RF Path Survey Findings

City of Florence, Colorado

Water and Public-Site Connectivity Study

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Executive Summary

The City of Florence engaged Talos Technologies to evaluate the viability of a 5 GHz wireless connectivity solution for water and public-site infrastructure — providing network reachability for IP cameras and industrial control systems at five remote sites (Lower Airport, Upper Airport, Canal Zone, East Tank, and North Pump Station), backhauled to the Southwest Treatment Plant (SWTP).

The deployed system used a fixed-wireless Base Station Unit (BSU) with a 90° sector antenna at the West Tank serving the five remote sites, with a point-to-point (PTP) link carrying aggregated traffic from West Tank back to SWTP. Talos modeled every link in the manufacturer's planning tool, installed the BSU and PTP backhaul in the field, captured live RF performance data at every site, and ran end-to-end throughput testing from each remote site to a server at SWTP. This report documents what was modeled, what was built, and what was measured.

Key Findings

- **The PTP backhaul (West Tank → SWTP) performs to specification**, comfortably exceeding the City's 100 Mbps backhaul requirement.
- Two of the five remote sites (North Pump Station and Canal Zone) **performed at or near modeled values**. One additional site (Lower Airport) modeled well but is **blocked by foliage in the signal path** and could not establish a usable link in leaf-on conditions.
- Two sites (East Tank and Upper Airport) delivered **substantially less throughput than modeled**. Investigation showed these sites sit near the edges of the BSU's 90° sector coverage, where antenna gain rolls off relative to the boresight value used by the planning tool.

Summary of Findings

Of the five subscriber sites tested, two meet design goals as built (North Pump Station, Canal Zone), one is not viable in leaf-on conditions due to foliage in the path (Lower Airport), and two associate but fall short of modeled per-subscriber throughput because their bearings place them at the edges of the BSU sector (East Tank, Upper Airport). The PTP backhaul to SWTP meets design goals.

This is a findings document. Per-site results, supporting analysis, and a measurement summary against the contracted scope follow.

1. Background and Scope

The City of Florence operates a distributed infrastructure footprint with control and monitoring equipment at multiple unmanned sites. Connectivity at these sites is needed for two primary classes of traffic:

- **IP camera streams** — typical bandwidth requirement of 2 to 8 Mbps per stream depending on resolution and codec settings.
- **Industrial control traffic** — bandwidth requirement is negligible (well under 100 kbps per device), but latency and reliability matter for control polling.

The aggregate per-site bandwidth requirement is on the order of 10 to 25 Mbps depending on camera count. The sites of interest in this study are the five remote sites named in the Executive Summary, plus the Southwest Treatment Plant (SWTP) as the network aggregation and egress point. The West Tank serves as the RF hub for the wireless distribution network.

1.1 Contracted Scope

This survey was conducted under the following contracted scope: "Talos will deploy 5 GHz test radios at Florence to evaluate point-to-point links. The survey includes measuring link performance, achievable throughput, end-to-end latency, spectrum occupancy, RSSI, and SNR. This engineering analysis is a critical step to validate the feasibility of deploying a new telemetry system under real-world RF conditions."

The deployed test architecture used a point-to-point Quickbridge link between the West Tank and SWTP (PTP topology) combined with a sector-based base station at West Tank serving the five remote subscriber sites (point-to-multipoint topology over what are individually point-to-point radio paths). Both arrangements were within the spirit of the contracted scope; both were instrumented and measured. The mapping of each contracted measurement deliverable to the methodology used to capture it is presented in Section 3, and per-site measurement results against the full contracted deliverable list appear in Appendix A.

2. System Architecture As Tested

The deployed test architecture mirrored the originally-proposed production design:

- **BSU at West Tank:** fixed-wireless base station with an external 90° dual-polarized sector antenna, operating in 5 GHz unlicensed spectrum.
- **PTP backhaul from West Tank to SWTP:** fixed point-to-point pair with directional integrated antennas, operating in 5 GHz unlicensed spectrum. Link distance approximately 2.9 miles.
- **Remote subscriber units at each site:** directional subscriber units, mounted and aligned to the BSU at West Tank.
- **Test server:** an iperf3 listener at SWTP, enabling end-to-end throughput measurement from each subscriber unit through the BSU and PTP backhaul to a host on the SWTP network.

2.1 Site Coordinates and Equipment Configuration

The table below lists each surveyed site with its coordinates, the antenna height at which it was tested, and the radio power settings used. These are the as-tested values for the deployment described in this report.

Site	Latitude	Longitude	Elev (ft)	Antenna ht (ft AGL)	Tx Power (dBm)	EIRP (dBm)
West Tank (BSU hub)	38.38837	−105.13846	5304	30	25	36
West Tank (PTP)	38.38836	−105.13842	5303	30	24	45

Site	Latitude	Longitude	Elev (ft)	Antenna ht (ft AGL)	Tx Power (dBm)	EIRP (dBm)
SWTP (PTP endpoint)	38.35002	−105.11779	5447	30	24	45
North Pump Station	38.38921	−105.13665	5278	15	18	32
Canal Zone	38.39407	−105.13084	5202	28	20	35
Lower Airport	38.39816	−105.11568	5151	30	25	46
East Tank	38.37698	−105.09801	5281	30	25	46
Upper Airport	38.42620	−105.11309	5389	30	25	46

Table 1. Site coordinates and as-tested equipment configuration.

3. Methodology

Each site was evaluated using three complementary techniques, with each contracted measurement deliverable mapped explicitly to the technique that captured it.

3.1 Three-Pillar Approach

- **Path modeling.** The manufacturer's planning tool produced a link budget, terrain profile, and Fresnel-zone clearance assessment for every path. This established expected modulation, received signal level, SNR, and theoretical maximum throughput against which field results would be compared.
- **Live RF data.** After installation, each subscriber unit was associated to the BSU and characterized through the radio management interface to capture live link details (RSSI, SNR, modulation, errors) and a 5 GHz spectrum scan at the site location.
- **End-to-end throughput.** iperf3 was run from each site to the SWTP server in both directions, with TCP and UDP at several offered load levels. UDP runs captured jitter and packet loss; TCP runs captured sustained throughput and retransmission behavior.

3.2 Contracted Deliverables — Measurement Mapping

Each measurement called out in the contracted scope was captured as follows:

Contracted deliverable	How it was captured
Link performance	End-to-end throughput and packet-loss behavior measured from every site; supplemented by radio-side modulation and retry statistics from the management interface.
Achievable throughput	iperf3 TCP and UDP runs in both directions between each site and the SWTP server, with multiple offered-load levels to identify the link's sustained-rate ceiling.
End-to-end latency	UDP jitter (variation in packet delivery time) captured during iperf3 UDP runs on every working link. Jitter is the directly measurable proxy for latency

Contracted deliverable	How it was captured
	variability over a fixed-wireless link of this kind; sub-millisecond jitter on the PTP backhaul and low single-digit-millisecond jitter on subscriber links are characteristic of low-latency operation appropriate for camera and control traffic. No fixed latency target was specified at engagement.
Spectrum occupancy	5 GHz spectrum scan captured at every site from the radio's onboard spectrum analyzer, recording per-channel utilization and average SNR across the UNII-1 and UNII-3 bands.
RSSI (Received Signal Strength Indicator)	Captured for every working link from the radio management interface, on a per-antenna basis at both ends of each link.
SNR (Signal-to-Noise Ratio)	Captured for every working link from the radio management interface, on a per-antenna basis at both ends of each link. Compared against the SNR value predicted by the planning tool for that path.

Per-site measurements against this deliverable list are tabulated in Appendix A.

3.3 Scope Boundary

The scope of this survey is bandwidth and link-performance viability under the conditions encountered during installation. It is not an availability assessment: no specific reliability or uptime target was defined at engagement, and the testing methodology did not include the long-duration telemetry that an availability validation would require. Inferences about weather behavior and seasonal variation are drawn separately and discussed in Sections 6.4 and 6.5. All testing was performed under clear-weather, line-of-sight conditions where the path geometry allowed it. Foliage was in spring/summer leaf-on state at the time of the survey.

4. Path Modeling

Before any field installation work, Talos built link budgets in the manufacturer's planning tool for the proposed BSU sector at West Tank and the PTP backhaul to SWTP. The planning environment uses coordinates, antenna heights, terrain elevation data, antenna patterns, the FCC regulatory profile, and the configured EIRP to compute received signal level, SNR, achievable modulation, and theoretical link throughput.

Figure 1 shows the resulting BSU sector geometry. The shaded triangle represents the 90° sector coverage projected from the West Tank Base Station; the five labeled markers are the proposed remote sites. The geometry of this overlay is central to the survey's negative findings: Upper Airport sits near the northern edge of the sector and East Tank sits near the southern edge, while Canal Zone, Lower Airport, and North Pump Station are well within the sector's primary coverage.

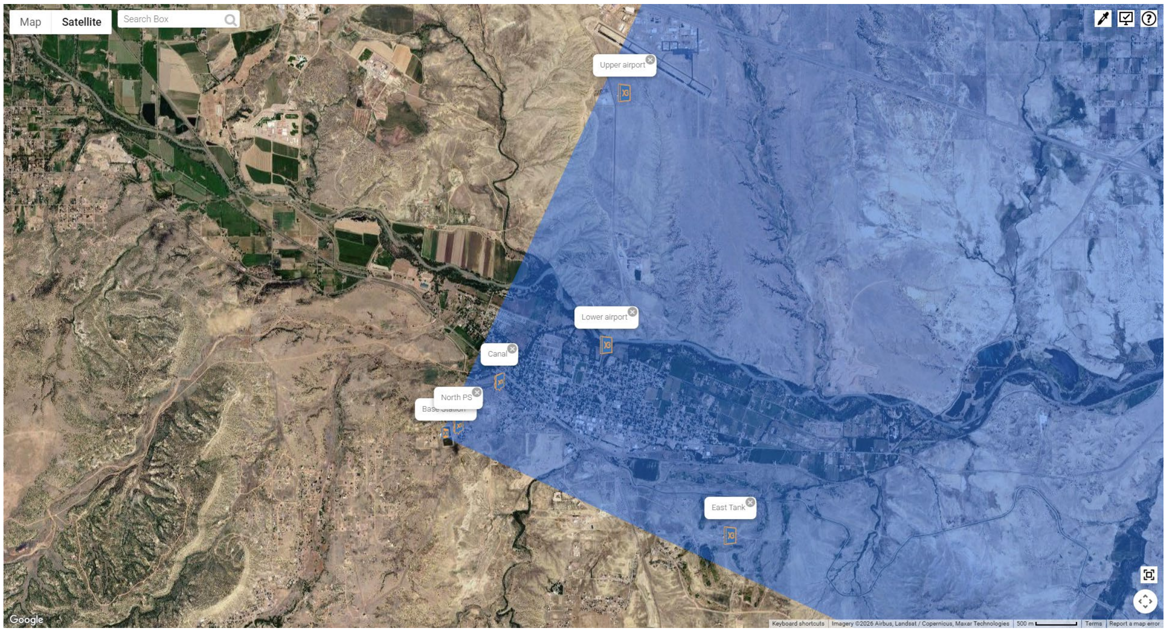

Figure 1. BSU sector geometry at West Tank — 90° coverage area and the five proposed remote sites. Upper Airport and East Tank are visible at the northern and southern edges of the sector, respectively.

Figure 2 plots theoretical PHY-layer throughput against link distance for several subscriber-antenna gains in the relevant product family. The horizontal grey line indicates the City's 100 Mbps design requirement.

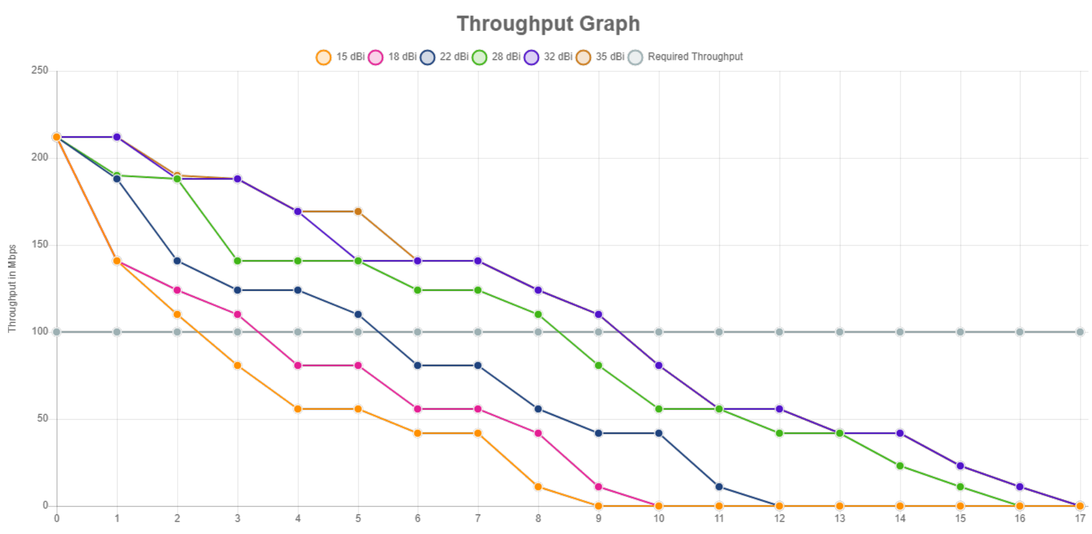

Figure 2. Modeled throughput versus link distance, planning tool output.

The planning tool's outputs were the reference against which field measurements were compared. The model predicted healthy fade margin on every modeled link in clear conditions. The divergence between modeled and measured performance at the problem sites — discussed in Sections 5 and 6 — reflects physical effects (vegetation in the path, antenna-pattern roll-off at sector edges) that the model does not account for, rather than any deficiency in the model itself.

5. Site-by-Site Results

Results below show modeled values from the planning tool alongside measured field results. The model's "Expected Throughput" column represents per-subscriber throughput when the BSU's airtime is shared across all five subscribers; the "Maximum Throughput" column represents the theoretical PHY-layer maximum for the link in isolation.

5.1 Results Summary

Site	Dist (mi)	Model max (Mbps)	Model expected (Mbps)	Measured TCP (Mbps)	Measured UDP loss	Status
North Pump Station	0.11	212	30	46.6	Negligible	**Performs as expected**
Canal Zone	0.57	169	30	37.7	14%	**Performs as expected**
Lower Airport	1.41	141	30	No link	—	**Foliage blockage**
East Tank	2.33	141	30	8.2	27%	**Sector-edge degraded**
Upper Airport	2.96	124	30	8.5	63% at 20M	**Sector-edge degraded**
PTP: West Tank → SWTP	2.88	633	633	104 TCP / 208 UDP	2.3%	**Performs as expected**

Table 2. Modeled vs measured results, all sites.

5.2 West Tank — BSU Hub

The West Tank hosts the RF hub of the design. A fixed-wireless BSU with an external 90° dual-pol sector antenna sits at this site, serves all five subscriber sites, and feeds the PTP backhaul to SWTP. The spectrum scan at the hub showed moderate utilization on the lower UNII bands and the cleanest occupancy on the upper UNII-3 channels, consistent with the operational channel choice. No persistent interferer was observed during the survey.

5.3 West Tank → SWTP — PTP Backhaul

The PTP backhaul is the highest-capacity element of the design, carrying all subscriber traffic into the City's wired network. Two directional radios with integrated dishes connect the West Tank to SWTP across a clear ~2.9-mile path. End-to-end iperf3 testing from a host on the West Tank network to the iperf3 server on the SWTP network produced 104 Mbps sustained TCP over a 30-second run and 208 Mbps received UDP at 2.3% packet loss when the link was operated in standard outdoor fixed-link mode. These results comfortably exceed the City's 100 Mbps design requirement for backhaul. End-to-end UDP jitter on this link was sub-millisecond throughout testing, indicating low-latency operation appropriate for time-sensitive traffic.

5.4 North Pump Station — Performs as Expected

North Pump Station is the closest subscriber to the BSU (~580 feet across an unobstructed parking lot) and sits near the boresight of the West Tank sector. Field results matched the model: the subscriber locked at the modeled data rate with strong SNR, and the spectrum at the operating channel was essentially unused. Figure 3 shows the spectrum scan at this site, which serves as the clean-spectrum reference for the survey.

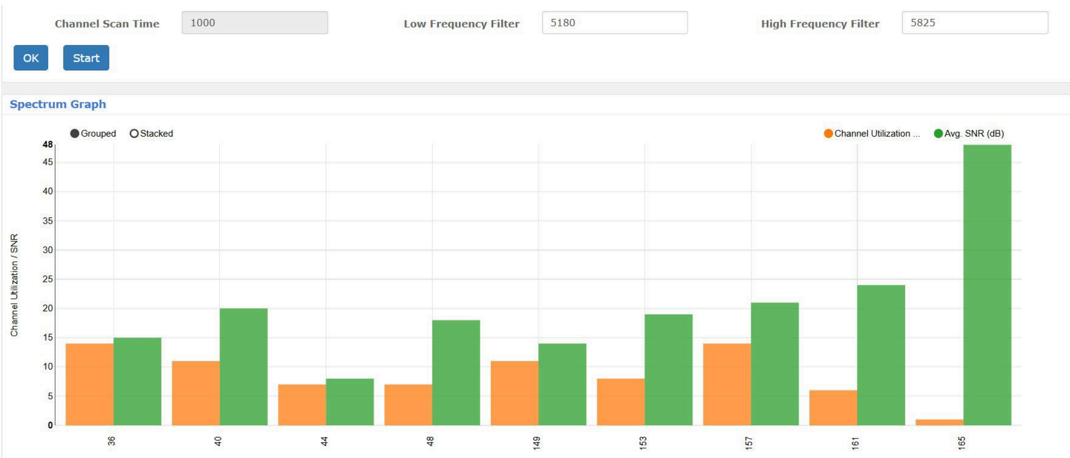

Figure 3. North Pump Station — 5 GHz spectrum scan, showing the operating channel essentially unused.

This site represents the best-case outcome of the wireless approach and provides the baseline against which other sites are measured.

5.5 Canal Zone — Performs as Expected

Canal Zone is roughly half a mile from the BSU, comfortably within the sector's effective coverage. The site exceeded the modeled per-subscriber expected throughput. UDP testing under load showed moderate packet loss consistent with shared-medium behavior, not a path problem.

5.6 Lower Airport — Path Blocked by Foliage

Lower Airport is approximately 1.4 miles from the BSU and is essentially centered in the sector pattern. The model predicted a healthy link. In the field, no usable link could be established in leaf-on conditions.

The cause of the failure is foliage along the path. The path traverses mature riparian vegetation along the watercourse between the West Tank and the airport. Foliage attenuation at 5 GHz frequencies is high enough that vegetation in the signal path consumes the link's fade margin and prevents association, regardless of the otherwise-healthy budget the model predicts. The planning tool's clear-path budget is accurate as documented; the real-world path simply does not meet the unobstructed-line-of-sight precondition the tool assumes.

5.7 East Tank — Sector-Edge Degradation

East Tank is approximately 2.3 miles from the BSU at a bearing that places the signal near the edge of the sector's coverage. The model predicted strong performance; the site instead delivered approximately 8 Mbps TCP uplink with high UDP packet loss under load. Radio-link diagnostics show a marked asymmetry between the subscriber-side and BSU-side SNR readings — the subscriber's directional antenna sees a strong signal while the BSU sees a much weaker return. This asymmetry is the signature of antenna-pattern roll-off on the BSU's sector antenna: the planning model assumes peak boresight gain regardless of arrival angle, while the real antenna delivers materially less gain near the edges of the coverage pattern.

5.8 Upper Airport — Sector-Edge Degradation

Upper Airport exhibits the same pattern as East Tank, on the opposite edge of the sector. Modeled per-subscriber throughput was not realized; measured TCP throughput was again approximately 8 Mbps in both directions. UDP testing at higher offered loads produced very high packet loss, indicating a link operating at a marginal modulation that cannot sustain higher offered rates. Figure 4 shows the spectrum scan at this site for reference; channel utilization at this location is higher than at the centered sites, with several channels showing elevated activity.

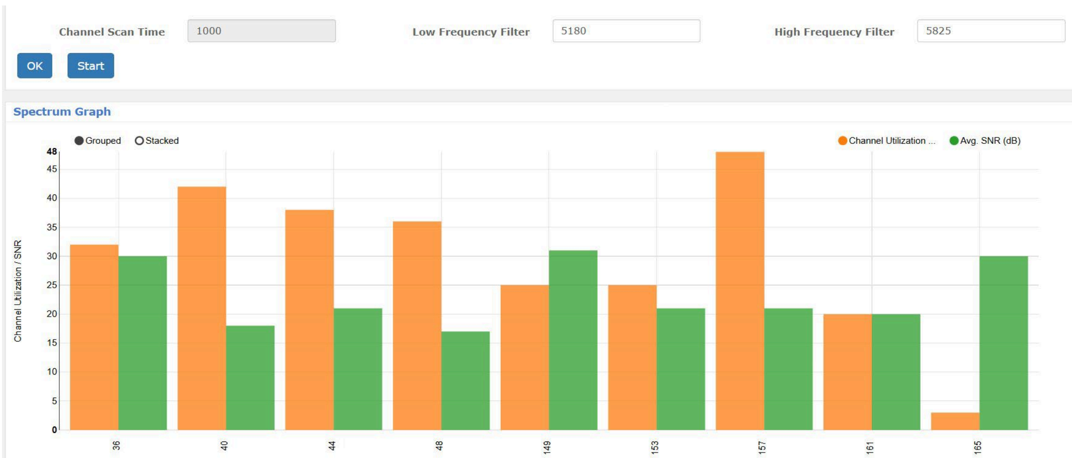

Figure 4. Upper Airport — 5 GHz spectrum scan.

Together, East Tank and Upper Airport illustrate the fundamental constraint of using a single 90° sector to cover sites whose bearings span most of that sector's azimuth. Both sites are within the nominal sector but at the edges where the antenna delivers reduced gain.

6. Cross-Cutting Technical Findings

6.1 Sector Coverage Geometry

The five remote sites are distributed across a wide azimuth range as seen from the BSU at West Tank. A single 90° sector can in theory cover this range, but only with significant gain roll-off near the edges of the coverage area. The path survey data confirms that real-world performance drops sharply for sites near the outer extent of the sector's coverage, regardless of what the link budget predicts based on boresight assumptions.

6.2 Radio Operating Mode

During PTP backhaul testing, the radios' operating mode was found to materially affect achievable throughput on this hardware family. The platform supports two modes — a newer mode optimized for high-density indoor environments and an older mode oriented at fixed outdoor links. In testing, the older mode produced substantially better throughput and lower packet loss than the newer mode in fixed point-to-point service. The newer mode's feature set (medium access scheduling for many concurrent stations, dense reuse coloring) provides no benefit on a clean two-radio path and appears to introduce overhead that degrades performance. For fixed wireless links of this character, the older mode is the higher-performing choice.

6.3 Foliage at 5 GHz Is a Hard Limit

5 GHz signals do not penetrate leafy vegetation. The Lower Airport result shows that a path with a strong link budget on paper will fail entirely if foliage occupies the signal path, regardless of the fade margin available in clear conditions. Successful operation through foliage at this frequency is not a function of link budget; it requires either physical clearance — sufficient antenna height to keep the signal above the canopy — or a path geometry that avoids the obstruction entirely.

6.4 Rain Fade and Atmospheric Attenuation

Rain fade is the dominant weather-related attenuation mechanism for outdoor microwave links, but the effect is strongly frequency-dependent and is small at 5 GHz. Over the longest path in this survey (just under three miles), even the heaviest rain rates produce only a few dB of additional path loss. Florence's semi-arid climate sees intense but brief summer convective storms; sustained heavy rain over the area required to fade a multi-mile link is uncommon. Compared against modeled fade margins on the working links, rain fade is not the binding factor in this deployment. Weather is unlikely to be the cause of observed outages on the working sites; equipment failure, power continuity, and lightning damage are more probable contributors.

6.5 Seasonal Behavior

Three seasonal factors merit attention for a 5 GHz deployment in Florence's environment: foliage state, temperature, and lightning.

- **Foliage.** The Lower Airport failure documented in Section 5.6 is caused by riparian vegetation in the signal path during leaf-on conditions. In leaf-off conditions (late fall through early spring), the same path budget would be available and the link would be expected to associate at or near its modeled performance. The site is therefore ***seasonally viable*** rather than unconditionally non-viable. East Tank and Upper Airport, by contrast, are not seasonal — the antenna-pattern geometry that limits them is the same year-round.
- **Temperature.** The hardware family is rated well beyond Florence's actual operating range. Cold-weather performance is not expected to be a problem. Radomes shed accumulated snow and ice on the integrated-antenna subscriber units; the external sector antenna at West Tank is more exposed but unlikely to fail catastrophically from typical Front Range winter conditions.
- **Lightning.** The Front Range sees among the highest lightning flash densities in the United States, peaking in late summer. Direct strikes are infrequent but devastating; nearby strikes induce surges that can damage Ethernet ports and PoE injectors. Surge protection on every PoE drop and proper grounding of antenna and mast hardware are standard practice for any outdoor RF deployment in this area.

The principal new finding from the seasonal analysis is that Lower Airport's failure is conditional on foliage state. Re-evaluating that path in leaf-off conditions would confirm whether the model's clear-path budget is realized once vegetation is out of the signal path.

7. Wireless Viability Summary

Combining the modeled link budgets, the live RF data, and the end-to-end throughput measurements, the viability of the 5 GHz wireless solution across each tested site is summarized in the table below.

Site	Viability finding
North Pump Station	Viable as designed. Throughput, SNR, and modulation all match the model.
Canal Zone	Viable as designed. Sustained TCP throughput exceeded the modeled per-subscriber expectation.
Lower Airport	Not viable as designed in leaf-on conditions. Foliage in the signal path consumes the available fade margin and prevents link association. May be seasonally viable in leaf-off conditions.
East Tank	Underperforms the modeled per-subscriber throughput. The site's bearing places it near the edge of the BSU sector, where effective antenna gain is below the boresight value the model assumes.
Upper Airport	Underperforms the modeled per-subscriber throughput. Same antenna-pattern geometry as East Tank, on the opposite edge of the sector.
PTP backhaul (West Tank → SWTP)	Viable as designed. End-to-end TCP and UDP throughput both exceed the City's 100 Mbps design requirement; jitter is sub-millisecond.

Table 3. Per-site viability summary.

In aggregate: of the five subscriber sites, two are viable as built (North Pump Station, Canal Zone), one is not viable in leaf-on conditions due to a path obstruction (Lower Airport), and two are viable as RF links but do not meet the modeled per-subscriber throughput because of the BSU sector's antenna geometry (East Tank, Upper Airport). The PTP backhaul to SWTP meets the design goals.

8. Conclusion

This survey produced a direct picture of the 5 GHz wireless solution as built and tested in Florence. Three of five subscriber sites and the PTP backhaul perform at or above their modeled values. One subscriber site fails to associate due to foliage in the path. Two subscriber sites associate but fall short of modeled per-subscriber throughput because their bearings place them near the edges of the BSU sector's antenna pattern, where the model's boresight gain assumption does not hold.

All six measurement categories called out in the contracted scope — link performance, achievable throughput, end-to-end latency, spectrum occupancy, RSSI, and SNR — were captured for every working link. Per-site measurements against this deliverable list are tabulated in Appendix A.

Appendix A. Measurement Summary

The table below summarizes the measurements captured at each site against the six contracted measurement deliverables. RSSI values are typical per-antenna received signal levels; SNR values are typical per-antenna signal-to-noise ratios; throughput values are end-to-end iperf3 results to the SWTP server.

Site	TCP (Mbps)	UDP loss	Jitter (ms)	RSSI (dBm)	SNR (dB)	Spectrum occupancy
North Pump Station	46.6	Negligible	< 1	−54 / −55	44 / 43	Operating channel essentially unused
Canal Zone	37.7	14%	~ 1	−65 / −65	33 / 33	Operating channel cleanest available
Lower Airport	No link	—	—	—	—	Not captured — no link associated
East Tank	8.2	27%	2 – 7	−71 / −78	27 / 20	Adjacent channels elevated; operating channel acceptable
Upper Airport	8.5	60–70% at 20M	1 – 5	−70 / −79	28 / 19	Multiple channels elevated at this location
PTP: West Tank → SWTP	104	2.3%	< 1	−72 / −72	25 / 26	Operating channel clean

Table A1. Per-site measurements against contracted scope deliverables.

Notes:

- TCP values are sustained end-to-end throughput from the site to the iperf3 server at SWTP.
- UDP loss is the packet-loss percentage observed at the iperf3 server for UDP runs at the offered loads used during the survey.
- Jitter is the directly measurable latency-related metric for UDP traffic, expressed as the variation in inter-arrival time of received packets. Low jitter implies low and stable latency. No fixed latency target was specified at engagement; the values observed are characteristic of fixed-wireless links of this kind and are appropriate for camera and control-system traffic.
- RSSI and SNR are reported as subscriber-side / BSU-side, capturing both ends of each link. The asymmetric values at East Tank and Upper Airport (with the BSU-side reading notably lower than the subscriber-side) reflect the antenna-pattern geometry discussed in Section 5.
- Spectrum occupancy is a qualitative summary of the channel utilization observed in the spectrum scan at each site location, normalized against the cleanest available channel.