CITY OF BOWLING GREEN

Pavement Management System Report

Public Works Department
Planning and Design Division
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Table of Contents

SECTION 1

EXECUTIVE SUMMARY 3

Organization of the Report 6

SECTION 2

INTRODUCTION

Program Goals 7

Overview of the Program 8

SECTION 3

DATA COLLECTION

Roughness and Surface Distress Survey 15

Deflection Survey 17

Data Update & Resurvey 17

SECTION 4

PAVEMENT ANALYSIS

Riding Comfort Index (RCI) Analysis 19

Surface Distress Index (SDI) Analysis 19

Structural Adequacy Index (SAI) Analysis 20

Pavement Quality Index (PQI) Analysis 20

Performance Prediction Modeling & Needs Analyses 20

Rehabilitation Programming Analysis 24

SECTION 5

ANALYSIS RESULTS

Present Status Analyses 26

Rehabilitation Needs Analysis 28

Rehabilitation Programming Analysis 28

Neighborhood Districts 32

Index of Tables

2.1 Functional Classification of Streets

4.1 Description of Pavement Classes

4.2 Functional Classification Statistics

4.4 Rehabilitation Alternatives

5.1 Budget Scenarios

5.2 Neighborhood Statistics

Index of Figures

1.1 Sectional Performance

2.1 Program Flow Chart

3.1 Examples of Surface Distresses

4.1 Performance Curves: Flexible Pavement

4.2 Performance Curves: Rigid Pavement

4.3 Performance Curves: Composite Pavement

5.1 Performance Indicators: RCI

5.2 Performance Indicators: SDI

5.3 Performance Indicators: SAI

5.4 Performance Indicators: PQI

5.5 Performance Indicators: Need Year

5.6 Budget Scenarios: PQI

Index of Maps

2.1 Street Ownership

2.2 Functional Classification

2.3 Pavement Types

3.1 Network Resurvey

5.1 RCI Ratings

5.2 SDI Ratings

5.3 SAI Ratings

5.4 PQI Ratings

5.5 Census Tracts

Section 1

Executive Summary

Background

The City of Bowling Green has maintenance responsibility for approximately 235 centerline miles, or 470 lane-miles, of roadway. The functionality of the street network is of paramount importance to the city. Transportation along this system is a basic need of the public. Given the need and importance, cost effective maintenance programming helps meet the needs of the public. The importance of street conditions to the public is evident. Recent citizen surveys (1998 & 1999) listed pavement conditions as a major concern. The City of Bowling Green has elected to utilize a pavement management system to help employ proper maintenance to retain a quality transportation network.

The City of Bowling Green awarded a contract to Stantec, Inc (formerly ITX/Stanley, Inc.) in 1997 in order to undertake the implementation of the pavement management system. Since that time, City staff using both existing data and specialized survey data from Stantec, Inc has consistently made updates. Currently, Stantec conducts a resurvey of half of the network each year for surface and ride conditions in three-year intervals. On the third year, only deflection or structural type testing is performed. This helps to ensure the data that is used is relatively current and appropriate decisions are made. Given all update methods, a large amount of data is stored and accessed. These operations are performed using specialized software called Pavement Management Application (PMA). The software allows multiple parameters and budgets to be evaluated very quickly. This allows the analyst to perform economic and “what if” scenario analyses to make informed decisions. The PMA data is then linked with the City’s geographic information system (GIS) for mapping and visualization.

Pavement Life Cycle

The pavement life cycle can be approximated or simplified by considering three major factors: pavement thickness and type, sub-grade strength, and traffic loading and type. One of the underlying principles of Pavement Management System is to employ the most effective rehabilitation technique at the optimal time. In most cases it is more cost effective to perform preventative maintenance earlier in the pavement’s life. The typical pavement will slowly deteriorate in the first third of its life. At this point in its life, less expensive rehabilitation can be used to bring the quality back up to a new pavement level. However, within the middle third of the pavement’s life, the pavement quality deteriorates at a much faster rate. Rehabilitation at this time in the pavement’s life is more costly to bring it up to a new level. The last third of the pavement’s life experiences very rapid deterioration that

can result in the need for a high cost reconstruction type project (see Figure 1.1). It has been our approach to weigh heavily on the optimal rehabilitation model while attempting to address roads that have an immediate need.

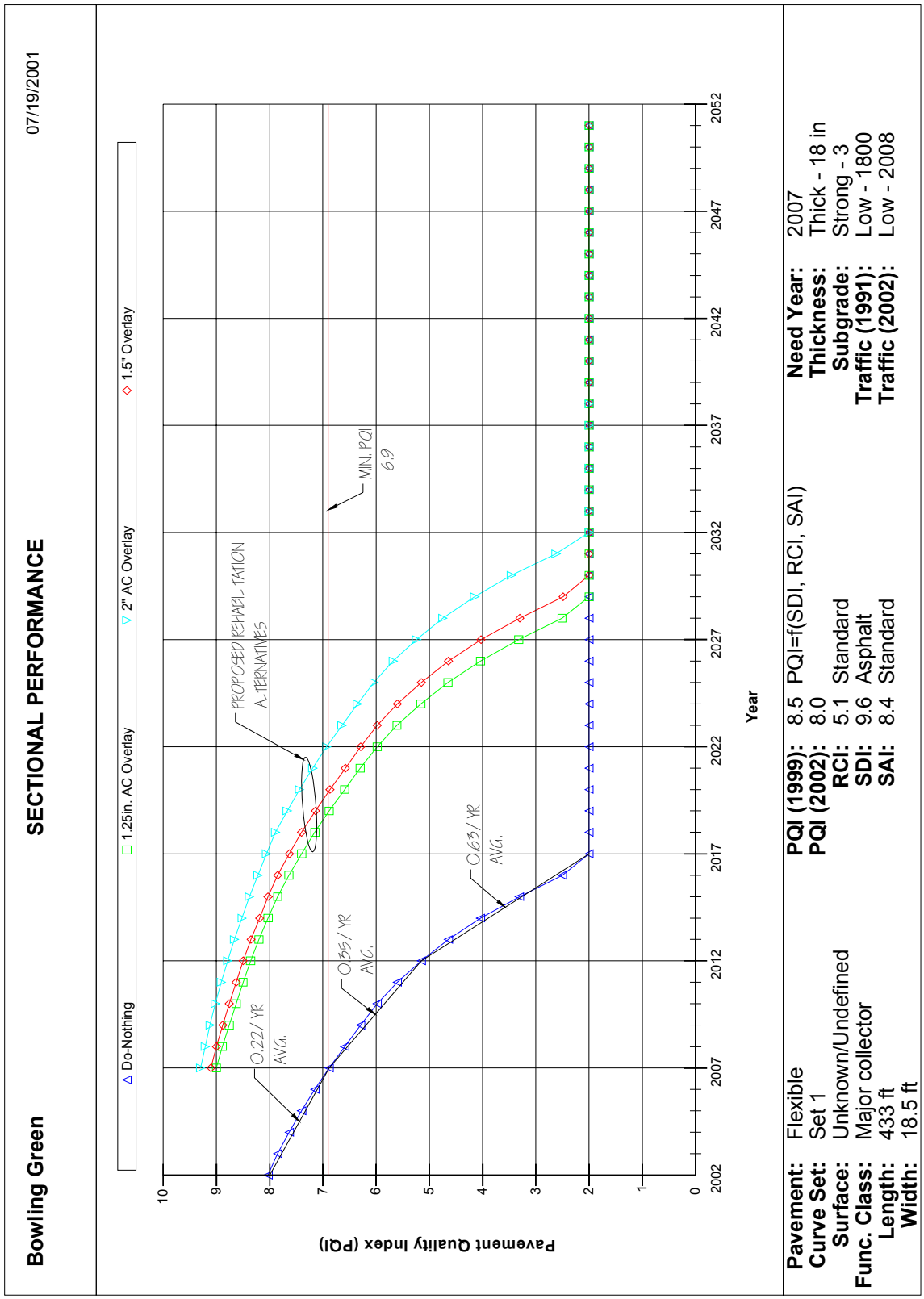


Figure 1.1

Analysis Process

The analysis of the City's Pavement Management System includes four main indices. These indices are Surface Distress Index (SDI), Ride Comfort Index (RCI), Structural Adequacy Index (SAI), and a composite of the previous indices, the Pavement Quality Index (PQI). A minimum acceptable PQI score has been developed for each type of functional classification. When the PQI for a given pavement section falls below the minimum, it is considered to be in need of rehabilitation.

Pavement characteristics (soil strength and pavement thickness) and traffic loading data are used to determine the typical performance curve the roadway will exhibit for each section of the network (approximately 2167 city maintained sections). Field data surveys are used to determine at what point the section is on the performance curve and therefore the section's remaining life performance. When this data shows the PQI below the minimum acceptable level, the section is classified as a need. When the section is considered a need, it then goes through a series of decision trees to determine potential rehabilitation strategies. These strategies are then used to perform an economic analysis to determine the optimal strategy. Given budget information, a rehabilitation program is developed.

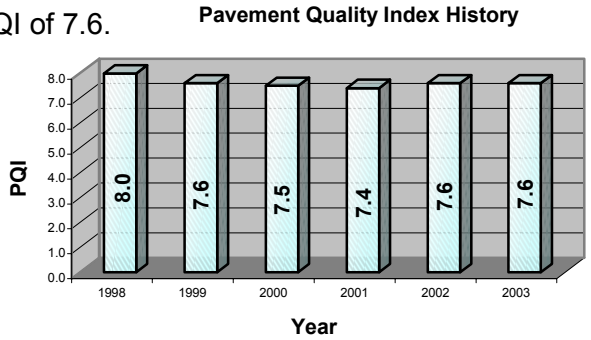
Rehabilitation Program

Currently, for the 2004 budget year, there is a backlog of current needs resulting in a "need driven" rehabilitation budget of $3 million, or 28.5% of the network (133 lane-miles). Since the needs outweigh more than the current budget will allow, a decision must be made about which project location receives rehabilitation. This is performed by a life cycle cost and benefit cost ratio analysis. The most cost effective rehabilitation technique and the most beneficial project locations are selected with this analysis.

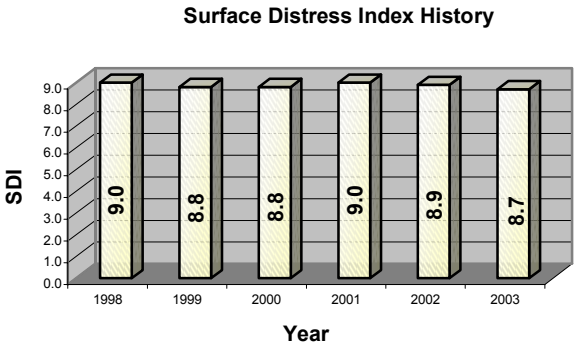
Multiple budgets are evaluated to determine the impact to the overall network. Annual budgets that were analyzed this year are $650,000, $1,000,000. The current rehabilitation program budget is $650,000, which comes from the Liquid Fuel Tax (LFT) revenues. The $1,000,000 budget is used in an effort to find a funding level that shows little degradation over the ten-year analysis period. Additionally, "need driven" and "do nothing" budgets are analyzed for comparative purposes.

Analysis Summary

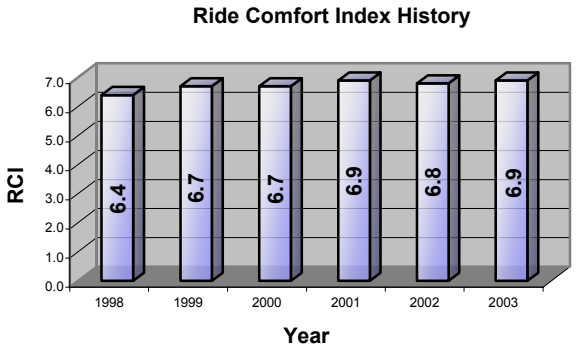
The entire 221-mile network has an overall average PQI of 7.6. This indicates a "good" condition exists over the entire system. Given the current budget, the average PQI after the ten-year analysis would be 7.9 and 32 miles of roadway (13.6%) would be below the minimum acceptable level (See Table 5.1). Though past values had shown a downward trend, an encouraging upward trend is now apparent.



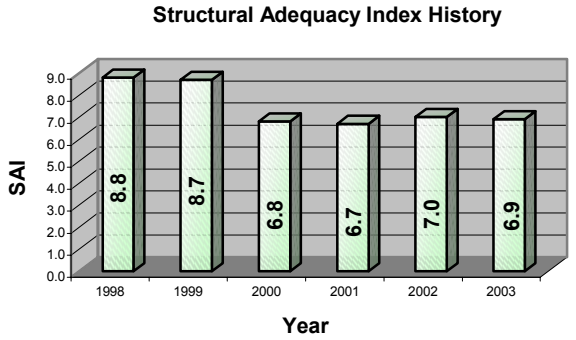
The average SDI for the network is 8.7. While this number has fluctuated, a very good level has been maintained throughout the past 6 year period. The SDI is determined by actual surface conditions on the road. The value considers the amount and type of distress, average area, and severity of the distress for each section of the network.



The RCI, however, typically runs at a lower level. The equipment used to evaluate the sections is extremely sensitive and detects even minor imperfections as well as major irregularities that exist throughout the network such as manholes, utility cuts, and transitions. The RCI for the current analysis is 6.9, which is at a fair level.



The SAI value pertains to a segment's ability to carry heavy loads. A special piece of testing equipment, called a Dynaflect, is used to determine the SAI. The Dynaflect measures deflection at varying distances from a test point to determine the stiffness of the pavement section; the stiffer the pavement, the stronger the section. Load related failure could occur on any classification of roadway. However, given the heavier traffic loading of minor collectors and above, only these classifications of road are measured (a total of 410 segments). The average SAI for the network is 6.9, which represents a "fair" rating. The substantial drop seen in 2000 is the result of a change in the model used to calculate SAI.



Organization of the Report

The body of the report contains the findings of the study that are summarized with a description of the field-testing program and subsequent analyses.

Computer reports containing the results of the Present Status Analysis, on a section-by-section basis, are supplied in Volume 2 along with the budget driven priority programs.

Section 2

Introduction

Program Goals using Pavement Management

A Pavement Management System has been developed with the duty of maintaining the street network for the City of Bowling Green. The Major underlying principle of the system is to maintain or improve the quality of pavement in the most economical way possible. Several goals and objectives have been developed to guide the program.

Develop a Planning Tool

The first goal of the program is to develop a planning tool. Although some long-range variables cannot be evaluated, reasonable assumptions can be made to perform the planning function. Planning provides foresight into maintenance and rehabilitation schedules and allows them to be coordinated with other activities, such as a major widening project or utility replacement.

Knowledge of Current Conditions

The pavement management system is also a status-reporting tool. Given access to the pavement data, monitoring of the current pavement conditions aids in determining how well a budget is impacting the system. The “Report Card” is widely used and assists in projecting needed funding.

An Objective Analytical Process

The system analyzes all data, regardless of geographic location. Rehabilitation recommendations are based solely on the available budget and the benefit-cost ratio. The process ensures that the funding is applied to the most economically feasible option. This technique results in the best rehabilitation strategy at the optimal time for the most economically beneficial location.

Optimal Usage of Limited Funds

One of the most valuable aspects of the system is its ability to optimize the use of limited funds. The cost effectiveness of performing the recommended maintenance/rehabilitation is calculated, thereby providing a means of measuring the value of the work. Past studies have shown that over time it is less expensive to invest in preventive maintenance and/or rehabilitation on an ongoing basis rather than reconstruction on a sporadic basis.

Overview of the Program

The City of Bowling Green retained Stantec, Inc. (formerly ITX Stanley, Inc.) to study the City's street pavement network. The primary objectives of the study are described below. The overall approach is summarized in the flow chart shown in Figure 2.1.

* To evaluate and quantify the condition of the street network in an objective, repeatable fashion;

* To estimate the rehabilitation requirements of pavements in the street network over a specified programming period;

* To develop ten year pavement rehabilitation programs for the street network for the current funding scenarios; and,

* To estimate the impact of these current funding scenarios on the condition of the street network.

To meet the first objective, pavement roughness and surface distress surveys were carried out on all 235 centerline miles of the City maintained streets. This group is subsequently referred to as the street network. The data from these surveys was used to determine four key pavement performance indicators:

* Surface Distress Index (SDI);

* Riding Comfort Index (RCI);

* Pavement Quality Index (PQI); and,

* Structural Adequacy Index (SAI).

The above indicators quantitatively describe the condition of the pavement street network at the time of the field surveys, or its present status.

The results of the analyses are used in conjunction with a long-term pavement performance model to estimate the rehabilitation requirements of the street network over a ten-year period beginning in 2004. An optimization program using life cycle economic analysis techniques was used in conjunction with the results of the performance modeling analysis and the current budget stream to develop a ten-year rehabilitation program. Finally, the impact of this rehabilitation program on the level of service provided by the network was estimated.

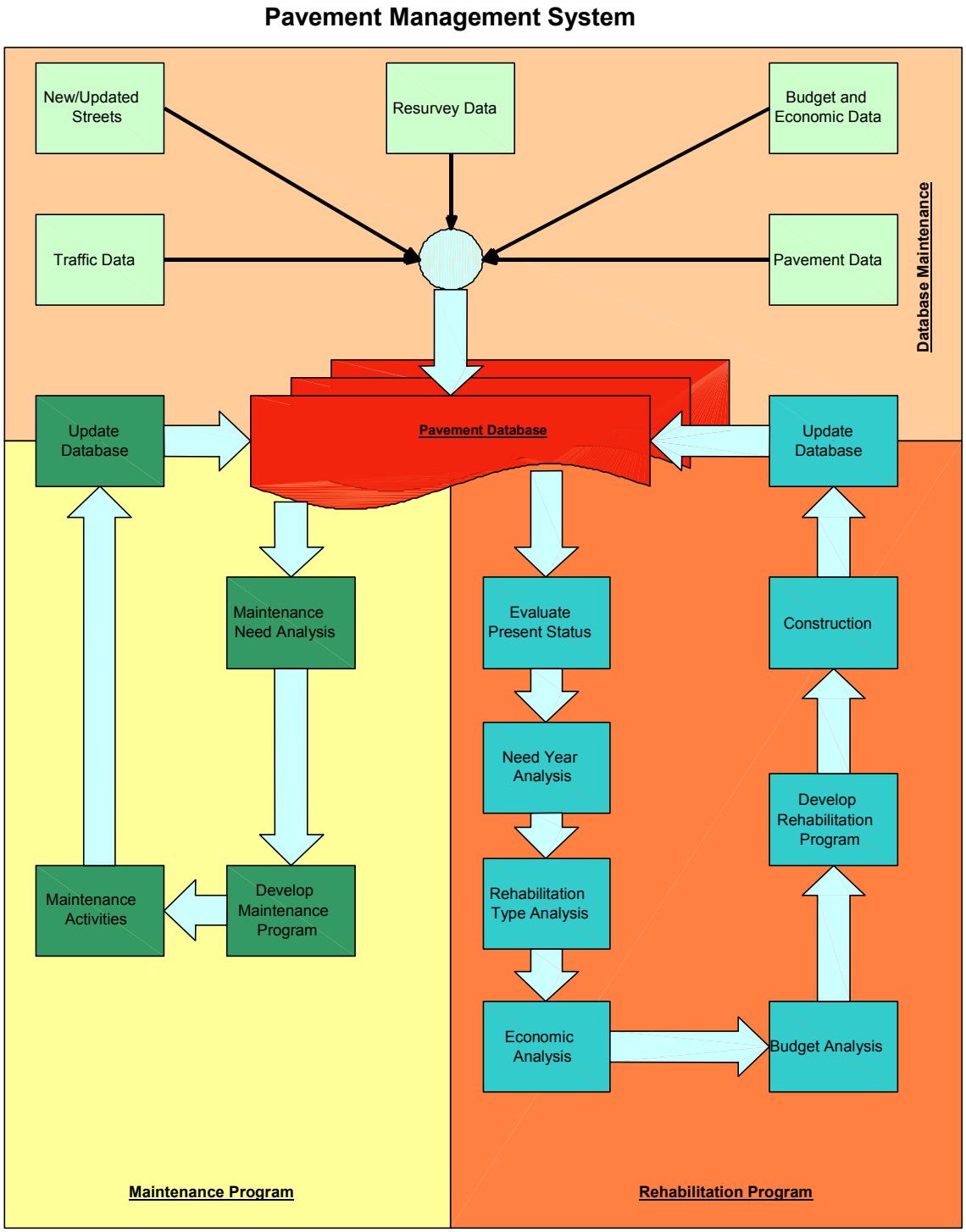

Pavement Management System
New/Updated Streets
Resurvey Data
Budget and Economic Data
Traffic Data
Pavement Data
Database Maintenance
Update Database
Pavement Database
Update Database
Maintenance Need Analysis
Evaluate Present Status
Construction
Need Year Analysis
Develop Rehabilitation Program
Maintenance Activities
Develop Maintenance Program
Rehabilitation Type Analysis
Economic Analysis
Budget Analysis
Maintenance Program
Rehabilitation Program

Figure 2.1

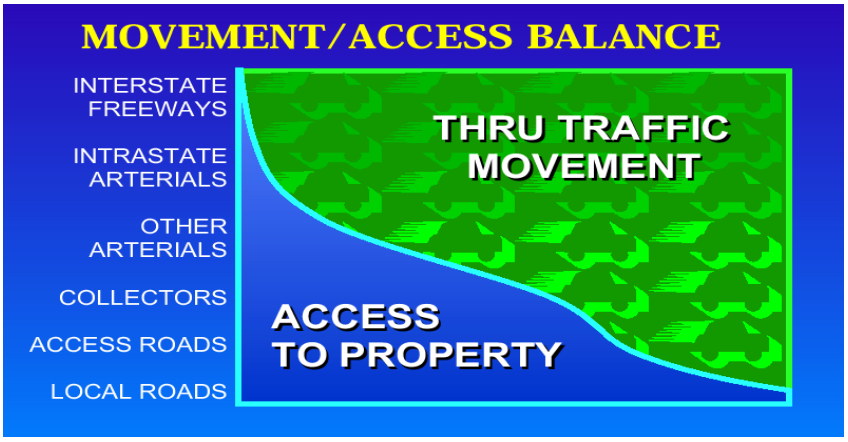
Network Parameters & Statistics

Ownership

There are approximately 307 total miles of roadway within the corporate limits of Bowling Green. Even though this amount of roads exists, not all of these are owned/maintained by the City of Bowling Green. The City maintained portion represents around 77% of this total amount. The other major owner/maintainer is the Kentucky Department of Highways (20%). Other owners include Western Kentucky University, private owners, and developers. The developers own streets that have not yet been formally accepted by the City. Ownership information is shown in Map 2.1.

Functional Class

The entire network has been classified with respect to the functional classification in which each roadway operates. The classification is inversely proportional to the number of accesses. Local roads have a high density of access points, yet they are considered to be in a low functional class. Roads classified as collectors generally have less access points and moderate mobility (capable of handling moderate traffic loading). Arterials provide the highest mobility and have very few entrances. Statistics for all classifications are presented in Table 4.3. A functional classification map is shown as Map 2.2.



Pavement Types

The City maintained system includes four pavement types. The vast majority of the network (99.1%) is asphalt, or flexible pavement. The second most common pavement type is concrete, or rigid. Rigid pavement comprises 0.9% of the network. The remaining pavement type is gravel, which only exists on a small number of alleys. These alleys have not been quantified due to the lower traffic levels. Pavement types are shown in Map 2.3.

Census Tracts

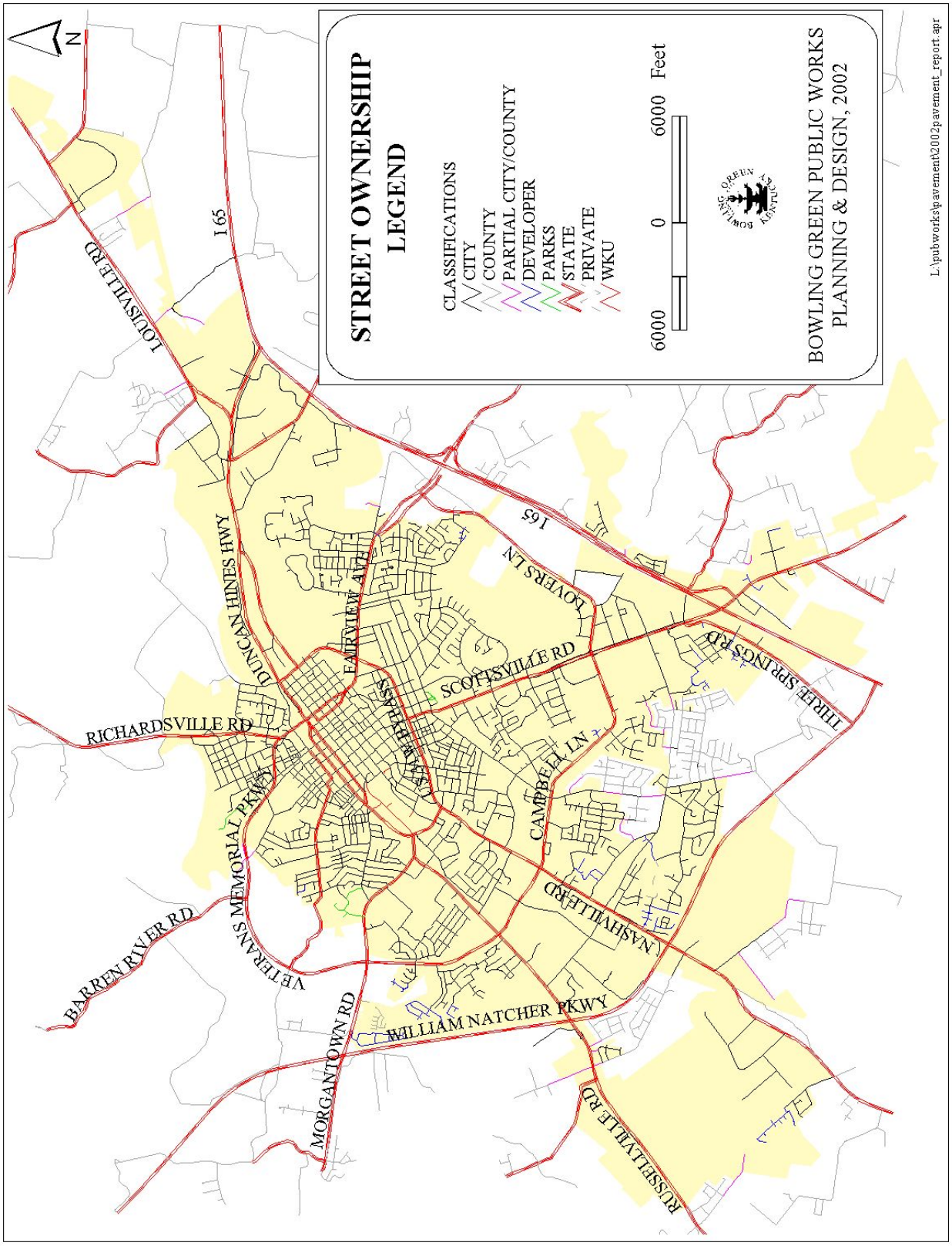
The United States Census Bureau has developed "census tracts" for the entire United States. These geographic boundaries are used for demographic related studies. Given the existence of these predefined areas, the tracts are used for individual study areas in the pavement management system. Area conditions have been analyzed in each of fourteen census tracts in the city limits (see Table 5.2). Census Tracts are shown in Map 5.5.

Traffic Data

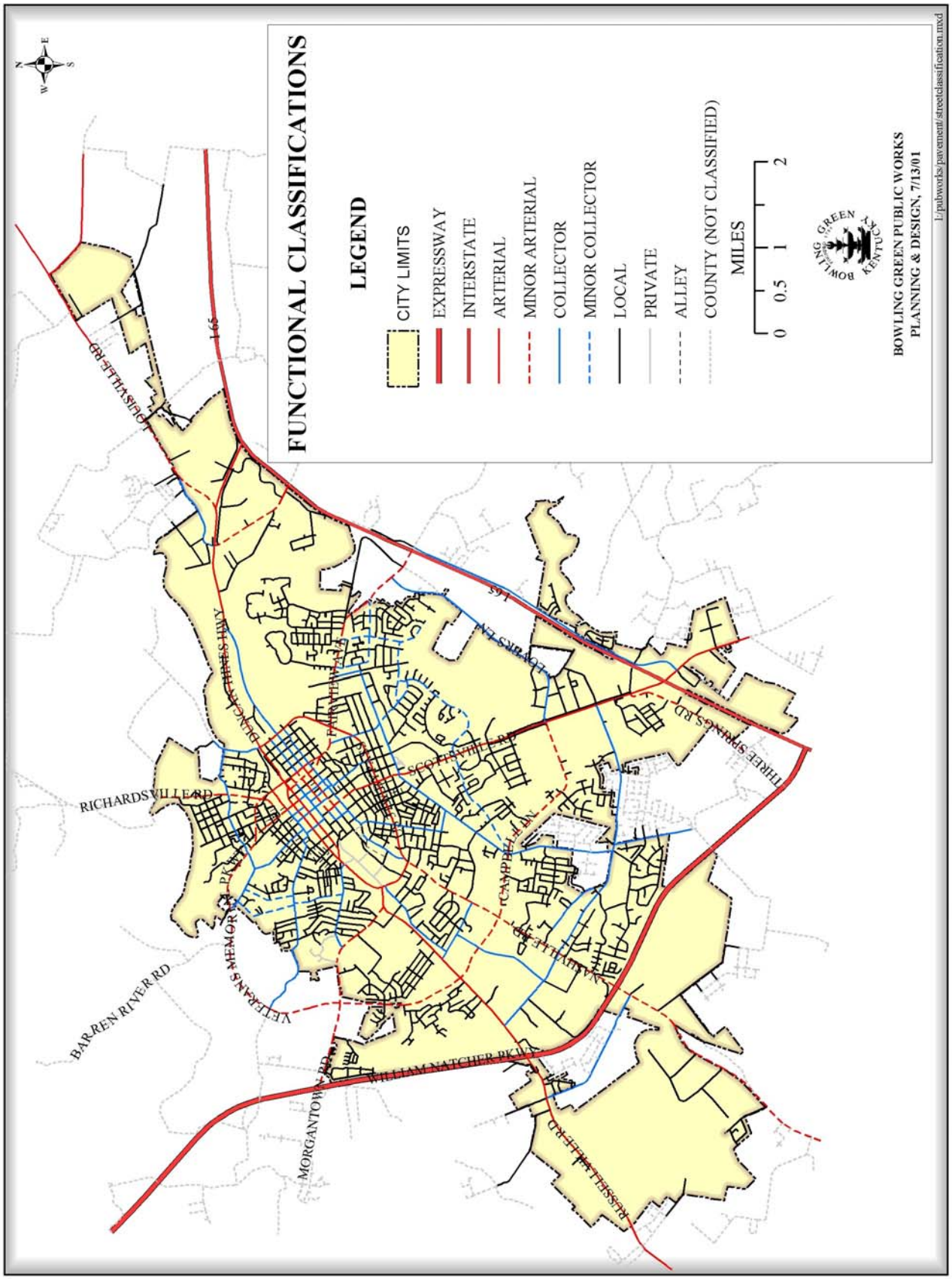
Traffic Data is a vital parameter in modeling pavement and its life cycle. While recent traffic count data exists for many of the higher classification sections, assumed and estimated data is used for modeling life cycles on other roadway sections. Another important factor, from an analytical standpoint, is the percentage of commercial/heavy traffic, since this type of traffic deteriorates a roadway much more quickly than light traffic loadings. A growth factor is applied to the traffic data, which accounts for increased traffic volume throughout the ten-year analysis period.

Functional Classification	Parameter Type	Level	Critical Level
Local Residential	Traffic Level	Low	AADT < 500
		Medium	501 ≤ AADT < 1000
		High	1000 ≤ AADT
Local Commercial	Traffic Level	Low	AADT < 1000
		Medium	1000 ≤ AADT < 5000
		High	5000 ≤ AADT
Minor Collector	Traffic Level	Low	AADT < 1000
		Medium	1000 ≤ AADT < 2000
		High	2000 ≤ AADT
Major Collector	Traffic Level	Low	AADT < 4000
		Medium	4000 ≤ AADT < 8000
		High	8000 ≤ AADT
Minor Arterial	Traffic Level	Low	AADT < 10,000
		Medium	10,000 ≤ AADT < 15,000
		High	15,000 ≤ AADT
Major Arterial	Traffic Level	Low	AADT < 17,000
		Medium	17,000 ≤ AADT < 25,000
		High	25,000 ≤ AADT
	Equivalent Granular Thickness	Thin	EGT < 10 in
		Medium	10 in ≤ EGT < 15 in
		High	15 in ≤ EGT

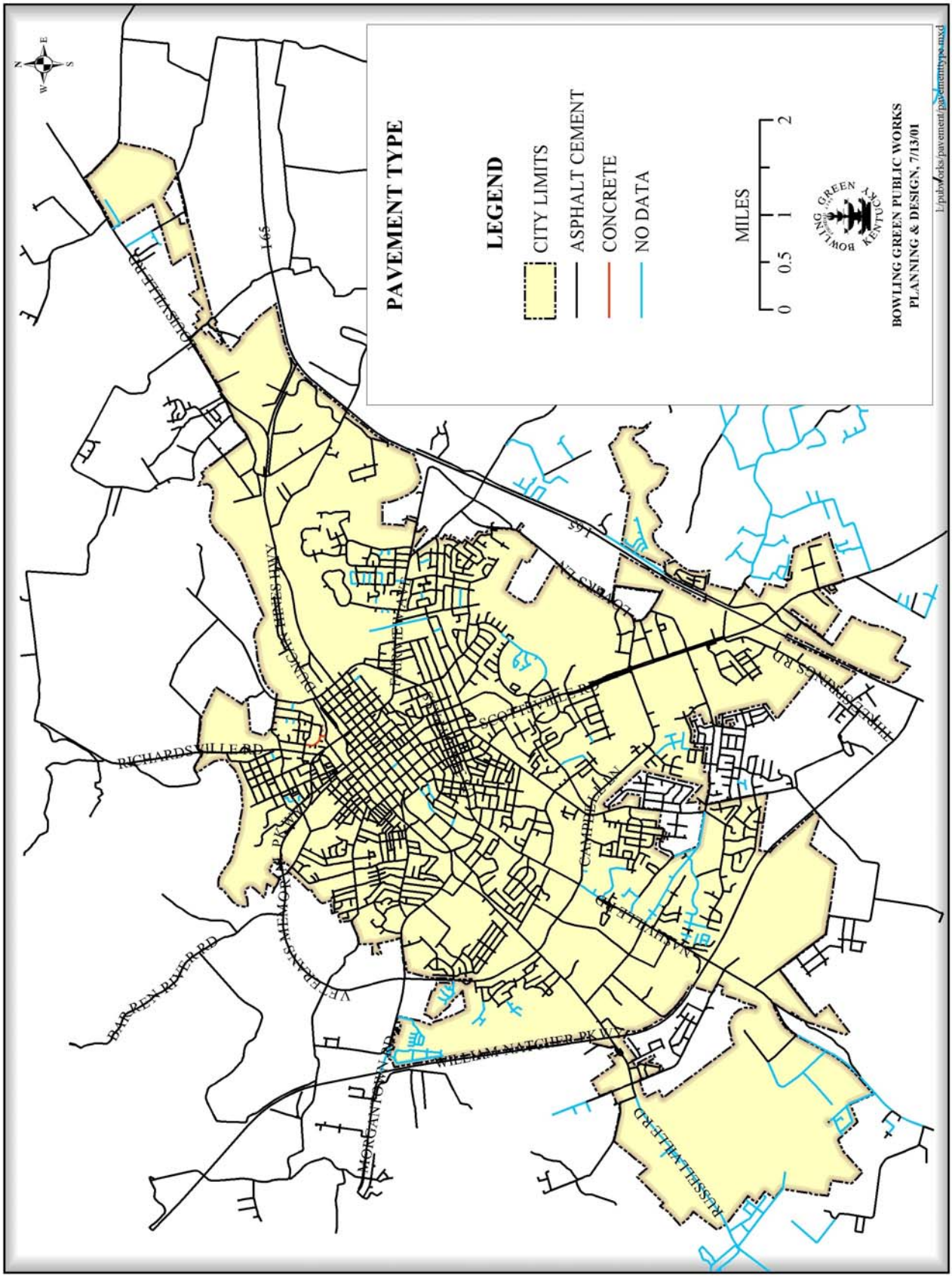
Table 2.1


STREET OWNERSHIP
LEGEND
CLASSIFICATIONS
CITY
COUNTY
PARTIAL CITY/COUNTY
DEVELOPER
PARKS
STATE
PRIVATE
WKU
6000
0
6000 Feet
BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN, 2002
L:\pubworks\pavement\2002pavement_report.apr
N
LOUISVILLE RD
I65
DUNCAN HINES HWY
FAIRVIEW AVE
I65
LOVERS LN
SCOTTSVILLE RD
THREE SPRINGS RD
RICHARDSVILLE RD
STATE PARK ST
CAMPBELL LN
MEMORIAL PKWY
NASHVILLE RD
BARREN RIVER RD
VETERANS
WILLIAM NATCHER PKWY
MORGANTOWN RD
RUSSELLVILLE RD

MAP 2.1


FUNCTIONAL CLASSIFICATIONS
LEGEND
CITY LIMITS
EXPRESSWAY
INTERSTATE
ARTERIAL
MINOR ARTERIAL
COLLECTOR
MINOR COLLECTOR
LOCAL
PRIVATE
ALLEY
COUNTY (NOT CLASSIFIED)
MILES
0 0.5 1 2
BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN, 7/13/01
L:/pubworks/pavement/streetclassification.mxd
RICHARDSVILLE RD
BARREN RIVER RD
VETERANS MEMORIAL PKWY
MORGANTOWN RD
WILLIAM NATCHER PKWY
RUSSELLVILLE RD
CAMPBELL LN
SCOTTSVILLE RD
THREE SPRINGS RD
LOUISVILLE RD
I-65

MAP 2.2


PAVEMENT TYPE
LEGEND
CITY LIMITS
ASPHALT CEMENT
CONCRETE
NO DATA
MILES
0
0.5
1
2
BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN, 7/13/01
I-65
RICHARDSVILLE RD
SCOTTSVILLE RD
BARREN RIVER RD
WILLIAM NATCHER PKWY
RUSSELLVILLE RD

MAP 2.3

Section 3

Data Collection

Roughness and Surface Distress Survey

The longitudinal roughness of each section was measured electronically using the Stantec RT-3000 Road Testing Unit. The testing speed of the RT-3000 unit was approximately 20 miles per hour.

The RT-3000 was also used to conduct the surface distress survey. This survey recorded the extent and severity of various distress classifications such as load associated cracking, nonload associated cracking, surface deformation and surface defects for two (2) pavement surface types. On asphalt surfaces, the following thirteen distress types were inventoried:

* patching
* rippling and shoving
* raveling and streaking
* flushing and bleeding
* distortion
* excessive crown
* edge cracking
* alligator cracking
* pot holes
* map cracking
* longitudinal cracking
* transverse cracking
* rutting

(See Figure 3.1)

On Portland Cement Concrete (PCC) surfaces, the following thirteen distress types were inventoried:

* patching
* scaling
* raveling
* polishing
* distortion
* C & D cracking
* coarse aggregate loss
* potholes
* joint sealant loss
* linear cracking
* transverse cracking
* joint spalling
* joint faulting

This survey was conducted on the 235 centerline-mile street network.

Examples of Surface Distress

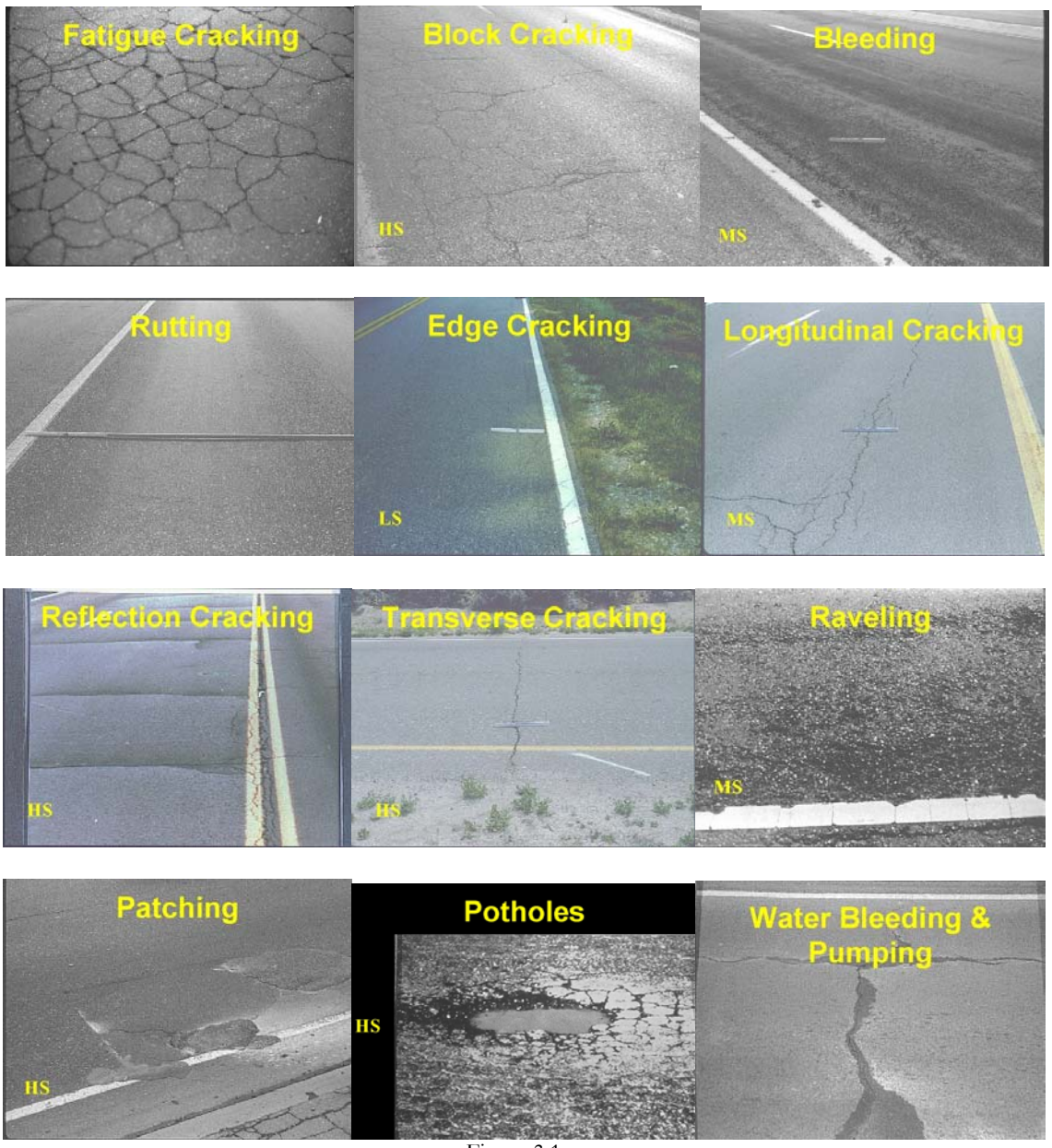


Figure 3.1

Pictures courtesy of University of Idaho http://www.uidaho.edu/its/

Deflection Survey

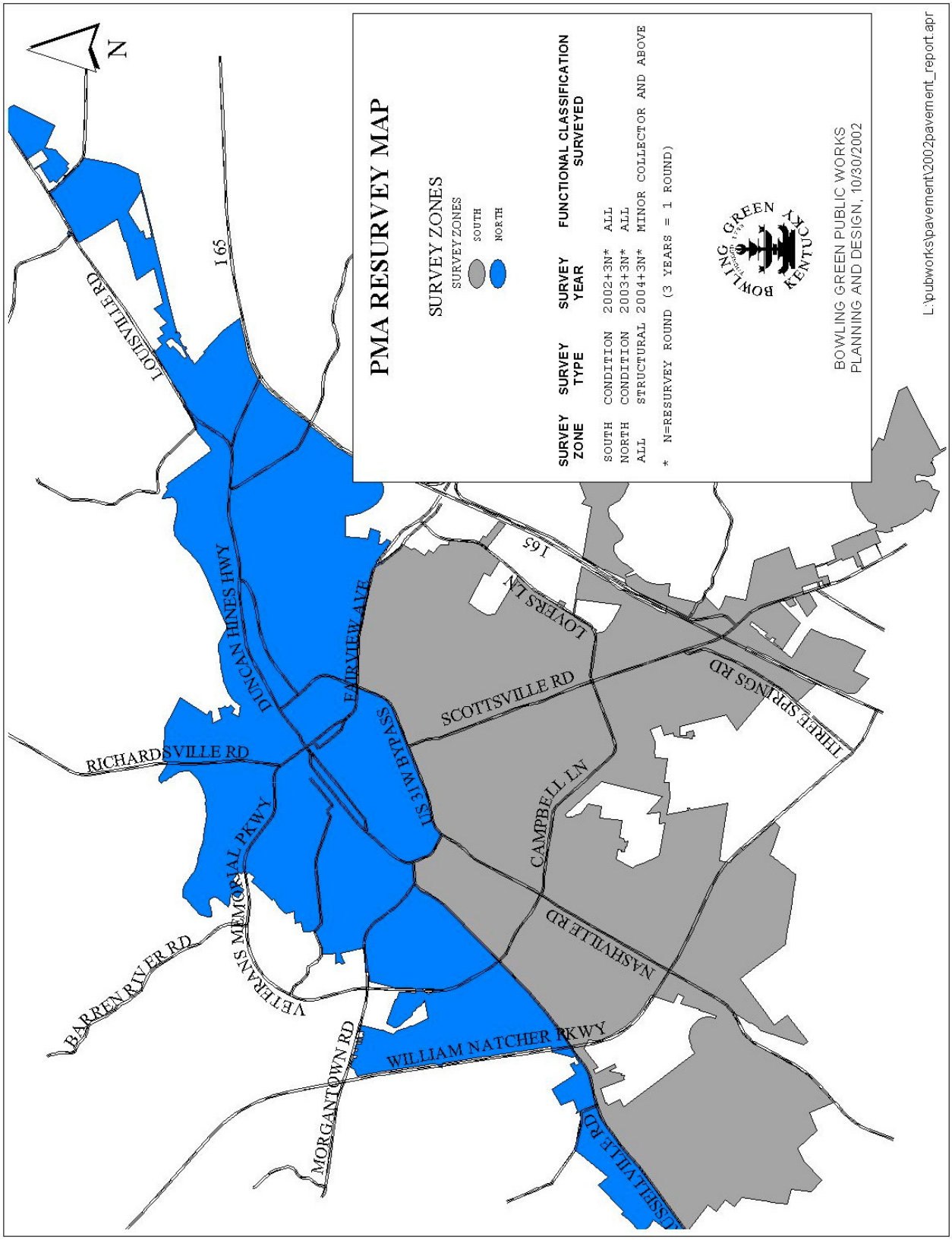
A dynamic deflection survey, used to indicate the load bearing capacity of the existing pavement structure, was undertaken in 1997, 2000, and 2003 using the Dynaflect on the arterials and collectors only. The Dynaflect is an electro-mechanical device that measures the dynamic deflection of a pavement structure caused by an oscillating load. The repetitive load, operating at 8 cycles per second, results in a dynamic force of 1,000 pounds. The material upon which the loading device rests deflects downward and upward in synchronization with the load. The amplitude of this induced motion is sensed by a set of five geophones spaced at set intervals from the loaded area. Thus the Dynaflect measures five deflections that define a deflection bowl or basin. The shape of the deflection basin is indicative not only of the strength of the pavement structure as a whole, but also of the bearing capacity of the different layers of the structure. The deflection testing is only performed on streets classified as collectors and above.

The Dynaflect survey was generally carried out with the load applied in the outer wheel path of the northbound or eastbound lanes of each session. Deflection data was collected at 300-foot intervals in the curb lane of a section with a minimum of 2 tests per section.

Data Update & Resurvey

When rehabilitation is performed, the data for the recommended segments is updated. The Riding Comfort Index (RCI) and Surface Distress Index (SDI) are “reset” to 10.0. At that moment, the software begins to age the pavement, and adjusts the indices accordingly. The date of rehabilitation is also entered for future reference.

A resurvey of all street sections occurs every three years. Throughout this three-year period, partial surveys are conducted during each of the three years. One half of the entire network is surveyed during the first year for surface and ride conditions. The other half is surveyed during the following year, and the third year is used to evaluate the entire network on a deflection or structural type basis. In order to maintain accuracy, the updated data is imported to the Pavement Management Application each year, and the process continues.


PMA RESURVEY MAP
SURVEY ZONES
SOUTH
NORTH
SURVEY ZONE
SURVEY TYPE
SURVEY YEAR
FUNCTIONAL CLASSIFICATION SURVEYED
SOUTH CONDITION 2002+3N* ALL
NORTH CONDITION 2003+3N* ALL
ALL STRUCTURAL 2004+3N* MINOR COLLECTOR AND ABOVE
* N=RESURVEY ROUND (3 YEARS = 1 ROUND)
BOWLING GREEN KENTUCKY
BOWLING GREEN PUBLIC WORKS
PLANNING AND DESIGN, 10/30/2002
L:\pubworks\pavement\2002pavement_report.apr
N
LOUISVILLE RD
165
DUNCAN HINES HWY
FAIRVIEW AVE
LOVERS LN
SCOTTSVILLE RD
THREE SPRINGS RD
RICHARDSVILLE RD
US 31W BYPASS
CAMPBELL LN
VETERANS MEMORIAL PKWY
NASHVILLE RD
BARREN RIVER RD
WILLIAM NATCHER PKWY
MORGANTOWN RD
RUSSELLVILLE RD

MAP 3.1

Section 4

Pavement Analysis

Riding Comfort Index (RCI) Analysis

The RT-3000 unit electronically measures and records the longitudinal roughness of pavements based on International Roughness Index (IRI) standards in an objective fashion. As the unit traverses a pavement, the profile elevations are collected at one foot spacing. This data is subjected to a vehicular displacement simulation to determine the pavement roughness (IRI). This data is summarized at 100 ft intervals and then correlated to an assessment of ride quality as determined by the ratings of a group of representative users of the pavements. This assessment of ride quality is termed the Riding Comfort Index (RCI). These roughness measurements therefore provide a rapid, objective, repeatable means of estimating the subjective RCI ratings of the traveling public.

The relationship between subjectively determined RCI values and objectively determined pavement roughness has been determined in various areas of North America for both urban and rural operating environments. The following equation, determined by correlating the ride quality ratings to roughness measurements collected by RT-3000 for a variety of pavements, was used to convert IRI based roughness to RCI values:

$$RCI = 25.3 - 3.62 * \ln(IRI)$$

where: IRI = International Roughness Index.

The RCI can vary in value from zero to ten. Through experience on similar projects, RCI values greater than 7.0 generally indicate good ride quality. Values in the 5.0 to 7.0 range indicate that a pavement is marginal from a riding comfort perspective. An RCI score less than 5.0 indicates poor ride quality.

Surface Distress Index (SDI) Analysis

The RT-3000 survey of distress provided a rating of the severity and extent of each of 13 surface distresses at each station (i.e., at 100 foot intervals) of each section in the network. These ratings were then transformed to a zero to ten scale for each of the 13 distress types. These ratings were combined using different weighting factors to generate a Surface Distress Index (SDI) for each station. An SDI score for the entire section was then computed based on the station SDI scores. A

rating of ten indicates a perfect (no distress) surface and a rating of zero indicates a totally unacceptable level of surface distress.

Structural Adequacy Index (SAI) Analysis

The structural adequacy of a pavement indicates the pavement's ability to carry expected traffic loads while providing an acceptable level of service. The structural adequacy of a pavement is determined by analyzing the measured deflection of the pavement under a controlled loading condition (using a Dynaflect device) and comparing this response to the maximum allowable deflection associated with anticipated loading conditions.

The deflection measurements were adjusted to compensate for seasonal and temperature variations. These measurements were then used along with traffic data to determine the Structural Adequacy Index (SAI) at each test station of each pavement section. The overall SAI for each section is calculated at a value of zero to ten. These values are used to calculate an overall network average. An SAI score of 5.0 or greater indicates that the pavement section is structurally adequate to carry the expected loadings over the upcoming year. An SAI score less than 5.0 indicates that the pavement section is structurally inadequate to carry the expected loadings over the upcoming year.

Pavement Quality Index (PQI) Analysis

The Pavement Quality Index (PQI), representing a combination of the RCI, SDI and SAI performance indicators, provides an overall indication of the condition of a pavement with regard to present and future service to the user. The present level of service is reflected in the RCI in that the typical user is most likely concerned with the rideability of a pavement. The future service, reflected in the SDI and SAI values, will show a potential to deteriorate when a pavement is somewhat distressed or is incapable of carrying expected loadings.

For most sections, (minor collector, local commercial, local residential, and alleys – 99.2% of the network), the PQI is primarily represented by its SDI value. A downward adjustment is made for pavement sections that are exhibiting poor ride characteristics. The magnitude of the adjustment depends on the RCI of the section. The PQI of the other 0.8% of the network is primarily represented by its RCI value, as these are sections that are traveled at higher speeds. A downward adjustment is also made for pavement sections that show distress. The magnitude of the adjustment depends on the amount of distress (SDI value).

In both of the above-mentioned PQI models, a further adjustment is made if that section contains SAI data. If the SAI is > 5.0, the PQI is adjusted upward. If the SAI <5.0, the PQI is adjusted downward, according the magnitude of the SAI.

The PQI varies between two and ten (with two representing the poorest possible pavement and ten representing the best possible pavement).

Performance Prediction Modeling & Needs Analyses

The PQI values of pavements typically decrease over time. In order to estimate the future rehabilitation requirements of a pavement network, it is necessary to model the deterioration of PQI values. The rate of decrease depends on many factors but it can be demonstrated that the principal

factors are the traffic loading conditions, the properties and thickness of the pavement structure layers, and the subgrade strength. The factors used to model pavement performance in the PMA procedure are equivalent granular thickness (3 levels), traffic volume (3 levels), and subgrade strength (2 levels). The levels referred to are defined according to the criteria of Table 4.1. This results in 18 possible classes as defined in Table 4.2 with each class assigned a performance curve. Each pavement type in turn has 18 curves as shown in Figures 4.1, 4.2, and 4.3.

Description Of Pavement Classes

CLASS NUMBER	THICKNESS	TRAFFIC	SUBGRADE
1	*Thin*	*Low*	*Strong*
2	*Thin*	*Medium*	*Strong*
3	*Thin*	*High*	*Strong*
4	*Thin*	*Low*	*Weak*
5	*Thin*	*Medium*	*Weak*
6	*Thin*	*High*	*Weak*
7	*Medium*	*Low*	*Strong*
8	*Medium*	*Medium*	*Strong*
9	*Medium*	*High*	*Strong*
10	*Medium*	*Low*	*Weak*
11	*Medium*	*Medium*	*Weak*
12	*Medium*	*High*	*Weak*
13	*Thick*	*Low*	*Strong*
14	*Thick*	*Medium*	*Strong*
15	*Thick*	*High*	*Strong*
16	*Thick*	*Low*	*Weak*
17	*Thick*	*Medium*	*Weak*
18	*Thick*	*High*	*Weak*

Table 4.1

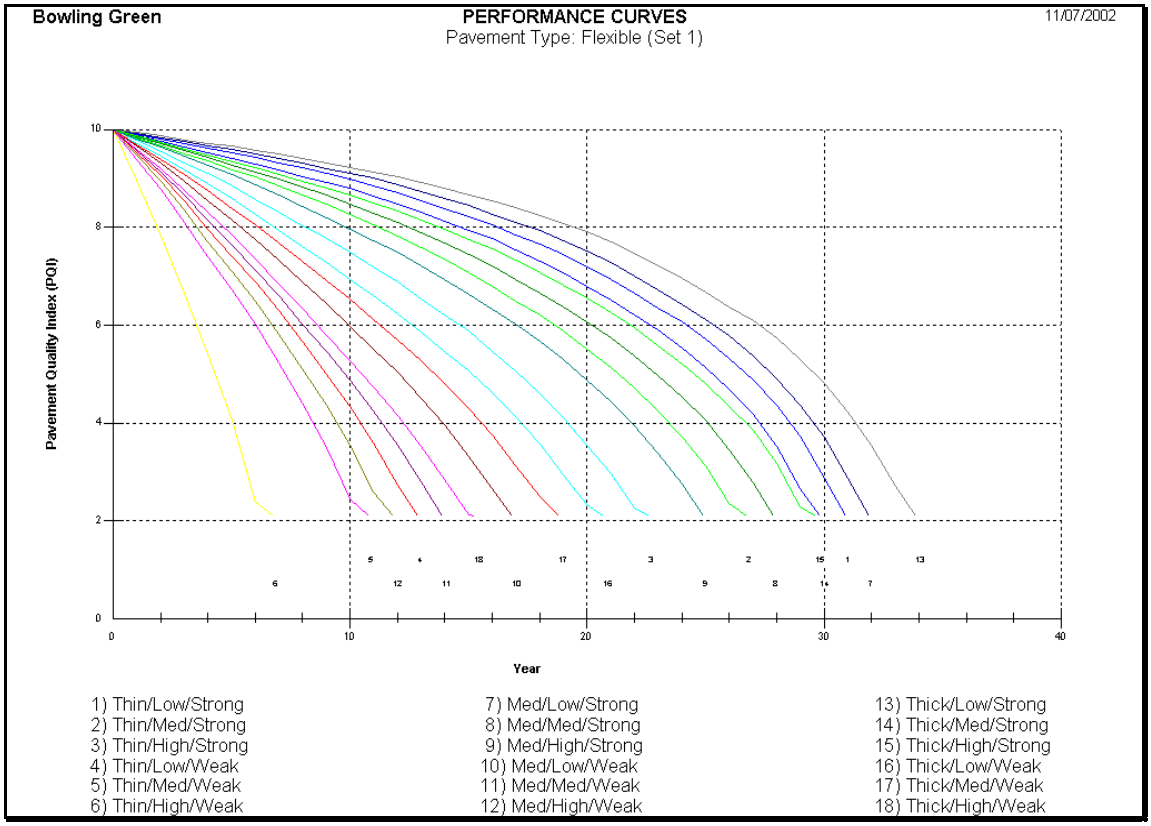


Figure 4.1

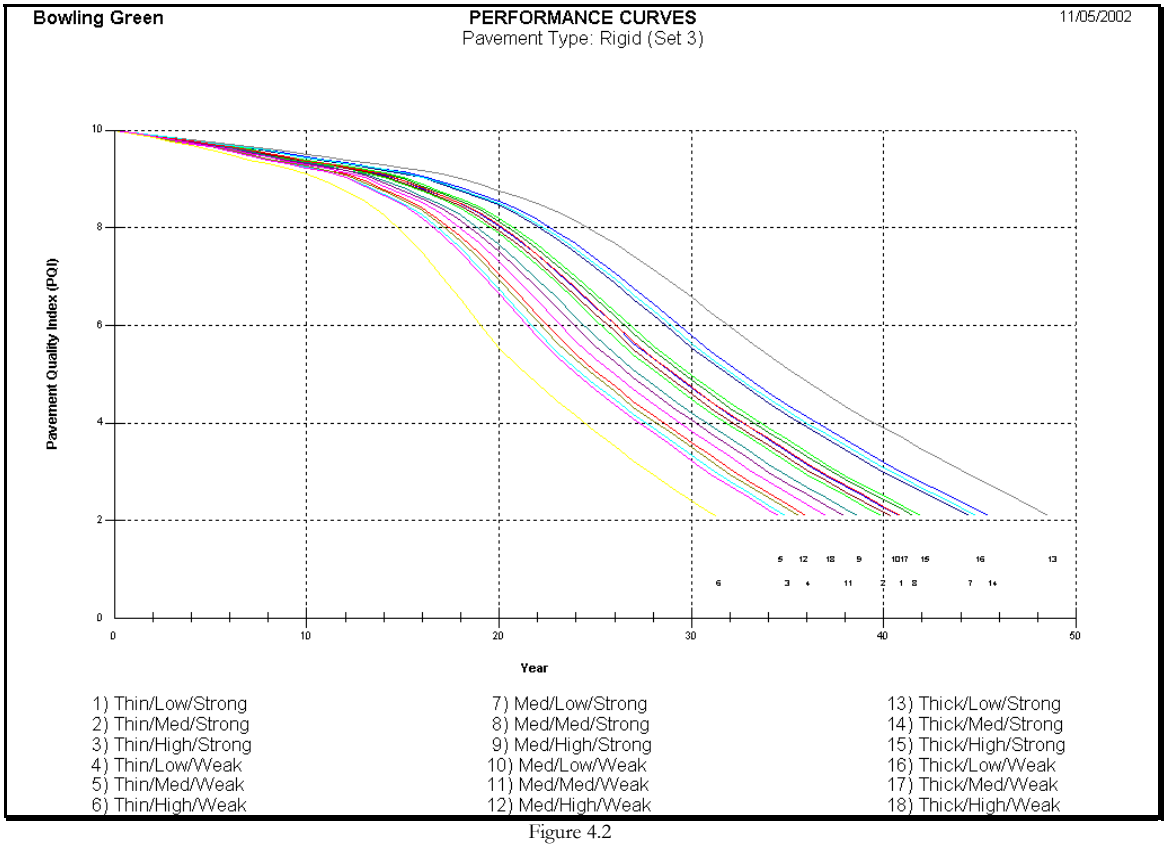


Figure 4.2

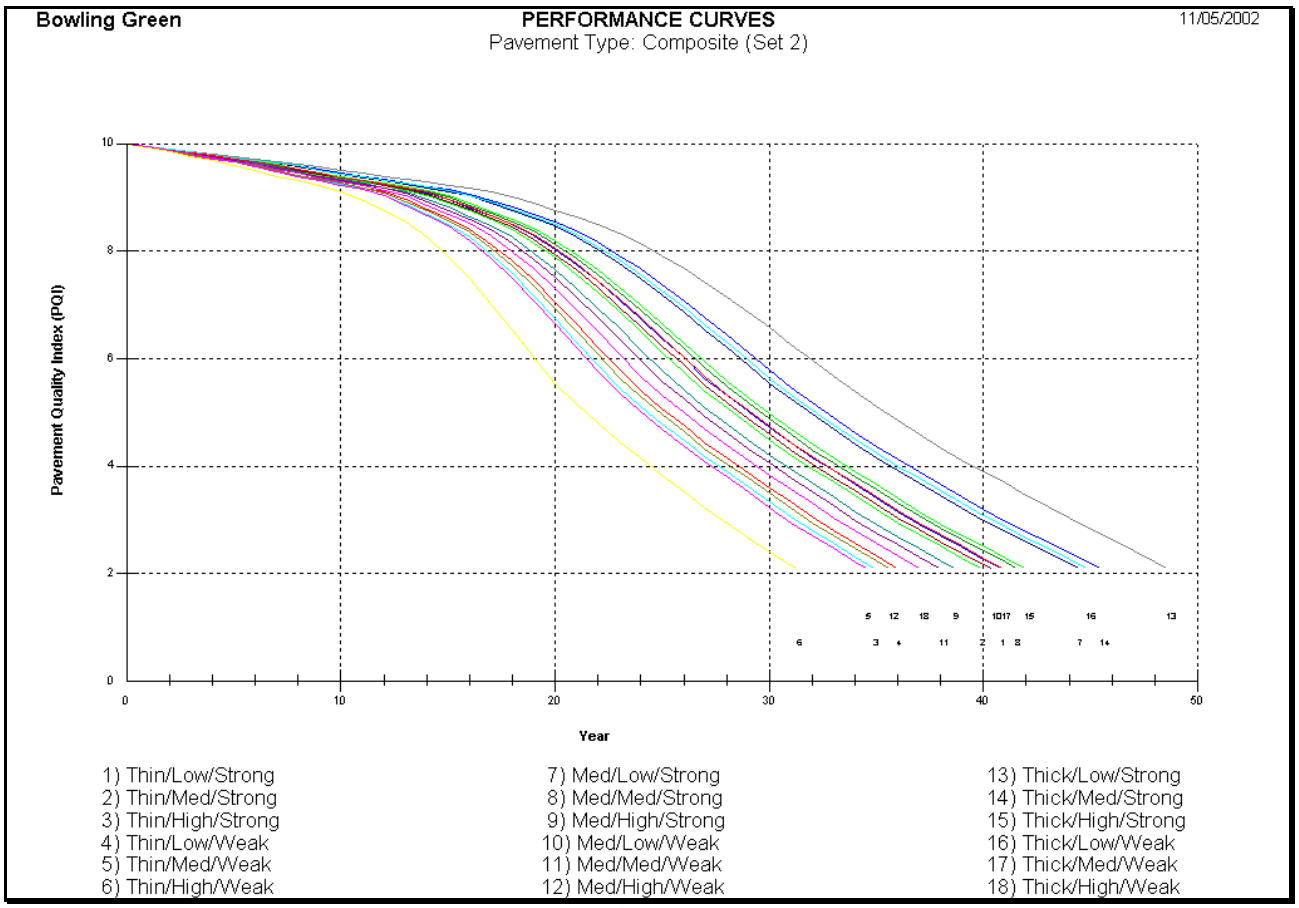


Figure 4.3

Functional Classification Statistics

Classification	*Total Length (ft)*	*% of Network*	*Avg PQI*	*Min Acceptable PQI*
Local Residential	180.2	76.7%	7.77	6.7
Local Commercial	10.0	4.3%	8.82	6.7
Minor Collector	9.0	3.8%	8.44	6.9
Major Collector	28.5	12.1%	8.01	6.9
Minor Arterial	2.6	1.1%	8.15	7.2
Major Arterial	0.6	0.3%	7.10	7.2

Table 4.2

The year in which the PQI of a section is predicted to fall to or below a minimum acceptable PQI level is defined as the "Need Year" for that section (i.e., the first year where improvement may be required). The minimum acceptable PQI level is related to the point at which a pavement's level of service, as provided to a typical user, is no longer adequate and therefore 'needs' attention (see Figure 1.1). The minimum acceptable PQI values range from 6.7 for local to 7.2 for major arterials (see table 4.3). This is similar to the levels used in other jurisdictions. Users of roads of higher functional classification, and likely higher speed limits, are not as tolerant of a poor pavement quality as they would be on local roads.

Rehabilitation Programming Analysis

An approach utilizing decision trees is employed to identify technically feasible rehabilitation strategies. A life cycle economic analysis is then performed to assess the relative cost effectiveness of each location. The ten-year rehabilitation program is developed from the results, maximizing the benefit of each dollar expended while keeping within the budget constraints specified for each year in the programming period. The final result of this analysis is a capital improvement program stating which pavement sections to rehabilitate, the year in which rehabilitation should be implemented for each section, and the type of rehabilitation strategy that should be implemented for each section. At this point, the project data is spatially examined using GIS. This allows the analyst to look for gaps or other logical changes that need to be made to the projects. This is an iterative process that optimizes the short term (1-3 year) planning.

Input Parameters

This analysis requires the identification of possible rehabilitation strategies for each section and their associated unit costs. Table 4.3 presents the rehabilitation strategies and associated unit costs that should be considered in the analysis. This data is updated on a yearly basis as determined by local market conditions. Decision trees, which identify the appropriate strategies to be considered under a wide range of conditions, were built for each combination of functional classification and pavement type.

A 10-year rehabilitation program for the proposed budget stream of $650,000 in 2004 and every year thereafter was assembled. For engineering reasons regarding the validity of results based on the limited reliability of pavement performance prediction beyond 10-year periods, rehabilitation programs are generally kept to within a 10-year period.

When assembling the programs, a rehabilitation project for a section can be implemented in its Need Year or any time thereafter depending on its cost effectiveness relative to other potential projects and the available budget. The cost effectiveness of a rehabilitation strategy on a given pavement section compares and evaluates the service life of the rehabilitation against its capital cost. Mathematically, the difference between the PQI's of the 'after-rehab' performance and the 'do-nothing' performance is divided by the capital cost of the rehabilitation and the weighted by the AADT. (The 'after-rehab' performance models the increase of the PQI at the time of the rehabilitation, whereas, the 'do-nothing' performance allows for no increase of the PQI). As a result, street sections with high values of cost effectiveness are prioritized higher than streets with low values.

PMA Rehabilitation Alternatives - Flexible Pavements

Code	*Description*	Alley	Local Residential	Local Commercial	Minor Collector	Major Collector	Minor Arterial	Major Arterial	cost / SF
0	Undefined								$0.00
1	1.25" AC Overlay	x	x	x					$0.28
9	1.25" Fiber Overlay			x	x	x			$0.27
7	1.5" Overlay		x	x	x	x	x	x	$0.33
13	1.5" Fiber Overlay			x	x	x	x	x	$0.32
2	2" AC Overlay		x	x	x	x	x	x	$0.44
14	2" Fiber Overlay			x	x	x	x	x	$0.43
3	3" AC Overlay					x	x	x	$0.66
4	4" AC Overlay							x	$0.88
15	2" Binder + 1.25" Surface Overlay			x	x	x	x	x	$0.70
8	E. Mill & 1.25" Overlay		x						$0.56
22	E. Mill + 1.25" Fiber Overlay			x	x	x			$0.55
5	E. Mill & 1.5" AC Overlay	x	x	x	x	x			$0.61
41	E. Mill + 1.5" Fiber Overlay			x	x	x	x	x	$0.60
6	E. Mill & 2" AC Overlay		x	x	x	x	x	x	$0.72
42	E. Mill + 2" Fiber Overlay				x	x	x	x	$0.71
44	FW. Mill 1.5" Overlay		x	x	x	x	x	x	$0.56
10	FW. Mill & AC Overlay (2")		x	x	x	x	x	x	$0.67
11	FW. Mill & 3" AC Overlay						x	x	$1.00
12	FW. Mill & 4" AC Overlay								$1.33
43	Cutouts + 1.5" Overlay	x	x	x	x	x			$0.39
16	C&G + 1.5" Overlay		x	x	x	x	x	x	$1.75
17	C&G + 2" Overlay			x	x	x	x	x	$1.86
18	C&G + 2" Fiber Overlay	x		x	x	x	x	x	$1.84
19	C&G + 2" Binder, 1.25" Surface			x	x	x	x	x	$2.12
20	RC: 6" DGA, 2" Base, 1.25" Surface		x	x	x	x	x	x	$1.19
21	RC: 10" DGA, 5" Base, 1.25" Surface			x	x	x	x	x	$2.15

Contract Prices (updated 11/7/03)

Surface:	$36.00 /ton
Base:	$35.00 /ton
Milling:	$34.00 /ton
DGA:	$12.60 /ton
Excav:	$5.00 /SY
C&G:	$17.00 /LF
Fiber AC:	$35.00 /ton

Table 4.3

Section 5

Analysis Results

Present Status Analyses

The following subsections summarize the street network at the time of the field surveys.

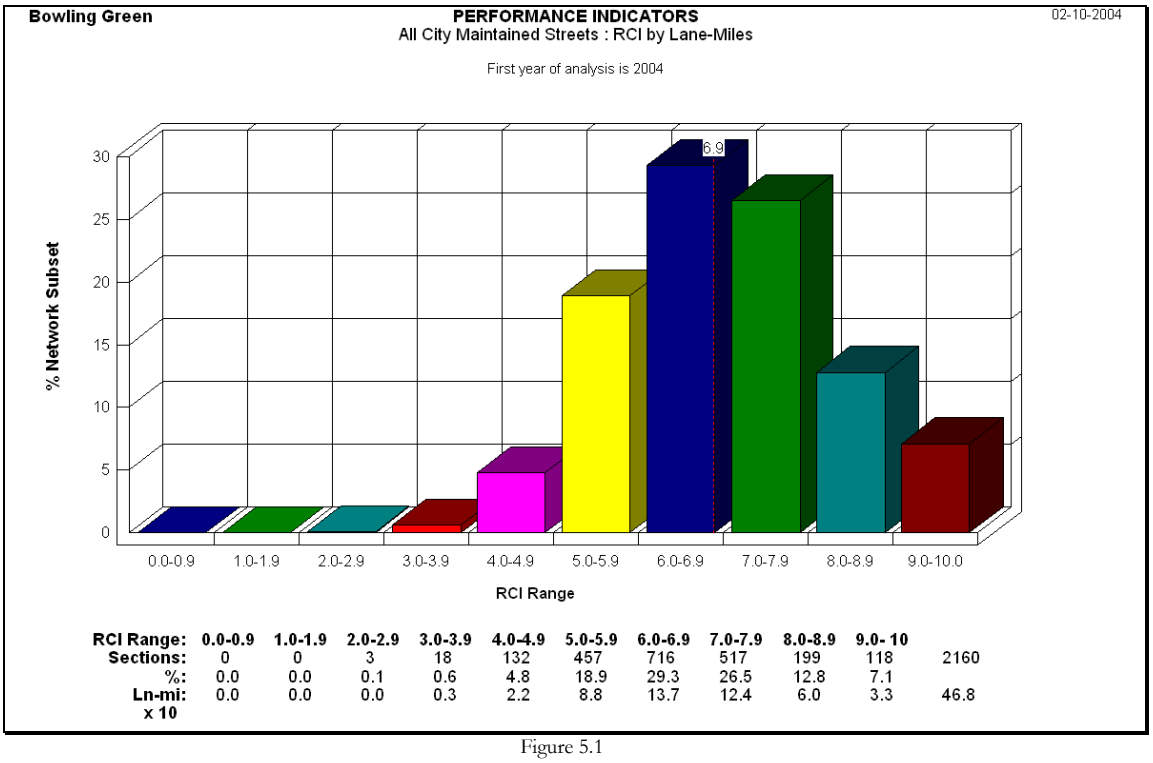
Riding Comfort Index (RCI) Analysis

A plot showing the distribution of RCI values for the current survey is shown in Figure 5.1. The plot shows that the network has a mean RCI of 6.9. An RCI value less than 5.0 is indicative of a pavement with poor ride quality characteristics. At the time of the survey, 25 lane-miles, or 5.5 percent of the network, fall into this category. Pavements with RCI values in the range of 5.0 to 7.0 are considered to have marginal ride quality characteristics, and approximately 225 lane-miles, or 38.2 percent of the network, fall into this category. The remaining 217 lane-miles, or 46.4 percent of the network, have RCI values greater that 7.0, which are indicative of good ride characteristics. RCI ratings are shown in Map 5.1.

Surface Distress Index (SDI) Analysis

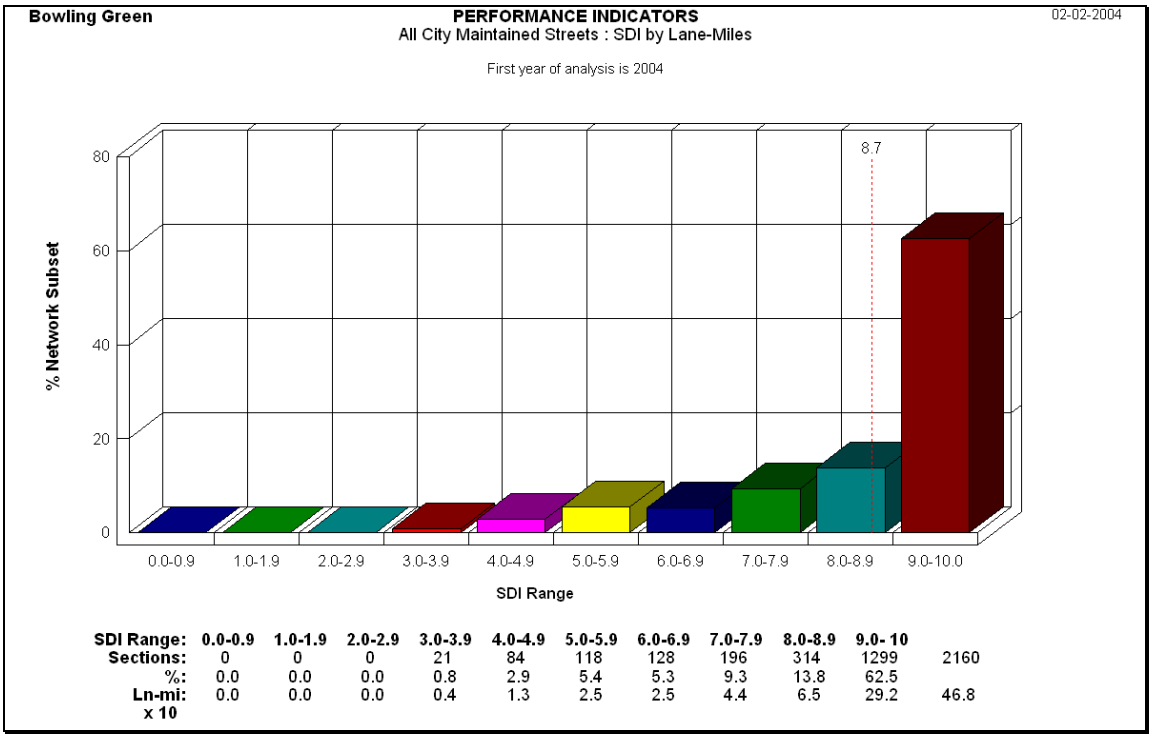
A plot showing the SDI distribution resulting from the current survey is shown in Figure 5.2. The mean SDI of 8.7 indicates that, generally speaking, the majority of the network is in acceptable condition. From a surface distress perspective, though, it is somewhat distressed. The plot shows that 357 lane-miles, 76.3 percent of the network, have SDI scores in the 8.0 to 10.0 range, which indicates that these pavements are non-distressed to slightly distressed. Roughly 44 lane-miles, or 9.3 percent of the network, have SDI scores in the 7.0 to 7.9 range which is indicative of pavements that are marginal with regard to surface distress. Approximately 67 lane-miles, or 14.4 percent of the network, have an SDI score less than 7.0, which indicates that significant distresses exist on these sections. SDI ratings are shown in Map 5.2.

The sectional SDI values used as input for the distribution shown in Figure 5.2 are presented in Volume 2 of this report.



RCI Range:	0.0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0- 10	
Sections:	0	0	3	18	132	457	716	517	199	118	2160
%:	0.0	0.0	0.1	0.6	4.8	18.9	29.3	26.5	12.8	7.1	
Ln-mi: x 10	0.0	0.0	0.0	0.3	2.2	8.8	13.7	12.4	6.0	3.3	46.8

Figure 5.1



SDI Range:	0.0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0- 10	
Sections:	0	0	0	21	84	118	128	196	314	1299	2160
%:	0.0	0.0	0.0	0.8	2.9	5.4	5.3	9.3	13.8	62.5	
Ln-mi: x 10	0.0	0.0	0.0	0.4	1.3	2.5	2.5	4.4	6.5	29.2	46.8

Figure 5.2

Structural Adequacy Index (SAI)

The distribution of sectional SAI values is presented in Figure 5.3. The distribution shows that the test sections have a mean SAI of 6.9, which indicates that the pavements tested are expected to be structurally adequate to carry the anticipated loadings over the upcoming year. The distribution shows that 8.3 percent of the network (7 lane-miles) contains sections with an SAI score below 5.0. A pavement with an SAI value less than 5.0 indicates that the pavement may be inadequate to carry the anticipated traffic loadings over the upcoming year. The remaining 91.7 percent (85 lane-miles) has values of 5.0 or greater, indicating that the pavements are considered to be structurally adequate to carry the anticipated traffic loadings. The sectional SAI values are presented in Volume 2 of this report. SAI ratings are shown in Map 5.3.

Pavement Quality Index (PQI) Analysis

A plot showing the PQI distribution for the current survey is shown in Figure 5.4. The average PQI of 7.6 indicates that, generally speaking, the network is in good condition. The vast majority of the pavements, some 339 lane-miles or 72 percent of the network, is currently providing an acceptable level of service to the users of the network. The remaining 129 lane-miles, or 28 percent of the network, are currently providing an unacceptable level of service to the users of the network. PQI ratings are shown in Map 5.4.

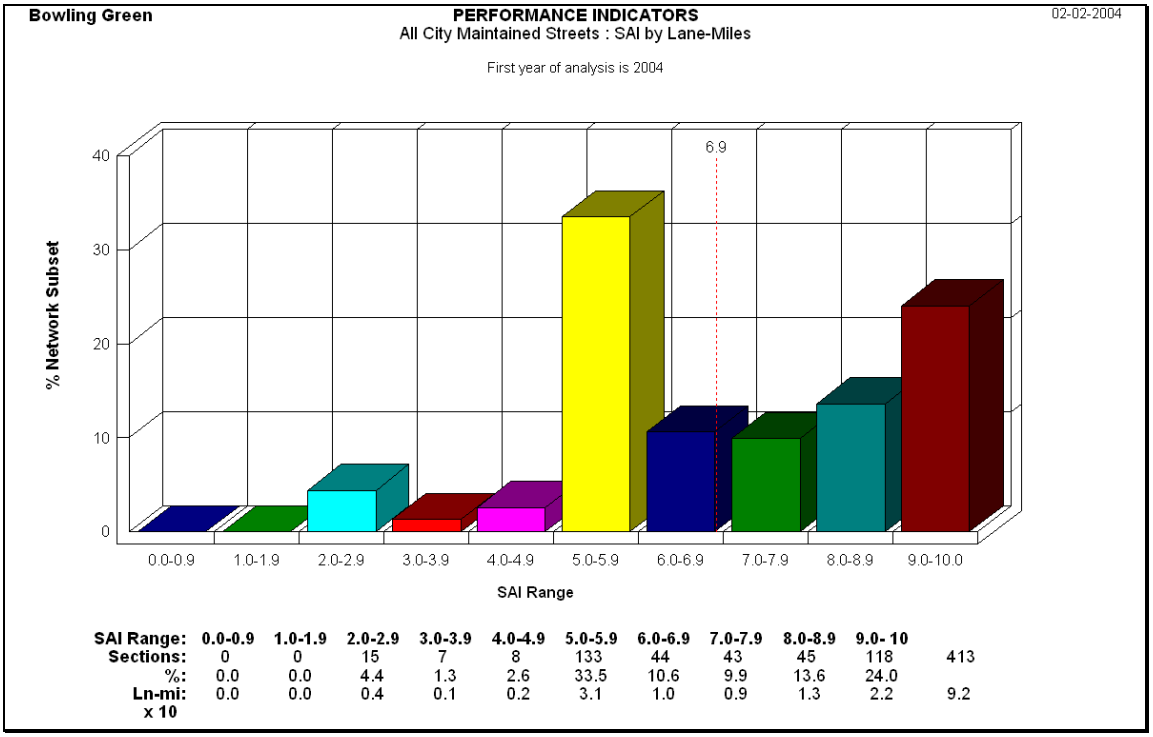
The PQI of each section is presented in Volume 2 of this report. These outputs provide a summary of the performance indicators of all sections in the network.

Rehabilitation Needs Analysis

The year in which the PQI of a section decreases to or below the minimum acceptable PQI level is defined as the Need Year of that section. The Need Year distribution for the City's street network is presented in Figure 5.5 and Table 5.1. The distribution shows that 133 lane-mi, or 28.5 percent of the street network, is expected to be in need of rehabilitation in 2004. This indicates that approximately $3,000,000 of rehabilitation is needed at this time. However, due to funding constraints, the unmet needs will be transferred to the next year to compete for the most economically feasible location. Further, roughly 2.5 to 6.7 percent of the network is expected to become in need of rehabilitation annually from 2005 to 2013. In all, approximately 67.7 percent of the network is expected to need rehabilitation in the upcoming ten-year period.

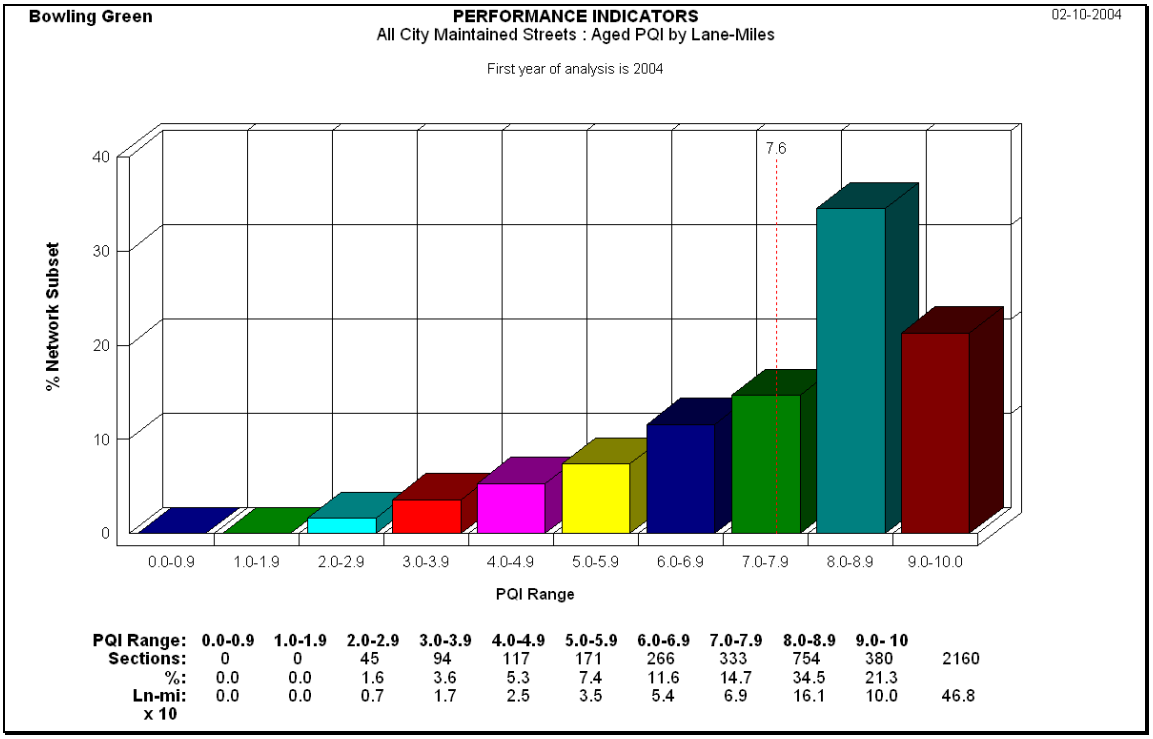
Rehabilitation Programming Analysis

A Rehabilitation Programming Analysis was conducted to assemble a ten-year rehabilitation program that identifies the rehabilitation strategies to be applied to individual pavement sections in each year of the programming period. The analysis used the City's budget of $650,000/yr. $1,000,000/yr was also considered to determine how an increase in that amount would impact the overall network throughout the analysis period. The program associated with the current budget is presented in Volume 2 of this report.



SAI Range:	0.0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0- 10	
Sections:	0	0	15	7	8	133	44	43	45	118	413
%:	0.0	0.0	4.4	1.3	2.6	33.5	10.6	9.9	13.6	24.0	
Ln-mi: x 10	0.0	0.0	0.4	0.1	0.2	3.1	1.0	0.9	1.3	2.2	9.2

Figure 5.3



PQI Range:	0.0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0- 10	
Sections:	0	0	45	94	117	171	266	333	754	380	2160
%:	0.0	0.0	1.6	3.6	5.3	7.4	11.6	14.7	34.5	21.3	
Ln-mi: x 10	0.0	0.0	0.7	1.7	2.5	3.5	5.4	6.9	16.1	10.0	46.8

Figure 5.4

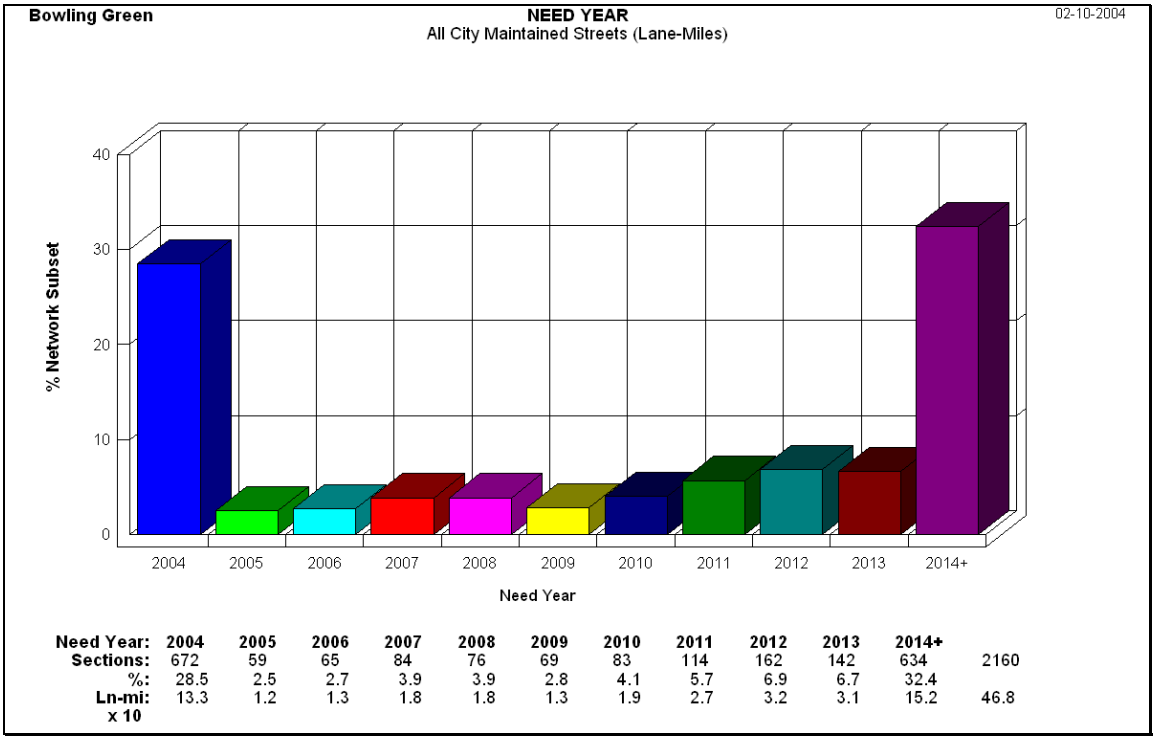


Figure 5.5

The impact of the rehabilitation program on the performance of the network was estimated for the proposed budget scenario. This is done by tracking the average PQI of the network and the percentage of the network that is in need of rehabilitation over the ten-year programming period. This data is shown in tabular format in Table 5.1 and in graphical form in Figures 5.6 - 5.9. In the proposed budget stream, the available budget is fully expended for a small unused portion. The remaining portions are insufficient to fund a rehabilitation project.

The values in Table 5.1 under the 'Do-Nothing Performance' heading show that the network average PQI could decrease from 7.7 in 2004 to 5.5 in the year 2013 if no rehabilitation is performed during this period. Similarly, the percentage of the network below the minimum acceptable level would increase from 28 percent in 2004 to 67.3 percent in year 2013. However, the current budget stream will result in a network average PQI of 7.9 in 2004, with the ability to maintain this rating throughout the ten-year period. These results show that the current budget stream will be sufficient to maintain the network at its current level of service. The budget required to properly address all rehabilitation needs as they occur is summarized in the 'Need Driven' column. This scenario assumes unlimited resources, and shows that some $6.7 million over a period of 10 years would be required to implement a program of this type with an average network PQI of 8.0.

Network Performance

Multiple Budget Scenarios

Year	Do Nothing		Need Driven		$650,000 Annually		$1,000,000 Annually	
	Avg PQI	% < Min. PQI	Avg PQI	% < Min. PQI	Avg PQI	% < Min. PQI	Avg PQI	% < Min. PQI
2004	7.7	28.0	8.7	0.0	7.9	22.0	8.0	19.0
2005	7.4	30.5	8.6	0.0	7.9	17.8	8.3	9.5
2006	7.2	33.1	8.5	0.0	8.0	12.2	8.4	3.6
2007	6.9	37.1	8.4	0.0	8.1	9.2	8.3	2.5
2008	6.7	41.0	8.3	0.0	8.1	6.7	8.2	2.7
2009	6.4	43.7	8.2	0.0	8.1	3.8	8.1	2.7
2010	6.1	47.8	8.1	0.0	8.1	2.9	8.0	2.7
2011	5.9	53.5	8.1	0.0	8.0	2.8	8.0	2.8
2012	5.6	60.5	8.0	0.0	8.0	3.1	7.9	3.1
2013	5.3	67.3	8.0	0.0	7.9	3.5	7.9	3.5

Table 5.1

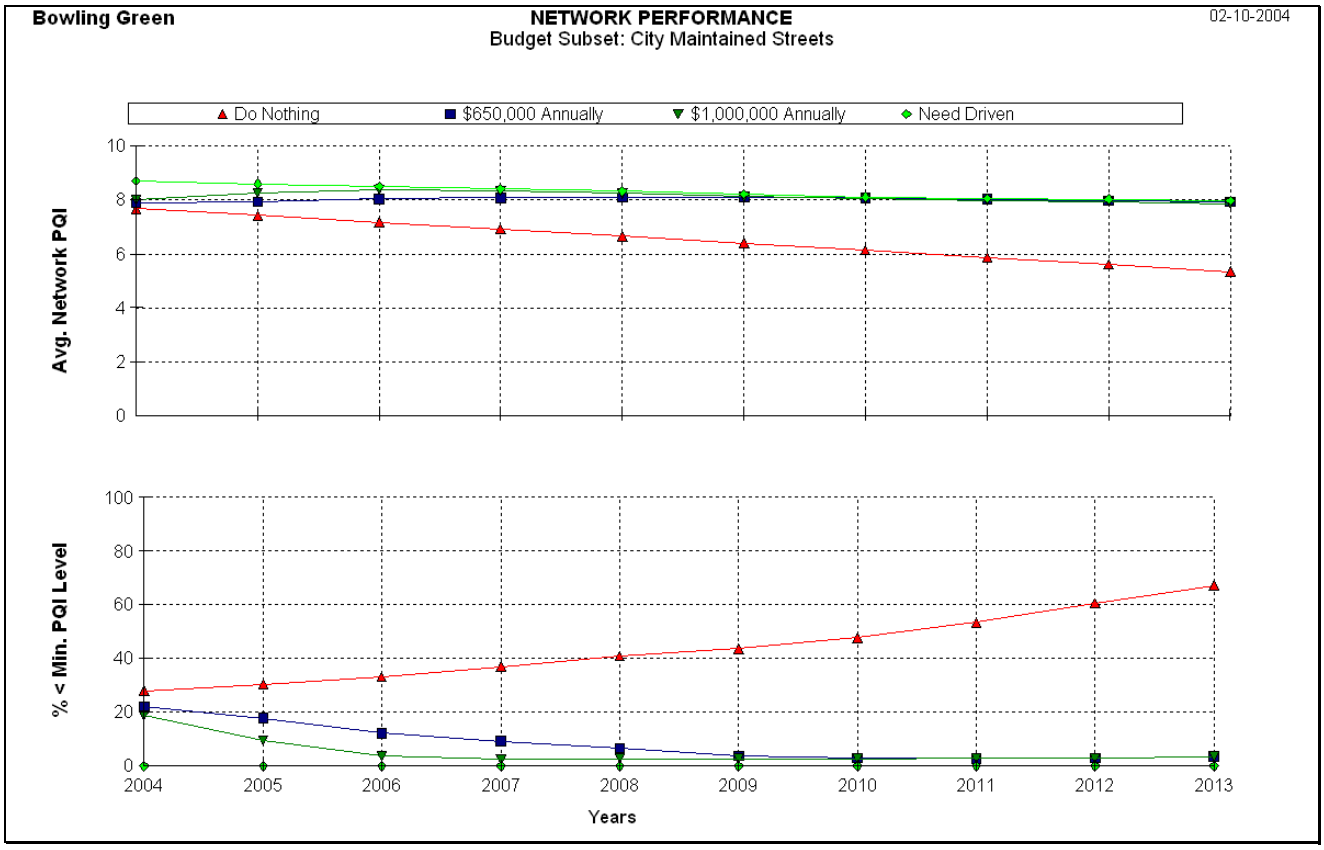


Figure 5.6

Neighborhood Districts

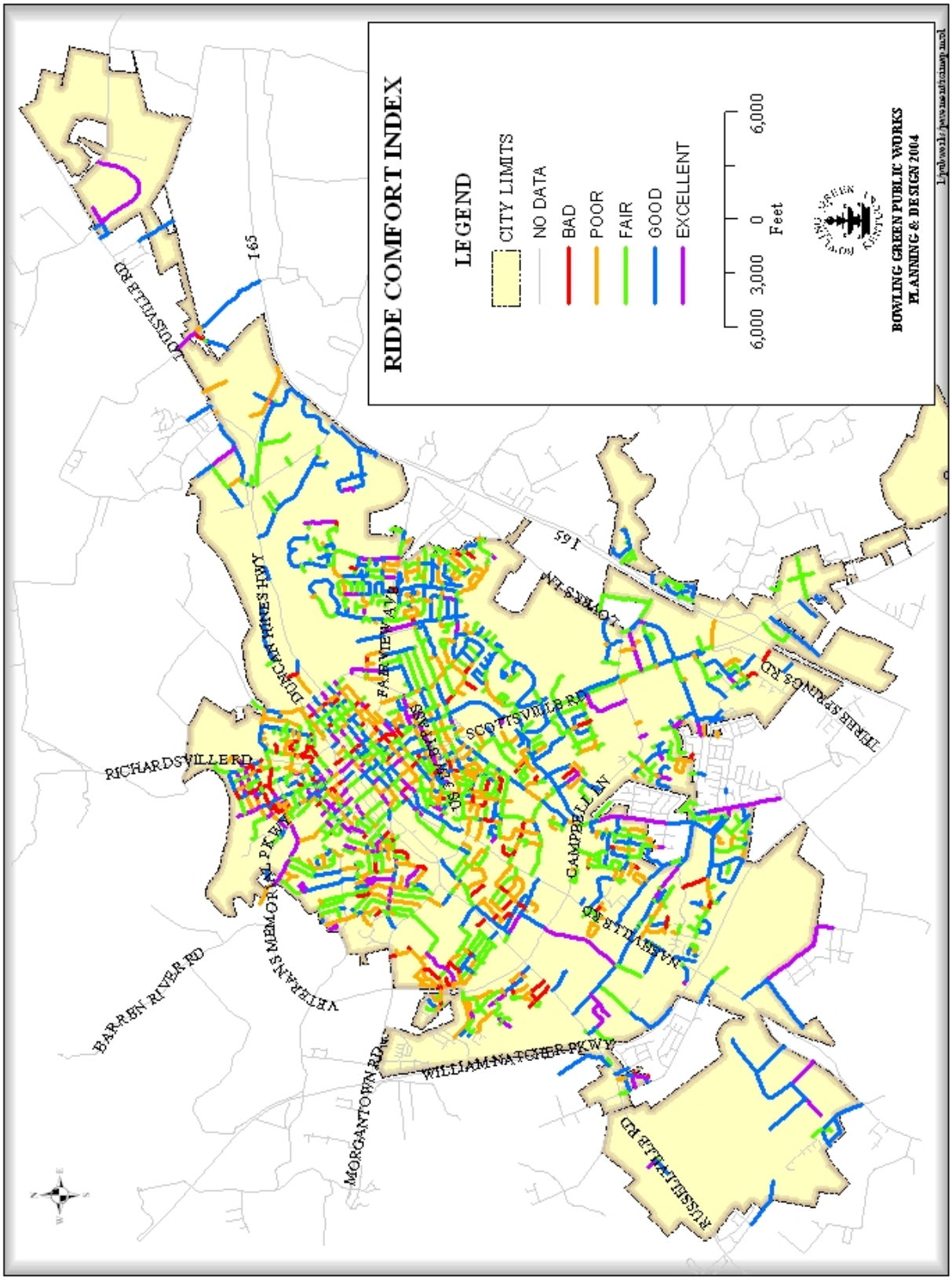
The City of Bowling Green is divided into 15 different census tracts, which will be referred to as neighborhoods in this report. Each of the City maintained streets can be referenced to one of the 14 tracts shown in Map 5.5, as data for the fifteenth tract (#17) has not yet been accumulated.

Table 5.2 displays the average indices (PQI, SDI, RCI, SAI) by neighborhood. The PQI ranges in value from 6.65 for neighborhood 11 to 8.87 for neighborhood 4. This shows little variation between neighborhoods and is encouraging to know that certain neighborhoods don't show neglect. This table also shows the percentage of the total network that is included in each neighborhood.

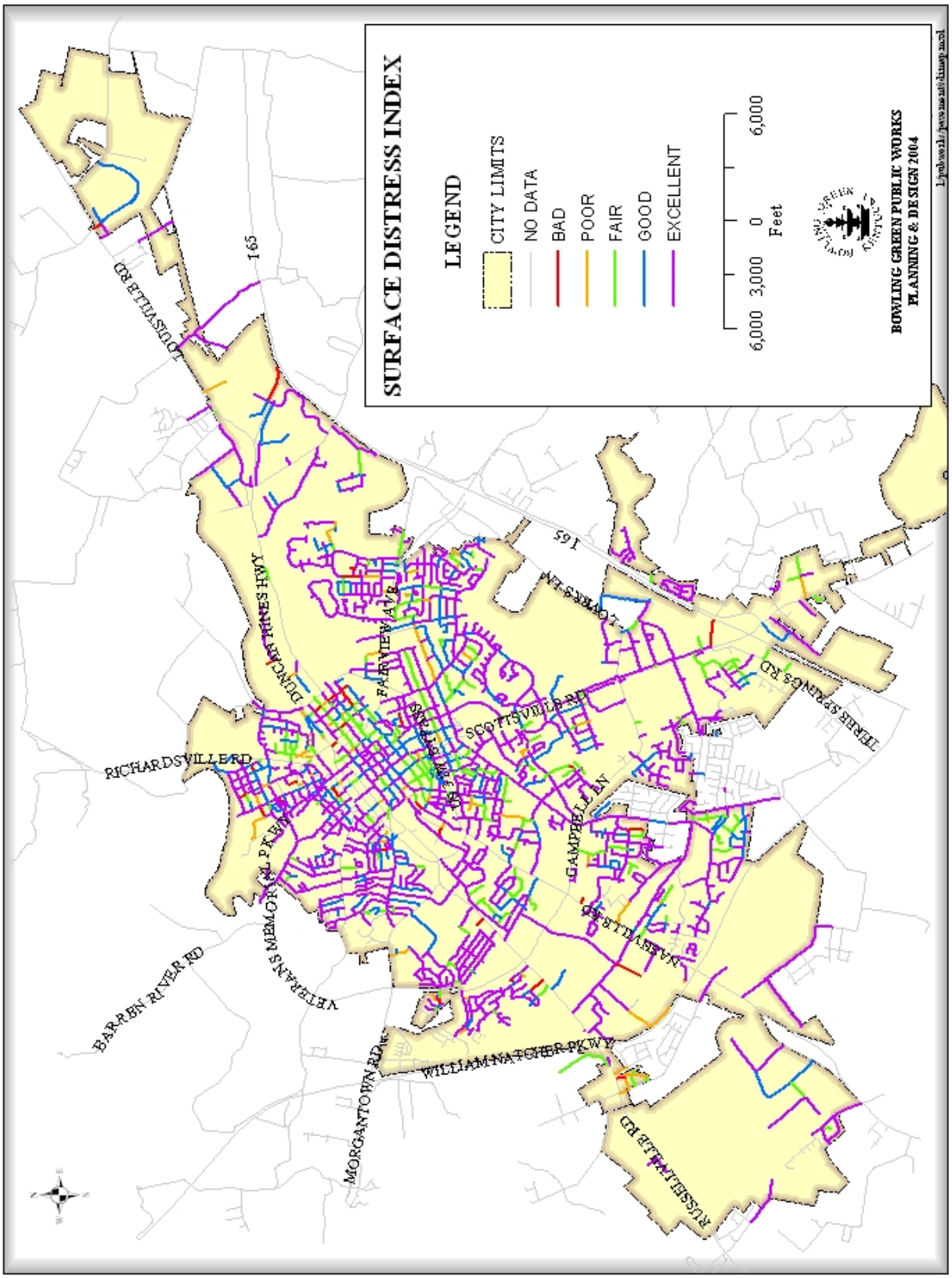
Average Indices By Neighborhood

Neighborhood #	No. of Sections	PQI	RCI	SDI	SAI	Total Miles	% of Network Lane Miles
1	74	7.20	6.36	8.40	7.21	5.97	3%
2	300	7.20	6.38	8.08	7.09	23.19	10%
3	171	7.69	6.19	8.55	7.88	12.84	5%
4	19	7.07	6.64	7.89	6.36	2.54	1%
5	140	7.15	6.10	8.12	7.19	11.25	5%
6	180	8.54	7.10	9.39	6.47	21.15	9%
7	152	8.57	7.51	9.23	5.76	18.01	8%
8	232	8.53	7.18	9.24	7.26	28.36	12%
9	208	8.14	6.49	9.04	7.72	20.28	9%
10	192	7.94	7.14	8.31	5.78	23.16	10%
11	46	9.27	8.82	9.60	5.38	7.70	3%
12	88	7.69	6.19	8.59	7.31	9.24	4%
13	73	7.50	7.10	7.94	9.25	13.90	6%
14	357	8.02	6.91	8.82	6.27	38.32	16%
17	4	9.38	8.78	9.70	-	1.62	1%
Network Average	**Σ 2236**	**7.99**	**6.99**	**8.73**	**6.92**	**Σ 237.53**	**Σ 100%**

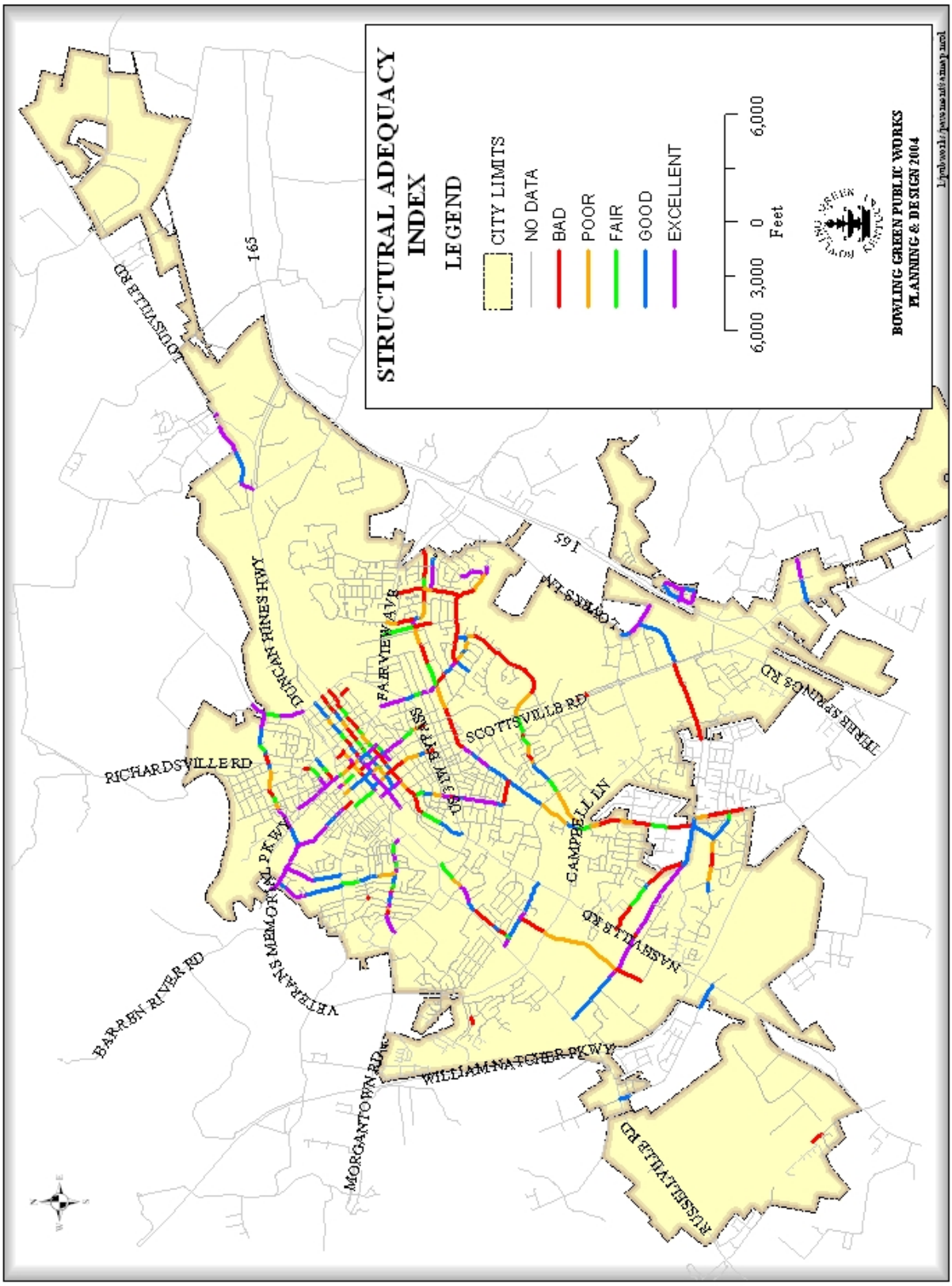
Table 5.2


RIDE COMFORT INDEX
LEGEND
CITY LIMITS
NO DATA
BAD
POOR
FAIR
GOOD
EXCELLENT
6,000 3,000 0 6,000
Feet
BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN 2004
165
LOUISVILLE RD
DUNCAN HINES HWY
FAIRVIEW AVE
SCOTTSVILLE RD
LOWERS LN
THREE SPRINGS RD
RICHARDSVILLE RD
CAMPBELL LN
NASHVILLE RD
VETERANS MEMORIAL PKWY
BARREN RIVER RD
WILLIAM NATCHER PKWY
MORGANTOWN RD
RUSSELLVILLE RD

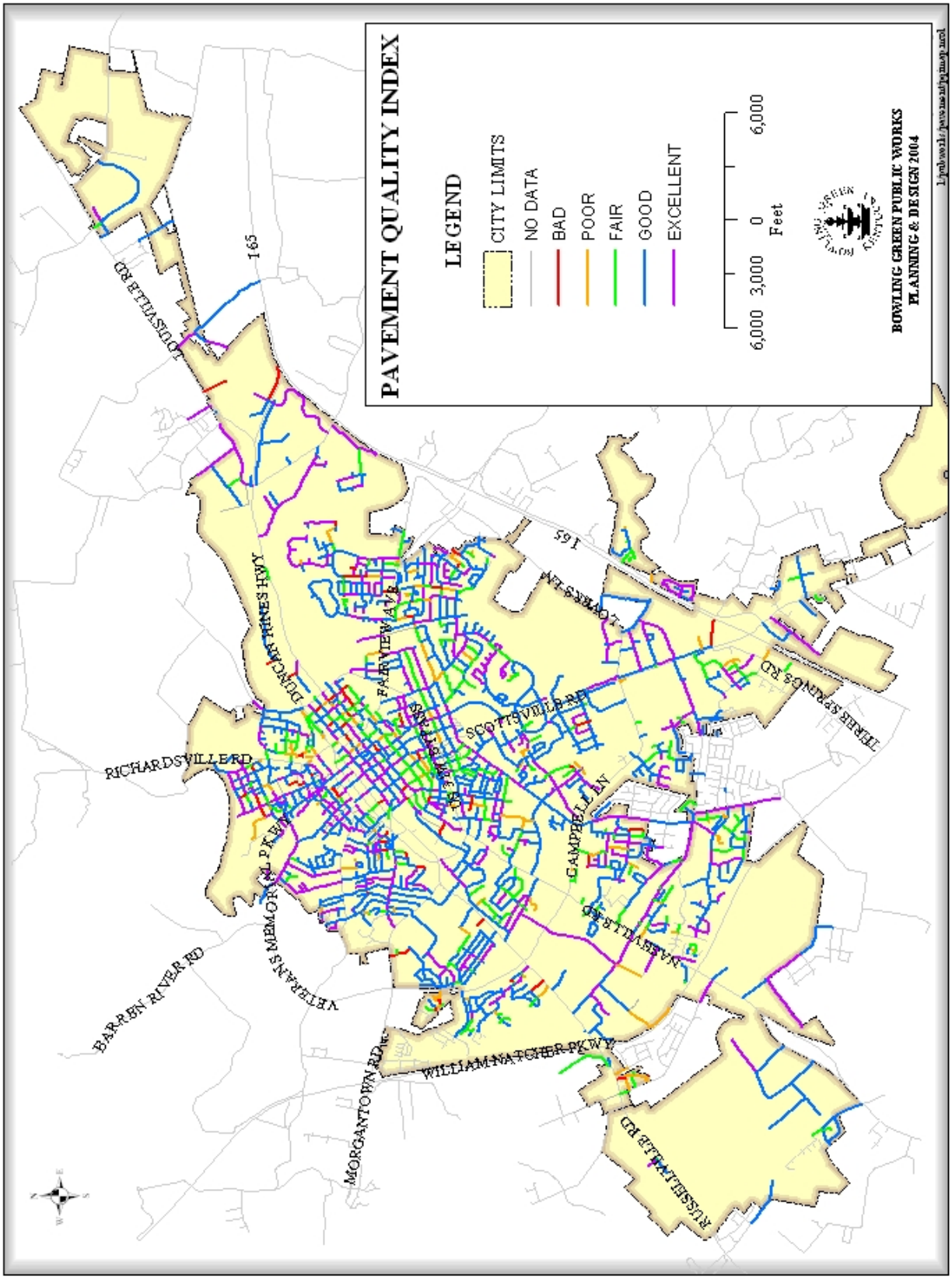
MAP 5.1


SURFACE DISTRESS INDEX
LEGEND
CITY LIMITS
NO DATA
BAD
POOR
FAIR
GOOD
EXCELLENT
6,000 3,000 0 6,000
Feet
BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN 2004
165
LOUISVILLE RD
DUNCAN HINES HWY
FAIRVIEW AVE
SCOTTSVILLE RD
LOWERS LN
THREE SPRINGS RD
RICHARDSVILLE RD
GAMPBELL LN
NASHVILLE RD
VETERANS MEMORIAL PKWY
BARREN RIVER RD
MORGANTOWN RD
WILLIAM NATCHER PKWY
RUSSELLVILLE RD

MAP 5.2


STRUCTURAL ADEQUACY INDEX
LEGEND
CITY LIMITS
NO DATA
BAD
POOR
FAIR
GOOD
EXCELLENT
6,000 3,000 0 6,000
Feet
BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN 2004
LOUISVILLE RD
165
DUNCAN HINES HWY
FAIRVIEW AVE
SCOTTSVILLE RD
RICHARDSVILLE RD
CAMPBELL LN
NASHVILLE RD
THREE SPRINGS RD
VETERANS MEMORIAL PKWY
BARREN RIVER RD
MORGANTOWN RD
WILLIAM NATCHER PKWY
RUSSELLVILLE RD

MAP 5.3


PAVEMENT QUALITY INDEX
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CITY LIMITS
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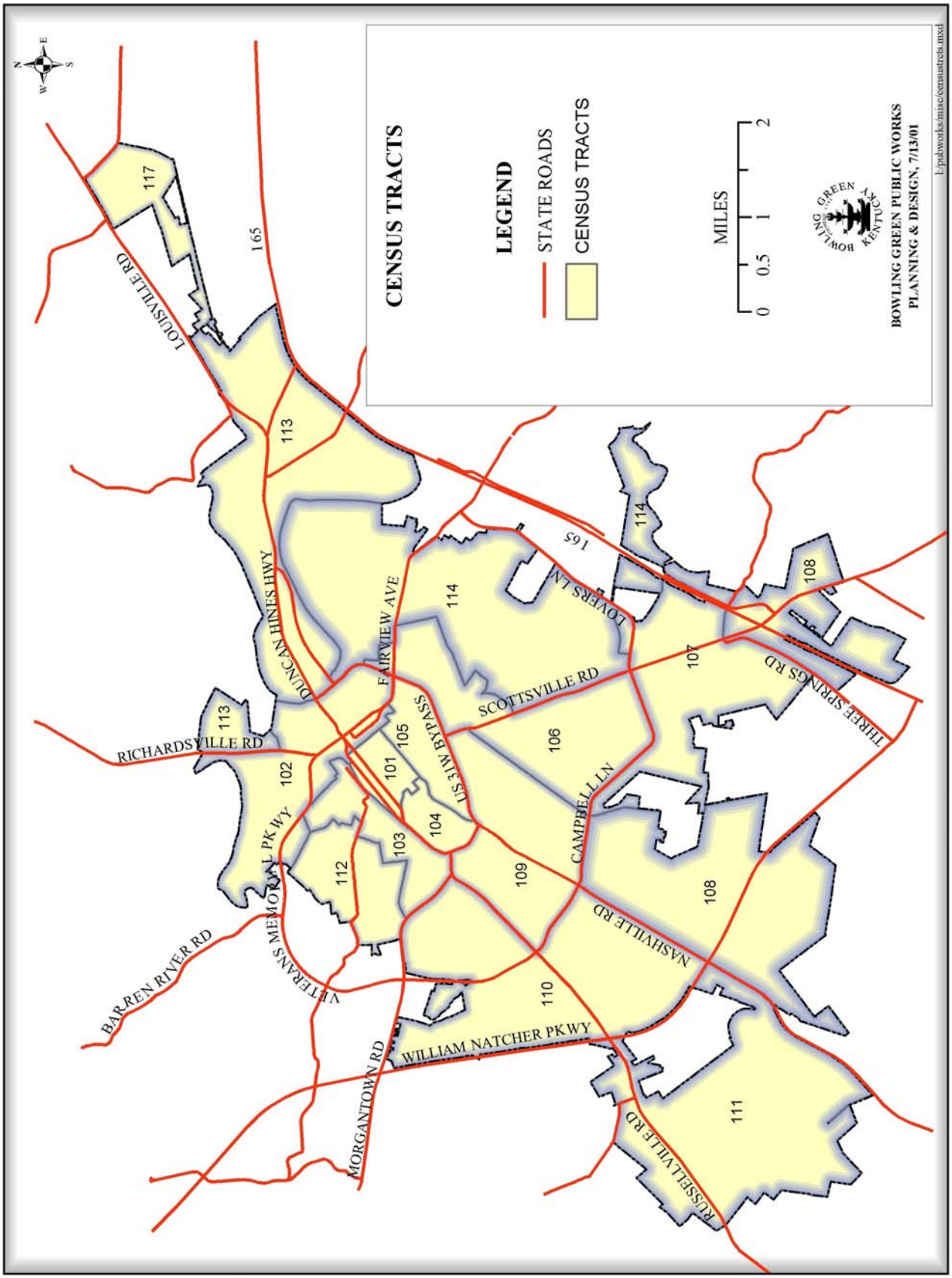
POOR
FAIR
GOOD
EXCELLENT
6,000 3,000 0 6,000
Feet
BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN 2004
165
LOUISVILLE RD
DUNCAN HINES HWY
FAIRVIEW AVE
SCOTTSVILLE RD
LOWERS LN
THREE SPRINGS RD
RICHARDSVILLE RD
CAMPBELL LN
NASHVILLE RD
VETERANS MEMORIAL PKWY
BARREN RIVER RD
MORGANTOWN RD
WILLIAM NATCHER PKWY
RUSSELLVILLE RD

MAP 5.4


CENSUS TRACTS
LEGEND
STATE ROADS
CENSUS TRACTS
MILES
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BOWLING GREEN PUBLIC WORKS
PLANNING & DESIGN, 7/13/01
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LOUISVILLE RD
165
117
113
DUNCAN HINES HWY
FAIRVIEW AVE
114
LOVERS LN
SCOTTSVILLE RD
107
THREE SPRINGS RD
108
RICHARDSVILLE RD
102
101
105
US 31W BYPASS
106
CAMPBELL LN
104
103
112
109
NASHVILLE RD
VETERANS MEMORIAL PKWY
BARREN RIVER RD
110
WILLIAM NATCHER PKWY
MORGANTOWN RD
RUSSELLVILLE RD
111

MAP 5.5