Statewide Public Safety Coverage Assessment and Analysis

Hatfield & Dawson Consulting Engineers
CSI Telecommunications Consulting Engineers
Radio Site Test.com

IWCE 2019
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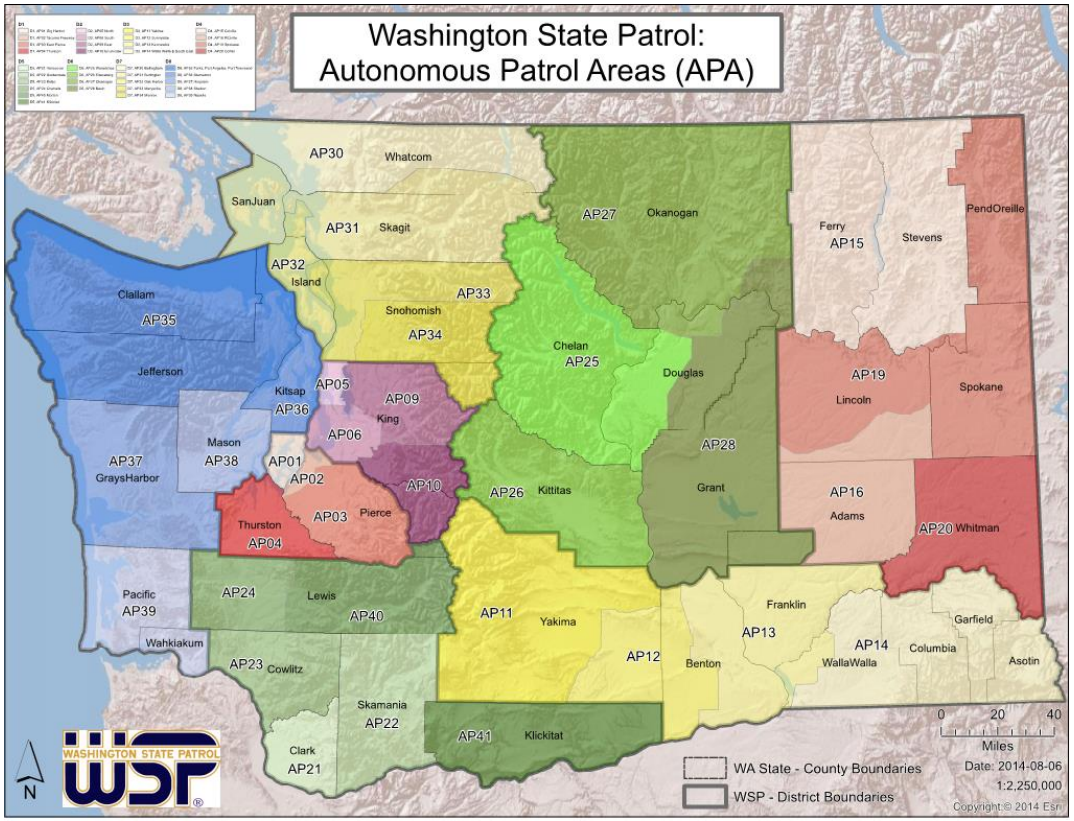
Project Requirements

1. Define WSP Coverage and Reliability Standards – VHF & 700 MHz. Document Standards for Other Statewide Public Safety Systems
2. Document Models and Methods for Statewide Coverage Prediction
3. Baseline Coverage Report with Statewide Coverage Maps (Existing VHF P25 Phase 1/NBFM System)
4. Gap Analysis Documenting Coverage and Performance Gaps
5. Recommendations for Short-Term and Long-Term System Improvements
6. RFIs to Vendors

WSP Districts and Administrative Patrol Areas ("APAs")



Challenges

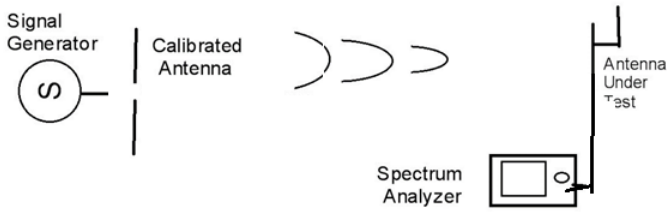
- Distributed project team: Washington and California

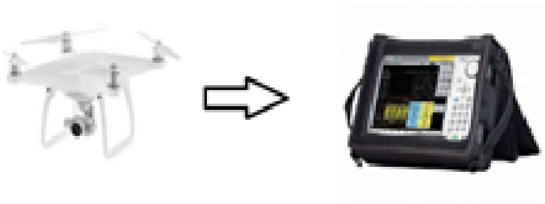
  Used Join.me screen sharing; vacation issues over 6-month project schedule

- Drive test measurements of 15 sites had to be coordinated, with WSP providing vehicles and drivers. Site access: road, snow-cat, chair lifts. Some changes in sites at last minute due to winter road damage, etc. WSP technical & administrative staff provided outstanding support.
- "Tribal knowledge" required for understanding of system configuration and operation and site selection.
- Custom software required to produce "round-trip" coverage maps and bounded coverage areas. Measurement data used to "calibrate" LULC attenuation values.
- Service areas needed to represent "real-world" view of normal operational areas
- Some APAs had a mix of digital and analog base station sites. Adjustment factor added to coverage maps for analog sites to compensate for analog/digital sensitivity difference.
- Not possible to model digital radio BER issues caused by long-delayed terrain reflections.
- Predicted coverage not shown correctly in areas with coverage provided primarily by reflections off of terrain (requires 3D ray-tracing model).
- Base station site data incomplete and/or incorrect for some sites.

Antenna Pattern Measurements
Measurement Configuration

1. Sig Gen to Spectrum Analyzer
    1. Calibrated antenna to calibrated antenna
        1. Walk in circle (30 yard Radius)
    2. Calibrated antenna to test antenna
        1. Walk in circle (30 yard Radius)

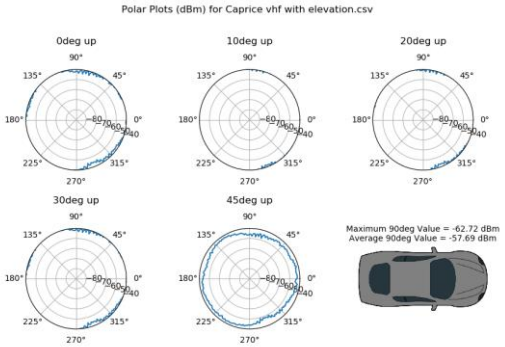


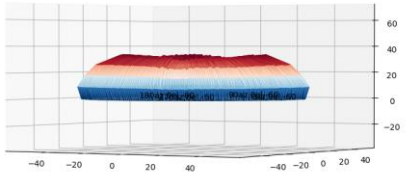


Antenna Pattern Measurements
Zero Span RSSI vs. Time / Azimuth

- Drone for Elevation

Antenna Pattern Measurements
VHF ¼ Wave, Center of Roof





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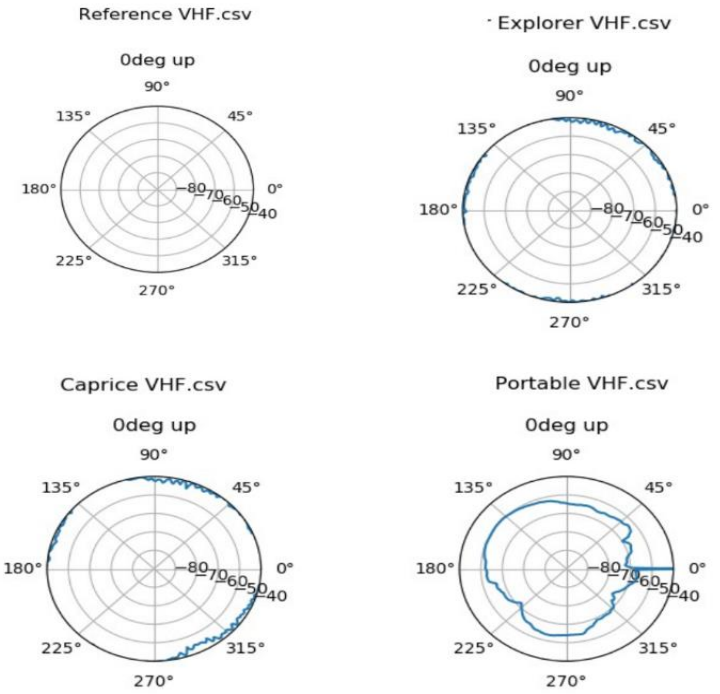
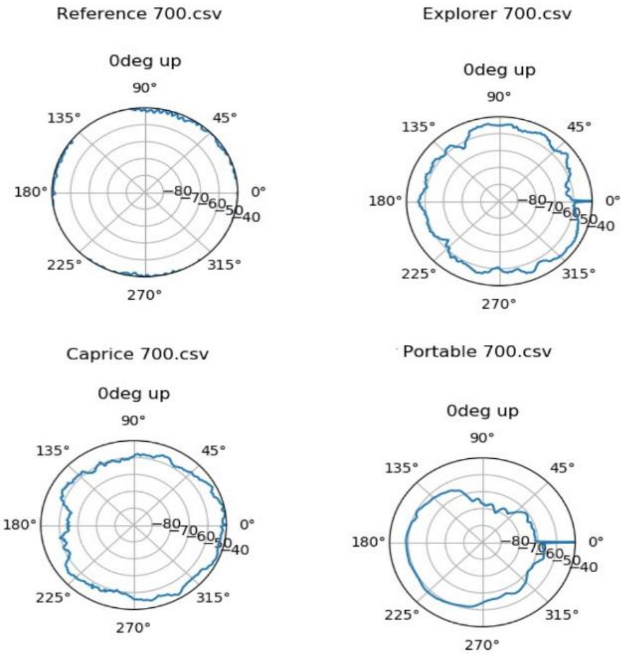
TOM B.

Antenna Pattern Measurements
VHF Azimuth Only



Antenna Pattern Measurements
700 MHz Azimuth Only & Measurement Results



Antenna and Vehicle Type	Measured Gain (dBd)*
Chevrolet Caprice – VHF Antenna	-1.97
Chevrolet Caprice – 700 MHz Antenna	-0.65
Ford Explorer – VHF Antenna	-1.95
Ford Explorer – 700 MHz Antenna	-1.65
Portable Radio – VHF Antenna	-17.4
Portable Radio – 700 MHz Antenna	-9.4

Portable Gain Values Based on Measured Data are Comparable to Measured Gain Values from Motorola

VHF Ambient Noise & Vehicle Noise Measurements

VHF ambient noise measurements made at representative locations statewide (based on mobile radio reduction in 5% BER sensitivity relative to value with antenna terminated).

Measured values ranged from 2 dB to >10 dB. Rural areas were not necessarily better than urban areas. High noise levels near buildings equipped with LED lights.

Vehicle and onboard systems noise (especially computer) added significantly to mobile radio noise and desensitization. 15 dB desensitization of mobile radios assumed for coverage modeling.

Condition	Received Power for 5% BER	
Antenna Port Terminated	-121.7	dBm
Antenna Connected - Vehicle & Systems Off	-118.4	dBm
Ambient VHF Noise	3.3	dB
Antenna Connected - Vehicle On Only (Heater Fan and AM/FM Radio Off)	-114.6	dBm
Antenna Connected - Vehicle On & Radar Only	-114.6	dBm
Antenna Connected - Vehicle On & Coban (Camera) Only	-113.0	dBm
Antenna Connected - Vehicle & Computer (On Battery; Charger Disconnected)	-113.0	dBm
Antenna Connected - Vehicle On & Computer Only (Charger Connected & Charging/Powering Computer)	-107.0	dBm
Antenna Connected - Vehicle On & All Systems On	-106.6	dBm
Receiver Desensitization with Vehicle Noise + Systems Noise	15.1	dB

Coverage and Reliability Standards – Other Statewide Standards

- Coverage and reliability standards used for other statewide public safety systems were difficult to obtain.
- Many statewide system have a mobile radio area coverage standard (typically 95%) defined in terms of highway coverage.
- For most of the statewide systems for which we were able to obtain defined coverage requirements, but no DAQ performance requirement was defined.
- Statewide systems that had defined area coverage and DAQ requirements (and requirements for blanket coverage of the entire state, not just highways) were typically in midwestern states that do not have the wide variation in terrain and land cover typical of western states such as Washington.
- Portable radio coverage requirements were typically not defined for statewide systems.

Coverage and Reliability Standards

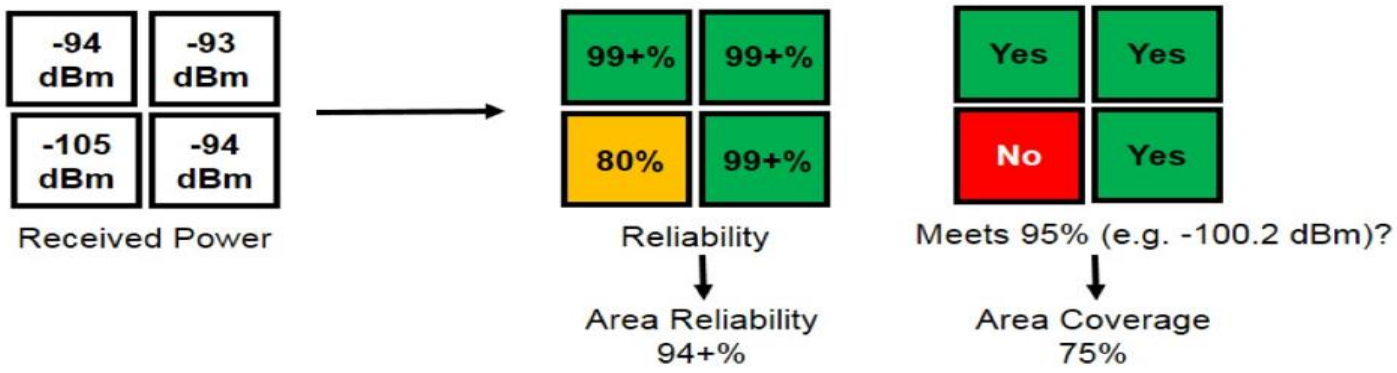
BAPC/CAR

- Bounded Area Percent Coverage/Covered Area Reliability
- Clarified definition in TSB-88.1-E & 88.3-E
  - Within the bounded area, what percentage of the tiles/area meet or exceed the desired criterion of tile probability at the desired DAQ
  - XX% of the desired area is covered at 9x% for DAQ 3.0/3.4

Coverage and Reliability Standards – Coverage vs. Reliability

Tile-Based Coverage vs. Reliability

- Reliability
  - Averages the individual reliability value of all tiles to determine the Average Area Reliability.
  - Not valid for CATP
- Coverage
  - $Prob_{reliability} \geq Prob_{target}$ -OR- Rel% ≥ Rel% Criterion [based on signal power or BER%]
  - Tile(s) either **MEET** coverage requirement or **NOT**
  - Valid for CATP

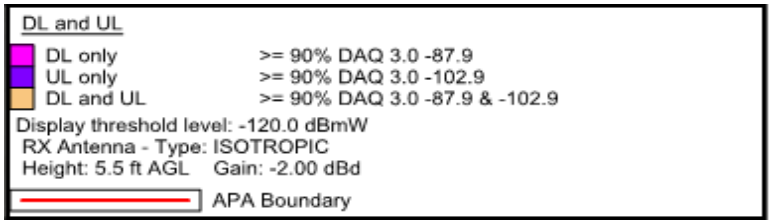


Coverage and Reliability Standards
Round Trip Reliability

- Starting to see this in bid requirements
- The probability of achieving a specified DAQ for both the UL & DL at a given tile.
- Requires comparing two separate studies to determine that both meet the requirement
  - Studies must be the same but can be either signal power or reliability
  - More complicated as the VHF portions have high mobile desense (typically 15 dB in the case of WSP) and different site desense values (1 dB to 20 dB)
  - EDX Signal Pro required a “hybrid study”
    - We defined and purchased this capability

Coverage Prediction Maps, EDX Hybrid Studies

- Four different Studies, three different comparisons
  - Two types of study, mobile & portable
  - Two different Criteria, 95% and 90%
    - Both meet criteria **color 1**
    - UL only meets criteria **color 2**
    - DL only meets criteria **color 3**
    - None meet criteria, **no color (clear)**



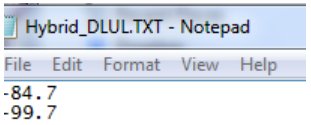
- Customer views desired (6 maps)
  - 4 Trooper maps to show only mobile and portable round trip 90% & 95%
    - Include WSP provided mileage post icons
  - 2 Gap Analysis maps to show the color coded results, mobile & Portable 90%
    - Include mileage post icons and number
- Determine the % of 35 APAs meeting these criteria (210 VHF studies)
  - Additional maps where 700/800 MHz systems utilized
- Determine the total APA area meeting these criteria statewide for VHF

Coverage Prediction Maps
Data Points

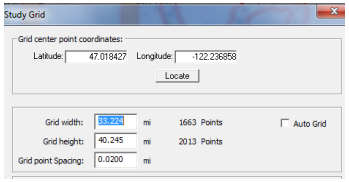
- Along a radial Up to 10,000 data points
  - More than enough based on data bases available
  - Length of radial (e.g. 30 miles)
  - Point spacing 30_{miles} x 5280_{feet} /$10{,}000_{points}$ = 15.8 ft (4.83 m)
  - 720 radial limit
    - Increased resolution for directional antennas
      - 720 radials @ 0.5 degree separation
      - 180 degree directional antenna allows 0.25 degree separation
- Direct to Grid method is too slow
- Study Grid up to 5,000 x 5,000 data points (being expanded in next version revision of software)
  - Size of horizontal and vertical dimensions
  - Point spacing
- Need good resolution along radial for terrain, obstructions and clutter
- Fewer points along study grid for speed of calculations

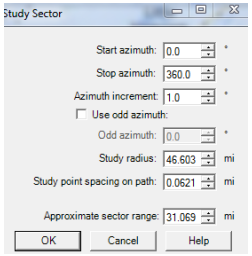
Coverage Prediction Maps Process

- Determine the study criteria
  - Signal power example to meet 95% DAQ 3.4 probability including desense
    - -126.6 $_{\text{dBm Noise Floor}}$ +1.65x5.6$_{\text{dB rel margin}}$ + 17.6 $_{\text{dB Cf/N}}$ +15 $_{\text{dB desense}}$ = -84.7 $_{\text{dBm}}$DL
  - Create Hybrid_DLUL.txt file within Project study folder



- Run Studies
  - Data bases
    - Antennas
    - Terrain 10 meter (32.8 ft)
    - Land Usage 5 meters (16.4 ft)
  - Models- Anderson 2D
- Study Grid parameters
- Radial parameters/Site



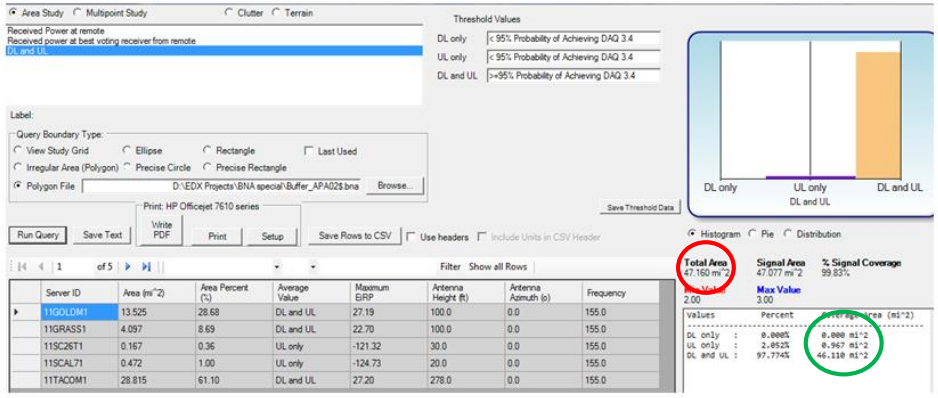


Coverage Prediction Maps - Example Study Query

121.9709 Area within APA Polygons in km^2

Corrected to mi^2 121.9709 x 0.386102= 47.0932 mi^2

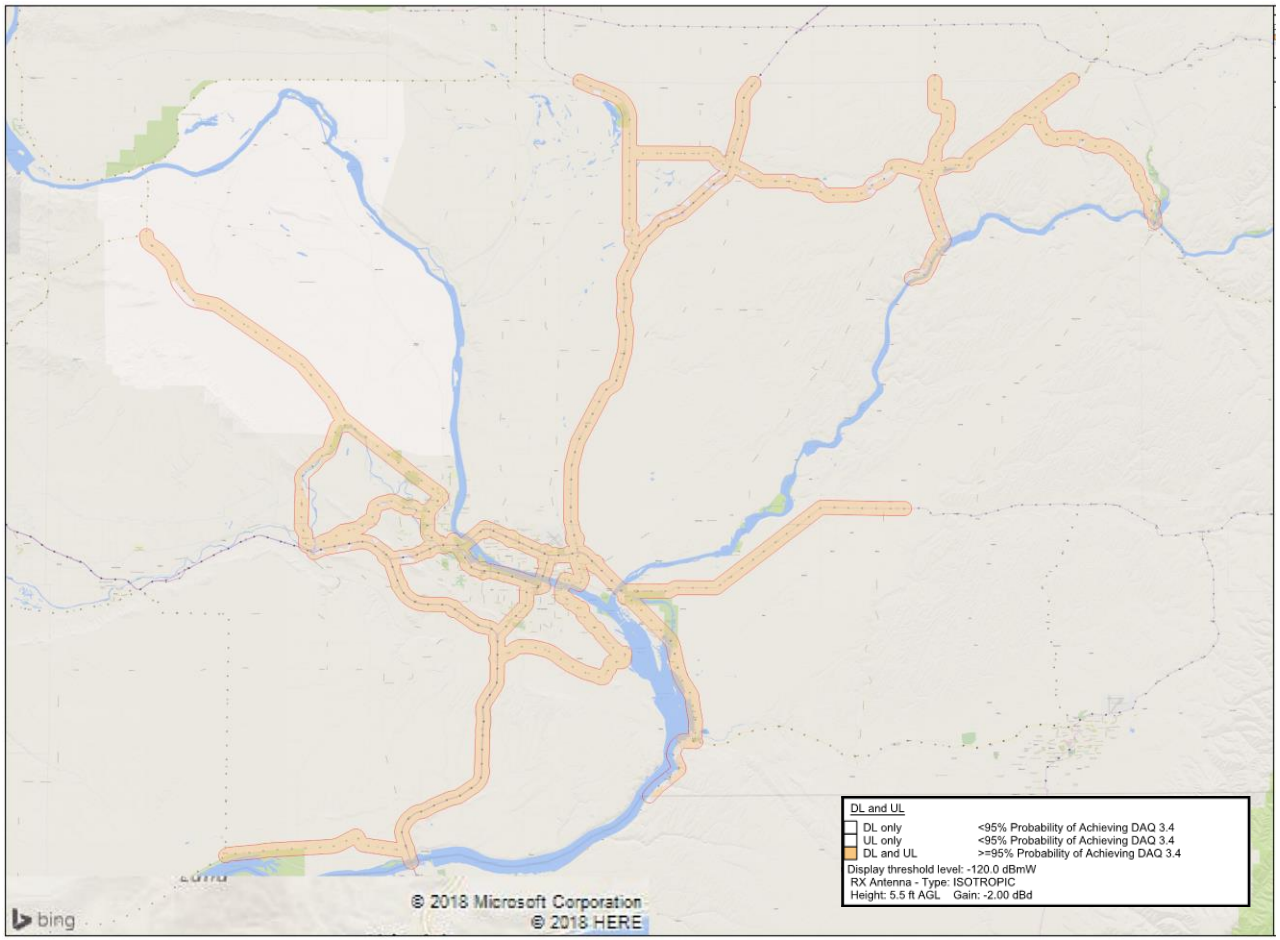
Mobile 95 3.4



Total Area (Mi^2)	47.160	Blue are input values				
Signal Area (Mi^2)	47.210					
Fort file, (km^2) corrected	121.9709	0.93744699				
0.386102	47.09					
		original %	Corrected %			
Rework for mobile and Portable						
Study		orig Mi^2	corr Mi^2	Updated	Original %	Corrected %
Mobile 3.4 95%	DL only	47.16	47.09	0.000	0.00%	0.00%
	UL only	47.16	47.09	0.967	2.05%	2.05%
	UL & DL	47.16	47.09	46.110	97.77%	**97.91%**
Mobile 3.0 90%	DL only	47.16	47.09	0.000	0.00%	0.00%
	UL only	47.16	47.09	1.108	2.35%	2.35%
	UL & DL	47.16	47.09	46.565	98.74%	**98.88%**
Portable 3.4 95%	DL only	47.16	47.09	8.575	18.18%	18.21%
	UL only	47.16	47.09	1.460	3.10%	3.10%
	UL & DL	47.16	47.09	36.990	78.44%	**78.55%**
Portable 3.0 90%	DL only	47.16	47.09	4.210	8.93%	8.94%
	UL only	47.16	47.09	0.928	1.97%	1.97%
	UL & DL	47.16	47.09	42.085	89.24%	**89.37%**

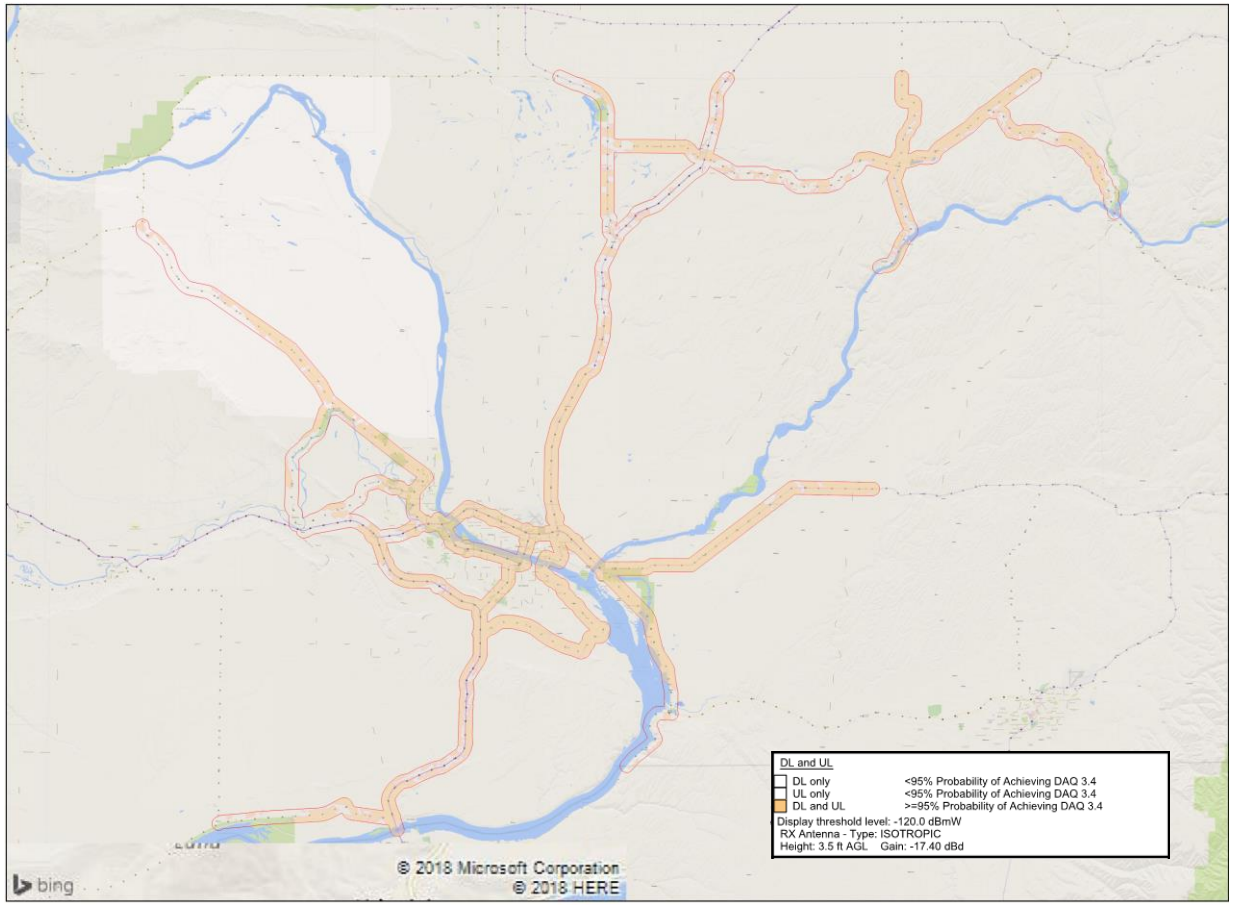
Coverage Prediction Maps – VHF APA Bounded Area Maps

Mobile Radio Round Trip Coverage Map – 95.9% R/T Coverage



Coverage Prediction Maps – VHF APA Bounded Area Maps

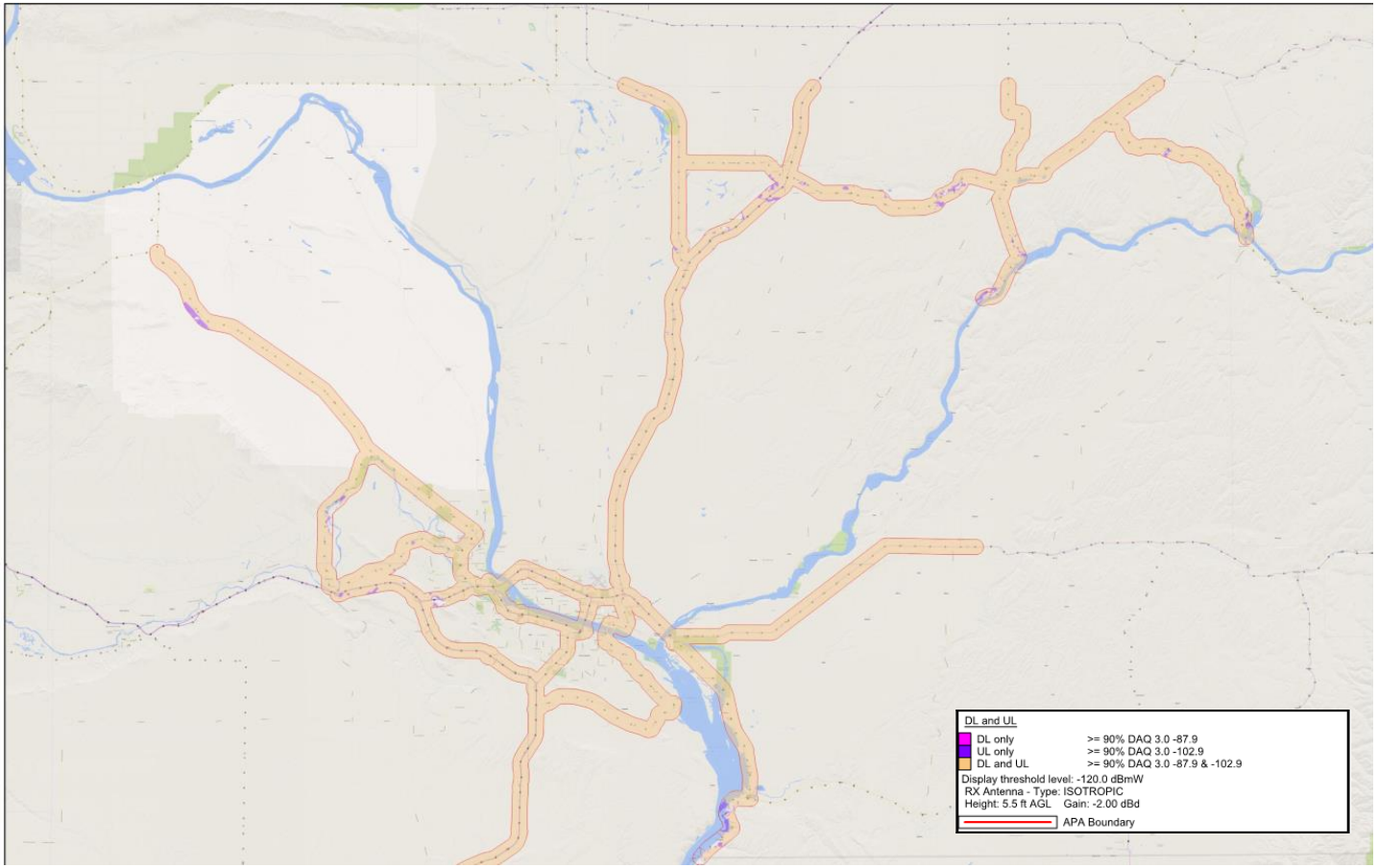
Portable Radio Round Trip Coverage Map – 66.7% R/T Coverage



- Note the significant reduction in coverage compared to the mobile radio map

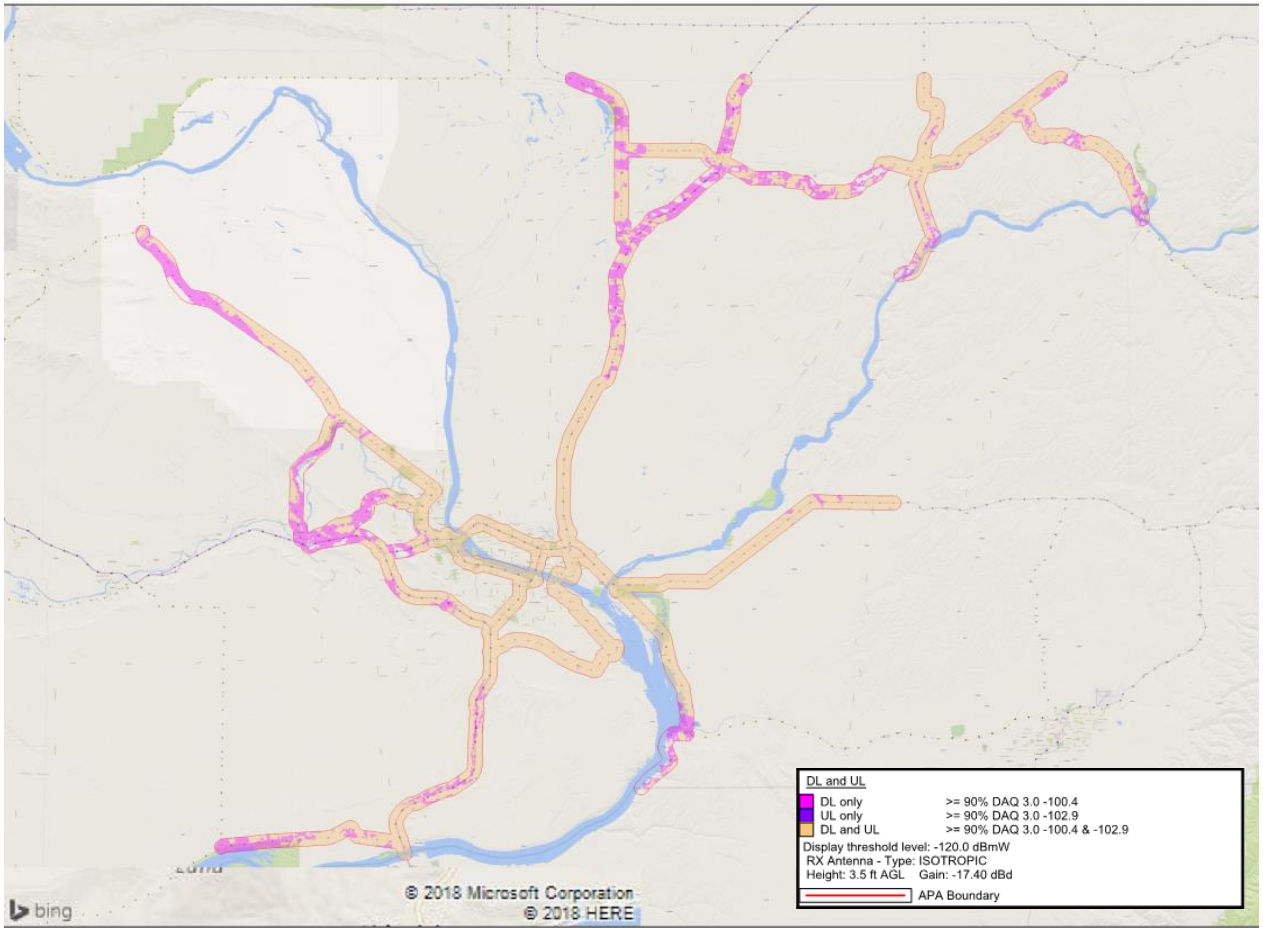
Coverage Prediction Maps – VHF APA Bounded Area Maps

Mobile Radio 90% DAQ 3.0 Gap Analysis Map – 97.4% R/T Coverage



Coverage Prediction Maps – VHF APA Bounded Area Maps

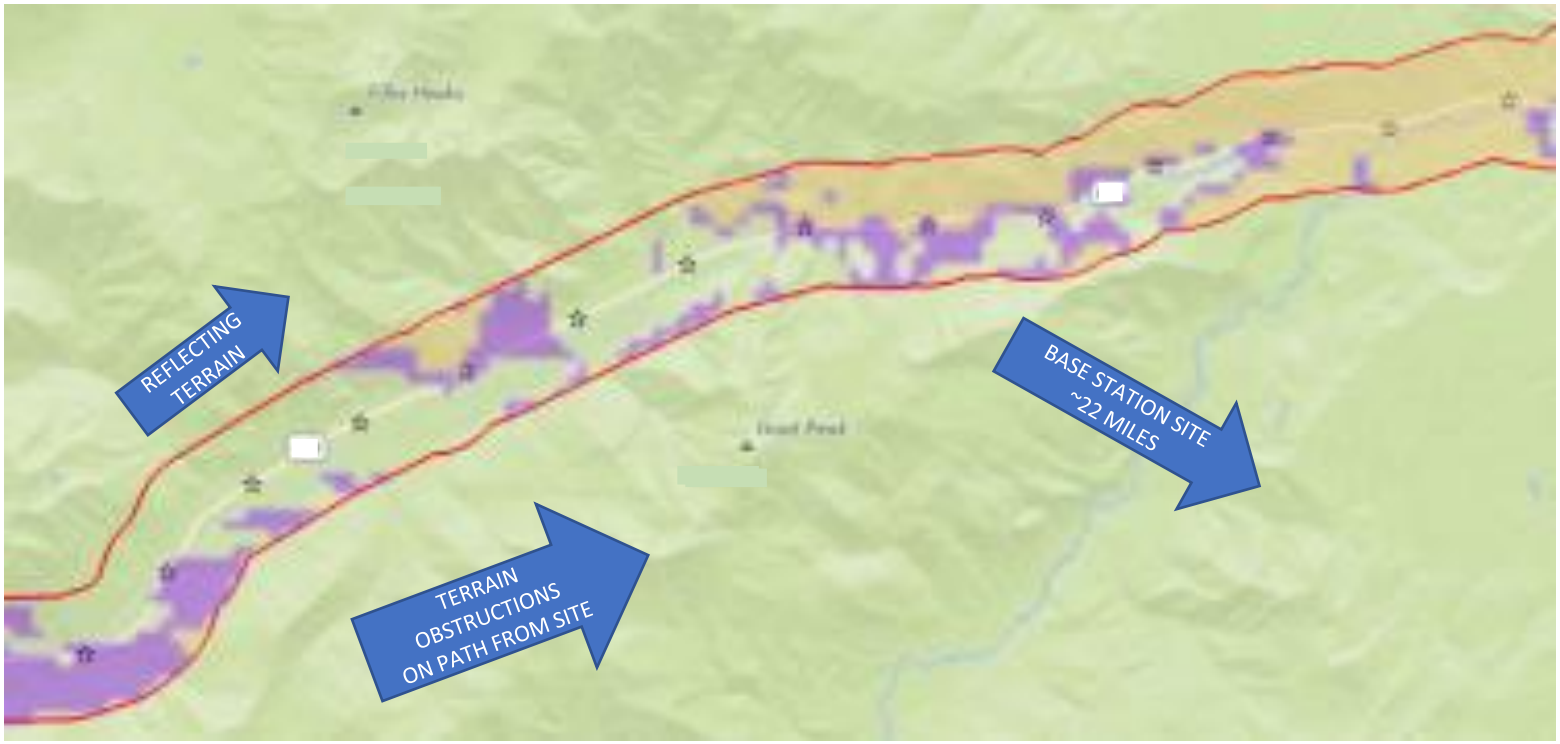
Portable Radio 90% DAQ 3.0 Gap Analysis Map – 73.7% R/T Coverage



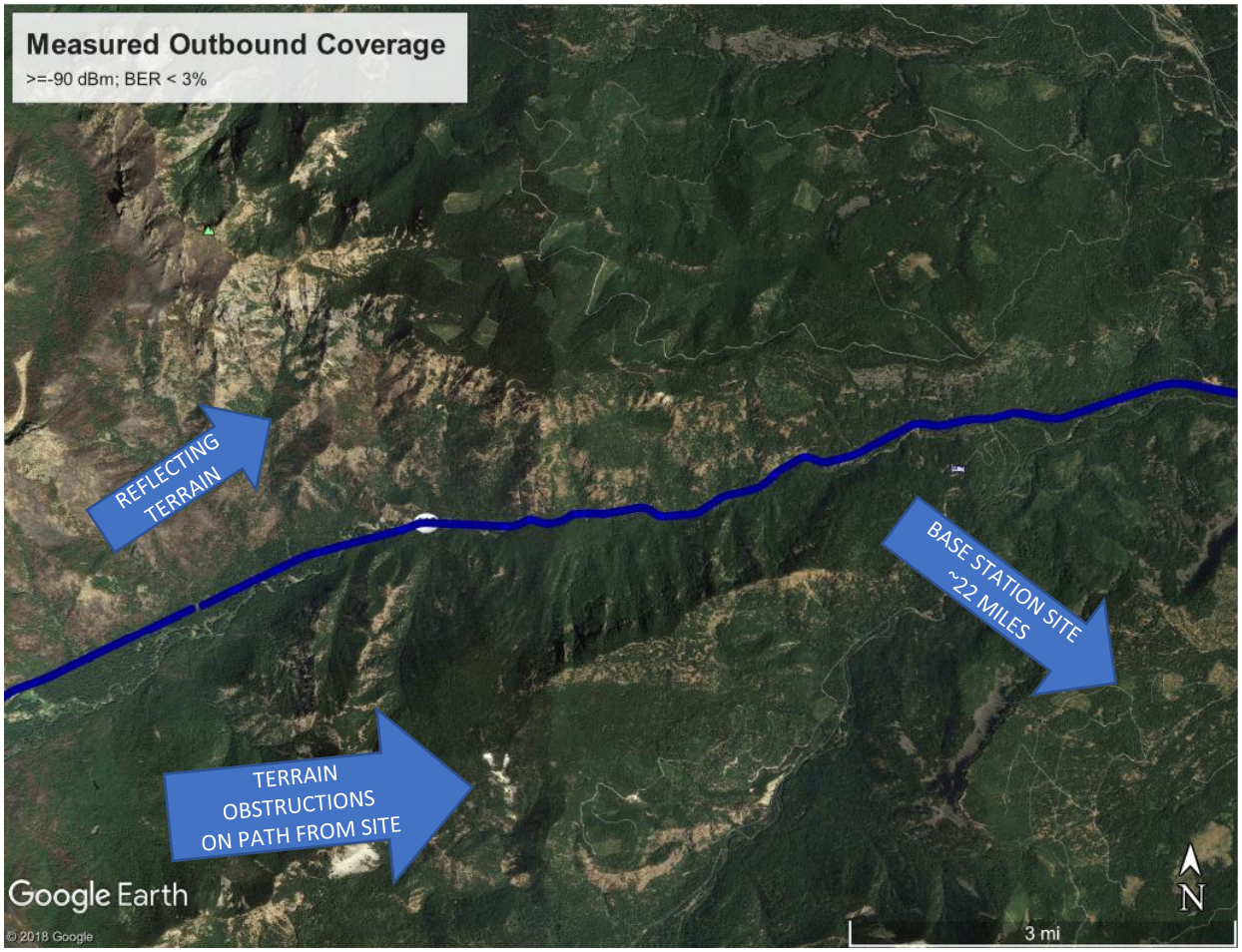
Coverage Prediction Maps – Modeling Limitations

- In areas where coverage is provided primarily by reflections off of terrain, the coverage prediction model showed coverage gaps where measurements showed good coverage.
- Typically, these areas are shadowed from the base station site but have terrain features beyond the terrain that produced the shadowing that are strongly illuminated by signals from the base station site.
- In these areas, BER rates remain low because the received signals at the mobile radio all came from the terrain reflections, and the delay spread among these signals is relatively low compared to a circumstance where there are both primary and reflected signals from the base station site.

PREDICTED COVERAGE IN SHADOWED AREA



MEASURED COVERAGE IN SHADOWED AREA



Comparison of Outbound & Inbound Measured Data

- Our basic assumption for the purposes of coverage modeling is that outbound and inbound signal paths are reciprocal for a given mobile radio location.
- This assumes that the TX and RX antenna heights are identical (or close to identical) at the base station site.
- Comparison of outbound and inbound measurement data along portions of the same measurement run shows that variations in measured signal power with location are comparable for the two sets of measurement data.
- The colors of the measurement point symbols in the map correspond to RSSI power ranges with green-yellow-orange = higher power to lower power. Outbound measurements are displayed as solid circles, while inbound measurement are displayed as circles with black centers.

TOM E.

OUTBOUND/INBOUND MEASUREMENT COMPARISON

TOM E.

Statewide VHF Coverage Prediction Analysis

Criteria	Percent Area Covered		Area Reliability
	DL Only	UL Only	UL & DL
Mobile DAQ 3.4/95% Reliability	0.2%	12.3%	78.1%
Mobile DAQ 3.0/90% Reliability	0.2%	10.4%	82.0%
Portable DAQ 3.4/95% Reliability	20.3%	2.2%	55.7%
Portable DAQ 3.0/90% Reliability	21.0%	2.0%	61.7%

- Coverage and reliability values are somewhat higher than shown above because some areas are well covered by reflected signals that were predicted to be extremely weak
- Considering the wide variation in terrain and in land use/land cover in the State of Washington, providing 78% of the total area within the APA coverage boundaries for all the APAs in the State with a round-trip signal that meets the mobile radio standard for “desirable” coverage is a significant achievement
- ***Perspective and context:*** Coverage gaps are not distributed evenly over the APAs, and any solutions intended to address coverage issues will be applied on an APA by APA basis
- Outbound coverage and reliability will increase significantly statewide if the impact of the vehicle-produced noise on VHF outbound coverage is reduced.
- Ongoing challenge at VHF is identifying additional frequencies for any new sites required.

GREG

COMPARISON OF SITE REQUIREMENTS – VHF VS. 700 MHz

APA 19 VHF & Hypothetical 700 MHz Site Designs

Band: ***Map Label:***	**VHF** **Existing System**	**700 MHz** **Identical to VHF**	**700 MHz** **Identical Plus TX & RX**	**700 MHz** **TX & RX Plus 2 Sites**	**700 MHz** **TX & RX Plus 3 Sites**	**700 MHz** **Modified 11 Site**
Sites:	CRESTON BUTTE LIBERTY LAKE (RX) MAGNISON BUTTE (RX) MICA PK MONUMENTAL MT MT SPOKANE RIVERSIDE ORV (RX) SPOKANE COUNTY JAIL (RX) SPOKANE DO STENSGAR_STRANGER	CRESTON BUTTE LIBERTY LAKE (RX) MAGNISON BUTTE (RX) MICA PK MONUMENTAL MT MT SPOKANE RIVERSIDE ORV (RX) SPOKANE COUNTY JAIL (RX) SPOKANE DO STENSGAR_STRANGER	CRESTON BUTTE LIBERTY LAKE MAGNISON BUTTE MICA PK MONUMENTAL MT MT SPOKANE RIVERSIDE ORV SPOKANE COUNTY JAIL SPOKANE DO STENSGAR_STRANGER	CRESTON BUTTE LIBERTY LAKE MAGNISON BUTTE MICA PK MONUMENTAL MT MT SPOKANE RIVERSIDE ORV SPOKANE COUNTY JAIL SPOKANE DO STENSGAR_STRANGER METALINE FALLS DOT+ RUBY MTN DOT+	CRESTON BUTTE LIBERTY LAKE MAGNISON BUTTE MICA PK MONUMENTAL MT MT SPOKANE RIVERSIDE ORV SPOKANE COUNTY JAIL SPOKANE DO STENSGAR_STRANGER COOKS MTN DOT+ METALINE FALLS DOT+ RUBY MTN DOT+	COOKS MTN DOT+ COULEE DAM CRESTON BUTTE MAGNISON BUTTE METALINE FALLS DOT+ MICA PK MT SPOKANE ODESSA DOT+ RUBY MTN DOT+ SCOOP MT DNR STENSGAR_STRANGER
UL & DL %:	**82.2%**	**75.4%**	**78.2%**	**81.1%**	**83.9%**	**90.4%**

(RX) - Receive-Only Site
TX & RX - All sites equipped with transmitters and receivers (repeaters)
DOT+ - Site Not Previously Used by WSP

- Conclusion: In this case, 700 MHz predicted to provide equal or greater coverage to VHF ***using a similar number of <u>different</u> sites.***

Recommendations

- Recommendations for VHF System Improvements (Short Term)
  - Add base station and voting receiver sites
    - Existing VHF system has 113 base stations and voting receiver sites
    - 37 new base station sites recommended.
  - Make antenna system and filtering system improvements at base station sites
  - Reduce impact of noise generated by vehicles and on-board systems
  - Linear Simulcast Modulation in areas with significant multipath reflections due to terrain
  - Simulcast Operation at some VHF sites where terrain allows
  - In-vehicle repeaters or wireless shoulder mics to improve portable coverage

- 700/800 MHz System Recommendations (Long Term)
  - Replace existing VHF System with Statewide 700/800 MHz Trunked Radio System
    - Phase 1 – Eastern Washington I-90 Corridor
    - Phase 2 – I-5 Corridor (Including sharing with SERS (Snohomish County), PSERN (King County), Thurston County and CRESA (Clark County) —expanding outward from existing WSP 700 MHz system)
    - Phase 3 – Rural areas not already covered in Phase 1 or Phase 2
  - Existing VHF system would remain in place during transition and for long-term backup
  - Use Existing + New VHF sites + 20% margin for 700/800 MHz System (176 sites assumed; actual number of sites required would be determined in detailed design)
  - Some sites in remote areas might remain VHF only (most radios are already dual band VHF/700-800 MHz).
  - In-vehicle repeaters or wireless shoulder mics to improve portable coverage

QUESTIONS??