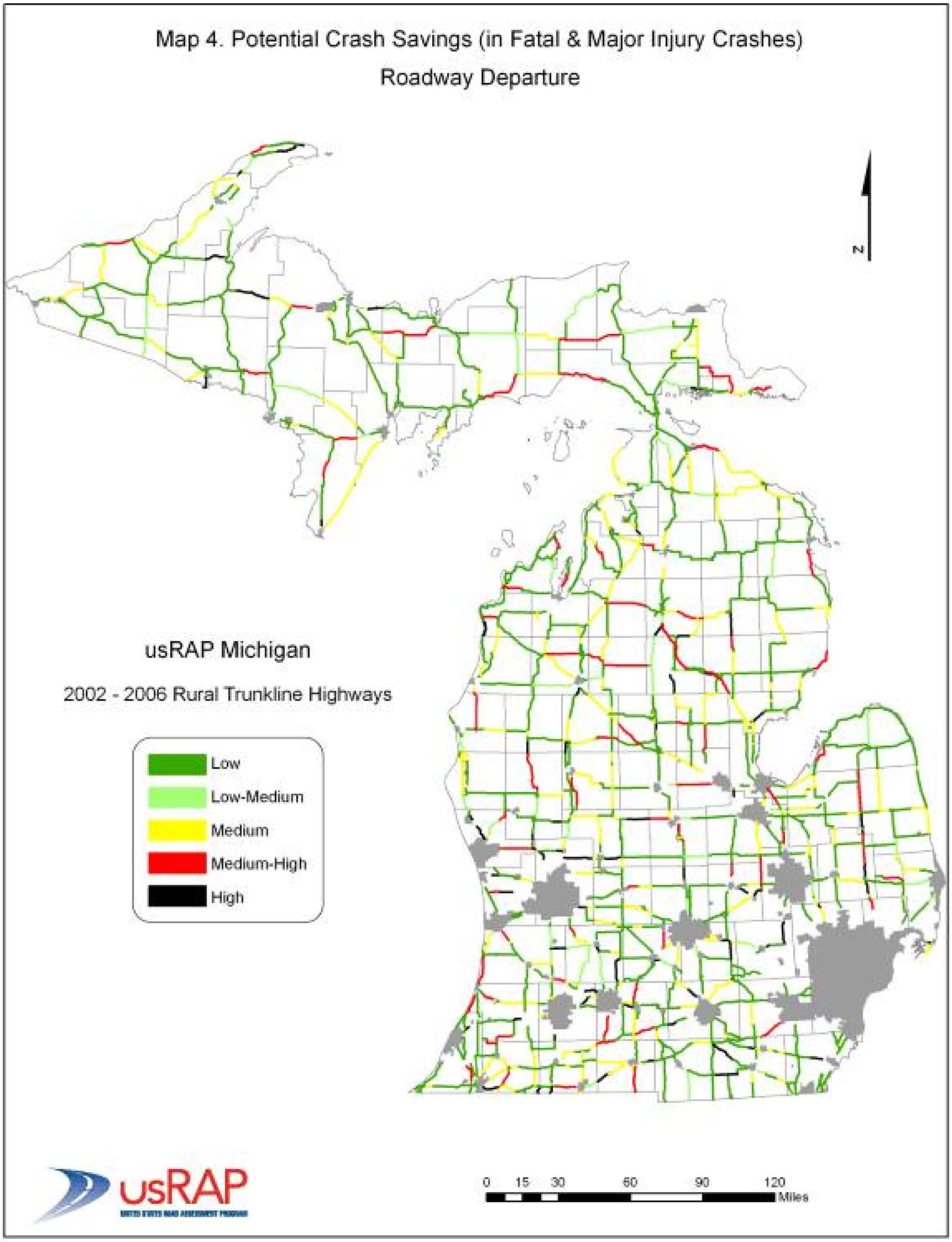


Figure 74. Michigan Map 4 for Roadway-Departure Crashes

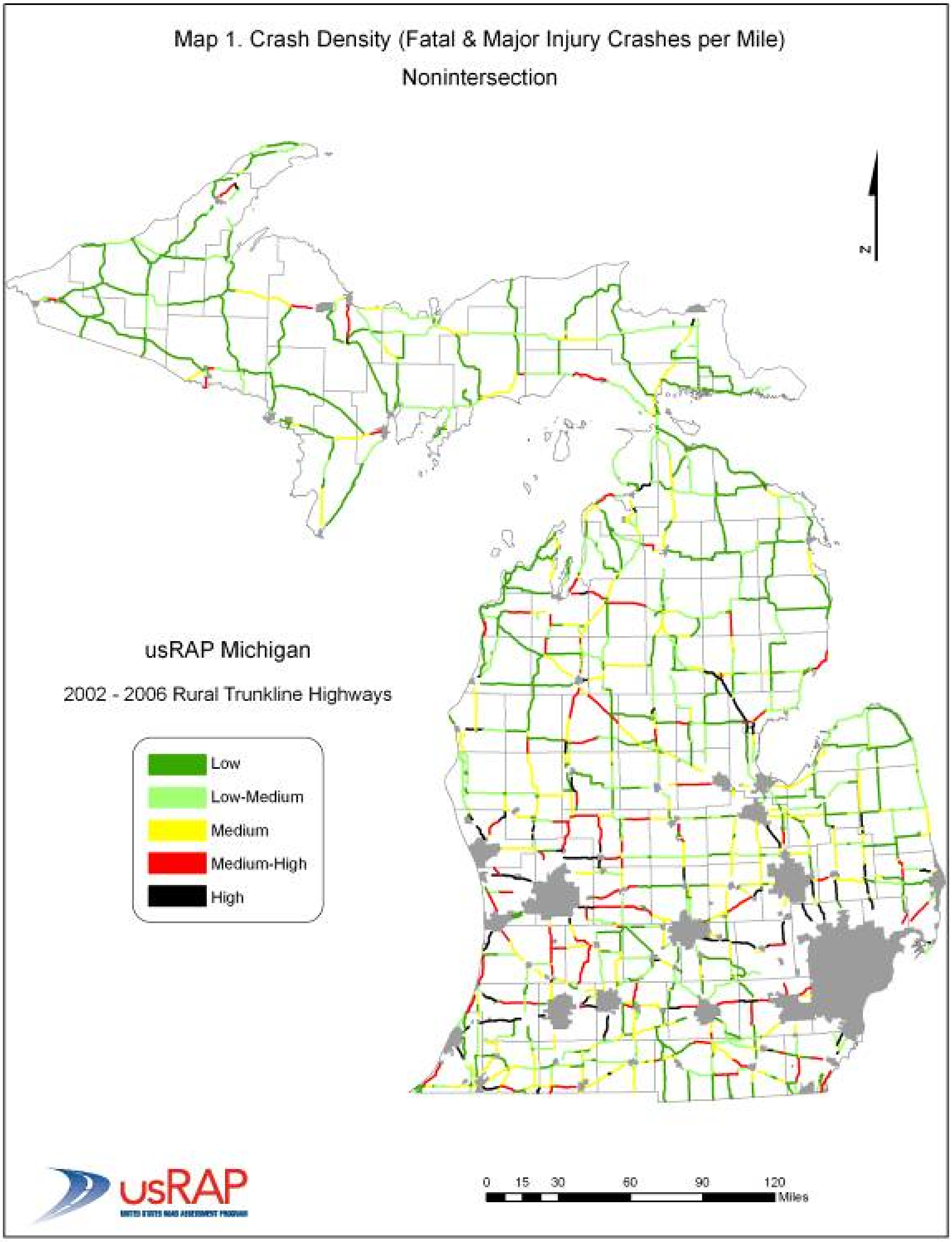


Figure 75. Michigan Map 1 for Nonintersection Crashes

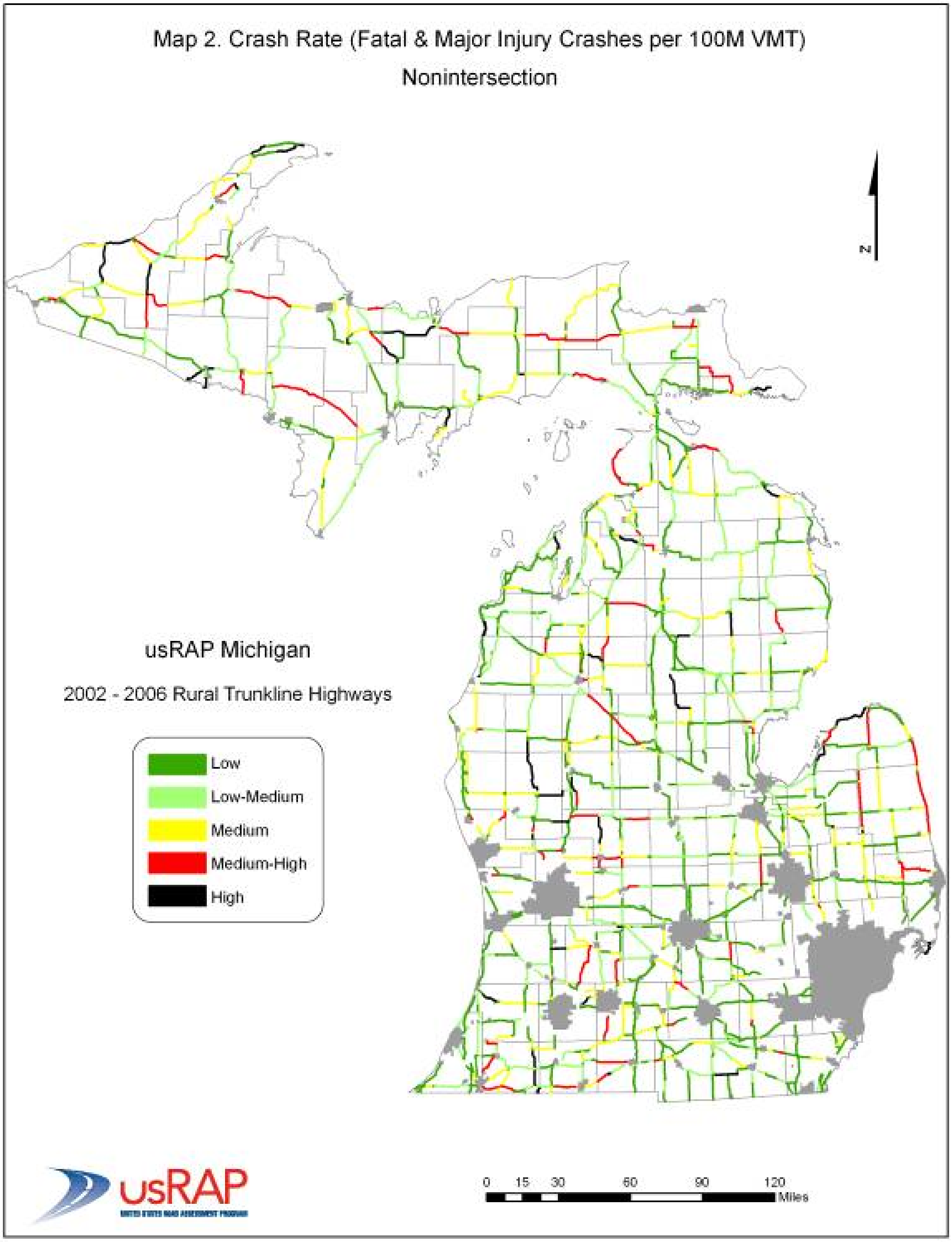


Figure 76. Michigan Map 2 for Nonintersection Crashes

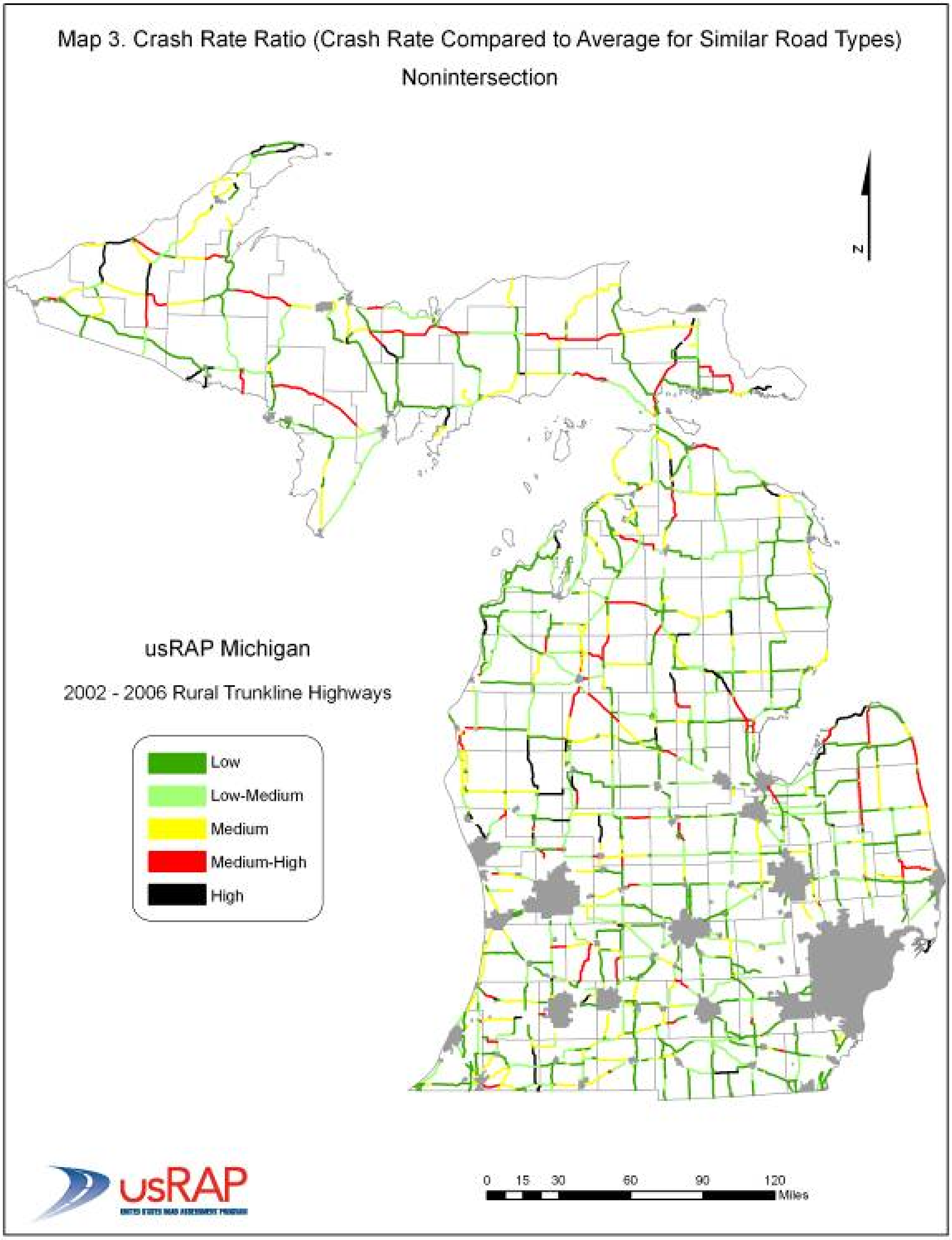


Figure 77. Michigan Map 3 for Nonintersection Crashes

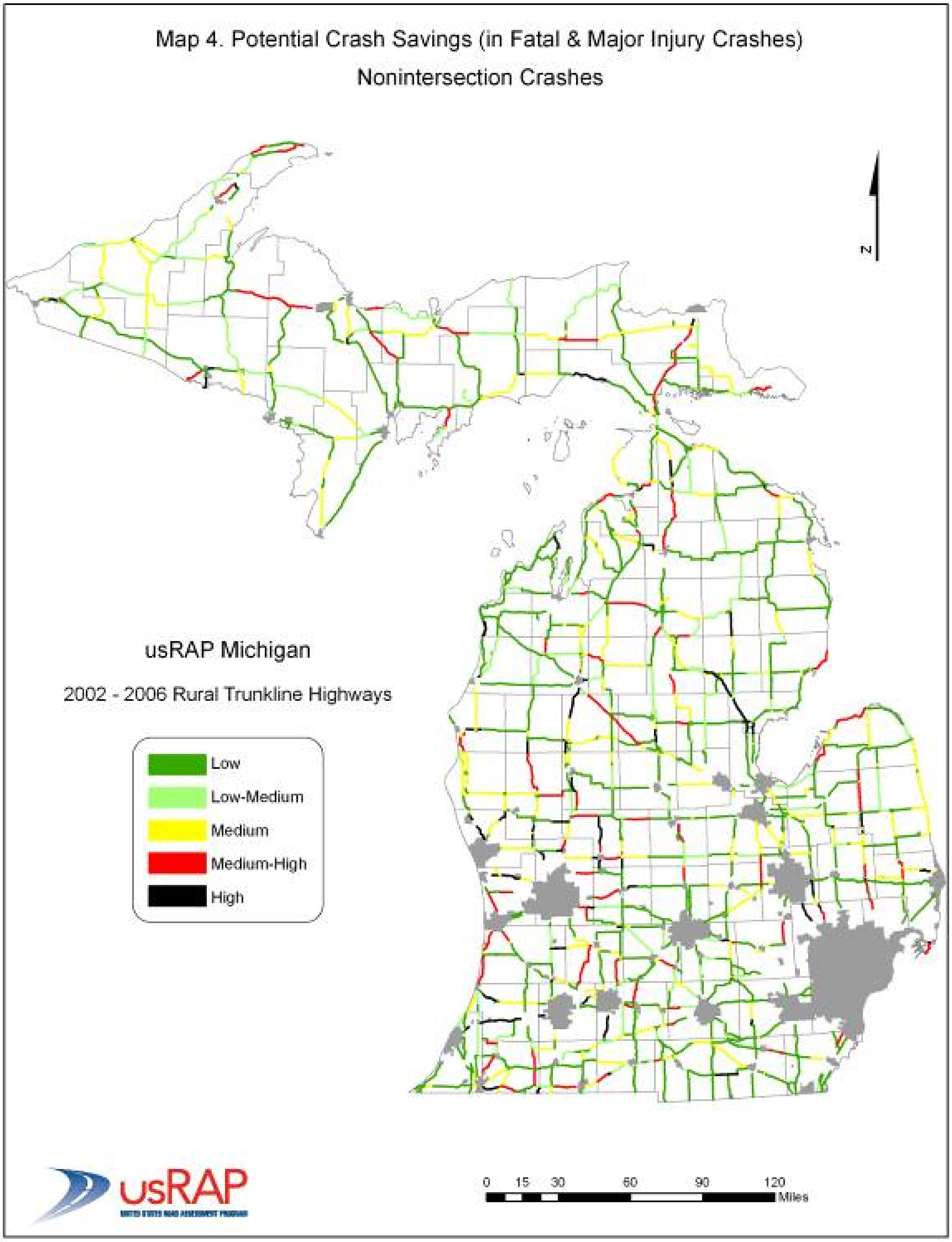


Figure 78. Michigan Map 4 for Nonintersection Crashes

The Michigan DOT encourages and supports the usRAP work with local agencies in Michigan that are finding value in the products aiding the improvement of their safety programs.

3.2 Activities in Other States

3.2.1 Use of usRAP Maps in Iowa

There have been several recent applications of the usRAP risk maps in Iowa. These applications are described below.

3.2.1.1 Road Safety Audits

In November, 2009, the Iowa DOT Office of Traffic and Safety began a new effort to identify candidate corridors for road safety audits. The usRAP team provided usRAP risk maps to the State Safety Engineer who distributed them to all assistant district engineers and district engineering field staff. The maps were specially prepared for this purpose to include two-lane primary highways based on the density (usRAP Map 1) and rate (usRAP Map 2) of fatal and major injury (serious) crashes, for eight years of crash data (2001-2008). District staff were informed that while each plot has its strengths and weakness for ranking highway corridors, corridors that showed rankings of high (i.e., top 5 percent, colored black on the maps) or medium high (next 10 percent, colored red on the maps) in both analyses possibly warranted further review. District staff were asked to take a close look for opportunities for low-cost safety improvements in those corridors as they begin to work on a 3R resurfacing concepts in these corridors. The Office of Traffic and Safety also offered to schedule road safety audits (RSAs) if district staff considered them beneficial.

3.2.1.2 Draft Iowa Route 150 Report

During field reviews and office meetings, members of the Iowa DOT district staffs asked how the various sections of Iowa Route 150 and US 52 in the safety audit sections compared to other similar roadways in the state. By referencing the four usRAP maps of fatal and serious injury crash data furnished by the usRAP team, the Safety Circuit Rider was able to cite that information in the draft final report (http://www.intrans.iastate.edu/reports/rsa_IA150.pdf, see appendix C).

3.2.1.3 Iowa 5-Percent Report

The Iowa Department of Transportation also considered the usRAP results in developing their approach to their 5-percent report that has been submitted to FHWA starting in 2006. After consideration of possible approaches, Iowa chose to base their 5-percent report on lane-departure crashes, multiple-vehicle cross-centerline crashes, single-vehicle run-off road crashes, and enforcement-related crashes, rather than on total fatal-and serious-injury crashes as in the usRAP risk maps. However, in preparing their 5-percent report, the Iowa DOT used the same segmentation of the roadway network that was originally developed for usRAP. Iowa's approach to 5-percent reporting is similar to the approach used by usRAP to develop supplementary risk maps for other states.

3.2.1.4 City of Ames Safety Planning Tool

usRAP risk maps, RPS/star rating, and safer roads investment plan protocols are being studied and incorporated into a safety planning tool being developed for the City of Ames. The project is supported by City of Ames, the Iowa DOT, and the Midwest Transportation Consortium (MTC) at Iowa State University. This represents an initial investigation of the potential use of these methodologies for local roads. Ranking and rating methods are being compared with NCHRP Plansaf, Empirical Bayes (EB), and conventional methods, using a recently released comparison technique published through the Transportation Research Board (TRB).

3.2.1.5 Low Volume Road Safety

InTrans (CTRE) at Iowa State University has developed some usRAP-style maps for the secondary road system in Iowa, including unpaved roads with traffic volumes from 100 to 400 veh/day (and higher). These are the highest volume gravel roads in Iowa, and represent only about 4,000 mi of the more than 70,000mi of unpaved roads in the state. Low-cost safety measures are expected to be more cost effective on these 4,000 mi of gravel road than they would be on gravel roads with volumes below 100 veh/day. A safety performance model is being developed for low-volume roads. Segmentation issues for very low-volume roads are being addressed, and conventional, EB, and usRAP analysis methodologies are being compared.

3.2.2 Use of usRAP Maps in New Jersey

The New Jersey DOT has utilized the usRAP maps to support and confirm some of their current program prioritized locations. These locations are developed from the state crash records database and present a prioritized list of crash-prone locations to be investigated and countermeasures to be implemented and evaluated. It is anticipated that the usRAP information will be used in the future in conjunction with an update of New Jersey's Comprehensive Strategic Highway Safety Plan to support improvement locations for selected emphasis areas.

Section 4.
Star Rating Validation Study

This section of the report presents the results of research to validate the iRAP star rating concept for application to U.S. roads. This research has developed star ratings using iRAP protocols for over 3,000 mi of roads in two U.S. States, Iowa and Washington, and compared those star ratings to observed crash frequencies for the same roads.

4.1 Overview of RPS and Star Rating Development

A star rating protocol for assessing the safety design features of roads was first developed in Europe by EuroRAP. EuroRAP used a Road Protection System (RPS) to rate the design features of roads that protected vehicle occupants from injury in crashes and then used those RPS values to assign star ratings to specific road sections. The EuroRAP star ratings ranged from one star (for roads with the fewest safety design features) to four stars (for roads with the most safety design features). These star ratings were developed from data obtained from field inspections for roadways of interest.

The usRAP Phase I pilot study applied the EuroRAP RPS criteria to a road network on state highways in Southeast Iowa and to county primary roads in two Michigan counties. usRAP also developed revised RPS criteria that incorporated consideration of not only the crash protection features considered by EuroRAP, but also roadway design features that reduce the likelihood of crashes. Trial application of these revised RPS criteria was reported in the usRAP Phase I report. The trial showed that the RPS criteria and star rating protocols could be applied to data reduced from both existing videologs and new videos obtained in the field, which provided a more repeatable process than field inspections.

At about the same time as the usRAP Phase I pilot study was underway, AusRAP was developing its own RPS criteria for application in Australia. AusRAP also included consideration of crash likelihood to the RPS criteria and expand the rating system to include a range from one to five stars.

iRAP was formed in 2005 to coordinate activities among EuroRAP, AusRAP, and usRAP. iRAP also began work in 2006 on adapting the star rating protocol to improve safety in low- and middle-income countries. iRAP's approach was to adopt the best concepts from EuroRAP, AusRAP, and usRAP and combine these into new RPS criteria and star rating protocols. The iRAP star rating criteria have incorporated both crash likelihood and crash protection considerations. Furthermore, iRAP has developed RPS and star rating criteria not only for vehicle occupants, but also for vulnerable road users including pedestrians, bicyclists, and motorcyclists. Like AusRAP, iRAP has implemented a star rating protocol that rates road sections with one to five stars.

iRAP protocols are now based on data for nearly 40 safety-related roadway design features which can be gathered from either field inspections or video photography. Figure 79 shows a photograph of a data collection vehicle that has been used in iRAP field work. This vehicle collects video images with three forward-facing cameras and integrates these data with GPS coordinates (latitude and longitude) and odometer data which facilitates direct mapping of the results. usRAP is investigating the availability of existing video information that could be used for future safety evaluations using the star rating protocol.

Figure 79. Data Collection Vehicle Used for iRAP studies

The iRAP RPS criteria and star rating protocol are more comprehensive than those developed in usRAP Phase I and appear promising for application as a road assessment tool in the United States. Furthermore, iRAP has developed a web-based software tool that can use the RPS data not only to develop star ratings for roads, but also to identify cost-effective programs of safety countermeasures. This web-based software tool is calibrated with available local crash data but does not require detailed crash data for individual sites. The development of practical and cost-effective countermeasure programs based on roadway data, rather than analysis of crash data, is a novel concept that has the potential to help highway agencies with limited or unreliable crash data.

This section of the report presents the results of research conducted to demonstrate the validity of the star rating concept for application in the United States by comparing star ratings to actual crash data for selected roads. Similar efforts have been undertaken in Europe and Australia, but this effort is intended to show the validity of the star rating concept under U.S. conditions. This is an important first step in demonstrating the applicability of the iRAP analysis software to U.S. roads.

4.2 Summary of the iRAP Star Rating Concept

The iRAP star rating protocol includes criteria to develop star ratings for vehicle occupants, motorcyclists, bicyclists, and pedestrians. The specific elements that are scored to develop each of these star ratings are as follows:

Vehicle-occupant or motorcyclist star rating
- Head-on RPS score
- Ran-off-road RPS score
- Junction RPS score (based on intersections, acceleration lanes, and other access points)

Bicyclist star rating
- RPS score for bicycle movements along the road
- RPS score for bicycle movement across the road
- RPS score for bicycle movements at junctions

Pedestrian star rating
- RPS score for pedestrian movements along the road
- RPS score for pedestrian movements across the road

The individual elements that are scored have been selected based on the ways in which the various types of highway user are most frequently killed or seriously injured. For example, head-on, run-off-road, and junction crashes represent the most frequent causes of death and serious injury for vehicle occupants and, collectively, represent at least 75 percent of vehicle occupant deaths and injuries. Each of the individual RPS scores can itself be expressed as a star rating for that aspect of safety. usRAP analyses have focused on vehicle occupant, bicycle, and pedestrian ratings. Motorcycle ratings have been included in iRAP because motorcycles constitute 50 percent or more of the vehicle fleet in some countries, particularly in Asia.

4.3 Description of Iowa and Washington Datasets

Roadway geometrics, traffic volume, and crash data needed to determine star ratings have been obtained for selected state highways in Iowa and Washington from review of videologs collected by the state highway agencies as well as from other existing state databases. The highways considered in the review included freeways, other multilane divided highways, multilane undivided highways, two-lane highways in rural, semi-urban, and urban areas. A few urban one-way streets were also included. Crash data in Iowa were obtained for a seven-year period, from 2001 through 2007, while crash data in Washington were obtained for a six-year period, from 2001 through 2006. Roadway characteristics and crash data for Iowa were obtained from the Iowa Department of Transportation. Roadway characteristics and crash data for Washington were obtained from the FHWA Highway Safety Information System (HSIS). Basic descriptive statistics for each dataset are presented below.

4.3.1 Summary of Validation Study Network

The Iowa database includes 1,471.3 mi of roadway; that for Washington includes 1,553.7 mi of roadway. Figures 80 and 81 present the roadway networks studied in Iowa and Washington, respectively. Data are available from rural, urban, and semi-urban areas for the following seven roadway types, as shown in Table 14.

Table 14. Proportion of Total Roadway Length by Roadway Type for the Iowa and Washington Networks

	Percentage of roadway length by roadway type	
Roadway type	Iowa	Washington
Two-lane undivided highways (2U)	39.9	38.2
Four-lane undivided highways (4U)	3.5	9.1
Four-lane divided highways (4D)	34.9	14.6
Four-lane divided freeways (4DF)	17.4	24.9
Six-lane divided highways (6D)	1.4	0.2
Six-lane divided freeways (6DF)	2.5	12.5
One-way streets (ONE)	0.4	0.5
	100.0	100.0

4.3.2 Crash Frequencies

Yearly crash frequencies are available for a number of crash types, including vehicle occupant, pedestrian, and bicycle crashes. The specific crash types considered in the star rating validation research are summarized in Table 15.

Table 15. Total Crash Frequencies by State for Crash Types Considered in Star Rating Validation Research

	Total crash frequency	
Fatal- and major-injury crash type	Iowa (7 yrs)	Washington (6 yrs)
All vehicle occupant crashes	1,882	2,436
Head-on plus opposite-direction sideswipe crashes	182	141
Single-vehicle run-off-road crashes	422	614
Junction crashes	677	542
Pedestrian crashes	79	225
Bicycle crashes	34	35

Seven-year total crash frequencies for each crash type category are shown in Table 16 for Iowa and corresponding six-year total crash frequencies are shown in Table 17 for Washington, separately for each area type and roadway type.

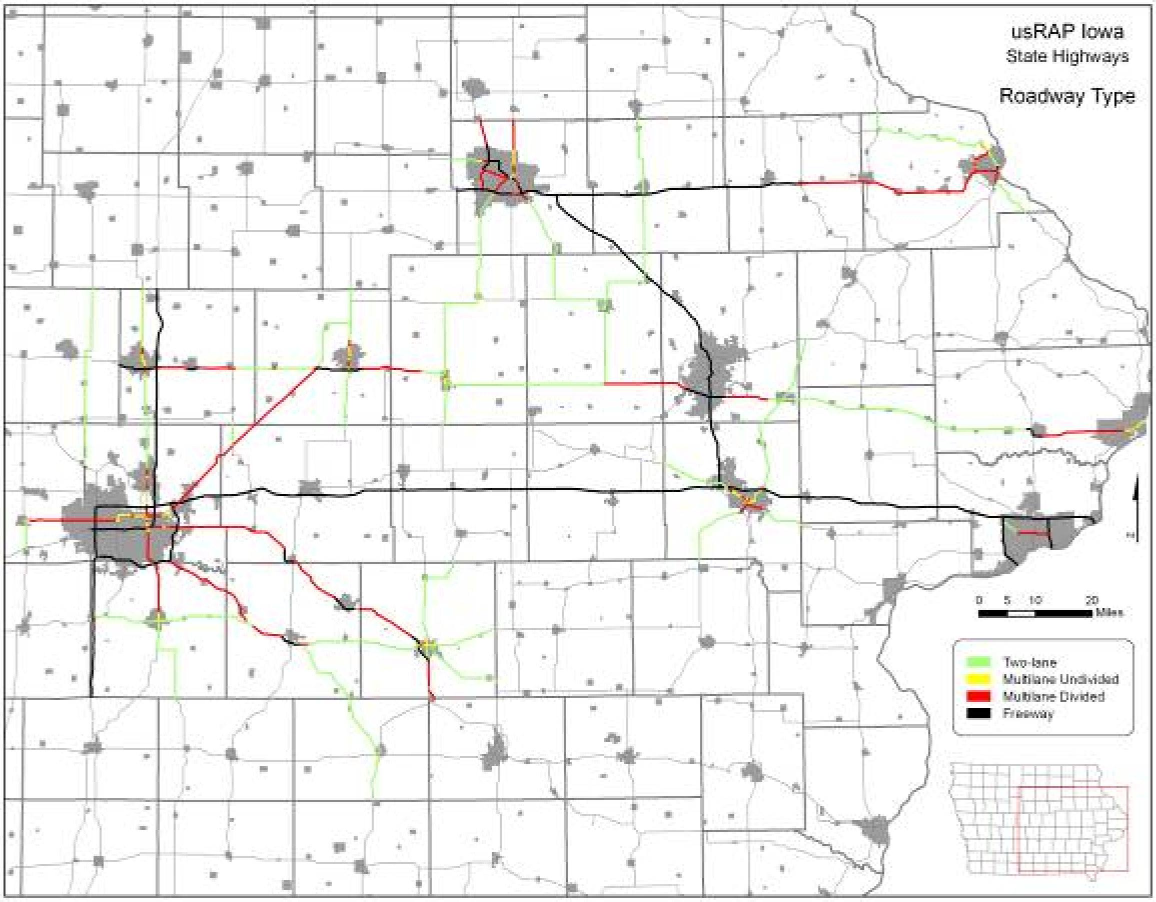


Figure 80. Roads Included in Star Rating Validation Study in Iowa

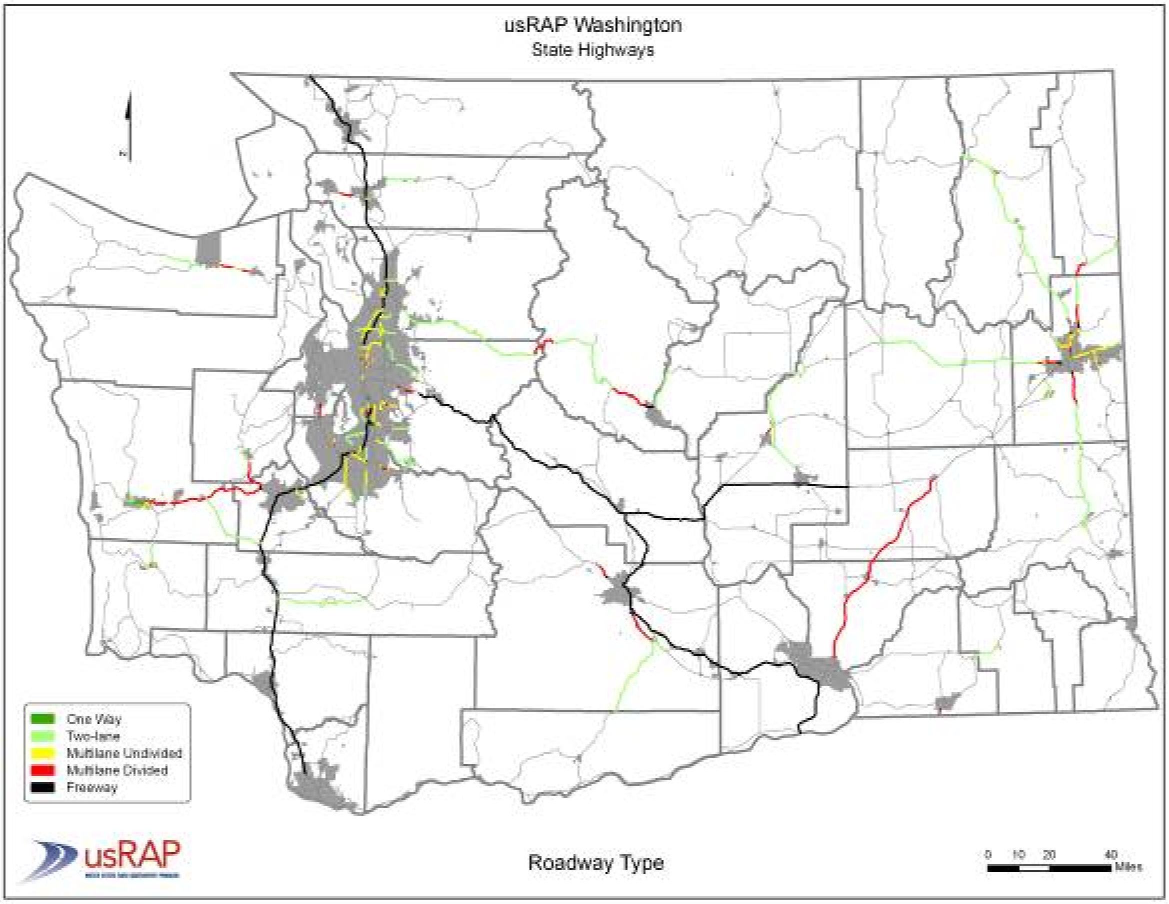


Figure 81. Roads Included in Star Rating Validation Study in Washington

Table 16. Basic Description of Iowa Roadway Dataset

Roadway type	Area type	Number of 100-m sections	Total length (mi)
Two-lane undivided highways (2U)	Rural	7,406	460.2
	Semi-urban	1,484	92.2
	Urban	562	34.9
	All	**9,452**	**587.3**
Four-lane undivided highways (4U)	Rural	75	4.7
	Semi-urban	76	4.7
	Urban	670	41.6
	All	**821**	**51.0**
Four-lane divided highways (4D)	Rural	6,282	390.4
	Semi-urban	873	54.3
	Urban	1,116	69.4
	All	8,271	513.9
Four-lane divided freeways (4DF)	Rural	3,729	231.7
	Semi-urban	75	4.7
	Urban	324	20.1
	All	**4,128**	**256.5**
Six-lane divided highways (6D)	Rural	46	2.9
	Semi-urban	77	4.8
	Urban	204	12.7
	All	**327**	**20.3**
Six-lane divided freeways (6DF)	Rural	24	1.5
	Semi-urban	6	0.4
	Urban	567	35.2
	All	**597**	**37.1**
One-way streets (ONE)	Urban	**82**	**5.1**
All roadways		**23,678**	**1,471.3**

Table 17. Basic Description of Washington Roadway Dataset

Roadway type	Area type	Number of 100-m sections	Total length (mi)
Two-lane undivided highways (2U)	Rural	7,945	493.7
	Semi-urban	516	32.1
	Urban	1,096	68.1
	All	**9,557**	**593.8**
Four-lane undivided highways (4U)	Rural	148	9.2
	Semi-urban	323	20.1
	Urban	1,800	111.9
	All	**2,271**	**141.1**
Four-lane divided highways (4D)	Rural	3,225	200.4
	Semi-urban	101	6.3
	Urban	331	20.6
	All	**3,657**	**227.2**
Four-lane divided freeways (4DF)	Rural	5,655	351.4
	Semi-urban	67	4.2
	Urban	506	31.4
	All	**6,228**	**387.0**
Six-lane divided highways (6D)	Urban	49	3.0
Six-lane divided freeways (6DF)	Rural	1,405	87.3
	Semi-urban	71	4.4
	Urban	1,640	101.9
	All	**3,116**	**193.6**
One-way streets (ONE)	Rural	11	0.7
	Semi-urban	10	0.6
	Urban	106	6.6
	All	**127**	**7.9**
All roadways		**25,005**	**1,553.7**

4.3.3 Crash Rates

Crash rates per mile per year and per 100 million veh-mi of travel (100 MVMT) were computed for all vehicle-occupant crash types based on the seven-year (Iowa) or six-year (Washington) crash frequency, section length (mi), and traffic volume (AADT in vehicles/day). For pedestrian and bicycle crashes, only a crash rate per mile per year was calculated. The computations were as follows:

$$\text{Crashes/mi/yr} = \frac{\text{Crash frequency}}{\text{Section length} \times \text{Number of years}} \quad (1)$$

$$\text{Crashes/100 MVMT} = \frac{\text{Crash frequency} \times 10^8}{\text{AADT} \times 365 \times \text{Number of years} \times \text{Section length}} \quad (2)$$

Crash rates corresponding to the crash frequencies shown in Tables 18 and 19 are shown in Tables 20 and 21, respectively, for each area type and roadway type.

4.3.4 Development of Validation Datasets

As noted above, the validation datasets for Iowa and Washington were assembled from a combination of video review and extraction of data from existing state databases. Any relevant data needed for the star ratings that were available from existing databases were used; the remainder of the data for the star ratings came from the videologs reviewed. Data were reduced from video frames at intervals of 100 m.

The safety features of the roadway networks studied were rated in accordance with protocols developed by iRAP to establish RPS scores and star ratings for each location at which data were reduced from the videos. There were a total of 23,678 Iowa and 25,005 Washington locations considered in the study. The data reduced for video frames at 100-m intervals along the roadway; each data point, in effect, represents a 100-m section of roadway. Crash frequencies were also determined for each 100-m road section.

Because of the limited frequency of crashes at any individual 100-m location, the 100-m sections were also aggregated into longer sections along a given route that were relatively homogeneous using the following criteria: same road type; same area type; and approximately equal posted speed limit. Applying these criteria to the 23,678 100-m sections in Iowa resulted in a total of 783 analysis sections with lengths ranging from 0.1 mi to 31.8 mi; the median value of road section length of 0.6 mi. Longer analysis sections were not constructed in the Washington database (see discussion in Section 4.5.1).

Table 18. Iowa Crash Frequencies by Crash Type, Roadway Type, and Area Type

Roadway type	Area type	Number of 100-m sections	Total length (mi)	Number of fatal and serious injury crashes in seven years					
				All VO	HO+SSOP	ROR	Junction	Pedestrian	Bicycle
Two-lane undivided highways (2U)	Rural	7,406	460.2	273	71	65	79	5	1
	Semi-urban	1,484	92.2	63	8	15	24	1	0
	Urban	562	34.9	53	6	7	17	8	4
	All	**9,452**	**587.3**	**389**	**85**	**87**	**120**	**14**	**5**
Four-lane undivided highways (4U)	Rural	75	4.7	4	0	0	3	0	0
	Semi-urban	76	4.7	10	0	0	7	1	0
	Urban	670	41.6	220	10	8	99	23	10
	All	**821**	**51.0**	**234**	**10**	**8**	**109**	**24**	**10**
Four-lane divided highways (4D)`	Rural	6,282	390.4	312	32	103	103	6	3
	Semi-urban	873	54.3	85	5	17	41	1	2
	Urban	1,116	69.4	298	9	27	168	12	8
	All	**8,271**	**513.9**	**695**	**46**	**147**	**312**	**19**	**13**
Four-lane divided freeways (4DF)	Rural	3,729	231.7	227	32	116	18	4	0
	Semi-urban	75	4.7	17	1	9	2	0	0
	Urban	324	20.1	46	3	10	10	1	0
	All	**4,128**	**256.5**	**290**	**36**	**135**	**30**	**5**	**0**
Six-lane divided highways (6D)	Rural	46	2.9	6	0	2	1	0	0
	Semi-urban	77	4.8	10	0	4	3	0	0
	Urban	204	12.7	91	0	2	59	9	3
	All	**327**	**20.3**	**107**	**0**	**8**	**63**	**9**	**3**
Six-lane divided freeways (6DF)	Rural	24	1.5	4	0	0	2	1	0
	Semi-urban	6	0.4	2	0	0	0	0	0
	Urban	567	35.2	128	5	35	19	3	0
	All	**597**	**37.1**	**134**	**5**	**35**	**21**	**4**	**0**
One-way streets (ONE)	Urban	82	5.1	33	0	2	22	4	3
All roadways		**23,678**	**1,471.3**	**1,882**	**182**	**422**	**677**	**79**	**34**

Table 19. Washington Crash Frequencies by Crash Type, Roadway Type, and Area Type

Roadway type	Area type	Number of 100-m sections	Total length (mi)	Number of fatal and serious injury crashes in six years					
				All VO	HO+SSOP	ROR	Junction	Pedestrian	Bicycle
Two-lane undivided highways (2U)	Rural	7,945	493.7	440	70	112	95	18	1
	Semi-urban	516	32.1	40	1	5	16	4	1
	Urban	1,096	68.1	159	14	18	48	16	2
	All	**9,557**	**593.8**	**639**	**85**	**135**	**159**	**38**	**4**
Four-lane undivided highways (4U)	Rural	148	9.2	9	2	1	2	0	0
	Semi-urban	323	20.1	60	5	4	21	12	3
	Urban	1,800	111.9	529	16	23	200	115	20
	All	**2,271**	**141.1**	**598**	**23**	**28**	**223**	**127**	**23**
Four-lane divided highways (4D)	Rural	3,225	200.4	214	6	102	54	4	2
	Semi-urban	101	6.3	18	3	4	6	0	0
	Urban	331	20.6	71	0	5	38	13	1
	All	**3,657**	**227.2**	**303**	**9**	**111**	**98**	**17**	**3**
Four-lane divided freeways (4DF)	Rural	5,655	351.4	384	8	193	15	14	1
	Semi-urban	67	4.2	2	0	2	0	0	0
	Urban	506	31.4	39	1	8	9	3	0
	All	**6,228**	**387.0**	**425**	**9**	**203**	**24**	**17**	**1**
Six-lane divided highways (6D)	Urban	**49**	**3.0**	**23**	**0**	**0**	**7**	**5**	**4**
Six-lane divided freeways (6DF)	Rural	1,405	87.3	115	5	54	2	2	0
	Semi-urban	71	4.4	9	0	7	0	0	0
	Urban	1,640	101.9	303	10	74	17	18	0
	All	**3,116**	**193.6**	**427**	**15**	**135**	**19**	**20**	**0**
One-way streets (ONE)	Rural	11	0.7	1	0	0	0	0	0
	Semi-urban	10	0.6	1	0	1	0	0	0
	Urban	106	6.6	19	0	1	12	1	0
	All	**127**	**7.9**	21	0	2	12	1	0
All roadways		**25,005**	**1,553.7**	**2,436**	**141**	**614**	**542**	**225**	**35**

Table 20. Iowa Crash Rates by Crash Type, Roadway Type, and Area Type

Roadway type	Area type	Number of 100-m sections	Total length (mi)	Fatal and serious vehicle-occupant crash rates (crashes/100 MVMT)				Fatal and serious crash rates (crashes/mi-yr)	
				All VO	HO+SSOP	ROR	Junction	Pedestrian	Bicycle
Two-lane undivided highways (2U)	Rural	7,406	460.2	5.9	1.5	1.4	1.7	0.0016	0.0003
	Semi-urban	1,484	92.2	7.3	0.9	1.7	2.8	0.0015	0
	Urban	562	34.9	7.8	0.9	1	2.5	0.0327	0.0164
	All	**9,452**	**587.3**	**6.3**	**1.4**	**1.4**	**1.9**	**0.0034**	**0.0012**
Four-lane undivided highways (4U)	Rural	75	4.7	5.1	0	0	3.8	0	0
	Semi-urban	76	4.7	10.7	0	0	7.5	0.0303	0
	Urban	670	41.6	14.3	0.7	0.5	6.4	0.0789	0.0343
	All	**821**	**51.0**	**13.7**	**0.6**	**0.5**	**6.4**	**0.0672**	**0.028**
Four-lane divided highways (4D)	Rural	6,282	390.4	3.5	0.4	1.1	1.1	0.0022	0.0011
	Semi-urban	873	54.3	4.2	0.2	0.8	2	0.0026	0.0053
	Urban	1,116	69.4	9.1	0.3	0.8	5.2	0.0247	0.0165
	All	**8,271**	**513.9**	**4.9**	**0.3**	**1**	**2.2**	**0.0053**	**0.0036**
Four-lane divided freeways (4DF)	Rural	3,729	231.7	2.8	0.4	1.4	0.2	0.0025	0
	Semi-urban	75	4.7	6.7	0.4	3.5	0.8	0	0
	Urban	324	20.1	3.4	0.2	0.7	0.7	0.0071	0
	All	**4,128**	**256.5**	**3**	**0.4**	**1.4**	**0.3**	**0.0028**	**0**
Six-lane divided highways (6D)	Rural	46	2.9	3.9	0	1.3	0.6	0	0
	Semi-urban	77	4.8	4.7	0	1.9	1.4	0	0
	Urban	204	12.7	14.1	0	0.3	9.1	0.1014	0.0338
	All	**327**	**20.3**	**10.6**	**0**	**0.8**	**6.2**	**0.0633**	**0.0211**
Six-lane divided freeways (6DF)	Rural	24	1.5	2.8	0	0	1.4	0.0958	0
	Semi-urban	6	0.4	9.6	0	0	0	0	0
	Urban	567	35.2	3.7	0.1	1	0.5	0.0122	0
	All	**597**	**37.1**	**3.7**	**0.1**	**1**	**0.6**	**0.0154**	**0**
One-way streets (ONE)	Urban	82	5.1	33.5	0	2	22.3	0.1121	0.0841

Table 21. Washington Crash Rates by Crash Type, Roadway Type, and Area Type

Roadway type	Area type	Number of 100-m sections	Total length (mi)	Fatal and serious vehicle-occupant crash rates (crashes/100 MVMT)				Fatal and serious crash rates (crashes/mi-yr)	
				All VO	HO+SSOP	ROR	Junction	Pedestrian	Bicycle
Two-lane undivided highways (2U)	Rural	7,945	493.7	6.2	1	1.6	1.3	0.0061	0.0003
	Semi-urban	516	32.1	5	0.1	0.6	2	0.0208	0.0052
	Urban	1,096	68.1	8.3	0.7	0.9	2.5	0.0392	0.0049
	All	**9,557**	**593.8**	**6.6**	**0.9**	**1.4**	**1.6**	**0.0107**	**0.0011**
Four-lane undivided highways (4U)	Rural	148	9.2	2.6	0.6	0.3	0.6	0	0
	Semi-urban	323	20.1	5.6	0.5	0.4	2	0.0996	0.0249
	Urban	1,800	111.9	8	0.2	0.3	3	0.1714	0.0298
	All	**2,271**	**141.1**	**7.4**	**0.3**	**0.3**	**2.8**	**0.15**	**0.0272**
Four-lane divided highways (4D)	Rural	3,225	200.4	5.7	0.2	2.7	1.4	0.0033	0.0017
	Semi-urban	101	6.3	6.3	1.1	1.4	2.1	0	0
	Urban	331	20.6	7.7	0	0.5	4.1	0.1053	0.0081
	All	**3,657**	**227.2**	**6.1**	**0.2**	**2.2**	**2**	**0.0125**	**0.0022**
Four-lane divided freeways (4DF)	Rural	5,655	351.4	4.2	0.1	2.1	0.2	0.0066	0.0005
	Semi-urban	67	4.2	2.6	0	2.6	0	0	0
	Urban	506	31.4	2	0.1	0.4	0.5	0.0159	0
	All	**6,228**	**387.0**	**3.8**	**0.1**	**1.8**	**0.2**	**0.0073**	**0.0004**
Six-lane divided highways (6D)	Urban	49	3.0	9.3	0	0	2.8	0.2737	0.219
Six-lane divided freeways (6DF)	Rural	1,405	87.3	2.3	0.1	1.1	0	0.0038	0
	Semi-urban	71	4.4	2.9	0	2.2	0	0	0
	Urban	1,640	101.9	2.1	0.1	0.5	0.1	0.0294	0
	All	**3,116**	**193.6**	**2.2**	**0.1**	**0.7**	**0.1**	**0.0172**	**0**
One-way streets (ONE)	Rural	11	0.7	5.3	0	0	0	0	0
	Semi-urban	10	0.6	9.8	0	9.8	0	0	0
	Urban	106	6.6	7.6	0	0.4	4.8	0.0253	0
	All	**127**	**7.9**	**7.5**	**0**	**0.7**	**4.3**	**0.0211**	**0**

4.4 RPS and Star Ratings

Vehicle-occupant, pedestrian, and bicycle RPS scores were computed for each 100-m section based on the presence or absence of safety-related features following current iRAP protocols. The vehicle-occupant RPS is based on three components: head-on RPS, run-off-road RPS, and junction RPS. Each RPS rating, in turn, is computed from components for crash likelihood and crash protection.

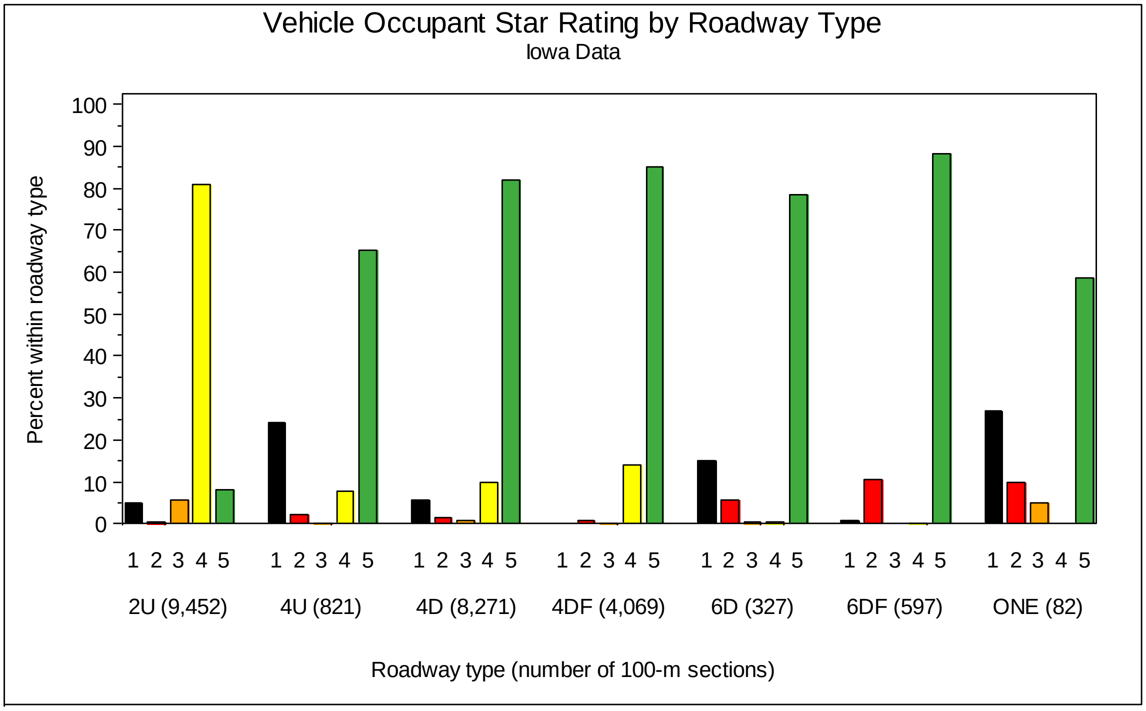
Star ratings have been derived from the calculated RPS values using current iRAP criteria. These star ratings formed the basis of the analysis in this task, focusing on the following six star ratings:

- Vehicle-occupant star rating
- Head-on star rating
- Run-off-road star rating
- Junction star rating
- Pedestrian star rating
- Bicycle star rating

The distribution of each type of star rating for 100-m sections across all three area types combined (rural, semi-urban, and urban) is shown separately for each roadway type in Figures 82 through 87. Iowa data are shown at the top and the Washington data at the bottom of each figure. Within each roadway type, the bars reflect the percentage of 100-m sections with ratings of one star, two stars, etc., and thus the percentages sum to 100 percent within each roadway type. The height of the bars does not reflect the total sample size (number of 100-m sections) within each roadway type; rather, the number of sections is indicated in parentheses beside the roadway type below each set of bars. It should be noted for the junction data in Figure 80 that the star ratings indicate primarily whether there is or is not a junction within an individual 100-m section. Of the 23,678 100-m sections in Iowa, 1,821 (or 7.7 percent) include a junction and generally have a junction star rating of 1; the rest of the 100-m sections do not include a junction and generally have a junction star rating of 5. Similarly, of the 25,005 100-m sections in Washington, 2,148 (or 8.6 percent) include an intersection.

4.5 Relationship Between Star Ratings and Crash Rates

Preliminary analyses in the usRAP Phase I pilot study found that the star rating of a road section, either by itself or in conjunction with ADT, is not sufficient information to predict the crash frequency for a roadway section for any given single or multi-year period. This result is not surprising given the high variability of crash data and the many nonroadway factors that influence crash occurrence. This finding was confirmed as part of the current research (see Section 4.6 of this report). However, despite the finding that star ratings do not provide sufficient information to predict crash frequency, there is evidence from Europe that crash rates do vary in the expected fashion between star rating



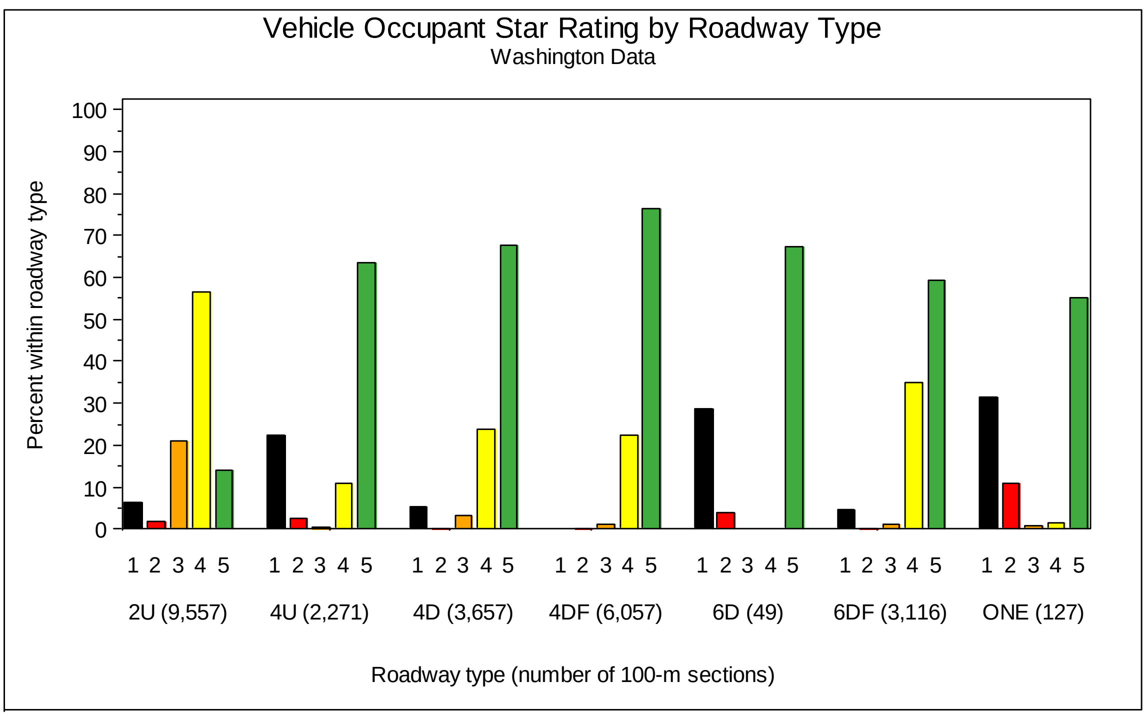
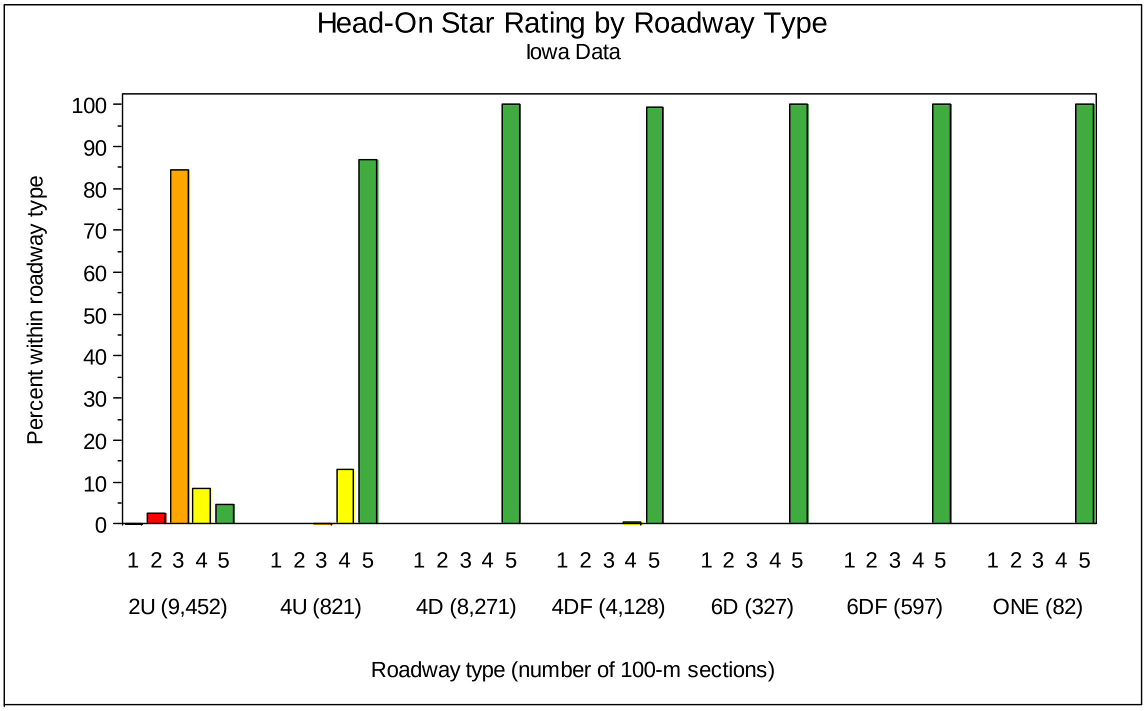


Figure 82. Vehicle-Occupant Star Rating Distribution for Iowa and Washington



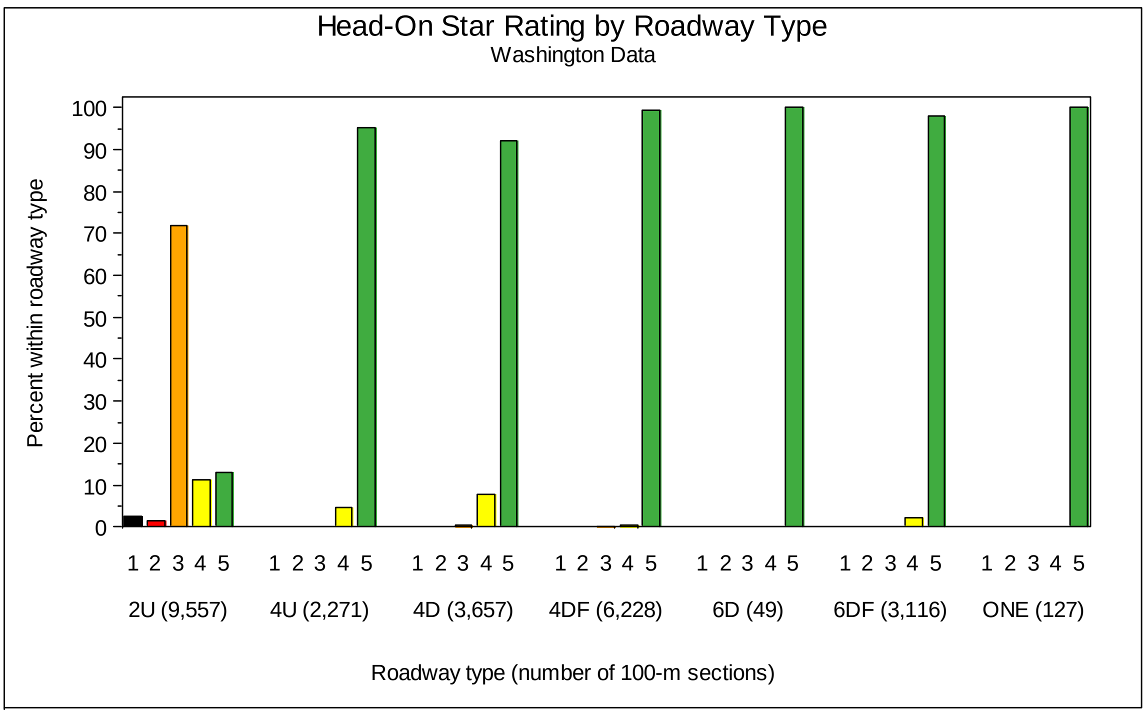
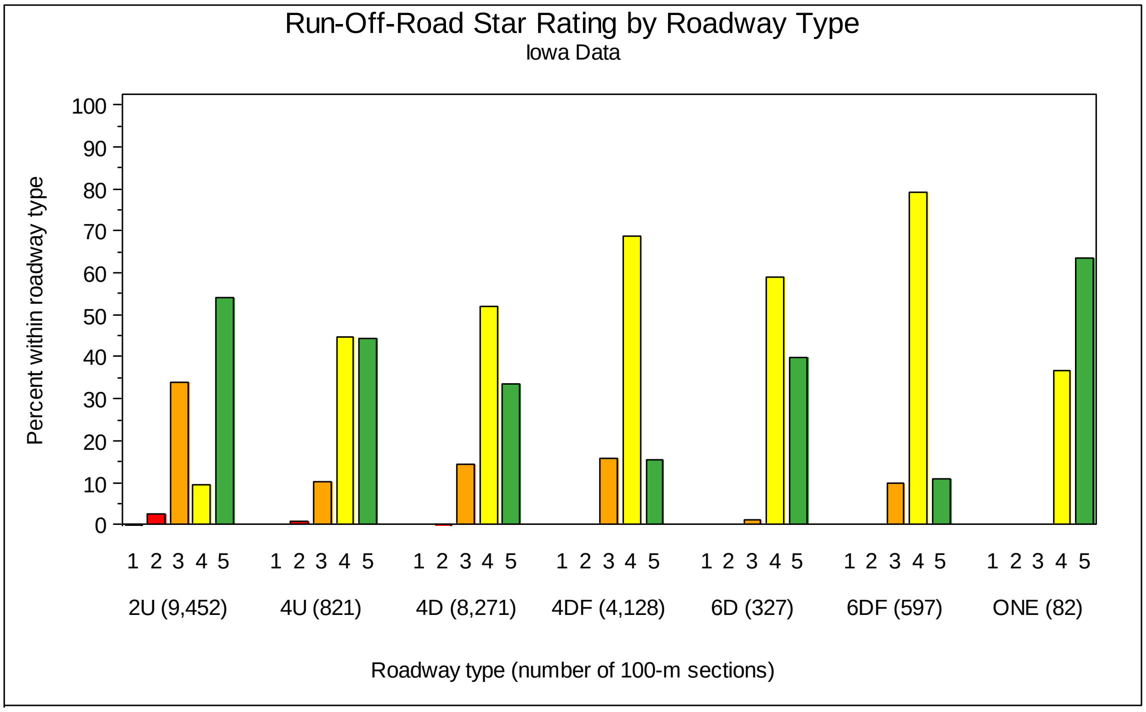


Figure 83. Head-on Star Rating Distribution for Iowa and Washington



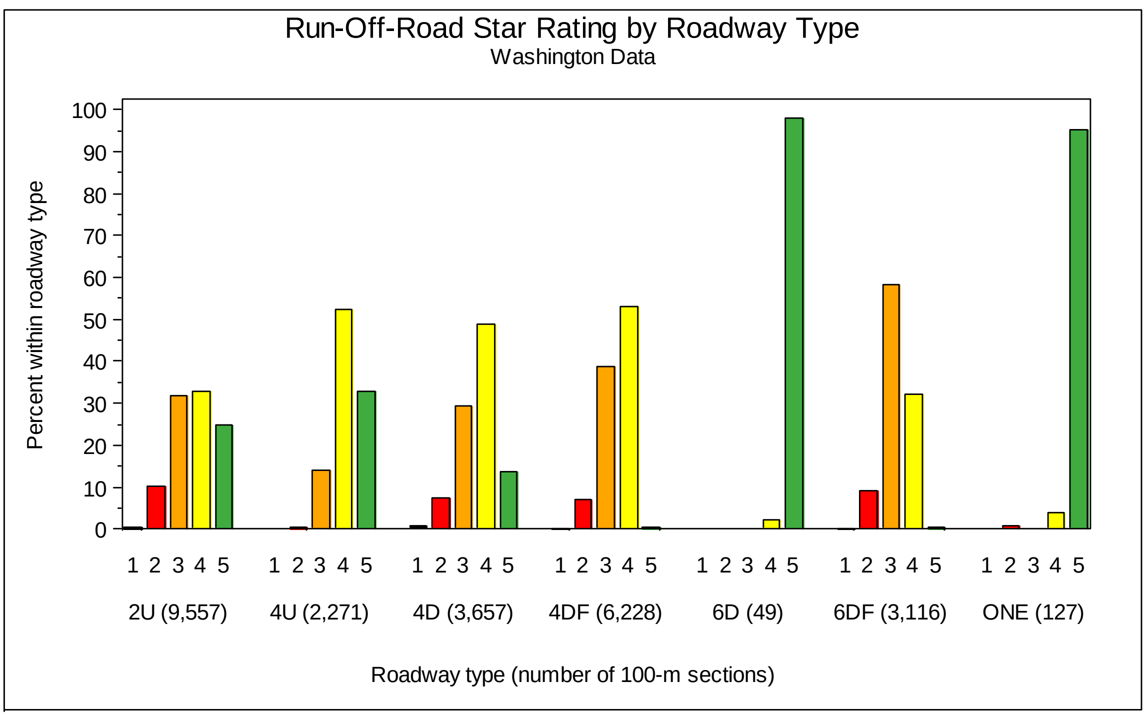


Figure 84. Run-off-Road Star Rating Distribution for Iowa and Washington

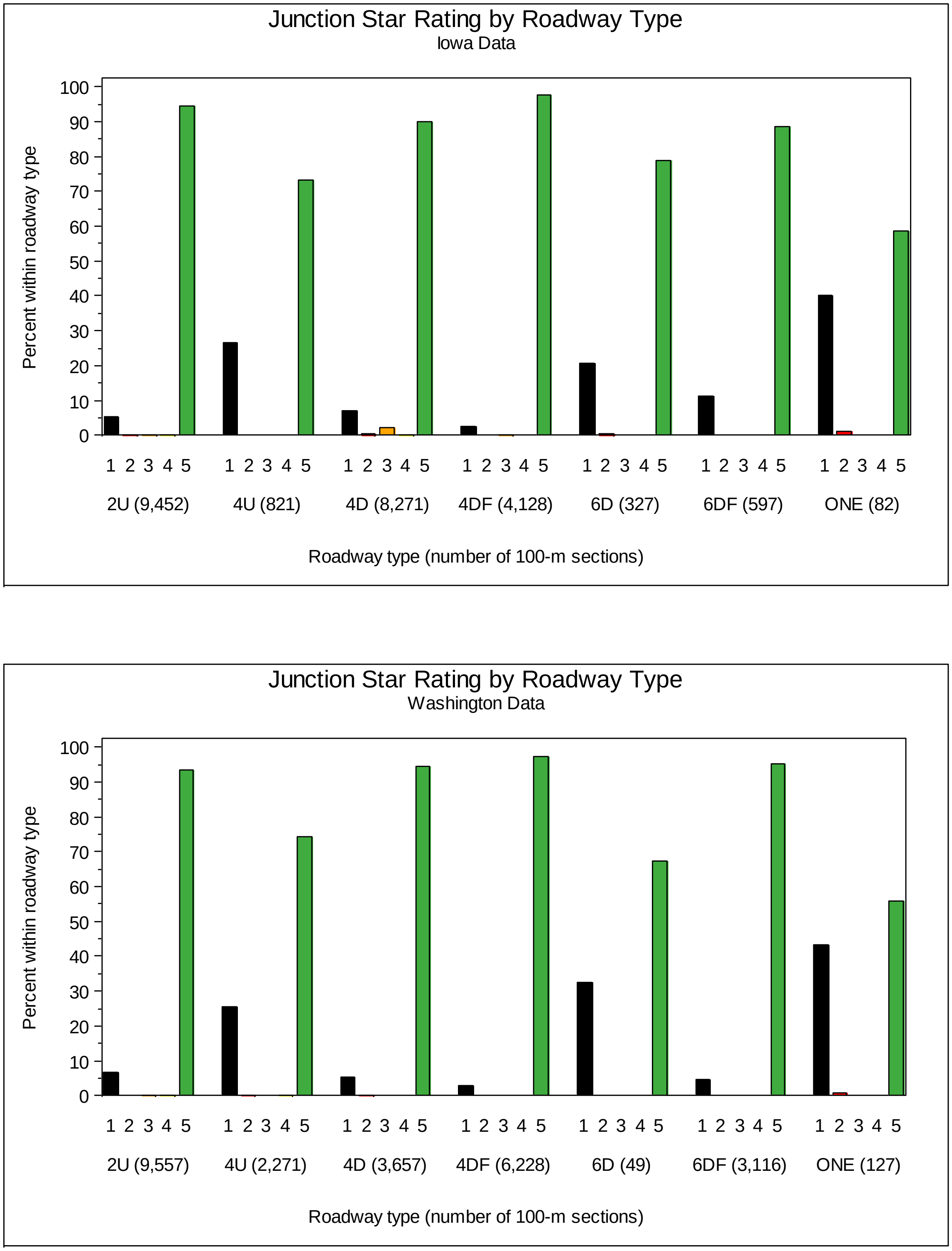
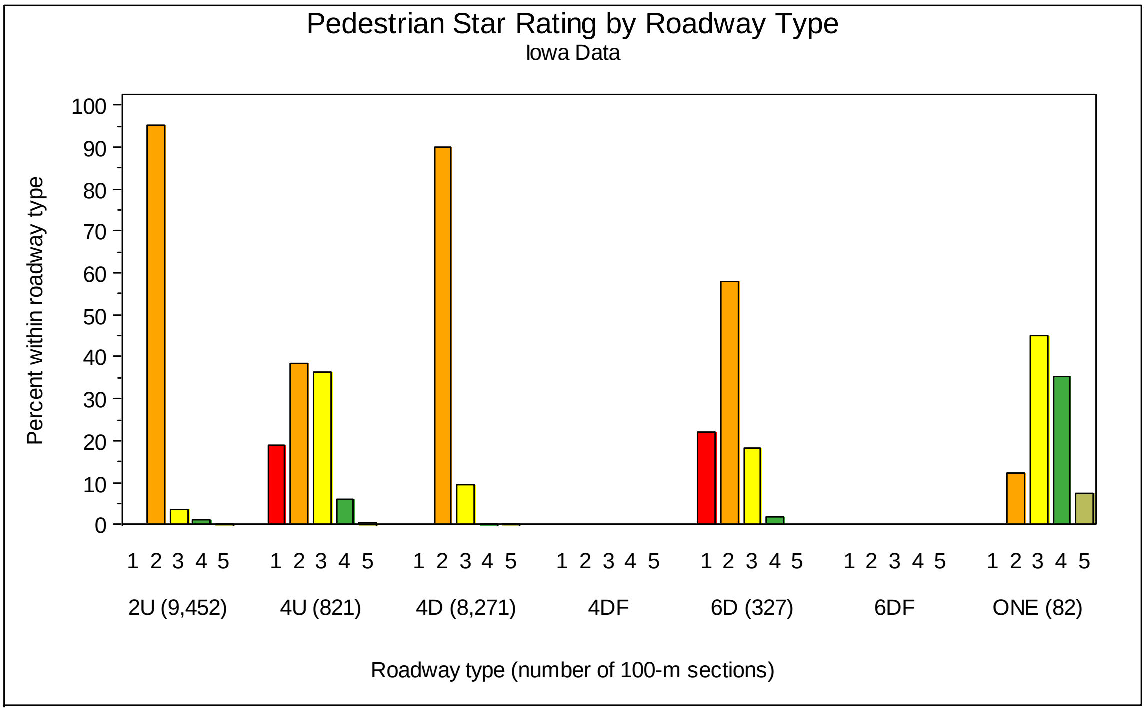


Figure 85. Junction Star Rating Distribution for Iowa and Washington



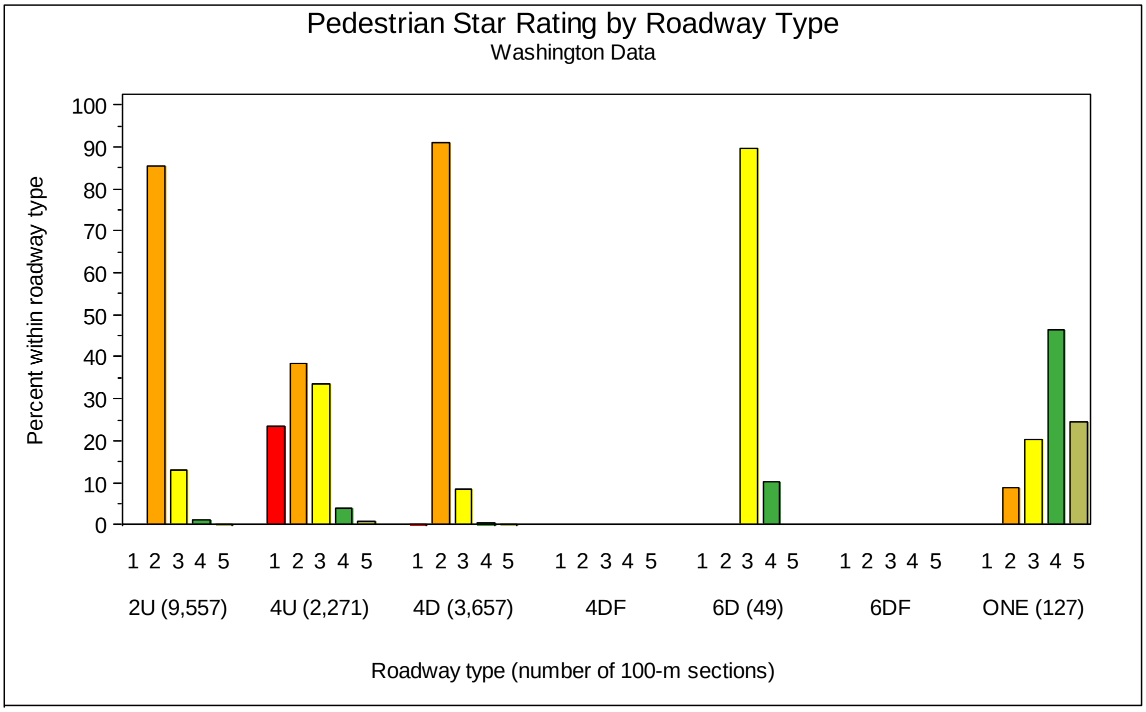
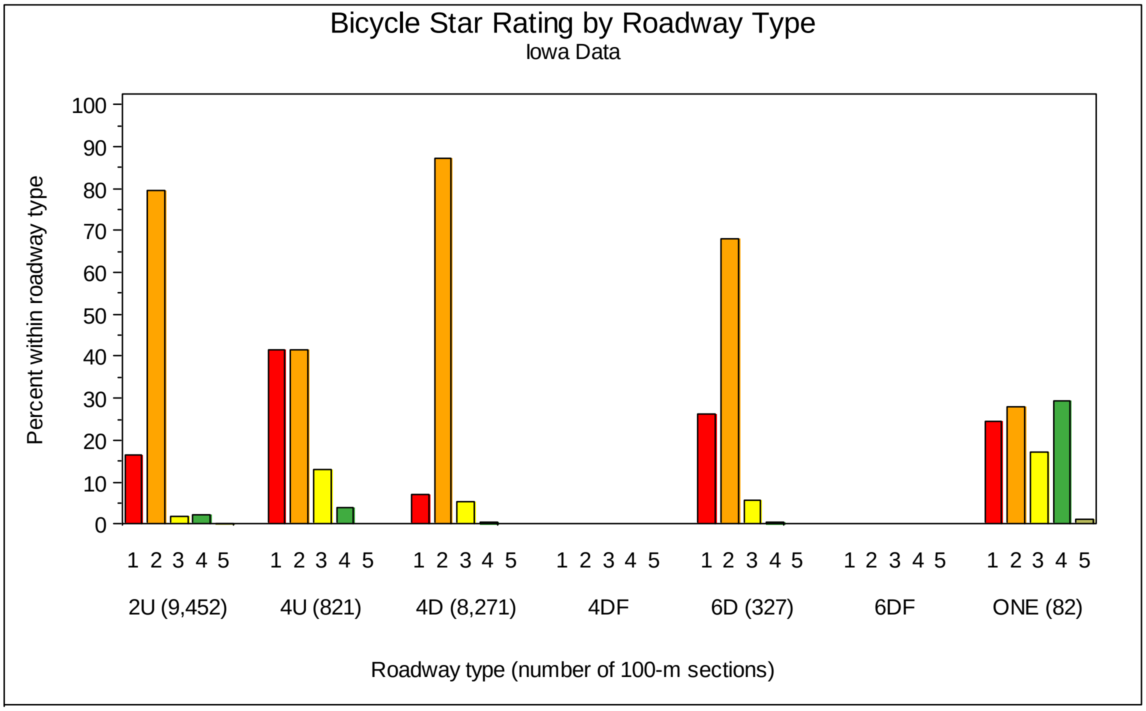


Figure 86. Pedestrian Star Rating Distribution for Iowa and Washington



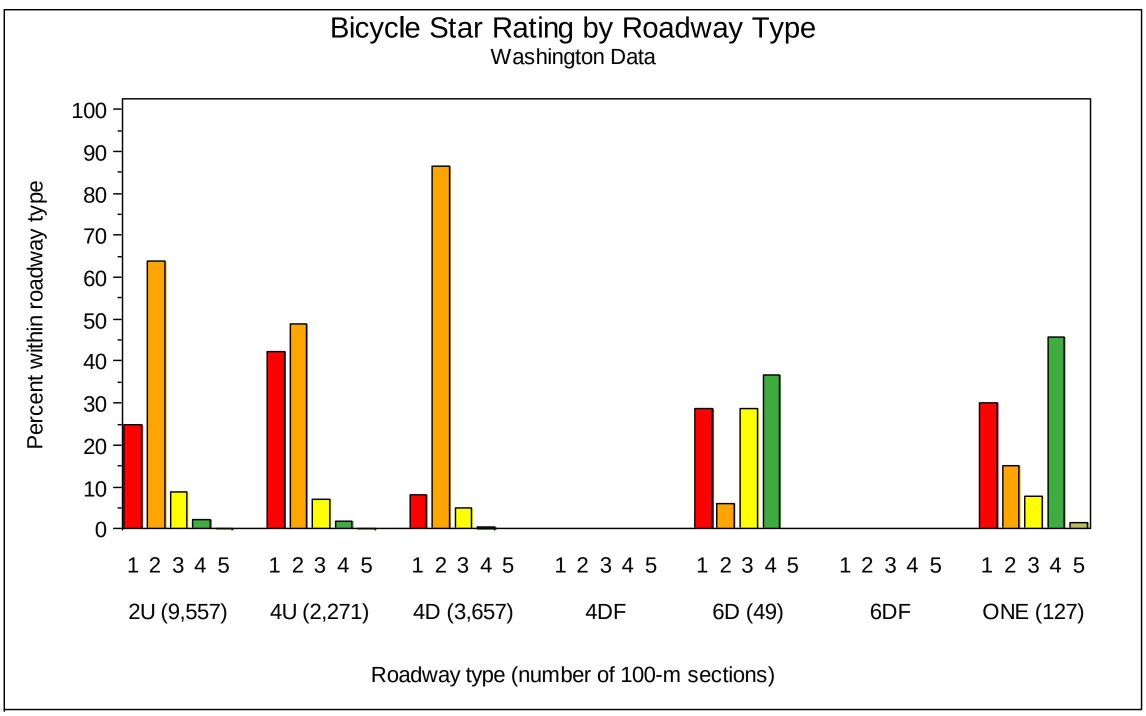


Figure 87. Bicycle Star Rating Distribution for Iowa and Washington

levels, with decreasing crash rates as star ratings increase. The existence of such relationships in U.S. data was explored in this research.

The relationship of star ratings to crash experience was assessed for the individual 100-m sections and for the longer analysis sections. To account for exposure, the following comparisons were made between star ratings and selected crash rates:

- Vehicle-occupant star rating with all fatal and serious injury crash rate (crashes per 100 MVMT)
- Head-on star rating with head-on plus sideswipe opposite direction fatal and serious injury crash rate (crashes per 100 MVMT)
- Run-off-road star rating with single-vehicle run-off-road fatal and serious injury crash rate (crashes per 100 MVMT)
- Junction star rating with junction fatal and serious injury crash rate (crashes per 100 MVMT).
- For bicycle and pedestrian crashes, crash rates were expressed in crashes per mi per year, therefore the following comparisons were made:
- Pedestrian star rating with pedestrian fatal and serious injury crash rate (crashes per mi year)
- Bicycle star rating with bicycle fatal and serious injury crash rate (crashes per mi year)

In all, star ratings and crash rates were compared for a large number of combinations of roadway type, area type, and crash rate, separately for Iowa and Washington. Plots of crash rates versus star rating for each group were drawn to investigate the nature of the relationship between them. Within each plot, comparisons of crash rates were made between pairs of star rating levels and across the range of star rating levels. Since roadway sections within a group do not necessarily fall into all five star rating levels, only selected comparisons were made based on the following criteria:

- No comparisons were made in cases of either insufficient roadway mileage and/or very low crash counts over the study period
- No comparisons were made if all roadway sections fell into a single star rating level
- If the roadway sections fell into only two star rating levels, then the two crash rates were simply compared
- If the roadway sections fell into three or more star rating levels, then each consecutive pair of star ratings was compared as well as the first to last star rating level to assess the overall trend

Unfortunately, the crash frequencies for pedestrian and bicycle crashes proved to be too low to assess the pedestrian and bicycle star ratings. However, there were sufficient data to assess the vehicle-occupant star ratings and its components for two-lane undivided highways, four-lane undivided highways, four-lane divided highways other than freeways, four-lane divided freeways, and six-lane divided freeways. These results are presented below.

In those cases were the road sections were classified into three or more star rating levels, a formal statistical analysis was performed to determine whether crash rates differ significantly among the star rating levels and whether the trend corresponded to an increasing or decreasing crash rate. This analysis was performed by means of a generalized linear model (a) assuming a Poisson distribution of crash counts, (b) assuming a power relationship between crash frequency and AADT, and (c) considering star rating as a categorical classification variable. Every significant trend found was then considered further and selected pairwise comparisons were each tested for statistical significance.

In those cases where the sections fell into only two star rating levels, the same statistical analysis was performed to test whether the crash rates between the two star rating levels are significantly different. Where observations are available for only two star rating levels, no formal assessment of a trend can be made (that requires data for three or more star rating levels). However, if a statistically significant difference is found between the crash rates for the two star rating levels, the direction of the difference is also known. A significance level of 0.05 (equivalent to a confidence level of 95 percent) was considered throughout.

The results are presented next by roadway type. For each roadway type, the various crash types that were analyzed are discussed individually. In each case, the Iowa results are discussed first, followed by the Washington results. The top portion in each figure shows the Iowa results and the bottom portion shows the Washington results.

4.5.1 Two-Lane Undivided Highways (2U)

Vehicle-Occupant Crashes (All Area Types). The relationship between star rating and crash rate for vehicle occupants on two-lane highways is illustrated in Figure 88
. These results are based on 100-m section data for all area types combined. The crash rate corresponding to each star rating level is indicated above the bar. For both Iowa and Washington, the statistical analysis showed a statistically significant effect of star rating on crash rates and an overall statistically decreasing trend. In other words, the higher the star rating, the lower the crash rate.

Iowa Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 1 vs. 3: Significant difference
- Star rating 3 vs. 4: Significant difference
- Star rating 4 vs. 5: Nonsignificant difference

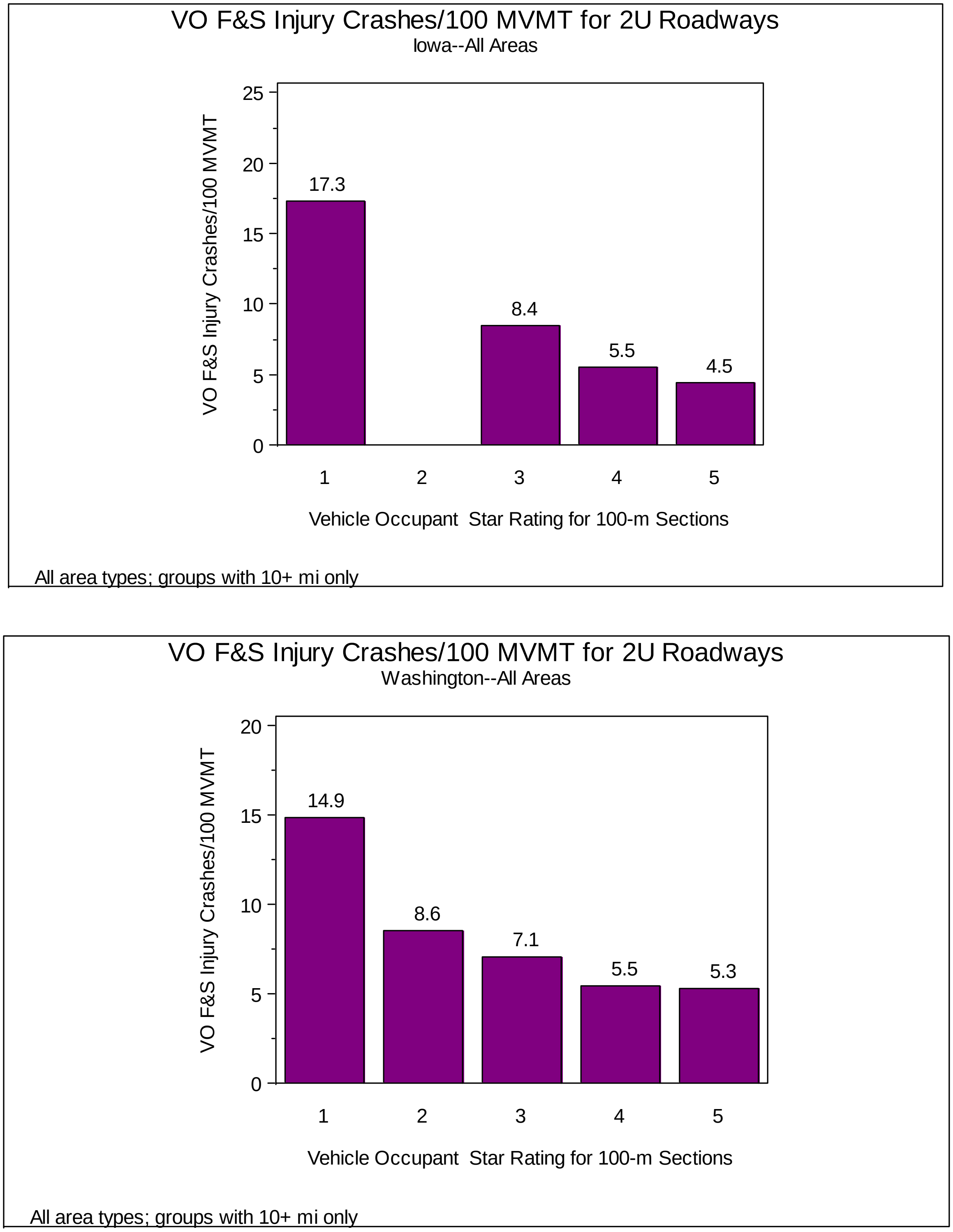


Figure 88. Vehicle-Occupant Crash Rate by Vehicle-Occupant Star Rating for Two-Lane Undivided Roadways in Iowa and Washington—All Area Types Combined

- Star rating 1 vs. 5: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.

Washington Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 1 vs. 2: Significant difference
- Star rating 2 vs. 3: Nonsignificant difference
- Star rating 3 vs. 4: Significant difference
- Star rating 4 vs. 5: Nonsignificant difference
- Star rating 1 vs. 5: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.

The relationship between star rating and crash rate for vehicle-occupant crashes on two-lane undivided highways in Iowa was further examined using the longer analysis sections discussed earlier (see Section 4.3.4). For each analysis section, comprised of a number of adjacent 100-m sections, an average star rating was calculated as the average of the individual 100-m star ratings, rounded to the nearest integer. These analysis sections are as homogeneous as practical, but achieving longer analysis sections necessarily makes those sections more diverse than the individual 100-m sections. Crash rates per 100 MVMT were calculated as shown earlier for each analysis section.

Figure 89 illustrates the relationship between star rating and crash rate for the longer Iowa analysis sections, including all area types combined. The longer analysis sections fall into only three vehicle-occupant star rating levels: 3 through 5. The low star rating of 1, shown in the top portion of Figure 88, has been averaged out in the process of assembling longer, less homogeneous sections. However, the decreasing trend from the three- to the five-star rating remains intact and the crash rates are approximately of the same magnitude at each star rating level when comparing the crash rates in the top portion of Figure 88 to those in Figure 89. It appears that the process of combining 100-m sections into longer analysis sections partially masks the high-to-low trend clearly shown in the top portion of Figure 88 for the 100-m sections. This masking effect was also observed for other roadway types and crash types. Therefore, it was decided that the relationships sought between star ratings and crashes were best illustrated with the use of 100-m sections, so the use of longer analysis sections was not pursued further.

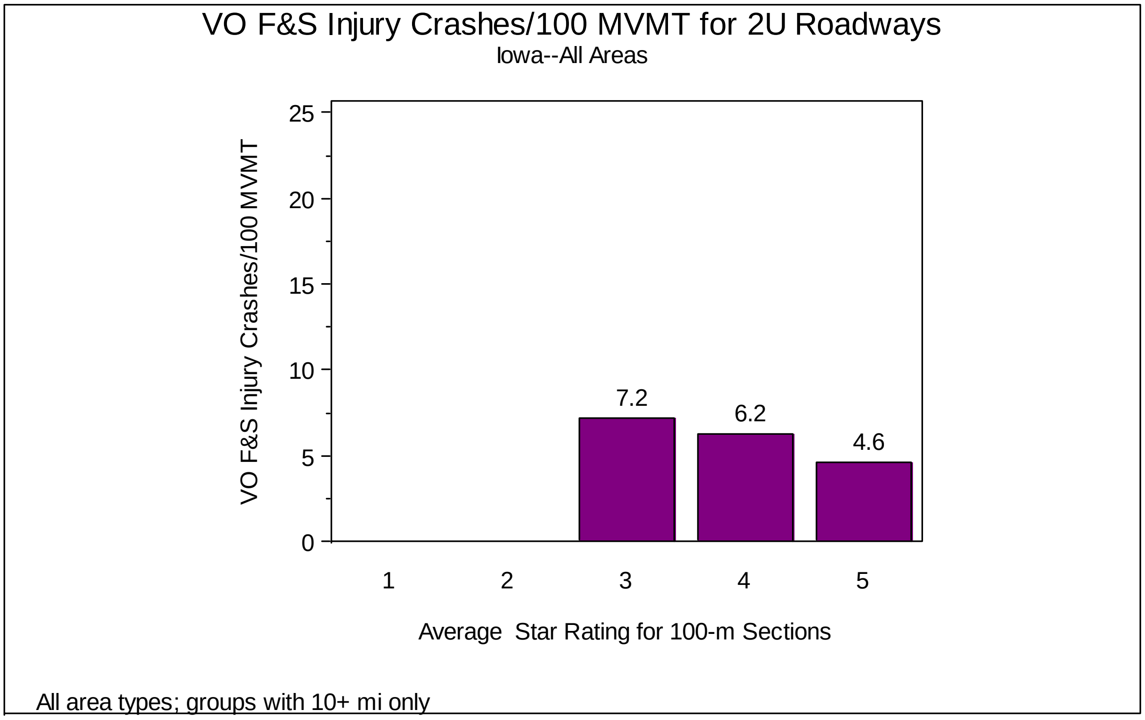
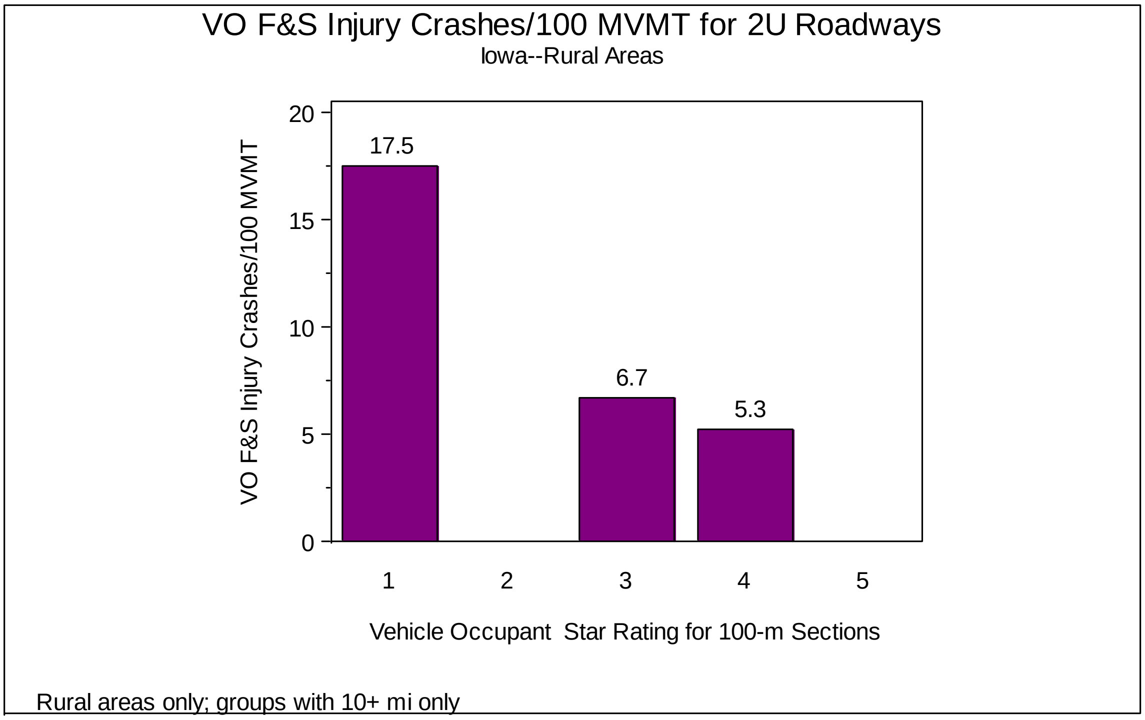


Figure 89. Vehicle-Occupant Crash Rate by Vehicle-Occupant Star Rating for Two-Lane Undivided Roadways in Iowa Based on Aggregated Analysis Sections

Vehicle-Occupant Crashes (Rural Areas Only). For both Iowa and Washington, Figure 88 shows a clear trend of decreasing crash rate with increasing star rating, which illustrates the expected relationship between star rating and crash rate. Initially, there was concern that this relationship might simply be an artifact of the area type influence, if most of the sections with lower star ratings were on semi-urban or urban roadways with higher crash rates. The analysis was therefore repeated with a focus on 100-m sections in rural areas only. The results are shown in Figure 90 for Iowa and Washington, indicating that the same significantly decreasing trend is present when two-lane highways are considered for rural areas only.

Iowa Data: Pairwise crash rate comparisons showed the following results for rural areas only:

- Star rating 1 vs. 3: Significant difference
- Star rating 3 vs. 4: Nonsignificant difference
- Star rating 1 vs. 4: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.



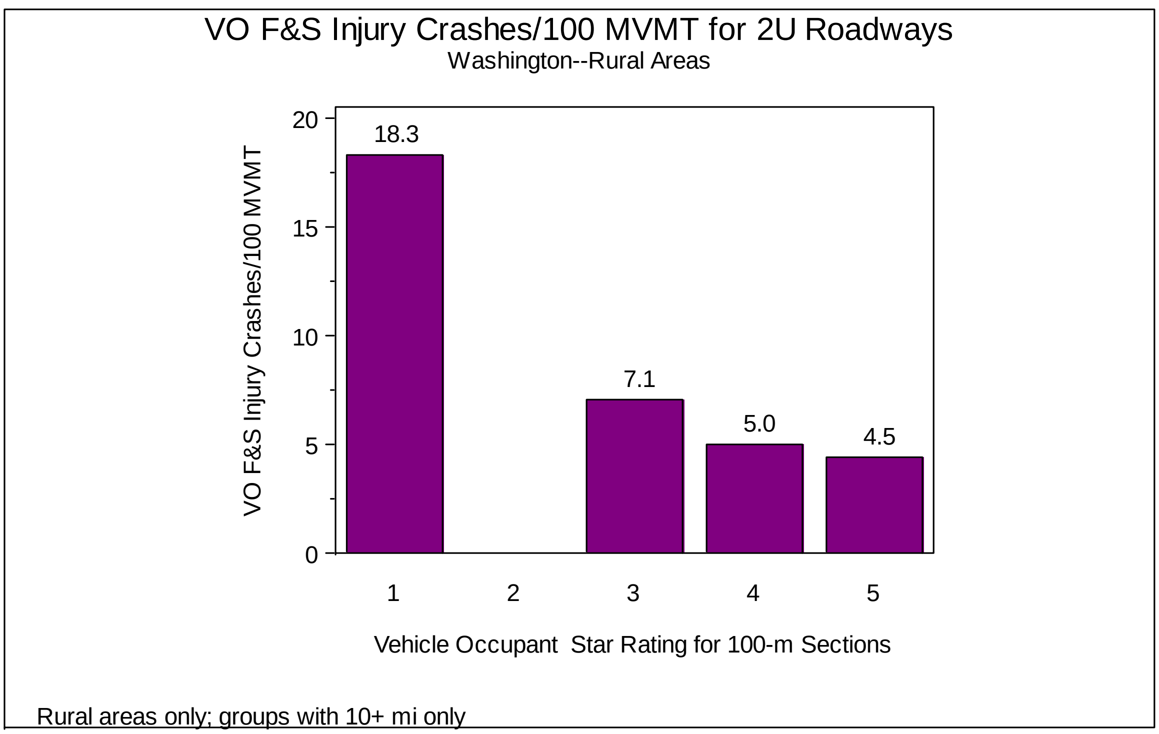


Figure 90. Vehicle-Occupant Crash Rate by Vehicle-Occupant Star Rating for Two-Lane Undivided Roadways in Iowa and Washington—Rural Areas Only

Washington Data: Pairwise crash rate comparisons showed the following results for rural areas only:

- Star rating 1 vs. 3: Significant difference
- Star rating 3 vs. 4: Significant difference
- Star rating 4 vs. 5: Nonsignificant difference
- Star rating 1 vs. 5: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.

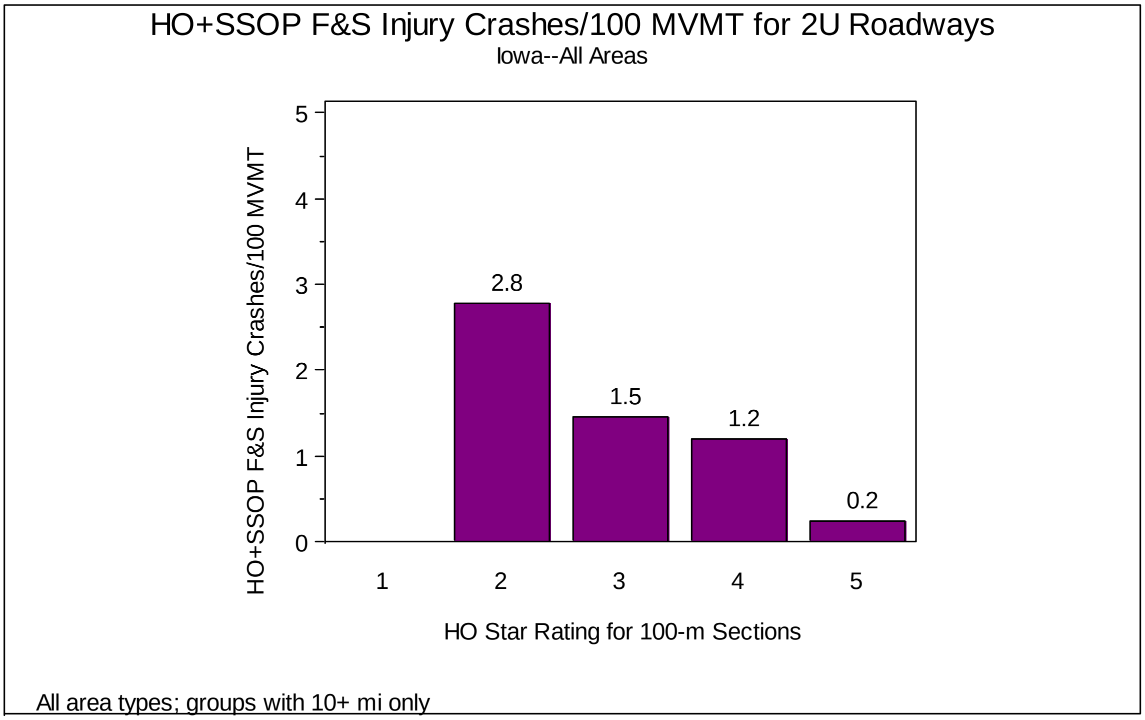
Head-On Plus Sideswipe Opposite-Direction Crashes. The relationship between head-on star rating and head-on plus sideswipe opposite-direction crash rate is illustrated in Figure 91. Iowa rural sections fell into four star rating levels only (all but one star) with similar crash rates as those shown in the top portion of Figure 91 for these two categories. Washington rural sections fell into four categories (all but two stars) with similar crash rates as those shown in the bottom portion of Figure 91 for these four categories. The statistical analysis of the data in Figure 91 showed a statistically significant effect of star rating on crash rates in both states; however, only Iowa shows an overall decreasing trend (i.e., the higher the star rating, the lower the crash rate) that is statistically significant at the 5-percent significance level. The Washington results show a decreasing trend that is marginally statistically significant (at the 10-percent significance level).

Iowa Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 2 vs. 3: Nonsignificant difference
- Star rating 3 vs. 4: Nonsignificant difference
- Star rating 4 vs. 5: Nonsignificant difference
- Star rating 2 vs. 5: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.

Washington Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 1 vs. 3: Nonsignificant difference
- Star rating 3 vs. 4: Nonsignificant difference
- Star rating 4 vs. 5: Nonsignificant difference
- Star rating 1 vs. 5: Nonsignificant trend at the 5-percent significance level, but significant decreasing trend at the 10-percent level.



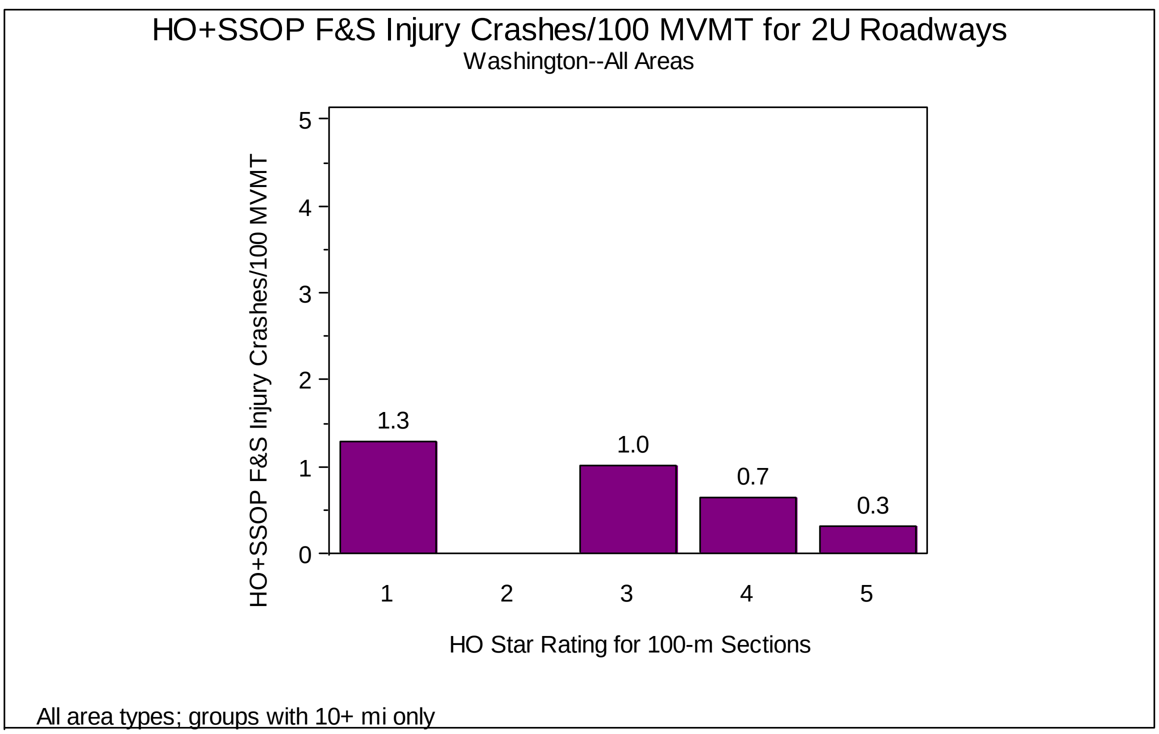


Figure 91. Head-On and Sideswipe Opposite-Direction Crash Rate by Head-On Star Rating for Two-Lane Undivided Roadways in Iowa and Washington

Run-Off-Road Crashes. The relationship between star rating and crash rate for run-off-road crashes is illustrated in Figure 92. The results for this crash type are mixed: the data from Iowa show an unexpected behavior which is not monotonic, while the Washington data show an overall decreasing trend (i.e., the higher the star rating, the lower the crash rate).

Iowa Data: Crash rates are monotonically increasing for star rating levels from two to four stars, then decreasing to the five-star rating. This relationship shown in the upper portion of Figure 92, which is not monotonic and, for a portion of the range, opposite to the direction expected, is the only anomalous result obtained in the star-rating validation study. Since the corresponding data from Washington shows a relationship in the extended direction, this one anomaly does not necessarily indicate the need for a change in the star rating protocol. However, this finding will be discussed with the Iowa Department of Transportation as part of the review of this report.

Washington Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 2 vs. 3: Nonsignificant difference
- Star rating 3 vs. 4: Nonsignificant difference
- Star rating 4 vs. 5: Nonsignificant difference
- Star rating 2 vs. 5: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.

Junction Crashes. The relationship between star rating and crash rate for junction crashes is illustrated in Figure 93. The 100-m sections are all rated as either one star or five stars, based on whether a given section contains, or does not contain, a junction (this was also evident in Figure 85). As such, the figures show the separation between sections including a junction, with low star rating and a high crash rate, and sections not including a junction, with a high star rating and a low crash rate. The crash rates in the two star rating levels are significantly different for both Iowa and Washington.

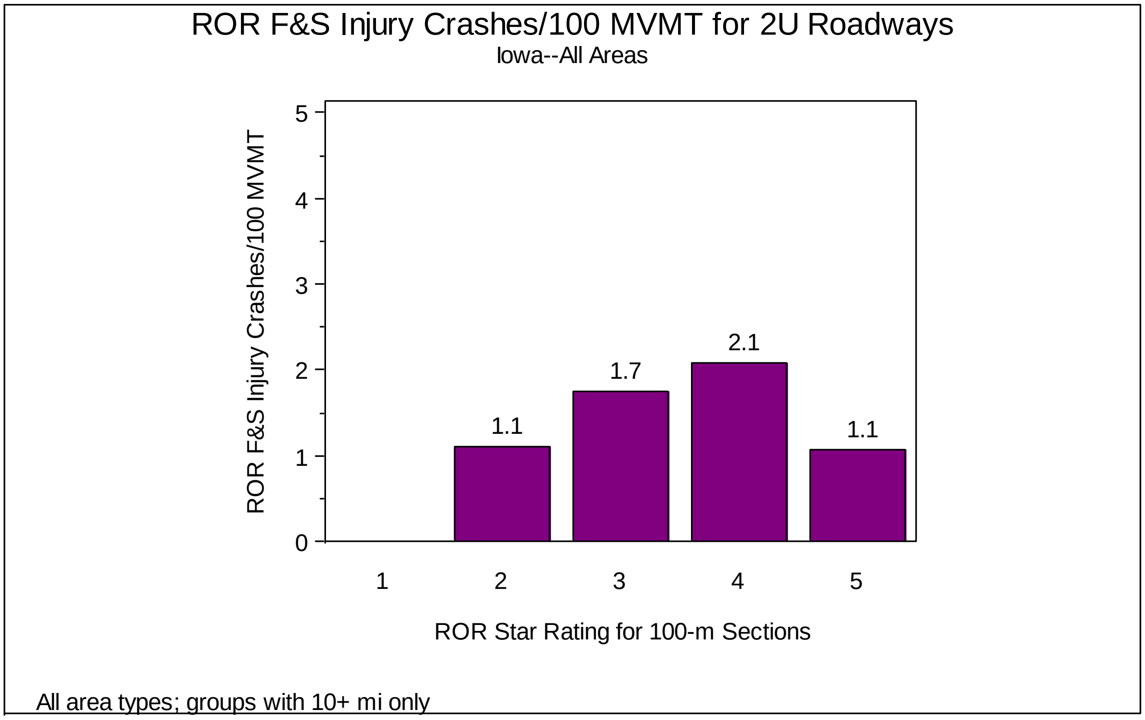
4.5.2 Four-Lane Undivided Highways (4U)

Vehicle-Occupant Crashes. The relationship between star rating and crash rate for vehicle occupants is illustrated in Figure 94 for all area types combined. While the sections classified into only two star rating levels for Iowa, three star rating levels for Washington were found and showed a statistically overall decreasing trend in that state.

Iowa Data: The 100-m sections classified into two star ratings only: 1 or 5. The difference in crash rates in the two star rating categories is in the expected direction and is statistically significantly.

Washington Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 1 vs. 4: Significant difference
- Star rating 4 vs. 5: Nonsignificant difference
- Star rating 1 vs. 5: Significant difference, indicating an overall trend in decreasing crash rate with increasing star rating.



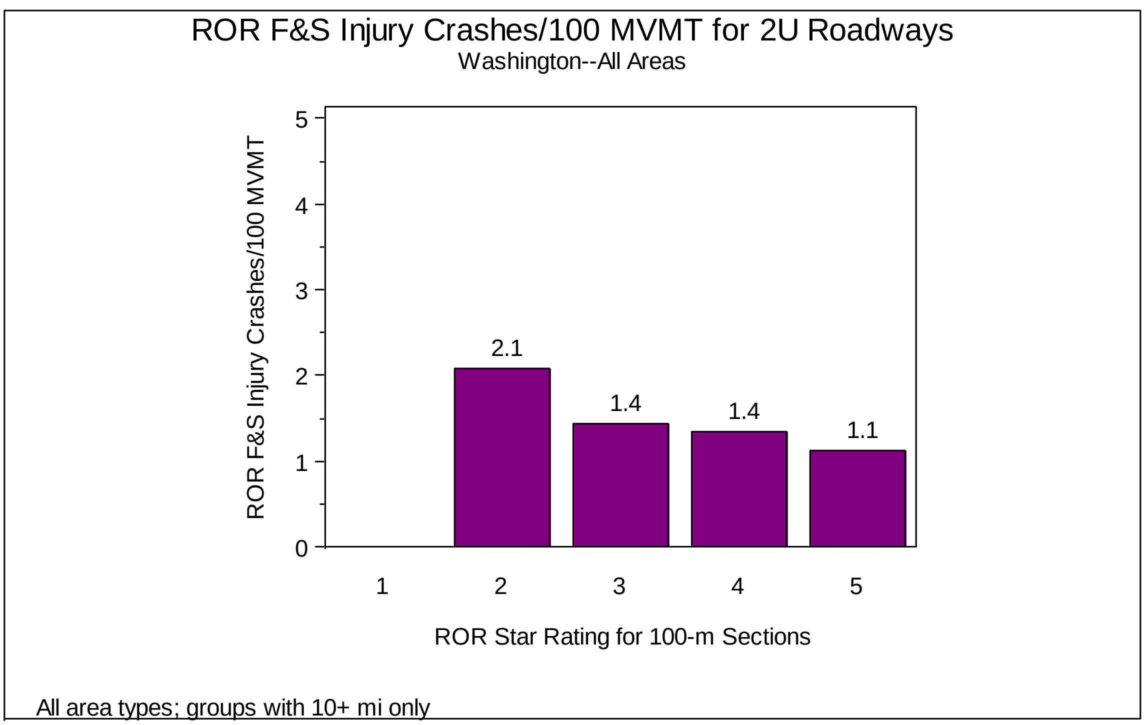
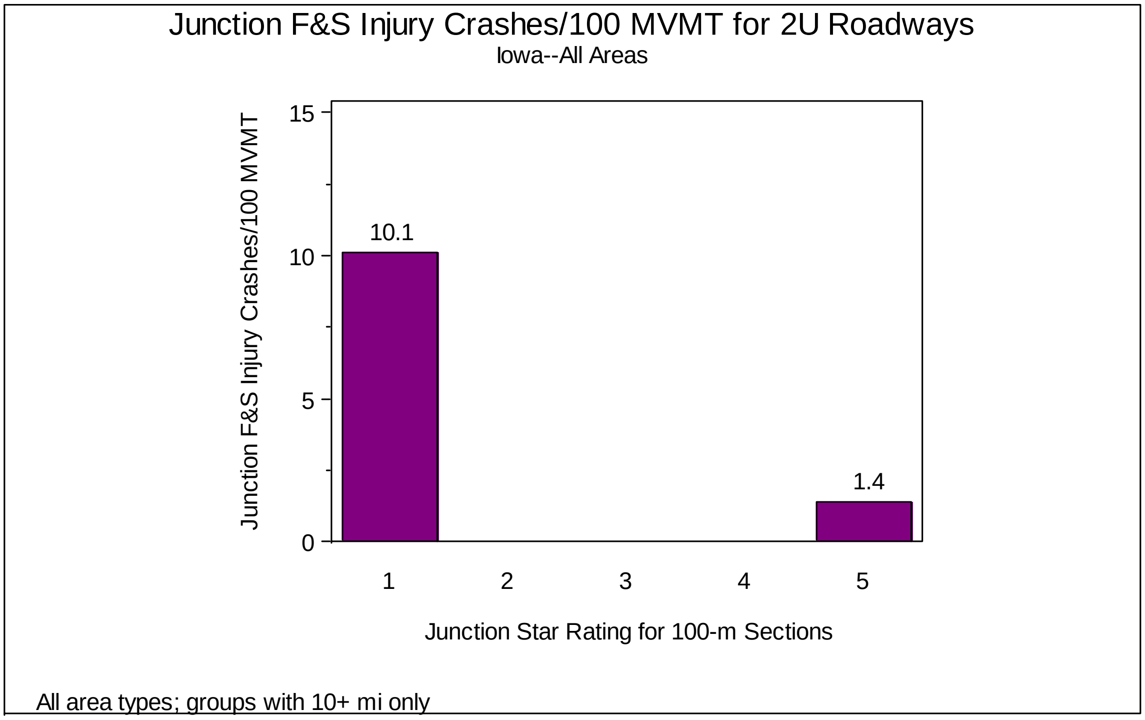


Figure 92. Run-Off-Road Crash Rate by Run-Off-Road Star Rating for Two-Lane Undivided Roadways in Iowa and Washington



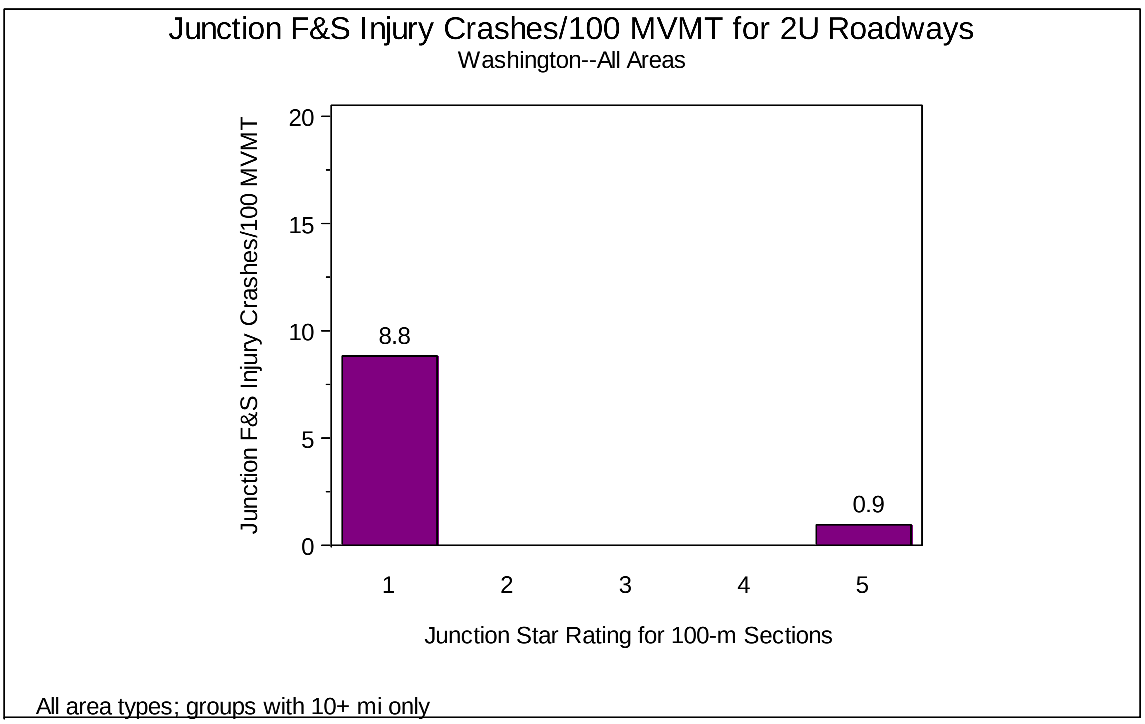
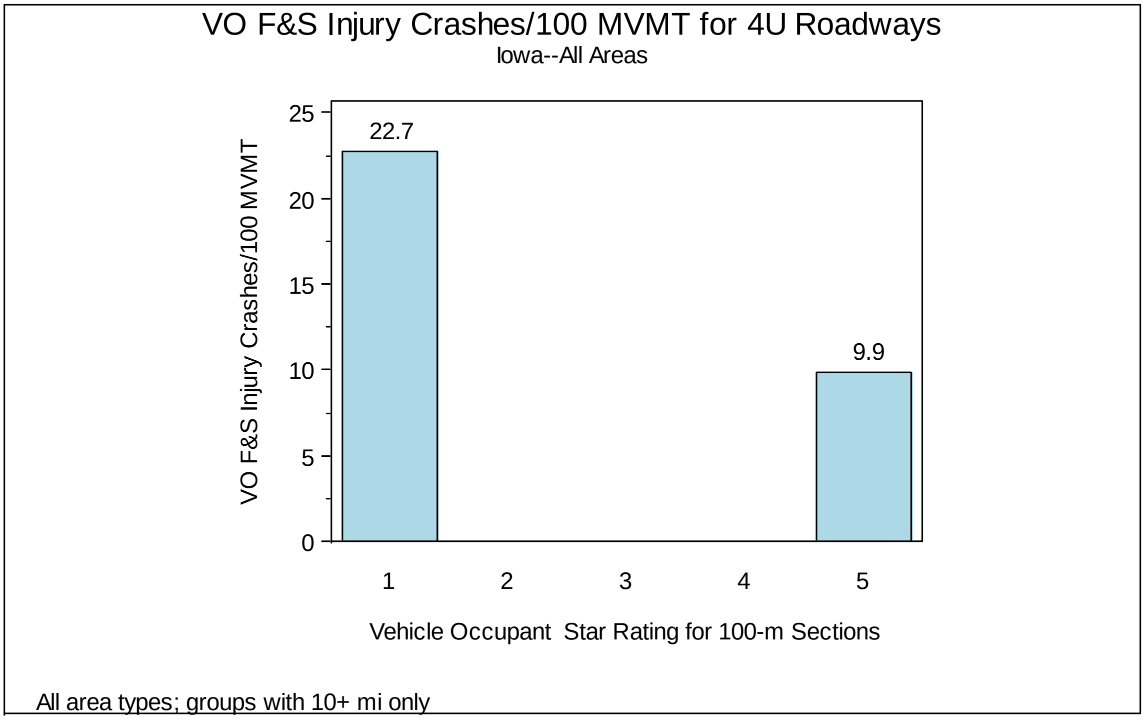


Figure 93. Junction Crash Rate by Junction Star Rating for Two-Lane Undivided Roadways in Iowa and Washington



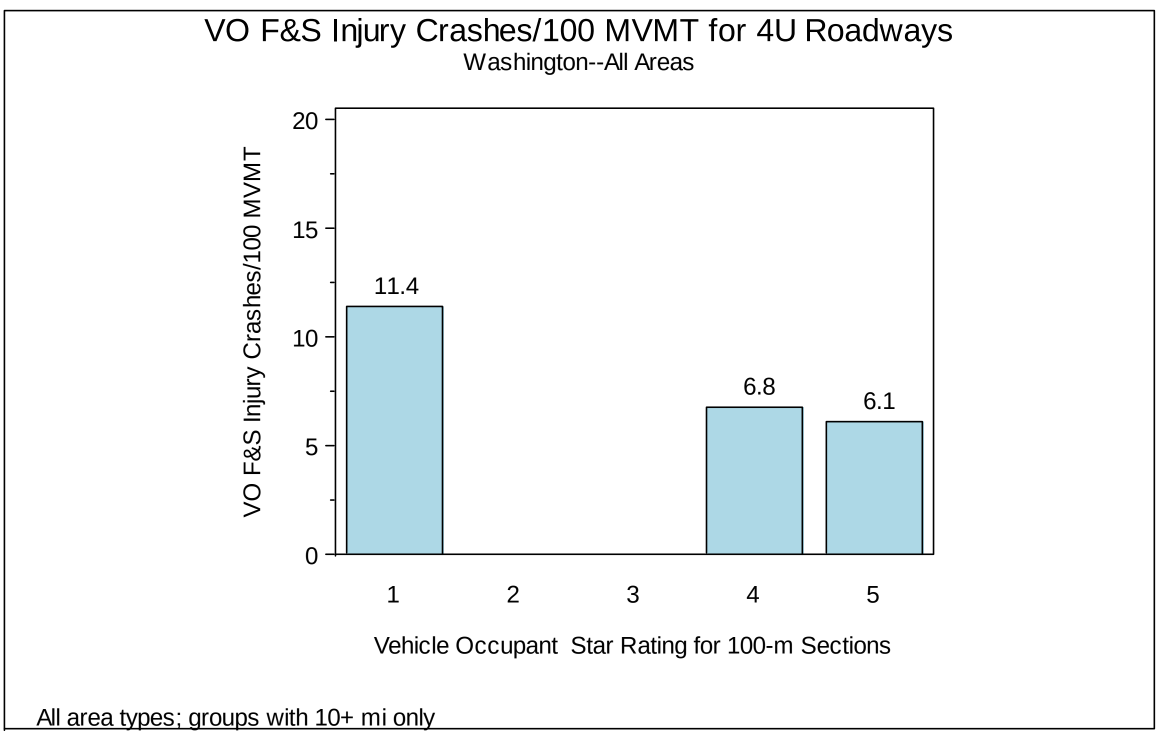


Figure 94. Vehicle-Occupant Crash Rate by Vehicle-Occupant Star Rating for Four-Lane Undivided Roadways in Iowa and Washington

Run-Off-Road Crashes. The relationship between star rating and crash rate for run-off-road crashes is illustrated in Figure 95 for all area types combined. While the sections are classified into only two star rating levels for Iowa, they are classified into three star rating levels for Washington. However, data set shows any statistically significant differences or trend.

Junction Crashes. The relationship between star rating and crash rate for junction crashes is illustrated in Figure 96 for all area types combined. As for two-lane undivided highways, the 100-m sections for four-lane undivided highways are all classified as either one star or five stars, based on whether a section contains, or not contains, a junction. As such, the figures shows the separation between sections including a junction with a high crash rate and a low star rating, and sections not including a junction, with a low crash rate and a high star rating. The crash rates for the two star rating levels are significantly different for both Iowa and Washington data.

4.5.3 Four-Lane Divided Highways Other Than Freeways (4D)

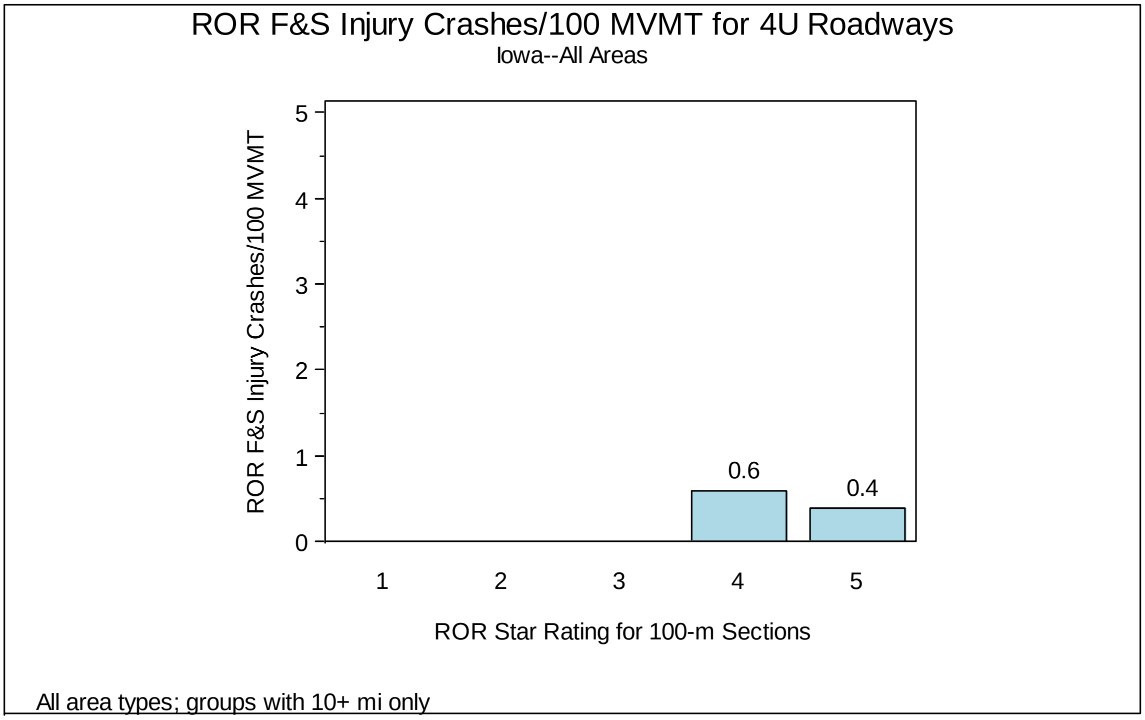
Vehicle-Occupant Crashes. The relationship between star rating and crash rate for vehicle occupants is illustrated in Figure 97 for all area types combined. For both Iowa and Washington, the 100-m sections were classified into only three star rating levels: 1, 4, or 5. The statistical analysis for both states showed an overall decreasing trend that was statistically significant (i.e., the higher the star rating, the lower the crash rate).

Iowa Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 1 vs. 4: Significant difference
- Star rating 4 vs. 5: Significant difference
- Star rating 1 vs. 5: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.

Washington Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 1 vs. 4: Significant difference
- Star rating 4 vs. 5: Nonsignificant difference
- Star rating 1 vs. 5: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.



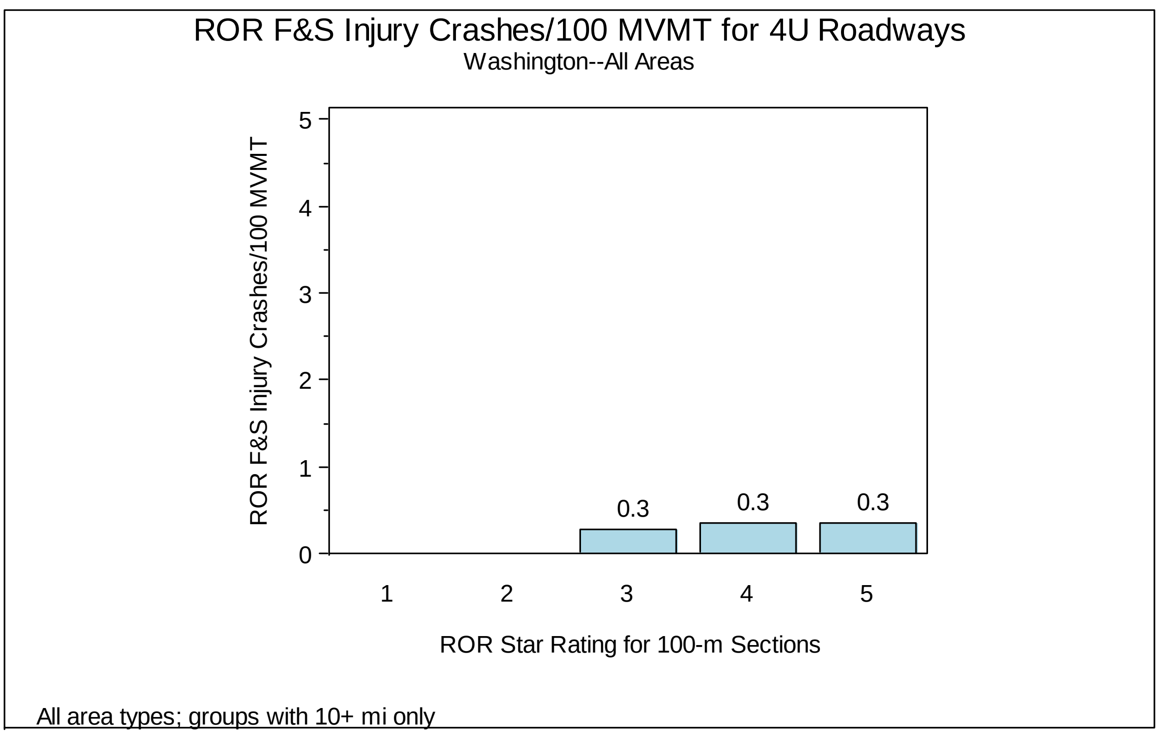
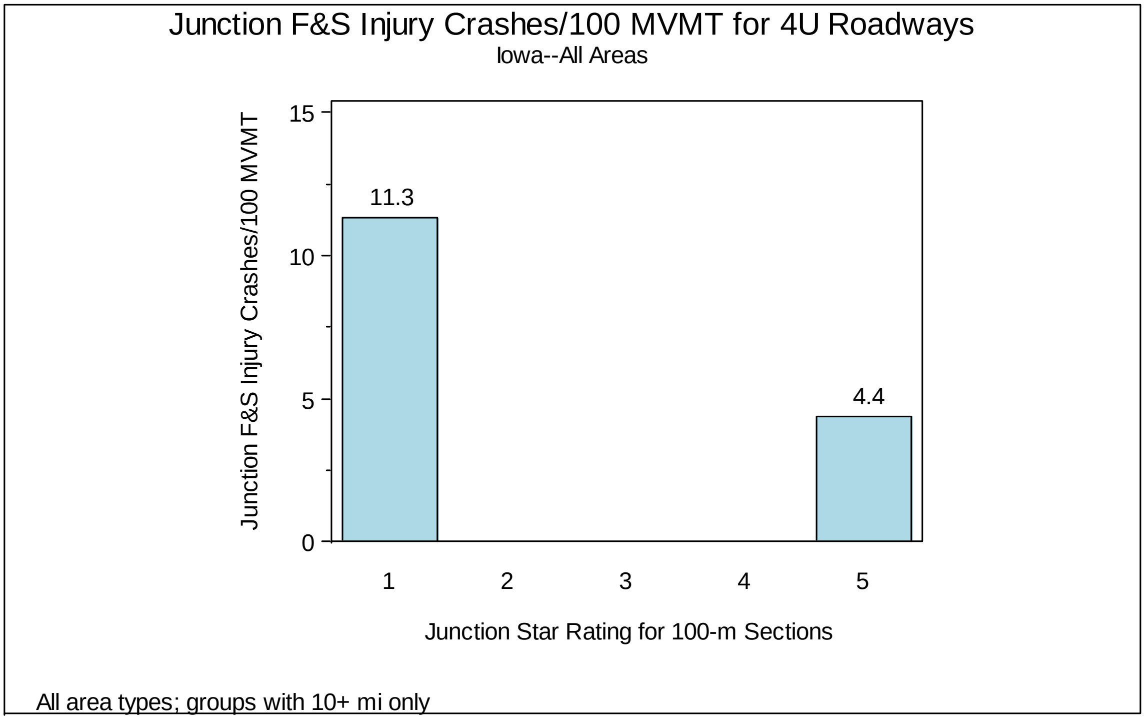


Figure 95. Run-Off-Road Crash Rate by Run-Off-Road Star Rating for Four-Lane Undivided Roadways in Iowa and Washington



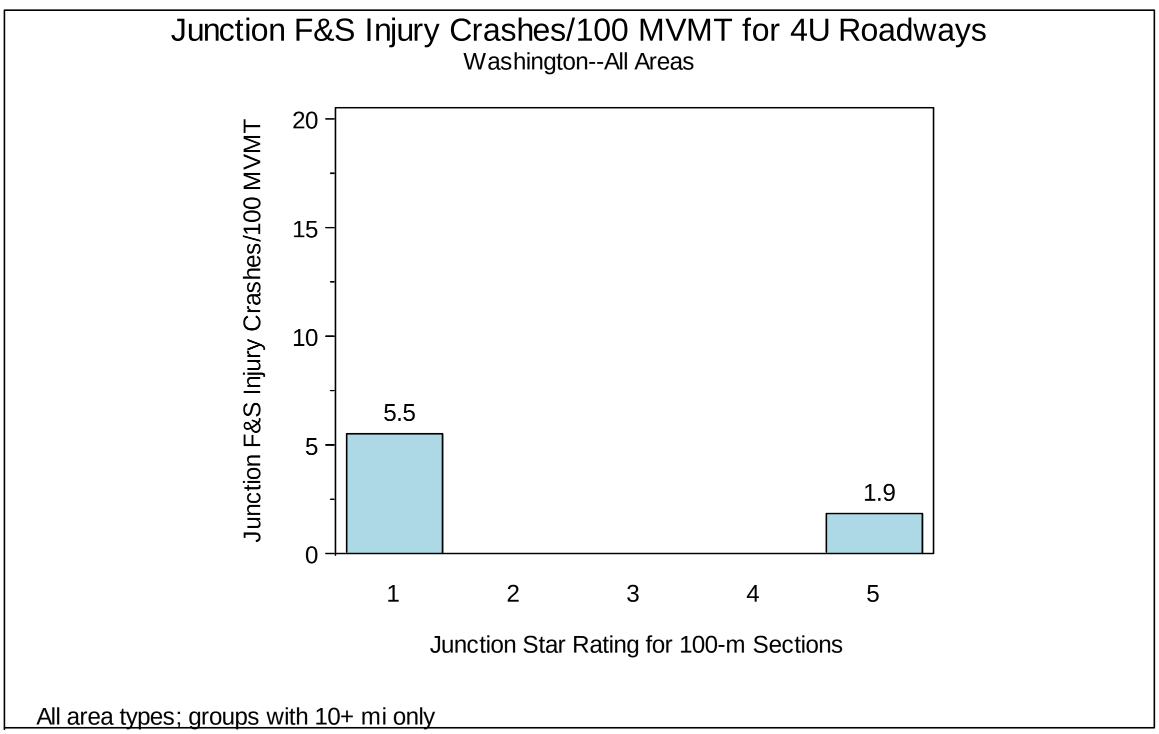
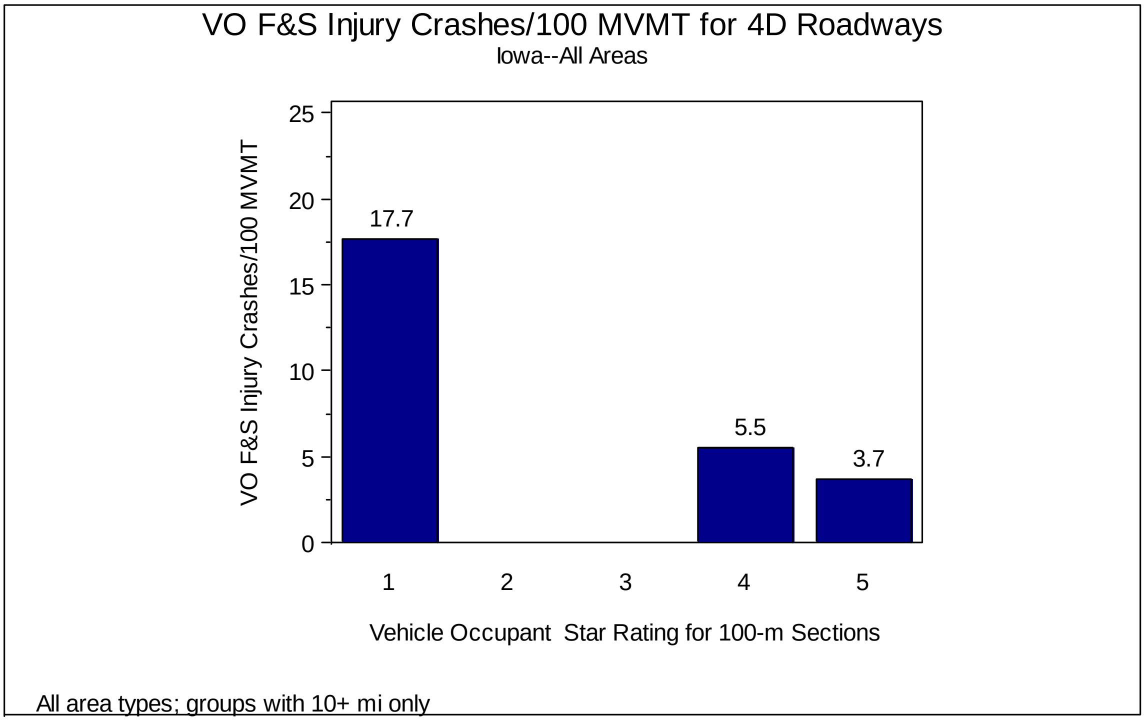


Figure 96. Junction Crash Rate by Junction Star Rating for Four-Lane Undivided Roadways in Iowa and Washington



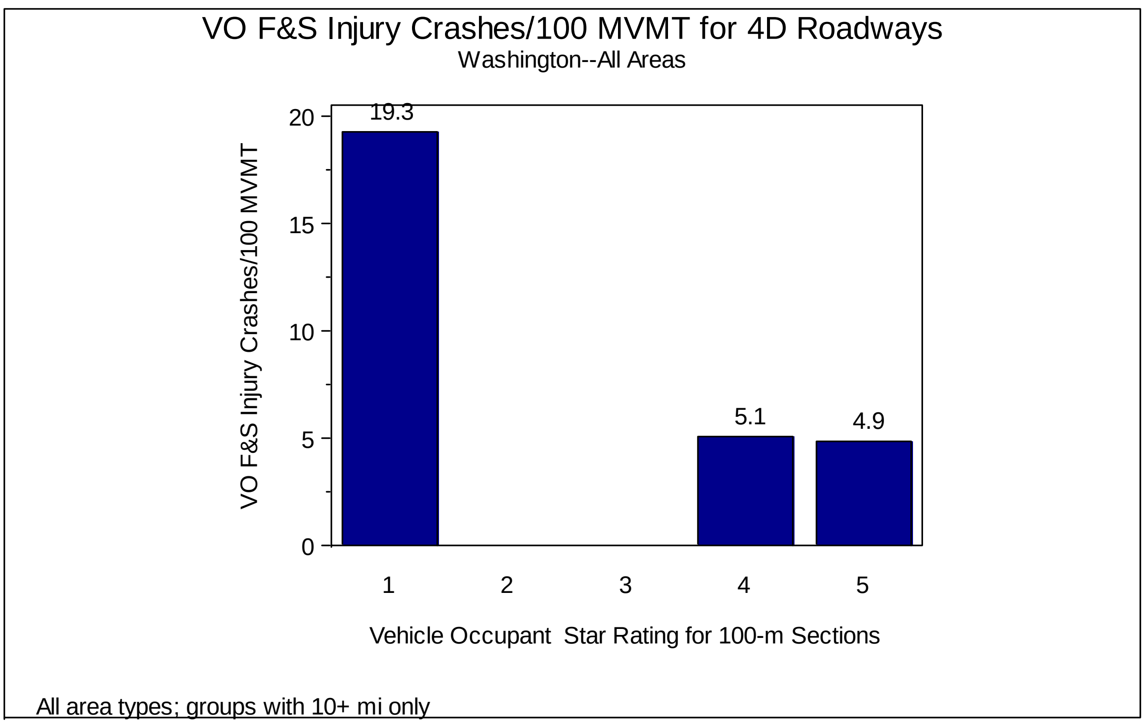


Figure 97. Vehicle-Occupant Crash Rate by Vehicle-Occupant Star Rating for Four-Lane Divided Roadways in Iowa and Washington

Head-On Plus Sideswipe Opposite-Direction Crashes. The relationship between head-on star rating and head-on plus sideswipe opposite-direction crash rate is illustrated in Figure 98 for Washington. There were insufficient data to examine this relationship for roadways in Iowa. The 100-m sections were classified into only two star rating levels, four and five stars. The difference between the crash rates for these two star rating levels is not statistically significant.

Run-Off-Road Crashes. The relationship between star rating and crash rate for run-off-road crashes is illustrated in Figure 99 for all area types combined. The 100-m sections in Iowa are classified into only three star ratings levels: 3, 4, or 5; the sections in Washington are classified into four star rating levels: 2 through 5. For both states, the pattern is not monotonic. These results are similar to the pattern observed earlier for two-lane undivided roadways in Iowa. Although the differences shown in Figure 94 are not statistically significant, there appears to be a general downward trend, particularly in the Washington data, which provides at least a suggestion of the expected downward trend in the relationship between crash rate and star rating.

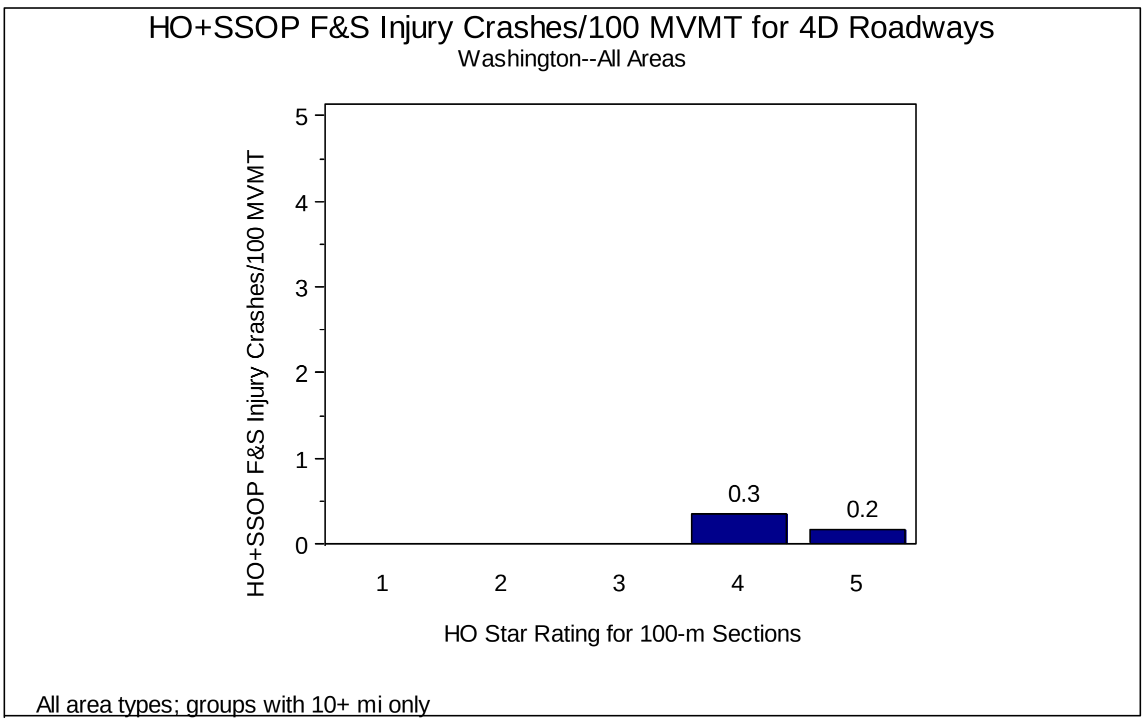
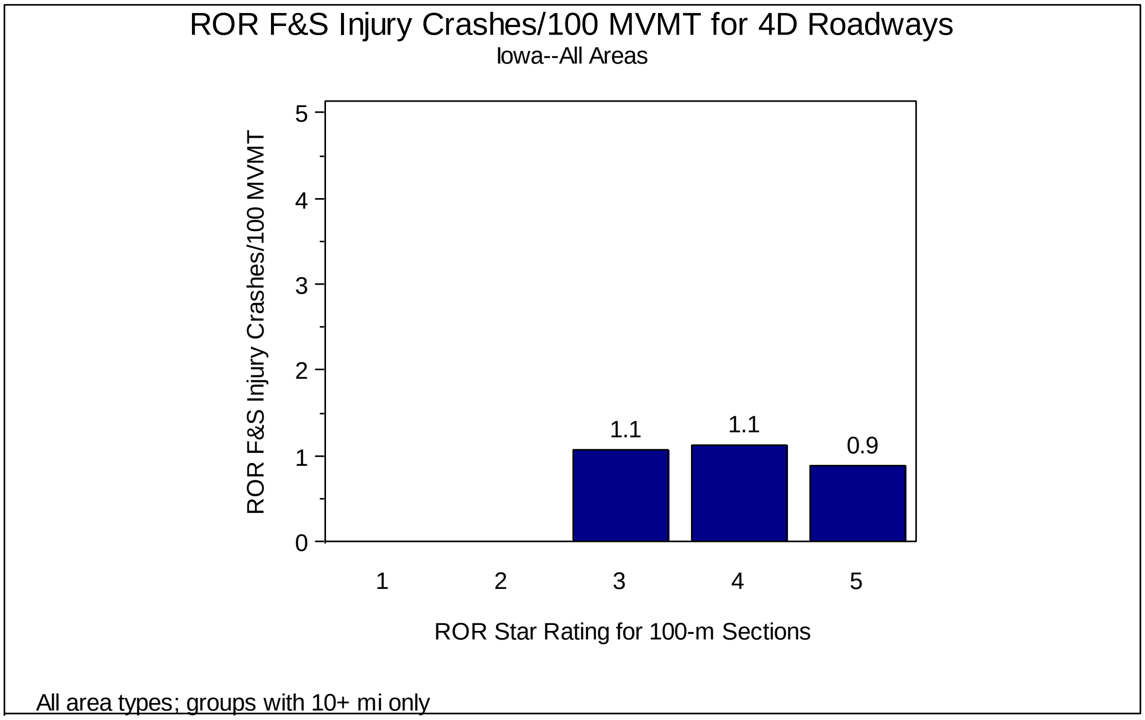


Figure 98. Head-On and Sideswipe Opposite-Direction Crash Rate by Head-On Star Rating for Four-Lane Undivided Roadways in Washington



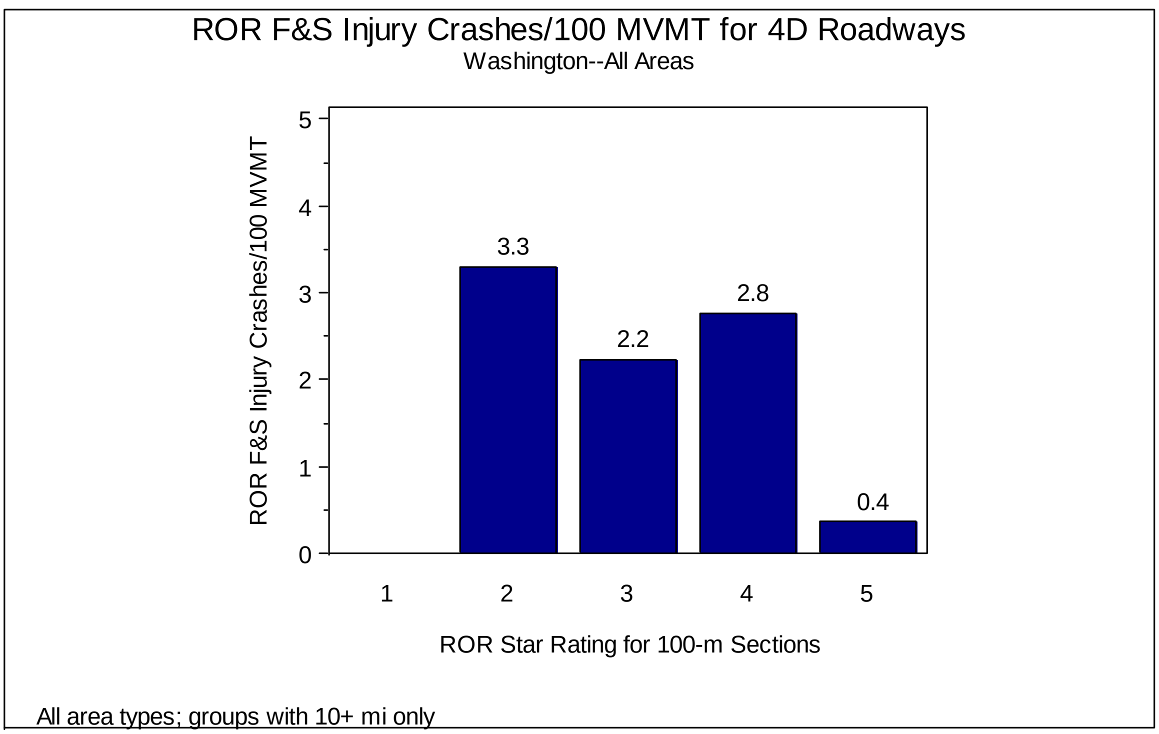


Figure 99. Run-Off-Road Crash Rate by Run-Off-Road Star Rating for Four-Lane Divided Roadways in Iowa and Washington

Junction Crashes. The relationship between star rating and crash rate for junction crashes on four-lane divided nonfreeways is illustrated in Figure 100 for all area types combined. The 100-m sections in Iowa are classified into only three star rating levels: 1, 3, or 5; those in Washington are classified into the more typical one-star and five-star levels. The statistical analysis showed a statistically significant effect of star rating on crash rates in both states and an overall statistically decreasing trend in Iowa.

Iowa Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 1 vs. 3: Significant difference
- Star rating 3 vs. 5: Significant difference
- Star rating 1 vs. 5: Significant difference, indicating an overall statistically decreasing trend

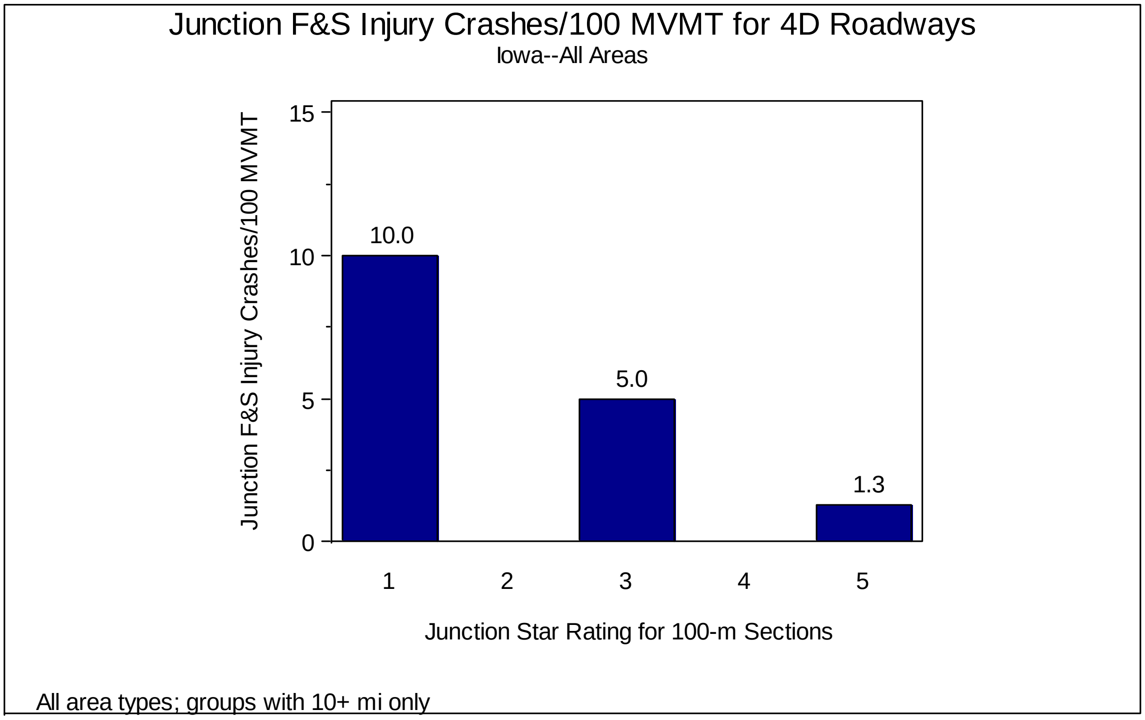
Washington Data: The crash rates between one-star and five-star roadway sections are significantly different, with one-star sections having higher crash rates than five-star sections.

4.5.4 Four-Lane Divided Freeways (4DF)

Vehicle-Occupant Crashes. The relationship between star rating and crash rate for vehicle occupants is illustrated in Figure 101 for all area types combined. For road sections in both Iowa and Washington, the 100-m sections classified into only two star rating levels: 4 or 5. No statistically significant differences between the star rating levels were found; for all practical purposes, the crash rates are identical in the two star rating levels for each state. In Iowa, the crash rate for the five-star category is slightly higher than that for the four-star category (3.1 vs. 2.4 crashes per 100 MVMT); in Washington, the crash rate for the five-star category is also slightly higher than that in the four-star category (4.4 vs. 3.8 crashes per 100 MVMT).

Run-Off-Road Crashes. The relationship between star rating and crash rate for run-off-road crashes is illustrated in Figure 102 for all area types combined. The 100-m sections in Iowa were classified into only three star rating levels: 3, 4, or 5; similarly, the 100-m sections in Washington were classified into three star ratings levels (different from those in Iowa): 2, 3, and 4. For all practical purposes, the crash rates are identical across the three star categories in each state (none of the pairwise comparisons was statistically significant).

Junction Crashes. The relationship between star rating and crash rate for junction crashes in Washington is illustrated in Figure 103 for all area types combined. The 100-m sections classified into the two star rating levels that are typical of junction crashes: 1 and 5. The junctions that were rated on four-lane divided freeways are primarily acceleration lanes. The difference in crash rates between the two star ratings is not statistically significant. There were insufficient data for four-lane divided freeway sections in Iowa to explore this relationship.



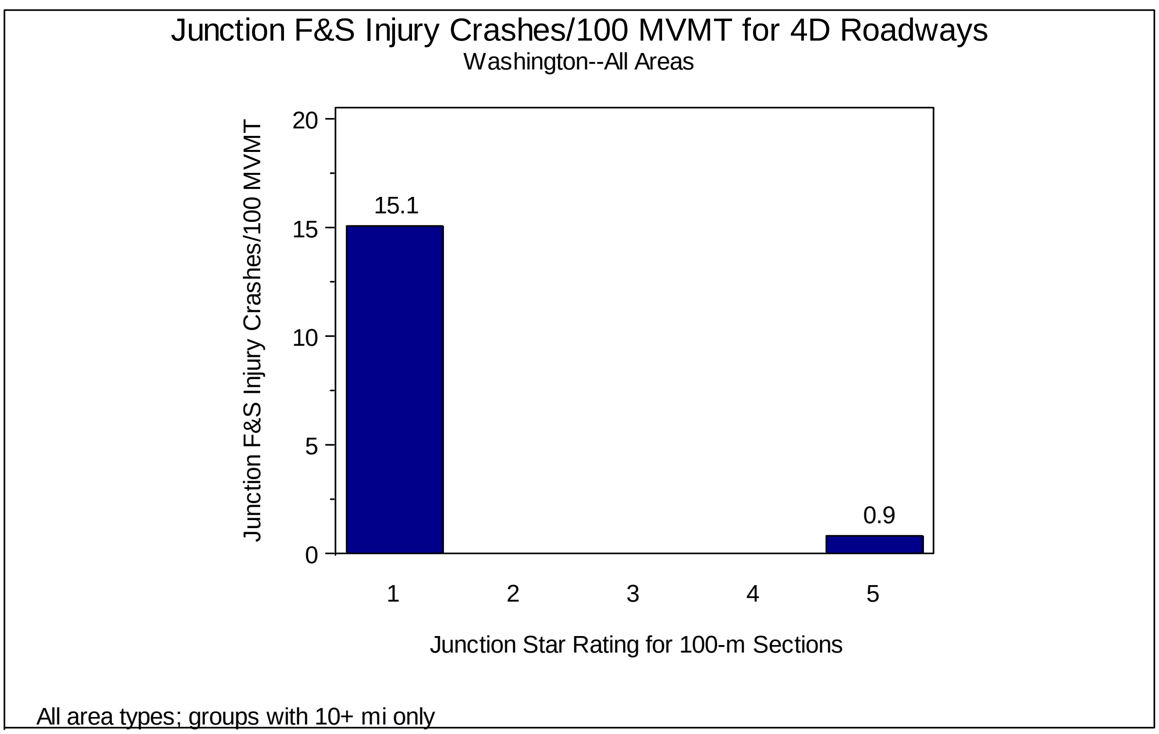
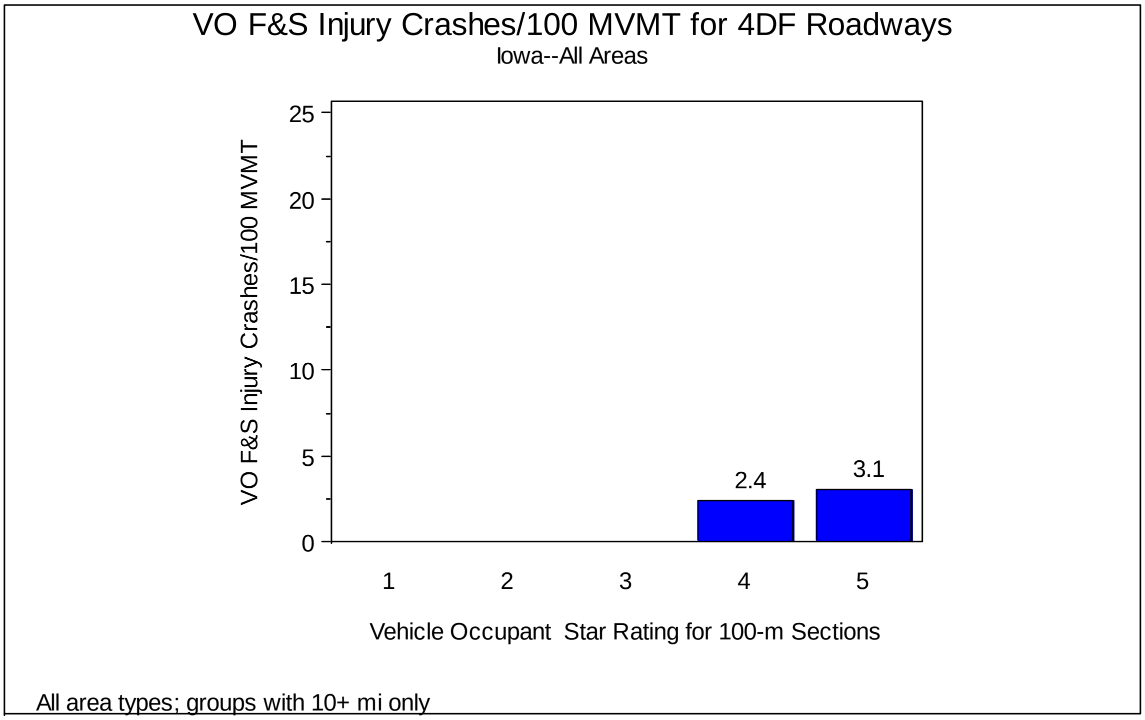


Figure 100. Junction Crash Rate by Junction Star Rating for Four-Lane Divided Roadways in Iowa and Washington



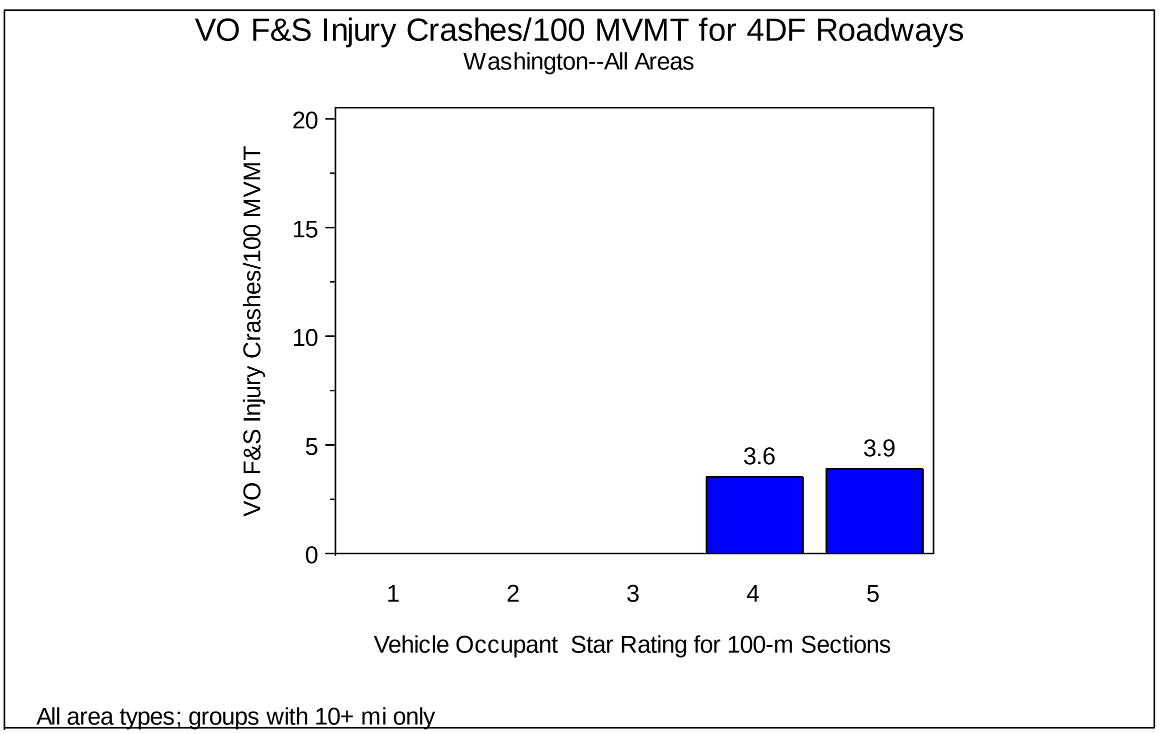


Figure 101. Vehicle-Occupant Crash Rate by Vehicle-Occupant Star Rating for Four-Lane Divided Freeways in Iowa and Washington

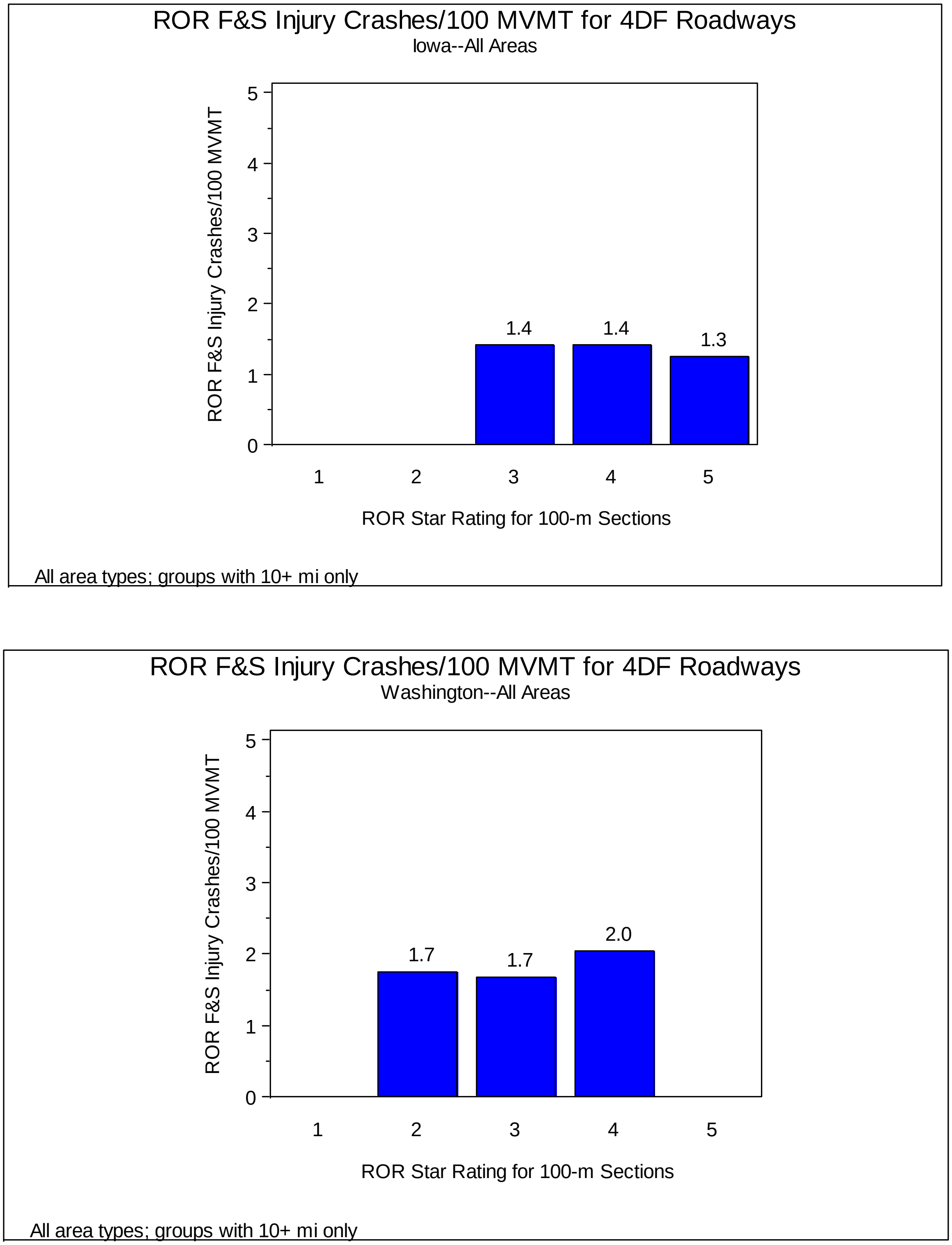


Figure 102. Run-Off-Road Crash Rate by Run-Off-Road Star Rating for Four-Lane Divided Freeways in Iowa and Washington

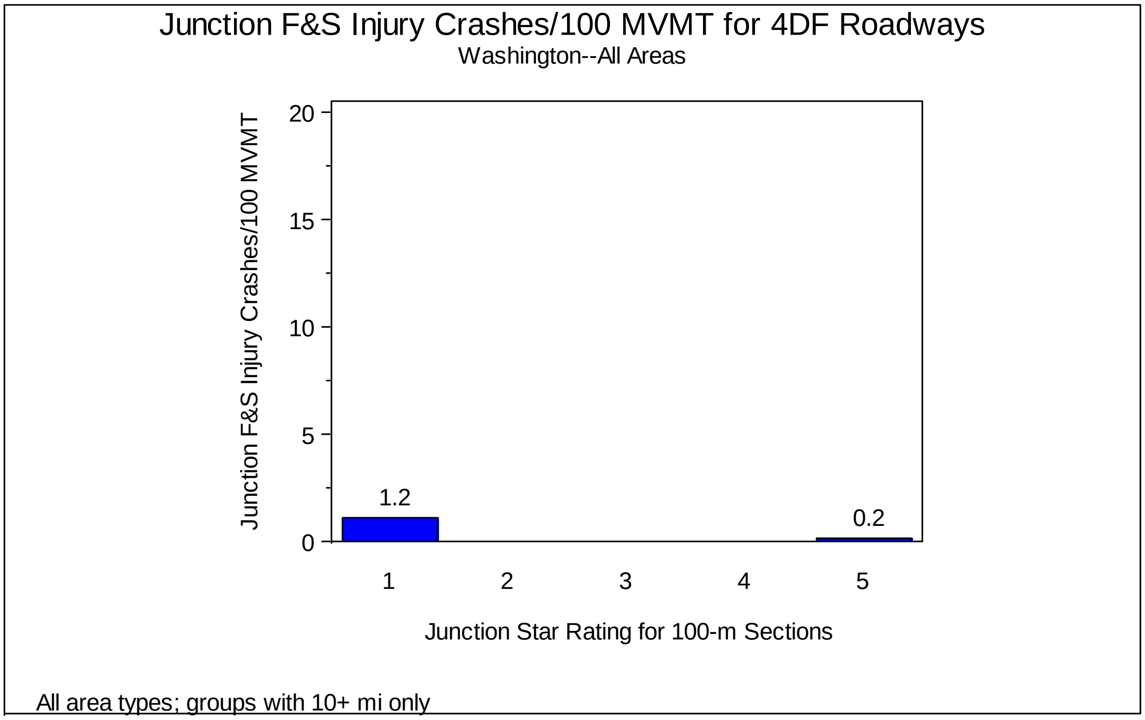


Figure 103. Junction Crash Rate by Junction Star Rating for Four-Lane Divided Freeways in Washington

4.5.5 Six-Lane Divided Highways (6D)

No results concerning the relationship between star ratings and crash rates of specific types were obtained for one of the following reasons: all star ratings fell into a single level; the total mileage in a group was below 10 mi; or crash counts were too low over the study period. This was the case for six-lane divided highway sections in both Iowa and Washington.

4.5.6 Six-Lane Divided Freeways (6DF)

Vehicle-Occupant Crashes. The relationship between star rating and crash rate for vehicle occupants on six-lane divided freeways in Washington is illustrated in Figure 104 for all area types combined for Washington only. The 100-m sections were classified into only two star rating levels: 4 or 5. For all practical purposes, the crash rates are identical in the two star rating levels; the difference in crash rate between these star-ratings is not statistically significant. There were insufficient data for six-lane divided freeway sections in Iowa to explore this relationship.

Run-Off-Road Crashes. The relationship between star rating and crash rate for run-off-road crashes is illustrated in Figure 105 for all area types combined for Washington only. The 100-m sections were classified into only three star rating levels: 2, 3, and 4. The statistical analysis showed a statistically significant effect of star rating on crash rates and an overall statistically decreasing trend; i.e., crash rates decreased as star ratings increased. There were insufficient data for six-lane divided freeway sections in Iowa to explore this relationship.

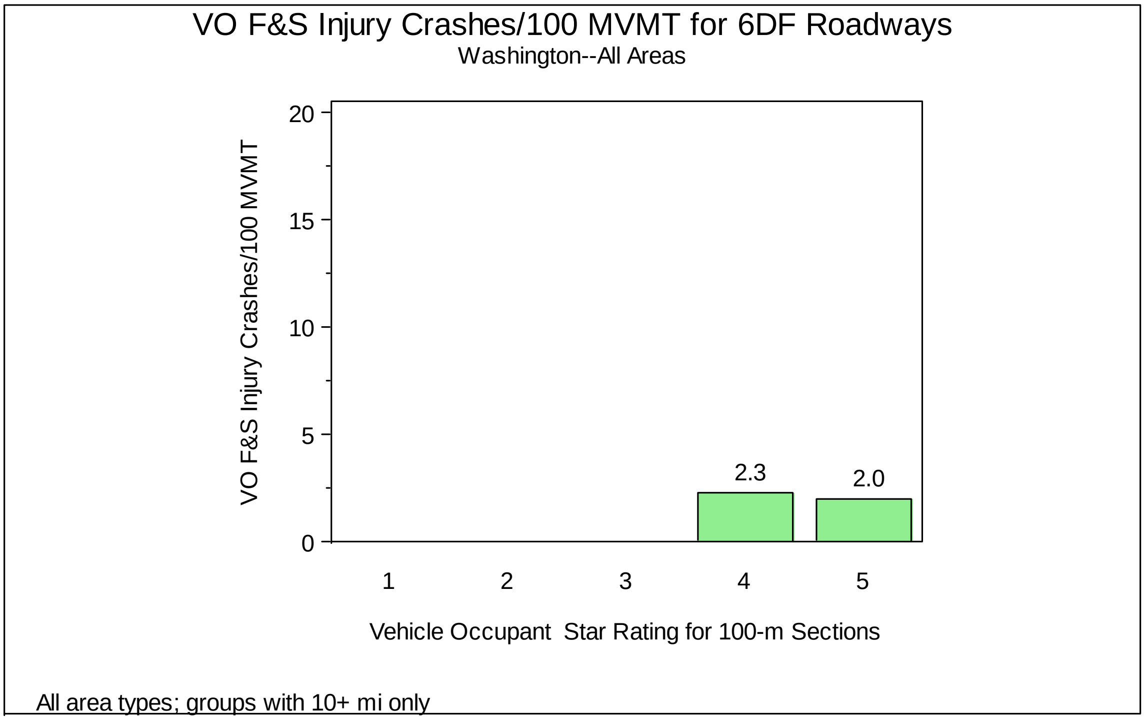


Figure 104. Vehicle-Occupant Crash Rate by Vehicle-Occupant Star Rating for Six-Lane Divided Freeways in Washington

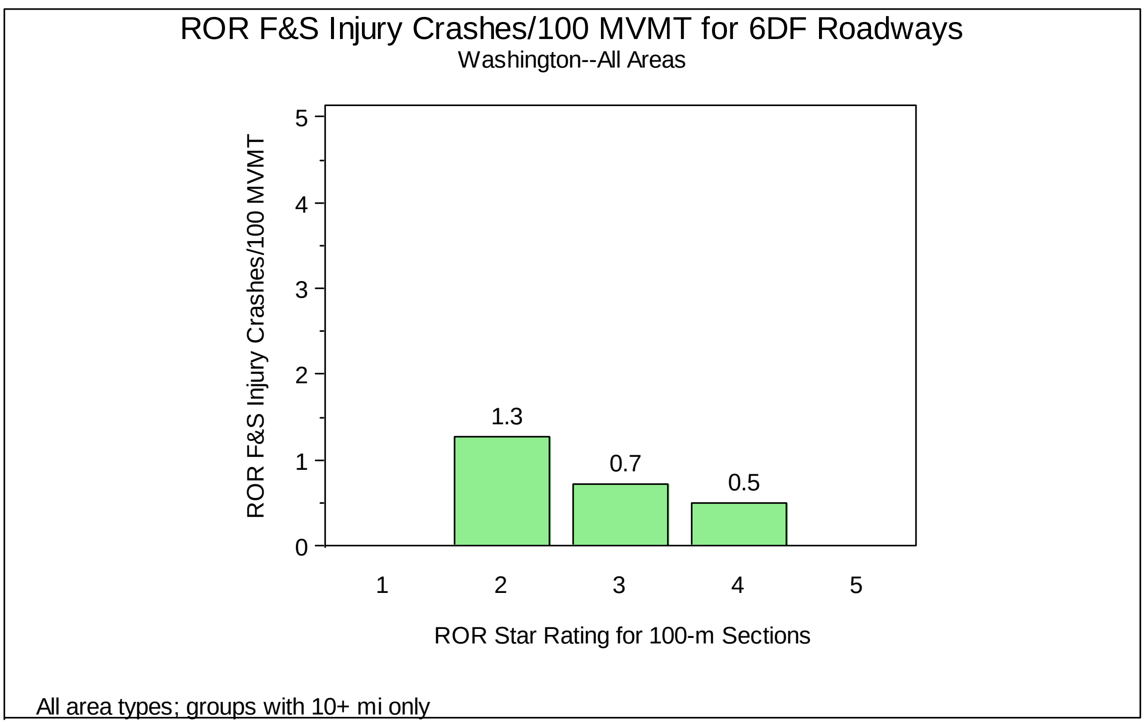


Figure 105. Run-Off-Road Crash Rate by Run-Off-Road Star Rating for Six-Lane Divided Freeways in Washington

Washington Data: Pairwise crash rate comparisons showed the following results across all area types:

- Star rating 2 vs. 3: Significant difference
- Star rating 3 vs. 4: Nonsignificant difference at the 5-percent significance level; is statistically significant at the 10-percent level
- Star rating 2 vs. 4: Significant difference, indicating an overall trend of decreasing crash rate with increasing star rating.

4.5.7 One-Way Streets

No results on the relationship between star ratings and crash rates of specific types are provided for one-way streets because the total mileage in that group was below 10 mi for both states.

4.6 Other Statistical Approaches

The relationships between star ratings and crash rates discussed above were based on the comparison of star ratings and crash rates calculated across all 100-m sections within a specific roadway type. As such, the analysis aggregated all available data for each roadway type and star rating level. Two other approaches that take into account the relationship between star rating and crash frequencies or crash rates at the individual 100-m section level (i.e., the least aggregated level) were implemented and are discussed next.

4.6.1 Correlation Analysis

Plots of crash rates versus star ratings were developed for all roadway types and crash types discussed above prior to estimating the correlation between the two. A correlation analysis assumes a linear relationship between crash rate and star rating. The plots, based on the 100-m section data, provided a visualization of the relationship between star rating and crash rate; however, none of the plots provided sufficient evidence of a linear relationship to perform a correlation analysis.

4.6.2 Negative Binomial Regression Analysis

In this approach, crash frequencies were modeled as a function of ADT rather than simply using crash rates. A negative binomial model was applied to each group of data: the crash frequency was assumed to be related to ADT through a power function; crash frequency was assumed to follow a negative binomial distribution; and star rating was considered a categorical variable with up to five levels. The ADT coefficient was estimated and the effect of star rating on crash frequency, while accounting for the effect of ADT, was estimated from the data for each specific roadway type and crash type. This modeling effort did not provide any meaningful relationships between crash frequency and star rating levels while accounting for the effect of ADT.

4.7 Summary of Findings for Validation Study

The validation study results presented in Section 4.5 provide strong evidence that crash rates for road sections generally decrease as star ratings increase, at least for roadway types with sufficient data and a sufficient range of star ratings to provide meaningful results. This trend was observed for:

- vehicle-occupant crashes as a whole and the corresponding star ratings for two-lane undivided highways, four-lane divided highways, and four-lane divided roadways. The existence of such a relationship could not be tested for four- and six-lane freeways, but the star ratings for freeways do not vary much.
- head-on plus sideswipe opposite-direction crashes and the corresponding star ratings for two-lane undivided highways. For other roadway types, there either were not sufficient data to assess this relationship or the differences in crash rate between the star rating levels were not statistically significant.
- run-off-road crashes and the corresponding star ratings for two-lane undivided highways and six-lane divided freeways. For other roadway types, the results were generally not statistically significant. There was an anomalous result for two-lane undivided highways in Iowa for which crash rates increased with increasing star ratings, but the Washington results for the same case showed the expected trend with crash rates decreasing as star ratings increase.
- junction crashes and their corresponding star ratings for two-lane undivided highways and four-lane undivided nonfreeways. Results for four- and six-lane freeways were not statistically significant but, of course, such freeways have very few junctions.

The lack of success in developing correlations or predictive relationships between star ratings and crash rate and in developing negative binomial regression models for the effect of star rating on crash frequency, while accounting for the effect of ADT, indicates that knowing the star rating for a road section is not sufficient information to predict the crash frequency for that particular section for any specific year or for a period of several years. This finding is not surprising given the high variability of crash frequency data. However, the results presented in Section 4.5 indicate clearly that there is a demonstrable relationship between star rating and crash rate, at least for those roadway types for which the star ratings vary substantially.

The lack of sufficient data to validate the pedestrian and bicycle star ratings is disappointing. Pedestrian and bicycle crashes are relatively rare events on U.S. roads compared to other countries where pedestrian and bicycle volumes are greater. It would be desirable to assemble a larger database to validate the pedestrian and bicycle star ratings for U.S. conditions. This could be accomplished with a limited effort that would reduce from the Iowa and Washington videologs only those data elements needed to determine the pedestrian and bicycle star ratings for an expanded road network.

4.8 Potential Application of the Star Rating Protocol in the U.S.

Most of the usRAP pilot study efforts to date have focused on risk mapping, which clearly provides an important safety management tool for roadway networks for which high-quality crash data are available. Star ratings were initially seen as a supplement to risk maps that could provide insight into variations in crash risk shown on the risk maps. However, three recent developments have shown a much expanded potential for use of the star rating protocol. These three developments are:

- the results of the validation study presented above show a clear relationship between the star ratings and crash risk, thus documenting the value of the star rating protocol, and
- iRAP has expanded the star rating protocol to include a methodology and web-based analysis software to formulate cost-effective countermeasure programs using the star ratings for roadways and the roadway data on which the star ratings are based
- ongoing discussions between usRAP and Navteq concerning collaboration on implementing the star rating protocol may substantially lower the cost of implementing star ratings in the U.S.

The star rating protocol now provides a capability that has not previously been available to highway agencies—selection of rational, cost-effective countermeasures for improving safety on a highway network without the need for detailed network-wide crash data. The iRAP analysis software suggests specific countermeasure programs for consideration by highway agencies, including proposed locations and benefit-cost ratios for each countermeasure. This approach should be particularly valuable to highway agencies without access to crash data or whose crash data lacks reliable crash location information.

Crash location data that can link individual crashes to specific roadway locations can be in the form of GPS coordinates (latitude and longitude) or roadway mileposts; these two crash location approaches can be tied together with a linear referencing system. However, many highway agencies do not have access to a crash data base including good crash location data or a reliable linear referencing system. Lack of reliable crash location data is a widespread problem particularly for agencies, such as county highway agencies, whose roads that are not on a state highway system and are not include in state highway agency crash location systems. As an example of this concern, consider the Federal high-risk rural roads program which provides funding for rural roads whose crash rates exceed the statewide average. The funding available under this program is underutilized for many reasons, one of which is that highway agencies without access to reliable crash location data cannot document the crash rates of candidate improvement sites.

The development of improved crash location data is desirable, but this is major undertaking that will require many years. The star rating protocol and the associated analysis software provide an alternative approach that is available for implementation now to develop cost-effective safety improvement programs for highway networks despite the lack of reliable crash data. The iRAP analysis software has been applied in low- and middle-income countries including Argentina, Chile, Costa Rica, Malaysia, Peru, and South Africa. Since the star rating protocol has now been validated, the analysis software has clear potential as a tool for application in the U.S., especially for agencies, such as counties, without access to automated crash location data.

As a first step in implementing this new approach, a demonstration program is needed with the following objectives:

- to demonstrate the usefulness of countermeasure programs based on the star rating protocol and the iRAP analysis software, and
- to demonstrate cost-effective methods for obtaining the roadway data needed as input to the analysis software. The potential availability of Navteq's video logs for this application and potential collaboration with Navteq on video data reduction may make application of the star rating protocol very cost effective.

usRAP will be seeking funding for such a demonstration program and state and county highway agencies interested in participating. The results of such a demonstration program would allow development and implementation of a usRAP safety analysis software tool for application in the U.S.

Section 5.
Findings and Recommendations

This section presents the findings and recommendations of the usRAP pilot program to date, including the Phase I, II, and III pilot studies. The following discussion addresses the three usRAP protocols—risk maps, star rating maps, and performance tracking—as well as planned next steps.

5.1 Risk Mapping

As a result of the usRAP Phase I, II and III pilot studies and the work accomplished to date by EuroRAP and AusRAP, risk mapping is becoming a mature protocol. usRAP has now prepared Maps 1 through 4 for seven states, including the three new states earlier in this report. EuroRAP has also worked with Maps 1 through 4, while AusRAP has focused on Maps 1 and 2. The best approaches to the development of risk maps using data typically available to U.S. highway agencies have been identified. Key principles that are well accepted include:

- risk maps should, whenever possible, be based on fatal and serious injury crashes; where this is not possible, risk maps based on fatal and all injury crashes may be considered
- multiple maps based on a range of risk measures should be developed, because no single risk measure provides a sufficiently complete description of the safety performance of a broad range of sites
- while multiple maps based on a range of risk measures are useful in completely describing the relative risks for specific roadway sections for safety professionals, the general public is likely to be confused if maps with more than one risk measure are presented. For communication with the general public, it is recommended that maps focusing on a single risk measure be used.
- the use of five risk categories, represented on risk maps by a defined sequence of five colors, appears appropriate
- the definition of risk categories based on percentages of road system length makes sense given the current state of safety data for the U.S. highway system. The use of a highest risk category representing 5 percent of the highway system in any jurisdiction is consistent with the SAFETEA-LU requirement for state highway agencies to identify 5 percent of roads with the most severe safety needs. It would be desirable to define risk categories based on uniform national benchmark risk levels, but this is difficult at present because consistent nationwide data on serious injury crashes are lacking.
- four road types are appropriate for defining average crash rates for use in preparing Maps 3 and 4. These road types are: freeways; multilane divided highways; multilane undivided highways; and two-lane highways. These road

types can be defined from data on number of lanes, median type, and access control. The sample size of multilane undivided highways is limited in some jurisdictions, but it still appears desirable to maintain multilane undivided highways as a road type distinct from multilane divided highways because of the increased risk inherent in the absence of a median.

- the results presented on risk maps must be carefully interpreted to avoid any suggestion that the display of a road segment in red or black on a particular map necessarily implies that the road segment has a safety problem that is correctable by a road infrastructure improvement. Some road sections shown in usRAP risk maps in red or black may have safety concerns that are correctable by road infrastructure improvements and others may not. A road segment may appear in red or black on Map 1 simply because that road has a high traffic volume with many vehicle-vehicle interactions that provide an opportunity for crashes to occur. A road segment may appear in red or black on Map 2 because it is traveled by a high proportion of impaired drivers or by a high proportion of vehicles with high rates of severe crashes, such as motorcycles. The maps prepared in the pilot study are useful, even though the crashes that occur on a given road may not be related to the design features of that road, because any concentration of crashes provides an opportunity for highway agencies and their safety partners to identify appropriate engineering, enforcement, and education strategies to reduce those crashes. A road section with a sufficient number of crashes can provide an appropriate location for implementing crash reduction strategies, even if the frequency of crashes on that road section is not unusually high given the characteristics of the road and the traffic that travels on it.
- the duration of the study period for preparing a risk map should be three to five years. Longer periods are desirable to obtain higher crash frequencies, especially for road types with relatively low traffic volumes. However, study period durations longer than five years are not desirable because they increase the likelihood that changes in road characteristics will occur.
- while most usRAP risk mapping efforts have focused on rural roads, the New Jersey pilot study performed in Phase II and the Utah pilot study presented in this report illustrate that the risk mapping concept is readily applicable to urban roads as well.
- supplementary risk maps addressing specific crash types of interest to highway and law enforcement agencies are a useful complement to the four basic risk map types.

A key issue that remains to be resolved is whether national benchmark risk categories should be developed for comparing travel risks across the U.S. Both EuroRAP and AusRAP have established fixed boundaries between the risk levels represented by the various colors on the risk maps. usRAP has not done this to date for two reasons. First, risk maps based on percentages of the road network are potentially useful to highway agencies in implementing the Federal 5-percent report requirement. Second, while the definition of a fatal crash has been standardized in the U.S., the definitions of serious injury crashes vary from state to state.

In Europe, the risk maps have shown substantial improvements over time in the risk levels for specific roads, with fewer and fewer roads in the highest risk categories, which is possible because there are fixed boundaries for these categories. By contrast, usRAP maps make it difficult to illustrate progress in improving safety over time, since there is always a fixed percentage of the road system in each risk category.

usRAP could develop risk maps based on fixed risk boundaries, as a replacement for or a supplement to the percentage-based risk boundaries, if serious injury crash frequencies with reasonably uniform definitions could be defined for all or most states. usRAP intends to work with Federal and state agencies to encourage the establishment of a uniform national definition for a serious injury crash and to encourage a uniform reporting system for serious injury crashes. One approach might be to create a national reporting system for serious injury crashes analogous to NHTSA's Fatality Analysis Reporting System (FARS).

AAAFTS is seeking funding for national implementation of the usRAP program. We see risk mapping as a core component of any future usRAP program and we hope that the funding level would be sufficient to continue providing risk mapping as a free service to participating highway agencies. Given sufficient funds, our goal would be to bring all 50 states into the risk mapping program within the first five years of a national program and to work with the states to identify the best uses for risk maps and to develop procedures to institutionalize risk mapping as a safety management tool.

5.2 Star Rating Maps

Star rating maps based on inspection of roads to determine the presence of features that reduce crash likelihood and severity have been developed in EuroRAP, AusRAP, and the usRAP Phase I pilot studies. The star rating protocol was first developed in EuroRAP based on a rating of road features that protect road users from death or serious injury, known as the Road Protection Score (RPS).

The star rating concept has evolved in AusRAP, in the usRAP Phase I pilot studies, and most recently in iRAP to include road features related to the reduction of crash likelihood, as well as features related to crash protection (i.e., crash severity reduction).

The assessment of the revised usRAP RPS methodology at the end of Phase I was that it represented an important step forward for RPS application in the U.S., but that it was not yet sufficiently proven for widespread application in the U.S. The usRAP advisory panel considered that additional work was needed on the RPS methodology to address crash likelihood factors more fully and to demonstrate the relationship of the star ratings to actual crash data.

The first goal of addressing crash likelihood factors more fully has been met by iRAP and demonstration of the relationship of star ratings to actual crash data has been presented in this report.

The results of the star rating validation study presented in Section 4 of this report provide strong evidence that crash rates for road sections generally decrease as star ratings increase, at least for roadway types with a sufficient amount of data and a sufficient range of star ratings to provide meaningful results. This trend has been observed for vehicle-occupant crashes and components of vehicle-occupant crashes including head-on crashes, junction crashes, and despite one anomalous result, run-off-road crashes.

Relationships between star ratings and corresponding crash types have been demonstrated for two-lane highways, four-lane undivided highways, and four-lane divided nonfreeways. This relationship could not be clearly demonstrated for freeways primarily because there is much less variation in the design features of freeways than for other roadway types (e.g., freeways are generally rated as either four or five stars). An expanded effort to validate the star ratings for pedestrians and bicycles under U.S. conditions would also be desirable.

As discussed in Section 4.8 of this report, usRAP is working to organize a program to demonstrate the star rating protocol and the iRAP analysis software in the United States. These tools have been implemented overseas, but have great potential for developing safety improvement programs for agencies that lack crash data with reliable crash location information. County highway agencies, in particular, might benefit from such a program. Thus, full implementation of usRAP could involve not just risk mapping, but also use of star ratings to characterize the safety performance of roads and a usRAP safety analysis software tool to develop safety improvement programs for selected road networks.

5.3 Performance Tracking

The performance tracking protocol was originated in EuroRAP, and initial U.S. work was conducted in usRAP Phase II. The performance tracking concept appears promising, but may potentially be limited in rural areas of many U.S. states to longer-term analyses, since data for short-term analyses may be too sparse for meaningful results. Further development of performance tracking protocol is anticipated.

5.4 Next Steps

The recommended next steps for the usRAP program are:

- complete the remaining activities in the usRAP Phase III pilot study, including the ongoing risk mapping work in New Mexico

- support the ongoing Roadway Safety Foundation studies in Utah and in Genesee County, Michigan, to demonstrate the use of usRAP risk maps in building public support for increased highway safety funding
- organize a demonstration program for the star rating protocol and the iRAP analysis software in the United States, as discussed in Section 4.8
- document the variations in current definitions and reporting practices for serious injury crashes and encourage the development of a uniform national definition and a national reporting system for severe injury crashes
- maintain ongoing liaison activities with the states participating in usRAP, leading to a decision on national implementation of usRAP, once appropriate funding sources have been identified
- prepare a final report of the three-phase usRAP pilot study effort with specific recommendations for national implementation