Spring 2023

South Lake Tahoe Fire Resiliency Project

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SANTA CLARA UNIVERSITY

Department of Civil, Environmental, and Sustainable Engineering

I hereby recommend that the

SENIOR DESIGN PROJECT REPORT

Prepared under my supervision by

KELSI RICE

&

WYATT RICH

Entitled

SOUTH LAKE TAHOE FIRE RESILIENCY PROJECT

Be accepted in partial fulfillment of the requirements for

The degree of

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

______________________________ Date 6/14/2023

Advisor- Hisham Said

______________________________ Date 6/9/2023

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______________________________ Date 6/9/2023

Department Chair -Aria Amirbahman

SOUTH LAKE TAHOE FIRE RESILIENCY PROJECT

By

Kelsi Rice

&

Wyatt Rich

SENIOR DESIGN PROJECT REPORT

Submitted to

The Department of Civil, Environmental, and Sustainable Engineering

Of

SANTA CLARA UNIVERSITY

In partial fulfillment of the requirements

for the degree of

Bachelor of Science in Civil Engineering

Santa Clara, California

Spring 2023

SOUTH LAKE TAHOE FIRE RESILIENCY PROJECT

Kelsi Rice and Wyatt Rich

Department of Civil, Environmental, and Sustainable Engineering

Santa Clara University, Spring 2023

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Jess Pitney	Stephen Tarantino

SOUTH LAKE TAHOE FIRE RESILIENCY PROJECT

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ABSTRACT

Our names are Kelsi Rice and Wyatt Rich. We are Seniors at Santa Clara University and are majoring in Civil, Sustainable and Environmental Engineering. Within our senior year at Santa Clara, it is a requirement that we complete a Senior Design Project. Our Senior Design Project is fire hardening the City of South Lake Tahoe's (City) utility lines. The last few months we have been analyzing the City's current utility infrastructure and the potential for new utility services to be implemented throughout the City. We have conducted an alternatives analysis to determine that the City of South Lake Tahoe is an ideal candidate for this project given the terrain of the City and the risk of public safety if a wildfire were to run rampant through the City. Our team believes, through our utilities analysis and the implementation of our proposed utility infrastructure, that we can provide the City with a solution for fire hardening its current utility infrastructure to promote life safety as well as property safety to its residents while minimizing cost.

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Introduction

The State of California has an epidemic of wildfires and is experiencing increasing levels of dryness, which is leaving the vast majority of forests loaded with fuel for blazing fires. In the last decade, fires have become exponentially more intense; oftentimes creating their own weather storms within the fire boundaries. With the exponential increase in extreme fire activity, towns and cities must begin making considerations to protect lives, property and the environment. Yet, the recent failure in building codes have caused many to question whether better efforts should be invested in local communities susceptible to fire hazards. Communities throughout the Western United States must take action to harden surrounding utility lines and neighborhoods to protect their citizens. The alternative analysis for this project was to best guide the team's efforts and findings for fire hardening utilities in high severity fire hazard zones, which were determined through the Cal Fire FHSZ Viewer (Cal Fire, 2022). This Cal Fire Viewer will aid in effectively implementing the fire hardening of utility lines process throughout identified towns. Through the analysis of defined criteria and constraints, the team's objective was to choose a multitude of towns and cities in California and further investigate utility fire hardening methods. Once the town was chosen by the team, an analysis that identified the constraints and criteria was conducted through GIS. The GIS model that was created allowed for the team to have clear identification of how the team should implement the different solution alternatives of replacing the current utility infrastructure with either underground or fire hardening the current overhead lines. Once the GIS map analysis was completed, project level circuit design analyses were conducted to exemplify a smaller, more detailed scope of work for both underground and overhead. These analyses were then utilized to conduct cost estimates for each project. After determining the respective cost for parts of the project it was determined by the team that the project would need to be phased in order to meet a reasonable project duration and budget. The phasing of this project was necessitated by the high cost of implementation and to make it a reasonable scope of work for the City of South Lake to undertake.

Alternatives Analysis

Table 1: Location Alternatives Analysis.

	Towns						Reason for Ranking
Criteria:	South Lake Tahoe, CA	Placerville, Ca	Big Sur, CA	Oroville, CA	Malibu, CA	Orinda, CA	
Ingress/Egress **(3)**	Medium	High	High	Low	Low	Low	The towns show an adequate amount of exit routes
High Risk for loss of life **(1)**	High	High	Low	Medium	Medium	Medium	Population in high fire areas within town
Trees around lines **(5)**	High	High	Medium	Medium	Low	Medium	How many trees surround the lines
Wooded areas within and around town (fire fuel) **(4)**	High	High	medium	Medium	Low	Medium	Amount of wooded areas that are potential for fire spread
Taking progressive actions for fire hardending **(8)**	Low	Medium	Low	High	Low	Low	Fire hardening actions that are already being taken by the town
Fire Hazard Severity Zones **(2)**	High	High	High	High	High	High	The community has a large percentage of high hazard fire zones
Subject to Public Safety Power Shutoffs (Fire Prevention) **(6)**	High	High	Medium	High	Medium	High	Has a history of many Public Safety Power Shutoffs
Impact to Critical Facilities **(7)**	High	Low	Low	Low	Low	Medium	Critical Facilities in close proximity to high fire hazard areas
Key: (#) - 1-8 rank the criteria in order of importance from most important to least							
Constraints:							
Terrain **(2)**	High	High	High	Medium	Low	Low	The town has a terrain that is considered complicated
Environmental Permitting **(4)**	High	Medium	Medium	Medium	Low	Low	Environmental factors that may prevent or delay construction
Agency Permitting **(5)**	High	Medium	Medium	Medium	Low	Low	Permitting factors that can prevent or delay construction
Public Opposition **(6)**	Medium	Low	Medium	Low	High	Medium	Public prevention or delay to construction
Utility Budgets **(1)**	High	High	High	Medium	Low	Low	Budget sufficency for utilities
CPUC Approval **(3)**	Medium	Medium	Medium	Medium	Medium	Medium	CPUC approval rating decided on need based factors
Key: (#) - 1-6 rank the constraints in order of importance from most important to least							
Key:	**Low - not a priority**		**Medium - somewhat of a priority**		**High - high priority**		

Alternatives

Alternative 1: South Lake Tahoe, CA

South Lake Tahoe is a small City situated between Lake Tahoe and a wide range of mountain peaks. The town is home to nearly 23,000 residents that would have to be evacuated through three (3) main ingress / egress routes: Highway 50 East, Highway 89 North, and Highway 89 South / Highway 50 West. The City's proximity to heavily wooded areas leaves it in a dangerous position, especially given its dense population density and likelihood of losing ingress / egress routes in the event of a fire. The fire severity zones throughout the community are very high given the surplus amount of combustible materials throughout neighborhoods. As a result of the utilities traveling over mountain passes and through dense forests, the City is subject to periodical power safety shut offs during red flag conditions. The City's vast critical infrastructure is heavily relied upon by members of the community and is affected severely by power losses. The community is sitting on predominantly rocky terrain making ground penetration difficult in many places. Given the community's popularity, it is subject to harsh environmental review, and the infrastructure must remain aesthetically pleasing. The utility budget for the community would be rather large given the amount of residents it serves, providing the local building department with reason to potentially grant permits for updating infrastructure.

Alternative 2: Placerville, CA

Placerville, CA is a small town located in northern California with a population of roughly 10,954 people. Placerville has four ingress and egress routes, Highway 50, Diamond Rd., Georgetown Rd. (193) and Highway 49. The lack of ingress and egress routes makes it a high priority when taking into consideration evacuation routes during wildfires. Due to

Placerville's highly wooded areas within and around town, it is susceptible to also having a high number of trees around lines which leads to a high risk for loss of life. Due to the high risk of wildfires and having a high percentage of fire hazard severity zones, Placerville is subject to a high amount of public safety power shut offs from PG&E (PG&E, 2019). Due to a lack of critical facilities, i.e. hospitals, fire stations, police departments, etc. within the Town of Placerville compared to other towns/cities, it is considered to be a low priority in terms of loss of critical facilities. The terrain of Placerville is mostly made up of Jurassic age, meta-volcanic and meta-sedimentary rock. This terrain makes it exceptionally complicated to do certain utility work. Due to the terrain within this area, utility budgets are high given that the work usually costs more. Based on the location of this town and the epidemic of California wildfires in this area, the California Public Utilities Commission (CPUC) may see a priority for approval for the implementation of the fire hardening of utility lines based on need given the circumstances. Given the wildlife that live in this area, the environmental permitting process is typically longer and could cause potential delay of construction. Agency permitting within this area should be standard and should not cause any concern for delay of construction.

Alternative 3: Big Sur, Ca

Big Sur, CA is situated in between the Santa Lucia Mountains and the Pacific Ocean. It has one main ingress and egress point: Highway 1. Big Sur is a community of 5,081 people which makes it very low on the scale in terms of high risk to loss of life. The community is situated close to the coast and is not completely submerged in deep forestry terrain. The means to update infrastructure would greatly surpass the existing utility budget for the area making it an unlikely approval from the CPUC. The Town is subject to occasional power safety shut offs, but they have minimal impact to critical infrastructure, as the Town is not very substantial. Environmental permitting would be extremely difficult given the strict regulations around construction in the area to preserve the natural beauty. The public would likely give strong push back to any major infrastructure projects, as it would significantly impact the Town and affect traffic.

Alternative 4: Oroville, CA

Oroville, CA is located in Butte County, and the population of the City is approximately 15,506 people. Oroville has many egress and ingress routes for evacuation, making it a lower priority for risk of loss of life. Oroville does not have a lot of wooded areas within Town, however it does have a lot of wooded areas around Town causing there to be a significant amount of trees around lines. PG&E, however, has made a significant impact in the reduction of trees around lines over the last few years due to the many fires that have occurred in Oroville and surrounding towns. Oroville is taking progressive action towards fire hardening and making it a high priority within their Town and is implementing laws and regulations for fire prevention. Due to the history of wildfires within this location, the Town is highly subject to public safety power shut offs. The terrain of this town allows for many different types of utility construction with minimal difficulty. The environment and the wildlife inhibiting this area may make the environmental permitting process take longer than usual, causing delay of construction. There is a low amount of public opposition in this area, which is beneficial for when construction begins. Budget for utilities within this Town is somewhat of a priority however due to its terrain, less costly options can be explored making the budget somewhat minimal in comparison to others (City of Oroville, 2022). Oroville, CA is a Town that needs fire hardening to utilities, however due to the history of many wildfires, actions are already being taken.

Alternative 5: Orinda, CA

The City of Orinda is a family-oriented community with a semi-rural setting within 20 minutes of downtown San Francisco. It is situated in Contra Costa County, North East of the San Francisco Bay, and it was incorporated as a City in 1985. Currently, Orinda is home to 19,475 residents and it has a reputation of having a well managed and stable municipal government. In case of an emergency, the City offers a preparedness plan with Highway 24 to Lamorinda area as their primary evacuation route. The City is protected with three (3) police departments, a county sheriff, two (2) fire districts plus the State Cal Fire and the California Highway Patrol (CHP) making this City a high priority in the team's analysis in terms of risk to critical facilities. The geography and dense woods around the area make Orinda a very high fire hazard severity zone.

Alternative 6: Malibu, CA

Malibu is a beach city in the Santa Monica Mountains area and part of Los Angeles County. It was incorporated as a City in 1991, and it has a reputation for historically being home to many Hollywood celebrities. Currently, Malibu is home to 10,654 residents in a region that experiences extreme drought conditions and rising temperatures classified as a warm summer Mediterranean climate. The City has experienced dozens of wildfires, with the 2018 Woolsey Fire being the most devastating one which burned 96,949 acres of land. The area is classified as a very high fire severity zone by Cal Fire. The City has four (4) evacuation zones and five (5) ingress and egress routes with multiple other routes for evacuation, thus making it much easier for evacuation in the event of a fire. The large proportion of ingress and egress routes in comparison to the population and the probability for loss of life made this City a low priority in the team's analysis. Malibu's budget is also quite large, especially considering the makeup of its population, allowing for fire hardening actions to be taken with little to no financial burden (City of Malibu, 2022).

Final Location Decision

After progressing through the alternative analysis, it was concluded that the City of South Lake Tahoe would be the most suitable location for the implementation of fire hardening utilities. The City ranks highly in the most critical criteria and constraints. Given this, the implemented solution will have the greatest overall impact on the community and positively affect the highest number of people. South Lake Tahoe also has a wide variety of terrain so different implementations can be utilized throughout the community where they will best meet the needs of the community and the budget given for the project.

General Site Details/Description

South Lake Tahoe, CA is located high in the Sierra Nevada Mountains. The history of South Lake Tahoe's geologic makeup dates back to about 24 million years ago due to the great uplifting of the Sierra Nevada block. According to a survey conducted by Michael S. Reichle, the

Acting State Geologist for California, “The older rocks in the area are seen as isolated remnants of metamorphosed, Paleozoic and Mesozoic volcanic and sedimentary rock that were introduced by the Jurassic and Cretaceous granitic rocks of the Sierra Nevada batholith” (Reichle, 2005). South Lake Tahoe is approximately 78 percent public land that is managed by the USDA Forest Service (Forest Service National, 2022). The basin is home to 17 million trees, mostly Jeffrey pines. While home to many trees, the City is also home to the following three endangered species: the Sierra Red Fox, Lahontan Cutthroat Trout, and the Mountain Beaver (El Dorado County, 2022).

Scope of work

In order to perform undergrounding of electric lines, the following steps were taken:

A. Determine the geographic makeup of South Lake Tahoe
B. Determine environmental regulations and local jurisdictional permit requirements
C. Determine how much mileage will be able to be implemented underground
D. Site walk of areas where underground utilities can be implemented
    a. Contact Liberty Utilities, South Lake Tahoe water and sewer, and South Lake Tahoe Inspection Department for attendance
E. Determine how many other utilities are underground in the area
    a. Call USA (Underground Service Alert) Mark and Locate for information on where existing utilities are located
F. Design where the location of boxes, main line and service trenches, as well as associated underground equipment will be located
    a. Determine where primary and secondary services would be needed
    b. Determine how many houses or businesses a transformer pad would feed based on load
    c. Determine where and how many transformer pads would be needed based on load
    d. Determine how many splice boxes would need to be implemented for the mileage
G. Determine the cost of undergrounding utilities
    a. Consider: geotechnical analysis, trenching, backfill, restoration, construction and safety costs
H. Determine cost of equipment, labor, inspection, permits and materials
I. Design conduit package
J. Research Easement and Right-of-way acquisition to ensure the project can be completed

    a. Determine the amount of underground easements and right of ways needed to accommodate all equipment, transformers, and conduit
K. Conduct a detailed Project Level Circuit Design Analysis
    a. Specify neighborhood best fit for a fire hardened overhead system
L. Cost Estimate Analysis

In order for Overhead Distribution lines with Fire Hardening Strategies to be implemented, the following steps were taken:

A. Determine the geographic makeup of South Lake Tahoe utilizing GIS software
B. Determine environmental regulations and local jurisdictional permit requirements
C. Determine how much mileage will need to be run via surface level transmission. Coordinate with underground and overhead transmission team to map out the most feasible route and type of transmission
D. Perform site walk via Google earth of specific areas of implementation and confirm conditions
E. Determine what fire hardening strategies need to be implemented
    a. Overhead Fire Hardening Strategies Analysis
F. Design system in AutoCAD
G. Conduct a detailed Project Level Circuit Design Analysis
    a. Specify neighborhood best fit for a fire hardened overhead system
H. Determine cost of equipment, labor, inspection, permits and materials
I. Cost Estimate Analysis

Design Criteria and Standards

There are several key performance measures and code requirements that the design team considered when fire hardening a city. The priorities included:

- Reliability and resiliency: the electric utility systems must be able to withstand fires and other disasters without failing and be able to quickly recover from any disruptions to maintain a consistent level of service.
- Safety: The team must prioritize safety of the public and workers as the number one priority. It is an ethical obligation and the duty of engineers to minimize the risk of accidents, injuries, or death.

- Efficiency: The system should be designed to operate efficiently and use resources wisely, to minimize the costs and reduce its environmental footprint.

Permitting/Codes

In addition to these general requirements, there are specific codes the team had to comply with depending on the Federal, State and County rules. It is important to note that the City of South Lake Tahoe shares the border with Nevada and those state codes must also be taken into account. There are local building codes, fire codes, electrical codes, and environmental regulations especially in South Lake Tahoe because it is surrounded by natural parks. These include the following:

City of South Lake Tahoe Codes:

- California Electrical Code 2019
- California Fire Code 2019
- California Historical Code 2019
- California Energy Code 2019

Underground/Overhead Codes:

- California Public Utility Commission (CPUC) GO95 (General Order for Overhead Electric Construction)
- CPUC GO128 (General Order for Construction of Underground Electric Supply and Communications Systems)
- CPUC GO 165 (General Order for Inspection cycles for electric distribution facilities)
- CPUC GO 174 (General Order for Rules for Electric Utility Substations)

Permits

- Encroachment Permit for County Maintained Roads
- Follow PG&E Requirements and Standards
- Jurisdictional permit (City, State or Highway)
- Environmental Permit (ERTC Permit)
- Utility Standards and Procedures

PG&E

- USA guidelines and standards before digging
- PG&E Greenbook for Electric Service: Overhead
  - Sections 4.0-4.10.6
- PG&E Greenbook for Electric Service: Underground
  - Sections 5.0-5.11
- ERTC Standards
  - Cultural Resources All Locations
  - Air/Hazardous Materials & Waste/Soil
  - Water Quality/Stormwater
- Community Wildfire Safety Program, System Hardening Contractor Construction
- Enterprise Contractor Safety Plan Management Procedure (PSSP)

OSHA

- California Code of Regulations, Title 8, Division 1, Chapter 4, Subchapter 5, Group 2, "High-Voltage Electrical Safety Order"
- OSHA Underground Construction (Tunneling) Regulations
  - Part #1926
  - Subpart: 1926 Subpart S

    - Standard Number: 1926.800
- OSHA Standards for Overhead Construction
    - Part # 1926
    - Subpart: 1926 Subpart CC
    - Standard Number: 1926.1408

Environmental/Political/Health & Safety

Based on these codes and regulations, the design team had to work closely with local officials and stakeholders to ensure that the plans are feasible, acceptable and align with the City's overall goals and objectives. There is also a list of factors that must be considered regarding how the project will impact the area in matters in addition to engineering. There are outside measures such as social, economical, political, environmental and cultural factors that must be addressed for the sake of the project being feasible. These factors include:

- Social: There is an impact in the local community, and the needs and concerns of the people who live and work in the City should be considered and these implementations should strive to minimize any negative impacts on the quality of their lives. These impacts include issues such as noise, traffic and construction, disruptions where engaging with local officials and community organizations to gather input and feedback by holding public meetings or conducting surveys should occur. There is a significant role with community organizations which can play a vital role in providing resources and support, and their input should be incorporated into the project since they are the primary beneficiaries.
- Economical: The cost estimate of the project must take into account the materials, labor,

equipment and all required expenses. The team should research potential funding sources, such as grants from government agencies and foundations. This project may also qualify for tax credits or incentives that could reduce the overall costs. This project will bring economic benefits to the community as well, therefore the change in property value, job creation and improved infrastructure must be part of the scope. Finally, there is an impact on local businesses such as disruptions with construction or changes with their business costs regarding electricity that must be communicated through.

- Political: The role of the local government is vital for the feasibility of the project by working with city officials to approve permits, complying with local codes and regulations. The team should also expect the potential for opposition to the project from local residents and anticipate addressing these concerns to build consensus for the project. Depending on the timing of the project, it could coincide with local elections and perhaps engage with candidates and political leaders that want to engage in any certain way with the project.
- Environmental: There is the potential impact on local wildfire and habitats, the potential for increased air and water pollution, and effects on the climate and ecosystems. There is also a potential for natural disasters, such as wildfires and earthquakes which can showcase how the improved electric utility services can help the City prepare better for these events. The City of South Lake Tahoe is surrounded by natural parks and wildlife preservation, which should be a priority in the environmental aspect. The noise of construction and other disruptions should provide the best serviceability to the residents and to the ecosystem.
- Cultural: These considerations involve the cultural values of the community, including

their attitude towards environmental conservation and sustainability. Also, the diversity in the area should be addressed and how improved electric utility services can be accessible to all members of the community. This project can also carry a cultural significance to the City and how this plan could preserve or enhance the local traditions. Overall, it was important for the team to take an inclusive approach to the planning.

Standard Cost Estimates

Linear Foot Cost Models

Underground Conduit Construction:

The linear foot cost model for underground conduit construction is shown in Table 2. This model is based on an average 100’ x 100’ service trench and the cost was determined through analysis with an industry expert for underground construction. The unit of measure, excavation, includes the prices for labor and equipment for trenching, backfill trench, and material. Due to the rough, rocky, granite terrain of the City of South Lake Tahoe, a rock adder has been implemented at $55 per linear foot. The conduit install includes three (3), four (4), and six (6) inch conduits increasing in price accordingly. The unit of measure, substructures, includes all potential structures that may be used throughout the project. The TX pad (Transformer) is priced at $10,000 each, the J pads, which are switches that switch the direction of the isolated electricity, are priced at $11,000 each. Secondary enclosures which are represented by #2, #3 and #5 electrical boxes are enclosures that are utilized when providing services off of the main line to customers. Primary enclosures are represented by #5, #6 and #7 electrical boxes are enclosures that are utilized along the mainline. Restoration includes compaction testing, softscape and hardscape. The compaction testing is priced based on two (2) groundsmen at a day rate of $1500 each. Softscape is included but not limited to bark, rock, grass, plants, etc. Hardscaping includes asphalt and concrete. The permitting that is included in this model is specific to the permitting process for underground construction. In the event of a special condition, other permits may need to be obtained.

Table 2: Linear Foot Cost Model for Underground Conduit Construction.

Underground		
Item	Unit of Measure	Unit Price
Excavation		
12"	LF	$100
18"	LF	$110
24"	LF	$125
ADD;Rock	LF	$55
Conduit Install		
3"	LF	$10
4"	LF	$16
6"	LF	$28
Substructures		
TX Pad	EA	$10,000
J Pad	EA	$11,000
Secondary Enclosure	EA	$8,000
Primary Enclosure	EA	$15,000
Restoration		
Compaction Testing	Per Day	$3,000
Softscape	Sq. Ft.	$7
Hardscape	Sq. Ft.	$9
Permits	EA	$600
Traffic Control	Per Day	$6,000

<u>Overhead Construction:</u>

The linear foot cost model for Overhead construction is shown in Table 3. This model is based on the average overhead equipment and pole types, and the cost was determined through analysis with an industry expert from a public utility company for overhead. The items for each pole type includes the prices for labor and equipment for the pole hole and backfill. Due to the rough, rocky, granite terrain of the City of South Lake Tahoe, a rock adder has been implemented at $3,000 per hole. There are different types of poles, one (1) through (5). Each pole type increases in number and price due to the amount of equipment placed on each pole making it more complex as it increases. Type 1 is the most simple pole and type 5 is the most complex with a significant amount of structures on the pole. Restoration includes compaction testing, softscape and hardscape. The compaction testing is priced based on two (2) groundsmen at a day rate of $1500 each. Softscape is included but not limited to bark, rock, grass, plants, etc. Hardscaping includes asphalt and concrete. The permitting that is included in this model is specific to the permitting process for overhead construction. In the event of a special condition, other permits may need to be obtained. Traffic control is estimated to be $6,000 per day and will last the duration of the entire project. Typical adders for Overhead Construction with the implementation of fire resistant mesh pole wraps and insulated conductors include a helicopter, set in the same hole, and the pole wrap itself.

Table 3: Linear Foot Cost Model for Overhead Construction.

Overhead		
Item	Unit of Measure	Unit Price
Excavation		
ADD;Rock	Per Hole	$3,000
Poles		
Type 1	EA	$8,000
Type 2	EA	$11,500
Type 3	EA	$16,800
Type 4	EA	$20,000
Type 5	EA	$24,000
Restoration		
Compaction Testing	Per Day	$3,000
Softscape	Sq. Ft.	$7
Hardscape	Sq. Ft.	$9
Permits	EA	$600
Traffic Control	Per Day	$6,000
Adders		
ADD; Helicopter	Per Hour	$300
ADD; Set in Same Hole	EA	$800
ADD; Pole Wrap	EA	$750

Designed Facilities

Underground Conduit Construction

The three (3) conduit configurations in Figure 1 show a one-way, a four-way and a six-way for underground electric lines. The one way is a demonstration of a single, four-inch (4”) conduit line with an envelope casing dimensions of 10-½”x10-½”. The four-way configuration is a 22-½”x22-½” envelope casing with four separates four inch (4”) conduit lines. The six-way configuration is a 22-½”x41-½” envelope with six (6), three-inch (3”) conduit lines. All quantities and dimensions follow the codes and regulations of the PG&E Greenbook for Underground Construction (Table 4, Table 5). These were the most common conduit configurations that will be utilized in South Lake Tahoe, CA Fire Hardening Project. All quantities for conduit may vary depending on variations that may be encountered during construction, however.

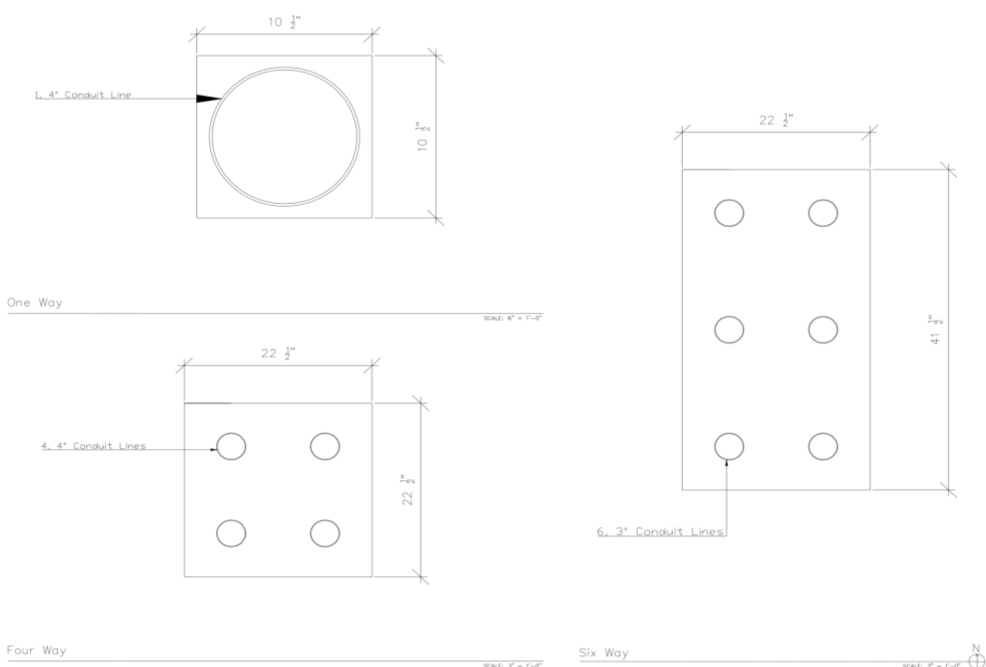

Figure 1: Conduit Configurations.

Envelope Design:

The concrete used for these configurations will be normal weight, and the aggregate used will be aggregate, ASTM C33 uniformly graded with a maximum aggregate size of ¾ inch type. The minimum compressive strength is f'c = 3,000 pound-force per square inch (psi). When using conduit lines two-way and larger, No. 4 reinforcing bars would be installed in all four corners of the conduit envelope. Reinforcing bars shall have an overlap of 15 inches and would be installed a minimum of three (3) inches from the top or bottom and one (1) inch from the side of the envelope (Villareal, pg. 17, 2022).

Table 4: Dimensions for Single Conduit Configurations (Villareal, pg. 17, 2022).

Dimensions for Single Conduit Configurations

Conduit		Envelope Dimensions	
Description	**Size**	**W**	**H**
Single	2"	8-1/2"	8-1/2"
	3"	9-1/2"	9-1/2"
	4"	10-1/2"	10-1/2"
	5"	Not Used	Not Used
	6"	12-1/2"	12-1/2"

Table 5: Dimensions for Multiple Conduit Configurations (Villareal, pg. 17, 2022).

Dimensions for Multiple Conduit Configurations

Conduit		Envelope Dimensions	
Description	Size	W	H
2-Way	3"	16"	9-1/2"
	4"	18"	10-1/2"
	5"	Not Used	Not Used
	6"	22-1/2"	12-1/2"
4-Way	4"	18"	18"
	5"	22-1/2"	20"
	6"	22-1/2"	22-1/2
6-Way	4"	18"	25-1/2"
	5"	Not Used	Not Used
	6"	22-1/2"	32"

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<u>Overhead Transmission Lines</u>

During the project's evaluation of constraints, the team identified the budget as one of the most significant limitations to consider. Consequently, it was necessary to designate specific areas where overhead infrastructure would be retained and reconstructed. An overhead fire hardening alternatives analysis was conducted to determine how the team would implement keeping some areas overhead while also ensuring that public safety was at the forefront of the project. Through this analysis, the team determined that implementing fire wrapping, in conjunction with forest management practices and adherence to city ordinances, would be the most advantageous hardening strategy. Following discussions with Cal Fire, it is recommended that the City incorporates a minimum 10' vertical tree liming approach to mitigate the risk of undercarriage fires in the event of a line failure. A 10' minimum vertical tree liming is the clearance of tree limbs from the ground upward 10’. Additionally, the inclusion of insulated conductors was deemed essential and factored into the cost estimate analysis for the overhead lines.

Overhead Fire Hardening Strategies Alternative Analysis

Table 6: Overhead Alternative Analysis.

	Fire Hardening Strategies					Reason for Ranking
Criteria:	Fire Wrapping	Steel Poles	Insulated Conductors	Forest Management	City Ordinances	
High Risk for loss of life (1)	Low	Medium	Low	Low	Low	The fire hardening strategies prove to not be a high risk for loss of life
Trees around lines (2)	Medium	Medium	Medium	Low	Low	The likelihood for trees around these lines to cause damage to the fire hardening strategies
Equipment Maintenance (3)	Low	High	Medium	Low	Low	The amount of maintenance that would be required
Key: (#) - 1-3 rank the criteria in order of importance from most important to least						
Constraints:						
Utility Budget (1)	Medium	High	Medium	High	Low	The budget for the town is not significantly large
Public Opposition (2)	Medium	Medium	Low	Medium	Medium	Civilians opinions on tree removal will play a huge role in this decision
Key: (#) - 1-2 rank the constraints in order of importance from most important to least						
Key: Low - not a priority Medium - somewhat of a priority High - high priority						

The second solution alternative for the circuit design is the reconstruction of the existing lines according to Figure 2. Equipment on service poles will meet the California code requirements for building standard codes regarding the clearances obtained with minimum distances for the construction illustrated. In addition to Figure 2, a 12’ circumference trimming boundary will be mandated from each line of conductors. This will serve to limit the number of tree branches or entire trees that could come into contact with the lines creating an ignition point. The two materials permissible for a service pole are wood and metal; however, through the team’s discussions with Cal Fire professionals, it has been determined that wood poles are the most beneficial following a fire. Steel poles lose their structural integrity at 932 degrees fahrenheit and thus would also have to be replaced following a fire. To ensure the integrity of the wood poles during a fire, the team chose to implement fire mesh wrapped poles that feature a flexible intumescent coating that begins to swell at 300 degrees Fahrenheit, as shown in Figure 3. The fire mesh itself is removable and replaced following a fire, and before it swells it is breathable, preventing wood rot on the pole. The fire mesh wrapped poles have been a proven solution in the industry to preventing failure of wooden poles during a fire. During the team’s analysis it was apparent that poles failing and falling into means of ingress/egress was a severe life safety issue, as it commonly prevented efficient evacuation of residents. Thus, it was essential to implement a method that would prevent poles from failing structurally. The utility company is responsible for the exclusive wiring installation in the pole and service entrance equipment. The team has also recommended the installation of insulated conductors for all of the lines included in this fire resiliency plan. The insulated conductors serve to avoid the lines sparking in the case of a foreign object, such as a tree branch or bird nest, falling onto the lines.

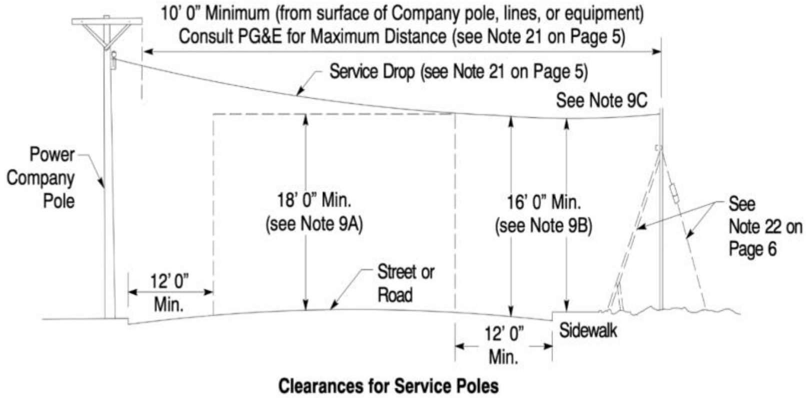

Figure 2: Overhead Pole Diagram.

Figure 3: Fire Mesh.

GIS Analysis

In order to develop a solution for fire hardening the town of South Lake Tahoe, this engineering thesis project involved the creation of a customized Geographic Information System (GIS) model. ArcPro GIS was the specific software utilized for the model as it is designed to store, analyze, manage, and present spatial or geographical data. This model was constructed through the compilation of various layers and data, with the assistance of a GIS analyst. The model was formed using numerous layers of data. The critical infrastructure included police stations, fire stations, hospitals, and schools. The critical infrastructure data was obtained from the open data platform from Tahoe Regional Planning Agency (TRPA). The fire severity zones layer was obtained from Cal Fire, and the population density from TRPA. The project's scope was defined by the regional boundary and the City limits of South Lake Tahoe, as demonstrated in Figure 4 . Within these boundaries, the team identified fire severity zones and crucial infrastructure such as fire stations, police stations, hospitals, and schools. These key facilities were considered essential for fire hardening, ensuring that residents would have access to shelter, communication centers, and medical services during fire emergencies. The fire severity zones were depicted in red for very high, orange for high, and yellow for moderate risk levels. These zones were determined by Cal Fire, utilizing established scientific methodologies that consider factors such as vegetation, fuel levels, fire behavior modeling, and the likelihood of ignition from sparks. The fire severity zones are divided into two (2) categories for fire severity: wildland and non wildland zones. The wildland zones are dominated by vegetation and are based on the well established scientific models to predict fire behavior. The surrounding regions of the project's region of interest are predominantly wildland zones. The second, non wildland, is predominantly urban areas or barren wetlands. The fire modeling in these regions is based on the transfer of embers from wildland areas adjacent to the region and associated fire spread through the urban vegetation into structures. The non wildland model also takes into account where embers are likely to fly based on local wind patterns, slope and tree coverage.

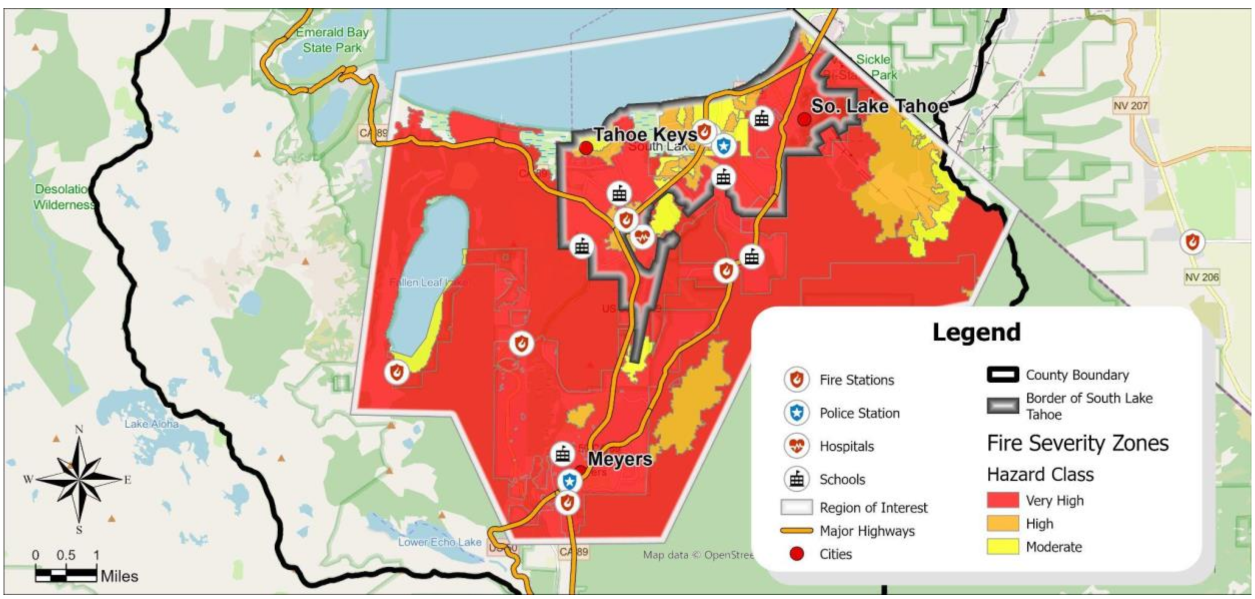

Figure 4: GIS Model of Fire Severity Zones, Infrastructure and Boundaries.

Additionally, the GIS model in Figure 5 included the depiction of distribution lines, high voltage transmission lines, and substations. Although the actual distribution line data was unavailable, the team generated the distribution line layer using street data and Google Earth as substitutes. The model differentiated between underground lines (indicated in purple) and overhead lines (depicted in blue) based on the fire severity zones and population densities throughout the region.

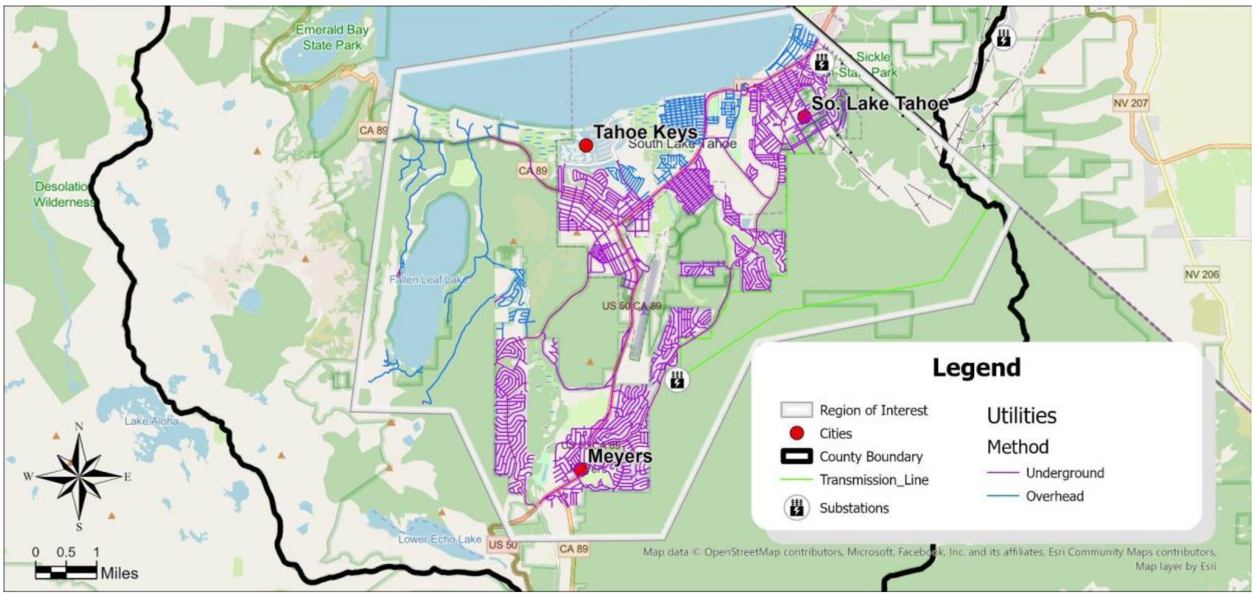

Figure 5: GIS Model of Utilities Both Overhead and Underground.

The culmination of all the layers and data used in this model is presented in this Figure 6. It also showcases the two (2) specific neighborhoods where the team conducted detailed cost analyses for both underground and overhead lines, providing a comprehensive understanding of the feasibility and economic considerations associated with each option that is discussed in the cost analysis.

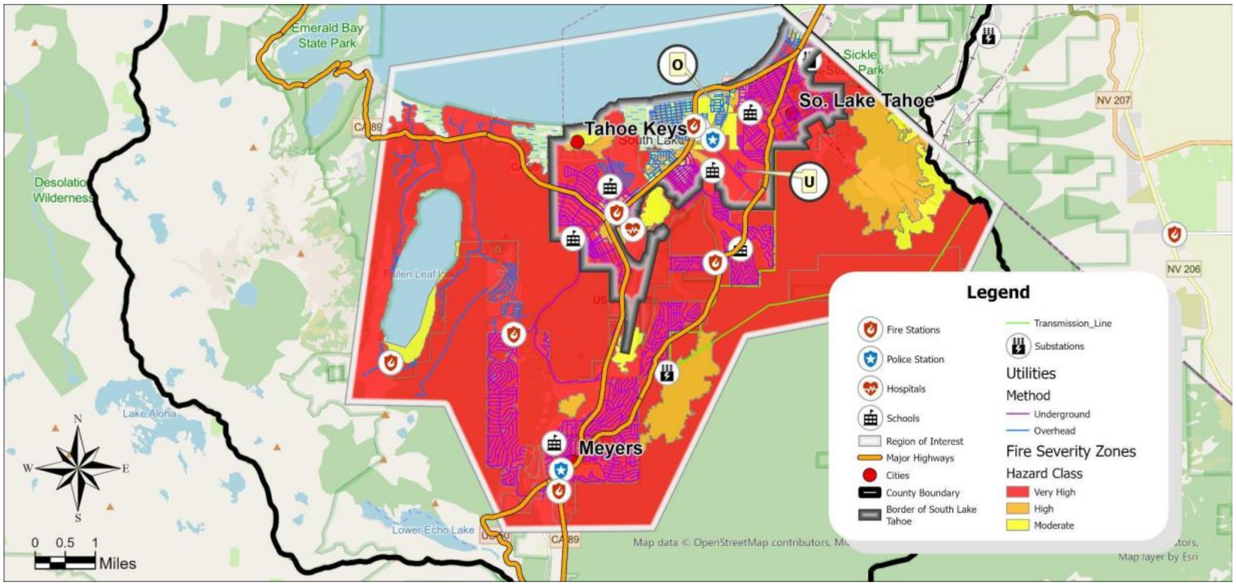

Figure 6: GIS Model.

Project-level Design

The team conducted two (2) project level circuit designs for both underground and overhead. These analyses were conducted to give insight on how a project-level design would be implemented for each design solution. Cost benefit analyses were conducted for each solution with the help of industry experts and the use of the California Public Utility Commissions (CPUC) standard cost estimates for each solution, per mile. The two (2) neighborhoods that the team chose to conduct the analyses are based on their locations within the constraints and criteria from the GIS Models. The neighborhood in Figure 7, is the neighborhood in which the underground detailed analysis was conducted and Figure 8 is the area in which the overhead detailed analysis was conducted.

<u>Underground Project-level Design</u>

A hand drawn detailed underground analysis was conducted with the help of an industry expert. Every utility box, transformer and switch that would be utilized for the total project length of 1.06 miles with 115 parcels within this neighborhood are taken into consideration. Based on the analysis, a complete and concise project for this neighborhood was created.

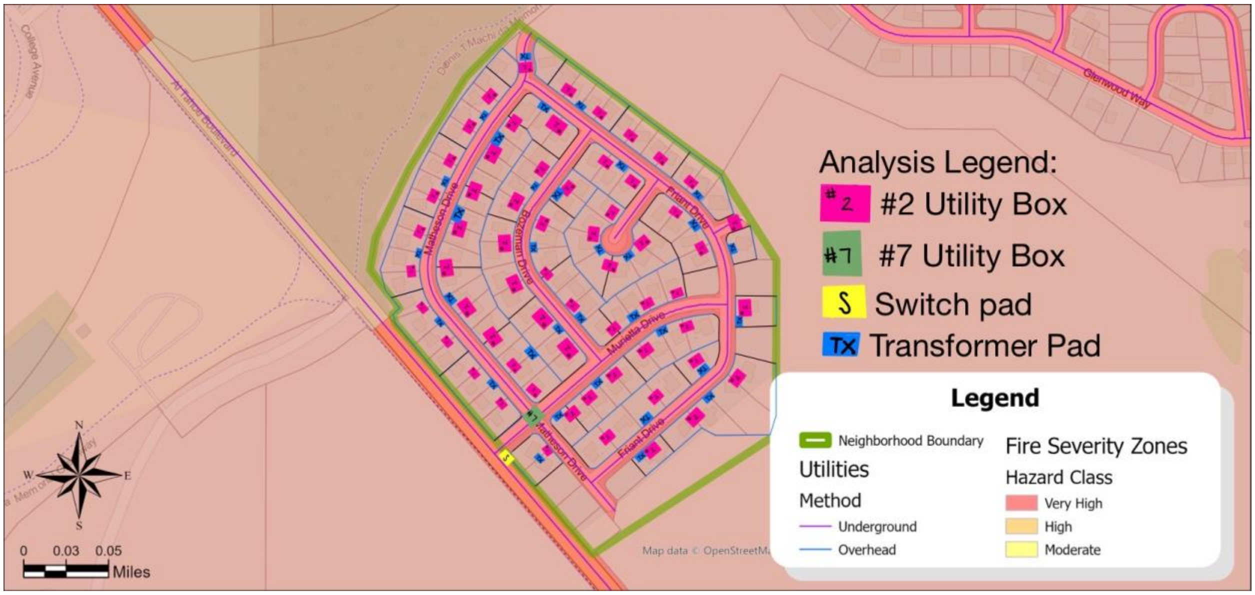

Figure 7: Underground Neighborhood Analysis.

This project-level design analysis was utilized to create a cost estimate analysis, Table 7, for the underground construction of this neighborhood. It was determined that for this neighborhood 12" and 18" trenches would be utilized, and there would be a rock adder for most of the project where 12" trenches were dug. This is due to the rocky terrain of the neighborhood. It was also determined that three inch (3") and four inch (4") conduit would be run through these trenches. The only secondary enclosures that were utilized were #2 boxes, serving two (2) homes per box. The only primary boxes that were utilized were #5 and #7 boxes. Utility #5 boxes were placed at every street junction to splice the conduit in every way it needed to be run. Near the entrance of the neighborhood a #7 box was implemented as well as a pad mounted switch. It was determined that there would only need to be one day of compaction testing, and there would need to be restoration of both softscape and hardscape. Two (2) permits would be needed to conduct this work, a city permit and environmental permit. Traffic control was estimated for 45 days; the duration that was predicted to complete the project. Environmental BMPs were taken into consideration as well. A general cost for equipment and material that would be needed to complete this project was also included. This gave a total project cost of $2.5 million for 1.06 miles.

Table 7: Linear Foot Cost Model for Underground Project-level Design.

Neighborhood Containing: Friant Dr, Bozeman Dr, Matheson Dr				
Item	Unit of Measure	Quantity	Unit Price	Total Cost
Excavation				
12"	LF	1500	$100	$150,000
18"	LF	4,112.60	$110	$452,386
ADD;Rock	LF	1,122.52	$55	$61,738
Conduit Install				
3"	LF	8,947.05	$10	$89,470.50
4"	LF	4,612.60	$16	$73,801.90
Substructures				
TX Pad	EA	30	$10,000	$300,000
Switch Pad	EA	1	$11,000	$11,000
Secondary Enclosure	EA	52	$8,000	$416,000
Primary Enclosure	EA	7	$15,000	$105,000
Restoration				
Compaction Testing	Per Day	1	$3,000	$3,000
Softscape	Sq. Ft.	1000	$7	$7,000
Hardscape	Sq. Ft.	3,459.45	$9	$31,135.05
Permits	EA	2	$600	$1,200
Traffic Control	Per Day	45	$6,000	$270,000
Environmental BMP's	EA	1	$2,000	$2,000
Equipment & Material	Lump Sum	N/A	$515,000	$515,000
			Total Project Cost:	**$2,488,731**

Overhead Project-level Design

The overhead analysis was conducted through the use of Google Maps and with the help of an overhead industry expert. The team went through Google Earth and marked all 95 poles for this neighborhood, and looked at the current type of poles that existed and its surroundings. The team then determined how to implement the fire hardening strategies that were analyzed in the overhead alternatives analysis.

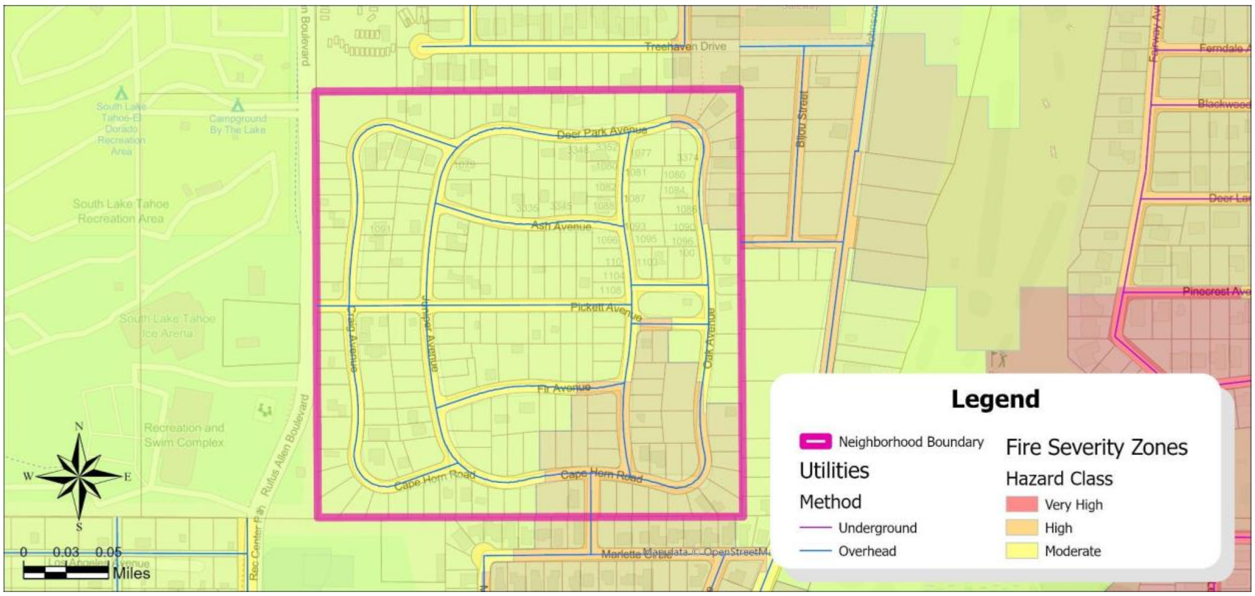

Figure 8: Overhead Analysis Neighborhood.

Based on the findings it was determined that there would be mostly Type 1 and Type 2 poles. Type 1 and Type 2 poles are typical poles that do not have a lot of equipment on them. They are what you would typically see driving down the road. It then was determined that there would be a few poles that needed to have more equipment for higher electric traffic, which led the team to implement Type 3 and Type 4 poles. The cost estimate, Table 6, for these poles include the demolition of the current poles and installation of the new poles. The team then determined the same one (1) day of compassion testing, restoration of both softscape and hardscape, as well as the same city and environmental permits. Traffic control would be implemented for the duration of the project which was estimated to be 36 days. Environmental BMPs were also considered, and the equipment and materials to complete this project were included as well. The fire wrapping and insulated conductors were also included in this analysis to fire harden the infrastructure. The total cost estimate for this project of 1.8 miles of overhead work was estimated to be approximately $1.8 million dollars.

Table 8: Linear Foot Cost Model for Overhead Project-level Design.

Ash Ave, Pickett Ave, Oak Ave, Cape Horn Rd, Craig Ave, Long Valley Ave, Fir Ave, Juniper Ave				
Item	Unit of Measure	Quantity	Unit Price	Total Cost
Excavation				
ADD;Rock	Per Hole	5	$3,000	$15,000
Poles				
Type 1	EA	68	$8,000	$544,000
Type 2	EA	17	$11,500	$195,000
Type 3	EA	7	$16,800	$117,600
Type 4	EA	3	$20,000	$60,000
Type 5	EA	0	$24,000	$0
Restoration				
Compaction Testing	Per Day	1	$3,000	$3,000
Softscape	Sq. Ft.	2000	$7	$14,000
Hardscape	Sq. Ft.	4,959.47	$9	$44,635
Permits	EA	2	$600	$1,200
Traffic Control	Per Day	36	$6,000	$216,000
Equipment & Material	Lump Sum	N/A	$515,000	$494,000
Adders				
ADD; Helicopter	Per Hour	0	$300	$0
ADD; Set in Same Hole	EA	6	$800	$4,800
ADD; Pole Wrap & Insulated Conductors	EA	95	$800	$76,000
			Total Project Cost:	**$1,785,235**

Phases of Systems Hardening Implementation

Upon completion of the cost estimates for the fire resiliency plan, it was concluded that the project would need to be phased over a period of 15 years. The total project cost is projected to be $694,499,000, which will be allocated across three (3) distinct phases. Phase 1 focuses on the construction within the designated City boundary of South Lake Tahoe. The estimated cost for Phase 1 is $279,271,000, covering the undergrounding of 98.87 miles and the reconstruction of 40.12 miles of overhead lines. The duration of Phase 1 is expected to be five (5) years.

Phase 2 involves the completion of the remaining region of interest, ensuring a more fire-resilient grid. The allocated budget for Phase 2 is $273,405,000, enabling the undergrounding of 101.49 miles and the reconstruction of 24.6 miles of overhead lines. Phase 2 is also projected to last five (5) years.

Phase 3 represents the culmination of the project, achieving the ultimate goal of undergrounding the entire region of interest and establishing the most fire-resilient infrastructure grid. This phase entails the undergrounding of 64.72 miles of lines, with a corresponding cost of $100,003,000. Additionally, Phase 3 includes the undergrounding of overhead lines that were previously fire hardened during Phases 1 and 2. Despite the duplication of effort, it was deemed financially justifiable due to the potential risk of untouched lines causing sparks before Phase 3 commences.

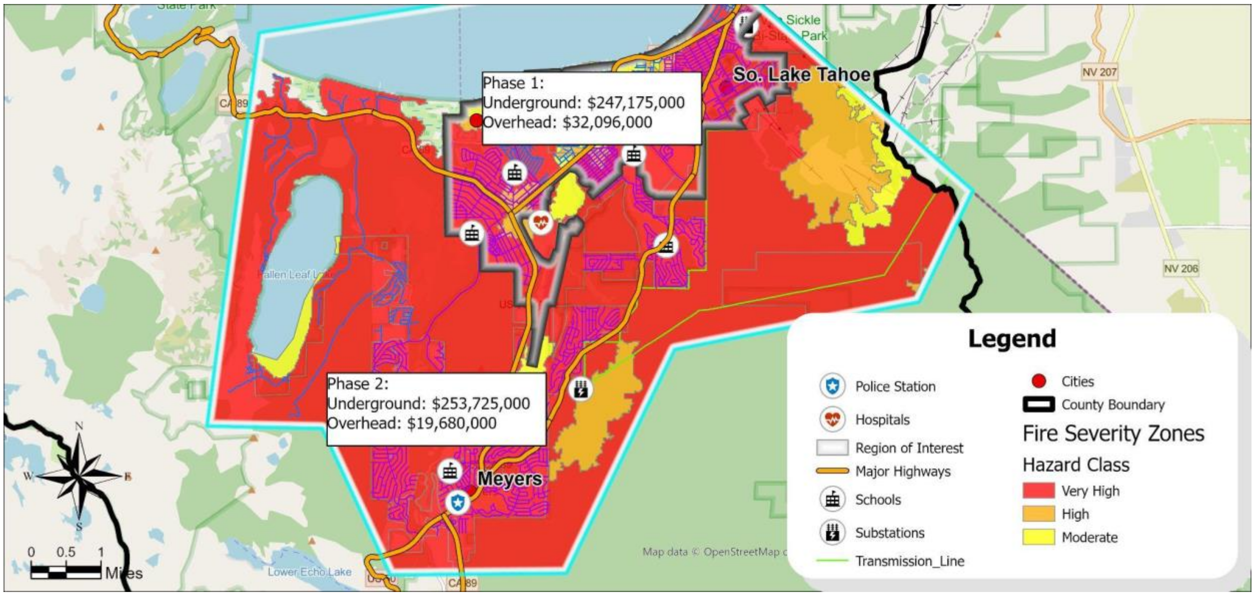

Figure 9: Phases 1 and 2 of 3.

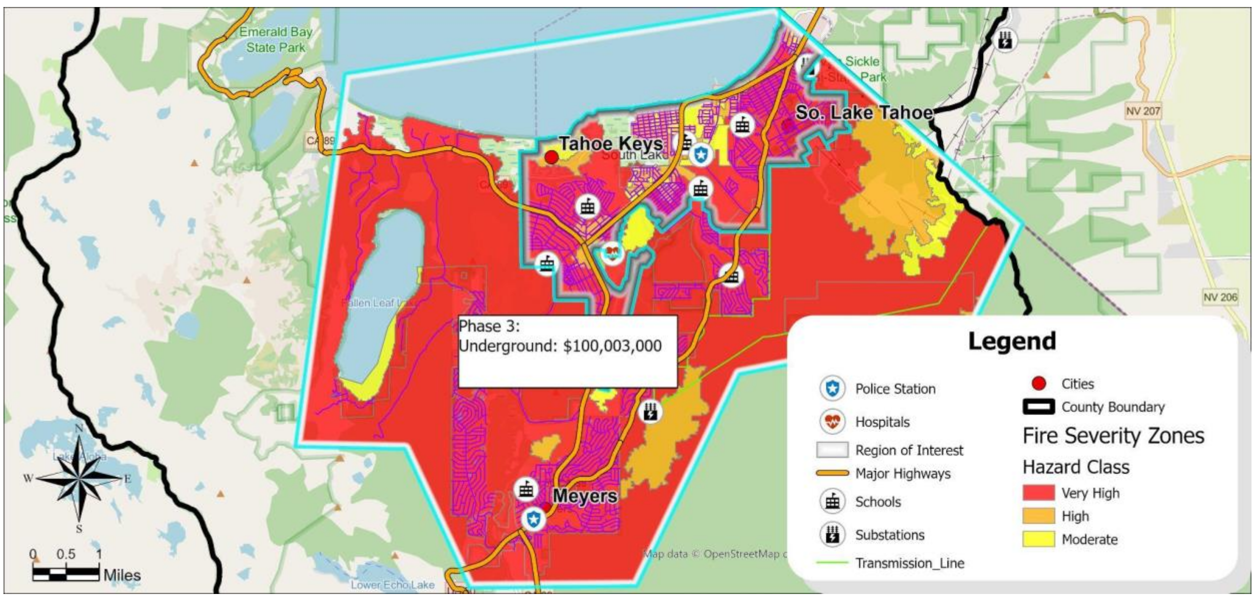

Figure 10: Phase 3 of 3.

Final Phase - Cost Estimate Analyses

Based on the California Public Utilities Commission, the average cost per mile for underground is $2.5 million and for overhead it is $800,000. Based on the regional cost estimate for all phases of the project, the team estimates a cost of roughly $600 million to complete all phases with the proposed designs.

Table 9: CPUC Avg. Project Cost Estimates for the Specified Project Region.

	Unit of Measure	Quantity	Avg. Unit Price	Total Cost
Underground Avg.	Per Mile	228.96	$2,500,000	$572,400,000
Overhead Avg.	Per Mile	36.12	$800,000	$28,896,000
			Total Avg. Project Cost:	**$601,296,000**

Conclusion

The South Lake Tahoe Fire Resiliency Project will help to mitigate wildfires which will in turn help ensure the life and property safety of the City of South Lake. Through research it was determined that two alternative solutions were best fit to provide a fire hardened system for this City, undergrounding utilities in high fire severity zones and fire hardening the current overhead infrastructures that are in low severity zones. An alternatives analysis was conducted to determine the fire hardening strategies for the overhead utility lines. This determined that the inclusion of fire mesh wrapping, and insulated conductors would provide the most amount of protection for the structural integrity of the poles in the event of a fire. The detailed designs for this project include an overview of the underground construction work that will be performed, as well as the overhead line work that is already implemented and will need to be fire hardened with the strategies. The underground construction throughout the City will use three (3) potential conduit layouts: one-way, four-way and six-way conduit configuration for running primary and secondary lines. There is a detail that indicates how the steel conduit encasement for the electric lines would be designed. The detail of the #5 Jensen box shows the configuration of how the primary and secondary lines will be run through the box for further splicing to homes and businesses. The hardening of the current overhead infrastructure as shown in the designs depicts fire mesh and insulated conductor equipment on service poles and their minimum clearances. A recommendation for the City is to implement a 10 foot minimum limb clearing, as well as a forest management program to promote the safety of their citizens in the event of a fire. The safest recommendation for the fire resiliency project in this city is to underground all utility lines. However, this recommendation comes with a hefty price. A three (3) phase plan is recommended by the team for how to break up the work over a 15-year period to make the prices more realistic. It has been proven by public utility companies that implementing underground is not only the safest option in the event of a fire, but it also is the more affordable option in comparison to overhead lines and the maintenance of those lines over several years. Through the implementation of the team's South Lake Tahoe Fire Resiliency Project, the City should be provided with more safety to their property and most importantly the lives of their citizens in the event of a wildfire.

References

About the forest. Retrieved from https://www.fs.usda.gov/main/ltbmu/about-forest

AMENDED PG&E public safety power shutoff (PSPS) report to the CPUC october 23-25, 2019 de-energization event. ().PG&E. Retrieved from https://www.pge.com/pge_global/common/pdfs/safety/emergency-preparedness/natural-disaster/wildfires/PSPS-Report-Letter-10.23.19-amend.pdf

City of malibu, californian adopted budget fiscal year 2022-2023. (). Retrieved from https://www.malibucity.org/ArchiveCenter/ViewFile/Item/490

City of oroville annual budget for the fiscal year 2022-2023. ().City of Oroville. Retrieved from https://www.cityoforoville.org/home/showpublisheddocument/20663/638004804666030000

FHSZ viewer. Retrieved from https://egis.fire.ca.gov/FHSZ/

Requirements for customer-owned poles. (2022). ().PG&E. Retrieved from https://www.pge.com/pge_global/common/pdfs/services/building-and-renovation/greenbook-manual-online/025055.pdf

Saucedo, G. (2005). *Geologic map of the lake tahoe basin, california and nevada.* ().California Department of Conservation California Geological Survey. Retrieved from https://www.conservation.ca.gov/cgs/Documents/Publications/Regional-Geologic-Maps/RGM_004/RGM_004_TahoeBasin_2005_Pamphlet.pdf

Villareal, L. (2022). *Underground conduits.* ().PG&E. Retrieved from https://www.pge.com/pge_global/common/pdfs/services/building-and-renovation/greenbook-manual-online/062288.pdf

Appendix A

Figure A-1: Conduit Configurations

https://drive.google.com/file/d/12QDkTkP-Srcy0MRjGorYj5MvVcHuMwR2/view?usp=share_link

Figure A-2: Surface Level Site Plan

https://drive.google.com/file/d/1Ux3aI_-28xNdmj0nbpUs7usZHRc0DCNf/view?usp=share_link

Figure A-3: Surface Level Transmission Line Elevation

https://drive.google.com/file/d/14CSJPpPfdlZIsgwL4kvbQS7sHSpDrnSA/view?usp=share_link

Figure A-4: Surface Level Transmission #5 Box

https://drive.google.com/file/d/1E78a2G97FjF5IrS2kCJikF3WEppS2HH0/view?usp=share_link