Limestone analytics

Final Report

Kingston Broadband Gap Analysis

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200 Princess Street, Kingston ON, K7L 1B2
www.limestone-analytics.com

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Credits

Limestone Analytics

Limestone is a Canada-based consulting firm specializing in the evaluation of international development projects and social programs. The firm is recognized for combining academic rigour, state of the art methods, and international development experience to provide customized evaluation and economic analysis services and to help their clients incorporate evidence to improve the design, financing, and implementation of their projects. Information about our current and past projects can be found at limestone-analytics.com.

Authors

Brett Crowley
Project Coordinator, Limestone Analytics

Warren Mabee, Ph.D.
Queen's University

Neal McKegney
Intern, Limestone Analytics

Bahman Kashi, Ph.D.
President, Limestone Analytics

Huw Lloyd-Ellis, Ph.D.
Queen's University

Emma Kinakin
Intern, Limestone Analytics

Katerina Gribbin
Intern, Limestone Analytics

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Executive Summary

This report presents the findings of the Kingston Broadband Gap Analysis, undertaken by Limestone Analytics (Limestone), in collaboration with researchers from Queen's University, for the City of Kingston (the City) and Utilities Kingston between April and December 2019. The objectives of the project were as follows:

- To define 'high-quality broadband Internet' & define an access target for the City;
- To geospatially identify gaps in access to high-quality broadband Internet service throughout the City;
- To estimate the costs & benefits of closing the gaps in access to high-quality broadband Internet services to residents and businesses in Kingston;
- To determine whether public intervention to close the gaps is required & justified.

The City and Utilities Kingston intend to use the findings from this study to guide the development of a 'Broadband Strategy,' which will seek to fill gaps in access to high-quality broadband Internet coverage, performance and pricing. This study recognizes that, as society moves into the 'digital age,' consumers' reliance on and intensity of Internet use will increase. Essential activities such as education, healthcare and government services are shifting to online delivery. Equitable access to high-quality broadband Internet service is necessary to benefit from these online activities.

Defining the target for high-quality broadband

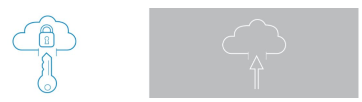
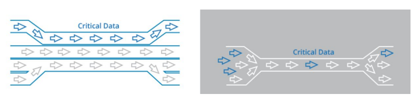
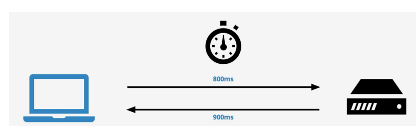
One of the biggest challenges of this project was overcoming the ambiguity of the definition of 'broadband.' The type of Internet service considered to be "broadband" has changed over time as technology has advanced, and today's definitions vary. Most mainstream definitions of broadband, including that of the Canadian Radio-television and Telecommunications Commission (CRTC) and the US Federal Communications Commission (FCC), focus only on the advertised download and upload bandwidth characteristics.

Table I: Defining broadband Internet

CRTC	FCC	Report Definition
50 Mbps[1] download and 10 Mbps upload.[2]	25 Mbps download and 3 Mbps upload.[3]	Speed, plus other attributes affecting quality.

[1] Megabits per second
[2] https://crtc.gc.ca/eng/archive/2016/2016-496.htm
[3] https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2018-broadband-deployment-report

Table II: Attributes that determine the quality of Internet service (BDO, 2017; iTel, 2019)

#	Attribute	Roadway analogy	Visual Description[4]
1	Availability	Is the road always open for you to drive on?	
2	Scalability	Can you increase the number of trips possible and go increasingly faster on the road whenever you want at no or minimal increased one-time cost?	
3	Symmetry	Does the highway run in both directions at the same speed so vehicles can travel both ways at the same time? ?	
4	Security	Does driving on the road expose you to theft or collisions?	
5	Dedicated service	Is there a lane on the road that only you are allowed to drive on?	
6	Quality of Service	Are there multiple lanes to handle all the traffic? Will the person with the most urgent need (say, a trip to the hospital) be given priority?	
7	Quality assurance	Can the Ministry of Transport guarantee how long it will take you to arrive at your destination?	
8	Latency	How long does it take for you to make a round trip on the road?	

Broadband is not binary: 'good' and 'bad' Internet defined by download and upload speeds. Rather, the broadband Internet should be seen as a spectrum of quality along which different network architectures can be categorised from 'poor' to 'best.'

[4] Visuals for attributes 1-7 come from iTel (https://itel.com/dedicated-fibre-versus-shared-fibre/) and for attribute 8 comes from Live Producers Online (https://liveproducersonline.com/latency/)

Fiber optic cable is the best available access media for delivering high-quality broadband Internet service. Most broadband Internet service today is delivered over networks built on a combination of fibre optic and copper cable - either copper telephone wires or coaxial television cables. Such networks may be structured in various topologies, which are collectively referred to as 'Fibre to the x', where 'x' could be **Home (FTTH), Premises (FTTP)**, **Building (FTTB)**, **Distribution point (FTTDp), Curb/Cabinet (FTTC),** or **Node (FTTN)**. Please note that FTTH and FTTP are used interchangeably in this report. Figure I shows a side-by-side comparison of these architectures at a very high level.

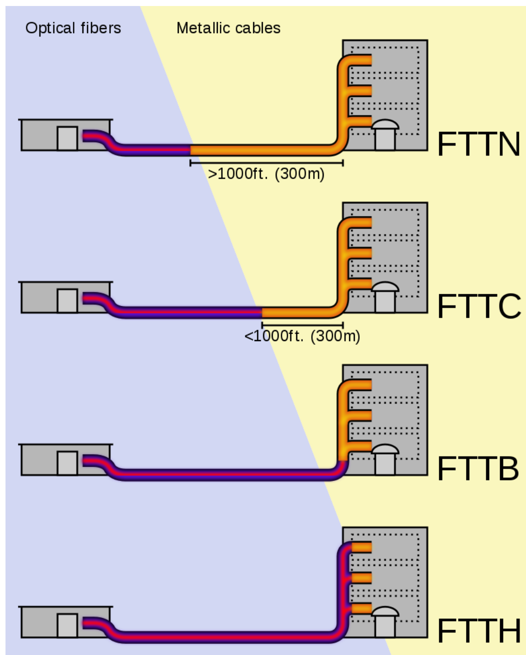


Figure I: Comparison of various FTTx topologies (Wikimedia Commons, 2019)

The closer the fibre optic cable gets to the Internet user's home or business network, the better the quality of broadband Internet service, which is why FTTP (or FTTH) can be considered the best available architecture.

Fibre to the Premises (FTTP) is the best broadband architecture available, and the only architecture capable of providing service that will meet society's current and future needs.

Identifying gaps in access to high-quality broadband

By surveying residents of Kingston, this study found a clear gap in access to high-quality broadband between rural and urban areas. Table III shows the gap in access and prices between rural and urban areas.

Table III: Comparison of speeds and prices for non-FTTP connections in Kingston

Location	Average speed (Mbps)		Average Price (CAD)
	Download	Upload	
Rural non-FTTP	10	2	$78
Urban non-FTTP	40	10	$63

Internet speed test data collected over the past five years indicate that urban residents have benefited from larger increases in download and upload speeds and decreases in latency[5] than their rural counterparts.

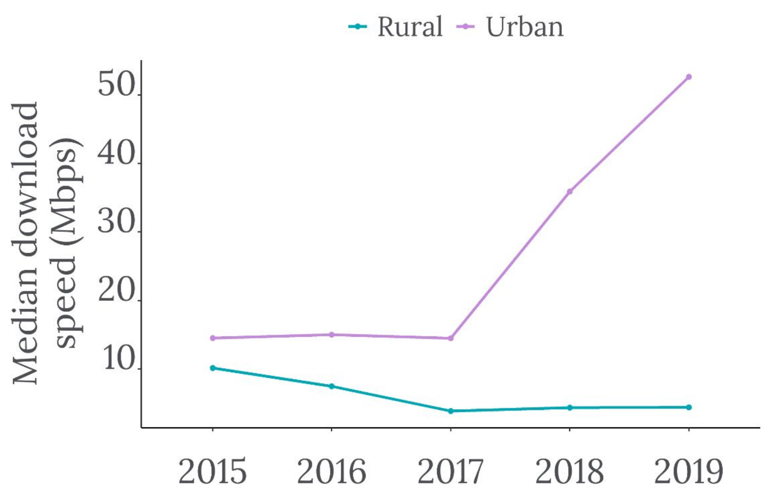


Figure II: Median download speeds recorded at unique locations in Kingston (CIRA 2019)

On average, Kingston's rural households pay more money for lower-quality Internet service. The 'digital divide' separating Kingston's rural and urban areas appears to have widened over the past five years.

[5] Latency is a measure of the amount of time it takes for a packet of data to be received, so lower latency is better.

What are the costs and benefits of closing the gaps in access to high-quality broadband?

The cost of bridging the gap in access to high-quality broadband Internet can be split into the capital expenditure (CAPEX) investment required to install new FTTP infrastructure, and operational expenditure (OPEX) required to maintain the infrastructure throughout the network's lifespan. To accurately estimate these costs, the project team sought to determine the extent of current FTTP network coverage at the street level.

Lack of access to Telecommunications Service Provider (TSP) data[6] imposed limitations on the project team's ability to accurately estimate the investment required to fill the gaps. Based on available data, a worst-case scenario costing exercise[7] was undertaken to conservatively estimate the cost of filling the gaps in access to high-quality broadband service. This exercise represents blanket FTTP access coverage throughout Kingston's entire rural zone.[8] Figure III shows the proposed FTTP network expansion footprint, and Table IV summarises the estimated Present Value (PV) of the cost to build this network in high, mid-range and low cost scenarios.

[6] Attempts were made to collect data from TSPs. WTC Communications and Utilities Kingston provided data, and the project team was in the process of arranging a data sharing agreement with Cogeco at the time this report was written. Bell, Rogers, Xplornet and Telus were also approached with a request to share information, but these TSPs did not provide information.
[7] The costing estimate is worst-case in that it assumes there is currently no FTTP service in rural Kingston. The project team is aware that this is not the case, but without TSP data it is impossible to accurately identify rural areas with current FTTP access.
[8] Due to limited data, the project team was not able to accurately identify underserved areas in Kingston's urban zone, but this is a known information gap that should be addressed in future data collection efforts.

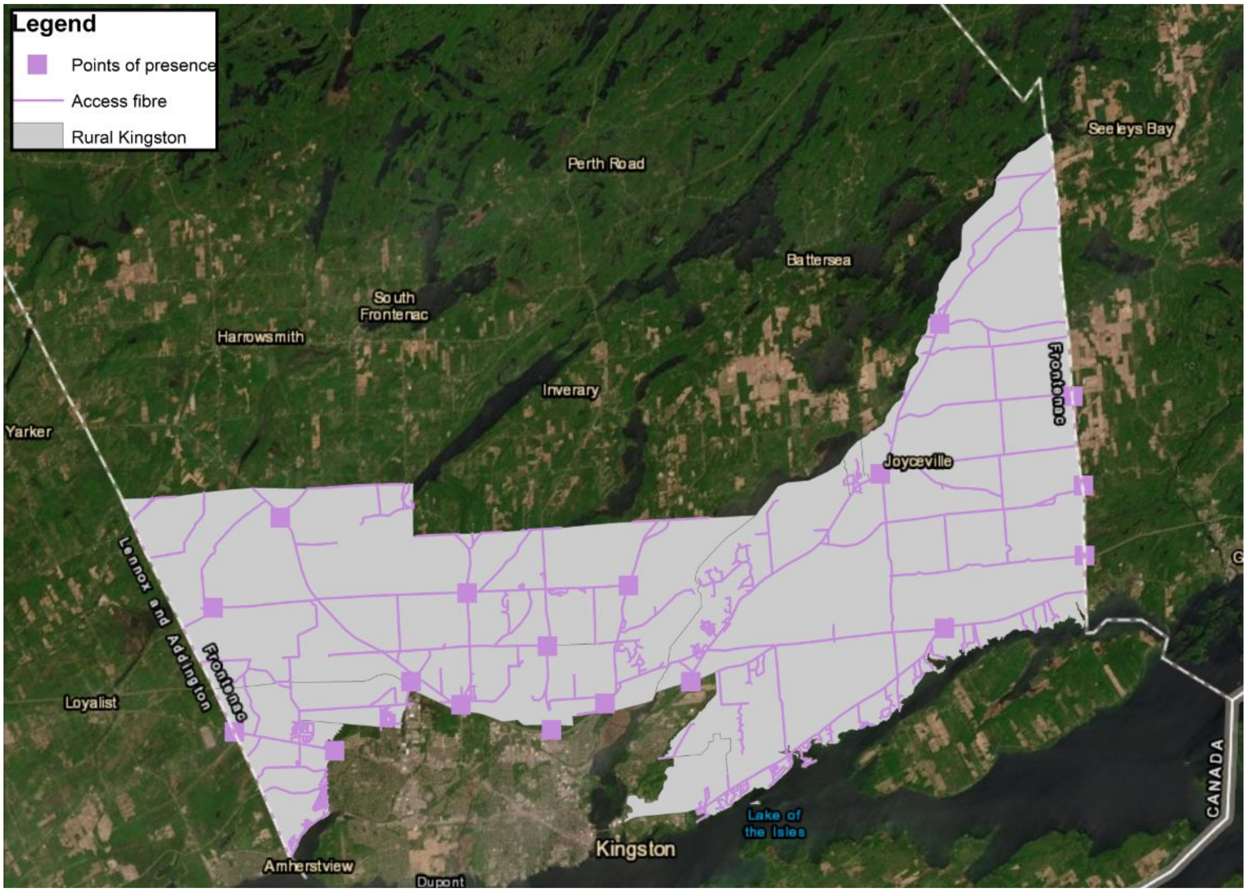


Figure III: Proposed FTTP network expansion[9]

Table IV: Present value of FTTP network CAPEX under various scenarios

Scenario	Present value of CAPEX (2019 CAD)	Per rural household (2019 CAD)
High cost	$87 Million	$12,687
Mid-range cost	$40 Million	$5,803
Low cost	$23 Million	$3,349

The highest cost of providing all rural Kingston with the infrastructure required for Fibre to the Premises (FTTP) can be from $23 to $87 Million.

[9] *Points of Presence* (POPs) are where the fibre optic strands are broken out and connected to routers. The routers manage the flow of Internet traffic to and from each premises.

Estimating **the benefits** of bridging the gap in access to high-quality broadband Internet is a nuanced exercise. Broadband Internet is used for a variety of purposes, some of those that are most commonly known are media streaming and online gaming. Other ways to utilize the Internet, which can come at a greater value, are online education and health services. However, these high-value benefits are less tangible today because these applications are in the early stages of development and thus not yet widely used. Broadband Internet access can also enable more individuals to telework, which is beneficial to teleworkers, their employers, other drivers that use the same roads, and the environment. Aggregating the value of these benefits in a single monetary term is not a straight-forward task. Furthermore, these benefits can evolve and new benefits can emerge over time, which makes it difficult to predict the value over any extended period of time.

This report takes a conservative approach and focuses primarily on quantifying residential consumers' perceived value of access to high-quality broadband Internet. This approach to valuation limits the value of benefits to what is perceived by consumers based on today's knowledge about the importance of broadband Internet, ignoring the values to other members of the society and how benefits can evolve over time. Results from the residential survey were used to estimate the gains for consumers that would result from expanding FTTP service to all of rural Kingston.

Under a conservative scenario, the value of access to broadband for rural residents of Kingston is estimated at $88 Million, or $12,812 per household in rural Kingston.

The CBA considers two different 'business-as-usual' scenarios, from the perspective of two types of TSPs. The first scenario is a 'brownfield' expansion, which applies to an incumbent TSP that currently provides broadband service over an existing, non-FTTP network in rural Kingston. The second scenario is a 'greenfield' expansion in which a new TSP enters the market and builds a network where it previously did not provide service.

Service providers benefit from the expansion by earning incremental revenue, which is the increase in revenue earned from the network expansion above and beyond the revenue that would have been earned in the business-as-usual scenario[10]. This incremental revenue is the 'Benefit to service providers' displayed in Table V below. Incremental revenue indicates whether the investment is more valuable to the TSP than the business-as-usual

[10] In the greenfield scenario, the TSP initially earned no revenue in the target areas. Therefore, in the greenfield scenario, incremental revenue is equal to the total revenue earned from the FTTP network.

scenario. TSPs also incur incremental OPEX costs[11], which are added to the CAPEX costs to determine the Total Cost of Ownership (TCO) over the life of the FTTP network.

Table V shows the results of a Cost Benefit Analysis (CBA) demonstrating how the various costs and benefits of FTTP network expansion are distributed amongst the key stakeholders in the economy in the worst case (high cost, brownfield expansion) scenario.

Table V: Worst case CBA results (2019 CAD)

Value streams	TSPs	Rural Consumers	Economy
Benefit to consumers		$88 Million	$88 Million
Benefit to service providers	$23 Million		$23 Million
TCO of FTTP network	-$101 Million		-$101 Million
Net Impact	-$77 Million	$88 Million	$10 Million

Conservative estimates from a Cost-Benefit Analysis show that expanding FTTP infrastructure to cover all of rural Kingston will result in a net benefit to the overall economy over a 20 year period.

Is government intervention to close the gaps in access to high-quality broadband justified and required?

The study also considers how consumer preferences affect the pricing policies of service providers. Prices form the revenue for service providers and are critical in understanding the business case of broadband Internet, and the role that public interventions, such as market regulation and subsidies, can play. Table V showed that, while the overall Net Present Value (NPV) of FTTP network expansion to cover all of rural Kingston is positive for the overall economy, it is overwhelmingly negative for service providers. This study reports the cost under three cost scenarios: Low, Mid-range and High. As illustrated in Figure IV, even in the best case (low cost, greenfield scenario), it takes 20 years before the increased revenue for service providers surpass the costs. Therefore, there is no business case for services providers to build a FTTP network in rural Kingston.

[11] Since OPEX is estimated as a percentage of revenue, incremental OPEX is also higher in the greenfield scenario than in the brownfield scenario.

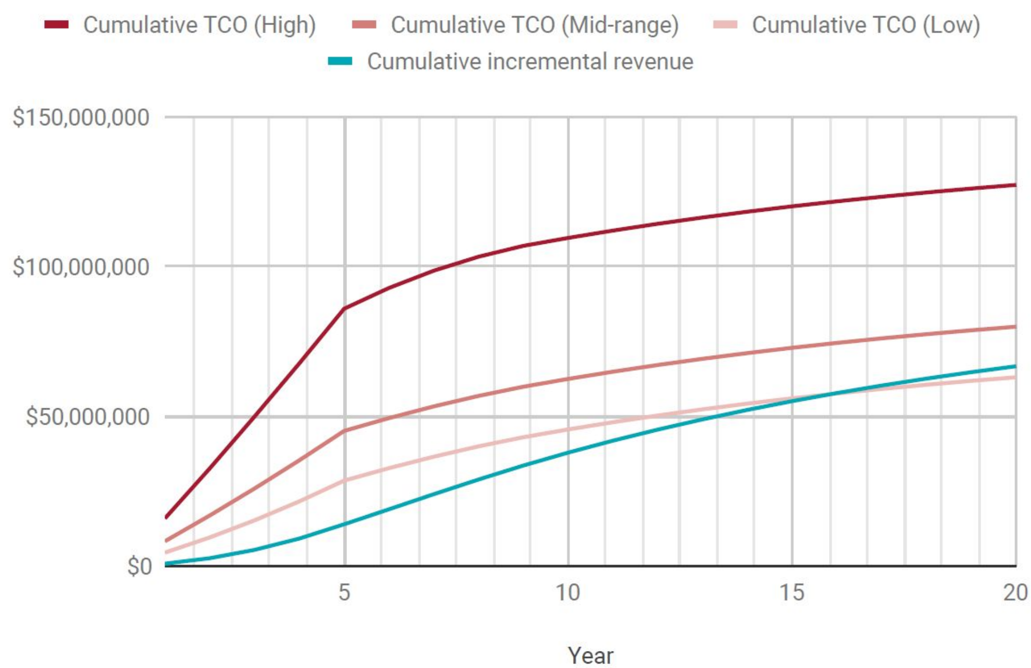


Figure XI: Cumulative TCO and incremental revenue over FTTP network in rural Kingston

Telecom Service Providers (TSPs) are not likely to further expand FTTP network coverage to all of rural Kingston in the near future because there is no business case for them to do so. Without public intervention, the gap will continue to exist and will expand over time.

Since the private sector has no incentive to close the gaps in access to FTTP Internet service, government intervention is required if this target is to be reached any time soon. Government intervention is justified by the fact that the overall economy will benefit from expanding FTTP Internet service to all of rural Kingston. The last remaining question is, what level of government support is required to create a viable business case for TSPs to build and operate a FTTP network in rural Kingston?

This study estimates that in order to bring the payback period for service providers to 5 years, the government needs to subsidize the CAPEX by more than 80%. However, it is critical to note that this analysis takes conservative measures of costs (high) and benefits (low). The value of subsidy needed, as reported by this study, is therefore the highest it will ever need to be.

Knowledge gaps and next steps

Existing knowledge gaps impose limitations on the comprehensiveness and accuracy of the results of this study. Continued efforts to obtain information from TSPs about their infrastructure and service coverage and pricing would help increase the focus and accuracy of the model's estimates. Another previously discussed knowledge gap stems from the constantly-evolving nature of society's use of the Internet. This study did not attempt to place an economic value on emerging or less tangible benefits to society. However, it is worth observing that the benefits estimated by the model represent a lower bound to the true benefits that society might expect to obtain from expanded access to high-quality broadband Internet.

To design and implement a public intervention to improve connectivity for rural Kingston, an analysis of the market is necessary to understand how service providers will react to alternative incentive structures. The high investment cost associated with the provision of high-quality broadband Internet results in the existence of market power.

This study paves the path for a number of follow-up activities that are listed below.

- Continued data collection from residents and businesses can help improve understanding of access and affordability gaps among subgroups based on income or other characteristics (beyond rural-urban).
- The findings of this study, and any future expansions, contain valuable information for the public. Such information can inform the choice of service provider or place of residence for consumers. It is therefore recommended to establish ongoing two-way engagement with the public through an interactive online portal.
- If data collection from consumers becomes an ongoing effort (e.g. through a web-based portal), future studies can monitor how Internet usage evolves over time, allowing the analysis to capture new sources of benefits.
- Data from service providers can improve the accuracy of the cost estimates and identify underserved areas at a more granular level. This will help identify where it makes the most economical sense to begin building out fibre optic facilities in rural areas by building off of existing infrastructure, and the phases of the build-out can be mapped to specific areas. The City should therefore continue to work with TSPs, the CRTC, ISED and others to obtain this information.
- A theoretical market model can help the industry better understand the incentive structure and the behaviour of TSPs in alternative settings such as rural and urban. Such an understanding will help policymakers replicate the results of this study in similar contexts.

Acronyms

5G	5th Generation Mobile Wireless Network
ARPU	Average Revenue per User
BAWG	Broadband Analytics Working Group
CASL	Canadian Anti Spam Legislation
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CIRA	Canadian Internet Registration Authority
CRTC	Canadian Radio-television and Telecommunications Commission
DA	Dissemination Area
DCE	Discrete Choice Experiment
DEM	Digital Elevation Model
DLA	Data Licensing Agreement
DMP	Data Management Plan
DOCSIS	Data Over Cable Service Interface Specification
DPON	DOCSIS over PON
DSL	Digital Subscriber Line
EBITDA	Earnings Before Income Tax, Depreciation and Amortization
EPON	Ethernet Passive Optical Network
FCC	Federal Communications Commission
FDX-DOCSIS	Full Duplex DOCSIS
FWS	Fixed wireless signal
FTTB	Fibre to the Building
FTTC	Fibre to the Curb/Cabinet
FTTDp	Fibre to the Distribution point
FTTH	Fibre to the Home
FTTN	Fibre to the Node
FTTP	Fibre to the Premises
FTTx	Fibre to the x
GB	Gigabyte
Gb	Gigabit
Gbps	Gigabits per second
GHG	Greenhouse gas
GIS	Geographic Information System
GPON	Gigabit Passive Optical Network

GREB	General Research Ethics Board
HFC	Hybrid Fibre Coax
ILEC	Incumbent Local Exchange Carrier
ISED	Ministry of Innovation, Science and Economic Development
IT	Information technology
ITU	International Telecommunications Union
KEDCO	Kingston Economic Development Corporation
Mb	Megabit
Mbps	Megabits per second
MDU	Multiple Dwelling Unit
MHz	Megahertz
MPK	Map Package
MTTR	Mean Time to Restore
MWTP	Marginal willingness to pay
NDA	Non-disclosure agreement
NPV	Net Present Value
NDT	Network Diagnostic Test
ONT	Optical Network Terminal
OPEX	Operational Expenditure
OSP	Outside Plant
PON	Passive Optical Network
GPON	Gigabit PON
PoP	Point of Presence
PtmP	Point to Multipoint
PtP	Point to Point
QoS	Quality of Service
RFI	Request for information
RFoG	Radio Frequency over glass
SLA	Service Level Agreement
SLO	Service Level Objective
TCO	Total Cost of Ownership
TSP	Telecommunication Service Provider
UK	Utilities Kingston
VDSL2	Very high bit rate Digital Subscriber Line 2
VoIP	Voice over Internet Protocol
WTP	Willingness to Pay

1. Introduction

The City of Kingston (the City) intends to develop a Broadband Strategy in an effort to fill gaps in high-quality broadband Internet coverage, performance and pricing. As a first step in executing the Broadband Strategy, Limestone Analytics (Limestone) began working with the City and Utilities Kingston (UK) in April 2019 to implement the Kingston Broadband Gap Analysis project. This project sought to build the evidence base required to expand access to high-quality broadband Internet in a way that is equitable, ubiquitous and financially and operationally sustainable, while providing the infrastructure required for the growth and prosperity of the City of Kingston. Limestone partnered with the Department of Economics and the Department of Geography and Planning at Queen's University to implement this project. This partnership allowed the team to provide services that are academically sound and practical at the same time.

This study was motivated by a recognition that, as society moves into the 'digital age,' consumers' reliance on and intensity of Internet use will increase. Essential activities such as education, healthcare and government services are shifting towards online delivery. To benefit from these online activities, consumers must have access to high-quality broadband Internet service. The problem is that due to market failures, a gap in access to high-quality broadband Internet service exists, and may, in fact, be widening in the City of Kingston. This gap tends to separate rural citizens from urban citizens, as well as low-income earners from high-income earners (even in urban areas).

"Most of the broadband telecommunications investment in the past decade was focused on larger cities with relatively high-density households and businesses. The effect of this investment was to widen the digital divide between cities and nonurban regions, especially rural areas, which are becoming relatively more isolated."

- ***The World Bank Group, Innovative Business Models for Expanding Fiber-Optic Networks and Closing the Access Gaps, 2018.***

1.1 Defining 'broadband'

One of the biggest challenges of this project was overcoming the ambiguity of the definition of 'broadband.' What type of Internet service is considered to be broadband has changed over time as technology has advanced, and today's definitions vary. Most mainstream definitions of broadband, including that of the Canadian Radio-television and Telecommunications Commission (CRTC) and the US Federal Communications Commission (FCC), focus only on the advertised download and upload bandwidth. However, Utilities Kingston (UK) provided the project team with a fuller, more comprehensive definition of broadband Internet.

Table 1-1: Defining broadband Internet

CRTC	FCC	Report Definition
50 Mbps[12] download and 10 Mbps upload.[13]	25 Mbps download and 3 Mbps upload.[14]	Speed, plus other attributes affecting quality.

"… the history of the internet has demonstrated that connections that were adequate at one point in time very quickly become inadequate as applications become more bandwidth-intensive and new services are adopted. Given this reality, it is possible that by the time broadband services meeting the minimum universal service objective criteria are rolled out in rural and remote Canada, they will already be straining to deliver adequate access to the latest applications and services in use at that time… The real challenge for rural Canada then is not achieving the CRTC's 50 [Mbps download]/10 [Mbps upload] universal service target for fixed broadband services, but developing a strategy to ensure more future-proof broadband services are, or will be, available even in small population centres across the country in the next few years."

- ***Rural Ontario Institute, Broadband Infrastructure for the Future, 2017.***

[12] 'Bits per second' (rate of information transferred) should not be confused with 'bytes' (amount of information transferred). In this case, "Megabits per second" or "Mbps" denotes the bandwidth which is "speed x capacity" of the connection, also known as the "information carrying rate".
[13] https://crtc.gc.ca/eng/archive/2016/2016-496.htm
[14] https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2018-broadband-deployment-report

In today's Internet market, broadband Internet service can be delivered over a variety of types of **access media** (the physical interface between people and technology), assembled in a variety of **topologies** (the layout of the physical technology), using a variety of **transport mechanisms** (the rules outlining how information is transferred from one place to another). All together, these three aspects of a broadband network create the network **architecture** (the logical framework for transporting data). Different network architectures offer varying capabilities, and these capabilities have evolved over the years as technology has improved. The experience of an Internet user is highly dependent on the architecture of the network over which her service is delivered. Table 1-2 identifies and defines some of the attributes of an Internet connection that affect the quality of the Internet service.

The key takeaway from Table 1-2 is that broadband is not binary: 'good' and 'bad' Internet defined by minimum download and upload speeds. Rather, broadband Internet should be seen as a spectrum of quality along which different network architectures can be categorised from 'poor' to 'best.'

Table 1-2: Attributes that determine the quality of Internet service (BDO, 2017; iTel, 2019)

#	Attribute	Description	Roadway analogy
1	Availability	High availability means the connection is available and performs as contracted at all times the user needs it.	Is the road always open for you to drive on?
2	Scalability	The connection bandwidth capacity may be dynamically scaled as users' require it free of lengthy time delays or costly upgrades to enable the increase.	Can you increase the number of trips you take on the road at any time?
3	Symmetry	Symmetrical service means the upload and download speeds are the same. Asymmetrical service means the download speeds are greater than the upload speeds.	Are there an equal number of lanes, with the same speed limit, running in both directions?
4	Security	A key determinant of Internet service's security is whether it is delivered over a private or public connection. Private connections between users provide higher security or are less vulnerable to hacking than public connections.	Does driving on the road expose you to theft or collisions?
5	Dedicated service	A connection is dedicated if it connects directly from the users' premises to the central office (CO) of the Telecommunication Service Provider (TSP). A connection is shared if multiple users connect to the CO of the TSP through a splitter or node device.	Is there a lane on the road that only you are allowed to drive on?
6	Quality of Service	Quality of Service (QoS) is the ability of the Internet connection to prioritize and differentiate a user's traffic on the network. For example, the connection might separate Web browsing packets from Voice over Internet Protocol (VoIP) packets (Skype is an example of an app that uses VoIP) such that VoIP session bandwidth is allocated correctly and the VoIP session is prioritized over other less latency-sensitive traffic.	If multiple people in your house need to drive on the road at the same time, will the person with the most urgent need (say, a trip to the hospital) be given priority?
7	Quality assurance	Quality assurance can be established through Service Level Agreements (SLA) or Service Level Objectives (SLO). A SLA provides users with commitments to network availability or uptime, mean time to restore, latency among other attributes with a remedy to the users if for non-performance. SLOs are uncommitted best-effort targets with no remedy to users for non-performance.	Can you take a trip and know exactly how long it will take you to arrive at your destination?
8	Latency	Latency is a measure of the amount of time it takes for a packet of data to be sent from your device to a data centre and back to your computer. Lower latency is therefore better, because it means less delay between an Internet user's request and the response they receive. Low latency is important for all voice and video traffic and other symmetrical applications.	Do you often face delays when you travel on the road?

1.2 Performance comparison of broadband alternatives

Having defined 'broadband' as a spectrum of quality, the next question that must be answered is: what broadband technology alternatives exist, and how do they compare with one another in terms of performance and cost? This section seeks to answer this question by exploring a variety of widely implemented broadband technologies and discussing the capacities and costs of each.

First, a comparison of fibre optic cable and copper cable is illustrative. Overall, fibre optic cable is a superior material for transmitting data than copper cable. Fibre optic cable is both lighter and smaller in diameter than copper cable, which is important for underground builds where space in existing conduit is limited. Fibre transmits data faster and offers higher data carrying capacity than copper, because data is transmitted over fibre as pulses of light rather than electricity. Fibre optic cable exhibits lower signal attenuation (reduction in signal strength) per unit distance than copper, meaning that fibre has a greater range than copper. Fibre is also impervious to electromagnetic interference, providing greater reliability and security of data transmission than copper cable (Optronics Plus). Copper networks consume more electricity and the cables require more frequent maintenance, meaning that fibre optic networks can offer significant operational expenditure (OPEX, or recurring costs related to operations and maintenance) savings (Barreto & Dargue, 2014).

However, many would argue that these differences in material properties do not preclude copper from playing a role in providing high-quality broadband service. Indeed, most broadband Internet service today is delivered over middle- and last-mile networks built on a combination of fibre optic cable and legacy copper transmission media - either twisted pair telephone cables or coaxial television cables. Such networks may be structured in various topologies, which are collectively referred to as 'Fibre to the x', or FTTx. FTTx topologies include:

- **Fibre to the Home (FTTH)/ Fibre to the Premises (FTTP)** - Fibre optic cable is run from the TSP's Central Office (CO) all the way to the customer's premises and connected to an Optical Network Terminal (ONT).
- **Fibre to the Building (FTTB)** - a layout often used to provide service to Multiple Dwelling Units (MDUs). Fibre optic cable is run from the CO to the MDU, and customers are connected to the network using copper wire.
- **Fiber to the Distribution point (FTTDp)** - fibre optic cable is run from the CO to a distribution point that is close (10s-100s of meters) to the customer's premises, and the final connection is made with copper wire.
- **Fibre to the Curb/Cabinet (FTTC)** - fibre optic cable is run from the CO to a cabinet that is moderately close (100s of meters - 1km) to the customer's premises, and the final connection is made with copper wire or coaxial cable.

- **Fibre to the Node (FTTN)** - fibre optic cable is run from the CO to a node that is relatively far (>1km) from the customer's premises, and the final connection is made with copper wire or coaxial cable.

Figure 1-1 shows a side-by-side comparison of these architectures at a very high level.

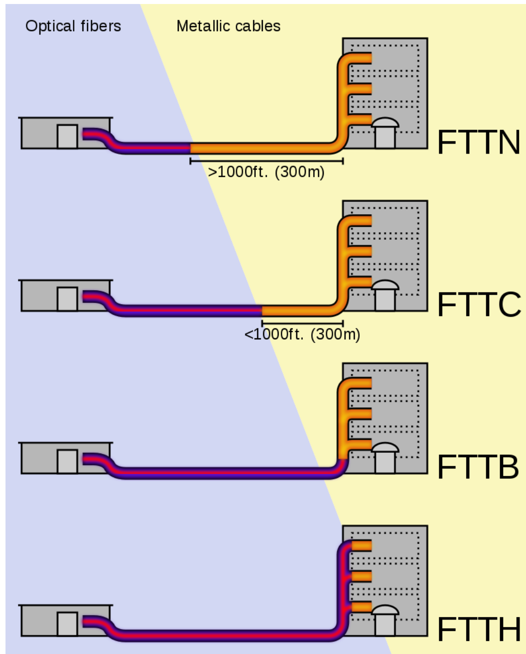


Figure 1-1: Comparison of various FTTx topologies (Wikimedia Commons, 2019)

By pursuing 'deep fibre' strategies (i.e. strategies that aim to bring fibre as close to customers' premises as is economically viable), TSPs have been able to implement these various FTTx topologies to enhance the services offered over legacy copper infrastructure, while avoiding the high capital investment needed to deliver FTTP broadband service. Generally speaking, the closer the fibre optic cable gets to the Internet user's home or business network, the better the quality of broadband Internet service, which is why FTTP can be considered the best available architecture. The following sections explore each of these various architectures in greater detail.

1.2.1 Fibre to the Premises

The two main categories of FTTP architecture are Passive Optical Network (PON) and Active Ethernet. As shown below in Figure 1-2, PON is a point-to-multipoint (PtmP) topology, whereas Active Ethernet is a point-to-point (PtP) topology.

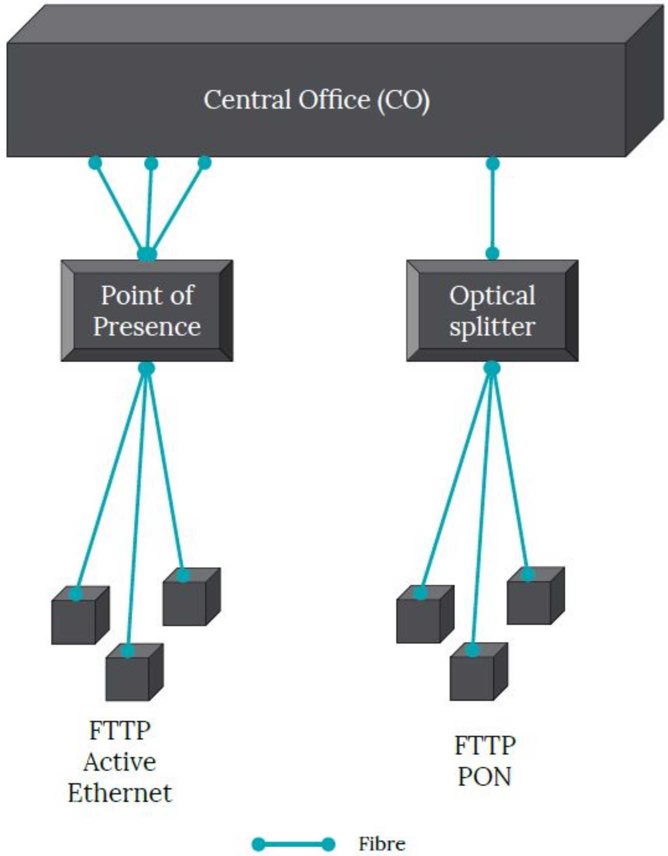


Figure 1-2: Comparison of FTTP topologies

Active Ethernet is superior to PON in terms of performance. Since customers have a direct fibre optic connection to the TSP's CO, the Internet service is highly available, dedicated and secure. In a PON architecture, on the other hand, CO resources are split by a passive (i.e. not powered) optical splitter and shared among customers. Because the resources are shared, the service is by definition not dedicated, it might not be highly available (the limited pool of shared resources might be depleted if everyone wants to use the resources at once) and it is less secure (because service is provided over a shared network, it is easier for information to be rerouted/hacked). For this same reason, Active Ethernet can be quality assured, while this might not be possible over PON (if the capacity of the limited pool of resources is exceeded by the resources demanded from all subscribers over the network at one time[15]). Active Ethernet service is capable of supporting QoS, but PON service does not offer this capability. Both Active Ethernet and PON architectures are scalable and can support symmetrical service, however PON's scalability is more limited than that of Active Ethernet (iTel Networks Inc, 2019).

[15] This can happen because of 'oversubscription' - that is, the sum of the capacity purchased by all subscribers on a network exceeds the capacity that the network is capable of providing. (Baliga et al, 2010). This is a comparable strategy to that of airline companies overbooking flights.

As might be expected based on its superior performance, Active Ethernet is also more expensive to implement and operate than PON architectures. This is largely because Active Ethernet requires greater lengths of fibre optic cable running directly from the CO all the way to each customer's premises. PON, on the other hand, uses fibre optic cables with relatively few fibre strands to connect the CO to an optical splitter, from which point fibre cables with higher strand counts are run the last mile to customers' premises. Each Active Ethernet connection is powered whereas PON relies on passive (i.e. not powered) splitters to share the resources from a single powered source, meaning that Active Ethernet is also more energy intensive at relatively low bitrates (Akeksic and Lovric, 2011).

Although Active Ethernet is superior to PON in performance, both variations of the FTTP architecture offer performance that is superior to any other widely implemented copper-based architecture. The following sections explain why this is the case.

1.2.2 Twisted-pair copper

Digital Subscriber Line (DSL) technology was originally developed to transmit data over twisted pair copper telephone wires which were never intended to serve that purpose. Early versions of DSL include Asymmetric Digital Subscriber Line (ADSL) and Very high bit rate Digital Subscriber Line (VDSL). FTTx paired with new DSL variants such as VDSL2, VDSL2+, ADSL2, ADSL2+ and G.Fast offer potential data download rates in the Gigabit per second (Gbps) range (Zafaruddin, S.M. et al, 2017). These DSL technologies may take advantage of various combinations of three innovative methods (Rong et. al, 2013) to improve broadband Internet performance:

- **Channel bonding**, where multiple copper pairs are combined into a single information channel;
- **Vectoring**, where digital cancellation techniques are used to eliminate **crosstalk**. Crosstalk is a phenomenon where broadband signals being carried along adjacent copper wires interfere with one another, thereby reducing broadband service performance. This phenomenon intensifies at higher electromagnetic frequencies - which is problematic because one of the reasons why VDSL2 and G.Fast are able to deliver higher bandwidth is because they operate at higher frequencies than their DSL predecessors (Heath, 2016).
- **Phantom mode**, where the two signals in a pair of copper wires are used to create a third signal, effectively creating a third 'virtual' wire over which information can be transferred.

Figure 1-3 shows a side-by-side comparison of some commonly deployed FTTx architectures with copper wire last-mile connections. Figure 1-4 compares the maximum theoretical bandwidth and bit rate of various DSL technologies. Borzycki notes that these values are only indicative maximum values specified in standards, and that the 'Reach achieved in service depends on cable design and its technical condition' (Borzycki, 2018).

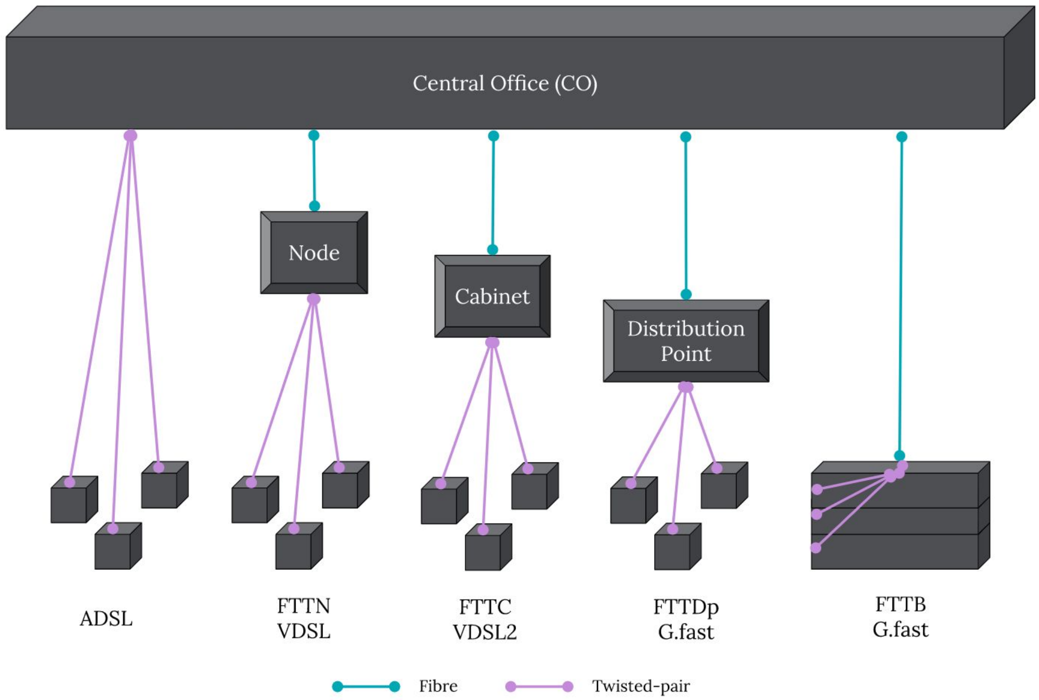


Figure 1-3: Comparison of common twisted pair broadband network architectures

System	Standard	Max. bandwidth occupied (MHz)	Max. bit rate [Mb/s]	Typical reach with a single 0.5 mm pair	Vectoring
ADSL2+	ITU-T G.992.5 (2009)	2.208	24	1600 m @ 20 Mb/s 3000 m @ 10 Mb/s	No
VDSL	ITU-T G.993.1 (2001)	12	52	1200 m @ 40 Mb/s	No
VDSL2	ITU-T G. 993.2 (2006)	30	200	250 m @ 200 Mb/s 800 m @ 50 Mb/s 3500 m @ 4 Mb/s	Optional
VDSL2+	ITU-T G. 993.2 Amd. 1 (2015)	35	300	200 m @ 300 Mb/s	Optional
G.fast	ITU-T G.9700 (2014) ITU-T G.9701 (2014)	106 212 (in the future)	1000	25–70 m @ 1000 Mb/s 100 m @ 500 Mb/s 250 m @ 250 Mb/s	Yes

Figure 1-4: Comparison of DSL technologies (Borzycki, 2018)[16]

However, even if these cutting-edge twisted pair specifications reach their full potential, they will still fall short of FTTP's download and upload speed capacity. Moreover, these advanced DSL systems carry other shortcomings such as the inability to provide symmetrical service and no native support for Quality of Service (QoS) (Multimedia over Coax Alliance). Achieving the theoretical capacities indicated in Figure 1-4 above can be difficult to achieve in practice, at-scale, outside of a controlled laboratory environment.

[16] The ITU is the International Telecommunications Union. MHz stands for Megahertz, which is the unit of measure for electromagnetic signal frequency.

Vectoring requires active (i.e. powered) equipment which increases a network's OPEX, and the effectiveness of vectoring can be reduced if different TSPs' copper wires interfere with each other (Rong et. al, 2013). These are serious limitations that undermine twisted pair copper's ability to provide 'future proof' high quality broadband service.

1.2.3 Coaxial cable

Coaxial copper cable, abbreviated to coax, was originally used to build cable television networks which were not originally designed to deliver data services. In 1997, Cable Television Laboratories Inc. (CableLabs) released the Data Over Cable Service Interface Specification (DOCSIS), allowing cable companies to provide broadband internet service over their existing coaxial networks (CableLabs, 2018). DOCSIS has evolved over the years to enable higher bandwidth and greater sophistication of broadband service, such as improved security and support for Quality of Service (Multimedia over Coax Alliance). DOCSIS version 3.0 was released in 2008 and enabled asymmetrical 1 Gigabit per second (Gbps) downstream / 100 Mbps upstream bit rate service over coaxial networks. DOCSIS 3.1 was released in 2016, offering an order-of magnitude increase in theoretical downstream bit rate capacity, enabling asymmetric 10 Gbps downstream / 2 Gbps upstream bit rate over coaxial infrastructure. The next version of DOCSIS, Full Duplex DOCSIS 3.1 (FDX-DOCSIS 3.1, also referred to as DOCSIS 4.0) promises to enable symmetrical broadband service by bringing the theoretical upstream bit rate capacity up to 10 Gbps. However, these are theoretical capacities that may be difficult to achieve cost-effectively at scale in a real-life broadband network.

The evolution of DOCSIS, along with strategic transformation of pure coaxial networks to Hybrid Fibre Coax (HFC) networks, has enabled cable providers to cost-effectively leverage legacy infrastructure to provide broadband services competitive with FTTP broadband. In fact, DOCSIS 3.1 enables download and upload bit rates superior to those available over commonly implemented FTTP Passive Optical Network (PON) architectures such as Gigabit PON (GPON) and Ethernet PON (EPON) (Borzycki, 2018). DOCSIS can even be incorporated into a PON architecture known as Radio Frequency over Glass (RFoG), an approach referred to as DOCSIS over PON (DPON). However, as discussed above, bandwidth is not the only factor affecting broadband quality. Broadband service delivered over coaxial cable is not highly available because network capacity is shared, and HFC networks have limited scalability. By comparison, FTTP Active Ethernet networks are both highly available and offer unlimited scalability.

From a business perspective, copper cables and the Outside Plant (OSP) active equipment needed to amplify electrical signals require more frequent maintenance and replacement than fibre optic network infrastructure, meaning that fibre optic networks can offer significant OPEX savings (Barreto & Dargue, 2014). A 2013 study of 350 small and medium fiber optic network service providers across North America found average OPEX savings of 20.4% annually by switching to FTTP networks (Lightwave, 2013). Although installing FTTP infrastructure carries relatively high capital expenditure (CAPEX, or up-front investment costs including equipment and labour), upgrading HFC networks from DOCSIS 3.0 to 3.1 can also involve high CAPEX depending on the physical condition and topology of the existing network infrastructure. Yet another significant advantage of fibre optics over copper is that fiber is generally the more energy efficient option. Aleksic and Lovric found in a 2011 study that, for data access rates in the 1 Gbps bit rate range and an uplink limit of 320 Gbps at a TSP's CO, FTTP-GPON networks are the most energy efficient network architecture relative to performance-competitive HFC and DSL architectures (Aleksic and Lovric, 2011). If the CO has unlimited uplink capacity, then 10 Gbps PtP Active Ethernet systems are the most energy efficient. These findings were echoed in a 2010 study by Baliga et. al, which found that even at much lower bit rates (as low as 5 Mbps) theoretical energy consumption is lowest in FTTP PON networks. (Baliga et al, 2010).

Figure 1-5 below provides a high-level, side-by-side view of the various coaxial architectures that have been discussed here.

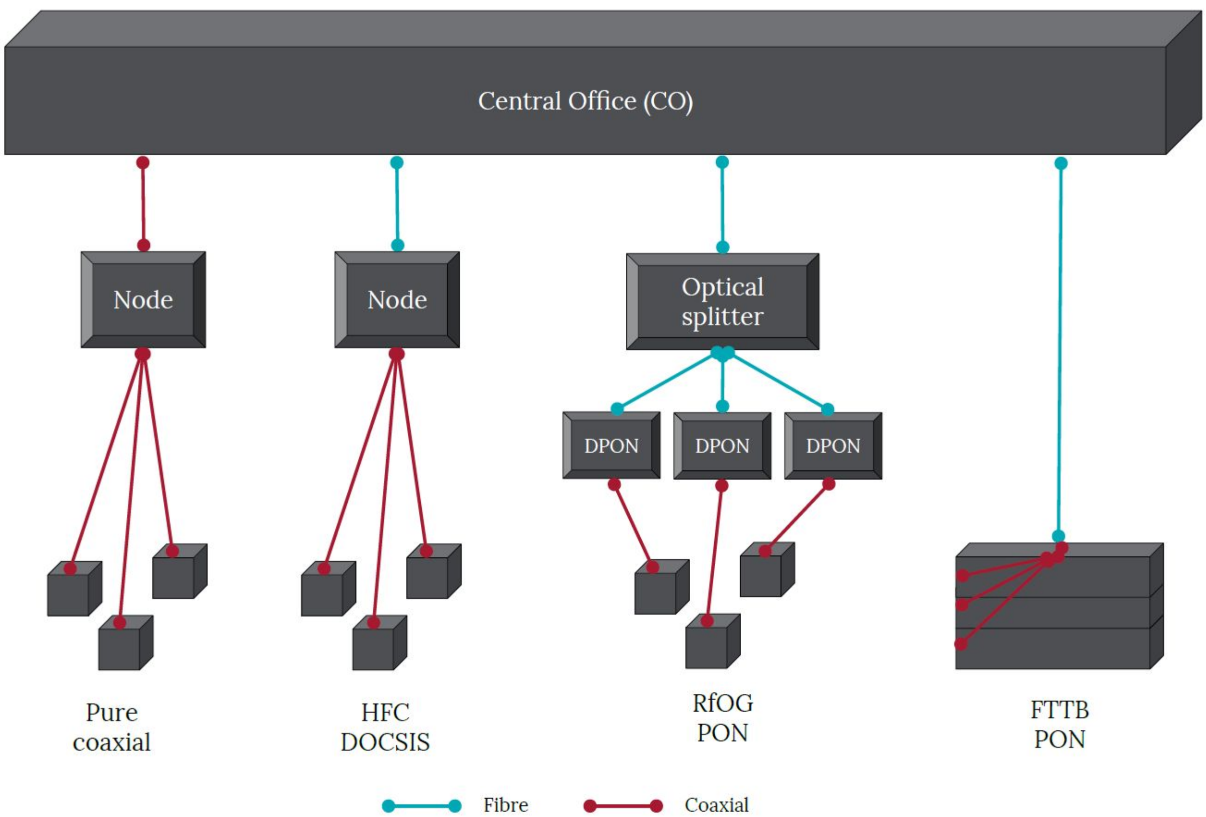


Figure 1-5: Comparison of common coaxial broadband network architectures

1.2.4 Fixed and mobile wireless

What about fixed wireless and mobile broadband technologies such as WiMAX, LTE and LTE's imminent successor, 5G? Simply put, wireless broadband technology is considered a complement rather than a substitute for fixed wireline technologies. Wireless broadband service is often delivered via shared access media (PtmP topology), meaning that while high data bandwidth and speed can be achieved, they cannot be guaranteed (The World Bank, 2018) (Wik Consult, 2015). While PtP wireless topologies will support dedicated service and allow for SLAs and Qos, wireless technology is inherently limited because it can be negatively impacted by line-of-sight issues, obstacles, environmental effects and electromagnetic interference. Conversely, fixed wireline broadband is impervious to most (in the case of copper) or all (in the case of fibre) of these effects (Vantage Point Solutions, 2017). This is not to say that these technologies do not have a place in the broadband ecosystem, but rather that wireless and wireline broadband technologies serve different purposes. Moreover, fibre is preferred by TSPs as backhaul for fixed and mobile wireless access networks because of its scalability and reliability. Given that 5G will rely on extensive fibre optic network coverage, the potential that 5G promises presents lends itself to the argument in favour of extending fibre optic networks as close to the customer premises as possible today.

> **"All broadband providers today – wired and wireless alike – realize that the way to increase broadband capability is to increase the amount of fiber in their network. Landline providers are replacing their copper cable with fiber, cable operators are replacing their coax cable with fiber, and even wireless providers are actually replacing their wireless networks with fiber by placing their towers (or small cells) closer to the customer."**
>
> - ***Vantage Point Solutions, Evaluating 5G Wireless Technology as a Complement or Substitute for Wireline Broadband, February 2017.***

1.2.5 Overview of performance comparison

Figure 1-6 provides an overview of how Internet service quality tends to vary by network architecture type.

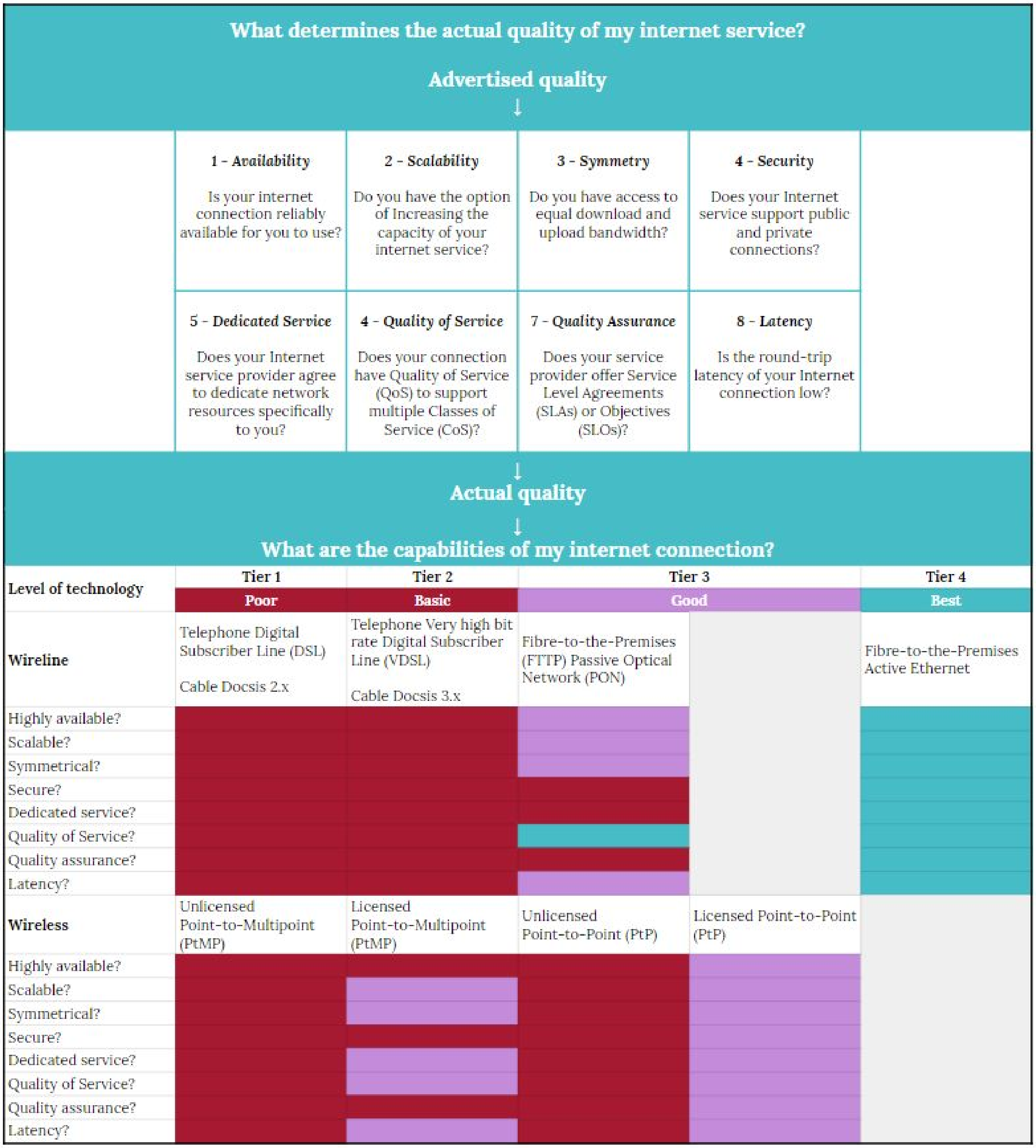


Figure 1-6: Performance comparison of broadband alternatives

1.3 Criteria for investment in broadband alternatives

Advances in DSL variants and DOCSIS have complicated investment decisions for TSPs facing the decision between incrementally upgrading aging networks with the latest DSL variant/DOCSIS, or overbuilding existing infrastructure in a shift toward providing FTTP service. From a TSP's perspective, the decision between maintaining and upgrading a legacy network or replacing it with FTTP architecture is influenced by several factors, which collectively pose numerous questions:

- **Mandate** - is the TSP's primary mandate to maximise profit, or maximise the value of the investment for Internet end-users?
- **Political context** - What broadband access targets have the government/CRTC set, and what types of investments are mandated and/or incentivized by regulations[17] and subsidies[18] with the aim of achieving these targets?
- **Timing** - what state of repair is the current infrastructure in? When was the infrastructure installed, and how much useful life is remaining? What is the CAPEX requirement for each alternative? What is the incremental OPEX requirement for each alternative? What is the anticipated time to market for a new network? For how long will the TSP need to operate two networks in parallel until all customers are switched over to the new network?
- **Competition** - how many competitors are active in the same area? What types of broadband service do they currently offer, and what are their strategies for upgrading their networks?
- **Demand** - what level of service is being demanded by customers? What is the anticipated incremental average revenue per user (ARPU) for each alternative? What is the occupied household density and average household income in the service area? What are the anticipated take-up rates for each of the alternatives?
- **Geotype** - what are the physical conditions of the environment in which the plant resides? Is underground conduit available for new OSP infrastructure? Are existing hydro poles available for aerial OSP? Will environmental conditions (temperature, precipitation etc.) affect OSP maintenance/replacement frequency differently for each alternative?

In practice for many TSPs, the big question is not 'should we build a FTTP network?' but rather 'what path should we follow to migrate to a FTTP network?' TSPs can keep short-term CAPEX low and maximise the value of existing assets by adopting an evolutionary strategy to extend the reach of fibre optic cable through an existing network (ARRIS Technologies Inc., 2015). Figure 1-7 demonstrates one decision pathway that a

[17] For example, Canada has universal telephone service because the CRTC mandated it. There is currently no equivalent regulatory mandate to achieve universal broadband Internet service.
[18] For example, 'The minimum speed requirements for projects to be considered for funding under the CRTC's Broadband Fund are 25 Mbps download and 5 Mbps upload.' (https://crtc.gc.ca/eng/internet/guid.htm).

telephone company (telco) might follow to gradually upgrade its twisted pair copper network to FTTP. Figure 1-8 shows how a cable company (cableco) might follow a similar, incremental path towards FTTP. The decision to take, or skip, any of the steps in these migration pathways depends on the TSP's answers to the questions listed above.

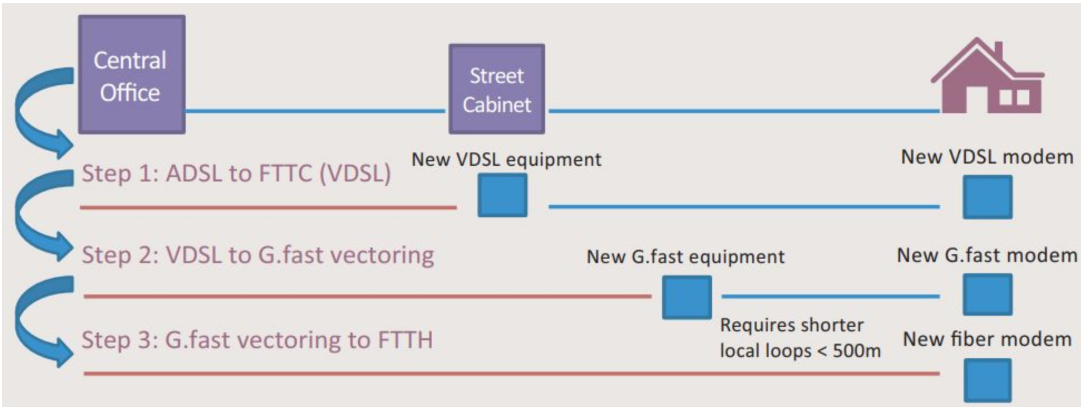


Figure 1-7: Possible upgrade pathway for a twisted pair copper network (The World Bank Group, 2018)

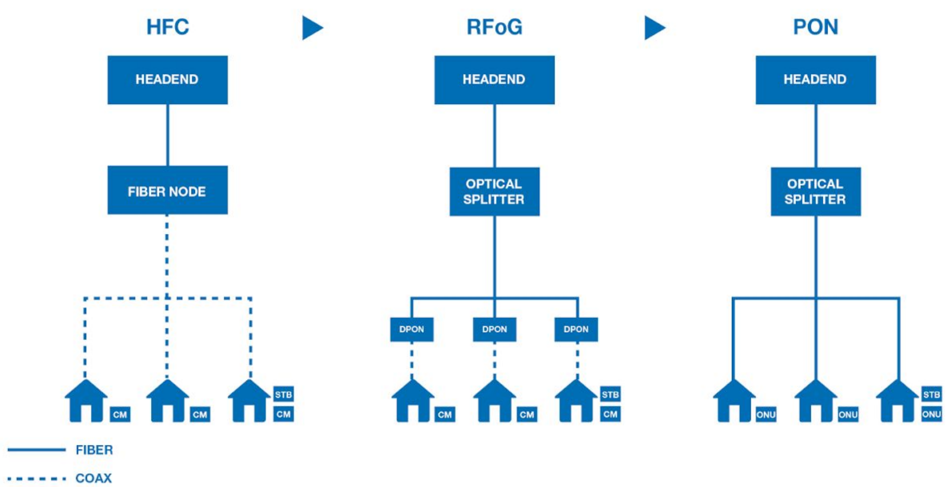


Figure 1-8: Possible upgrade pathway for a coaxial cable network (Aria Technologies Inc.)

1.4 The Digital Divide

At this point, it has been shown that there is a range of quality in the broadband internet market, and that TSPs must choose what level of quality to offer their customers. By logical extension of these two facts, the level of broadband quality available to consumers depends on what type of service is offered by TSPs. If TSPs' investment criteria favour low-quality broadband in a certain area, then that is what consumers in that area will be able to access. Conversely, consumers in areas where investment criteria favour high-quality broadband will gain access to high-quality broadband services. This type of spatial variation in the type of broadband technology favoured by investment criteria has created a 'digital divide' throughout society.

"Parties generally agreed that there is insufficient incentive for private-sector players to make investments that will close the gap between service and price levels in urban centres and areas in the rest of Canada. This is largely due to the lower population levels in these areas and the accompanying lower levels of return on investment that carriers receive."

- ***What We Heard Report, Innovation, Science and Economic Development Canada, June 2019.***

In an area where household density and average household income are low, it can be difficult for TSPs to maintain profit margins and recover the capital required to pursue a 'revolutionary' strategy and overbuild a legacy copper network with a FTTP network. In such cases, TSPs can earn higher short-term profits from the 'evolutionary' approach of making gradual, incremental upgrades to existing networks. If there is little competition in this area (i.e. if monopoly or oligopoly power exists) the TSP(s) can pursue the evolutionary strategy with low risk of losing customers to competitors pursuing a revolutionary strategy. These are also areas where TSPs are able to exert a greater degree of control over broadband pricing.

At the opposite end of this spectrum are areas where household density, average household income and the level of competition are all high. In such cases, TSPs may have no choice but to aggressively upgrade networks to FTTP architecture and keep prices low in order to compete with one another and smaller TSPs. These environments create the conditions for companies such as FibreStream to emerge. FibreStream is a small independent service provider that currently only services condominiums in Toronto and offers symmetrical 50 Mbps FTTP service for $35 CAD per month.[19]

The digital divide is thus manifested through two main barriers:

1. Lack of available high-quality broadband service options resulting from slow deployment of high-quality broadband network architecture.
2. Inability to access high-quality broadband service due to unaffordable prices.

Households for which the second obstacle is the barrier to high-quality broadband access are considered to be in 'digital distress.' It is important for decision makers to keep this second barrier at the forefront of the decision-making process when making plans to close

[19] https://www.fibrestream.ca/internet

the digital divide; expanding FTTP networks to the furthest geographical reaches of society will not close the digital divide if citizens can't afford to access these expanded networks.

> **"From a long-term innovation perspective, limited incentives to deploy FTTP networks in Canada are likely to pose a major barrier to making broadband usage more affordable on a quality-adjusted basis… international evidence suggests that the transition from legacy DSL and cable broadband to fibre is likely to matter significantly in terms of affordability for higher speeds and improved network capacity. Relative to legacy platforms, end-to-end fibre connections offer vast improvements in capacity, speeds and symmetry, allowing the delivery of content and applications with a guaranteed minimum level of reliability. In addition to documenting the persistence of the digital divide, the literature has increasingly recognized that geographic network coverage is not in itself enough to ensure widespread access and use."**
>
> - ***Affordability of Communications Services*, Reza Rajabuin, David Ellis and Catherine Middleton, March 2016.**

Public sector institutions can play a key role in compensating for profit-driven broadband network investment decisions that widen the digital divide. In Canada, the CRTC has adopted a facilities-based approach to encouraging competition between TSPs. The idea of this approach is that, as the basis for competing to win subscribers, TSPs will invest in upgrading their networks as technology advances, thereby improving the quality and pricing of broadband service options available to consumers. A result of this regulatory approach that is unique among major utilities is that service providers end up overbuilding each other's infrastructure to the same civic address; a theoretical parallel is multiple water distribution companies building parallel distribution pipes along each street. A negative consequence of this approach is that scarce resources are dedicated to duplicate efforts.

Another negative consequence is that, due to prohibitively high market entry costs, it is very difficult and in low-density and low-income areas practically impossible for new companies to enter the broadband market and build out their own infrastructure. A market where these conditions are present is considered a natural monopoly. To further promote competition, the CRTC obligates broadband facility owners to lease capacity over parts of their networks to other service providers 'under rates, terms and conditions that are set by the CRTC' (CRTC, 2019). This regulatory tactic aims to overcome the barriers to facilities-based competition that are present due to the fact that the broadband Internet market has all the traits of a natural monopoly.

In spite of these regulatory measures, Incumbent Local Exchange Carriers (ILECs) hold a great deal of market power with little economic incentive to adopt a revolutionary approach to network upgrades in underserved areas. ILECs are TSPs that previously held a monopoly in the communities where they provided telephone or cable services. The effects of this market power in the context of the digital divide in Canada remain prominently evident. In 2018, the CRTC found that while 86% of all Canadians have access to broadband service capable of offering 50 Mbps download and 10 Mbps upload speeds, only 41% of Canadians living in rural areas have access to such services (CRTC, 2018). An interesting and concerning counterpart to this is that, despite having lower rates of access to high bandwidth service, rural Canadians on average paid comparable amounts to Canadians overall for Internet service between 2013-2017 (CRTC, 2019). In fact, in 2017 rural Canadians actually paid *more* on average for Internet service. What Figures 1-9 and 1-10 indicate is that Canadians living in rural areas are, on average, paying more on a per unit of bandwidth basis than Canadians living in urban centres.

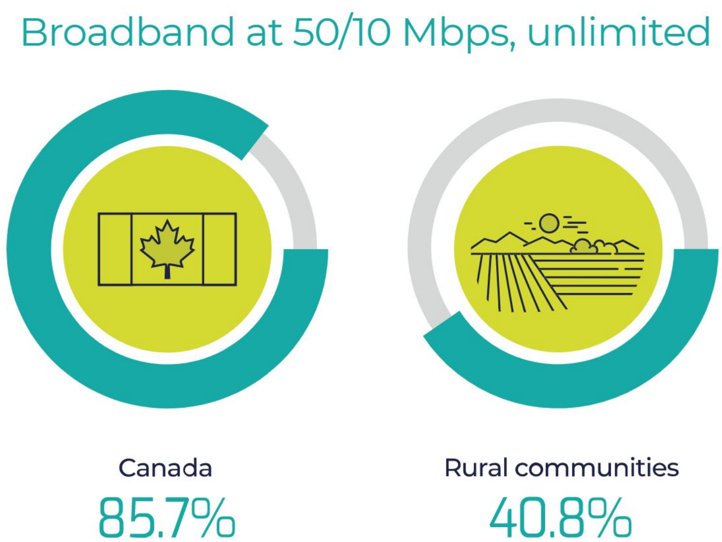


Figure 19: Percentage of all and rural Canadians with access to Internet service that meets the CRTC's definition of high-speed broadband (CRTC, 2018)

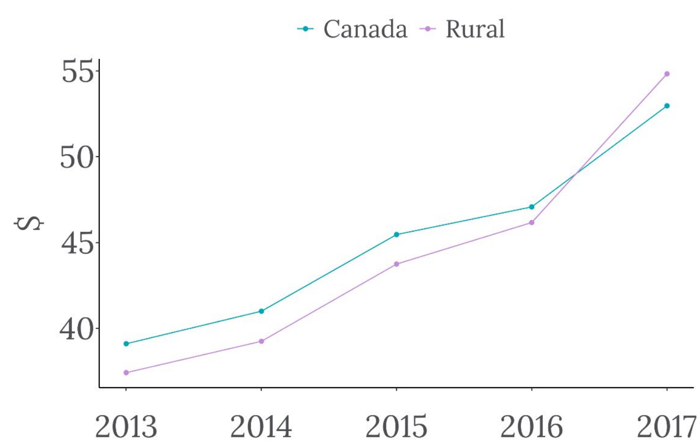


Figure 1-10: Average monthly price paid for Internet service in CAD (CRTC 2019)

A study published in May 2019 found that 62% of Canadians are not fully satisfied with their TSP, and that of those people 77% cited the price of their internet service as a cause for dissatisfaction (Innovation, Science and Economic Development Canada, 2019). The same study found that 40% of Canadians were not fully satisfied with the quality of their internet service - and of these people, 56% were not very or not satisfied at all.

"In cases where private-sector incentives to reinvest in network capacity are not sufficient, the growing consumer demand for network resources can precipitate congestion on network facilities, which in turn degrades actual service quality levels (i.e. speeds) relative to the "best effort" rates specified in retail contracts between operators and subscribers. Where such private-sector incentives are limited because of high costs or low revenues relative to a provider's reservation rate of return on capital expenditures, this gap tends to get larger over time. If rural communities are to benefit from price/quality combinations approximating those on offer in low-cost urban centres, then it is likely that public subsidies and other private-sector inducements will be needed to contain the growth of supply-side bottlenecks."

- ***Affordability of Communications Services*, Reza Rajabuin, David Ellis and Catherine Middleton, March 2016.**

1.5 The Kingston Broadband Gap Analysis

The Kingston Broadband Gap Analysis project set out to quantify the value of broadband Internet and identify geospatial gaps in access to high-quality broadband Internet within the City of Kingston's boundaries. Data were collected from a variety of primary and secondary sources in an attempt to achieve these objectives. The most fruitful data collection activity was an online survey of residential Internet consumers. This survey yielded over 300 responses which resulted in a dataset that allowed the project team to estimate the value of access to broadband Internet to both rural and urban residential consumers.

Attempts were made to collect data from small local businesses and larger enterprise Internet consumers but few responses were elicited. Lack of participation from these important perspectives limited the project team's ability to fully estimate the private benefits of broadband Internet service to all types of consumers. Additionally, efforts were made to obtain information from TSPs regarding the location and capabilities of their Internet service infrastructure and services. Although several TSPs initially expressed willingness to participate in the project, only Utilities Kingston and WTC Communications provided the requested information. The project team was in the process of working out a data sharing agreement with Cogeco Inc. at the time this report was written.

Secondary data made openly available by the Government of Canada enabled the project team to map fixed and mobile wireless Internet coverage zones, but the team did not have sufficient data to map wireline infrastructure coverage. Lack of access to this data imposed significant limitations on the project team's ability to quantify the gaps in access to high-quality broadband service, as well as to estimate the investment required to fill those gaps. A separate Knowledge Management Plan has been prepared to guide the City in ongoing efforts to obtain information from TSPs and other sources to build on this study's findings.

Based on available data, the project team took the following approach:

1. To estimate the service gaps, the residential survey data was analyzed to compare average prices and performance levels for different types of Internet service plans in rural and urban areas. Various secondary data sources were drawn from to provide a more comprehensive picture of gaps in high-quality broadband service.

2. A worst-case scenario costing exercise was undertaken to conservatively estimate the cost of filling the gaps in access to high-quality broadband service. This exercise focused on Kingston's rural areas[20] and assumes FTTP network infrastructure must be installed along every populated roadway in rural Kingston, and that no civic addresses in Kingston are currently connected to a FTTP network.

3. Residential survey respondents were categorised into two groups - those with a FTTP connection, and those without one. A Willingness to Pay (WTP) analysis was undertaken to conservatively estimate the economic value of FTTP broadband service and non-FTTP broadband service (referred to as "Basic Internet").[21]

4. A Cost Benefit Analysis (CBA) model was developed to simulate how expanding FTTP service to all underserved areas in rural Kingston might affect residents, TSPs and the government.

The remaining sections of this report presents the findings from the economic and geospatial analysis described above. Section 2 begins by reporting a number of summary statistics from the residential survey data. Section 3 presents the results of the geospatial and economic gap analysis. Sections 4 and 5 estimate the costs and benefits of expanding FTTP network coverage. Finally, the results of the CBA are presented and interpreted in Section 6 with a discussion of the implications of this project's findings for the City of Kingston moving forward.

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[20] Due to limited data, the project team was unable to identify underserved areas in Kingston's urban zone, but this is a known information gap that should be addressed in future data collection efforts.
[21] The WTP analysis estimates the value consumers place on three commonly advertised characteristics of Internet service - download and upload speed and latency. A representative FTTP plan was defined as 1000 Mbps download, 1000 Mbps upload and 1000 GB data. A representative Basic Internet package was defined as 10 Mbps download, 2 Mbps upload, and 100 GB data.

1.6 Performance is a moving target

While FTTP Active Ethernet is considered to be the best currently available broadband network architecture, this definition can change for future iterations of this study without needing to modify the analytical methodology of the study. The value of Internet service is estimated based on the limited set of Internet service plan characteristics that TSPs typically advertise and thus residential Internet subscribers typically understand and make decisions based on - download speed, upload speed and data cap.[22] To enable comparisons of the relative value of different types of Internet service, the project team asked residents to indicate what type of access media they use to connect to the internet, and then grouped the survey responses into two groups - those with a fibre connection and those without one. If the access gaps and economic value of a network with a different type of access media - say, 5G - need to be estimated in the future, the criteria for categorizing survey responses can be updated to reflect this without necessarily needing to collect any new information about each resident's Internet service plan. This flexibility will enable the City and UK to re-use the methodology applied in this project in the future to make comparisons and track changes over time.

[22] Some TSPs do not allow data that is published on their web sites to be downloaded and privately held. However, plan characteristics for two major local TSPs, Bell and Cogeco, can be found at the following links:
Cogeco: https://www.cogeco.ca/en/internet/packages
Bell: https://www.bell.ca/Bell_Internet/Internet_access

2. Data collection

Data was collected from a number of different sources and compiled to assess the gaps in access to high-quality broadband Internet and estimate the economic value of expanding access to high-quality broadband Internet. The most heavily-used source of data was the residential, home-based business and farm survey, which was made publicly available online for residents of Kingston to provide information about their home Internet subscriptions. A second public survey targeted towards small businesses was also made available online, but for a variety of reasons discussed in the document titled *2019 Kingston Broadband Knowledge Management Plan* there were only a handful of responses.

An RFI was sent out to TSPs soliciting information about providers' existing infrastructure and service offerings. It was hoped that such information could be used to produce comprehensive maps of broadband coverage in Kingston. The following TSPs were formally approached with a Request for Information (RFI):

- Utilities Kingston
- WTC Communications
- Cogeco Inc.
- Rogers Communications Inc.
- Xplornet Communications Inc.
- Telus Communications
- Bell Canada

Only Utilities Kingston and WTC Communications provided the requested information. The project team was in the process of working out a data sharing agreement with Cogeco Inc. at the time this report was written.

A similar RFI was sent out to a number of 'anchor' institutions and business Internet consumers to gather detailed technical information about Internet plan subscriptions. The Government of Canada has identified anchor institutions such as libraries, schools, hospitals and local government buildings as worthy of 'special consideration' for broadband funding:

> **"Connecting anchor institutions to high-speed broadband networks strengthens the capacities of local health and education systems, improves access to government services, and enhances the social and economic opportunities of rural and remote residents. It also improves the business case for extending broadband to households and businesses in the surrounding areas."**
>
> - ***High-Speed Access for All: Canada's Connectivity Strategy*, Government of Canada, 2019.**

The following businesses and institutions provided information in response to the enterprise RFI:

- Algonquin & Lakeshore Catholic District School Board
- Correctional Service Canada
- J.E. Agnew Food Services Ltd
- Kingston Frontenac Public Library
- Kingston Community Health Centres
- Kingston Regional Hospital Laundry
- Kingston Orthopaedic Pain Institute
- Mine Design Technologies
- Novari Health
- PrintFleet
- Saint Lawrence College
- United Way KFL&A

Several of these twelve business/institutions have multiple sites throughout the City, so information was received for 49 Internet plans throughout the City. The project team intended to use this data to explore how broadband service options and pricing varies by location and number of providers. However, in the absence of TSP data such an analysis was not possible. Another potential use of the enterprise data was to identify underserved areas where anchor institutions are served with FTTP, which would reveal opportunities to extend FTTP infrastructure from anchor institutions to residential consumers. One such location was identified in Kingston Mills neighbourhood, which is a useful finding given that (as is shown in Section 3) this is an underserved residential area. Unfortunately the other 48 sites all fell within Kingston's urban zone where gaps in access to high-quality broadband are much more difficult to identify without TSP data. For these reasons, the project team was not able to carry out a detailed analysis with the enterprise data, but this dataset could potentially be expanded and compared against any TSP data that is obtained in the future.

In addition to the primary data collection efforts, several secondary datasets were identified. Much of the analysis would not have been possible without access to these secondary datasets, which include:

- 2016 Census data from Statistics Canada;
- A Digital Elevation Model of the City of Kingston from Natural Resources Canada;
- The Spectrum Management Authorization Data Extract from the Ministry of Innovation, Science and Economic Development;
- Real estate sold listings within the City of Kingston in 2018 from a local real estate agent;
- Various datasets from the City of Kingston's Open Data Portal.

The real estate sold listings did not end up being used in the analysis. This dataset was obtained with the intent of conducting a hedonic regression analysis to make an inference about how much value people place on having a high-speed internet connection at home. Hedonic regression analysis is a statistical method whereby the value of a good or service (in this case high-speed broadband internet) can be estimated by determining how much it contributes to the value of another good or service (in this case the value of real estate). To complete such an analysis, the real estate data needed to be linked to Statistics Canada census data, but the dataset required to make this linkage is a third-party proprietary dataset published by DMTI Geospatial that requires a license to use for commercial purposes, which was not procured for this project.

2.1 Residential, home-based business and farm survey

The purpose of the residential, home-based business and farm survey was twofold:

1. To assess Kingston residents' current Internet plan characteristics and use behaviours in order to understand the gap in broadband coverage, service, performance and rates; and
2. To estimate the economic value of broadband Internet services to residential, home-based business and farm users.

This survey included questions about home Internet service providers and plan characteristics, common uses of the Internet at home, and demographics. To estimate the value that Kingston residents currently place on their home Internet subscription, a Discrete Choice Experiment (DCE) was designed and included in the survey. A DCE is a specialized questionnaire that asks the respondent to repeatedly choose one preferred option from a set of alternatives. The results of this DCE provided the information needed to conduct a Willingness to Pay (WTP) analysis and estimate the economic value of residential access to broadband Internet. The survey also included questions about residents' uses of and preferences for Internet service to provide insight into the broadband access gap and assess how Internet use might change if access to broadband Internet was expanded. Finally, the survey included a section on telecommuting behaviour in order to calculate the potential 'telecommuter surplus' in Kingston.

2.1.1 Summary statistics

The survey was open to the public from late June to mid August 2019. A total of 312 complete responses were received from within the City of Kingston's municipal boundary. Since each response represents a household and there are 53,518 households in Kingston (Statistics Canada, 2016), the sample represents 0.58% of Kingston's households. With this sample size, the survey results have a margin of error of 5.53% at the 95% confidence level. This means that 95% of the time, the percentage of Kingston's entire population that would select an answer is within 5.53% of the percentage of survey respondents who actually selected an answer.

2.1.2 Limitations

The Interim Report for this project included a discussion of a number of issues with the residential survey data. These issues will not be discussed in full again in this section, but a brief overview and updated results are provided for each issue. The Interim Report has been included as an Appendix to this report.

2.1.2.1 Representativeness of sample

The distribution of ages and household incomes was monitored throughout data collection to ensure the sample would be representative of Kingston's population as a whole. Since the survey was administered through self-selection, it was not possible to perfectly mirror the characteristics of Kingston's population. Figure 2-1 shows that people under the age of 24 and over the age of 55 are under-represented in the survey responses.

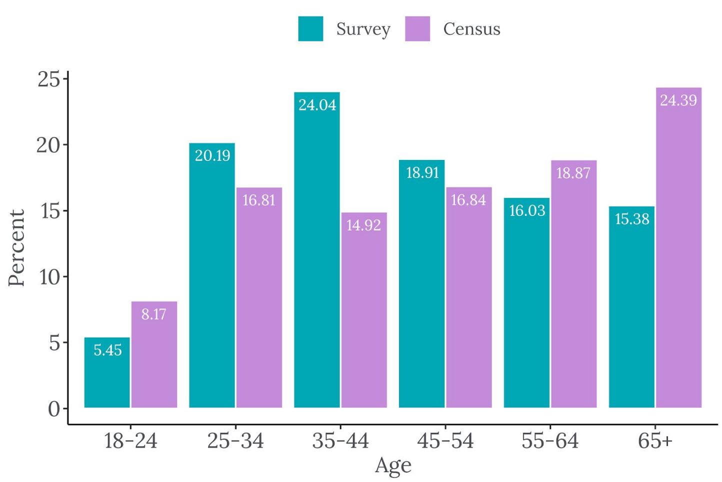

Figure 2-1: Age distribution of survey respondents

Table 2-1 shows the median value of reported Internet plan characteristics, as well as the percentage of people with an unlimited data plan, broken down by age bracket. There is no clear trend for median price or the percentage of people with an unlimited plan. People under the age of 24 appear to pay less than other age groups, possibly because people in this age bracket are students who are eligible for student discounts on Internet plans. There is a clear trend in median download speed purchased, with younger people purchasing higher download speeds than older people. Since people under the age of 24 are under-represented, this biases the overall median download speed purchased downward. However, since people over the age of 55 are also under-represented, there is an upward bias in the median download speed to offset the downward bias from under-representation of younger people. People under the age of 24 and people over the age of 65 both report higher purchased upload speeds than people of ages in between.

Since both of these age brackets are under-represented, the overall median purchased upload speed in the sample might be lower than the true value for Kingston.

Table 2-1: Summary statistics by age bracket

Age bracket	Median Price (2019 CAD)	Median Download Speed Purchased (Mbps)	Median Upload Speed Purchased (Mbps)	Percent with Unlimited Data	Count
18-24	$55	300	100	65%	17
25-34	$74	60	10	83%	63
35-44	$68	52	10	72%	75
45-54	$70	60	20	86%	59
55-64	$74	40	10	52%	50
65+	$76	40	33	54%	48

When looking at the distribution of household incomes of the survey respondents, households with very high incomes (>$200K) are over-represented, while low-income households are under-represented as shown in Figure 2-2.

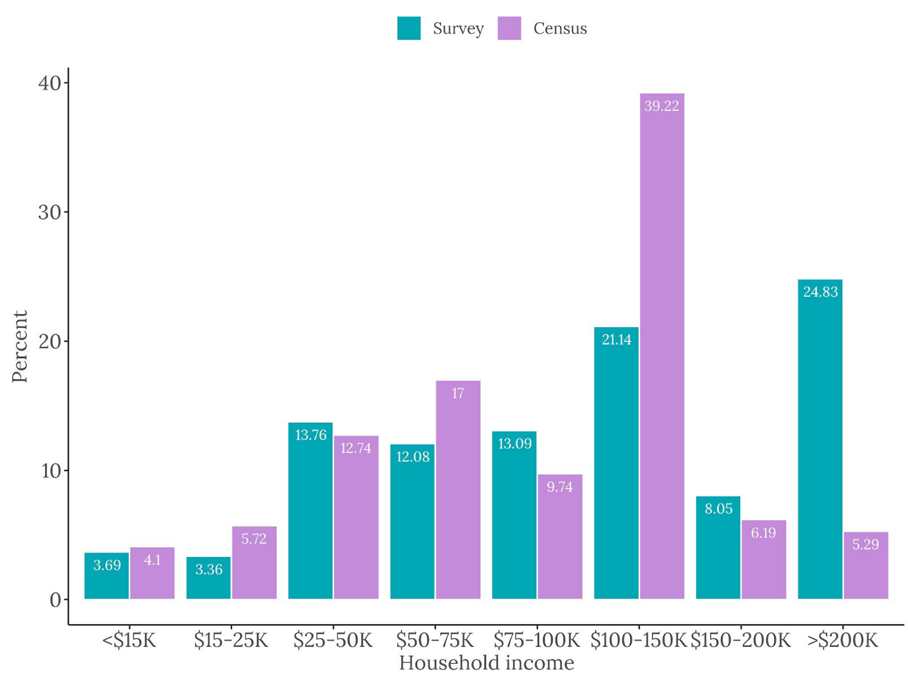

Figure 2-2: Distribution of household income of survey respondents

Table 2-2 shows that there are no clear trends in the median reported Internet plan characteristics across household income brackets.

Table 2-2: Summary statistics by income bracket

Income bracket	Median Price (2019 CAD)	Median Download Speed Purchased (Mbps)	Median Upload Speed Purchased (Mbps)	Percent with Unlimited Data	Count
<$15K	$70	40	10	55%	11
$15-25K	$60	90	10	50%	10
$25-50K	$60	40	15	76%	41
$50-75K	$70	60	10	67%	36
$75-100K	$70	40	10	64%	39
$100-150K	$70	60	10	79%	63
$150-200K	$80	60	10	92%	24
>$200K	$75	40	25	61%	74

Of the 312 survey responses, 266 originated from 121 different urban dissemination areas (DAs) and 46 came from 18 different rural DAs. DAs are geographic areas that Statistics Canada uses to aggregate census data. Each of Kingston's 43 neighbourhoods is made up of one or more DAs. Figure 2-3 shows that the distribution of rural and urban respondents is very close to the breakdown of Kingston's population based on 2016 Census data. Figure 2-4 shows counts of survey responses in each survey DA.

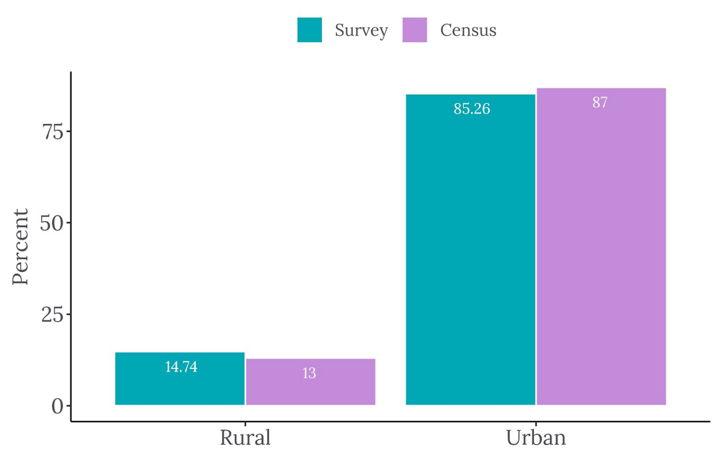

Figure 2-3: Distribution of survey respondents by location

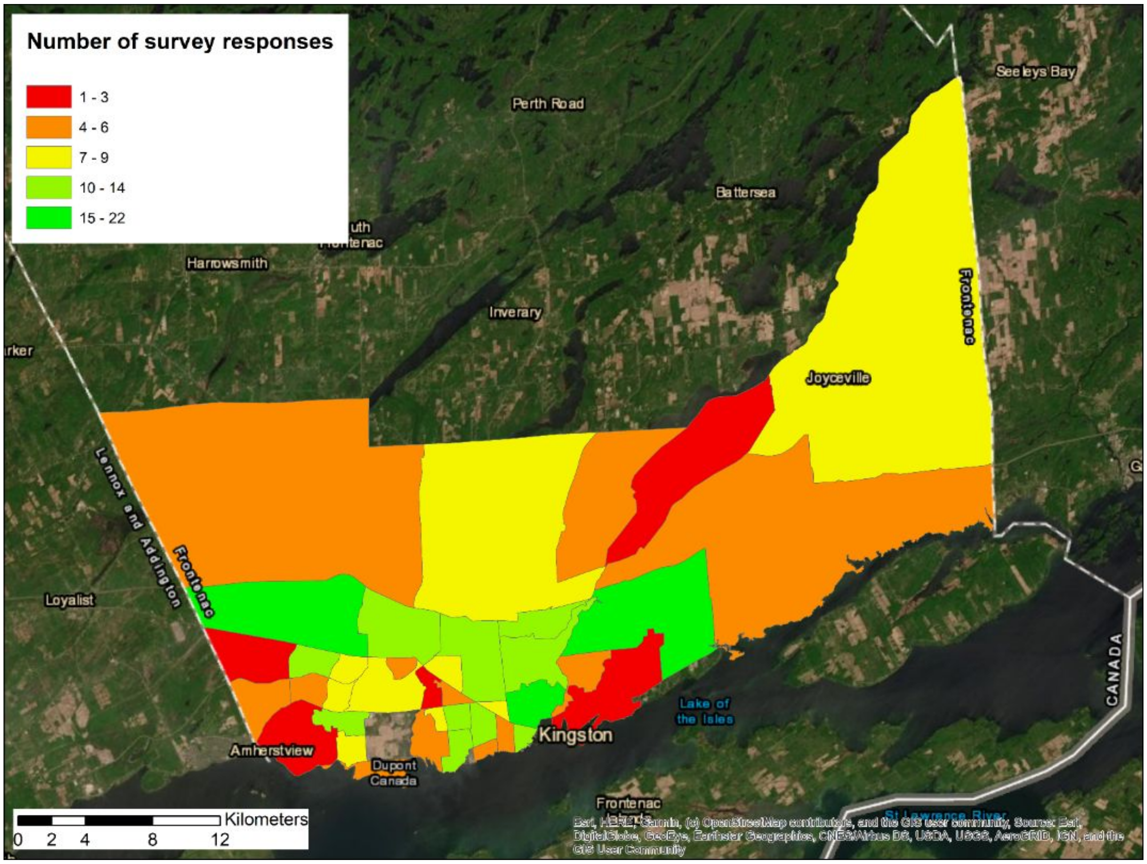

Figure 2-4: Map of survey response counts

2.1.2.2 Participants randomly selecting answers

The mean response time to the survey was 12.4 minutes, and the median response time was 11.24 minutes. This is consistent with the times observed at the time of writing of the Phase 1 report. These results do not include response times over 30 minutes, as such responses times are assumed to be the result of respondents leaving the survey open in their browser. The distribution of survey completion times is shown in Figure 2-5.

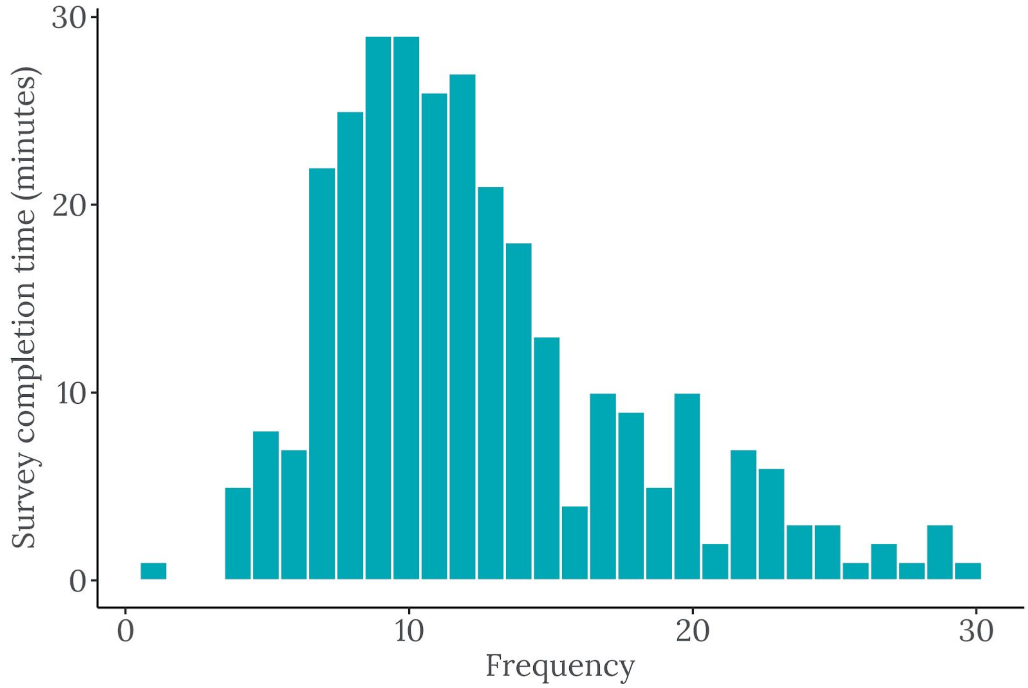

Figure 2-5: Distribution of survey completion times

The distribution of survey completion times is in line with what was observed in the Phase 1 Report and during piloting.

2.1.2.3 Non-random sample

Because the survey was administered in a non-random way, it is possible that selection bias was introduced to the sample through self-selection by people who care a lot about their Internet or are generally dissatisfied with their Internet. To check for such selection bias in the survey responses, the mean Internet subscription download speeds reported by survey respondents were compared against the speeds reported by the CRTC in its 2018 *Communications Monitoring Report*. The comparison in Figure 2-6 shows that the survey respondents have faster Internet speeds on average than the speeds observed by the CRTC in 2018.

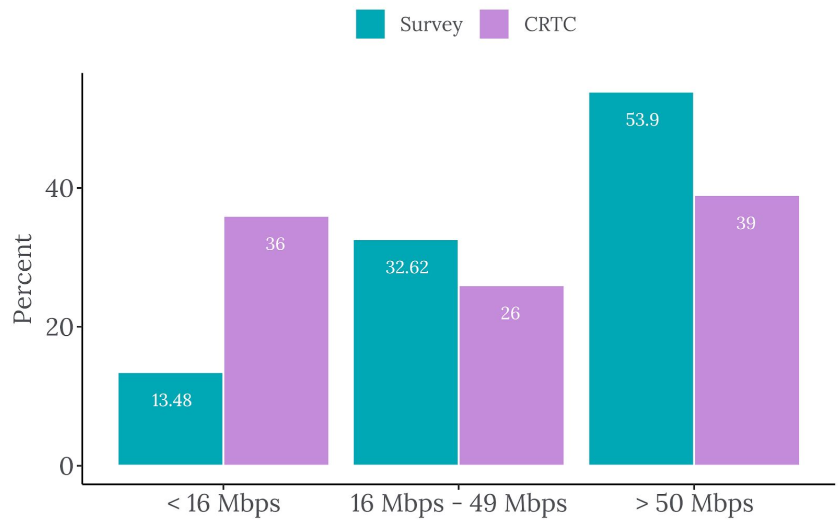

Figure 2-6: Comparison of reported download speeds

Another way of assessing whether or not selection bias is present in the sample is by looking at how many people reported wanting a service that is unavailable. Figure 2-7 shows that almost half of the survey respondents do not desire a service that is unavailable, which suggests that these respondents are not dissatisfied with their existing service.

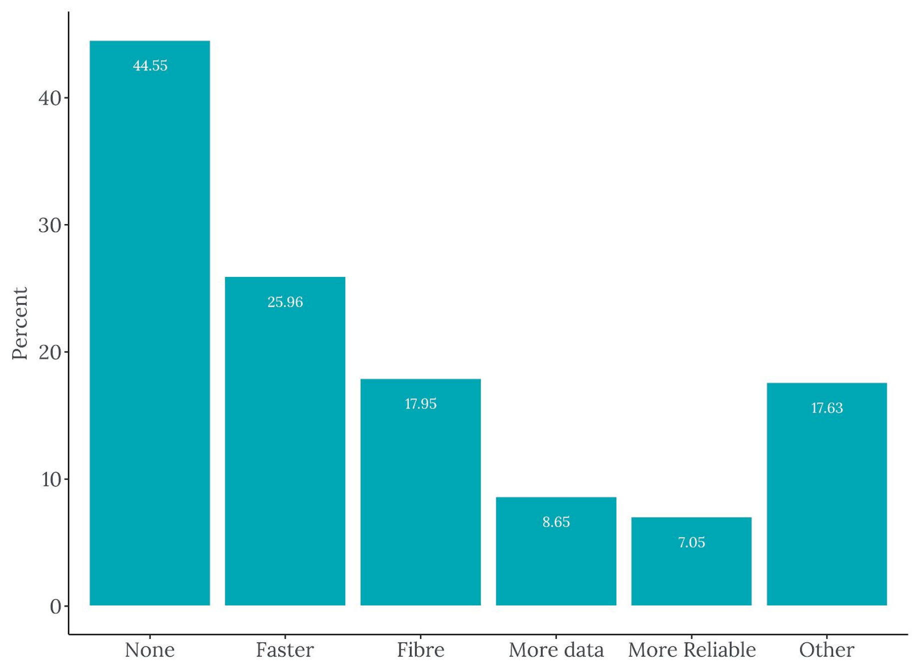

Figure 2-7: Percent of respondents reporting a desire for a service that is unavailable

These results suggest that selection bias does not have a significant impact on the survey results.

2.1.2.4 Representativeness of Discrete Choice Experiment options

For the DCE results to be valid, it is important for the options available in the experiment to reflect potential plans that could actually appear in the market. Table 2-3 shows the summary statistics of the Internet plan characteristics reported in the survey (excluding respondents who did not know the answers to the questions). Table 2-4 shows the values of attributes used in the choice experiment. The results have not changed considerably from what was reported during the Phase 1 report. Since the distribution of commonly offered download and upload speeds is skewed, the median value provides the best indication of representative Internet plan characteristics.

Table 2-3: Summary statistics for plan characteristics

Variable	Mean	Median	Std Dev	Min	Max
Price - Internet Only (2019 CAD)	$75	$70	$28	$25	$285
Price - Bundle (2019 CAD)	$153	$145	$76	$20	$545
Advertised Download Speed (Mbps)	192	50	308	5	1500
Advertised Upload Speed (Mbps)	121	10	238	1	1000
Data Allowance (GB)	154	125	135	1	500

Table 2-4: Choice Experiment Design

Attribute	Description	#	Levels
Price	Monthly price before tax, 2019 CAD	12	$15 to $125 in $10 dollar increments
Download Speed	The speed that data can be transmitted from a server to a computer measured in megabytes per second (Mbps)	8	4, 10, 25, 50, 75, 100, 300, 1000
Upload Speed	The speed that data can be transmitted from a computer to a server measured in megabytes per second (Mbps)	4	1, 3, 25, 100
Data Cap	The maximum amount of data that can be used per month (GB).	4	50, 150, 300, Unlimited

3. Gap analysis

One of the main objectives of the Kingston Broadband Gap Analysis project was to explore the digital divide in Kingston geospatially. Due to low engagement of business Internet consumers and TSPs it is not currently possible to comprehensively map broadband Internet service coverage in Kingston. However, the project team used the results of the residential survey as well as open source secondary data to shed light on how the digital divide is manifested in Kingston.

3.1 Maps of residential survey responses

The project team used the results of the residential survey to identify differences in Internet service access, plan characteristics, pricing, performance and use in different areas of Kingston. Using the City of Kingston's land use designation definitions, DAs were assigned a binary categorization of either urban or rural. Although approximate, this categorization allowed the team to make significant comparisons between areas with similar characteristics. Figure 3-1 displays which areas of Kingston were categorised as rural (purple) and which are categorised as urban (teal) for the analysis.

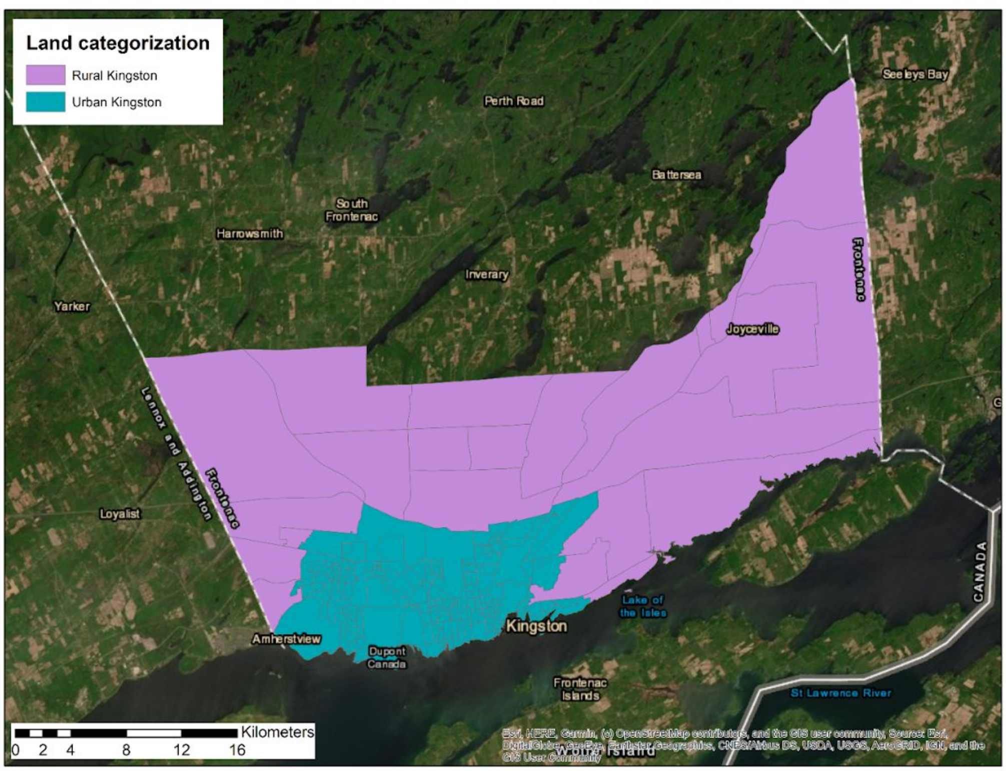

Figure 3-1: Urban and rural areas in Kingston

One of the questions that this project sought to answer is how Internet subscription prices vary spatially throughout the City. Although the sub-groups at neighbourhood level are too small to show differences with statistical significance, a number of maps were produced to spatially display point statistics. It is worth noting that these maps may lead to a distorted perception of a particular neighbourhood's situation, because some neighbourhoods only received one or two survey responses. Neighbourhoods in which no result could be calculated based on the available data were given hollow symbology.

Figure 3-2 shows a heatmap of the mean price paid for Internet service in different neighbourhoods. The median value is shown rather than the mean because the distribution of prices is skewed to the right, meaning that the mean value can be disproportionately affected by high values. The same is true for other variables where the median value is presented in this report.

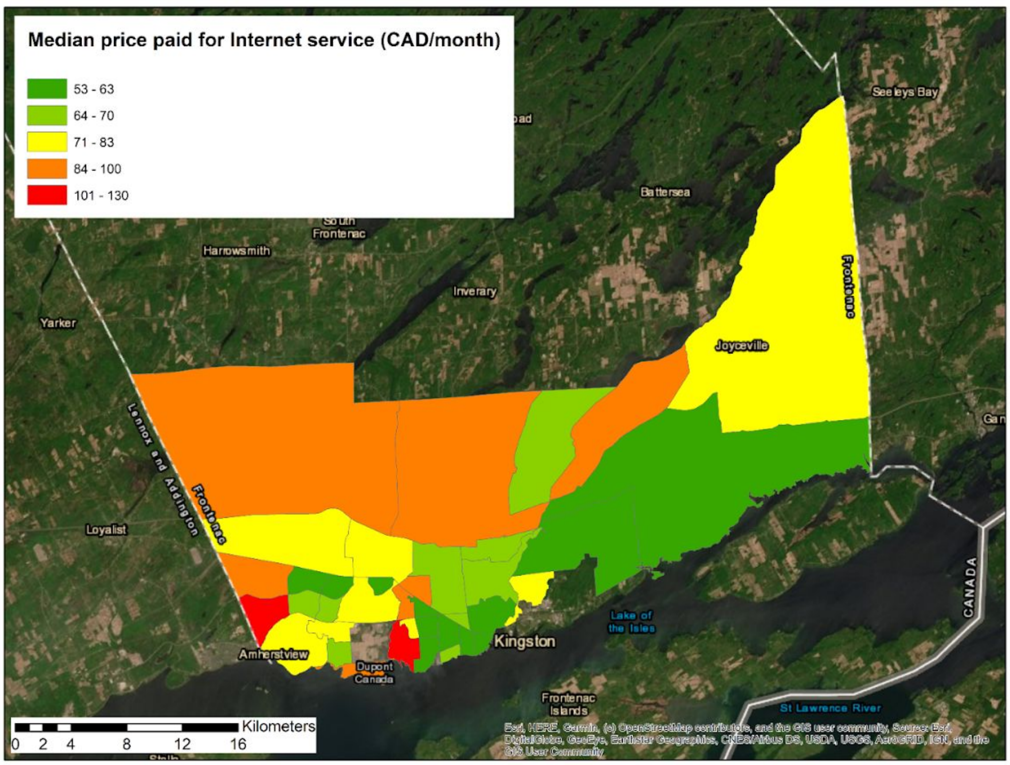

Figure 3-2: Median price paid for residential Internet subscription by neighbourhood

The map shows that median prices in the northern and western neighbourhoods of the City are higher than median prices paid in the downtown core and east end. However, the map does not demonstrate a clean division of pricing across rural and urban areas. - there are pockets of high median prices in urban Kingston. While it is worth knowing where people tend to pay higher prices for Internet service, this map does not adjust the price consumers pay to account for the quality of the service they purchase.

Figure 3-3 shows the median price of Internet subscription per Mbps of download speed advertised, while Figure 3-4 shows the median price of Internet subscription per Mbps of download speed recorded from the survey speed test. These maps show a clearer divide between rural and urban areas - people in rural areas generally pay more per Mbps of download purchased than people in urban areas. There are a few exceptions where there are areas of relatively poor performance in the urban zone. One might hypothesize that these are areas of relatively low household density and/or low average household income, and therefore places where TSPs do not provide as many high-quality broadband service options. However, the project team did not find a relationship between household density or income and the price paid per unit download speed purchased in each neighbourhood.

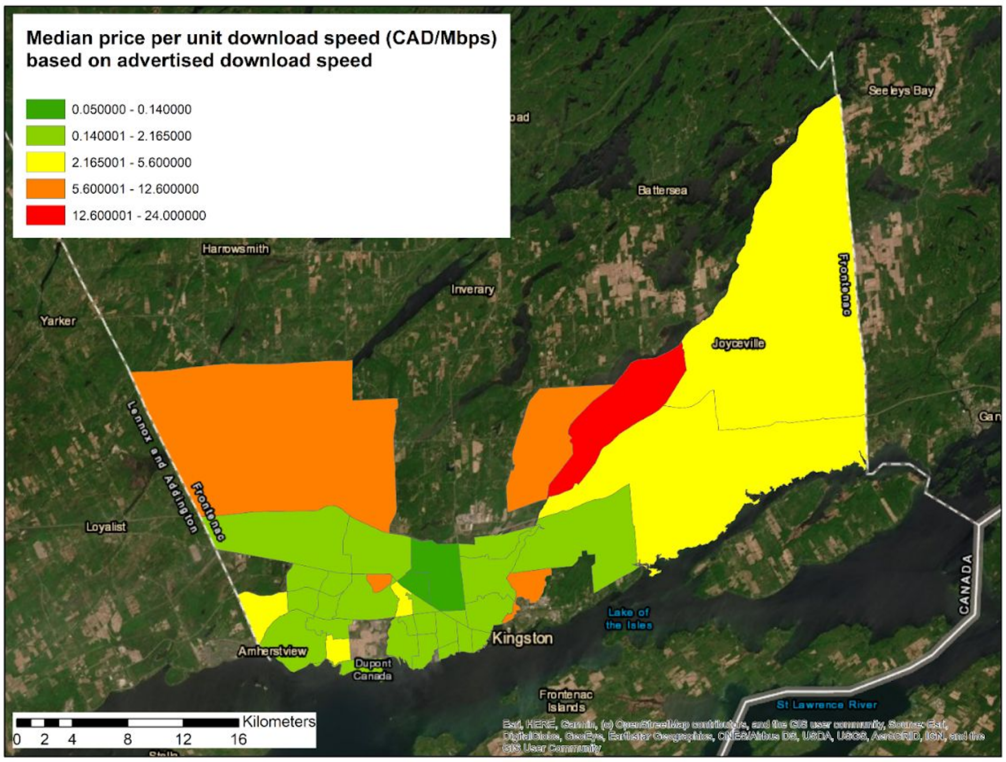

Figure 3-3: Median Internet subscription price per median download speed purchased

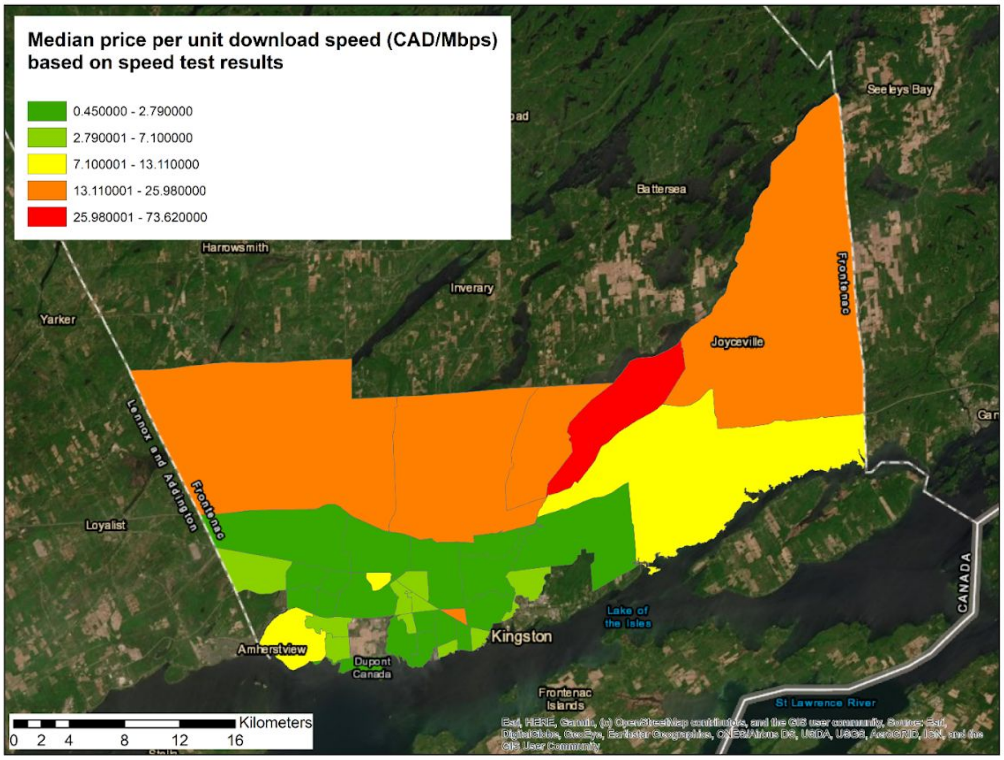

Figure 3-4: Median Internet subscription price per median speed test download speed result

3.2 CIRA speed test data

The City of Kingston obtained a dataset of Internet speed test records from the Canadian Internet Registration Authority (CIRA). CIRA's Internet performance test is built on M-Lab's Network Diagnostic Test (NDT), which is the speed test platform that was embedded in the residential survey. As such, the results from the survey speed test are comparable to the CIRA dataset. However, there are several things to keep in mind when comparing the CIRA data to the residential survey data:

- The CIRA data might include results from non-residential sites (businesses, institutions etc);
- Since the CIRA data records doesn't include demographic information, there is no way to assess how representative the CIRA data is of Kingston's population;
- There could be a selection bias in the CIRA records, because people only voluntarily run speed tests when they are interested in the quality of their Internet service (Bauer et al, 2010) (OECD, 2015) (Feamster and Livingood, 2019);
- Speed test results recorded by the NDT tend to be lower than speeds advertised by a TSP, because the NDT sends data to servers outside the TSP's network. This NDT was designed to provide results that are reflective of users' typical Internet browsing experience.

As of November 2019, there were over 2000 speed test results recorded within the City of Kingston's boundaries between 2015 and 2019. The mean recorded download and upload speeds and latency at each location in Kingston was calculated (many sites ran multiple speed tests), and these mean values were grouped by location (rural vs. urban) and by the year during which the test was recorded. The median of these grouped means was then calculated to provide an aggregate measure of download and upload speeds and latency by location and year. Table 3-1 lists how number of unique sites at which mean CIRA speed test results were recorded between 2015 and 2019.

Table 3-1: Number of unique sites at which speed tests results were recorded

Year	Rural	Urban
2015	19	107
2016	18	61
2017	18	103
2018	13	47
2019	32	69
Total	100	387

The median test results were plotted and are shown below in Figures 3-5 to 3-7. The relationships between each test result and location, after accounting for the year in which the test was recorded, are not statistically significant. However, the point estimates indicated that urban residents have benefited from larger increases in download and upload speeds and decreases in latency than their rural counterparts. This can likely be largely attributed to Bell's Fibre project[23] and Cogeco's DOCSIS 3.1 upgrades.[24] These figures suggest that TSPs have invested more heavily in improving broadband Internet service in urban areas than in rural areas, effectively widening the digital divide. When interpreting Figure 3-5, remember that latency is a measure of the round-trip time it takes for a packet of data to be sent and received, so lower latency is better.

23 https://www.thewhig.com/2014/05/22/bell-to-bring-new-network-to-city/wcm/2549c952-eb64-aec4-d1c1-645c350b8e60

24 https://www.newswire.ca/news-releases/cogeco-connexion-enhances-its-gigabit-offering-in-ontario-markets-692173431.html

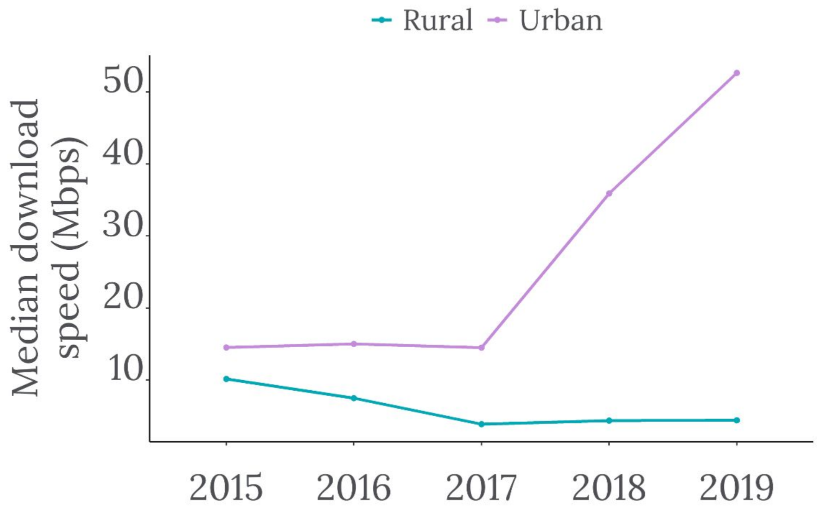

Figure 3-5: Median download speeds recorded at unique locations in Kingston

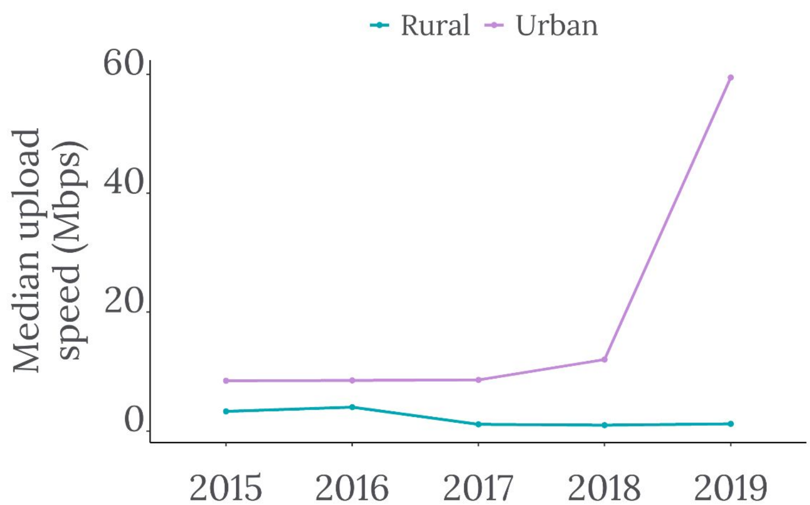

Figure 3-6: Median upload speeds recorded at unique locations in Kingston

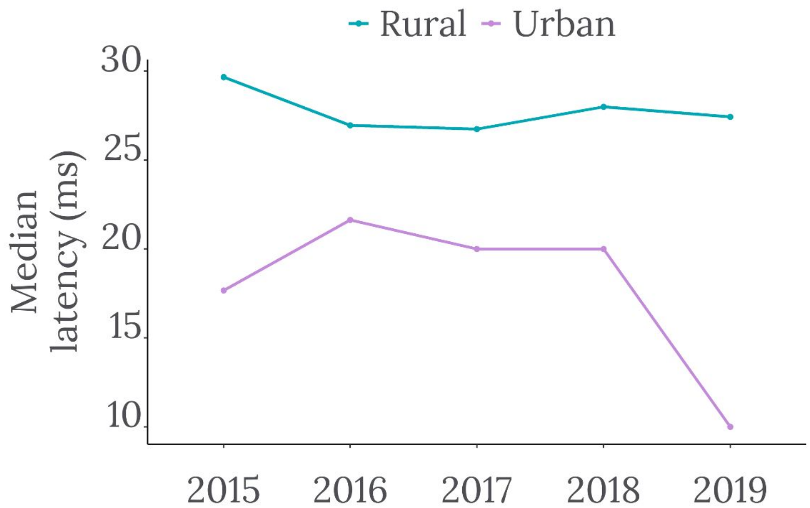

Figure 3-7: Median latencies recorded at unique locations in Kingston

The speed test results from the survey and from the CIRA data set from 2019 were aggregated by neighbourhood and mapped in Figures 3-8 to 3-10. These maps further demonstrate the digital divide separating rural from urban areas in Kingston's north and west end,[25] with some pockets of poor performance in the urban zone. These urban areas of poor performance may be areas where TSPs have not invested as heavily in broadband network upgrades. However, as has been mentioned, there are cases where lack of access to high-quality broadband varies at the street level - a house on one street might have access to FTTP, while a house around the corner does not have access. Without access to detailed TSP data, the data presented in Figures 3-8 to 3-10 can only provide clues as to which urban areas might be underserved.

[25] It is worth nothing here that, while Kingston Mills neighbourhood fairs poorest across all three measures, the results for this neighbourhood are based off of a single speed test.

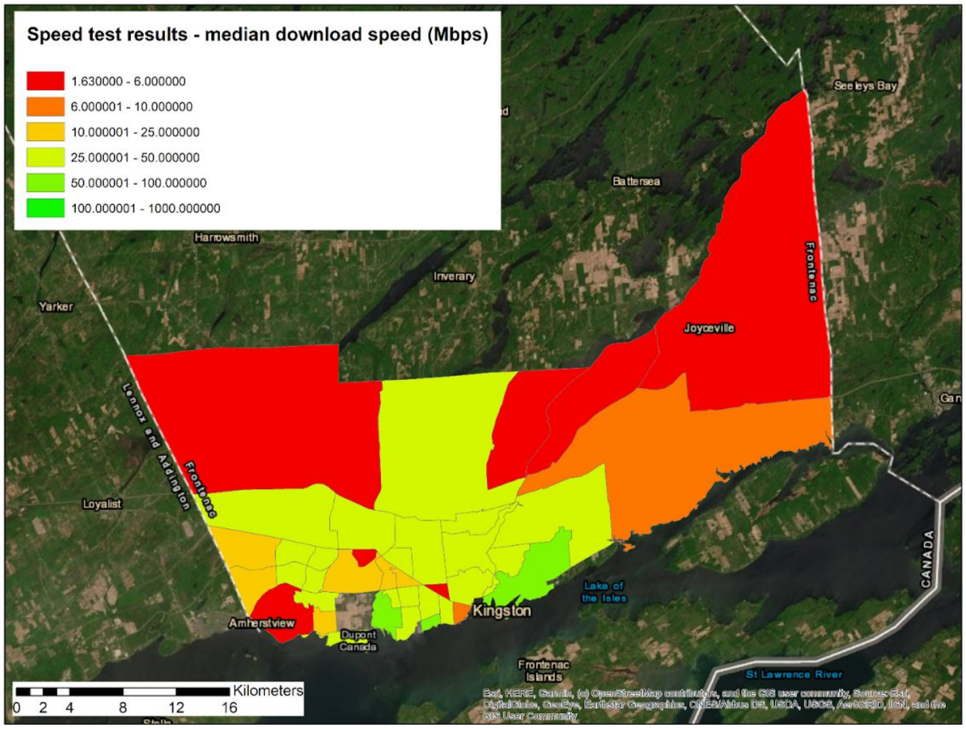

Figure 3-8: Speed test results – median download speed in Mbps

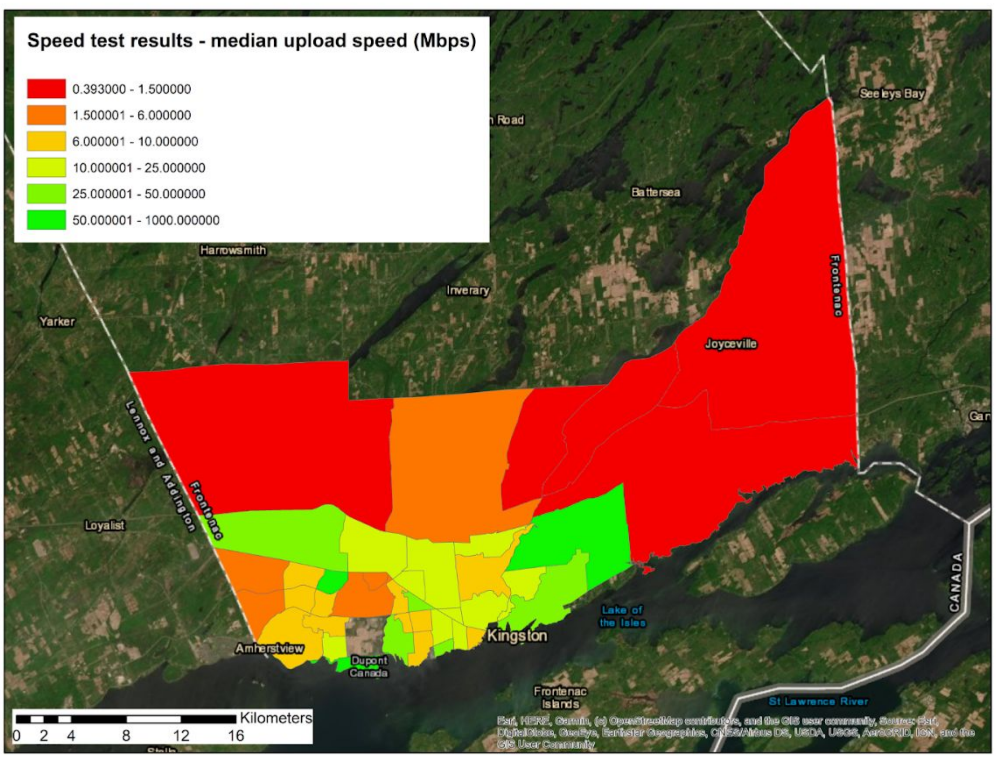

Figure 3-9: Speed test results – median upload speed in Mbps

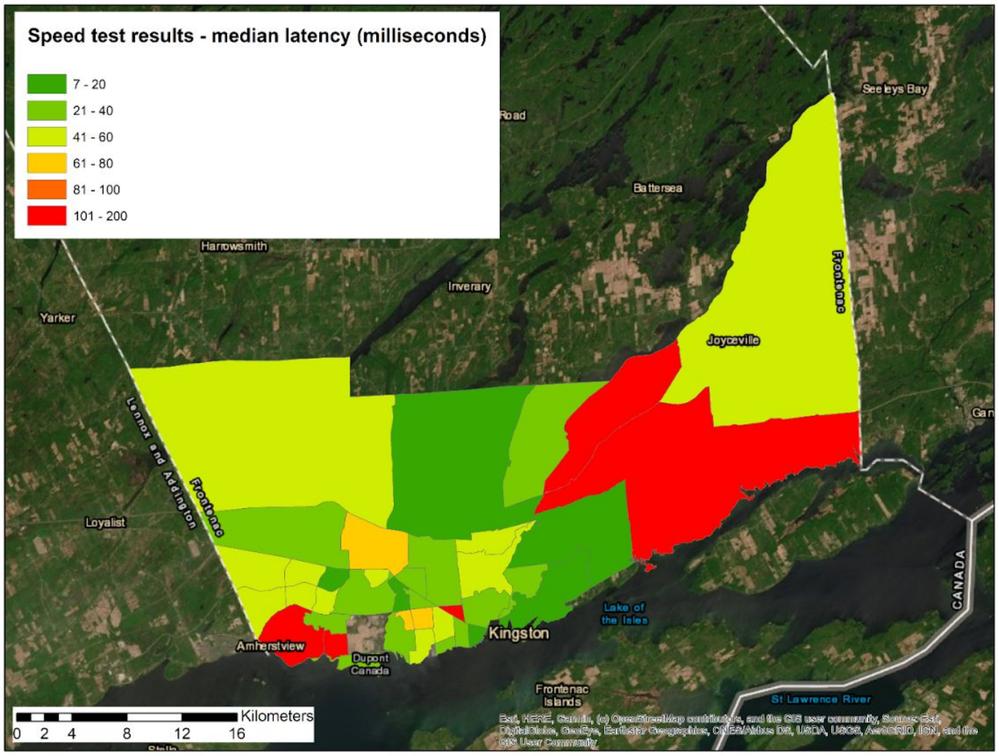

Figure 3-10: Speed test results – median latency in milliseconds

3.3 Service coverage

The survey responses were broken down by the Internet service connection type that participants reported subscribing to. In urban areas, cable and fibre Internet combined make up the majority of Internet service connections. In rural areas the distribution of connection types is flatter, with fixed wireless and fibre being the two most common connection types. Figure 3-11 shows these results.

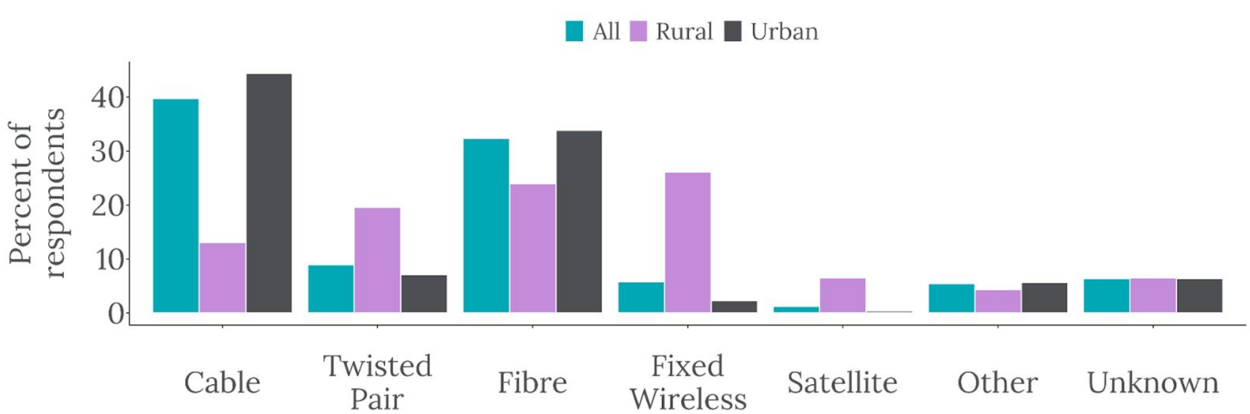

Figure 3-11: Internet subscriptions by connection type

3.3.1 Wireline service coverage

Since only two TSPs provided data indicating where their infrastructure is situated, the project team was not able to produce comprehensive maps of coverage areas for wireline broadband service. However, the residential survey results are able to shed some light on disparities in service coverage. While Fibre 3-11 shows that fibre was the second most frequently reported broadband connection in rural areas, Figure 3-12 shows that all of these connections are located in just three of Kingston's fourteen rural neighbourhoods. To respect survey respondents' privacy the exact locations of these connections cannot be shown, but all of the reported rural fibre connections are located in areas that have relatively high population density and/or are located adjacent to the urban zone. Figure 3-13 shows the opposite side of this story by displaying rural DAs in which 25 survey respondents reported that they would like a fibre connection but it is unavailable. It should be pointed out that there is overlap between these two maps, which means that even though some households in a particular DA might have access to fibre, others in the same DA do not.

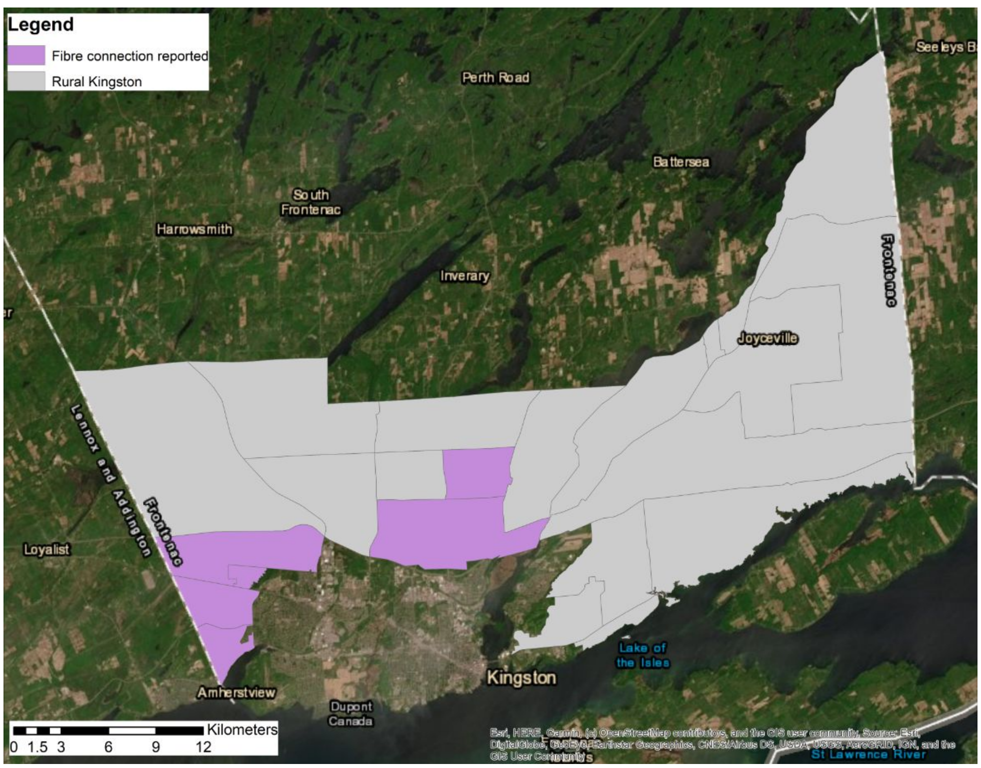

Figure 3-12: Rural DAs in which a fibre connection was reported

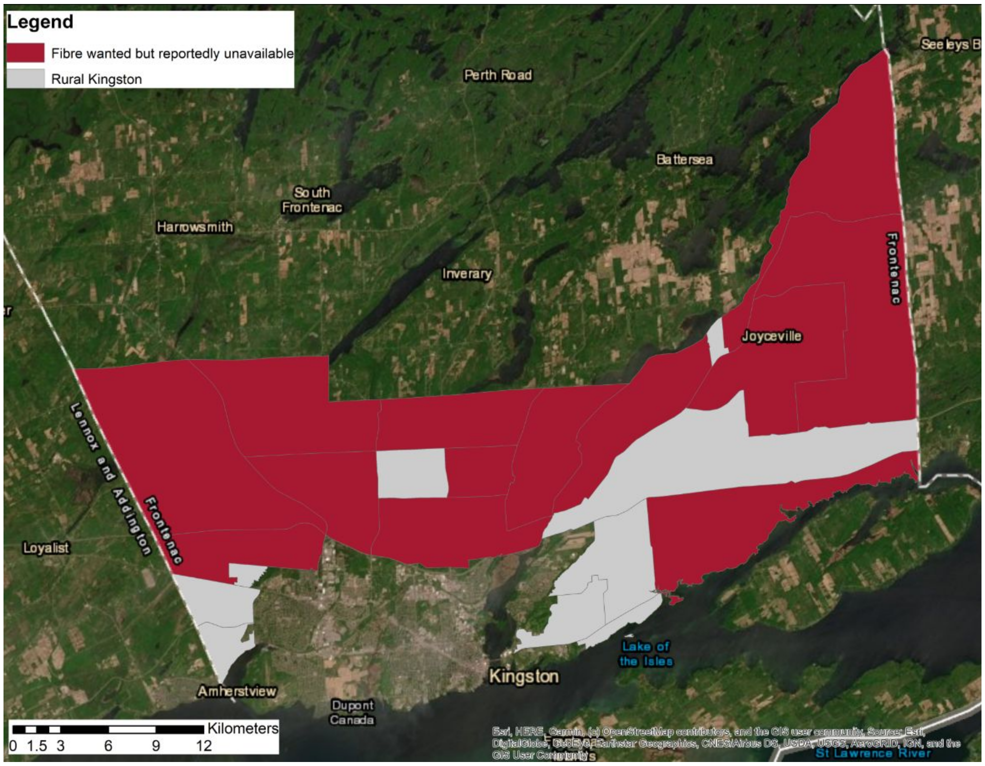

Figure 3-13: Rural DAs in which a fibre connection is desired but reportedly unavailable

3.3.2 Wireless service coverage

An open dataset published by the Ministry of Innovation, Science and Economic Development provides information on the location, ownership and attributes of wireless Internet infrastructure across all of Canada. Using this dataset, the project team mapped coverage areas for fixed wireless and mobile cellular service towers throughout Kingston (Figures 3-14 and 3-15).

As was discussed in the introduction, wireless broadband coverage areas are influenced by a range of factors including environmental and geographic factors. Wireless broadband service is often delivered via shared access media, meaning that while high data bandwidth and speed can be achieved, they cannot be guaranteed (The World Bank, 2018) (Wik Consult, 2015). Moreover, wireless broadband service can be negatively impacted by line-of-sight issues, obstacles, environmental effects and electromagnetic interference (Vantage Point Solutions, 2017). For these reasons, the coverage areas displayed in Figures 3-14 and 3-15 are approximate.

A white paper published by Interisle Consulting Group was used to determine fixed wireless coverage radii. In this paper a 5 mile (8.04 km) radius is outlined for 70% probability of successful fixed wireless signal (FWS) in a mixed-use landscape with moderate elevation changes. Based on the Interisle Consulting Group paper, within the 8.04 km fixed wireless range, 66% of the coverage radius nearest the fixed wireless tower

(5.32 km) is estimated to have full signal strength. For 4G mobile coverage, a distance of 5 km was used as a coverage radius based off cell provider information as well as a 2011 report from Defence Research and Development Canada.

The Digital Elevation Model (DEM) from the Government of Canada was used to conduct a line-of-sight analysis to identify which areas in the City of Kingston are and are not in the direct line of site of a cell tower. While there are many environmental and equipment factors at play, a line of sight is a critical factor in fixed wireless signal quality. Inspection of these maps provide useful information about current gaps in 4G mobile and fixed wireless coverage from major rural providers in the area (Bell and Rogers for 4G mobile and WTC, Xplornet and KOS for fixed wireless).

This geospatial analysis helps to determine where wireless delivery of Internet service in Kingston may be impeded by topography. Additionally, radio spectrum assets previously granted by the government for TSPs providing fixed wireless may be used for 5G delivery. Therefore, this data set can be used as a base for further analysis should the City wish to explore options for 5G Internet infrastructure development in the future.

Figure 3-14 shows the coverage and visibility zones for fixed wireless service, while Figure 3-15 shows coverage and visibility zones for 4G cellular service. In both maps, areas of poor cell tower visibility were coloured white, while areas of clear cell tower visibility were coloured black. In Figure 3-14, the intensity of the colour of the coverage area decreases with distance from the tower, indicating a decrease in signal strength. The visibility layer was overlaid with the cell coverage area layer to simultaneously display theoretical coverage and visibility. The interpretation is that wireless broadband service is better in areas on the map where the colour is more intense (signal is stronger) and where the underlying visibility layer is darker (tower visibility is good). Inspection of these maps shows that there are significant areas in Kingston's north-west and north-east (west of Highway 38 north of the 401, as well as in Kingston Mills) where zones of low signal strength and visibility overlap. The lower the signal strength and the poorer the visibility, the lower the available bandwidth. Furthermore, there are areas where only a single Wireless Internet Service Provider is available, meaning that residents have no alternative options if the service is unaffordable or poor quality.

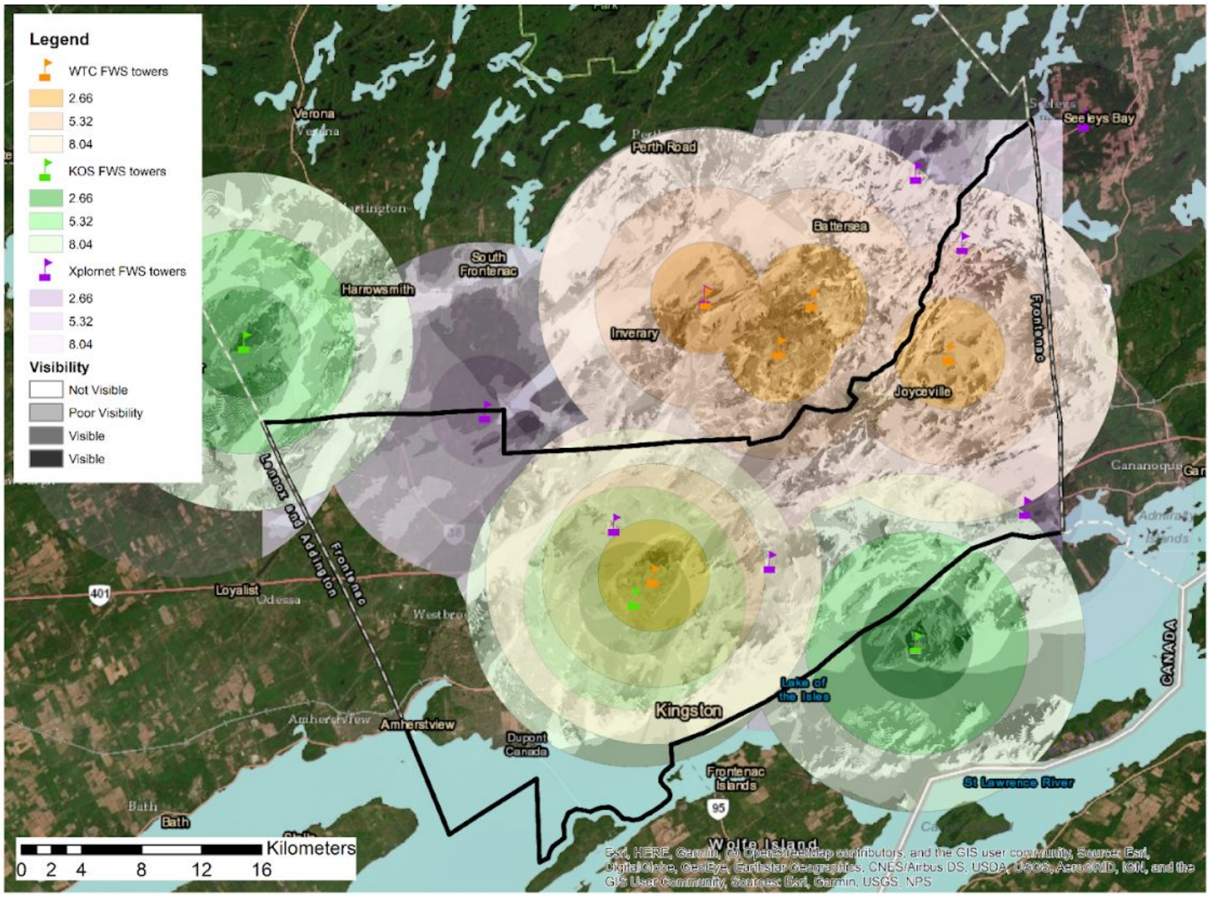

Figure 3-14: Fixed wireless service coverage and visibility zones

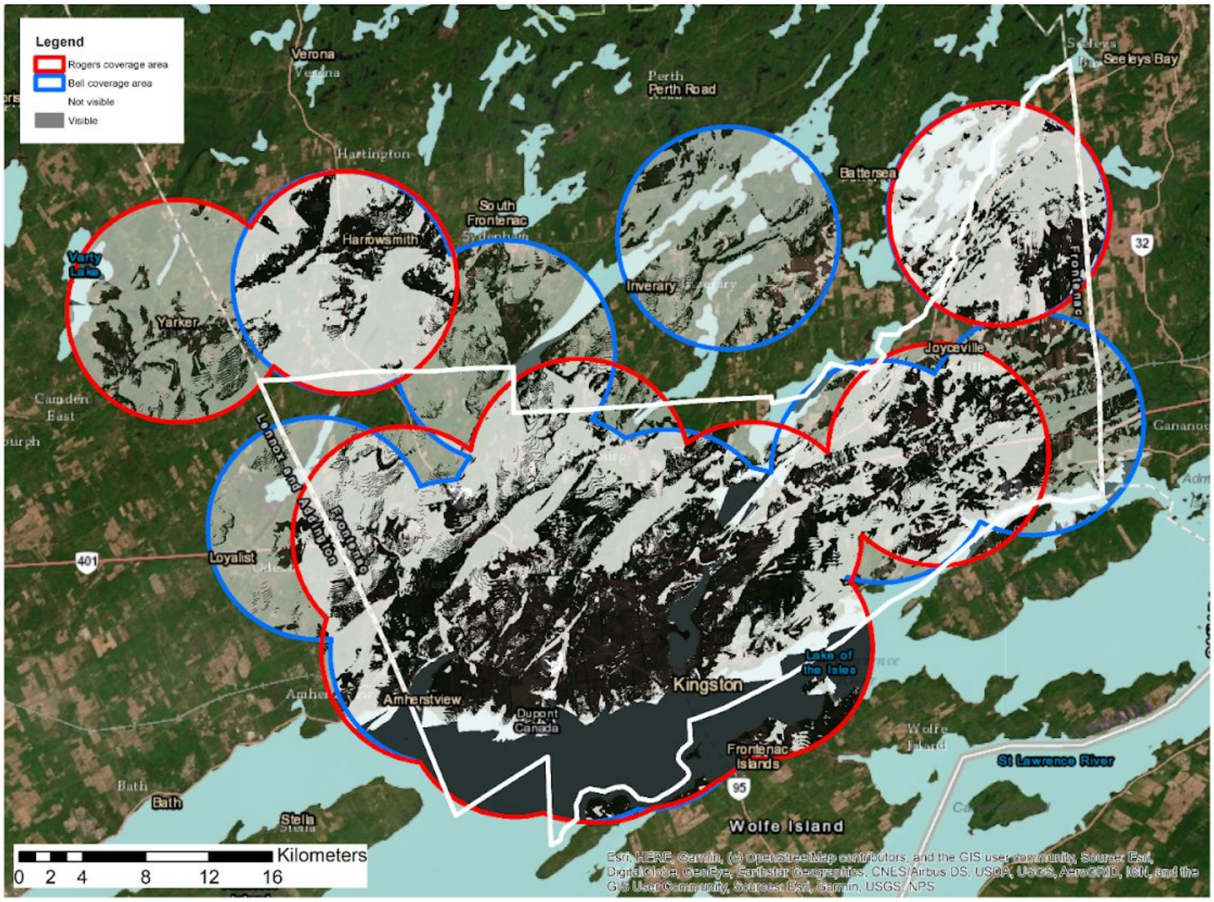

Figure 3-15: 4G mobile cellular coverage and visibility zones

An additional secondary source of data that shows the gap in access to broadband between rural and urban areas is the 2018 National Broadband Data published by the Government of Canada. The Ministry of Innovation, Science and Economic Development collects information from TSPs about where the TSPs offer different types of Internet service. This information is then compiled and aggregated over a grid of hexagons that are approximately 25 km^2 each. Figure 3-13 shows how access to Internet service that meets the CRTC's current definition of broadband (50 Mbps download, 10 Mbps upload) varies within the City of Kingston. The National Broadband Data adds further evidence demonstrating the presence of the digital divide between Kingston's rural and urban areas. However, it is important to remember that this particular representation of the digital divide has two main limitations:[26]

[26] There is a third, significant problem with how this data is collected and used. The data is provided by TSPs, and is used by the CRTC to determine what areas are eligible for funding through the Broadband Fund. However, if even a single subscriber within one of the 25km^2 hexagons has access to 50/10 fixed broadband service, then the entire area is considered by the CRTC to have access. This assumption grossly overestimates the level of coverage in many areas and means that, as a result, no areas within the City of Kingston are currently eligible for… (continued on next page)

- It quantifies the digital divide based on an oversimplified definition of high-quality broadband based on threshold upload/download speeds;
- The area over which the results are aggregated hides the service gaps that exist in low-income and relatively low household density urban areas.

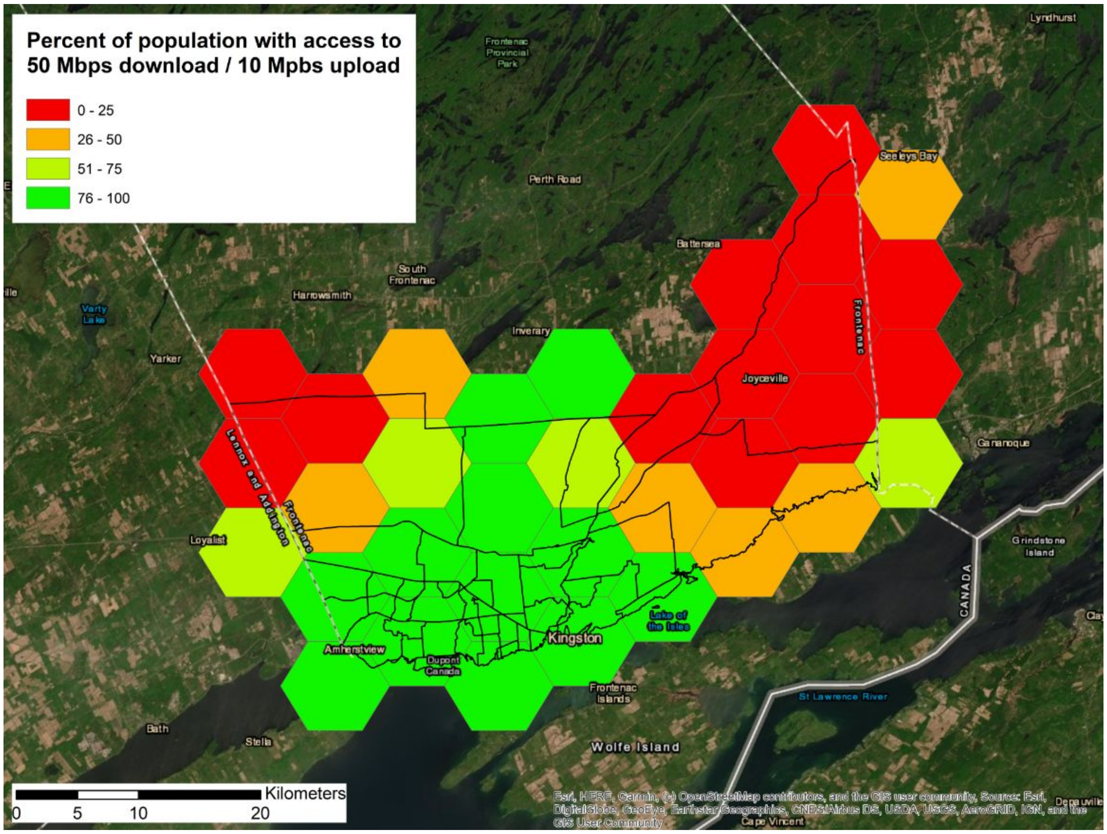

Figure 3-16: Percentage of the population that has access to Internet service that meets the CRTC definition of broadband (50 Mbps download, 10 Mbps upload)

3.4 Consequences of the digital divide

The survey results show some interesting differences between rural and urban residents' respective experiences with home Internet service. One of the more telling observations is how participants responded to the question '*Are there any Internet services that you want but are unavailable?*' 45% of respondents indicated that there are no Internet services that they want that are unavailable. However, this percentage is unevenly split between rural and urban residents. Only 6% of rural residents (3/46) indicated that there are no Internet services they want that are unavailable, whereas 51% of urban residents (136/266) indicated that there are no Internet services they want that are unavailable. The Chi-square test of independence shows that there is a statistically-significant ($p < 0.05$) difference in the way rural and urban residents responded to this question, suggesting that

funding through the Broadband Fund, as can be seen on this map: https://crtc.gc.ca/cartovista/fixedbroadbandandtransportye2018_en/index.html there is a gap in the quality and range of Internet service provider and plan options available to rural residents.

Qualitative analysis of the open-ended comments that survey participants provided further supports the idea that options are limited for residents of rural areas. A number of themes were identified in the comments, and tallies of references to each of these themes were added up. The most striking result shown in Table 3-2 below is that 74% (14/19) of rural residents who provided an open-ended comment cited lack of access to certain Internet service options as a concern. More than a third of all comments (both rural and urban) cited high prices as a concern. Other prominent concerns were related to quality of service, including issues such as slower-than-advertised upload and download speeds and poor connection reliability. While poor performance in any one of the identified thematic areas is grounds for any individual consumer's dissatisfaction, it is the combination of all of these themes that makes the situation untenable for consumers collectively.

Table 3-2: Percent of comments citing specific concerns

Measure	All n = 80	Rural n = 19	Urban n = 61
High prices	34%	21%	38%
Limited selection of providers and/or plans	31%	74%	18%
Poor quality of Internet service	14%	5%	16%
Slow speeds	13%	10%	13%
Poor reliability	11%	16%	10%
Data use constraints	9%	5%	10%
Information asymmetry	9%	10%	8%
Lack of competition in market	9%	5%	10%
Poor customer service	8%	5%	8%
Disproportionate prices for service provided	6%	10%	5%
Barriers to switching providers	3%	0%	3%
Lack of trust in providers	1%	0%	2%
Safety of technology	1%	0%	2%
Privacy infringement	1%	0%	2%

The gap analysis clearly shows that the 'digital divide' between rural and urban areas in Kingston is real. Rural residents pay more money for Internet service, both in terms of absolute prices and on a price per quality basis. Moreover, the wireless service coverage mapping and line-of-sight analysis shows that there are large areas in rural Kingston where wireless Internet service quality may be reduced. Given that the gap in access to broadband Internet service between rural and urban areas exists in Kingston, the question is: what will it cost to bridge this gap, and what would be the economic value of doing so?

4. The cost of bridging the gap

The cost of bridging the gap in access to high-quality broadband Internet can be split into two components - the CAPEX investment required to install new FTTP infrastructure, and the OPEX required to maintain the infrastructure throughout the network's lifespan. Precisely calculating these costs is an engineering and management design activity that is beyond the scope of this project. However, by using the data collected through this project and making some educated assumptions about the current state of broadband infrastructure coverage in Kingston, the CAPEX to expand access to FTTP Internet to Kingston's underserved rural areas was calculated. OPEX costs are estimated to be 60% of the revenue generated by the network, based on annual reports published by TSPs.[27]

In Section 3, Figure 3-12 showed that there are some places in rural Kingston where FTTP service is available. However, the extent of this coverage is impossible to assess without knowing exactly where infrastructure exists. In some cases, a survey respondent on one street reported wanting a FTTP connection but that it was not available, while a respondent from a house right around the corner reported having a FTTP connection. This type of street-level differentiation between access and non-access will only be possible with full participation from TSPs. The project team considered web-scraping TSPs' websites to determine what type of Internet service is available at every civic address in Kingston, but this exercise would have violated the TSPs' website terms and conditions and was therefore not undertaken. Due to these limitations, the project team took the most conservative approach and estimated the cost to expand access to high-quality broadband to the entire rural are within the City's boundaries.

Figure 4-1 shows the proposed FTTP network expansion that was designed for the purposes of the cost estimation exercise. Using road segment and civic address datasets from the City of Kingston's Open Data portal, the FTTP network was designed such that access fibre will be run along every populated road segment that falls within Kingston's rural zone. The total length of access fibre needed to cover this area is 442 km. There are 6,870 civic addresses within the rural zone. While not all of these addresses are residential buildings, it was assumed that all of these addresses might potentially subscribe to an Internet service.

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[27] Bell OPEX: 59% of revenue in 2018:
https://www.bce.ca/investors/AR-2018/2018-bce-annual-report.pdf,
Rogers OPEX: 50% of revenue in 2018:
https://about.rogers.com/wp-content/uploads/2019/01/Rogers-Q4-2018-Press-Release.pdf,
Cogeco OPEX: 54% of revenue in 2018:
http://www.annualreports.com/HostedData/AnnualReports/PDF/TSX_CGO_2018.pdf

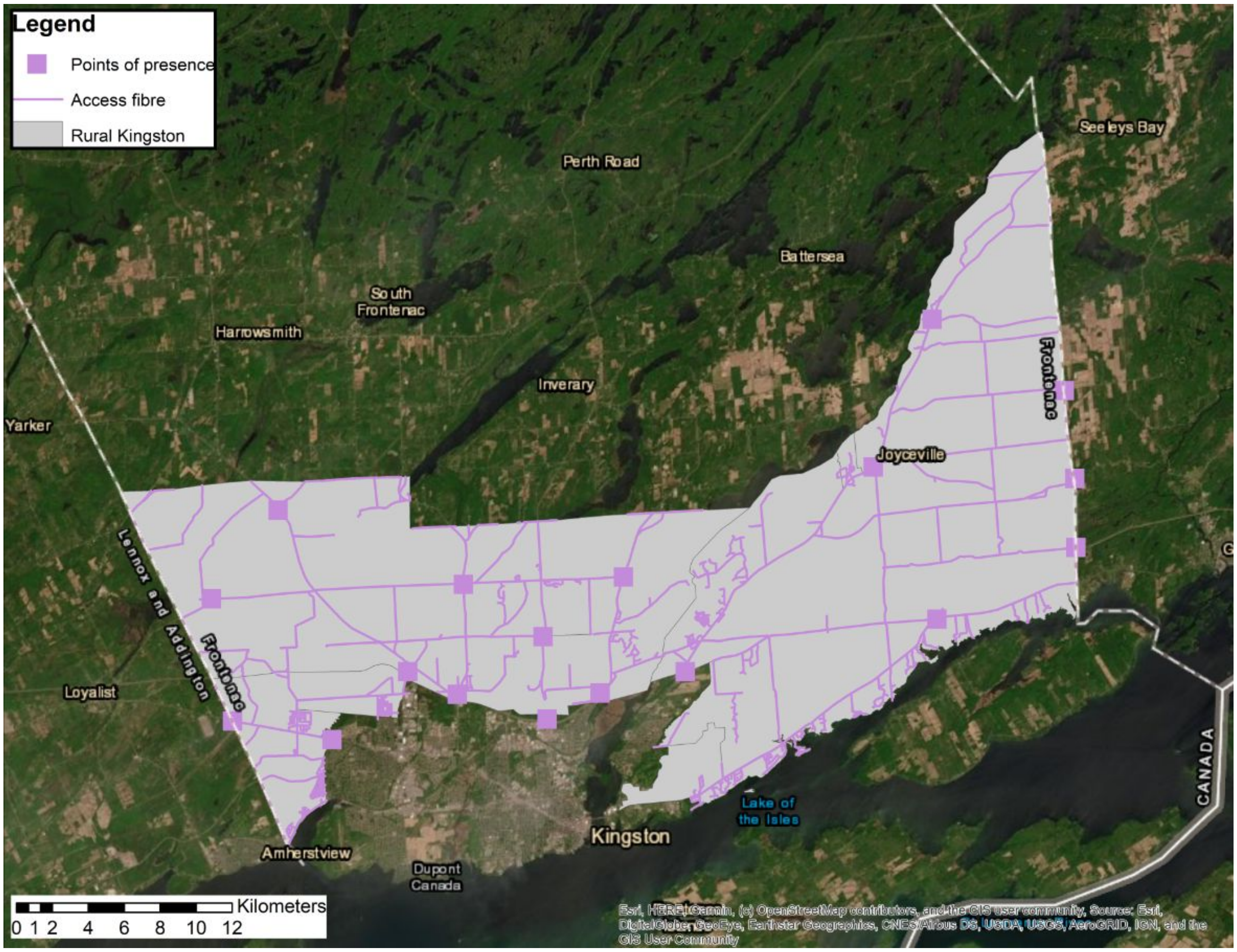

Figure 4-1: Proposed FTTP network expansion

With input from Utilities Kingston, WTC and Cogeco, the project team established unit cost estimates for three scenarios - a high cost scenario (Active Ethernet FTTP architecture), a mid-range and a low cost scenario (PON FTTP architecture). For the high cost-scenario, Utilities Kingston provided guidance in identifying 18 locations where Points of Presence (PoPs) are needed. A PoP is a location within a network where electronic components are installed to enable customers to access the Internet. Utilities Kingston also provided the project team with unit cost estimates for laying access fibre (both overhead on hydro poles and buried underground), last-mile connections to customer premises, and PoPs. Detailed breakdowns of these unit cost estimates are included in Appendix A of this report.

For the mid-range and low cost estimates, Cogeco and WTC respectively provided estimated unit costs for installing access fibre in rural Kingston. WTC also provided an estimated cost per PON cabinet, which was used for both the mid-range and low cost estimates. During an online public webinar by RVA LLC on December 17, 2019, the presenter cited a range of typical last-mile FTTP connection costs in rural areas.[28] The upper limit of this range was lower than the estimate provided by Utilities Kingston, so the upper and lower limits of this range were used for the mid-range and low cost scenarios respectively. Table 4-1 shows a summary of the unit costs for access and last-mile fibre in each scenario. Detailed cost estimates are also included in Appendix A along with the Utilities Kingston estimates.

Table 4-1: FTTP network unit costs

Scenario	Access fibre cost per km		Last-mile fibre cost per premises	Cost per PoP or PON system
	Aerial	Buried		
High cost	$78,044	$190,131	$11,204	$166,171 (PoP)
Mid-range cost	$66,950	$75,000	$3,625	$165,319 (PON system)
Low cost	$25,000	$25,000	$3,300	$165,319 (PON system)

Table 4-2 summarises the Present Value (PV) of the estimated CAPEX of the FTTP network under each of the three scenarios. Some key assumptions underpin these estimates:

- The analysis considers a 20 year time period, with an annual rate of 8.3% applied to discount the value of capital (Damodaran, 2019).
- Access fibre costs assume a 70%/30% split between overhead and underground fibre, except for the low-cost scenario which assumes all access fibre is aerial.
- The number of last-mile connections is estimated based on the number of rural civic addresses in the City of Kingston's civic addresses dataset, Kingston's projected annual population growth rate of 0.5% and an average of 2.39 persons per housing unit over a 20 year period (Watson, 2019).
- It will take five years for the expansion to be completed. In each year, one fifth of the required infrastructure is installed in one of five 'Expansion Zones.'
- In each Expansion Zone, 40% of civic addresses subscribe to FTTP in the first year of access in that expansion zone, after which the take rate increases by 10% per year up to a maximum of 80%.
    - In Year 1, Expansion Zone 1 gains access to FTTP, and 40% of addresses in Expansion Zone 1 subscribe to FTTP.

[28] RVA LLC is a marketing research and consulting company that publishes an annual *North American Fibre Broadband Report*. The report costs $2,450 USD and was not procured for this project, but the numbers cited during the presentation are based on the report's findings. More information about RVA and the report can be found here: https://www.rvallc.com/ftth-reports/

- In Year 2, Expansion Zone 2 gains access to FTTP, 40% of addresses in Expansion Zone 2 subscribe to FTTP, the rate of FTTP subscription in Expansion Zone 1 increases to 50%.
- This continues until 80% of the addresses in all five Expansion Zones subscribe to FTTP, and the remaining 20% have access to FTTP but have opted out of subscribing.

Table 4-2: PV of FTTP network CAPEX under various scenarios

Scenario	Present value of CAPEX (2019 CAD)	Per household (2019 CAD)
High cost	$87 Million	$12,687
Mid-range cost	$40 Million	$5,803
Low cost	$23 Million	$3,349

5. The value of bridging the gap

Estimating the value of bridging the gap in access to high-quality broadband Internet is a complex and nuanced exercise. Broadband Internet creates value for many different stakeholders in the economy, and these benefits can often overlap. Additionally, existing benefits can evolve and new benefits can emerge over time, which makes quantifying the value over any extended period of time difficult to accurately predict.

This report focuses primarily on quantifying residential consumers' perceived value of access to high-quality broadband Internet to consumers, while also considering the financial implications for TSPs and the government. As such, the value of bridging the gap depends largely on consumer preferences. This section first explores the current state of residents' Internet plan characteristics, uses and preferences, and then goes on to describe the approach taken to quantify the value of expanding access to high-quality broadband Internet to all residents of Kingston.

5.1 Current consumer preferences

The residential survey sought to characterise Internet plan characteristics as well as behaviours associated with Internet use.

5.1.1 Plan characteristics

The survey responses were broken down by the Internet service connection type to which participants reported subscribing. Table 5-1 compares the median download and upload speeds purchased and median price paid for FTTP and non-FTTP Internet service, in rural and urban areas respectively. The numbers presented in this table are key inputs to estimation of the private valuation of broadband discussed later in this section.

Table 5-1: Comparison of median speeds and prices by connection type and location

Location and Connection Type	Download Mbps	Upload Mbps	Price CAD
Rural non-FTTP	10	2	$78.50
Urban non-FTTP	40	10	$63.00
Rural FTTP	300	300	$85.00
Urban FTTP	300	300	$80.00

5.1.2 Telecommuting

50% of respondents reported that one or more members of the household telecommutes over the Internet. Figure 5-1 shows the distribution of the reported number of telecommuters per household.

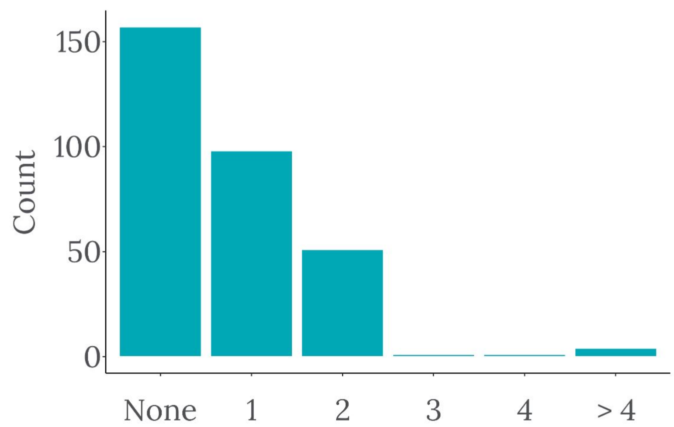

Figure 5-1: Number of telecommuters per household

Of the respondents who reported at least one member of the household telecommuting, the number of telecommuting days was calculated. The distribution of the number of telecommuting days is shown in Figure 5-2.

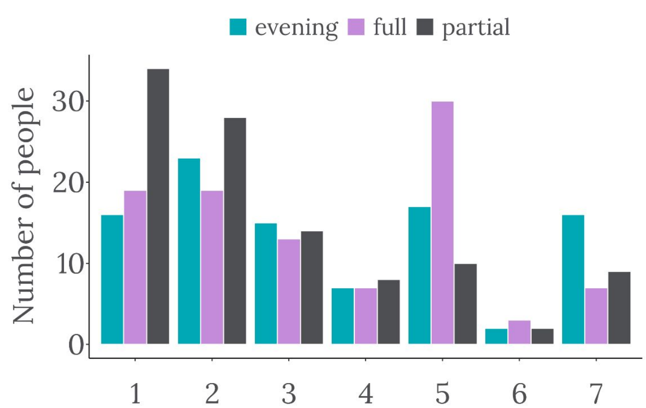

Figure 5-2: Number of telecommuting days per week

The respondents who reported that no one in the household regularly telecommutes were asked to cite the main reason why no one telecommutes. The histogram of reasons cited is shown in Figure 5-3. 43% of respondents who reported no telecommuters in the household cited 'Other' as the main reason why no one in the household telecommutes. This suggests that the listed options were missing at least one other important reason why no one in the household telecommutes. Only 2 respondents reported that an insufficient home Internet connection is the main barrier preventing them from telecommuting.

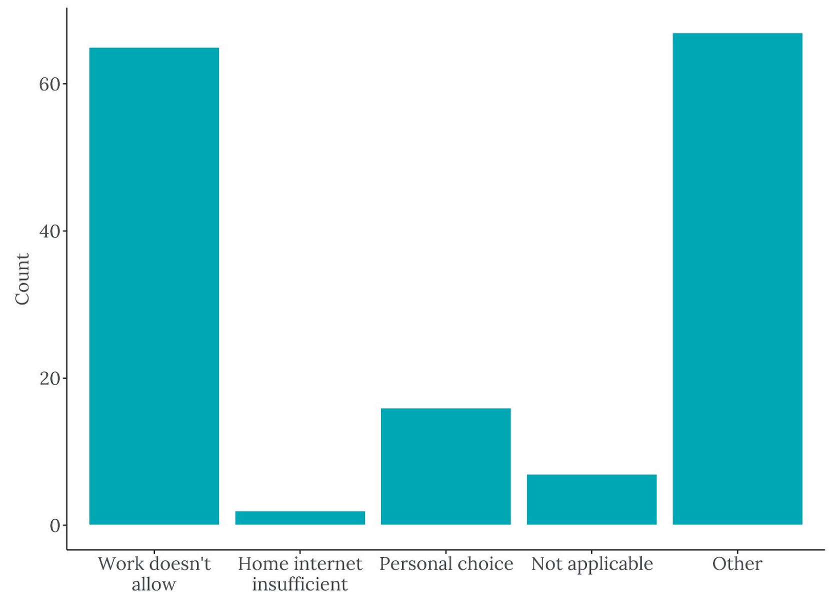

Figure 5-3: Reasons cited for not telecommuting

Those who responded that at least one person in the household telecommutes were asked what activities are undertaken when telecommuting. Figure 5-4 shows the frequency of various telecommuting activities. These activities were presented as options to survey participants because they are activities that depend on having highly available, high-bandwidth, symmetrical broadband service. The fact that telecommuters are engaging in these activities all or some of the time has major implications for the type of broadband infrastructure that needs to be built to support telecommuters' needs.

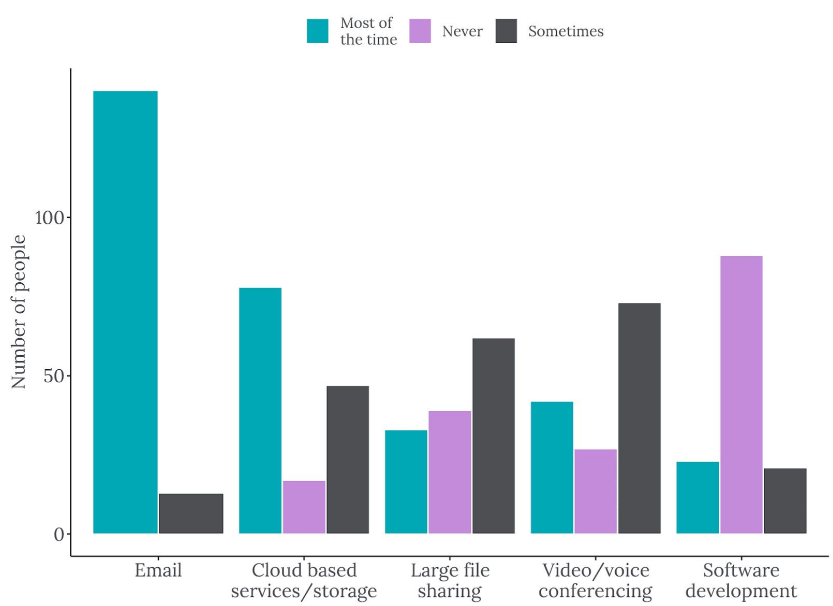

Figure 5-4: Frequency of reported telecommuting activities

5.1.3 Home-based Businesses

1% of all respondents report owning or operating a farm, while 15% report operating a business or organization out of their residence. Figure 5-5 shows what activities the Internet is used for among home-based business owners/operators.

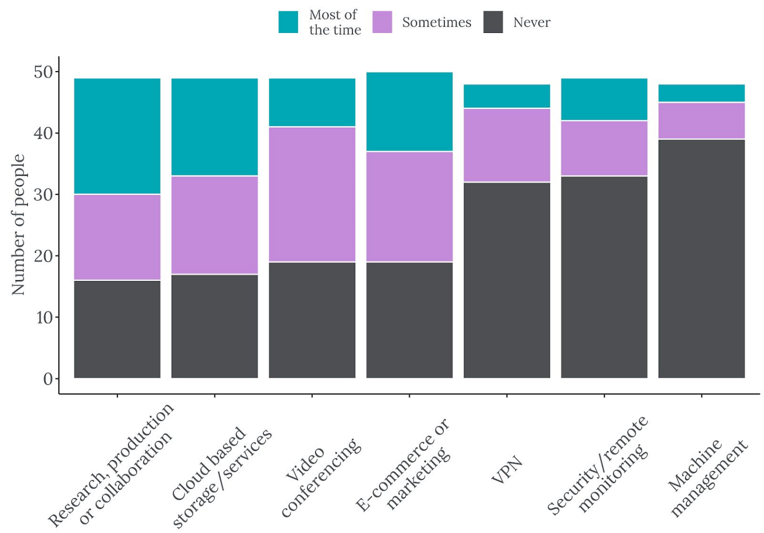

Figure 5-5: Internet use activities of home-based business owners/operators

Figure 5-6 shows how business owners' behaviour would change if they had access to faster and/or more reliable Internet. There is very little variation in the responses to this question across categories, which suggests that the question was either poorly understood or else people selected the same answer for all categories. The answers to the question are also ambiguous, because a respondent could interpret the options as either 'getting more work done' or 'spending less time doing.' These different interpretations of what constitutes a 'positive' change in behaviour might contaminate the results of this question.

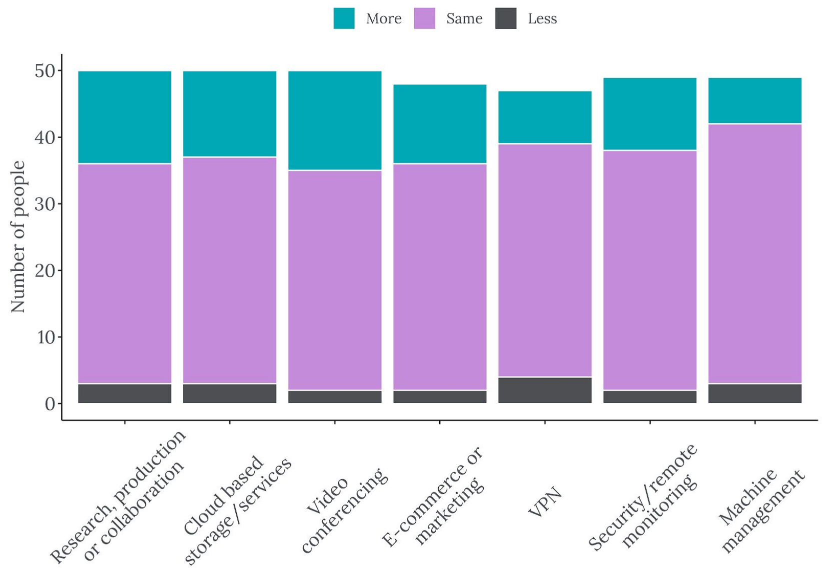

Figure 5-6: Change in home business Internet use activity frequency

5.2 Economic valuation of private benefits of broadband

This section introduces important concepts such as Willingness to Pay and Consumer Surplus, and describes how these concepts were used to value the private benefits of access to broadband. An estimate of the economic value of rural residents' perceived benefits from expanding high-quality broadband access to all of rural Kingston is presented. The section concludes by comparing the value of the benefits of high-quality broadband with the previously estimated costs.

5.2.1 Consumer Willingness to Pay

Like many products, an Internet service consists of a bundle of characteristics (e.g. download and upload speed, maximum usage, etc.) that consumers value in different ways. These valuations combine in some way to contribute to the price that the consumer is willing to pay for the overall Internet package. We refer to the effect that a unit increase in the quantity of a particular characteristic (e.g. a GB of maximum usage capacity) has on the consumer's overall Willingness to Pay (WTP) as the marginal Willingness to Pay (MWTP) for that characteristic.

For many characteristics on which consumers place positive value, we typically find that the WTP is increasing with its quantity but at a decreasing rate (diminishing marginal utility). This implies that the MWTP is a decreasing function of the quantity of the characteristics currently being consumed. Thus, the MWTP is much like a demand curve for a specific characteristic (e.g. download speed), holding all other characteristics constant. For a consumer who is currently consuming a download speed of 100 Mbps, for example, the MWTP curve tells us how much he/she would be willing to pay for the next additional Mbps.

In principle, if all consumers were identical and if an Internet service provider were to offer a package consisting of specific quantities of several characteristics, the MWTP curve tells us the price per unit that the consumer would be willing to pay for each characteristic. Multiplying by the quantity of each and summing across all the characteristics then yields the consumer's overall Willingness to Pay for the package.

5.2.2 Consumer surplus

Because MWTP is decreasing with the quantity of the characteristic, x, a consumer who is offered a package with a lower quantity of this characteristic, would have been willing to pay a higher unit price (e.g. price per Mbps). Since the price per unit paid for the package consisting of x^* is lower, the consumer pays less for these inframarginal units than they are worth to her. The difference, represented by the area under the MWTP curve and above the unit price in Figure 5-7, is the contribution to consumer surplus coming from this characteristic. This represents a dollar valuation of the potential net benefit accruing to the consumer from the characteristic as part of the overall package.

Consumer surplus can be thought of as the difference between the maximum amount of money a person would pay for an Internet plan (the value of the plan) and what they actually pay for the plan (the price of the plan). It is the money that is 'leftover' after paying for Internet service.

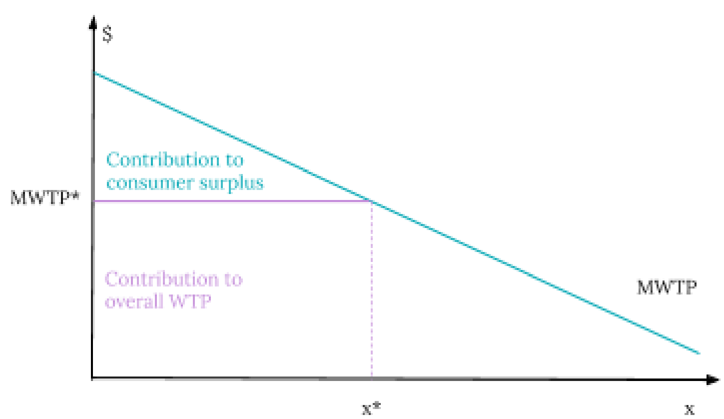

Figure 5-7: Graphical depiction of consumer surplus

5.2.3 Feasible choices

A consumer's WTP for a particular Internet package depends on the choices that are feasible. In general, this WTP will be higher if the consumer has few alternatives available. For example, rural households may be willing to pay more for basic Internet services if there are no other providers in the area. Another way to say this is that with few substitutes, their demand is more inelastic allowing providers to profitably restrict supply and raise the price. Thus, in interpreting a consumer's WTP it is crucial to know what choices are available.

5.2.4 Eliciting consumers' Willingness to Pay from a Discrete Choice Experiment

In general, it is very difficult to assess WTP using observations on prices, characteristics and quantities in the actual market. This is partly because it is tricky to identify whether changes in prices and quantities are the result of supply or demand shifts. Moreover, in an uncontrolled environment it is not always clear what are the feasible choices available to decision-makers. Finally, in the face of a lot of unobservable factors, the estimated relationship between package prices and the underlying characteristics is likely to suffer from various biases.

Discrete choice experiments (DCE) are designed to elicit consumers' WTP in a simple experiment in which the nature and joint distribution of feasible choices can be controlled. By asking consumers to select their preferred Internet package from several combinations of choice sets, we can build up a picture of their relative preference for Internet packages with various characteristics and prices. This information can be used to determine statistically the average extent to which consumers are willing to trade off changes in package prices with changes in the characteristics available to them. This gives us a way to estimate their average MWTP.

Designing a DCE that is meaningful, balanced and feasible to conduct is an involved process that is discussed in detail in Appendix B. In the DCE conducted here, we asked respondents to choose packages each consisting of a price and three key characteristics: download speed (Mbps), upload speed (Mbps) and data usage capacity (GB). The prices and alternative quantities of each characteristic in each package were in the same range as those currently offered in the Kingston market. We used the choice data from the DCE, to estimate a MWTP curve for each characteristic by fitting a parsimonious conditional logistic regression model. Importantly, the model assumes that, while consumers may value alternative packages differently, the marginal impact of each characteristic on this valuation is the same across them. Moreover, the curvature of the MWTP curves is calibrated using urban non-fibre consumers as a reference point. Further details of the estimation approach, its assumptions and the interpretation are provided in Appendix C.

5.2.5 Estimation results

Figures 5-8 to 5-10 depict the estimated MWTP curves for each of the three characteristics together with their associated 95% confidence interval bounds.[29] By construction, the fitted curves exhibit a similar shape but over different ranges. The confidence bounds are wider for upload capacity than for the other two characteristics indicating more uncertainty in our estimate of the respondents' average marginal valuation.

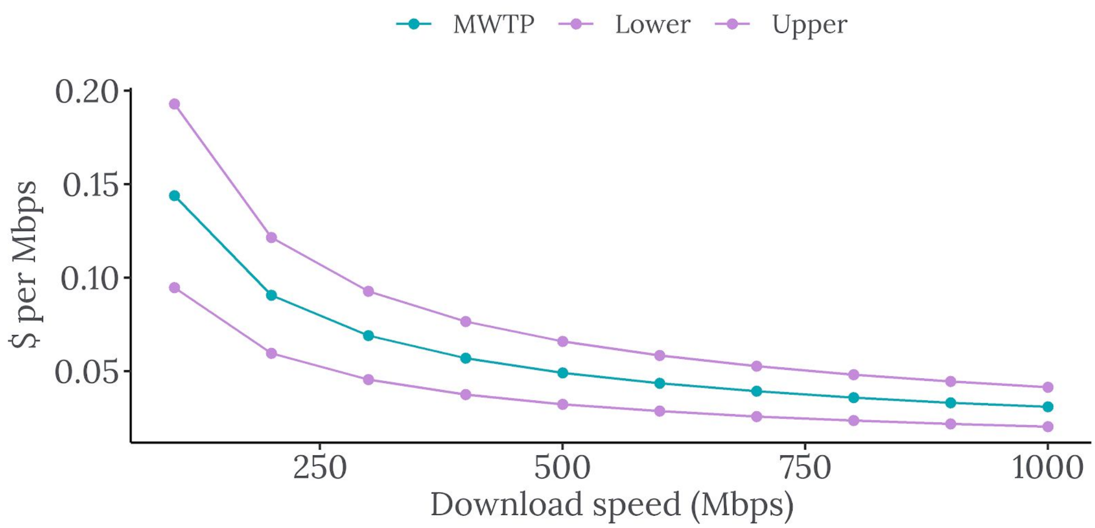

Figure 5-8: Marginal Willingness to Pay for download speed

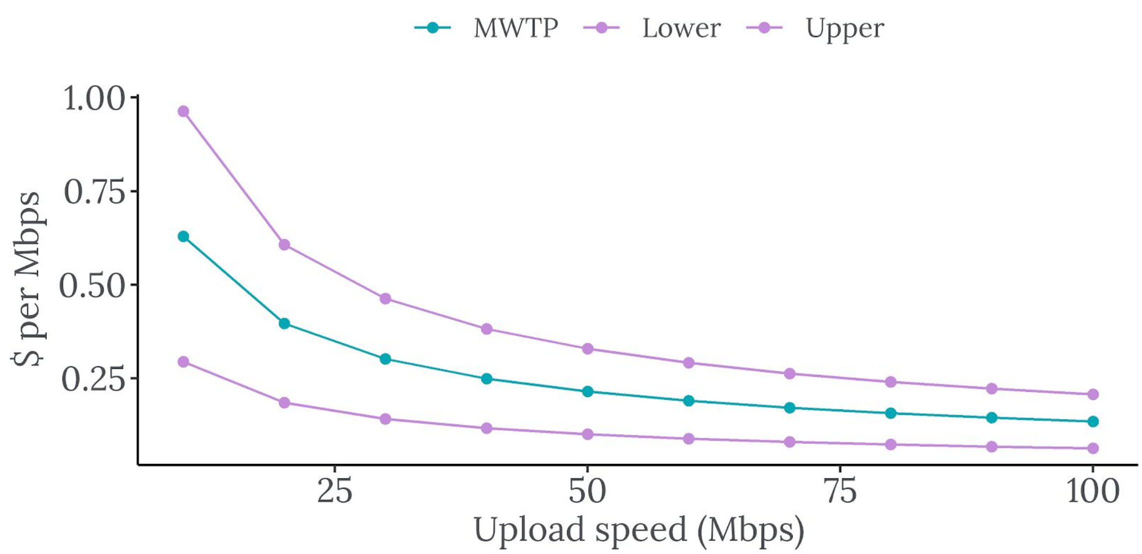

Figure 5-9: Marginal Willingness to Pay for upload speed

[29] That is, for any sample drawn from this population, the value of the average MWTP would be within these bounds 95% of the time.

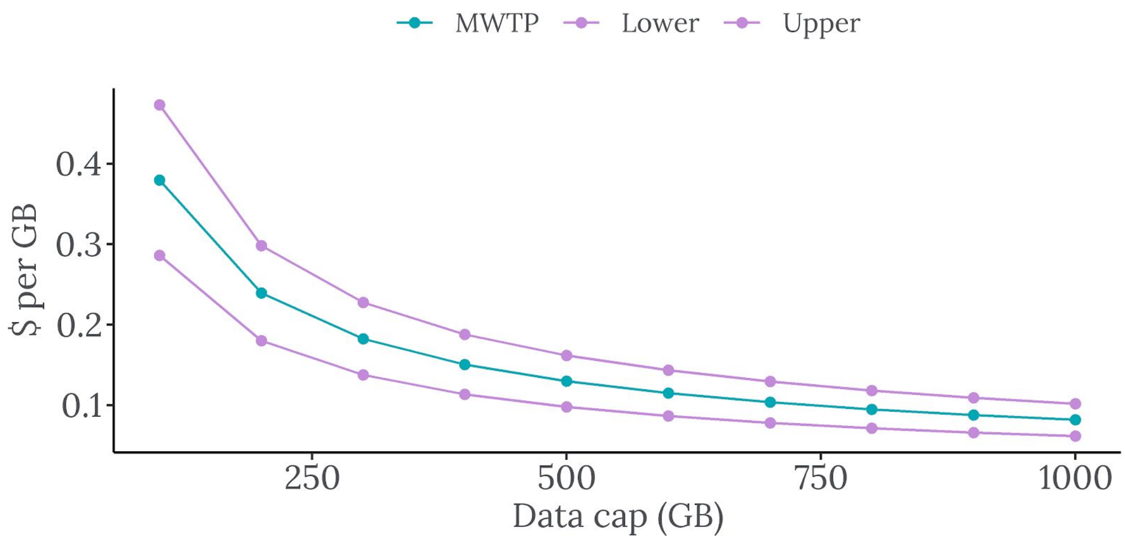

Figure 5-10: Marginal Willingness to Pay for data cap

Based on these estimated MWTP curves, one can compute a point estimate of the average willingness to pay for any particular Internet package. For example, the average WTP for a package with up to 300 Mbps download speed, 20 Mbps upload speed and 500 GB data cap is given by $(300 \times 0.07) + (20 \times 0.40) + (500 \times 0.13) = \$94$.[30]

5.2.6 Market structure

In order to connect the WTP estimates from the DCE to the actual Internet market in Kingston, it is necessary to have a sense of the market structure. Based on observing the residential survey data and anecdotal evidence, the project team posited that there are essentially three stylized market segments with different structures within the overall Internet market in Kingston:

1. The rural non-FTTP market is (locally) monopolistic. Customers are charged a high average price ($78.50) for limited Internet package characteristics, reflecting their average WTP in a context with little choice. This WTP in a limited-choice scenario is different from the WTP estimated using the DCE data from the residential survey, which represents the average WTP in a scenario where several Internet options are available.
2. The urban Basic Internet market seems fairly competitive with many small (resellers) and large players but little room for bargaining over prices. It overlaps with the FTTP market. The average price is relatively low ($63) and reflects consumers' average WTP for Basic Internet in a context with choice (and therefore is assumed to be consistent with the average preferences expressed in the DCE). The price variation that does exist seems to be more related to the quality of service

[30] The associated 95% confidence interval around this point estimate is [$66, $121], which is quite wide. This likely reflects the small survey sample size.

than bargaining by consumers. For example, 80% of the variation in prices per Mbps download speed are associated with differences across providers.

3. The market for FTTP (rural and urban combined) is oligopolistic with a few large TSPs. Based on the DCE, we estimate that the average WTP for a typical high quality fibre service is relatively high ($142) but the marginal cost of supplying additional customers is likely relatively low (unlike the fixed costs). As a result, some customers are able to negotiate better deals and discounts where there is more competition between the TSPs. This drives the average price paid down ($80 urban/ $85 rural). This characterization is consistent with the fact that 75% of the variation in prices per Mbps of download speed is "within" TSPs rather than across them.

The existence of these three different market segments provides the theoretical basis estimating the private value of expanding access to FTTP Internet to all rural residents in Kingston.

5.2.7 Valuation of gain in consumer surplus

Using the WTP estimation results along with the Internet plan characteristics presented in Table 5-1 above, the project team estimated the NPV of the gain in consumer surplus over a 20 year period that would result from expanding access to FTTP internet to all of rural Kingston. This estimation relies on some of the same assumptions that informed the FTTP network CAPEX cost estimation in Section 4. For completeness, those assumptions are included here:

- The analysis considers a 20 year time period, with an annual rate of 8.3% applied to discount the value of capital (Damodaran, 2019).
- The number of last-mile connections is estimated based on the number of rural civic addresses in the City of Kingston's civic addresses dataset, Kingston's projected annual population growth rate of 0.5% and an average of 2.39 persons per housing unit over a 20 year period (Watson, 2019).
- It will take five years for the expansion to be completed. In each year, one fifth of the required infrastructure is installed in one of five 'Expansion Zones.'
- In each Expansion Zone, 40% of civic addresses subscribe to FTTP in the first year of access in that expansion zone, after which the take rate increases by 10% per year up to a maximum of 80%.
    - In Year 1, Expansion Zone 1 gains access to FTTP, and 40% of addresses in Expansion Zone 1 subscribe to FTTP.
    - In Year 2, Expansion Zone 2 gains access to FTTP, 40% of addresses in Expansion Zone 2 subscribe to FTTP, the rate of FTTP subscription in Expansion Zone 1 increases to 50%.
    - This continues until 80% of the addresses in all five Expansion Zones subscribe to FTTP, and the remaining 20% have access to FTTP but have opted out of subscribing.
- In each Expansion Zone there are three population segments:

- Segment A - Residents without access to FTTP (limited options environment)
- Segment B - Residents with access to FTTP who opt out of subscribing to FTTP (full options environment)
- Segment C - Residents with access to FTTP who subscribe to FTTP (full options environment)

A consumer's WTP for an Internet package depends partly on what is available to that consumer in the market. The DCE assumes that a full range of Internet service packages, from low-quality DSL to high-quality FTTP, is available to the survey respondent. However, as has been shown in the gap analysis, the reality is that many residents of Kingston do not have access to a full range of Internet service package options. These people fall into 'Segment A' of the population defined above. For consumers in Segment A, low-quality Internet service is better than no Internet service, and their WTP is higher than what the WTP estimates predict. For example, the average price paid in rural Kingston (limited options environment) for a 'Basic Internet' package offering 10 Mbps download, 2 Mbps upload and 100 GB data limit is $78.50 per month. The WTP analysis estimates that Kingston residents' average WTP for Basic Internet (in a full options environment) is $48.32 per month. However, since the average consumer in Segment A is paying $78.50 in rural Kingston, her WTP for Basic Internet must be at least $78.50 per month. Since the true average WTP of consumers in Segment A cannot be estimated from DCE (which simulates a full options environment), the average price paid for Basic Internet ($78.50) in Segment A is used as a conservative estimate of the WTP for Basic Internet in Segment A.

Segments B and C of the population represent environments in which all Internet service options are available to residents. As such, the WTP estimates are representative of residents in these population segments. Table 5-2 summarises the characteristics of each population segment that were used to estimate the gain in consumer surplus.

Table 5-2: Characteristics of rural broadband population segments

Broadband service	Environment	WTP (2019 CAD)	Source of WTP estimate	Average monthly price (2019 CAD)
Basic 10 Mbps download, 2 Mbps upload, 100 GB data capacity	Limited options	$78.50	Residential survey	$78.50
	Full options	$48.32	WTP analysis	$48.32
FTTP 1000 Mbps download, 1000 Mbps upload, 1000 GB data capacity	Full options	$142.01	WTP analysis	$142.01

The net gain in consumer surplus per household is an estimate of the extra income that would have to be given to a household to improve its welfare as much as the resulting change in their Internet package (net of any price change). Because the DCE provides relative valuations, a normalization was made so that rural residents experience no change in consumer surplus if they choose to opt out of FTTP once they gain access. The monthly net gain in consumer surplus per household is then multiplied by the number of subscriptions in the population segment (assumes one subscription per household), and the PV of the net gain in consumer surplus is calculated over the anticipated 20 year lifespan of the fibre network.

These representative values were used to estimate the gain in consumer surplus that would result from expanding FTTP service to all of rural Kingston. The method used to calculate the change in consumer surplus per consumer is described in Appendix C. This change in consumer surplus per consumer is then multiplied by the number of consumers in each Expansion Zone, for each population segment, in each year. An annual rate of 8.3% is used to discount the time value of money to its PV (Damodaran, 2019). **The PV of the estimated gain in consumer surplus over 20 years is valued at $88 Million (2019 CAD), or $12,812 per civic address in rural Kingston.** A quick comparison of this value against the PV of the estimated CAPEX required to expand FTTP service to all of rural Kingston shows that the gain in consumer surplus outweighs even the high cost scenario CAPEX ($87 Million). A detailed discussion of the implications of these quantified costs and benefits of FTTP network expansion ensues in Section 6. First, however, the remainder of this section explores some of the additional and external impacts of access to high-quality broadband that are not or might not be embodied in residents' valuation.

5.3 Additional and external impacts of broadband

The value assigned to the benefits to the consumers in this report is based on the private benefits that consumers get from the internet today. The most tangible uses of broadband connectivity for households today are online video streaming and gaming. It is reasonable to expect that the range of activities that require broadband will change over time. Activities such as online education and health will have a greater private value for the consumers (emerging benefits). Such uses of the internet can also come with benefits for society as a whole by reducing the cost of providing free education and public health (external benefits).

However, there are good reasons to believe that the private value of some activities and behaviours enabled by high-quality broadband internet is not embodied in consumers' current preferences for Internet packages. This is because the possibilities enabled by the Internet are constantly evolving, and so consumers may not yet recognize the value of emerging possibilities and factor them into the choices made in the DCE. For example, if a consumer's employer does not allow telecommuting, he may not factor the cost-savings from telecommuting into his WTP for FTTP Internet. If, however, his employer comes to recognize that there are cost-savings to allowing employees to telecommute and begins to allow employees to telecommute, the employee may then factor his personal cost-savings of telecommuting into his choices. The potential impacts on telecommuting of increased access to high-quality broadband and the possible ensuing value to the economy is explored below.

In addition to private impacts that may not be embodied in residents' WTP, there are likely to be external impacts on society resulting from increased access to high-quality broadband that are not captured in individual residents' WTP for Internet. These include external impacts on the wellbeing of society that could arise from the digitization of healthcare, education, government services and other activities of day-to-day life. Some of these potential external impacts were explored in the Literature Review for this project, and they constitute potential additional economic value that is also discussed below.

5.3.1 Impact on telecommuting

One of the opportunities presented by increased access to high-quality broadband Internet is the potential it creates for telecommuting. The potential benefits of increased telecommuting include cost savings for telecommuters, decreased greenhouse gas (GHG) emissions, cost savings for businesses that employ telecommuters, and decreased traffic on Kingston's roads. Due to limitations in available data, this section considers only the first two of these potential sources of benefits.

In order for the benefits of telecommuting to be attained as a result of increased access to high-quality broadband Internet, three conditions must be met:

1. Expanding access to high-quality broadband Internet must lead to an increase in telecommuting;
2. The decrease in distance travelled by cars to work must be greater than any increase in distance travelled by those same cars for other purposes.
3. Any costs associated with transitioning from conventional commuting to telecommuting must not exceed the value of the benefits.

Among households with no telecommuters only two survey respondents cited an insufficient Internet connection as the main barrier to telecommuting (Figure 5-3 above). Analysis of the survey responses shows no significant relationships between whether or not any members of a household telecommute and the household's home Internet plan characteristics (download speed, upload speed, and latency). There are a few possible explanations for this observation. One is that the sample size is simply too small to detect any significant relationships. Another is that, based on the comparison shown in Figure 2-6, households with low purchased Internet download speeds (< 16 Mbps) may be under-represented in the survey sample. Yet another possible explanation is that people who need to telecommute tend to choose to live in places where they know the available

Internet services will meet their telecommuting needs. A third possible explanation is that, even where available Internet plans are relatively slow and unreliable, the service still fulfills most of telecommuters' current needs.

While an insufficient Internet connection was rarely cited as the most significant barrier to telecommuting, the majority of households with no telecommuters stated that the main barrier to telecommuting is that their work does not allow them to do so. If, as a result of expansion of FTTP Internet infrastructure in Kingston, some employers decided to allow some employees to telecommute, it is possible that these employees might gain additional benefits not currently factored into their WTP.

5.3.1.1 Telecommuter Surplus

A paper written by Dr. Helen Hambly (Hambly & Lee, 2018) estimates the private benefits of telecommuting, referred to as 'telecommuter surplus.' Using the results from the residential survey data from this project, the methodology used by Dr. Hambly was applied to estimate the telecommuter surplus for residents of Kingston.

The benefit side of telecommuter surplus is derived through two mechanisms - vehicular savings by spending less money on gas, and increased productivity by spending less time commuting. To calculate these benefits, the residential survey asked respondents to report how many people in the household regularly telecommute, how many full and partial days per week each person telecommutes, and how many kilometres of driving the household avoids each week through telecommuting. The survey also makes sure to distinguish between people who do and don't normally commute by car to work. Only people who normally drive to work are included in the calculation of savings through reduced spending on gas. Both people who do and people who don't normally drive to work are included in the calculation of increased productivity resulting from less time spent commuting. It is assumed that only full-day telecommuting produces telecommuter surplus.

75 residents from 54 different households were reported to avoid a total of 9,751 km of driving per week by telecommuting. This is an average of 130 km avoided per telecommuter per week. Assuming the cost of driving a midsize car in Ontario is $0.68 per km (CAA, 2019) and that there are 46 work weeks in a year (a guess) then the average annual vehicular savings from not driving per telecommuter can be calculated as:

$$\textit{Total vehicular savings from not driving} = \frac{0.68 \times 46 \times 9{,}751}{75} = \$4,067$$

In addition to the 75 residents that avoid driving km by telecommuting, 54 residents from 39 households were reported to telecommute but not normally drive to work. These residents do not stand to gain any telecommuter surplus through vehicular savings, but they do stand to gain from increased productivity resulting from less time spent commuting. Among the 129 residents (75 regular drivers and 54 regular non-drivers) who could gain by increased productivity, a total of 409 full and partial telecommuting days per week are reported. This gives an average of 3.2 days per telecommuter. Evening telecommuting is not counted towards productivity gain, because it is assumed that most people who telecommute in the evening would not normally return to work in the evening. This assumption may not be valid if any respondents who typically work night shifts interpreted 'evenings' as their regular shift, but since many shift working jobs are hands-on in nature it is safe to assume that telecommuting is not yet an option for many of these workers anyway.

If the average hourly wage is $26.92 (Statistics Canada, 2019) and this is a valid measure of the opportunity cost of time, and the average time spent commuting is 38 minutes per day (based on a median one-way commute time of 19 minutes from the *City of Kingston 2008 Household Travel Survey* data for both car and non-car commute travel), then the annual productivity savings from not commuting per telecommuter is:

$$\textit{Total productivity savings from not commuting } 26.82 \times \frac{38}{60} \times 46 \times \frac{409}{129} = \$2,486$$

The average annual cost of an annual Internet subscription reported in the residential survey is $875. Subtracting this amount from the previously-calculated benefits yields the average annual telecommuter surplus:

$$\textit{Average annual telecommuter surplus per telecommuter } = \$4,067 + \$2,486 - \$875 = \$5,678$$

This estimate of telecommuter surplus falls well below the estimated range of telecommuter surplus amounts calculated by Hambly for Southwestern Ontario ($13,956 - $20,568). This is not surprising, since the area covered by Hambly's study is much larger than Kingston and is closer to Toronto, which is a much larger employment market than Kingston. Hambly's study focused only on rural telecommuters, whereas the estimated telecommuter surplus for Kingston calculated here accounts for both urban and rural telecommuters. Presumably, urban telecommuters would have a shorter conventional commute than rural telecommuters, which would bias the estimated commute time downwards relative to the rural-only average commute time.

5.3.1.2 GHG Avoidance

If workers in Kingston telecommute more, and any subsequent increase in non-work driving distance is less than the decrease in commuting driving distance, there will be a reduction in GHG emissions as a result of telecommuting. Using the reported driving distance avoided by telecommuting from the residential survey, 46 weeks of work in a year and a value of 176 g CO2 per kilometre of driving[31] (Natural Resources Canada, 2019), estimates of GHG avoidance from telecommuting were calculated and are summarised in Table 5-2. Note that numbers do not add up perfectly in all cases due to rounding.

[31] This is the reported emissions for the Honda Civic, which was the car with the highest sales in Canada in 2018 and is thus selected as a representative car for the calculations.

Table 5-2: Estimates of GHG avoidance from telecommuting

Measure	All	Rural	Urban
Number of households in Kingston[32]	53,518	5,782	47,736
% of surveyed households that avoid driving by telecommuting	17% (54/312)	28% (13/46)	15% (41/266)
Average number of km avoided per week	180	164	186
Total yearly avoided tons CO2 from telecommuting among surveyed households	87	19	68
Household average yearly avoided tons CO2 from telecommuting	1.6	1.5	1.7
Total yearly avoided tons CO2 from telecommuting among all households in Kingston	14,557	2,428	12,173

5.3.2 External impacts

As the infrastructure for day-to-day needs such as healthcare, education and government services becomes increasingly digitized, citizens will become more heavily reliant on high-quality broadband Internet for a broader array of day-to-day activities. This increase in the value of the high-quality broadband Internet to consumers will be reflected in an increase in consumers' WTP for high-quality broadband Internet over time. However, there are many potential external impacts of providing residents, businesses and institutions with access to these online activities, the value of which will not be embodied in consumers' WTP. The Literature Review for this project explored some of the potential external impacts of access to broadband Internet on health and education outcomes.

This project did not collect data to quantify such external impacts specifically within the context of Kingston. To keep the residential survey short enough that residents would be willing to complete it, and to limit the level of sensitivity of the collected data, the residential survey did not ask participants for detailed information about online education and healthcare activities. Instead, the survey asked simply whether or not participants use their home Internet for online education and health activities. 124 respondents (40%) report using their home Internet for online education, and 32 respondents (10%) report using their home Internet for online healthcare services.

It is a complex task to assign causality of, for example, decreased healthcare costs or improved education outcomes to having access to a high-quality broadband Internet

[32] There are 6870 civic addresses in rural Kingston, based on the shapefile from the City of Kingston's Open Data Portal. However, this shapefile doesn't distinguish between residential and non-residential civic addresses. For the CBA, the number of civic addresses is used to estimate the number of subscriptions (since non-residential addresses are also possible sources of Internet subscriptions). For the telecommuting calculations, the calculation uses the number of households.

connection at home. If such causality exists, then the expansion of FTTP broadband coverage to Kingston's currently underserved areas offers even greater value than what has been quantified in this report. This possibility is further discussed in the following section.

6. Cost Benefit Analysis and the case for public intervention

The previous two sections of the report have presented estimates of the costs and benefits of expanding FTTP broadband service coverage to Kingston's rural underserved areas. These sections also discussed the costs and benefits that this study has not quantified but that are important to consider when deciding how best to close the digital divide. Table 6-1 provides a concise summary of these key costs and benefits.

Table 6-1: Summary of estimated costs and benefits of FTTP network expansion over 20 years

Costs and Benefits		Estimated NPV (2019 CAD)
FTTP network CAPEX	High estimate	**$87 Million**
	Mid-range estimate	**$40 Million**
	Low estimate	**$23 Million**
Change in FTTP network OPEX		**?**
Change in TSP revenue		**?**
Change in consumer surplus		**$88 Million**
Emerging benefits		**?**
External benefits		**?**

There are three critical questions that the numbers in Table 6-1 cannot answer. They are:

1. Will the private market close the digital divide in Kingston on its own?
2. If the answer to Question 1 is 'no,' is government intervention (subsidy) justified to incentive TSPs to close the digital divide in Kingston?
3. If the answer to Question 2 is 'yes,' what level of government intervention (subsidy) creates a viable business case for TSPs to close the digital divide in Kingston?

To answer these three questions, the project team conducted a Cost Benefit Analysis (CBA) to look at the financial feasibility of FTTP network expansion from the perspective of TSPs, rural residential Internet users, the government, and the overall economy. First, however, some important context on the structure of the Internet market in Kingston is offered below.

6.1 CBA methodology

The CBA model considers two benefit streams, two cost streams and one transfer between stakeholders. Table 6-2 shows how these capital streams distributed among the stakeholders in the CBA model.

Table 6-2: Distribution of impacts among stakeholders in CBA model

Capital streams	TSPs	Rural Consumers	Government	Economy
B1 - Incremental consumer surplus		✓		✓
B2 - Incremental TSP revenue	✓			✓
C1 - CAPEX	✓			✓
C2 - Incremental OPEX	✓			✓
T1 - Government subsidy	✓+		✓-	

The CBA considers two different 'business-as-usual' scenarios, from the perspective of two types of TSPs. The first scenario is a 'brownfield' expansion, which applies to an incumbent TSP that currently provides broadband service over an existing, non-FTTP network in rural Kingston. The second scenario is a 'greenfield' expansion in which a new TSP enters the market and builds a network where it previously did not provide service. The only capital streams that change in the brownfield versus greenfield scenario are the incremental revenue collected by TSPs and the incremental OPEX incurred by TSPs[33]. The methodology used to estimate each capital stream under the two scenarios is described in detail below.

Benefit 1 (B1): The methodology used to calculate incremental consumer surplus was described above in Section 5.2.8 with more technical details in Appendix B, but is summarised here for convenience. The incremental consumer surplus is calculated for three population segments:

- Segment A - Residents without access to FTTP (limited options environment)
- Segment B - Residents with access to FTTP who opt out of subscribing to FTTP (full options environment)
- Segment C - Residents with access to FTTP who subscribe to FTTP (full options environment)

[33] In the greenfield scenario, the TSP initially earned no revenue in the target areas. Therefore, in the greenfield scenario, incremental revenue is equal to the total revenue earned from the FTTP network. Since OPEX is estimated as a percentage of revenue, incremental OPEX is also higher in the greenfield scenario than in the brownfield scenario.

The net gain in consumer surplus per household is an estimate of the extra income that would have to be given to a household to improve its welfare as much as the resulting change in their Internet package (net of any price change). Because the DCE provides relative valuations, a normalization was made so that rural residents experience no change in consumer surplus if they choose to opt out of FTTP once they gain access. The monthly net gain in consumer surplus per household is then multiplied by the number of subscriptions in the population segment (assumes one subscription per household), and the NPV of the net gain in consumer surplus is calculated over the anticipated 20 year lifespan of the fibre network.

Benefit 2 (B2): The incremental revenue collected by TSPs over the FTTP network lifespan is calculated by taking the difference between estimated revenue with FTTP network expansion, and estimated revenue without FTTP expansion, for each population segment in each year of the FTTP network lifespan. In the greenfield scenario, revenue without FTTP expansion is $0 (since the TSP does not provide service in the target expansion area), so incremental revenue is equal to total revenue collected from the FTTP network expansion. To demonstrate the incremental revenue in the brownfield scenario, consider in Year 1 of the network expansion:

- Segment A - 5,507 households are left without FTTP access in Year 1. These households paid $78.50 for Basic Internet before this year, and they still pay $78.50 for Basic Internet this year. Therefore, incremental ARPU from Segment A in Year 1 (and all other years) is $0.
- Segment B - 826 households gained access to FTTP, but opted out of subscribing. These households paid $78.50 for Basic Internet before this year, but now that FTTP is available their TSPs have lowered the price of Basic Internet service to $48.32 (the average WTP for Basic Internet) to incentivise people to stay with Basic Internet.[34] The incremental ARPU is therefore $48.32 - $78.50 = -$30.18, so the incremental

[34] In reality, this would likely depend on how many TSPs are in the area. If there is initially only one provider in the area charging $78.50 for Basic Internet, and that same provider builds out the FTTP network, the provider doesn't have to worry about consumers switching to a different provider offering a new, lower price for Basic Internet. In this case, the sole TSP would continue to charge $78.50 for Basic Internet.

One the other hand, if two TSPs serve the area with Basic Internet at $78.50, and one of the TSPs installs a FTTP network, the other TSP might drop the price of Basic Internet to incentivise its customers to stay with Basic Internet rather than switching to FTTP from the other provider. In that case, the FTTP provider would also have to drop the price of its Basic Internet service to keep that product competitive with the second TSP's equivalent offering.

What this means for the analysis is that the estimated incremental revenue is conservative, because it assumes the worst case scenario for TSPs collectively, which is that they are required to drop their prices for Basic Internet service.

revenue from Segment B in Year 1 is -$30.18/ household/ month * 826 households * 12 months = -$299,189.

- Segment C - 551 households subscribe to FTTP. These 551 households originally paid $78.50/ month for Basic Internet, and are now paying $142.01/month for FTTP Internet. The incremental ARPU for these households is $142.01 - $78.50 = $63.51, so the incremental revenue from Segment C in Year 1 is $63.51/ household/ month * 551 households * 12 months = $419,745.

The total incremental revenue in Year 1 is therefore $419,745 - $299,189 = $120,565.

Cost 1 (C1): The methodology used to estimate the CAPEX required for FTTP network was described above in Section 4 with technical details in Appendix A, but the key assumptions are repeated here in brief for convenience:

- The analysis considers a 20 year time period, with an annual rate of 8.3% applied to discount the value of capital (Damodaran, 2019).
- Access fibre costs assume a 70%/30% split between overhead and underground fibre installation, except for the low-cost scenario which assumes all access fibre is aerial.
- The number of last-mile connections is estimated based on the number of rural civic addresses in the City of Kingston's civic addresses dataset, Kingston's projected annual population growth rate of 0.5% and an average of 2.39 persons per housing unit over a 20 year period (Watson, 2019).
- It will take five years for the expansion to be completed. In each year, one fifth of the required infrastructure is installed in one of five 'Expansion Zones.'
- In each Expansion Zone, 40% of civic addresses subscribe to FTTP in the first year of access in that expansion zone, after which the take rate increases by 10% per year up to a maximum of 80%.
    - In Year 1, Expansion Zone 1 gains access to FTTP, and 40% of addresses in Expansion Zone 1 subscribe to FTTP.
    - In Year 2, Expansion Zone 2 gains access to FTTP, 40% of addresses in Expansion Zone 2 subscribe to FTTP, the rate of FTTP subscription in Expansion Zone 1 increases to 50%.
    - This continues until 80% of the addresses in all five Expansion Zones subscribe to FTTP, and the remaining 20% have access to FTTP but have opted out of subscribing.

Cost 2 (C2): As described in Section 4, OPEX is calculated as a percentage of annual revenue. In the greenfield scenario, initial revenue is $0, so incremental OPEX is simply calculated as 60% of revenue earned from the FTTP network. In the brownfield scenario, the change in OPEX as a percentage of revenue cannot be accurately estimated, but it is expected that the FTTP network will bring operational efficiencies that lower OPEX relative to the existing network. For the purposes of this report, OPEX is set as 60% of revenue both before and after FTTP network expansion in the brownfield scenario, which is conservative under the theory that OPEX would actually decrease, because in this case OPEX is strictly a function of revenue.

Transfer 1 (T1): The subsidy or grant provided by the government to TSPs is simply calculated as a percentage of the CAPEX required to build FTTP Internet infrastructure in rural Kingston.

Up to this point a number of assumptions have been declared, and these are parameters that can be modified in the future as more data becomes available. It is important to note that the CBA takes as inputs outputs from the WTP analysis and residential survey summary statistics, but these values are not necessarily generalizable to the City of Kingston's entire population for reasons discussed in Section 2.1.2. As such, the results of the CBA should not be interpreted as precise estimates but rather as best-effort approximations given the limitations of the available data.

6.2 CBA results

The CBA results are presented in this section, answering each of the above-listed critical questions.

6.2.1 Will the private market close the digital divide in Kingston on its own?

If the private market is going to close the digital divide in Kingston on its own (i.e. without government intervention), there must be a viable business case for TSPs to build and operate a FTTP network in rural Kingston. The CBA models the business case by comparing the incremental[35] revenue generated from the FTTP network to the Total Cost of Ownership (TCO), which is the costs required to build and maintain the network.

6.2.1.1 Brownfield scenario

Figure 6-1 shows the incremental annual, undiscounted net cash flows, or Earnings Before Income Tax, Depreciation and Amortization (EBITDA) of the TSP in each year of the network's lifespan. Figure 6-2 shows the cumulative Present Value (PV) of the TCO in the high, mid-range and low cost scenarios over the FTTP network's lifespan, along with the cumulative PV of incremental revenue collected over the same time period. The results show that, while the FTTP network will become relatively more profitable on an annual basis than the existing infrastructure within seven to nine years (Figure 6-1), TSPs will not break even on the investment in FTTP network infrastructure even in the low cost scenario (Figure 6-2).

[35] The word 'incremental' is used to mean 'relative to the status quo situation.' In other words, the revenue streams presented in this section are not the total amount of revenue TSPs collect during the FTTP network lifespan, but rather how much more (or less) revenue they will collect during the FTTP network lifespan than they would have collected if the status quo was maintained.

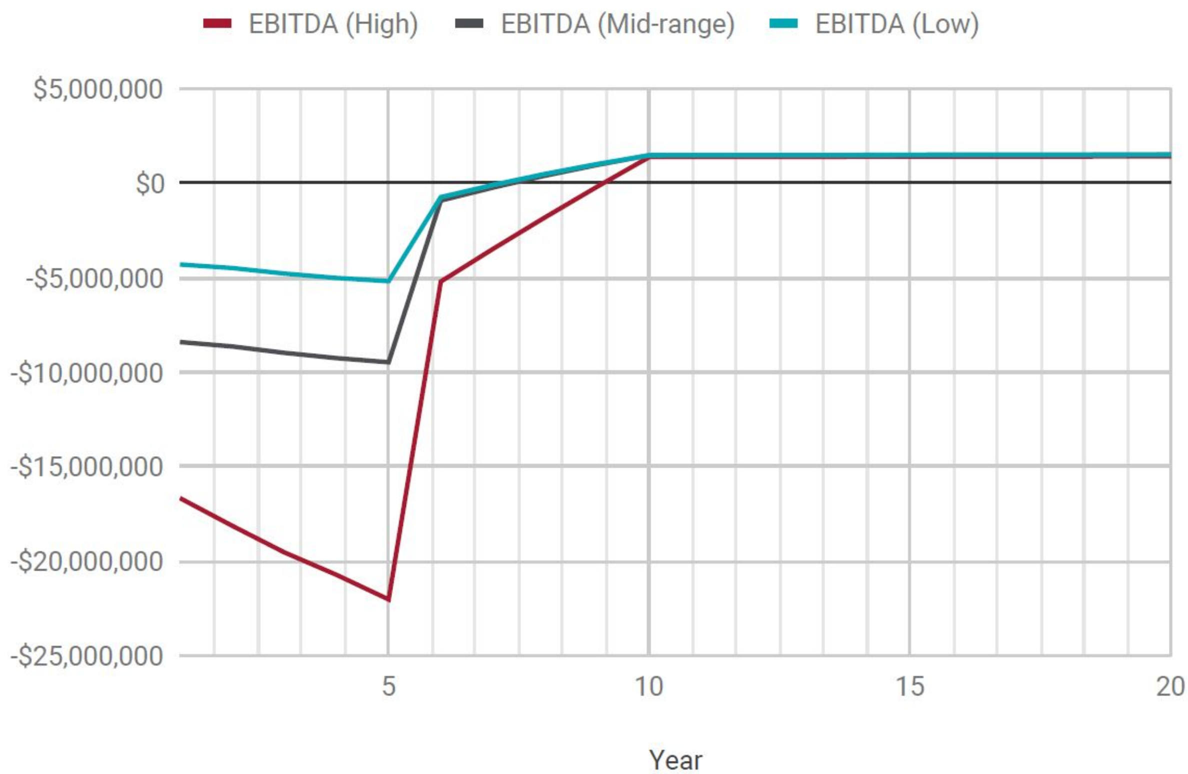

Figure 6-1: Incremental annual EBITDA over brownfield FTTP network lifespan

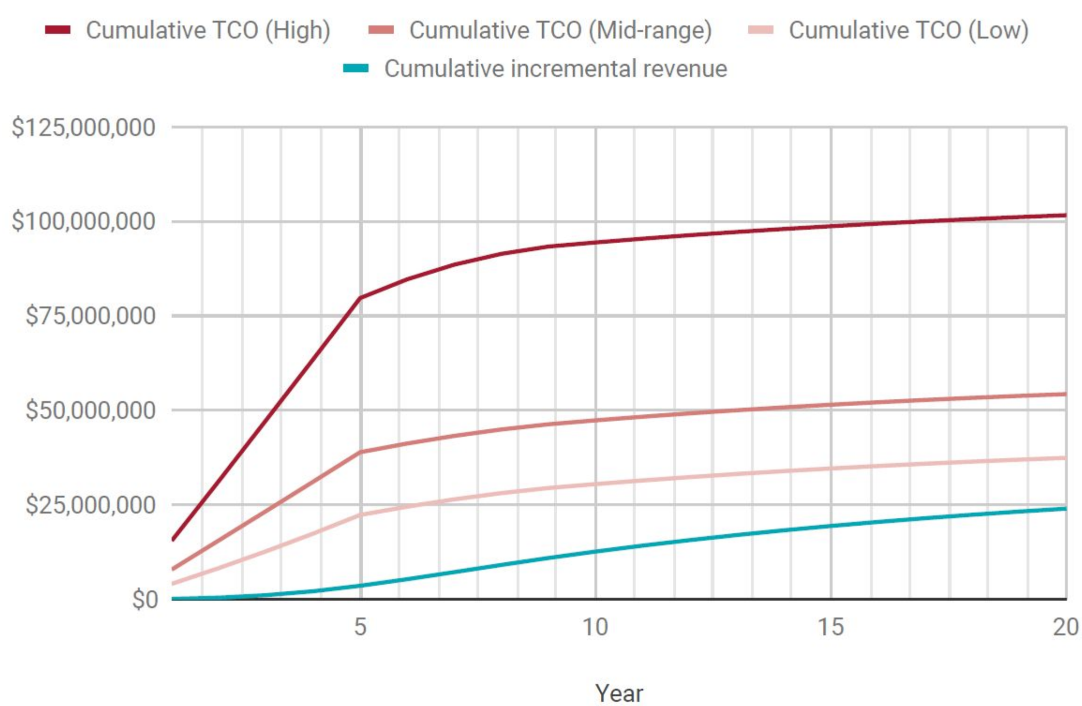

Figure 6-2: Cumulative TCO and incremental revenue over brownfield FTTP network lifespan

6.2.1.2 Greenfield scenario

The greenfield scenario is slightly more viable than the brownfield scenario. As shown in Figures 6-3 and 6-4, the greenfield FTTP network becomes profitable within 6 to 8 years, and the TSP would break even on the investment in year 16 of the network's lifespan, in the low cost scenario.

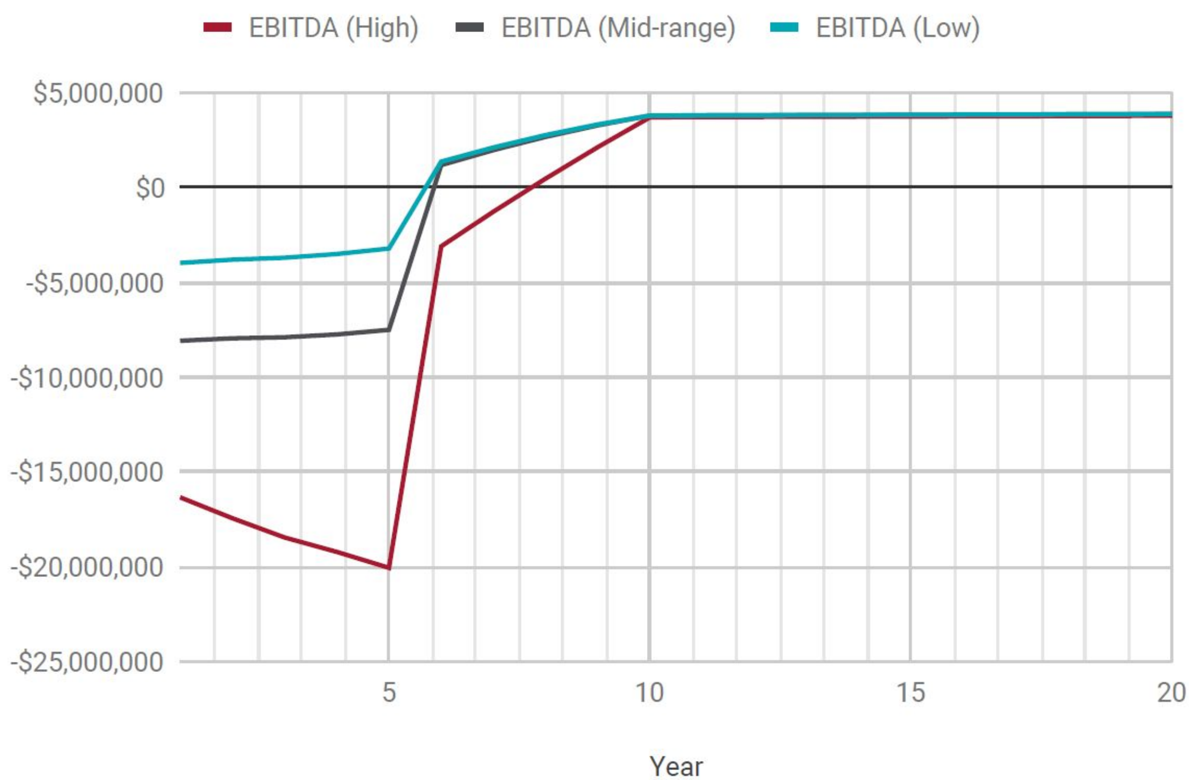

Figure 6-3: Incremental annual EBITDA over greenfield FTTP network lifespan

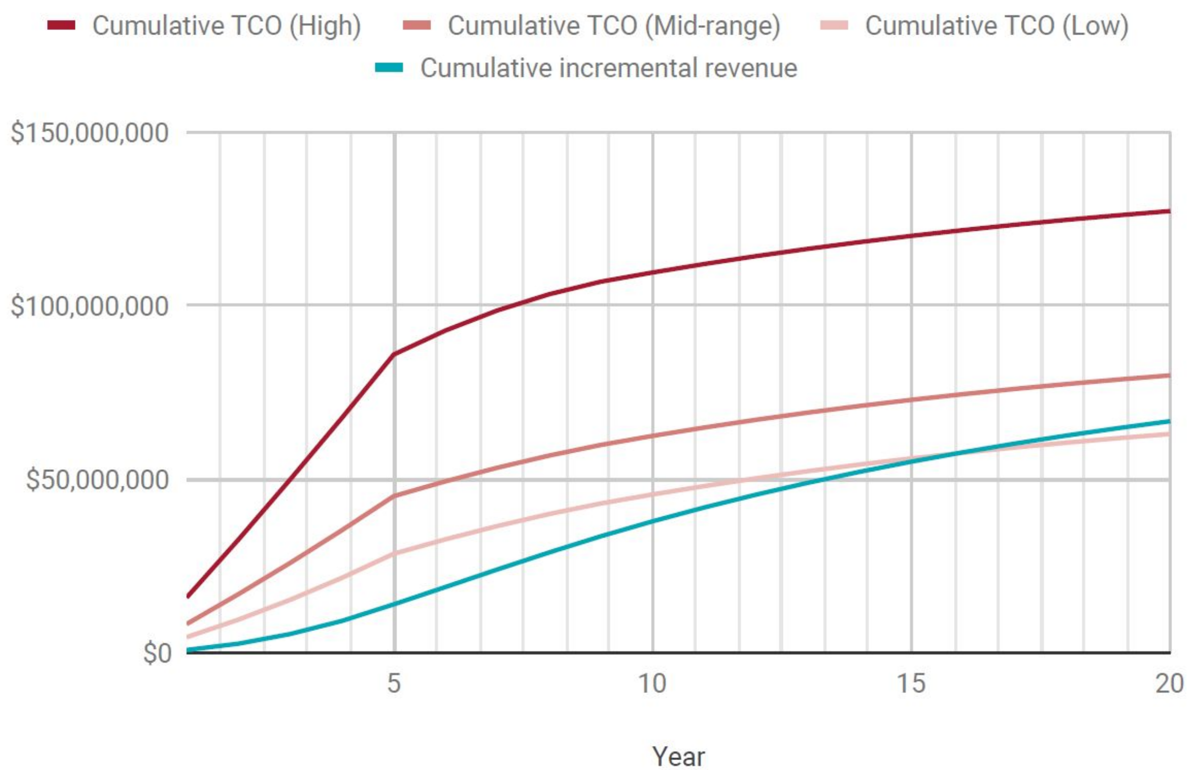

Figure 6-4: Cumulative TCO and incremental revenue over greenfield FTTP network lifespan

The results of both the brownfield and greenfield scenario analyses confirm what might be expected based on the findings of the gap analysis - there is no business case for TSPs to invest in building out FTTP infrastructure in Kingston's rural areas. These findings echo a conclusion made in a 2015 analysis conducted by RBC Capital Markets:

> **"Population density by neighbourhood will be a key determinant of the type of returns generated on FTTH. The ability to amortize the relatively fixed cost of FTTH deployment in any given area over a higher number of premises naturally lowers the cost per premise and should improve returns (all else being equal). For less dense rural areas, FTTH is unlikely to payout and thus telecom operators are better off deploying wireless technologies, such as satellite, fixed-wireless and/or LTE/5G wireless in these areas of the total footprint."**
>
> - ***Telecom Scenario Report, RBC Capital Markets, August 2015.***

RBC's report also observes that rapid investment in FTTP throughout the sector would reduce TSPs' valuation, and suggests that FTTP deployment should proceed at a 'measured pace' to avoid strategic and financial instability within the market. While a 'measured pace' of FTTP deployment may benefit TSPs' bottom lines, this approach will allow the digital divide to persist and widen as high density, high income areas are prioritized over low density, low income areas.

6.2.2 Is government intervention justified?

This question is simpler to answer than the previous. The short answer is 'yes' - government intervention to create a viable business case for FTTP network expansion to rural Kingston is justified. The justification comes from the fact that the CBA shows there is an overall net benefit to the economy over 20 years as a result of FTTP expansion to Kingston's rural areas. Table 6-3 shows this overall net benefit, and how the value streams are distributed amongst the key stakeholders in the economy in the worst case (high cost, brownfield expansion) scenario. In reality, there would likely be other stakeholders (private investors, contractors etc.) and other capital streams (taxes etc.), but these stakeholders and capital streams are excluded from this analysis.

Table 6-3: Worst case CBA results (2019 CAD)

Value streams	TSPs	Rural Consumers	Economy
Benefit to consumers		$88 Million	$88 Million
Benefit to service providers[36]	$23 Million		$23 Million
TCO of FTTP network	-$101 Million		-$101 Million
Net Impact	-$77 Million	$88 Million	$10 Million

6.2.3 What level of government intervention will create a viable business case?

Given that:

- TSPs are not likely to further invest in expanding FTTP infrastructure to cover all of rural Kingston on its own any time soon; and
- government intervention is justified by anticipated overall benefits to the economy resulting from FTTP network expansion;

The final question that must be answered is: What level of government intervention will create a viable business case for TSPs to close the digital divide separating Kingston's rural and urban areas? To answer this question, a decision making criterion or criteria is/are needed to determine whether or not a business case is to be considered 'viable.' Each company has its own policies to guide investment decisions. Table 6-4 shows what percentage of the CAPEX would need to be covered by government funding to achieve a specific payback period within the range of three to eight years under each cost scenario.

[36] Service providers benefit from increased revenue

Table 6-4: Percentage of CAPEX subsidized to achieve payback period (ARPU = $142)

Payback period (years)	Greenfield			Brownfield		
	High	Mid	Low	High	Mid	Low
3	77%	67%	55%	89%	85%	79%
4	75%	64%	51%	88%	83%	76%
5	73%	60%	47%	86%	80%	73%
6	70%	56%	41%	84%	77%	69%
7	67%	52%	36%	82%	74%	65%
8	65%	48%	31%	80%	71%	62%

The results show that in order to bring the payback period for service providers to 5 years, the government needs to subsidize just under half of the CAPEX in the best-case scenario and almost 90% of the CAPEX in the worst-case scenario.[37] However, it is critical to remember here that this analysis takes conservative measures of costs (high) and benefits (low). The value of subsidy needed, as reported by this study, is therefore the highest it will ever need to be for any given payback period.

Government subsidy can be implemented in different shapes and must be coupled with regulatory mechanisms that sets standards for service quality and prices. A detailed discussion of the industrial organization aspects of the broadband market is beyond the scope of this study. However, such a study would be required for the design of the regulatory policies to accompany the subsidy.

[37] The Frequently Asked Questions page of the Connect to Innovate (CTI) fund website states that 'Typically the maximum amount of funding that an applicant could request for new backbone and new last-mile was up to 75% of the total eligible costs'. The Application Guide for the Broadband Fund does not stipulate a limit on the percentage of a project that is eligible for funding.

7. Conclusion

High-quality broadband Internet is an increasingly valuable service, and ensuring equitable and universal access to high-quality broadband Internet within the City of Kingston will have positive effects on the economy. The definition of high-quality broadband is often over-simplified by policy makers, resulting in broadband connectivity targets that will not meet the current and future needs of Internet users. Broadband Internet should be seen as a spectrum of quality along which different network architectures can be categorized from 'poor' to best.' FTTP is the best broadband architecture available, and the only architecture capable of providing service that will meet society's current and future fixed broadband needs.

Across Canada, there is a 'digital divide' in access to high-quality broadband Internet. One dimension in which the digital divide can be categorised is between rural areas and urban centres. On average, Kingston's rural households pay more money for lower-quality Internet service. Moreover, the digital divide separating Kingston's rural and urban areas appears to have widened over the past five years.

The estimated cost of providing all of rural Kingston with the infrastructure required for FTTP broadband service ranges from $23 Million to $87 Million (2019 CAD). A conservative estimate of the value of access to FTTP broadband for Kingston's rural residents is $88 Million (2019 CAD). Conservative estimates from a Cost-Benefit Analysis show that expanding FTTP infrastructure to cover all of rural Kingston will result in a net benefit to the overall economy over a 20 year period.

Despite the positive implications that FTTP expansion would have for Kingston's rural residents and overall economy, TSP are not likely to further expand FTTP network coverage to all of rural Kingston in the near future because there is no business case for them to do so. Without public intervention, the gap will continue to exist and will expand over time. Therefore, there is a case for public intervention to provide the subsidies needed for equitable access to high-quality broadband Internet connectivity.

7.1 Knowledge gaps

Existing knowledge gaps impose limitations on the comprehensiveness and accuracy of the results of this study. Continued efforts to obtain information from TSPs about their infrastructure and service coverage and pricing would help increase the focus and accuracy of the model's estimates. Another previously discussed knowledge gap stems from the constantly-evolving nature of society's use of the Internet. This study did not attempt to place an economic value on emerging or less tangible benefits to society. However, it is worth observing that the benefits estimated by the model represent a lower bound to the true benefits that society might expect to obtain from expanded access to high-quality broadband Internet.

To design and implement a public intervention to improve connectivity for rural Kingston, an analysis of the market is necessary to understand how service providers will react to alternative incentive structures. The high investment cost associated with the provision of high-quality broadband Internet results in the existence of market power (such as monopoly and oligopoly).

7.2 Next steps

This study paves the path for a number of follow-up activities that are listed below.

- Continued data collection from residents and businesses can help improve understanding of access and affordability gaps among subgroups based on income or other characteristics (beyond rural-urban).
- The findings of this study, and any future expansions, contain valuable information for the public. Such information can inform the choice of service provider or place of residence for consumers. It is therefore recommended to establish ongoing two-way engagement with the public through an interactive online portal.
- If data collection from consumers becomes an ongoing effort (e.g. through a web-based portal), future studies can monitor how Internet usage evolves over time, allowing the analysis to capture new sources of benefits.
- Data from service providers can improve the accuracy of the cost estimates and identify underserved areas at a more granular level. This will help identify where it makes the most economical sense to begin building out fibre optic facilities in rural areas by building off of existing infrastructure, and the phases of the build out can be mapped to specific areas. The City should therefore continue to work with TSPs, the CRTC, ISED and others to obtain this information.
- A theoretical market model can help the industry better understand the incentive structure and the behaviour of TSPs in alternative settings such as rural and urban. Such an understanding will help policymakers replicate the results of this study in similar contexts.

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Appendix A: FTTP network CAPEX unit costs

This Appendix presents the unit costs that were provided by Utilities Kingston, Cogeco and WTC to establish the cost estimates for the high, mid-range and low cost scenarios.

High cost scenario

Utilities Kingston provided unit costs for access and last-mile FTTP Active Ethernet network infrastructure, which are presented in Tables A-1 to A-4 below.

Table A-1: Access fibre per km (overhead)

Description	Number per Km.	Unit Price	Cost
Lashing fibre cable	1000.00	$ 3.50	$ 3,500.00
Overlashing on existing strand and cable	500.00	$ 4.25	$ 2,125.00
New Steel Strand, 5 mm.	1000.00	$ 5.00	$ 5,000.00
Install new Steel Strand and Hardware	500.00	$ 3.00	$ 1,500.00
Anchor	2.00	$ 130.00	$ 260.00
Install Anchor	2.00	$ 275.00	$ 550.00
Down-Guy - Standard	2.00	$ 125.00	$ 250.00
Install Down-Guy	2.00	$ 200.00	$ 400.00
Install 4" U-Guard	2.00	$ 100.00	$ 200.00
Install 66" x 6" Anchor	2.00	$ 275.00	$ 550.00
Install Rock Anchor	2.00	$ 275.00	$ 550.00
Make Ready per pole[38]	3.00	$ 5,000.00	$ 15,000.00
Install Bonds	3.00	$ 150.00	$ 450.00
Fibre cable (48-strand, including loop backs)	1100.00	$ 4.00	$ 4,400.00
Rail Crossing permit	0.25	$ 3,000.00	$ 750.00
Supply splice enclosure	0.25	$ 620.00	$ 155.00
Splice set up, prepping cables etc.	48.00	$ 20.00	$ 960.00
Fusion splice	48.00	$ 19.00	$ 912.00
Bi-directional OTDR testing	48.00	$ 10.00	$ 480.00
Bi-directional attenuation testing	48.00	$ 10.00	$ 480.00
SSA Permits and Engineering	13.00	$ 1,500.00	$ 19,500.00
Labour	1000.00	$ 2.00	$ 2,000.00
Trucking	1000.00	$ 1.00	$ 1,000.00
		Subtotal Cost	**$ 60,972.00**

[38] Pole span are 75 metres apart = 13 poles per 1,000 metres

Table A-2: Access fibre per km (underground)

Description	Number per Km.	Unit Price	Cost
Rod and rope unoccupied duct	1000.00	$ 2.50	$ 2,500.00
Pull cable, unoccupied duct	1000.00	$ 2.75	$ 2,750.00
Trenching, good soil	700.00	$ 65.00	$ 45,500.00
Trenching, rock	300.00	$ 185.00	$ 55,500.00
Supply and install 3" duct	1000.00	$ 15.00	$ 15,000.00
Supply and Install Rhino Cabinet	4.00	$ 2,135.00	$ 8,540.00
Fibre cable (48-strand, including loop backs)	1100.00	$ 4.00	$ 4,400.00
Rail Crossing permit	0.25	$ 3,000.00	$ 750.00
Supply and Install Handhole (18"x30"x24")	3.00	$ 700.00	$ 2,100.00
Supply and Install Manhole (36"x60"x50")[39]	3.00	$ 1,500.00	$ 4,500.00
Proof conduit inc. pull string & duct pull	1000.00	$ 7.00	$ 7,000.00
Splice set up, prepping cables etc.	48.00	$ 20.00	$ 960.00
Fusion splice	48.00	$ 19.00	$ 912.00
Bi-directional OTDR testing	48.00	$ 10.00	$ 480.00
Bi-directional attenuation testing	48.00	$ 10.00	$ 480.00
SSA Permits and Engineering	13.00	$ 2,500.00	$ 32,500.00
Labour	1000.00	$ 2.00	$ 2,000.00
Trucking	1000.00	$ 1.00	$ 1,000.00
		Subtotal Cost	**$ 148,540.00**

[39] Handhole vs Manholes would be either/or in reality

Table A-3: Last-mile fibre

Description	Units	Units/Premises	Unit Price	Cost
Rod and rope unoccupied duct	metres	50.00	$ 2.50	$ 125.00
Pull cable, unoccupied duct	metres	50.00	$ 2.75	$ 137.50
Trenching, good soil	metres	35.00	$ 65.00	$ 2,275.00
Trenching, rock	metres	15.00	$ 185.00	$ 2,775.00
Supply and install 1" duct	metres	50.00	$ 15.00	$ 750.00
Fibre cable (2-strand)	metres	50.00	$ 1.50	$ 75.00
Proof conduit inc. pull string & duct pull	metres	50.00	$ 7.00	$ 350.00
Supply Fibre Optic Customer Premises Panel	#	1.00	$ 150.00	$ 150.00
Patch Panel termination	#	1.00	$ 100.00	$ 100.00
Media converters	#	1.00	$ 750.00	$ 750.00
Fibre Optic Pigtails (2 m)	#	1.00	$ 22.00	$ 22.00
Fibre Optic Patchcords (3 m)	#	1.00	$ 85.00	$ 85.00
Supply splice enclosure	#	1.00	$ 620.00	$ 620.00
Splice set up, prepping cables etc.	#	1.00	$ 350.00	$ 350.00
Fusion splice	#	1.00	$ 19.00	$ 19.00
Bi-directional OTDR testing	#	1.00	$ 10.00	$ 10.00
Bi-directional attenuation testing	#	1.00	$ 10.00	$ 10.00
Labour	metres	50.00	$ 2.00	$ 100.00
Trucking	metres	50.00	$ 1.00	$ 50.00
			Unit subtotal cost	**$ 8,753.50**

Table A-4: Point of Presence

Description	Number per POP	Quantity	Unit Price	Cost
Racks[40]	2.00	0	$ 500.00	$ -
Cabinet (incl: HVAC, security system)	1.00	1	$ 20,000.00	$ 20,000.00
UPS	1.00	1	$ 3,600.00	$ 3,600.00
Generator	1.00	0	$ 5,000.00	$ -
HVAC[41]	1.00	0	$ 5,000.00	$ -
Cabinet concrete base	1.00	1	$ 10,000.00	$ 10,000.00
Electricity service installation	1.00	1	$ 10,000.00	$ 10,000.00
Fibre installation	1.00	1	$ 5,000.00	$ 5,000.00
Switch	4.00	1	$ 14,000.00	$ 56,000.00
Security system[42]	1.00	0	$ 5,000.00	$ -
Fibre	4.00	1	$ 2,000.00	$ 8,000.00
Proof conduit inc. pull string & duct pull	1.00	1	$ 7.00	$ 7.00
Supply and install 3" duct	1.00	1	$ 15.00	$ 15.00
Supply Fibre Optic Patch Panel	1.00	1	$ 510.00	$ 510.00
Patch Panel termination	1.00	1	$ 18.00	$ 18.00
Multi-Media Converter Chassis[43]	20.00	1	$ 750.00	$ 15,000.00
Fibre Optic Pigtails (2 m)	20.00	1	$ 22.00	$ 440.00
Fibre Optic Patchcords (3 m)	20.00	1	$ 85.00	$ 1,700.00
			Subtotal Cost	**$ 130,290.00**

The HST rate of 13% was applied to each of the subtotal cost of each component, and a contingency of 15% was added on to the pre-tax subtotal cost as well. Table A-5 summarises the total unit costs that were used to model the cost of the FTTP Active Ethernet network expansion.

Table A-5: Summary of unit costs used to model FTTP Active Ethernet network

Component	Subtotal unit cost	Contingencies	HST	Total unit cost
		15.00%	13.00%	
Access fibre overhead	$ 60,972	$ 9,146	$ 7,926	$ 78,044
Access fibre underground	$ 148,540	$ 22,281	$ 19,310	$ 190,131
Last-mile fibre	$ 8,754	$ 1,313	$ 1,138	$ 11,204
PoPs	$ 130,290	$ 19,544	$ 16,938	$ 166,771

[40] Included in Cabinet
[41] Included in Cabinet
[42] Included in Cabinet
[43] 20 customers per Chassis

Mid-range cost scenario

Cogeco provided estimates that were used for the mid-range cost scenario. For access fibre, estimates of $50 CAD/metre and $75 CAD/metre were given for overhead and underground access fibre respectively. Both of these amounts are assumed to include HST. The overhead access fibre estimate did not include a make ready factor, so the same factor that was provided by Utilities Kingston ($15 CAD/metre) was taxed at 13% and added to Cogeco's estimate, bringing the total estimate for overhead access fibre to $66.95 CAD.

For last-mile fibre, Cogeco's estimates were $50 CAD/metre and $125 CAD/metre for overhead and underground respectively. Again, the overhead estimate does not account for a make ready factor, but it is assumed that any make ready required is included in the access fibre costs. Furthermore, as with the access fibre it is assumed that 70% of final connections will be overhead and 30% will be buried. Using these parameters and assuming an average 50 metre final connection distance, a weighted average final connection cost of $3,625 CAD/premises was used for the mid-range cost scenario.

WTC provided an estimated cost per PON cabinet of $70,000 USD. This estimate includes one GPON card that can serve 256 customers. Each cabinet can house up to five cards, serving up to 1,280 customers. Each additional card costs $10,000 USD. Assuming each cabinet is filled and applying an exchange rate of 1.33 CAD per USD and 13% tax rate, the cost of a PON cabinet was calculated to be $165,319 CAD.

Low cost scenario

WTC provided estimates broken down by rural vs urban setting, rather than access and last-mile. The estimated cost per km to install FTTP is $25,000-$30,000 which includes engineering, conduit, fibre, tracer wire, and vaults for distribution and pulling the fibre through along the way. The low end estimate of $25,000 was used for all access fibre in the low cost scenario. In a presentation by RVA LLC on December 17, 2019, the findings of RVA's 2019 Broadband Provider Study were shared via webinar. During this presentation, a range of $2,500 - $6,000 USD was cited for last-mile FTTP connections in rural areas. The low estimate of $2,500 USD was used for the low cost scenario. The same estimate of $165,319 CAD that was used for the mid-range cost scenario PON cabinet costing was used again in the low-cost scenario.

Appendix B: The Discrete Choice Experiment

To assess consumer's willingness to pay, a discrete choice experiment was designed using four main characteristics: price, download speed, upload speed, and data allowance. There are many other characteristics that consumers may care about that are not commonly listed by Internet service providers. For example, the reliability of an Internet connection, the latency of a connection, or the ability to mark specific downloads as high priority (Rosston et al., 2010; Liu et al, 2018). Only these four basic attributes were used in order to restrict design size as well as the cognitive burden on participants. As seen in Liu et al (2018) not including latency may upwardly bias download speed. Latency was left out as a characteristic due to sample size constraints. Furthermore, since plans by Internet service providers do not generally include latency it can be argued that these plans are more representative of the plans that consumers are choosing over.

The final design has four alternatives, and 24 questions in total, split into four blocks of six. Dominated alternatives (defined as alternatives that were lower in price, with a higher download speed, upload speed, and data allowance) were taken out of the design. Respondents were randomly assigned to blocks, then questions within blocks were randomly shown to respondents to minimize the order effect. The alternative cost given for data allowance was $4. The two largest service providers in Kingston, Bell and Cogeco, offer additional data at a rate of $4 with a $100 cap, or $2/GB with no limit.

Table B-1: Attributes, Levels and Description

Attribute	Description		Levels
Price	Monthly price before tax	12	$15 to $125 in $10 dollar increments
Download Speed	The speed that data can be transmitted from a server to a computer measured in megabytes per second (Mbps)	8	4, 10, 25, 50, 75, 100, 300, 1000
Upload Speed	The speed that data can be transmitted from a computer to a server measured in megabytes per second (Mbps)	4	1, 3, 25, 100
Data Allowance	The maximum amount of data that can be used per month (GB).	4	50, 150, 300, Unlimited

There were two main considerations when choosing the values for this design. First, plans needed to be plausible in the Kingston market. While there are some outliers, notably plans with 1.5 GB download/upload, most people have plans with speeds that fall within the specified values. Secondly, the design was created recognizing that the final sample size was likely to be small. The final design for this paper uses 24 questions split into four blocks. In contrast, Liu et al (2018) use 120 questions grouped into 15 blocks of eight questions for a sample size of 978 households. Having a large number of blocks is common in the literature but, in this case, there was a concern that having sufficient representation from relevant groups (e.g rural or low income participants) across all blocks would be challenging, given the small anticipated sample size of around 200-400. Additionally, the survey has multiple sections that are not related to the choice experiment, which limits the option of increasing the number of questions that each participant completes, as this creates a substantial time commitment. Given the trade off between the additional information gained from more values, and the risk of reducing the data quality or quantity, the decision was made to use a relatively small number of values.

Appendix C: Estimating WTP from the DCE

We assume that the utility function of respondent h when choosing alternative i from choice set c takes the quasi-linear random form:

$$U_{hic} = F(X_{hic}) - \beta p_{hic} + \nu_{hic}$$

where X_{hic} denotes a vector of quantities consumed of each characteristic; p_{hic} denotes the price of the package, β is a preference parameter (marginal utility of income) and ν_{hic} represents an idiosyncratic preference of respondent h. We allow for possible non-linearity in the function F(.) to reflect diminishing marginal utility, for example. Note that this model implicitly assumes that while the utility derived by any given household for any given Internet package (combination of price and characteristics) varies, the marginal valuation of these characteristics is assumed to be the same for all households. This is a restriction that can be tested (see below).

The idiosyncratic terms are assumed to be independently and identically distributed with an extreme value type I distribution. Consequently, the probability that individual h chooses alternative i amongst the 4 alternatives in choice set c follows a conditional logistic form. The observed choices of participants are then used to construct a likelihood function, which is then optimized with respect to the parameters of the model.

Various representations of F(.) could be considered, in principle. For example, Liu et al. (2018) allow for a fairly flexible, piecewise linear specification for each characteristic. While such a specification is possible here, it requires the estimation of a large number of parameters. With relatively few respondents, it appears that such a specification is subject to a sparse-data bias which yields over-estimates of the effect of certain characteristic values.

An alternative approach is to specify a continuous function and impose a specific functional form. For example, one could limit the number of parameters by estimating a quadratic function, which would allow for some non-linearity. One problem with the quadratic function, however, is that it is not generally monotonic in its arguments which can pose a problem for interpretation.

The approach taken here is to limit the number of parameters to estimate by imposing a simple functional form given by

$$F(X) = \sum_{i=1}^{N} f_i(x_i)$$

where x_i denotes the i th element of X and

$$f_i(x) = (\alpha_i/\lambda)(x^{\lambda} - 1)$$

Here α_i denotes a parameter associated with preference for characteristic i and $\lambda \in [0,1]$ determines the curvature of the function. This so-called Box-Cox transformation allows for curvature which encompasses linear (λ =1) and natural logs (λ = 0). Note that a key simplifying assumption here is that utility is separable with respect to characteristics: the marginal utility of each characteristics does not depend on the quantity of the others.

The implied function for the marginal Willingness-to-Pay for characteristic i is then:

$$MWTP_i = (\alpha_i/\beta)x_i^{\lambda-1}$$

This is the amount a respondent would be willing to pay for one more Mbps/GB, given that he/she is already consuming an amount x. This means that if they were literally charged a price per Mbps/GB, this is the price per MB they would be willing to pay to consume x Mbps/GB.

The average WTP is then calculated as the MWTP multiplied by x_i and summed over all characteristics:

$$WTP = \sum_{i=1}^{N} (\alpha_i/\beta)x_i^{\lambda}$$

For any given value of λ, we estimated the remaining preference parameters using conditional logit. Errors were bootstrapped and clustered at the individual level.

The value of λ was set so that the point-estimate of the WTP implied by this procedure for urban respondents with no fibre (the reference group) was equal to the average price they actually paid. As in the DCE, most of these urban respondents have a choice and have chosen a Basic Internet package, so the average price they actually pay should be consistent with the average WTP from the DCE. In contrast, for example, most rural households with no fibre don't have the same choices, so the average price they actually pay (very high) will not be consistent with the WTP implied by the DCE.

The average surplus of the household measured in dollar terms can be expressed as

$$U/\beta = \sum_{i=1}^{N} (\alpha_i/\beta\lambda)(x_i^{\lambda} - 1) - p$$

The change in average consumer surplus between package 1 and package 2 is then

$$CS_2 - CS_1 = (1/\lambda)(WTP_2 - WTP_1) - (p_2 - p_1).$$