Broadband Funding Optimization Tool

Model Inputs and Assumptions

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About Vernonburg Group

Vernonburg Group is a full-service consulting firm focused 100 percent on closing the global digital divide. We work with companies, governments, non-profits, and other organizations that have a vested interest in seeing billions more people and things connected to the Internet. The work we perform for our clients encompasses digital equity programming design and implementation, large scale broadband project feasibilities, public sector and private sector fundraising, broadband mapping and economic modelling, broadband policy and regulation, and market research and risk assessment. We believe that affordable broadband access should be a human right. We also believe that technologies and business models already exist that could be used to close the broadband gap and increase adoption. With the right technologies, policies, and partnerships, the broadband gap can be closed once and for all.

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I. Introduction

The Vernonburg Group Broadband Funding Optimization Tool is a simple online dashboard that enables state and territorial broadband offices to see how – with prudent management of available public funding – they can achieve the goal of extending high-speed (100/20 Mbps or better) broadband connectivity to all unserved and underserved locations in the United States, extend connectivity to community anchor institutions (CAIs) and further other deployment and non-deployment digital equity priorities.[1] These goals can be achieved if state and territorial broadband offices set their Extremely High Cost Per Location Thresholds at levels that appropriately include a mix of broadband-capable fiber, terrestrial fixed wireless, and satellite technologies. The dashboard enables states and territories to model and budget the policy choices and trade-offs involved in setting the Threshold under scenarios the user generates.

Knowing there is sufficient funding to achieve the goal of ubiquitous broadband, CAI connectivity and digital equity priorities will come as good news for those state and territorial broadband offices and interested stakeholders, which have been concerned that available federal and state funding resources, along with private sector matches, would fall short of that goal. The Broadband Funding Optimization Tool demonstrates that state broadband offices need not settle for Internet for *Almost* All. With the funding they have been provided, state and territorial broadband offices can achieve Internet for All, as envisioned in the bi-partisan federal Infrastructure Investment and Jobs Act (IIJA or Infrastructure Act).

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The purpose of this document is to describe some of the key data inputs and outputs and assumptions that were used to develop the Broadband Funding Optimization Tool. This document also describes assumptions Vernonburg Group developed to model the cost of deploying fiber, fixed wireless, and satellite technologies in areas with different population densities.

II. Key Features of the Broadband Funding Optimization Tool

- Our tool focuses on an “Internet for all” solution that provides all unserved and underserved locations with broadband using an optimal mix of fiber, fixed wireless, and satellite and provides the corresponding “Extremely High Cost Per Location Threshold” to achieve this optimal mix.
- Our tool is adaptable and scalable to reflect different policy choices that various broadband offices may be considering and can help inform those choices by providing a clear understanding of the cost of those decisions.
- Our tool allows users to set their own “Extremely High Cost Per Location Threshold” and study the impact of different thresholds on the percentage of unserved and underserved locations reached with fiber, fixed wireless, or satellite technologies, as well as the total cost, while always ensuring that, at a minimum, 100% of unserved location are reached.
- Our tool initially reserves some portion of funds to connect community anchor institutions (CAIs) and further other deployment and non-deployment efforts. This enables states and territories to see how they can extend connectivity to all unserved and underserved locations, as well as to CAIs, such as schools and community centers, and promote other deployment and non-deployment digital equity priorities.
- Our model enables the user to customize the costs to local conditions and policy choices; for example, by varying the percentage of locations in a given state or territory reached with buried fiber. This enables a state or territory with higher forest fire risks or weather event risks to increase buried fiber percentages. Alternatively, a state or territory with lower climate-related risks might choose to lower the percentage of buried fiber in favor of aerial, which the tool also permits.
- Our model customizes the fixed wireless costs to the housing density.
- Our model includes fiber drop costs (fiber connections from the street to the home).
- Our model and the resulting tool are designed to help users understand the impact of different thresholds on policy choices and technology mix, but the underlying data can also help states assess bidding parameters in the evaluation phase of their selection process.

III. Key Data Sources, Models, Inputs, and Outputs

A. Data Sources Used

1. FCC Public BDC Data

The latest available Federal Communications Commission (FCC) Broadband Data Collection (BDC) data that incorporates the CostQuest fabric (updated at least once per month) is used to establish the list of unserved and underserved locations. This data is publicly available at a census block level for each state. Obtaining this data at a location level requires a high-cost CostQuest license.

2. Current Funded Areas

As required under the IIJA to avoid duplicative funding, we remove FCC Rural Digital Opportunity Fund (RDOF), USDA ReConnect, and USDA Community Connect funded areas from the list of unserved and underserved locations and ensure that we also remove any funding for these areas from the list of funding sources.[2]

3. Grant Funds Available

The total grant funds available are extracted from Broadband Equity, Access, and Deployment (BEAD) Volume 1 submissions or BEAD five-year action plans submitted to NTIA by the states and territories – this includes BEAD funds as well as other available federal and state funds. We ensure that we only include funds that are available for deployment efforts and remove any funds for RDOF, ReConnect or Community Connect projects where funds have already been allocated. Where a state has not submitted a five-year action plan, we use their BEAD allocation and American Recovery Plan Act (ARPA) Capital Projects Fund (CPF) allocation to calculate the total funds available. Generally, the total funds from BEAD and the Capital Projects Fund make up more than 90% of the available funding in most states and territories.

4. Building density

To calculate building density at a census block level, we use census area and number of houses in a census block from the latest 2020 Decennial census. In cases where no houses are present, but the FCC shows that there are fabric locations, we make use of the FCC locations to calculate building density. This would occur if there was a factory or business in a location with no residential houses.

B. Modelling the Costs for Fiber, Fixed Wireless and Satellite

1. Costs for Fiber

Our fiber cost model is provided in Appendix A. We use a statistical model to estimate the cost of building out end-to-end fiber networks to unserved and underserved locations. The model maps housing density to fiber cost by studying previously funded fiber projects. This allows us to quickly create a cost estimate for any area from a census block to state level.

Local costs can differ widely due to availability of existing infrastructure, cost of rights-of-way and permits, terrain, the costs and availability of skilled labor, the use of aerial versus buried fiber, and the accuracy of the infrastructure and broadband availability data. As such, the result of this model should be used as a guide and not quoted as a final cost. Local knowledge of the area could help fine tune the model to better suit local environments.

To accommodate local knowledge of the area, we allow the user to fine tune the amount of buried or aerial fiber in the model which is discussed later.

2. Costs for Fixed Wireless

To estimate the cost of fixed wireless, we leveraged Vernonburg Group's practical knowledge of the cost of deploying different fixed wireless technologies in a variety of settings, along with deployment cost information provided by a variety of US wireless ISPs. We reviewed the cost of deploying both 4G and 5G fixed wireless technologies typically utilized on various exclusive-use licensed spectrum bands, as well as the Wi-Fi-based and proprietary technologies deployed on various unlicensed or license-by-rule spectrum bands.

We estimate that High Frequency Fixed Wireless (suitable for higher building densities) is approximately half the cost of aerial fiber and Low Frequency Fixed Wireless (suitable for lower building densities) is approximately one third the cost of aerial fiber. Per below, the cost of deploying buried fiber is higher than the cost of deploying aerial fiber.

We define low building densities as populations which are less than 10 buildings per square mile and high building densities as populations that are more than 100 buildings per square mile. We use a blended model between 10 to 100 buildings per square mile to gradually scale the cost between one third of the cost of fiber (for low building densities at 10 buildings per square mile) to half the cost of fiber (for high building densities at 100 buildings per square mile).

3. Costs for Satellite

For very low-density housing where fixed wireless costs reach the Extremely High Cost Per Location Threshold or where fixed wireless costs reach $10,000 per location (whichever is less), we use satellite. Note when fixed wireless costs reach $10,000, this connotes a census block with approximately one house per square mile. To calculate the cost of satellite we made use of Starlink's RDOF submission. Starlink was originally awarded $885.5 million to provide 100/20 Mbps service to 642,925 locations across 35 states. This calculates to an average of $1,378 per location, but with two years inflation, at approximately 11% per year since 2020, this calculates to an average of $1,667 per location; which is the amount we use in our model for each location served with satellite.[3] In addition, we assume a 25% private sector match for satellite bids, which calculates to an average cost of $2,223 per location.

4. Buried Versus Aerial Fiber

To customize the model for higher cost buried fiber or lower cost aerial fiber, we use a set of answers to Frequently Asked Questions written by the Rural Broadband Association and the Fiber Broadband Association.[4] The report states that fiber costs (including formulation and engineering, attachment fees and completion) run between $8 to $25 per foot for aerial fiber and $12 to $50 per foot for buried fiber.

Using these figures, the average cost of aerial fiber is $16.50 per foot, the average for buried fiber is $31 per foot, and on average, buried fiber is 1.88 times more costly than aerial fiber. When the buried slider (discussed in C.2.) is set at 0% it is 100% aerial fiber and when it is set at 100% it is 100% buried fiber and 1.88 times the cost compared to when it is set at 0%.

C. Inputs on Dashboard

All the inputs shown in the Dashboard in Figure 1 are described below.

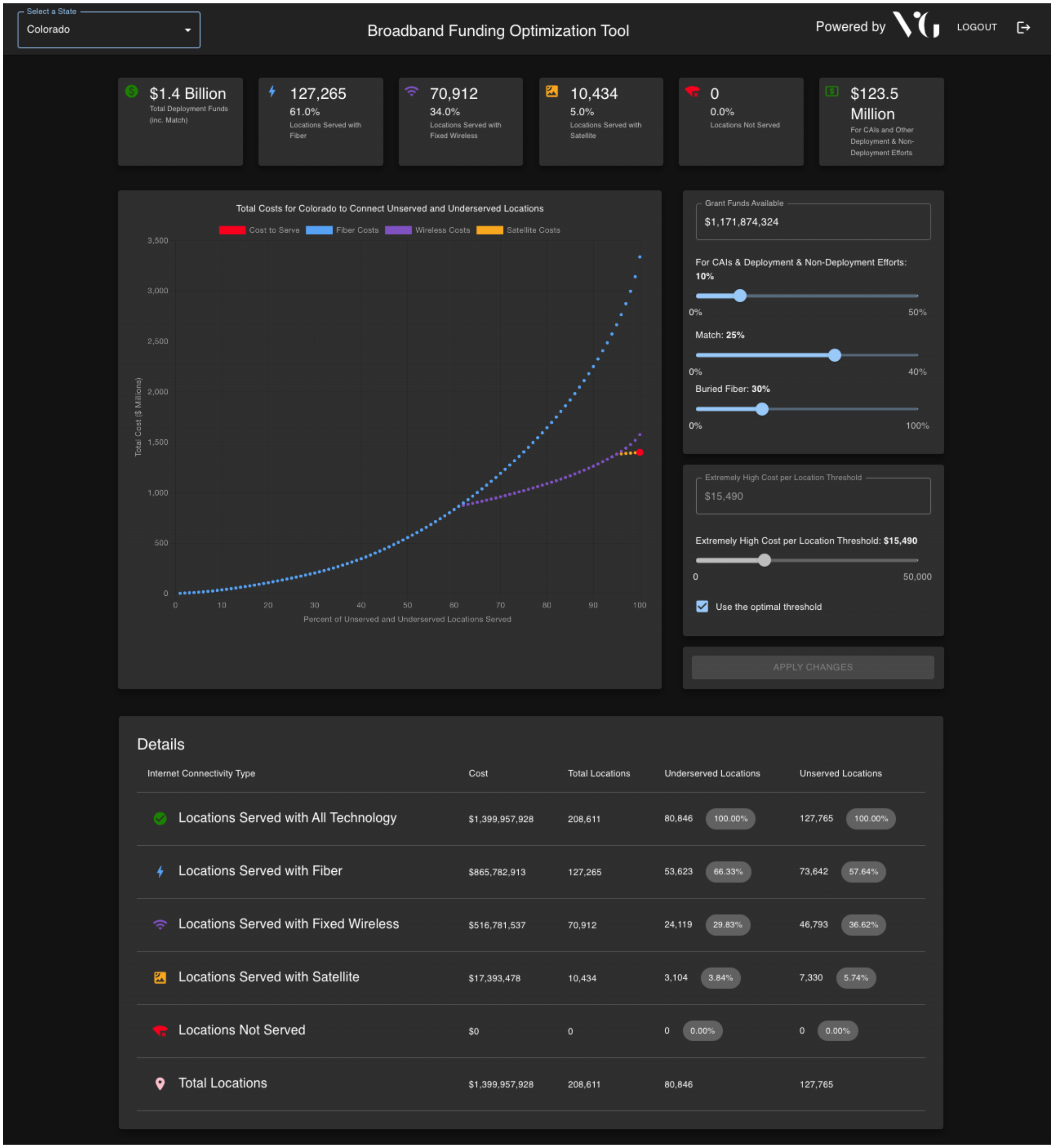

Figure 1: Broadband Funding Optimization Tool Dashboard

1. Grant Funds Available

A default value is filled in from sources described in A.3. but the user can customize this value if they know that there are more or less funds available.

2. Buried Fiber

This is set to a default value based on sources described in B.4. but the user can customize based on local knowledge of typical fiber deployments in the state.

3. Funds for CAIs & Non-Deployment Efforts

This describes a percentage of funds to remove from the grant funds available for CAIs and non-deployment efforts. This is set to 10% by default but can be customized by the user.

4. Match

This describes match percentage network operator subgrantees will contribute to the total project costs and is set at 25% by default and can be customized by the user.

5. Extremely High Cost Per Location Threshold

An optimal value for the Extremely High Cost Per Location Threshold (EHCPLT) is calculated by the tool to ensure all unserved and underserved locations are served (See Section E.) This is effectively an output, but the user can override this value by unchecking "Use the optimal threshold" and entering a custom value. Note, if the optimal EHCPLT is higher than $20,000 per location due to a large amount of available funding, the tool will automatically cap this value $20,000. We consider fiber builds with costs above $20,000 per location– requiring at least a $5,000 per location match – as a wasteful expenditure of public resources, at risk of lacking commercial sustainability and undermining a variety of public policy goals (including service affordability), and better suited to alternative technologies such as fixed wireless.

D. Outputs on Dashboard

All the outputs shown in the Dashboard in Figure 1 are described below.

1. Total Deployment Funds (Including Match)

This describes the total amount of funds available for deployment after funds "For CAIs & Deployment & Non-deployment Efforts" are removed from "Grant Funds Available" and "Match" is added.

2. Locations Served with Fiber

This provides the total unserved and underserved locations served with fiber and the percentage out of the total unserved and underserved locations.

3. Locations Served with Fixed Wireless

This provides the total unserved and underserved locations served with fixed wireless and the percentage out of the total unserved and underserved locations.

4. Locations Served with Satellite

This provides the total unserved and underserved locations served with satellite and the percentage out of the total unserved and underserved locations.

5. Location Not Served

This provides the total underserved locations served that cannot be served due to funding running out and the percentage out of the total unserved and underserved locations.

6. Remaining Funds for CAIs and Other Non-Deployment and Deployment Efforts

This provides the amount of remaining funds for CAIs and all other deployment and non-deployment efforts. This is the total of the pre-reserved funds from the input, “For CAIs & Deployment & Non-deployment Efforts” as well as funds remaining after all unserved and underserved locations are served.

IV. Process Logic for Choosing Extremely High Cost Per Location Threshold

The Extremely High Cost Per Location Threshold is a cost threshold set by each state or territorial broadband office. Broadband offices are required to select prospective subgrantees proposing to deploy end-to-end fiber to specific locations below this cost threshold. If no qualifying end-to-end fiber proposal that is below this threshold is submitted for a location, the broadband office may select prospective subgrantees proposing to deploy alternative technologies, such as fixed wireless using entirely unlicensed spectrum to serve last mile locations and other alternative technologies “meeting the BEAD Program’s technical requirements [that] would be less expensive.”

The optimal Extremely High Cost Per Location Threshold will be set at a level to use up all deployment funds (i.e., those funds not set aside for CAIs and other deployment and non-deployment purposes) to reach all unserved and underserved areas with an optimal mix of fiber, fixed wireless, and satellite technologies.

In the case where not all unserved and underserved locations can be reached, unserved areas will be prioritized to ensure 100% of all unserved locations can be reached and remaining funds will be used to connect as many underserved locations as possible.

Appendix A: Vernonburg Group Fiber Cost Model

This Appendix describes a methodology for estimating the cost of fiber broadband deployments. It is useful in the context of planning for broadband grant implementation, such as the National Telecommunications and Information Administration's (NTIA's) BEAD program.

There are two methods to build a cost model for fiber expansion. The first method uses a statistical model that looks at previous fiber projects in different housing densities and uses curve fitting techniques to best fit these data points with a mathematical function. The second method uses combinatorial mathematical techniques to find the shortest fiber path along a road network or a set of potential paths to reach locations that need to be served. The most popular algorithm that is used to find the shortest path along a road or other network is the Steiner Tree algorithm.[5]

For this study, we use a statistical model to estimate the cost of building out end-to-end fiber networks to unserved and underserved locations. The Steiner Tree algorithm is best suited to the project phase where a more detailed and accurate plan is required for determining the cost of a project.

Note that creating a model for the cost of fiber can be challenging due to a multitude of factors including: the availability of existing infrastructure, cost of right-or-way and permits, terrain, the cost and availability of skilled labor, the percentage of aerial versus buried fiber, and the accuracy of the infrastructure and broadband availability data. For this reason, there will be large variability between the projects studied when building the statistical model and local knowledge of the area could help fine tune the model to better suite local environments.

Summary of Existing Models

The Fiber Broadband Association (FBA), a fiber industry trade association, and Cartesian, a specialist consulting firm, produced a study on the cost to construct a fiber to the home (FTTH) network that passes US households in areas with different housing densities, measured as houses per square mile.[6] Plotting the cost of fiber construction projects versus household density produced a model shown in figure 2. This study yielded the following cost ranges for urban and rural areas in the US:

- Urban: costs range from $700 to $1,500 per location passed
- Rural: costs range from $3,000 to $6,000 per location passed

This costing study did not look at projects below approximately ten houses per square mile.

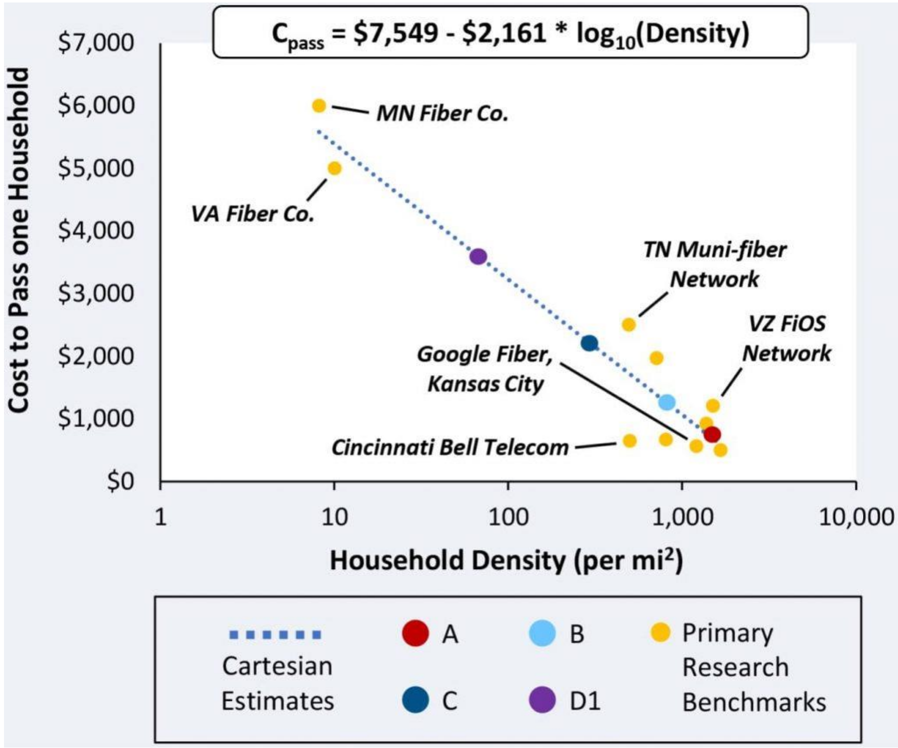

Figure 2. Cartesian Model for Cost to Pass One Household vs Household Density[1]

To account for inflation, this model was escalated by ten percent per annum over two years and the minimum cost to provide fiber to a home was assumed to be $1,000.

The model with escalation and the minimum cost requirement produced the following equation:

$$HH\ passed = \max\left(1.21(7549 - 2161\log_{10} density), 1000\right)$$

Another recent study by Tarana Wireless[7] looked at public-domain data from 132 projects funded by state-level broadband offices since early 2019, in a set of five states (Alabama, California, Michigan, Nebraska, and Virginia). The projects were chosen specifically to represent the wide range of fiber deployment conditions and challenges across the US. The deployments examined were designed to serve a total of 52.7 thousand homes at an aggregate cost of $733.5M ($13.9 thousand per household served on average). This data was used to model the potential cost per house served with fiber for different household densities. The study by Tarana included many projects below 10 households per square mile and therefore provides a better model at low household densities. Note this model used the cost to serve a house and included the drop to the household as opposed to the Cartesian study which looked at the cost to pass a house (i.e., without accounting for drop costs). However, due to the low household density of the projects in the Tarana study, where most of the cost involves extending fiber to pass a household, including the drop cost will only slightly over-inflate the cost to pass a location.

The model produced the follow equation with a log-log regression of approximately 30 percent[8] (to account for inflation, this model was escalated by 10 percent per annum over two years):

$$HH\ passed = 1.21 * 10^{(4.44 - 0.33 \log_{10} density)}$$

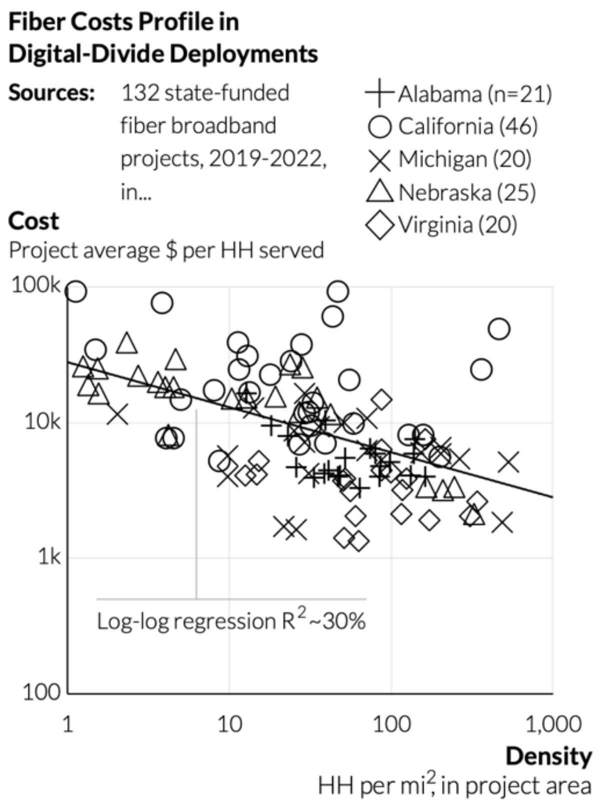

Figure 3. Tarana Model for Average Project Cost per Household Served vs Household Density[2]

A New Blended Fiber Cost Model

Vernonburg Group sought to develop a model suitable for geographies with varying housing densities from urban to remote rural areas. To do so, we combined the Cartesian and Tarana models. The Cartesian model was mostly based on projects that had a housing density greater than 100 houses per square mile, a few projects between 100 and 10 houses per square mile, and none with less than 10 houses per square mile. The Tarana model had a good spread of projects across all housing densities, but, most importantly, a good number of projects included housing densities that were less than 10 houses per square mile.

To combine the models, we used the Cartesian model to estimate costing for areas with more than 100 houses per square mile and used the Tarana model for areas with less than 10 houses per square mile. For areas between 10 and 100 houses, we used a mix of the two models with a gradual increased use of the Cartesian model instead of the Tarana model as the housing density increased from 10 to 100 square miles. The result of this model is shown in Figure 4 and Figure 5.

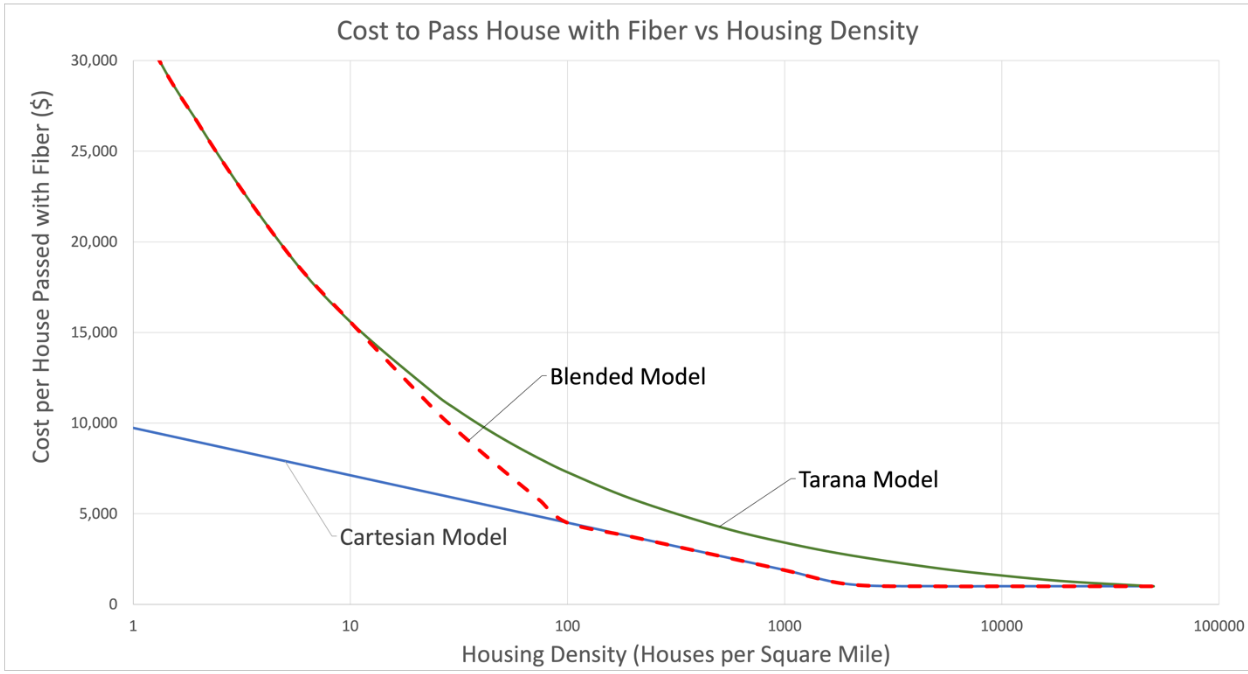

Figure 4. Combination of Tarana and Cartesian Model to Calculate Cost per House Passed with Fiber

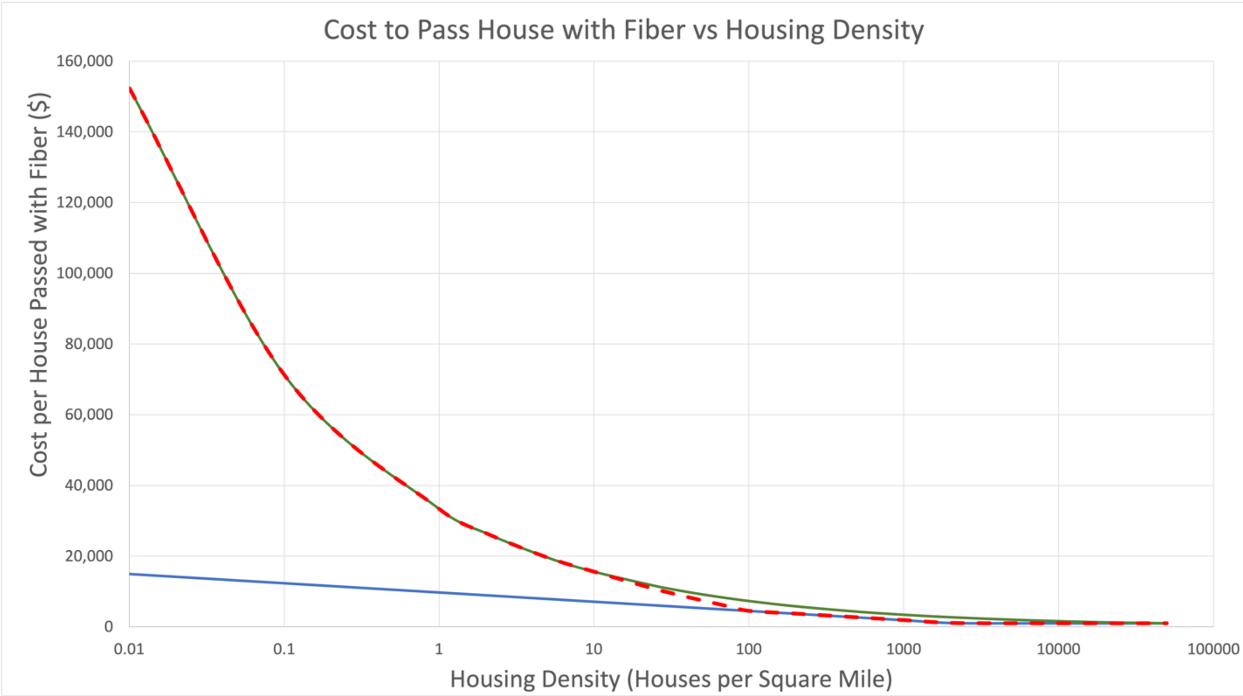

Figure 5. Combination of Tarana and Cartesian Model to Calculate Cost per House Passed with Fiber (Log scale)

Below are some key assumptions in the model:

1. Inflation since December 2020 is assumed to be 10 percent per annum from December 2020 to December 2022 and the model reflects an estimated cost at the beginning of 2023.
2. We only calculate the cost to pass a location. The cost to service multiple buildings or units in a building with a fiber drop or using other technology to create a drop are an additional cost.
3. Household density in "households per square mile" is calculated at the census block level and assumes that the average household density for unserved and underserved locations is roughly the same as the household density for all locations in the census block. Due to the nature of how census blocks are created, where the Census Bureau tries to keep the population of a census block to between 600 and 3000 people, this assumption generally holds apart from a few edge cases in very large remote census blocks.
4. Terrain (slate, rocks, mountains, etc.) is averaged out in the model as some projects have challenging terrain and others do not.

We used three reports to inform the inflation assumption. A report by CBRE, a US commercial real estate services and investment firm that studied 2022 US construction costs, calculated the construction escalation to be 11.5 percent from 2020 to 2021 and predicted a 12.5 percent to 14.1 percent increase from 2021 to 2022.[9] CBRE predicted a return between two percent and four percent (on par with historical averages) by in 2023 and 2024.

Another report by David McGarry, a retired construction industry expert, using multiple data sources on completed construction projects found the following escalation trends between 2019 to 2022 using data from completed projects and escalation trends using modelling between 2023 to 2024.[10]

Table 1. Construction Cost Trends Analysis by David McGarry

	Measured				Prediction	
	2019	2020	2021	2022	2023	2024
Non-residential buildings	4.69%	2.39%	8.00%	12.20%	4.87%	3.72%
Non building construction	4.06%	-0.31%	7.90%	13.80%	4.70%	3.48%
Residential constructions	3.51%	4.53%	14.00%	15.80%	2.17%	4.04%

According to Blair Levin, Senior fellow at Brookings Metro, the average inflation for fiber projects in 2022 was about 20 percent.[11]

Checking Vernonburg Group's Model Against ReConnect Projects

In order to test the model, Vernonburg Group collected cost information for US Department of Agriculture (USDA) ReConnect grants and loans in 2022 and 2023 and plotted the housing density versus the estimated build cost and compared this to the predicted values from the Vernonburg Group model.

The ReConnect project estimated build cost is a lower bound[12] of the actual potential cost and was calculated using the following logic:

1. For 100 percent loans, we added no match.
2. For 100 percent grants that are "Alaska Native Corporations, Tribal Governments, Colonias, Persistent Poverty Areas and Socially Vulnerable Communities" or "Projects serving areas where 90% of households lack sufficient access to broadband" grants, no match was added.
3. For all projects from the year 2022, we added five percent inflation.
4. For a 100 percent grant that is not in category 2, we added the minimum requirement of a 25 percent match.
5. For 50/50 grant/loan, we added a minimum of 25 percent match on the grant component.

Note the ReConnect grants are for houses connected with fiber but given the low housing density of these projects, this will only be marginally more than the cost to pass a house with fiber. In addition, given our use of a lower bound for the cost of the ReConnect project, this cost will be immaterial in the analysis.

We also removed a few outliers with very low total premises numbers that skew the data. For example, we removed a project in Puerto Rico with a single site for $8,783,520 million and a project in Palau with six sites for $34,991,340 million.[13]

Below is a plot showing the results. Ninety-three of the ReConnect projects have "cost per premises" values that are above our prediction for the corresponding housing density and 42 of the ReConnect projects have "cost per premises" values that are below our prediction. The average percentage difference between the ReConnect projects with "cost per premises" values that are above the Vernonburg Group model prediction is 377.92 percent. The average percentage difference between the ReConnect projects with "cost per premises" values that are below the Vernonburg Group model prediction is 29.38 percent.

This shows that our model is more likely to under-predict fiber costs rather than over-predict fiber costs for projects across the US.

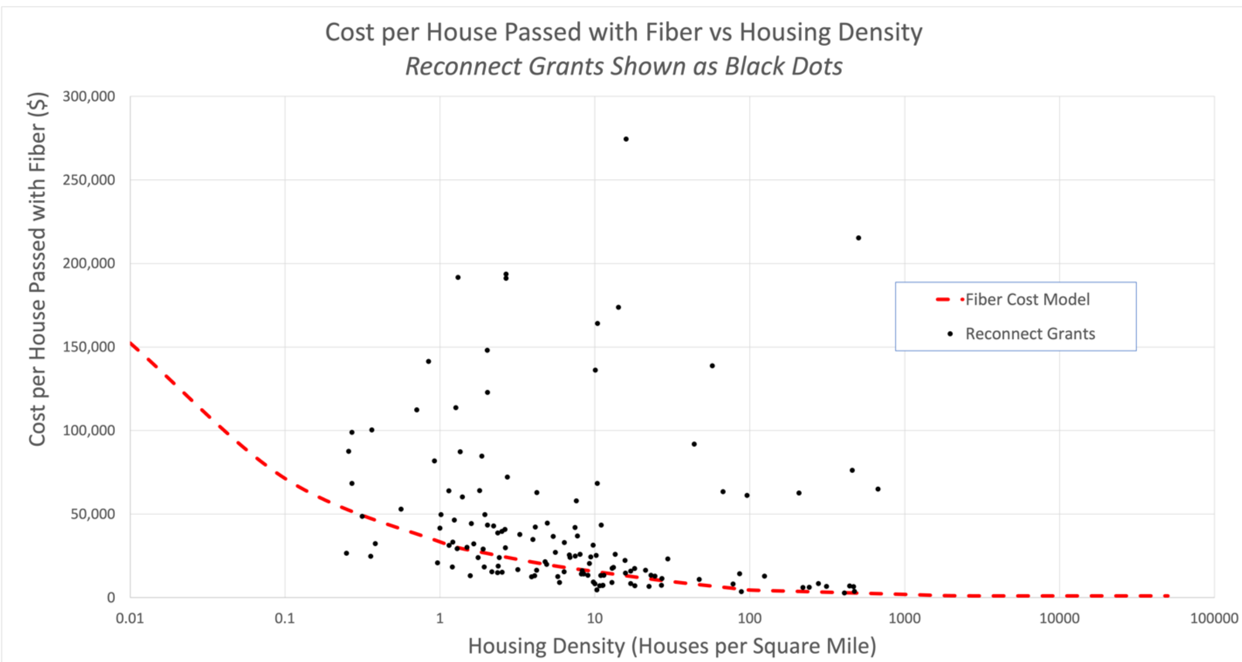

Figure 6. Comparing Vernonburg Group Model to ReConnect Grants

Endnotes

[1] Vernonburg Group would like to acknowledge the support of WISPA – Broadband Without Boundaries in preparing this Broadband Funding Optimization Tool. Vernonburg Group was solely responsible for determining the inputs and assumptions and developing the results in the tool.

[2] Since we only have data at a census block level, we must estimate the unserved and underserved locations removed in the portion of the funded areas polygons that cut through a census block. However, in the case of a full census block being in the funded area, we can accurately remove all unserved and underserved locations. We estimate that that this can cause up to a +/- 5% error margin in the true number of unserved and underserved locations to service after funded areas are removed. If we had licensed CostQuest data, this error margin would be removed.

[3] Goovaerts, Diana. "FCC rejects LTD Broadband, Starlink RDOF bids." Fierce Telecom. Aug 10, 2022. Available at: https://www.fiercetelecom.com/broadband/fcc-rejects-ltd-broadband-starlink-rdof-bids

[4] The Rural Broadband Association. "#FiberDelivers Frequency Asked Questions." Q1 2021. Available at: https://www.ntca.org/sites/default/files/documents/2021-06/FiberDelivers%20FAQs%20Final%206%203%2021.pdf

[5] The Steiner Tree algorithm is a powerful optimization technique employed in the realm of expanding fiber networks. Primarily used in telecommunications and network design, this algorithm addresses the challenge of efficiently connecting a set of terminal points, such as homes, businesses, or data centres through an optimal network of fiber optic cables. Connection lengths can be constrained along roads in the case of buried fiber or pole routes in the case of aerial fiber. The Steiner Tree algorithm can also introduce additional, strategically placed "Steiner Points" that are effectively points where fiber intersections occur to help reduce the length of fiber used. The key goal of the Steiner Tree algorithm is to minimize the total length of fiber optic cables required to connect these key locations, and plays a crucial role in reducing installation costs, minimizing signal attenuation, and enhancing overall network performance.

[6] Kim, Jonathan. "Fiber Optic Network Construction: Process and Build Costs." Dgtl Infra. July 28, 2022. Available at: https://dgtlinfra.com/fiber-optic-network-construction-process-costs/

[7] Tarana. "New Study of Real-World Fiber Broadband Costs." Available at: https://www.taranawireless.com/fiber-study/

[8] Note that, using a log-regression on this data, like that used by the Cartesian study, yielded a regression of only 10 percent and was discarded.

[9] CBRE, "2022 U.S. Construction Cost Trends." 2022. Available at: https://www.cbre.com/insights/books/2022-us-construction-cost-trends/01-introduction

[10] Zarenski, Ed. "Construction Inflation 2023." May 19, 2023. Available at: https://edzarenski.com/2022/12/20/construction-inflation-2023/

[11] McGarry, David. "Fiber Providers Feeling the Heat of Inflation as Cost of Materials, Labor Rise." Broadband Breakfast. September 8, 2022. Available at: https://broadbandbreakfast.com/2022/09/fiber-providers-feeling-the-heat-of-inflation-as-cost-of-materials-labor-rise/

[12] Due to the lack of information on the true cost to build out fiber in a ReConnect project, we calculated the lower bound for the project cost.

[13] U.S. Department of Agriculture. "ReConnect round three awardees." Available at: https://www.usda.gov/reconnect/round-three-awardees