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BROADBAND INFRASTRUCTURE COST GAP ANALYSIS

Minnesota Department of Employment and Economic Development (DEED)
December 2024

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1. EXECUTIVE SUMMARY

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1.1 GOALS FOR THE ANALYSIS

ESTIMATING COSTS FOR UNIVERSAL BROADBAND COVERAGE

The state seeks to estimate the costs to close the broadband infrastructure gap in Minnesota.

The Minnesota Department of Employment and Economic Development (DEED) Office of Broadband Development's (OBD) goal for this analysis is to produce cost models that estimate the costs to close Minnesota's broadband infrastructure gap in all unserved and underserved areas of the state, using both wireline and fixed wireless deployment scenarios.

DEED requests that the estimates include the costs to deploy fiber-to-the-premises (FTTP) and fixed wireless (FW) to all unserved and underserved locations.

PLANNING FOR UNIVERSAL BROADBAND SERVICE WITH FEDERAL FUNDING

The state seeks to optimize its use of funding from the federal Broadband Equity, Access, and Deployment (BEAD) Program.

The BEAD Program provides significant funding in the near term to advance Minnesota's goals for universal service. The State of Minnesota was allocated approximately $651.8 million through the BEAD Program,* which is administered by the National Telecommunications and Information Administration (NTIA). DEED will administer a grant program to subaward this funding to internet service providers (ISP) and other entities to deploy broadband infrastructure.

The establishing statute for the program, the Infrastructure Investment and Jobs Act (IIJA), and NTIA rules require states to design their BEAD grant programs to achieve universal service with the funds awarded through the program. In addition, NTIA has prioritized certain technologies (i.e., end-to-end fiber deployment, also called fiber-to-the-premises) over other technologies in most cases.

However, the amount of BEAD funding allocated to Minnesota—like in many states—may not be sufficient to achieve universal coverage with fiber. The state's unique characteristics and needs, coupled with funding limits, require detailed planning for how funding is distributed throughout the state and what types of projects and technologies are prioritized.

*Minus administrative expenses, the state's total BEAD allocation is $628 million. This report uses $628 million as the available BEAD funding for analysis of deployment scenarios.

GOALS FOR THE BROADBAND INFRASTRUCTURE COST GAP ANALYSIS

1	**Universal coverage**	Bring broadband access to all Minnesota residents, meeting NTIA requirement for universal service
2	**Funding optimization**	Estimate infrastructure cost to maximize the impact of the available BEAD allocation
3	**Technical feasibility**	Determine the most cost-effective technologies for broadband deployment across the state

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1.2 ANALYTICAL MODEL ESTIMATES COSTS FOR UNIVERSAL COVERAGE AND A TECHNOLOGY MIX WITHIN THE STATE'S BEAD ALLOCATION

ABOUT THE ANALYTICAL MODEL

This report analyzes four potential deployment scenarios to define the potential range of costs to close the broadband infrastructure gap.

CTC developed an analytical model that analyzes the economics of a wide range of technology configurations for deploying broadband. The model outputs multiple, data-based scenarios that highlight the implications and likely tradeoffs of various technology and grant strategy choices.

In alignment with the state's goals, the model analyzed four potential deployment scenarios to achieve universal broadband coverage: three scenarios including wireline deployment*, and a fourth scenario for fixed wireless.

First, Scenario 1 estimates the cost to provide a fiber connection to all locations in the state that are not served by a wireline connection. Then, Scenarios 2 and 3 evaluate universal coverage objectives from the perspective of the BEAD Program: what would it cost to connect all BEAD-eligible locations with fiber? If this cost exceeds the state's BEAD funding, what is an optimal mix of technologies to maximize fiber coverage and achieve coverage of all BEAD-eligible locations within the state's BEAD allocation?

Scenario 3 solves for this technology mix by estimating the cost threshold at which a location is too expensive to connect with fiber—the Extremely High Cost per Location Threshold (EHCPLT), per the terminology of the BEAD Program. Locations above this threshold can be assigned to fixed wireless or satellite, if the evaluation does not support a business case for fixed wireless.

In addition, Scenario 4 estimates the cost to provide fixed wireless broadband infrastructure to all unserved and underserved locations in the state.

*For the purposes of this report, we assume "wireline coverage" and "wired infrastructure" predominantly consists of fiber, although some cable companies may use a hybrid solution.

THREE POTENTIAL SCENARIOS INCLUDING WIRELINE DEPLOYMENT

1

Universal wireline coverage

Providing wireline infrastructure to all locations not served by a wireline connection

2

BEAD wireline coverage

Providing wireline infrastructure to all BEAD-eligible locations

3

BEAD broadband coverage

Providing broadband infrastructure to all BEAD-eligible locations

FOURTH POTENTIAL SCENARIO FOR WIRELESS DEPLOYMENT

4

Universal wireless coverage

Providing fixed wireless broadband infrastructure to all unserved and underserved locations

IDENTIFYING THE STATE'S UNSERVED AND UNDERSERVED LOCATIONS AND PASSINGS

Approximately 99,000 passings are unserved and underserved and an additional 93,848 are served only by wireless.

Based on service availability data from the FCC and the state's BEAD Challenge Process,* approximately 99,000 passings** in Minnesota are unserved or underserved per the BEAD Program's definitions (i.e., BEAD-eligible locations***).

An additional 93,848 passings are only served by wireless service.

Scenario 1 analyzes the costs to provide universal wireline coverage to the approximately 193,000 total passings that are unserved, underserved, or served only with fixed wireless. Scenarios 2 and 3 analyze the costs to provide coverage to the 99,000 BEAD-eligible unserved and underserved passings (i.e., excluding those currently served with fixed wireless) — either through fiber alone, or a mix of technologies. Scenario 4 uses the same 99,000 unserved and underserved passings as Scenarios 2 and 3 to analyze the cost of providing universal fixed wireless service.

To enable more granular evaluations of cost expectations throughout the state, unserved and underserved locations are grouped into analysis areas by Census Block Groups (CBG), with tribal lands as unique analysis areas.

*See the Appendix and Section 2 of this report for additional detail about data sources.

**Passings are equivalent to the number of multiple-dwelling units per broadband serviceable location.

***BEAD program rules define unserved locations as those that lack access to 25 Mbps download speed and 3 Mbps upload speed (25/3 Mbps), while underserved locations have access to speeds faster than 25/3 Mbps but less than 100/20 Mbps.

GENERATING TWO TYPES AND A RANGE OF COST PROJECTIONS FOR EACH SCENARIO

The model estimates network deployment cost and grant funding required within an expected range from low to high cost.

Two types of cost projections are estimated for each scenario: the capital cost to deploy the network infrastructure (**total investment needed**), as well as the grant funding from the state that would be required to attract service providers to install and operate the network infrastructure (**grant funding required**).

Each scenario also provides an expected range of costs from low to high. Applicants to a grant program will typically fall into one of three categories based on the type of service provider they represent, which have different cost structures that will produce a range of proposal costs. A **telco upgrade** (i.e., a build by an incumbent telco or power company owning the poles) can typically leverage scale and existing infrastructure for a **low-cost** model, with a **cable expansion** (i.e., expansion by a cable operator from its nearby service area) representing the **medium-cost** model. A new entrant or small entity is a **higher-cost** model given the applicant's lack of scale and lack of infrastructure.

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1.3 KEY FINDINGS

GRANT FUNDING REQUIRED FOR WIRELINE SCENARIOS COULD RANGE FROM $2.1 BILLION TO $628 MILLION*

1

Universal wireline coverage

193k

passings covered by fiber

Estimated grant funding required:
$2.1B

Estimated total investment needed:
$2.8B

2

BEAD wireline coverage

99k

passings covered by fiber

Estimated grant funding required:
$1.1B

Estimated total investment needed:
$1.5B

3

BEAD broadband coverage

90k

passings covered by fiber

Estimated grant funding required:
$628M**

Estimated total investment needed:
$950M

*Granular cost breakdowns by CBG-based analysis areas are attached in the cost data file. Note that the statewide estimates above reflect the cable expansion model discussed in the previous slide. We find that in Minnesota the economics of deployment will, in general, likely be similar to a cable expansion model, and thus the cable expansion estimate (typically, the middle-cost model) represents the most reasonable baseline for statewide analysis and comparison.

**$628 million represents the state's total BEAD funding allocation minus administrative expenses.

CLOSING THE GAP WITH FIXED WIRELESS COULD REQUIRE $35 MILLION IN GRANT FUNDING

4

Universal wireless coverage

92k

passings covered by fixed wireless

Estimated grant funding required:
$35M

Estimated total investment needed:
$105M

ACHIEVING UNIVERSAL WIRELINE OR BEAD WIRELINE COVERAGE EXCEEDS THE STATE'S BEAD ALLOCATION

The estimated funding required to achieve universal wireline coverage to all locations across the state that lack a wireline connection ($2.1 billion) is more than **three times** the state's BEAD allocation.

Even in a best-case, low-cost telco upgrade model, with an incumbent telco using overlash or new cable on existing attachments and in existing conduit where available, the estimated grant funding required exceeds available BEAD funding. A cable expansion or new entrant model for any provider other than an incumbent telco would require hundreds of millions of dollars in additional funding, largely due to pole attachments, conduit, make-ready, and pole replacement costs.

Providing fiber coverage to all BEAD-eligible locations would also exceed the state's BEAD allocation, requiring an estimated $1.1 billion in grant funding.

THE STATE COULD REACH MORE THAN 90 PERCENT OF BEAD-ELIGIBLE LOCATIONS WITH FIBER

The optimal technology mix to reach the BEAD-eligible unserved and underserved locations, assuming the most likely, conservative costs (i.e., a cable expansion model) and the state's $628 million BEAD allocation,* is 90 percent fiber, 1 percent fixed wireless, and 8 percent satellite.

The model selects fiber for locations wherever there exists a positive business case for it. Fixed wireless is selected only in the areas in which fiber is not financially viable but there exists a business case for fixed wireless, which represents a relatively narrow window in the financial model because the cost of fixed wireless with sufficient capacity and coverage, using licensed technology, is also high in most cases.

In this scenario, serving 8 percent of BEAD-eligible locations with satellite would result in approximately 0.5 percent of all passings in Minnesota receiving satellite (including passings that are currently served).

The model estimates an Extremely High Cost Per Location Threshold of $30,000.

*$628 million represents the state's total BEAD funding allocation minus administrative expenses.

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2. OVERVIEW OF ANALYTICAL MODEL AND METHODOLOGY

ABOUT THE ANALYTICAL MODEL

To answer the complex questions posed in developing a plan to serve all underserved and unserved locations in Minnesota, the model provides analyses of the economics of a wide range of technology configurations for deploying broadband.

The analytical model outputs multiple, data-based scenarios that highlight the implications and likely tradeoffs of various technology and grant strategy choices.

These scenarios can inform the state's policymakers, including assisting in BEAD funding decisions to best position the state to meet its goals. The model enables consideration of multiple alternative scenarios for how funds are allocated and awarded, with respect to type of infrastructure (fiber versus fixed wireless or satellite), business case (to project how much match an investor may be willing to provide for access to funds in a given area), and ubiquity of coverage (to enable consideration of how far available funds will go based on scenarios in which the highest cost and most remote locations are included or not).

GENERAL INPUTS AND OUTPUTS FOR THE MODEL

As described in detail in the following sections, the analytical model performs engineering analysis and estimates costs. Inputs to and outputs from the model are shown below.

Scenario inputs

- Unserved locations
- Underserved locations
- Served locations (potential providers)
- Tower locations and heights
- Financial (ARPU, IRR, inflation)
- Local cost data (physiographic regions)
- Desk review of utility pole conditions

Statewide outputs

- Design and costing
- Grant funding estimation
- Optimal mix of technologies
- Extremely High Cost Per Location Threshold

INVESTMENT NEEDED VS. GRANT FUNDING ESTIMATES

The cost to build a network is only one component of understanding the likely amount of funding requested by applicants to a grant program. The model estimates two types of costs.

Estimated total investment needed

Represent the sum of estimated deployment costs, including match, incurred during a five-year grant period:

- Includes estimated design, permitting, and construction-related labor and materials
- Includes customer premises equipment (CPE) and drop costs for customers activated during the five-year grant performance period
- Includes network electronics required to support the achieved take-rates
- Does not include ineligible operating expenses, such as customer support and maintenance of equipment and fiber infrastructure
- Does not assess business case (profitability) or grant funding required to incentivize applications for a particular service areas

Estimated grant funding required

Reflect the likely amount of BEAD and additional grant funds required to attract applications:

- Projects how much money an applicant would require to be incented to build a given project area, assuming the applicant requires an internal rate of return (IRR) of 8% over a 20-year timeframe, taking into account costs incurred and revenues generated beyond the grant performance period
- Takes into account ineligible costs impactful to the business case, including certain operating expenses
- Estimates the match provided by applicant, calculated based on business case

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2.1 GENERATING FIBER NETWORK DESIGN COST INPUTS

THE MODEL USES GRAPH THEORY TO PLAN ROUTES

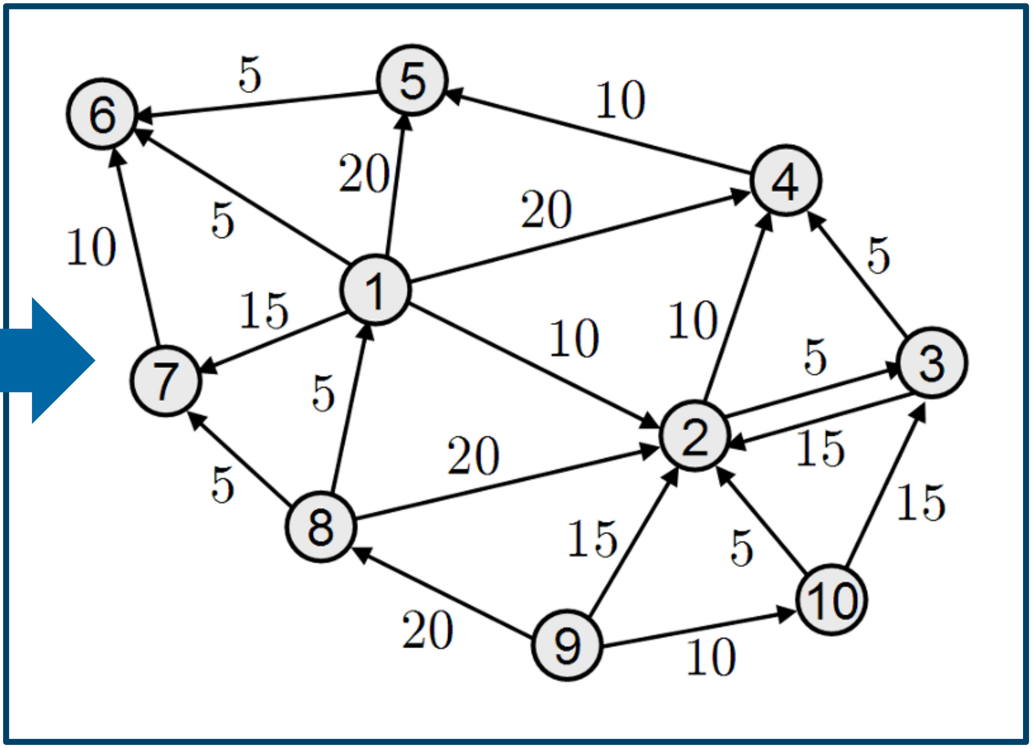
Graph theory provides the mathematical basis to design a network and determine the amount and distance of fiber necessary to connect a set of locations.

Used most frequently to determine relationships and contacts for social networks, graph theory can be applied to a road network to determine the distance between two locations and calculate the shortest route and least costly route between them.

Minnesota's road network serves as potential routes for fiber deployment in the right-of-way. Once locations are labelled according to their service status from service availability data, graph theory can be used to connect unserved areas with served areas and model service extensions from existing infrastructure.

Forming a graph of all routes and all locations throughout the state provides the basis to design a fiber network.

PLANNING FIBER ROUTES WITH GRAPH THEORY



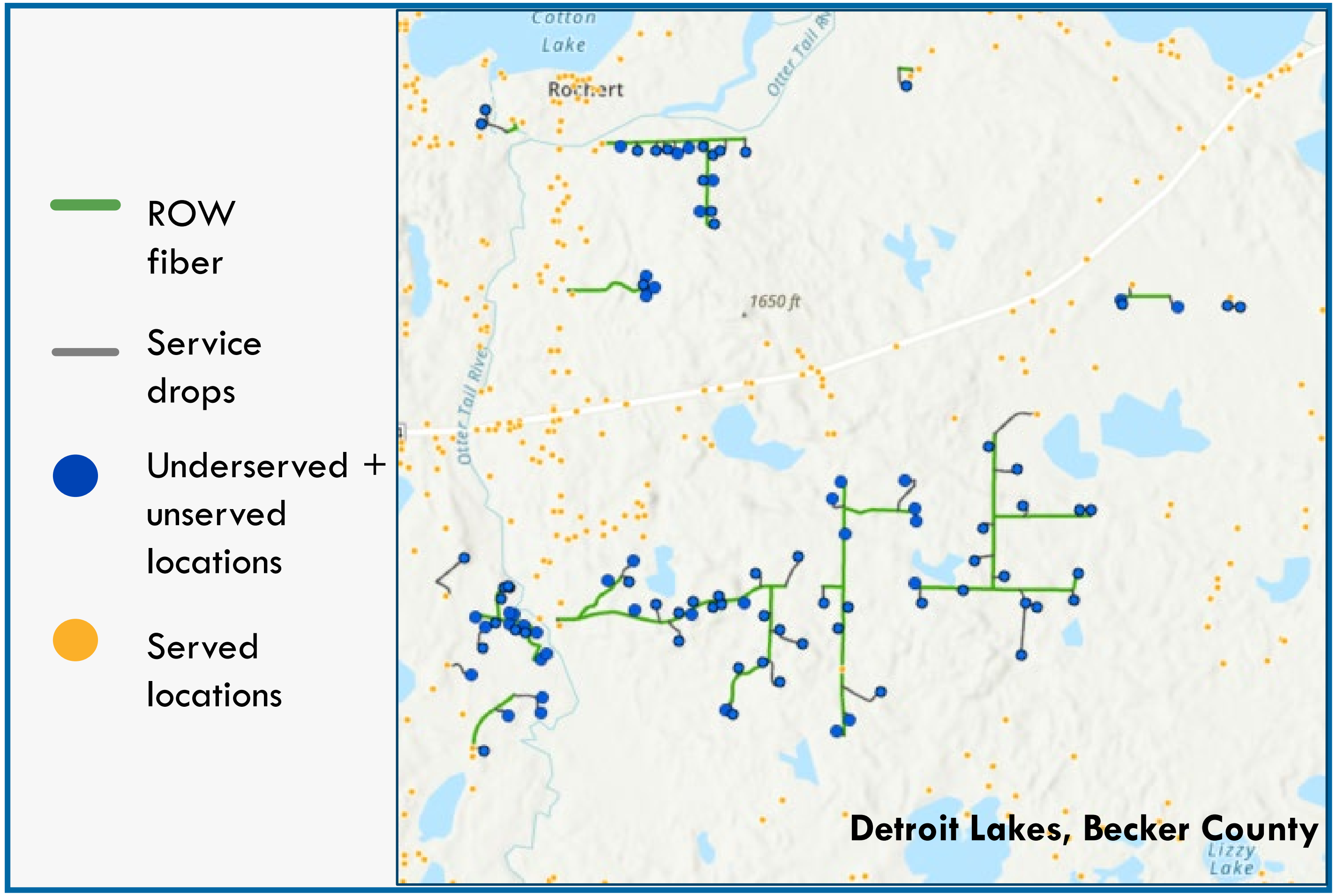
As shown above, locations with their service availability status (represented by white dots in the image on the left above) and potential routes on the road network (red lines) can be converted to a mathematical model (shown in the image on the right) of nodes (shown by the numbered dots) and edges (arrows). This model, which specifies relationships between nodes and edges such as distance and other cost factors, can be used to solve for the most efficient way to connect unserved locations to served areas.

THE MODEL DESIGNS THE MOST EFFICIENT MEANS TO CONNECT TARGET LOCATIONS TO EXISTING INFRASTRUCTURE

The map theory algorithm selects optimal fiber routes from served areas to eligible locations.

The model adds service drops based on distance from road and includes a full range of capital and operating costs.

Cost inputs are based on CTC's engineering and operations experience.



SCENARIO PLANNING

As described in the following slides, key inputs drive the modeling of state-specific deployment scenarios.

- **Broadband Serviceable Locations (BSL):** As a foundation for the analysis, we identified the state's unserved, underserved, and served locations.
- **Areas for analysis:** To provide a more granular basis for estimating costs, we defined analysis areas containing unserved and underserved locations by Census Block Groups, with tribal lands as unique analysis areas.
- **Scenarios for analysis:** In alignment with the state's goals, we defined four potential deployment scenarios for closing the broadband infrastructure gap: 1) universal wireline coverage, 2) BEAD wireline coverage, 3) BEAD broadband coverage, and 4) universal wireless coverage.
- **Physiographic cost regions:** We developed two different regional cost structures to account for variation in deployment costs due to geography and topography.
- **Applicant cost categories:** We generate three cost estimates depending on the type of service provider an applicant represents. These applicant categories have different cost structures that will produce a range of proposal costs from low to high.

UNIVERSAL WIRELINE LOCATION DATASET

Scenario 1 analyzes the cost to serve all locations without wireline coverage.

The Scenario 1 dataset includes locations that are only served by licensed fixed wireless or only served by DSL, as well as those that are unserved and underserved.

The set of locations for Scenario 1 was generated as follows:*

1. Determine service availability from Federal Communications Commission (FCC) Broadband Data Collection (BDC) data for fiber and cable service.

2. Perform deduplication using fiber and cable-based federal grants from the FCC Broadband Funding Map, the Border-to-Border grant program, and the Line Extension grant program.

3. Add the unserved community anchor institutions (CAI) to the unserved and underserved locations after deduplication to create a final list of unserved and underserved locations used as inputs for the model.

*See the "Sources" slide for more information about data sources.

BEAD-ELIGIBLE LOCATION DATASET

Scenarios 2, 3, and 4 analyze costs to serve the state’s unserved and underserved locations.

The dataset for Scenarios 2 and 3 excludes locations that are only served by licensed fixed wireless, which are not eligible locations for the BEAD Program. Scenario 4 uses the same dataset that excludes locations that are already served by licensed fixed wireless because it analyzes the cost to extend fixed wireless coverage.

The set of locations for Scenarios 2, 3, and 4 was generated as follows:*

1. Select unserved and underserved locations using locations with a post-challenge status of “0” or “1” in the post-challenge locations CSV file.
2. Perform deduplication using fiber and cable-based federal and state grants including the Border-to-Border grant program and the Line Extension grant program.
3. Add the unserved community anchor institutions (CAI) to the unserved and underserved locations after deduplication to create a final list of locations entering the model as unserved and underserved.

*See the “Sources” slide for more information about data sources.

ACCOUNTING FOR ENFORCEABLE COMMITMENTS

Deduplication was performed on both datasets to remove locations that have enforceable commitments for service that are not reflected in the data.

Deduplication was performed using fiber- and cable-based federal and state grants including the Border-to-Border grant program and the Line Extension grant program.

Federal grant funding was determined from the FCC Broadband Funding Map for the following programs:*

- Connect America Fund Phase II (CAF-II) (mixed technology grants with fixed wireless were removed)
- Community Connect
- Enhanced Alternative Connect America Cost Model (EACAM)
- Tribal Broadband Connectivity Program (TBCP)
- ReConnect
- Rural Digital Opportunity Fund (RDOF)
- Capital Projects Fund (CPF)

Grants exclusively offering DSL or fixed wireless technology were excluded.

*Project area polygons were evaluated as enforceable commitments for the following federal programs: CAF-II, Community Connect, EACAM, TBCP, ReConnect, and RDOF. Location ID-level data were evaluated for the CPF and TBCP programs (location ID was not available for TBCP program data in several cases). State grants from the Border-to-Border grant program were matched to the address fabric both by Location ID and latitude-longitude. State grants from the Line Extension program were matched to the address fabric both by Location ID and address geocoding.

DEFINING ANALYSIS AREAS

Costs are estimated on a per Census Block Group basis, with tribal lands as unique analysis areas.

Unserved and underserved locations were grouped into 3,218 areas for analysis based on Census Block Groups (CBG), with tribal lands as unique analysis areas.

CBG-level analysis was agreed upon in consultation with DEED because the scale of CBGs offers enough granularity to evaluate differences in location densities and cost expectations throughout the state.

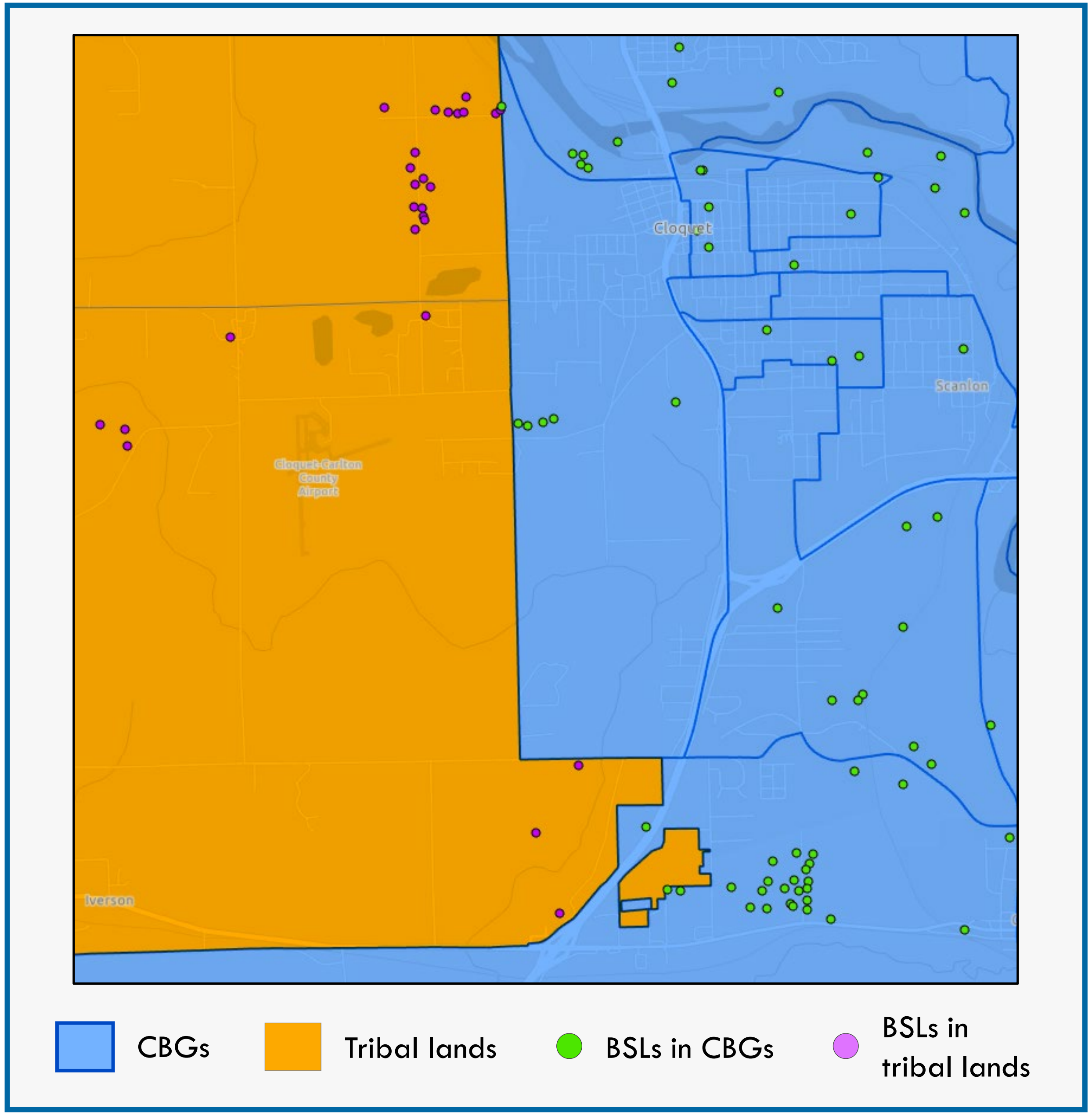
The attached cost data file provides cost estimates for each of the four potential deployment scenarios for each CBG and tribal analysis area.

CONSTRUCTION OF INITIAL ANALYSIS AREAS

A set of comprehensive analysis areas that cover the entire state were created using a base layer of CBGs with the incorporation of tribal lands as unique analysis areas.

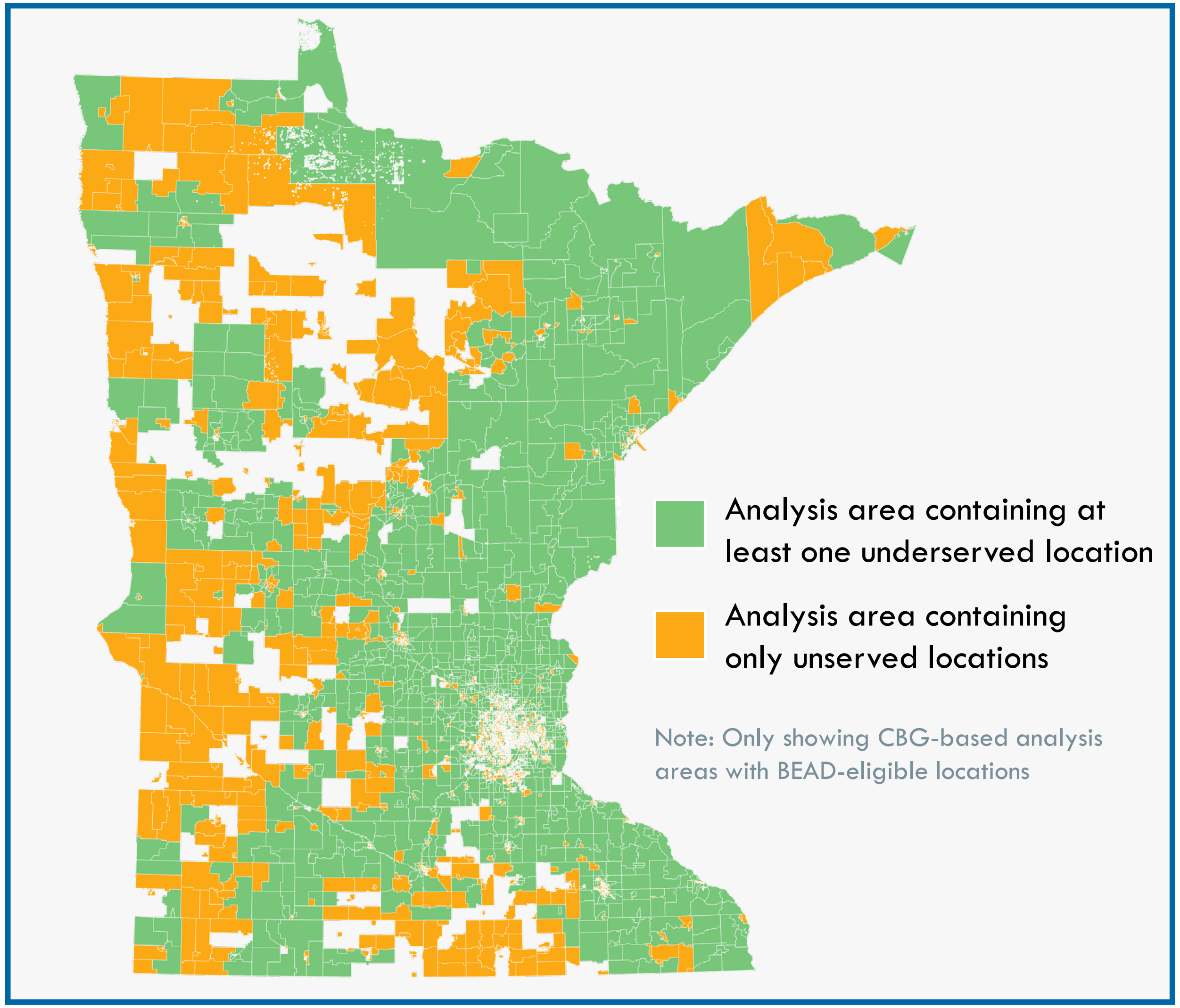
Tribal areas were superimposed on the base layer of CBGs and replaced the CBG areas where they intersected, constituting their own analysis areas.

Many tribes have land that is not contiguous. For this model, each tribe's land was treated as a single analysis area, even if its land was not contiguous. This provides a consistent approach to modeling across the state and provides the option of managing the CBGs separately from tribal land and treating each tribe's land and BSLs as singular entities.



CBG-level analysis is consistent with past NTIA and FCC practices as well as industry practices in planning and building networks.

CBGs range in physical sizes but are comparable in population.



3,218

Analysis areas contain unserved + underserved locations

SCENARIO BREAKDOWN

We analyzed four potential deployment scenarios, based on the locations served and type of technology used.

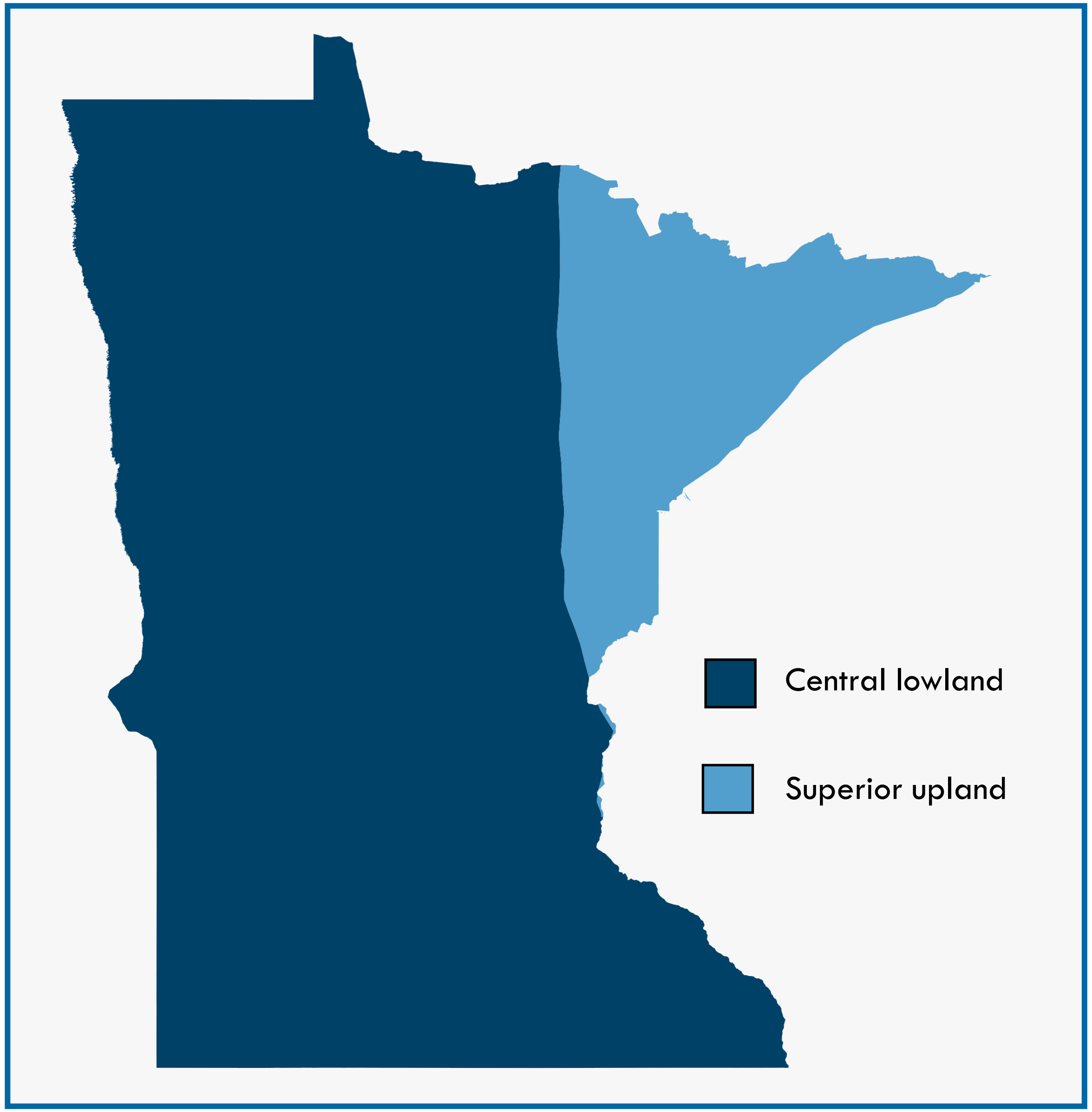
1. **Universal wireline coverage:** This scenario estimates costs to provide wireline infrastructure to all locations not served by a wireline connection.
2. **BEAD wireline coverage:** This scenario estimates costs to provide wireline infrastructure to all BEAD-eligible locations.
3. **BEAD broadband coverage:** This scenario estimates costs to provide broadband infrastructure to all BEAD-eligible locations.
4. **Universal wireless coverage:** This scenario estimates costs to provide fixed wireless broadband infrastructure to all unserved and underserved locations.

PHYSIOGRAPHIC COST REGIONS

Deployment costs will vary across the state due to geographic and topological factors.

CTC's analysis found variation between two "physiographic cost regions" in Minnesota: the Central Lowland and the Superior Upland (shown to the right). The model applies different cost structures to account for this variation.*

Using fiber routes generated by the model, for example, CTC engineers performed a desk survey of routes within the two regions to 1) estimate relative percentages of underground versus aerial construction, and 2) estimate the costs to perform "make-ready" on existing utility poles (both significant factors in the cost of deployment).



*The effective per foot cost of construction is comprised of a different breakdown of aerial vs. underground and a unique per foot cost for make-ready construction derived from CTC's desk survey. We did not vary the other constituent unit prices for labor and materials between regions. The effective per foot cost will vary with each analysis area based on density of that area, which impacts quantities of certain items like handholes, taps, and splices, in addition to the specific physiographic region inputs applied.

APPLICANT COST CATEGORIES

The economics of fiber deployment–and thus projects–depend partially on the type of the applicant.

Applicants to a broadband infrastructure grant program will typically fall into one of three categories, depending on the type of service provider they represent. These categories have different cost structures that will produce a range of proposal costs from low to high:

- *Telco upgrade (low):* An upgrade by an incumbent telecommunications service provider, such as Lumen proposing a fiber-to-the-premises (FTTP) build, typically represents the lowest-cost model due to the applicant's scale and existing infrastructure (e.g., pole attachments and conduit that originated with its copper-line infrastructure).

- *Cable expansion (middle):* A cable operator can typically expand from its current service area at a low cost, although it may not have the same reach of infrastructure to eligible locations as a telco.

- *New entrant/small entity expansion (high):* Deployment by a new entrant or small entity typically represents a higher-cost model given the applicant's lack of scale economics.

Cost estimates were generated for all three applicant categories for each deployment scenario. However, in Minnesota the economics of deployment will, in general, likely be most similar to a cable expansion model. While a grant program could receive a range of proposals for projects in different areas of the state, the cable expansion cost estimate represents a reasonable baseline for statewide analysis and comparison.

LOW- TO HIGH-COST MODELS BASED ON BUILD ASSUMPTIONS

	Telco Upgrade (low)	Cable Expansion (middle)	New Entrant/Small Entity Expansion (high)
Critical cost element	Low upgrade cost given scale & existing infrastructure	Low expansion cost given scale & existing infrastructure	Higher expansion cost given lack of scale economics
Example type of build	Lumen building FTTP while relying on pole attachments and conduit from its copper plant	Cable operators expanding from current service areas	New operator starting local operations, expanding from served areas
Aerial build	Overlash	New attachments on utility poles	New attachments on utility poles
Underground build	Existing conduit	New conduit build	New conduit build
Middle-mile requirements	Existing	Existing	Need for middle-mile bridge
Incremental cost for back-office/CSR	Negligible	Negligible	Modest to high
Scale economics in materials	Very high	Very high	Low to modest

EXTREMELY HIGH COST PER LOCATION THRESHOLD

The EHCPLT determines which locations may be assigned to a technology other than fiber.

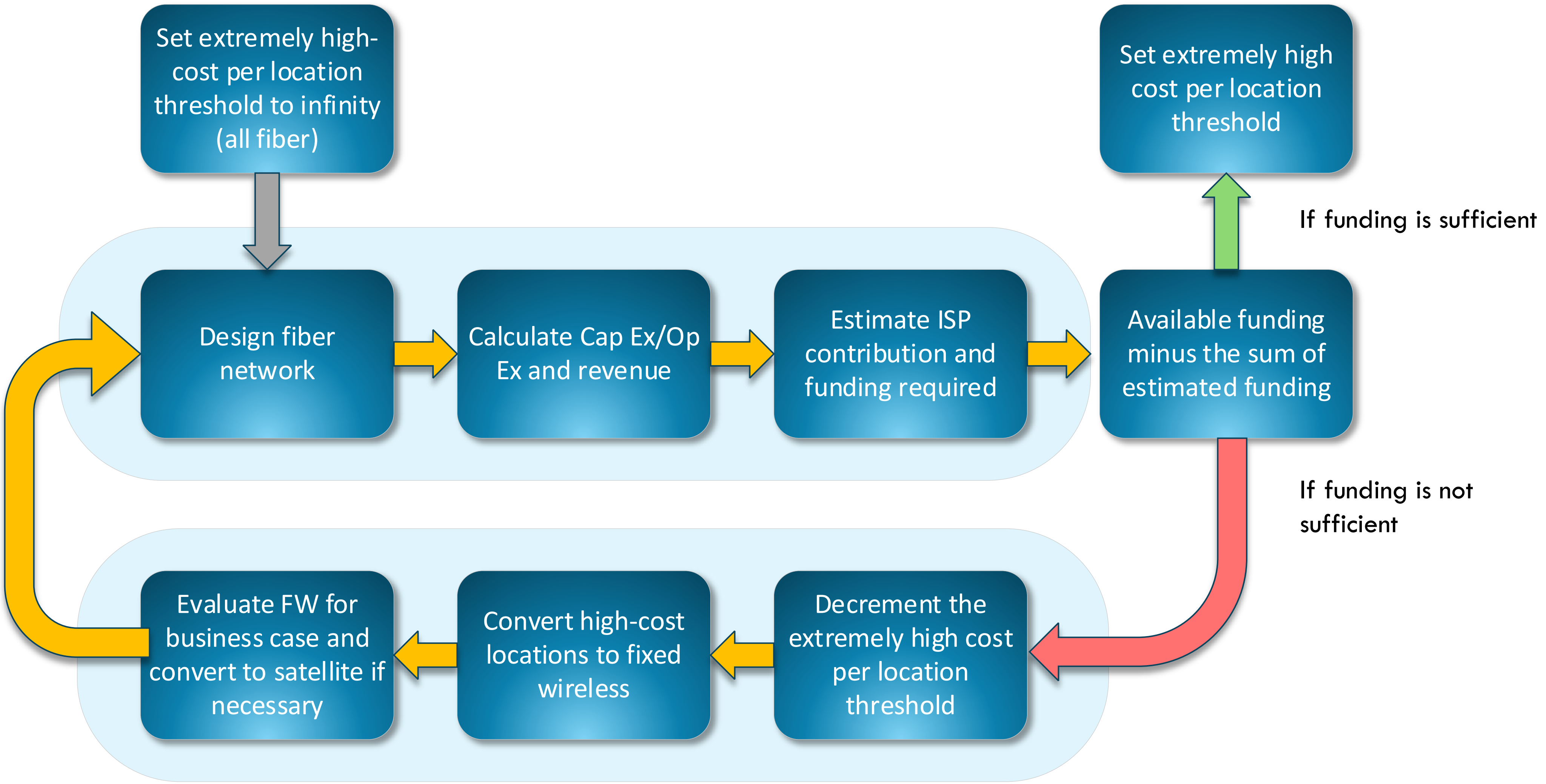
DEED is interested in determining not only the costs for universal fiber coverage (Scenarios 1 and 2), but how much fiber coverage can be achieved with the funding the state has available (Scenario 3). This requires determining the cost threshold at which a location is too expensive to connect with fiber—an Extremely High Cost per Location Threshold (EHCPLT), per the terminology of the BEAD program.

As detailed in the diagram on the following slide, the EHCPLT is determined as follows:

- Design fiber to all locations (i.e., set the threshold to infinity).
- Calculate the costs associated with that network and estimate how much ISPs might contribute to that cost.
- Compare this estimated cost to the state's available funding.
- If the funding is not sufficient, shift the highest-cost percentile of locations to technology other than fiber, generate the new estimated total cost to serve all locations, and compare that cost to the available funding.
- Repeat this process until the point is reached where the estimated cost matches available funding.

This threshold can be used determine the optimal mix of technologies to serve locations within an available budget and maximize fiber coverage.

DETERMINING THE EXTREMELY HIGH COST PER LOCATION THRESHOLD AND THE TECHNOLOGY MIX



THIS PROCESS CAN BE APPLIED BEYOND THE BEAD PROGRAM

The EHCPLT is used to solve for a technology mix within an available budget.

Section 3c of this report uses this process to generate an EHCPLT and technology mix prioritizing fiber based on the state's BEAD allocation.

However, the same approach can be used to solve for an optimal technology mix within any available budget. If the state were to augment BEAD funding with additional funding, for example, the same process could be applied to solve for the technology mix within that budget.

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2.2 GENERATING WIRELESS NETWORK DESIGN COST INPUTS

WIRELESS NETWORK DESIGN

Potential coverage was modeled based on existing tower infrastructure to develop a wireless site design.

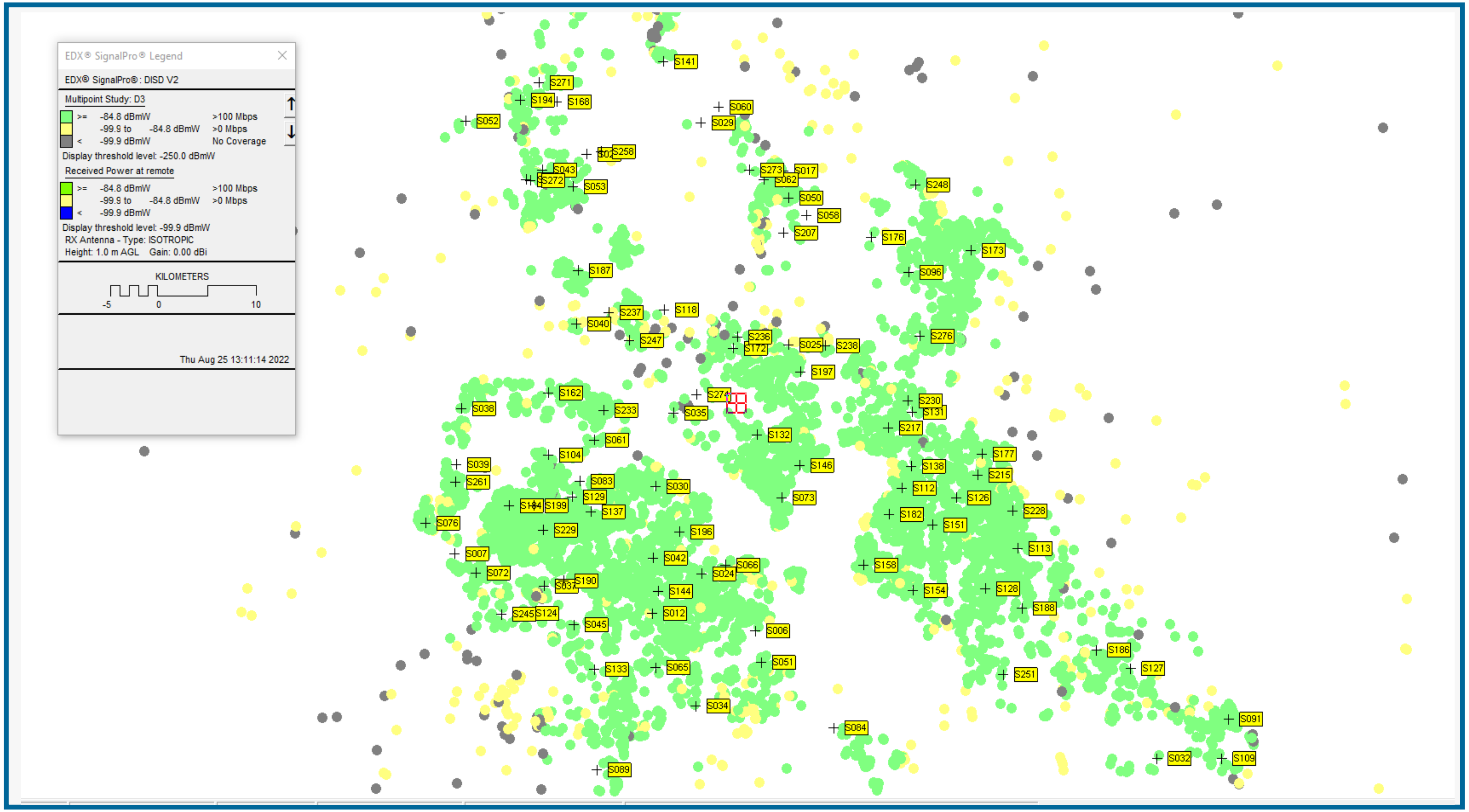
To generate inputs for financial modeling of wireless scenarios, we designed wireless service based on the locations of existing towers and best in class radio frequency (RF) propagation models, and derived a wireless cost based on the tower area cost and number of connected locations.*

Potential coverage using a five-meter digital terrain and clutter database was modeled across unserved and underserved locations based on existing tower infrastructure. Under Scenario 4 (BEAD broadband coverage), the EHCPLT process was used to determine which locations are too costly to serve with fiber and are assigned to fixed wireless. Based on this remaining list of high-cost locations, a site selection algorithm was used to determine the minimum number of tower sites required to cover those locations and develop a wireless site design.

*For additional details on the assumptions underlying the wireless analysis, see "Appendix: Additional Details on Methodology."

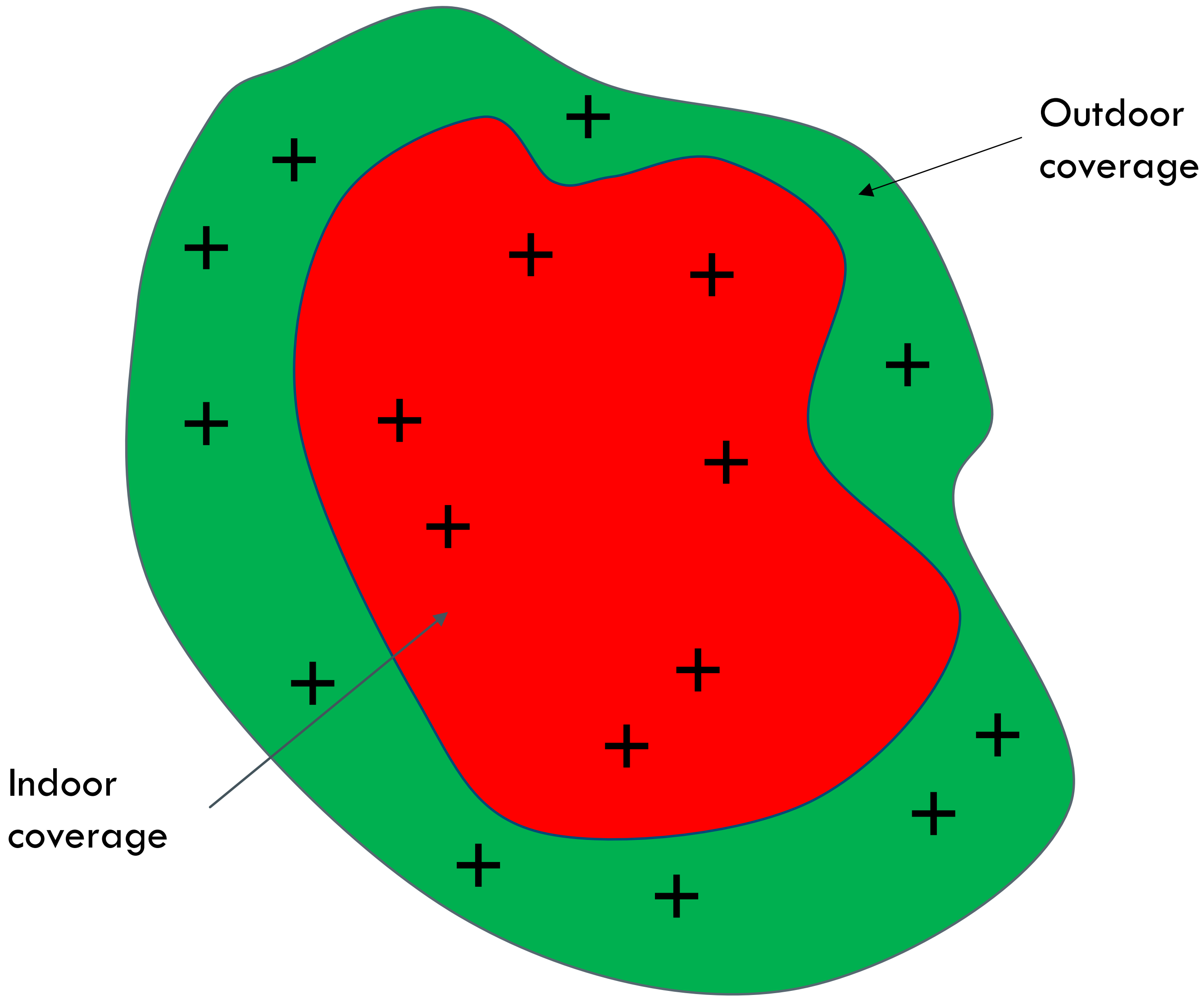
Propagation analyses were calculated from each tower to each unserved and underserved location.

In the example shown to the right, green indicates areas with sufficient signal strength for indoor coverage, while yellow indicates locations with outdoor coverage. Black dots indicate locations with no coverage.



Locations with outdoor coverage that need an external antenna are more costly than locations that have a strong enough signal for indoor coverage.

The model distinguishes which connections need to have an external antenna based on signal intensity.



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2.3 ESTIMATING COSTS FROM NETWORK DESIGN INPUTS

FIBER COST MODEL OVERVIEW

The cost model combines area-specific fiber designs and cost metrics to produce estimates of capital deployment costs.

Designs for each analysis area produce area-specific inputs for the cost model

- Fiber route miles
- Number of passings
- Average service drop length

Desk survey of statistically valid sampling of network routes produces inputs applied to all analysis areas within a particular physiographic region

- Percentage of aerial versus underground route mileage
- Utility pole make-ready requirements (percentage of poles requiring make-ready, number of existing attachment relocations required per pole, percentage of pole replacements)

Generates cost estimates per analysis area based on specific design and survey inputs

- Applies unit pricing for labor, materials, and equipment estimated based on recent regional project data
- Includes cost components that vary with linear distances and serviceable passings (density-dependent)

Key outputs include:

- Total fiber distribution plant construction cost
- Core equipment cost per passing
- Distribution equipment cost per customer
- Average cost of service drops and CPE per customer

FIXED WIRELESS COST MODEL OVERVIEW

The cost model combines area-specific designs and cost metrics to produce estimates of capital deployment costs.

Designs for each analysis area produce tower-specific inputs for the cost model

- Plant footage for extension from BEAD FTTP routes to fixed wireless towers
- Site selection and dimensioning
- Number of total passings covered and type of CPE required (indoor versus outdoor)

Incorporates backhaul costs based on tower-specific requirements

- Uses outputs of fiber cost model to estimate applicable backhaul fiber costs
- Incorporates applicable network equipment and installation costs for fiber or point-to-point, licensed wireless backhaul

Generates cost estimates per analysis area based on specific design inputs

- Applies unit pricing for labor, materials, and equipment estimated based on recent regional project data
- Includes cost components that vary with type and quantity of CPE (indoor versus outdoor) based on RF coverage analysis

FIBER AND WIRELESS FINANCIAL MODELS

The financial model combines outputs of the cost model with estimated operating costs and financial assumptions to project grant funding required on per analysis area basis.

The financial model produces a 20-year cash flow statement for each analysis area, combining:

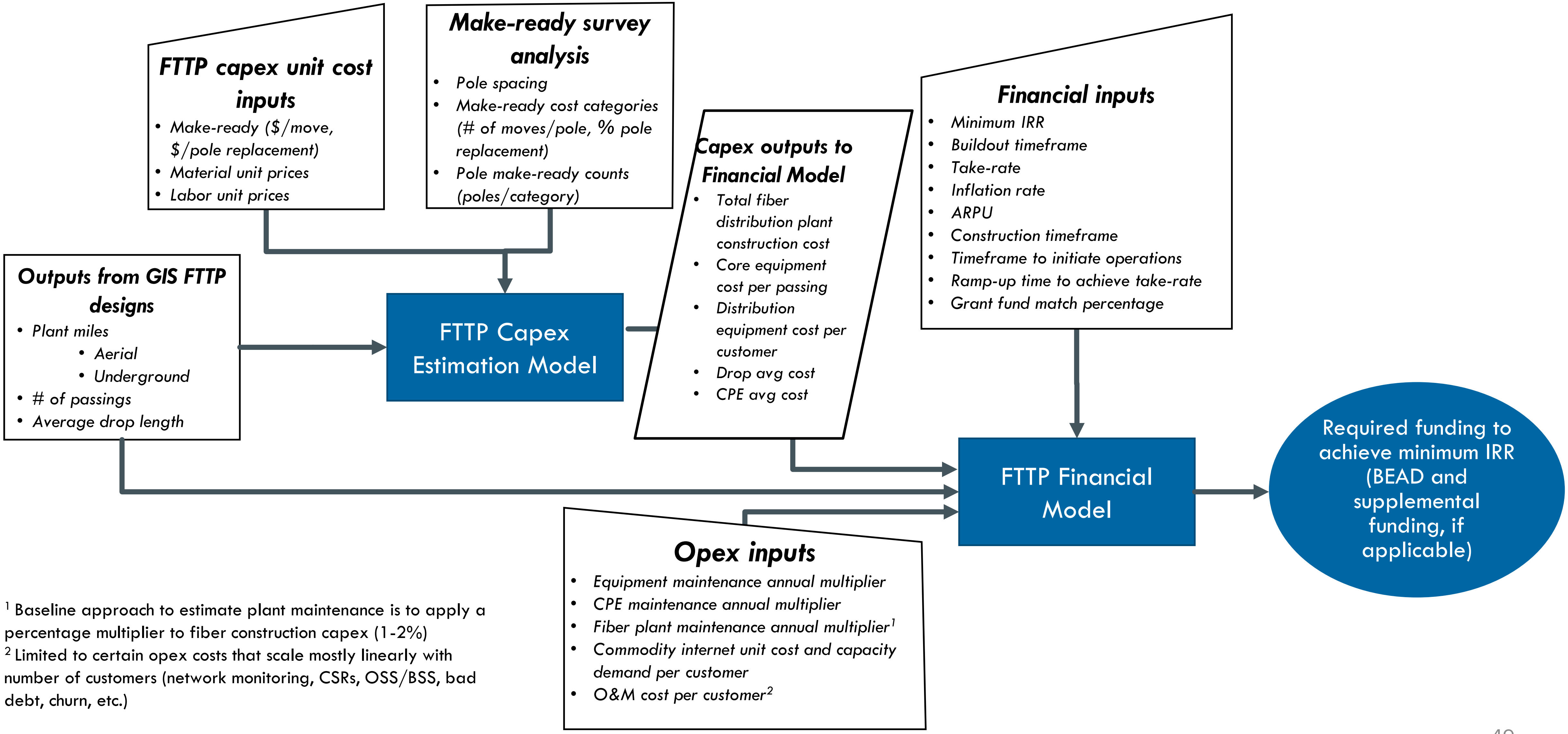
- Capital cost estimates
- Operating and maintenance cost estimates
- Financial assumptions around revenues (take-rate and ARPU) and inflation
- Timeline assumptions around buildout and operations ramp-up

It determines the amount of grant funding revenue, applied against eligible expenses on a reimbursement basis, required to achieve a minimum target IRR.

- Used a target IRR of 8 percent
- Requires matching funds of 25 percent
- Assumes expenditure of grant fundings and matching funds proportionately

The model is applied per analysis area for both fiber and fixed wireless technologies separately.

FTTP FINANCIAL MODEL



[1] Baseline approach to estimate plant maintenance is to apply a percentage multiplier to fiber construction capex (1-2%)

[2] Limited to certain opex costs that scale mostly linearly with number of customers (network monitoring, CSRs, OSS/BSS, bad debt, churn, etc.)

FIXED WIRELESS FINANCIAL MODEL

Outputs from RF fixed wireless designs

- *Plant footage for extension from BEAD FTTP routes to fixed wireless towers*
- *Site selection and dimensioning*
- *# of total passings covered*
  - *Indoor CPE*
  - *Outdoor CPE*

Fixed wireless capex cost inputs

- *RAN hardware and installation costs per tower*
- *Wireless core network equipment incremental cost per RAN*
- *Wireless backhaul equipment and installation costs per tower*
- *CPE unit costs*
  - *Indoor CPE*
  - *Outdoor CPE*

Capex outputs from FTTP Capex Estimation Model

- *Average fiber construction cost per foot (blended aerial / underground based on FTTP Capex Estimate Model inputs)*

Financial inputs

- *Minimum IRR*
- *Buildout timeframe*
- *Take-rate*
- *Inflation rate*
- *ARPU*
- *Construction timeframe*
- *Timeframe to initiate operations*
- *Ramp-up time to achieve take-rate*
- *Grant fund match percentage*
- *Monthly or capitalized tower lease selection / discount rate for capital lease calculation*

Opex inputs

- *Tower lease monthly cost*
- *Equipment maintenance annual multiplier*
- *CPE maintenance annual multiplier*
- *Fiber plant maintenance annual multiplier*[1]
- *Commodity internet unit cost and capacity demand per customer*
- *Backhaul leased circuit cost*
- *Technical / engineering staffing cost per tower*
- *O&M cost per customer*[2]

Fixed Wireless Financial Model

Required funding to achieve minimum IRR (BEAD and supplemental funding, if applicable)

[1] Baseline approach to estimate plant maintenance is to apply a percentage multiplier to fiber construction capex (1-2%)

[2] Limited to certain opex costs that scale mostly linearly with number of customers (network monitoring, CSRs, OSS/BSS, bad debt, churn, etc.)

2.4 CONSIDERING EXISTING INFRASTRUCTURE AND ENVIRONMENTAL CHALLENGES

EXISTING INFRASTRUCTURE

The model assumes broadband will expand from existing infrastructure including backbone/middle-mile fiber and leverage existing infrastructure where possible.

Like other states, Minnesota has a range of backbone and middle-mile networks. These are provided by companies including the major incumbent local exchange carriers and Fiber Minnesota. The model considers backbone and middle-mile costs by incorporating recurring costs into the operational budget and a capital cost to extend fiber to the new service area. Because this is a statewide aggregate model and different subgrantees will address connectivity in different ways, it does not link each individual area to specific middle-mile routes, but estimates costs based on industry averages.

The model estimates percentages of aerial and underground outside cable plant based on a photometric desk survey and includes the cost of right-of-way permitting, make-ready, and pole replacement in capital costs. It includes pole attachment fees in the operational costs.

ENVIRONMENTAL CHALLENGES AND RESILIENCY

Cost projections include costs for resilient facilities and fiber networks built to robust industry standards.

Broadband networks face risks from traditional sources including weather and accidents, with weather potentially becoming more severe as climate changes. Network infrastructure such as critical cabinets and interconnection points need to be in secure facilities away from flood areas and have sufficient backup power. New infrastructure should limit as much as possible any remote power supplies, which potentially fail in extended outages.

Key best practices include identifying and managing potential single points of failure in a network. Routes serving hundreds of locations or more need to have physically redundant paths, whether underground or aerial. Broadband providers should analyze the history of failure from storms or accidents of potential routes and consider underground construction in highly-impacted areas.

By prioritizing fiber broadband over other technologies, the state is increasing resiliency by building infrastructure that minimizes outdoor power supplies, is less susceptible than copper or cable to corrosion or breakage, and provides capacity both for fiber-to-the-premises and expanded mobile broadband, which can serve as a backup broadband option.

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3. WIRELINE COVERAGE SCENARIOS COULD REQUIRE A RANGE OF GRANT FUNDING FROM $2.1 BILLION TO $628 MILLION, WITH $35 MILLION REQUIRED FOR A UNIVERSAL WIRELESS SCENARIO

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3.1 SCENARIO 1: UNIVERSAL WIRELINE COVERAGE WOULD REQUIRE AN ESTIMATED $2.1 BILLION IN GRANT FUNDING

UNIVERSAL WIRELINE COVERAGE

Scenario 1 estimates the costs to provide wireline infrastructure to all locations not served by a wireline connection.

Providing universal fiber coverage to all locations in the state that lack a wireline connection is estimated to require more than $2 billion in grant funding from the state—more than **three times** the funding allocated to the state through the BEAD Program.

The following slides summarize the cost estimates and key findings for this scenario. Detailed cost estimates for each analysis area are provided in the attached cost data file.

ESTIMATED COSTS FOR 100 PERCENT FIBER STATEWIDE

100% fiber to

193,000 passings

Estimated 5-year total investment needed

$2.8B

Estimated 5-year grant funding required

$2.1B

SUMMARY OF INVESTMENT NEEDED

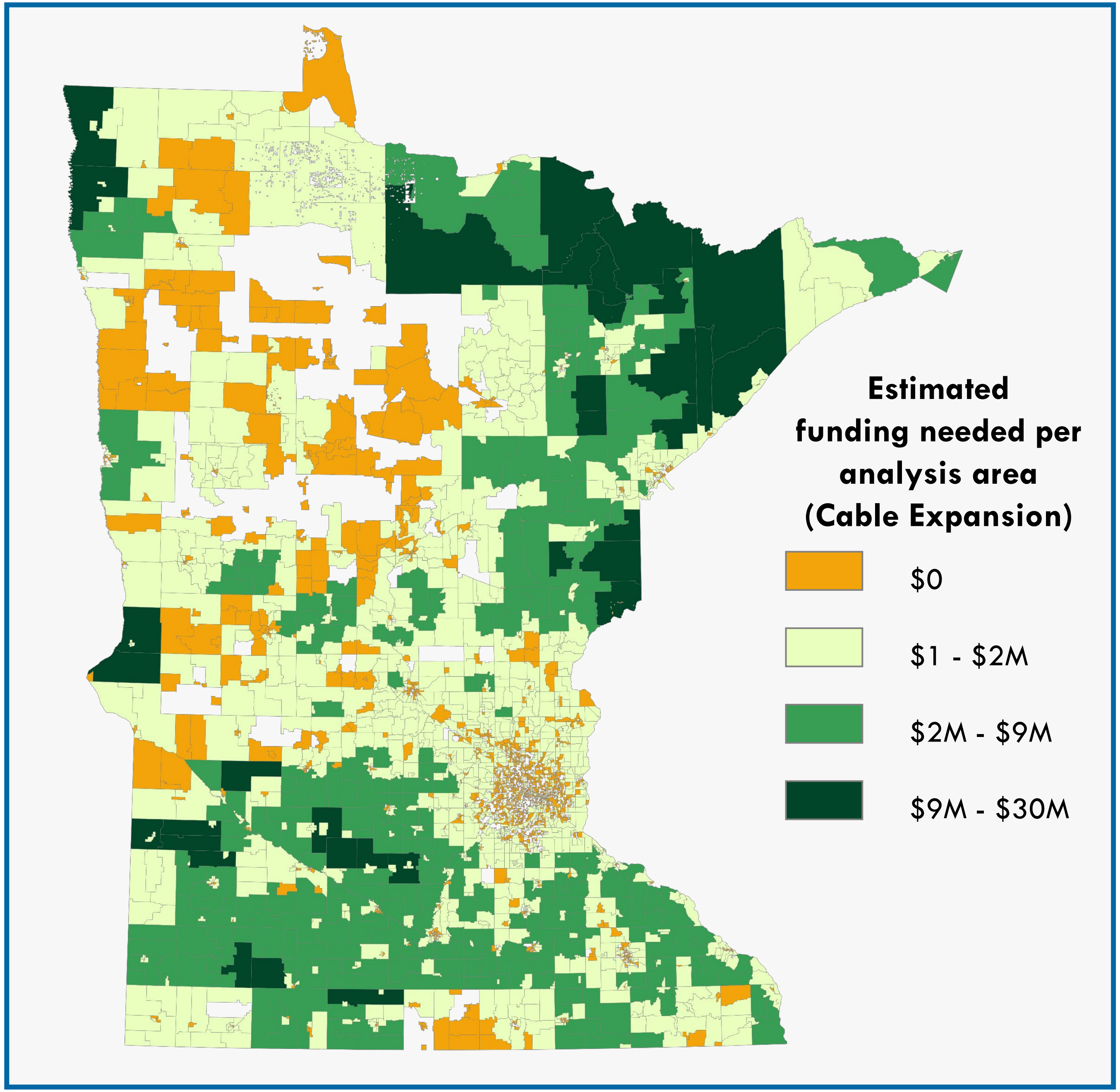
Cost model	Electronics/RAN	CPE	Drops	OSP	Total
Telco Upgrade	$60M	$85M	$190M	$1.9B	$2.2B
Cable Expansion	$55M	$70M	$230M	$2.4B	$2.8B
New Entrant	$55M	$70M	$230M	$2.4B	$2.8B

GRANT FUNDING REQUIRED FOR 100% FIBER

Cost model	5-year investment needed (exclusive of operational costs)	5-year grant funding
Telco Upgrade	$2.2B	$1.4B
Cable Expansion	$2.8B	$2.1B
New Entrant	$2.8B	$2.5B

ACHIEVING 100 PERCENT FIBER COVERAGE WOULD REQUIRE AN ESTIMATED $2.1 BILLION IN TOTAL GRANT FUNDING, IN ADDITION TO PROJECTED MATCH

The map to the right shows the distribution of grant funding required across the state, by CBG-based analysis area, to achieve 100 percent fiber connectivity. Areas colored white contain no unserved or underserved locations.

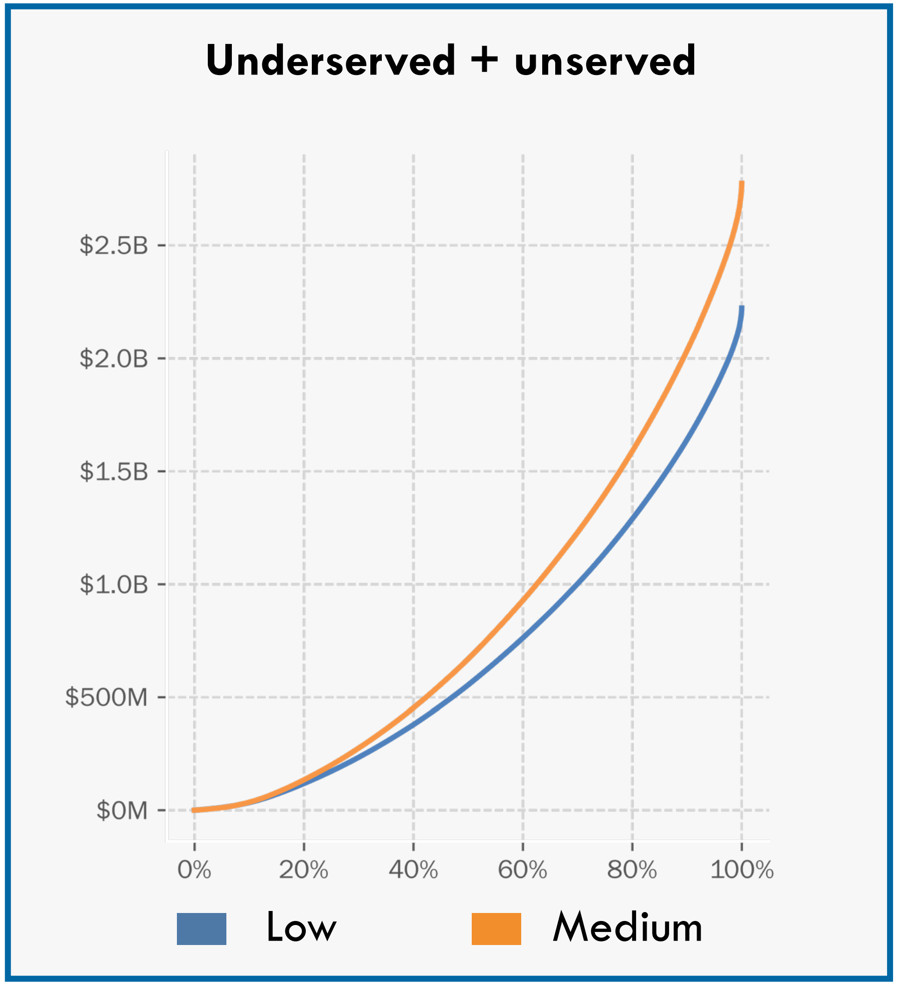


Note: Only showing CBG-based analysis areas with BEAD-eligible locations

HIGHEST COST 1% OF PASSINGS ACCOUNT FOR 6% OF TOTAL COST

The highest-cost locations significantly impact the overall cost: 10 percent of unserved and underserved passings account for 30 percent of the total investment needed.

Percentile of passings	% of total investment needed	Estimated funding/passing	Funding required
1%	6%	> $64,000	$190M (9%)
4%	16%	> $39,000	$460M (22%)
8%	25%	> $30,000	$730M (35%)
10%	30%	> $28,000	$860M (41%)



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3.2 SCENARIO 2: WIRELINE COVERAGE TO ALL BEAD-ELIGIBLE LOCATIONS WOULD REQUIRE AN ESTIMATED $1.1 BILLION IN GRANT FUNDING

BEAD WIRELINE COVERAGE

Scenario 2 evaluates the costs to provide wired infrastructure to all BEAD-eligible locations.

Providing fiber coverage to all BEAD-eligible locations would require an estimated $1.1 billion in grant funding—significantly exceeding the state's BEAD allocation, although a lower cost than achieving universal wireline coverage (Scenario 1).

The following slides summarize the cost estimates and key findings for this scenario. Detailed cost estimates for each analysis area are provided in the attached cost data file.

ESTIMATED COSTS FOR 100 PERCENT FIBER STATEWIDE TO BEAD-ELIGIBLE LOCATIONS

100% fiber to

99,000 passings

Estimated 5-year total investment needed

$1.5B

Estimated 5-year grant funding required

$1.1B

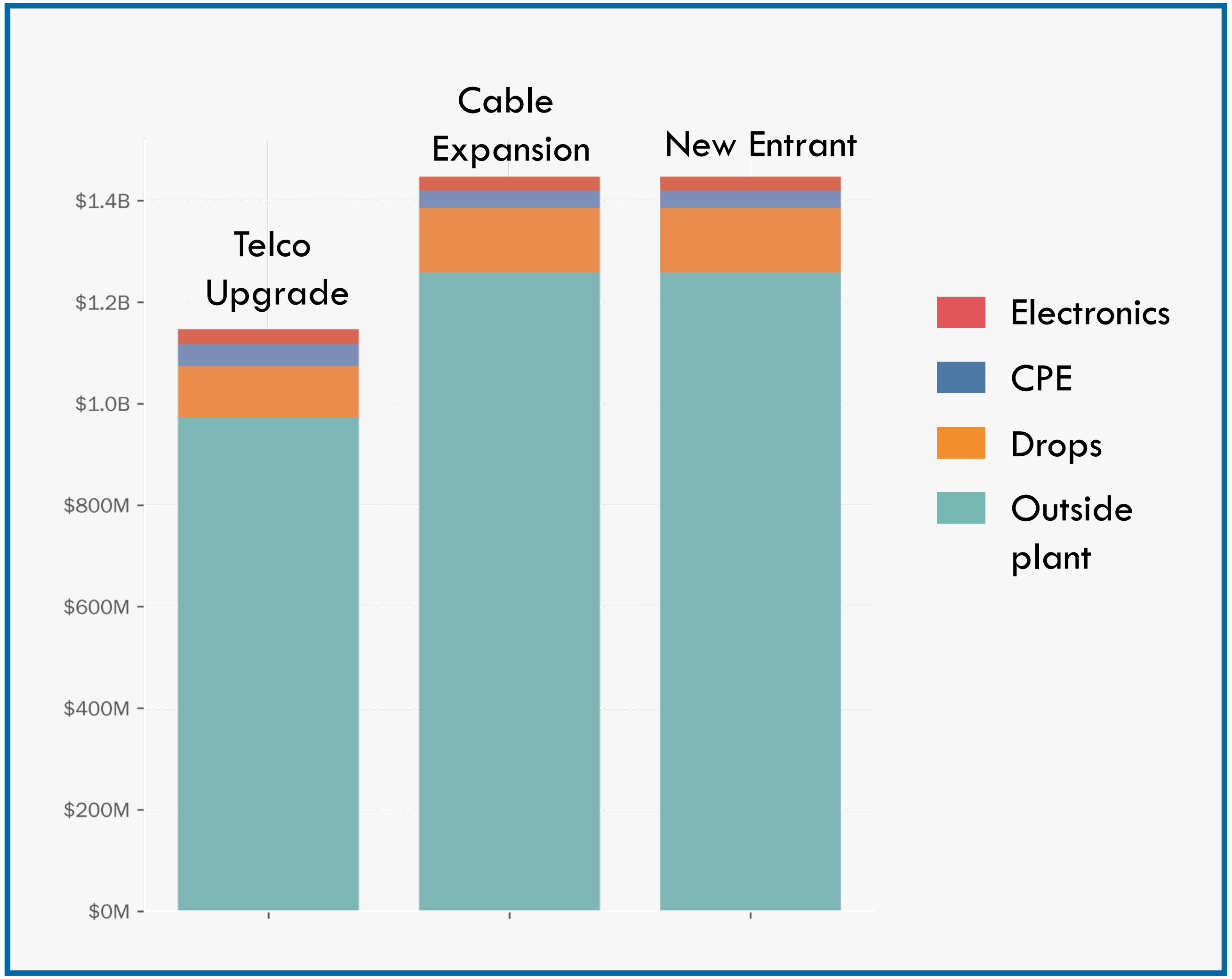
SUMMARY OF INVESTMENT NEEDED

Cost model	Electronics/ RAN	CPE	Drops	OSP	Total
Telco Upgrade	$30M	$45M	$110M	$1.0B	$1.2B
Cable Expansion	$30M	$35M	$130M	$1.3B	$1.5B
New Entrant	$30M	$35M	$130M	$1.3B	$1.5B

GRANT FUNDING REQUIRED FOR 100% FIBER

Cost model	5-year investment needed (exclusive of operational costs)	5-year grant funding
Telco Upgrade	$1.2B	$700M
Cable Expansion	$1.5B	$1.1B
New Entrant	$1.5B	$1.4B

FIVE-YEAR FIBER INVESTMENT NEEDED



As shown in the figure to the left, the estimated total investment needed is notably lower in a telco upgrade model primarily due to a telco's ability to leverage its existing infrastructure to reduce outside plant costs.

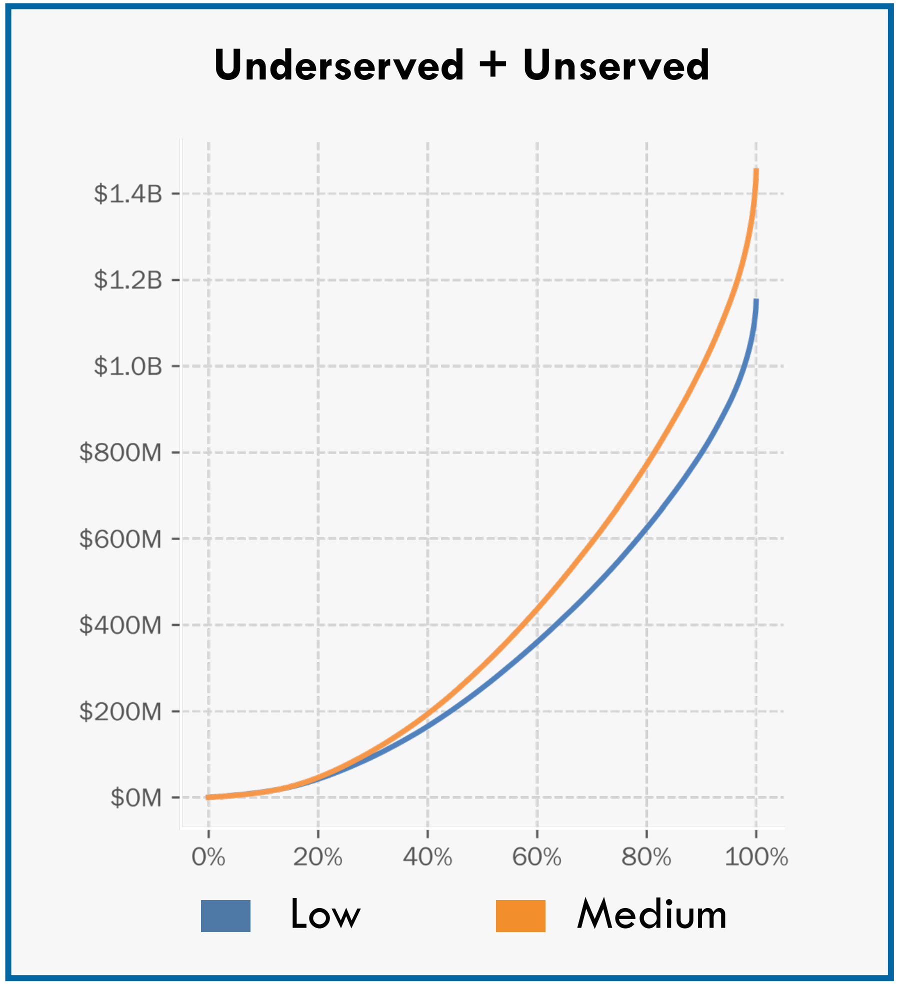
New fiber attachments, make-ready, pole replacement, and new conduit make up more than $290 million of the difference between a telco upgrade and cable expansion model.*

* Note that the ramp up to a 70 percent take-rate will take longer than the five-year deployment period; in this scenario, BEAD funds will fund a 66.5 percent take-rate within the five-year deployment time for the telco upgrade model, and 52.5 percent for the cable expansion model.

HIGHEST-COST 1% OF PASSINGS ACCOUNT FOR 7% OF TOTAL

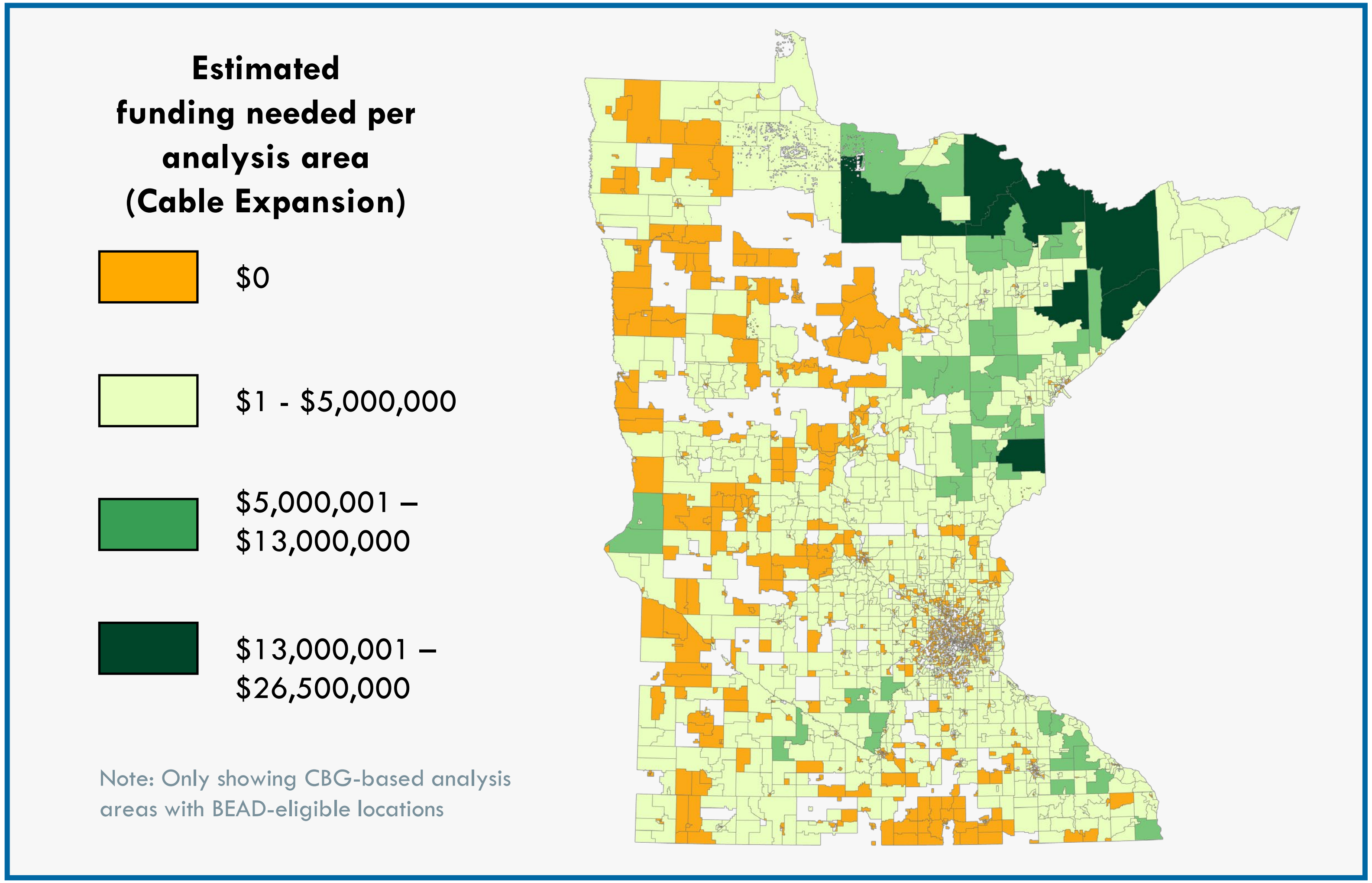
As in Scenario 1, the highest-cost passings have an outsize impact on the overall total: 12 percent of unserved and underserved passings account for 40 percent of the total investment needed.

Percentile of passings	% of total investment needed	Estimated funding/passing
1%	7%	> $140,000
4%	20%	> $50,000
7%	30%	> $35,000
12%	40%	> $25,000

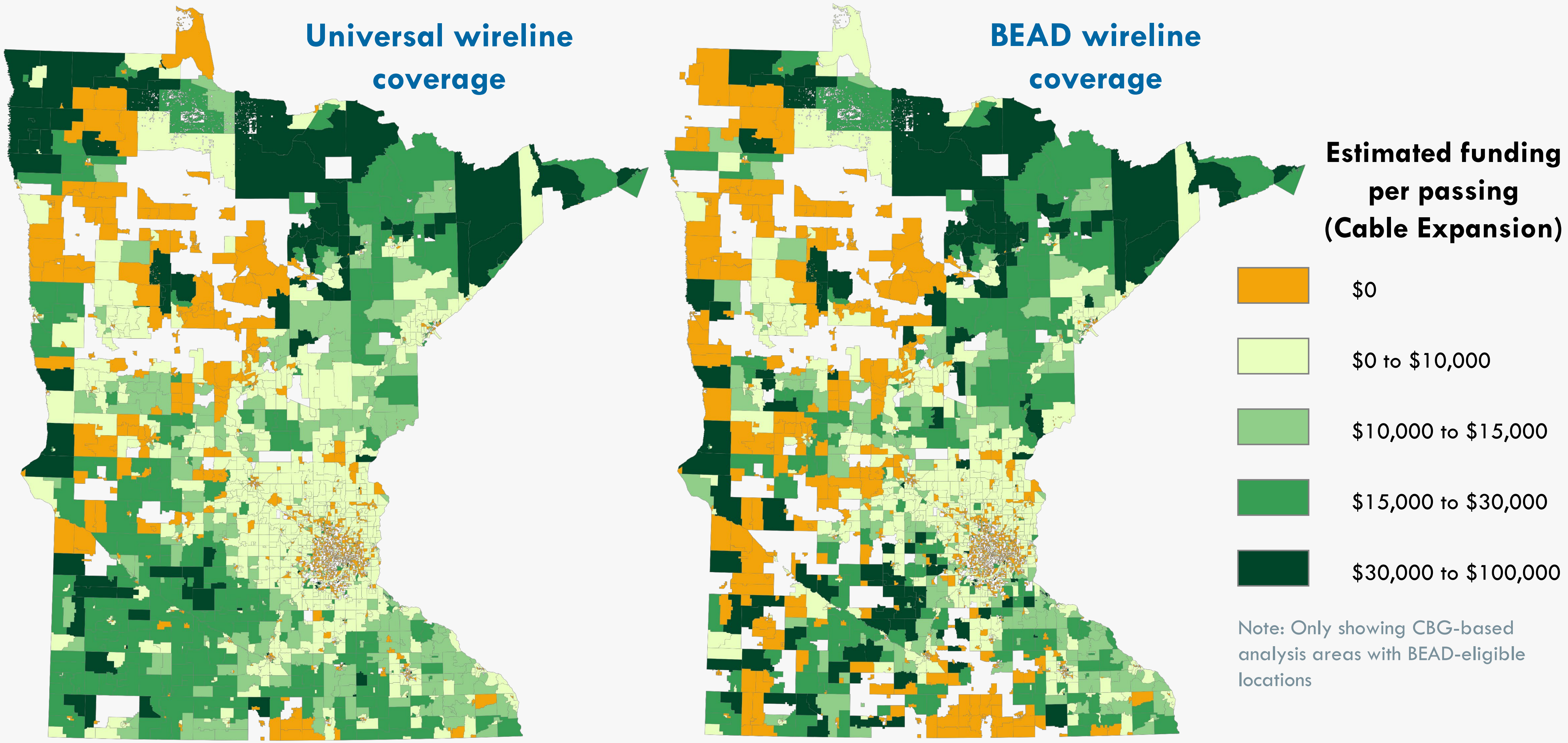


100% FIBER REQUIRES $1.1 BILLION IN TOTAL GRANT FUNDING, IN ADDITION TO PROJECTED MATCH

The map to the right shows the distribution of grant funding required across the state, by CBG-based analysis area.



COMPARING AVERAGE GRANT FUNDING REQUIRED PER PASSING FOR UNIVERSAL WIRELINE AND BEAD WIRELINE COVERAGE



Note: Only showing CBG-based analysis areas with BEAD-eligible locations

GRANT FUNDING REQUIRED PER PASSING MAY DECREASE IN SOME AREAS IN A UNIVERSAL WIRELINE SCENARIO

In both scenarios, the highest costs per passing are in the lowest-density areas generally located in the more remote and less served areas of the state.

The maps on the previous slide compare the estimated average grant funding required per passing by CBG-based analysis area for the universal wireline and BEAD wireline scenarios. As shown, while including more locations in the universal wireline scenario raises the total estimated funding required, the funding required per passing may decrease in some areas because of the increased density of locations passed.

The highest-cost locations (represented by the analysis areas shaded in dark green) are generally located in the more remote areas of the state and areas that lack existing service.

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3.3 SCENARIO 3: BROADBAND COVERAGE TO ALL BEAD-ELIGIBLE LOCATIONS COULD BE ACHIEVED FOR $628 MILLION THROUGH A TECHNOLOGY MIX INCLUDING 90 PERCENT FIBER

BEAD BROADBAND COVERAGE

Scenario 3 evaluates the costs to provide broadband infrastructure to all BEAD-eligible locations.

As demonstrated by Scenario 2, the estimated cost to deploy fiber to all BEAD-eligible locations in Minnesota exceeds the state's BEAD allocation. Therefore, this scenario develops an optimized mix of fiber, fixed wireless, and satellite technology, with a preference for fiber, to serve the post-challenge BEAD-eligible locations based on the state's BEAD allocation.

According to the rules of the BEAD Program, the state must prioritize funding for end-to-end fiber projects, followed by those that deliver qualifying other Reliable Broadband Service (i.e., cable, DSL, or licensed fixed wireless delivering at least 100/20 Mbps), and may fund Alternative Technologies (e.g., unlicensed fixed wireless and low earth orbit (LEO) satellite)* where the cost to deploy Reliable Broadband Service exceeds a subsidy cost per location defined by the state as its Extremely High Cost Per Location Threshold (EHCPLT).**

The following slides summarize the cost estimates and key findings for this scenario. Detailed cost estimates for each CBG-based analysis area are provided in the attached cost data file.

*Alternative technologies must meet the BEAD technical requirements, including delivering speeds of at least 100/20 Mbps.
**See, Reliable Broadband Service & Alternative Technologies Guidance, NTIA, https://broadbandusa.ntia.gov/sites/default/files/2024-01/BEAD_Reliable_Broadband_Service_Alternative_Technologies_Guidance.pdf; Proposed BEAD Alternative Broadband Technology Guidance, NTIA, https://broadbandusa.ntia.gov/sites/default/files/2024-08/Draft_BEAD_Alternative_Broadband_Technology_Policy_Notice_for_Public_Comment.pdf.

TECHNOLOGY MIX

The state could reach more than 90 percent of BEAD-eligible passings with fiber.

Based on our analysis, the following mix of technologies maximizes fiber coverage while achieving universal coverage for BEAD-eligible passings within the state's BEAD allocation:

- 90 percent fiber
- 8 percent satellite
- 1 percent fixed wireless

This distribution assumes an EHCPLT of $30,000, above which the state's highest-cost locations are assigned to fixed wireless or satellite, if an area is not likely to support a business case for fixed wireless.

Analysis using a cable expansion model indicates a wide range of fiber deployment, from 0 percent to 100 percent, with lower percentages occurring more frequently in the northern and southwestern portions of the state.

Fixed wireless technology is well-suited for areas with moderate population density that lack the dense clusters necessary to establish a strong business case for fiber deployment.

Serving 8 percent of BEAD-eligible passings with satellite would result in approximately 0.5 percent of all passings in Minnesota receiving satellite (including passings that are currently served).

OPTIMIZED MIX OF TECHNOLOGIES TO MEET REQUIREMENT OF 100% SERVICE WITHIN BEAD BUDGET

The following table summarizes the technology mix calculated to optimize the state's use of its BEAD funding, based on a cable expansion cost model. Estimated funding is exclusive of match but assumes the match expected from ISPs based on the business case.

99,000 Unserved + Underserved

Estimated 5-year total investment needed	EHCPLT	% FW
$950M	$30,000	1%
Estimated 5-year grant funding required	**% Fiber**	**% Satellite****
$628M*	90%	8%

*$628 million represents the state's total BEAD funding allocation minus administrative expenses.

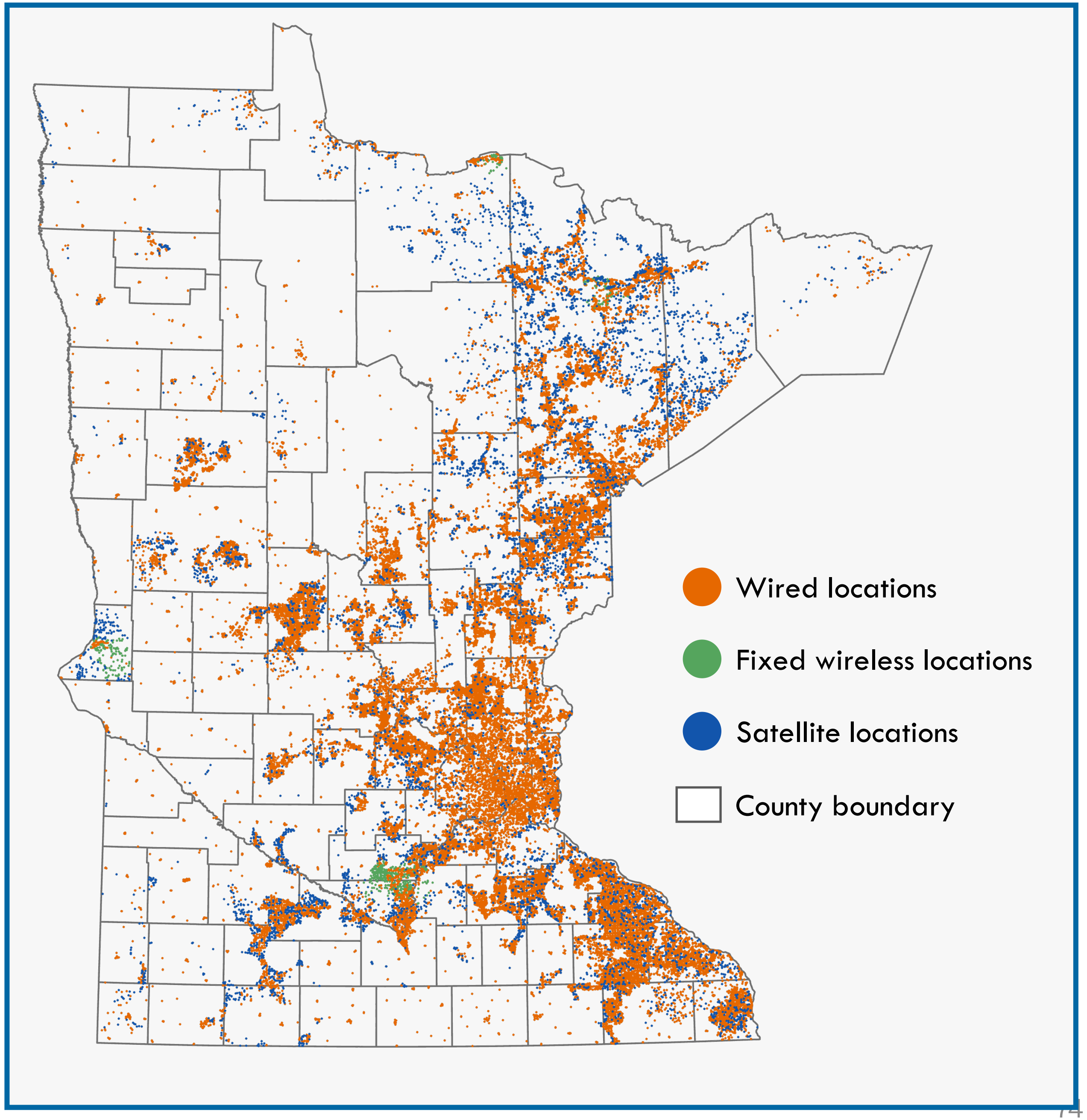
**Satellite estimates assume a cost per passing of $1,250, which includes the external antenna, cabling from the antenna to indoor equipment, and labor for installation; and does not include the recurring monthly cost of service.

THE MODEL DESIGNS FIBER IN MODERATE DENSITY AREAS, FIXED WIRELESS IN LOW DENSITY AREAS WHERE IT IS COST-EFFECTIVE, AND SATELLITE FOR REMAINDER

The model selects fiber for locations wherever there exists a positive business case for it. Fixed wireless is selected only in the areas in which fiber is not financially viable but there exists a business case for fixed wireless, which represents a relatively narrow window in the financial model because the cost of fixed wireless with sufficient capacity and coverage, using licensed technology, is also high in most cases.

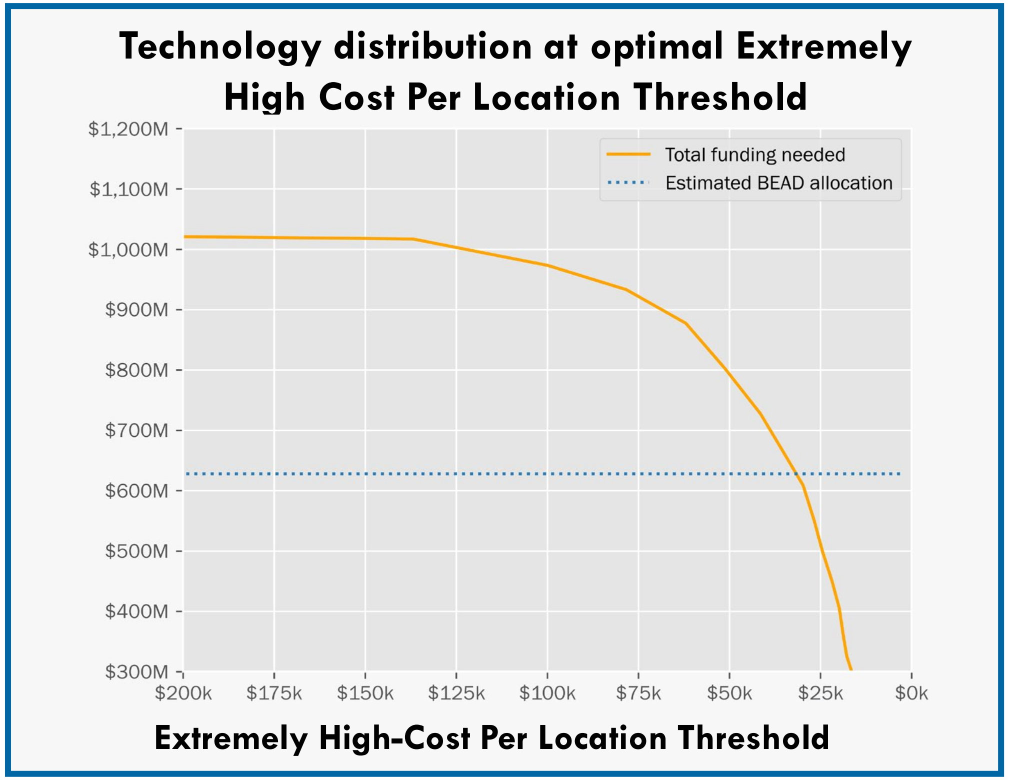
The locations that are too expensive to serve with fiber are generally not in dense enough clusters to support a fixed wireless business case as the densest areas are served with fiber.

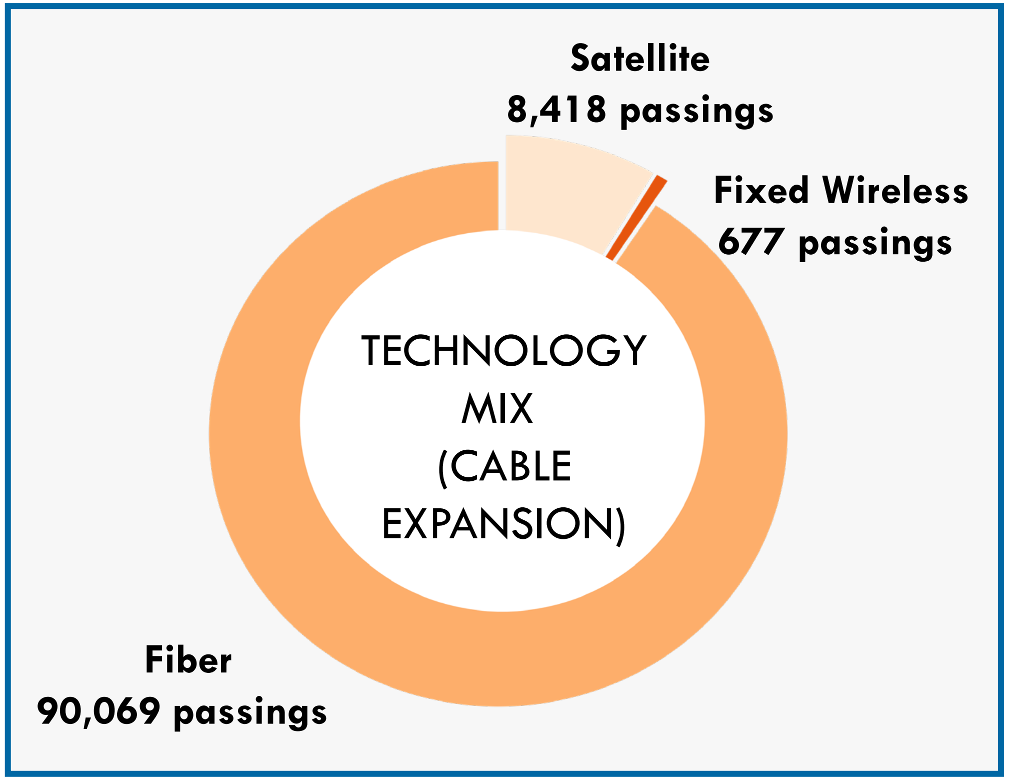
Based on the estimated technology mix, 8 percent of locations are predicted to rely on satellite service. These locations are scattered throughout the state but are more prevalent in the northeastern regions, particularly in mountainous areas.



THRESHOLD OF $30,000 MAXIMIZES FIBER WITHIN AVAILABLE BEAD FUNDING

Higher-cost passings convert from fiber to fixed wireless or satellite, depending on cost-effectiveness, as the Extremely High Cost Per Location Threshold is reduced. The optimal technology mix is found when grant funds needed equal the BEAD allocation, as shown in the graph to the left.





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3.4 SCENARIO 4: UNIVERSAL WIRELESS COVERAGE WOULD REQUIRE AN ESTIMATED $35 MILLION IN GRANT FUNDING

UNIVERSAL WIRELESS COVERAGE

Scenario 4 evaluates the costs to provide fixed wireless broadband infrastructure to all unserved and underserved locations.

A universal wireless solution to connect the state's unserved and underserved locations by fixed wireless would require an estimated $35 million in grant funding.*

Evaluating the dataset of unserved and underserved locations, the model finds that some locations have insufficient signal or no connection with existing towers and likely do not support a business case for fixed wireless. These locations are assigned to satellite service in this scenario, resulting in 92,000 of the total 99,000 locations connected with fixed wireless.

The following slides summarize the cost estimates and key findings for this scenario. The estimates presented on the following slides reflect the total cost to connect locations with fixed wireless and satellite, per the model. Detailed cost estimates are provided in the attached cost data file.

*Note that if some of these unserved and/or underserved locations in denser areas were to be connected by fiber, it would change the business case.

ESTIMATED COSTS FOR FIXED WIRELESS STATEWIDE

Fixed wireless to 92,000 passings

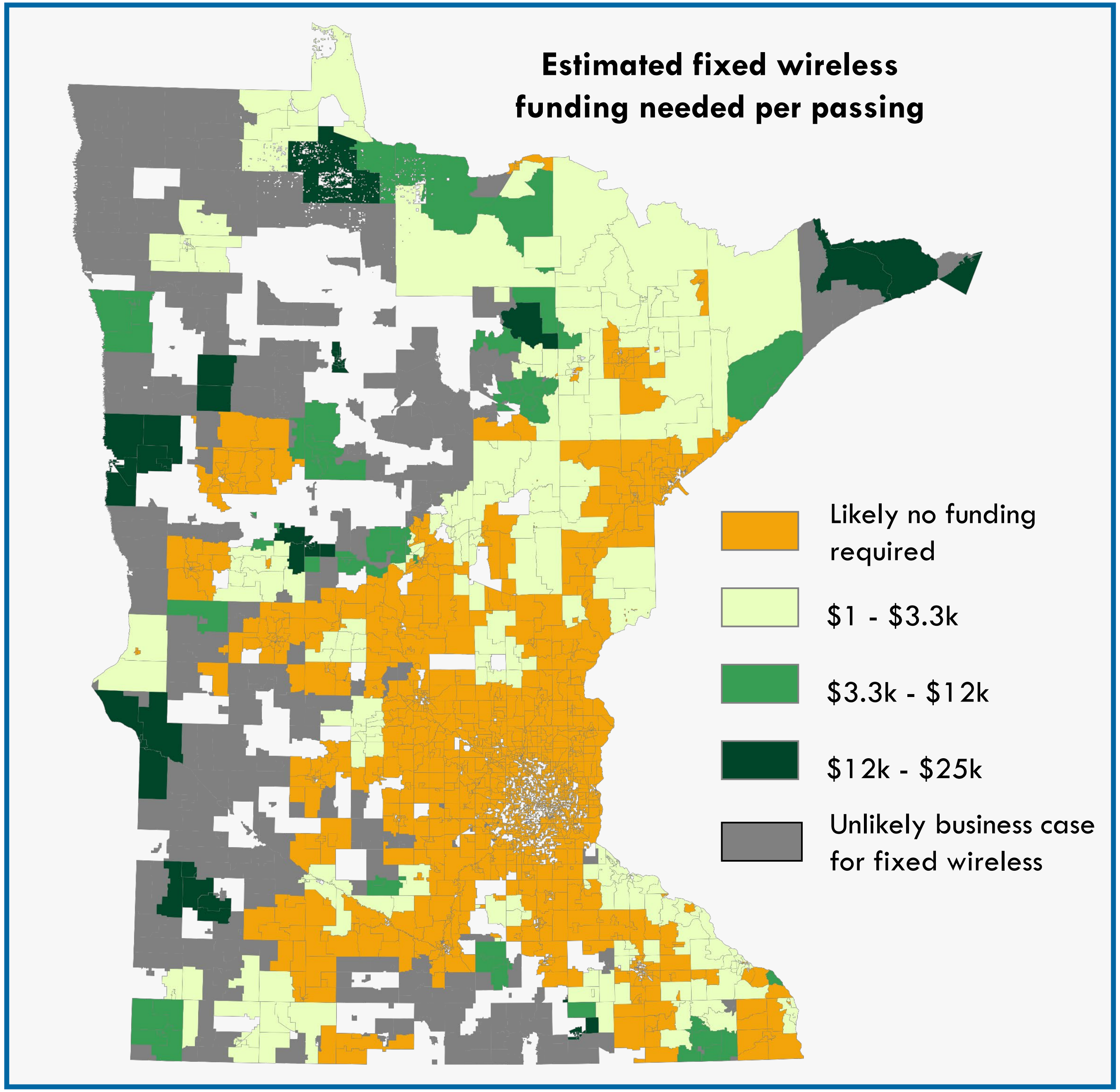
Estimated 5-year total investment needed

$105M

Estimated 5-year grant funding required

$35M

The map to the right shows the estimated average grant funding required per passing for each CBG-based analysis area to connect Minnesota's unserved and underserved locations by fixed wireless.



Note: Only showing CBG-based analysis areas with BEAD-eligible locations

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ATTACHMENT: COST DATA FILE

COST DETAIL BROADBAND GAP ANALYSIS V6.XLSX

The attached cost data Excel file provides the results of the analysis for all four scenarios aggregated by analysis area. Each spreadsheet includes the following data for each scenario.

Result	Description
Analysis area	A unique ID for each CBG and tribal land analysis area
County or tribal land name	The name of the county or tribal area containing the analysis area
Number of locations	The number of fabric locations in each analysis area
Percent of locations by classification	The percent of locations classified as unserved or underserved
Number of passings	The total number of multiple-dwelling units (MDU) per location in each analysis area
Percent of passings by classification	The percent of passings classified as unserved or underserved
Total funding required*	The total estimated grant funding required to provide coverage in each analysis area
Total investment needed*, **	Total estimated deployment costs, including match, for broadband infrastructure over a five-year grant period in each analysis area
Estimated investment per passing*, **	The average investment cost per passing in each analysis area

* The middle-mile investment is factored into these estimates.
** Estimates are also projected out one, two, and three years with a 3.5 percent annual inflation escalator applied.

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APPENDIX: ADDITIONAL DETAILS ON METHODOLOGY

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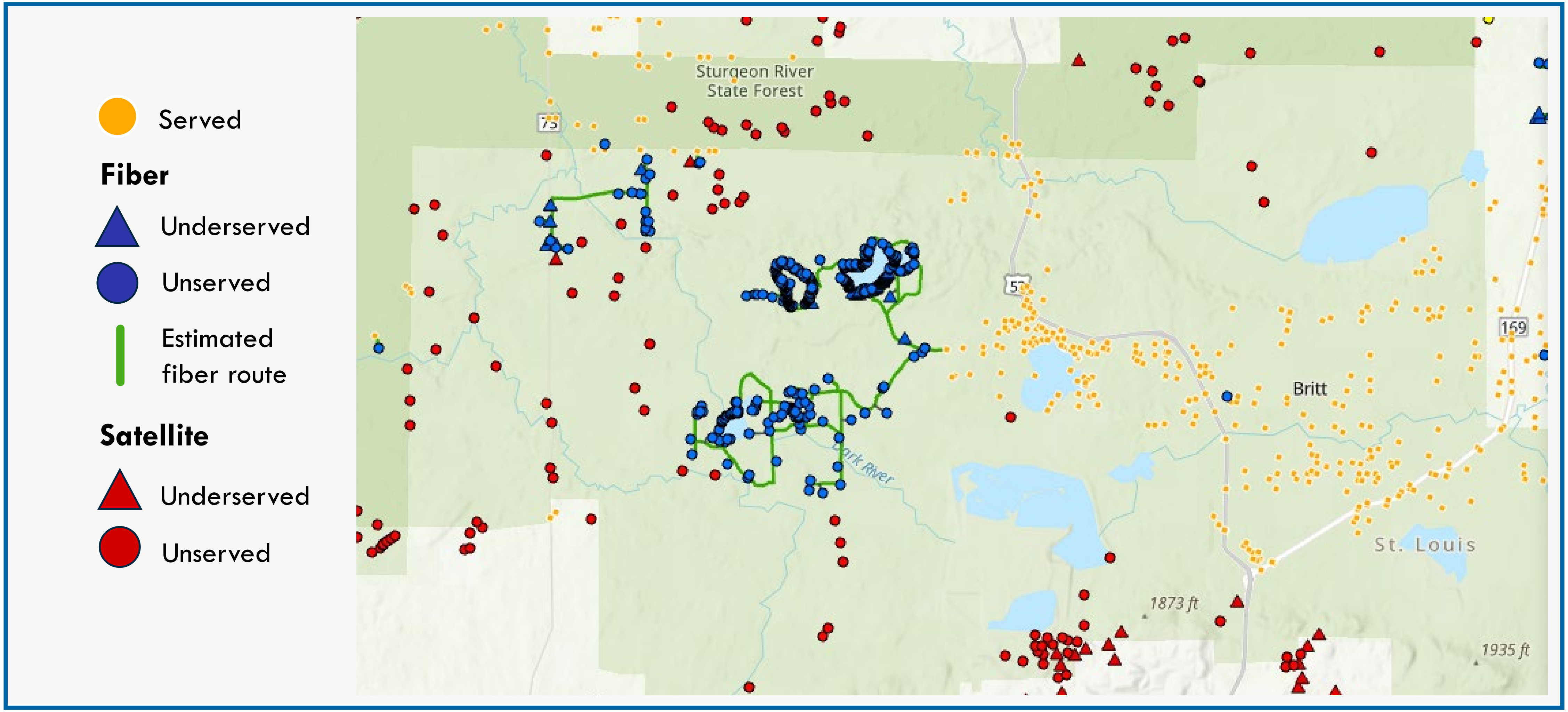
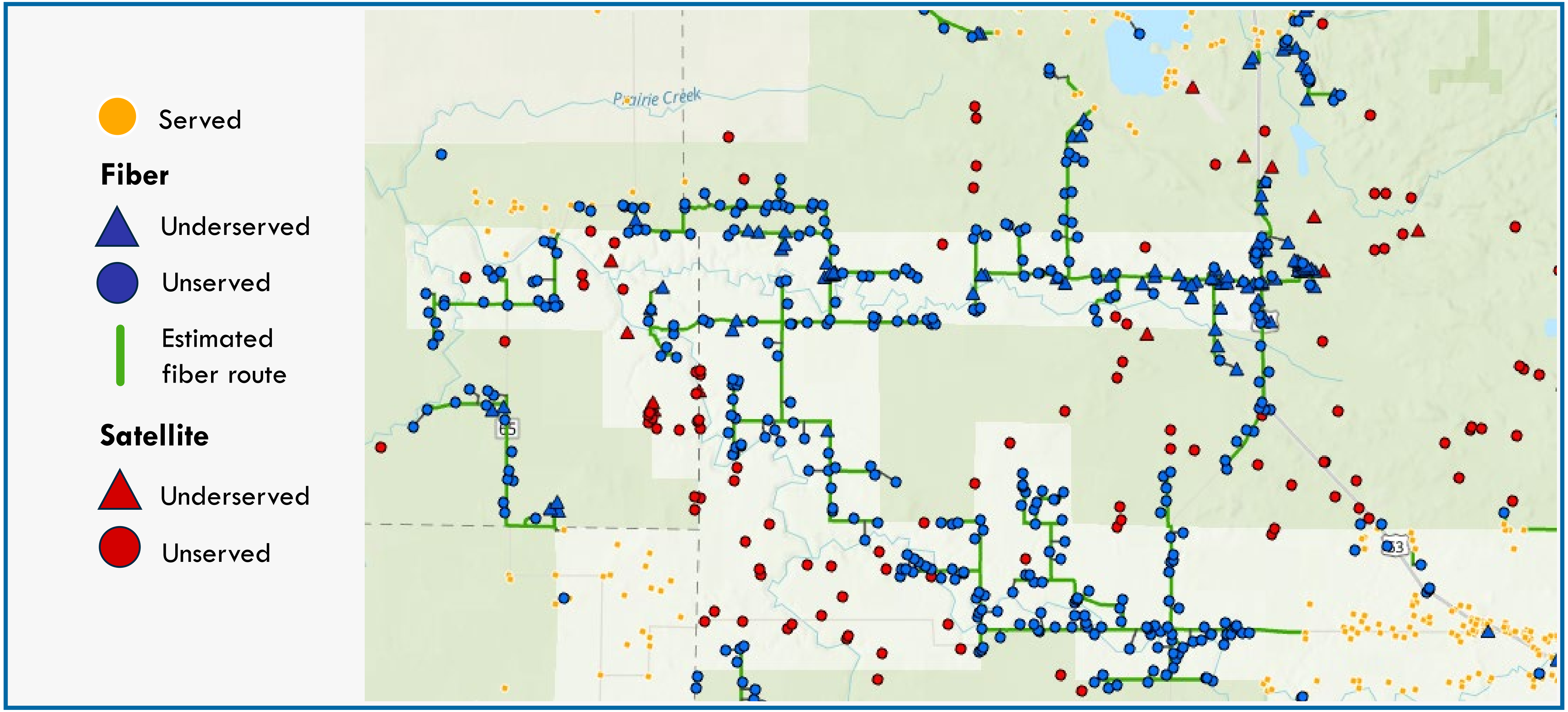
MODELING EXAMPLES

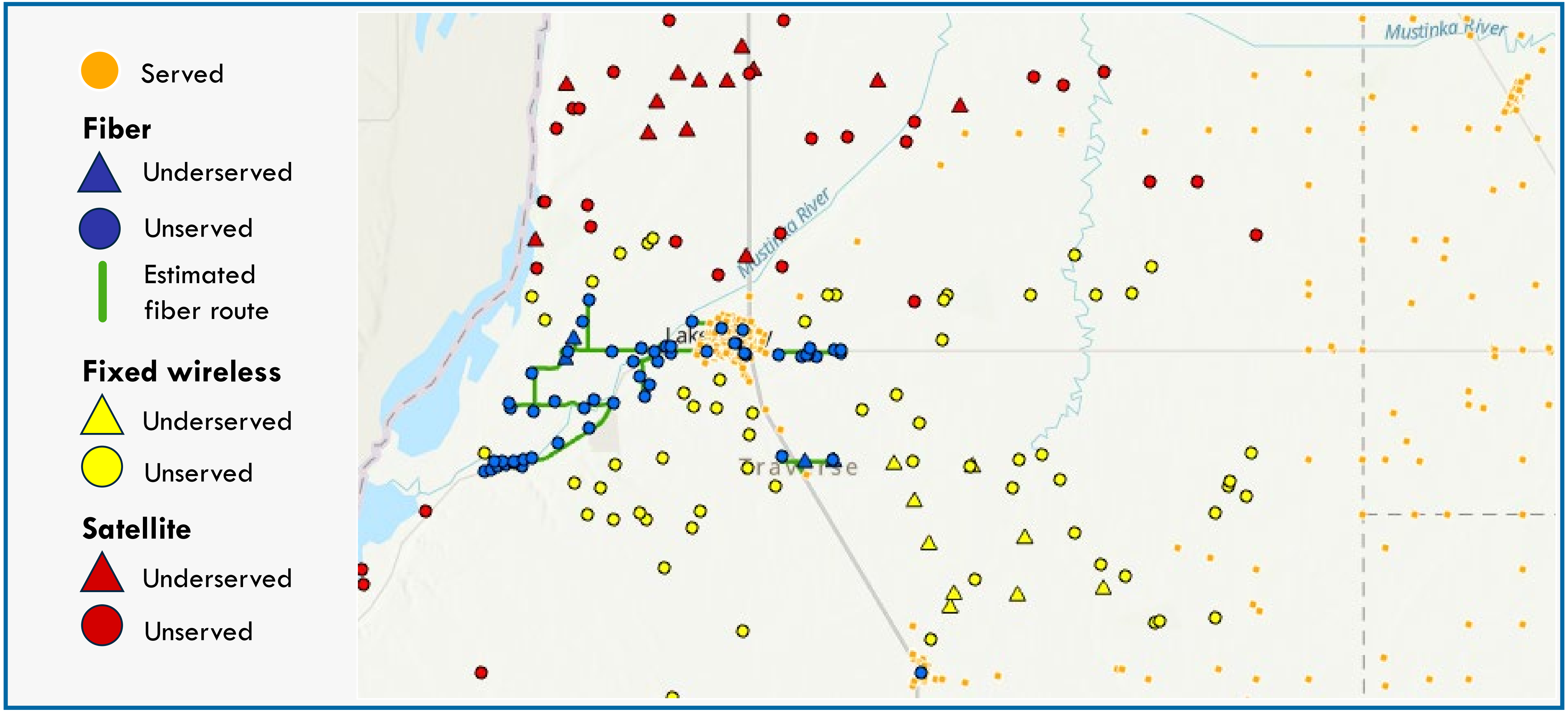
MODELING A TECHNOLOGY MIX IN THE NW OF VIRGINIA, SAINT LOUIS COUNTY



MODELING A TECHNOLOGY MIX IN GREANEY, SAINT LOUIS COUNTY



MODELING A TECHNOLOGY MIX IN WHEATON, TRAVERSE COUNTY



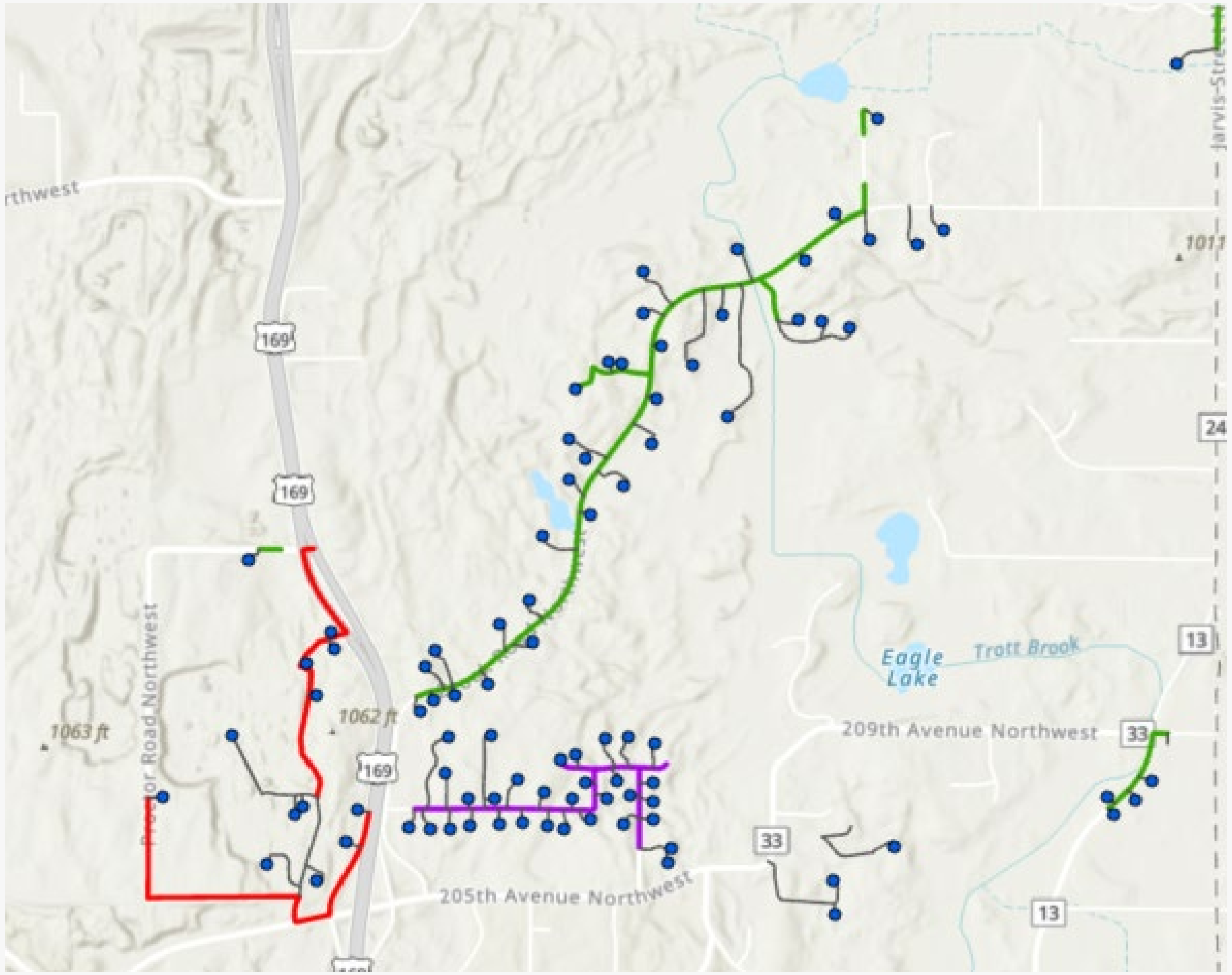
MODELING FIBER CONNECTIONS IN ELK RIVER, SHERBURNE COUNTY

Strong business case

Moderate business case

Difficult business case

Unserved/underserved



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DATA SOURCES AND ASSUMPTIONS

DATA SOURCES

Sources for map data used in all analyses, unless otherwise noted:

- Address Fabric: V4 – December 31, 2023
- BDC Service Availability Data (universal wireline location dataset): V4 – December 31, 2023 (updated October 30, 2024)
- Service Availability Status (BEAD-eligible location dataset): V4 preliminary post-challenge data sent to CTC by DEED October 31, 2024
- Grant Deduplication: FCC Broadband Funding Map (updated October 31, 2024), Border-to-Border Broadband Development Grant Program (updated September 13, 2024), and Broadband Line Extension Connection Program Round 3 (updated November 5, 2024)
- Community Anchor Institutions (CAI): post_challenge_cais.csv
- Towers: Homeland Infrastructure Foundation-Level Data for Cellular Towers and Microwave Service Towers

Sources for cost model data inputs used in all analyses, unless otherwise noted: CTC

WIRELESS ASSUMPTIONS

- **5G coverage and capacity layers**
  - 3GPP N41 and N71 scenario (typical T-Mobile configuration) at 2.6 GHz and 600 MHz
  - System Bandwidth: 100 MHz for N41 at 2.6 GHz , 20x20 MHz for N71 at 600 MHz
  - 4:1 TDD Downlink to Uplink ratio
  - 3 sector sites
  - Massive MIMO sector antennas are assumed resulting in 3x to 6x capacity gains
- **Site pool: List of all known vertical assets for a given state**
- **RF propagation**
  - Radio propagation using terrain and clutter databases is calculated from every Nth site in the site pool to every Mth unserved location.
  - Coverage is determined using a 5G massive MIMO gNodeB configuration and typical off the shelf indoor and outdoor CPE types.
  - Coverage results and parent site information are stored for future use by the tool (NxM matrix).
- **Use of wireless technologies in tool**
  - High-cost locations are evaluated for fixed wireless. Coverage results are pulled from the coverage matrix.
  - Parent sites are identified for site selection.
  - Site selection process dimensions a site design that minimizes the number of sites required to cover locations in high-cost projects.
  - Locations exceeding the high-cost limit are converted to satellite.