Las Virgenes Municipal Water District

SCADA Communication System Review

Preliminary Engineering Report

Draft (January 25, 2012)

Version Log

Version	Date	Author	Note
0.10	October 1, 2011	LFT	Inception
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1. ABOUT THIS DOCUMENT

The purpose of this document is to provide Las Virgenes Municipal Water District (District) a preliminary engineering report outlining potential benefits derived from upgrading the existing SCADA communication system to currently available wired and wireless networking technologies. The existing system provides communication to the District's potable, reclaimed, and composting facilities. The overall focus is migration of the existing system from a serial radio network to an Ethernet based wireless network. The document outlines options for the communication system architecture, radio, and network equipment. While options for Ethernet to serial protocol conversion are covered, PLC replacement options are outside the scope of this document.

2. EXISTING SYSTEMS

The existing system consists of spread spectrum radios, leased line modems, and data trunk lines between main sites.

In 1998, MSO worked with the District to develop the potable communication system upgrade for the Y2K replacement project. The project was initiated to replace the BIF control system which used tone telemetry over telephone lines. The BIF equipment was obsolete and communication over the telephone lines failed regularly.

The District already had some sites using Modicon PLCs so it was a natural choice to continue using the same manufacturer. Modicon (now Schneider Electric) uses a simple industry standard serial communications protocol (Modbus) that was well suited for distributed communications systems of the day. Although antiquated by today's standards, equipment existed to transport the Modbus protocol from serial to Ethernet networks and back to serial again providing the backbone of the existing communications system. This equipment included Modicon's serial bridge multiplexor and NR&D's MEB serial to Ethernet Bridge which was relatively new at the time.

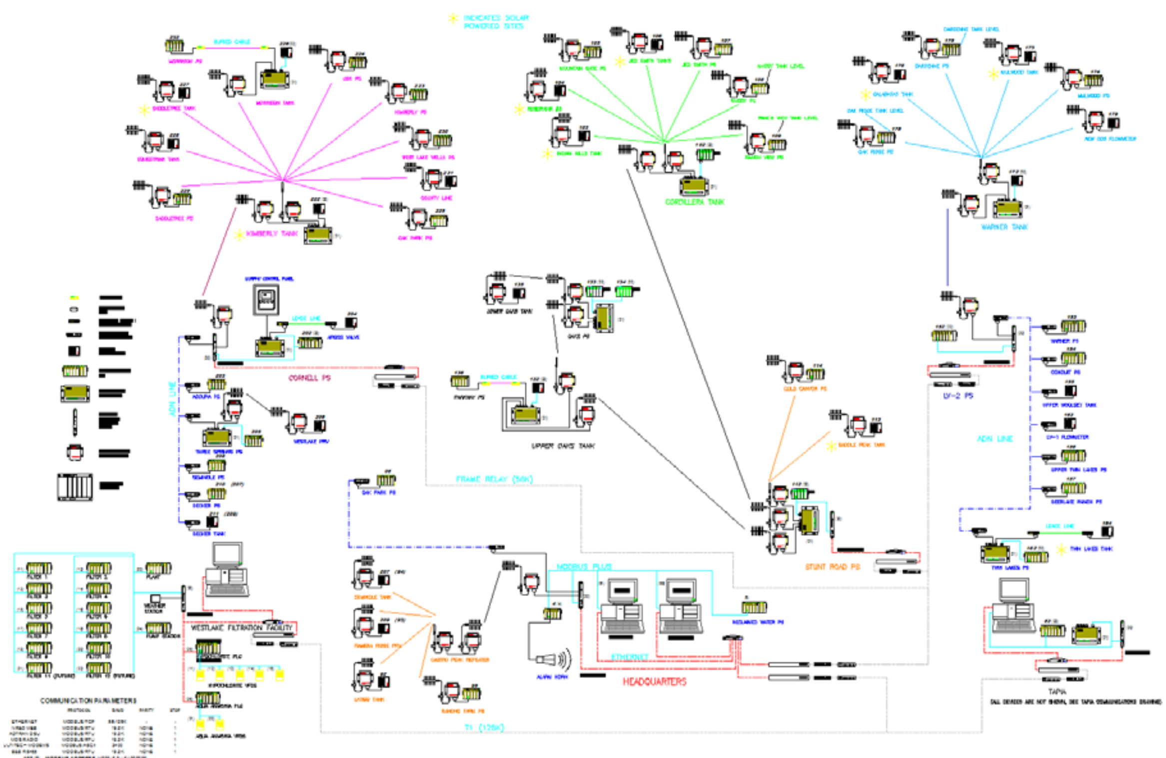


Figure 2-1 Existing SCADA Communication Layout

2.1 Radio Sites

The existing system uses MDS 9810 unlicensed spread spectrum radios at most of the sites. Water distribution facilities are predisposed to typical radio system architectures – the District is no exception. Tanks on hills were prime locations for radio repeaters while pump stations at lower elevations in the valleys could typically see their tank repeater site. Certain sites were selected as major repeaters since they had a commanding view to multiple surrounding sites.

Figure 2-2 MDS 9810 Spread Spectrum Radio

The radios have a range of approximately eight miles from a directional yagi or eight miles radius from an omnidirectional antenna at a repeater site. Most of the District's sites were within the above mentioned radius from their selected repeater site. The radios were addressable to prevent cross talk from different agencies or overlapping repeaters. We've used this version of radio on other power and water projects with great success.

At 900 MHz and less than 1 Watt/m radiated power output, the radio signals need a direct or near direct line of sight between the sites. The 900 MHz radio waves do not "bend" around obstacles like the lower 150 MHz or 450 MHz frequencies do. Therefore line of site is necessary for a radio path to be viable. Therefore sites obscured by hills or blocked by other terrain are not accessible by the radios.

2.2 Leased Line Sites

Sites not viable for radios due to line of site or other reasons were implemented using ADN leased line modems. These modems were digital modems on digital telephone lines which were supposed to be more reliable than regular analog telephone lines. The sites were multi-dropped together to reduce the cost and number of leased lines. The collector modem was at one of the communication hubs and each remote site had a modem. The modems are AC powered and require an inverter to provide power from the battery backup during power outages.

Figure 2-3 Leased Line ADN Modem

2.3 Hub Sites and Communications Backbone

Remote sites are concentrated at so-called hub sites which are in turn connected to the Frame Relay communications backbone which connects the hub sites to District headquarters. Therefore the hub sites have a considerable array of equipment including: Frame Relay termination, CSU/DSU, Ethernet router and switch, and finally an Ethernet to serial bridge. These sites also have wall mount racks for the equipment and a small uninterruptable power supply (UPS).

Figure 2-4 NR&D MEB-TCP Ethernet to Serial Bridge

2.4 Networked District Facilities

Connection to the Tapia Water Reclamation Facility (TWRF) and the Westlake Filtration Plant (WLFP) is established via dedicated T1 line with District headquarters. Each of these facilities has significant internal network infrastructure which is beyond the scope of this document. Alternatives to the T1 line need to be investigated as the District prefers to be self reliant for all communication paths where feasible.

2.5 Data Transfer

In order to support automatic operation many of the sites share data: tank level, flow, pressure, or number of pumps running or required to run. Some tank sites utilize buried cables for transmitting analog signals to a pump station, while other tank sites have a PLC requiring radios to read the data as necessary. The existing serial protocol doesn't support peer-to-peer communications, so PLCs located at hub sites were programmed to read and write the data to other sites as necessary.

2.6 Limitations of the Existing System

The existing system, while quite fast at the time, is now limited in speed, bandwidth, and flexibility when compared with current wireless technologies. Over the years the addition of new facilities consumed additional network bandwidth. Arguably the current communication system is at or past its peak communication bandwidth.

The existing communication network requires field devices communicate via a single protocol – Modbus. The protocol requires a master which queries the data from the remote devices known as slaves. The original design allows multiple masters via Modicon bridge multiplexors and NR&D's MEB TCP Ethernet to serial bridges. While these devices provided greater flexibility they also limited access by other serial protocols because they will only route Modbus related protocols. This protocol limit precludes the use of security cameras, voice over IP (VOIP) phones and certain types of so-called smart sensors.

The existing system provides security through device-unique keying, slave device addressing, and the Modbus protocol. However Modbus is an open source protocol and with proper knowledge and equipment security could be compromised.

3. CURRENT TECHNOLOGIES

The SCADA industry typically lagged behind most other industries in adopting new communication technologies. The lag was often due to equipment cost and the slow speed with which vendors modified their equipment to take advantage of new technologies. While this lag still exists it is significantly less than it used to be. The near universal adoption of TCP/IP on Ethernet as the de facto standard for communication networks has had the greatest single impact.

Ethernet communication hardware in SCADA systems has become prevalent at all levels of control systems. In the past, Ethernet was only available on the largest of PLC controller platforms because it required large form factor modules for the large Ethernet interface card. Now, Ethernet communications is available on many of the smallest PLC controllers. Ethernet communication typically provides higher speed communications on all PLC platforms.

In addition, Ethernet communication supports peer-to-peer communication protocols. So if a pump station needs to read the nearby tank level, the pump station PLC can be programmed to read the tank level directly rather than relying on a repeater or hub site to relay the data to the pump station PLC. Arguably this adds traffic to the network but the network support significantly greater bandwidth and it also eliminates the need for the intermediate device to read and write the data.

Typically most industrial Ethernet networks use TCP/IP to route traffic from source to destination. This allows multiple protocols to coexist on the network thereby allowing PLCs from multiple vendors on the same network. Further this allows other devices such as IP security cameras, VOIP phones, and other smart networked equipment and sensors to benefit from one common network.

Figure 3-1 Schneider Electric and Allen Bradley Ethernet PLCs

3.1 Ethernet Radio Options

In the last decade, Ethernet radios have significantly improved with reasonably fast data rates, good security, high reliability, and much lower cost. Industrial grade Ethernet radios are now available in a wide range of frequencies and data rates.

Frequency	Data Rate
450 MHz (licensed)	19 Kbps
900 MHz (unlicensed)	256 to 1024 Kbps
2.4 GHz (unlicensed, similar to 802.11b, g, n)	11 to 54 Mbps

5.X GHz (unlicensed, similar to 802.11a)	54 to 300 Mbps
6 GHz and up (licensed)	100 to 1000+ Mbps

Table 1 Radio Frequency and Data Rates

Most of these radios are similar to commercial grade wireless access points for home or office – they require a unique network name and some form of secure code for the remote sites to connect to the master or access point. Other security functions include encryption and a white list of remote radios that are allowed to connect to the master radio.

3.1.1 Backhaul Radios

The options for the backhaul or trunk radios are in the higher frequencies of 2.4 GHz and above. These provide higher data rates and are generally referred to as broadband radios. The 2.4 GHz unlicensed band has been in use for over 10 years and is fairly congested. The 5 GHz unlicensed band has been in use for over 5 years and is getting congested. However with careful planning and fine tuning of the configuration it can be a very cost effective option, especially with the newer technology.

There are two bands within the 5GHz band: the UNII band (5.255-5.325, 5.495-5.705 GHz) and the ISM band (5.725 - 5.875GHz). The UNII band has a lower output power than the ISM band and is therefore used less often due to its reduced range. Many of these radios can be set for different channel bandwidths, the wider channels provide higher data rates but also increase the chances for interference. For example a radio capable of 300 Mbps with a 40 MHz channel would be reduced to 30 Mbps with a 5 MHz channel. Most of the radios can automatically adjust their data rates depending on how strong the signal is. As the signal gets weaker the radio keeps a connection working by reducing the data rate which reduces the receive sensitivity.

The power output of these radios is much less than the 900 MHz radios and therefore require higher gain antennas to achieve similar distances. As a result omnidirectional antennas are more suited for single plant applications and not for the District’s needs. Additionally as the antenna gain increases the beam of the antenna becomes much narrower. To achieve links of 8 or 10 miles, a 3 foot dish is required and the beam is only 3 degrees wide. It becomes very important that the antenna mast not only handle the higher wind loading brought on by the dish antenna but also remain rigid enough to prevent antenna deflection and loss of signal. The installation is more challenging as the antennas take more effort to align and frequency or channel selection requires more planning and tuning to optimize the system for reliability and speed.

Most of the 5 GHz radios provide enhanced features that add to the RF performance of the radios. As an example the radios provide for 2 or 3 coax connections to the antennas for different polarizations which can be set manually by a web-interface or automatically by the radio. Some of the radios are able to use the multiple signal paths to achieve high performance even when the signal is being distorted by buildings or other obstructions.

In addition to the much higher bandwidth, these radios provide very short latency from 5 to 10 ms compared to 100 to 200 ms with 900 MHz radios. Less latency makes it feel like you're on the wired network. Cost for these radios varies widely depending on the desired bandwidth and age of the technology. Some of the radios we have used have older technology and maximum bandwidth of 54Mbps. These cost from $2,500 to $3,500 (radio and antenna only) for a pair of radios depending on the antennas. Newer radios with higher bandwidth, latest technology, and maximum bandwidth of 300Mbps cost from $6,000 to $8,000 (radio and antenna only) depending on antennas.

All of the 5 GHz radios utilize power over Ethernet (POE) which uses extra conductors in the Ethernet cable to provide power to the radio. Unfortunately not all radio vendors meet the POE 48VDC standard and some require proprietary POE equipment to provide 12 or 24 VDC.

Figure 3-2 Backhaul Antenna Installation and Mast

Many of the broadband radios combine the transceiver and antenna into one package that mounts on the radio mast resembling a pizza box. These integrated radios have limited antenna gain and only work for shorter distances of three to five miles.

Figure 3-3 Tank Mounted Antenna Mast with Integrated Transceiver and Antenna

Another option is to use semi-licensed 4.9 GHz radios. These radios are a little more costly than the 5 GHz radios and are designated for public-safety use. An FCC application is required to use these radios. The FCC will determine if the District qualifies and if there are other existing users of this band in the District's area. If there are other users it will require the District work with that agency or agencies to determine if sharing of the frequency band is possible. If there are no existing users in the area the District will become the frequency coordinator for the area.

A final option is to use licensed broadband radios. These operate in the 6 to 23 GHz and higher frequencies. The bandwidth goes up into the multi-gigabit range but so does the price with a pair of radios costing $15,000 to $25,000 (radio and antenna only). These radios are often two part units with an outdoor unit and an indoor unit. They also require larger antennas are more expensive to install than the other options.

3.1.2 Point to Multipoint Radios

The backhaul network connects to the field sites via point-to-multipoint radios. MDS has three 900MHz Ethernet radio models: iNET, iNET II, and Mercury. All three use the 902-928 spread spectrum frequencies but they are not compatible products. The iNET II uses a wider channel than the iNET, and the Mercury uses an even wider channel. The iNET 900 operates at 256/512 Kbps, iNET II operates at 512/1024 Kbps, and the Mercury supports up to 5Mbps. The higher bandwidth of the Ethernet iNET and iNET II require a stronger radio signal with an RSSI of better than -75. The Mercury requires even stronger strong signal strength and with its very wide channels has very limited range for most SCADA applications.

Figure 3-4 MDS iNET II 900 MHz Spread Spectrum Ethernet Radio

The 900 MHz Ethernet iNET radios use the same radio antenna, cables, and surge protectors as the existing 900 MHz serial spread spectrum radios. The Mercury radio requires an additional GPS antenna. While the iNET radios can be a direct replacement of the MDS 9810 serial radios, the iNET radios will not work as well at sites with weak radio links. Weak links are more pronounced with Ethernet as the sites will no longer need to be polled in rotation. Instead Ethernet will support multiple connections to a single site with multiple sites being polled simultaneously. This faster polling rate will make the communication errors more pronounced as more retries will be required.

Another option for a 900 MHz radio is the Trio J Series which costs about $500 less than the MDS iNET radio. However while MSO has significant practical experience with iNET radios we have little practical experience with the Trio radios and therefore should further test the Trio radios before considering them as an alternate to the iNETs.

Figure 3-5 Trio J Series 900 MHz Spread Spectrum Ethernet Radio

3.2 Ethernet to Serial Conversion

Even though the radio network and PLCs are both in need of being upgraded the radio network is being upgraded first to support any future PLC upgrade. This means the field sites will require an interim solution to convert the Ethernet ModbusTCP protocol to serial Modbus. Two options exist for this interim need: dedicated Ethernet to serial conversion hardware or configure the iNET radio as an Ethernet to serial bridge. Some sites may be better served by one or the other.

3.2.1 Dedicated Ethernet to Serial Converter

In the original design there are several large Ethernet to serial converters installed at the communications hubs. These serial to Ethernet converters were expensive (approx. $4,000) and have large form factors. The converters were too large to put in small tank or PRV site panels and were too expensive for thirty plus sites.

Smaller less expensive Ethernet to serial converters have since been developed. Current day converters bridge between Ethernet and serial communication media as well as provide protocol conversion, e.g. ABCIP to Modbus. There are some limitations to the protocol conversion but it does provide an easy and inexpensive way to bridge protocols. In this scenario the Ethernet port of the radio would be plugged into an Ethernet switch or directly into the converter. The inclusion of an Ethernet switch would allow service personnel to connect locally to the PLC without disconnecting the network.

Figure 3-6 Digi One IAP Protocol Bridge and Lantronix Ethernet to Serial Bridges

The Ethernet to serial converters are typically DIN rail mountable and are DC powered which works well with the existing back up power at the sites. These bridges can be added to existing sites with minor wiring modification and power demand.

Sites that require multiple serial devices to be bridged to the Ethernet network can utilize a multiple port bridge. These devices provide the bridging described above but not the protocol conversion. The single and multiple port devices can be configured through the Ethernet network and provide valuable diagnostics over the network.

Figure 3-7 Digi One Port Server TS Multiple Port Ethernet to Serial Bridge

3.2.2 iNET as Serial Radio

The iNET radios can be configured to operate as a serial radio and convert ModbusTCP to serial Modbus. In this scenario the serial port of the radio would be connected directly to the serial port of the PLC. However this option would not work by itself at a site with multiple Modbus devices needing conversion and would require service personnel to disconnect the PLC from the network in order to connect directly to it.

3.3 Security Cameras (IP Cameras)

Security cameras have evolved from co-axial closed-loop cable systems to live streaming on Ethernet networks. However, IP cameras do require significant bandwidth on a network and a few high resolution cameras streaming constantly can decimate even a hardwired network. Newer cameras have the ability to limit the data or can be activated by motion. However the cameras can be needlessly triggered by animals and on windy days. Our experience is it's best to break up the radio network into several smaller sub networks to separately handle the camera traffic. However this method requires additional radios at the main repeater sites and additional networking equipment.

The topic of security cameras must be discussed during the network design if the District seriously expects to implement IP cameras or other network devices in the future. This discussion should include SNMP monitoring software also.

4. PROPOSED SYSTEM

Advances in communication equipment provide the possibility of a robust, high speed, fault tolerant, and flexible Ethernet SCADA communication network. The SCADA network needs to be built and sized from the control center at District headquarters (HQ) out to the sites since all the data must come back to this location. District headquarters currently has Ethernet connectivity to some sites. Low speed frame relay (56 Kbps) is used to connect to the Cornell and LV2 pump stations while higher speed T1 (1.5Mbps) circuits connect to the Rancho Las Virgenes Composting Facility (Rancho), Tapia Water Reclamation Facility (Tapia) and Westlake Filtration Plant (WLFP). With proper planning these paths can be retained and incorporated into the new system to serve as a backup if desired. However these links, especially the frame relay links, are bandwidth limited, so their performance as backup links will be significantly limited compared with the backhaul radios potential data rate of 20 Mbps.

One of the District's spoken desires is to eliminate or at least reduce their dependence on outside agencies for communication links. Doing so will provide annual cost savings based on the number of lines replaced but it will also mean the District will be responsible for maintaining critical portions of their communication network. MSO's approach is to design a backhaul radio network with multiple paths between nodes making up the backhaul network. This will require two or possibly three pairs of radios at some sites, as opposed to the current one pair, as well as multiple port routers to support the routed network design. If a radio or path obstruction problem occurs the network will route to a backup path to seamlessly restore communications. Recognize it may not be feasible or economical to have a backup path for all backhaul sites.

4.1 Proposed Backhaul Radio Network

The main data collection facilities are HQ, WLFP, Tapia, and Rancho. Unfortunately these sites are all in valleys which limit the radio path options. MSO has developed a preliminary network plan for the backhaul sites. This was developed based on our experience with the District's existing system and our topographic mapping software. This proposed plan is to be reviewed with District staff prior to MSO conducting any field testing in case the District's review alters the proposed paths.

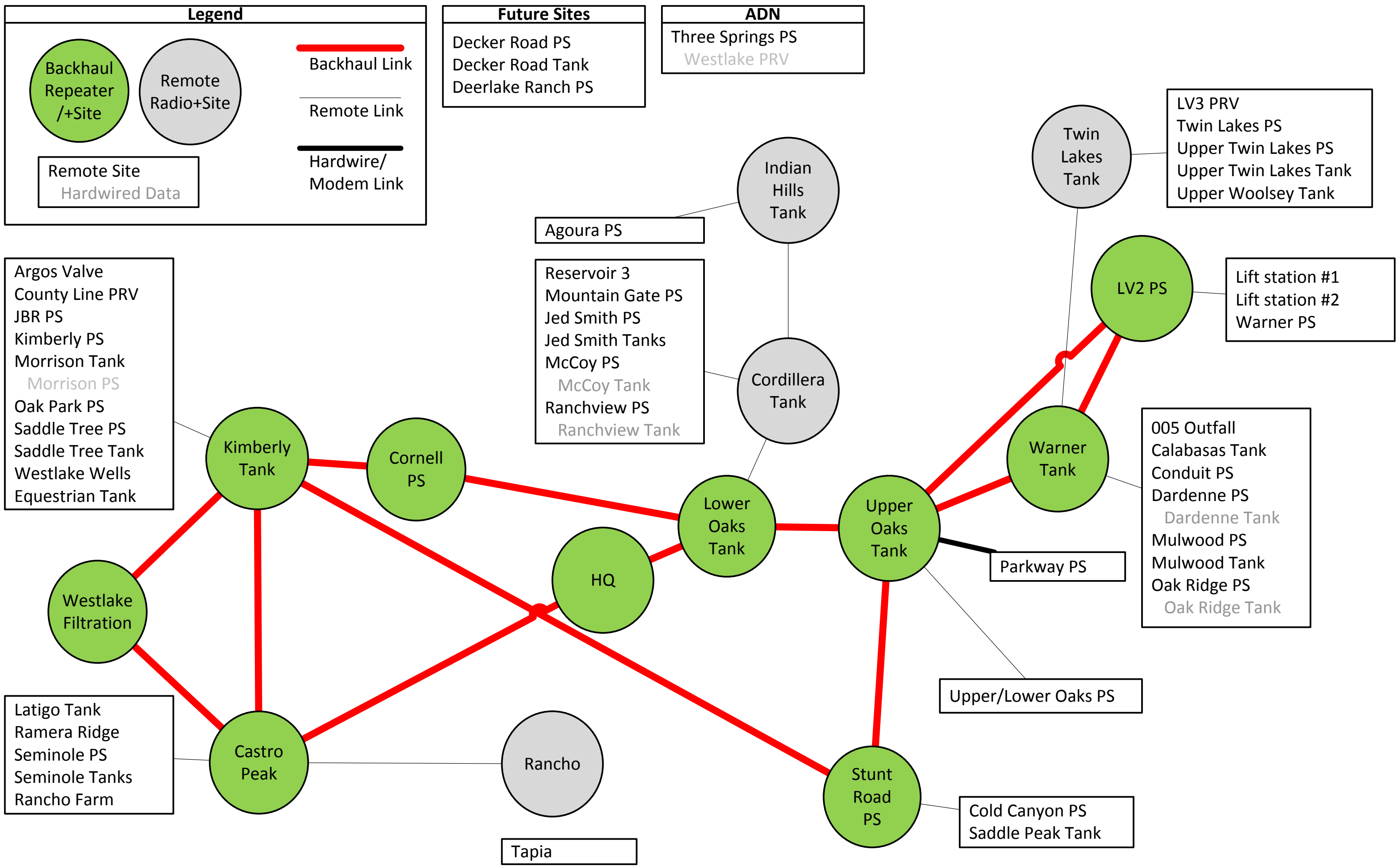


Figure 4-1 Logical Network Diagram

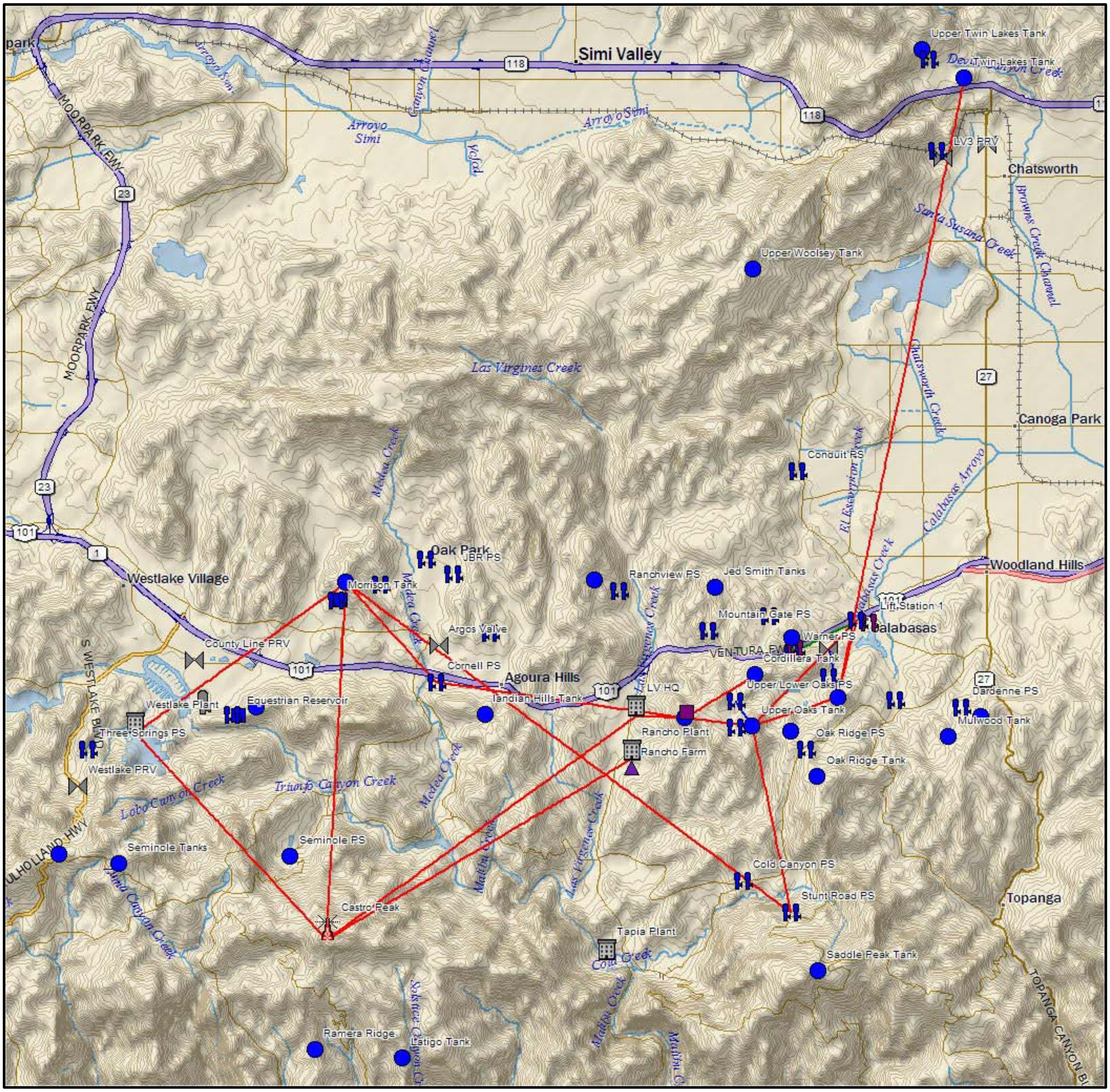


Figure 4-2 Proposed Backhaul High Speed Radio Paths

The figure above shows all of the District sites under consideration with the proposed high speed radio links shown in red. At this time we have not found a suitable radio path into Tapia from the proposed backhaul network. One possible solution is to install a string of radios along Las Virgenes Road to connect Tapia to Rancho or HQ.

4.1.1 Backhaul Network West Side

The first major link is from HQ to Castro Peak from which three major network segments emanate to WLFP, Kimberly Tank, and Rancho. Kimberly Tank connects to Cornell PS and back to WLFP. If an alternate link from HQ to Lower Oaks Tank can be established we believe this will provide a link back to Cornell PS thereby providing a backup path to Kimberly Tank and all of the west side sites.

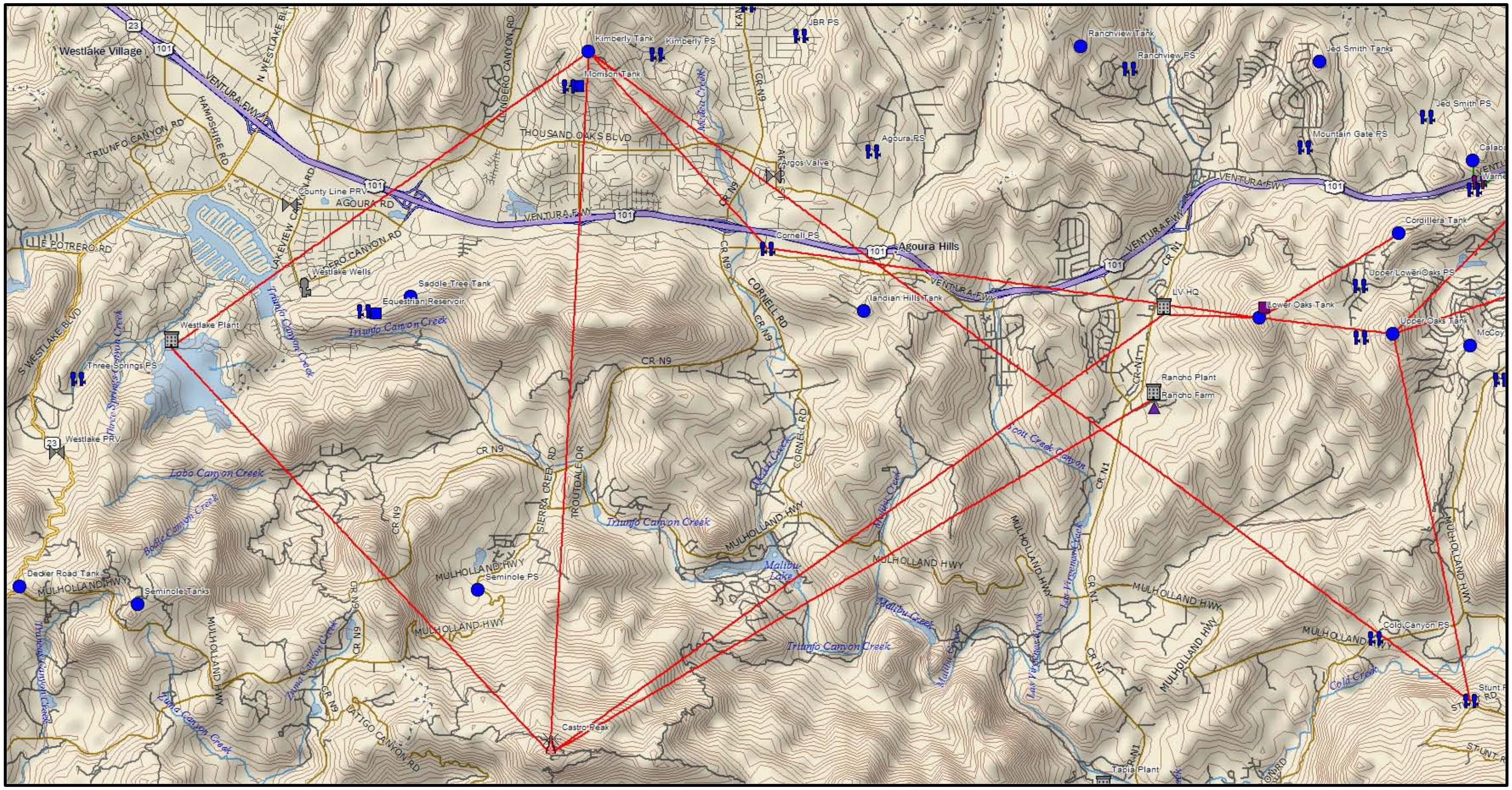


Figure 4-3 Backhaul Network West Side

4.1.2 Backhaul Network East Side

The eastern side of the proposed backhaul network is predicated on at least one of the following links being established: Castro Peak to Upper Oaks Tank, Kimberly Tank to Stunt Road PS, or HQ to Upper Oaks Tank via Lower Oaks Tank. From Upper Oaks Tank direct links can be established to Stunt Road PS, Warner Tank, and LV2. From Warner Tank direct links can be established to LV2 and the single link to Twin Lakes Tank. Lower Oaks Tank will provide the single link to Cordillera Tank. Another alternate path to the west side from HQ can be established to Kimberly Tank via Stunt Road PS.

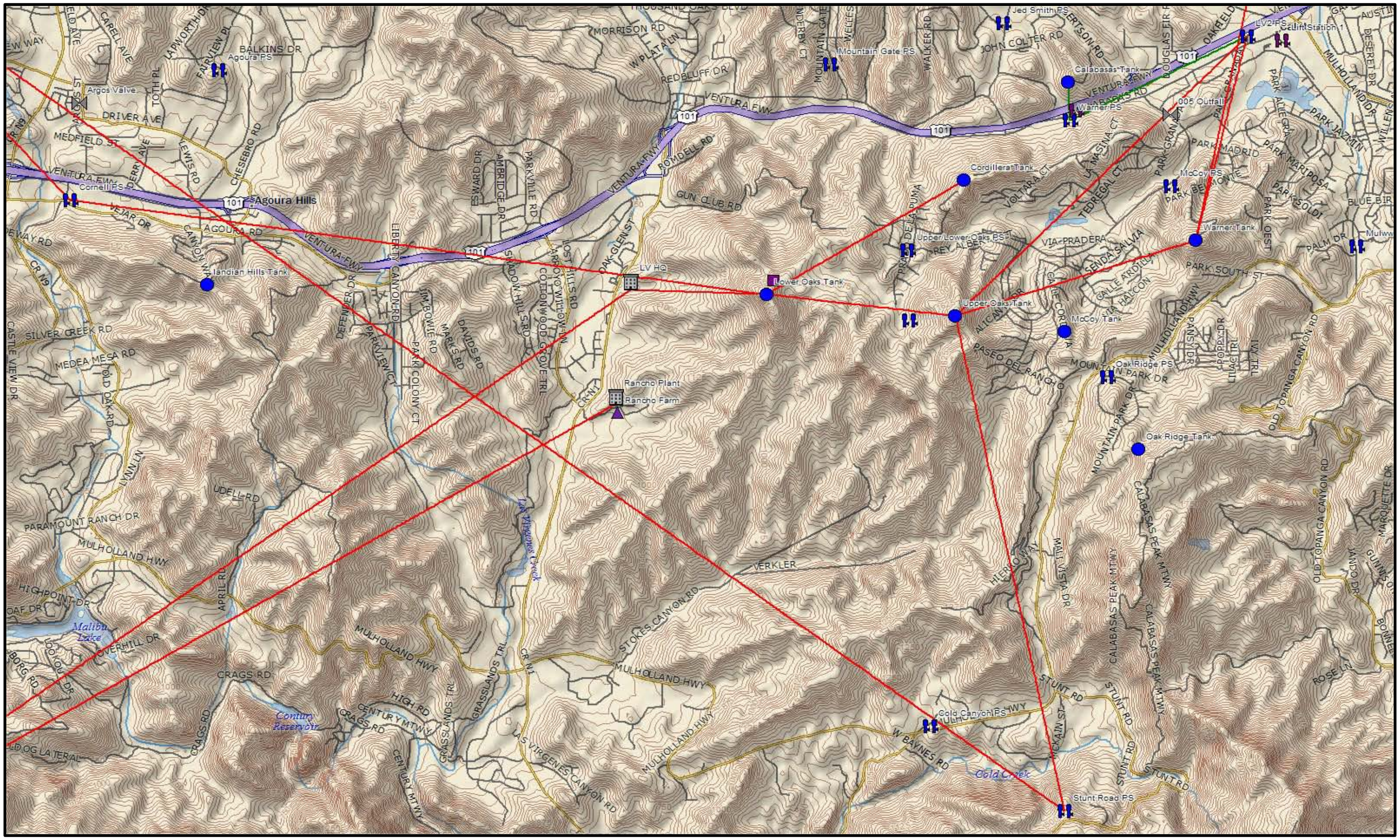


Figure 4-4 Backhaul Network East Side

4.1.3 District Headquarters

The District's headquarters is a campus like facility with several office buildings presenting itself as more of a office environment. Adding radios and large profile antennas will be a challenge aesthetically. The antenna mast needs to be substantial enough to support the larger antennas and be tall enough to establish the necessary links with other sites. The hill south of the main headquarters building limits where the mast can be located and still be in line with Castro Peak. During testing we will investigate suitable locations for the mast, antennas, and radios. It may be necessary to rent a lift if there is no suitable structure to mount the antennas to for testing purposes.

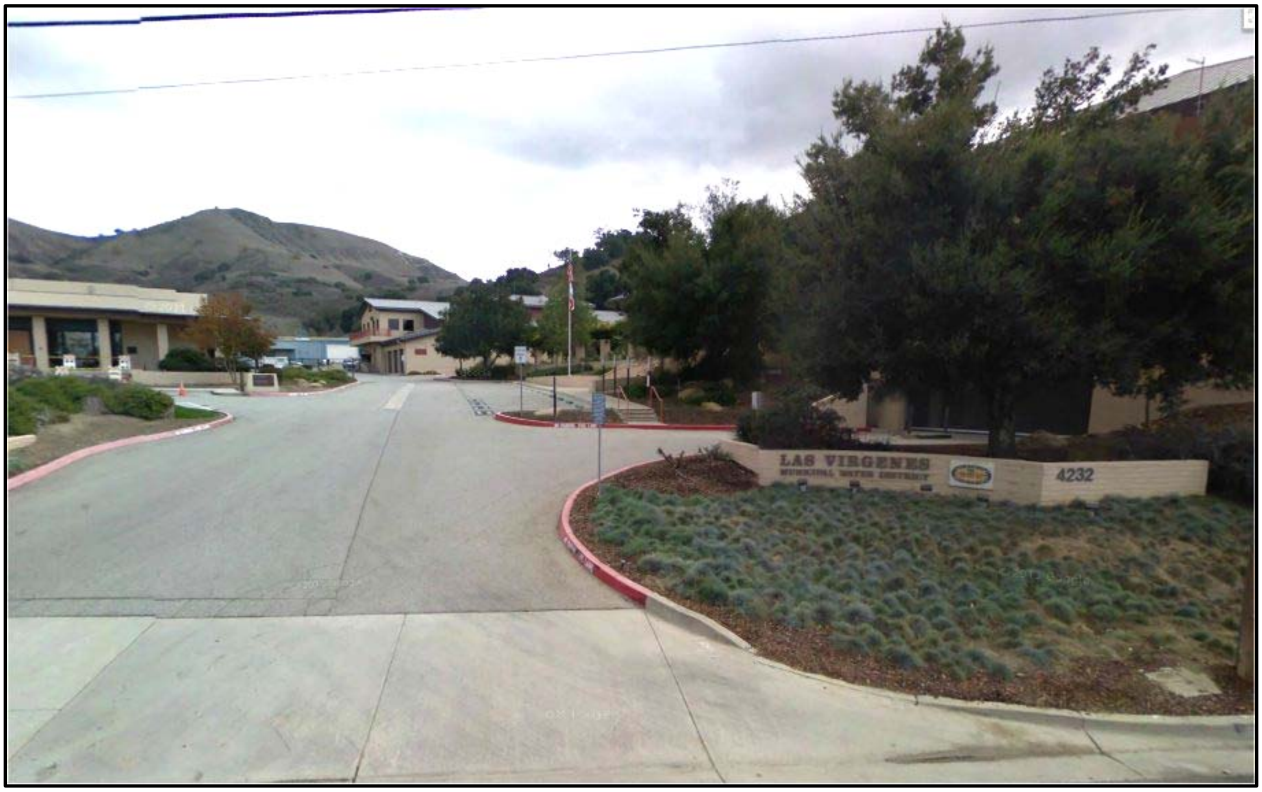


Figure 4-5 District Headquarters Looking East

4.1.4 Castro Peak

Castro Peak is one of the highest elevations in the District and is visible to HQ, Rancho, and WLFP. It is currently a repeater site collecting data at HQ from Ramera Ridge, Latigo Tank, and Seminole Tank. Two problems exist with this site: it is a leased site and the dirt road leading to the site may not be passable during rainy weather. The proposed backhaul network's equipment requirements may require lease negotiations in order to set up the additional equipment. The existing tower may need to be evaluated to determine if it can handle the wind loading for three or four panel or dish antennas. We will use certified tower technicians to mount the antennas during the test phase. There are multiple towers and users of this site and testing will determine if there are any other 5 GHz radios installed on the adjacent towers that could cause problems with the proposed District radios.

Figure 4-6 Castre Peak Aerial View

4.1.5 Headquarters to Castro Peak

This is an existing proven radio path that has worked well with the 900 MHz radios. At just over six miles the proposed 5 GHz radios will require higher gain antennas at least at one end of the path. We plan to test the path with an integrated (transceiver and antenna) radio at HQ and a two foot dish or two foot square panel antenna at Castro Peak.

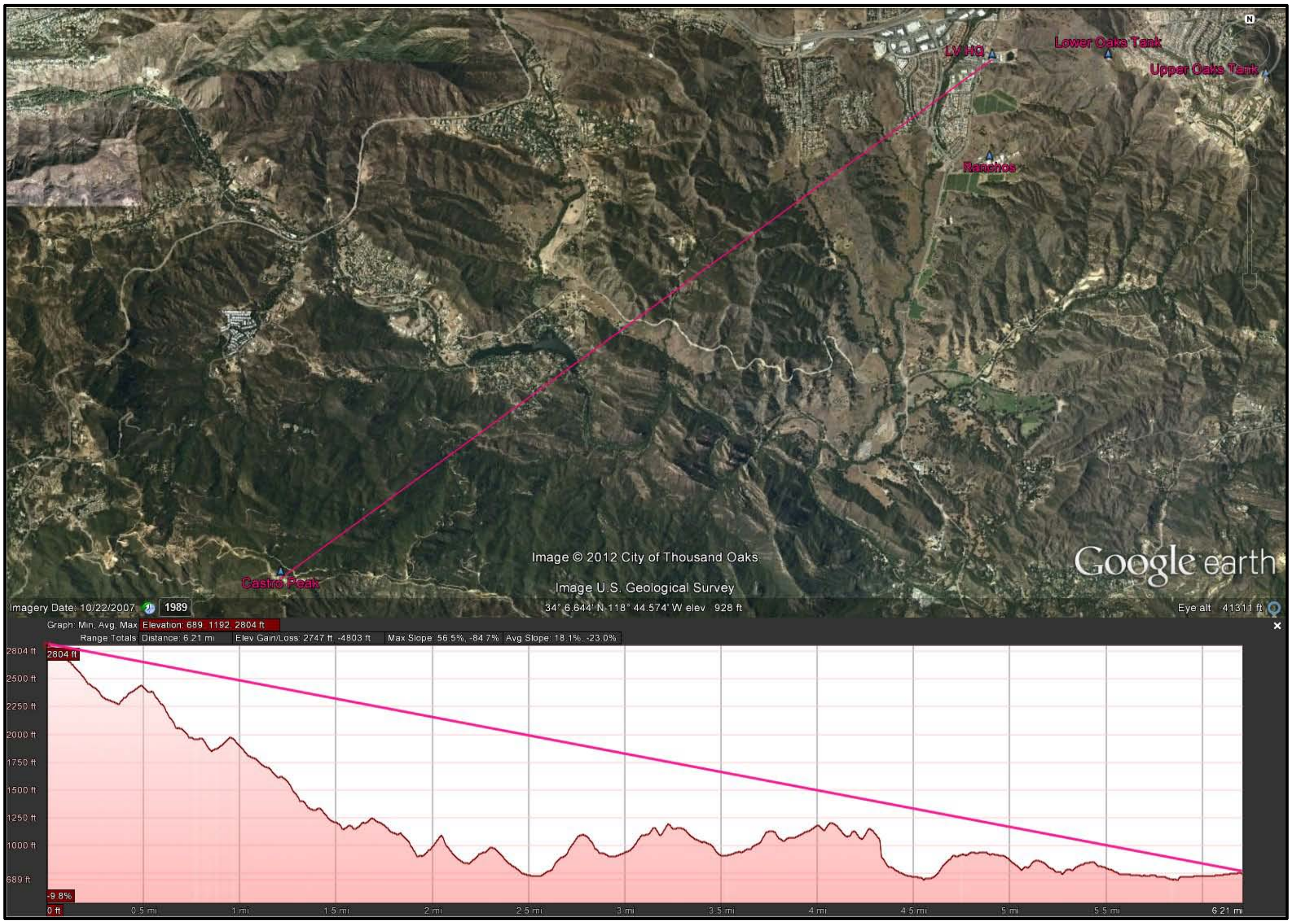


Figure 4-7 HQ to Castro Peak Path and Profile

4.1.6 Castro Peak to Rancho

This path is nearly identical to the HQ to Castro Peak path only slightly shorter. Since Rancho is so close to HQ and the paths are very similar it is probably not required to test this path unless the field testing of the HQ to Castro Peak suggests otherwise. If tested the same radio and antenna configuration will be used as for the HQ to Castro Peak link. Rancho will not have a backup radio path as no other reasonable options have been identified.

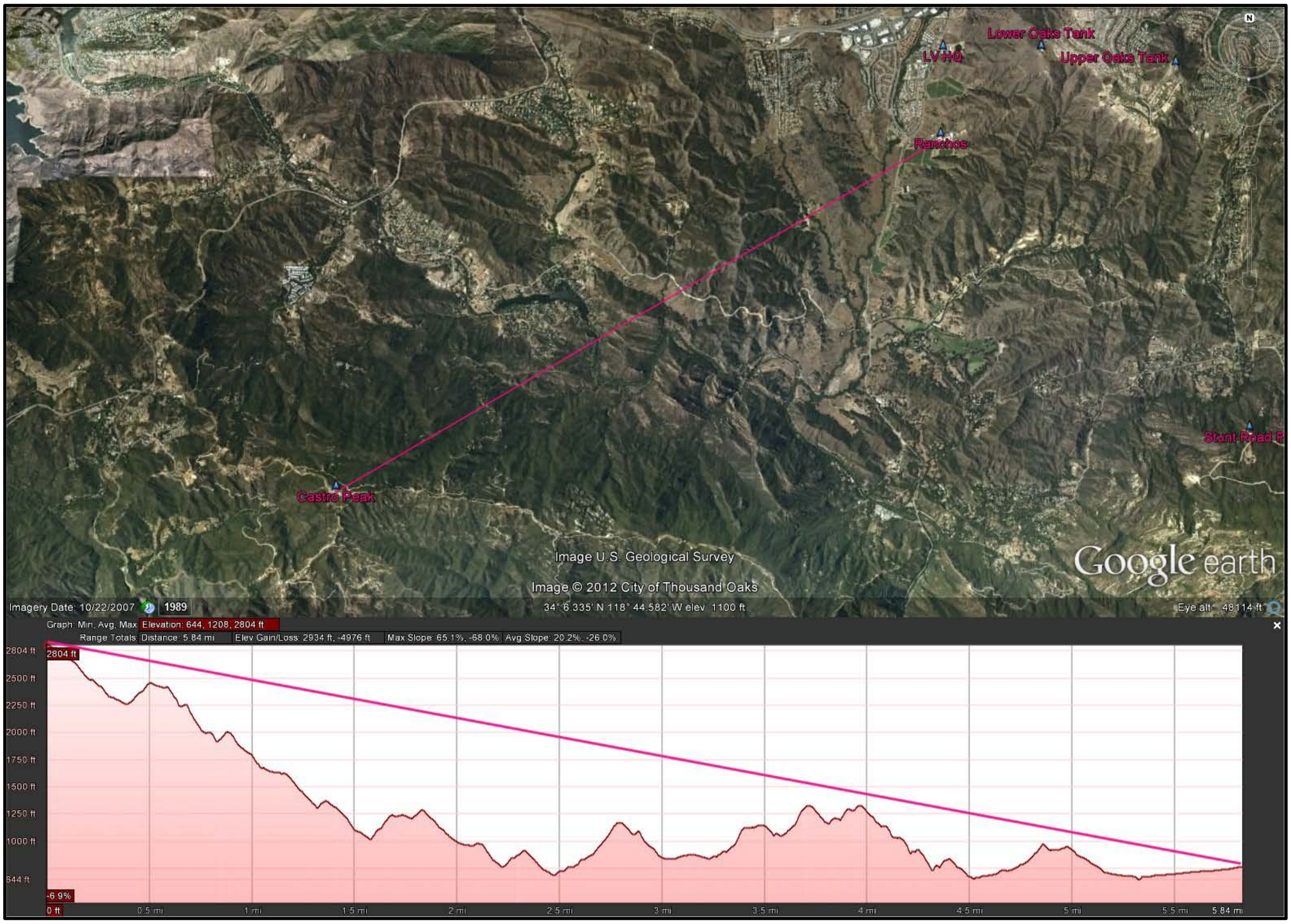


Figure 4-8 Castro Peak to Rancho Path and Profile

4.1.7 Castro Peak to WLFP

This radio path is just less than five miles in length and looks good topographically. For this link test we will use a two foot dish or two foot square panel antenna and integral radio at Castro Peak and an integral radio at WLFP.

During testing we will need to determine where the radio and antenna mast should be mounted. The antennas for the two links (Castro Peak and Kimberly) will require five feet of separation on the mast. We will need roof access during testing.

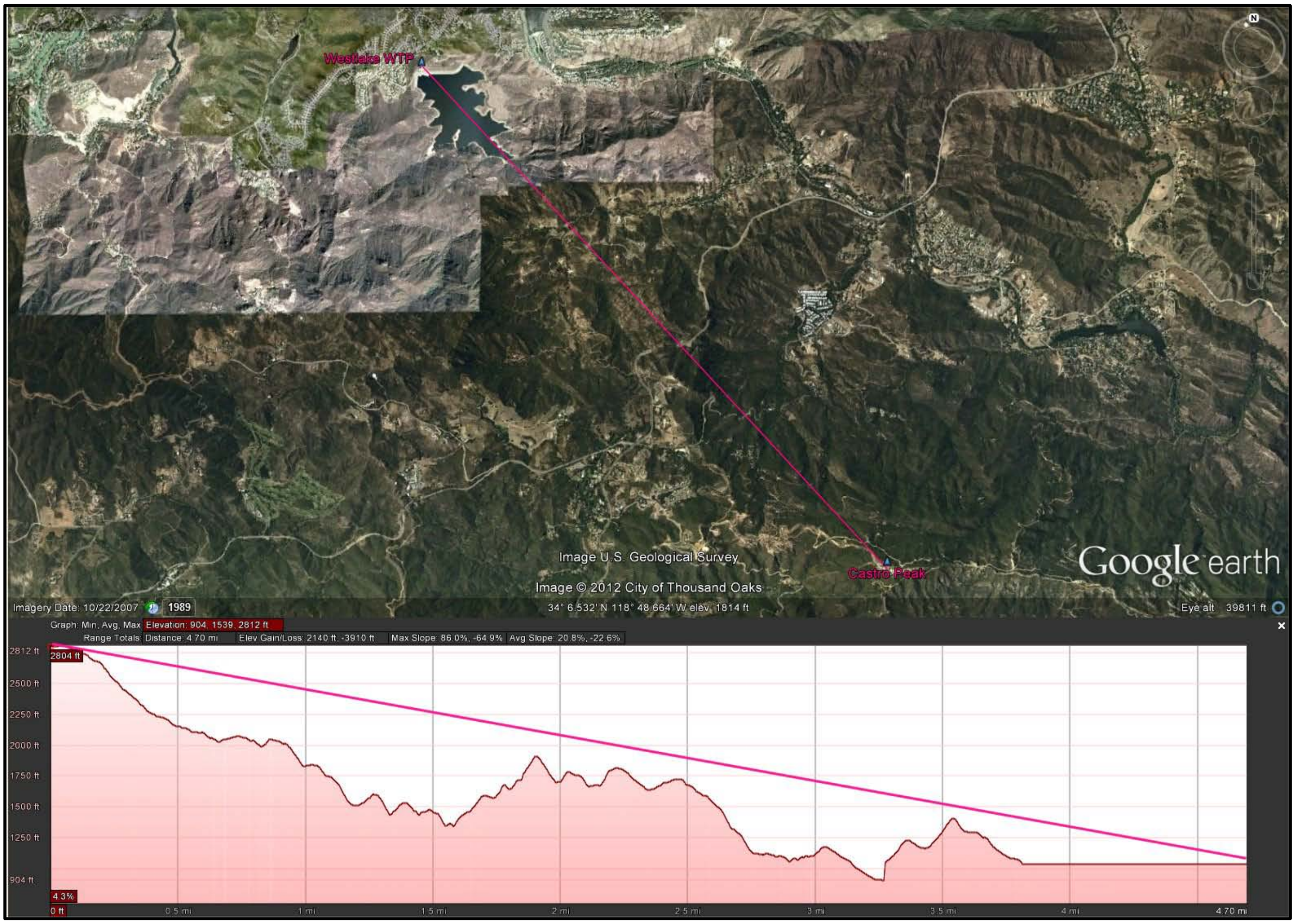


Figure 4-9 Castro Peak to WLFP Path and Profile

4.1.8 Kimberly Tank to WLFP

This path just over four miles and is expected to provide a backup path on the west side of the backhaul network. Kimberly Tank is recessed into a hill and is largely hidden from view. It will require a substantial radio mast to support three or four 5 GHz antennas and multiple 900 MHz antennas. This site is solar power and will need extensive additions to its solar panels and batteries to support the proposed equipment. The WLFP antenna will need to be located five feet from the Castro Peak on the WLFP mast.

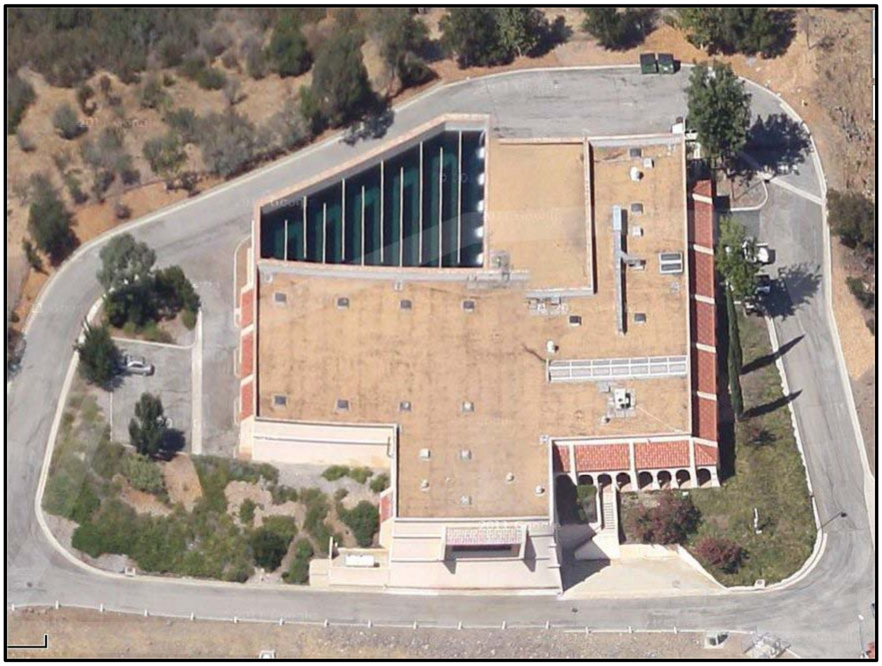


Figure 4-11 WLFP

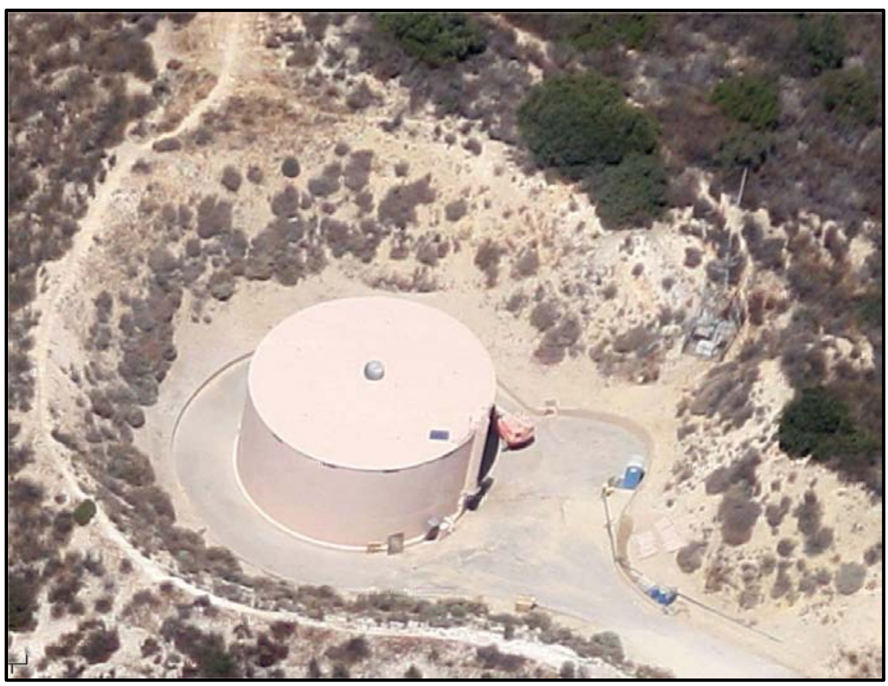


Figure 4-10 Kimberly Tank

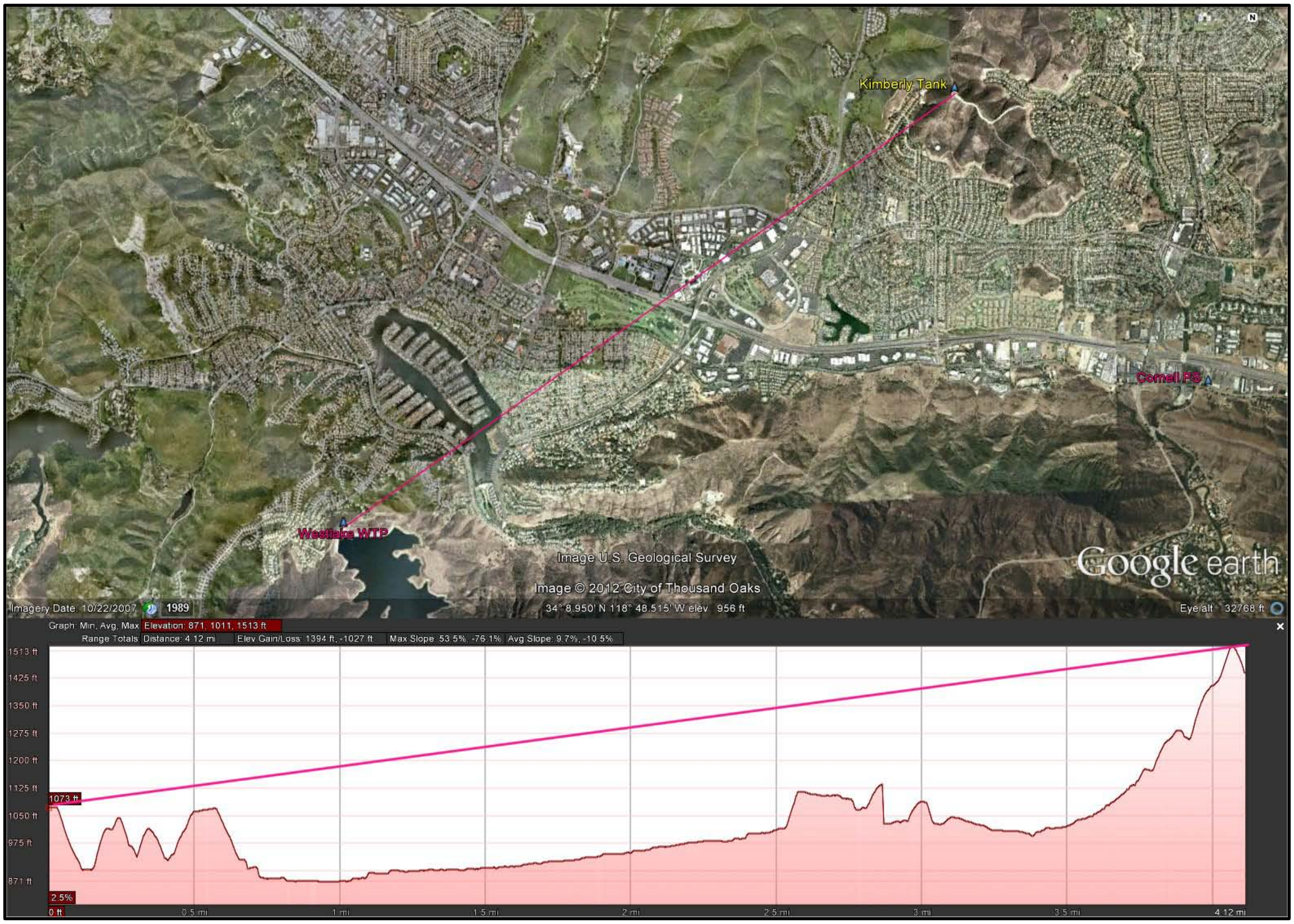


Figure 4-12 Kimberly Tank to WLFP Path and Profile

4.1.9 Kimberly Tank to Cornell PS

This path is currently used by the 900 MHz radios and works well. However the topographic profile indicates there is some interference so it's possible we may have trouble getting the 5 GHz radios to work. It may be necessary to have a lift or bucket truck at Cornell PS to determine what height mast or tower will be needed to make the path work. The existing radio antenna is attached to a tripod mast on top of the pump station. This mast will not be sufficient for the new 5 GHz radio and antenna.

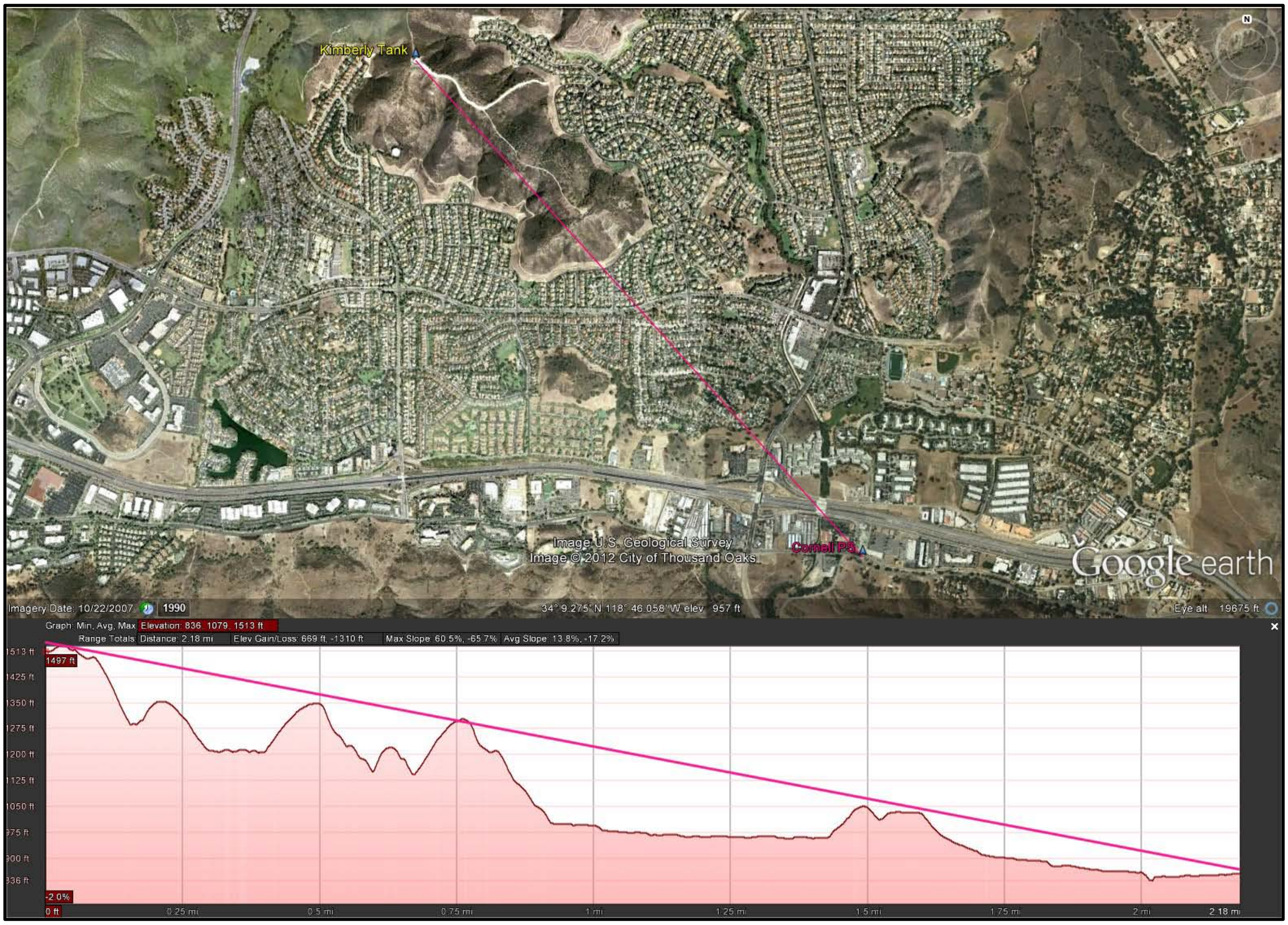


Figure 4-13 Kimberly Tank to Cornell PS Path and Profile

4.1.10 Cornell PS to Lower Oaks Tank

This potential path looks good and at only four miles in length we can likely use the integral radios at both ends. The trees at the east are a concern as they are in the radio path and may require too much height to overcome.

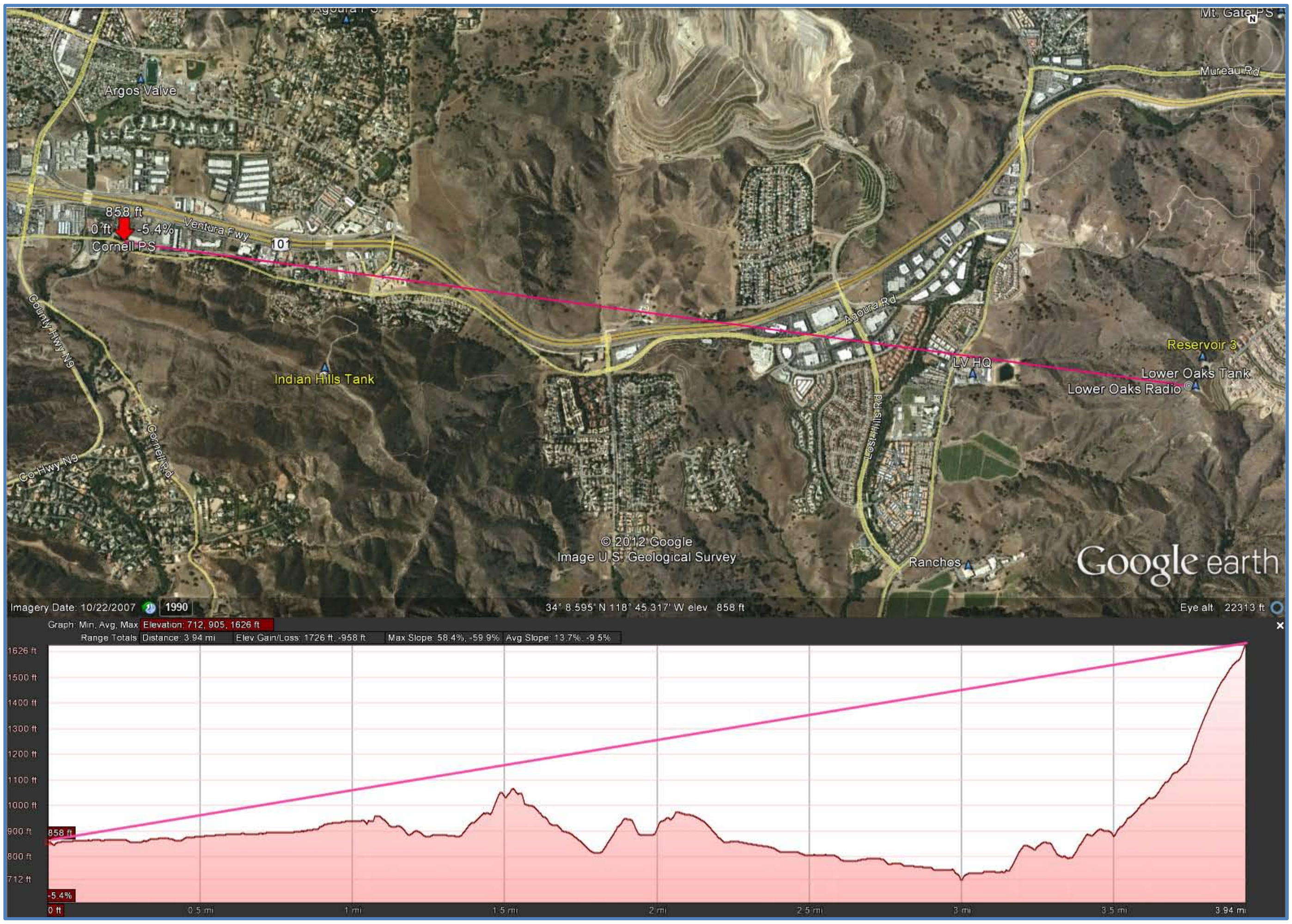


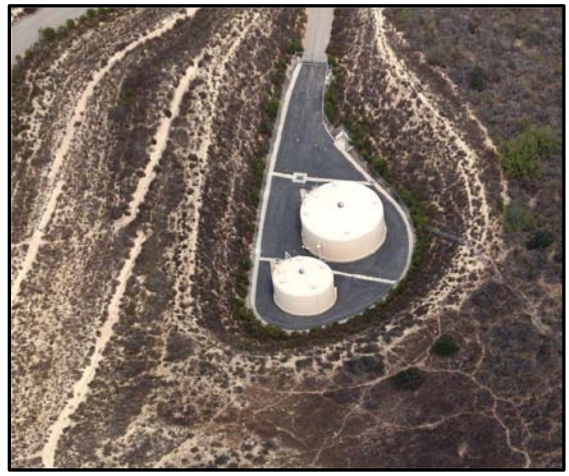
Figure 4-14 Cornell PS to Lower Oaks Tank Path and Profile

4.1.11 Headquarters to Lower Oaks Tank

This path is potentially critical to the proposed backhaul network for the east side. The path looks good and is under a mile in length. Likely the integral radios will work for both ends or we can use smaller external antennas due to the short path length. The tank site is cut into the hill with the highest point approximately twenty five feet higher than the tank. Hopefully a short radio mast on the hill will be the least visible to the neighbors and still provide adequate height for the HQ, Cornell PS, and Upper Oaks Tanks links.

Figure 4-15 Headquarters to Lower Oaks Tank Path and Profile

4.1.12 Lower Oaks Tank to Upper Oaks Tanks



Upper Oaks Tanks are above ground tanks but the site is cut into a hill and the tanks are mostly hidden from view. The tanks were built after the previous SCADA communications upgrade so the tanks were not part of that communication plan. The site is one of the higher tank elevations and offers good line-of-site to many other tanks and pump stations. It is viewed as a key site in this new radio network. It could have as many as four 5 GHz radio/antennas.

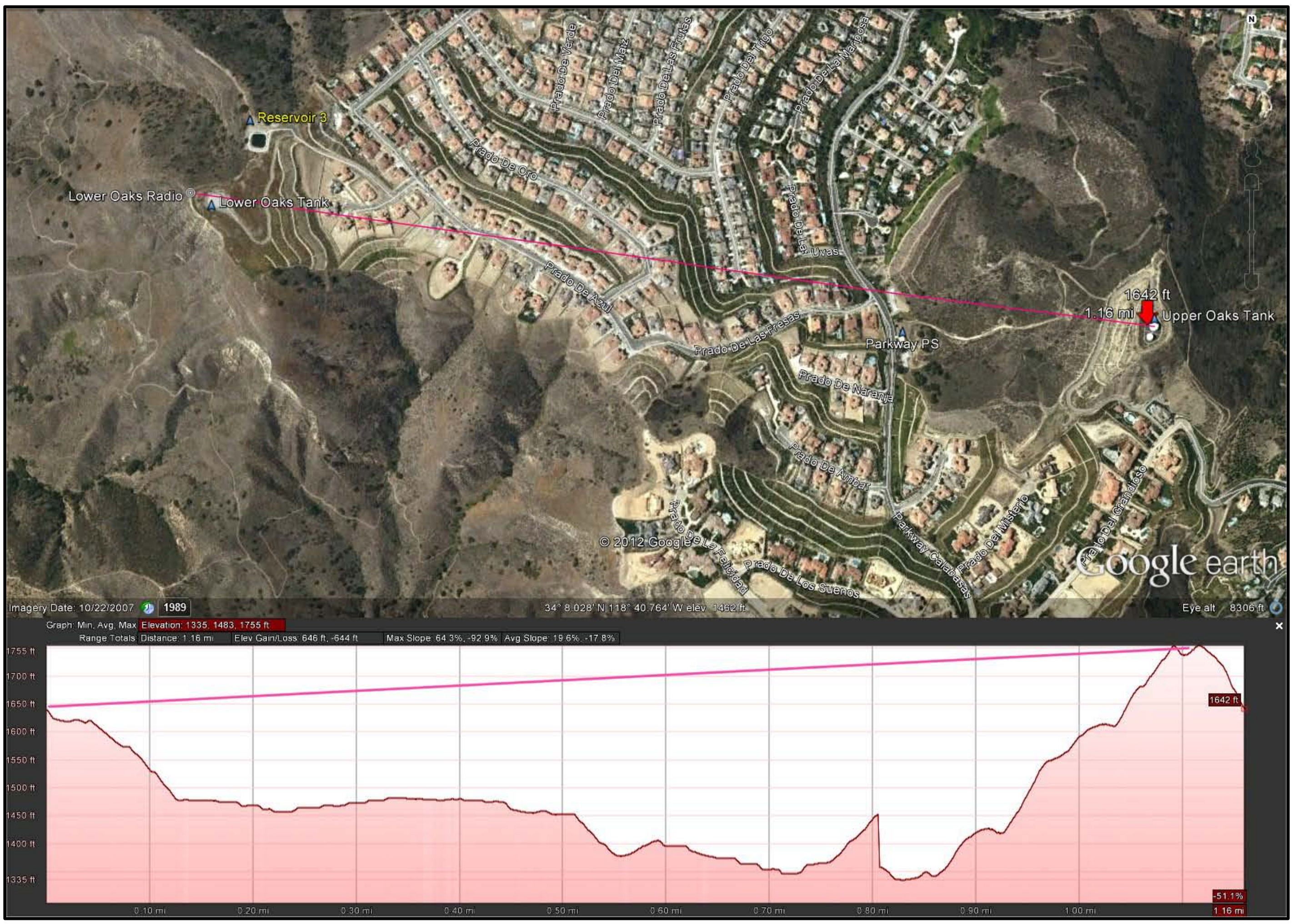


Figure 4-16 Lower Oaks Tank to Upper Oaks Tanks Path and Profile

4.1.13 Upper Oaks Tanks to Warner Tank

This path is a short distance and looks good topographically. There should be no problems getting this path to work except for the trees that mostly surround Warner Tank. Warner Tank is also an important site both for backhaul and for gathering data from local sites. It will need a taller radio mast to accommodate the additional proposed radios.

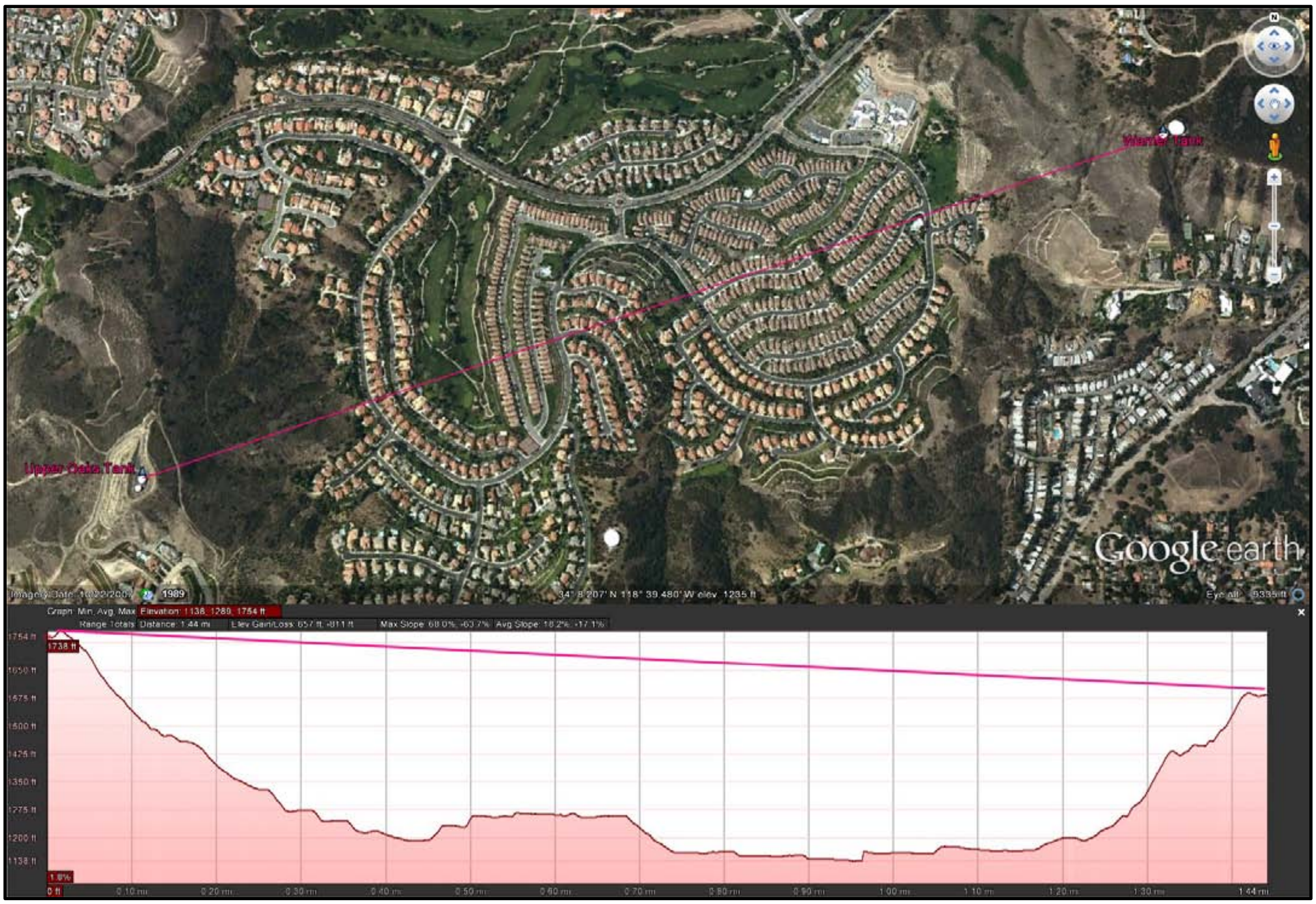


Figure 4-17 Upper Oaks Tank to Warner Tanks Path and Profile

4.1.14 Upper Oaks Tanks to LV2 PS

This path is only 2.5 miles long and looks good except for the odd spike in the profile image which does not appear real. This link will be a backup path to the Warner Tank to LV2 path which is an existing path that works well.

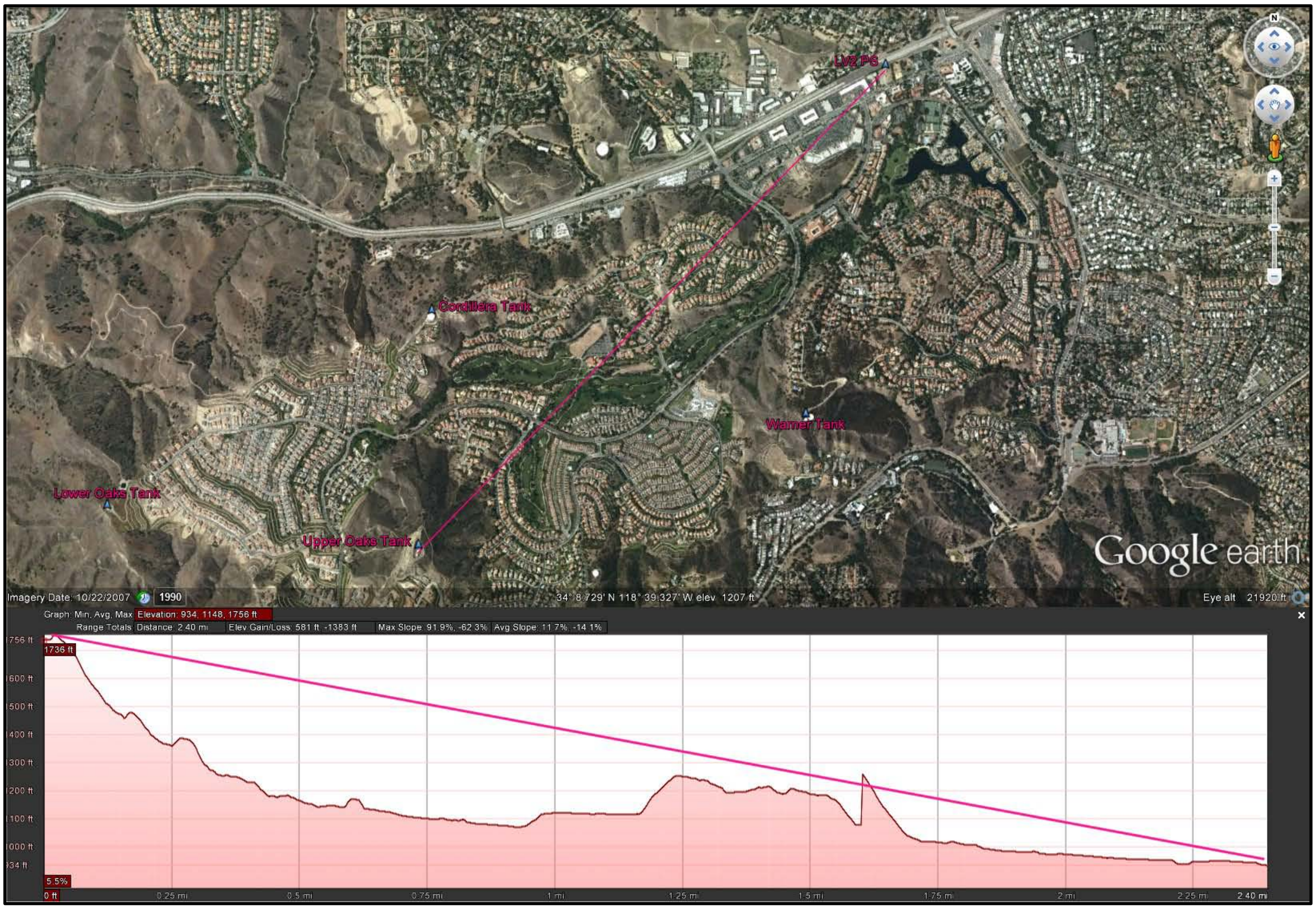


Figure 4-18 Upper Oaks Tanks to LV2 PS Path and Profile

4.1.15 Warner Tank to Twin Lakes Tanks

This profile is good but the path is one of the longer paths at ten miles. Higher gain antennas will be required for this path with a three foot dish at one end and a two foot dish or square panel antenna at the other end.

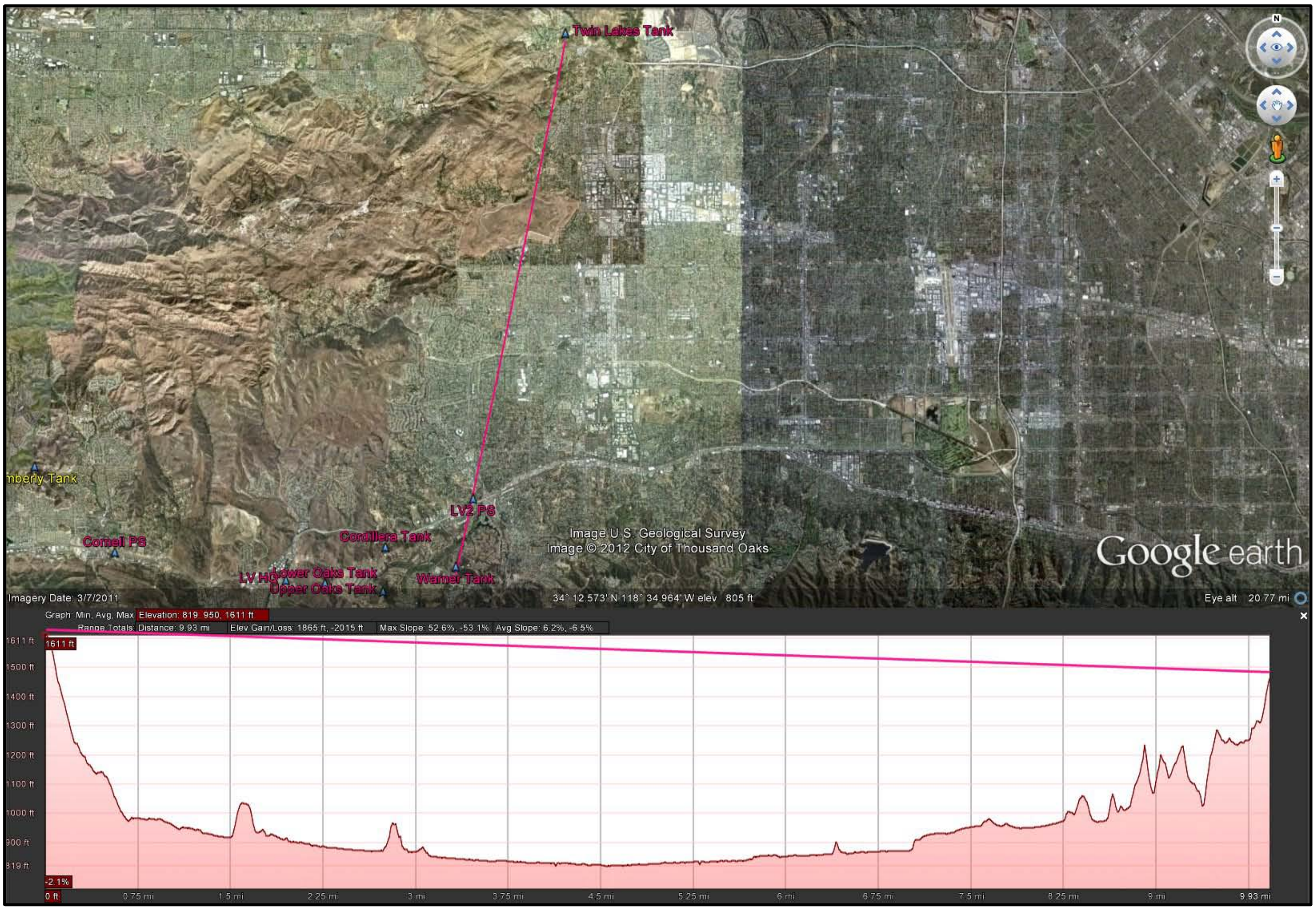


Figure 4-19 Warner Tank to Twin Lakes Tanks Path and Profile

4.1.16 Upper Oaks Tanks to Stunt Road PS

Other paths that are being considered part of the backhaul network are Cordillera Tank and Stunt Road PS. Cordillera Tank can easily be connect to Lower Oaks Tank which is only 1.5 miles away. Stunt Road PS currently picks up the Upper Oaks Tanks with a very strong link at three miles in length which should also work well as a 5 GHz path.

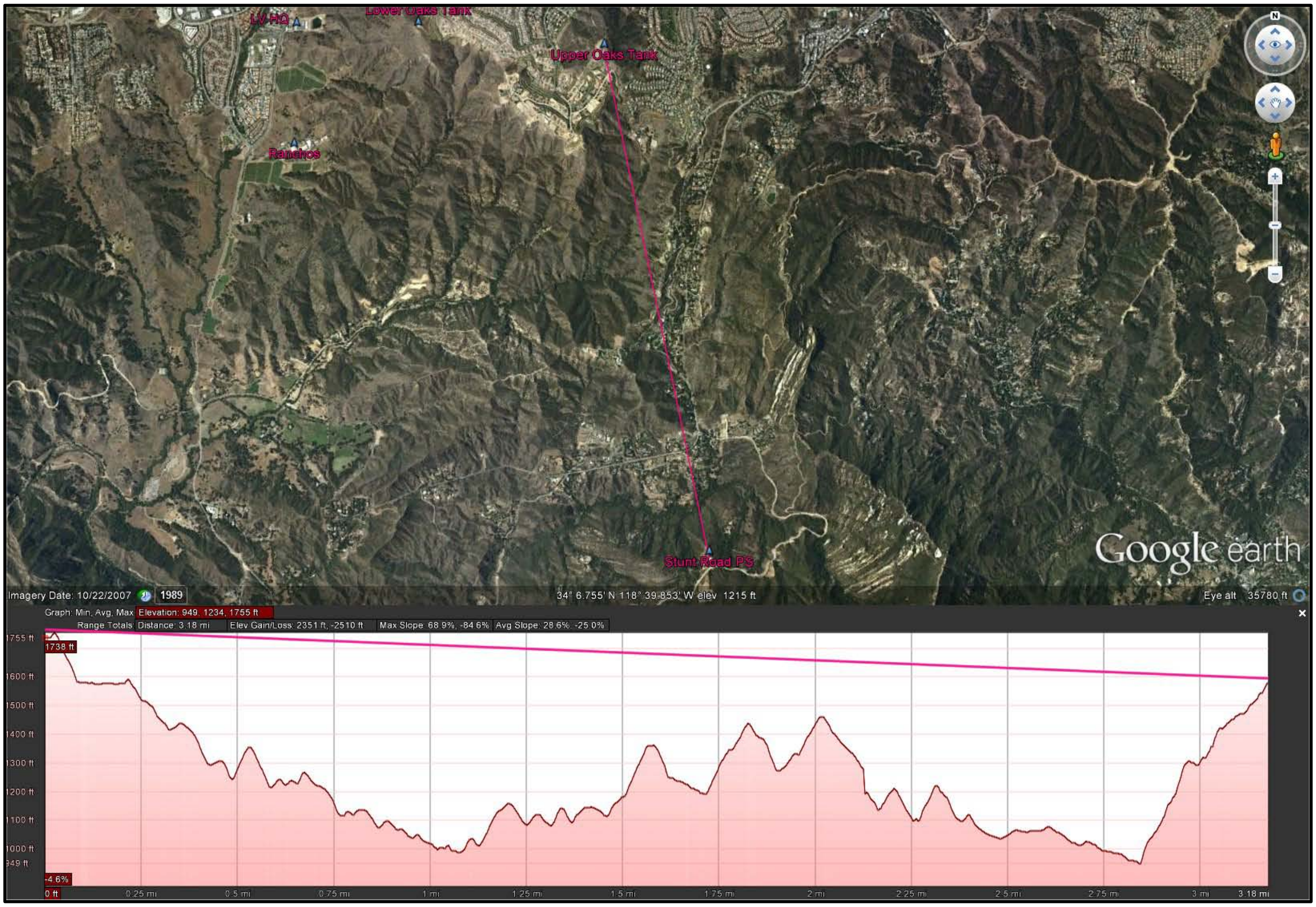


Figure 4-20 Upper Oaks Tanks to Stunt Road PS Path and Profile

4.1.17 Kimberly Tank to Stunt Road PS

This is an optional backup path that could be used in place of the Lower Oaks Tank to Cornell PS path. The profile appears good but the distance is nearly nine miles so high gain antennas will be required. The concern is the tower at Stunt Road PS is a lighter duty tower and may not be suitable for mounting larger antennas.

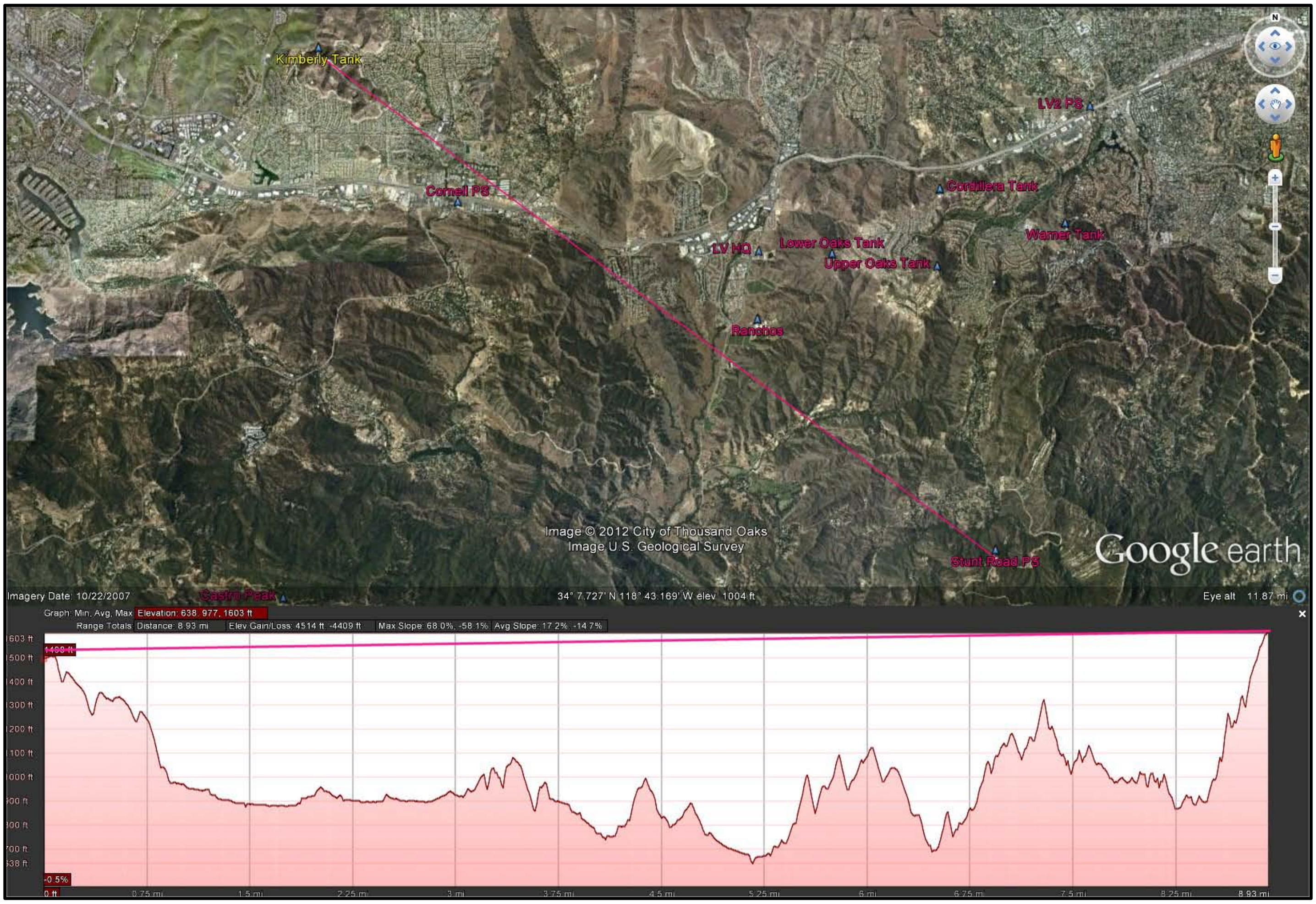


Figure 4-21 Kimberly Tank to Stunt Road PS Path and Profile

5. Budgetary Cost Estimate

Site Name	Description	Qty.	Cost	Extended
System Design and Configuration	General Project Management			
	Network Design and Configuration			
	Enclosure Design and Drawings			
	Installation/Cutover			
				$85,000
Castro Peak Repeater	Trunk Radio	3	$3,000	$9,000
	Antennas, mounts and jumpers	3	$1,000	$3,000
	900 Mhz AP Radio and antenna	2	$2,000	$4,000
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	0	$400	$0
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$15,000	$15,000
				$46,200
Cordillera Tank Repeater	Trunk Radio	1	$3,000	$3,000
	Antennas, mounts and jumpers	1	$700	$700
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	0	$7,000	$0
	Industrial Network Switch, Managed	0	$700	$0
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$2,000	$2,000
				$15,600
Cornell Pump Station Repeater	Trunk Radio	2	$3,000	$6,000
	Antennas, mounts and jumpers	2	$700	$1,400
	900 Mhz AP Radio and antenna	0	$2,000	$0
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$10,000	$10,000
				$32,600
Equestrian Tank Repeater	Trunk Radio	0	$3,000	$0
	Antennas, mounts and jumpers	0	$700	$0

	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	0	$7,000	$0
	Industrial Network Switch, Managed	0	$700	$0
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$5,000	$5,000
				$14,900
Headquarters	Trunk Radio	2	$3,000	$6,000
	Antennas, mounts and jumpers	2	$700	$1,400
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	0	$400	$0
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$10,000	$10,000
				$32,600
Indian Hills Tank Repeater	Trunk Radio	0	$3,000	$0
	Antennas, mounts and jumpers	0	$700	$0
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	0	$7,000	$0
	Industrial Network Switch, Managed	0	$700	$0
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$2,000	$2,000
				$11,900
Kimberly Tank Repeater	Trunk Radio	3	$3,000	$9,000
	Antennas, mounts and jumpers	3	$700	$2,100
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$5,000	$5,000
				$33,700
Lower Oaks Tank Repeator	Trunk Radio	4	$3,000	$12,000
	Antennas, mounts and jumpers	4	$700	$2,800
	900 Mhz AP Radio and antenna	0	$2,000	$0
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700

	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$15,000	$15,000
				$45,400
LV2 Pump Station Repeater	Trunk Radio	2	$3,000	$6,000
	Antennas, mounts and jumpers	2	$700	$1,400
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$10,000	$10,000
				$35,000
Rancho Las Virgenes	Trunk Radio	1	$3,000	$3,000
	Antennas, mounts and jumpers	1	$700	$700
	Router	0	$7,000	$0
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	0	$400	$0
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$5,000	$5,000
				$16,900
Stunt Road PS Repeater	Trunk Radio	2	$3,000	$6,000
	Antennas, mounts and jumpers	2	$700	$1,400
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$5,000	$5,000
				$30,000
Tapia Water Reclamation Facility	Main Trunk Site	0	$0	$0
Twin Lakes Tank Repeater	Trunk Radio	1	$3,000	$3,000
	Antennas, mounts and jumpers	1	$1,000	$1,000
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	0	$7,000	$0
	Industrial Network Switch, Managed	0	$700	$0

	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$5,000	$5,000
				$18,900
Upper Oaks Tank Repeater	Trunk Radio	4	$3,000	$12,000
	Antennas, mounts and jumpers	4	$700	$2,800
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$5,000	$5,000
				$37,400
Warner Tank Repeater	Trunk Radio	2	$3,000	$6,000
	Antennas, mounts and jumpers	2	$1,000	$2,000
	900 Mhz AP Radio and antenna	1	$2,000	$2,000
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	1	$400	$400
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$10,000	$10,000
				$35,600
Westlake Filtration Facility	Trunk Radio	2	$3,000	$6,000
	Antennas, mounts and jumpers	2	$700	$1,400
	Router	1	$7,000	$7,000
	Industrial Network Switch, Managed	1	$700	$700
	Ethernet to Serial Bridge	0	$400	$0
	Radio Enclosure with backup power	1	$7,500	$7,500
	Mast and installation	1	$10,000	$10,000
				$32,600
Remote Radio Sites	Radio Site	38	$2,530	$96,140
ADN Modem Sites	Modem Site	4	$2,050	$8,200

Sub Total	**$628,640**
Contingency at 15%	**$81,546**
Total (w/o tax)	**$710,186**