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MEMORANDUM

November 30, 2022

To: Bryan Davis
Organization: Chittenden County Regional Planning Commission
From: Theja Putta and Michael Blau
Project: Chittenden County Regional Planning Commission Active Transportation Plan Update

Re: Task 3.1 Bicycle Network Analysis – FINAL DRAFT

Introduction

The Bicycle Network Analysis examines existing bicycle network connectivity, as well as the impacts of potential improvements; these include systemic changes like building more low-stress routes in high need communities (such as minority, low-income, and low-vehicle access census tracts), as well as corridor-specific changes.

Network connectivity can be a difficult concept to describe, understand, and crucially to measure. While traditional methods of aggregating mileage of bike lanes or measuring as-the-crow flies distance between destinations and bike facilities are easy to measure, they fail to capture the importance of having an interconnected network of low-stress bike routes connecting people to their destinations. BNA aims to capture the importance of the interconnectedness of bicycle routes by measuring access to destinations.

There are four main components to this analysis which are described in greater detail in the following sections of this document.

1. Data Consolidation
2. Level of Traffic Stress
3. Connectivity Analysis
4. BNA Scores

Data Consolidation

BNA requires many datasets to accurately measure and visualize a bicycle network's connectivity. These datasets do not follow the same structure, which warranted a data consolidation process so that the all the necessary information can be joined to one routable network that can be used for subsequent processes in the analysis.

Routable Network

Connectivity analysis requires a routable street network consisting of segments and intersections. For this analysis, a routable network is imported from Open Street Map (OSM)[1] which is a crowdsourced geographic database of the world. The imported network contains all streets and paths where bicycle travel is allowed. It excludes limited-access highways, private roads, and roads that are used as driveways and alleyways that generally do not form part of the larger network. The OSM network has information needed for this analysis like number lanes, speed limit, and bike facility information. However, this data is not always complete or up-to-date. We complemented OSM data with other datasets to fill data gaps.

Supplementary Network Data

The following datasets are used to fill the missing gaps in the OSM network:

- Annual Daily Traffic (ADT) – published on Vermont Open Geodata Portal[2]
- On-street bike facilities and off-street trails – provided by the Chittenden County Regional Planning Commission (CCRPC)
- Speed Limits – provided by CCRPC
- Number of lanes – provided by CCRPC

The above data are joined to the routable OSM network using a combination of automated geospatial and manual processes. Any remaining data gaps after this data join process is complete are filled using assumed values based on functional classification of streets.

Level of Traffic Stress

Level of Traffic Stress (LTS) is the stress on a bicyclist due to roadway and traffic conditions. It was first proposed by Furth, Mekuria, and Nixon in 2012[3]. LTS values can range from 1 to 4, with LTS 1 being the lowest stress and LTS 4 being the highest stress. LTS 1 and LTS 2 are generally considered low-stress, which is acceptable to the majority of the adult population. Peter Furth has since released updated LTS criteria (v.2.0)[4] with more refined stress values for segments. A segment's LTS value depends on factors such as number of lanes, traffic volume, speed, presence of bike facility, parking lane, width of bike lanes, etc. In addition to the stress values for a segment, there can also be stress at intersection crossings, which varies depending on the number of crossing lanes, speed, volume, and traffic control device present at the intersection.

Toole Design performed an LTS analysis in 2017 for the County's previous Active Transportation Plan. Reviewing 2017 analysis results revealed that the LTS calculations might be outdated due to changes to the network since the previous plan. Previous LTS calculations also do not include crossing stress, which is necessary for accurately measuring connectivity. As a result, the current BNA needed updated LTS values.

The LTS criteria used in this analysis are a slight modification of LTS v2.0 based on Toole Design's previous work in the field. These LTS criteria are shown in Appendix A. Using the LTS criteria, every segment in the routable OSM network is assigned a stress level. After applying the criteria in Appendix A, the LTS values for some segments were manually overridden based on the feedback from CCRPC after examining the initial results. These changes primarily involved raising or lowering stress levels on certain segments based on the presence of new facilities, or CCRPC field observations of traffic volumes, number of lanes, etc.

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[1] https://www.openstreetmap.org/

[2] https://geodata.vermont.gov/datasets/2558e517c3454f76b564e7d37e32ca3a/explore

[3] https://transweb.sjsu.edu/sites/default/files/1005-low-stress-bicycling-network-connectivity.pdf

[4] https://cpb-us-w2.wpmucdn.com/sites.northeastern.edu/dist/e/618/files/2014/05/LTS-Tables-v2-June-1.pdf

In addition to the segment stress, crossing stress values are also assigned where appropriate. Generally speaking, higher crossing stress applies to lower functional class streets when they cross a higher functional class street without any intersection control devices like signals, stop signs, or median crossing islands. Figure 1 shows a map of all segments in the County classified by LTS values. Many of the busier roads in the area are high-stress – unless they have a bike facility along them – which leads to a disconnected network, since low-stress residential roads do not form longer continuous routes.

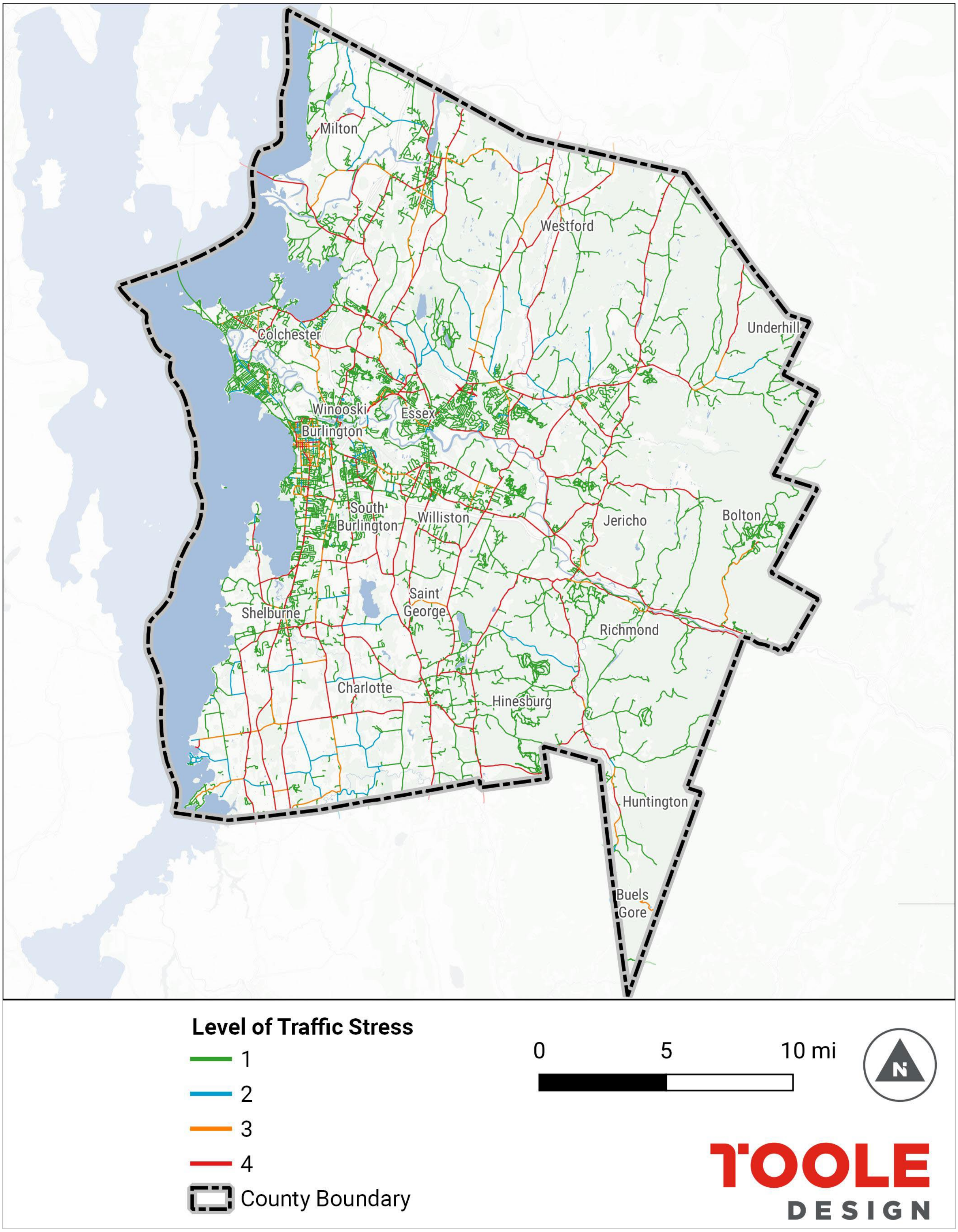

Figure 1: LTS Map of Chittenden County

Connectivity Analysis

Connectivity analysis is done at a block-to-block level. For each census block, a shortest path is calculated both along the low-stress network (LTS 1-2) and overall network (LTS 1-4) within three miles. Travel along the low-stress network often requires longer distances than the overall network, which can be a barrier when the low-stress distance far exceeds the overall network distance. To account for this, a maximum detour of 25 percent is applied to low-stress routes when compared to overall network distance. BNA's routing algorithm takes into account both segment stress and crossing stress – a low-stress route is possible only if it does not require travel along any high-stress links or high-stress crossings. The output of this analysis is a list of census block pairs that are connected using either the low-stress links or all links.

BNA Scores

The project team calculated BNA scores for the baseline network and two network improvement scenarios. Baseline network consists of the street and bike network as it exists currently. The two network improvement scenarios show BNA scores when LTS for certain street segments are reduced to low-stress. While the segments to be included in the scenarios are considered to be low-stress, this analysis does not look at or specify the nature of the improvement that makes those segments low-stress.

Baseline Network Results

The final step of BNA is to assign a score to each block on a scale of zero to 100 based on the destinations that can be reached using both low-stress and high-stress networks with higher scores suggesting greater accessibility to destinations. The destinations used in the analysis include different categories based on the type of destinations. Each census block is assigned a score for each individual type of destination and scores are aggregated based on weights assigned to that destination type. A full list of destinations and their weights is given in Appendix B.

A location's BNA score depends on two factors: 1) whether there are destinations nearby, and 2) whether the low-stress network connects to those destinations. In other words, low-stress network is only one aspect of having accessibility to destinations. In this analysis, we calculated two types of BNA measures with each one highlighting the two factors:

- Measure 1 – A measure that highlights the difference between high-stress and low-stress networks (Figure 2).
- Measure 2 – A recalculated measure 1 that incorporates destination density (Figure 1).

Measure 1

This measure first looks at the total number of destinations of each type that are connected to each block using the high-stress network. It then looks at how many of those destinations are also accessible using only the low-stress network. The magnitude of this measure depends on the difference between the destinations accessible using the two networks. If a block does not have access to a certain type of destinations using the high-stress network, that destination sub score is not included in the final measure. This ensures that only the destination types that are reachable on the overall network within a three-mile distance are considered in the overall measure. This measure is useful in identifying locations that have a large difference in connectivity between the low-stress and high-stress networks. The result is that some outlying areas with fewer destinations show high connectivity if those destinations are accessible by both low-stress and high-stress networks.

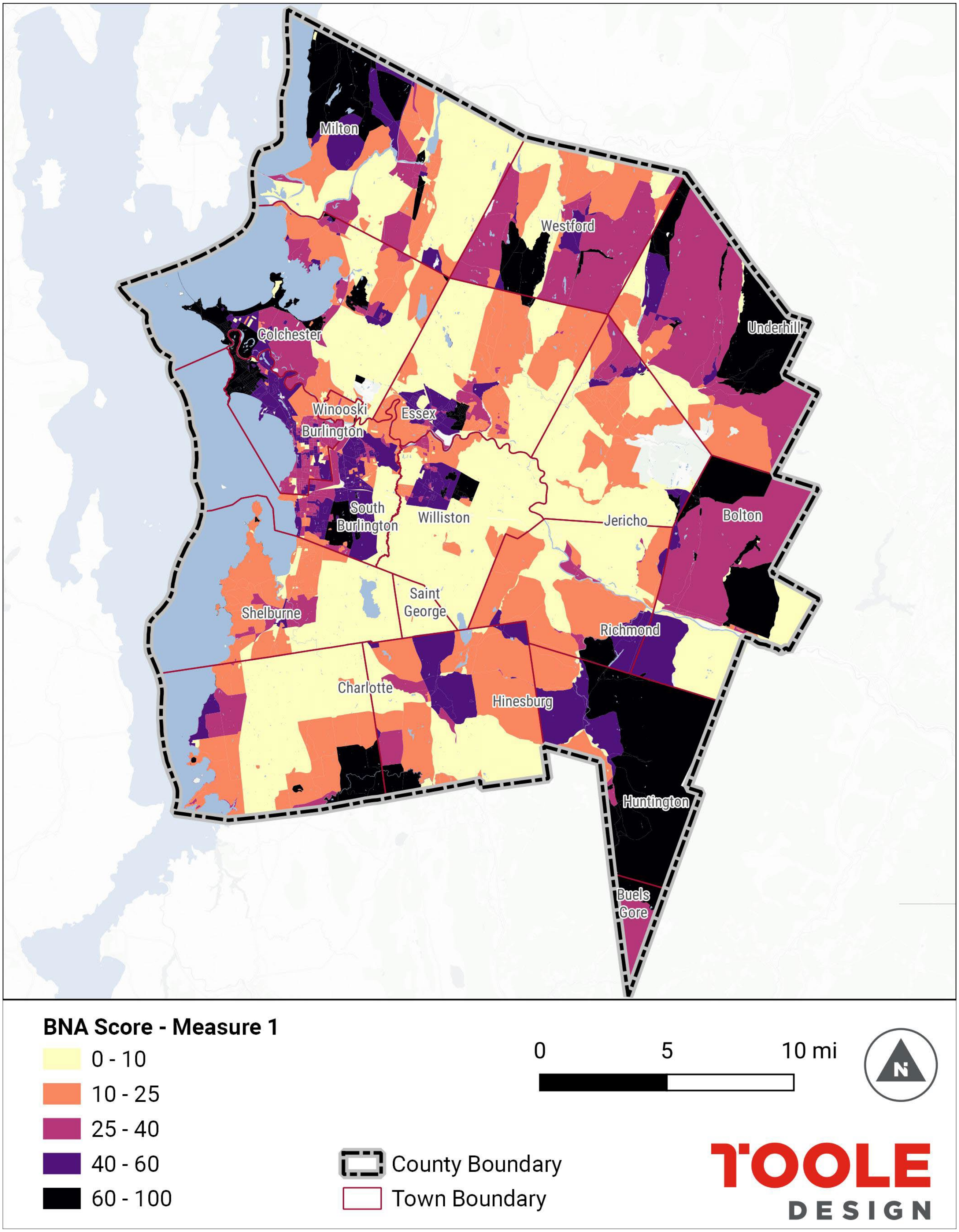

Figure 2: BNA Score - Measure 1

Measure 2

Like measure 1, this measure starts by looking at the number of destinations reachable using high-stress and low-stress networks from each block. However, any block without high-stress network access to a given destination type automatically gets a score of zero for that destination type. This means that blocks with higher scores have more destinations nearby and those destinations are accessible by low-stress network, whereas in measure 1, blocks can get higher scores even if there are not many destinations nearby. This measure is a useful way to combine the effect of both the low-stress network and proximity to destinations. As a result, destination-rich areas in and around Burlington get higher scores than the outlying areas.

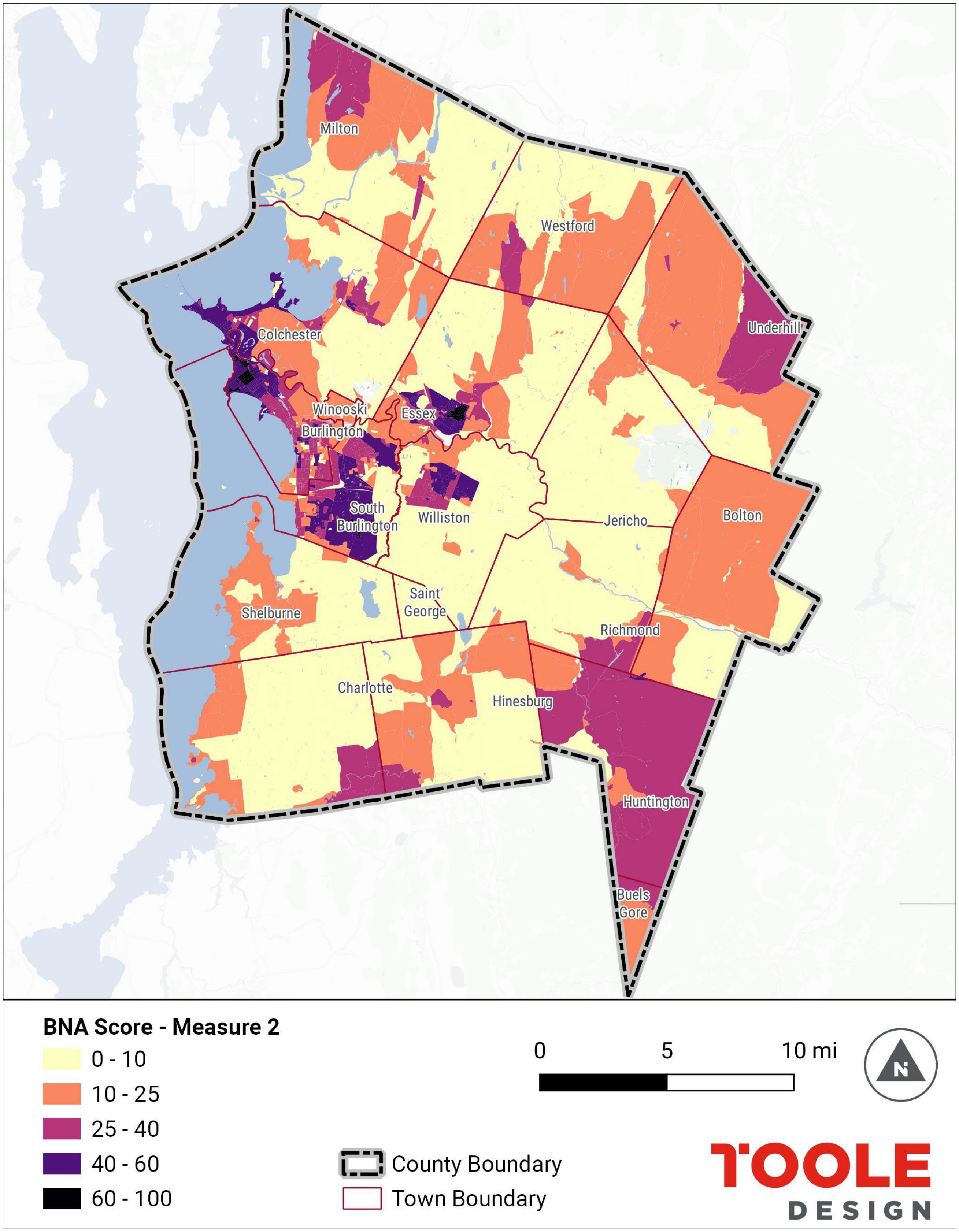

Figure 3: BNA - Measure 2

Scenario 1 – Route 2 Improvements

This scenario looks at improvements along the Route 2 corridor (Figure 4) from the Lake Champlain waterfront in Burlington, continuing through South Burlington, and ending at Tafts Corner in Williston. South Burlington received a RAISE grant to design and construct a separate walk/bike bridge over I-89 at Exit 14. This bridge will close a critical gap, and a scenario reducing LTS going both west and east to complement this project would be informative. This corridor scenario also captures several other planned projects, including Burlington's Conceptual Design of the Great Streets – Main Street project, South Burlington's Williston Road Bike/Ped Improvements between Dorset and Midas Drive/White Street in draft FY23-26 TIP, and potential active transportation facilities on Williston's draft Official Map. The scenario assumes that all the segments included (show in purple below) are low-stress (LTS 1 or 2) and any high-stress crossings along those segments are also assumed to be low-stress.

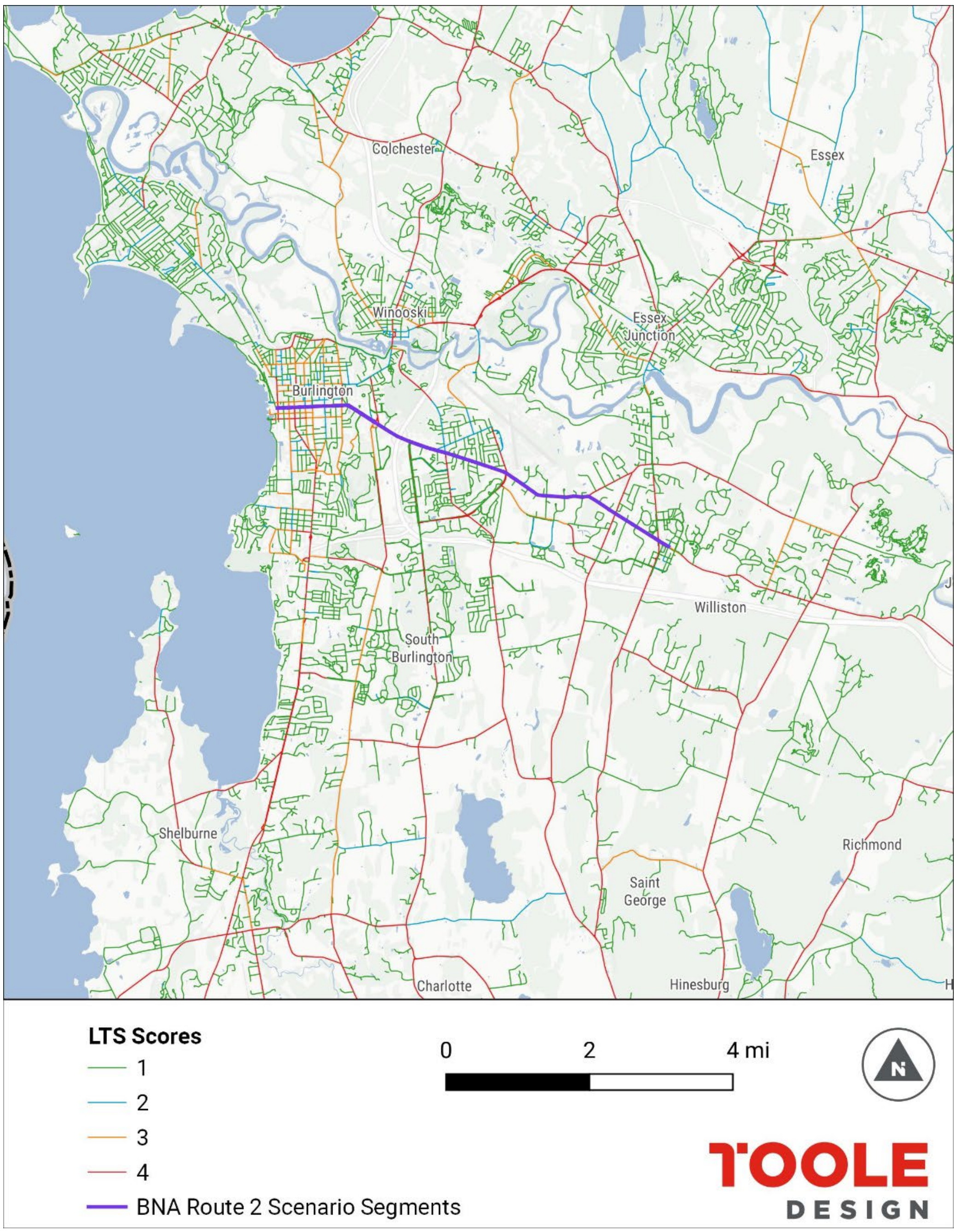

Figure 4: Route 2 Network Improvement Scenario

Scenario 1 – BNA Scores

For BNA scenario scores, access to destinations for census blocks is recalculated using a network with the scenario segments converted to low-stress. All the destination categories and weights are the same as that of the baseline network. As explained in the baseline condition, two types of scores are calculated (Measure 1 and Measure 2). These scores are shown in Figure 5 (Measure 1) and Figure 6 (Measure 2). As expected, both BNA score measures for the Census Blocks immediately adjacent to Route 2 increased since those blocks now have low-stress access to the destinations along that corridor. In addition, some blocks which are not immediately adjacent to Route 2, like those in the southern part of South Burlington, also saw improvement in BNA scores. This change indicates that network improvements along a given corridor can have a positive impact on locations away from the corridor as well. This is especially true if the improvements work to remove significant barriers to connectivity, as is the case in this scenario.

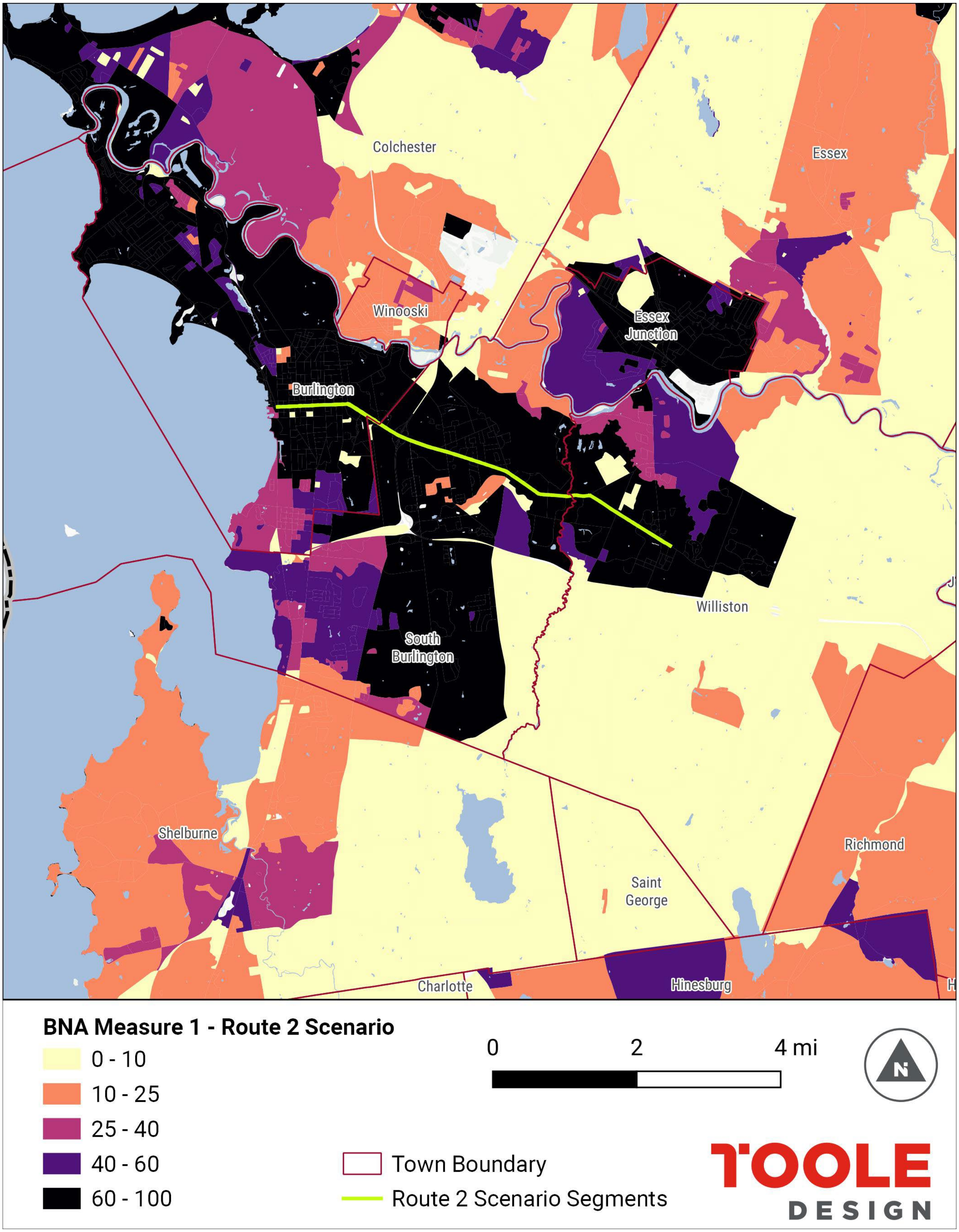

Figure 5: BNA Score - Measure 1 - Route 2 Scenario

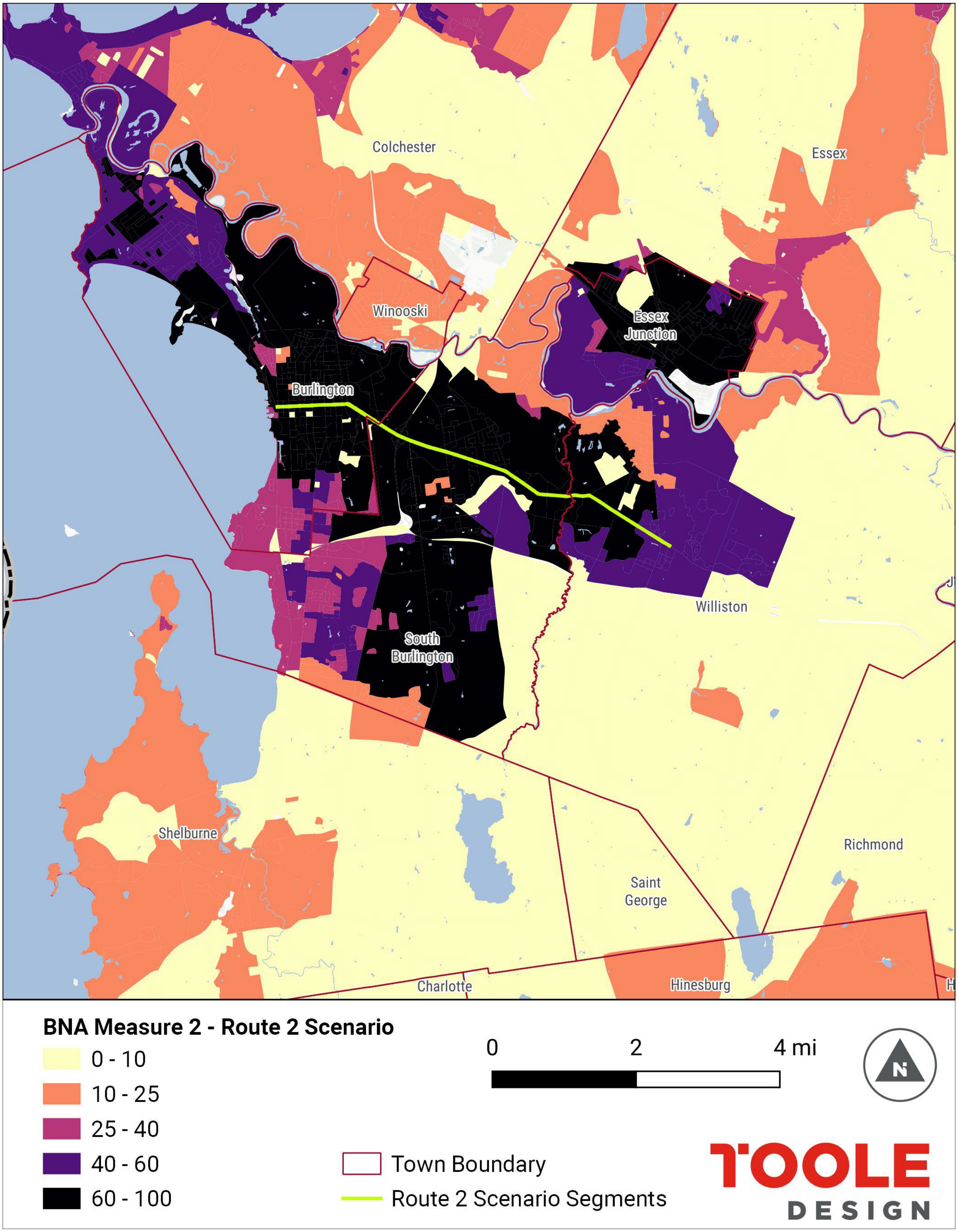

Figure 6: BNA Score - Measure 2 - Route 2 Scenario

Scenario 2 – Equity Focused Improvements

This scenario examines network improvements from an equity perspective. CCRPC staff and the project team identified candidate segments by first selecting all the high-stress segments in Census Tracts within the top 50 percent for at least one of the three equity indicators below:

1. Percent of BIPOC population
2. Percent of households without vehicle access
3. Percent of households with income below poverty level

CCRPC staff then reviewed the candidate segments and flagged segments to be included or excluded in the equity scenario. These decisions were informed by professional expertise, local knowledge, and previous planning efforts.[5] The project team made some minor adjustments to the reviewed segments to fill gaps in the review process and to select a final shortlist of scenario segments, shown in Figure 7.

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[5] Previous planning efforts include the following documents:

- Essex/Essex Junction Bike/Ped Plan
- Colchester Official Map
- planBTV Walk Bike
- Shelburne Bike Ped Connectivity Study
- Winooski Transportation Master Plan
- South Burlington Official Map

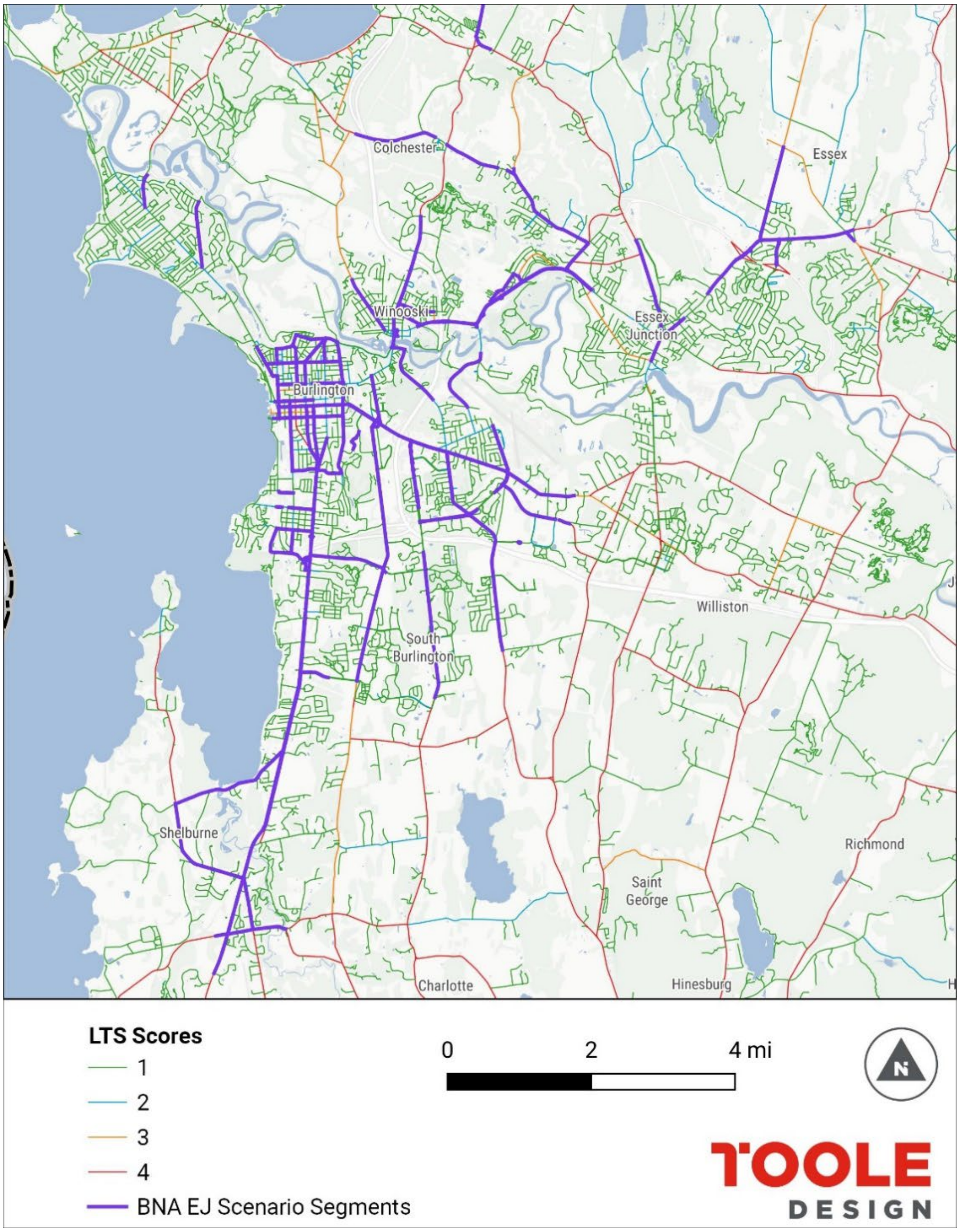

Figure 7: BNA EJ Scenario Segments

Scenario 2 – BNA Scores

As in the earlier scenario, scores were calculated by assuming that the network improvements on the selected segments lower both the segment and crossing stress values along them. The two BNA score measures are shown in Figure 8 (Measure 1) and Figure 9 (Measure 2). Since this scenario includes improvements to many high-stress segments in EJ tracts, increased BNA scores are very apparent in those tracts. Almost the all of Burlington, South Burlington, Winooski, and Essex Junction get very high scores under both BNA measures. It is also worth noting that the improvements did not extend too far beyond these scenario segments. This is likely due to higher stress on roads that connect to the scenario segments from outside the EJ tracts. While this scenario includes several network improvements that may not be possible to implement in a short time frame, these can be included in the County's long range planning efforts, as they have a quantifiably large network benefit.

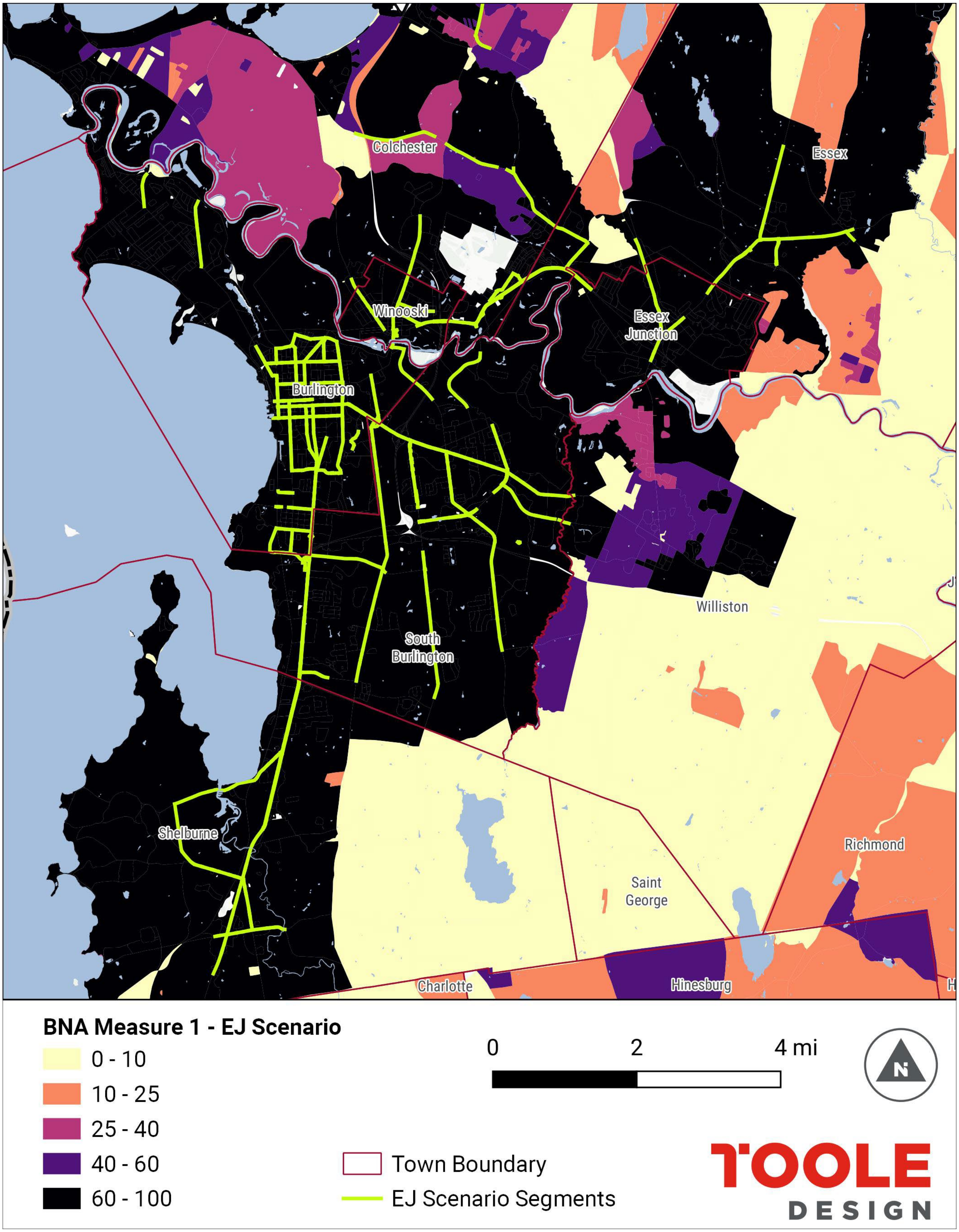

Figure 8: BNA Score - Measure 1 - EJ Scenario

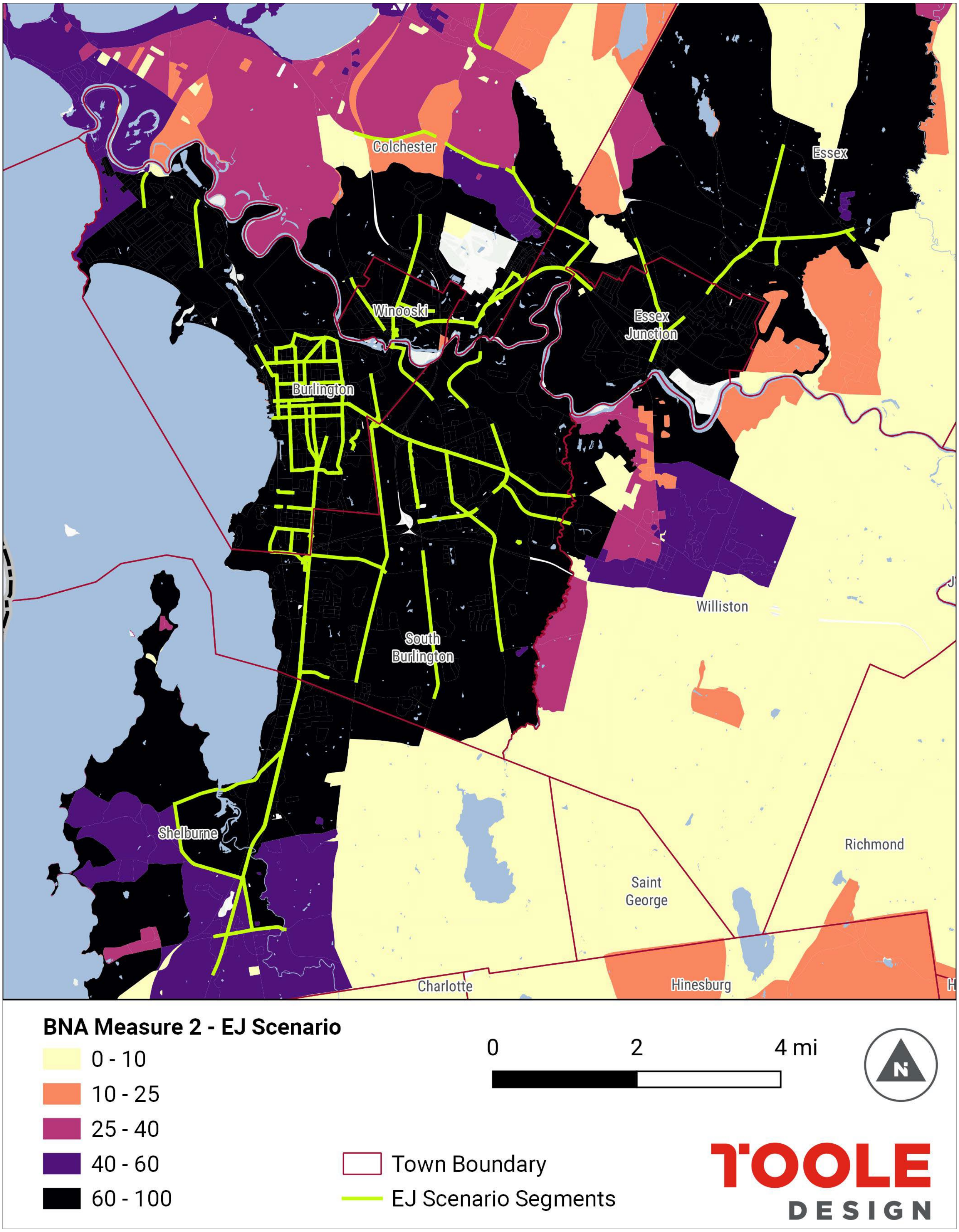

Figure 9: BNA Score - Measure 2 - EJ Scenario

APPENDIX A

LTS Tables

Mixed traffic criteria

Number of lanes	Effective ADT*	Prevailing Speed ≤ 20 mph	25 mph	30 mph	35 mph	40 mph	45 mph	50+mph
Unlaned 2-way street (no centerline)	0-750	LTS 1	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	751-1500	LTS 1	LTS 1	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4
	1501-3000	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
	3000+	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
1 thru lane per direction (1-way, 1-lane street or 2-way street with centerline)	0-750	LTS 1	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	751-1500	LTS 2	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4
	1501-3000	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4
	3001-6000	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
	6001-10000	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
	10001+	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
2 thru lanes per direction	0-6000	LTS 3	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
	6001-12000	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
	12001+	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
3+ thru lanes per direction	any ADT	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4

* Effective ADT = ADT for two-way roads; Effective ADT = 1.67*ADT for one-way roads

Bike lanes and shoulders not adjacent to a parking lane

Number of lanes	Bike lane width	Prevailing Speed ≤ 25 mph	30 mph	35 mph	40 mph	45 mph	50+ mph
1 thru lane per direction, or unlaned	6+ ft	LTS 1	LTS 1	LTS 2	LTS 3	LTS 3	LTS 4
	4 or 5 ft	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4
2 thru lanes per direction	6+ ft	LTS 2	LTS 2	LTS 3	LTS 4	LTS 4	LTS 4
	4 or 5 ft	LTS 2	LTS 2	LTS 3	LTS 4	LTS 4	LTS 4
3+ lanes per direction	any width	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4

Notes
1. If bike lane / shoulder is frequently blocked, use mixed traffic criteria.
2. Qualifying bike lane / shoulder should extend at least 4 ft from a curb and at least 3.5 ft from a pavement edge or discontinuous gutter pan seam
3.Bike lane width includes any marked buffer next to the bike lane.

Bike lanes alongside a parking lane

Number of lanes	Bike lane reach = Bike + Pkg lane width	Prevailing Speed ≤ 20 mph	25 mph	30 mph	35 mph	40+ mph
1 lane per direction	15+ ft	LTS 1	LTS 1	LTS 2	LTS 2/3*	LTS 4
	14 ft	LTS 2	LTS 2	LTS 2/3*	LTS 3	LTS 4
	12-13 ft	LTS 2	LTS 2/3*	LTS 2/3*	LTS 3	LTS 4
2 lanes per direction (2-way) 2-3 lanes per direction (1-way)	15+ ft	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4
	14 ft	LTS 2/3*	LTS 2/3*	LTS 3	LTS 4	LTS 4
	12-13 ft	LTS 2/3*	LTS 2/3*	LTS 3	LTS 4	LTS 4
other multilane		LTS 3	LTS 3	LTS 3	LTS 4	LTS 4

Notes
1. If bike lane is frequently blocked, use mixed traffic criteria.
2. Qualifying bike lane must have reach (bike lane width + parking lane width) ≥ 12 ft
3.Bike lane width includes any marked buffer next to the bike lane.
* Rating depends on parking turnover. Low turnover (i.e. residential) = LTS 2, high turnover (i.e. commercial or mixed use) = LTS 3

APPENDIX B

BNA Destinations

Category	Category Weight	Category Destinations	Destination Weight
People	15	Population - Block level	N/A
Opportunity	20	Jobs - Block level	35
		Schools	35
		Colleges	10
		Universities	20
Core Services	20	Doctors	20
		Dentists	10
		Hospitals	20
		Pharmacies	10
		Supermarkets	25
		Social Services	15
Recreation	15	Parks	60
		Community Centers	40
Retail	15	Retail Locations from OSM	N/A
Transit	15	Bus stops and stations from OSM	N/A