



Feasibility Study for the Expansion of

# BIKE SHARE TORONTO

Prepared for:  
The Toronto Parking Authority



April 2016

## STUDY TEAM

### Toronto Parking Authority

- Marie Casista

### City of Toronto Transportation Services

- Alyssa Krantzberg
- Dilya Niezova
- Adam Sweanor
- Sean Wheldrake

### Motivate Company Toronto Inc. Operator of Bike Share Toronto

- Scott Hancock

### WSP | MMM

- Aaron Baxter
- Shawn Chow
- Jay Cranstone
- Kris Hall
- Dave McLaughlin
- Jason Neudorf

Unless otherwise noted, photos in this report are from WSP | MMM.



# CONTENTS

<b>SUMMARY</b>	<b>1</b>
<b>BACKGROUND</b>	<b>2</b>
<b>What is Bike Share Toronto?</b>	2
<i>Bike Share &amp; Public Policy</i>	2
<i>Why Bike Share Is Important</i>	3
<b>About this Study</b>	6
<b>Characterization of the Existing Network</b>	7
<b>METHODOLOGY</b>	<b>8</b>
<b>Bike Share Ridership Factors</b>	8
<b>Bike Share Ridership Potential Mapping</b>	9
<b>Model Validation</b>	10
<b>Identifying Areas for Expansion</b>	11
<b>RESULTS AND RECOMMENDATIONS</b>	<b>13</b>
<b>Expansion from the Existing Network</b>	13
<i>Phase 1</i>	13
<i>Phase 2</i>	15
<i>Phase 3 – 5</i>	15
<b>Satellite Expansion</b>	16
<i>Phase 1</i>	16
<i>Phase 2</i>	17
<b>Recommendation and Principles for Station Siting</b>	18
<b>Recommendations for Future Evaluation</b>	18
<b>CONCLUSION</b>	<b>19</b>

## FIGURES

<b>Figure 1 - Existing ridership usage by month and rider type</b>	7
<b>Figure 2 - Bike Share Station Potential Surface</b>	10
<b>Figure 3 - Proposed Expansion Areas</b>	12
<b>Figure 4 - Proposed Satellite Expansion Areas</b>	12
<b>Figure 5 - Phase 1 expansion from the existing network</b>	14
<b>Figure 6 - Phase 2 expansion from the existing network</b>	14
<b>Figure 7 - Initial Satellite Expansion Area</b>	16
<b>Figure 8 - Phase 2 Satellite Expansion Area</b>	17

## APPENDICES

<b>Appendix 1 - Detailed Explanation of the Indicators</b>	
<b>Appendix 2 - Maps</b>	
<b>Appendix 3 - References</b>	



## SUMMARY

In 2015, the Toronto Parking Authority -operators of Bike Share Toronto-committed to expanding the existing bike share network by up to 100 stations and associated bikes annually. The first 100 stations will be realized in partnership with Metrolinx. This will be a significant expansion to the existing 80 station bike share network. The TPA retained MMM Group Limited to assist staff in developing a framework for prioritizing expansion. A spatial analysis model was developed to identify positive growth areas and illustrate the relative potential and challenges to bike share usage across the City of Toronto. This report details the methodology used to develop the framework, and how it can be applied to minimize expansion risks and maximize benefits to Bike Share Toronto, its users and the communities across Toronto that host the network.

Drawing on a combination of data sources, MMM developed a series of data-driven indicators that were combined into a spatial model, or map, illustrating bike share ridership potential across the entire City.

After verifying the predictive potential of the ridership model through regression analysis against the performance of existing Bike Share Toronto stations, GIS spatial analysis techniques were used to identify areas of least risk for expansion under two lenses. The first lens addressed generally contiguous expansion of the existing network, while the second addressed possible locations for new satellite networks anchored around TTC and GO Transit hubs.

The analysis results were used to generate more detailed recommendations to guide the initial phases of bike share expansion, as well as strategic recommendations for future updates and refinement of the analysis model and expansion program. These include recommendations regarding how new data sources can be incorporated into the framework and how station usage data from the early expansion phases can be analyzed and used to strengthen and refine the predictive and descriptive capacity of the analysis model.



# BACKGROUND

## WHAT IS BIKE SHARE TORONTO?

Bike Share Toronto is a bike sharing system in the City of Toronto that provides an active transportation option that complements Toronto's broader multi-modal transportation system. The bike share system was initiated in 2011 and was transferred to the Toronto Parking Authority in 2014. TPA re-branded the program as Bike Share Toronto and contracted Motivate to be the service provider and operator of the program.

Bike Share Toronto operates with approximately 1,000 purpose-built bicycles spread across 80 self-serve docking stations located throughout the City's Downtown. Bikes can be rented and returned to any docking station within the system. The system operates year-round, 24 hours a day, 7 days a week and is designed to extend and enhance the public transit system and support personal mobility by encouraging one-way bike share trips less than 30 minutes in duration.

Bike Share Toronto caters to both one-time / infrequent users as well as regular users who generally purchase memberships ranging from a month to a year in duration. These members receive a physical key that enables them to unlock a bike from the docking stations. Casual users, or "short-term" members, can also access the system by purchasing 24- or 72-hour passes from any station kiosk with a credit card. No additional trip fees are charged to either long-term or short-term members if a bicycle is returned to any bicycle docking station within 30 minutes. Additional incremental fees are charged, however, for trips longer than 30 minutes.

## Bike Share & Public Policy

The Toronto Official Plan is a 20 year plan that outlines the long term vision, objectives and policies of the City with respect to safe and sustainable growth and development; the conservation of natural and cultural heritage; and the provision of the necessary infrastructure. In particular, the Plan addresses how the City will facilitate more desirable travel patterns and encourage more sustainable travel behavior over this timeframe. Key goals, objectives and policies in the Plan refer to:

- ▶ encouraging cycling as a preferred, more efficient mode for making local trips and reducing car dependency;
- ▶ supporting transit by creating cycling linkages to transit stations;
- ▶ fostering safer and more attractive conditions for cycling; and,
- ▶ promoting cycling as a healthier clean-air alternative to other modes of travel.

At the time of this Report, the City is in the midst of an Official Plan Review; undertaking a number of studies which will culminate in a comprehensive update to the Plan. The review and update to the transportation policies of the Plan, entitled "Feeling Congested", was adopted by Council in 2014, and is in various stages of implementation. This update established a Bicycle Policy Framework that targets an increase in cycling modal share to at least 20% of all trips within the Downtown and surrounding areas and an expansion of the bike sharing system to 5,000 bicycles.<sup>1</sup>

The existing and emerging planning policies outlined above stem in part from priorities established by the Toronto Bike Plan – adopted in 2001 and updated in 2009. In particular, the 2009<sup>2</sup> update included a "strategic direction" to launch a "public bicycle

<sup>1</sup> <http://www1.toronto.ca/City%20Of%20Toronto/Feeling%20Congested/PDFs/FeelingCongestedToolkit-Web.pdf>

<sup>2</sup> <http://www.toronto.ca/legdocs/mmis/2009/pw/bgrd/backgroundfile-21588.pdf>



system” which would eventually become Bike Share Toronto<sup>3</sup>. Accordingly, the City has pursued infrastructure and policy initiatives to reinforce and support a public bike share system, including the expansion of cycling lanes and trails along key corridors throughout the City and encouraging the provision of bike share stations in new developments<sup>4</sup>.

## Why Bike Share Is Important

Public bicycle systems can have numerous benefits for

a city and its inhabitants, ranging from the reduction of congestion and emissions, to promoting healthy living through cycling and providing residents and visitors with an active mobility option. Furthermore, these systems can have comparatively low implementation and maintenance costs and short implementation timeframes relative to other types of transportation investments.<sup>5</sup> For reference, Bike Share Toronto registered 1.25 million trips between October 2014 and September 2015, translating into at least 3,000 km/day.

## Benefits of public bike systems can include:



### Transportation Demand Management

- ▶ Public bicycle systems increase the number of trips made by bicycle in cities that have launched major programs. This reduces the need for trips on other modes, particularly for short trips that might otherwise have been made by car. This can have a positive impact on congestion.<sup>6</sup>
- ▶ Public bicycle programs increase the reach of transit and walking trips, serving to fill the gap between a user’s transit stop and their final destination, and allowing users to access locations that would otherwise be out of reach on foot.<sup>7</sup>



### Affordability and Equity

- ▶ The cost of cycling or ability to own a bicycle may be prohibitive to some. A public bicycle system offers opportunities for people to cycle who may otherwise not have had the opportunity to do so due to a lack of access to a bicycle, or the availability of secure bicycle parking.
- ▶ Public bicycle systems represent an important opportunity to provide practical and more affordable transportation options to individuals who choose not to own a motor vehicle, as well as support lower income communities, which may have low automobile ownership rates and high transit dependency.
- ▶ The annual Bike Share Toronto membership equates to \$7.50 per month, making it one of the most cost-effective means of moving about within the Bike Share Toronto area of coverage.

<sup>3</sup> <http://www.toronto.ca/legdocs/mmis/2010/pw/bgrd/backgroundfile-28853.pdf>

<sup>4</sup> <http://www.toronto.ca/legdocs/mmis/2014/pg/bgrd/backgroundfile-71992.pdf>

<sup>5</sup> The Bike-share Planning Guide, Institute for Transportation & Development Policy, New York, 2013.

<sup>6</sup> <http://www.planetizen.com/node/80576/study-capital-bikeshare-reduces-congestion>

<sup>7</sup> Fuller et al., Impact Evaluation of a Public Bicycle Share Program on Cycling: A Case Example of BIXI in Montreal, Canada, American Journal of Public Health, January 17, 2013. P.e1





### Public Health

- ▶ Cycling contributes to overall physical activity, which is associated with a number of physical health benefits; including reduced body mass index (BMI), reduced risk of heart disease, stroke, and other chronic life-threatening illnesses.<sup>8</sup> Cycling can also have a positive impact on mental health. To this end, a public bike system provides an opportunity to increase access to physical activity and potentially lower costs associated with health care.
- ▶ Bike share systems provide a healthy transportation option and, by virtue of increasing access to bicycles, can increase the likelihood that the local population will cycle.<sup>10</sup>
- ▶ Studies have shown that bike sharing programs have been helpful in attracting new cyclists and encouraging riders to cycle more often.<sup>11</sup>
- ▶ Evidence also exists to indicate that commuting by walking or cycling increases commute well-being. A study conducted in Portland identified bike commuters as having the highest measure of commute well-being.<sup>12</sup>



### Environment

- ▶ Cycling is a sustainable transportation option, and studies have shown associations between cycling for transportation and reduced noise and air pollution.
- ▶ A public bicycle program aligns well with the City of Toronto's sustainable transportation and environmental objectives. In particular, Toronto's sustainable transportation strategy seeks to achieve an 80% reduction in greenhouse gas emissions in the City by 2050 from 1990 levels. Public bicycle programs have significantly increased the number of trips made by bicycles in cities that have launched major programs. Studies have shown that public bicycle programs have contributed to reductions in personal vehicle trips and associated greenhouse gas emissions.<sup>14</sup>



### Economy and Tourism

- ▶ Public bicycle programs have been able to reduce the personal cost of urban transportation for users.<sup>15</sup>
- ▶ A public bicycle system can help communities attract and retain residents.<sup>16</sup>
- ▶ National and international press coverage of public bicycle systems can promote the City to visitors, businesses, and employers.

<sup>8</sup> Birmingham Bikeshare Feasibility Study, Regional Planning Commission of Greater Birmingham, 2014. P.6

<sup>9</sup> Obis. Optimising Bike Sharing in European Cities: A Handbook. June 2011.

<sup>10</sup> <http://ajph.aphapublications.org/doi/pdf/10.2105/AJPH.2012.300917>

<sup>11</sup> The Bike-share Planning Guide, Institute for Transportation & Development Policy, New York, 2013.

<sup>12</sup> <http://bikeportland.org/2013/01/30/bike-commuters-are-happiest-and-other-psu-research-tidbits-82448>

<sup>13</sup> Fuller et al., Impact Evaluation of a Public Bicycle Share Program on Cycling: A Case Example of BIXI in Montreal, Canada, American Journal of Public Health, January 17, 2013. P.e1

<sup>14</sup> In its first season of operation, users of the Denver B-Cycle public bicycle system took over 100,000 trips and rode more than 200,000 miles (321,870 km). A survey of members showed that over 40% of trips replaced a vehicle trip, resulting in nearly a 16,000 gallons (60,570 litres) savings in gasoline consumption and avoiding over 300,000 pounds (136,080 kg) of greenhouse gas emissions. Noted in 2011 Annual Report. B-Cycle Denver. Retrieved from <https://denver.bcycle.com/docs/librariesprovider34/default-document-library/annual-reports/dbs-2011-annual-report.pdf?sfvrsn=2>

<sup>15</sup> Birmingham Bikeshare Feasibility Study, Regional Planning Commission of Greater Birmingham, 2014. P.7

<sup>16</sup> Birmingham Bikeshare Feasibility Study, Regional Planning Commission of Greater Birmingham, 2014. P.8



- ▶ Bike Share Toronto helps to achieve the goals of the Toronto Bike Plan with respect to supporting bicycle tourism in the City, as public bicycle systems can provide a new and different way for tourists to see the City, which in turn can assist in strengthening Toronto’s economic benefits from tourism.
- ▶ Cities that implement public bicycle systems may strengthen their image as “green” or innovative cities, as public bicycle systems are associated with sustainable, technology-inspired cities.<sup>17</sup>
- ▶ The increased visibility of bicycles throughout a city can assist in transforming a city’s cycling culture.
- ▶ A public bicycle system also creates local jobs associated with the operation and maintenance of the system, as well as provision of the operations.
- ▶ Public bicycle systems can help to generate investment in local businesses within the service area. Studies have shown that businesses located in proximity to public bicycle stations experience an increase in economic activity.<sup>18</sup>

<sup>17</sup>The Bike-share Planning Guide, Institute for Transportation & Development Policy, New York, 2013.

<sup>18</sup>A study undertaken in Minneapolis/St. Paul in 2012, noted that bike share users spent an additional \$150,000 at businesses located in the vicinity of a bike share station over the course of one season. Noted in Birmingham Bikeshare Feasibility Study, Regional Planning Commission of Greater Birmingham, 2014. P.9



## ABOUT THIS STUDY

Recognizing the growing demand for cycling and multi-modal travel choices, the TPA has committed to expanding Bike Share Toronto.<sup>19</sup> The expansion seeks to expand to up to 500 new docking stations and up to 5,000 new bicycles over a five year period. TPA has formed a partnership with Metrolinx to realize the first year of expansion through an investment of \$4.9 million which translates to approximately 1000 new bikes and associated docking stations in the City of Toronto and the GTHA. Approximately 90% of these stations will be located outside of the current service area, with the remaining 10% of stations used to increase the density of stations within the existing service area. Overall, this constitutes a fivefold expansion of the current system, and will play a transformative role in the future of Bike Share Toronto and transportation in the City of Toronto.

To assist Bike Share Toronto, and its funding partners, the Toronto Parking Authority retained MMM Group Limited to develop a feasibility framework for system expansion. The Framework is designed to assist Bike Share Toronto to identify areas of higher ridership potential as well as provide contextual information to facilitate system optimization and efficiencies. It formalizes the current understanding of the contributing factors that impede or promote bike share ridership, based on the study team's research into bikeability theory<sup>20</sup>, lessons from bike share systems around the world and our expertise in spatial data and analysis techniques.

Throughout the study process, the study team met at key milestones to discuss the study approach, available data, and review preliminary findings. Discussion and comments from those meetings were incorporated into subsequent analyses through an iterative and collaborative process. This feedback from staff at the TPA, Bike Share Toronto and its operator, Motivate, was instrumental in developing a sound understanding of Bike Share Toronto operations and in guiding the structure of the Framework.

The centrepiece of the Framework is a GIS model that can assess the validity of potentially relevant

data sources, as well as allow any number of the verified inputs to be incorporated into a single, easily interpreted, indicator of bike share ridership potential. The model was developed and tested with existing spatial information sources available to the Study Team and Bike Share Toronto. The initial model outputs are intended to be used as due diligence results to help Bike Share Toronto minimize risks in their initial stages of system expansion. Recommendations from this study indicate how this output should be used to guide expansion and how future revisions and iterations of the model could be made to improve the accuracy and precision of predicting ridership potential and optimum station location analysis.

Although the study establishes a methodology and framework for delineating areas of future expansion, it is not intended, at this time, for its initial results to form a comprehensive and prescriptive plan that should dictate precisely where and when expansion should occur. Rather, the study recommends areas for expansion which are thought to pose a reduced risk and maximum benefit to Bike Share Toronto, but which will still be subject to more detailed local-level analysis by TPA and the operator. While the initial study results assist in identifying areas of high ridership and station potential, it is anticipated that the continual inclusion of actual performance data after each subsequent phase of expansion will improve the potential of the model to granularly and reliably predict the magnitude of ridership at any candidate station location.

This study does not assume a particular docking station or bicycle equipment technology, focussing rather on the relative potential for bike share ridership regardless of the functionality and operational characteristics of the equipment.

It is also assumed that the study recommendations will be subject to specialized financial and business planning analysis as equipment is confirmed and implementation is advanced, as this was not part of the current scope of this study.

<sup>19</sup> <http://www.thestar.com/news/gta/transportation/2015/07/06/bike-share-toronto-to-double-with-49-million-from-metrolinx.html>

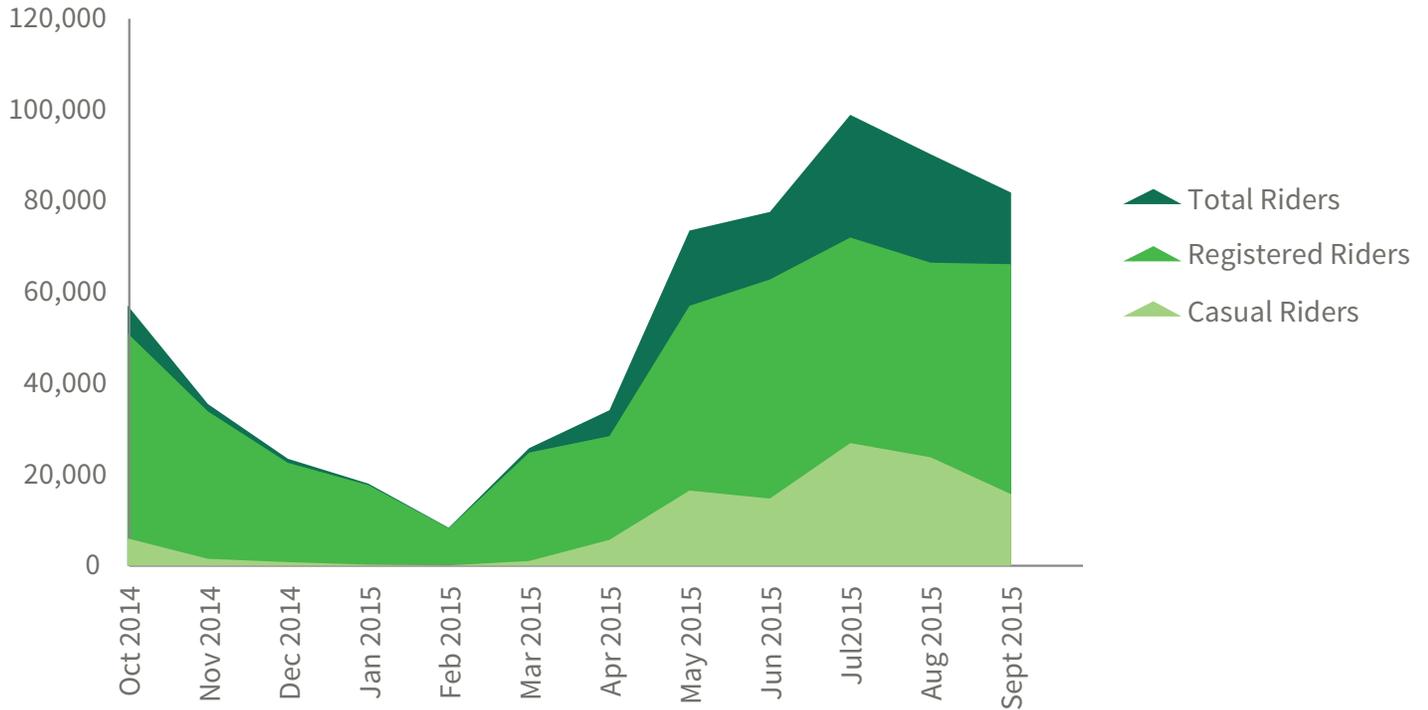
<sup>20</sup> <https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676>



## CHARACTERIZATION OF THE EXISTING NETWORK

The existing bike share network consists of 80 stations with a service area of approximated 12.4km<sup>2</sup>, or an average density of roughly 6.5 stations / km<sup>2</sup>. The average distance between stations is 328m, with the minimum distance being 130m and the maximum

651m. Preliminary examination of ridership data reveals that there is a notable difference in bike share usage patterns between casual and registered users, as well as at different points of the year. Figure 1 shows the distribution of trips taken by casual and registered users over a 12 month period.



**Figure 1** - Existing ridership usage by month and rider type



# METHODOLOGY

The methodology used to select data sources and determine how they should be combined into an overall measure for bike share potential and interpreted to inform study recommendations can be described in four steps. These categories speak to the identification of bike share ridership factors, integrating these factors into a single model or mapped indicator, validation of the model or indicator and interpretation.

## BIKE SHARE RIDERSHIP FACTORS

Bike share ridership is influenced by a wide range of factors. This study, while not exhaustive, considers the relative value of some of the most prominent factors raised in professional and academic literature on the topic<sup>21,22</sup>. Through the course of identifying factors for consideration, a set of inclusion criteria

were developed. This set of criteria were used to screen data sources prior to their inclusion in the analysis undertaken, in order to identify the most relevant factors that influence bike share ridership in the context of this study. Inclusion criteria for data sources consisted of the following:

1. Provide comprehensive coverage across the geographic extent of the City of Toronto; and
2. Demonstrate an observed correlation in literature, or a correlation that could be reasonably expected, between the data source and bike share ridership.

Data sources collected were used to develop a set of twenty-two (22) potential indicators. These indicators were classified into four categories that consider their effect on bike share ridership:



### 1. Population and employment densities: A higher concentration of people would correlate to increased ridership.

#### The indicators in this category are:

- a. Population density
- b. Job density
- c. High density residential land use
- d. Density of likely Bike Share Toronto users
- e. Density of recent residential development



### 2. Attractions and Points of Interest: Higher concentrations of Toronto attractions would correlate to increased ridership.

#### The indicators in this category are:

- a. Proximity to the lakeshore and waterfront
- b. Proximity to city parks
- c. Business Improvement Areas
- d. Hotels
- e. Cultural spaces
- f. Places of interest
- g. University and college campuses



<sup>21</sup> [http://ascelibrary.org/doi/abs/10.1061/\(ASCE\)UP.1943-5444.0000273](http://ascelibrary.org/doi/abs/10.1061/(ASCE)UP.1943-5444.0000273)

<sup>22</sup> <https://bikepedantic.files.wordpress.com/2012/08/cabi-trb-paper-revision-final.pdf>



### 3. **Bikeability: Areas that are perceived to be conducive to cycling activity would correlate to increased ridership.**

The indicators in this category are:

- Topography
- Intersection density
- Proximity to cycling infrastructure
- Proximity to population serving businesses



### 4. **Transportation Mode: The typical modes that people choose to travel about the City would correlate to ridership in terms of the likelihood for Bike Share to replace or extend a trip segment.**

The indicators in this category are:

- Total non-auto origin and destination trips
- Ratio of walking trips to auto trips
- Ratio of cycling trips to auto trips
- Proximity to frequent walking routes
- Proximity to frequent cycling routes
- Proximity to rapid transit stations

**Appendix 1** provides greater detail for each of the indicators, including descriptions, data sources, data types, references, and potential sources of uncertainty.

#### BIKE SHARE RIDERSHIP POTENTIAL MAPPING

A variety of spatial processing techniques were used to develop a grid of 30m-wide analysis zones or cells, covering the entire City of Toronto, for each of the twenty-two indicators. For each grid cell, a value was assigned for the vector and magnitude of each indicator at that location. In order to combine indicator grids into an overall measure for bike share ridership potential, it was first necessary to normalize or standardize each grid to a common scale. This was carried out by proportionally rescaling the results of each indicator grid to a value between 1 (low potential to influence ridership) and 10 (high potential to influence ridership). This process also assigned equal weight to each grid indicator (e.g. topography is

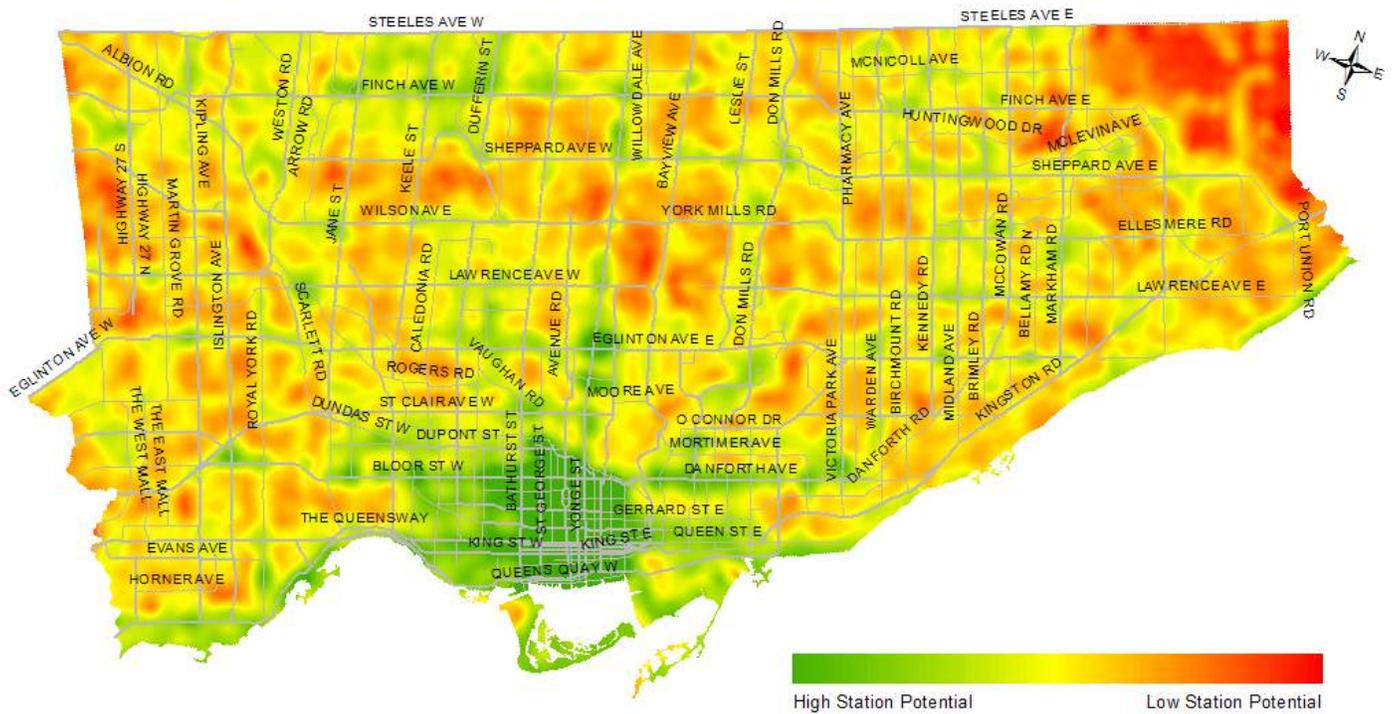
no more or less influential than population density to ridership potential).

All of the individual grids were then combined into a single surface or map by taking the sum of all values within each 30m<sup>2</sup> cell. This resulted in an overall bike share ridership potential score between 22 (lowest potential) to 220 (highest potential). Assuming that a bike share station service area can be approximately represented by a 300m radius around the actual station, an overall Bike Share Station Potential Surface<sup>23</sup> was calculated by determining the average ridership potential value within 300m of each 30m<sup>2</sup> grid cell. This allows a new value to be calculated for each grid cell that represents the relative potential of a bike share station within its 30m<sup>2</sup> area. The results of this process are shown in Figure 2.

A larger format of this map and all other maps in this report have been included in **Appendix 2**.

<sup>23</sup>A “surface” is a term from GIS which indicates a continuous uninterrupted area spanning the entire City.





▲ **Figure 2 - Bike Share Station Potential Surface**

## MODEL VALIDATION

Multiple linear regression analysis was conducted against station usage data from the existing 80 stations in the downtown network to test the Bike Share Station Potential Surface described in the previous section. MMM was provided with Bike Share Toronto ridership data from October 2014 to September 2015. From this, the total number of trips originating and departing from each station was calculated, providing a measure of total trips per year per station. This was used as the independent variable in the regression analysis. The primary dependent variable was taken as the average value of the four (4) closest 30m<sup>2</sup> cells in the Bike Share Station Potential Surface. The number of docks per station and the distance to the next bike share station was controlled for by adding both values as dependent variables.

The results of this analysis indicated a strong correlation ( $p = 5.9e-7$ ) between the Bike Share Station Potential Surface and observed station usage<sup>24</sup>, with a low, though acceptable, coefficient of determination (adjusted  $R^2 = 0.23$ ). Although this demonstrates insufficient correlation to enable the model to predict precise ridership numbers, it is thought to be strong enough to indicate ridership potential. It is anticipated that the continual inclusion of actual performance data after each subsequent phase of bike share network expansion will improve correlation and enable predictive uses. This topic is discussed in the Recommendations for Future Evaluation section.

<sup>24</sup> A low “p” value here suggests we can reject the null hypothesis with 99% confidence, or that we can’t say there is no correlation.



## IDENTIFYING AREAS FOR EXPANSION

Based on funding available, including Metrolinx partner funding, it is projected that Bike Share Toronto could grow by approximately 100 additional stations each year for the next five years. Of the approximately 100 new stations per year, we make the assumption that 90 of these would be located adjacent to or outside of the existing service area and the remaining 10 would be deployed within the existing service area.

Drawing from existing research on bike share systems, retaining a relatively dense and contiguous network of stations is important for the success of any bike share system.<sup>25</sup> In other words, the success of a bike share system is dependent on the providers ability to “connect the dots” with contiguous areas of high potential for bike share stations.

To establish maximum and minimum station density limits for the expansion areas, a 300m route buffer<sup>26</sup> was calculated from each existing station in the bike share system to average station catchment or service areas. From this, it was calculated that the existing network operates at density of roughly 6.5 stations / km<sup>2</sup>. This figure was assumed to be the maximum density for the expansion areas under the assumption that the existing downtown network will remain as is or more dense than the expansion areas for the foreseeable future. Results from the Toronto Bike Share Customer Survey were used to establish the minimum station density. This survey revealed that station distances beyond a 5-10 minute walk (or roughly 420m – 840m assuming a walking speed of 1.4 m/s) are a significant deterrent to bike share use. Based on this constraint, a minimum density value of 4 stations / km<sup>2</sup> was established, which is equivalent to approximately one station for every 500m (~6 minute walk). Thus, to accommodate the provision of 90 stations, each phase of the expansion area would have to be between 13.8 km<sup>2</sup> and 22.5 km<sup>2</sup> in size.

While the model developed in this study provides a framework for expansion which could, in theory, be used to calculate expansion areas over the next 5

years and beyond, the initial results are based solely on performance characteristics from the existing downtown-based system. For this reason, the study team recommends a limited two staged expansion in areas considered to have the “least risk” for expansion. “Least risk”, for the purposes of the recommendation is defined as areas with higher contiguous station potential in proximity to either the existing bike share network or in proximity to rapid transit stations (TTC Subway / RT stations or GO Train stations). Data collected during these two stages of expansion should then be used to refine and calibrate the model for subsequent years or phases of expansion.

To identify areas of “least risk”, a network analyst<sup>27</sup> dataset was created, based on the City’s street network. Highways where cycling is prohibited were removed (e.g. Highway 401, Gardiner Expressway/ Queen Elizabeth Way, Don Valley Parkway, Highway 427 etc.), and existing Bike Share, Toronto Transit Commission (TTC) Subway / Rapid Transit, and GO train station locations were added. These station locations were established as points of origin for expansion for study purposes. A key consideration in the network analysis was that any expansion should either radiate from the existing network or, in the case of satellite expansion, stem from a TTC or GO train station. An impedance layer<sup>28</sup> was therefore added to the network dataset based on the Bike Share Station Potential Surface which allowed the expansion into higher potential areas to be favoured over lower potential areas. To further accentuate higher potential areas, areas with the lowest ridership potential were classified as barriers to expansion and excluded from further consideration.

Using the density guide of 4.0 to 6.5 stations / km<sup>2</sup>, breakpoints were set in the model such that adequately sized areas for 90 stations were identified. Figure 3 presents the results for expansion stemming from the existing network.

An evaluation of areas for potential satellite networks

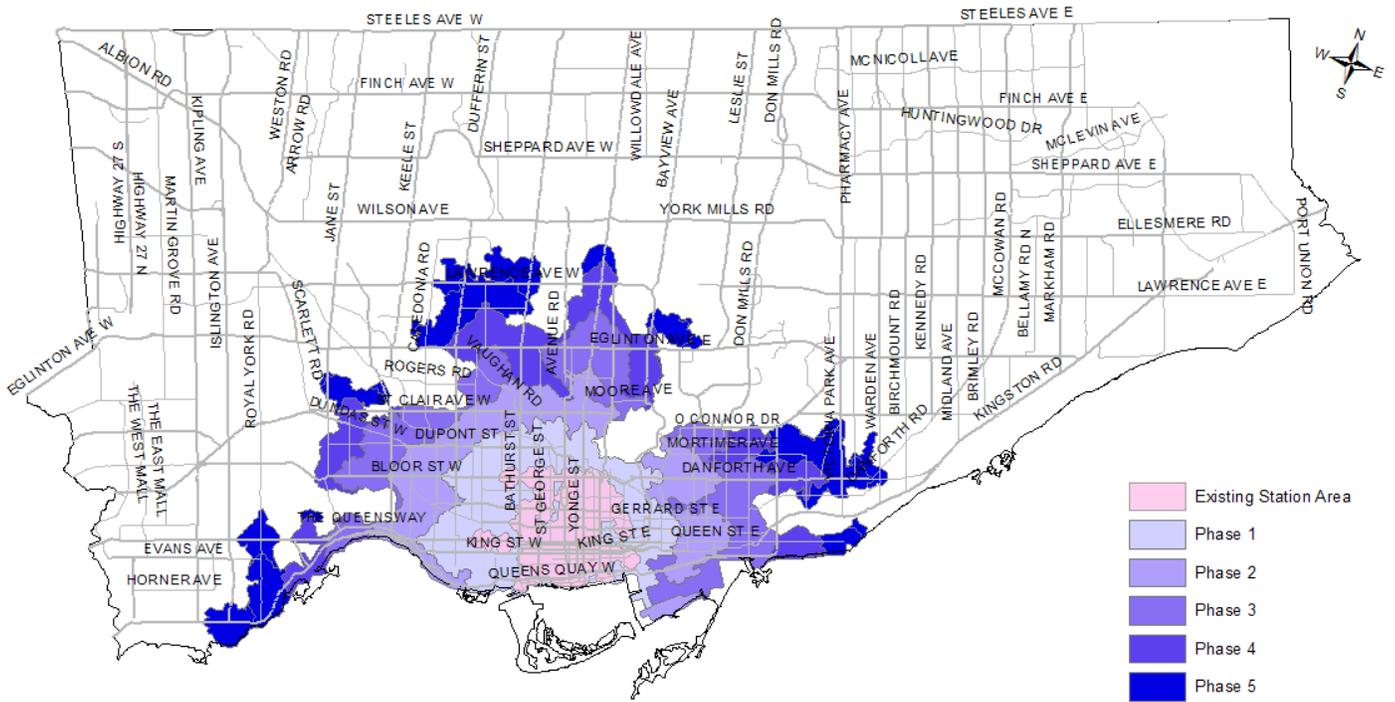
<sup>25</sup> [http://nacto.org/wp-content/uploads/2015/09/NACTO\\_Walkable-Station-Spacing-Is-Key-For-Bike-Share\\_Sc.pdf](http://nacto.org/wp-content/uploads/2015/09/NACTO_Walkable-Station-Spacing-Is-Key-For-Bike-Share_Sc.pdf)

<sup>26</sup> A “route buffer” indicates the actual distance along the road network. Walking distance as supposed to “as the crow flies”.

<sup>27</sup> A “network analyst” dataset is one which is based on a road or street network. When calculating length and area in a network dataset, the route distance is calculated as supposed to the linear distance.

<sup>28</sup> In a network analyst dataset, an impedance layer can be added such that it variably restricts movement through the network. A common use is to use slope as the impedance layer, such that moving uphill requires more energy than moving downhill. In our case, slope is just one of the twenty-two indicators used to express “impedance to bike share potential”.

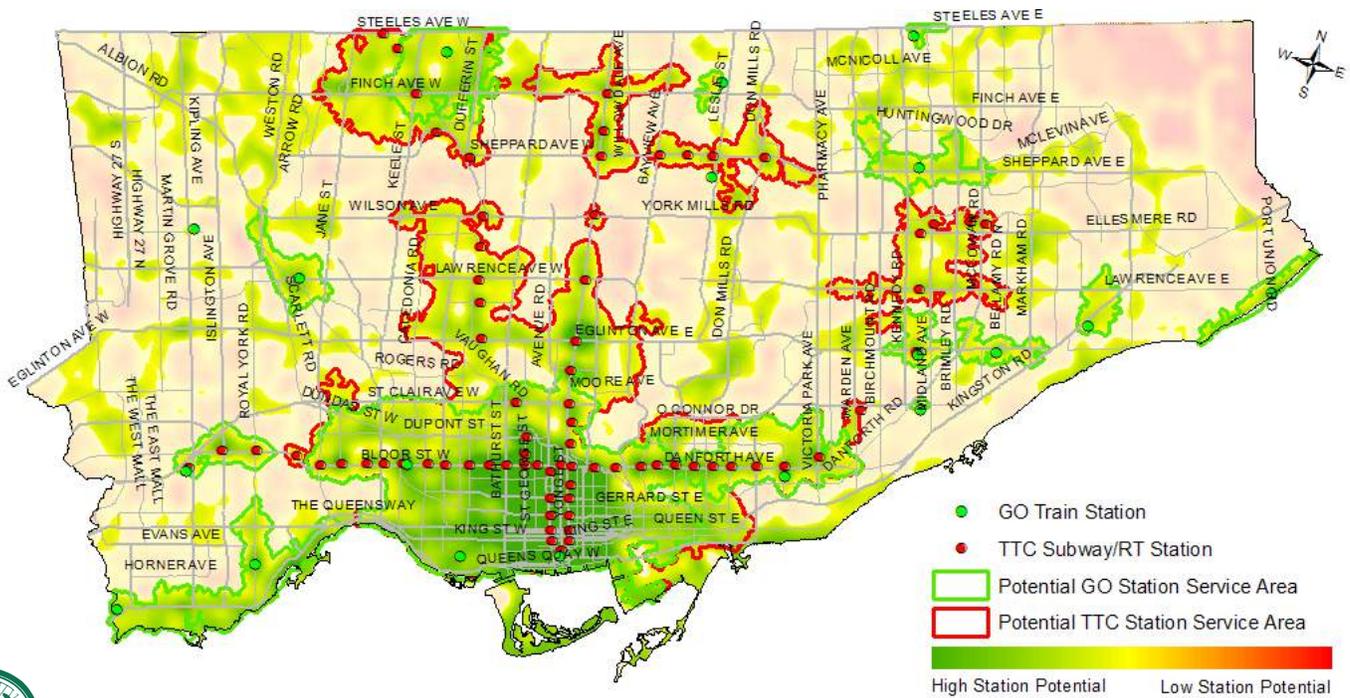




▲ **Figure 3 - Proposed Expansion Areas**

was also conducted. In order to identify areas of “least risk”, areas with higher station potential and the least amount of fragmentation from barriers to expansion were identified. Potential satellite zones representing larger contiguous areas of higher potential were more appealing as they offered more options for station siting and establishing a network. The results of the

analysis are shown in Figure 4, which identifies four main potential Satellite networks including: York University, North York Civic Centre, Sheppard Subway Corridor (Yonge St. to Don Mills Rd.), and Scarborough Town Centre.



▲ **Figure 4 - Proposed Expansion Areas**



# RESULTS & RECOMMENDATIONS

The results of our methodology and analysis, using available data, were used to inform the development of two least-risk expansion directions. The first direction addresses relatively contiguous expansion outward from the existing network and the second addresses the establishment of a series of satellite networks. Both directions include multiple phases and specific recommendations. It is stressed that system performance results from the initial expansion phases should be input in the model to enable further model refinement and calibration to inform the implementation of later phases. The section concludes with general recommendations for station siting and directions for future evaluation.

The geographic boundaries of the expansion areas outlined in this report are conceptual in nature and intended to be refined as additional local siting factors are identified as part of future site-specific station planning work. Larger than anticipated transit station activity, at a Mobility Hub for instance, could warrant a site-specific departure from the initial recommendations contained in this report.

The phasing strategies recommended in the report are also intended to be conceptual in nature, speaking to sequencing rather than the specifics of timing. Based on the above, TPA may elect to implement a hybrid approach combining both an element of existing network expansion as well as satellite expansion. This type of expansion approach would take the form of linear extensions (fingers reaching out from the existing core area) that would serve to build demand and connection to key destinations before prioritizing network contiguity through the more radial expansion as proposed in the report.

## EXPANSION FROM THE EXISTING NETWORK

Outward expansion of the existing network is conceptually organized into five phases. This expansion is premised on generally contiguous expansion from the downtown core. The initial phases will introduce a number of stations with potentially

new usage characteristics; stations that will be designed to serve neighbourhoods/communities with intermediate population and job densities that are lower than those observed in the downtown core, but higher than those in the outlying suburban areas of the city. Data gathered from these stations will help calibrate the model by providing a more varied and complete dataset. In particular, it will be notable to observe how the inner/streetcar suburb forms associated with the general age of development in these areas will affect ridership.

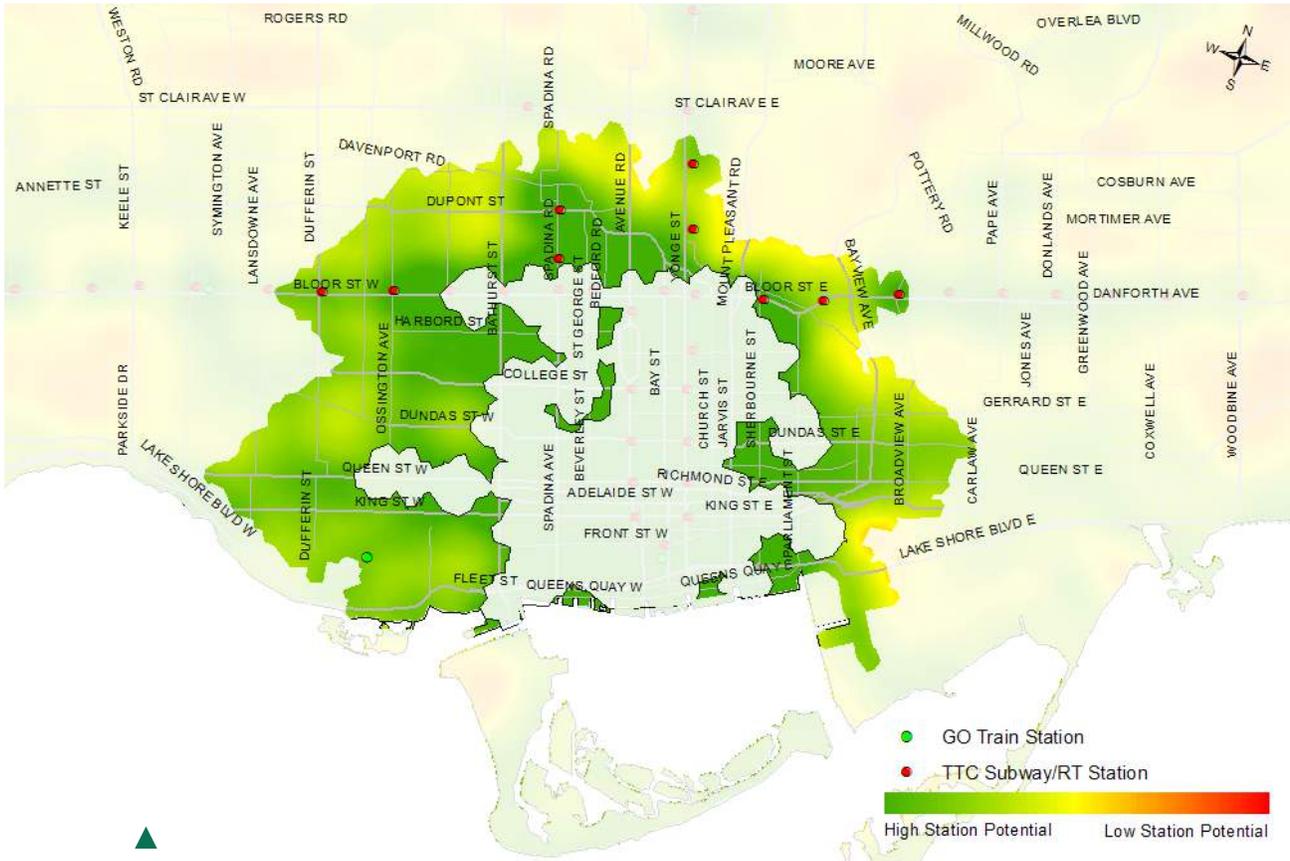
## Phase 1

The recommended expansion of the Bike Share system in Phase 1, as shown in Figure 5, would serve to extend the network radially: south-west to Liberty Village; westwards to Bloor St. and Dufferin St.; north-west to Dupont St. and Christie St.; north to Dupont and Rosedale or Summerhill TTC Stations; east to St. James Town, with a possible extension across the Don Valley to Broadview TTC Station; and south-east toward the intersection of Queen St. and Pape Ave. The proposed expansion in this initial phase presents the lowest risk and highest potential for growth in ridership, given that areas within the downtown core not covered by the existing network poses a relatively high degree of ridership potential.

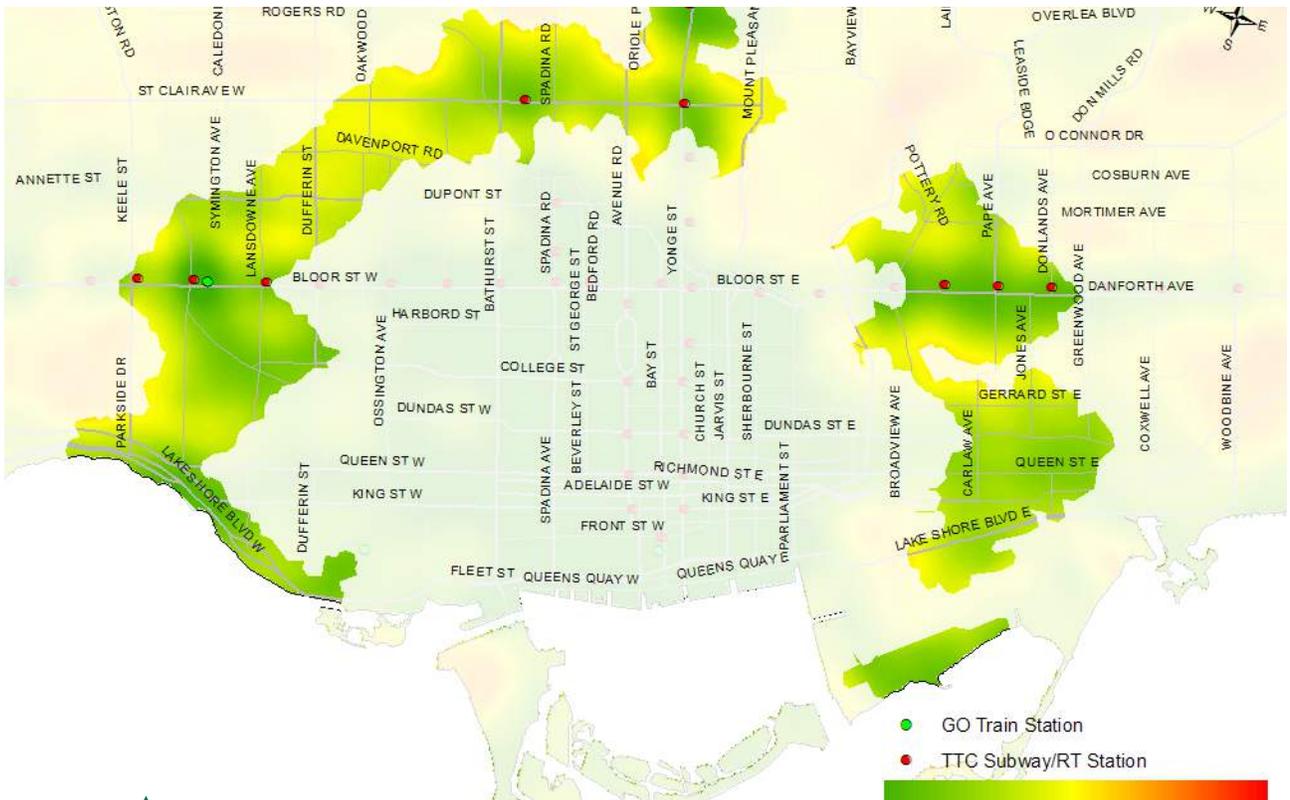
The area covered in phase 1 is roughly 20.3 km<sup>2</sup>, which would allow for 90 stations at an average density of 4.4 stations / km<sup>2</sup>. While this is an appropriate density, it is noted that the allotted stations need not necessarily be placed such that they evenly cover the entire identified area.

The Station Potential across this area is relatively high with no presence of larger low potential areas. Station siting should focus on network connectivity from the existing network and between new stations, with special attention to key transportation arteries and a connection to the Exhibition GO Station and Liberty Village.





▲ **Figure 5** - Phase 1 expansion from the existing network



▲ **Figure 6** - Phase 2 expansion from the existing network



## Phase 2

It is recommended that the second phase of expansion, as shown in Figure 6, continue radially from the area defined in Phase 1. This expansion will include the following areas: south along the waterfront at Sunnyside and Cherry beaches; west to Roncesvalles and Dundas West GO/TTC Station; north to St Clair Ave.; east to Danforth Ave. and Greenwood Ave.; and, south-east to Greenwood Ave. between Queen St. and Gerrard St. The area covered in Phase 2 is roughly 21.1 km<sup>2</sup>, which would allow for 90 stations at an average density of 4.3 stations / km<sup>2</sup>.

As in the initial phase of expansion, this second phase would introduce a number of stations with potentially new usage characteristics: the provision of additional stations along the waterfront would contribute to an interconnected lakeshore route which could be attractive for casual riders and visitors to the city. Extending the network to the Dundas West GO/TTC station could provide opportunities to promote ridership among users arriving or departing on the GO train or Union Pearson Express; and stations on St. Clair Ave. should be considered in order to provide coverage to the surrounding neighbourhood. However, in the case of St. Clair Ave. it should be noted that there are steep grades in the area that may increase operational costs and negatively impact ridership. As with the introduction of new stations in Phase 1, data gathered from new stations added in Phase 2 will help calibrate the model by providing a more varied and complete dataset.

The Station Potential across the Phase 2 area is mixed, with some areas representing a higher potential than others. When siting stations, the primary focus should be on areas with high potential such as: the Lakeshore (Sunnyside Beach and Cherry Beach); the Bloor-Landsdowne-Dundas area; St Clair Ave. between Christie St. and Yonge St.; Danforth Ave.; Queen St E. and Dundas St. E. Placing a station at the Bloor/Pearson Express Train station would also be desirable. Once stations have been sited in these key areas, the remaining allotted stations should be placed in the lower potential areas with the aim of maximizing network connectivity.

## Phase 3 – 5

It is recommended that model results be regenerated after incorporating performance data from Phases 1 and 2 in order to more accurately determine areas of least risk for expansion in Phases 3 – 5. However, a preliminary discussion of potential candidate areas that draws on the results of the expansion analysis is provided for consideration.

At the West end of the City, there may be opportunities to expand the network along the Lakeshore through Mimico/New Toronto toward the border with Mississauga. Other opportunities for expansion may exist along the TTC Subway line to Jane and Old Mill Stations. Additionally, the small hub around Islington TTC station could provide a strong linkage in Phase 4 or 5 between the recommended expansion over the Humber River along Bloor St. W., and along Royal York Rd. down to Lake Shore Blvd.

Toward the North end of the City, expansions along Eglinton Ave. and Lawrence Ave. may be desirable, with the possibility of adding connective stations along Vaughan Rd., Marlee Ave., and Yonge St. However, as noted in Phase 2, the impact of the grade change as expansion moves northward could have a significant impact on ridership and operational costs, and impacts should be identified from the Phase 1 and 2 station data before heavily investing in northerly expansion. Connection to the hub around the Weston GO station may also be desirable in Phase 5 or later as construction on the Eglinton LRT is completed.

In the East, Danforth Ave. is identified as having high potential for expansion between Greenwood Ave. and the GO station on Main St. Similarly, Queen St. E., Lake Shore Blvd. through the Beaches, Leslieville, Ashbridges Bay, and Woodbine Beach are all identified as having a high potential for expansion in Phases 4 or 5. Connections along Cosburn Ave. and extensions toward Thorncliffe Park may also be desirable in Phase 5, particularly if combined with the possibility of evaluating tourism and casual rider potential of stations in the Don Valley along the Don Trail system.



## SATELLITE EXPANSION

Of the four satellite areas identified by the initial model results, the York University satellite appears to be the most promising. The satellite zone covers a relatively large area, providing a greater range of options for station siting. There are also a number of higher potential areas which can support the development of a strong network, supported by a large employment district and a large university population. It is noted however, that the initial model results are based on the assumption that the TTC Spadina extension stations are already in operation. Delays in the completion of the stations could therefore warrant a delay in expansion to the area. Furthermore, Metrolinx has announced plans to possibly relocate the existing York University GO station in favour of a new station at Downsview, which could also impact results for this area.<sup>29</sup>

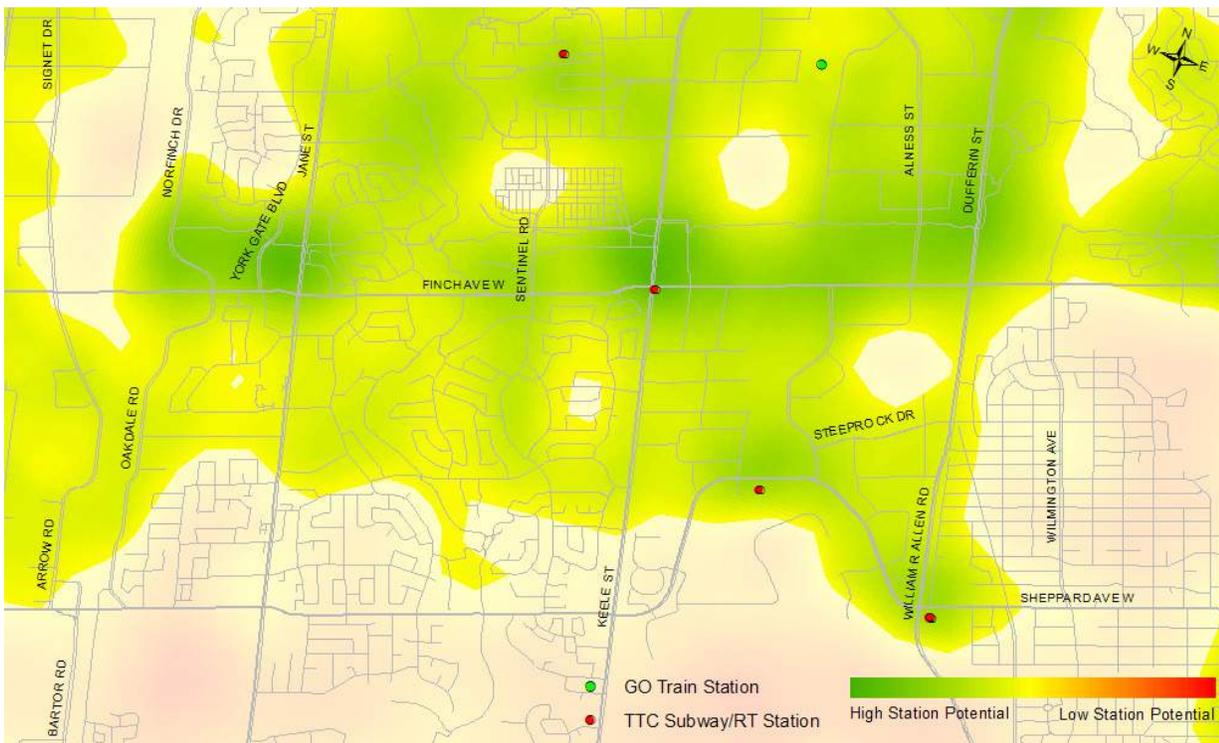
An Environmental Assessment is being initiated by the City in 2016 for Yonge St. between Sheppard Ave. and the Finch Hydro corridor. If a satellite network were to be launched in these areas it would be prudent to

coordinate expansion with that Study, and particularly during detailed station placement design and implementation to leverage opportunities for station siting and further reduce risks.

The remaining potential satellite network around Scarborough Town Centre does not represent as strong an option for satellite expansion as the York University Satellite or the other two options due to the relatively low density of intersections where connectivity would rely on the Kennedy Rd.- Lawrence Ave - Midland Ave. - Ellesmere Rd. rectangle. It is recommended that a potential satellite in Scarborough Town Centre be reevaluated at a later time, possibly in conjunction with the completion of the Scarborough Subway/LRT in the 10+ year horizon.

### Phase 1

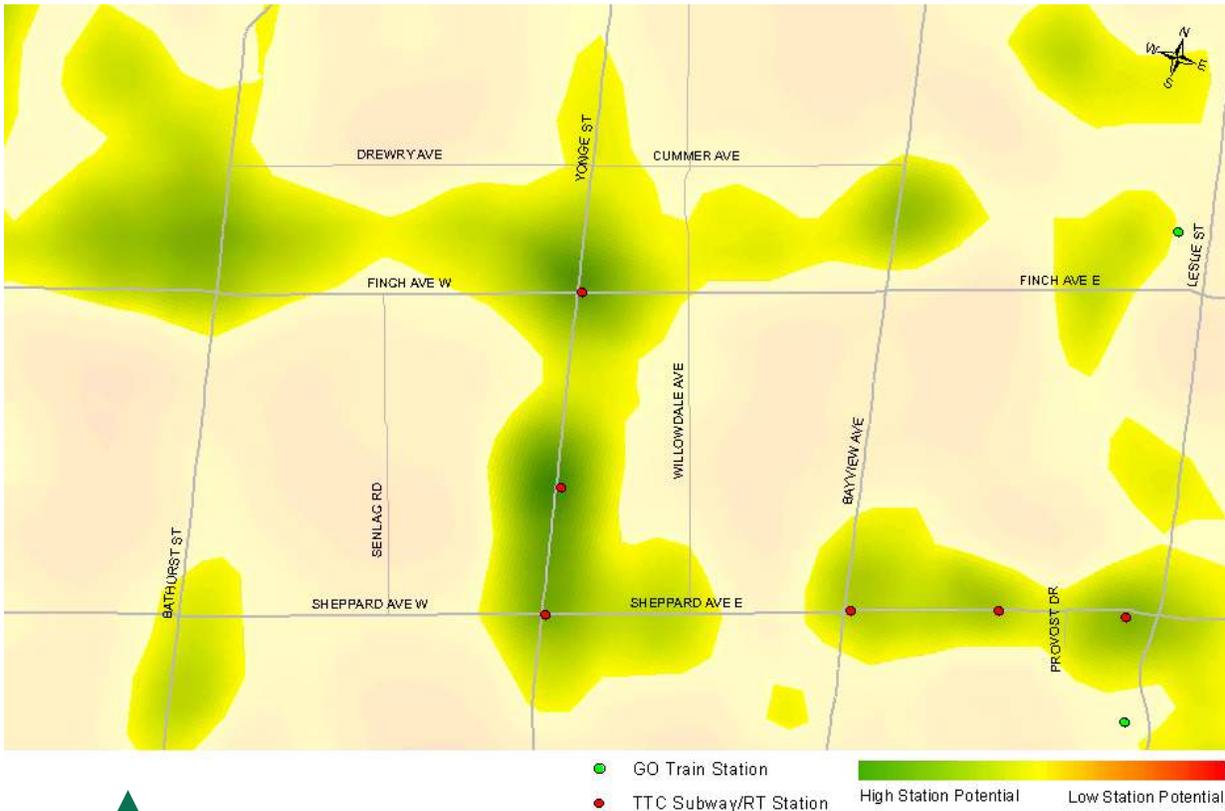
The expansion area for Phase 1 is shown in Figure 7. In this area, it is recommended to create an initial network connecting the existing York University GO Station, the TTC Spadina Extension Subway Stations, and the York University Campus, with the timing



**Figure 7 - Initial Satellite Expansion Area - York University Campus Area**

<sup>29</sup> [http://www.metrolinx.com/en/docs/pdf/board\\_agenda/20100519/2010\\_GO\\_BCA\\_Board\\_Presentation\\_FINAL.pdf](http://www.metrolinx.com/en/docs/pdf/board_agenda/20100519/2010_GO_BCA_Board_Presentation_FINAL.pdf)





**Figure 8 - Phase 2 Satellite Expansion Area - North York City Centre**

for the rollout of this network contingent on the completion of the Spadina Subway Extension. The initial network would have a larger nodal point at the GO and TTC Stations, with smaller stations located within the York University Campus and distributed between The Pond Rd. in the South, Black Creek Pioneer Village in the West, Steeles Ave. in the North, and Keele St. in the East. This area is roughly 2.7 km<sup>2</sup> which allows for siting of 12-13 stations at a density of 4.5 stations / km<sup>2</sup>.

### Phase 2

In a second phase of satellite expansion, as shown in Figure 8, we recommend an additional satellite network in the North York Civic Centre along Yonge St. between the Finch Hydro corridor and trail (just north of Finch Ave.) and Sheppard Ave. This area is roughly 4.13 km<sup>2</sup>, which translates to approximately 16-17 stations at a density of 4 stations / km<sup>2</sup>. Additionally, depending on the relative success of the York University Satellite Expansion in Phase 1, the option of adding more stations to the Phase 1 area as well as stations between the two satellites along the Finch Hydro Corridor multi-use trail could be desirable.



## RECOMMENDATION AND PRINCIPLES FOR STATION SITING

The following are a series of recommendations and general principles for consideration in the siting of future stations:

- ▶ Consider minimum station density
- ▶ Avoid siting stations outside well-served or higher station potential areas
- ▶ Activity in the existing service area will likely increase as a result of overall reinforcement tied to expansion
- ▶ Stations with low activity may still be important in terms of network connectivity. As the network expands, the model can be improved to incorporate nodal stations of high activity, and connective stations for improved user experience.

## RECOMMENDATIONS FOR FUTURE EVALUATION

It is recommended that model results be regenerated after Phase 1 expansion performance results become available. Results from the new stations will be instrumental in refining the predictive capacity of the model and more accurately delineating the areas of least risk for future expansion.

It is also recommended that, in a subsequent iteration of this study, additional factors be incorporated to further consider impacts on ridership, including but not limited to:

- ▶ Assessing ridership on a monthly as supposed to annual level to factor in the influence of seasonality and inclement weather
- ▶ Relationship between convenient public transit and increased bike share ridership:
  - Locations where transit is more/less frequent
  - Locations where transit is more/less congested

- ▶ Include additional data sources (weather) and/or further differentiate existing sources (ex. Grocery Stores, Convenience Stores, Restaurants, Entertainment)
- ▶ Rigorous evaluation of the individual indicators through further statistical analysis<sup>30</sup>
- ▶ Characterization of urban form and public realm (e.g. age of buildings, right-of-way width, roadside parking, streetcar tracks)
- ▶ Characterization of rider profiles (e.g. casual vs registered) and generation of separate potential surfaces for each profile
- ▶ Characterization of station profiles (e.g. downtown stations, residential stations and mobility hub stations) to develop an understanding of how those may generate different types of usage and how they may work together in a contiguous network.
- ▶ Conduct another customer survey with the principal focus of seeking feedback that would help refine our understanding of how the bike share network is being used, results which could then be used to further refine and calibrate the model. Notable question themes would include:
  - From the list of the developed indicators, which are more or less of a factor for encouraging ridership;
  - What mode of transportation does the use of bike share replace? Walk, private cycle, public transit, automobile? Responses from these questions could also be used to develop a measure for greenhouse gas reduction by approximating assess the extent to which bike trips are replacing automobile and transit trips.

---

<sup>30</sup>Statistical analysis could entail a multiple non-linear regression analysis. For example, certain factors such as population and employment densities or proximity to points of interest may better fit an inverse logarithmic curve, where factors such as number of docks per station or distance between stations may be better with a negative binomial curve



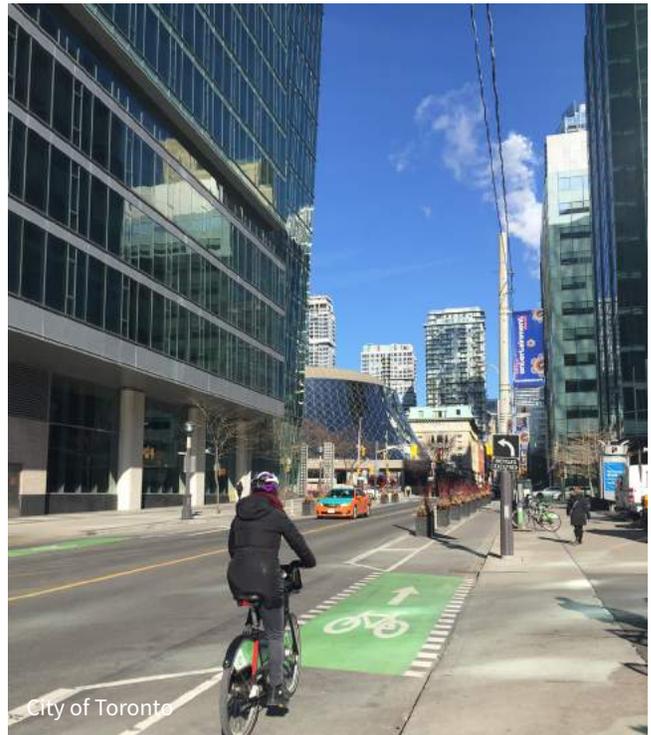
# CONCLUSION

As the City of Toronto through the Toronto Parking Authority / Bike Share Toronto moves to expand their current bike share network, they join a host of other cities across the world in offering a mode of transportation that has demonstrated positive impacts and benefits, including but not limited to improved public health, reduced environmental impacts, increased public transit through multi-modal trips and enhanced individual transportation choices. This expansion is also a response to City policies which aim to establish a bike share network of upward of 5,000 bicycles and increase the modal share of bicycle trips within the City to at least 20%.

The methodology established in this study and the resulting framework for expansion offer a data-driven approach to guide the expansion of the Bike Share Toronto network. The report's initial findings provide recommendations for areas of "least risk" for expansion. More importantly it calls for the continuous gathering of relevant data to improve the model and its predictive potential. This provides an ongoing method for Bike Share Toronto to accomplish their due diligence in station siting and continually "lessen" the risk in expanding the network.

Although developed to meet the current needs of the City of Toronto, the framework established in this study could also serve as a model for other municipalities that currently have or are considering bike share systems. As the Bike Share Toronto system expands, the model can be evaluated on its abilities to transform data sources into ridership potential predictions, a model other municipalities may choose to adopt if or when the requisite data is available.

In addition to this report, the Toronto Parking Authority / Bike Share Toronto were provided with: a detailed report appendix describing how the indicators were developed and used; as well as a geodatabase of all source information and results.





100 Commerce Valley Dr W,  
Thornhill, ON, Canada L3T 0A1  
e: [mmm@mmm.ca](mailto:mmm@mmm.ca)  
t: 905.882.1100  
f: 905.882.0055



# APPENDIX 1

## DETAILED EXPLANATION OF INDICATORS

**Appendix 1 - Detailed explanation of the indicators**

Category	Indicator name	Source organization	Source dataset	Year
Population and employment densities	Population density	Statistics Canada	2011 Census Profile	2011
	Job density	Environics Analytics	Business Locations	2012
	High density residential land use	City of Toronto	Address Points; Property Boundary	2015
	Density of likely bike share users	Tetrad Pccensus; Bikeshare Toronto Customer Survey Result	Population, Income and Education	2011
	Density of new developments	MMM Group Ltd.	PRIME	2016
Attractions and Points of Interest	Proximity to the lakeshore waterfront	City of Toronto	Toronto Centreline	2015
	Proximity to city parks	City of Toronto	Parks	2015
	Business Improvement Areas	City of Toronto	Business Improvement Areas	2015
	Hotels	City of Toronto	Hotel Association Member List	2013
	Cultural spaces	City of Toronto	Cultural Spaces	2014
	Places of interest	City of Toronto	Places of Interest and Toronto Attractions	2014
	University and college campuses	City of Toronto	School Locations	2014
Bikeability	Slope	Natural Resources Canada	Digital elevation model, Greater Toronto Area	1999
	Intersection density	City of Toronto	Intersection File	2015
	Proximity to cycling infrastructure	City of Toronto	Bikeways	2015
	Proximity to population serving businesses	Environics Analytics	Business Locations	2012
Transportation Mode	Total non-auto origin and destination trips	University of Toronto - Data Management Group	Transportation Tomorrow Survey 2011	2012
	Ratio of walking trips to auto trips	University of Toronto - Data Management Group	Transportation Tomorrow Survey 2011	2012
	Ratio of cycling trips to auto trips	University of Toronto - Data Management Group	Transportation Tomorrow Survey 2011	2012
	Proximity to frequent walking routes	University of Toronto - Data Management Group	Transportation Tomorrow Survey 2011	2012
	Proximity to frequent cycling routes	University of Toronto - Data Management Group	Transportation Tomorrow Survey 2011	2012
	Proximity to rapid transit stations	GO Transit; City of Toronto	GO Transit GTFS; TTC Routes and Schedules	2016

### Appendix 1 - Detailed explanation of the indicators

Indicator name	Hypothesis	Units of measure
Population density	There is a direct relationship between population density and ridership potential	Number of residents per square km
Job density	There is a direct relationship between job density and ridership potential	Total number of employees within 300m
High density residential land use	There is a direct relationship between the proportion of high density land use and ridership potential	Ratio of high density residential property area to non high density residential property area by Dissemination Area
Density of likely bike share users	There is a direct relationship between where likely bikeshare users live and ridership potential	Likely User Score per square km
Density of new developments	There is a direct relationship between the density of new developments and ridership potential	Number of residential units completed or under construction from 2011 by square kilometer
Proximity to the lakeshore waterfront	There is a direct relationship between proximity to the lakeshore waterfront and ridership potential	Boolean
Proximity to city parks	There is a direct relationship between proximity to City Parks and ridership potential	Boolean
Business Improvement Areas	There is a direct relationship between proximity to Business Improvement Areas and ridership potential	Boolean
Hotels	There is a direct relationship between proximity and frequency of hotels and ridership potential	Number of hotels within 300m
Cultural spaces	There is a direct relationship between proximity and frequency of cultural spaces and ridership potential	Number of cultural spaces within 300m
Places of interest	There is a direct relationship between proximity and frequency of places of interest and ridership potential	Number of places of interest within 300m
University and college campuses	There is a direct relationship between proximity and frequency of Colleges and Universities and ridership potential	Number of colleges and universities within 300m
Slope	The is a direct inverse relationship between slope and ridership potential	Slope, rise over run
Intersection density	There is a direct relationship between intersection density and ridership potential	Number of intersections within 300m
Proximity to cycling infrastructure	There is a direct relationship between the proximity of bikeway density and ridership potential	Weighted length of cycling infrastructure within 300m
Proximity to population serving businesses	There is a direct relationship between population serving business density and ridership potential	Number of population serving businesses within 300m
Total non-auto origin and destination trips	There is a direct relationship between the total number of non-auto travel originating or departing in an area and ridership potential	Density of non-auto travel origins and departures
Ratio of walking trips to auto trips	There is a direct relationship between the ratio of walking trips to auto trips in an area and ridership potential	Ratio of walking trips to auto trips
Ratio of cycling trips to auto trips	There is a direct relationship between the ratio of cycling trips to auto trips in an area and ridership potential	Ratio of cycling trips to auto trips
Proximity to frequent walking routes	There is a direct relationship between proximity to frequent walking routes and ridership potential	Number of trips per meter within 300m
Proximity to frequent cycling routes	There is a direct relationship between proximity to frequent cycling routes under 5 km and ridership potential.	Number of trips per meter within 300m
Proximity to rapid transit stations	There is a direct relationship between proximity to rapid transit stations and ridership potential	Boolean

## Appendix 1 - Detailed explanation of the indicators

Indicator name	Surface creation methodology
Population density	Population totals by Census Dissemination Area area
Job density	Point statistics within 300m, sum of Environics Business Size Class
High density residential land use	Obtained land use by interesecting address point file with property boundary file to get relative area. Calculated ratio for each Census Dissemination Area.
Density of likely bike share users	Weighted Income, Population, and Education brackets by the distribution of respondents from the Customer Survey.
Density of new developments	Total count of residential units by Census Dissemination Area
Proximity to the lakeshore waterfront	Calculated a 300m linear buffer from the lakeshore polyline.
Proximity to city parks	Calculated a 300m linear buffer from City Parks and Parkettes
Business Improvement Areas	Calculated a 300m linear buffer from Business Improvement Areas
Hotels	Point statistics within 300m, sum of number of hotels
Cultural spaces	Point statistics within 300m, sum of cultural space locations
Places of interest	Point statistics within 300m, sum of Point of Interest locations
University and college campuses	Point statistics within 300m, sum of College and University point locations
Slope	Calculated slope from elevation
Intersection density	Point statistics within 300m, sum of connective intersections. Excluded intersections for cul-de-sacs, end of lines, pedestrian-only crossings, and highways.
Proximity to cycling infrastructure	Line statistics within 300m, bikeway path class by length of bikepath. Bikepath classes are: Signed Routes, Sharrows, Park Roads Cycling Connections (1); Bike Lanes, Minor Multi-use Pathway, Contra-Flow Bike Lanes (2); Major Multi-use Pathway, Cycle Tracks (3)
Proximity to population serving businesses	Point statistics within 300m, sum of population serving businesses, determined by the following 2-digit NAICS designations: 44-45: Retail Trade; 54: Professional, Scientific and Technical Services; 61: Educational Services; 62: Health Care and Social Services; 71: Arts, Entertainment and Recreation; 72: Accommodation and Food Services; 81: Other Services; 91: Public Administration
Total non-auto origin and destination trips	Sum of all origin and destination non-auto trips by Transportation Assessment Zone (TAZ). Non auto trips are all trips by walking, cycling, or public transit.
Ratio of walking trips to auto trips	Number of all origin and destination walking trips by auto trips by TAZ
Ratio of cycling trips to auto trips	Number of all origin and destination cycling trips by auto trips by TAZ
Proximity to frequent walking routes	For each origin destination path completed by walking with at least one endpoint in the City of Toronto, calculated the shortest route between each TAZ centroid pair. Performed line statistics within 300m on the resulting polyline, number of trips by length of route.
Proximity to frequent cycling routes	For each origin destination path completed by cycling under 5 km linear distance with at least one endpoint in the City of Toronto, calculated the shortest route between each TAZ centroid pair. Performed line statistics within 300m on the resulting polyline, number of trips by length of route.
Proximity to rapid transit stations	Created 300m network buffer from station locations

**Appendix 1 - Detailed explanation of the indicators**

<b>Indicator name</b>	<b>Reclassification schema</b>
<b>Population density</b>	Equal Interval
<b>Job density</b>	Equal Interval
<b>High density residential land use</b>	Equal Interval
<b>Density of likely bike share users</b>	Equal Interval
<b>Density of new developments</b>	Equal Interval
<b>Proximity to the lakeshore waterfront</b>	Manual: Within 300m of lakeshore waterfront - 1 All other locations - 10
<b>Proximity to city parks</b>	Manual: Within 300m of Park - 1 All other locations - 4
<b>Business Improvement Areas</b>	Manual: Within 300m of BIA - 1 All other locations - 5
<b>Hotels</b>	Equal Interval
<b>Cultural spaces</b>	Equal Interval
<b>Places of interest</b>	Equal Interval
<b>University and college campuses</b>	Equal Interval
<b>Slope</b>	Defined Interval based off of Bikeability Mapping Schema Developed by Winters,M. (2011) - pp 109. <a href="https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676">https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676</a>
<b>Intersection density</b>	Defined Interval based off of Bikeability Mapping Schema Developed by Winters,M. (2011) - pp 109. <a href="https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676">https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676</a>
<b>Proximity to cycling infrastructure</b>	Defined Interval based off of Bikeability Mapping Schema Developed by Winters,M. (2011) - pp 109. <a href="https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676">https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676</a>
<b>Proximity to population serving businesses</b>	Defined Interval based off of Bikeability Mapping Schema Developed by Winters,M. (2011) - pp 109. <a href="https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676">https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0071676</a>
<b>Total non-auto origin and destination trips</b>	Equal Interval
<b>Ratio of walking trips to auto trips</b>	Equal Interval
<b>Ratio of cycling trips to auto trips</b>	Equal Interval
<b>Proximity to frequent walking routes</b>	Equal Interval
<b>Proximity to frequent cycling routes</b>	Equal Interval
<b>Proximity to rapid transit stations</b>	Within 300m of rapid transit station - 1 All other locations - 10

## Appendix 1 - Detailed explanation of the indicators

Indicator name	Sources of uncertainty
<b>Population density</b>	Population totals were obtained at the DA level, and as with any polygon based data point, the value may not be equally distributed across the entire area.
<b>Job density</b>	The environics dataset gives the number of employees per organization by class range instead of absolute amount. This dataset is therefore not suitable for approximating exact totals, but nonetheless is useful as a point of relative comparison across the whole city. Business locations are offered as point data, which would be less precise for locations with a large footprint.
<b>High density residential land use</b>	Land use characteristics were taken from the City of Toronto address data and are therefore area subject to the relative uncertainty present in that dataset.
<b>Density of likely bike share users</b>	The distribution taken from the Customer Response Survey may not accurately represent the actual distribution of bikeshare riders.
<b>Density of new developments</b>	The PRIME dataset does not cover developments where the number of units being developed is less than 6 or the Gross Floor Area is less than 1,000 m <sup>2</sup>
<b>Proximity to the lakeshore waterfront</b>	A discrete 300m linear buffer may not be the most precise measure for waterfront proximity. With more station usage data, in subsequent iterations of the model a measure for route distance to closest water feature or line of sight to waterfront could be developed.
<b>Proximity to city parks</b>	City parks and city parkettes may not have the same degree of influence. A network buffer may be more correlative than a linear buffer.
<b>Business Improvement Areas</b>	A network buffer may be more accurate than a linear buffer.
<b>Hotels</b>	Did not validate information layer to determine if all hotels are included. A measure for number of hotel rooms may be more accurate than a simple count of hotels
<b>Cultural spaces</b>	The layer for cultural spaces is from the City's Make Space for Culture initiative and may not include all spaces used for cultural purposes that would have an impact on bikeshare ridership potential
<b>Places of interest</b>	The layer is from the City's Points of Interest and Attractions dataset and may not include all locations that would have an impact on bikeshare ridership potential
<b>University and college campuses</b>	This dataset only supplied school locations as point files. During the course of this study we were not able to find nor did we have the time to produce a polygon representation of the campuses, or campus building entrances and exits. The latter may be a more accurate predictor of bikeshare ridership potential.
<b>Slope</b>	The elevation dataset supplied values at 30m resolution
<b>Intersection density</b>	Intersection density alone may not be as accurate of a predictor as other intersection characteristics such as volume of auto traffic and quality of road condition.
<b>Proximity to cycling infrastructure</b>	The weights applied to the bikepath class may not correlate to actual bikeshare rider preferences. Suggest basing weights off of results from a subsequent customer survey
<b>Proximity to population serving businesses</b>	Business locations are offered as point data, which would be less precise for locations with a large footprint.
<b>Total non-auto origin and destination trips</b>	TTS totals are projected from sample survey data and may not represent actual observed mode of transportation.
<b>Ratio of walking trips to auto trips</b>	TTS totals are projected from sample survey data and may not represent actual observed mode of transportation.
<b>Ratio of cycling trips to auto trips</b>	TTS totals are projected from sample survey data and may not represent actual observed mode of transportation.
<b>Proximity to frequent walking routes</b>	TTS totals are projected from sample survey data and may not represent actual observed mode of transportation.
<b>Proximity to frequent cycling routes</b>	TTS totals are projected from sample survey data and may not represent actual observed mode of transportation.
<b>Proximity to rapid transit stations</b>	A discrete 300m network buffer may not be the most precise measure for proximity to rapid transit. With more station usage data, in subsequent iterations of the model a measure for route distance to closest rapid transit station could be developed.

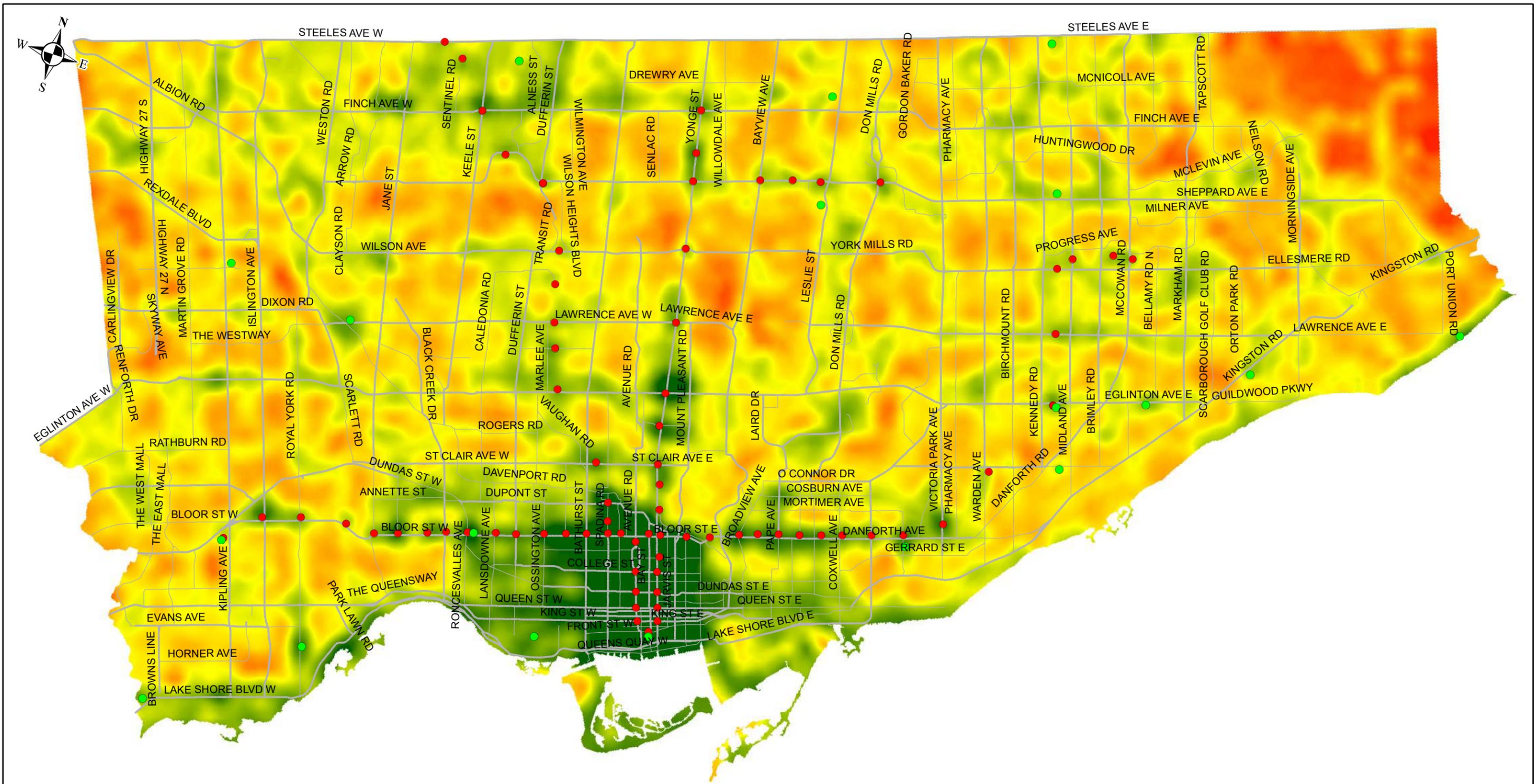
### Appendix 1 - Detailed explanation of the indicators

Indicator name	Source URL
Population density	<a href="https://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/index.cfm?Lang=E">https://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/index.cfm?Lang=E</a>
Job density	<a href="http://www.environicsanalytics.ca/">http://www.environicsanalytics.ca/</a>
High density residential land use	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=91415f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=1a66e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=91415f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=1a66e03bb8d1e310VgnVCM10000071d60f89RCRD</a> ; <a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=91415f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=1a66e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=91415f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=1a66e03bb8d1e310VgnVCM10000071d60f89RCRD</a>
Density of likely bike share users	<a href="http://www.tetrad.com/software/pcensus-desktop/">http://www.tetrad.com/software/pcensus-desktop/</a>
Density of new developments	N/A
Proximity to the lakeshore waterfront	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=9acb5f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=9acb5f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD</a>
Proximity to city parks	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=da6389fe9c18b210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=02e6e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=da6389fe9c18b210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=02e6e03bb8d1e310VgnVCM10000071d60f89RCRD</a>
Business Improvement Areas	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=8c5d5f9cd70bb210VgnVCM1000003dd60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=8c5d5f9cd70bb210VgnVCM1000003dd60f89RCRD</a>
Hotels	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=ad6d9ec1e9013410VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=ad6d9ec1e9013410VgnVCM10000071d60f89RCRD</a>
Cultural spaces	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=4f6bdda2f1405410VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=4f6bdda2f1405410VgnVCM10000071d60f89RCRD</a>
Places of interest	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=d90ac71db136c310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=d90ac71db136c310VgnVCM10000071d60f89RCRD</a>
University and college campuses	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=16a91e22fe370410VgnVCM10000071d60f89RCRD&amp;vnextchannel=02e6e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=16a91e22fe370410VgnVCM10000071d60f89RCRD&amp;vnextchannel=02e6e03bb8d1e310VgnVCM10000071d60f89RCRD</a>
Slope	<a href="http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/63a9ba8c-ce26-5b02-9d1c-de9badd5a786.html">http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/63a9ba8c-ce26-5b02-9d1c-de9badd5a786.html</a>
Intersection density	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=e659522373c20410VgnVCM10000071d60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=e659522373c20410VgnVCM10000071d60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD</a>
Proximity to cycling infrastructure	<a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=9ecd5f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=9ecd5f9cd70bb210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD</a>
Proximity to population serving businesses	<a href="http://www.environicsanalytics.ca/">http://www.environicsanalytics.ca/</a>
Total non-auto origin and destination trips	<a href="http://www.transportationtomorrow.on.ca/">http://www.transportationtomorrow.on.ca/</a>
Ratio of walking trips to auto trips	<a href="http://www.transportationtomorrow.on.ca/">http://www.transportationtomorrow.on.ca/</a>
Ratio of cycling trips to auto trips	<a href="http://www.transportationtomorrow.on.ca/">http://www.transportationtomorrow.on.ca/</a>
Proximity to frequent walking routes	<a href="http://www.transportationtomorrow.on.ca/">http://www.transportationtomorrow.on.ca/</a>
Proximity to frequent cycling routes	<a href="http://www.transportationtomorrow.on.ca/">http://www.transportationtomorrow.on.ca/</a>
Proximity to rapid transit stations	<a href="http://www.gotransit.com/publicroot/en/schedules/DeveloperResources.aspx">http://www.gotransit.com/publicroot/en/schedules/DeveloperResources.aspx</a> ; <a href="http://www1.toronto.ca/wps/portal/contentonly?vnextoid=96f236899e02b210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD">http://www1.toronto.ca/wps/portal/contentonly?vnextoid=96f236899e02b210VgnVCM1000003dd60f89RCRD&amp;vnextchannel=7807e03bb8d1e310VgnVCM10000071d60f89RCRD</a>



# APPENDIX 2

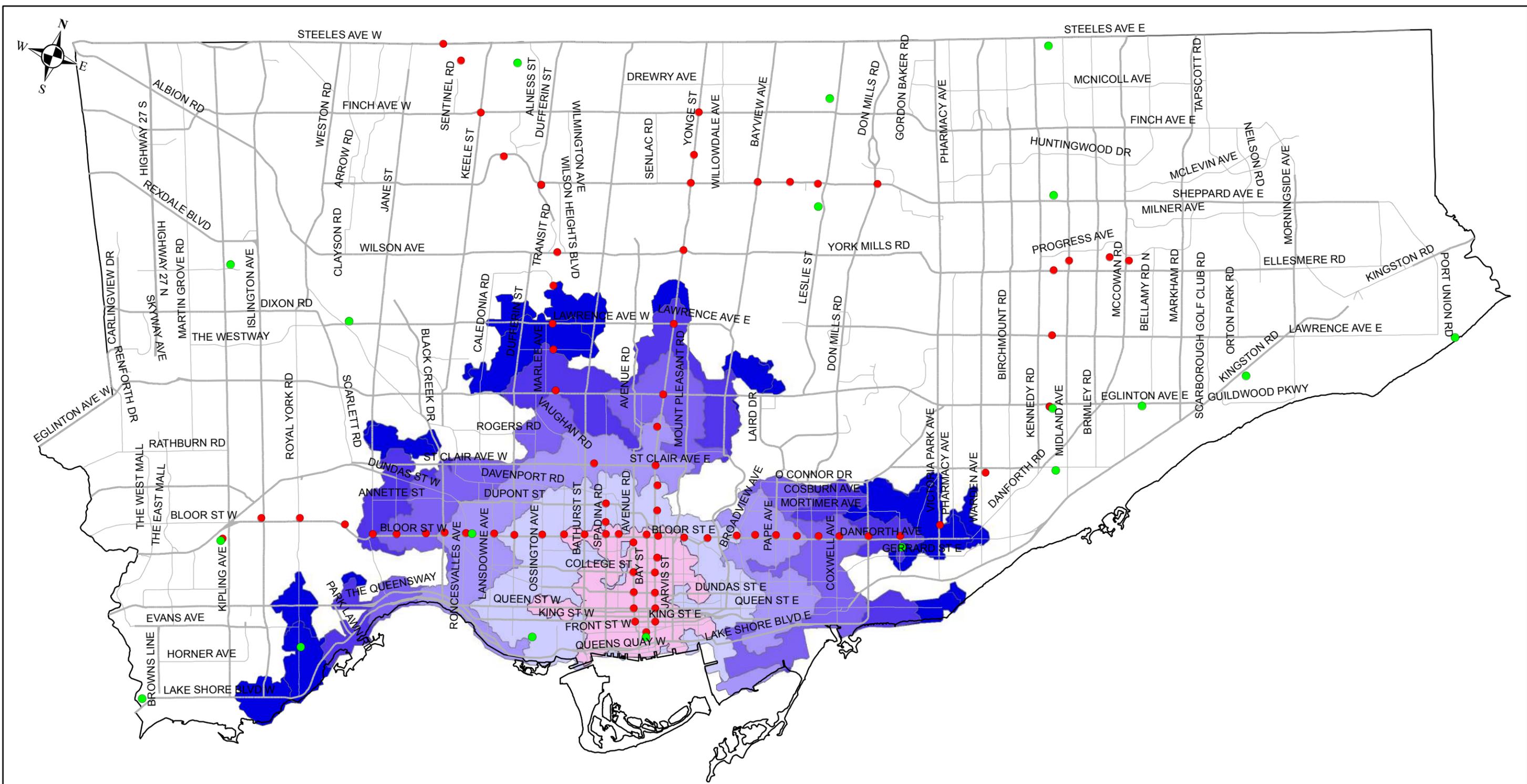
MAPS



**Legend**

- GO Train Station
- TTC Subway/RT Station
- Major Arterial Street
- Minor Arterial Street
- Low Station Potential
- High Station Potential

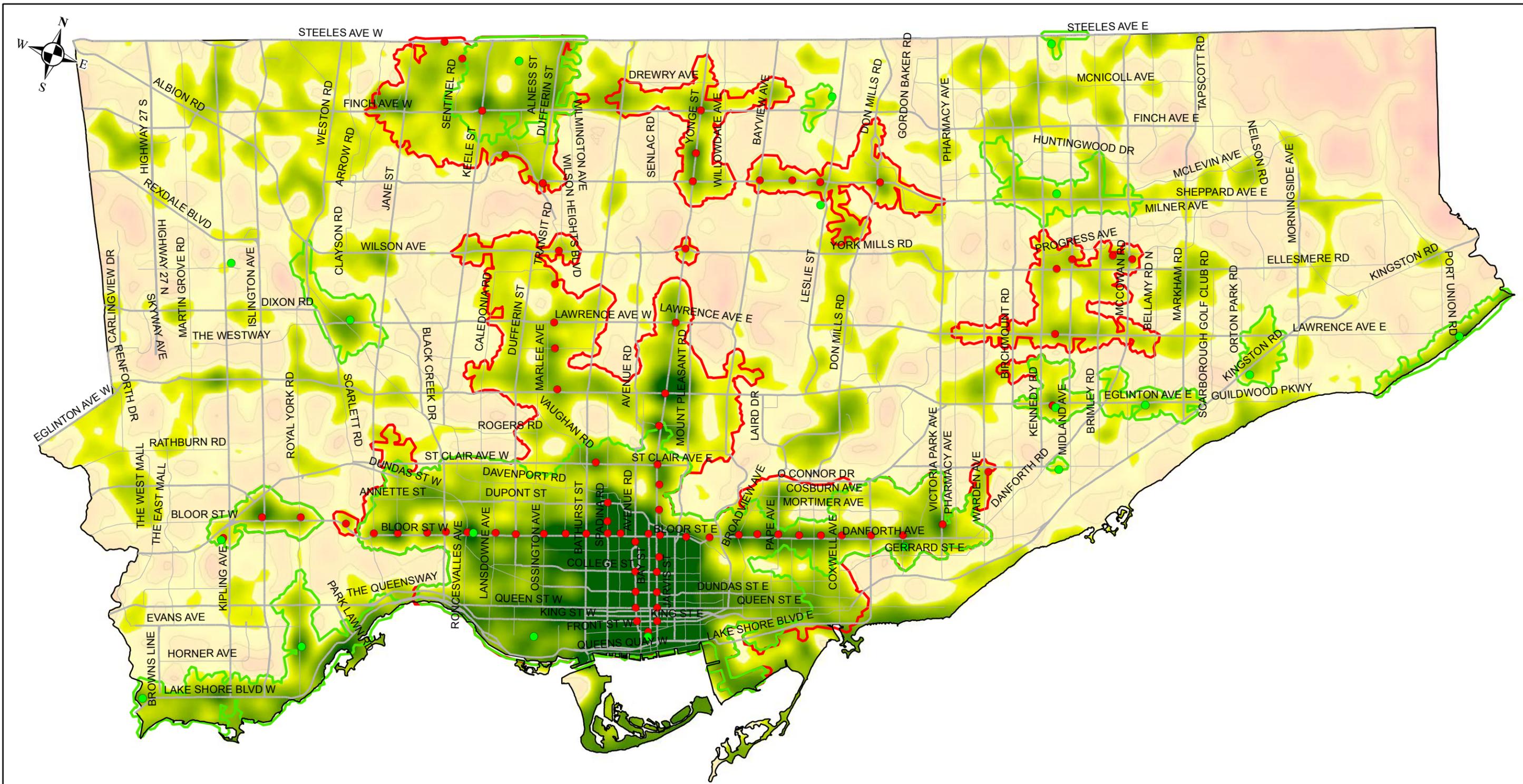
Client: <b>Toronto Parking Authority</b>		
Title: <b>Bike Share Station Potential Surface</b>		
Prepared by:		
1615093-001	1:110,000	Review: AB
Date: February 18, 2016		<b>Figure: 2</b>
© Queen's Printer for Ontario		



**Legend**

- GO Train Station
- TTC Subway/RT Station
- Major Arterial Street
- Minor Arterial Street
- ▭ City of Toronto Boundary
- ▭ Existing Station Area
- Proposed Expansion Phases**
- ▭ Phase 1
- ▭ Phase 2
- ▭ Phase 3
- ▭ Phase 4
- ▭ Phase 5

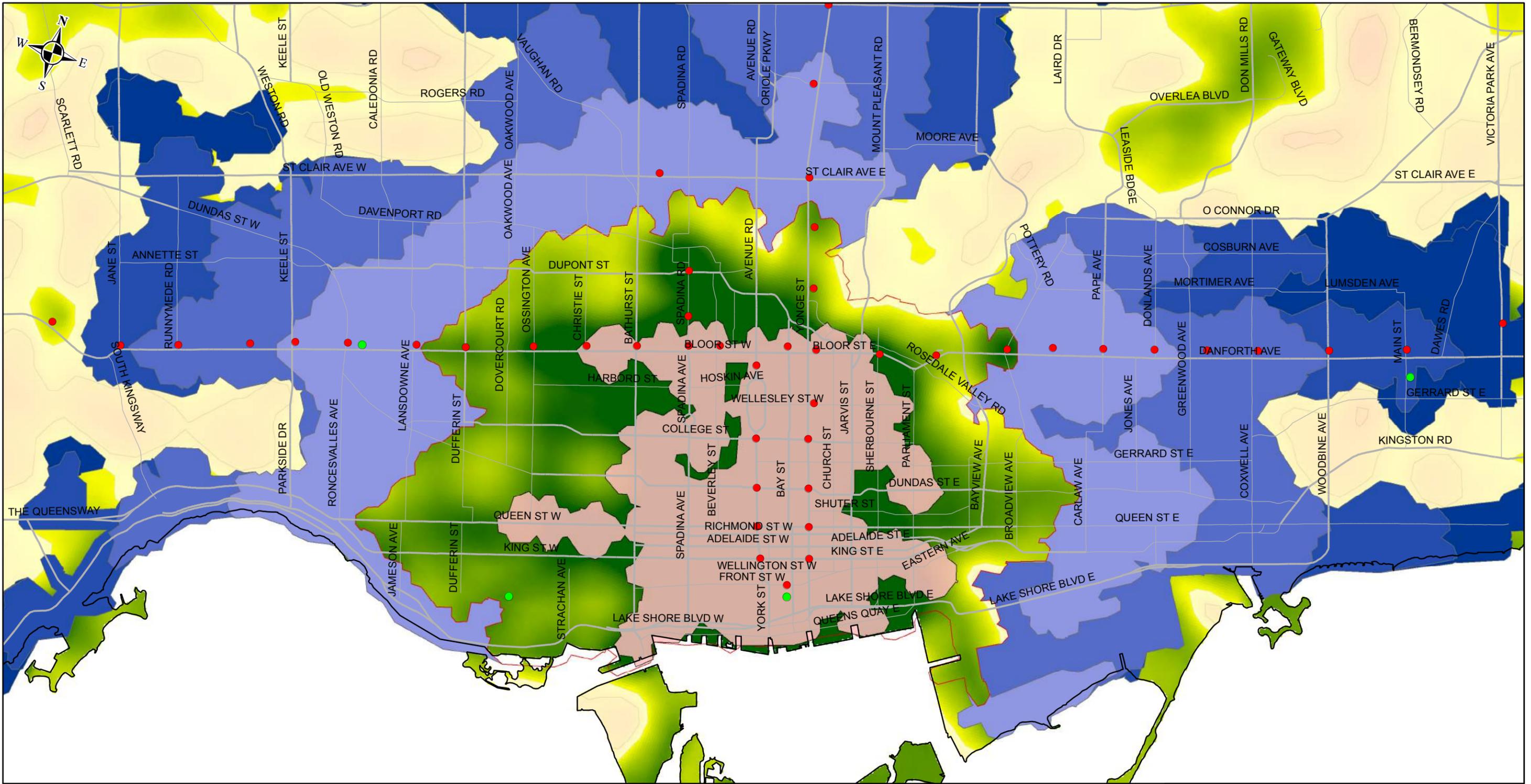
Client: <b>Toronto Parking Authority</b>		
Title: <b>Proposed Expansion Areas</b>		
Prepared by:		
1615093-001	1:110,000	Review: AB
Date: February 18, 2016		<b>Figure: 3</b>
© Queen's Printer for Ontario		



**Legend**

- GO Train Station
- TTC Subway/RT Station
- Major Arterial Street
- Minor Arterial Street
- City of Toronto Boundary
- Potential GO Station Service Area
- Potential TTC Station Service Area
- Barriers to Expansion (semi-transparent white)
- Low Station Potential (red) to High Station Potential (green)

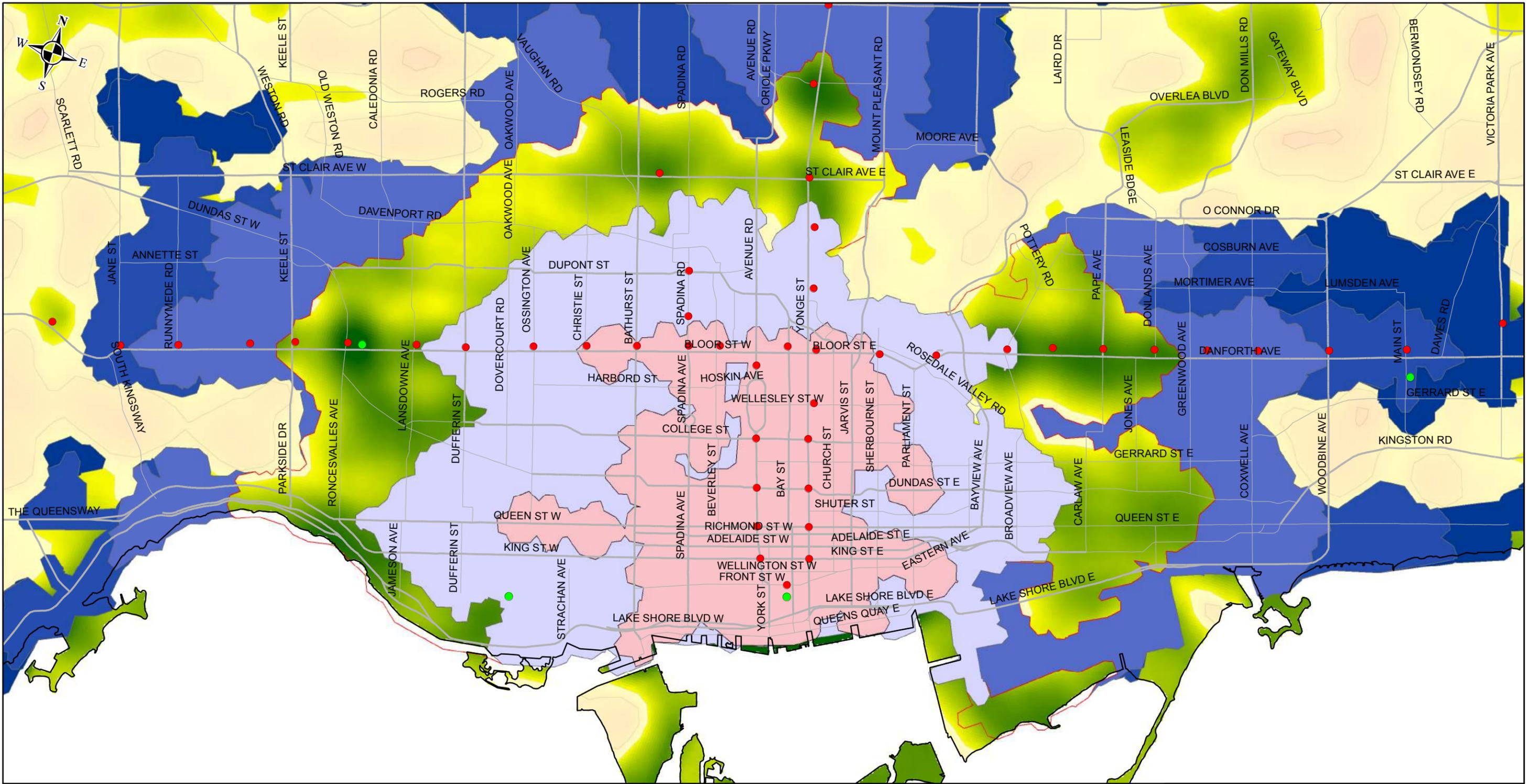
Client: <b>Toronto Parking Authority</b>		
Title: <b>Proposed Satellite Expansion Areas</b>		
Prepared by:		
1615093-001	1:110,000	Review: AB
Date: February 18, 2016		<b>Figure: 4</b>
© Queen's Printer for Ontario		



**Legend**

- GO Train Station
  - TTC Subway/RT Station
  - Major Arterial Street
  - Minor Arterial Street
  - City of Toronto Boundary
  - Existing Station Area
  - Barriers to Expansion (semi-transparent white)
  - Low Station Potential
  - High Station Potential
- Proposed Expansion Phases**
- Phase 1
  - Phase 2
  - Phase 3
  - Phase 4
  - Phase 5

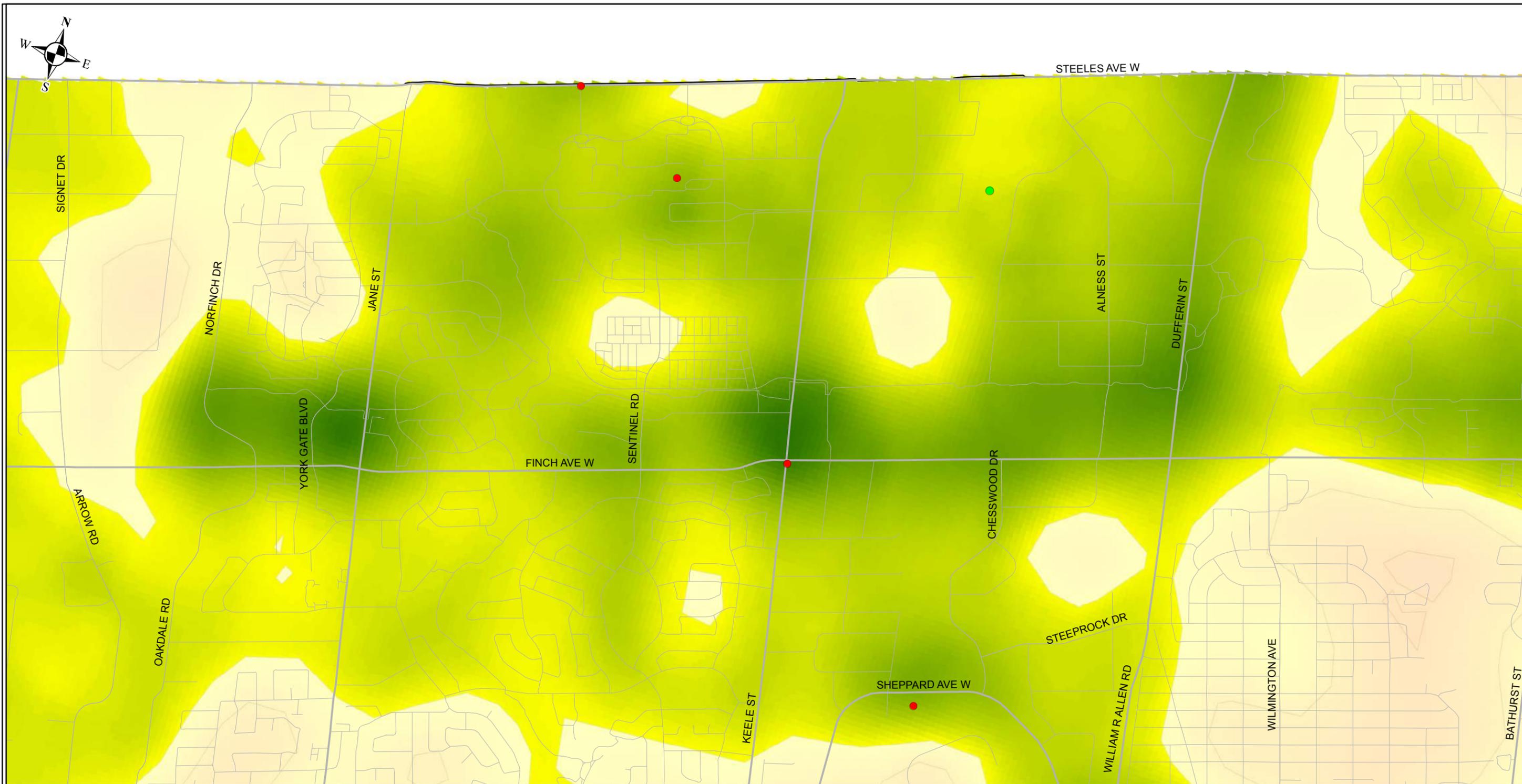
Client: <b>Toronto Parking Authority</b>		
Title: <b>Phase 1 expansion from the existing network</b>		
Prepared by:		
1615093-001	1:45,000	Review: AB
Date: February 18, 2016		<b>Figure: 5</b>
© Queen's Printer for Ontario		



**Legend**

- GO Train Station
  - TTC Subway/RT Station
  - Major Arterial Street
  - Minor Arterial Street
  - City of Toronto Boundary
  - Existing Station Area
  - Barriers to Expansion (semi-transparent white)
  - Low Station Potential
  - High Station Potential
- Proposed Expansion Phases**
- Phase 1
  - Phase 2
  - Phase 3
  - Phase 4
  - Phase 5

Client: <b>Toronto Parking Authority</b>		
Title: <b>Phase 2 expansion from the existing network</b>		
Prepared by:		
1615093-001	1:45,000	Review: AB
Date: February 18, 2016		<b>Figure: 6</b>
© Queen's Printer for Ontario		

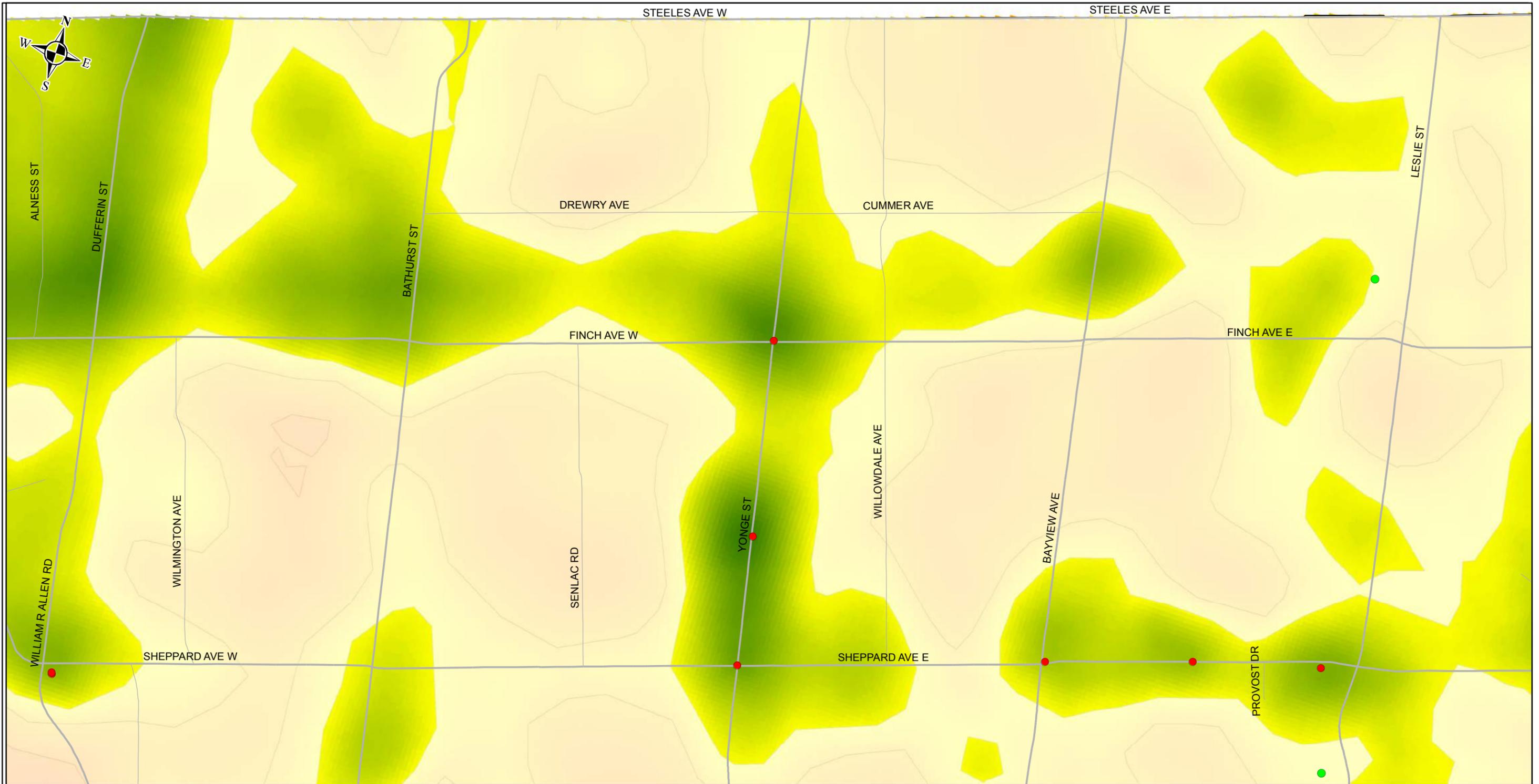


**Legend**

- GO Train Station
- TTC Subway/RT Station
- Major Arterial Street
- Minor Arterial Street
- Local Streets
- City of Toronto Boundary
- Existing Station Area
- Barriers to Expansion (semi-transparent white)



Client: <b>Toronto Parking Authority</b>		
Title: <b>Initial Satellite Expansion Area - York University Campus</b>		
Prepared by: 		
1615093-001	1:20,000	Review: AB
Date: February 18, 2016		<b>Figure: 7</b>
© Queen's Printer for Ontario		



**Legend**

- GO Train Station
- TTC Subway/RT Station
- Major Arterial Street
- Minor Arterial Street
- City of Toronto Boundary
- Existing Station Area
- Barriers to Expansion (semi-transparent white)
- Low Station Potential
- High Station Potential

Client: <b>Toronto Parking Authority</b>		
Title: <b>Phase 2 Satellite Expansion</b>		
Prepared by: 		
1615093-001	1:24,000	Review: AB
Date: February 18, 2016		<b>Figure: 8</b>
© Queen's Printer for Ontario		



# APPENDIX 3

## REFERENCES

# REFERENCES

- Brasuell, J. (2015). "Study: Capital Bikeshare Reduces Congestion." *Planetizen: The Urban Planning, Design, and Development Network*. Planetizen, 26 Aug. 2015. Web. 17 Feb. 2016.
- Buck, D. and Buehler, R. (2011). "Bike Lanes and Other Determinants of Capital Bikeshare Trips". *Transportation Research Board 91st Annual Meeting, 22-26 Jan. 2012*. Web 17 Feb. 2016.
- Büttner, J. (2011). "Optimising Bike Sharing in European Cities: A Handbook". *Intelligent Energy Europe*. June 2011. Web 17 Feb. 2016.
- City of Toronto. (2009). *Staff Report: Toronto Bike Plan – New Strategic Directions*. From General Manager, Transportation Services. 25 May 2009. Web. 17 Feb. 2016.
- City of Toronto. (2010). *Staff Report: Proposed Public Bicycle Program*. From General Manager, Transportation Services, Deputy City Manager and Chief Financial Officer. 1 Apr. 2010. Web. 17 Feb. 2016.
- City of Toronto (2013). *Feeling Congested: Toronto Talks Transportation - Phase 2 Toolkit*. Toronto Official Plan and Municipal Comprehensive Reviews. Web. 17 Feb. 2016.
- City of Toronto. (2014). "Feeling Congested?" *Recommended Official Plan Amendment for Selected Transportation Policies: Official Plan Comprehensive Review*. 11 Jul. 2014. Web. 17 Feb. 2016.
- Denver Bike Sharing. (2011). *2011 Annual Report*. Denver B Cycle. Web 17 Feb. 2016.
- Fuller, D. et al. (2013). "Impact Evaluation of a Public Bicycle Share Program on Cycling: A Case Example of BIXI in Montreal, Quebec." *American Journal of Public Health 103.3: e85–e92*. PMC. Web. 17 Feb. 2016
- Institute for Transportation & Development Policy. (2013). *The Bike-share Planning Guide*. Web. 17 Feb. 2016.
- Kalinowski, T. (2015). "Bike Share Toronto to double with \$4.9 million from Metrolinx". *The Toronto Star*. 6 Jun.2015. Web 17 Feb. 2016.
- Maus, J. (2013). "Bike Commuters are Happiest (and Other PSU Research Tidbits)". *BikePortland.org*. 30 Jan. 2013. Web 17 Feb. 2016.
- Metrolinx (2010). "GO Transit Rail Improvements Benefits Case Analysis (BCA)". *Metrolinx Board of Directors Meeting , 19 May 2010*. Web 17 Feb. 2016.
- National Association of City Transportation Officials (2015). Walkable Station Spacing is Key for Bike Share. Web 17 Feb. 2016.

- Regional Planning Commission of Greater Birmingham. (2014). Birmingham Bikeshare Feasibility Study. Web 17 Feb. 2016.
- Wang, X., Lindsey, G., Schoner, J., and Harrison, A. (2015). "Modeling Bike Share Station Activity: Effects of Nearby Businesses and Jobs on Trips to and from Stations." J. Urban Plann. Dev., Web 17 Feb. 2016.
- Winters, M. (2011). "Improving Public Health through Active Transportation : Understanding the Influence of the Built Environment on Decisions to Travel by Bicycle." T. University of British Columbia, 2011. Web. 17 Feb. 2016.