Final Report

9-1-1 Radio System Engineering Study

Prepared for
Gallatin County 9-1-1

Prepared by
Joe P. Blaschka, Jr., P.E.
Peter Abraham
Mike Norin
ADCOMM Engineering Company

Date Prepared
September 8, 2015

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September 8, 2015

Ms. Kerry O'Connell, Director
Gallatin County 9-1-1
1705 Vaquero Parkway
Bozeman, MT 59718

RE: Gallatin County 9-1-1 Radio System Engineering Project — Final Report

Dear Ms. O'Connell:

Please find attached the Final Report deliverable for the *Radio System Engineering* project. As one of six milestones and the final deliverable for the project, this report pulls together all of the individual reports developed by ADCOMM, including:

- Current State report *(originally delivered June 23, 2015)*
- Technology Review report *(delivered June 23, 2015)*
- High-Level Design and Strategic Directions report *(delivered July 20, 2015)*
- User Needs and Gap Analysis report *(delivered August 25, 2015)*

Please let me know if you or any of the other stakeholders have any questions or comments regarding the Final report.

It has been a pleasure working with Gallatin County and the various project stakeholders. Thank you for your business.

Sincerely,

ADCOMM Engineering Company

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Joe Blaschka, Jr., P.E.

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Acronyms and Abbreviations

AC	alternating current
ADCOMM	ADCOMM Engineering Company
AGL	above ground level
AMSL	above mean sea level
ASR	Antenna Structure Registration
BER	bit error rate
CAD	computer-aided dispatch
DC	direct current
EAS	emergency alert system
EMS	emergency medical services
EOC	emergency operations center
ERP	effective radiated power
FCC	Federal Communications Commission
FD	fire department
FM	frequency modulation
GCSO	Gallatin County Sheriff's Office
GHz	gigahertz
ID	identification
L&J	Gallatin County Law and Justice Center
MHz	megahertz
MSU	Montana State University
NAD83	North American Datum of 1983
P25	APCO Project 25
PD	police department
RF	radio frequency
SAR	search and rescue
UHF	ultra high frequency
UPS	uninterruptable power supply
VAC	volts alternating current
VDC	volts direct current
VHF	very high frequency

Current State

Executive Summary

As part of the Gallatin County Radio Engineering Study project (the "project"), ADCOMM Engineering Company (ADCOMM) staff members visited a number of radio sites in Gallatin County to perform a review of the existing infrastructure equipment along with an evaluation of the sites' suitability for use with an upgraded radio system. This report details ADCOMM's findings.

In August 2014, ADCOMM visited 18 radio sites in Gallatin County, including the 9-1-1 communications center in Bozeman. These sites support the five primary public safety dispatch channels along with the alphanumeric paging/alerting system. During the site visits, high-level system information was collected, along with performance measurements to characterize the existing radio systems. ADCOMM found a range of conditions at the sites visited, some of which could accommodate equipment for an upgraded radio system, while others would need some level of improvement. In cases where a fault condition was found or the performance of a particular system was not as expected or within manufacturer specification, personnel from Gallatin County were immediately notified so corrective action could be taken.

ADCOMM also developed high-level system drawings and computer-generated coverage predictions of the current radio systems to illustrate the configuration and coverage provided by the existing systems.

Introduction

Project Purpose and Scope

In February 2014, ADCOMM was contracted by Gallatin County to perform a radio system study. In general, the purpose of this project was to determine the state of the existing public safety two-way radio communication systems in use by stakeholders in the county, identify the operational needs of the radio systems' users, identify potential technologies and their applicability to a replacement/upgraded radio system, and develop a high-level system design for such a system, followed by solution selection and implementation preparation.

Based on this contract, the project consists of the following phases:

1. **Phase One: Information Gathering and Education.** The deliverables of Phase One are the Current State Report ***(this report)***, the User Needs and Gap Analysis, and the Technology Review. The purpose of this phase is to generate information needed by ADCOMM and by stakeholders to fully understand the existing systems, both for comparison purposes and to identify the needs of the systems' users.

2. **Phase Two: Solution Development.** Using the information gathered during Phase One, Solution Development's deliverable is a list of potential solutions, with rough order of magnitude costs, to the challenges faced by Gallatin County's radio systems. The end of Phase Two is a joint meeting to discuss and evaluate each of the potential solutions, with the County decided on one or more potential solutions for further development. Selection of the solution at this stage begins to set the strategic direction.

3. **Phase Three: Strategic Direction and High-Level Design.** During Phase Three, the selected solution is developed further to yield a strategic direction document and a high-level design. The solution will be divided into a series of implementable modules, with estimated costs, implementation time, and impact to the voice systems identified. The High-Level Design will be sufficient to drive the detailed engineering needed as the first step toward acquisition and implementation.

4. **Phase Four: Final Study Report.** The Final Study Report is a combination of all the deliverables created in the project with a summary and explanatory text for use in grant justifications and budget discussions. ADCOMM anticipates an in-person delivery of the final report to Gallatin County decision makers and stakeholders at a combined meeting.

5. **Phase Five: Solution Selection and Implementation Preparation.** Following the Final Study Report release, stakeholders will meet to identify specific solutions for implementation. These solutions will be further developed to produce engineering drawings, detailed system price estimates, and technical specifications for use in procurement and implementation. Solution development will be for voice radio system changes only.

Note that the following are not included in the scope of work for the current project: technical procurement reviews and assistance, vendor selection, technical support during contract negotiations, implementation engineering services, and/or project management.

Current State Report Deliverable

The Current State Report is a section of the Final Report that identifies the performance of the radio systems being used today. ADCOMM approaches this from both a technical and operational perspective; it is important to correlate the user experience with the measured performance of the systems.

1. At each of the County's 15 radio sites,[1] ADCOMM will:

    a. Identify the relevant equipment by make, model, and serial number (as available) and evaluate each piece of equipment against industry standard lifecycle expectations and manufacturer-identified end-of-life and end-of-support.

    b. Evaluate equipment's actual performance compared to manufacturer's specification, including voice radio and transport mechanisms such as microwave, RF links, leased copper, fiber, and other WAN infrastructure. By measuring basic functionality and consulting maintenance documentation, ADCOMM will gather information such as:

        i. Transmitter output power, at radio
        ii. Power at output of combiner/filter
        iii. FM deviation
        iv. Receiver sensitivity
        v. Reference oscillator stability
        vi. Audio levels
        vii. Bit error rate (BER) testing, as applicable

[1] Per the County's direction, this study considers only the 15 radio sites identified and does not consider any of the radio equipment that may be installed at fire stations and emergency services buildings throughout the county. Should a need to consider that equipment as a resource for use during a system transition or to develop additional sites, ADCOMM would look to the County for current inventory and status information.

viii. Maintenance and error report logs, as available

c. Perform antenna sweeps to determine antenna system return loss.

d. Perform cursory visual inspection of associated systems such as grounding, shelter, backup power, battery, alarm reporting, access, tower, feedline, and grounds-keeping/vegetation abatement.

e. General spectrum analysis at each site to identify potential interfering signals and effective receiver sensitivity measurements at each site.[2]

2. ADCOMM will interview field users specifically regarding areas with poor reception.

3. ADCOMM will create computer predictions of coverage based on existing County equipment to yield a picture of the systems' performance without interference.

4. ADCOMM will perform field strength measurements at real world locations away from the sites as a "ground truth" verification of users' experience and expected coverage.

5. Combining the predicted coverage, field measurements, and users' experiences, ADCOMM will identify the actual coverage and potential improvements in the systems' performance.

Note that evaluation of field radios/subscriber units is not included in the scope of work for the current project.

Overview

In the second half of 2014, in conjunction with Gallatin County 9-1-1 personnel, ADCOMM visited the Gallatin County 9-1-1 communications center and the remote radio sites used for first responder communications. During these visits, high-level system information was collected to gain an understanding of current communication capabilities along with an assessment of current site conditions and suitability for a radio system expansion or upgrade.

Coverage predictions for existing radio systems can be found in Appendix A. These predictions illustrate where mobile and portable coverage is predicted to be available today.

Dispatch Radio Resources

Gallatin County's consolidated 9-1-1 center[3] dispatches for most law enforcement, fire, and emergency medical services (EMS) agencies in Gallatin County. However, it does not provide primary dispatch service for Yellowstone National Park or the town of West Yellowstone in the southern portion of the county.

Telecommunicators (dispatchers) at the 9-1-1 center have access to a variety of radio resources/ channels for communicating with first responders in the field. Dispatch staff use Motorola MCC7500 consoles for accessing these resources. Gallatin County's console system is redundantly connected to the main radio dispatch system controller in Helena via microwave and a telephone line T1 circuit; however, as of August 2014, only the T1 circuit was operational.

[2] Identification of any offending transmitters and mitigating the interference is not included in the scope of this project.

[3] Located in a shared facility with Bozeman Fire Station 3 at 1705 Vaquero Parkway, Bozeman, Montana.

The primary voice dispatch channels used by law enforcement, fire, and EMS agencies employ conventional analog technology using VHF high-band frequencies (150 to 160 MHz). Bozeman Police Department and Bozeman Fire Department each have one dispatch channel that serves the Bozeman area. Two additional channels (Law North and Fire North) are used for law enforcement and fire dispatching throughout the other portions of northern Gallatin County. Another channel (South), with selectable standalone repeaters depending on geographic location of the user(s), is used in the southern part of the county (the "Canyon" and Big Sky areas), which is shared by fire and law enforcement users. Gallatin County Sheriff's Office (GCSO) also has a north-county tactical channel (GCSO TAC) that can be accessed by dispatch through the consoles as necessary. The infrastructure equipment for these channels is generally owned, operated, and maintained by the Gallatin County 9-1-1 center.

Other repeated channels, including Law West, Fire East, Fire Central, Fire West, Big Sky Fire TAC, and Search and Rescue (SAR) are available as tactical resources but generally are not accessible by dispatch. In addition, a variety of tactical simplex channels, such as GTAC1/2/3, Gold, national mutual aid VCALL/VTACs, and state mutual aid channels are available for field users.

Additional voice channels are available through the Montana Statewide Interoperable Public Safety Radio System, which is a VHF Project 25 (P25) Phase 1 trunked radio system; however, this system is not normally used for primary communications by Gallatin County agencies or the dispatch center. This equipment was originally owned and installed by the State of Montana, but it has since been transferred to the individual counties (e.g., Gallatin County). The equipment associated with the "state" trunked radio system was not included in ADCOMM's Current State system review.

Gallatin County also owns and operates a private UHF simulcast alphanumeric paging system used for fire and EMS alerting as well as other personnel alerting.

The following sections describe the configuration of each of the primary radio channels available on the 9-1-1 dispatch consoles. High-level block diagrams of the radio system and dispatch channels are available in Appendix B.

Bozeman PD Dispatch

The Bozeman PD channel is a conventional repeated analog channel consisting of a single transmitter located at the Kenyon Water Tower site in southeast Bozeman along with three voter receivers at Kenyon Water Tower, 9-1-1 Center, and the Gallatin County Emergency Operations Center (EOC). The receiver voting comparators are located at the Kenyon Water Tower site. Console audio connectivity for the Bozeman PD channel is normally provided via the 23 GHz microwave link between the 9-1-1 center and Kenyon Water Tower. Backup access to the channel is available to dispatch via a standby control station at the 9-1-1 center.

The Bozeman PD channel uses the following frequencies:

- 154.7250 MHz base transmit/mobile receive
- 155.6700 MHz base receive/mobile transmit

Bozeman Fire Dispatch

The Bozeman Fire channel is a standalone conventional repeated analog channel consisting of a single repeater (transmitter and receiver) located atop the Nelson Story Tower on the Montana

State University (MSU) campus in southwest Bozeman. There are no additional voted receivers. Dispatch accesses the repeater via an RF control station at the 9-1-1 center.

The Bozeman Fire channel uses the following frequencies:

- 154.2500 MHz base transmit/mobile receive
- 158.9100 MHz base receive/mobile transmit

Law North Dispatch

The Law North channel is the primary dispatch channel for GCSO and other local law enforcement agencies (e.g., Belgrade PD) in northern Gallatin County, except Bozeman PD. This conventional repeated analog channel consists of three non-simulcast repeaters at Bridger Ridge, the 9-1-1 Center, and the Law and Justice Center. However, the transmitter at the 9-1-1 Center is currently disabled, and the transmitter power at the Law and Justice Center is reduced in conjunction with using an in-building antenna intended to provide coverage only to a small area inside the facility. As a result, practically speaking all talk-out coverage is provided by the Bridger Ridge site. Note that although the Law and Justice Center and Bridger transmitters operate simultaneously, they are ***not*** synchronized for simulcast, since the intent is for the Law and Justice site to cover only a small area inside the building.

Receiver audio from the three sites is voted using comparators located at the 9-1-1 center. Connectivity to Bridger Ridge and the Law and Justice Center is provided by various microwave links.

The Law North channel uses the following frequencies:

- 154.9950 MHz base transmit/mobile receive
- 153.8150 MHz base receive/mobile transmit

Fire North Dispatch

The Fire North channel is the primary communications channel for fire and EMS agencies in northern Gallatin County, except Bozeman Fire. Note, however, that dispatch alerting is accomplished via the alphanumeric paging system; it is not normally done on the Fire North channel. This conventional repeated analog channel consists of five ***steered*** (non-simulcast) transmitter sites and six voted receiver sites. The transmitters are located at the Bridger Ridge, High Flats, Nixon Ridge, Timberline, and 9-1-1 Center sites, with Bridger Ridge being the ***default*** transmit site. Voted receivers are located at these same sites plus the Willow Creek site.

With the transmitter steering system, dispatch can manually select one of the transmit sites via the console, or the system can select what is estimated to be the "best" transmit site for a particular user based on which site was voted on the immediately previous talk-in transmission (normally by having the field user momentarily key the subscriber radio).

The Fire North voting comparators and transmitter steering equipment are located at the 9-1-1 center. Connectivity to the various remotes sites is provided by various microwave links and a UHF to Willow Creek from Nixon Ridge.

The Fire North channel uses the following frequencies:

- 154.0550 MHz base transmit/mobile receive
- 158.8800 MHz base receive/mobile transmit

South Dispatch

The South channel (a.k.a., GCSO South) is the primary dispatch and communications channel for both law enforcement and fire users in southern Gallatin County, including Big Sky, U.S. Highway 191, and areas within Yellowstone National Park for mutual aid. Note that Gallatin County 9-1-1 does not dispatch for the town of West Yellowstone. The "South" channel consists of three selectable standalone analog repeaters, one each at Eagle Head, Andesite-Yellowstone Club (near Big Sky Resort), and Duck Creek. The repeaters are not interconnected. As such, simulcast is not possible and they do not use receiver voting.

The Eagle Head and Andesite-Yellowstone Club repeaters are accessed through the 9-1-1 dispatch consoles via a control station at the Big Sky Fire Station, which has connectivity to the 9-1-1 center via a telephone company four-wire landline circuit. Connectivity with the Duck Creek repeater is provided by the State of Montana Public Safety Microwave System.

All three South repeaters use the following frequencies:

- 158.7900 MHz base transmit/mobile receive
- 155.7000 MHz base receive/mobile transmit

GCSO TAC

The GCSO TAC channel is an analog simplex (non-repeated) channel consisting of a single base station located at the High Flats site. Dispatch accesses the base station via an 11 GHz microwave link between the 9-1-1 center and the High Flats site.

The GCSO TAC channel uses the following frequency:

- 158.9100 MHz transmit/receive

Alphanumeric Paging

The Gallatin County alphanumeric paging system used for personnel alerting consists of a six-site simulcast system (plus a standby simulcast site at Gallatin EOC), which covers the north part of the county, and two standalone sites at Big Sky Fire and Horse Butte in the south part of the county. The DX Radio paging terminal, Zetron Model 600 Wireless Data Manager, and Zetron Model 620 Wireless Data Encoder are located at the 9-1-1 center.

Under normal ("main") operation, the simulcast sites include 9-1-1 Center, Bridger Ridge, Kenyon Water Tower, Nixon Ridge, Timberline, and Round Springs. Dispatch pages originate in the computer-aided dispatch (CAD) system and are fed to the paging terminal. In turn, pages are sent via a UHF link transmitter (465.5000 MHz) to the High Flats site, where they are repeated on another UHF frequency (460.5000 MHz) for broadcast to the remote simulcast sites. All of the simulcast paging sites except 9-1-1 Center receive pages over-the-air from this link repeater and then retransmit them over a third UHF frequency, the designated paging frequency (453.4250 MHz). In addition to the simulcast sites, standalone paging transmitters at Big Sky Fire and Horse Butte are activated via telephone line connections. A switch at the 9-1-1 center allows the High Flats paging repeater to be bypassed by having the 9-1-1 Center link transmitter operate directly on the link frequency to the remote sites (460.5000 MHz).

In the event of a failure of the paging link transmitter and/or local paging transmitter at the 9-1-1 center, standby transmitters at the Gallatin EOC can be activated. Under such circumstances, the EOC site would operate in the same manner as the main site at the 9-1-1 center, having a local simulcast paging transmitter and a link transmitter to High Flats. This link

transmitter can also be put in bypass mode, allowing the High Flats link transmitter to be bypassed, thus transmitting the link signal directly to the remote simulcast sites.

The alphanumeric paging system uses the following frequencies:

- 453.4250 MHz subscriber paging frequency (programmed into pagers)
- 465.5000 MHz link from 9-1-1 Center (or EOC when in standby mode) to High Flats
- 460.5000 MHz link from High Flats (or 9-1-1 Center/EOC when in bypass mode) to remote simulcast sites

Gallatin County Radio Sites

Introduction

The Gallatin County 9-1-1 Center operates a multi-channel, multi-site VHF analog voice radio system that provides voice communications for Law, Fire, and EMS.

Each site is configured differently, based on number of channels, type of channels (steered transmitter repeaters, standalone conventional repeaters, and voted receivers) and types of installed equipment (differing manufacturers). Connectivity between the sites is made possible by combinations of microwave, phone lines, and UHF radio links.

In addition to the voice radio system, Gallatin County 9-1-1 also operates a multi-site UHF alphanumeric paging system. Connectivity to the sites for the paging transmitters are primarily provided by UHF radio links; two of the sites are connected via phone line.

ADCOMM Engineering Company (ADCOMM) was contracted to inventory and to perform an evaluation of the current state of the VHF voice radio system and the UHF paging system. ADCOMM performed the site visits in August of 2014. From this exercise, ADCOMM was to provide a general assessment of the sites.

The locations of the sites that ADCOMM visited are shown in Figures 1 and 2. The names of these sites are listed in Table 1. Please see Table C-1 in Appendix C for the listings of voice channels per site.

Paging System Summary

The Gallatin County 9-1-1 Center operates a multi-site simulcast UHF alphanumeric paging system on 453.425 MHz. Paging control is initiated at the 9-1-1 Center and distributed to the sites via microwave, UHF links, and telephone.

Simulcast technology allows for multiple sites with overlapping radio coverage to transmit on the same frequency and CTCSS tone with minimal distortion in the user's operational areas. This is possible by synchronizing the timing, the phase, and the amplitude of downlink/out-bound signals at each of the transmitter sites.

Under normal conditions, the pages are initiated by dispatchers at the 9-1-1 Center and then transmitted on the first UHF link frequency (460.500 MHz). The first link frequency is monitored by a paging repeater at High Flats, which then repeats it to the second link frequency (465.500 MHz). The outlying paging sites monitor the second link frequency and then rebroadcasts locally on the main paging frequency (453.425 MHz). Intermediate to the second link frequency receiver and the main paging frequency transmitter are Zetron Model 620 and Zetron 66; Model 620s are used at a site with DX Engineering paging transmitters and Model 66s are used at sites using mobile radios as paging transmitters.

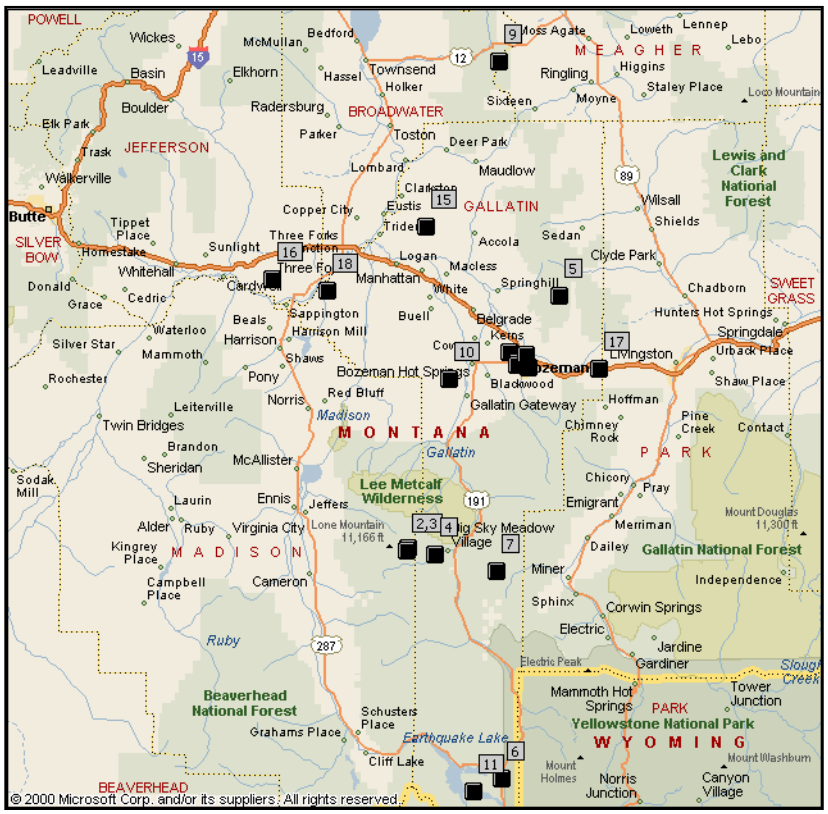


FIGURE 1
Location of All Gallatin County 9-1-1 Radio Sites

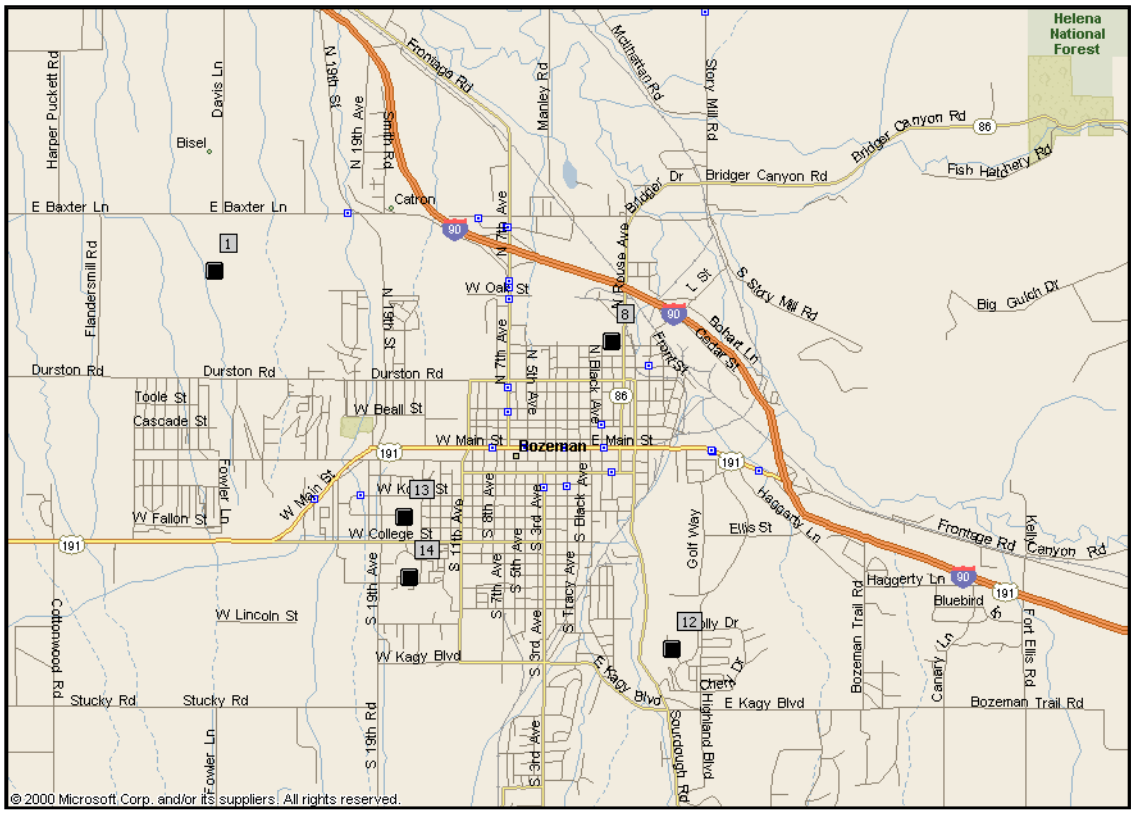


FIGURE 2
Location of Gallatin County 9-1-1 Radio Sites Within Bozeman, Montana

TABLE 1
Sites Visited by ADCOMM and Listing of Equipment Types

Site Name	Map No.	Voice Channel	Paging	Voice Channel Site Connectivity
9-1-1 Center	1	Yes	Yes	Microwave
Andesite: Big Sky Resort	2	No Active Gallatin County 9-1-1 Equipment		
Andesite: Yellowstone Club	3	Yes		Control Station
Big Sky Fire Station	4	Yes	Yes	Telephone
Bridger Ridge	5	Yes	Yes	Microwave
Duck Creek	6	Yes		Microwave
Eagle Head Mountain	7	Yes		Control Station
Emergency Operations Center	8	Receive Only	Yes	Microwave
Grassy Mountain	9	No Gallatin County 9-1-1 Equipment at Site		
High Flats	10	Yes	Yes	Microwave
Horse Butte	11		Yes	Telephone
Kenyon Water Tower	12	Yes	Yes	Microwave
Law and Justice	13	Yes		Microwave
Montana State University	14	Yes		None
Nixon Ridge	15	Yes	Yes	Microwave
Round Springs	16		Yes	Microwave
Timberline	17	Yes	Yes	Microwave
Willow Creek	18	Receive Only		UHF and Microwave

The first exception to the UHF link is the 9-1-1 Center, which has a direct connection. The second two exceptions are Big Sky Fire Department and Horse Butte; both receive their paging control over telephone. Please refer to Figure 3.

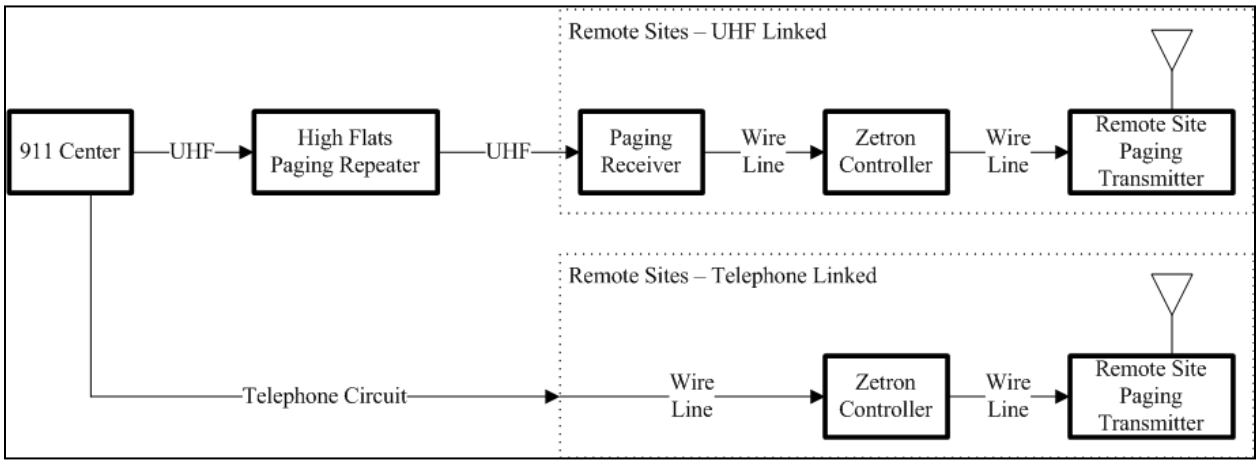


FIGURE 3
Paging System Control Connections

Under standby conditions, the Emergency Operations Center (EOC) radio site serves as a backup to the 9-1-1 Center. The EOC is redundant to the 9-1-1 Center for the main paging frequency and the first link frequency. In the event that the EOC is needed for use, the EOC will receive paging control over the microwave system. Please refer to Figure 4.

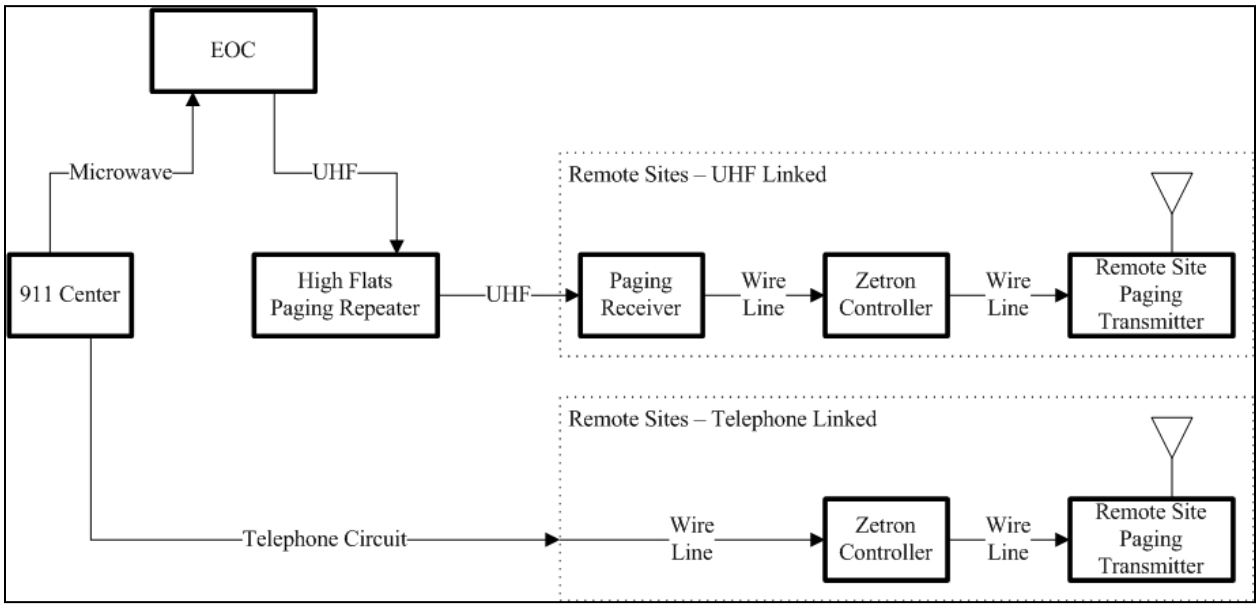


FIGURE 4
Paging System Control Connections Under Stand-By Conditions

The location of the paging transmitters is listed in Table 2.

TABLE 2
Sites with Paging Equipment

Site Name	Map No.	UHF Link No. 1	Paging Repeater UHF Link No. 2	Paging Transmitter	Paging Control Connectivity
9-1-1 Center	1	Main		Yes	Direct
Big Sky Fire Station	4			Yes	Telephone
Bridger Ridge	5			Yes	UHF
Emergency Operations Center (Back to 9-1-1 Center)	8	Backup		Backup	Microwave
High Flats	10		Repeater Main and Backup	Yes	UHF
Horse Butte	11			Yes	Telephone
Kenyon Water Tower	12			Yes	UHF
Nixon Ridge	15			Yes	UHF
Round Springs	16			Yes	UHF
Timberline	17			Yes	UHF

Radio System Summary

The Gallatin County 9-1-1 Center operates several voice channels that covers different portions of the county through the combination of conventional repeaters, receive voting, and transmitter steering technology. The channels are listed in Table 3.

TABLE 3
Sites Visited by ADCOMM and Listing of Gallatin County 9-1-1's Radio Equipment

Channel Name	Steered Transmitter	Standalone Conventional Repeaters	Receiver Voting	Dispatch Access
Big Sky Fire — Tactical		x		Not Accessible
Bozeman Fire		x		Control Station
Bozeman PD		x	x	Console
Bozeman PD — Tactical		x		Not Accessible
Fire East Tactical		x		Console
Fire North	x	x	x	Console
Fire West		x		Not Accessible
GCSO — Tactical		x		Not Accessible
Law North	x	x	x	Console
Law West		x		Not Accessible
South — Big Sky		x		Control Station
South — Duck Creek		x		Console
South — Eagle Head		x		Control Station

Please see Table C-1 in Appendix C for the listings of voice channels per site.

Standalone conventional repeaters are automatic relay stations that are usually located in high locations, such as mountain tops or tall buildings, near the primary users' operational area. When installed in an advantageous location, repeaters allow two or more stations to communicate over large areas, beyond that of direct (simplex or talk around) communications.

Standalone conventional repeaters are able to receive on one radio frequency and simultaneously transmit on another radio frequency; the two frequencies are often referred to as the repeater pair.

Dispatch communicates through standalone conventional repeaters through a direct wire-line connection or through a control station. Direct wire-line connections provide talk-through capability. In the event the wire-line connection is lost, the repeater will continue to operate. Control station access is the equivalent accessing the repeater through a fixed mobile connected to the dispatcher's console.

Voting technology allows for multiple sites with different uplink/in-bound receiver coverage areas to function as a single receiver with continuous wide-area receive coverage. This is possible by comparing all of the received signals at a centralized location, via a receiver voter. The voter then selects the best received signal. The best received signal is then used for retransmission or repeated at dispatch or both, based on system design.

Transmitter steering extends a channel's outbound/downlink coverage by selectively choosing a specific repeater transmitter from a group of repeaters with the same transmit frequency and CTCSS. The specific transmitter is selected by one of two criteria, either manually by dispatch or by a transmitter steering controller based on the best signal as decided upon by the receiver voter.

Transmitter steering with voting technology allows for wide area coverage using multiple sites with the same repeater pair without the cost and complexity of simulcast.

In the Gallatin County 9-1-1 radio system, Motorola Quantars are used for radio transmitters; the exception is Eagle Head using a Codan repeater. Motorola Quantars, Motorola AstroTAC, and Codan receivers are used for the receivers. Voting is performed by Raytheon JPS SNV-12s and Motorola AstroTACs.

Microwave links are used for the transport of voted received audio, selected voted audio to be retransmitted and dispatcher initiated transmitter audio. Willow Creek is the exception in that a UHF link is used to transport the Fire North audio to Nixon Ridge; from Nixon Ridge, the audio is then transported over microwave.

In a typical installation, four-wire connections to the microwave are provided by channel banks. A channel bank provides multiple four-wire E&M connections; a single connection is allocated to a single radio. The multiple four-wire E&M connections allow for multiple radios and other devices to share the single microwave link. Gallatin County 9-1-1 typically uses a two-tier channel bank system. The first channel bank is an intermediate Harris channel bank that connects the microwave link to the second CoastCom channel bank. The Harris channel bank provides a T1 drop for the CoastCom channel bank. The CoastCom channel bank then provides the four-wire E&M connections needed to interface with the receivers and transmitters.

General Assessment

During the site evaluation process, ADCOMM assessed the following:

- Inventory of Gallatin County 9-1-1's equipment and listing of other site occupants
- Radio system performance
  - Voice channel transmit power measurement
  - Voice channel receiver sensitivity measurement
  - Paging transmitter power measurement
- General installation practices
  - Rack and equipment installations
  - Grounding
  - Cable management
- Antenna feed line system sweeps
- General site assessment
  - Access requirements
  - Backup power availability
  - Shelter environmental control

- Vegetation upkeep
- Available space for future growth

General Installation Practices

As part of the general physical installation assessment, the following was noted:

- Signs of excessive wear and tear, such as gouges, dents, or other noticeable physical damage
- Signs of natural forms of aging, such as rust, mold, peeling paint, or peeling labels
- General installation quality of the equipment
- Plumb and true installations of racks and equipment

Cable management is the manner in which cables are routed and dressed between two connecting devices. While there are no standards for cable management, the following was noted in trying to access the cable management practices:

- Free hanging and loose cables that could easily be snagged
- Coiled cables not dressed and or physically secured
- Poor terminations based on visual inspections

Poor grounding is an issue that could reduce the life of the components of a radio system. In the event of a lightning strike or a power surge, the electrical energy from these events looks for the path of least resistance to ground. In the event that any of Gallatin County 9-1-1's equipment becomes a part of this path, good grounding will provide a path outside of the equipment itself. Good grounding requires a shelter ground system and a proper connection to the ground system. As a part of the assessment, the following was noted:

- Existence of a master ground bus inside the shelter
- Existence of a ground halo inside the shelter
- Connections between equipment, racks, and the site's ground system
- Installation practices of PolyPhaser lightning suppression devices
- Feed line ground kits

Antenna Feed Line System Assessment Process

The antenna feed line system's performance was assessed by performing return-loss sweeps. The sweep is a system level measurement that measures the entire performance from antenna to the point to where the antenna feed line system connects to the radio device. The sweep includes intermediate connecting devices such as jumper cables and lightning suppression PolyPhasers.

Since the entirety of the antenna feed line system was swept, a marginal sweep or failed sweep may be caused by a single element of the feed line system; in the case of these, further explanations and recommendations are given on a per site and per channel basis.

Return loss is measured in dB; a larger absolute value of measured return-loss correlates to a more resonant and better performing system. Please refer to Table 4 on how return-loss values will be interpreted for the purposes of this assessment. Some prefer VSWR[4] instead of return-loss; Table 4 shows the correlation between return-loss and VSWR.

[4] The relationship between return loss and VSWR is as follows: Return-Loss (dB) = 20 x log [(VSWR – 1) / (VSWR + 1)]

TABLE 4
Return-Loss Correlated with VSWR and Interpreted Performance

Measured Return-Loss	Correlated VSWR	Performance Status	Response
-6.0 dB	3.0:1	Fail	Requires immediate attention
-9.5 dB	2.0:1	Fail	Requires immediate attention
-14 dB < RL < -9.5 dB	1.5 < VSWR < 2:1	Marginal	Maintenance should be scheduled Manufacturer considers this as fail
-14.0 dB	1.5:1	Pass	No response required
-19.0 dB	1.25:1	Pass	No response required
RL < -20 dB	VSWR < 1.22:1	Ideal	No response required

Most manufacturers specify -14 dB return-loss as the pass/fail threshold. For this assessment, a marginal range is defined to help define and prioritize a maintenance response.

For the purpose of this assessment, ideal will be return-losses higher than -20 dB.

In addition to the sweep performance, the following was noted:

- Evidence of acute turns or kinks in the feed line
- Proper installation of PolyPhaser
- Grounding of feed line at the shelter exterior and tower base

Sweep performance results per channel are reported in the site assessment section.

9-1-1 Center — Radio Site

Date Visited: Monday, August 11, 2014
Latitude: 45° 41' 43.13" N
Longitude: 111° 5' 1.37" W
Elevation (approx.): 4,750 feet AMSL

The Gallatin County 9-1-1 Center radio site is located near downtown Bozeman and is adjoined with Bozeman Fire Department Station 3. The site is located at 1705 Vaquero Parkway, Bozeman, MT 59718, and is accessible by paved roads (see Figures 5 and 6).

The equipment is installed in the equipment room that is adjacent to the dispatch area. The antenna support structure is a three-leg metal tower that is approximately 150 feet tall. The site does have a backup generator.

FIGURE 5
Gallatin County 9-1-1 Center Radio Site

The site assessment in the following sections only addresses the radio system within the equipment room, not the dispatch center's backup, telephone, or logging equipment.

This site is solely occupied by Gallatin County 9-1-1 radio equipment.

Equipment List — Paging

The paging equipment for this site is listed in Table 5.

The first DX Engineering paging transmitter operates on the main frequency of 453.425 MHz. The second DX Engineering paging transmitter is the paging link transmitter that normally operates on 460.500 MHz and can be switched to 465.500 MHz if necessary. Switching allows for redundancy for the High Flats paging repeater site.

The two Motorola CM200 radios and the Zetron Model 66 transmitter controllers are turned off and are no longer in use.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 6.

FIGURE 6
Gallatin County 9-1-1 Center Site Radio Equipment

TABLE 5
Paging Equipment Inventory

Equipment	Function	Power	Measured Transmit Power
DX Engineering	Main Paging Transmitter	12 VDC	N/A
DX Engineering	Link Paging Transmitter	12 VDC	N/A
Zetron Model 620	Wireless Data Encoder	12 VDC	—
Motorola CM200	Paging Transmitter	12 VDC	—
Motorola CM200	Paging Transmitter	12 VDC	—
Zetron Model 66	Transmitter Controller	12 VDC	—

TABLE 6
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Bozeman Fire	Motorola Quantar	Control Station	-48 VDC	35 watts	-118 dBm
Bozeman Police	Motorola Quantar	Control Station	120 VAC	25 watts (per code plug)	N/A
Bozeman Police	Codan Receiver	Voted Receiver	120 VAC	—	-124 dBm
Fire North	Motorola Quantar	Repeater Steered Transmitter	-48 VDC	86 watts	-127 dBm
Fire North	Motorola AstroTAC 3000	Receiver Voter	-48 VDC	—	—

TABLE 6 (cont.)
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Law North	Motorola Quantar	Repeater Steered Transmitter Inactive	120 VAC	15 watts	-118 dBm
Law North	Motorola AstroTAC 3000	Receiver Voter	-48 VDC	—	—

The Bozeman Police Codan receiver did not improve the uplink performance after it was installed; portable transmissions from within the dispatch center were consistently scratchy and often unreadable. During the site assessment, it was discovered that the receiver's audio connection was not connected to the microwave system. The audio needs to be transported over the microwave to the voter located at the Kenyon Water Tank. Once connected, the voted receiver operated as expected; test transmissions with a portable from within the dispatch center confirmed the improved receiver coverage.

On the day of the site visit, the equipment room stored a VHF P25 trunked site that was not installed for operational use. This equipment is part of the State of Montana system. It had no antenna systems connected to it nor was it powered up. It occupies four racks of space: two for the radio equipment and two for the transmitter combiners. Since this time, it has been moved to the EOC.

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 150 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 7.

TABLE 7
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Bozeman Fire	< -20 dB	Ideal	1-5/8-inch	N/A	N/A	Duplexer should be retuned
Bozeman Police	N/A	N/A	1-5/8-inch	N/A	N/A	Unable to measure
Bozeman Police	< -19 dB	Pass	1-5/8-inch	N/A	N/A	No feed line filtering
Fire North Law North	< -18 dB	Pass	1-5/8-inch	N/A	N/A	Shared transmit antenna
Fire North Law North	< -18 dB	Pass	1-5/8-inch	N/A	N/A	Shared receive antenna

The Bozeman Fire duplexer ports return-loss sweeps show that the transmit port is resonant approximately 500 kHz below the transmit frequency (see Figure 7).

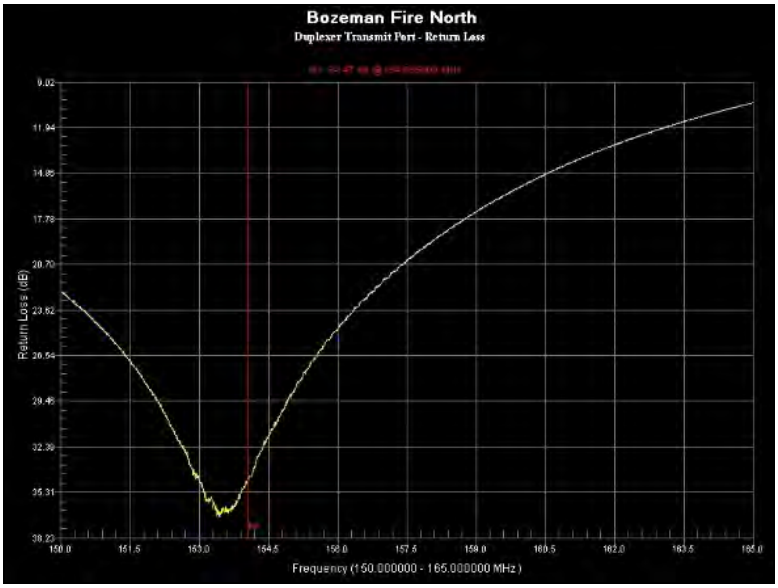


FIGURE 7
Bozeman Fire Duplexer Transmitter Port Measurement Sweep

The antenna feed line systems for Bozeman Police control station and the paging equipment were not measured due to an ongoing active incident. Measuring the return-loss would have rendered the channel as non-operational for dispatch.

The Bozeman Police Codan receiver has a direct connection to the antenna feed line system with no type of notch-pass filtering.

Fire North and Law North share a transmit antenna via a Sinclair transmitter combiner and a receive antenna via a Sinclair receive multi-coupler.

All the antenna feed line systems have PolyPhaser lightning suppression devices installed and grounded to the master ground bus.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 8.

The channel banks may have additional four-wire wire-line circuits available for future use; the available capacity will need to be verified.

Site and Equipment Grounding

The equipment room has a master ground bus and a ground halo.

Most of the racks have a ground bus that is connected to the site's ground system.

Not all of the individual pieces of Gallatin County 9-1-1's equipment are connected to the rack ground bus.

Backup Power

Backup power is provided by batteries and a generator.

TABLE 8
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Aviat Eclipse	Microwave	Kenyon Water Tank
Harris Intraplex	Channel Bank	T1 Connection/Drop Local 4W E&M Connections
Aviat Eclipse	Microwave	High Flat
Harris Intraplex	Channel Bank	T1 Connection/Drop
CoastCom	Channel Bank	Local 4W E&M Connections
Motorola PTP Series	Microwave	Emergency Operations Center
CoastCom	Channel Bank	T1 Connection/Drop Local 4W E&M Connections
Motorola PTP Series	Microwave	Law and Justice
CoastCom	Channel Bank	T1 Connection / Drop Local 4W E&M Connections

Battery backup power is provided from a battery stack and an Eaton Powerwave 9390 UPS.

The on-site generator's manufacturer, model, and rating were not recorded

General Site Condition

The equipment is installed in the equipment room that is adjacent to the dispatch area.

The equipment room has 20 racks and two VHF cavity combiner racks; there is little space for additional racks.

All racks with the radio equipment, except for the trunked radio system racks, are seismically braced and restrained.

The installation practices are clean. Cable management is contained with cable trays on the ceiling and cable stand-offs on the racks.

Temperature control is provided by an unidentified HVAC system.

This site has no issues with vegetation overrun.

Recommendations

- Install a notch-pass cavity filter in the Bozeman Police voting receiver antenna feed line system.
- Verify the transmitter operation of the Law North (CCSO) Quantar as it only transmits 15 watts.
- Ground Gallatin County 9-1-1's radio equipment that still needs to be connected to the site's ground system.
- Retune Bozeman Fire duplexer transmitter port so that it resonates at the transmit frequency.
- Sweep the Bozeman Police, Fire North, and paging equipment antenna feed line systems as part of preventive maintenance and high-level assessment.

Andesite — Big Sky Resort

Date Visited: Monday, August 18, 2014
Latitude: 45° 16' 24.7" N
Longitude: 111° 23' 41.1" W
Elevation (approx.): 8,725 feet AMSL

The Andesite — Big Sky Resort radio site is located on Big Sky Resort property, about 1 mile southeast of the main resort area on a mountain top and requires four-wheel drive for access. The site is owned by AT&T Wireless and is currently not used by Gallatin County 9-1-1.

The shelter was built by Fibrebond and is approximately 10 feet by 20 feet; the shelter was installed in 1993 (see Figures 8 and 9). The shelter has roof hatch access and is located near a ski lift, both of which attest to the amount of snow that accumulates during the winter months. The antenna support structure is an approximately 40-foot-tall metal monopole. The site does have a backup generator.

FIGURE 8
Andesite — Big Sky Resort Radio Site

This site is occupied by AT&T Wireless and by inactive Gallatin County 9-1-1 equipment, specifically an inactive paging transmitter and an inactive UHF paging repeater.

Equipment List — Paging

The paging equipment for this site is listed in Table 9.

The paging equipment is inactive and powered off.

The UHF paging repeater is two Motorola Radius CM200 mobile radios in a "back-to-back" configuration; this configuration allows for repeater function.

Equipment List — Radio

There is no radio equipment at this site.

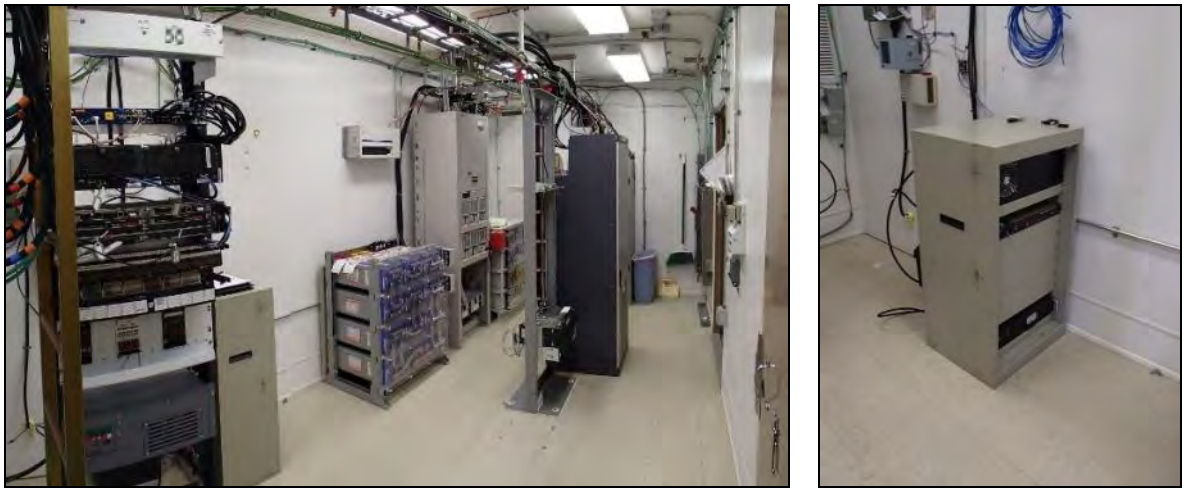


FIGURE 9
Andesite — Big Sky Resort Site Radio Equipment

TABLE 9
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
Motorola Radius M1255 Mobile Radio	Paging Transmitter	12 VDC	N/A
N/A	Amplifier	12 VDC	N/A
Zetron Model 66	Transmitter Controller	12 VDC	-
Motorola Radius CM200 Mobile Radio	UHF Paging Repeater Inactive	12 VDC	N/A

Tower and Antenna Systems

The antenna support structure is a metal monopole that is approximately 40 feet tall and is approximately 150 feet from the shelter.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 10.

TABLE 10
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -20 dB	Ideal	1-5/8-inch	N/A	N/A	
UHF Repeater Receive	< -8 dB	Fail	1-5/8-inch	N/A	N/A	
UHF Repeater Transmit	N/A	N/A	1-5/8-inch	N/A	N/A	Feed line cut at shelter exterior

Because the feed line run is routed inside the monopole, the exact location of the Gallatin County 9-1-1 antennas on the monopole is unknown.

The UHF repeater transmitter feed line is physically cut at the shelter exterior; therefore, there is no antenna connected to this system nor was a measurement sweeps taken.

The UHF repeater's receive antenna feed line system sweeps fails; the sweeps ripple up to 8 dB. Distance-to-fault measures show that there is an issue at the 60-foot length and at the 190-foot length; most likely a poor feed line transition and an issue at the antenna itself (see Figures 10 and 11).

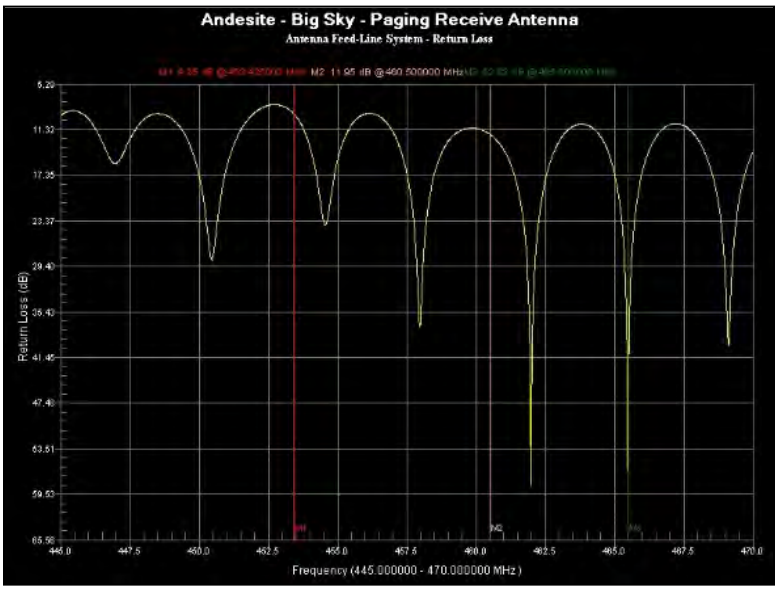


FIGURE 10
Paging Receiver Antenna Feed Line System Return-Loss

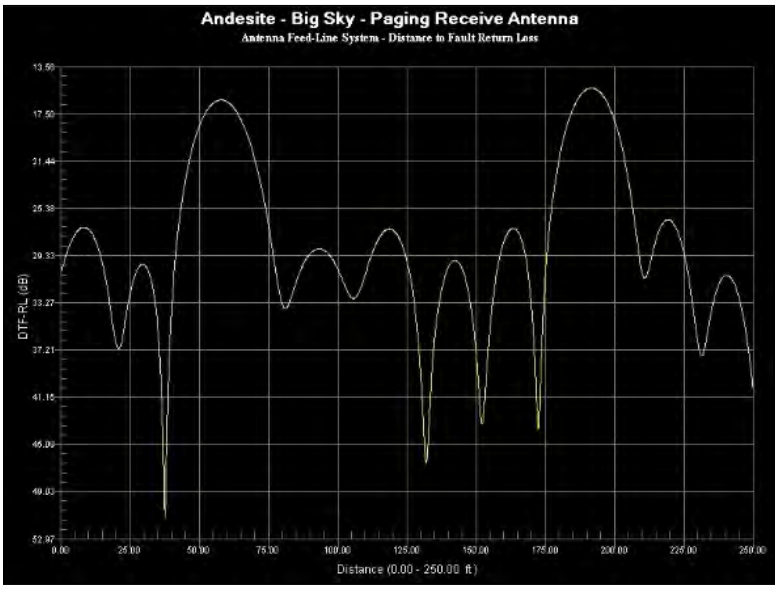


FIGURE 11
Paging Receiver Antenna Feed Line System Distance-to-Fault

Each of the three feed line systems does have a PolyPhaser lightning suppression device installed with a direct connection to the ground bus. There are feed line ground kits installed at the tower base and at the shelter exterior.

Space is available on the monopole for additional antennas at the top of the monopole as well as at the middle.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site.

The paging transmitter was originally controlled by a telephone link provided by Three Rivers Telephone.

The telephone link was carried on the neighboring ski lift. During ski lift operations, significant noise was present on the telephone line, which would affect paging operations.

There are currently no available telephone circuits at this site. Three Rivers Telephone is currently working with Big Sky Report to install a new multi-circuit line at this site; the timeline for completion has not yet been defined. Any potential future expansion by Gallatin County 9-1-1 would be dependent on the completion of this project or the use of a different transport.

Site and Equipment Grounding

The site has a master ground bus and a ground halo. It has been reported that parts of the ground halo have been disconnected because of reported ground loop issues.

The rack has no ground bus but has one of its legs connected to the master ground bus.

The individual pieces of Gallatin County 9-1-1's equipment are not directly connected to any part of the ground system.

Backup Power

Backup power is provided by batteries and a generator.

There is a 12 VDC battery backup located next to the cabinet.

Generator backup is provided by a Kohler 50 generator; the generator's rating is unknown.

Additionally, there are two AT&T owned battery stacks inside the shelter. The voltage of the two battery stacks was not verified; it is unknown if they are +24 VDC or -48 VDC.

General Site Condition

The room is approximately 10 feet by 20 feet and has two 19-inch equipment racks, three AT&T cabinets, and a Gallatin County 9-1-1 half cabinet. Each of the 19-inch equipment racks is half empty. There is space for at least three additional racks.

Gallatin County 9-1-1's half cabinet is not bolted to the floor and the UHF repeater's receiver cavity is not physically secured. Additionally, the transmit cavity and the circulator have been bypassed in the antenna system; the site is not in use and the configuration reflects this.

The installation practices inside the shelter are clean. Cable management is contained with cable trays on the ceiling and cable stand-offs on the racks.

Temperature control is provided by two Bard wall-mount HVAC units: a 20WA4 and a 20WA6.

There are no issues with vegetation overrun.

Gallatin County 9-1-1 is paying approximately $120 per year to rent space at this site.

Recommendations

- Remove the unused equipment.

Recommendations (if this site is to be used for potential future coverage)

- Determine and fix ground loop issue.
- Install a 19-inch equipment rack for potential future Gallatin County 9-1-1 equipment. Bolt the rack to the floor and seismically secure the racks. Bond the rack to the site's ground system.
- Wait for Three Rivers Telephone to install new circuits if future solutions require connectivity or implement another form transport.

Andesite — Yellowstone Club

Date Visited: Monday, August 18, 2014
Latitude: 45° 16' 7.9" N
Longitude: 111° 23' 55.8" W
Elevation (approx.): 8,725 feet AMSL

The Andesite — Yellowstone Club radio site is located in the Yellowstone Club residential community, about 1 mile southeast of the Big Sky Resort area. Site access is available via paved residential roads. It is owned by the Yellowstone Club Community.

The shelter is Yellowstone Club Community's "Maintenance Building Central Telemetry Unit;" the shelter can be considered to be a residential industrial building. The antenna support structure is a three-leg metal tower that is approximately 35 feet tall (see Figures 12 and 13). The site does have a backup generator.

FIGURE 12
Andesite — Yellowstone Club Radio Site

This site is occupied by an unidentified VHF occupant that may be using Motorola's MotoTRbo digital radio technology and two Gallatin County 9-1-1 repeaters.

Equipment List — Paging

There is no Gallatin County paging equipment at this site.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 11.

The Fire-Tac Quantar was not operational during the site visit and measurements were not taken.

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 35 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 12.

FIGURE 13
Andesite — Yellowstone Club Site Radio Equipment

TABLE 11
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
South	Motorola Quantar	Repeater	120 VAC	127 watts	-118 dBm
Fire-Tac	Motorola Quantar	Repeater	120 VAC	N/A	N/A

TABLE 12
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
South	< -14 dB	Pass	LMR-400	~15 feet	S	Duplexer should be retuned
Fire-Tac	< -15 dB	Pass	LMR-400	~15 feet	N	

Each antenna uses a three-floor standoff mount.

The South channel uses a Motorola 0185417U02 duplexer. Although the duplexer ports' return-loss are within the pass range (receive at 17.1 dB and transmit at 15.5 dB), each port has three resonance dips that do not match the repeater's frequencies. The duplexer should be retuned (see Figures 14 and 15).

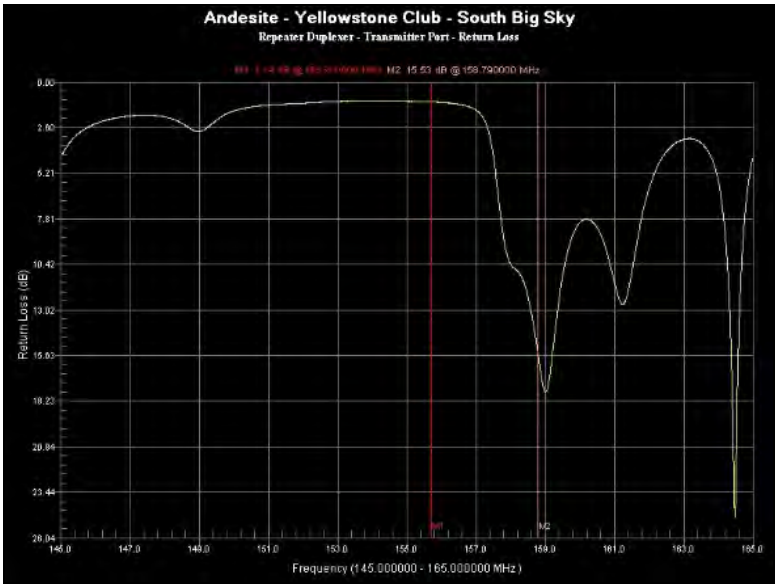


FIGURE 14
South Channel Duplexer Transmit Port Return-Loss

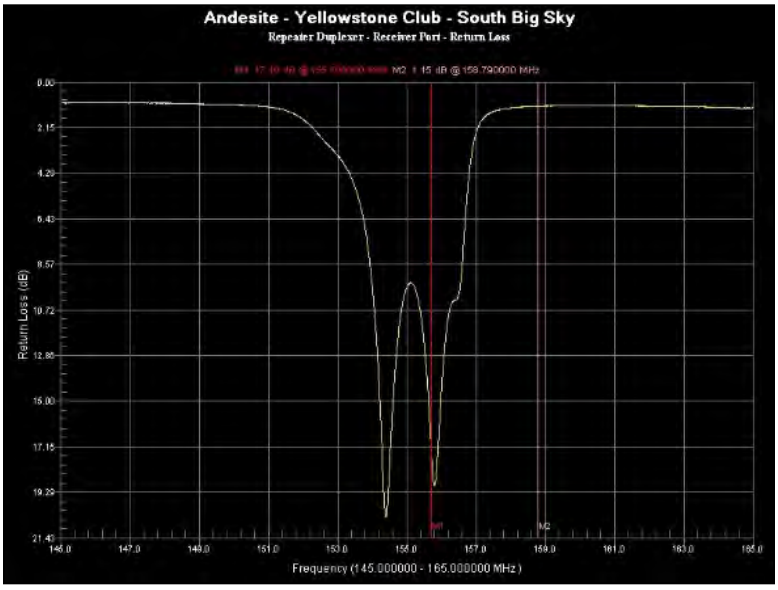


FIGURE 15
South Channel Duplexer Receive Port Return-Loss

The Fire-Tac duplexer port measurement is not available for assessment.

There is no PolyPhaser lightning suppression device installed.

There are no feed line ground kits.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site. Each repeater operates as a standalone conventional repeater.

During the time of the site visit, there were no microwave occupants and there were no known telephone circuits for wire-line control. Three Rivers Telephone is the local telephone provider and they should be able to provide four-wire circuits for wire-line radio control for potential future Gallatin County 9-1-1 equipment.

Site and Equipment Grounding

There is no ground system at this site; there is no master ground bus and no ground halo.

The racks are not connected to a ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to a ground system.

Backup Power

Backup power is provided by a generator.

There is no battery backup power at this site.

Generator backup is available in the adjacent shelter. The shelter was not accessible on the day of the visit; therefore, the generator's manufacturer and rating is unknown.

General Site Condition

The room is a large open area with three CompaCabinets and is used for temporary storage. The building is not accessible by the general public. The two Gallatin County 9-1-1's CompaCabinets are locked and bolted to the floor. There is space for additional racks.

The repeaters' 120 VAC is provided by an extension cord that runs the length of the wall; the extension cord is not physically secured and could inadvertently be pulled from the wall.

The installation practices are clean. There are no cable management devices in place; feed line is cable managed by securing the runs against the wall.

Temperature control is provided by an unidentified HVAC system.

There are no issues with vegetation overrun as it is controlled by the Yellowstone Club Community's landscaping personnel.

Recommendations

- Install a site ground system.
- Ground Gallatin County 9-1-1's radio equipment.
- Ground Gallatin County 9-1-1's antenna feed line systems, including the installation of a PolyPhaser lightning suppression device and feed line ground kits.
- Retune the South channel duplexer so that it matches the repeater's frequencies and verify on a yearly basis.

- Sweep the Fire-Tac duplexer as part of preventive maintenance and high-level assessment.
- Verify that the on-site generator provides backup power to the AC receptacles used by the ground Gallatin County 9-1-1 repeaters. Install a battery backup system if not.
- Install an AC receptacle closer to the CompaCabinets so that an AC extension cord is not needed.

Big Sky Fire Station

Date Visited: Monday, August 18, 2014
Latitude: 45° 15' 33.18" N
Longitude: 111° 18' 42.68" W
Elevation (approx.): 6,525 feet AMSL

The Big Sky Fire Station radio site is located in the town of Big Sky. The site is located at 650 Rainbow Trout Run, Big Sky, MT 59716, and is accessible by paved roads (see Figure 16). It is owned by the Big Sky Fire Department.

The equipment is installed in a storage area near the vehicle bays. The antenna support structure is the roof of the two-story station. The site does have a backup generator.

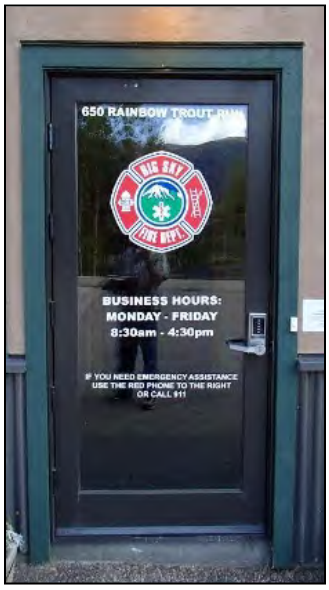


FIGURE 16
Big Sky Fire Department Radio Site

This site is solely occupied by Gallatin County 9-1-1 radio equipment (see Figure 17).

Equipment List — Paging

The paging equipment for this site is listed in Table 13.

The paging equipment is power by 12 VDC through Samlex American power supply.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 14.

The Motorola Astro Consolette is a control station that enables the dispatch center to communicate through the South channel located at the Andesite — Big Sky radio site. The Consolette is powered by 120 VAC.

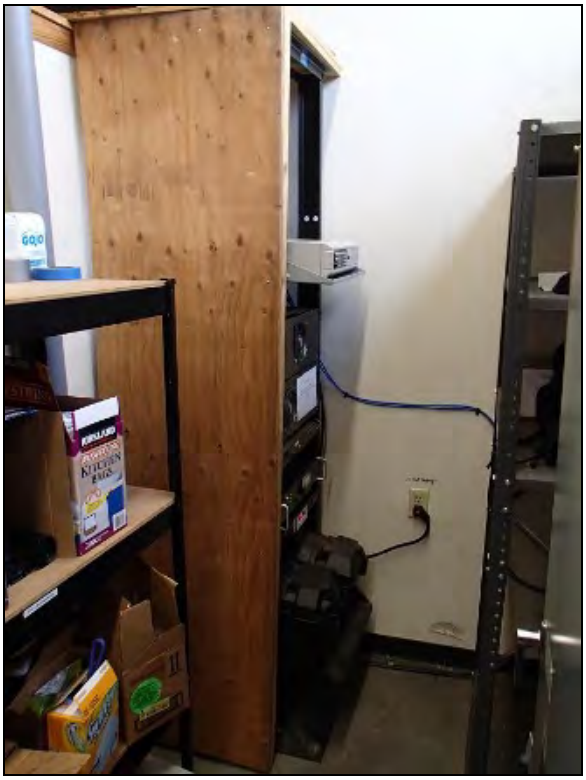


FIGURE 17
Big Sky Fire Department Site Radio Equipment

TABLE 13
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
Motorola Radius M1225 Mobile Radio	Paging Transmitter	12 VDC	105 watts
TE Systems 4512S	Power Amplifier	12 VDC	—
Zetron Model 66	Transmitter Controller	12 VDC	—

TABLE 14
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
South – Big Sky	Motorola Astro Consolette	Control Station	120 VAC	N/A	N/A

Tower and Antenna Systems

The antenna support structure is the roof of the two-story fire station.

The antennas are installed at different locations on top of the roof, each with a height of approximately 45 feet.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 15.

TABLE 15
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -20 dB	Ideal	LMR-400	~35 feet	N/A	
South – Big Sky	< -16 dB	Pass	LMR-400	~35 feet	N/A	

There are no PolyPhaser lightning suppression devices installed.

There are no feed line ground kits installed.

Space is available on the roof for additional antennas.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site.

Four-wire connectivity back to the 9-1-1 dispatch center is provided by Three Rivers Telephone. Additional circuits for potential future equipment should be possible.

Site and Equipment Grounding

There is no ground system at this site; there is no master ground bus and no ground halo.

The racks are not connected to a ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to a ground system.

Backup Power

Backup power is provided by batteries and a generator.

There is a battery located on the bottom of the rack that is connected to the paging equipment. The Motorola Astro Consolette control station does not have battery backup.

The generator is an Olympian D100P19 generator, rated to 100 kW.

General Site Condition

The room is an approximately 5-foot by 10-foot private storage area near the vehicle bays.

There is space for at least three additional racks if the storage shelves were removed.

The Motorola Astro Consolette and the Samlex American power supply share an extension cord that is routed to the closest AC receptacle. Although there is a warning above the AC receptacle that states "Do Not Unplug," the extension cord is not physically secured and could inadvertently be pulled from the AC receptacle.

All items are installed in a single rack that is covered by a wood outer shell.

The rack is not bolted to the floor. Additionally, although the rack has a wooden cover and is in a nonpublic area, the equipment still can be inadvertently moved or unplugged. An incident occurred where the paging system ceased to transmit pages; it was discovered that the enable switch on the Zetron Model 66 Transmitter Controller had been set to off.

The installation practices are clean.

Temperature control is provided by the station's HVAC system. The storage area has an open ceiling, so the HVAC system is shared with the vehicle bay.

There are no issues with vegetation overrun.

Recommendations

- Bolt the rack to the floor; move the rack so that there is 3 feet of clearance from the wall.
- Install a site ground system.
- Ground the radio equipment and the rack.
- Ground the antenna feed line systems, including the installation of a PolyPhaser lightning suppression device and feed line ground kits.
- Verify that the on-site generator provides backup power to the AC receptacles used by the radio equipment. Install a UPS power system for the consolette if not.
- Install an AC receptacle closer to the rack so that an AC extension cord is not needed.
- Add a button shield so that buttons are not inadvertently pressed.
- Add cable management devices, such as cable trays, if potential future equipment is to be installed.
- Remove the storage shelves and reallocate this room as a dedicated secured equipment room if potential future equipment is to be installed.

Bridger Ridge

Date Visited: Tuesday, August 19, 2014
Latitude: 45° 49' 0.8" N
Longitude: 110° 55' 46.9" W
Elevation (approx.): 8,500 feet AMSL

The Bridger Ridge radio site is approximately 10 miles northeast of Bozeman. Site access requires both a four-wheel drive vehicle and foot access; the final quarter mile is only accessible by foot. If equipment needs to be brought in, then helicopter access may be required. The site is owned by the Bridger Ridge Radio Communications Users Association.

There are two shelters at this site (see Figure 18). Gallatin County 9-1-1's paging equipment is installed in the brown shelter and the voice channel equipment is installed in the blue shelter. There are two 30-foot three-leg towers that Gallatin County 9-1-1 uses. One is used by the paging system and the other by the radio system. The site does have a backup generator.

FIGURE 18
Bridger Ridge Radio Site

The brown shelter is occupied by Amateur Radio repeaters (VHF and UHF) and Gallatin County 9-1-1's paging transmitter (see Figure 19).

The blue shelter is occupied by Department of Natural Resources and Conservation, Department of Transportation, three unidentified repeaters, and Gallatin County 9-1-1's voice repeaters and Gallatin County 9-1-1's microwave system (see Figure 20).

Equipment List — Paging

The paging equipment in the brown building is listed in Table 16.

The paging equipment in the brown building is installed in a single half rack.

The paging equipment in the blue building is listed in Table 17.

FIGURE 19
Bridger Ridge Site Blue Building Paging Equipment

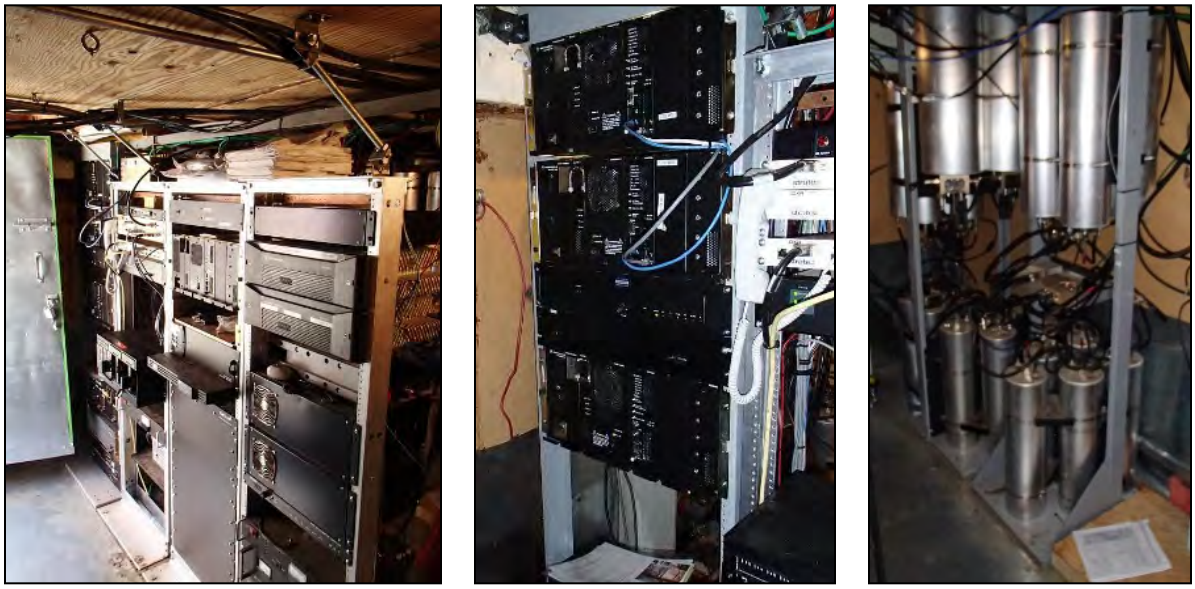


FIGURE 20
Bridger Ridge Site Brown Building Radio Equipment

TABLE 16
Paging Equipment Inventory — Brown Building

Manufacturer and Model	Function	Power	Measured Transmit Power
DX Engineering	Paging Transmitter	12 VDC	76 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	-

TABLE 17
Paging Equipment Inventory — Blue Building

Manufacturer and Model	Function	Power	Measured Transmit Power
Motorola Quantar	Paging Repeater Inactive	N/A	N/A

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 18.

TABLE 18
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Fire North	Motorola Quantar	Repeater Steered Transmitter	-48 VDC	103 watts	-128 dBm
Law North (CCSO)	Motorola Quantar	Repeater	-48 VDC	100 watts	-128 dBm
UHF Repeater	Motorola Quantar	Repeater Inactive	-48 VDC	N/A	N/A

The UHF repeater was previously used for Gallatin County 9-1-1's MDT. This repeater is not actively used but is configured as an analog voice repeater.

Tower and Antenna Systems

There are two 30-foot three-leg towers that Gallatin County 9-1-1 uses. One is used by the paging system and the other by the radio system.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 19.

TABLE 19
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -20 dB	Ideal	RG-58A	30 feet	N/A	
Paging Receiver	< -20 dB	Ideal	RG-58A	30 feet	N/A	
Fire North	< -20 dB	Ideal	LMR-400	25 feet	N/A	Shared transmit antenna Input filter needs to be retuned
Sheriff Office North	< -20 dB	Ideal	LMR-400	20 feet	N/A	Shared transmit antenna Input filter needs to be retuned
Receive Antenna	N/A	N/A	LMR-400	25 feet	N/A	Shared receive antenna

There are three antenna feed line systems in use by Gallatin County 9-1-1: one for the paging transmitter, one for the voice channel transmitters, and one for the voice channel receivers.

The paging antenna is installed on the tower that is on the north side of the brown building. The paging receive antenna is 7-element Yagi.

The radio system antenna is located on the north most tower of the site; it is approximately 25 feet north of the blue building.

The voice repeaters' transmitters use a Sinclair YB2-10208-01 transmit combiner; the antenna system is shared with non-Gallatin County 9-1-1 equipment.

The transmit antenna feed line system for Fire North and GCSO North could not be directly swept as it was a shared system with other occupants via cavity combiners; a direct measurement would take the other radios off the air.

Return loss sweeps were measured at each repeaters' cavity input, and the measurement sweeps show that the each cavity is not tuned to their respective transmit frequency. Fire North was measured to be about 2 MHz below its transmit frequency. GCSO North was measured to be about 150 kHz below its transmit frequency (see Figures 21 and 22).

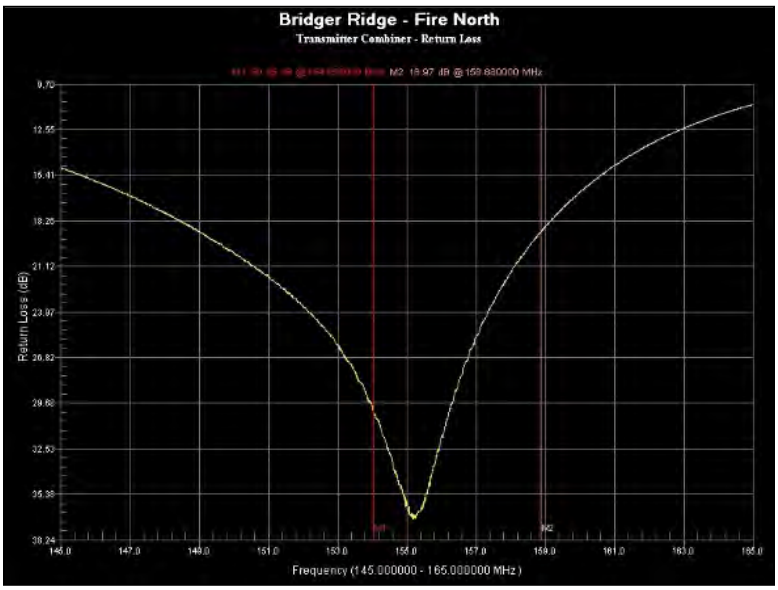


FIGURE 21
Fire North Transmitter Combiner Cavity Return-Loss

The voice repeaters' receive systems use a Sinclair CC22129-7-1F receive multicoupler with Time Microwave Systems LMR-400. The antenna system is shared with non-Gallatin County 9-1-1 equipment. The receive antenna is located on the 25-foot level of the tower.

The receive antenna feed line system for Fire North and GCSO North could not be directly swept as it was shared with other occupants via a receiver multi-coupler; a direct measurement would take the other radios off the air.

Each antenna system connected to Gallatin County 9-1-1's equipment has an inline PolyPhaser lightning suppression device installed.

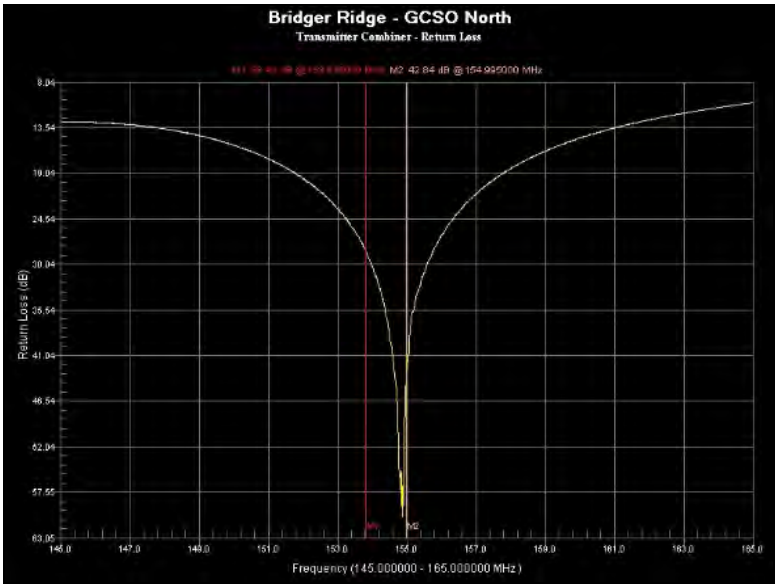


FIGURE 22
GCSO North Transmitter Combiner Cavity Return-Loss

The voice channel feed line system has feed line ground kits.

The paging antenna system does not have a feed line ground kit.

Space is available for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 20.

TABLE 20
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Stratex Networks DMC DXR	Microwave	High Flats
Harris Intraplex	Channel Bank	T1 Connection / Drop
CoastCom	Channel Bank	Local 4W E&M Connections

The microwave system connects to the radios on site through two channel banks.

The Harris channel bank connects directly to the microwave system through a T1 interface and the CoastCom channel bank. The CoastCom channel bank provides the four-wire wire-line connections.

Additional four-wire wire-line circuits for potential future equipment may be possible; the available capacity needs to be verified.

Site and Equipment Grounding

Both shelters have a master ground bus and a ground halo.

The paging rack and its equipment are not connected the site's ground system. The other Gallatin County 9-1-1 racks are connected to their site's ground halo.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to a ground system.

Backup Power

Backup power is provided by batteries and a generator.

The on-site generator is a Cummins OSKAB-1229031 rated to 15 kW.

General Site Condition

In the blue shelter, Gallatin County 9-1-1's equipment is installed across five racks. There is no room for additional racks.

In the brown shelter, the paging rack is a half rack installed on a shelf. There is no room for additional racks.

The installation practices are clean. Cables are managed well even though there are no cable management devices in place.

Neither shelter has temperature control.

The vegetation outside the shelters and surrounding areas are maintained well. There are no issues with vegetation overrun.

The Bridger Ridge Radio Communications Users Association has plans to build a new site sometime during 2015. The new site will be on the same land and is planned to be 14 feet by 20 feet. The same towers will exist with the potential of adding two more towers.

Recommendations

- Connect the paging rack to the shelter's ground system.
- Connect all equipment to each shelter's ground system.
- Retune Fire North's transmitter combiner cavity so that it matches the transmit frequency.
- Retune GCSO North's transmitter combiner cavity so that it matches the transmit frequency.
- Install temperature control at both shelters.
- Wait for the new shelter before considering expanding the radio system at this site.

Duck Creek

Date Visited: Wednesday, August 20, 2014
Latitude: 44° 46' 37.3" N
Longitude: 111° 6' 37.4" W
Elevation (approx.): 6,600 feet AMSL

The Duck Creek radio site is approximately 8 miles north of the town of West Yellowstone. This site is located immediately off of U.S. Highway 191 and is accessible via a paved and a crushed gravel road. The site is owned by the Department of Transportation.

The 10-foot by 12-foot shelter was built by PFS Corporation and installed in 2005. The antenna support structure is a three-leg metal tower that is approximately 100 feet tall (see Figure 23). The site does have a backup generator.

FIGURE 23
Duck Creek Radio Site

This site is occupied by the Department of Transportation, the Federal Bureau of Investigation, and Gallatin County 9-1-1 equipment. Gallatin County 9-1-1 has a standalone repeater and microwave equipment installed at this site (see Figure 24).

Equipment List — Paging

There is no paging equipment at this site.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 21.

The Motorola Quantar is specified to have a receive sensitivity of -119 dBm. Although the South repeater does not meet the performance specifications, it should not be considered a "hard failure." Receiver performance should be monitored to ensure the site is not beginning to fail.

FIGURE 24
Duck Creek Site Radio Equipment

TABLE 21
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
South Channel Same as Andesite	Motorola Quantar	Repeater	-48 VDC	60 watts	-115 dBm

The Motorola Quantar on the South channel is currently a standalone repeater with no connectivity to dispatch. During the site visit, the Quantar had four-wire connections to the microwave system; connectivity to dispatch requires making appropriate connections at the dispatch center and was in the planning stages.

The repeater is programmed with the same frequencies and CTCSS tones as the Andesite South repeater; there is enough geographic isolation and terrain blockage between the two repeaters to allow them to be programmed to the same channel. This repeater was put into service the week prior to the site visit.

The repeater's coverage towards the north is reported to be poor. The coverage south into West Yellowstone is reported to be good.

Tower and Antenna Systems

There is a 100-foot tower located approximately 15 feet from the shelter.

The Gallatin County 9-1-1 antenna system for this site is listed in Table 22.

The return-loss sweeps for the duplexer's transmit and receive ports show that the ports are not tuned for the repeater pair. The transmit port was measured to be resonant approximately 25 kHz higher than the transmit frequency. The receive port was measured to be resonant about 25 kHz below the receive frequency. Additionally, the sweeps also show that each port has multiple resonance dips that do not match the repeater's frequencies (see Figures 25 and 26).

TABLE 22
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
South Channel	< -20 dB	Ideal	LMR-400	60 feet	SW	Duplexer should be retuned

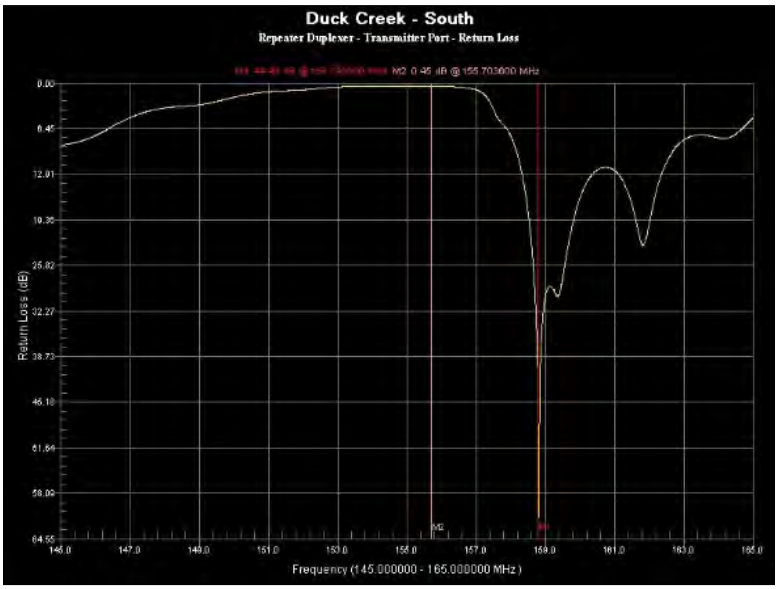


FIGURE 25
South Duplexer Transmit Port Return-Loss

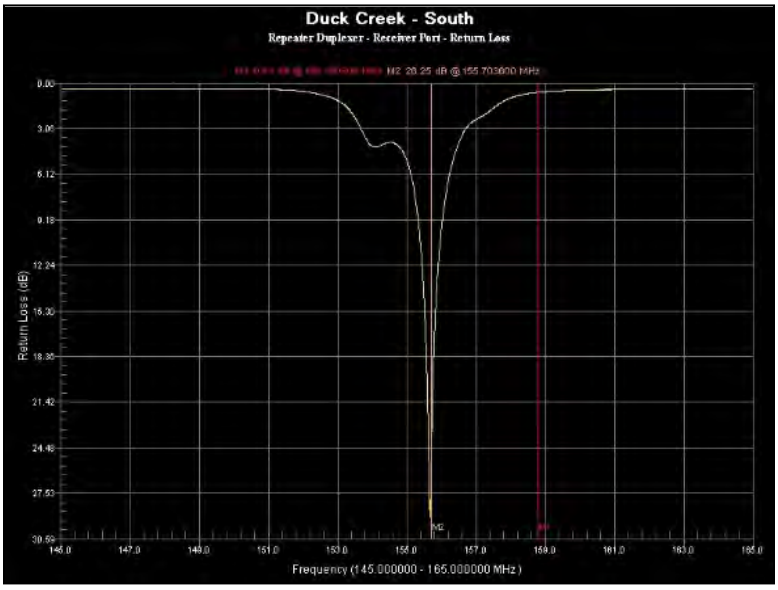


FIGURE 26
South Duplexer Receive Port Return-Loss

The feed line system does have a PolyPhaser lightning suppression device installed.

Feed line ground kits are installed at the tower base and at the shelter exterior.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 23.

TABLE 23
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Stratex Networks DMC DXR	Microwave	State of Montana Public Safety Microwave System
Harris Intraplex	Channel Bank	T1 Connection/Drop Local 4W E&M Connections

The microwave system connects to the radio on site through a single channel bank.

The Harris channel bank connects directly to the microwave system through a T1 interface and to the repeater through a four-wire wire-line connection.

Additional four-wire wire-line circuits for potential future equipment may be possible; the available capacity needs to be verified.

The channel bank that provides the four-wire wire-line connections currently has two VF-25 cards installed, each capable of carrying four circuits. Currently, only one circuit is being used.

Site and Equipment Grounding

The site has a master ground bus and a ground halo.

The rack with the Quantar repeater is connected directly to the ground halo, and the rack with the microwave equipment is connected directly to the master ground bus.

The individual pieces of Gallatin County 9-1-1's equipment are not directly connected to any part of the ground system.

Backup Power

Backup power is provided by batteries and a generator.

Only the microwave system has battery backup; the South repeater does not.

Generator backup is available in the adjacent shelter. The generator's shelter was not accessible on the day of the visit; therefore, the manufacturer and rating is unknown.

General Site Condition

The room is approximately 10 feet by 12 feet and has three 19-inch equipment racks; Gallatin County 9-1-1's repeater and microwave equipment is located on two separate racks. There is space for three to six additional racks.

The microwave rack is seismically braced against the cable tray; the other two racks are not.

The installation practices inside the shelter are clean. Cable management is contained with cable trays on the ceiling and cable stand-offs on the racks.

Temperature control is provided by a single Bard wall-mount HVAC unit.

There are no issues with vegetation overrun.

Recommendations

- Seismically brace the two racks that currently do not have bracing.
- Bond the individual pieces of equipment to the site's ground system.
- Install ground bus on each rack mounted and bond it to the site's ground system. In this way, any future equipment that is installed will more likely be grounded.
- Retune the duplexer so that it matches the repeater's frequency.

Eagle Head Mountain

Date Visited: Tuesday, August 19, 2014
Latitude: 45° 13' 26.0" N
Longitude: 111° 7' 23.2" W
Elevation (approx.): 10,000 feet AMSL

The Eagle Head Mountain radio site is approximately halfway between Bozeman and West Yellowstone. The site is remotely located and requires helicopter access. The site is owned by the United States Forest Service.

The equipment shelter is an approximately 8-foot by 12-foot insulated freight container; the earliest documentation in the shelter is dated 1979. There are several wooden poles and metal tripods surrounding the tower; Gallatin County 9-1-1's antenna is mounted on a tripod. Refer to Figure 27.

FIGURE 27
Eagle Head Radio Site

There is no commercial power available so the site is purely a solar powered site. The solar power system uses both an array of solar cells and a battery bank (see Figure 28). The battery bank is located in a shelter that is immediately adjacent to the equipment shelter. The battery conditions are reported via Amateur Radio APRS.

This site is occupied by Amateur Radio, the United Stated Forest Service, the Department of Transportation, and Gallatin County 9-1-1 equipment. Gallatin County 9-1-1 has a standalone conventional repeater (see Figure 29).

Equipment List — Paging

There is no paging equipment at this site.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 24.

FIGURE 28
Eagle Head Solar Cells and Batteries

FIGURE 29
Eagle Head Site Radio Equipment

TABLE 24
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Law South	Daniels	Repeater	+12 VDC	10 watts[1]	-125 dBm

[1] The repeater transmitter module transmits 10 watts and is connected to a 30-watt power amplifier. On the day of the site visit, it was discovered that the power amplifier was non-functional and that the transmit power out of the power amplifier was measured to be 5 watts. The amplifier also could have been introducing distortion as well, but this was not verified. The amplifier module was pulled from service; the right photograph in Figure 29 shows the repeater system with it removed.

There is also a legacy wideband only repeater installed below the Daniels Electronics repeater that also operates on Law South, a Motorola TA487A. This repeater is turned off and requires a site visit to turn it on as remote activation is currently not possible. Please note that wideband operation is not permissible following the 2013 FCC narrowbanding mandate.

Tower and Antenna Systems

The antenna is installed on a short wood pole 6 feet from the shelter, on the northeast side. The antenna is a nine-bay loop antenna.

The Gallatin County 9-1-1 antenna system for this site is listed in Table 25.

TABLE 25
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Law South	< -20 dB	Ideal	LDF4-50A	2 feet	N/A	Duplexer should be retuned

The repeater's feed line systems uses a Sinclair Q2330ER VHF duplexer. The return-loss sweeps for the duplexer's transmit and receive ports show that each port has multiple resonance dips that do not match the repeater's frequencies (see Figures 30 and 31).

The feed line system does have a PolyPhaser lightning suppression device installed. The PolyPhaser is on the floor, against the wall and connected to the ground halo.

There are no feed line ground kits installed.

Space is available on the other towers for additional antennas. Space is also available to add additional towers to the site.

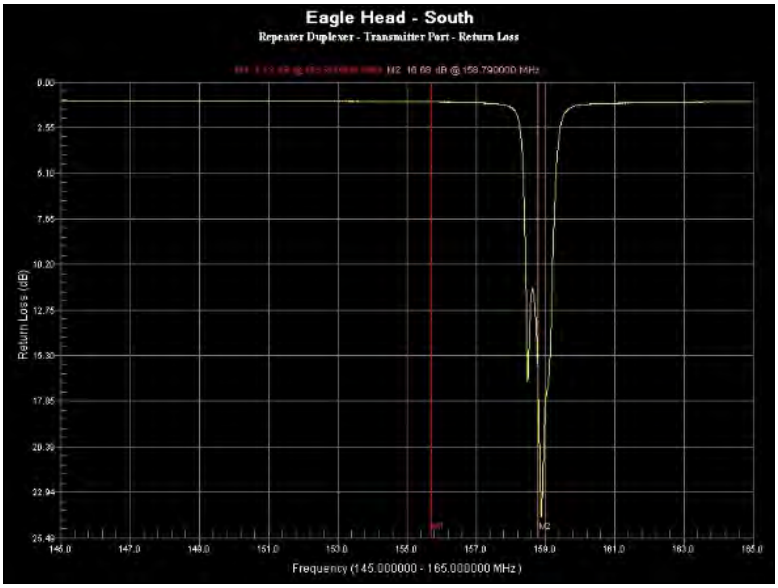


FIGURE 30
South Duplexer Transmit Port Return-Loss

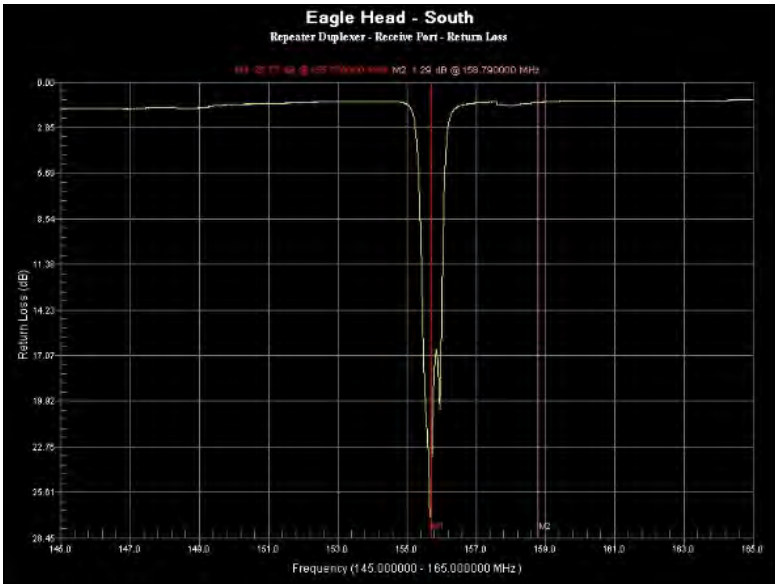


FIGURE 31
South Duplexer Receive Port Return-Loss

Equipment List — Microwave and Intersite Connections

This site has no microwave or intersite connectivity. The repeater operates as a standalone conventional repeater.

Site and Equipment Grounding

The site has a master ground bus and a ground halo. The ground system appears to be two metal rods driven into the ground.

The racks are not connected to the ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to the ground system.

Backup Power

The site is operates on battery power charged by solar cells.

The solar cells are 15 Kyocera KC80s, each rated for a maximum of 80 watts with a Vpmax of 16.9 volts and Ipmax of 4.73 amperes. The battery bank operates at a nominal 13.6 VDC.

There is no generator backup or secondary battery backup at this site.

From documentation found in the battery room, it appears that the batteries were installed in September 2002. The last recorded battery maintenance check occurred in October 2010.

General Site Condition

The room is approximately 8 feet by 12 feet; it has two 19-inch equipment racks and one work table. Gallatin County 9-1-1's equipment is located in one rack. There is space for two additional racks.

The racks are not seismically braced.

The installation practices inside the shelter are relatively clean. There are no cable management devices in place.

There is no temperature control at this site. The temperature is typically cold due to its location and altitude, even during summer months. On the day of the site visit, the outdoor site temperature was in the low 50 degrees Fahrenheit range. The cooling fans on the equipment have been disconnected because of the current they pull from the battery banks.

There are no issues with vegetation overrun.

Recommendations

- Seismically brace the two racks.
- Bond the individual pieces of equipment to the site's ground system.
- Retune the duplexer so that it matches the repeater's frequency.

Emergency Operations Center

Date Visited: Tuesday, August 12, 2014
Latitude: 45° 41' 20.7" N
Longitude: 111° 1' 59.6" W
Elevation (approx.): 4,775 feet AMSL

The Emergency Operations Center radio site is located in Bozeman, approximately 2.5 miles west of the Gallatin County 9-1-1 Dispatch Center. The site is located on the 300 block of East Tamarack Street, Bozeman, MT 59715, and is accessible by paved roads. The site is owned by Gallatin County 9-1-1.

The 12-foot by 24-foot shelter was built by ThermoBond Corporation and is approximately 5 years old. The antenna support structure is a three-leg metal tower that is approximately 100 feet tall (see Figure 32). The site does have a backup generator.

FIGURE 32
Emergency Operations Center Radio Site

This site is occupied by the Department of Transportation, an emergency alert system (EAS), the control radios for the backup dispatch center located in the Emergency Operations Center and Gallatin County 9-1-1 equipment (see Figures 33 and 34).

Equipment List — Paging

The paging equipment for this site is listed in Table 26.

TABLE 26
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
DX Engineering	Paging Transmitter	12 VDC	83 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	—
DX Engineering	Paging Repeater to High Flats	12 VDC	83 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	—

FIGURE 33
Emergency Operations Center Site Radio Shelter Interior

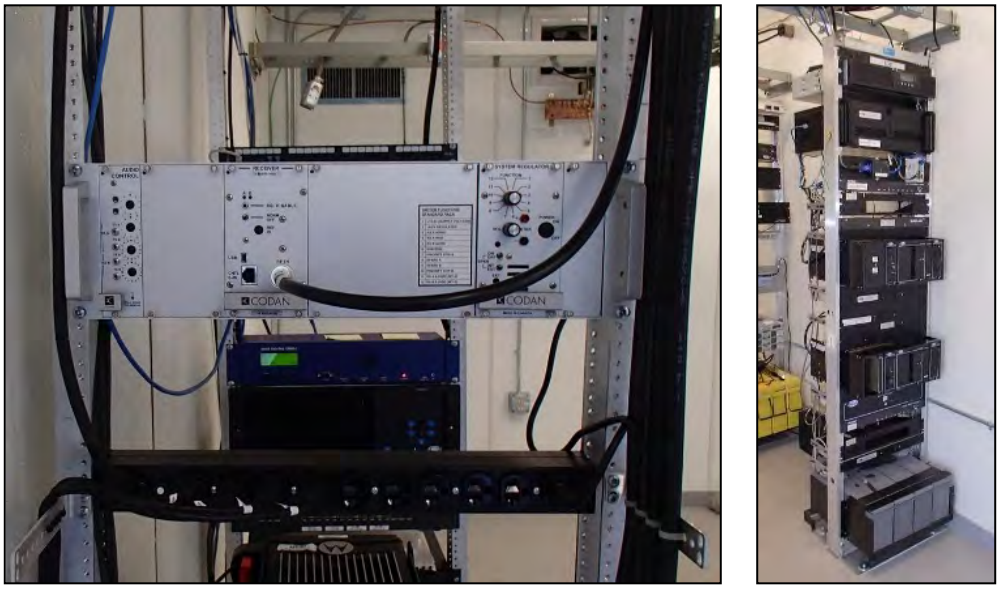


FIGURE 34
Emergency Operations Center Site Radio and Paging Equipment

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 27.

TABLE 27
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Bozeman Police	Codan Receiver	Voted Receiver	120 VAC	—	-119 dBm

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 100 feet tall and is located approximately 15 feet from the shelter.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 28.

TABLE 28
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -19 dB	Pass	AVA-50	80 feet	SE	
Paging Repeater	< -19 dB	Pass	AVA-50	80 feet	SW	
Bozeman Police	< -18 dB	Pass	AVA-50	100 feet	N/A	No feed line filtering

Each radio system has their own separate antenna feed line systems.

The paging repeater uses a duplexer and a Yagi antenna aimed at the High Flats radio site.

The Bozeman Police antenna feed line system does not have an in-line notch cavity filter.

All feed line runs have PolyPhaser lightning suppression devices installed; these devices are mounted directly into the ground bus near the cable entry.

Feed line ground kits are installed at the tower base and at the shelter exterior.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 29.

TABLE 29
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Stratex Networks	Microwave	Kenyon Water Tank
Stratex Networks	Microwave	High Flat
Motorola PTP Series	Microwave	9-1-1 Center
Harris Intraplex	Channel Bank	Local 4W E&M Connections

The Stratex Networks microwave system connects to a Harris channel bank that provides four-wire wire-line connections. The channel bank currently has six VF-25 cards installed, each capable of carrying four circuits. Currently, only one circuit is being used.

Site and Equipment Grounding

The site has a master ground bus and a ground halo.

The voted receiver rack is not grounded. The microwave rack and the remaining racks have a direct connection to the master ground bus.

The individual pieces of Gallatin County 9-1-1's equipment are not directly connected to any part of the ground system.

Backup Power

Backup power for the microwave system is provided by batteries on the bottom of the rack and the site generator.

The Bozeman Police receiver does not a have a battery backup. The receiver has a 12 VDC connection on the rear to facilitate a battery backup connection.

Generator backup for the site is provided by a Cummins DGCB-5880108 generator; the generator is rated for 60 kW.

General Site Condition

The room is approximately 12 feet by 24 feet; it has four 19-inch equipment racks. Gallatin County 9-1-1's equipment is located in three of the racks. There is space for 8 to 11 additional racks.

Each of Gallatin County 9-1-1's systems (voted receiver, paging, and microwave) are installed on separate racks. The voted receiver shares the rack with the Emergency Operations Center's control radios.

All three of Gallatin County 9-1-1's racks are seismically braced; the fourth rack is not. The control radio is not physically secured to the rack.

The installation practices inside the shelter are clean. Cable management is contained with cable trays on the ceiling and cable stand-offs on the racks.

Temperature control is provided by two Bard wall-mount HVAC units.

There are no issues with vegetation overrun.

Recommendations

- Seismically brace the four racks.
- Physically secure the Emergency Operation Center's control radio to the rack.
- Bond the individual pieces of equipment to the site's ground system.
- Add filtering to the Bozeman Police voting receiver.

Grassy Mountain

Date Visited: Thursday, August 21, 2014
Latitude: 46° 19' 13.0" N
Longitude: 111° 6' 45.7" W
Elevation (approx.): 7,400 feet AMSL

The Grassy Mountain radio site is located approximately 45 miles north of Bozeman. The site is located in a remote area with unmaintained dirt and gravel roads and requires four-wheel drive vehicles for access and basic logging tools (saw, axe, etc.) to clear trees that may have fallen. The site is jointly owned by Gallatin County 9-1-1 and the State of Montana; it was given to them by AT&T.

The 11-foot by 18-foot shelter was built by Mobile International Corporation; the onsite documentation suggests it was installed in 1990. The antenna support structure is a three-leg metal tower that is approximately 60-foot tall (see Figure 35). The site does have a backup generator.

FIGURE 35
Grassy Mountain Radio Site

This site is occupied by the decommissioned AT&T equipment and a Kenwood repeater with an unidentifiable owner. The frequency listed on the Kenwood repeater is 153.605 MHz; an FCC license search shows that this is licensed to Vigilante Electric Co-Op within the surrounding areas, but the Grassy Mountain radio site is not listed as a licensed location.

Gallatin County 9-1-1 has no equipment at this site (see Figures 36 and 37).

Equipment List — Paging

There is no Gallatin County 9-1-1 paging equipment at this site.

Equipment List — Radio

There is no Gallatin County 9-1-1 radio equipment at this site.

FIGURE 36
Grassy Mountain Site Shelter Interior

FIGURE 37
Grassy Mountain Generator and Generator Shelter

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 150 feet tall.

There are no Gallatin County 9-1-1 antenna systems at this site.

There are six decommissioned AT&T microwave antennas on the tower.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site.

Site and Equipment Grounding

The site has a ground halo but no master ground bus.

Backup Power

There is an existing battery stack and generator; the condition of each is not known.

The site does have a 22 VDC 1200 AH battery stack that was installed in October 2010.

The generator is an Onan 60 Genset, rated for 39.5 kW.

General Site Condition

The room is approximately 11 feet by 28 feet; it has two rows of 24-inch equipment racks. These racks need to be removed if Gallatin County 9-1-1 wishes to install equipment at this site.

The shelter does have cable trays on the ceiling allowing for cable management.

The original installation practices inside the shelter are clean and have the potential to be clean again if new equipment is installed.

A majority of the space within the site is occupied by decommissioned AT&T equipment. The tower is occupied by decommissioned AT&T microwave antennas. These can be removed.

The site grounding system may need to be updated to meet current Motorola R56 standards.

The battery covers have warped over time and fallen off.

There are a number of dead insects, but there is no evidence of bug or rodent infestation.

Temperature control is provided by two Marvair wall-mount HVAC units. The conditions of these units are unknown.

There are no issues with vegetation overrun.

Recommendations (if the site is to be used)

- Remove all unused equipment, radio equipment, and antenna systems.
- Test the existing site ground system, replace if necessary.
- Install a master ground bus inside the shelter.
- Replace the ground bus at the shelter exterior.
- Install a ground at the tower base.
- Verify the operation of the generator; replace if necessary.
- Verify the operation of the HVAC system; replace if necessary.
- Remove existing battery stack.

High Flats

Date Visited: Thursday, August 14, 2014
Latitude: 45° 38' 15.9" N
Longitude: 111° 16' 4.7" W
Elevation (approx.): 5,650 feet AMSL

The High Flats radio site is located approximately 10 miles southwest of Bozeman. The site is located in a remote area and is accessible via dirt and gravel roads; a four-wheel drive vehicle is necessary during periods of heavy rain. The site is owned by Gallatin County 9-1-1.

The approximately 10-foot by 30-foot shelter was built by Thermobond Corporation and installed in 2005. The antenna support structure is a three-leg metal tower that is approximately 100 feet tall. The site does have a backup generator. Refer to Figure 38**.**

FIGURE 38
High Flats Radio Site and Generator

This site is occupied by Search and Rescue, United States Forest Service, and Gallatin County 9-1-1 equipment.

Gallatin County 9-1-1 has paging equipment, several repeaters, and microwave equipment installed at this site (see Figures 39 and 40).

Equipment List — Paging

The paging equipment for this site is listed in Table 30.

The paging transmitter receives its paging control through a collocated paging repeater.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 31.

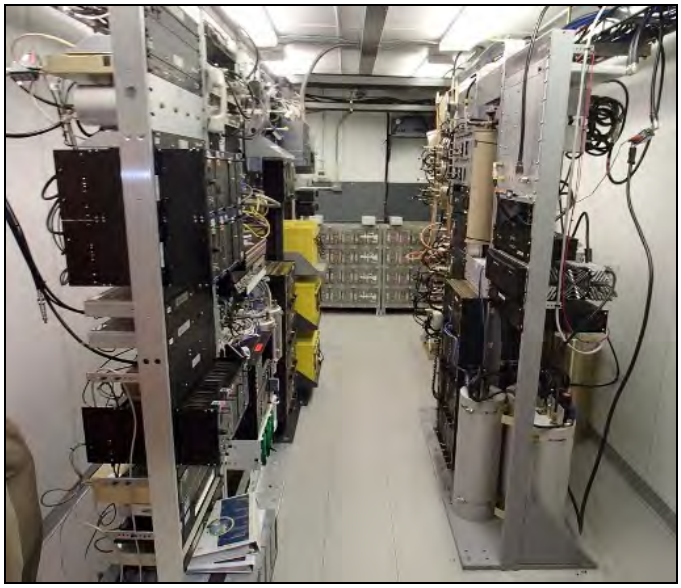


FIGURE 39
High Flats Site Shelter Interior

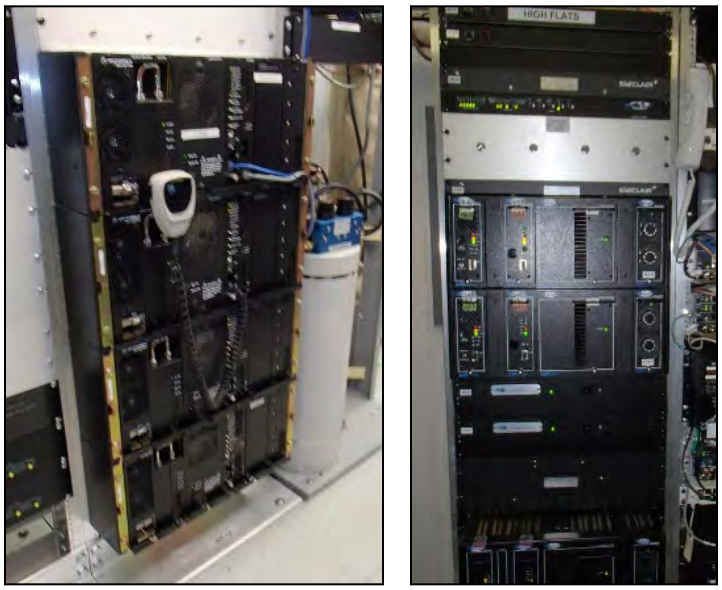


FIGURE 40
High Flats Site Radio and Paging Equipment

TABLE 30
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
DX Engineering	Paging Transmitter	12 VDC	82 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	—
DX Engineering	Paging Repeater Main	12 VDC	71 watts
DX Engineering	Paging Repeater Backup	12 VDC	58 watts

TABLE 31
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Fire North	Motorola Quantar	Repeater Steered Transmitter	-48 VDC	93 watts	-126 dBm
Sheriff Office Tactical	Motorola Quantar	Base Station	-48 VDC	89 watts	-122
South	Motorola Quantar	Control Station	-48 VDC	N/A	N/A
Fire North	Motorola Quantar	Repeater	-48 VDC	N/A	N/A
UHF Repeater Inactive	Motorola Quantar	Repeater	-48 VDC	N/A	N/A
VHF Standby	Motorola Quantar	Base Station	-48 VDC	N/A	N/A

The inactive UHF repeater was previously used for MDT.

The stand-by VHF base station is programmed with eight channels.

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 100 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 32.

TABLE 32
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -20dB	Ideal	1-5/8-inch	100 feet	N/A	
Paging Receiver	< -20dB	Ideal	N/A	N/A	N/A	Cavity should be retuned
Paging Repeater	< -20dB	Ideal	N/A	N/A	N/A	Duplexer should be retuned Shared between Main and Backup Repeaters
Fire North	< -17 dB	Pass	½-inch	60 feet	SE	Duplexer should be retuned
Sheriff Office Tactical	< -18 dB	Pass	1-5/8-inch	100 feet	N/A	
South	< -20 dB	Ideal	½-inch	N/A	N/A	Duplexer should be retuned
VHF Standby Base Station	N/A	N/A	1-5/8-inch	40 feet	NE	
SAR Repeater	< -5 dB	Fail	N/A	N/A	N/A	Duplexer should be retuned Antenna system should be repaired

The paging receiver antenna feed line system connects to the paging receiver via an intermediate cavity filter. The return-loss sweeps for the cavity filter shows that the filter resonates approximately 225 kHz below the receive frequency (see Figure 41).

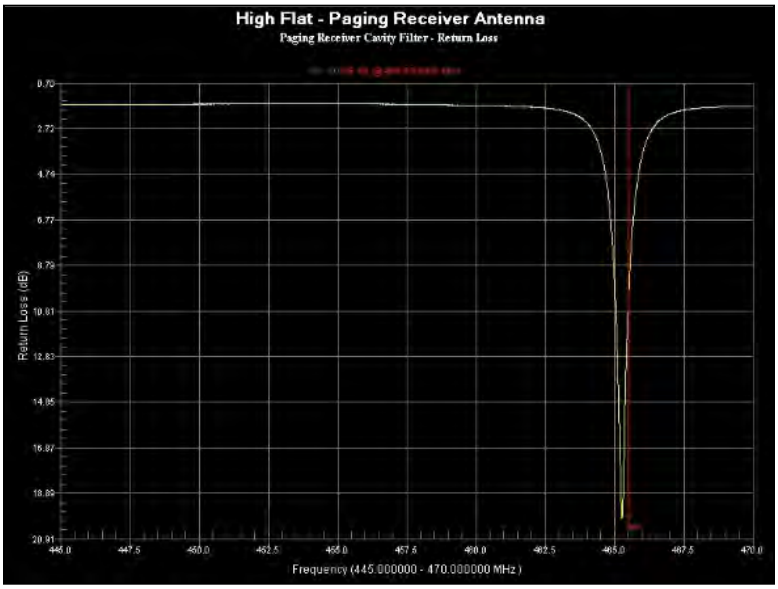


FIGURE 41
Paging Receiver Cavity Filter Return-Loss

The paging repeater's return-loss sweeps for the duplexer's transmit and receive ports show that each port has multiple resonance dips that do not match the repeater's frequencies (see Figures 42 and 43).

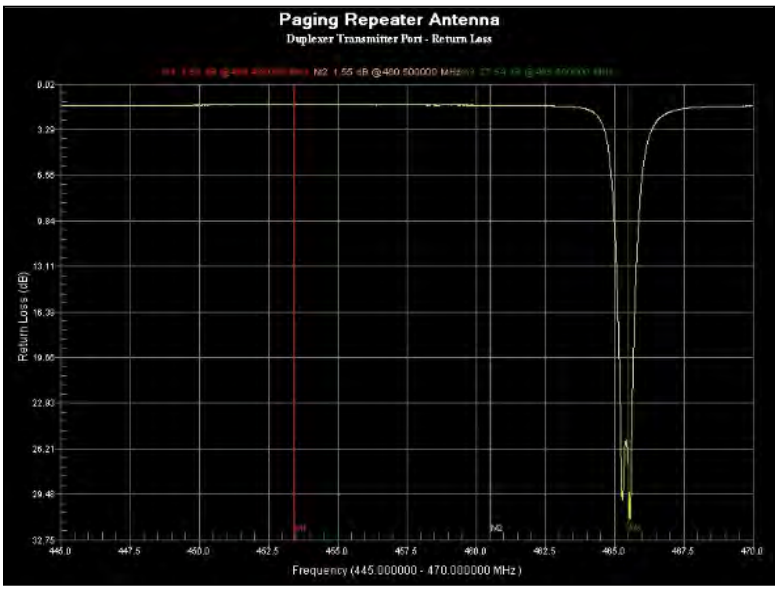


FIGURE 42
Paging Transmitter Duplexer Transmit Port Return-Loss

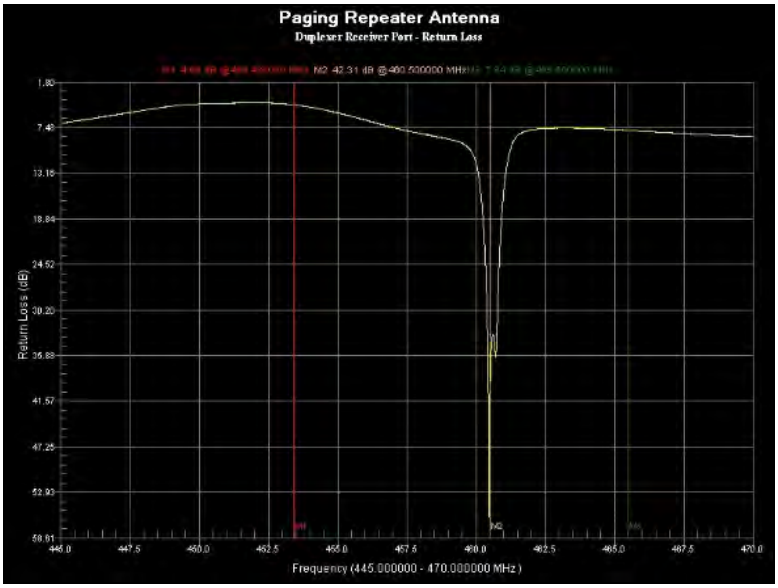


FIGURE 43
Paging Transmitter Duplexer Receive Port Return-Loss

The Fire North feed line systems use a Telewave TPRD-15446 duplexer. The return-loss sweeps for the duplexer's transmit and receive ports show that each port has multiple resonance dips that do not match the repeater's frequencies (see Figures 44 and 45).

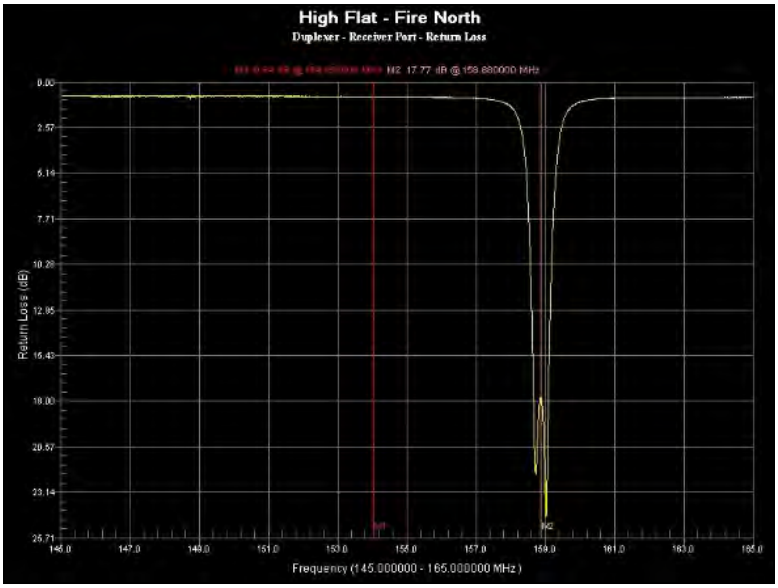


FIGURE 44
Fire North Duplexer Receive Port Return-Loss

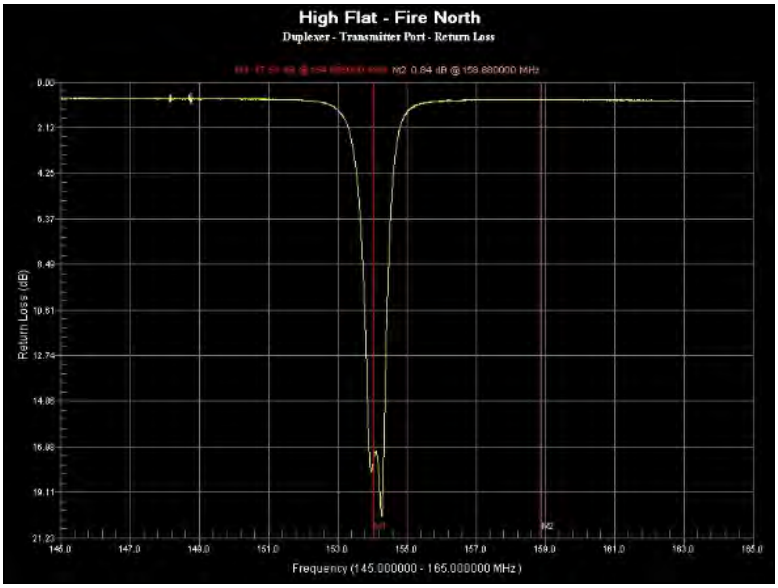


FIGURE 45
Fire North Duplexer Transmit Port Return-Loss

The South control station uses a transmit/receive switch to connect to the antenna feed line system. In between the switch and the Quantar's transmit port is a cavity filter. The return-loss sweeps for the cavity filter show that there is multiple resonance dips that do not match the transmitter frequency (see Figure 46).

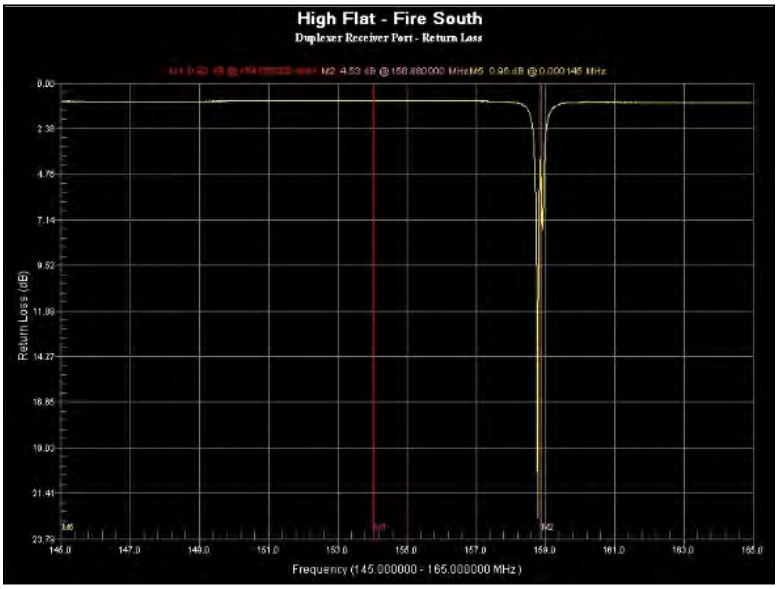


FIGURE 46
South Control Station Cavity Return-Loss

While on site, the SAR repeater antenna system was swept because this repeater has been reported to provide extremely poor coverage, even in close proximity to the site.

The measurement sweeps show that the transmit antenna feed line system has a return-loss of 5.5 dB at the transmit frequency; this can be categorized as failed and requires immediate maintenance. Distance-to-fault measures show that there is an issue at the 102.5-foot length, most likely a poor transition from the feed line transition to the antenna or a faulty antenna (see Figures 47 and 48).

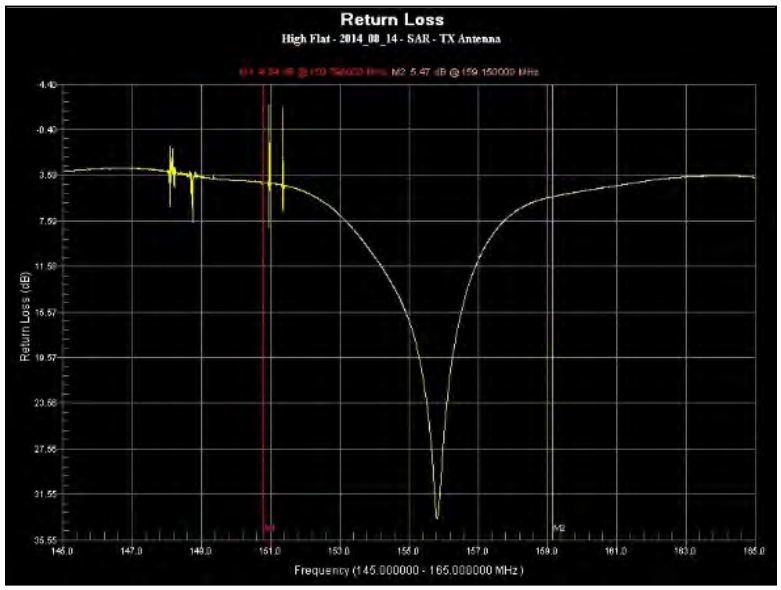


FIGURE 47
SAR Antenna System Return-Loss

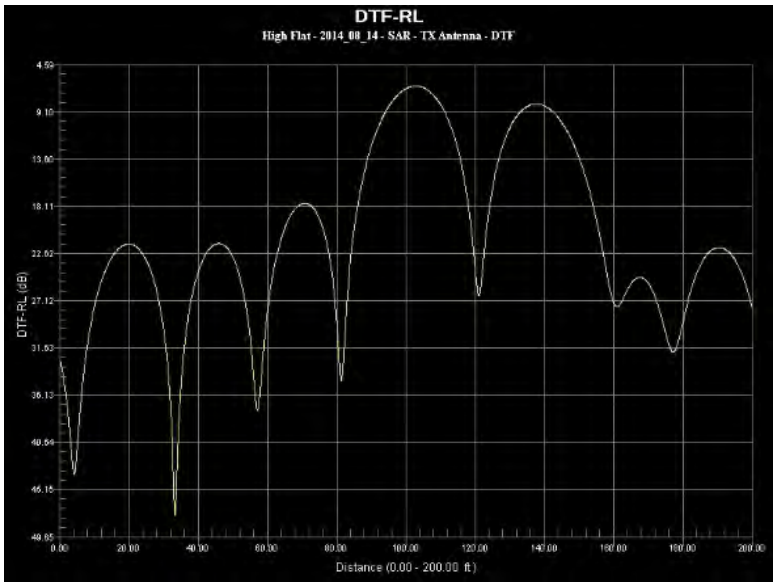


FIGURE 48
SAR Antenna System Distance-to-Fault

The SAR return-loss sweeps for the duplexer's receive port show that it is resonant at two different parts of the band—one at the repeater's receive frequency and one in the 155.0 to 155.5 MHz range. Although this does not affect the receive sensitivity of the Quantar, it

potentially allows for interfering signal to degrade the receiver's performance. Additionally, the sweeps also show that the port has multiple resonance dips (see Figure 49).

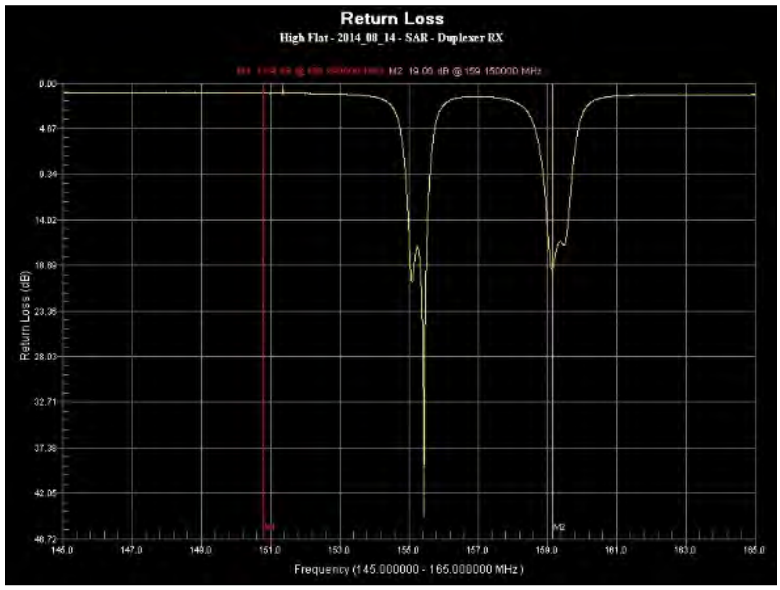


FIGURE 49
SAR Receive Duplexer Port Return-Loss

Each of the feed line systems does have a PolyPhaser lightning suppression device installed with a direct connection to the ground bus.

There are feed line ground kits installed at the tower base and at the shelter exterior.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 33.

TABLE 33
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Aviat Eclipse	Microwave	Nixon Ridge
Aviat Eclipse	Microwave	Timberline
Stratex Networks	Microwave	Bridger Ridge
Stratex Networks	Microwave	Emergency Operations Center
Harris Intraplex	Channel Bank	East T1 Connection/Drop
Harris Intraplex	Channel Bank	West T1 Connection/Drop
CoastCom	Channel Bank	Local 4W E&M Connections

Site and Equipment Grounding

The site has a master ground bus but no ground halo.

The rack has a ground bus, and it is connected to the master ground bus.

The individual pieces of Gallatin County 9-1-1's equipment are connected to the rack ground bus.

Backup Power

Backup power is provided by batteries and a site generator.

The paging system has a battery backup located on the bottom of the rack. There is also a battery stack within the shelter.

Generator backup is provided by a Generac Power System, model 9494450100 generator; the generator is rated for 75 kW.

General Site Condition

The room is approximately 10 feet by 30 feet; it has ten 19-inch equipment racks and two racks of VHF cavities. Gallatin County 9-1-1's equipment is located in four of the racks. There is one empty rack. There is space for at least one additional rack.

The racks are seismically braced.

Behind one of the racks are four VHF cavities; each cavity is part of the receive path of the four Quantars. These cavities are not physically secured.

The installation practices inside the shelter are clean. Cable management is contained with cable trays on the ceiling and cable stand-offs on the racks.

Temperature control is provided by a single Bard wall-mount HVAC units.

This site has no issues with vegetation overrun within the site fence.

Recommendations

- Physically secure the loose cavities; possible install a new rack for this purpose.
- Verify the locations of the antennas on a weather-permissible day.
- Retune the South control station's transmit cavity filter so that it resonates on the repeater's transmit frequency.
- Retune the local paging's receiver notch-pass cavity filter so that it resonates on the receive frequency.
- Retune the paging repeater duplexer so that it matches the repeater's frequency.
- Further investigate the SAR repeater antenna feed line system to determine the exact nature of its failure and remedy as necessary.
- Retune the SAR repeater's duplexer so that the receive port resonates on the repeater's receive frequency.

Horse Butte

Date Visited: Wednesday, August 20, 2014
Latitude: 44° 45' 4.04" N
Longitude: 111° 11' 45.12" W
Elevation (approx.): 7,075 feet AMSL

The Horse Butte radio site is located approximately 8 miles northwest of West Yellowstone. The site is accessible via dirt and gravel roads; a light four-wheel drive vehicle is recommended. The site ownership is unknown; the keys to the site were provided by Search and Rescue volunteer personnel.

The shelter is an 8-foot by 10-foot concrete building with no documentation that refers to its builder or age; the earliest dated documentation in the shelter is from January 2003. The antenna support structure is a three-leg metal tower that is approximately 70 feet tall. The shelter is adjacent to an AT&T Wireless shelter; both share the same tower (see Figure 50). The site does not have a backup generator.

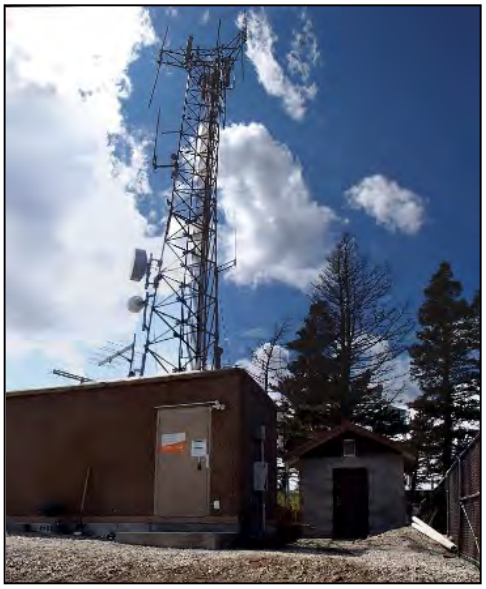


FIGURE 50
Horse Butte Radio Site

This site is occupied by Search and Rescue, television broadcast on UHF channels 28, 30, 32, and 34 (as per documentation), an unidentifiable VHF repeater, and Gallatin County 9-1-1 paging equipment (see Figures 51 and 52).

Equipment List — Paging

The paging equipment for this site is listed in Table 34.

Although the Transmitter Power Amplifier's label was unreadable, it may be a TE Systems 4512S as this would be comparable to the paging system installed at the Big Sky Fire Station.

FIGURE 51
Horse Butte Site Shelter Interior

FIGURE 52
Horse Butte Site Radio Equipment

TABLE 34
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
Motorola Radius M1255 Mobile Radio	Paging Transmitter	12 VDC	N/A
N/A	Transmitter Power Amplifier	12 VDC	114 watts
Zetron Model 66	Transmitter Controller	12 VDC	—

Equipment List — Radio

There is no Gallatin County 9-1-1 radio equipment at this site.

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 150 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 35.

TABLE 35
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -20 dB	Ideal	LMR-600	~45 feet	SE	Two duplexers in-line

The antenna feed line system has two unused in-line duplexers; the two duplexers are cascaded into each other with the other ports connected to each other (i.e., not used).

The feed line is not physically secured at the 30-foot level of the tower.

The feed line systems do have a PolyPhaser lightning suppression device installed and connected to the site's ground system.

There are feed line ground kits installed at the shelter exterior but not at the tower base.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site.

The wire-line control link for the paging transmitter is provided by CenturyLink Telephone.

Site and Equipment Grounding

The site has an external ground bus and but no ground halo.

The racks are not connected to the ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to the ground system.

Backup Power

There is no generator backup at this site.

Gallatin County 9-1-1 does have a 12 VDC battery backup, located in the adjacent rack. The condition of the battery is not known.

General Site Condition

The shelter is approximately 8 feet by 10 feet and has four 19-inch equipment racks, a work bench, and a heater. Two of the racks are half empty. There is space for one to two additional racks, if the work bench is removed.

The racks are not seismically braced.

The installation practices inside the shelter are poor. There are no cable management devices in place. Feed lines and wires hang from the ceiling. Cables on the south wall are free hanging. There are feed lines and wires that are routed through the ceiling, causing some of the ceiling tiles to be displaced or sag. As mentioned above, there are two unused in-line duplexers.

Temperature control is provided by a standalone wall heater; there is no cooling unit.

This site has no issues with vegetation overrun.

Recommendations

- Ground the paging equipment to the site's existing ground system.
- Seismically brace the racks.
- Remove the two duplexers that are currently in the antenna feed line system. Once removed, properly cable manage the feed line system.
- Cable manage and physically secure the wire-line telephone connection so that it would not be inadvertently pulled.
- Perform a routine maintenance check on the batteries on a yearly basis.
- Physically secure the feed line on the tower, specifically at the 30-foot level. And if necessary, replace the remaining feed line securing devices.
- Consider relocating Gallatin County 9-1-1's equipment to the AT&T Wireless shelter or the Teton Communications, Inc., shelter.

Kenyon Water Tower

Date Visited: Tuesday, August 12, 2014
Latitude: 45° 39' 42.5" N
Longitude: 111° 1' 32.0" W
Elevation (approx.): 5,100 feet AMSL

The Kenyon Water Tower radio site is located in the southeast area of Bozeman. The site is accessible by paved residential roads. The site is owned by the City of Bozeman.

The approximately 8-foot by 20-foot shelter was built by Thermobond Corporation and installed in 2008. The antenna support structure is the water tower with a documented height of 40 feet, as per a 2002 VoiceStream Wireless drawing. The paging receive antenna is located on the shelter's ice bridge. The site does have a backup generator. Refer to Figure 53.

FIGURE 53
Kenyon Water Tower Radio Site

This site is occupied by the water department, city recreational department, and Gallatin County 9-1-1 equipment (see Figures 54 and 55).

Equipment List — Paging

The paging equipment for this site is listed in Table 36.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 37.

The power requirements for the Raytheon/JPS Communication SNV-12 are unknown as the rear of the rack was not accessible.

Tower and Antenna Systems

The antenna support structure is the water tower and is approximately 40 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 38.

FIGURE 54
Kenyon Water Tower — Shelter Racks and Gallatin County 9-1-1 Racks

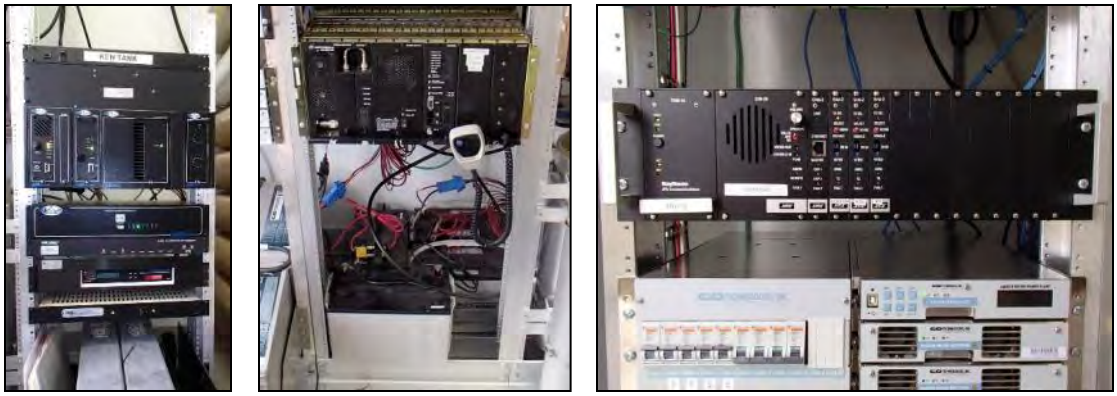


FIGURE 55
Kenyon Water Tower Site Paging, Radio, and Voting Equipment

TABLE 36
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
DX Engineering	Paging Transmitter	12 VDC	83 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	-

TABLE 37
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Bozeman Police	Motorola Quantar	Repeater	120 VAC	107 watts	-129 dBm
Bozeman Police	Raytheon/JPS Communication SNV-12	Receiver Voter	N/A	-	-

TABLE 38
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -20 dB	Ideal	LMR-600	~40 feet	Top of Water Tank	Duplexer should be retuned
Bozeman Police	< -17 dB	Pass	LMR-600	~40 feet	Top of Water Tank	

The repeater uses a Sinclair YB2-09923-01 duplexer.

The antennas locations on the water tank could not be identified as the feed lines are routed through an underground conduit.

The Bozeman Police duplexer return-loss sweeps show that the receive port has three resonance dips, each of which does not match the repeater's frequencies (see Figure 56). The sweep results for the transmit port are not available.

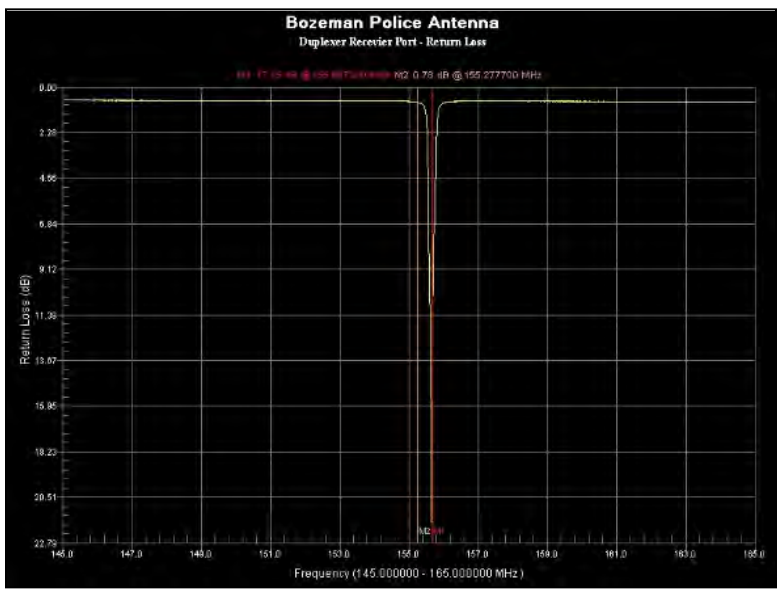


FIGURE 56
Bozeman Police Duplexer Receiver Port Return-Loss

Each antenna system does have a PolyPhaser lightning suppression device installed. The repeater's PolyPhaser is mounted directly on the master ground bus, whereas the paging system's PolyPhaser is located above the rack and is connected to the master ground bus via a ground wire.

Feed line ground kits are installed at the shelter exterior. It is unknown if there are any at the water tank base because that location was not accessible.

Space is available on the water tank for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 39.

TABLE 39
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Stratex Networks	Microwave	9-1-1 Center
Stratex Networks	Microwave	Emergency Operations Center
Harris Intraplex	Channel Bank	Local 4W E&M Connections

Site and Equipment Grounding

The site has a master ground bus and a ground halo.

The rack has a ground bus, but it is not connected to the site's ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to the site's ground system.

Backup Power

Backup power is provided by batteries and a generator.

The paging equipment and the Quantar both have individual dedicated battery backup systems. It is unknown if the JPS Voter is connected to a battery backup system.

The on-site generator is a Generac Power System. The specific model was not attainable.

General Site Condition

The room is approximately 8 feet by 20 feet; it has six 19-inch equipment racks and three VHF cavity racks. Gallatin County 9-1-1's equipment is located in three of the racks.

The racks are not seismically restrained but are firmly pressed against the cable trays.

The racks have less than 3 feet of space from the rear of the rack to the wall. Rear access is not possible.

The installation practices inside the shelter are clean. Cable management is contained with cable trays.

Temperature control is provided by a single Bard wall-mount HVAC units.

This site has no issues with vegetation overrun within the site fence.

Recommendations

- Ground the racks and equipment to the site's existing ground system.
- Physically secure the loose cavities; if possible, install a new rack for this purpose.
- Verify the location of each antenna for documentation purposes.
- Reinstall the pager's PolyPhasers to within 2 feet of the shelter's cable entry.

- Retune the Bozeman Police duplexer receive port so that it resonates on the receive frequency.
- Sweep the Bozeman Police duplexer transmitter port to ensure that it is tuned correctly.
- If additional racks are installed, install them so that there is 3 feet of clearance so that preventive maintenance is possible.

Law and Justice

Date Visited: Tuesday, August 12, 2014
Latitude: 45° 40' 24.8" N
Longitude: 111° 3' 34.3"
Elevation (approx.): 4,850 feet AMSL

The Law and Justice radio site is located near the center of Bozeman. The site is located at 615 South 16th Avenue, Bozeman, MT 59715, and is accessible by paved roads. The site is owned by the Gallatin County Justice Court.

The radio equipment is located in the Records Room (Room 102) in the basement. The antenna support structure is two-fold (see Figure 57). The receive antenna is located on a 60-foot tower that is located in the back of the building. The transmit antenna is located inside the building. The site does not have a backup generator.

FIGURE 57
Law and Justice Radio Site

Gallatin County 9-1-1 is the only occupant of this site. The actual radio site within Room 102 is a 5-foot by 7-foot area that has been sectioned off by a non-secured screen fence (see Figure 58).

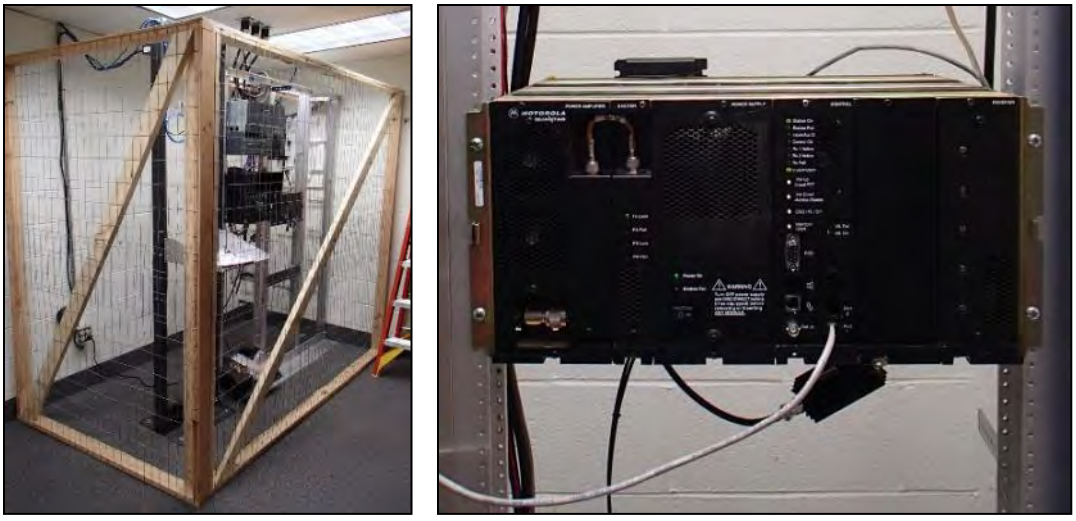


FIGURE 58
Law and Justice Site Shelter Interior and Radio Equipment

Equipment List — Paging

There is no Gallatin County 9-1-1 paging equipment at this site.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 40.

TABLE 40
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Law North	Motorola Quantar	Repeater	-48 VDC	39 watts	-119 dBm

The Law North repeater does not operate as a steered transmitter. Since the repeater's outbound coverage is highly localized within and surrounding the Law and Justice building, the repeater transmits simultaneously without simulcast synchronization.

Tower and Antenna Systems

The repeater uses separate antenna systems for receive and transmit. The receive antenna is located on a 60-foot tower that is located in the back of the building. The transmit antenna is located inside the building; the exact nature of the transmit antenna system is unknown.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 41.

TABLE 41
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Law North Receive Antenna	< -6 dB	Fail	LMR-400	60 feet	N/A	Feed line issue near the antenna.
Law North Transmit Antenna	< -8 dB	Fail	LMR-400	Indoor	Indoor	Feed line issue near the antenna.

The feed line runs exit the room through the ceiling; therefore, an assessment of the routing inside the building was not feasible.

The receive antenna feed line system was swept and measures 6.2 dB of return-loss at the receive frequency; the system sweep fails. Distance-to-fault measures show that there is an issue at the 117.5-foot length, most likely a poor transition from the feed line transition to the antenna or an issue with the antenna itself (see Figures 59 and 60).

The transmit antenna feed line system was swept and measures 8.3 dB of return-loss at the transmit frequency; the system sweep fails. Distance-to-fault measures show that there is an issue at the 67.5-foot length (see Figures 61 and 62).

The receive antenna feed line system does have a PolyPhaser lightning suppression device installed. This PolyPhaser is mounted directly on an ungrounded ground bus in an enclosed cabinet located outside the building and adjacent to the tower.

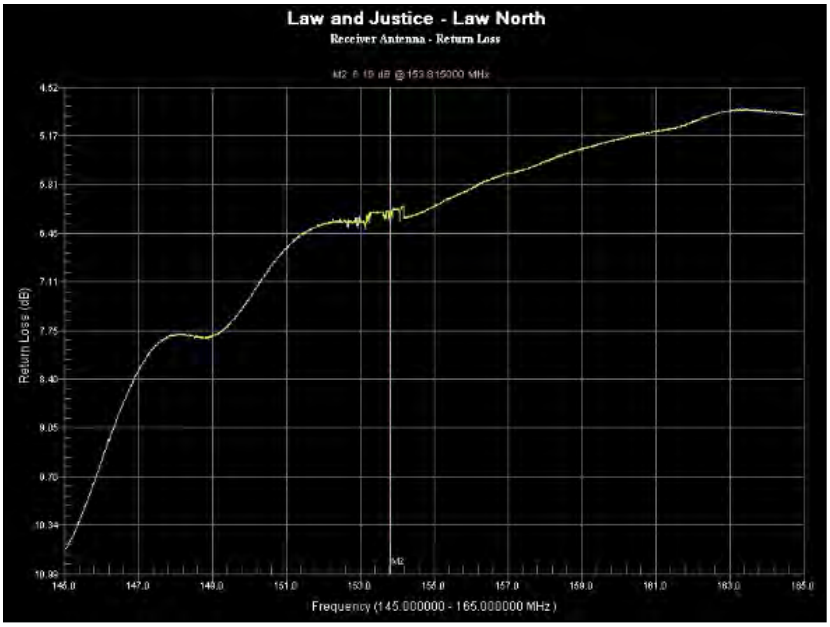


FIGURE 59
Receive Antenna Feed Line System Return-Loss

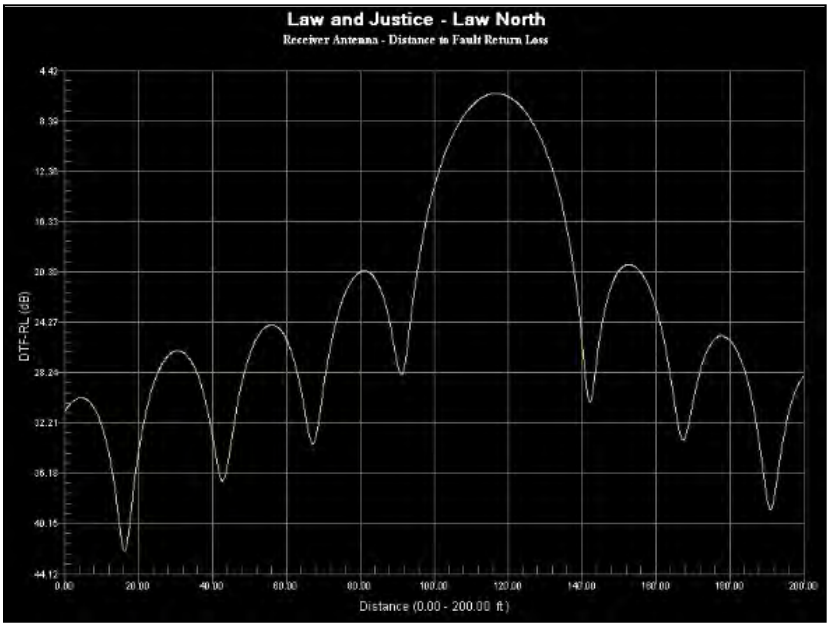


FIGURE 60
Receive Antenna Feed Line System Distance-to-Fault

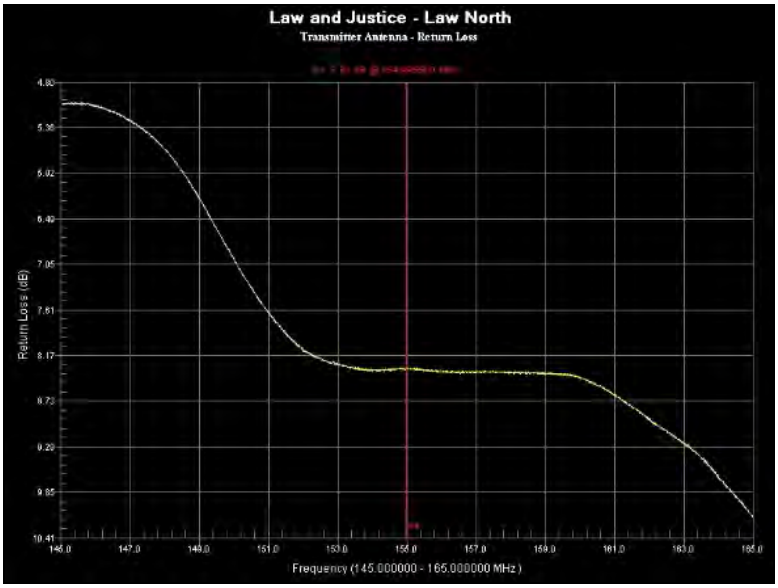


FIGURE 61
Transmit Antenna Feed Line System Return-Loss

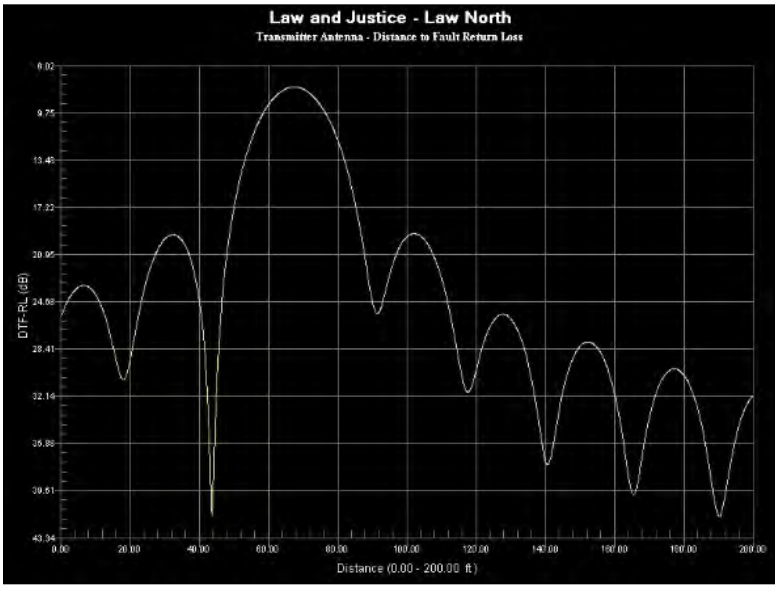


FIGURE 62
Transmit Antenna Feed Line System Distance-to-Fault

The receive antenna feed line does have a feed line ground kit at the tower base.

The transmit antenna is an indoor antenna. The antenna system type or any connections to ground was not determined.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 42.

TABLE 42
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Motorola PTP Series	Microwave	9-1-1 Center
CoastCom	Channel Bank	Local 4W E&M Connection

Site and Equipment Grounding

The site does not have a ground system.

The racks do have a ground bus, but they are not connected to a ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to a ground system.

Backup Power

The site has no battery backup or generator backup.

General Site Condition

The designated equipment area is approximately 5 feet by 7 feet and it has four 19-inch equipment racks. One of the racks is empty, the microwave rack only has two rack units of occupied space, and the remaining two racks are half empty.

The racks are not seismically restrained.

The installation practices are clean. The cables are managed well even though there are no cable management devices in place. If additional equipment were to be installed, then cable management devices should be installed.

Temperature control is by provided by the building; the location probably could not sustain a large number of high power heat generating devices.

This facility has no issues with vegetation overrun.

Recommendations

- Install a battery backup system for the microwave, repeater, and channel bank.
- Connect the PolyPhaser's ground bar to the building's ground system.
- Install a connection to the building's ground system in the equipment room. Ground all equipment after the connection has been installed.
- Seismically brace the racks.
- Verify the locations of the transmit antenna for documentation purposes.
- Further investigate the transmit antenna feed line system to determine the exact nature of its failure and remedy as necessary.
- Further investigate the receive antenna feed line system to determine the exact nature of its failure and remedy as necessary.

Montana State University

Date Visited: Wednesday, August 13, 2014
Latitude: 45° 40' 5.6" N
Longitude: 111° 3' 32.1" W
Elevation (approx.): 4,875 feet AMSL

The Montana State University radio site is located in Bozeman on the university campus, specifically in the Nelson Story Tower Apartments. The site is located on the 1600 block of West Garfield Street, Bozeman, MT 59717, and is accessible by paved roads. The site is owned by the Montana State University Housing Department.

The radio equipment is located on the top floor in a room that serves as a hallway between the elevator and roof access. Because the equipment is located on campus housing, access requires obtaining a key for the elevator from the Housing Department. The antenna support structure is the building itself, the two antennas are approximately 16 floors high (see Figure 63). The site does not have a backup generator.

FIGURE 63
Montana State University Radio Site

Gallatin County 9-1-1 is the only occupant of this site (see Figures 64 and 65).

Equipment List — Paging

There is no Gallatin County 9-1-1 paging equipment at this site.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 43.

The Motorola Quantar is specified to have a receive sensitivity of -119 dBm. Although the Police Tactical repeater does not meet the performance specifications, it should not be considered a "hard failure." Receiver performance should be monitored to ensure the site is not beginning to fail.

Tower and Antenna Systems

The antenna support structure is the building itself, which is approximately 16 floors high.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 44.

FIGURE 64
Montana State University Site Shelter Interior

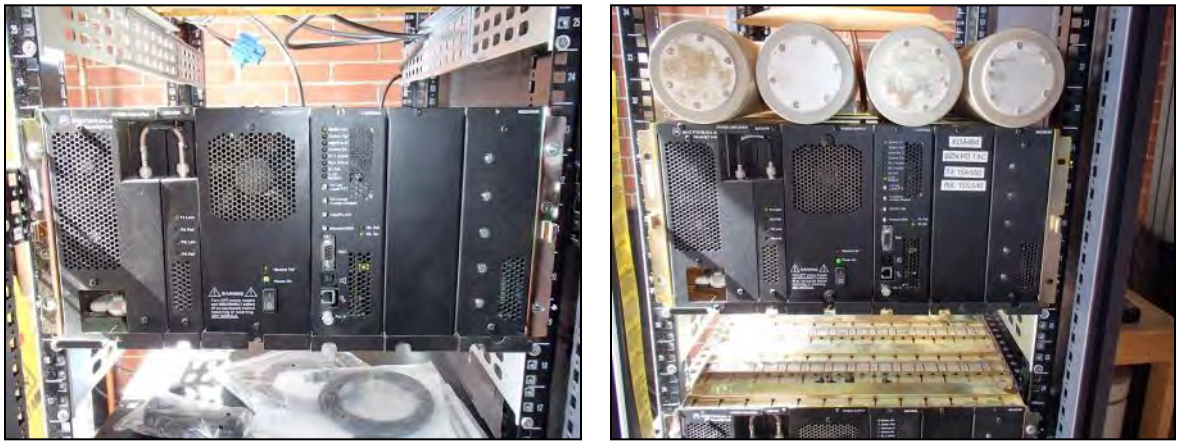


FIGURE 65
Montana State University Site Radio Equipment

TABLE 43
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Bozeman Fire	Motorola Quantar	Repeater	120 VAC	107 watts	-125 dBm
Bozeman Police Tactical	Motorola Quantar	Repeater	120 VAC	91 watts	-117 dBm

TABLE 44
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Bozeman Fire	< -17 dB	Pass	LDF4-50A	~200 feet	Roof	
Bozeman Police Tactical	< -20 dB	Ideal	LMR-400	~200 feet	Roof	Duplexer should be retuned

Each feed line run exits the room through holes drilled through the wall, not a manufactured shelter cable entry.

The Bozeman Police Tactical antenna is located near the room's northeast corner. The feed line run is unsecured as it crosses the roof and runs up the wall.

The Bozeman Police Tactical duplexer return-loss sweeps for the duplexer's transmit and receive ports show that each port has multiple resonance dips that do not match the repeater's frequencies (see Figures 66 and 67).

The Fire antenna is located above the room, near the southeast corner.

The Bozeman Fire feed line system's distance-to-fault measurement show that there is an issue at the 90-foot length, most likely a poor transition from the feed line transition to the antenna (see Figures 68 and 69).

Each antenna feed line system does have a PolyPhaser lightning suppression device installed, but they are not grounded as there is no ground system in place.

There are no feed line ground kits installed.

Space is available on the building for additional antennas.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site.

The Quantars are standalone conventional repeaters. Dispatch connects to these repeaters via control stations.

Site and Equipment Grounding

The site does not have a ground system.

The racks are not connected to a ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to a ground system.

Backup Power

Backup power is provided by a Tripp-Lite SmartPro UPS, one per repeater.

There is no generator backup at this site.

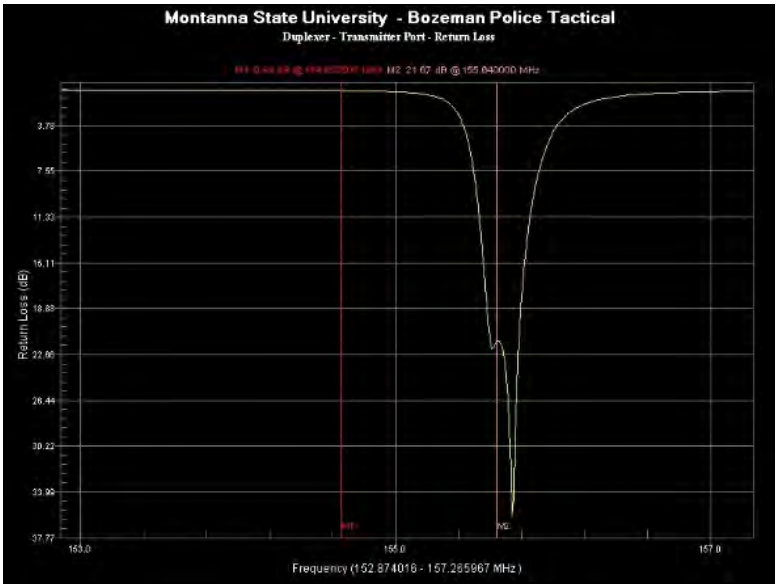


FIGURE 66
Bozeman Police Tactical Duplexer Transmit Port Return-Loss

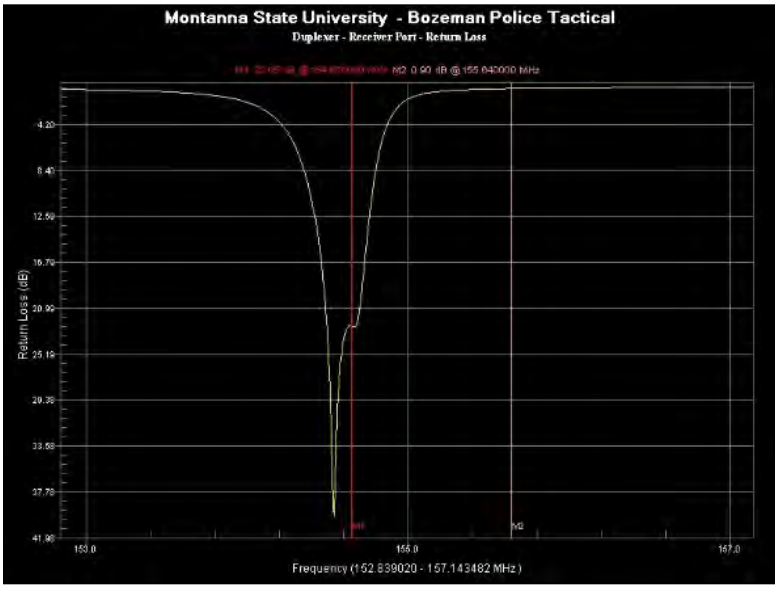


FIGURE 67
Bozeman Police Tactical Duplexer Receive Port Return-Loss

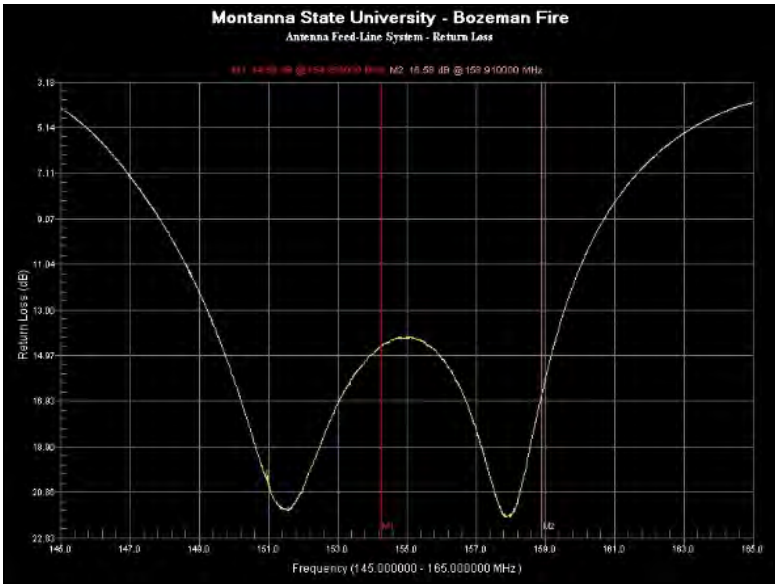


FIGURE 68
Bozeman Fire Antenna Feed Line Return-Loss

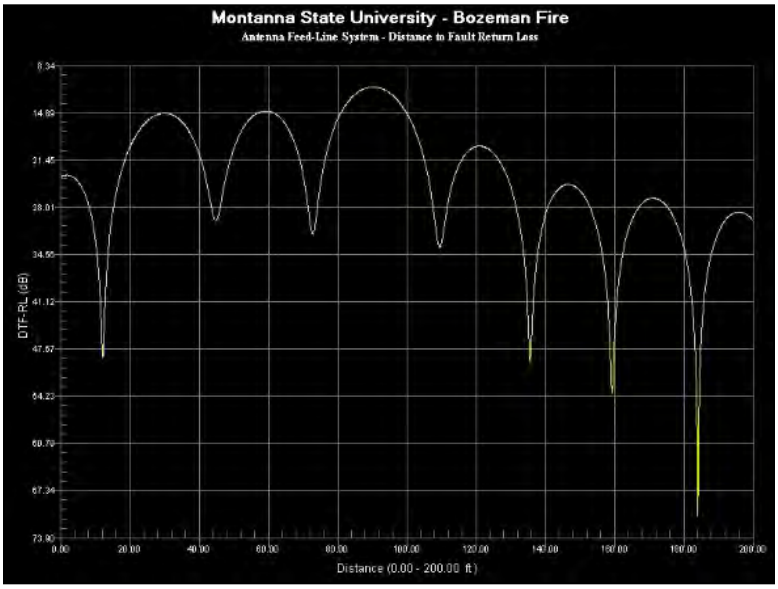


FIGURE 69
Bozeman Fire Antenna Feed Line Distance-to-Fault

General Site Condition

The equipment is located in a 6-foot by 10-foot hallway inside an enclosed cabinet. The Police Tactical duplexer is not secured inside the rack; the Fire duplexer is located in an adjacent wood cabinet.

The installation practices are clean for a hallway installation. The cables are contained within the enclosed cabinets and the feed line runs are routed against the wall.

The area has no temperature control. On the day of the site visit, the outside temperature was in the mid-60 degrees Fahrenheit range while the inside felt hot; there was no temperature gauge on site to determine the actual room temperature.

There is no generator backup for this building.

This facility has no issues with vegetation overrun.

Recommendations

- Physically secure the Police Tactical duplexer within the rack.
- Retune the Bozeman Police Tactical duplexer so that the resonance dips matches the repeater's frequency.
- Provide cable management for the Police Tactical feed line as it is routed from the building exterior to the antenna.
- Install a connection to the building's ground system in the equipment room. Ground all equipment and PolyPhasers after the connection has been installed.

Nixon Ridge

Date Visited: Friday, August 15, 2014
Latitude: 45° 57' 55.6" N
Longitude: 111° 20' 18.7" W
Elevation (approx.): 5,675 feet AMSL

The Nixon Ridge radio site is located approximately 25 miles northwest of Bozeman and is one of the northernmost sites. The site is located in a remote area and is accessible via logging and gravel roads. A four-wheel drive vehicle is necessary for access; a snowcat may be required for winter access. The site is owned by Gallatin County 9-1-1.

The approximately 11-foot by 17-foot shelter was built by L&R Communications and installed in 2006. The antenna support structure is a three-leg metal tower that is approximately 100 feet tall (see Figure 70). The site does have a backup generator.

FIGURE 70
Nixon Ridge Radio Site

Gallatin County 9-1-1 and the VHF Trunked System are the only two occupants of this site (see Figures 71, 72, and 73).

Equipment List — Paging

The paging equipment for this site is listed in Table 45.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 46.

The AstroTAC receives the UHF link from the Willow Creek radio site; the UHF link connects the Willow Creek voted Fire receiver to the Fire voter system.

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 100 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 47.

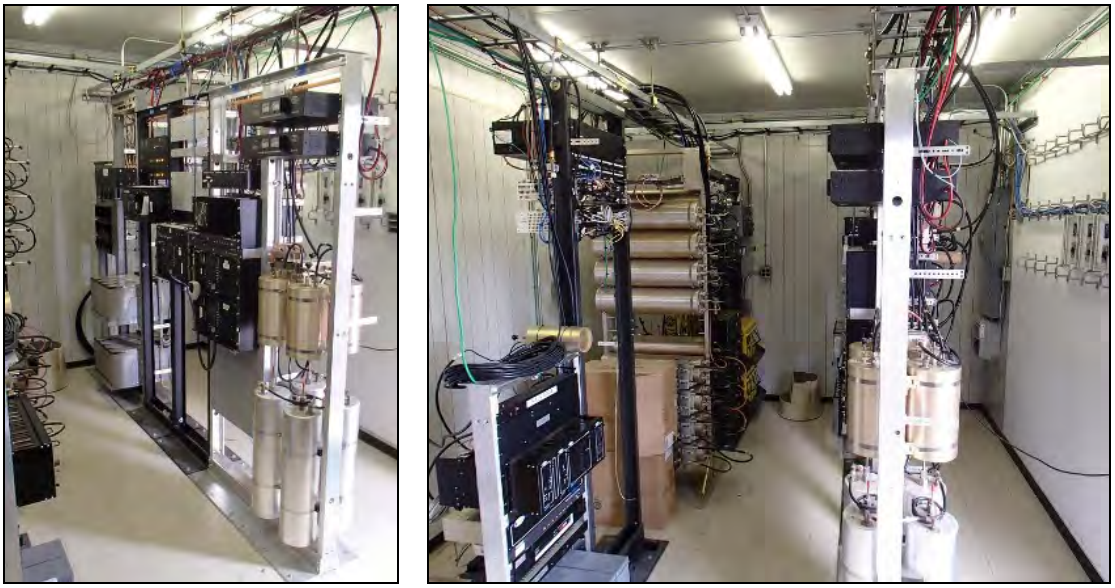


FIGURE 71
Nixon Ridge Site Shelter Interior

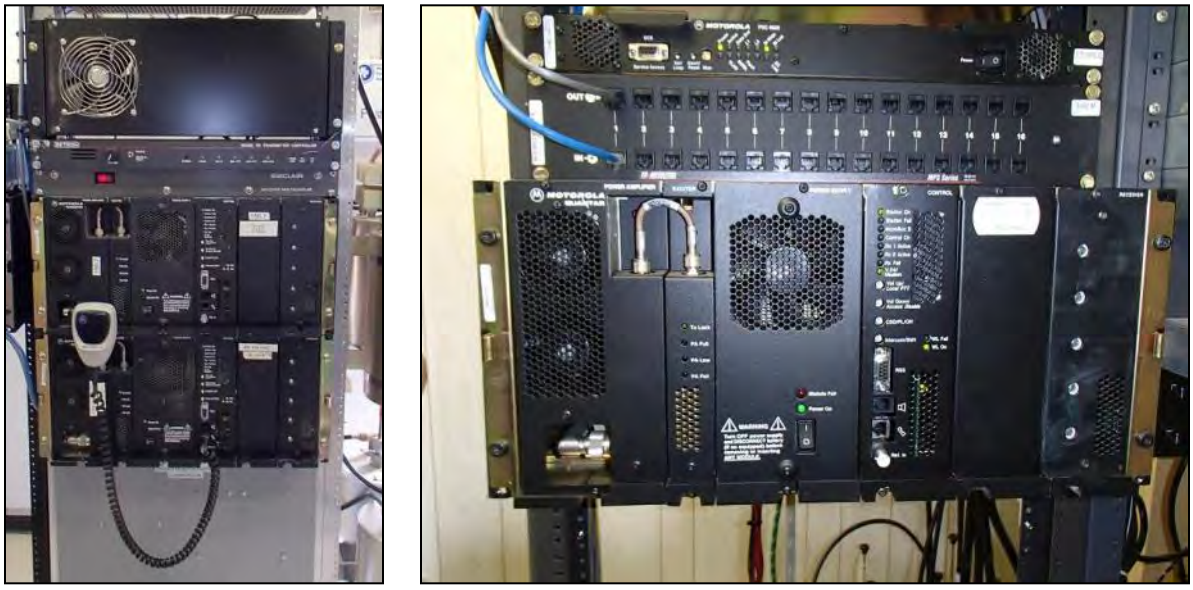


FIGURE 72
Nixon Ridge Site Radio Equipment

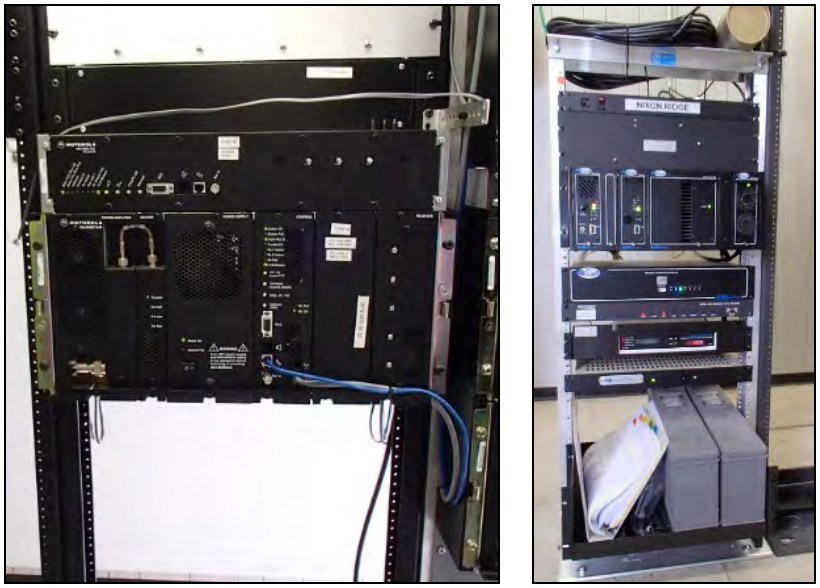


FIGURE 73
Nixon Ridge Site Radio and Paging Equipment

TABLE 45
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
DX Engineering	Paging Transmitter	12 VDC	77 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	—

TABLE 46
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Fire North	Motorola Quantar	Repeater Steered Transmitter	-48 VDC	117 watts	-125 dBm
Fire West	Motorola Quantar	Repeater	-48 VDC	96 watts	-119 dBm
Law West	Motorola Quantar	Repeater	120 VAC	94 watts	-126 dBm
Fire	Motorola AstroTAC	UHF Link Receiver	-48 VDC	—	N/A

TABLE 47
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Receiver	< -20 dB	Ideal	1-5/8-inch	70 feet	E	Notch filter should be retuned
Paging Transmitter	< -20 dB	Ideal	LMR-600	N/A	N/A	Antenna type and location not identifiable

TABLE 47 (cont.)
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Fire North Repeater Transmit	< -13 dB	Marginal	AVA-50A	N/A	N/A	One repeater using a shared antenna system
Fire North Repeater Receive	< -20 dB	Ideal	AVA-50A	N/A	N/A	One repeater using a shared antenna system
Fire West	< -18 dB	Pass	AVA-50A	60 feet	S	Duplexer should be retuned
Law West	< -18 dB	Pass	LDF4-50A	30 feet	SW	Duplexer should be retuned
Fire UHF Link Receiver	N/A	N/A	1-5/8-inch	40 feet	SW	No feed line filtering

The paging receiver connects to its antenna feed line system through an intermediate notch-pass cavity filter. The antenna is a 7-element Yagi.

The paging receiver antenna feed line system's intermediate notch-pass cavity filter was swept and the return-loss was 8.8 dB at the receive frequency; the filter resonates approximately 275 kHz below the receive frequency (see Figure 74).

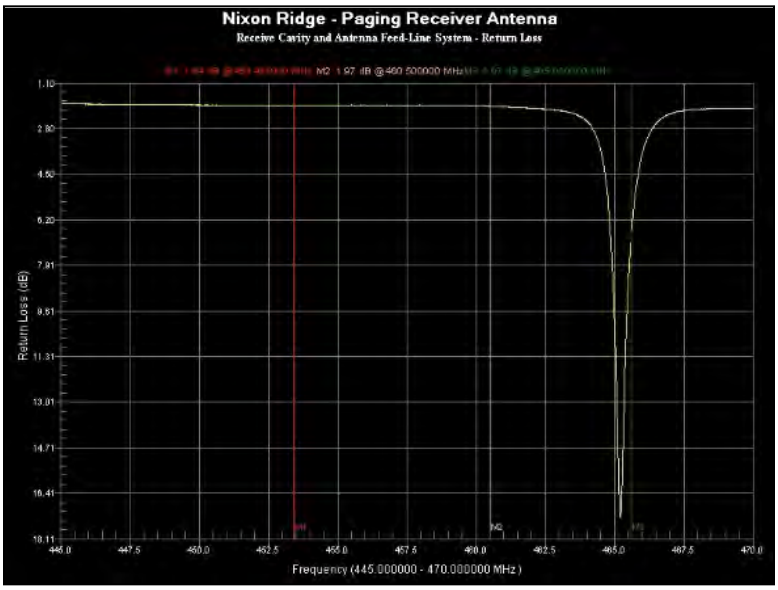


FIGURE 74
Paging Receiver Cavity Filter Return-Loss

The paging transmit antenna could not be identified without climbing the tower.

The Fire North Quantar uses a separate antenna feed line system for transmit and receive. The transmit system uses a Telewave M104-150-4TPC four-port transmitter combiner and a Telewave TWRD-150-1R receiver multicoupler. The Fire North Quantar is the only device

connected to them. The antenna locations and types could not be identified without climbing the tower.

The Fire North Transmit antenna feed line system measurements show the return-loss to be 13.8 dB at the transmit frequency; this system is marginal and should be further investigated (see Figure 75). The distance-to-fault measurement was not available for analysis.

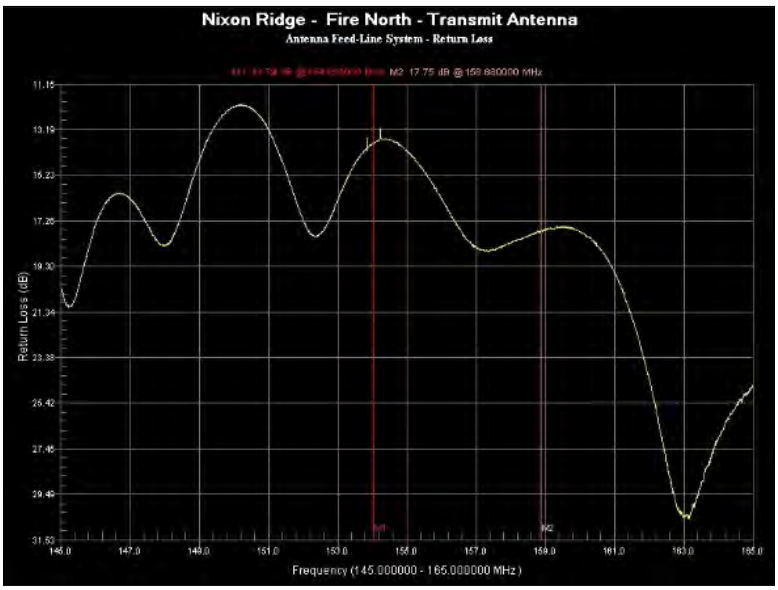


FIGURE 75
Fire North Antenna System Return-Loss

The Fire North Transmit Combiner Port was swept and the sweep shows that the cavity is resonant approximately 800 kHz above the transmit frequency (see Figure 76).

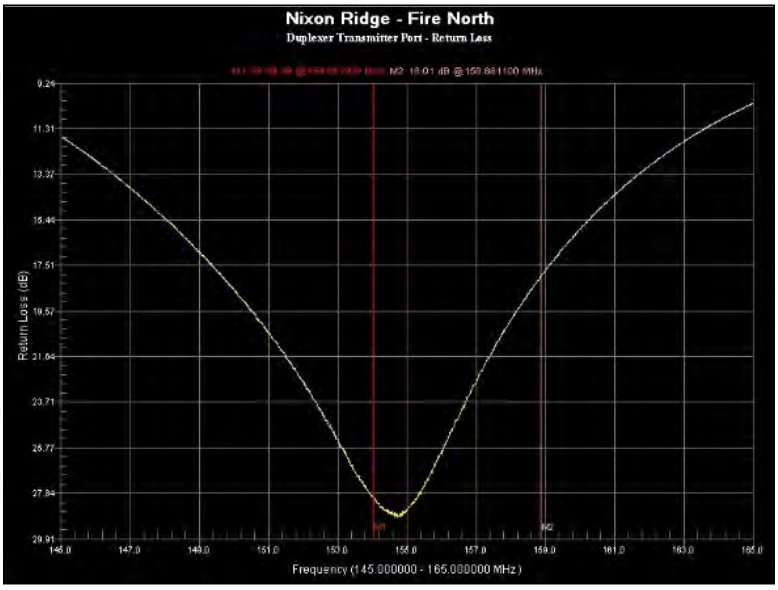


FIGURE 76
Fire North Antenna Transmits Port Return-Loss

The Fire West Quantar uses an unlabeled duplexer and an unlabeled multicoupler as part of its antenna feed line system; both of these devices share the same antenna feed line system through a T-Connector. The antenna system is also shared with Roads. The antenna is an 8-bay loop omnidirectional.

The Fire West duplexer was swept and the transmit port sweeps show that the port has a second resonance dip that is approximately 950 kHz higher than the transit frequency (see Figure 77).

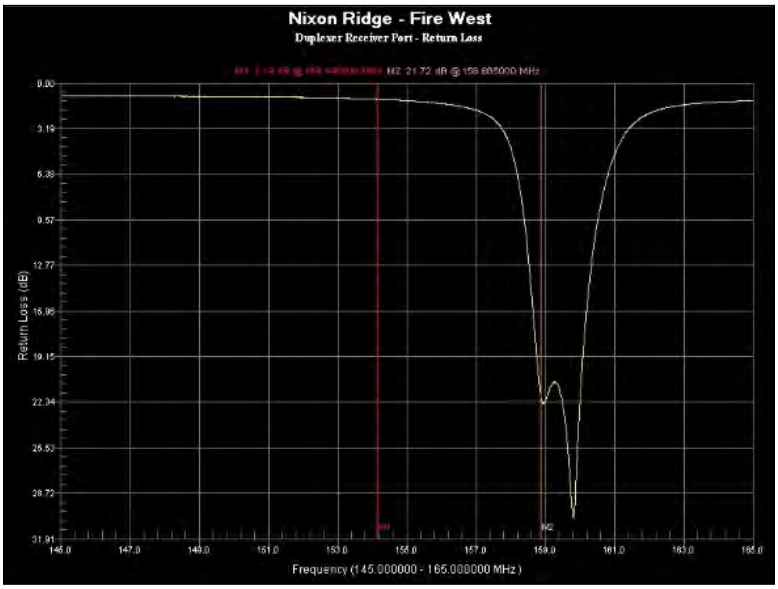


FIGURE 77
Fire West Duplexer Transmitter Port Return-Loss

The Law West Quantar uses an unlabeled duplexer as part of its antenna feed line system. The antenna is a dual loop omnidirectional.

The Law West duplexer was swept and the receive port return-loss sweeps show that the port has two resonance dips, each of which does not match the repeater's frequencies; they are approximately 50 kHz too low and 20 kHz too high (see Figure 78).

The AstroTAC UHF receiver has a direct connection to its feed line. The antenna is a 4-element Yagi pointing toward Willow Creek.

Only the Fire West antenna feed line system has a grounded PolyPhaser lightning suppression device. The other Gallatin County 9-1-1 antenna feed line systems do have an inline PolyPhaser lightning suppression device, but they are not connected to the site's ground system.

Except for Law West, all of the Gallatin County 9-1-1 antenna feed line systems have feed line ground kits.

Space is available on the tower for additional antennas.

FIGURE 78
Law West Duplexer Receiver Port Return-Loss

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 48.

TABLE 48
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Harris Stratex	Microwave	High Flats
Harris Stratex	Microwave	Montana System
Harris Intraplex	Channel Bank	T1 Connection/Drop
CoastCom	Channel Bank	Local 4W E&M Connections

Site and Equipment Grounding

The site has a master ground bus and a ground halo and rack-mounted ground bars.

Not all of the Gallatin County 9-1-1 racks are connected to the sites ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to the site's ground system.

Backup Power

Backup power is provided by batteries and a generator.

Battery backup is provided from a dedicated paging battery stack and a site battery stack.

The generator is a Generac Power System, model 949440100 generator and is rated for 75 kW.

General Site Condition

The room is approximately 11 feet by 17 feet; it has ten 19-inch equipment racks and a rack of VHF cavities. Six of the 19-inch equipment racks are on one side of the shelter and the remaining racks are on the other side. Three of the racks are at least half empty and could potentially support more equipment.

The racks are seismically restrained.

Outside of grounding, the installation practices are clean.

Temperature control is provided by a wall-mount HVAC units specifically manufactured for equipment shelters. The manufacturer label was not readable.

This facility has no issues with vegetation overrun.

Recommendations

- Ground Gallatin County 9-1-1's radio equipment and equipment racks.
- Ground Gallatin County 9-1-1's PolyPhaser lightning suppression devices to the site's ground system.
- Install and ground feed line ground kits for Law West.
- Verify the locations of the Fire North antenna for documentation purposes.
- Consider removing the Fire North transmitter combiner system since there are no other transmitters connected to it.
- Retune the paging receiver notch-pass cavity filter so that it resonates on the receive frequency.
- Retune the Law West receive port duplexer so that both resonance dips matches the repeater's receive frequency.
- Retune the Fire West receive port duplexer so that both resonance dips matches the repeater's receive frequency.
- Retune the Fire North transmit port duplexer so that both resonance dips matches the repeater's transmit frequency.
- Further investigate the Fire North transmit antenna feed line system to determine the exact nature of its failure and remedy as necessary.

Round Springs

Date Visited: Thursday, August 21, 2014
Latitude: 45° 51' 6.4" N
Longitude: 111° 48' 54.9" W
Elevation (approx.): 6,250 feet AMSL

The Round Springs radio site is the westernmost radio site and is located approximately 37 miles west of Bozeman. The site is located in a remote area and is accessible via logging and gravel roads; a four-wheel drive vehicle is necessary for access and winter access may require a snowcat. The site is owned by Crown Castle and was previously owned by AT&T.

The approximately 10-foot by 20-foot shelter was built by Thermobond. The shelter's age is unknown, but the earliest dated entry in the log book is 2000. The antenna support structure is a three-leg metal tower that is approximately 160 feet tall (see Figure 79). The site does have a backup generator.

FIGURE 79
Round Springs Radio Site

This site is occupied by ATA&T, two VHF Amateur Radio repeaters (144 MHz and 220 MHz), a UHF Amateur Radio link transmitter (440 MHz), and Gallatin County 9-1-1 paging equipment (see Figures 80 and 81).

Equipment List — Paging

The paging equipment for this site is listed in Table 49.

Equipment List — Radio

There is no Gallatin County 9-1-1 radio equipment at this site.

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 160 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 50.

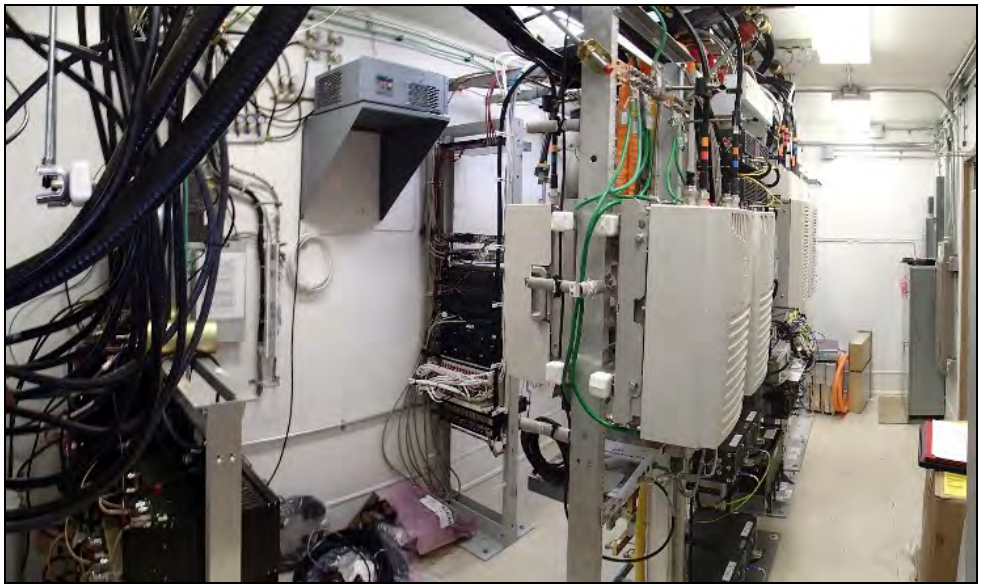


FIGURE 80
Round Springs Shelter Interior

FIGURE 81
Round Springs Site Racks and Paging Equipment

TABLE 49
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
DX Engineering	Paging Transmitter	12 VDC	109 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	—

TABLE 50
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Receiver	< -20 dB	Ideal	LMR-400	60 feet	SE	
Paging Transmitter	< -20 dB	Ideal	AVA5-50A	15 feet	SE	

The paging system uses two separate antenna feed line systems for transmit and receive.

The receive antenna feed line system has an inline UHF filter, labeled with "465.500" and "3-1128." The antenna is a 7-element Yagi.

The receive antenna feed line run up the tower is not taut and is secured via nylon tie-wraps.

The transmit antenna is a 6-foot omnidirectional.

Both systems have inline PolyPhaser lightning suppression devices installed and each are connected to the master ground bus.

Neither system has a feed line ground kit installed at the shelter exterior nor at the tower base.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site.

Paging control is received from the UHF paging repeater at High Flats.

Site and Equipment Grounding

The equipment room does have a master ground bus and ground halo.

The rack is connected to the site's ground system.

The individual pieces of Gallatin County 9-1-1's equipment are not connected to the site's ground system.

Backup Power

Backup power is provided by batteries and a generator.

Battery backup power is provided from a dedicated battery stack on the bottom of the rack. There is also a battery stack within the shelter.

The generator is a Generac Power System, model 99A08790-S generator and is rated for 35 kW.

General Site Condition

The designated equipment area is approximately 10 feet by 20 feet with 11 equipment racks, not including the DC Plant or AT&T cabinet. Gallatin County 9-1-1 has one full-sized rack and one half rack that are adjacent to each other. The paging equipment is installed in the half rack; the full-sized rack is occupied by the unused legacy equipment.

The racks are not seismically restrained.

The installation practices are clean.

Temperature control is provided by two Bard wall-mount HVAC units.

This facility has no issues with vegetation overrun.

Recommendations

- Remove unused legacy equipment.
- Install feed line ground kits for both the transmit and receive antenna feed line systems at both the shelter exterior and at the tower base.
- Tighten the receive feed line run along the tower so that it is taut.
- Secure the receive feed line run with stainless steel feed line mounting hardware.
- Seismically brace the racks.

Timberline

Date Visited: Wednesday, August 13, 2014
Latitude: 45° 39' 31.9" N
Longitude: 110° 48' 25.1" W
Elevation (approx.): 6,175 feet AMSL

The Timberline radio site is located approximately 11 miles east of Bozeman and is the eastern-most site. The site is located in a remote area and is accessible via logging and gravel roads; a four-wheel drive vehicle is necessary for access and a snowcat may be required during winter snowfall. The site is owned by Gallatin County 9-1-1.

The shelter was built by Trachte and is divided into two rooms. The equipment room is approximately 11 feet by 13 feet and the generator room is approximately 5 feet by 11 feet. The antenna support structure is a three-leg metal tower that is approximately 180 feet tall (see Figure 82). The site does have a backup generator.

FIGURE 82
Timberline Radio Site

Gallatin County 9-1-1 and the VHF trunked system are the only two occupants of this site (see Figures 83 and 84).

Equipment List — Paging

The paging equipment for this site is listed in Table 51.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 52.

This site also is a VHF trunked site.

FIGURE 83
Timberline Site Radio Shelter Interior

FIGURE 84
Timberline Site Radio and Paging Equipment

TABLE 51
Paging Equipment Inventory

Manufacturer and Model	Function	Power	Measured Transmit Power
DX Engineering	Paging Transmitter	12 VDC	95 watts
Zetron Model 620	Wireless Data Encoder	12 VDC	—

TABLE 52
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Fire North	Motorola Quantar	Repeater Steered Transmitter	-48 VDC	117 watts	-127 dBm
Fire East	Motorola Quantar	Repeater	-48 VDC	106 watts	-127 dBm

Tower and Antenna Systems

The antenna support structure is a three-leg metal tower that is approximately 180 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 53.

TABLE 53
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Paging Transmitter	< -20 dB	Ideal	AVA-50A	N/A	N/A	Antenna not identifiable
Paging Receiver	< -20 dB	Ideal	LMR-400	N/A	N/A	Antenna not identifiable
Fire North + Fire East Repeater Transmit	< -20 dB	Ideal	AVA-50A	80 feet	NW	Shared antenna system Cavities should be retuned
Fire North + Fire East Repeater Receive	< -18 dB	Pass	AVA-50A	N/A	N/A	Shared antenna system antenna not identifiable

The paging system uses two separate antenna feed line systems for transmit and receive.

The paging transmit antenna could not be identified without climbing the tower; it is believed to be a 3-foot omnidirectional at the 140-foot or 160-foot level of the tower.

The paging receiver connects to its antenna feed line system through a notch-pass cavity filter. The antenna could not be identified without climbing the tower; it is believed to be a Yagi.

The transmit antenna system is shared between Fire North and Fire East via a Telewave M104-150-4TPC combiner. The antenna is a 20-foot omnidirectional.

The ports of the transmitter combiner were also swept and shows that the Fire North port resonates approximately 660 kHz below its transmit frequency and Fire East port resonates approximately 625 kHz above its transmit frequency (see Figures 85 and 86).

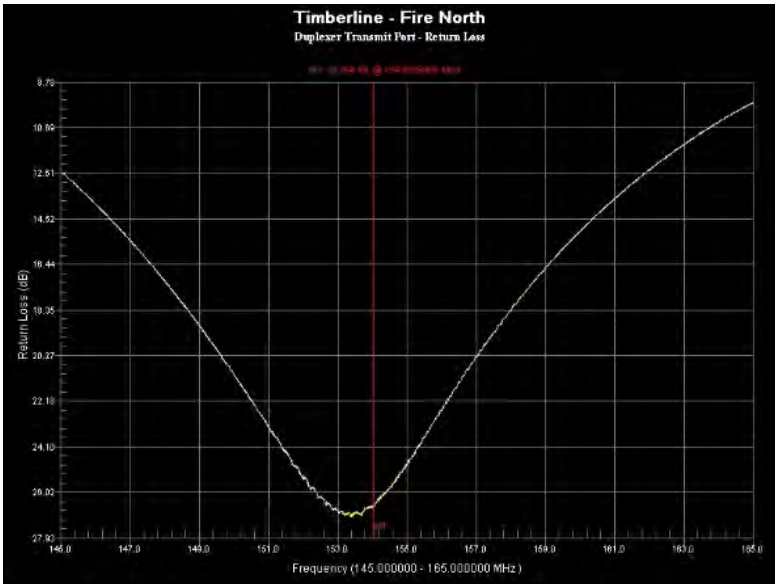


FIGURE 85
Fire North Duplexer Transmit Port Return-Loss

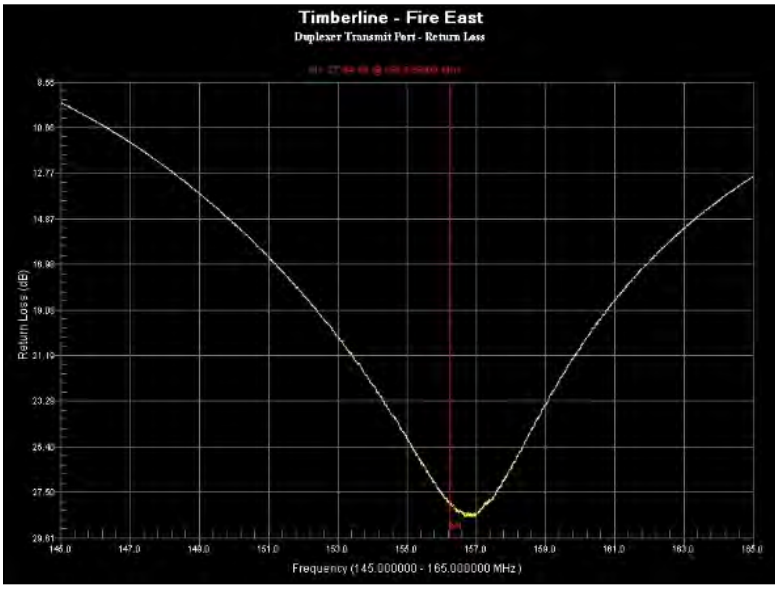


FIGURE 86
Fire East Transmit Port Return-Loss

The receive antenna system is shared between Fire North and Fire East via a Telewave TPCP-1544C Filter and a Telewave TWR8-150-1R multicoupler. The antenna could not be identified without climbing the tower; it believed to be an omnidirectional located at the 120-foot level.

The shared Fire receive antenna feed line system has an intermediate band pass filter before connecting to the receiver multi-coupler. The filter has a pass band from 157.650 MHz

to159.950 MHz; any additional channels that may be added would need to operate within these limits.

The paging receiver antenna feed line system connects to the paging receiver via an intermediate notch-pass cavity filter. The filter was swept and the return-loss show that the filter resonates approximately 200 kHz below the receive frequency (see Figure 87).

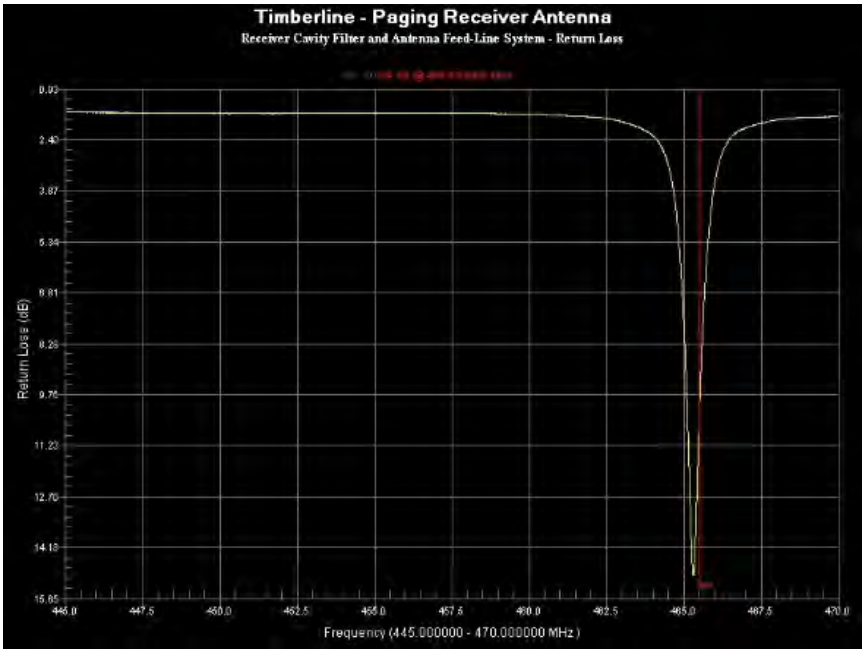


FIGURE 87
Paging Receiver Cavity Filter Return-Loss

All the antenna feed line systems have a PolyPhaser lightning suppression device installed and they are connected to the master ground bus via a 12-gauge wire.

The paging transmitter feed line has a feed line ground kit installed at the shelter exterior. The other antenna systems do not have a feed line ground kit installed at the shelter exterior. There are no feed line ground kits installed at the tower base.

Space is available on the tower for additional antennas.

Equipment List — Microwave and Intersite Connections

The Gallatin County 9-1-1 microwave and channel bank equipment for this site is listed in Table 54.

TABLE 54
Microwave and Channel Bank Equipment Inventory

Equipment	Function	Target Location/Purpose
Aviat Eclipse	Microwave	High Flats
Harris Intraplex	Channel Bank	T1 Connection/Drop
CoastCom	Channel Bank	Local 4W E&M Connections

Additional four-wire wire-line circuits for potential future equipment may be possible; the available capacity needs to be verified.

Site and Equipment Grounding

There is a master ground bus and a ground halo.

Gallatin County 9-1-1's racks are grounded.

Only the Fire North Quantar is connected to ground; the rest of Gallatin County 9-1-1's radio equipment is not.

Backup Power

Backup power is provided by batteries and a generator.

Battery backup power is provided from a battery stack.

The on-site generator's manufacturer, model, and rating were not recorded.

The generator is a Generac Power System, model 9494450100 generator, and is rated for 35 kW.

General Site Condition

The equipment room is approximately 11 feet by 13 feet and has six 19-inch equipment racks. One of the racks is half empty and there is space to install one additional rack.

The racks are not seismically restrained.

The installation practices are clean.

Temperature control is provided by a wall-mount HVAC unit specifically manufactured for equipment shelters. The manufacturer label was not readable.

This facility has no issues with vegetation overrun.

Recommendations

- Bond the VHF trunked system and its PolyPhaser to site ground.
- Ground the PolyPhasers with a 6-gauge or larger wire.
- Install feed line ground kits at the tower base and at the shelter entry.
- Bond the Fire West repeater and the paging equipment to site ground.
- Seismically brace the racks.
- Verify the locations of the antennas for documentation purposes.
- Retune the Fire North transmit cavity and the Fire East transmit cavity to resonate at their appropriate frequencies.
- Tune the paging's receiver notch-pass filter so that it resonates on the receive frequency.

Willow Creek

Date Visited: Friday, August 15, 2014
Latitude: 45° 49' 38.1" N
Longitude: 111° 38' 43.2" W
Elevation (approx.): 4,150 feet AMSL

The Willow Creek Ridge radio site is located approximately 30 miles west of Bozeman and 6 miles southwest from the town of Three Forks. The site is located at 107 Main, Willow Creek, MT 59760, and is accessible by paved roads. It is owned by the Willow Creek Rural Fire District.

The radio equipment is located in a storage area of Station 1. The antenna support structure is the roof of the building (see Figure 88). The site does not have a backup generator.

FIGURE 88
Willow Creek Radio Site

Gallatin County 9-1-1 is the only occupant in the storage room. The room is approximately 10 feet by 16 feet. This site serves as a voted receiver for Fire and is installed in a Motorola CompaCabinet (see Figures 89 and 90). This site differs from the other sites in that it uses a UHF radio link to transport the received audio.

Equipment List — Paging

There is no Gallatin County 9-1-1 paging equipment at this site.

Equipment List — Radio

The Gallatin County 9-1-1 radio equipment for this site is listed in Table 55.

The voted receiver audio is transported to Nixon Ridge via a UHF link (458.300 MHz). The Quantar contains both the VHF Fire receiver and the UHF link transmitter. The UHF link's transmit measurement is recorded in Table 55.

Tower and Antenna Systems

The antenna support structure is the roof of the fire station, approximately 30 feet tall.

The Gallatin County 9-1-1 antenna systems for this site are listed in Table 56.

FIGURE 89
Willow Creek Site Equipment Location

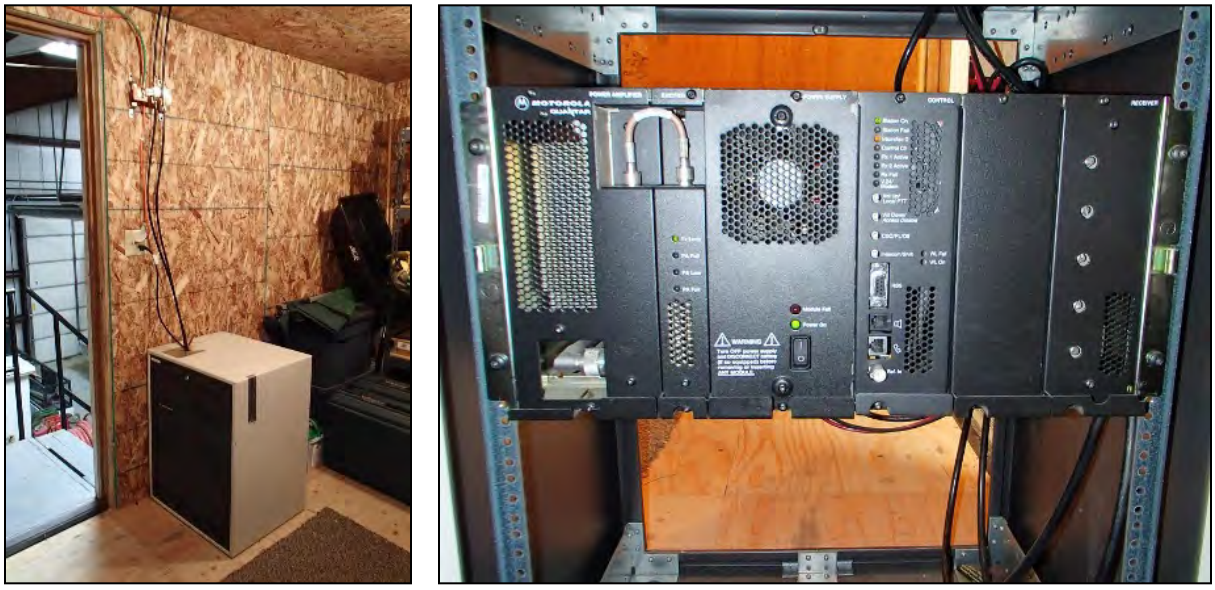


FIGURE 90
Willow Creek Site Radio Equipment

TABLE 55
Radio Equipment Inventory

Channel	Equipment	Function	Power	Measured Transmit Power	Measured Receiver Sensitivity
Fire	Motorola Quantar	Voted Receiver	120 VAC	12.5 watts	-127 dBm

TABLE 56
Antenna System and Performance

Channel	Return-Loss	Performance Status	Feed Line Type	Antenna Height	Tower Leg	Notes
Fire	< -14 dB	Pass	LMR-400	~35 feet	Roof	None
UHF Link	< -20 dB	Ideal	LMR-400	~30 feet	Roof	None

The Quantar does not use a duplexer because transmit and receive occur in separate bands. Separate antenna feed line systems are used for VHF receive and UHF transmit. The feed line runs exit the room through the ceiling.

The VHF receive antenna is a 20-foot VHF omnidirectional.

The Fire receive antenna feed line sweep of the results in a return-loss of 14.5 dB at the receive frequency; the system passes and is functional. Distance-to-fault measures show that there is an issue at the 101.5-foot length (see Figures 91 and 92).

The transmit antenna is a 3-element UHF Yagi mounted below the VHF antenna.

Both antenna feed line systems have a PolyPhaser lightning suppression device installed. Each PolyPhaser is mounted directly on the ground bus.

The antenna systems do not have a feed line ground kit at the building entry or at the antenna base.

Space is available on the station's roof for additional antennas.

Equipment List — Microwave and Intersite Connections

There is no Gallatin County 9-1-1 microwave equipment at this site.

The voted receiver audio is transported to Nixon Ridge via a UHF link (458.300 MHz). The UHF signal is received at Nixon Ridge and then routed to the Fire channel voter over microwave.

Site and Equipment Grounding

There is a ground bus above the CompaCabinet. It is unknown to what ground system the ground bus connects to.

The CompaCabinet is not connect to the ground system.

The Quantar is not connected to the ground system.

Backup Power

Backup power is provided by a 12 VDC battery backup that sits unsecured and open behind the CompaCabinet.

There is no generator backup for this building.

General Site Condition

The storage room is approximately 10 feet by 16 feet. The CompaCabinet is the only communication installation in the room. The remainder of the room is occupied by storage shelves and storage bins. Space is available for additional racks if the storage shelves and storage bins were removed.

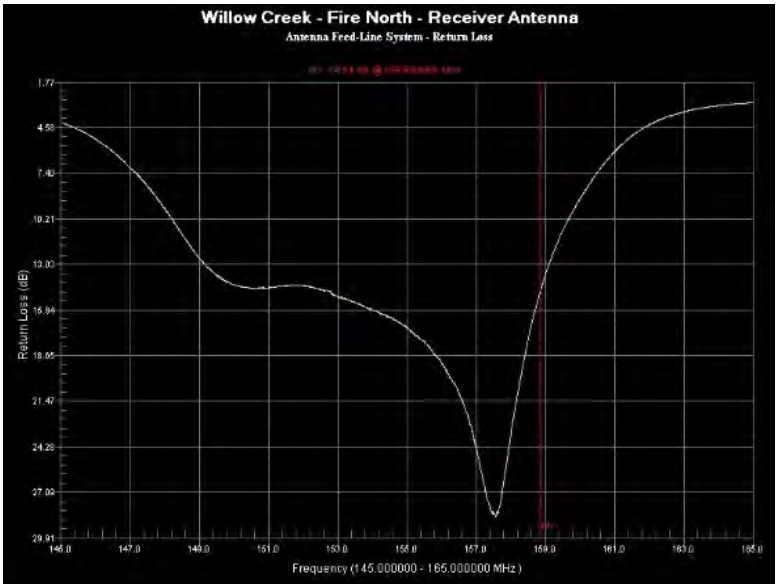


FIGURE 91
Antenna Feed Line System Return-Loss

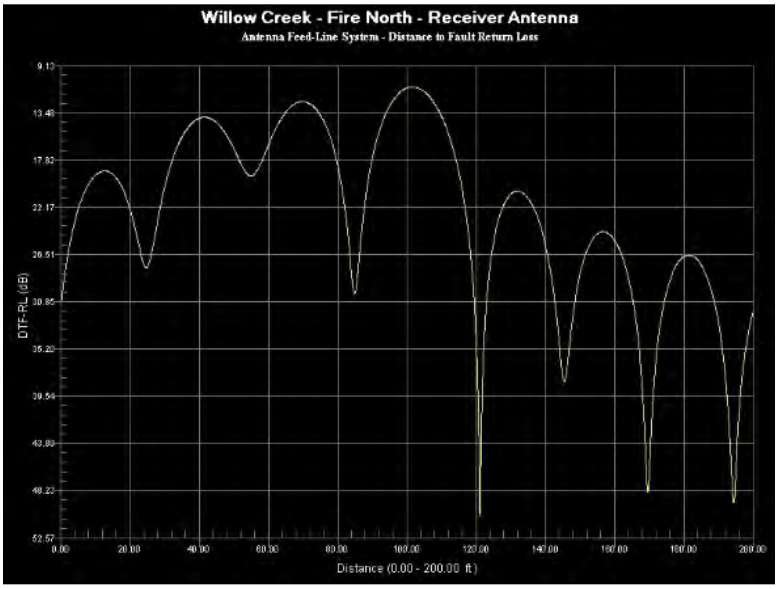


FIGURE 92
Antenna Feed Line System Distance-to-Fault

The CompaCabinet is not seismically braced.

The installation practices are clean. If additional equipment were to be installed, then cable management devices would need to be installed.

There is no temperature control within the room.

This facility has no issues with vegetation overrun as it is located in a populated town.

Recommendations

- Connect the Quantar to the master ground bus.
- Physically secure the CompaCabinet.
- Install the battery backup in a physically secure ventilated cabinet. It should be physically secured so that the DC wiring will not inadvertently be pulled on. It should be installed in a structure so that the terminals are not exposed.
- Further investigate the receiver antenna feed line system to determine the exact nature of the issue at the 101.5-foot length and remedy as necessary.

Potential New Site for Horse Butte

Horse Butte is a paging only site with a 150-foot tower that is located approximately 8 miles northwest of West Yellowstone. The shelter is shared with other occupants. The site ownership was not determined during the site visit.

Installation practices are generally poor with no easily accessible ground system, no backup generator, and no shelter cooling system.

Adjacent to the Horse Butte shelter is an AT&T Wireless shelter; it has a cell site reference number MTU2814 and the posted telephone contact is 800-638-2822. Both shelters are enclosed in the same fence and share the same tower. The amount of available space within the AT&T Wireless shelter is unknown.

Approximately 100 feet to the east is another shelter that is owned by Teton Communications, Inc., with a reference of HEB012001 and a posted telephone contact number of 208-522-0750. The shelter has a mostly empty 100-foot tower and it is also enclosed in the same fence as Gallatin County 9-1-1's shelter and AT&T Wireless' shelter. The amount of available space within the Teton Communications, Inc., shelter is unknown.

Potential Additional Site for Round Springs

Round Springs is a paging only site with a 160-foot tower; it is the westernmost radio site within Gallatin County 9-1-1 Network. The site is owned by Crown Castle and is shared with other occupants.

The installation practices are generally clean with limited space for additional equipment.

There are two facilities in close proximity to this site that may be available for future installations. One is approximately 150 feet southwest of the current facility (45° 51' 5.11"N, 111° 48' 56.26"W) and the other is approximately 800 feet southwest (45° 50' 59.25"N, 111° 48' 59.43"W). The owners of these facilities were not identified during the site visit.

The amount of space within each shelter is unknown. Each tower appears to have space for additional antennas.

Potential Additional Site for Willow Creek

Willow Creek is a voted receiver site at the Willow Creek Fire Station with an antenna height of approximately 35 feet. This site is located approximately 7 miles southwest of Three Forks. As such, the up-link coverage into Three Forks is poor and could be improved.

There is a cell tower that is located approximately 1 mile southeast from the town of Three Forks (45° 52' 38.5" N, 111° 32 '4.6" W). Installation of equipment at this site would improve radio coverage into Three Forks. Gallatin County 9-1-1 has expressed interest in installing equipment at this site if possible.

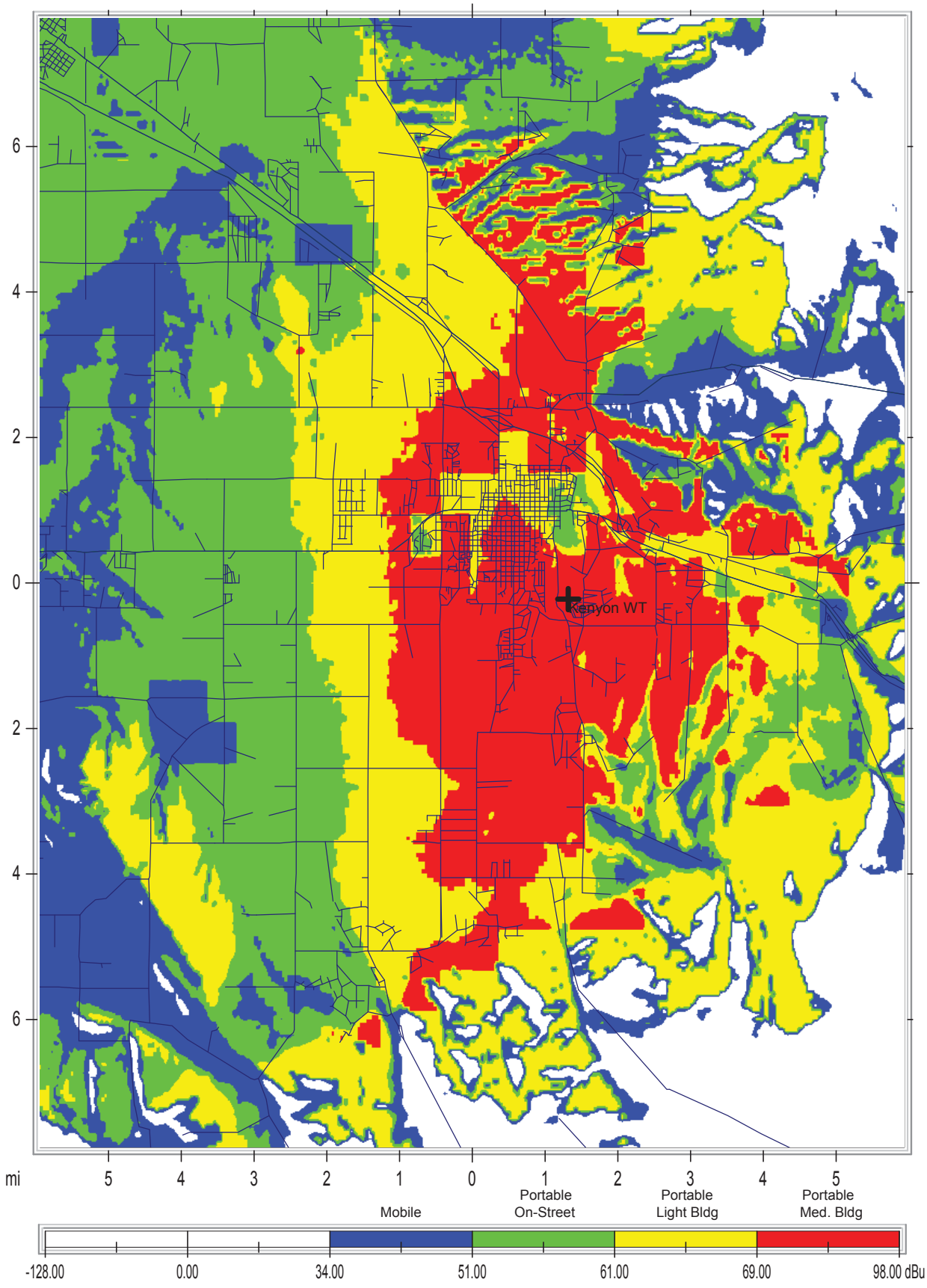
The cell tower was view from a distance. The site contact information typically posted on a site's shelter or security fence was not obtained. The size of the shelter or the amount of space available for additional equipment is unknown. The tower's available space is unknown. A site visit is needed to obtain the information.

A search on the FCC ULS website show the cell site has 41 active licensees and 151 active call signs associated with it; included in these results were AT&T, Cingular Wireless, T-Mobile, and Verizon Wireless.

Summary

The existing radio sites used to support Gallatin County's public safety voice dispatch systems and alphanumeric paging system visited and evaluated by ADCOMM reveal a wide variety of conditions. In some cases, sites are generally in adequate condition, while in others site improvements will be required to adequately support an upgraded system. In cases where existing equipment or antenna systems were found to be faulty, Gallatin County was immediately notified so corrective actions could be taken.

Appendix A
Existing System
Coverage Predictions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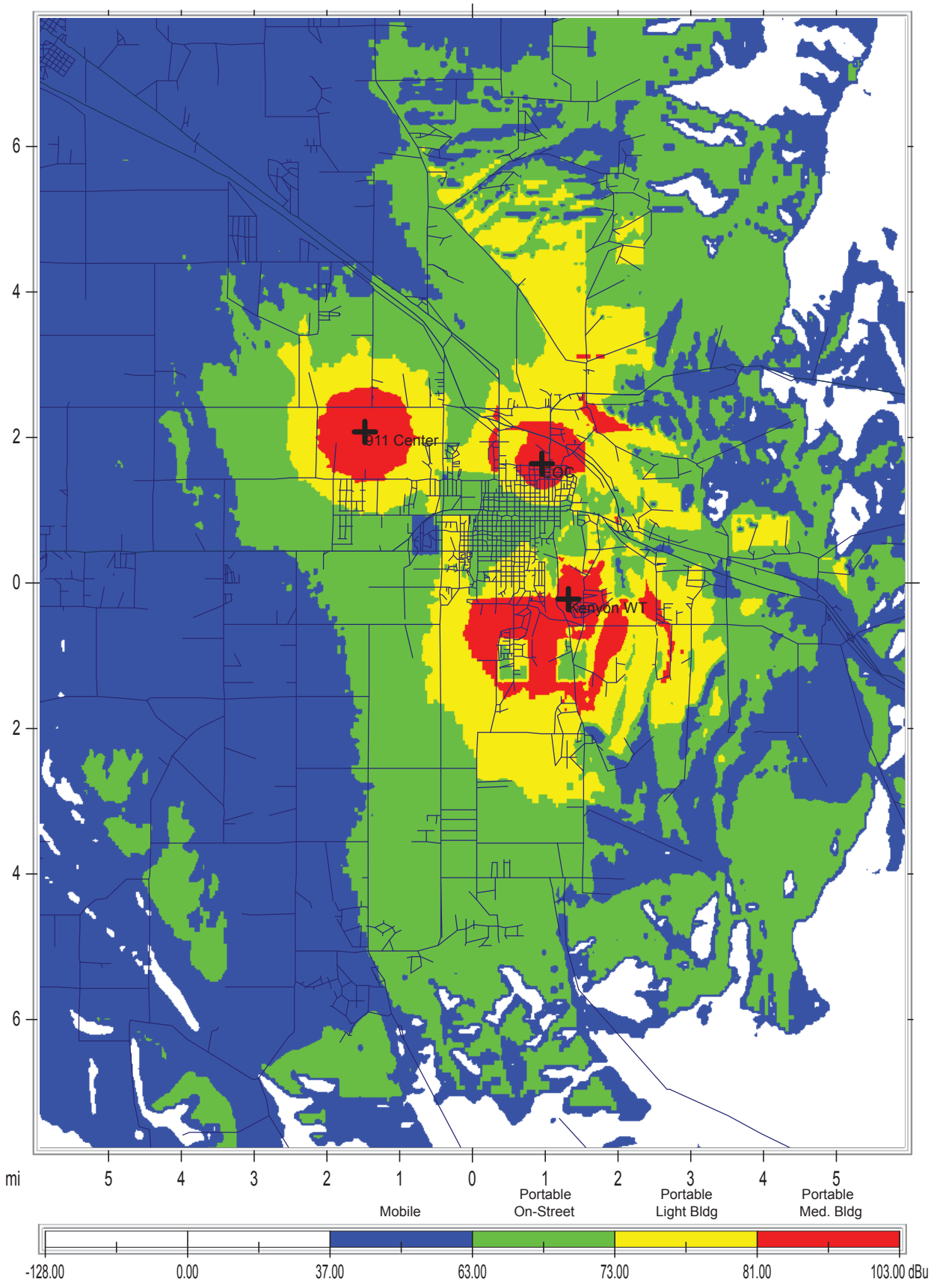
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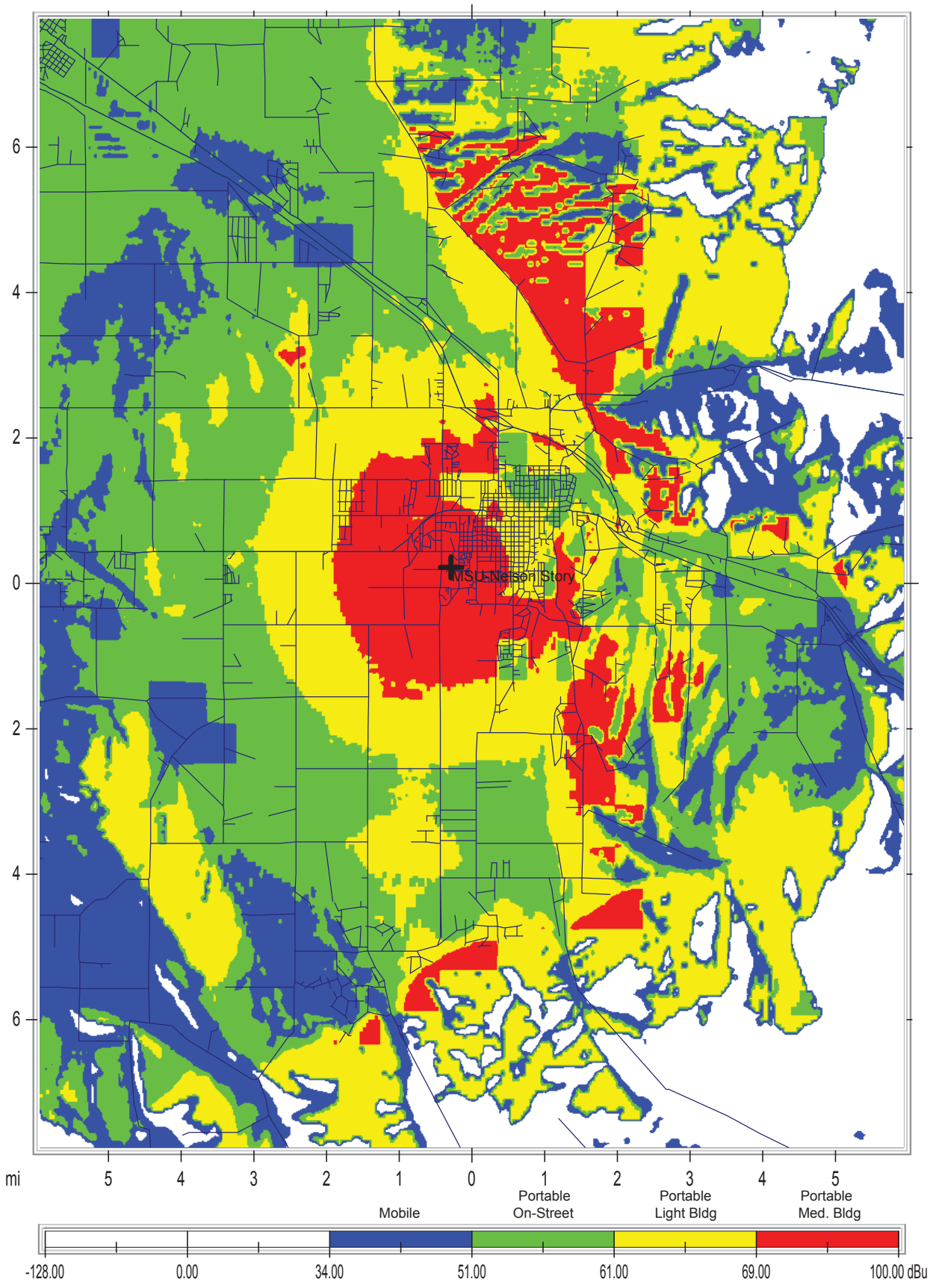
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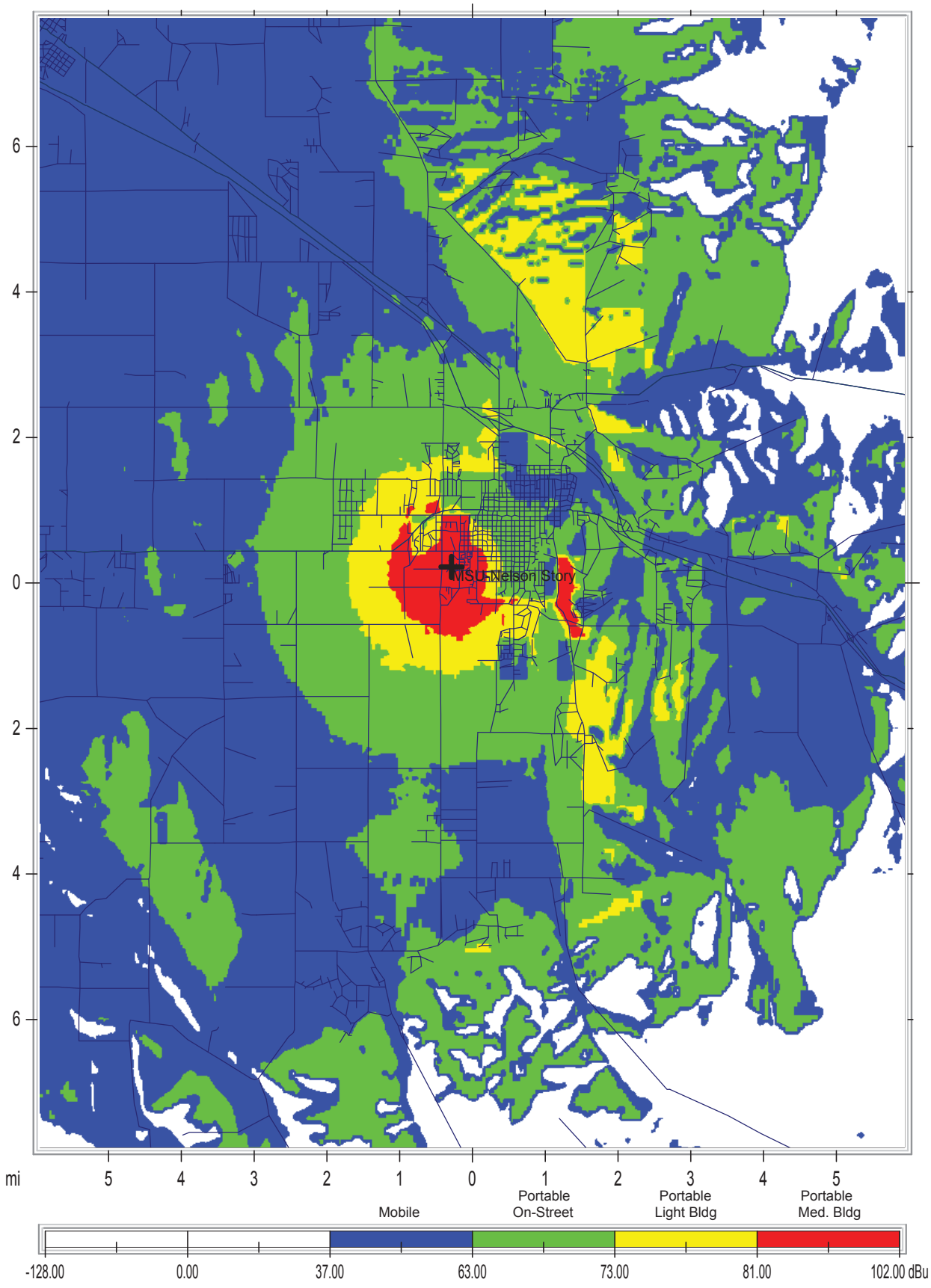
MSU-Nelson Story
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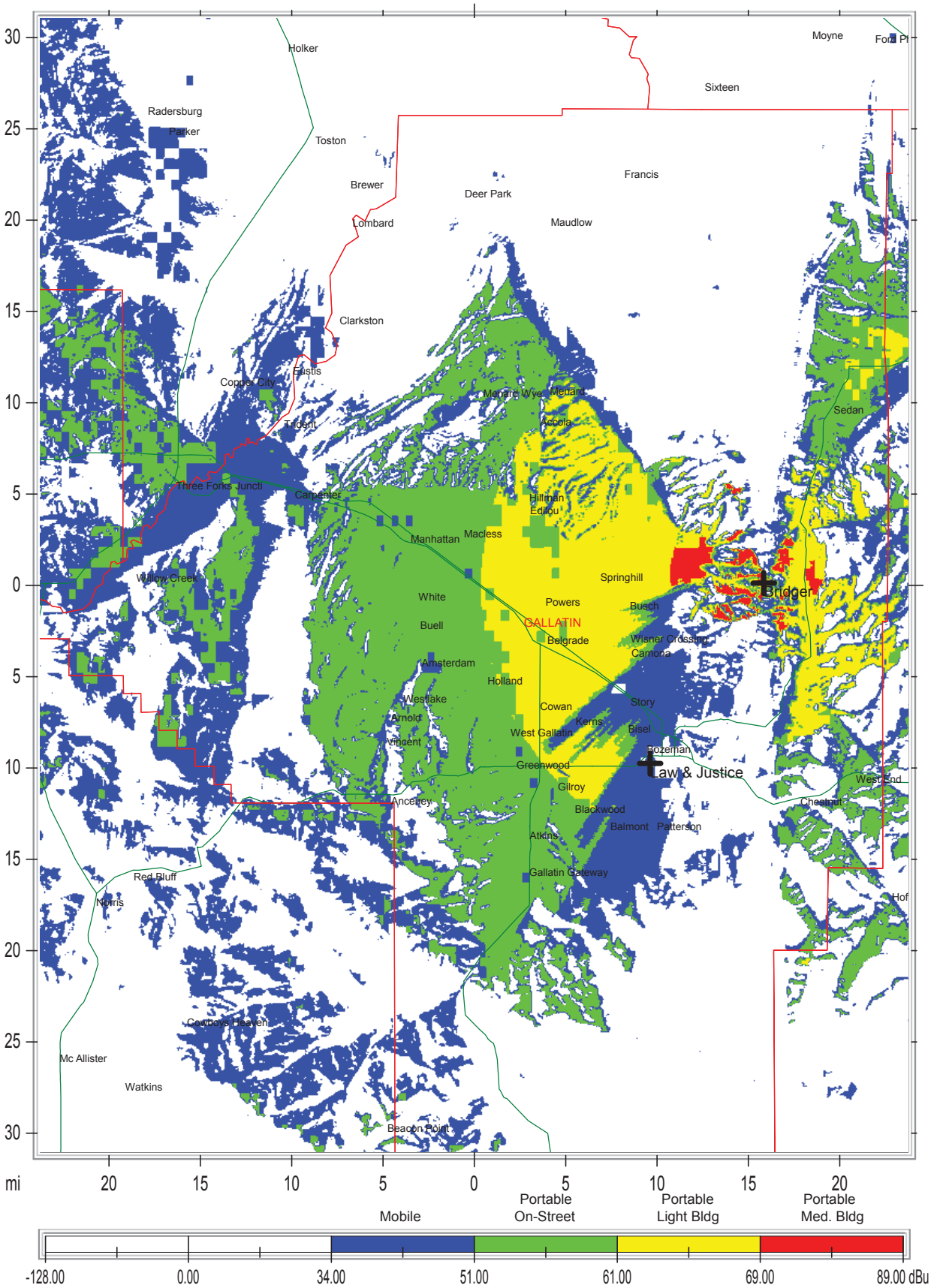
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Carpenter
Hillman
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Macless
Willow Creek
Springhill
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GALLATIN
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Camoca
Amsterdam
Holland
Westlake
Cowan
Story
Arnold
Kerns
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Greenwood
Law & Justice
Gilroy
West End
Ancency
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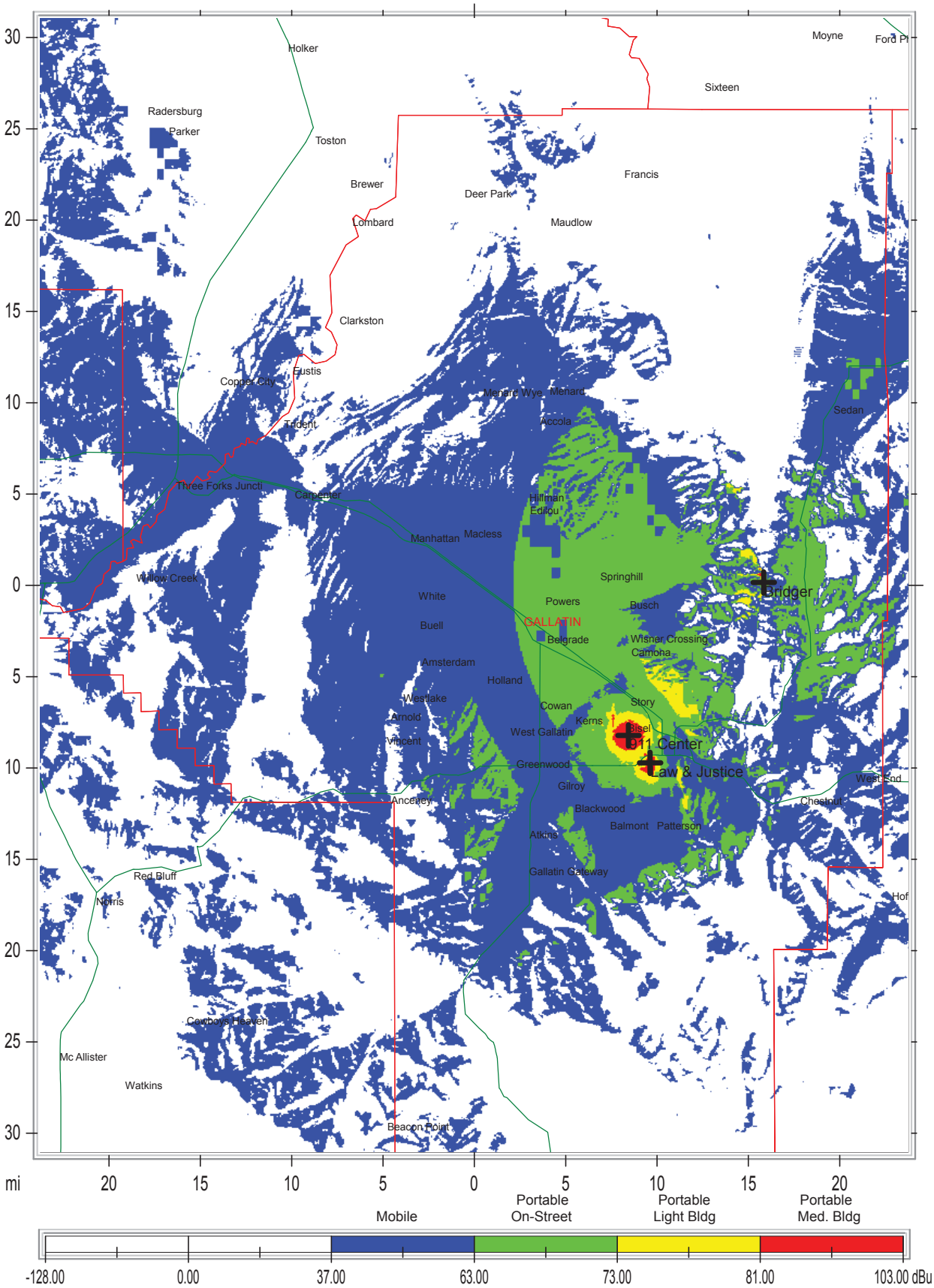
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Arnold
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Vincent
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Law & Justice
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West End
Gilroy
Ancelley
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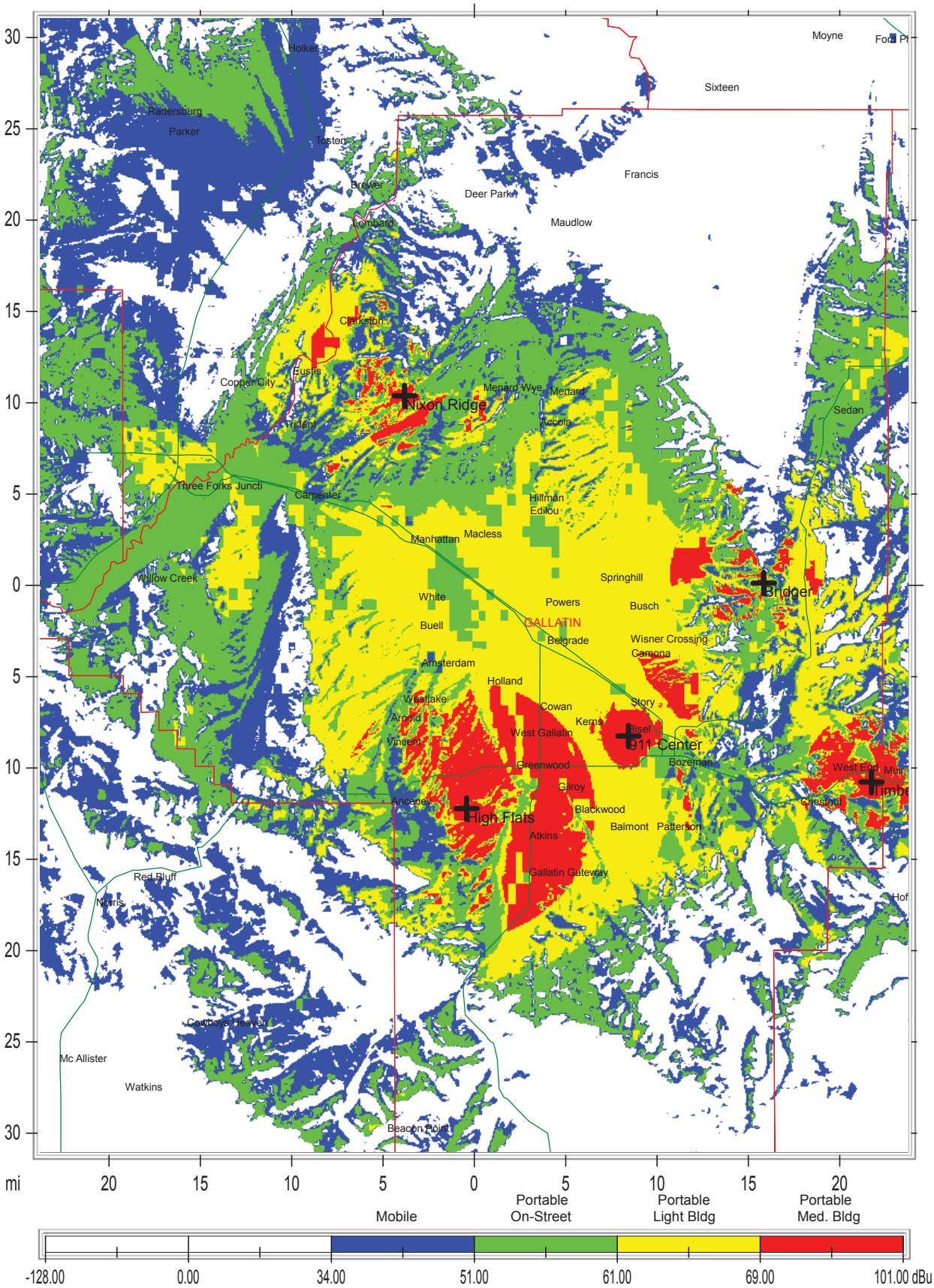
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Menard Wye
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Macless
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Bridger
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GALLATIN
Belgrade
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Camona
Amsterdam
Holland
Westlake
Cowan
Story
Arnold
Kerns
West Gallatin
Bisel
911 Center
Vincent
Bozeman
Greenwood
Gilroy
Anceney
High Flats
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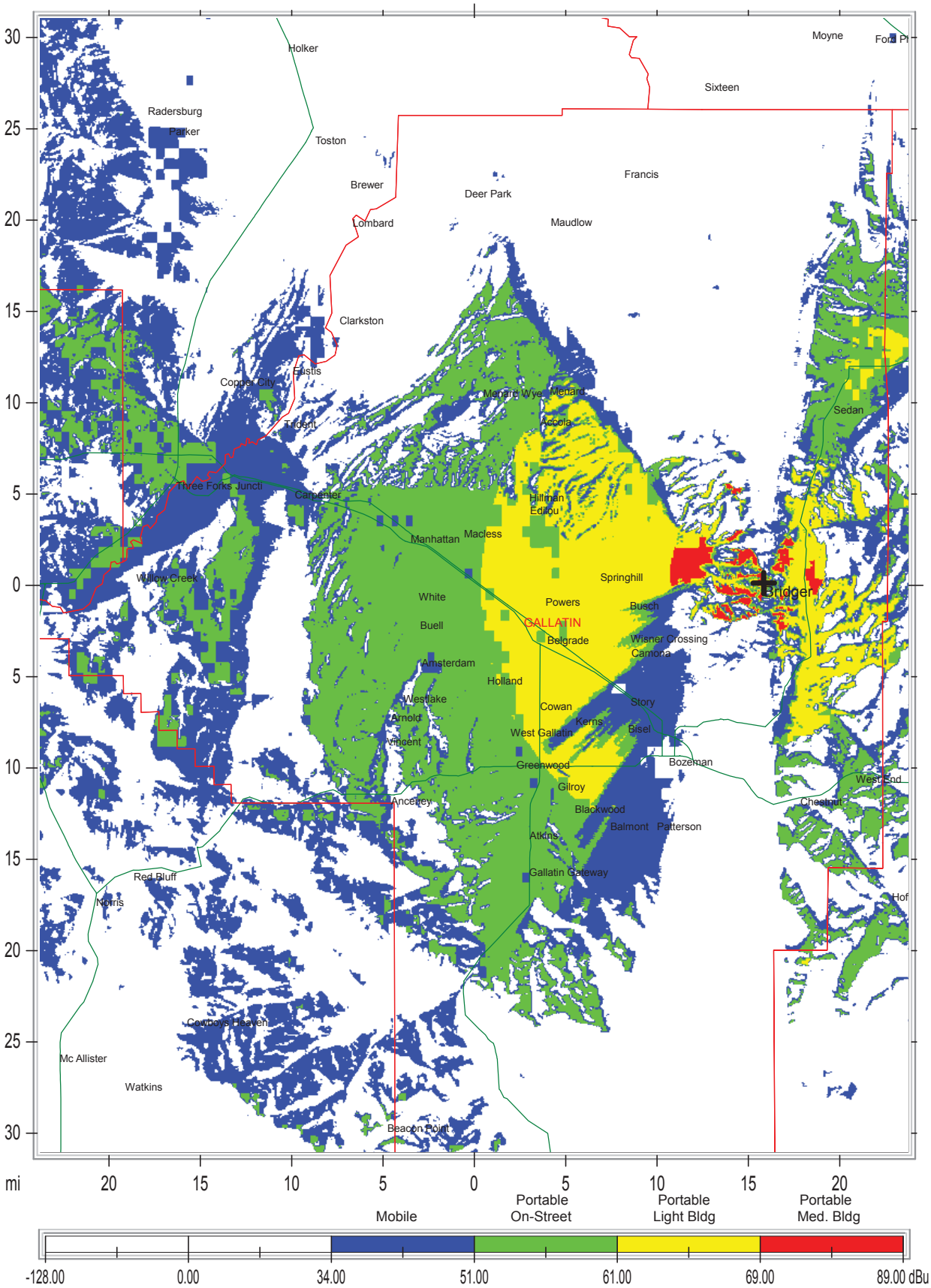
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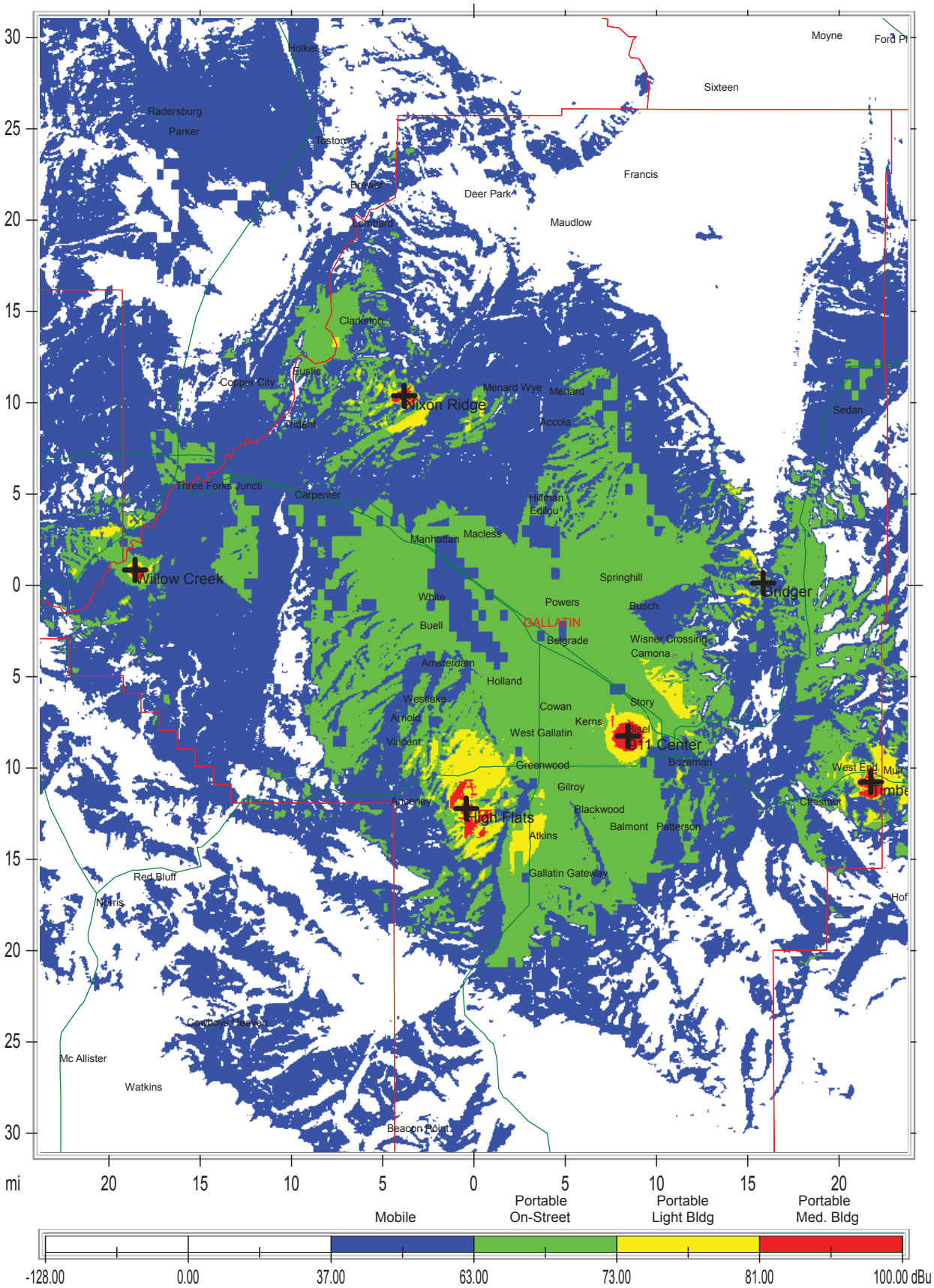
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Bisel
Vincent
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Bozeman
Greenwood
West End
Gilroy
Chestnut
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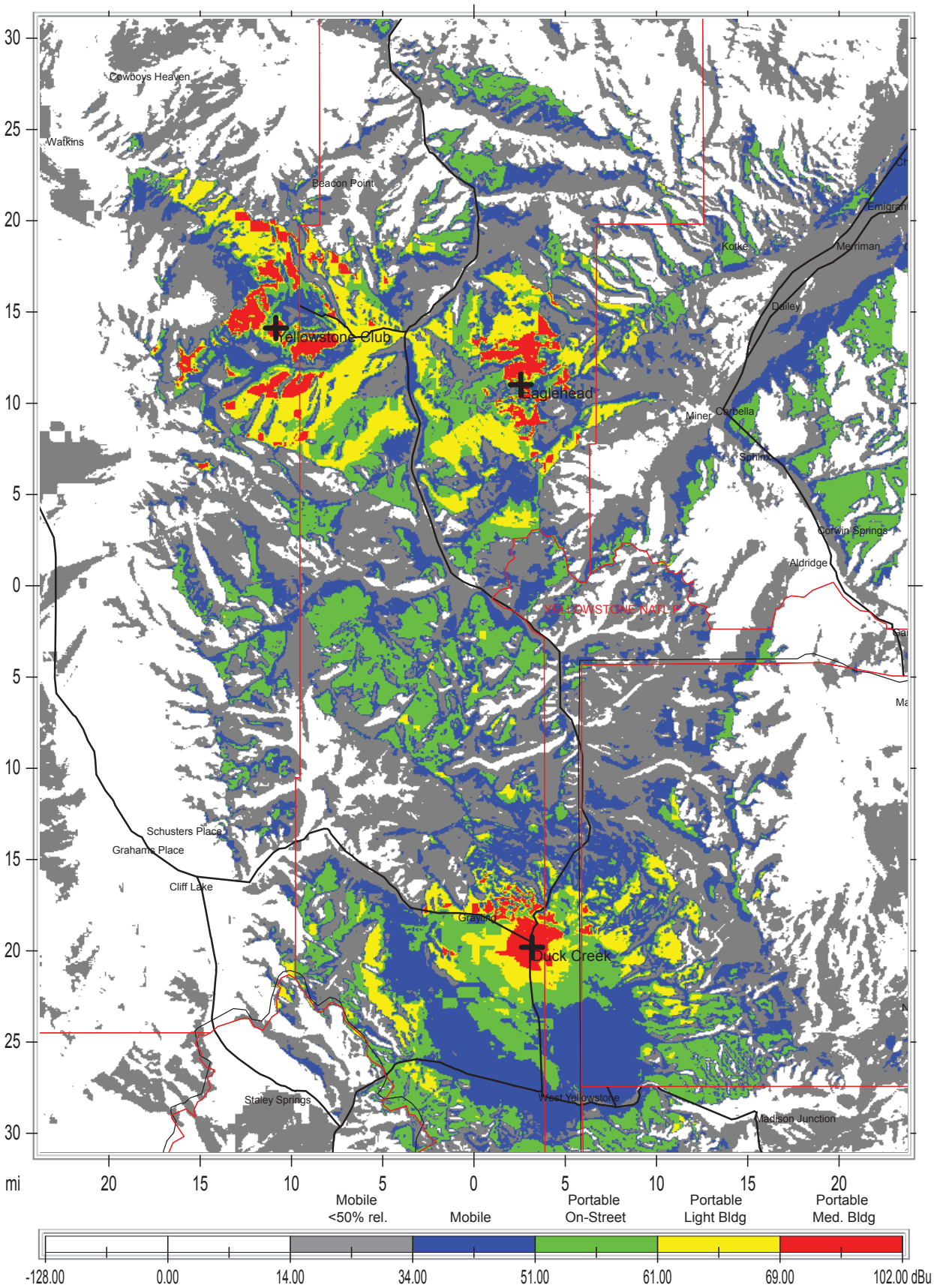
Cowboys Heaven
Watkins
Beacon Point
Yellowstone Club
Eaglehead
Emigrant
Kotke
Merriman
Dailey
Miner
Carbella
Springs
Corwin Springs
Aldridge
YELLOWSTONE NAT'L P
Schusters Place
Grahams Place
Cliff Lake
Gravling
Duck Creek
Staley Springs
West Yellowstone
Madison Junction
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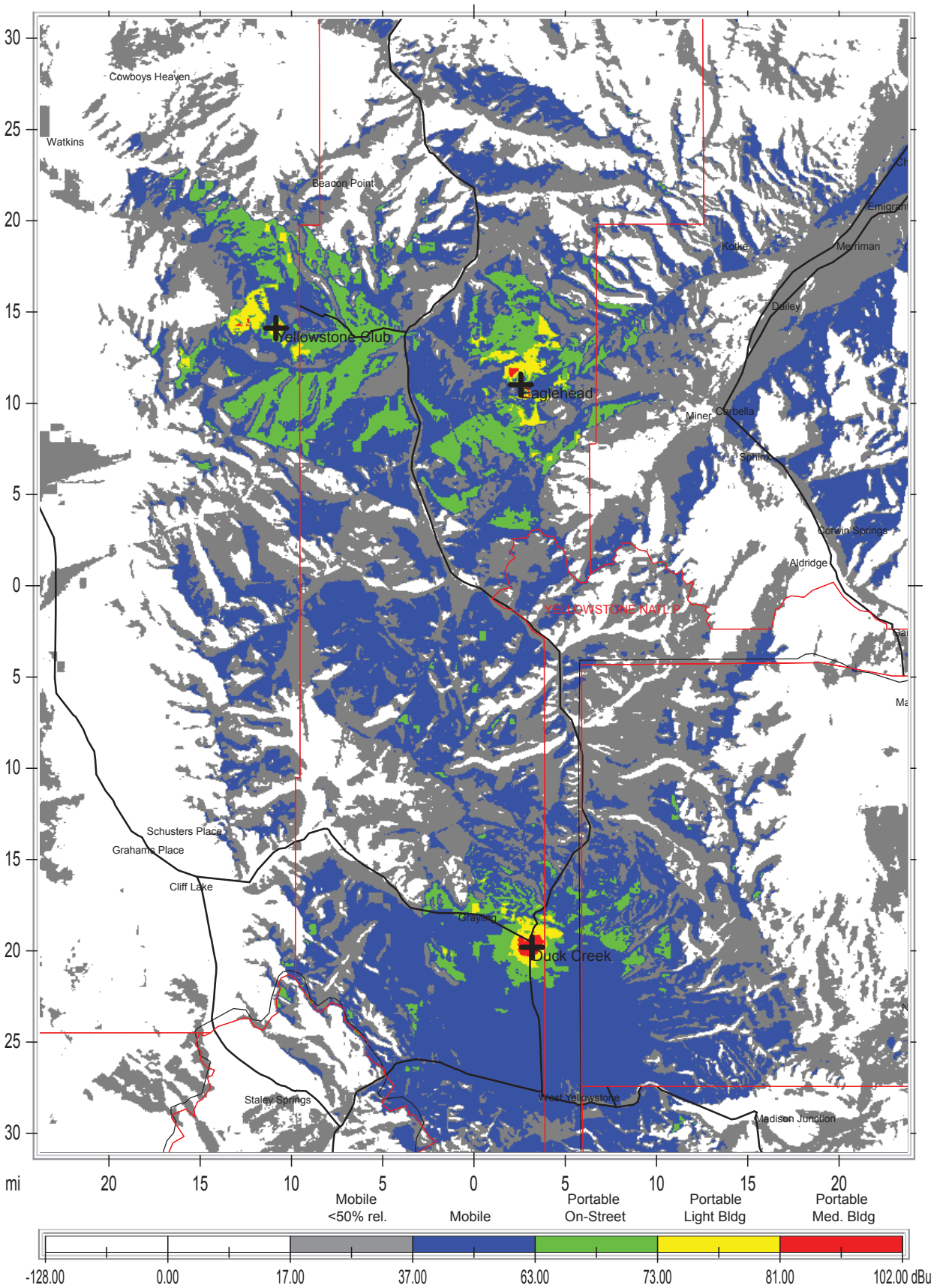
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Grahams Place
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102.00 dBu

Appendix B
High-Level Existing System Block Diagrams

GALLATIN COUNTY, MONTANA

9-1-1 RADIO ENGINEERING STUDY

EXISTING PUBLIC SAFETY RADIO SYSTEM

HIGH LEVEL SYSTEM DRAWINGS (PN0634-XXXX)

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BOTHELL, WA 98012-8827
VOICE: 425.489-0125
FAX 425.488.3952

DATE	03-13-2015	DWG #	PN0634 - 0000
PREPARED BY	M. NORIN	SCALE	

GALLATIN COUNTY
9-1-1 RADIO ENGINEERING STUDY

COVER SHEET

SHEET	SIZE	REV
1 OF 1		-

GALLATIN COUNTY, MONTANA
9-1-1 RADIO ENGINEERING STUDY
EXISTING PUBLIC SAFETY RADIO SYSTEM

DRAWING TABLE OF CONTENTS

PN0634-0100	EXISTING SYSTEM BLOCK DIAGRAM
PN0634-0200	EXISTING SYSTEM INTERCONNECTION BLOCK DIAGRAM
PN0634-0300	EXISTING ALPHANUMERIC PAGING SYSTEM BLOCK DIAGRAM
PN0634-0400	BOZEMAN PD VHF BLOCK DIAGRAM
PN0634-0500	BOZEMAN FIRE VHF BLOCK DIAGRAM
PN0634-0600	LAW NORTH VHF BLOCK DIAGRAM
PN0634-0700	GCSO TAC BLOCK DIAGRAM
PN0634-0800	FIRE NORTH VHF BLOCK DIAGRAM
PN0634-0900	GCSO SOUTH VHF BLOCK DIAGRAM

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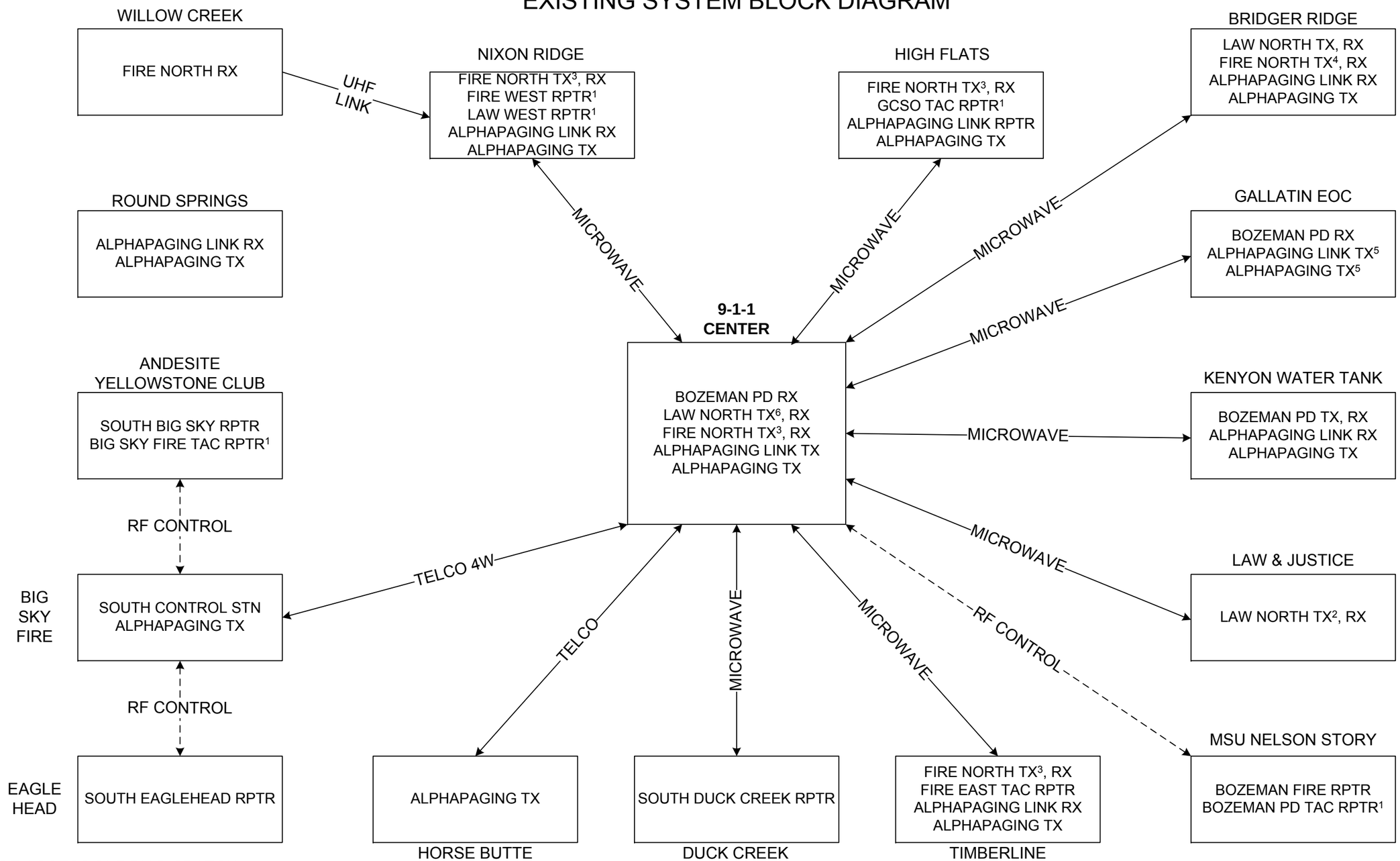
GALLATIN COUNTY
9-1-1 RADIO ENGINEERING STUDY

TABLE OF CONTENTS

DATE	03-13-2015	DWG #	PN0634 - 0001						
PREPARED BY	M. NORIN	SCALE		SHEET	1 OF 1	SIZE		REV	-

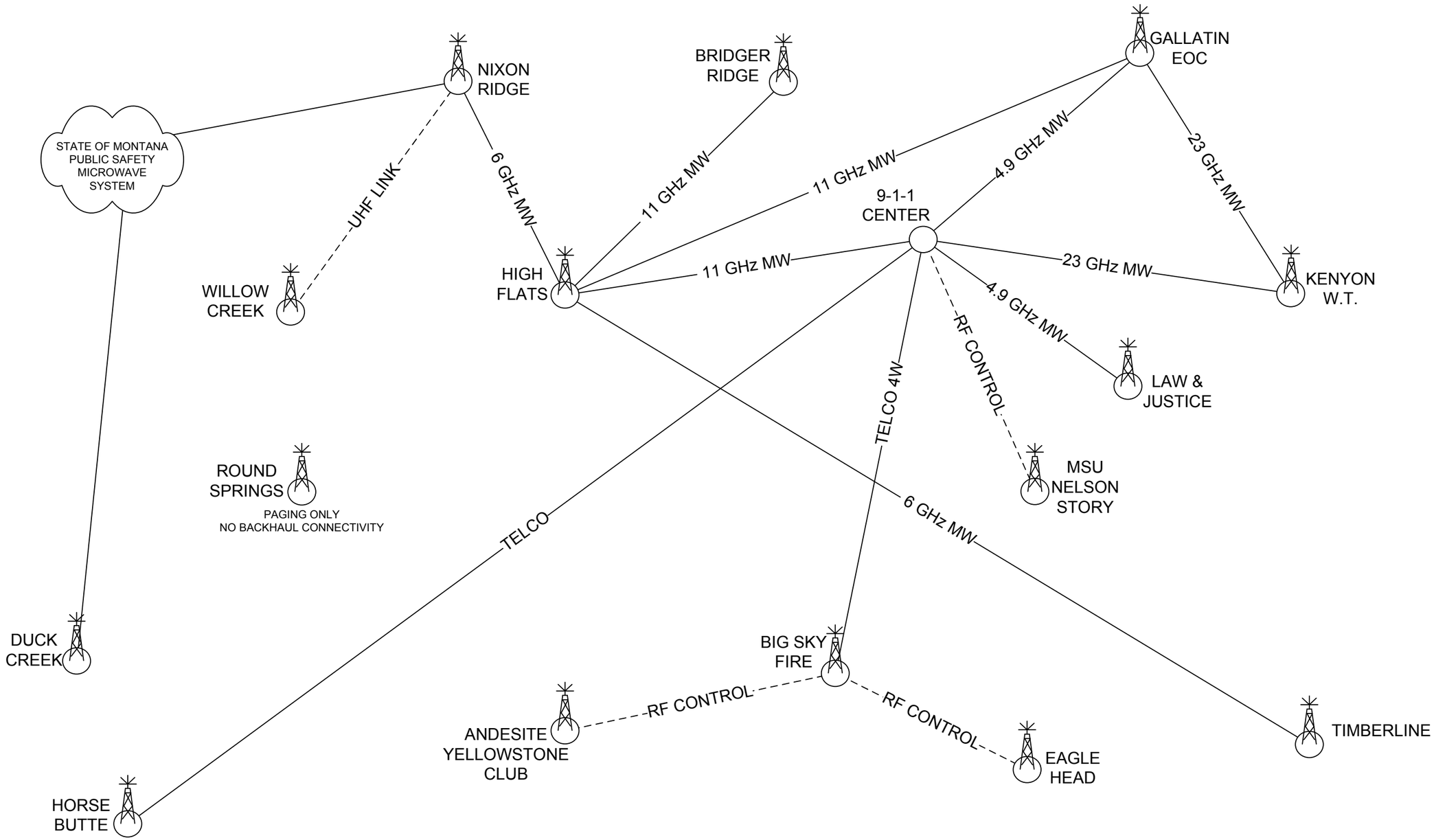
EXISTING SYSTEM BLOCK DIAGRAM



1 NOT ACCESSIBLE BY DISPATCH
2 IN-BUILDING COVERAGE ONLY
3 STEERED TRANSMITTER
4 STEERED TRANSMITTER, DEFAULT
5 STANDBY
6 DISABLED

ADCOMM ENGINEERING COMPANY www.adcommeng.com	SPECIALISTS IN PUBLIC SAFETY COMMUNICATIONS ENGINEERING 3929 184th PLACE SE BOTHELL, WA 98012-8827 VOICE: 425.489-0125 FAX 425.488.3952		GALLATIN COUNTY 9-1-1 RADIO ENGINEERING STUDY	
DATE	03-13-2015	DWG #	PN0634 - 0100	EXISTING SYSTEM BLOCK DIAGRAM
PREPARED BY	M. NORIN	SCALE		SHEET 1 OF 1 · SIZE · REV -

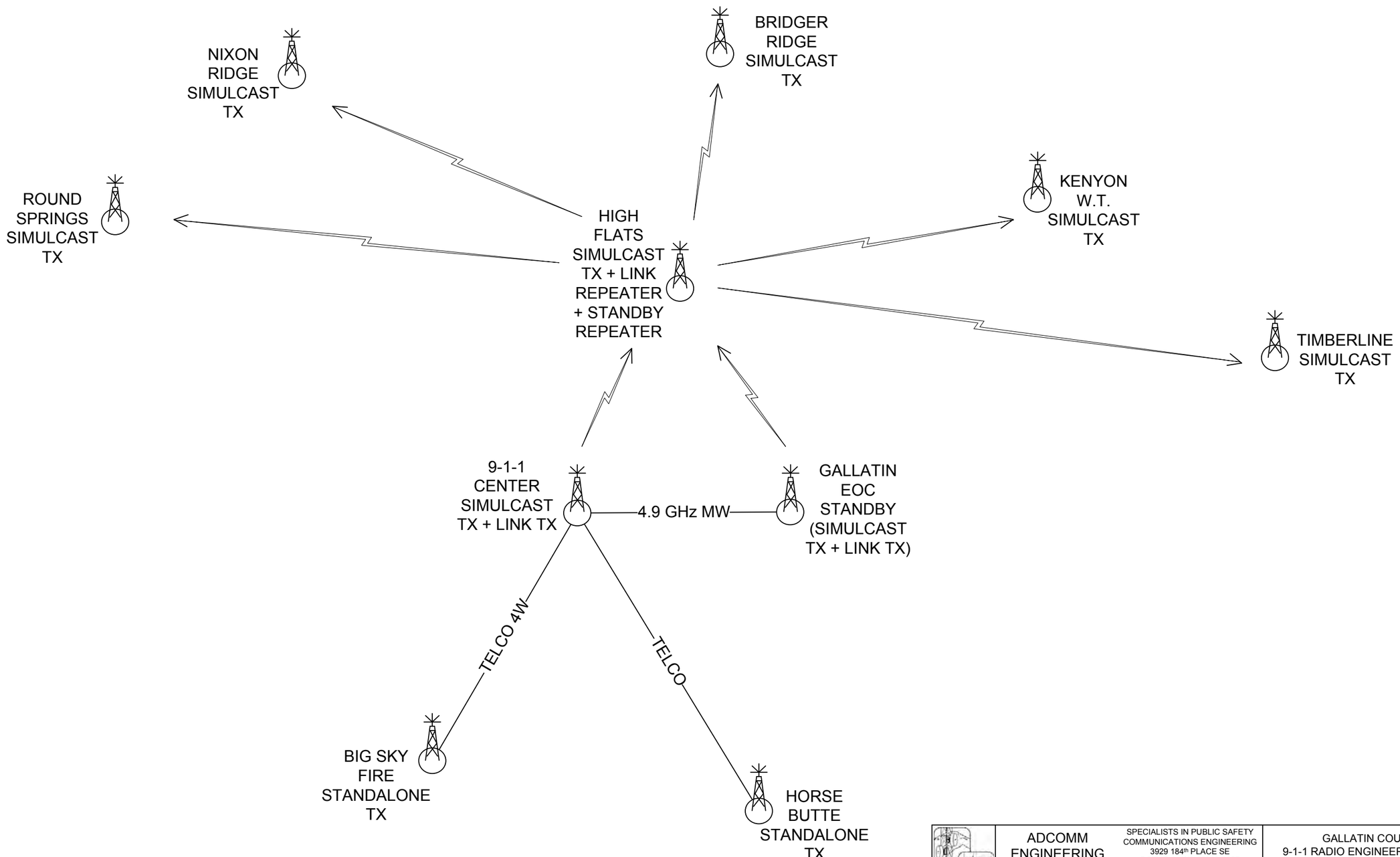
EXISTING SYSTEM INTERCONNECTION DIAGRAM



NOT TO SCALE AND SITES OFFSET FOR CLARITY
UHF ALPHANUMERIC PAGING LINKS NOT SHOWN

	ADCOMM ENGINEERING COMPANY www.adcommeng.com	SPECIALISTS IN PUBLIC SAFETY COMMUNICATIONS ENGINEERING 3929 184th PLACE SE BOTHELL, WA 98012-8827 VOICE: 425.489-0125 FAX 425.488.3952		GALLATIN COUNTY 9-1-1 RADIO ENGINEERING STUDY				
DATE	03-13-2015	DWG #	PN0634 - 0200	EXISTING SYSTEM INTERCONNECTION DIAGRAM				
PREPARED BY	M. NORIN	SCALE		SHEET	1 OF 1	SIZE		REV -

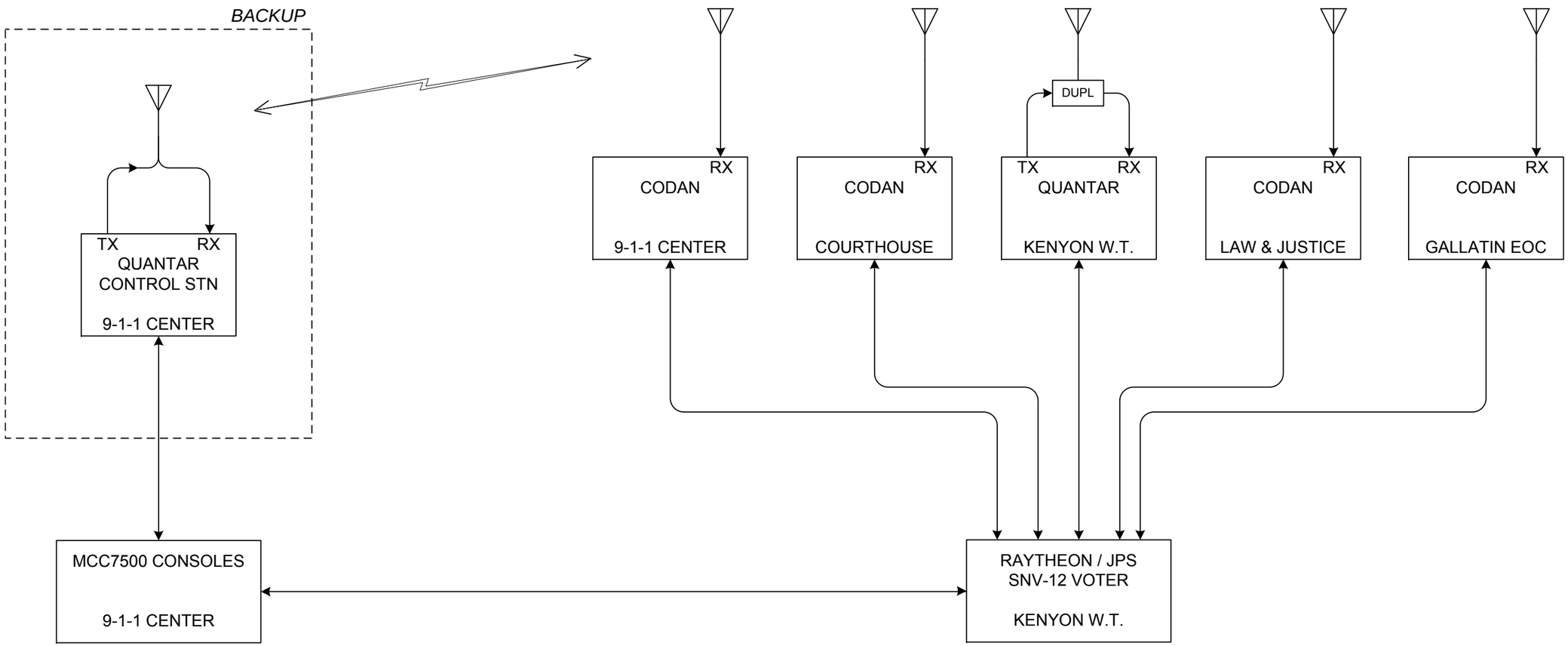
EXISTING UHF ALPHANUMERIC PAGING SYSTEM BLOCK DIAGRAM



NOT TO SCALE AND SITES OFFSET FOR CLARITY

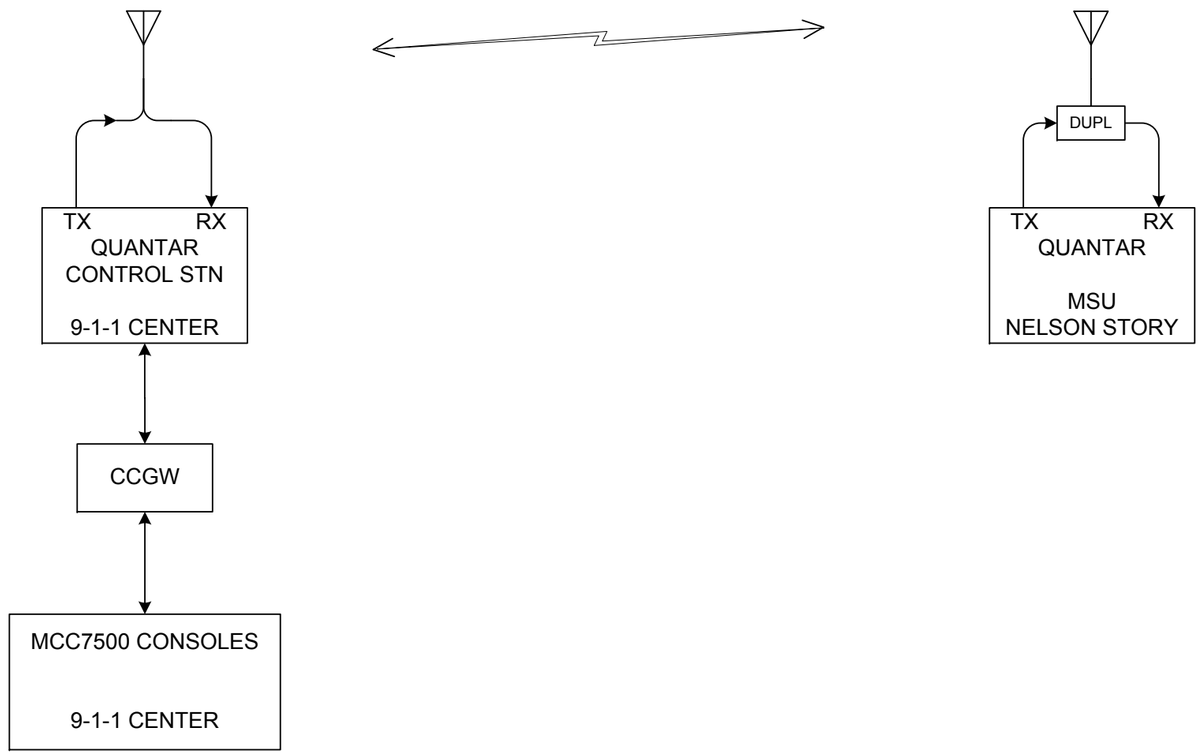
ADCOMM ENGINEERING COMPANY www.adcommeng.com	SPECIALISTS IN PUBLIC SAFETY COMMUNICATIONS ENGINEERING 3929 184th PLACE SE BOTHELL, WA 98012-8827 VOICE: 425.489-0125 FAX 425.488.3952			GALLATIN COUNTY 9-1-1 RADIO ENGINEERING STUDY
DATE	04-06-2015	DWG #	PN0634 - 0300	EXISTING UHF ALPHANUMERIC PAGING SYSTEM BLOCK DIAGRAM
PREPARED BY	M. NORIN	SCALE		SHEET 1 OF 1 SIZE REV -

EXISTING BOZEMAN PD BLOCK DIAGRAM



	ADCOMM ENGINEERING COMPANY www.adcommeng.com	SPECIALISTS IN PUBLIC SAFETY COMMUNICATIONS ENGINEERING 3929 184th PLACE SE BOTHELL, WA 98012-8827 VOICE: 425.489-0125 FAX 425.488.3952			GALLATIN COUNTY 9-1-1 RADIO ENGINEERING STUDY				
					EXISTING BOZEMAN PD BLOCK DIAGRAM				
DATE	04-21-2015	DWG #	PN0634 - 0400						
PREPARED BY	M. NORIN	SCALE		SHEET	1 OF 1	SIZE		REV	A

EXISTING BOZEMAN FIRE BLOCK DIAGRAM



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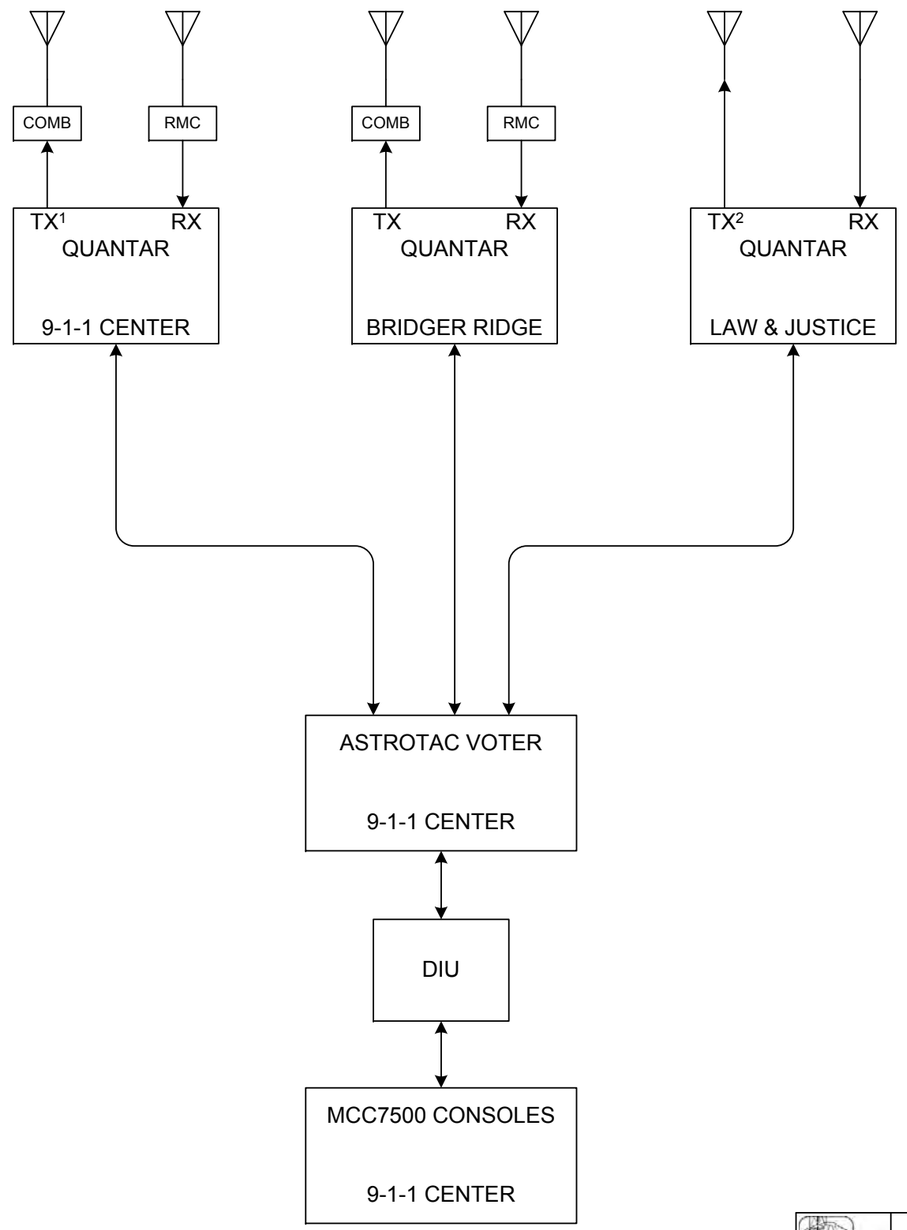
GALLATIN COUNTY
9-1-1 RADIO ENGINEERING STUDY

EXISTING BOZEMAN FIRE BLOCK DIAGRAM

DATE	03-17-2015	DWG #	PN0634 - 0500
PREPARED BY	M. NORIN	SCALE	

SHEET	1 OF 1	SIZE		REV -

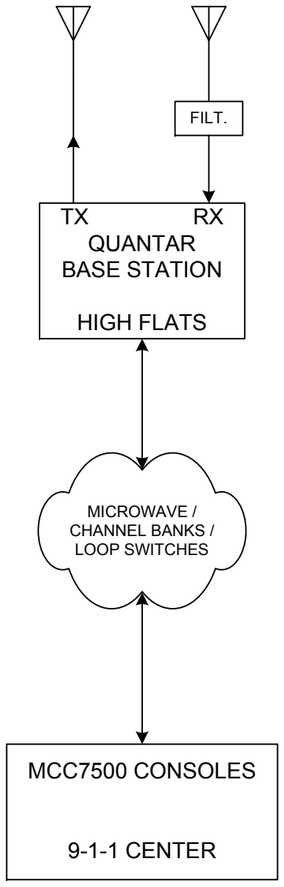
EXISTING LAW NORTH BLOCK DIAGRAM



[1] DISABLED
[2] IN-BUILDING COVERAGE ONLY

	ADCOMM ENGINEERING COMPANY www.adcommeng.com	SPECIALISTS IN PUBLIC SAFETY COMMUNICATIONS ENGINEERING 3929 184th PLACE SE BOTHELL, WA 98012-8827 VOICE: 425.489-0125 FAX 425.488.3952			GALLATIN COUNTY 9-1-1 RADIO ENGINEERING STUDY				
					EXISTING LAW NORTH BLOCK DIAGRAM				
DATE	03-17-2015	DWG #	PN0634 - 0600						
PREPARED BY	M. NORIN	SCALE		SHEET	1 OF 1	SIZE		REV	-

EXISTING GCSO TAC BLOCK DIAGRAM



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BOTHELL, WA 98012-8827
VOICE: 425.489-0125
FAX 425.488.3952

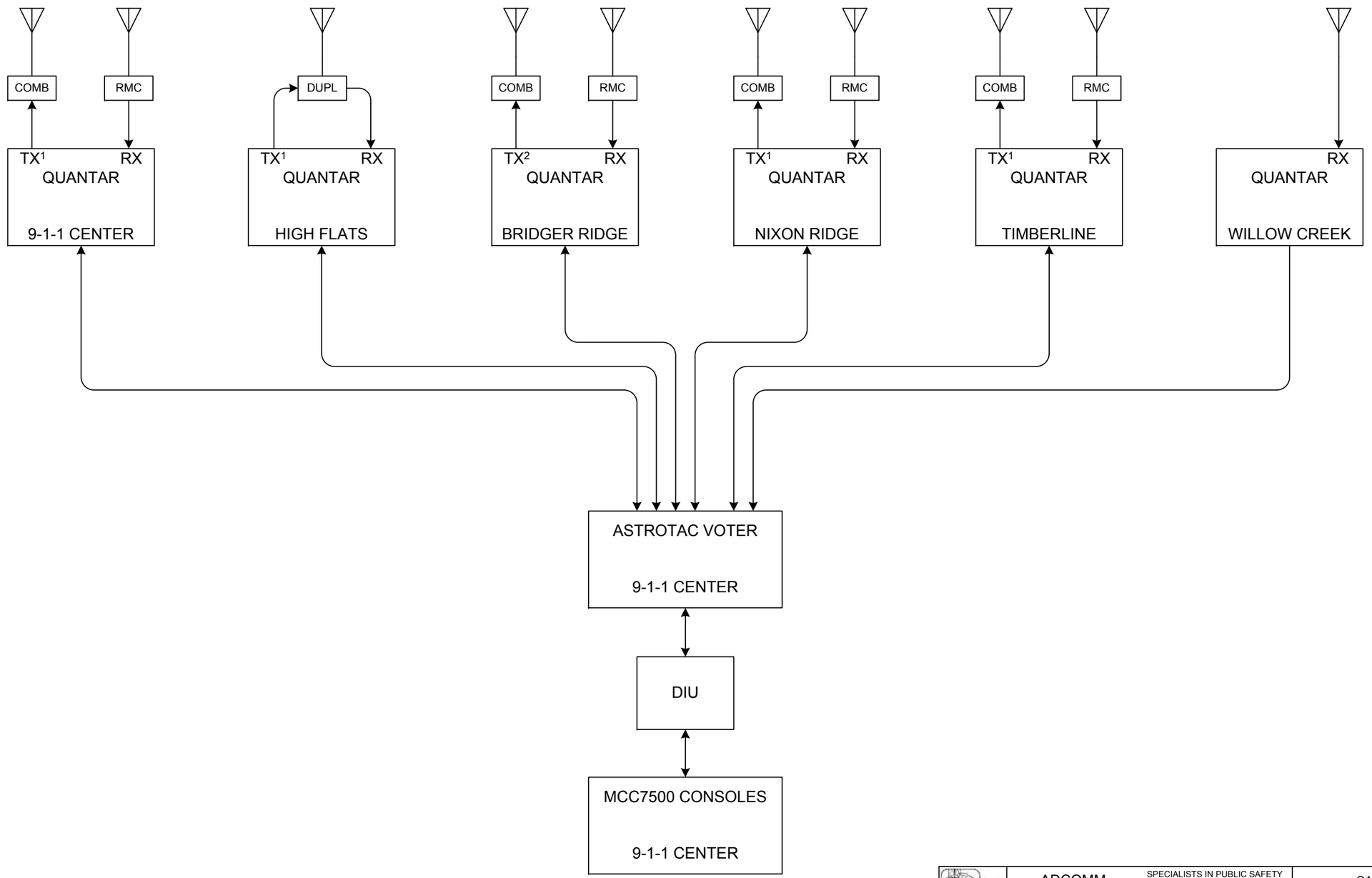
GALLATIN COUNTY
9-1-1 RADIO ENGINEERING STUDY

EXISTING GCSO TAC
BLOCK DIAGRAM

DATE	03-17-2015	DWG #	PN0634 - 0700
PREPARED BY	M. NORIN	SCALE	

SHEET	1 OF 1	SIZE		REV -

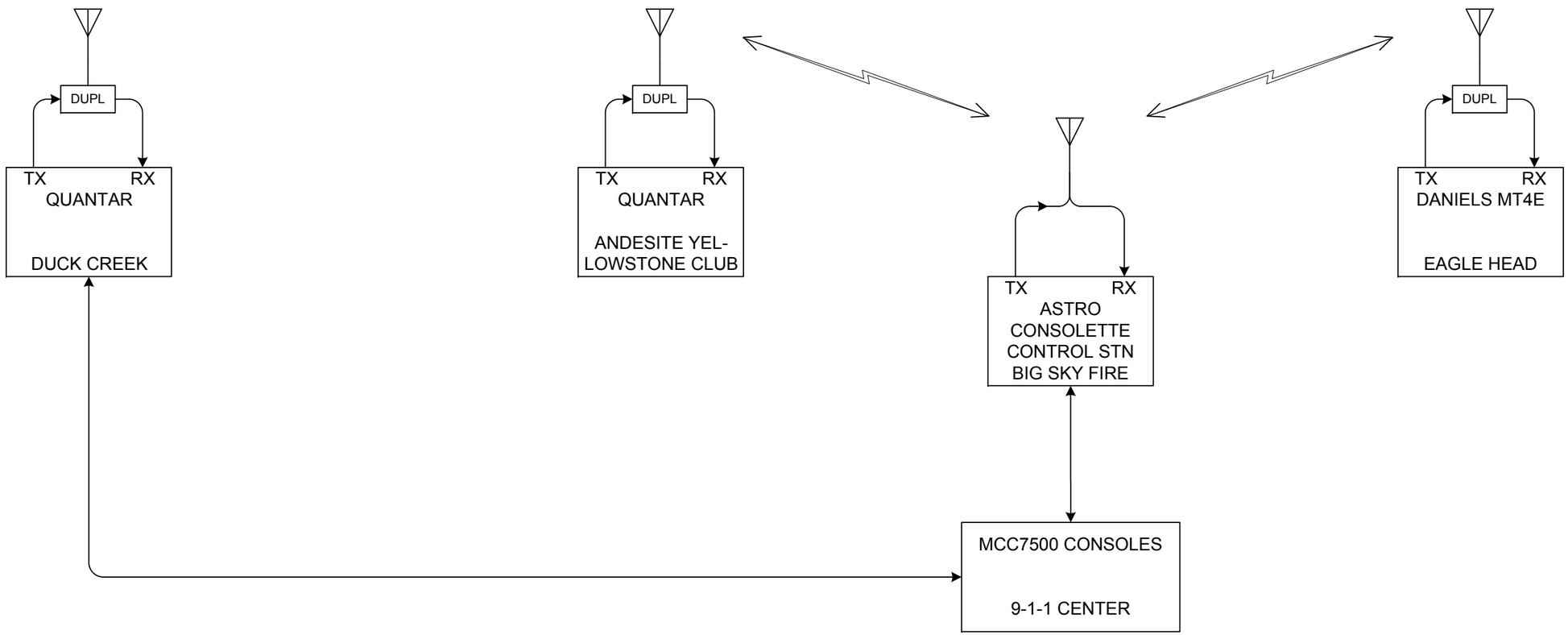
EXISTING FIRE NORTH BLOCK DIAGRAM



[1] STEERED TRANSMITTER
[2] STEERED TRANSMITTER, DEFAULT

	ADCOMM ENGINEERING COMPANY www.adcommeng.com	SPECIALISTS IN PUBLIC SAFETY COMMUNICATIONS ENGINEERING 3929 184th PLACE SE BOTHELL, WA 98012-8827 VOICE: 425.489-0125 FAX 425.488.3952			GALLATIN COUNTY 9-1-1 RADIO ENGINEERING STUDY				
					EXISTING FIRE NORTH BLOCK DIAGRAM				
DATE	03-17-2015	DWG #	PN0634 - 0800						
PREPARED BY	M. NORIN	SCALE		SHEET	1 OF 1	SIZE		REV	-

EXISTING GCSO SOUTH BLOCK DIAGRAM



	ADCOMM ENGINEERING COMPANY www.adcommeng.com	SPECIALISTS IN PUBLIC SAFETY COMMUNICATIONS ENGINEERING 3929 184th PLACE SE BOTHELL, WA 98012-8827 VOICE: 425.489-0125 FAX 425.488.3952			GALLATIN COUNTY 9-1-1 RADIO ENGINEERING STUDY				
					EXISTING GCSO SOUTH BLOCK DIAGRAM				
DATE	03-17-2015	DWG #	PN0634 - 0900						
PREPARED BY	M. NORIN	SCALE		SHEET	1 OF 1	SIZE		REV	-

Appendix C
Listing of Channels Per Site

APPENDIX C
Listing of Channels Per Site

TABLE C-1
Listing of Gallatin County 9-1-1's Channels at Sites

Site Name	Map No.	Steered Transmitter	Conventional Repeaters	Voted Receive	Paging	Voice Channel Site Connectivity
9-1-1 Center	1	Fire North Law North	**SO North**	Bozeman PD	Yes	Microwave
Andesite: Big Sky Resort	2	No Active Gallatin County 9-1-1 Equipment				
Andesite: Yellowstone Club	3		South Big Sky Fire-Tac		No	Control Station
Big Sky Fire Station	4				Yes	Telephone
Bridger Ridge	5	Fire North Law North	SO North		Yes	Microwave
Duck Creek	6		South		No	Microwave
Eagle Head Mountain	7		South		No	Control Station
Emergency Operations Center	8			Bozeman PD	Yes	Microwave
Grassy Mountain	9	No Gallatin County 9-1-1 Equipment				
High Flats	10	Fire North	SO Tactical		Yes	Microwave
Horse Butte	11				Yes	Telephone
Kenyon Water Tower	12		Bozeman PD	Bozeman PD	Yes	Microwave
Law and Justice	13		Law North		No	Microwave
Montana State University	14		Bozeman Fire Bozeman PD-Tac		No	None
Nixon Ridge	15	Fire North	Fire West Law West		Yes	Microwave
Round Springs	16				Yes	
Timberline	17	Fire North	Fire East Tac		Yes	Microwave
Willow Creek	18			Fire North	No	UHF and Microwave

Does not include control stations.

Appendix D
Voice Channel Transmitter and Receiver Measurements

APPENDIX D

Voice Channel Transmitter and Receiver Measurements

The transmit power and receiver sensitivity was measured directly from each antenna port for all the voice channels. The Quantar transmitters are rated for 100 watts and can be adjusted down to 12.5 watts. The transmit power parameters were not determined during the site visits; a low measured transmit power may be part of the system's intended design. The measurements are listed in Table D-1.

TABLE D-1
Voice Channel Transmitter and Receiver Measurements

Site Name	Channel	Equipment	Measured Transmit Power	Measured Receiver Sensitivity
9-1-1 Dispatch Center	Law North (CCSO)	Motorola Quantar	15 watts	-118 dBm
9-1-1 Dispatch Center	Fire North	Motorola Quantar	86 watts	-127 dBm
9-1-1 Dispatch Center	Bozeman PD	Motorola Quantar	25 watts (per Code Plug)	N/A
9-1-1 Dispatch Center	Bozeman PD	Codan Receiver	RX only	-124 dBm
Andesite — Yellowstone Club	South	Motorola Quantar	127 watts	-118 dBm
Bridger Ridge	Fire	Motorola Quantar	103 watts	-128 dBm
Bridger Ridge	Law North (CCSO)	Motorola Quantar	100 watts	-128 dBm
Duck Creek	South	Motorola Quantar	60 watts	-115 dBm**
Eagle Head	South	Daniels (Exciter only)	10 watts*	-126 dBm
EOC	Bozeman PD	Codan Receiver	RX only	-119 dBm
High Flat	Fire North	Motorola Quantar	93 watts	-126 dBm
High Flat	SO TAC	Motorola Quantar	89 watts	-122 dBm
Kenyon Water Tank	Bozeman PD	Motorola Quantar	107 watts	-129 dBm
Law and Justice Center	Law North (CCSO)	Motorola Quantar	39 watts	-119 dBm
Montana State University	Bozeman Fire	Motorola Quantar	107 watts	-125 dBm
Montana State University	Bozeman PD Tac	Motorola Quantar	91 watts	-117 dBm**
Nixon Ridge	Fire North	Motorola Quantar	117 watts	-125 dBm
Nixon Ridge	Law West	Motorola Quantar	96 watts	-119 dBm
Nixon Ridge	Fire West	Motorola Quantar	94 watts	-126 dBm

TABLE D-1 (cont.)
Voice Channel Transmitter and Receiver Measurements

Site Name	Channel	Equipment	Measured Transmit Power	Measured Receiver Sensitivity
Timberline	North	Motorola Quantar	117 watts	-127 dBm
Timberline	Fire East	Motorola Quantar	106 watts	-127 dBm
Willow Creek	Fire	Motorola Quantar		-127 dBm
	UHF Link		12.5 watts	

*On the day of the site visit, the Eagle Head power amplifier was discovered to be not functional. The power amplifier is in the transmit path between the exciter and the repeater's duplexer; its purpose is to increase the transmit power from 10 watts to 30 watts. The power out of the power amplifier was measured to be 5 watts. Additionally, there were end user reports that the coverage from this site had noticeably decreased; a power reduction from 30 watts to 5 watts would correlate to approximately halving the radius, which would validate the end user reports. Prior to leaving the site, the power amplifier was taking out of the transmit path and Daniels/Codan was contacted for warranty and replacement.

** The Motorola Quantar is specified to have a receive sensitivity of -119 dBm. Although the South repeater at Duck Creek and the Police Tactical repeater at Montana State University do not meet Motorola's performance specifications, it should not be considered a "hard failure." The receiver performance should be monitored to ensure the site is not beginning to fail.

Appendix E
Paging Equipment
Transmitter Measurements

APPENDIX E

Paging Equipment Transmitter Measurements

The transmit power was measured directly from the antenna transmit port. The transmitters are rated for 100 watts and can be adjusted down to 50 watts, as per the manufacturer manual. The transmit power parameters were not determined during the site visits; therefore a low measured transmit power may be part of the system's intended design. The measurements are listed in Table E-1.

TABLE E-1
Paging Transmitter Measurements

Site Name	Equipment	Function	Measured Transmit Power
Big Sky Fire Station	Motorola Radius M1225 Mobile Radio TE Systems 4512S	Paging Transmitter	105 watts
Bridger Ridge	DX Engineering	Paging Transmitter	76 watts
EOC	DX Engineering	Paging Repeater to High Flats	83 watts
EOC	DX Engineering	Paging Transmitter	83 watts
High Flat	DX Engineering	Main Paging Repeater from EOC to Outlying Sites	71 watts
High Flat	DX Engineering	Standby Paging Repeater from EOC to Outlying Sites	58 watts
High Flat	DX Engineering	Paging Transmitter	82 watts
Horse Butte	Motorola Radius 1225 Mobile Radio Unidentifiable PA	Paging Transmitter	114 watts
Kenyon Water Tank	DX Engineering	Paging Transmitter	83 watts
Nixon Ridge	DX Engineering	Paging Transmitter	77 watts
Round Springs	DX Engineering	Paging Transmitter	109 watts

Final Report

Gallatin County
9-1-1 Radio System Engineering Study
Technology Review

Prepared for
Gallatin County 9-1-1

Prepared by
Joe Blaschka, Jr., P.E.
Mike Norin
ADCOMM Engineering Company

Date Prepared
June 23, 2015

ADCOMM Engineering Company
Bridging the Gap Between Operations and Technology®

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Acronyms and Abbreviations

ADCOMM	ADCOMM Engineering Company
DMR	digital mobile radio
EMS	emergency medical services
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FD	fire department
FDMA	frequency division multiple access
FirstNet	First Responder Network Authority
FM	frequency modulation
GHz	gigahertz
GPS	global positioning system
IP	Internet Protocol
LMR	land-mobile radio
LTE	Long-Term Evolution
MHSB	monitored hot-standby
MHz	megahertz
NTIA	National Telecommunications and Information Administration
P25	APCO Project 25
PD	police department
PSTN	public-switched telephone network
PTT	push-to-talk
RF	radio frequency
TDMA	time division multiple access
UHF	ultra high frequency
VHF	very high frequency
VoLTE	Voice over LTE

Technology Review

Executive Summary

As part of the Gallatin County 9-1-1 Radio System Engineering Study project (the "project"), ADCOMM Engineering Company (ADCOMM) evaluated a number of radio technologies and the viability of each with regards to an upgraded radio system for the county. This report details ADCOMM's findings.

Many two-way land-mobile radio (LMR) technologies and options exist today, some of which might be appropriate for use in an updated radio system for Gallatin County while others are not. In general, the primary technologies and options can be categorized by frequency band, system architecture, and air interface technology.

The primary public safety LMR frequency band options are low-band VHF (30 to 50 MHz), high-band VHF (150 to 174 MHz), UHF (450 to 470 MHz), 700 MHz, and 800 MHz, with each band having its own advantages and disadvantages. Since all users in the county currently use VHF, it would be advantageous for a new system to also be on VHF so at least some existing mobile and portable radio equipment could be reused. Unfortunately, it is most difficult to find usable new frequencies in the VHF band. It may be possible that at least some number of additional VHF channels could be licensed, but that may not be sufficient to meet the channel needs of users in the county. The VHF frequency congestion is made worse by the use of VHF by the State of Montana for their trunked radio system and the extensive use of the "color" VHF channels statewide for interoperability. As a result, costs notwithstanding, it may be preferable to deploy a new system using the UHF frequency band.

Numerous system architecture technologies are available, including standalone base stations and repeaters, receiver voting, transmitter steering, multicast, simulcast, trunking, and various combinations thereof. Given the size of Gallatin County, and to maximize frequency-use efficiency while reducing operational complexity, ADCOMM believes that simulcast technology (in conjunction with receiver voting) makes the most sense for the core areas of the county, primarily the Gallatin Valley, including Bozeman.

Further, with the relatively small number of channels needed, a conventional (non-trunked) system would likely be most cost-effective in meeting the needs of users in the county. Either analog FM or Project 25 (P25) digital could be used with such a conventional system. For channels where encryption is desired, P25 is recommended.

If a transition to UHF and/or P25 is undertaken, consideration must be given to interoperability and mutual aid, since the vast majority of surrounding counties and other mutual aid agencies would continue to operate on VHF analog.

In addition to the LMR system itself, there are various technology options available for providing radio site connectivity, or *backhaul*, such as microwave, fiber, telephone lines, radio frequency (RF) links, and control stations. To support a simulcast system, highly reliable and stable connectivity is needed. Wherever possible, ADCOMM recommends using licensed microwave systems; however, fiber and telephone company T1 circuits may also be viable in some circumstances.

To augment the existing or updated LMR system, agencies may also wish to consider limited use of vehicular repeaters, which can provide portable radio coverage where only mobile

service is available. Such repeaters have limitations, but they can be effective when used properly.

At this time, ADCOMM does not believe the *FirstNet* public safety broadband network will be a viable option for use in Gallatin County, particularly for push-to-talk (PTT) voice, any time in the foreseeable future.

Introduction

Project Purpose and Scope

In February 2014, ADCOMM was contracted by Gallatin County to perform a radio system study. In general, the purpose of this project was to determine the state of the existing public safety two-way radio communication systems in use by stakeholders in the county, identify the operational needs of the radio systems' users, identify potential technologies and their applicability to a replacement/upgraded radio system, and develop a high-level system design for such a system, followed by solution selection and implementation preparation.

Based on this contract, the project consists of the following phases:

1. **Phase One: Information Gathering and Education.** The deliverables of Phase One are the Current State Report, the User Needs and Gap Analysis, and the Technology Review ***(this report)***. The purpose of this phase is to generate information needed by ADCOMM and by stakeholders to fully understand the existing systems, both for comparison purposes and to identify the needs of the systems' users.

2. **Phase Two: Solution Development.** Using the information gathered during Phase One, Solution Development's deliverable is a list of potential solutions, with rough order of magnitude costs, to the challenges faced by Gallatin County's radio systems. The end of Phase Two is a joint meeting to discuss and evaluate each of the potential solutions, with the County decided on one or more potential solutions for further development. Selection of the solution at this stage begins to set the strategic direction.

3. **Phase Three: Strategic Direction and High-Level Design.** During Phase Three, the selected solution is developed further to yield a strategic direction document and a high-level design. The solution will be divided into a series of implementable modules, with estimated costs, implementation time, and impact to the voice systems identified. The High-Level Design will be sufficient to drive the detailed engineering needed as the first step toward acquisition and implementation.

4. **Phase Four: Final Study Report.** The Final Study Report is a combination of all the deliverables created in the project with a summary and explanatory text for use in grant justifications and budget discussions. ADCOMM anticipates an in-person delivery of the final report to Gallatin County decision makers and stakeholders at a combined meeting.

5. **Phase Five: Solution Selection and Implementation Preparation.** Following the Final Study Report release, stakeholders will meet to identify specific solutions for implementation. These solutions will be further developed to produce engineering drawings, detailed system price estimates, and technical specifications for use in procurement and implementation. Solution development will be for voice radio system changes only.

Note that the following are not included in the scope of work for the current project: technical procurement reviews and assistance, vendor selection, technical support during contract negotiations, implementation engineering services, and/or project management.

Technology Review

The goal of the Technology Review is to provide Gallatin County with an overview of current and future technologies in voice radio systems, along with an evaluation of each technology's applicability in the County's circumstance. The Technology Review is intended to give Gallatin County decision makers a firm foundation in the technologies that are available so informed decisions can be made in the Strategic Direction portion of the project. Options for frequency bands, system architectures/access configurations, and modulation modes are discussed. In addition, brief discussions of backhaul technology options and other technology considerations are included.

Overview

Many different two-way radio technologies and options exist today, some of which would be appropriate for use in Gallatin County while others are not generally recommended. For the LMR system that users access directly with their radios, these technologies and options can be categorized by frequency band, system architecture (including distribution configuration and system access configuration), and modulation mode or air interface technology. Each of these categories are described and examined in relation to the Gallatin County radio project in the next sections of this report.

In addition to the LMR system itself, there is a variety of technology options available for providing radio site connectivity (backhaul), such as microwave, RF links, control stations, etc. A description and evaluation of each of the primary connectivity methods is also included.

Lastly, there are other technologies available that can be used to augment a standalone LMR system, such as vehicular repeaters, alphanumeric paging (currently used by Gallatin County), and perhaps at some point in the future even a potential replacement of private LMR systems altogether by the First Responder Network Authority ("FirstNet"). A description of these technologies and their viability is included as well.

LMR System Technologies and Options

Frequency Bands

Numerous frequency bands have been assigned by the Federal Communications Commission (FCC) for LMR use. Each of the bands detailed below has frequencies allocated for public safety use, as would be appropriate for Gallatin County's radio system.

Low-Band VHF

The low-band VHF frequency band, commonly referred to simply as "low band," consists of spectrum in the 30 to 50 MHz range. Although it can provide better coverage in areas with hilly and mountainous terrain compared to other frequency bands, there are significant issues related to low band. Because of these issues, low band is no longer commonly in use.

One issue with low band is that it is significantly more susceptible to propagation "skip" than the other frequency bands. Under *skip* conditions, co-channel users can be heard and cause interference from distances of hundreds or even thousands of miles. Skip is often unpredictable and little can be done to control it.

Another issue with low band is that antennas and filtering equipment is much larger than with other bands. This can impact tower loading as well as equipment shelter space utilization. For example, low band cavity filters can be 7 to 8 feet tall, whereas a VHF high band cavity might be 3 feet tall.

Further, because of the limited demand for low band equipment, there are a limited number of suppliers of low band fixed infrastructure equipment (i.e., repeaters, base stations, antennas, filters, etc.) as well as subscriber equipment (i.e., mobile and portable radios).

If low band were to be used by Gallatin County, all radio infrastructure and subscriber equipment would need to be replaced. In addition, interoperability with surrounding agencies using other frequency bands (most commonly *high-band* VHF) would be impeded with a change to low band.

Because of the significant number of downsides, **ADCOMM does not recommend Gallatin County pursue a low-band solution.**

High-Band VHF

The LMR high-band VHF frequency band, commonly referred to simply as "VHF," consists of spectrum in the 150 to 174 MHz range. Many public safety as well as industrial/business systems use VHF, including virtually all public safety users in Gallatin County. Although it does not provide coverage as effectively as low band in hilly and mountainous areas, VHF does provide somewhat better non-line-of-sight coverage than UHF, 700 MHz, and 800 MHz.

While not totally immune from it, VHF frequencies suffer far less from skip than low band. On the other hand, in all but the most remote locations, the VHF band suffers from a high noise floor, which has a direct impact on radio system performance, effectively reducing usable range or coverage. Measurements taken by ADCOMM confirmed that the noise level at many locations in Gallatin County is relatively high, particularly at several radio sites and at various locations in and around Bozeman and Belgrade.

Another one of the more significant issues with VHF is limited frequency availability. This is partly due to the band's popularity, but it is further impacted by the lack of an efficient *band plan*.[1] For instance, it is possible to have one VHF frequency be used as a repeater transmit ("output") frequency by one licensee and as a mobile transmit/repeater receive ("input") frequency by another licensee some distance away, potentially creating interference between the two systems.

In most areas of the country, it is difficult at best—or not feasible at all—to deploy a *trunked* radio system at VHF due to the limited frequency availability and the co-channel spacing requirements for a trunked system. Although the Montana "state" trunked VHF radio system has sites in and around Gallatin County, expansion of this system in Gallatin County with additional frequencies may not be possible due to the *exclusive-use* frequency coordination requirements for a trunked system. Even for a conventional (non-trunked) system, depending on how many total channels are desired, there may not be a sufficient number of VHF frequencies available to meet Gallatin County's needs.

[1] FCC band plans define how the frequencies in a particular band may be used, particularly in regard to *base transmit* and *mobile transmit* use. Efficient band plans group base transmit frequencies in one part of a band and mobile transmit frequencies in another part of a band and include frequency separation between the two. Inefficient band plans allow for more haphazard use of frequencies within a band.

Because agencies in Gallatin County already use VHF, depending on whether the upgraded system uses analog or P25 digital, it may be possible to reuse many of the existing mobile and portable radios, thus reducing the overall project cost. Further, interoperability with surrounding agencies that continue to use VHF would be unaffected. Due to its popularity, VHF infrastructure and subscriber equipment is readily available from numerous manufacturers.

Because of the existing inventory of subscriber units, favorable propagation characteristics, and interoperability, **ADCOMM believes using VHF could be a viable option for Gallatin County but only if a sufficient number of frequencies can be licensed. Due to the high noise floor and lack of available frequencies, however, VHF would not be ideal.**

UHF

The UHF frequency band for LMR operations consists of spectrum in the 450 to 470 MHz range. Many public safety and industrial/business systems use UHF, although somewhat less so in more rural areas including Montana. Because they are higher frequencies, UHF does not generally propagate as far as VHF or low band. As a result, in some cases a greater number of sites may be required to provide comparable coverage. On the other hand, the noise floor at UHF tends to be lower than at VHF, which can make up for some or all of the reduced coverage. Further, due to its shorter wavelength, in-building coverage at UHF is often better than at VHF.

As with VHF, UHF infrastructure and subscriber equipment is readily available from numerous manufacturers. In addition, particularly in more rural areas, there is better availability of UHF frequencies due to its lower popularity as well as having an efficient band plan. In some areas around the country, it is still feasible to deploy trunked systems at UHF due to having better frequency availability. There are likely a sufficient number of UHF frequencies available in Gallatin County for an upgraded conventional system or conceivably even a trunked system.

Because Gallatin County does not currently use UHF, all new radios would need to be purchased, significantly increasing overall project costs. Further, since the vast majority of surrounding agencies would still be using VHF, interoperability would be impacted, likely requiring some users to carry multiple radios or more expensive dual-band radios.

ADCOMM believes UHF would be a good option for Gallatin County if interoperability and the costs for new subscriber radios can be managed.

700 MHz

The 700 MHz *narrowband* LMR frequency band consists of spectrum in the 769 to 775 MHz and 799 to 805 MHz ranges.[2] The 700 MHz band is reserved for use by public safety and governmental entities; there are no industrial/business channels. Compared to the other LMR bands, 700 MHz is the "newest," having been allocated by the FCC to public safety in the early 2000s in conjunction with the subsequent transition to digital broadcast television. All *general-use* channels in the 700 MHz LMR band are required to use digital modulation (e.g., P25); analog is not permitted.

The biggest advantage of the 700 MHz band is frequency availability, with no known current use in Montana. Unfortunately, 700 MHz propagates even shorter distances than UHF. While suitable for many urban and suburban environments, a potentially significant number of

[2] This does not include the 700 MHz *broadband* spectrum reserved for the nationwide FirstNet public safety long-term evolution (LTE) network.

additional sites could be required to provide the necessary coverage, particularly in the rural and mountainous areas of Gallatin County.

As with UHF, the purchase of new 700 MHz mobile and portable radios would be required for all agencies. Interoperability with surrounding agencies would also be complicated by a move to 700 MHz.

Because of the greater number of sites required, high subscriber unit replacement costs, and interoperability issues, **ADCOMM does not recommend 700 MHz for Gallatin County.**

800 MHz

The 800 MHz LMR frequency band consists of spectrum in the 806 to 821 MHz and 851 to 866 MHz ranges. Propagation characteristics of 800 MHz are similar to 700 MHz, thus an 800 MHz system would require essentially the same number of sites as a 700 MHz system. In fact, many systems today use a mix of 700 and 800 MHz channels to meet their capacity requirements. Unlike 700 MHz, analog modulation is permitted on 800 MHz channels. Note that there are no manufacturer-supported analog trunked options available (only conventional analog is supported).

The only known 800 MHz public safety system in Montana is operated by the City of Billings. As such, there would be no issue with licensing a sufficient number of 800 MHz channels for a new system in Gallatin County. As with 700 MHz, though, additional sites would be required to provide comparable coverage to VHF or even UHF, thus increasing system costs.

Since there are no 800 MHz radios in use today, new mobile and portable radios would be needed for all agencies. In addition, interoperability with surrounding agencies would be impeded with a shift to 800 MHz.

As with 700 MHz, because of the greater number of sites required, high subscriber replacement costs, and interoperability issues, **ADCOMM does not recommend 800 MHz for Gallatin County.**

System Architectures

Radio system architectures can be broken into two primary access configurations: *conventional* and *trunked*. The key difference between these two configurations is how frequencies are assigned to users and their associated transmissions. In addition, there are various technologies available for providing wide-area coverage, including receiver voting, simulcast, multicast, and transmitter-steering, which are often used in conjunction with both conventional and trunked systems. This section describes each of these technologies, their associated advantages and disadvantages, and potential applicability to Gallatin County.

Conventional Base Station Systems

Conventional base station simplex radio systems are the simplest form of VHF and UHF *frequency modulation* (FM)[3] LMR communications technology today and have stayed relatively the same since the 1950s. Base station, mobile, and portable radio communication range are all limited by line-of-sight and signal propagation. Simplex systems use one frequency per channel (see Figure 1). Conventional base stations are not used on any of the main Gallatin County dispatch channels.

[3] Frequency modulation is a method of transmitting information on an analog channel by varying the carrier frequency.

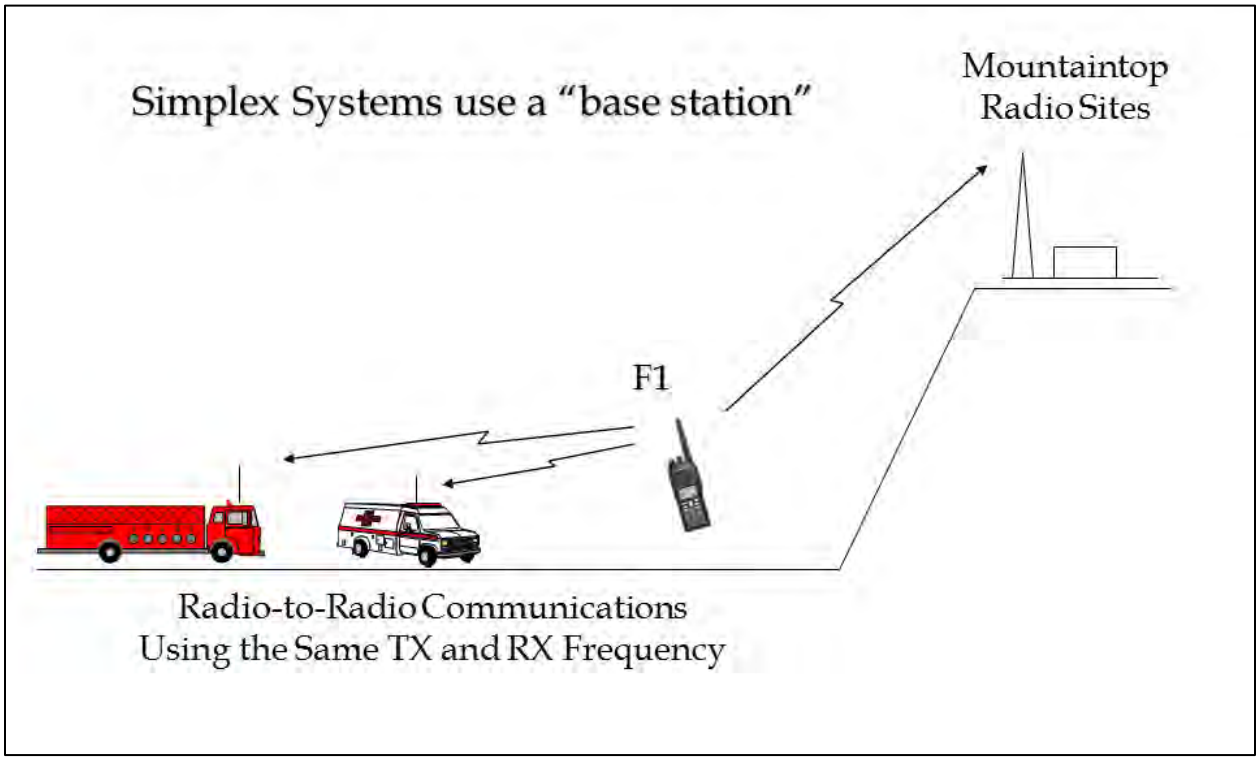

FIGURE 1
Simplex Base Station System

Advantages

- The use of a single base station is the least-cost technology solution to provide limited area communications coverage.

Disadvantages

- Single conventional base stations on mountaintops require microwave or telephone control circuits.
- Multiple conventional base stations must be strategically located throughout the desired service areas.
- The use of a single conventional base station may not provide the necessary radio coverage required in the desired service areas (see Figure 2).
- A mobile or portable radio user can interfere with dispatcher transmissions.
- Multiple conventional base stations on the same frequencies using different CTCSS require dispatcher and user training so that the correct base station is used in the specified operating area. As an example, it is possible for a radio user to respond back to a dispatcher on a base station that does not have overlapping coverage. This condition may cause missed communications and confusion.

Due to their limited capability and coverage, **ADCOMM does not recommend Gallatin County use conventional base stations for its system upgrade.**

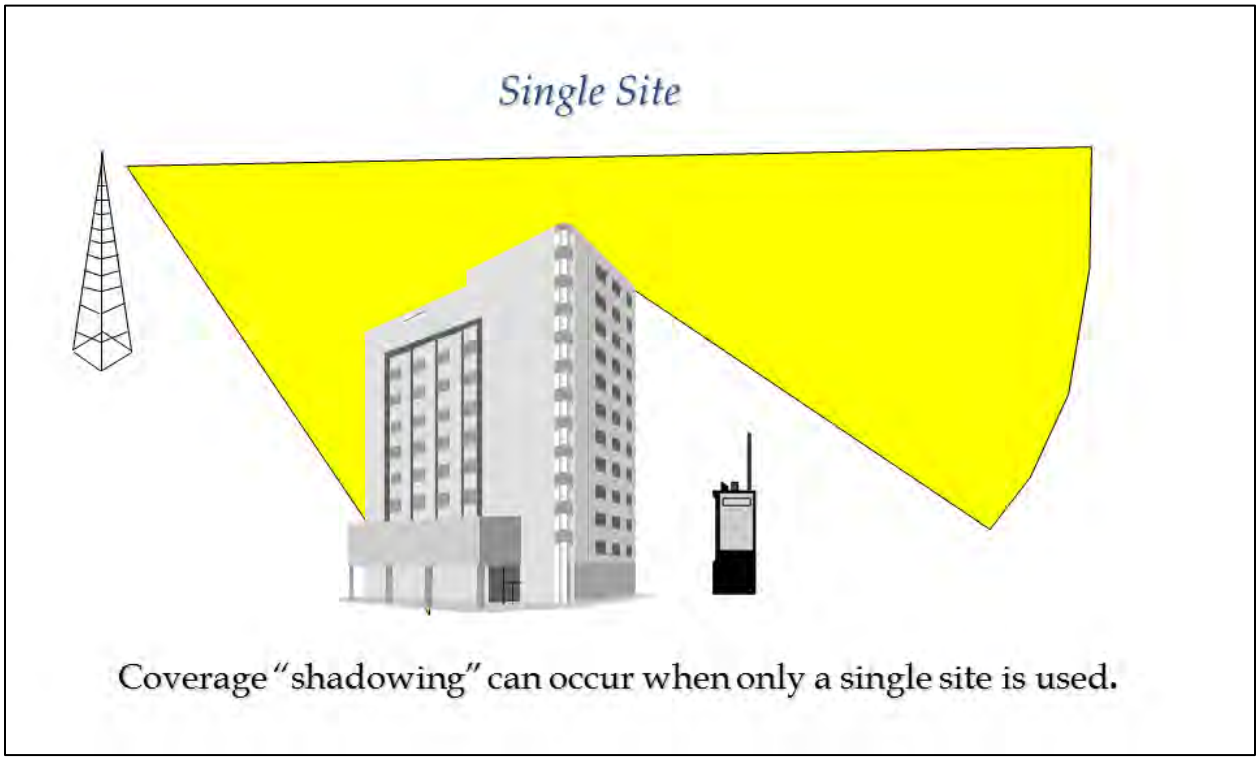

FIGURE 2
Single-Site Coverage

Conventional Repeater Systems

Conventional repeater systems extend the range of mobile and portable radios by receiving a low power signal, amplifying the signal, and automatically retransmitting it at a higher power level. Repeaters are often located on mountaintops or buildings to increase the radio coverage. Repeater systems use two frequencies per channel (see Figure 3). The vast majority of the existing radio systems in Gallatin County employ conventional repeaters.

Advantages

- The use of a single conventional repeater is the least-cost technology solution to provide limited area communications coverage while allowing a dispatcher and other radio users to hear both sides of a conversation at the same signal strength.
- Single conventional repeaters can be standalone devices that do not require microwave or telephone control circuits.
- Multiple conventional repeaters can be strategically located throughout the desired service areas.

Disadvantages

- The use of a single conventional repeater may not provide the necessary radio coverage required in the desired coverage area (see Figure 2).
- A mobile or portable radio user can interfere with dispatcher transmissions.
- Multiple conventional repeaters on the same channels require dispatcher and user training so that the correct repeater is used in the desired coverage area. As an example, it is possible for a radio user to respond back to a dispatcher or other radio user on a repeater that does

not have overlapping coverage. This condition may cause missed communications and confusion.

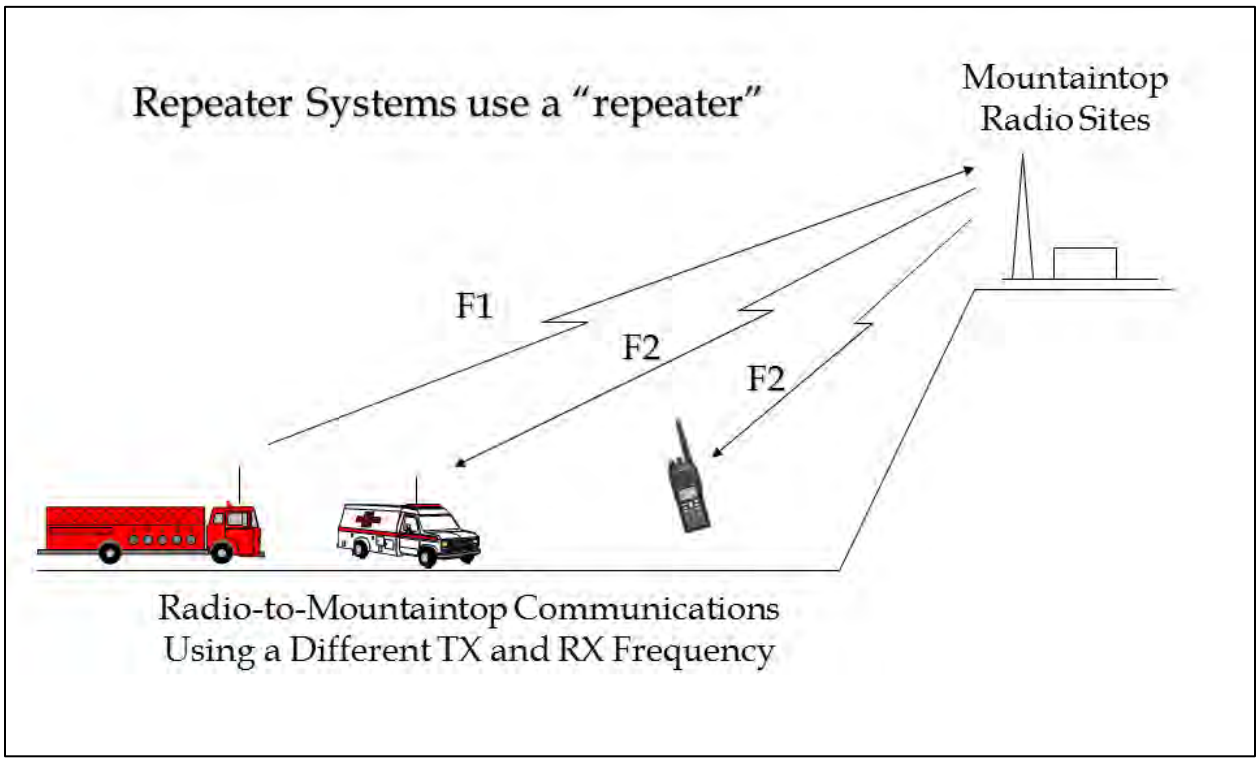

FIGURE 3
Repeater System

Although not as ideal in some situations as other technologies, such as simulcast or multicast, given their affordability and relative ease of deployment, **ADCOMM believes the strategic use of conventional repeaters continues to be appropriate for addressing portions of Gallatin County's communication needs**, particularly tactical uses and in very rural areas with relatively low usage.

Voting Receiver Systems

A voting receiver system has dedicated radio receivers that are strategically located so one or more of the receivers will receive a good quality signal from a mobile or portable radio transmitting from anywhere in a desired service area. The output of the receivers is connected to a centrally located device called a voting comparator (or "voter"). Because the same signal may reach several voting receivers at once, the comparator continuously compares the received signals, selects the receiver with the best audio quality, and then routes the receive audio to a dispatcher and/or repeater transmitter. The selection and change-over from one receiver to another is rapid enough to prevent loss of any words. Voting receivers are normally co-located with repeater transmitters or can be located as a standalone receiver in critical coverage areas (see Figure 4).

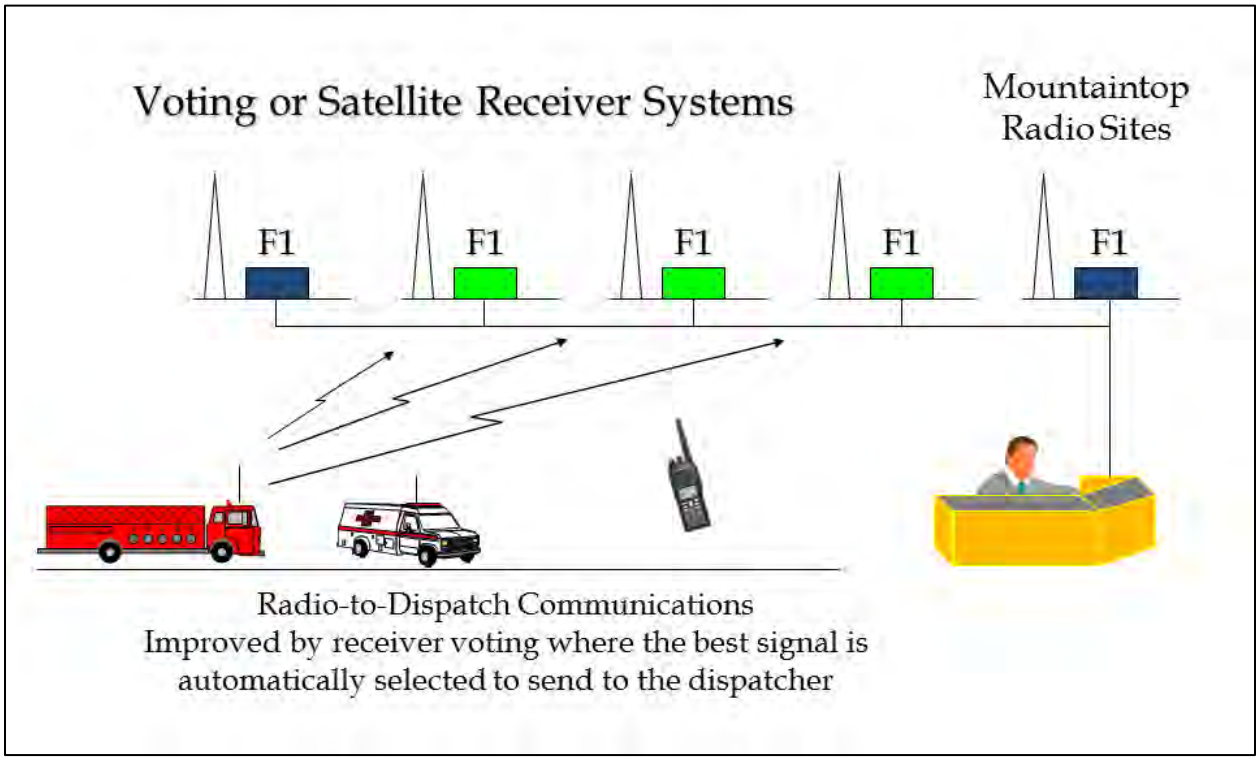

FIGURE 4
Voting Receiver System

It is common for a low-power portable radio to hear a high-power repeater yet be unable to talk to a dispatcher or other radio user on a repeater system because of a weak talk-in signal. A repeater system with numerous voting receivers can greatly improve portable radio communications in the specified operating area of the transmitter.

Currently in Gallatin County, voting receiver systems are used with the Bozeman PD, Law North, and Fire North channels.

Advantages

- The benefit of a voting receiver system is to extend the talk-in or talk-back range from low power radios in the field to the dispatcher and other radio users on the repeater system.
- Radio users do not need to remember to switch between radio sites to communicate with a dispatcher or other radio user when using a single channel voted radio system.

Disadvantages

- A dedicated communications link must connect the dispatch center with each radio site.
- Costs more than constructing multiple standalone repeater systems.
- Requires higher levels of preventive maintenance and operating costs.

With their effectiveness at improving talk-in coverage from field users and simplifying radio and dispatch operations, **ADCOMM believes expanded use of voting receivers would be an extremely beneficial part of any radio system upgrade for Gallatin County.**

Dispatcher-Controlled Repeater Transmitter Steering Systems

A dispatcher-controlled transmitter steering system can be used in conjunction with a receiver voting system. One of the methods of preventing interference with multiple repeaters sharing

the same channel is to allow only one repeater transmitter site to be active at one time. This can be controlled by the dispatcher via a dispatch console (see Figure 5).

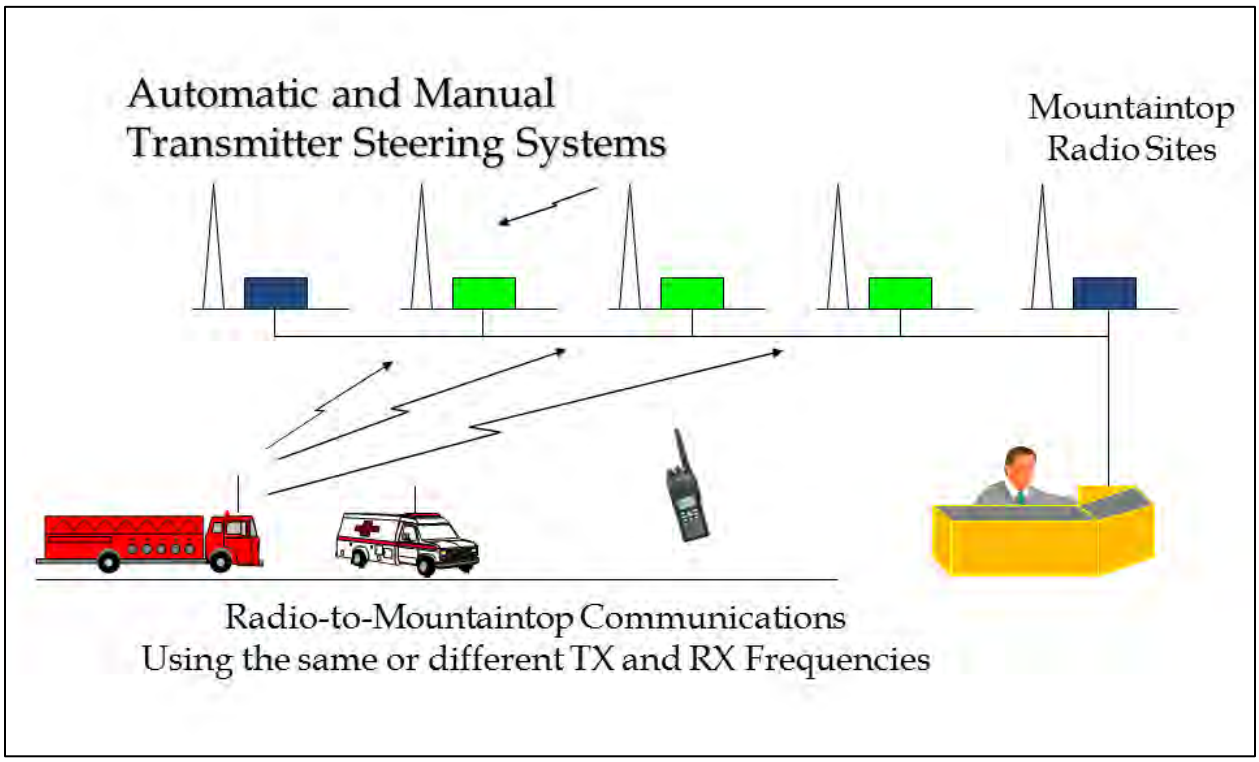

FIGURE 5
Automatic/Manual Transmitter Steering System

Currently, Gallatin County's Fire North channel is a transmitter steering system whereby a 9-1-1 dispatcher can manually select a transmitter at one of five remote sites depending on the location of the incident or field user(s) being contacted. Voting receivers are also used on the Fire North channel to improve talk-in coverage.

Advantages

- Can eliminate the possibility of two users keying up two different repeaters at the same time causing interference between repeaters.
- The dispatcher can select the best repeater transmitter to a single or group of mobile or portable radio users.
- Less expensive than other advanced wide-area coverage systems.

Disadvantages

- A dedicated communications link must connect the dispatch center with each remote radio site.
- One repeater transmitter cannot provide the radio coverage throughout the desired service area. There may be times when two units that need to intercommunicate are separated over enough distance they cannot hear each other because the single site does not provide adequate coverage.
- The dispatcher must know the coverage area of each selectable repeater transmitter and the location of the field unit.

- Dispatchers performing other duties and may be unable to switch the transmitter between the sites to provide the necessary radio coverage.
- As the dispatcher switches the active transmitter between sites, some radio users may miss important communications because the selected transmitter may be weak in their area.

Due to the number of sites that are required to effectively cover Gallatin County or even just the northern portion of the county, expanded use of transmitter steering systems would generally only serve to increase operational complexity while not always being effective in providing the necessary coverage. As such, **ADCOMM generally does not recommend manual transmitter steering systems as a primary system architecture for Gallatin County's updated radio system.** That said, depending on the chosen frequency band and its associated frequency availability, transmitter steering could still be an option for covering southern Gallatin County, albeit less preferred than other options such as simulcast or multicast.

Automatic Transmitter Steering Systems

An automatic transmitter steering system is normally used in conjunction with a receiver voting system. It operates on the theory the best transmitter site to reach a particular mobile or portable radio user was also the last site that received the best signal. When a mobile user calls a dispatcher, the voting system comparator selects the best audio quality receiver. On the assumption the dispatcher will immediately answer the mobile radio user that just called, the transmitter steering system remembers the last receiver the voting comparator selected and automatically selects the transmitter co-located with the voting receiver site. If standalone receivers are deployed, the transmitter steering controller system can be preprogrammed to use a transmitter for a group of receivers in a specified operating area. A default transmitter location can also be selected for an initial "first of day" dispatch (see Figure 6).

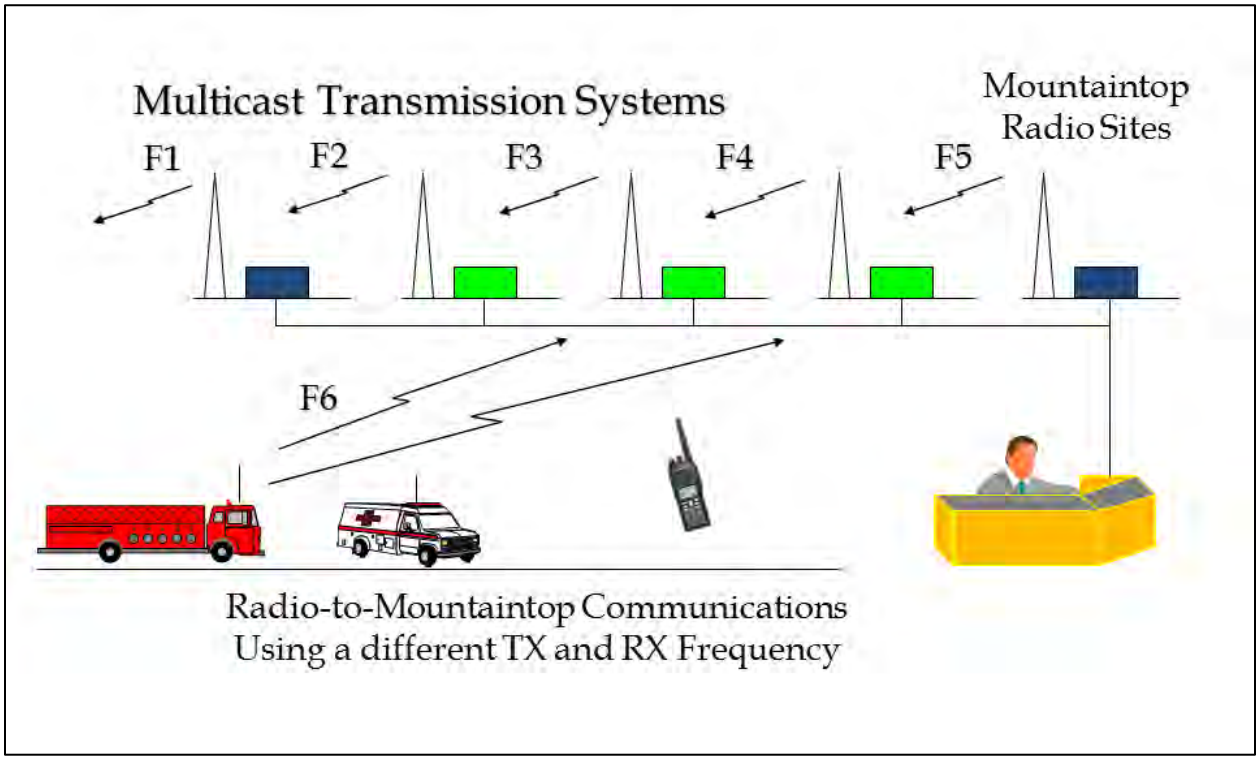

FIGURE 6
Multicast Transmission System

Currently, Gallatin County's Fire North channel is a transmitter steering system that has the ability to automatically select a transmitter site based on the receiver most recently selected by the voting comparator. The default transmitter site for Fire North is Bridger Ridge.

Advantages

- Transmitter steering is a relatively inexpensive way to have the benefits of multiple transmitter sites.
- Less expensive than other advanced wide-area coverage systems.

Disadvantages

- A dedicated communications link must connect the dispatch center with each radio site.
- The comparator could make the wrong decision because of a weak signal received simultaneously by multiple receivers. This could cause the faraway transmitter to be automatically selected and in turn could cause the response from a dispatcher or other radio users to be unreadable.
- Another condition that could cause the wrong automatic transmitter selection is when a second radio user calls a dispatcher just before the dispatcher responds to the first radio user. The first radio user may not hear the dispatcher because of a faraway transmitter being selected by the last transmission of the second radio user.

Transmitter steering systems can be made to work successfully in the right application. A typical application where it will work the best is an area where there is significant transmitter overlap and most of the communications are initiated by the mobile unit to the dispatch center.

Due to the number of sites that are required to effectively cover Gallatin County or even just the northern portion of the county, expanded use of transmitter steering systems would generally only serve to increase operational complexity while not always being effective in providing the necessary coverage. As such, **ADCOMM does not generally recommend transmitter steering systems as a primary system architecture for Gallatin County's updated radio system.** Again, depending on the chosen frequency band and its associated frequency availability, automatic transmitter steering could potentially be an option for covering southern Gallatin County, albeit a less preferred option than simulcast or multicast.

Multicast Transmission Systems

Multicast technology can be used when an abundant number of radio frequencies are available. Multicast is a wide-area radio system configuration using simultaneous transmissions of identical audio on separate frequencies from each transmitter site. Each transmitter is equipped with a receiver, and a receiver voting system is then used to select the best received signal. Multicast technology is a spectrum-*inefficient* technology (see Figure 6).

Multicast is not currently used in Gallatin County.

Advantages

- Dispatchers do not need to worry about transmitter selection.
- Less expensive than simulcast technology.

Disadvantages

- Radio users need to switch channels as they traverse the various radio coverage areas.
- A dedicated communications link must connect the dispatch center with each repeater radio site.

- Costs more than constructing multiple standalone repeater systems.
- Requires higher levels of preventive maintenance.

Practically, there are an insufficient number of VHF frequencies available to deploy multicast in Gallatin County, except perhaps in the southern part of the county. Even at UHF, given the number of channels desired and number of sites required for coverage, there are likely an insufficient number of frequencies available except for southern Gallatin County. As such, **ADCOMM believes multicast is not a practical option for Gallatin County, except perhaps to cover the southern part of the county if simulcast is not viable there.**

Simulcast Transmission Systems

Simulcast technology has been in existence since approximately the 1960s. However, the technology has improved significantly in recent years to the point where the maintenance issues have been reduced to manageable levels. Simulcast technology allows the use of the same frequency to transmit the same information simultaneously from multiple radio sites with overlapping coverage. Simulcast is basically "controlled interference" from multiple transmitters. This is accomplished by having accurate frequency control, audio phase, and amplitude control from the transmitters. A two-way radio system using simulcast technology always uses a receiver voting system. Simulcast uses multiple transmitters usually operating at lower power levels spread throughout the specified service area to improve coverage. Each transmitter is equipped with a receiver, and the receiver voting system is used to select the best received signal (see Figure 7 and Figure 8).

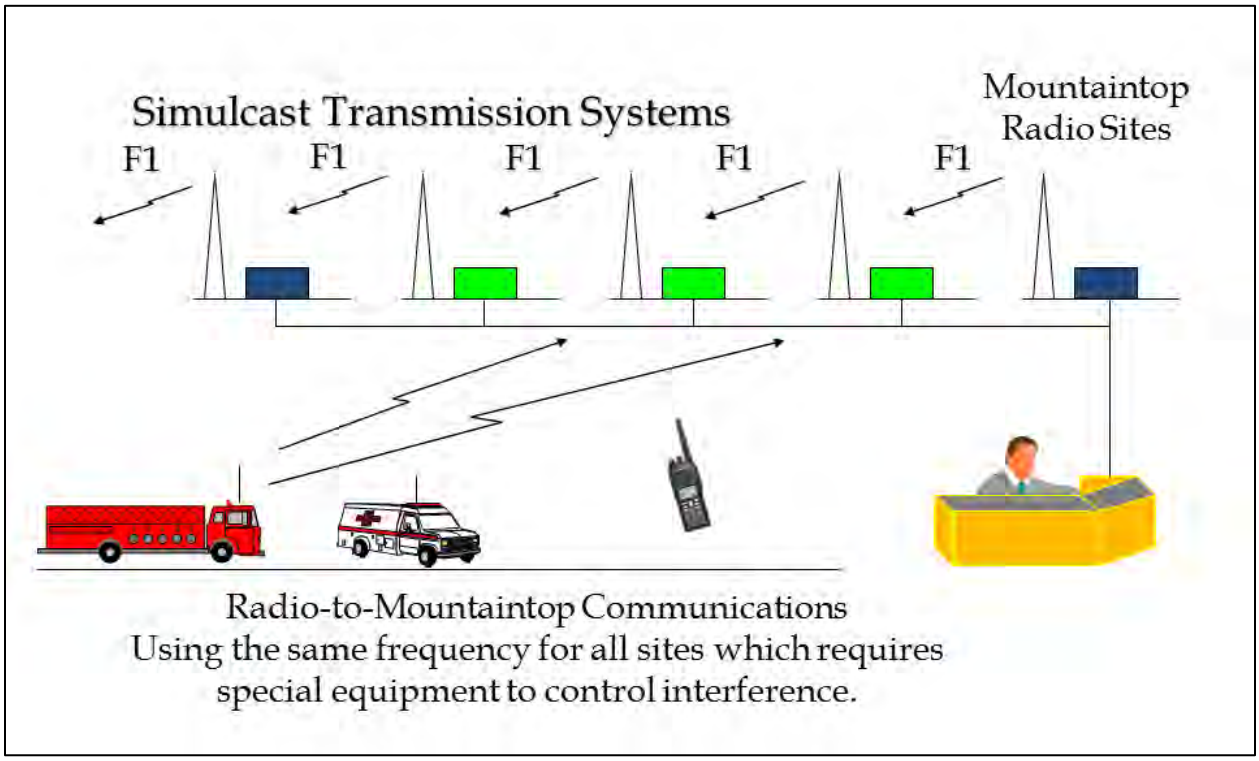

FIGURE 7
Simulcast Transmission System

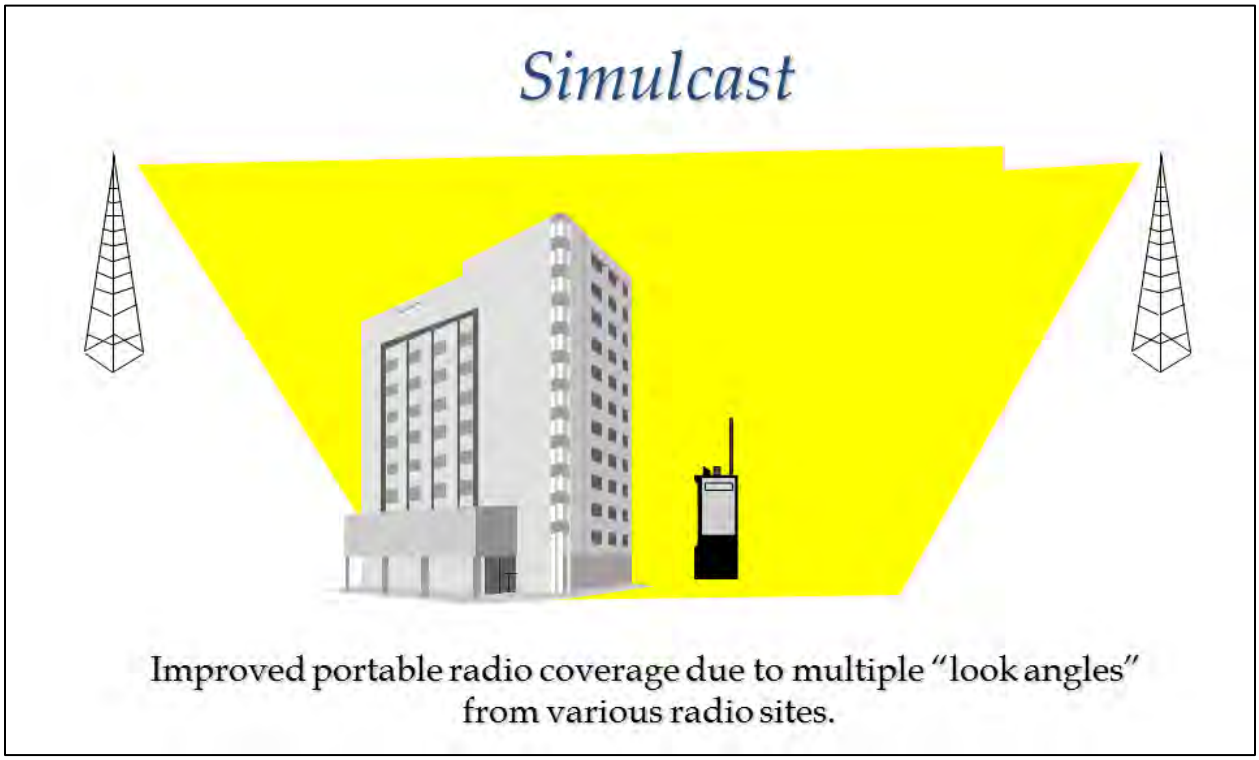

FIGURE 8
Simulcast Coverage

Simulcast technology is a spectrum-*efficient* technology because it allows the use of lower power transmitters thus reducing the amount of signal that travels outside the operational area, and it allows wide areas to be covered by a single frequency. Simulcast is relatively expensive to implement because of the special techniques required. It is used on many public safety systems and virtually all wide-area alphanumeric paging systems, both commercial and private.

To a dispatcher or radio user in the field, simulcast technology acts like a single transmitter with wide-area coverage. Unlike manual or automatic transmitter steering, no dispatcher or radio user intervention is required.

Currently in Gallatin County, simulcast is only used with the alphanumeric paging system.

Advantages

- Dispatchers and radio users do not need to worry about transmitter selection.
- If desired, a single radio channel can have countywide radio coverage.

Disadvantages

- A dedicated communications link must connect the dispatch center with each repeater radio site.
- Costs more than constructing multiple standalone repeater systems.
- Requires higher levels of preventive maintenance.

Due to limited frequency availability, the number of channels desired, and the dramatically improved coverage and ease of user operation, **ADCOMM believes simulcast technology is preferred as a foundation of Gallatin County's upgraded radio system.**

Trunked Radio Systems

Trunked technology was originally developed in the late 1800s and early 1900s as the basis of the public-switched telephone network (PSTN) still used today (circuit switched, not IP[4] based). Trunked radio technology has only been around since approximately 1980, facilitated primarily by the development and use of small and inexpensive microprocessors in mobile radios.

Trunked radio technology is commonly used when a limited number of radio frequencies are available. Trunked technology is spectrum-efficient because trunked systems distribute the radio users among all of the available frequencies automatically. This provides much better utilization of the limited frequency resources as compared to conventional systems, whose channel resources can go unused even when there is a demand for service on other channels. The actual assignment of a frequency is not under the control of the radio user or dispatcher. The term *talkgroup* is used to identify a virtual communications channel. It is possible to have more talkgroups than actual radio frequencies on a trunked radio system. The trunking control computer assigns a talkgroup to a particular frequency for communicating. When a talkgroup is not being used, it does not use system resources. In most cases, a dedicated data channel is used to communicate the channel assignments and special features between the controller and each radio on the trunked system. Originally most trunked systems used proprietary technology, but most recent systems, in particular those that are P25-based, use standards-based technology.

Trunked user radios are typically capable of having between 48 and 1000+ talkgroups, depending on the radio brand and model. Trunked technology is generally expensive to implement and manage. Most trunked systems require regular system controller and software updates, typically unnecessary with conventional systems. Simulcast technology is often also deployed by many trunked system vendors. Trunked technology is used on many public safety systems throughout the world.

None of the Gallatin County's primary radio systems is trunked. However, the Montana "state" radio system, portions of which have been inherited by Gallatin County, is a trunked system.

Advantages

- Spectrum-efficient when limited frequencies are available.
- Dispatchers and radio users do not need to worry about frequency selections.
- Advanced communications features commonly come standard with most trunking systems.

Disadvantages

- A dedicated communications link must connect the dispatch center with each repeater radio site.
- Costs more than constructing multiple standalone repeater systems.
- Requires higher levels of preventive maintenance and upgrades.

Because of the relatively small number of channels needed by users in Gallatin County, the high initial and ongoing costs and complexity of a trunked system likely cannot be justified at this time.

Modulation Modes (Air Interface)

In addition to having multiple frequency band and system architecture options, there are several modulation mode (air interface) options available for LMR systems. The air interface is

[4] IP, or Internet Protocol, is a network and transport protocol used for exchanging packet data over a network, such as the Internet.

the radio-based link between the subscriber units and the base stations and/or repeaters. There are two primary categories of air interface: analog and digital. Analog radio technology has been in use for nearly 100 years and has fundamentally changed very little. On the other hand, digital radio technology has been used in earnest for less than 20 years and comes in many varieties, most of which are not compatible with one another. The following sections describe the most common LMR air interface technologies and their viability with regards to the Gallatin County radio system upgrade project.

Analog FM

Even with significant moves toward digital technology around the country, analog FM is still the most commonly used LMR air interface. Gallatin County's primary dispatch channels operate in analog mode, as do those of most surrounding mutual aid agencies. Widespread use of analog technology facilitates straightforward interoperability.

With the continued move toward digital systems, many manufacturers are dropping support for certain analog systems, particularly trunked analog systems. Conventional analog repeaters, base stations, and subscriber units are still widely available and are generally less expensive than comparable digital versions. A wide variety of analog mobile and portable radios are available at a variety of price-points, with all generally being compatible with one another.

One advantage of analog technology is that, unlike digital, it is compatible with tone/voice alerting systems, although such systems are no longer used by fire and EMS agencies in Gallatin County (the alphanumeric paging system is used for alerting). In addition, even though analog voice signals can get "scratchy" in weak coverage areas or become difficult to understand when interference is present, oftentimes a transmission can still be understood, or at the very least the users know a transmission was attempted and a retry can be requested. This often is not the case with digital systems.

Limited encryption options are available for analog radio systems and are often not standards-based. Range and intelligibility are often impacted with analog encryption systems. P25 digital is a much better option for encrypted communications.

If minimizing costs is a primary factor and encryption and/or trunking is not needed, analog FM could be an appropriate technology for some or all radio channels in Gallatin County.

Project 25 Digital

Project 25 is a suite of open standards for digital two-way radio communication typically used by public safety agencies in North America. Development of the standards started in the early 1990s and continues today. P25 is intended to ultimately provide a foundation for interoperability. However, its use is not mandated, and it should not be considered a "silver bullet" for interoperability. Users must not only have P25-capable equipment but their equipment must also operate on the same frequency band(s) as the agencies they intend to interoperate with. For example, a VHF P25 radio *cannot* communicate with an 800 MHz P25 radio, even though they are both P25-capable (unless, of course, multi-band radios are used). As P25 infrastructure is deployed in more areas, interoperability is expected to improve. However, it will still be many years, if ever, before P25 reaches all parts of the country, particularly in rural areas. This is primarily due to the significant expense of replacing analog infrastructure and subscriber equipment with P25 equipment.

There are two primary variants of P25: *Phase 1* and *Phase 2*. P25 Phase 1 uses a 12.5 kHz narrowband-compliant *frequency division multiple access* (FDMA) digital air interface, whereby

each channel supports a single talk-path. P25 Phase 2 is a newer technology that uses a 6.25 kHz-equivalent narrowband-compliant two-slot *time division multiple access* (TDMA) digital air interface, which support two talk-paths in each 12.5 kHz channel.

At least a basic level of compatibility exists between all vendors' P25 equipment, allowing end users to have a choice when selecting equipment. However, many vendors also offer proprietary "features," which if relied upon can consequently reduce equipment choices. All P25 Phase 2 radios are capable of also operating in Phase 1 mode, providing backward compatibility if configured properly. Further, all P25 radios are capable of analog operation. With proper equipment programming, user training, and procedures, this can reduce issues interoperating with surrounding agencies that are still using analog systems.

Digital Audio

P25 systems employ digitally encoded audio using a process known as *vocoding* ("voice encoding"). Compared to a traditional analog system, digitally vocoded audio improves the spectral efficiency and thus the capacity of the system, while also enabling features such as background noise cancellation. One of the primary advantages of P25 is the ability to use standards-based encryption, with no loss in audio quality or range compared to unencrypted operation. By comparison, analog encryption techniques normally result in a reduction in audio quality and/or coverage.

Because of the way it reproduces audio, digital systems sound *different* than analog systems. Whether it is better or worse than analog is subjective, but suffice it to say that it may take some users a short period of time to get used to the difference. In addition, because there is no discernable background noise or "static" in a digital system, if a user keys his or her radio but does not speak, other users may not know the channel is actually in use because it will remain silent. In addition, there is no "squelch tail" with digital systems as there often is with analog repeaters.

Unlike analog systems, there generally is not a gradual degradation in service quality when approaching the edge of coverage with a digital P25 system. Similar to digital cellular telephones, coverage/audio quality is usually very good until hitting a sharp drop off to very poor service or even out of range. Digital systems such as P25 are often able to maintain high quality audio at greater distances from radio sites than comparable analog systems, which can result in users experiencing "better" overall coverage.

An important downside of P25 to consider, particularly in mountainous environments such as those found in southern Gallatin County, is its susceptibility to *multipath* and other types of interference. Because reliable decoding of the digital signal is required to recover the transmitted audio, any corruption of the signal can result in garbled audio or no audio whatsoever. Multipath interference, often resulting from signals reflecting off of hills, canyon walls, or even multiple simulcast transmitters, can be highly destructive to P25 signals. Although analog signals are affected by such interference as well, it is often still possible to understand the message being transmitted through the distortion.

Other Considerations

P25 radios are more expensive than comparable analog-only radios. Many grants, however, require the purchase of P25-capable radios. While this may not be an issue for radios purchased under a grant, if additional radios are needed at some point in the future and grant funding is not available, it may cost significantly more to purchase the same model(s) of P25 radio than it would have for comparable analog-only radios.

Currently in Gallatin County, only the trunked "state" system operates in P25 mode. This system is not generally used for day-to-day dispatch operations for Gallatin County users, however.

If a trunked system or use of encryption is desired, P25 digital (either Phase 1 or Phase 2) would be the most appropriate technology for Gallatin County.

DMR

Digital mobile radio (DMR) is an open digital radio standard specified for professional mobile radio users developed by the European Telecommunications Standards Institute (ETSI) and is used throughout the world. The standard was originally ratified in 2005. DMR was designed as a low-cost, entry level radio system for commercial use. It is typically targeted at the professional industrial and business markets and was not designed for mission-critical communications such as public safety. DMR is available for conventional operation ("Tier II") as well as for trunked operation ("Tier III").[5]

DMR uses a 6.25 kHz-equivalent narrowband compliant two-slot TDMA air interface (12.5 kHz per channel), ***but it is not compatible with P25***. DMR systems are intended to have low complexity, low cost, and offer competition between radio manufacturers, facilitated by the open standard. DMR also offers advanced capabilities such as location-based (GPS) tracking, text messaging, and allows for third-party development of other applications. As with P25, however, some manufacturers have added proprietary "features" that may be incompatible with other vendors' radios.

DMR systems typically do not offer the redundancy or other important features that are available with public safety-grade systems such as P25. For instance, the primary DMR suppliers do not offer simulcast capability. Also, the ETSI standard does not itself support encryption, although some vendors have implemented encryption using standard algorithms. DMR portable and mobile radios are not normally designed to have the same survivability (e.g., hardening, waterproof) and ergonomics as many public safety radios. Further, options such as noise canceling microphones are not typically available, which can be critical for life-safety operations in high-noise environments.

Because it was not designed for mission-critical public safety communications, **ADCOMM does not recommend Gallatin County consider DMR for its radio system upgrade.**

Backhaul Options

An important consideration for an LMR system is the connectivity between remote radio sites and the dispatch center. Various backhaul technologies are available, each having its own distinct advantages and disadvantages, and are described in this section. Importantly, the type(s) of backhaul employed can have an impact on the overall reliability of the system. Depending on what makes most sense for the individual radio sites, it is possible that a combination of backhaul methods could be used for the upgraded Gallatin County radio system.

Leased Lines

Leased lines, sometimes referred to simply as *copper*, *telco circuit*, *phone line*, or T1, are dedicated communication circuits typically provided by a landline telephone company used for connecting remote radio sites to a centralized location, often a dispatch center. Such circuits are avail-

[5] One of the most popular DMR products in the United States is Motorola's *MOTOTRBO™* product.

able with different capacities. Leased lines are not always available at remote mountaintop sites, however.

The primary advantage of using leased lines is that they often have low up-front costs and can often be installed in a relatively short period of time. However, the ongoing costs, depending primarily on line distance and capacity, can be high. In addition, leased line reliability is not always adequate for mission-critical communication systems. The maintenance and repair of such lines is out of the control of the customer; the service provider must be relied upon to restore outages. In addition, leased lines are not always suitable for implementing simulcast technology.

Licensed Microwave

FCC-licensed private point-to-point microwave systems can provide highly reliable, high-bandwidth connections to remote radio sites. The most common microwave bands include 6 GHz, 11 GHz, and 18 GHz. Gallatin County currently also operates some 23 GHz links. Microwave systems require line-of-sight between path endpoints, which can pose significant challenges in some areas, particularly in southern Gallatin County. In addition, microwave paths are distance-limited, with higher frequencies being limited to shorter paths. Further, higher frequency microwave paths, including those at 18 and 23 GHz, can be negatively impacted by rain and snow, causing outages or reduced performance.

Licensed microwave has the advantage that it is controlled entirely by the licensee and is afforded interference protection from other microwave users. Reliance on a third party is not necessary for repairs and maintenance. In addition, with proper system design, such as use of loop protection and/or *monitored hot-standby* (MHSB), license microwave can provide robust redundancy in the event of a partial system outage. The stability of microwave makes it a good choice to use with a simulcast system. Since microwave radios operate continuously, their use at alternative-power (e.g., solar) sites can be challenging due to their power supply requirements.

Upfront costs can be high for licensed microwave equipment. However, ongoing costs are minimal, and it may even be possible to generate revenue from spare capacity or trade for other services.

Unlicensed Microwave

Unlicensed microwave, while similar in many respects to *licensed* microwave, does not afford any interference protection from other users. As a result, its reliability is impossible to guarantee, especially since the interference environment can change over time. Many unlicensed microwave bands, including 2.4 GHz and 5.8 GHz, are shared with consumer devices such as wireless routers, cordless phones, and even Bluetooth devices.

Although unlicensed microwave equipment can be less expensive than licensed equipment and there is not any coordination or licensing costs, its use is not generally recommended for mission-critical communication systems.

Fiber

Fiber optic cables are able to provide high-capacity communications connectivity over both short and long distances. The chief impediment to using fiber is its installation, which can be cumbersome and expensive, particularly when installed underground. Where it is already in place, fiber can be a good option for connecting radio sites and dispatch centers. However, it may not be practical to install new fiber to remote mountaintop radio sites. The stability and bandwidth capacity of fiber make it suitable for simulcast operations.

Fiber connections are generally reliable; however, unlike microwave they are subject to "back-hoe fades," where an underground cable is inadvertently cut by digging. Such cuts can take many hours (or longer) to repair. In addition, fiber cables and telephone lines installed above ground can be susceptible to natural and manmade disasters such as fires.

RF Links

Point-to-point RF links, using radios in non-microwave frequency bands such as VHF or UHF, can be used for connectivity to remote radio sites. Such links are relatively low capacity compared to microwave and fiber since a separate link is needed for each remote base station or repeater. Although RF links can potentially be operated over long distances, frequency availability can make this difficult in some areas. The additional equipment associated with an RF link also increases the number of failure points in the system.

In areas where phone lines and fiber are not available and microwave is impractical, RF links can be a low capacity yet effective, moderate-cost alternative.

RF Control Stations

The least desirable method of controlling remote repeaters is the use of RF *control stations*. These are essentially mobile radios configured to access the radio system as any other subscriber would by simply transmitting on a repeater's receive/input frequency and listening on the repeater's transmit/output frequency (control stations cannot be used to access simplex base stations). Because they simply act as another subscriber radio, control stations do not offer *console priority* capability, whereby a dispatcher can override another user on the system, as may be necessary in the event of a stuck field user's microphone. Leased lines, microwave, fiber, and RF links generally do offer console priority.

Control stations are relatively inexpensive to implement, although in some cases it may be necessary to install them at a remote location that is able to access the necessary repeater(s). Such is the case with the existing control station at Big Sky, which is used to access the Andesite and Eaglehead south repeaters. Depending on how they are implemented, control stations can increase system complexity and the number of failure points.

Other Technology Considerations

In addition to the primary system technology options detailed above, some additional options and technologies worth noting are included in this section.

Shared-Use Channels

In the case of a conventional system (as opposed to a trunked system), because of the limited availability of new frequencies, the deployment of *shared-use* channels would improve radio resource efficiency, in particular for tactical and/or on-demand needs. For example, today in southern Gallatin County, the primary dispatch channel is a shared-use channel, used by both fire/EMS and law enforcement. While perhaps not always ideal, shared-use channels can be beneficial in some instances since it facilitates straightforward interoperability between agencies that are all using a common radio channel.

Vehicular Repeaters

A *vehicular repeater* is a device installed in a vehicle and connected to a mobile radio that acts as a repeater for a relatively small area around the vehicle, allowing one or more nearby users to use portable radios to "talk through" to another radio channel. This allows use of portable radios in areas where only mobile coverage is available.

Vehicular repeaters can be operated in a *cross-band* configuration, whereby a portable radio on one frequency band (e.g., UHF) is used to talk through to a channel on another frequency band (e.g., VHF). This configuration simplifies the necessary in-vehicle equipment configuration. It is also sometimes possible to operate an *in-band* vehicular repeater, whereby the portable radio and mobile radio operate in the same band (e.g., both VHF). This configuration normally requires additional equipment, such as filters, to be installed in the vehicle. There may also be restrictions on which channels can be accessed due to frequency separation requirements of the repeater. If a cross-band configuration is used, portable radios would of course need to be capable of operating in the associated frequency band (e.g., UHF in the aforementioned example).

Regardless of the band configuration, caution should be taken with the use of vehicular repeaters. Interference and device conflicts can occur when more than one vehicular repeater is enabled in the same vicinity. Manufacturers have implemented algorithms to mitigate such problems; however, conflicts might still occur, so their use should be coordinated and users be made aware that conflicts can occur. The devices should be disabled or powered off when not in use.

In cases where portable coverage is needed but only mobile coverage is available, ADCOMM believes limited use of vehicular repeaters, particularly in less populated areas, could be beneficial in Gallatin County.

FirstNet

FirstNet is an independent authority within the National Telecommunications and Information Administration (NTIA) of the Federal Government, created under the Middle Class Tax Relief and Job Creation Act of 2012. The purpose of FirstNet is to establish, operate, and maintain a nationwide interoperable public safety broadband communications network. To fulfill these objectives, Congress allotted $7 billion and 20 MHz of radio spectrum in the 700 MHz band to build the network. It is widely recognized, however, that significant additional funding, with varying estimates between $10 billion and $50+ billion, will be needed to fully construct the network.

The FirstNet network is intended to be a standards-based *Long-Term Evolution* (LTE) network—the same technology employed in many commercial "4G" cellular networks. Initially, the LTE network will provide wireless data service only; there will be no standards-based voice or push-to-talk capability. The vision, however, is to eventually be able to support push-to-talk and other voice traffic, using technology such as *Voice over LTE* (VoLTE). FirstNet is essentially a public safety cellular system that would provide similar coverage as commercial cellular systems provide.

Except for some very small initial build-outs around the country, the FirstNet system does not exist today. If successful, it will take many years and significant additional funding to fully construct the network. Due to efficiencies of scale and usage demand, it is anticipated that the network will first be constructed in larger cities, followed by smaller cities and eventually rural areas.

Because of the lack of funding certainty and anticipated construction timeframes, ADCOMM does not believe FirstNet will be available in Gallatin County any time in the foreseeable future.

Summary

Although there are a variety of LMR technology options available, ADCOMM believes there are two primary options worth considering for Gallatin County.

Given the relatively small number of channels needed in Gallatin County, it is not believed that the expense and complexity of a trunked system is warranted. As such, a multi-channel, conventional simulcast system is believed to be most appropriate as the foundation for Gallatin County's updated radio system, perhaps augmented with some combination of standalone repeaters, transmitter steering, and/or multicast to cover outlying areas. A move to simulcast would provide significantly improved coverage for users as well as simplified operation for both field users and dispatchers alike.

One of the two primary options would be to continue to use VHF for the new system, which would allow many of the existing subscriber radios to be reused, at least for analog operation. If P25 is used instead, at least some subscriber radios would need to be upgraded or replaced. In addition, the limited availability of additional VHF frequencies may impact the number of channels that could actually be deployed.

The second alternative, primarily to overcome the limited availability of VHF frequencies, would be to deploy the new system at UHF, which has more available frequencies in Gallatin County. Unfortunately, a move to UHF would require the purchase of all new mobile and portable radios, significantly increasing overall project costs.

Final Report

Gallatin County 9-1-1 Radio System Engineering Study High-Level Radio System Design and Strategic Directions

Prepared for
Gallatin County 9-1-1

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Date Prepared
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Acronyms and Abbreviations

ADCOMM	ADCOMM Engineering Company
BDH	Bozeman Deaconess Hospital
EMS	emergency medical services
EOC	Gallatin County Emergency Operations Center
ERP	effective radiated power
FCC	Federal Communications Commission
Gallatin 9-1-1	Gallatin County 9-1-1
GPS	global positioning system
IP	Internet Protocol
MHz	megahertz
MHSB	monitored hot-standby
MSU	Montana State University
OTAP	over-the-air programming
OTAR	over-the-air rekeying
P25	APCO Project 25
RF	radio frequency
UHF	ultra high frequency
VHF	very high frequency
WSCA	Western States Contracting Alliance

High-Level Radio System Design

Executive Summary

This report describes a radio system option based on the current state report, user input, technology review, and radio coverage analysis. The final recommendation is for a new radio system using UHF frequencies in the Gallatin Valley and Bozeman areas, VHF frequencies in the extreme north and south areas, and a mix of standalone, simulcast, and multicast technologies chosen to optimize the system performance at the lowest cost for each type of terrain and use. The system would be a mix of Project 25 digital technologies and narrowband analog depending on what is appropriate for the terrain and use. The estimated total system cost is approximately $21,000,000.

The level of detail in this phase of the project was defined by the project scope to be adequate to define a budget and to define the system for future detailed design efforts when the Gallatin County public safety users decide to move forward with funding.

Introduction

Project Purpose and Scope

In February 2014, ADCOMM was contracted by Gallatin County 9-1-1 to perform a radio system study. In general, the purpose of this project was to determine the state of the existing public safety two-way radio communication systems in use by stakeholders in the county, identify the operational needs of the radio systems' users, identify potential technologies and their applicability to a replacement/upgraded radio system, and develop a high-level system design for such a system, followed by solution selection and implementation preparation.

Based on this contract, the project consists of the following phases:

1. **Phase One: Information Gathering and Education.** The deliverables of Phase One are the Current State Report, the User Needs and Gap Analysis, and the Technology Review. The purpose of this phase is to generate information needed by ADCOMM and by stakeholders to fully understand the existing systems, both for comparison purposes and to identify the needs of the systems' users.

2. **Phase Two: Solution Development.** Using the information gathered during Phase One, Solution Development's deliverable is a list of potential solutions, with rough order of magnitude costs, to the challenges faced by Gallatin County's radio systems. The end of Phase Two is a joint meeting to discuss and evaluate each of the potential solutions, with the County deciding on one or more potential solutions for further development. Selection of the solution at this stage begins to set the strategic direction.

3. **Phase Three: Strategic Direction and High-Level Design.** During Phase Three, the selected solution is developed further to yield a strategic direction document and a high-level design ***(this report)***. The solution will be divided into a series of implementable modules, with estimated costs, implementation time, and impact to the voice systems identified. The High-Level Design will be sufficient to drive the detailed engineering needed as the first step toward acquisition and implementation.

4. **Phase Four: Final Study Report.** The Final Study Report is a combination of all the deliverables created in the project with a summary and explanatory text for use in grant justifications and budget discussions. ADCOMM anticipates an in-person delivery of the final report to Gallatin County decision makers and stakeholders at a combined meeting.

5. **Phase Five: Solution Selection and Implementation Preparation.** Following the Final Study Report release, stakeholders will meet to identify specific solutions for implementation. These solutions will be further developed to produce engineering drawings, detailed system price estimates, and technical specifications for use in procurement and implementation. Solution development will be for voice radio system changes only.

Note that the following are not included in the scope of work for the current project: technical procurement reviews and assistance, vendor selection, technical support during contract negotiations, implementation engineering services, and/or project management.

High-Level Radio System Design

Following the earlier project phases, the High-Level Radio System Design describes the county's ultimate radio system, or the desired end-state. The High-Level Design is not a fully engineered solution but rather a guiding document for the full set of engineering documents needed for procurement and implementation. The High-Level Design includes the following elements:

1. Recommended radio sites
2. Transport recommendations, as applicable
3. Composite and individual coverage maps for each radio site
4. Overall channel plan and per-site channel plan, as applicable

The direction taken for the High-Level Design was based on the identified user needs, system requirements, available technology options, and feedback from the project stakeholders. This was done over a series of meetings with the stakeholders describing the technology, system options, and the final consensus approach.

Recommended Voice Radio System

Based on the technology options identified in the Technology Review report, in conjunction with the identified needs of the users and feedback provided by project stakeholders, ADCOMM recommends the following for Gallatin County's upgraded public safety radio system:

1. Continue operation of all systems in *conventional* (non-trunked) mode, appropriate for the relatively small number of channels needed.

2. Deploy a three-channel *simulcast and voted-receive* system for **City of Bozeman** police, fire, and EMS users, consisting of three simulcast transmit sites and nine voted-receive sites. Under normal circumstances, one channel would be used for Bozeman Fire/EMS, one for Bozeman PD, and one for use as needed (see Figure 1, "Bozeman Simulcast").

3. Deploy a three-channel *simulcast and voted-receive* system for **north county** law enforcement, fire, and EMS users (generally non-Bozeman), providing coverage north of the Gallatin Range and consisting of 10 simulcast transmit sites and 15 voted-receive sites. Under normal

circumstances, one channel would be used for Fire/EMS, one for law enforcement (including GCSO and Belgrade PD), and one for use as needed (see Figure 2, "North Simulcast").

4. Deploy one shared-use *multicast and voted-receive* channel for **south county** law enforcement, fire, and EMS users, providing coverage generally between Spanish Creek Road and West Yellowstone, including Big Sky, consisting of five transmit sites and six voted-receive sites (see Figure 3, "South Multicast").
5. Deploy one standalone repeater at Hyalite Canyon for shared-use by law enforcement, fire, and EMS users ("Hyalite").
6. Deploy one standalone repeater in the vicinity of Hatfield Mountain for shared-use by law enforcement, fire, and EMS users in the extreme north portions of the county ("Hatfield").
7. Deploy the Bozeman, North, Hyalite, and Hatfield systems using Project 25 (P25) Phase 1 digital technology to facilitate encrypted-voice capability and provide improved coverage relative to narrowband analog.
8. Deploy the South system using analog FM technology to maintain straightforward interoperability with other agencies in the Canyon/Big Sky/Yellowstone areas and to avoid some of the coverage problems associated P25 digital in canyons due to multipath.
9. Deploy the Bozeman and North systems using UHF frequencies (450 to 470 MHz) to take advantage of the lower RF noise environment in this band, improved simulcast optimization control, and to allow for a sufficient number of channels to be licensed.
10. Deploy the South system using VHF frequencies to maintain straightforward interoperability with other agencies in the Canyon/Big Sky/Yellowstone areas and to take advantage of the improved non-line-of-sight coverage of VHF frequencies compared to UHF.
11. Deploy the Hyalite and Hatfield standalone repeaters using VHF frequencies, if possible, to maximize coverage in the rural (and relatively low RF noise) areas served by these sites.
12. Replace other existing standalone repeaters (e.g., fire tactical, search-and-rescue, etc.), and deploy additional as necessary, with stations that will continue to be manufacturer-supported for the foreseeable future, using existing frequencies.
13. Deploy licensed microwave links using IP-based technology to all new sites, as possible. For low capacity and/or alternative-power sites, use of UHF links may be sufficient in place of microwave.
14. Deploy dual-band (VHF-UHF) user radios to accommodate the dual-band nature of the radio system infrastructure.

Because many of the new systems are proposed to be deployed in the UHF frequency band, which is not currently used by most Gallatin County users, new subscriber radios (mobiles and portables) that are capable of operation on these frequencies will be needed for most agencies. Further, since many areas will continue to employ VHF infrastructure, and to maintain interoperability with surrounding mutual aid agencies, dual-band radios will be essential in many circumstances.

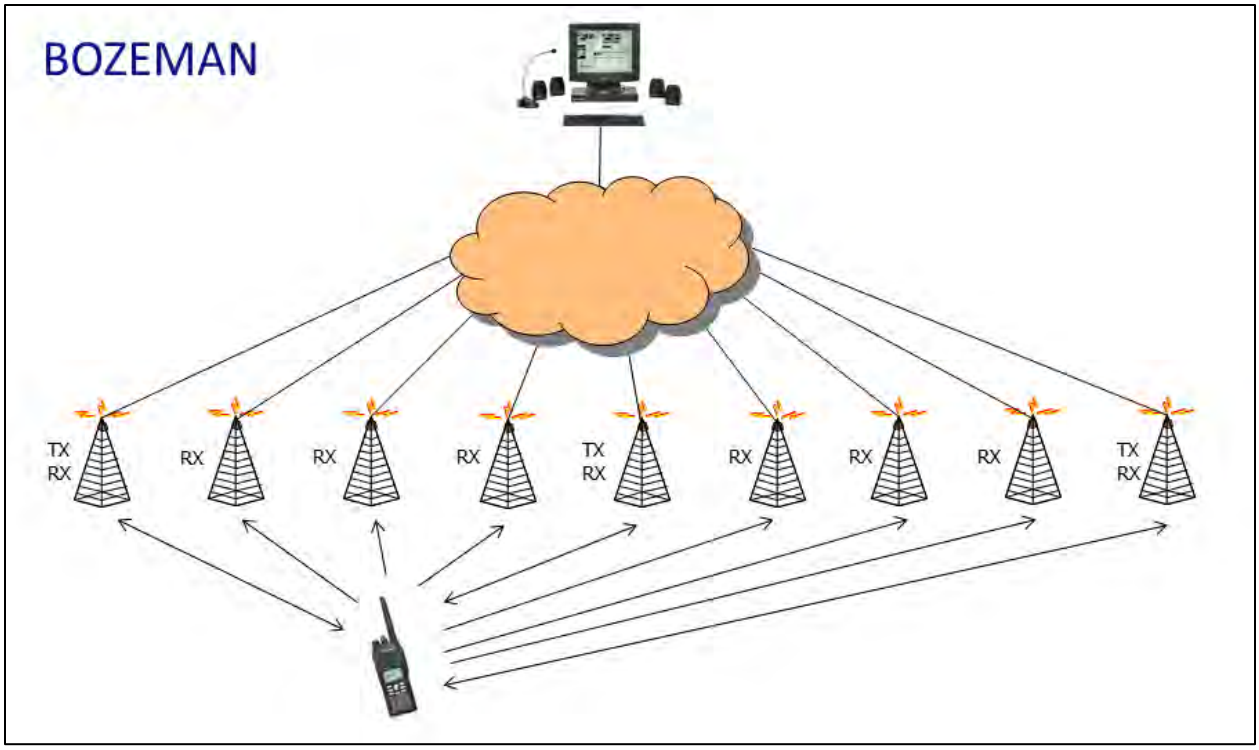


FIGURE 1
Proposed Nine-Site Bozeman Simulcast/Voted System Configuration (one of three channels)

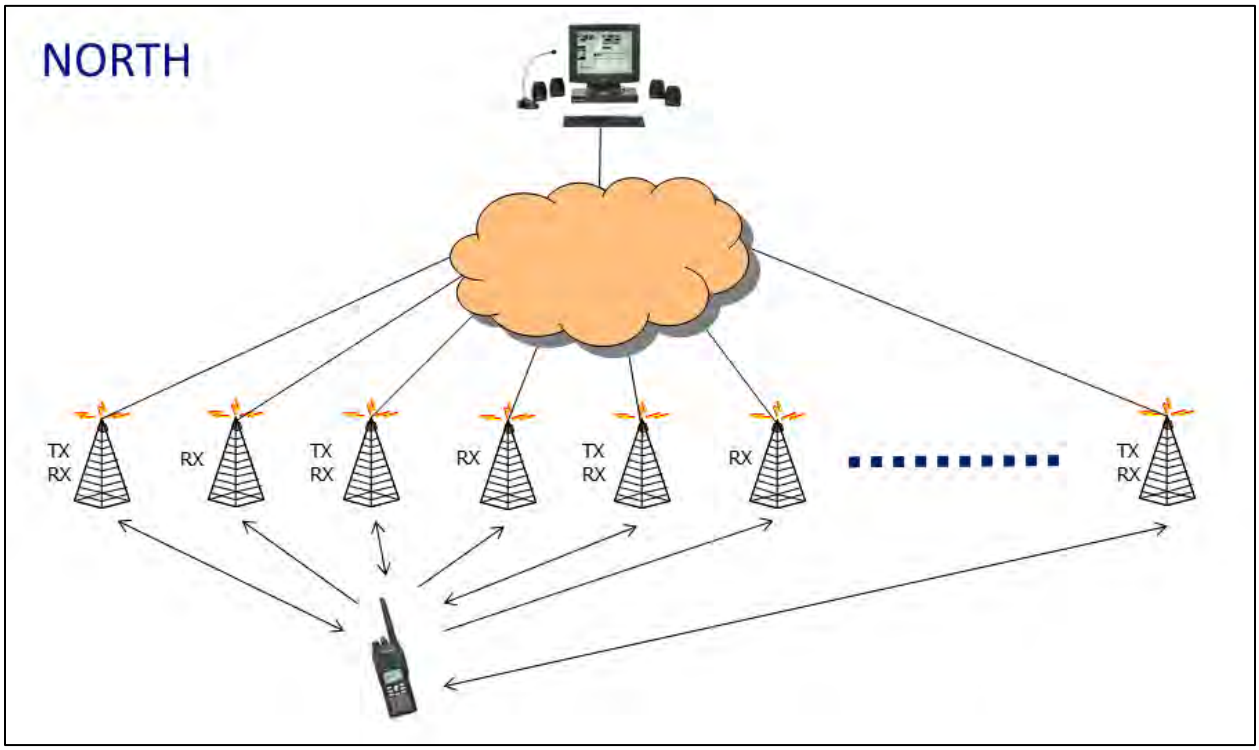


FIGURE 2
Proposed 15-Site North Simulcast/Voted System Configuration (one of three channels)

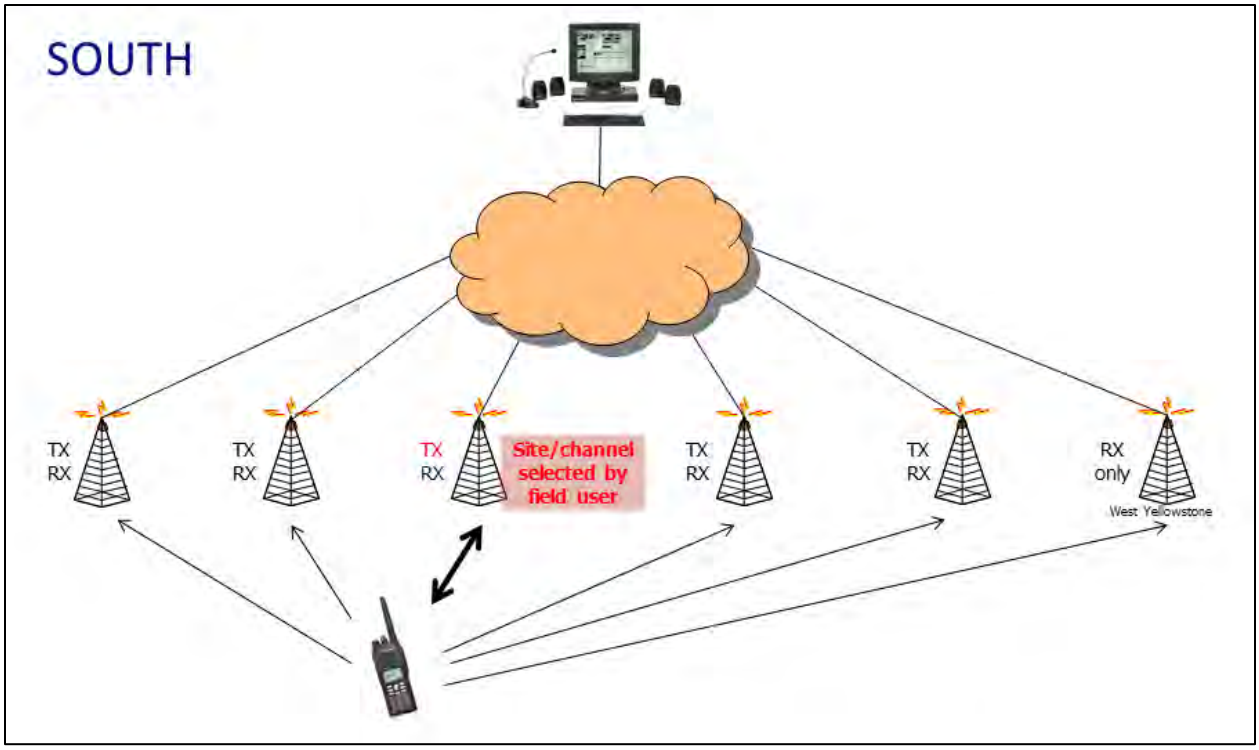


FIGURE 3
Proposed Six-Site South Multicast/Voted System Configuration

Proposed Sites

To leverage existing assets and favorable site agreements, ADCOMM recommends deploying the proposed radio systems using existing Gallatin County radio sites to the extent possible. However, in some cases, additional or relocated sites are recommended. The following sites are recommended for the proposed radio system.

1. 9-1-1 Center
   45° 41′ 43.2″ N, 111° 05′ 01.4″ W[1]
2. Belgrade Water Tower
   45° 46′ 24.3″ N, 111° 10′ 07.0″ W
3. Big Sky Resort
   45° 16′ 24.7″ N, 111° 23′ 41.1″ W
4. Bozeman Deaconess Hospital (BDH), new building
   45° 40′ 06.3″ N, 111° 01′ 24.9″ W
5. Bozeman High School
   45° 40′ 57.5″ N, 111° 03′ 11.5″ W
6. Bridger Ridge
   45° 49′ 00.6″ N, 110° 55′ 47.0″ W

[1] All listed site coordinates at NAD83.

7. Bridger Woods / Green Mountain
   45° 41′ 48.3″ N, 110° 53′ 22.3″ W
8. Cinnamon Mountain
   45° 07′ 48.5″ N, 111° 16′ 06.8″ W
9. Cobleigh Hall (MSU)
   45° 39′ 59.6″ N, 111° 02′ 45.6″ W
10. Eaglehead
    45° 13′ 26.0″ N, 111° 07′ 23.2″ W
11. Four Corners (fire station)
    45° 40′ 32.6″ N, 111° 11′ 28.4″ W
12. Gallatin County Courthouse
    45° 40′ 46.7″ N, 111° 02′ 30.4″ W
13. Gallatin County Emergency Operations Center (EOC)
    45° 41′ 20.2″ N, 111° 01′ 59.0″ W
14. Garnet Mountain
    45° 25′ 35.6″ N, 111° 12′ 24.4″ W
15. Hatfield Mountain
    46° 05′ 24.2″ N, 110° 58′ 31.7″ W
16. High Flats
    45° 38′ 15.9″ N, 111° 16′ 04.7″ W
17. Horse Butte
    44° 45′ 04.0″ N, 111° 11′ 45.1″ W
18. Hyalite Canyon
    45° 26′ 47.7″ N, 110° 56′ 33.3″ W
19. Kenyon Water Tower
    45° 39′ 42.3″ N, 111° 01′ 31.6″ W
20. Law and Justice Center
    45° 40′ 24.9″ N, 111° 03′ 32.4″ W
21. Lombard/Toston
    46° 07′ 00.6″ N, 111° 22′ 51.5″ W
22. Madison River (Montana Rail Link)
    45° 46′ 03.7″ N, 111° 34′ 44.8″ W
23. Manhattan (Little Apple Technologies)
    45° 51′ 22.0″ N, 111° 20′ 03.2″ W
24. Nixon Ridge
    45° 57′ 55.7″ N, 111° 20′ 18.9″ W
25. Three Forks (American Tower)
    45° 52′ 38.5″ N, 111° 32′ 04.6″ W

26. Timberline
    45° 39′ 31.7″ N, 110° 48′ 25.0″ W
27. West Bozeman (Crown Castle)
    45° 40′ 23.3″ N, 111° 06′ 22.8″ W
28. West Yellowstone (fire station)
    44° 39′ 30.4″ N, 111° 06′ 24.0″ W
29. Willow Creek (fire station)
    45° 49′ 38.1″ N, 111° 38′ 43.2″ W

In addition to the remote radio sites and equipment, simulcast control and voting equipment will be needed for the various systems. Depending on the particular vendor chosen, it is anticipated that this equipment will generally consist of several racks of equipment. It is recommended that this equipment be installed at a readily accessible location, such as the 9-1-1 center, for maintenance purposes.

Channel Plan

Each of the proposed simulcast, multicast, and standalone subsystems will use different radio sites to provide the necessary coverage. The sites anticipated to be included for each subsystem are detailed in this section.

Bozeman Simulcast (three channels)

Transmit and Receive Sites

1. 9-1-1 Center
2. EOC
3. Kenyon Water Tower

Receive-only Sites

1. Bozeman Deaconess Hospital
2. Bozeman High School
3. Cobleigh Hall (MSU)
4. Courthouse
5. Law and Justice Center
6. West Bozeman

North Simulcast (three channels)

Transmit and Receive Sites

1. 9-1-1 Center
2. Belgrade Water Tower
3. Bridger Ridge
4. Bridger Woods/Green Mountain
5. High Flats
6. Kenyon Water Tower
7. Lombard/Toston
8. Madison River
9. Nixon Ridge
10. Timberline

Receive-only Sites

1. Four Corners
2. Law and Justice Center
3. Manhattan
4. Three Forks
5. Willow Creek

South Multicast (one channel)

Transmit and Receive Sites

1. Big Sky Resort
2. Cinnamon Mountain
3. Eaglehead
4. Garnet Mountain
5. Horse Butte

Receive-only Sites

1. West Yellowstone

Hyalite Canyon Standalone (one channel)

Transmit and Receive Sites

1. Hyalite Canyon

Hatfield Mountain Standalone (one channel)

Transmit and Receive Sites

1. Hatfield Mountain

Table 1 summarizes the proposed channel plan by site and channel, indicating how many transmitters and receivers are needed for each.

Coverage Predictions

Composite computer-generated coverage predictions for the proposed Gallatin County radio system can be found in Appendix A. Individual-site coverage predictions can be found in Appendix B. The Longley-Rice propagation model was used to make the computations. Composite "talk-out" (that is, from the fixed radio sites—including dispatch—to field units) and "talk-in" (from field units into the system) plots are included for each proposed subsystem. The predictions did not take into account any ambient interference from other radio systems or man-made obstacles in the desired service areas, as these can be highly variable.

It is important to note that there are limitations to the accuracy of computer-generated coverage predictions due to resolution and accuracy limitations of the terrain and land-use ("clutter") databases employed, along with multipath factors, propagation conditions, and other approximations inherent with the propagation model employed. As such, caution should be used when interpreting the accuracy of the predictions. Specific points on any particular prediction map might not accurately reflect the actual signal at those locations. That said, coverage predictions can provide a good general indication of coverage across an area.

TABLE 1
Channel Plan by Site

Disptach Channels →	Bozeman Simulcast (UHF)		North Simulcast (UHF)		South Multicast (VHF)		Standalone-Dispatch (VHF)		Standalone-Tac, other (VHF or UHF)		**Total**	**Total**
Site ↓	TX	RX	TX	RX	TX	RX	TX	RX	TX	RX	**TX**	**RX**
9-1-1 Center	3	3	3	3							**6**	**6**
Belgrade			3	3							**3**	**3**
Big Sky Resort					1	1			1	1	**2**	**2**
Bozeman Deaconess Hosp.		3							1	1	**1**	**4**
Bozeman HS		3									**0**	**3**
Bridger Ridge			3	3							**3**	**3**
Bridger Woods/Green Mt			3	3							**3**	**3**
Cinnamon Mt					1	1					**1**	**1**
Cobleigh Hall (MSU)		3									**0**	**3**
Courthouse		3									**0**	**3**
Eaglehead					1	1					**1**	**1**
EOC	3	3									**3**	**3**
Four Corners				3							**0**	**3**
Garnet Mt					1	1					**1**	**1**
Hatfield Mt							1	1			**1**	**1**
High Flats			3	3							**3**	**3**
Horse Butte					1	1					**1**	**1**
Hyalite Canyon							1	1			**1**	**1**
Kenyon W.T.	3	3	3	3							**6**	**6**
Law & Justice Center		3		3							**0**	**6**
Lombard/Toston			3	3							**3**	**3**
Madison River			3	3							**3**	**3**
Manhattan				3							**0**	**3**
Nixon Ridge			3	3					1	1	**4**	**4**
Three Forks				3							**0**	**3**
Timberline			3	3					1	1	**4**	**4**
West Bozeman		3									**0**	**3**
West Yellowstone						1					**0**	**1**
Willow Creek				3							**0**	**3**
Other - locations TBD									8	8	**8**	**8**
	TX	RX	TX	RX	TX	RX	TX	RX	TX	RX	**TX**	**RX**
Total stations	9	27	30	45	5	6	2	2	12	12	**58**	**92**
Total sites	3	9	10	15	5	6	2	2	12	12	**19**	**29**

The maps in Appendix A and Appendix B illustrate where mobile and various levels of portable on-belt coverage are predicted to be available today with 95 percent reliability, using assumed parameters, including:

- 100 watts effective radiated power (ERP)[2] or the currently authorized ERP, whichever is lower, for each station
- Directional or omnidirectional transmit antennas to mitigate simulcast overlap interference as necessary
- Omnidirectional receive antennas

Areas in blue indicate mobile coverage for a 50-watt mobile station, and areas in green, yellow, and red indicate various levels of portable coverage for a 5-watt portable radio worn on-belt.

[2] Effective radiated power takes into consideration the transmitter output power along with antenna system gains and losses, such as transmission line and connector losses, combiner loss, and antenna gain.

Backhaul

The proposed radio system will require robust digital connectivity between the various remote radio sites, simulcast control equipment, and dispatch center. It is also recommended that redundant connectivity configurations be used. This can be accomplished with redundant equipment as discussed below.

Loop Configuration

In a loop configuration, all of the sites in the loop are connected together in such a way that the sites have two connections back to the primary site (see Figure 4).

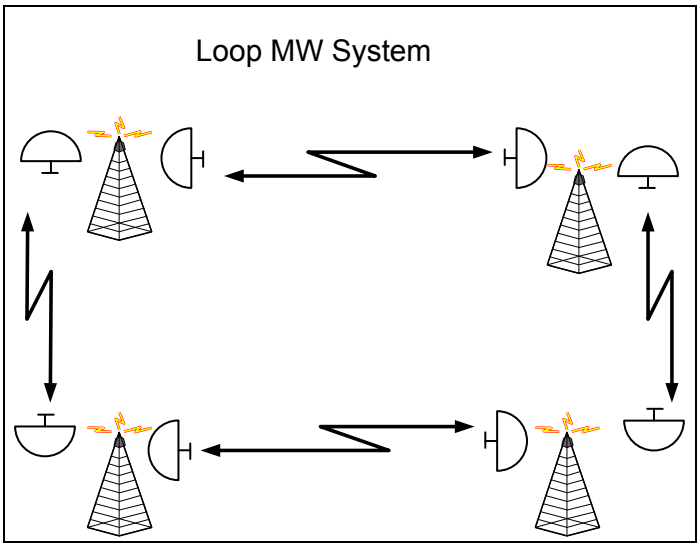


FIGURE 4
Loop Microwave System

One of the significant advantages with this approach is that even the loss of one of the antennas at a site will not result in the loss of connectivity. There is additional protection from path fading as well since it is unlikely that both paths into a site will fade at the same time. The biggest drawback to a loop system is the additional cost for the antennas and loop switching equipment. Note that the loop protection can be provided by other technologies such as fiber. If fiber is available between two locations, the fiber could be used in lieu of microwave.

Monitored Hot-Standby (MHSB)

Monitored hot-standby systems have electronic equipment redundancy but do not have antenna redundancy. If the antenna is damaged, the connection to the site may be lost. In addition, if the path fades, the connection to the site may also be lost. MHSB equipment is often used at locations where it is not feasible to get another path into a site. For example, a site may be located in a valley or on the side of a mountain where there are not two locations that have a clear view of the site. A typical system diagram is shown in Figure 5.

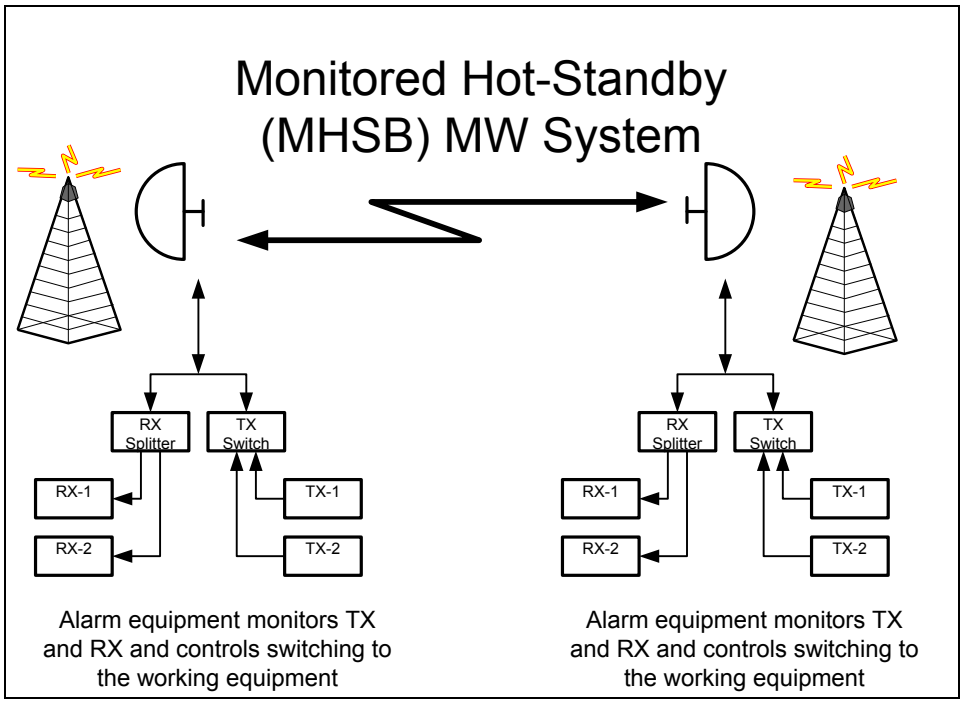


FIGURE 5
MHSB Microwave System

Many systems use a mix of loop and MHSB technologies. It is anticipated the Gallatin County system would use a mix of these two technologies depending on the final design.

Wherever possible, it is recommended that licensed microwave be deployed where fiber or existing microwave is not available. The frequency band for each microwave hop will depend on the final overall microwave/backhaul plan, including system layout, path lengths, required link capacities, and frequency availability. In order to maximize capacity, operational flexibility, and manufacturer support, it is recommended that all backhaul systems be *Internet Protocol* (IP)-based.

Budgetary Costs

Table 2 identifies a high-level breakdown of estimated capital costs for the proposed radio system upgrades. Ongoing system maintenance and operational costs are not included.

Table 3 identifies estimated unit costs for various tiers of subscriber equipment. The high tier is for dual-band (e.g., VHF and UHF) equipment, while the low and medium tiers are for single-band (i.e., UHF only) equipment. Installation, setup, and a normal mix of accessories are included in the Table 2 cost estimates. The high-tier and medium-tier equipment include advanced features[3] such as encryption, over-the-air rekeying (OTAR), over-the-air programming (OTAP), and GPS, while the low-tier equipment does not include any such advanced features.

[3] Note that some advanced features may be vendor-proprietary, not P25 standards-based.

TABLE 2
Radio System Upgrade Capital Cost Estimate Summary

Item	Estimated Cost
VHF/UHF radio infrastructure equipment[4] (29 sites)	$3,000,000
Site antenna systems	$1,100,000
Site improvements, new site development (29 sites)	$4,600,000
New subscriber radios, including installation (est. qty. 1,500)	$7,500,000
New consoles (0)	$0
Microwave and networking	$3,400,000
Alphanumeric paging system improvements	$240,000
Equipment installation	$3,000,000
FCC licensing	$140,000
Engineering, project management, consulting	$1,200,000
Sales tax (0%)	$0
Contingency (20%)	$4,800,000
TOTAL	**$28,980,000**[5]

TABLE 3
Estimated Subscriber Radio Costs

Item	Estimated Unit Cost
Mobile, high-tier (dual-band, including enhanced features)	$5,500
Mobile, medium-tier (single-band, including enhanced features)	$4,500
Mobile, low-tier (single-band, no advanced features)	$2,500
Portable, high-tier (dual-band, including enhanced features)	$5,000
Portable, medium-tier (single-band, including enhanced features)	$4,000
Portable, low-tier (single-band, no advanced features)	$2,000

Summary

Based on the identified user needs and consideration of technologies currently available, ADCOMM believes that a hybrid VHF/UHF radio system, operating in a combination of analog and P25 Phase 1 digital modes, in conjunction with simulcast and multicast technologies, would meet the radio communication needs public safety users in Gallatin County while significantly extending the supported lifespan of the system. Such a system would offer significant operational improvements over the existing radio systems, primarily enhanced coverage and increased channel capacity. However, some operational and procedural changes may be required, in particular regarding interoperability with surrounding agencies. In

[4] Includes nine dispatch channels (three Bozeman Simulcast, three North Simulcast, one South Multicast, Hyalite Canyon, and Hatfield Mountain) plus an estimated 11 standalone repeater (e.g., tactical) channels.

[5] Note that budget numbers discussed previously of approximately $21,000,000 did not include user radios.

addition, improvements to the existing alphanumeric paging system are warranted to improve its reliability.

ADCOMM estimates that approximately 29 radio sites would be necessary to provide the desired coverage throughout Gallatin County. The total estimated capital cost for the project is $29.0 million.[6]

[6] This estimate includes the new radio system infrastructure equipment, installation, site improvements, licensed microwave backhaul, replacement subscriber units, FCC licensing, engineering, project management, and 20 percent contingency.

Strategic Communications Plan

It appears that while Gallatin 9-1-1 has made some significant improvements to their radio communications infrastructure over the last 5 years it was done to resolve specific problems and not part of a larger strategic communications plan. This is quite often the case for agencies that are in areas that have significant growth. What worked for them a decade or two ago, no longer works. This includes not only the technology but also the approach to managing and maintaining the network.

The growth in the Gallatin County area has been significant over the last few years with the population nearing or possibly exceeding 100,000 within a year or so. Current annual growth has been in the range of a bit more than 2 percent to over 8 percent. It is not known if these rates will continue. The influence of the university and the living environment will continue to bring in high-tech industries where the location of the industry depends on access to the Internet, a pool of educated talent, and a great living environment. This will continue to put pressure on providing services, including law enforcement, fire, and EMS to a group of citizens that expect these services as opposed to the more traditional rural approach of handling things yourself and only relying on others' services as a last resort.

This growth has already resulted in the existing public safety communications infrastructure being inadequate for the mission of the responders. Rapid growth also complicates the long-term planning process. The systems needed for the future should be planned and implemented today, which means additional demands on the current citizens to fund a system to support the citizens 5 to 10 years down the road. However, the long lead time of making significant capital improvements to the radio system dictate that the planning and implementation process need to start now so the systems can be in place as soon as possible given the current system inadequacy.

Strategic Planning Areas

ADCOMM sees the following areas for which Gallatin 9-1-1 needs to include in a strategic plan related to the radio communications infrastructure.

- Radio infrastructure system
- Interoperability and interface to the State of Montana
- Interface to dispatch technology and equipment
- Radio systems operation and maintenance
- Radio system funding

These will be discussed in additional detail below.

Radio Infrastructure System

The system approach recommended by ADCOMM should provide adequate service for 5 to 8 years. However, this depends on how fast Gallatin 9-1-1 can fund and implement the system. The basic system architecture allows for some expansion should the growth remain high and additional resources are required. However, the needs of Gallatin County will continue to change based on the economic drivers in the county. While it is expected the growth will continue, it is possible but likely not probable that the growth could slow or stop. As a result,

Gallatin 9-1-1 should start working on a strategic plan review and revision in the 2020 time frame looking out the next 5 to 8 years. One reason this is critical is so that capital expenditures for radio system equipment 8 to 10 years from now can take into consideration any changes in the strategic plan.

The current recommended strategic approach is as follows:

- Continue to use conventional technology as opposed to trunking.
- Move the Gallatin Valley area to a UHF system.
- Procure dual-band user radios.
- Provide dispatch and operational wide area channels for both Bozeman and the Gallatin Valley.
- Use VHF in the south end of the county and extreme north end.
- Continue to use alphanumeric paging.
- Implement Project 25 Phase 1 technology in the Gallatin Valley/Bozeman area to support encryption and improved coverage.
- Implement narrowband analog technology in the southern portions of the county where multipath will negatively affect digital communications.
- Implement a backhaul microwave infrastructure that supports digital IP communications for system interconnection where feasible and other appropriate technology in the rural areas. Note that some of the current radio system traffic is supported by the State microwave system. Some of the State's network uses equipment owned by Gallatin 9-1-1. Gallatin 9-1-1 should develop a comprehensive approach to how they will interface and operate with the State's microwave network. At this point, the State's network does not have adequate maintenance resources allocated to it and maintenance and other work can be delayed.

Interoperability and Interface with the State of Montana and Other Users

The majority of the users in rural Montana currently use VHF radio systems. The State of Montana operates a large VHF trunking system that appears to have only been marginally accepted by the rural non-state users. In addition, Gallatin 9-1-1 currently operates Motorola consoles that are connected to the State of Montana system allowing access to both local county-owned resources as well as the State's trunking system.

The maintenance, operation, and upgrades to a trunking radio system represent significant costs and personnel resources. The current state system has much equipment that is no longer manufactured by their system vendor and at some point will need to be replaced. This represents a significant cost. In addition, the system was not designed for the requirements of local responders in terms of coverage or capacity. As a result, ADCOMM does not believe using trunking technology and/or teaming with the State of Montana is in the best interest of Gallatin County public safety responders from both a technology and a cost point of view. Interface to the State trunked radio system can be done through inexpensive control stations instead of the expensive console interface currently being used. This, of course, could change should the state

legislature decide to fully fund a state-wide system that would provide local services. It appears this is not likely.

In addition to the State trunking system, there is extensive use of VHF analog for fire communications throughout the state. The state has developed a "color channel" system where many if not all agencies use these same frequencies and common nomenclature to aid in responding to large fires and other mutual aid incidents. ADCOMM recommends that any system design approach continue to support this concept and system. This is one of the reasons for the use of dual-band radios.

The current recommended strategic approach is as follows:

- Continue to support the VHF Color Channel system widely used in Montana[7]
- Develop a standalone console system approach instead of being tied to the State of Montana radio system
- Provide interface into the State of Montana trunked radio system by control stations
- Keep some VHF narrowband analog tactical repeaters in operation in Gallatin County for VHF mutual aid, which is expected to be primarily fire response but could be other agencies as well

Interface to Dispatch Technology and Equipment

The current dispatch consoles are connected through the State of Montana central radio system controller. This approach makes sense if Gallatin 9-1-1 made extensive use of the State radio network. However, the existing system makes only occasional use of the State radio system with almost all communications being handled locally. The current system configuration requires even local transmissions to travel to the radio system controllers and back. Given that the direction recommended for Gallatin 9-1-1 is to develop their own radio system network, it makes little sense to continue to use the state controllers. The existing console system can be converted to a standalone system with all of the communications remaining in the Gallatin County area.

The current recommended strategic approach is as follows:

- Convert the existing console system to standalone operation or replace it
- Provide control stations to interface to the State P25 trunking system

Radio Systems Operation and Maintenance

Radio system operation and maintenance is critical to the long-term success of the radio communications system. In addition, proper maintenance can maximize the significant investment made in the radio system infrastructure. However, this has become more difficult and expensive for the reasons below:

- Due to the nature of equipment maintenance, vendor radio shops often have less technical skills than in the past
- Many radio system technicians have retired or are getting close to retirement

[7] Mutual Aid and Common Frequencies Manual 2011, Montana Department of Administration.

- Newer technicians are primarily trained in data and computer systems not radio systems
- There are few schools that teach radio system technology
- The test equipment required to maintain a new technology system can costs tens of thousands of dollars. For example, a fully functional radio service monitor can cost $50,000 or more.
- The technology changes faster requiring more training, which is expensive

This has created a significant problem for radio system operators as they invest in new systems and want to keep those systems operating. This problem is exacerbated when an agency is located some distance from a major metropolitan area where there is usually a greater density of radio equipment and customers supporting a more fully staffed radio shop. The situation in Gallatin County is made worse by the fact that the radio system required will be fairly complex and will require ongoing technical support. This support is not just for the radio system but includes microwave, consoles, radio sites, towers, alarm equipment, and user support for programming and operating user radios. It will take dedicated personnel to learn and be able to maintain the system.

There are three basic approaches to providing system management and maintenance:

1. **Vendor Centric Maintenance**
   A vendor centric maintenance approach is where virtually all of the work is contracted out to local vendors and they are responsible for essentially all of the system maintenance but where the management of the maintenance and system is still with Gallatin 9-1-1. Using this approach, there would be a "Technical Systems Manager" who would be essentially a contract manager. The Technical Systems Manager would need to have a basic understanding of the system and be able to troubleshoot at a very high level in order to know which maintenance contractor to call for service. Different maintenance contractors could be used for different aspects of the system. For example, one local radio shop might maintain the radio portion of the system, the microwave vendor might maintain the microwave equipment, another contractor might maintain the generators and DC power systems, etc. This would allow Gallatin 9-1-1 to pick the best contractor for the work. While the maintenance contractors would do the majority of the work, some small maintenance activities and system alarm monitoring would be done by the Technical System Manager. The primary disadvantage with this approach is the lack of control over the person doing the work and their level of expertise. This approach may be less expensive than an approach where Gallatin 9-1-1 uses their own personnel.

2. **Gallatin 9-1-1 Centric Maintenance**
   The Gallatin 9-1-1 centric maintenance approach is where virtually all of the work is done by Gallatin 9-1-1 personnel with some work contracted out to local vendors for specialty items such as generator and HVAC repair Using this approach, there would be a "Technical Systems Manager" who would be the system manager and would manage one or more technical support staff. The Technical Systems Manager would need to have a good understanding of the system and be able to troubleshoot to provide support to the radio maintenance technician. All alarm monitoring and maintenance response would be done by Gallatin 9-1-1 personnel. The primary advantage with this approach is control over the personnel, quality of work, and level of training. The primary disadvantage of this approach is cost.

3. **Managed Services Approach**
   The managed services approach can take several forms. The most common are:

   - The operations and maintenance of the system are contracted out to a third party but the agency retains ownership of the equipment
   - The operations and maintenance of the system are contracted out to a third party who owns and operates the system on behalf of the agency
   - The management of the system maintenance and operations are contracted out to a firm that can supply high-level technical support but the day-to-day repairs are handled by local vendor forces.

Each of these approaches has advantages and disadvantages, however, for a system of the type and size of Gallatin 9-1-1's, it does not appear that managed services would be a cost-effective approach due to the cost (because of the size of the system). However, depending on the technical resources available, a hybrid approach may be warranted.

The current recommended strategic approach is as follows:

Gallatin 9-1-1 should invest in their own technical support staff for their radio infrastructure and supplement their staff with vendor support where required. This would require a technical systems manager and at least one radio technician depending on the support available from the local radio shops. The Technical Systems Manager should be responsible for all of the technical systems operated by Gallatin 9-1-1 including CAD and the telephone system. Contracted services would be used to provide support for systems such as generators and HVAC as well as to provide high-level technical support if required. The Technical Systems Manager should report directly to the Gallatin 9-1-1 Director. The estimated cost for this is:

Salaries, benefits	$300,000
Annual parts budget, repairs, calibration	$50,000
Operating expenses (fuel, etc.)	$10,000
Annual training	$10,000
Annual contracted services	$100,000
Estimated Annual Cost	**$470,000**
Initial capital expense	$250,000

Radio System Funding

The radio system infrastructure needs both a source of capital funding and ongoing funds. Long gone are the days of paying a few thousand dollars to put a repeater on a mountain top and then not doing anything with it for 20 to 30 years as was often the case in many systems.

Gallatin 9-1-1 is currently designed to operate with funding from a voter approved "mill levy" property tax. This provides the bulk of the Gallatin 9-1-1 operating and maintenance funds with some funding available for improvements. However, the approximately $29,000,000 cost of upgrading and replacing the existing system cannot be supported by the current mill levy. As a result, moving forward with the radio system improvements may require multiple funding sources. These could be:

- **Voter approved bond for the majority of the initial capital cost**
  Given the life of the technology deployed, a bond duration of 10 to 15 years would be appropriate with the shorter duration being the best. The technology life of the system will be between 10 and 15 years so one does not want to still be paying for a system that needs to be replaced or updated.
- **Grant funding**
  Grant funding has generally been decreasing over the last several years. However, there are still some Homeland Security and Aid to Firefighter Grants available. These could be used to offset some of the capital costs and could possibly allow some work to progress prior to receiving funding though the voter-approved bonding process.
- **Bank financing**
  Bank loans could be used to fund a portion of the system, especially if the mill levy rate could be raised enough to provide debt service of the bank loans. The major drawback with this approach is the higher interest rates that would be paid on the loans.
- **User fees**
  Radio system user fees could be used to support the initial cost and the operation of the system. In many places, user fees provide the funds for the maintenance and operation of the radio system infrastructure. However, user fees are generally not popular with the users.
- **City and county general fund funding**
  The city and county governments could help fund their portions of the capital and operational costs of the radio system. This could be done within the normal bonding capacity of the local government entity or through direct appropriations. This approach is sometimes successful if a larger government entity can afford to pay for their portion of the radio system before other funding is available.

ADCOMM does not have a specific funding recommendation other than that Gallatin 9-1-1 will likely need more than one funding source and should try to obtain grants when possible.

Radio System Implementation Planning

The existing radio system has more or less grown "organically" over the last decade. There have been several system approaches that have been tried and for one reason or another were not successful. As a result, the existing system has a variety of different radio coverages and operating requirements depending on what frequency one is operating on. The goal of the new system is to provide an engineered system where the various system elements are designed to work together in a complementary fashion. Obtaining this result will require detailed system engineering as well as site development, project management, and system commissioning. This work will not be done in a few months. A project of this magnitude is likely a 48- to 60-month project including engineering and final acceptance. In addition, it is important to move the project forward in an approach that is cost efficient. To that end, ADCOMM recommends the following approach as outlined below. Note that these stages do not operate in a strictly serial fashion. There is considerable overlap. For example, once a site has been selected and engineered, the permitting process can start, even if other sites are still in the design or lease negotiation phase.

Stage 1 — Detailed System Engineering and Project Management

During this stage the following is completed:

- Detailed system design, drawings, specifications, etc. for:
  - The radio system
  - The microwave system
  - The radio sites and site improvements
  - The ancillary equipment such as DC power, alarm system, etc.
  - The installation of the equipment engineered above

In this stage, all of the final site selections would be made, and the process of working with existing and possible new site land owners would start to make sure the proposed site improvements would be acceptable to them.

This stage also includes project management, which occurs throughout the duration of the project.

Stage 2 — Radio Site Permitting and System Procurement

This step starts the radio site construction permitting process. There are several locations where sites will need to be developed and permitting is a pacing item—without the permits construction cannot start. While the permitting process is ongoing, decisions about how the systems will be procured will be made and the procurement process will occur. There may be a variety of procurement processes used depending on the equipment. For example, some equipment may be available on the WSCA or other purchasing contracts.[8]

Site permitting can be an especially onerous process due to not only local objections but also due to the Federal Communications Commission (FCC) tribal notification requirements. As a result, site development can take as long as 18 to 24 months.

At this point, ADCOMM is not recommending the system be procured as a single large system procurement. It is ADCOMM's experience that single large system procurements are very expensive as the system contractor would mark up the price of all the other systems from anywhere between 25 and 50 percent. It is our experience there is low risk to independently procure systems that have a well-defined interface to other systems. This includes things like the alarm system, DC power, microwave and data network, antennas, transmission line, and combiners, and site work.

System Implementation and Staging

As they become ready, the new equipment installation can occur. In some cases, the equipment and systems may be staged at either the factory or a local installation contractor's facility. This will depend on the specific system. For example, it might be possible to stage the microwave equipment as an entire system at the factory prior to shipping but it may not make sense to stage the radio system equipment at the factory, rather stage it at a local shop. This process would occur as sites are available since certain equipment is required to make other equipment functional; the installations would occur in this approximate order.

[8] http://www.naspovaluepoint.org/#/home/contracts

1. Site-related equipment including towers, shelters, etc.
2. Ancillary systems such as DC power, alarm monitoring equipment
3. Microwave and other system interconnection equipment
4. Radio system infrastructure
5. System commissioning (this would occur for each subsystem)
6. System acceptance (this would occur for each subsystem)

System Commissioning and Acceptance

After each system is implemented all of the technical parameters will be verified and final system adjustments made. At that time, drive testing and a sample set of users will be asked to use the system to get their input. In addition, user training will take place. After the system has been in successful operation for 30 to 60 days, it will be accepted.

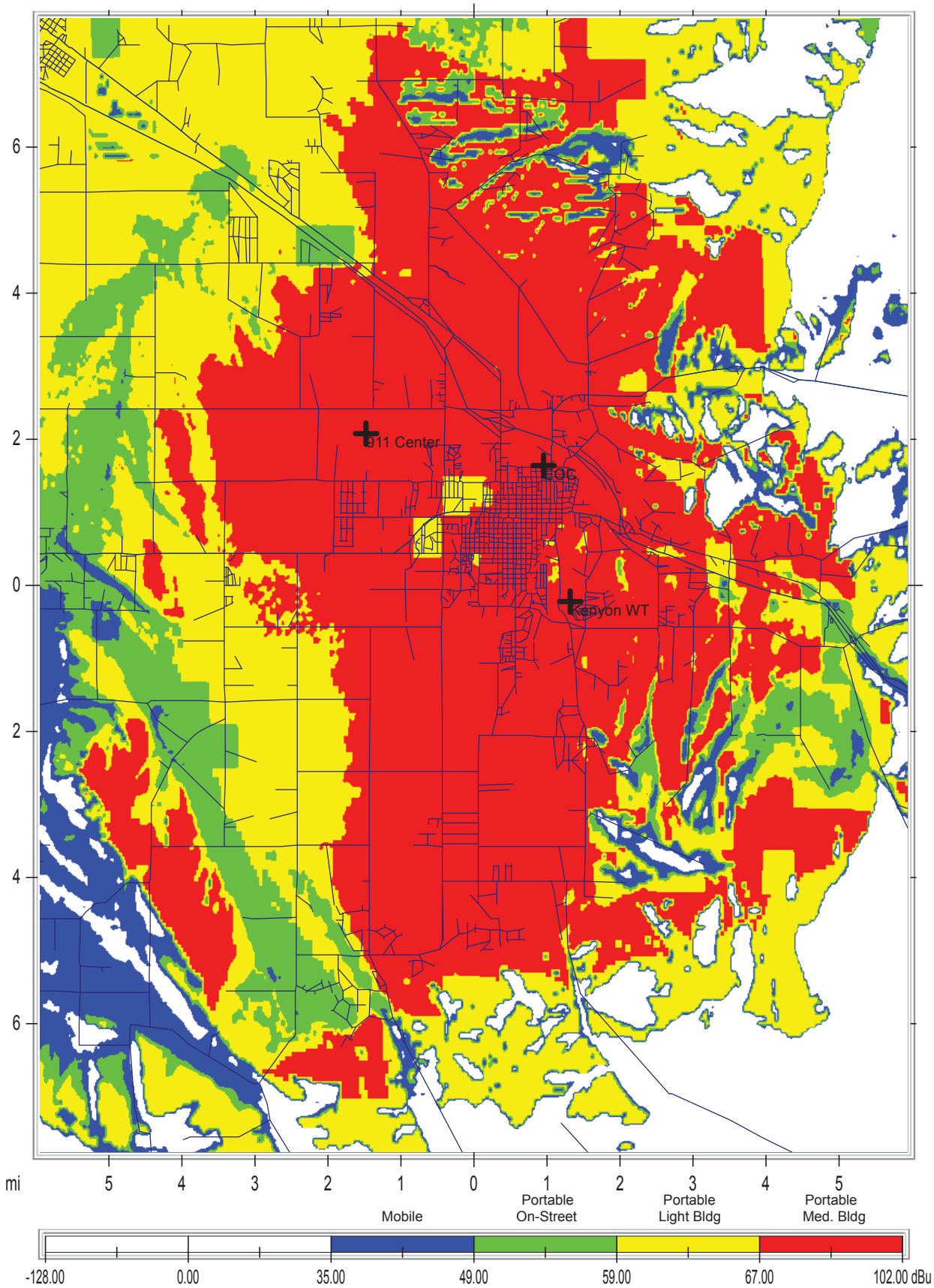
Final Project Closeout

Once the systems have been accepted, it will be critical to obtain all of the system documentation, as-built documents, training materials, and account for all of the equipment purchased. When this is done, the project will be considered complete. This process for closeout will occur during the project so that as-builts will be obtained and filed as the systems are completed.

Next Steps

If Gallatin 9-1-1 has some existing funding to start the detailed engineering process, we recommend this be done. This will help to move the project forward, provide some visibility that things are happening, and help refine the costs and site locations. This work can be moving forward while the remaining funding is being obtained.

Appendix A
Proposed Radio System Coverage Predictions (Composite)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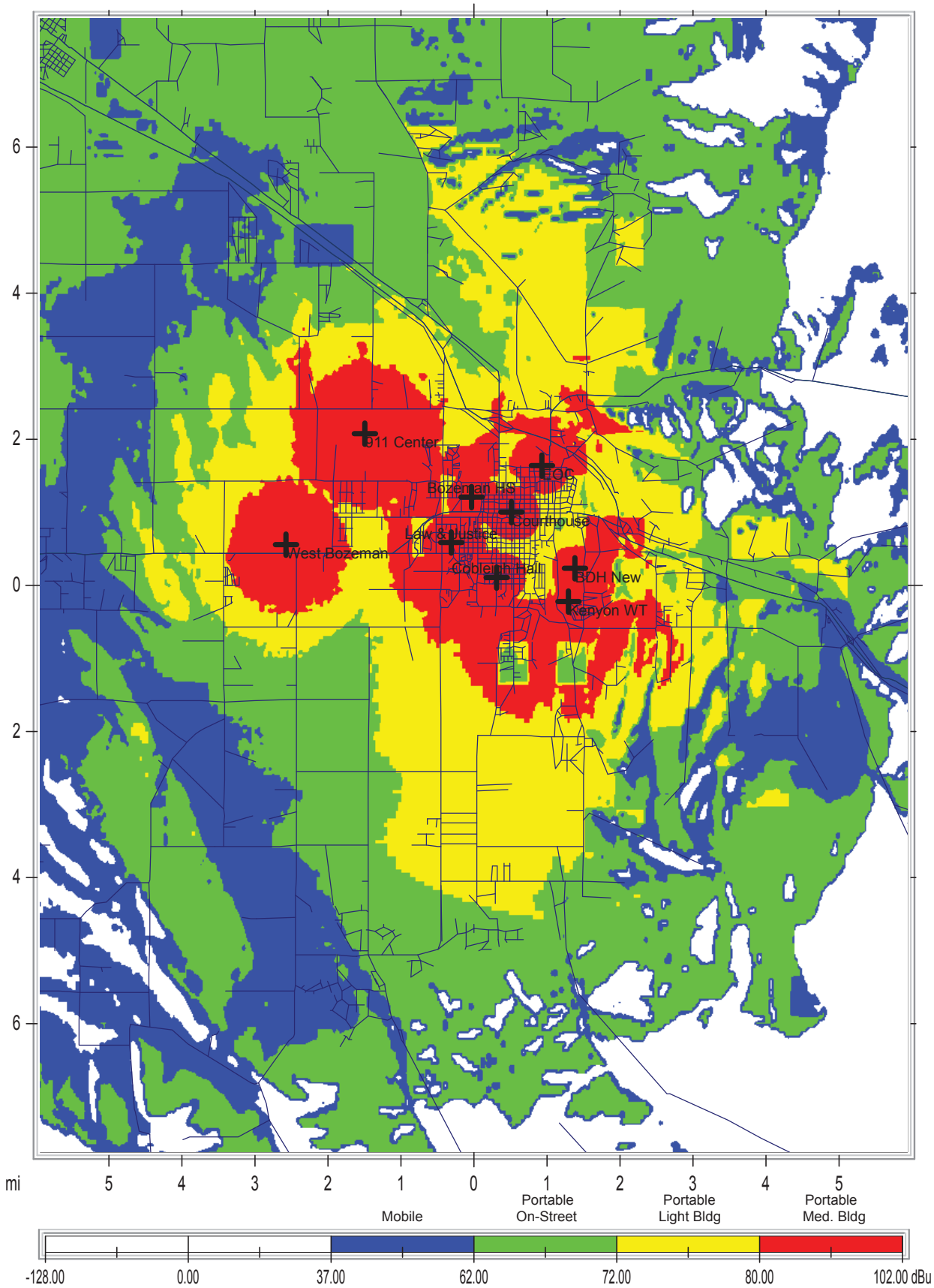
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Courthouse
Law & Justice
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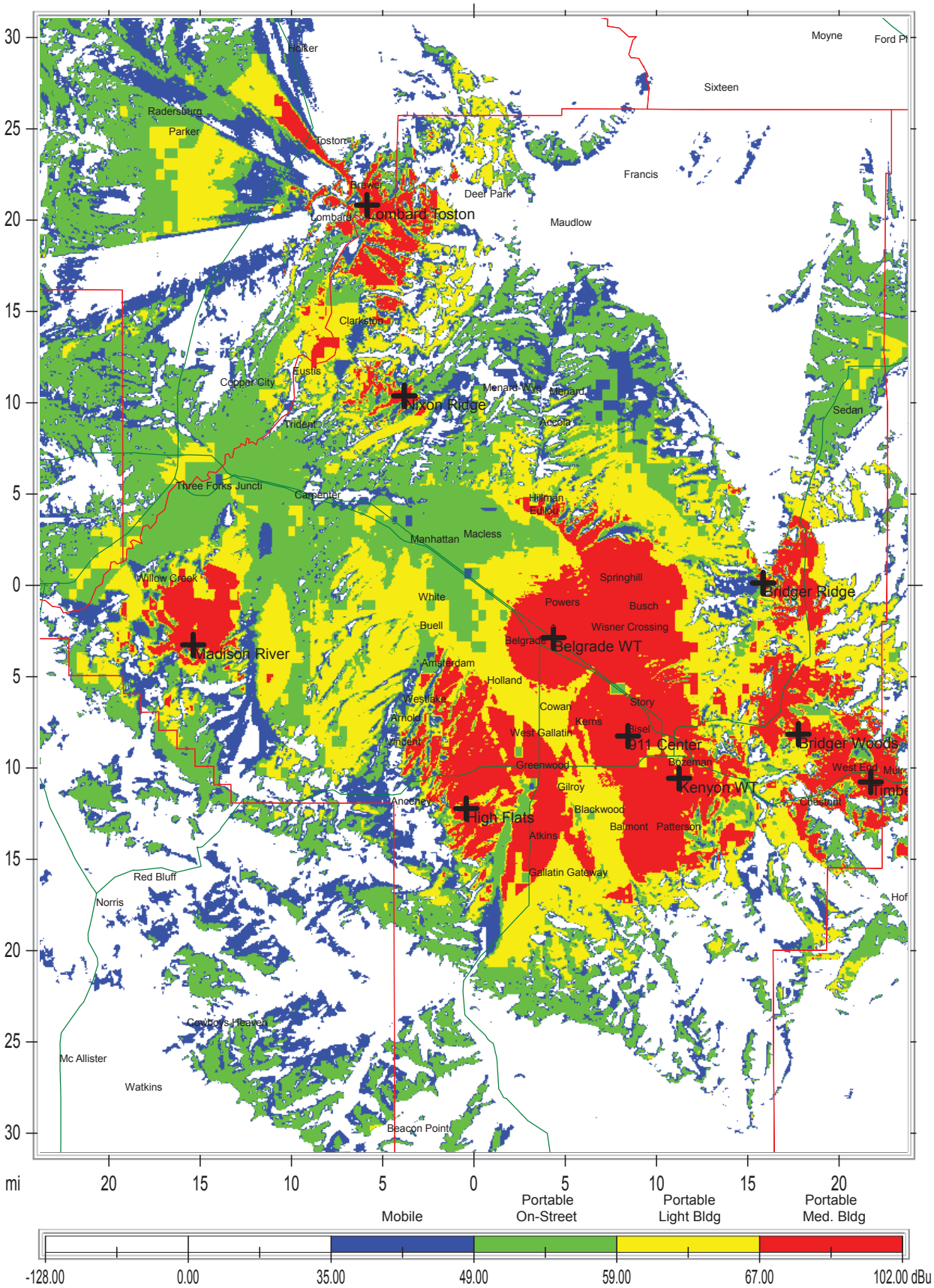
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Copper City
Nixon Ridge
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Cowan
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Kerns
Bisel
West Gallatin
911 Center
Bridger Woods
Vincent
Greenwood
Bozeman
West End
Gilroy
Kenyon WT
Timber
Anceney
Chestnut
High Flats
Blackwood
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Patterson
Atkins
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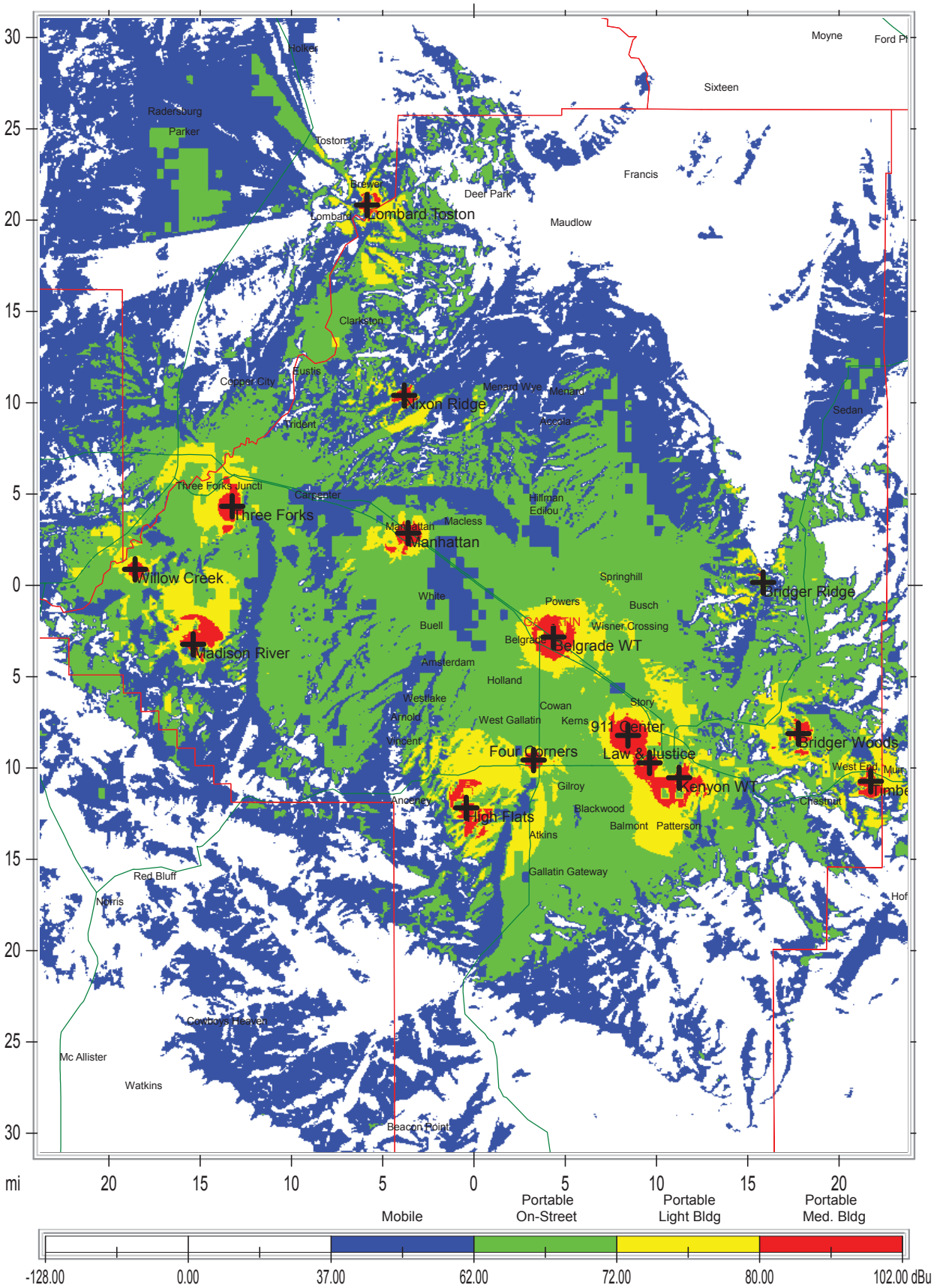
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Bridger Woods
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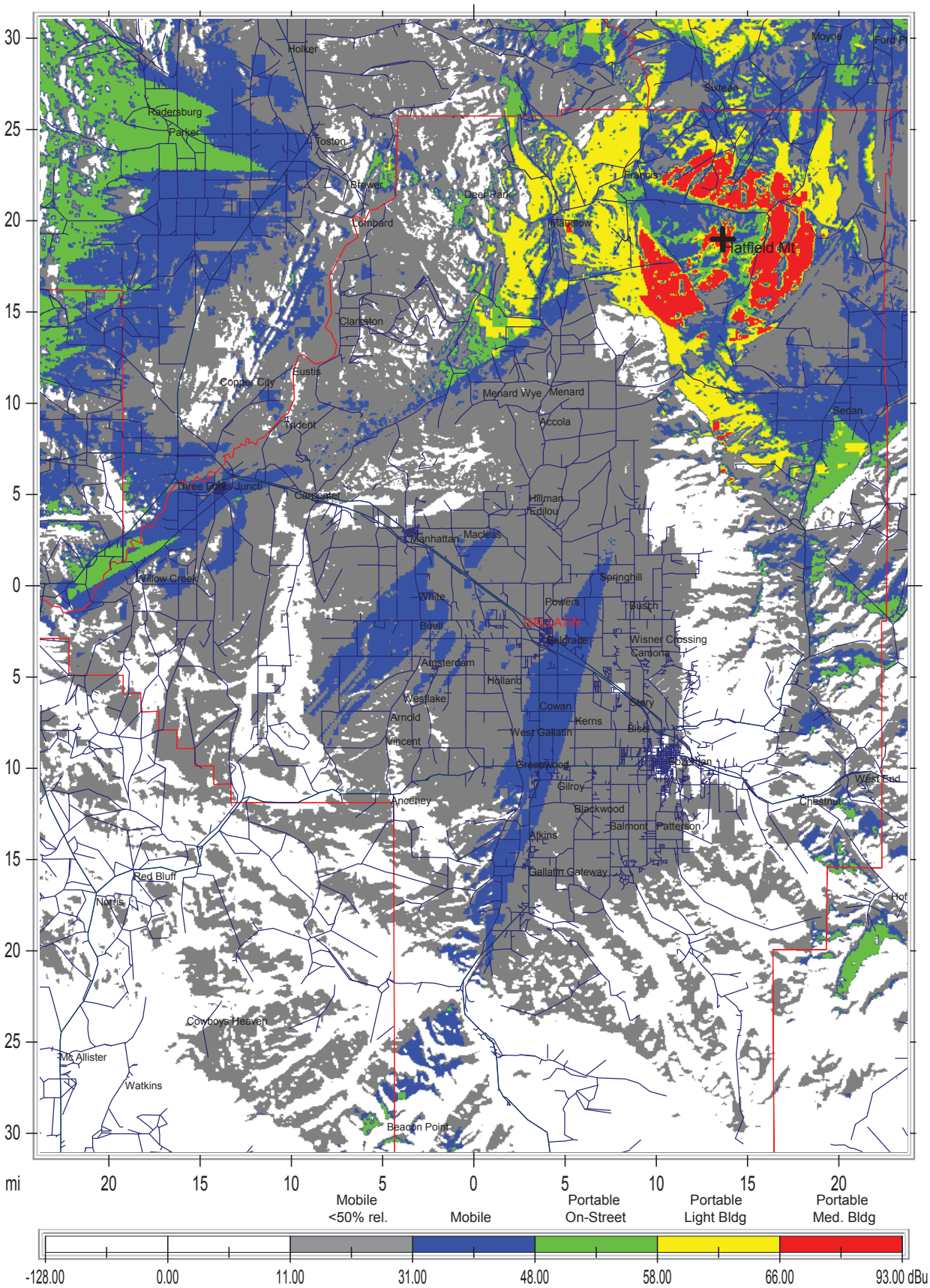
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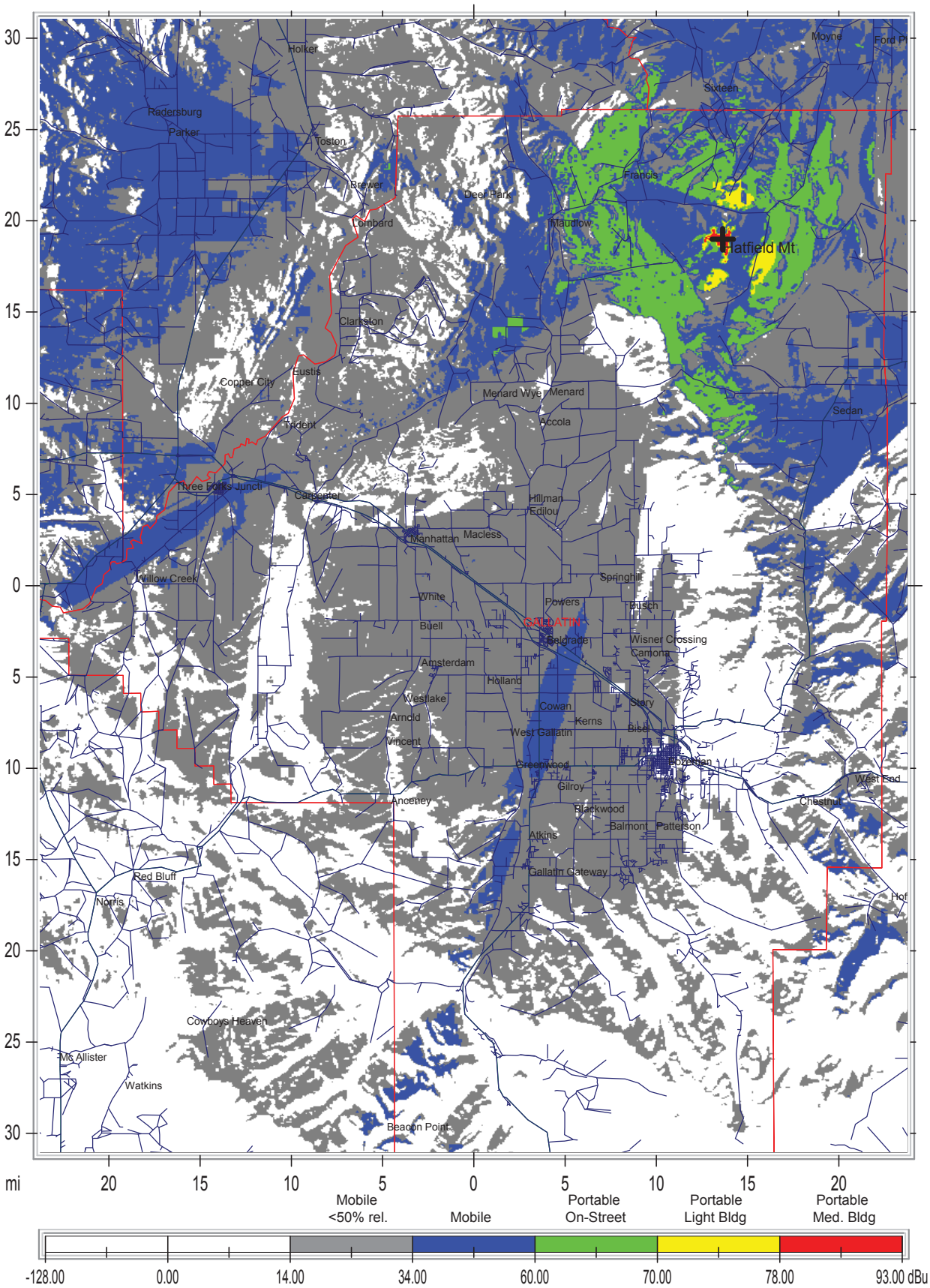
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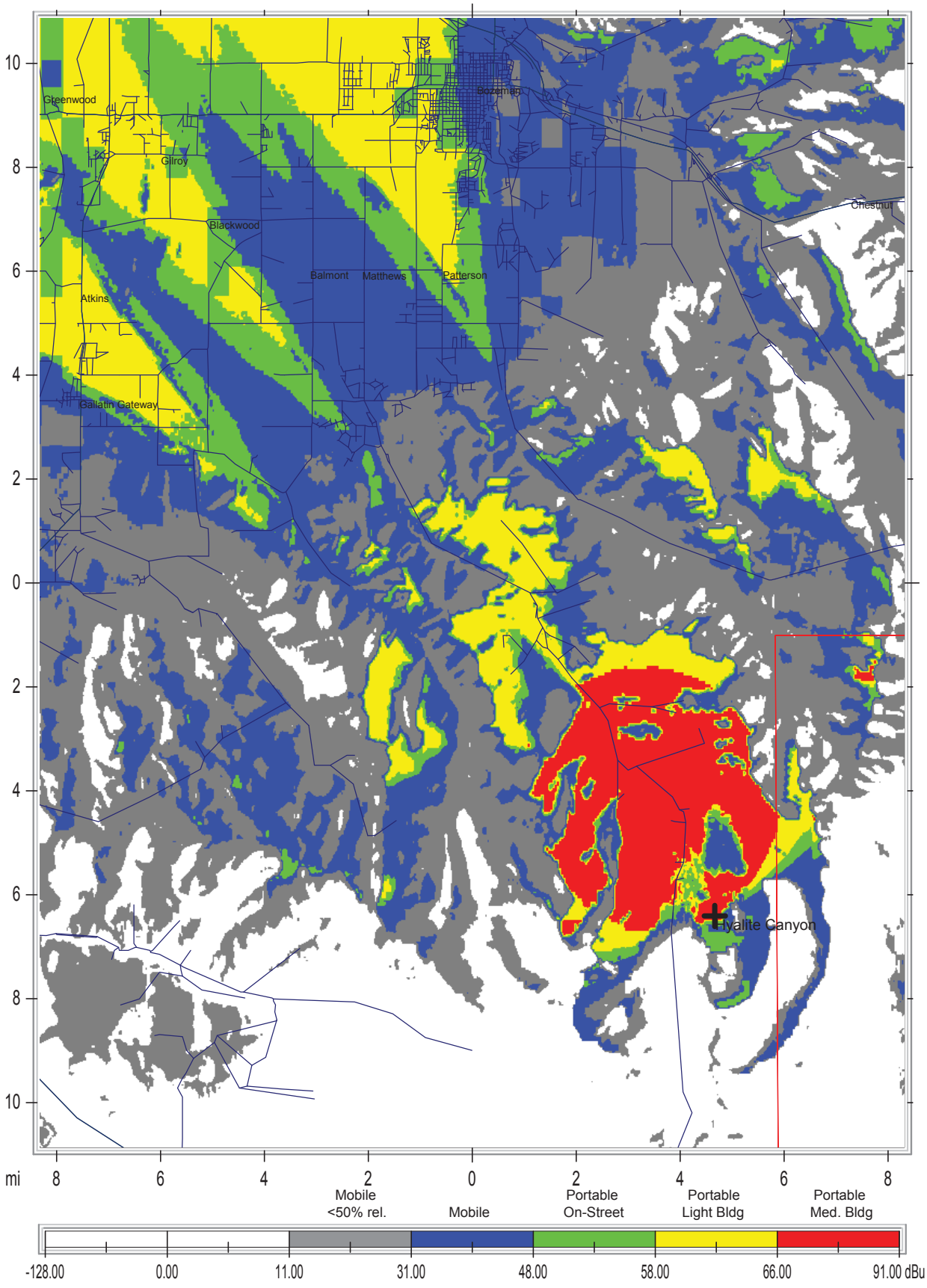
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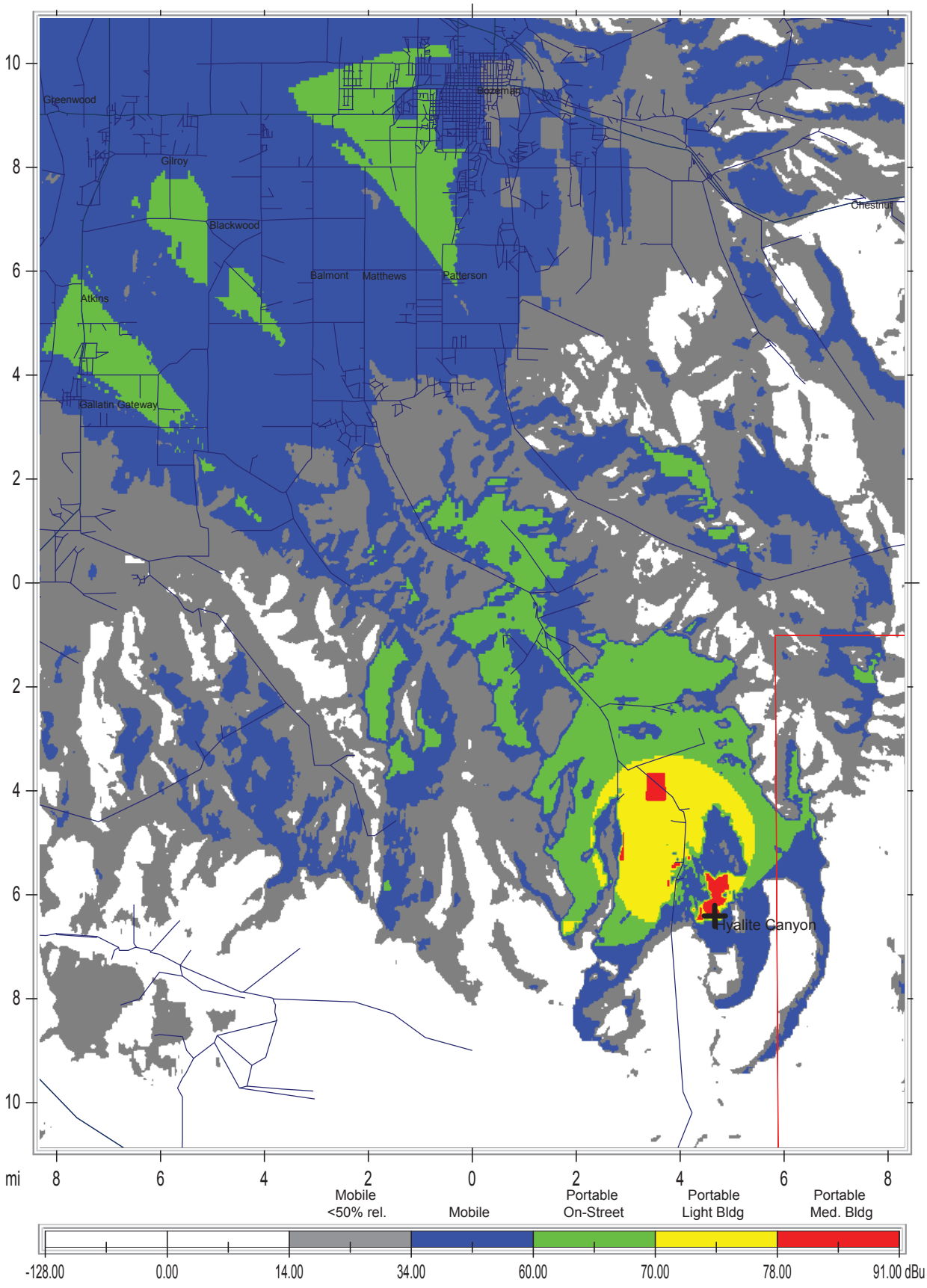
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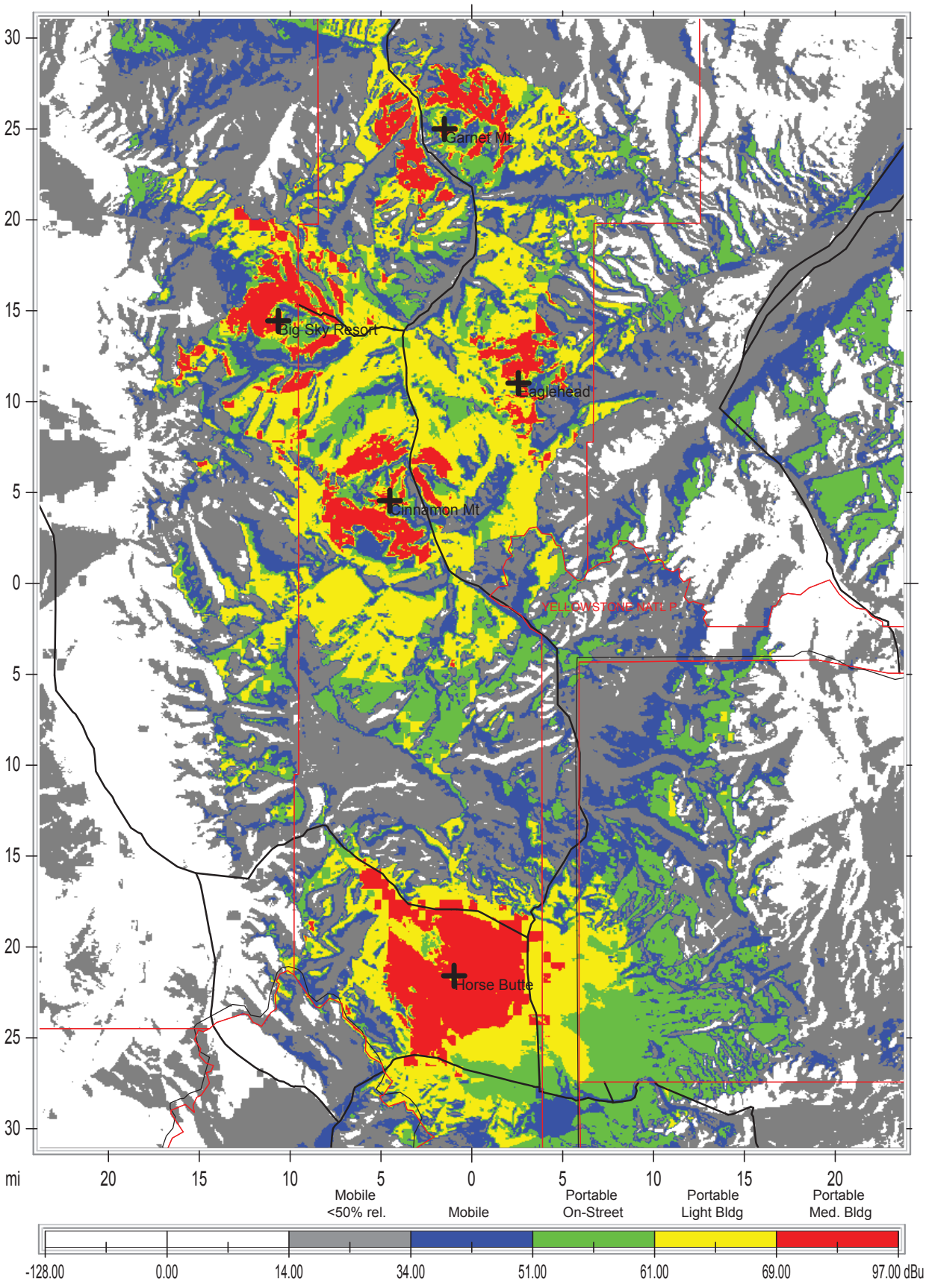
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Cinnamon Mt
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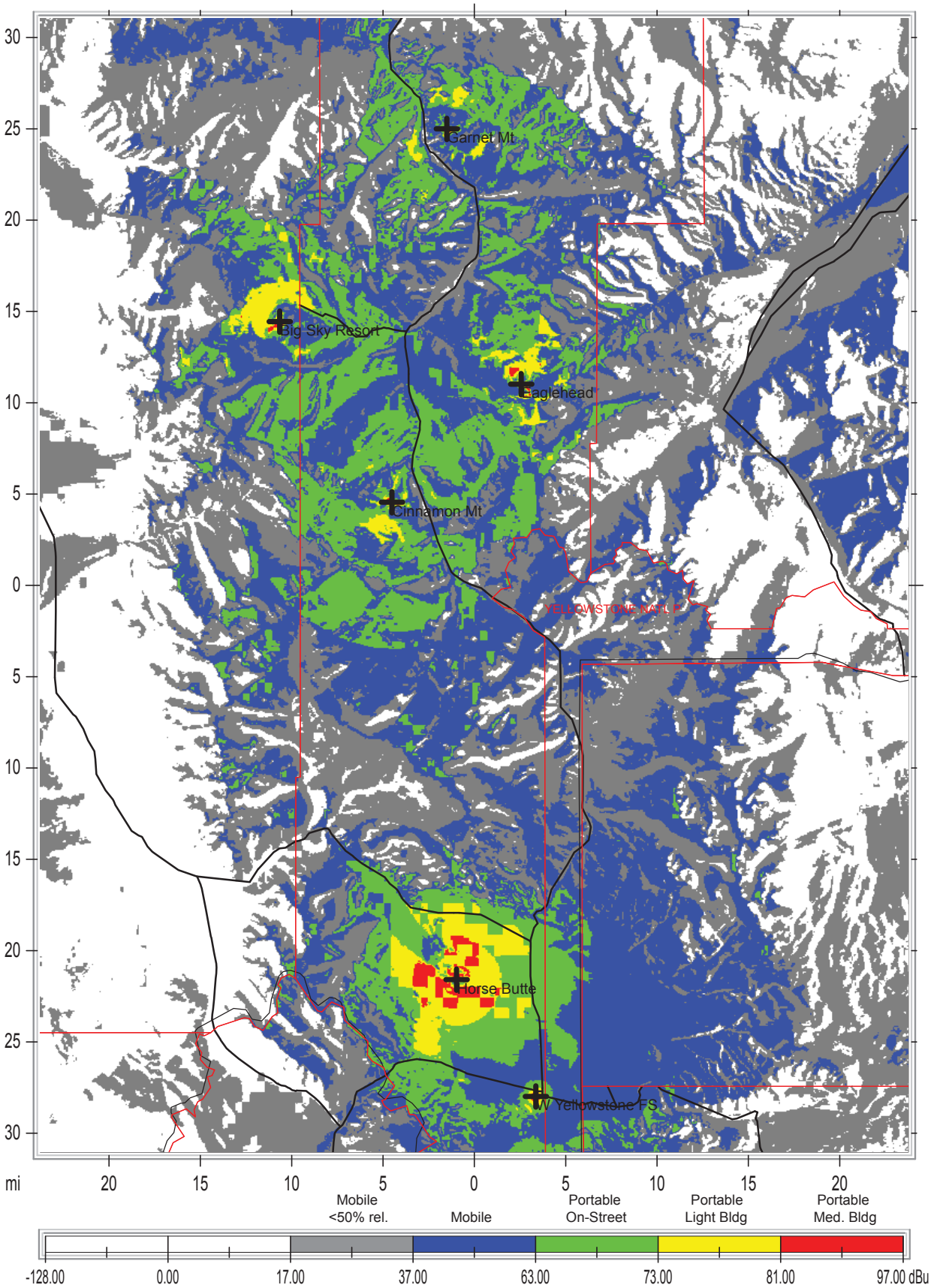
Garnet Mt
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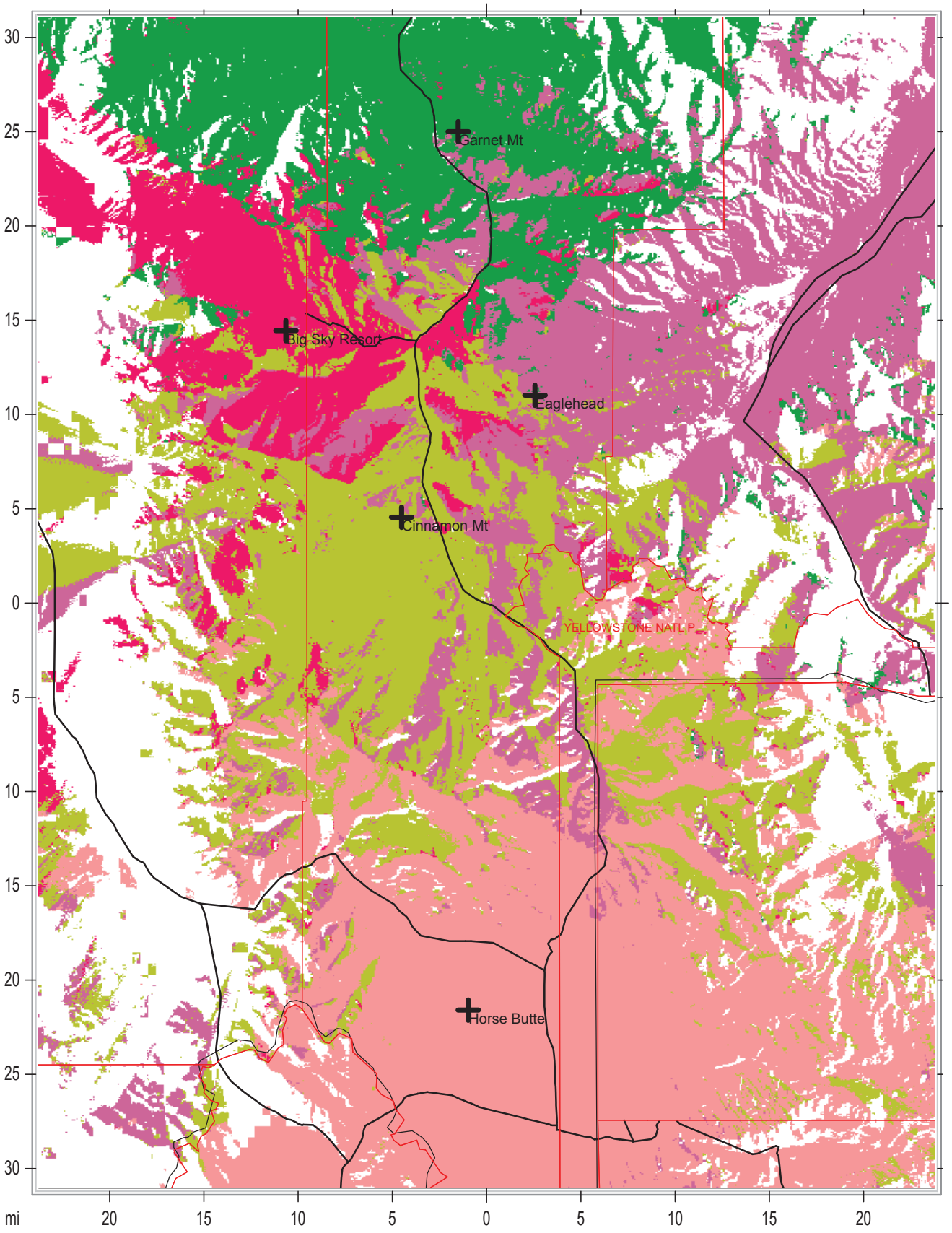
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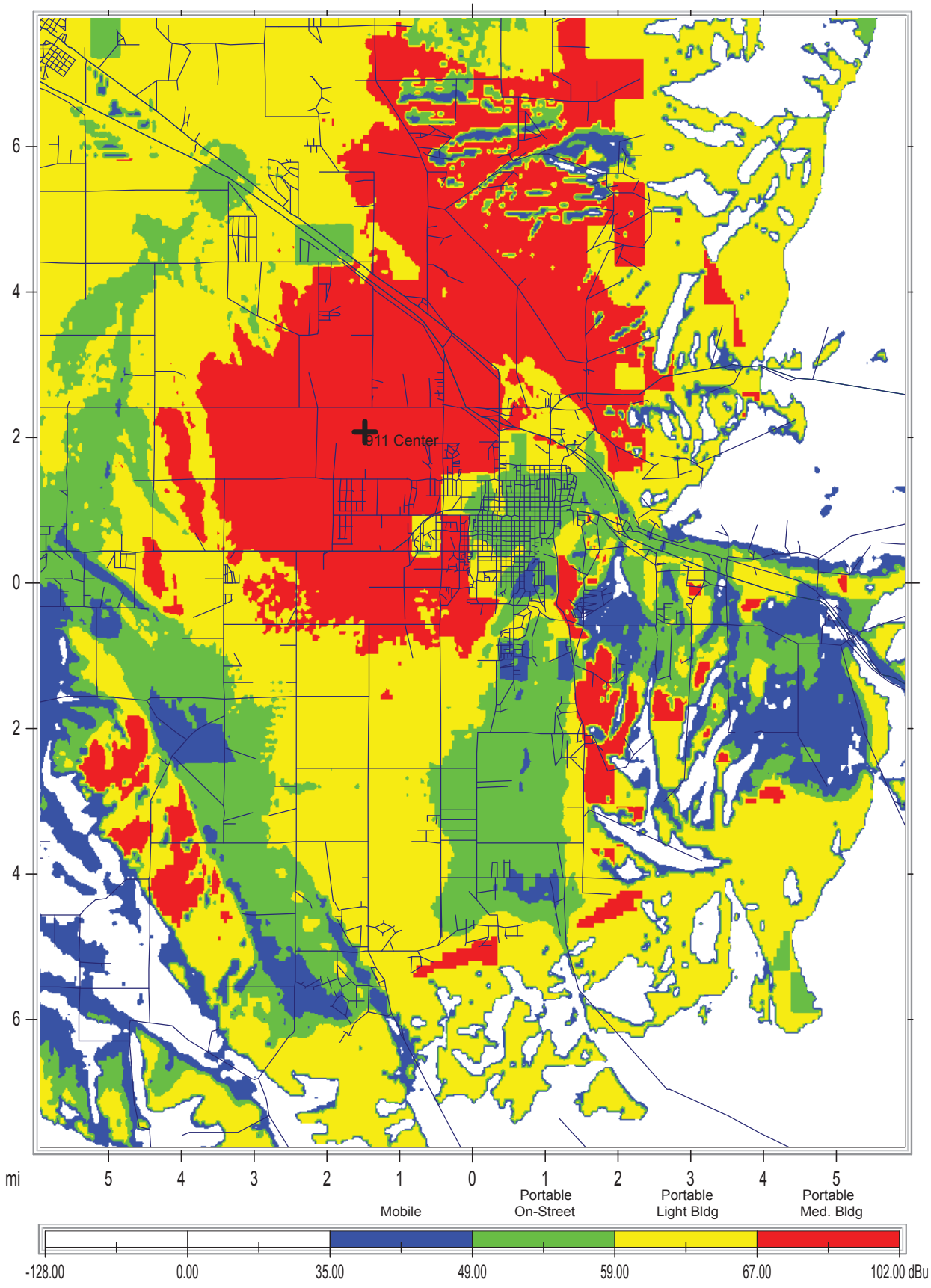
Appendix B
Proposed Radio System Coverage Predictions (Individual Sites)

BOZEMAN SIMULCAST TALK-OUT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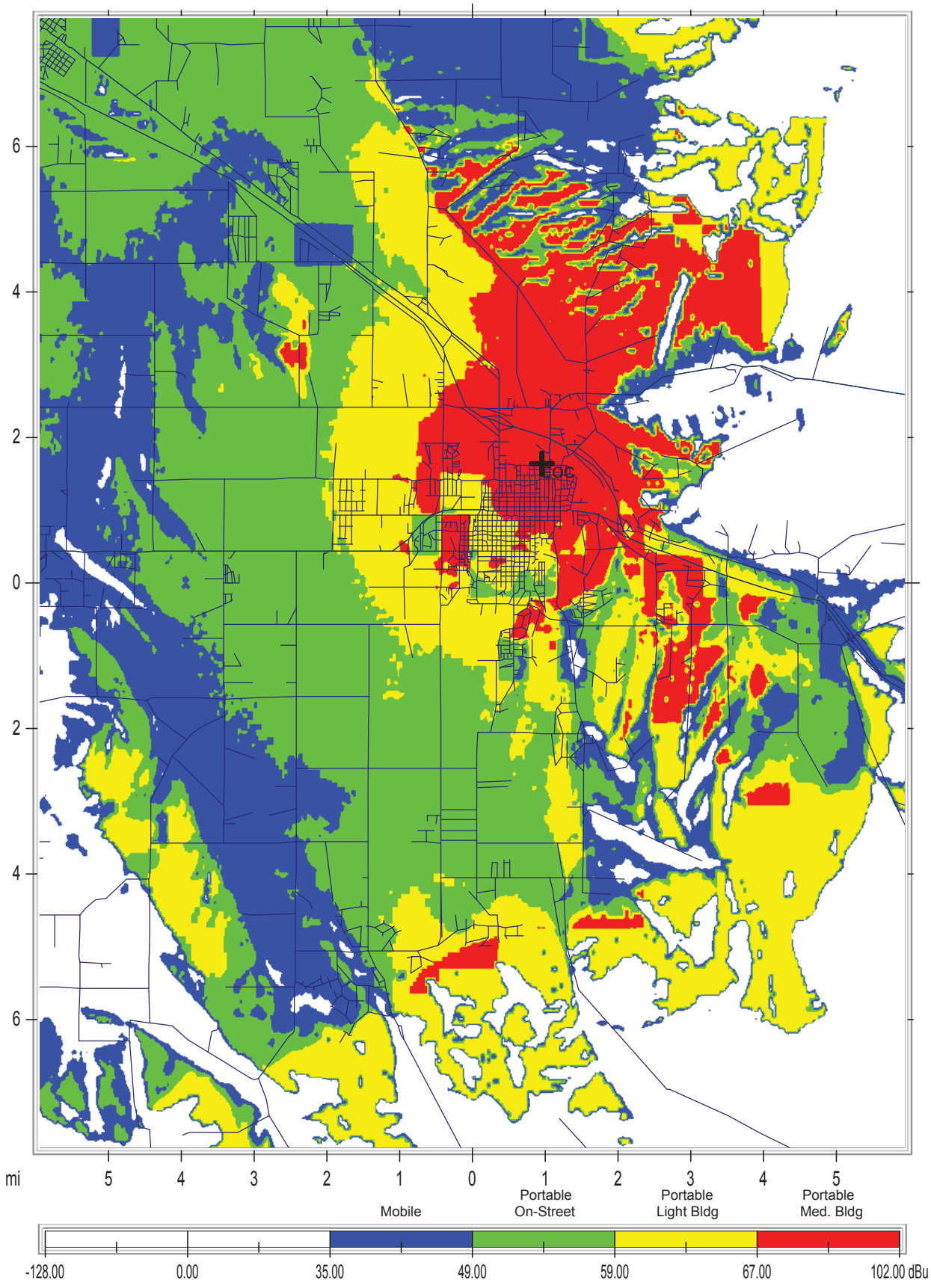
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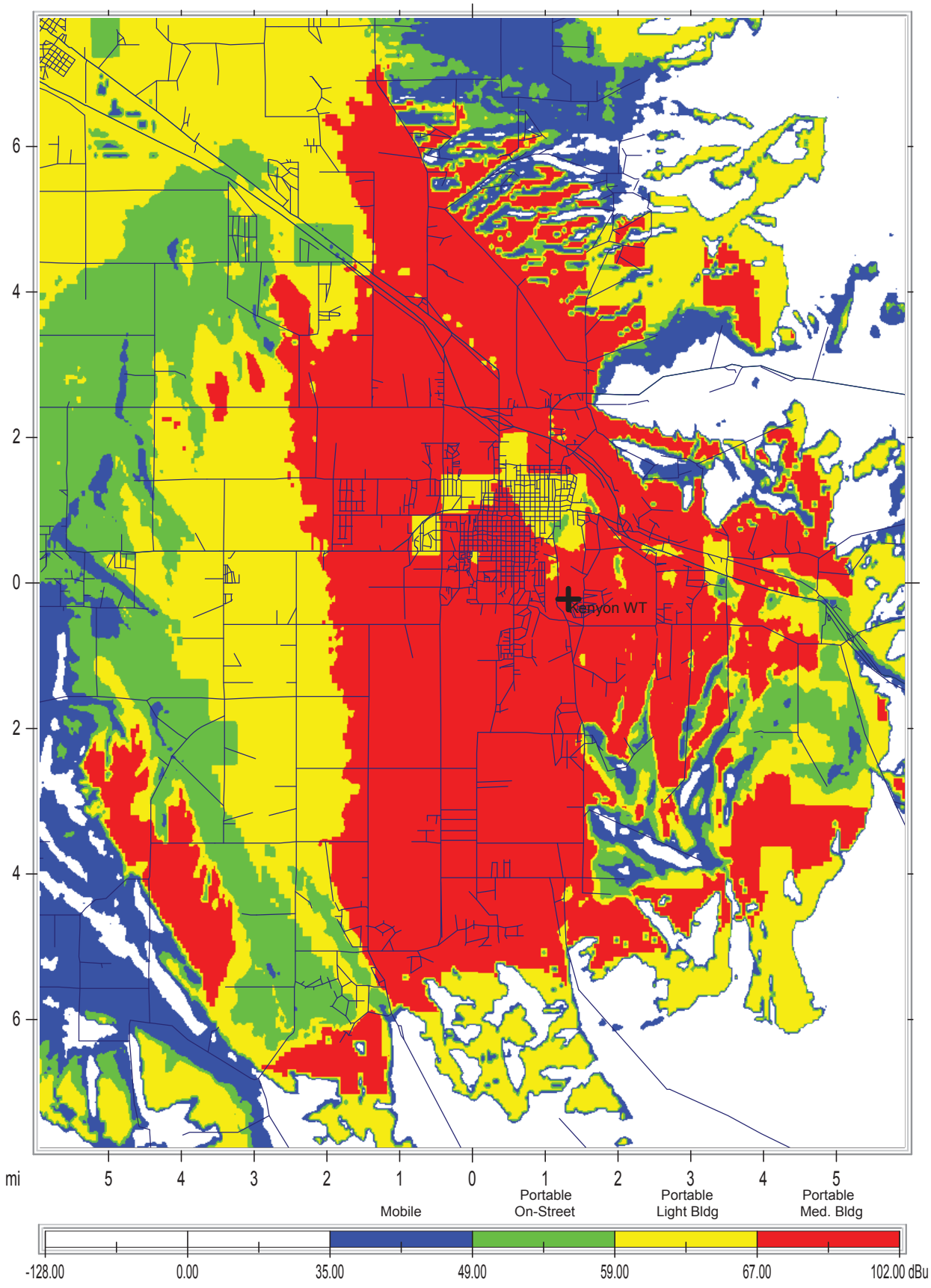
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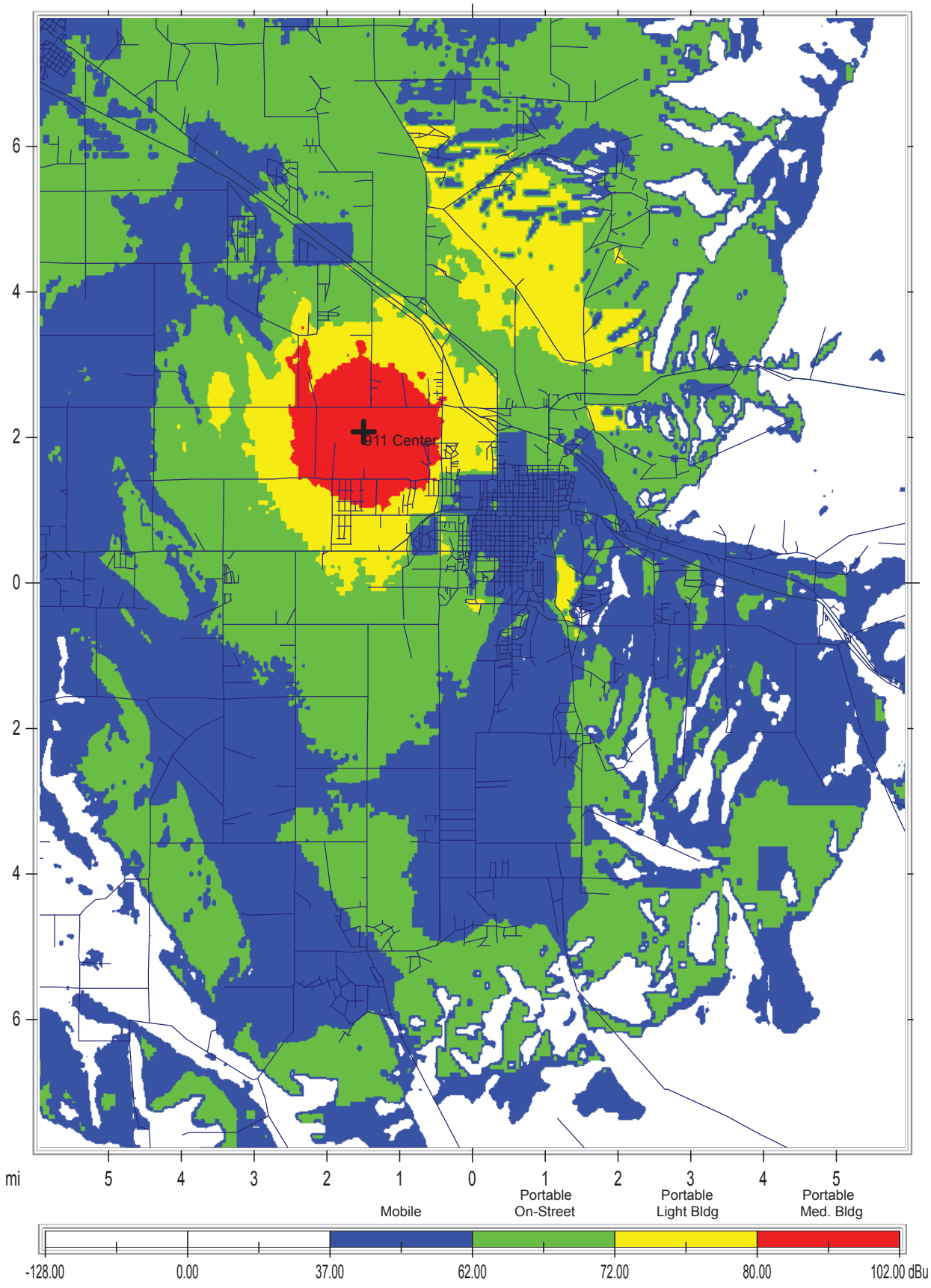
BOZEMAN SIMULCAST TALK-IN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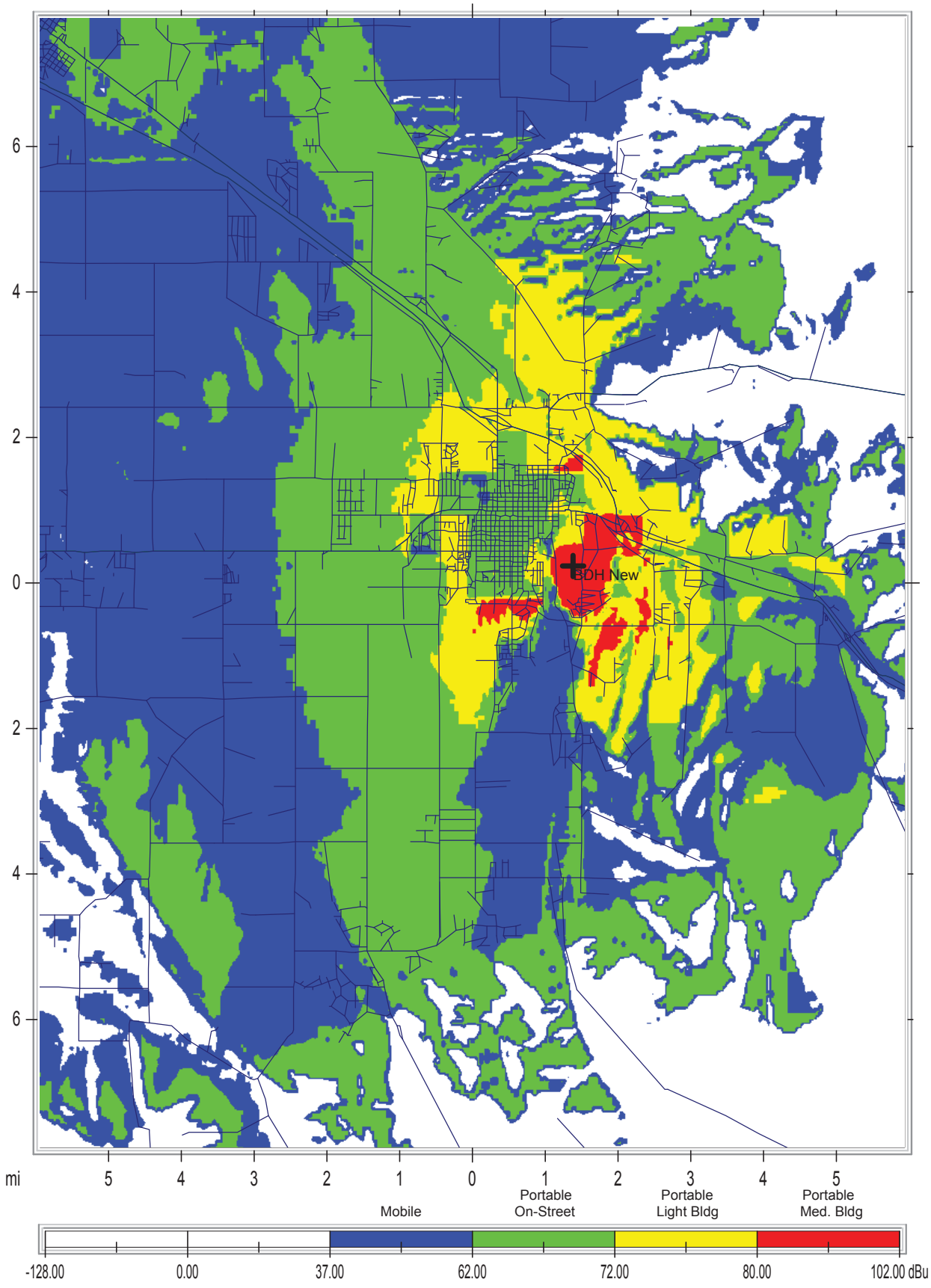
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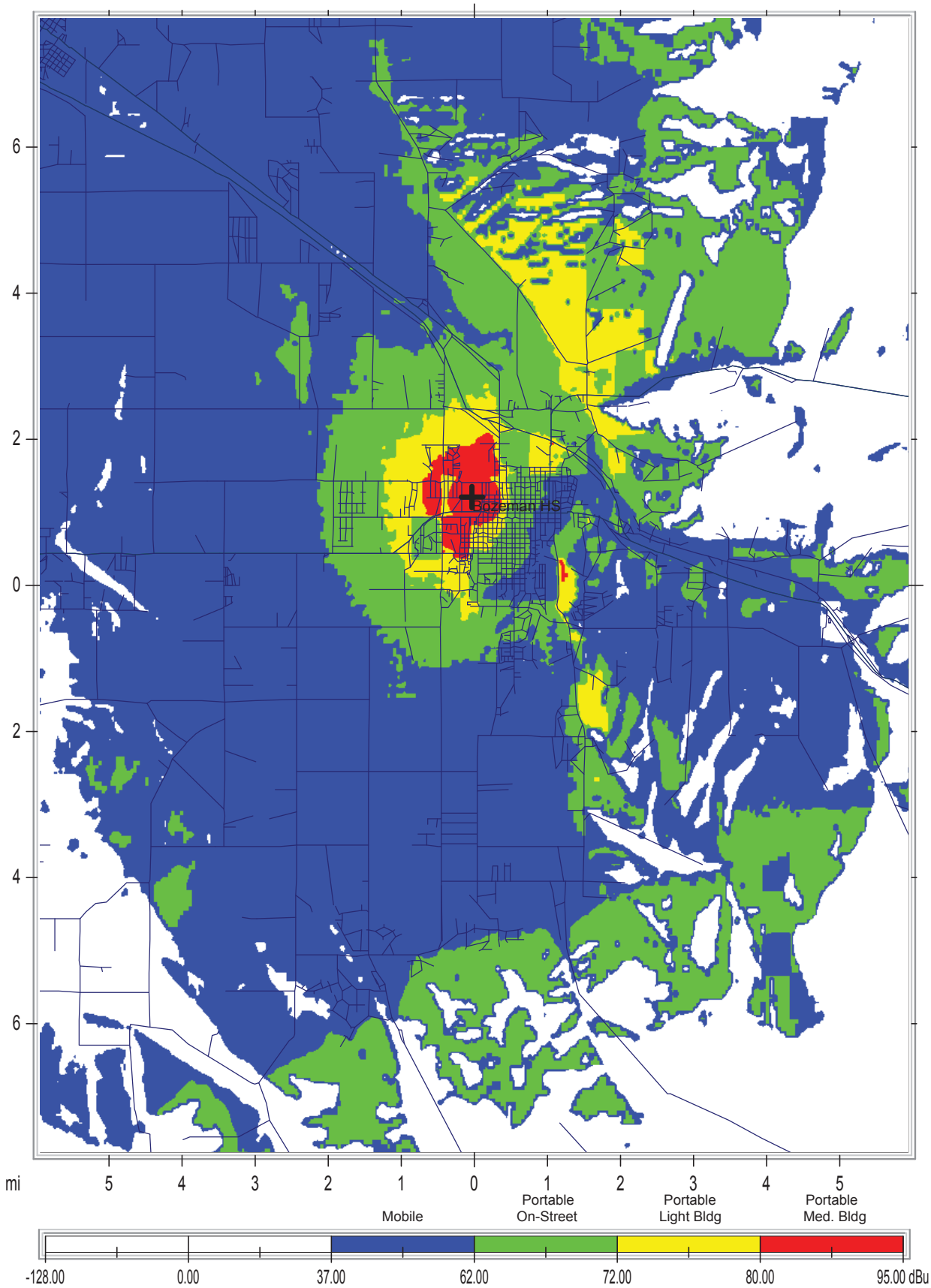
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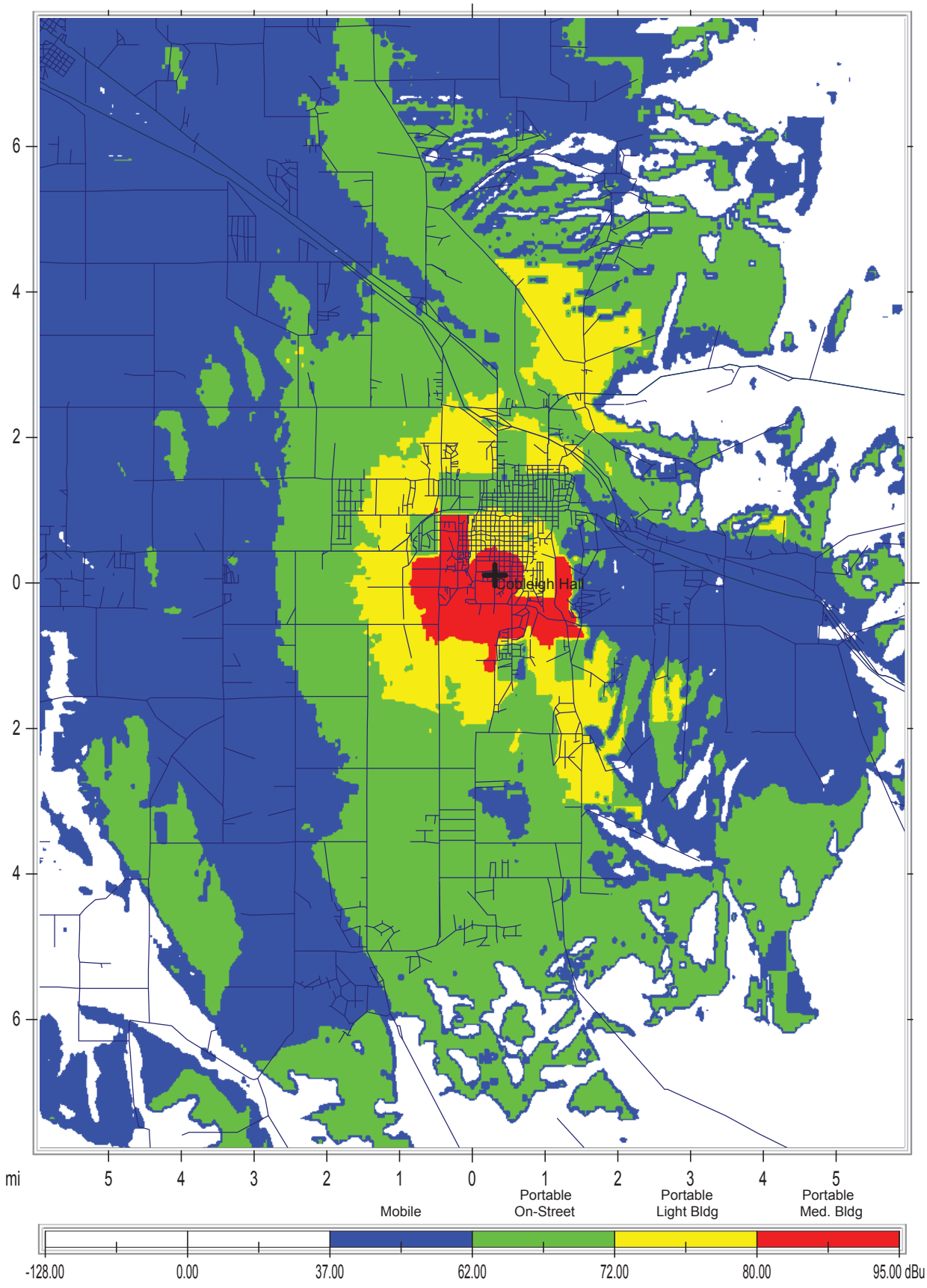
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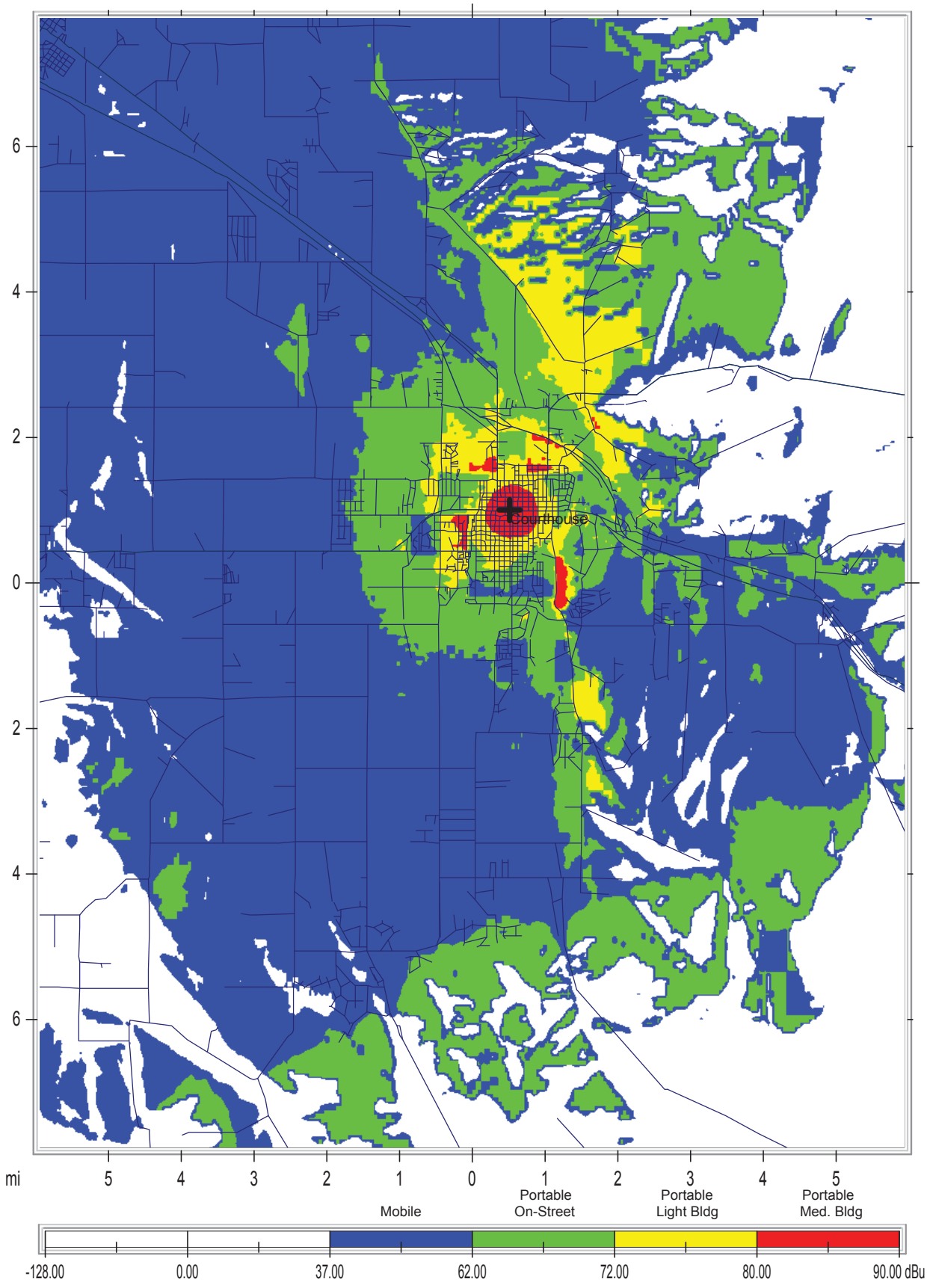
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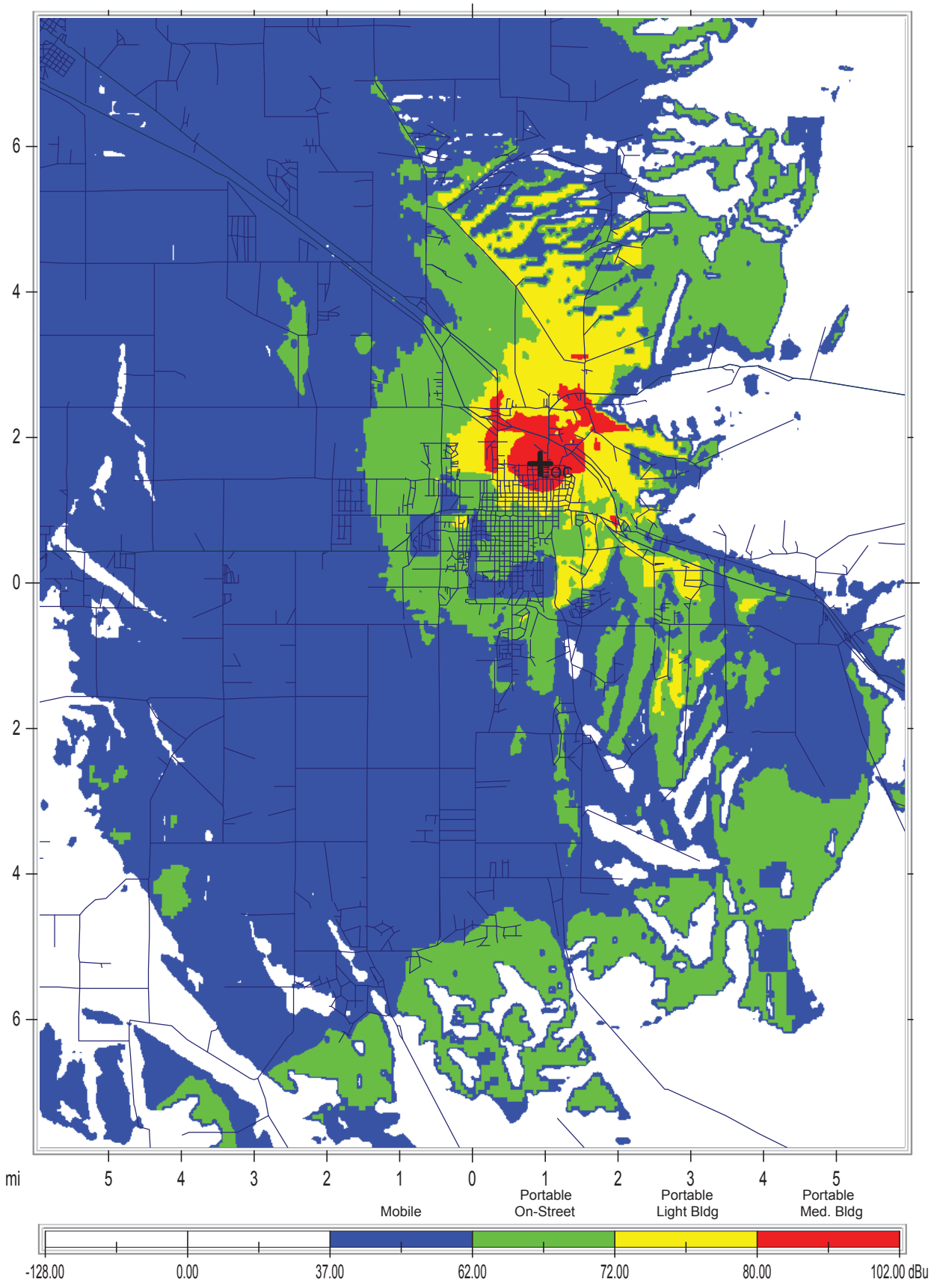
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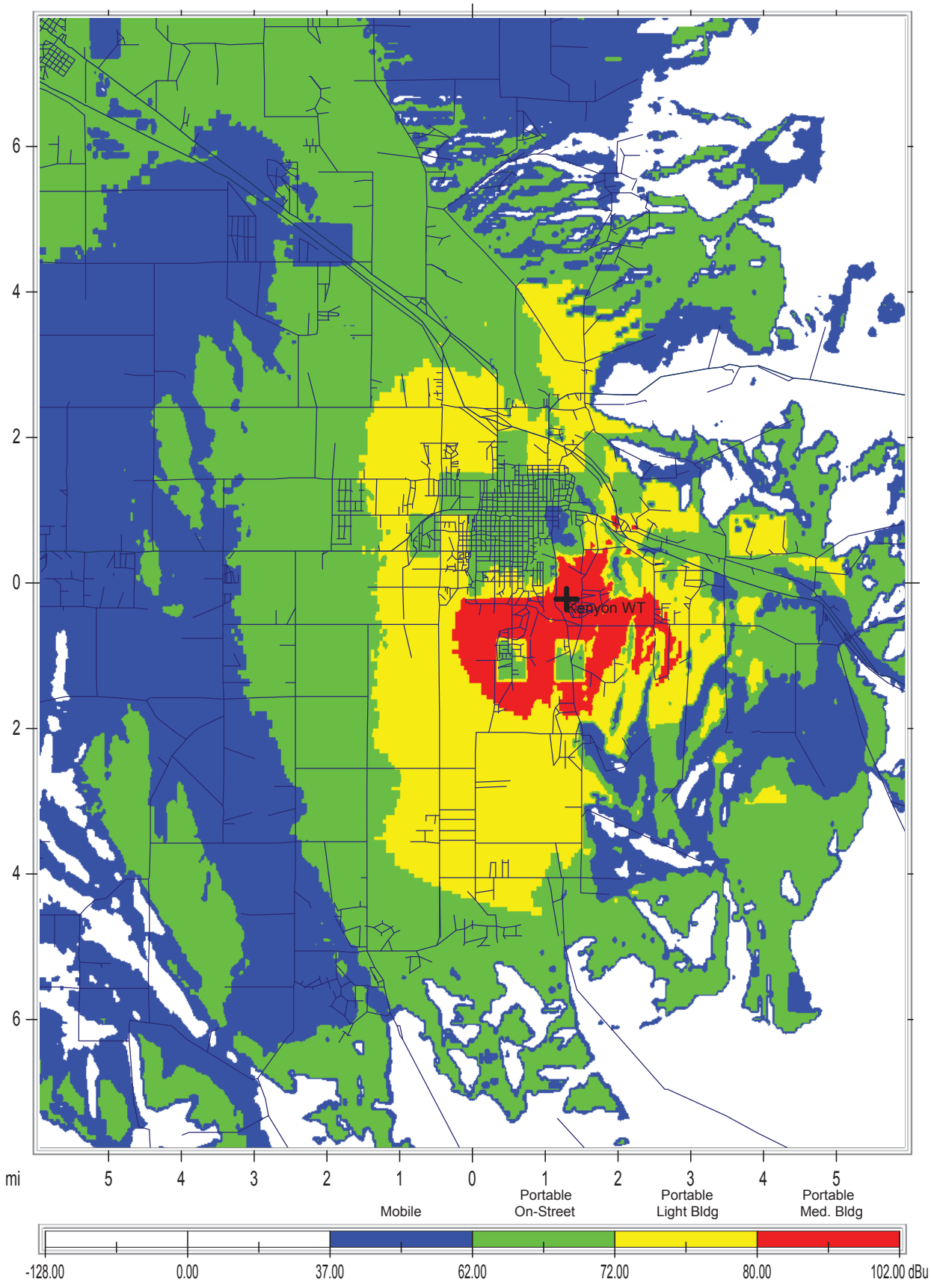
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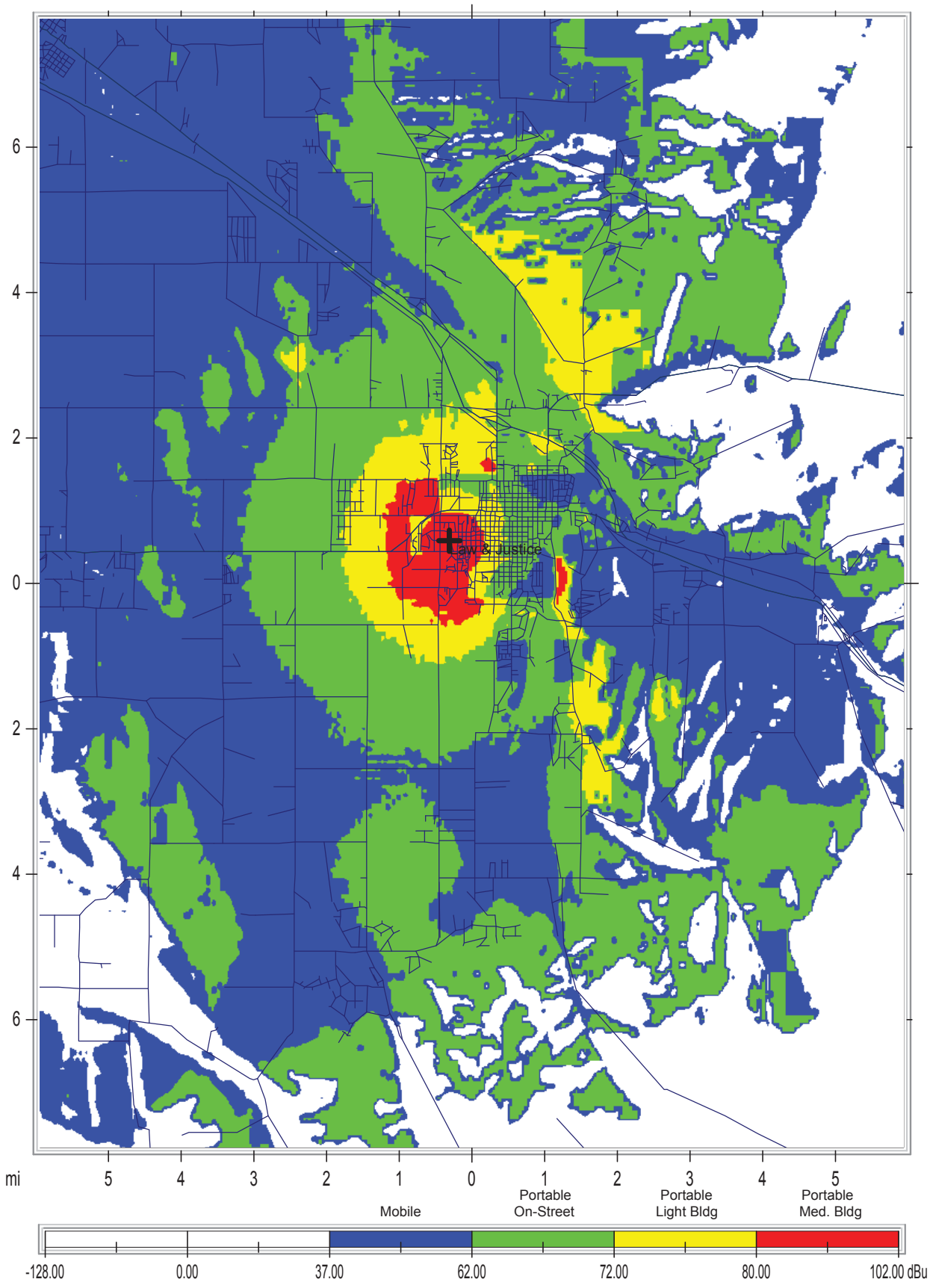
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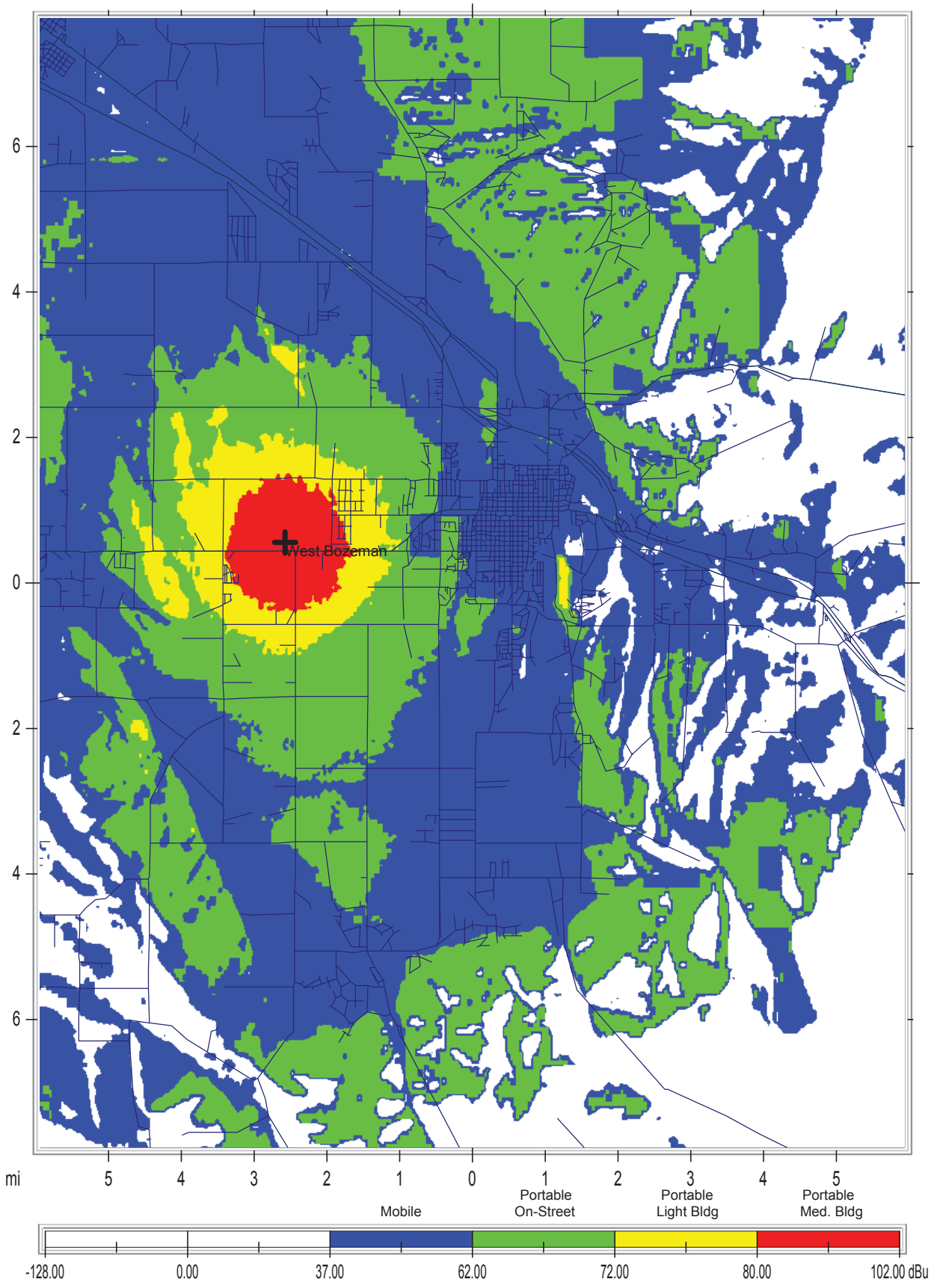
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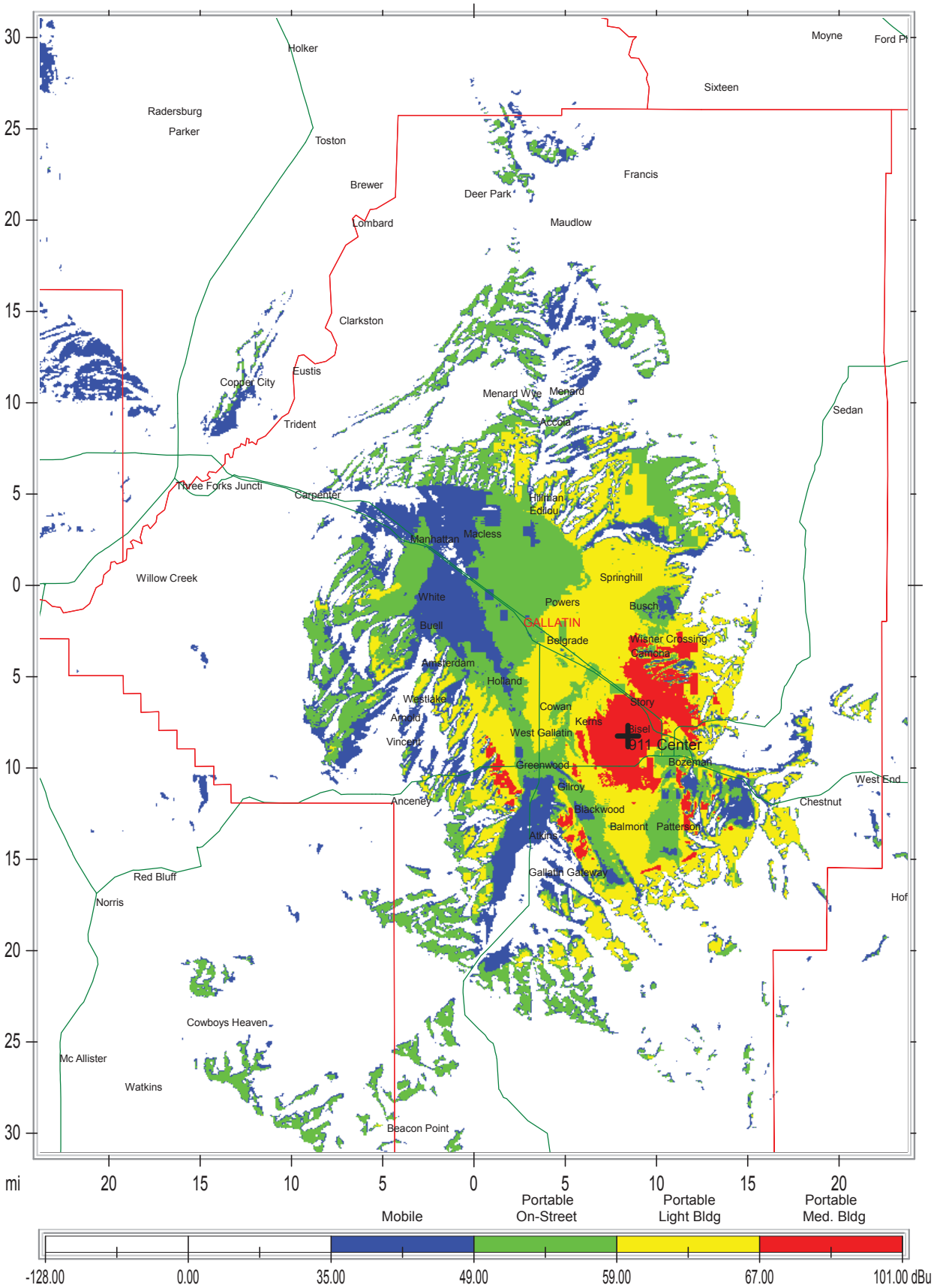
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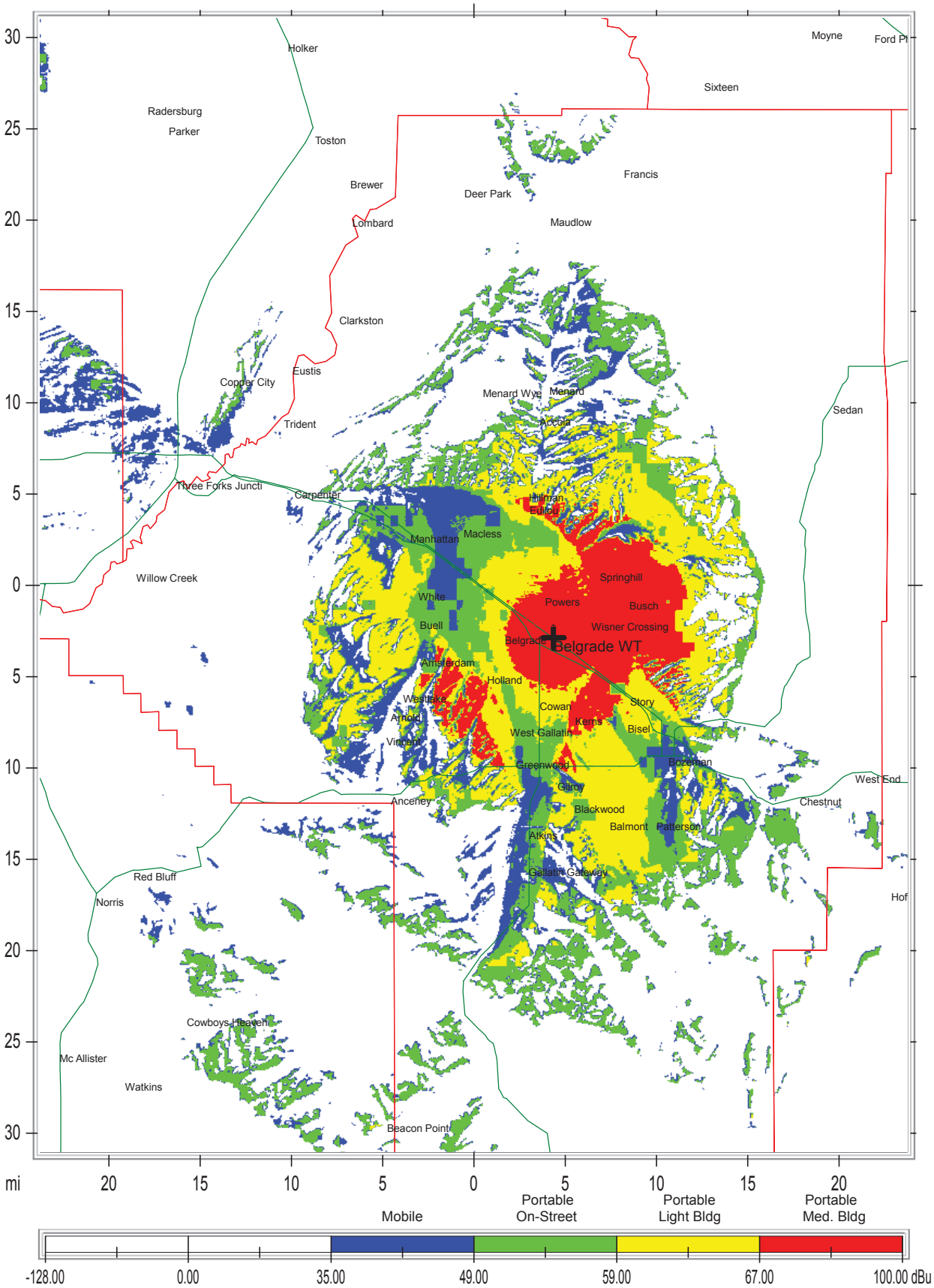
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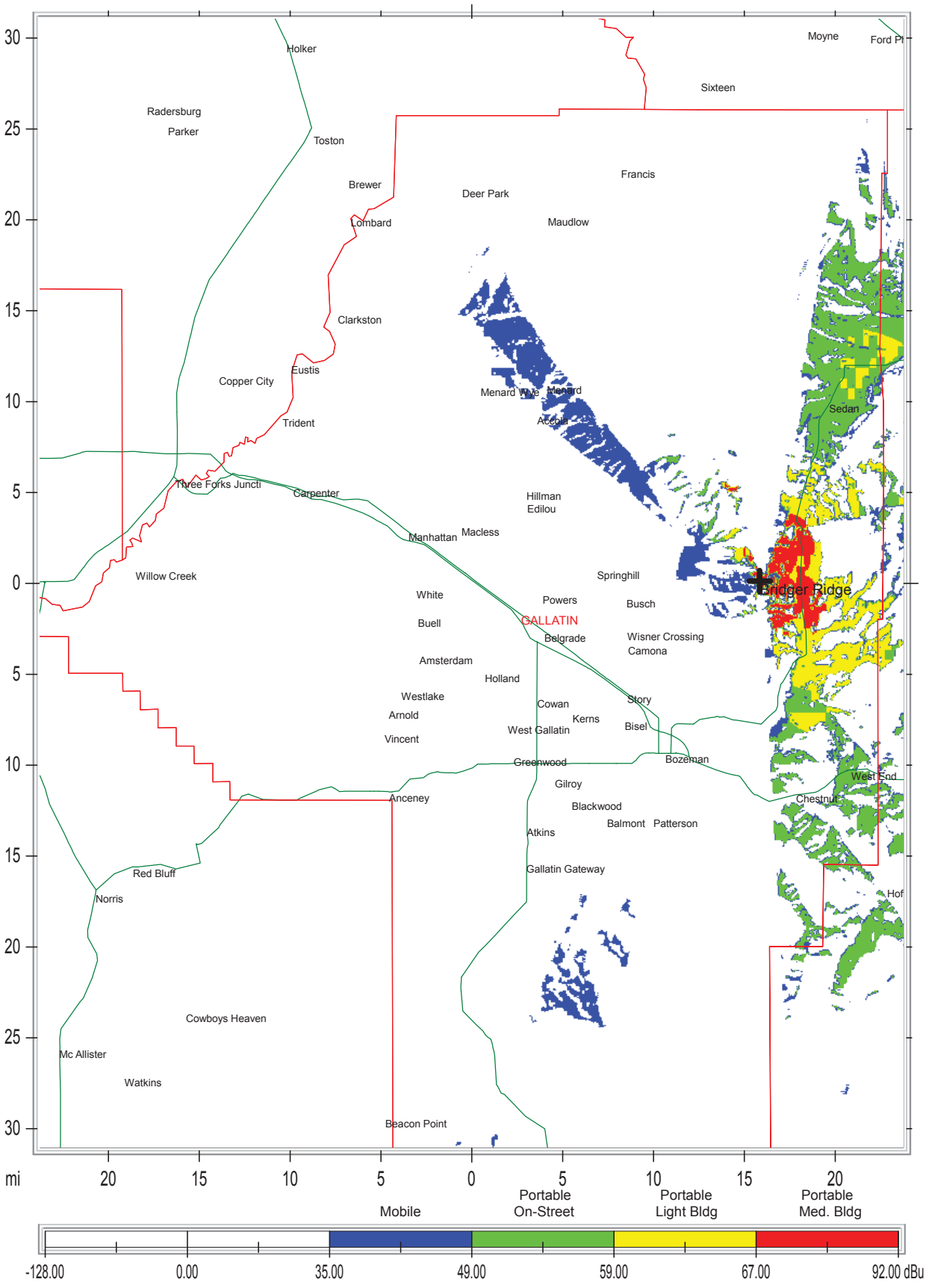
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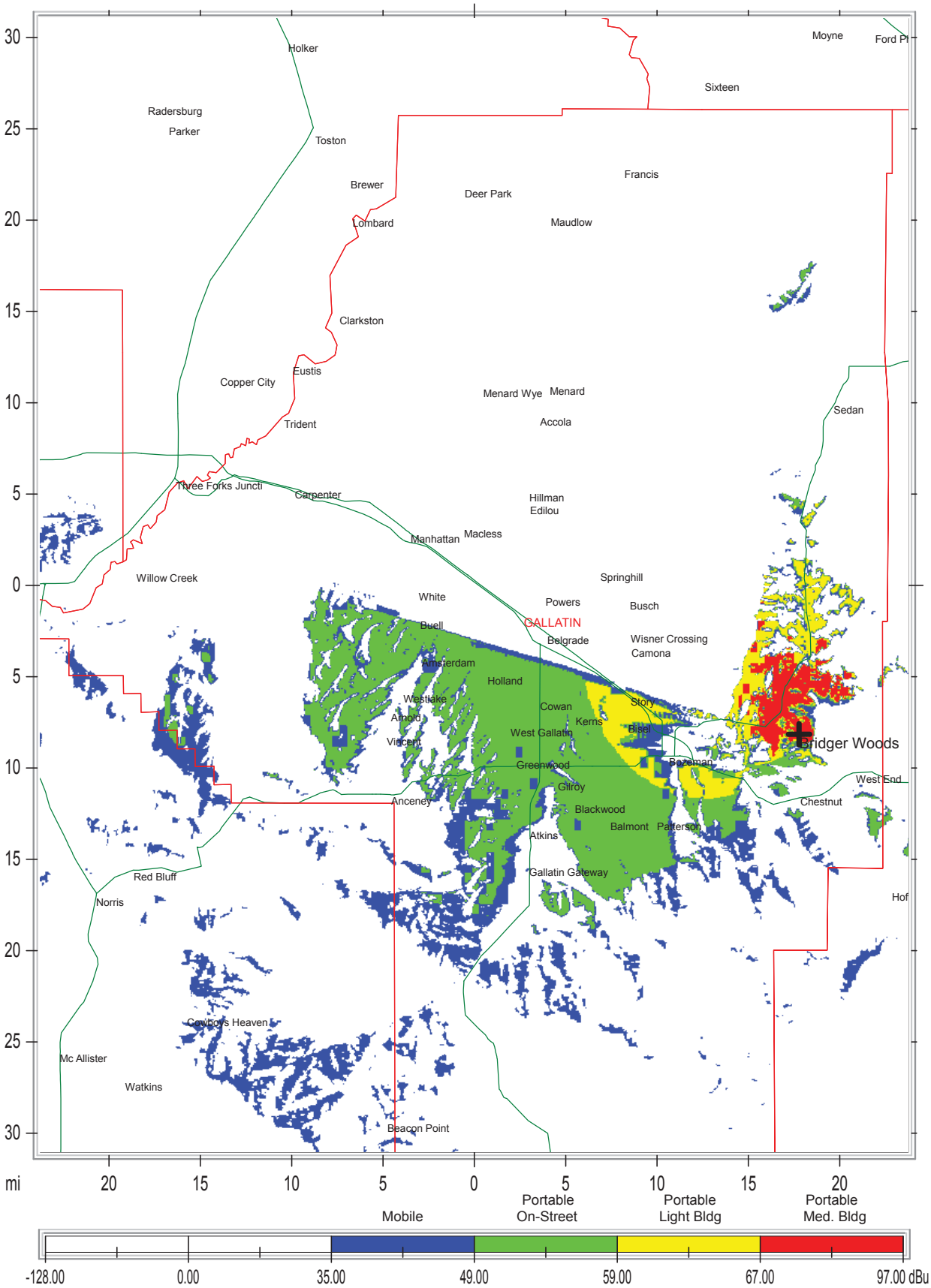
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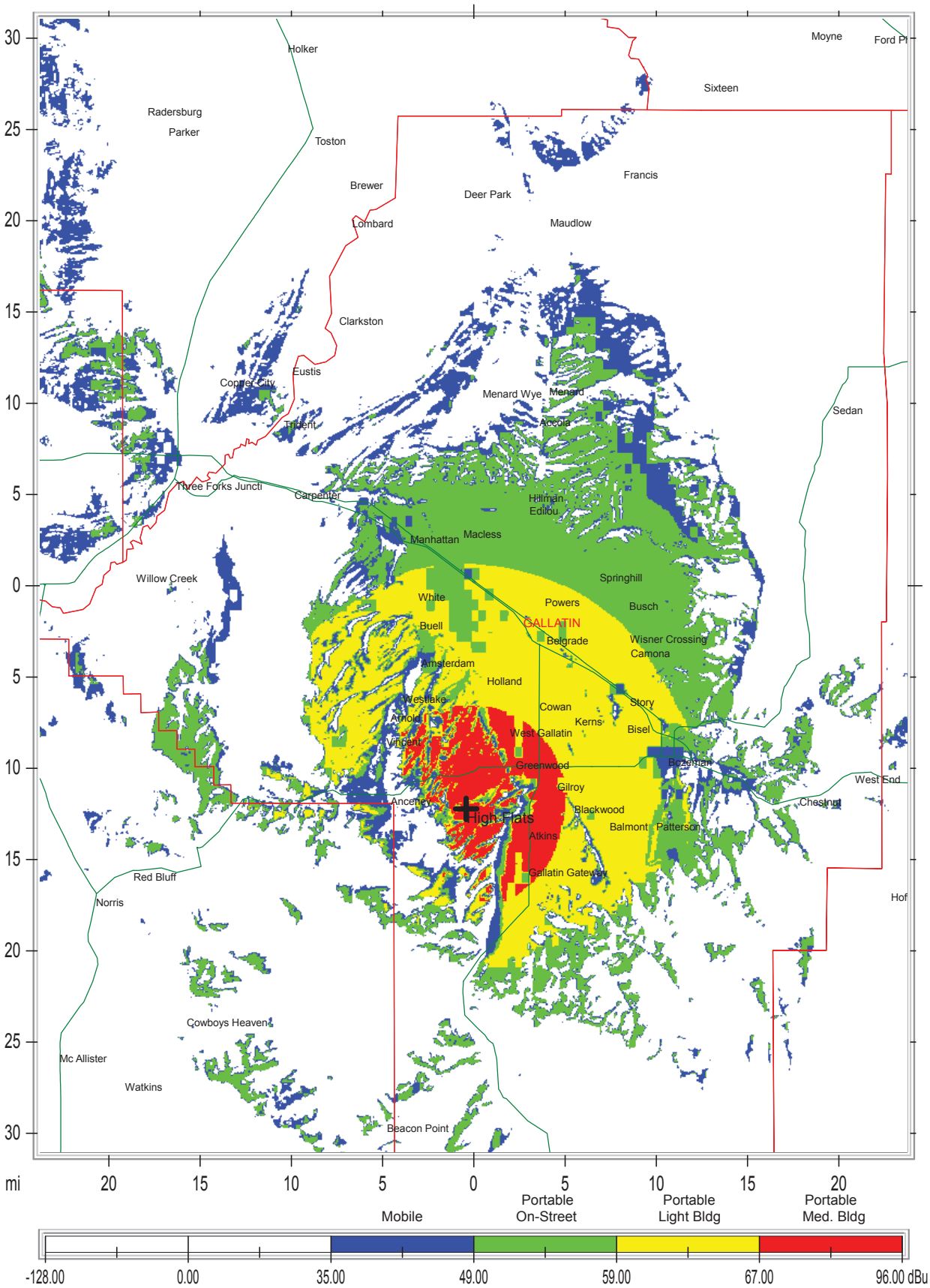
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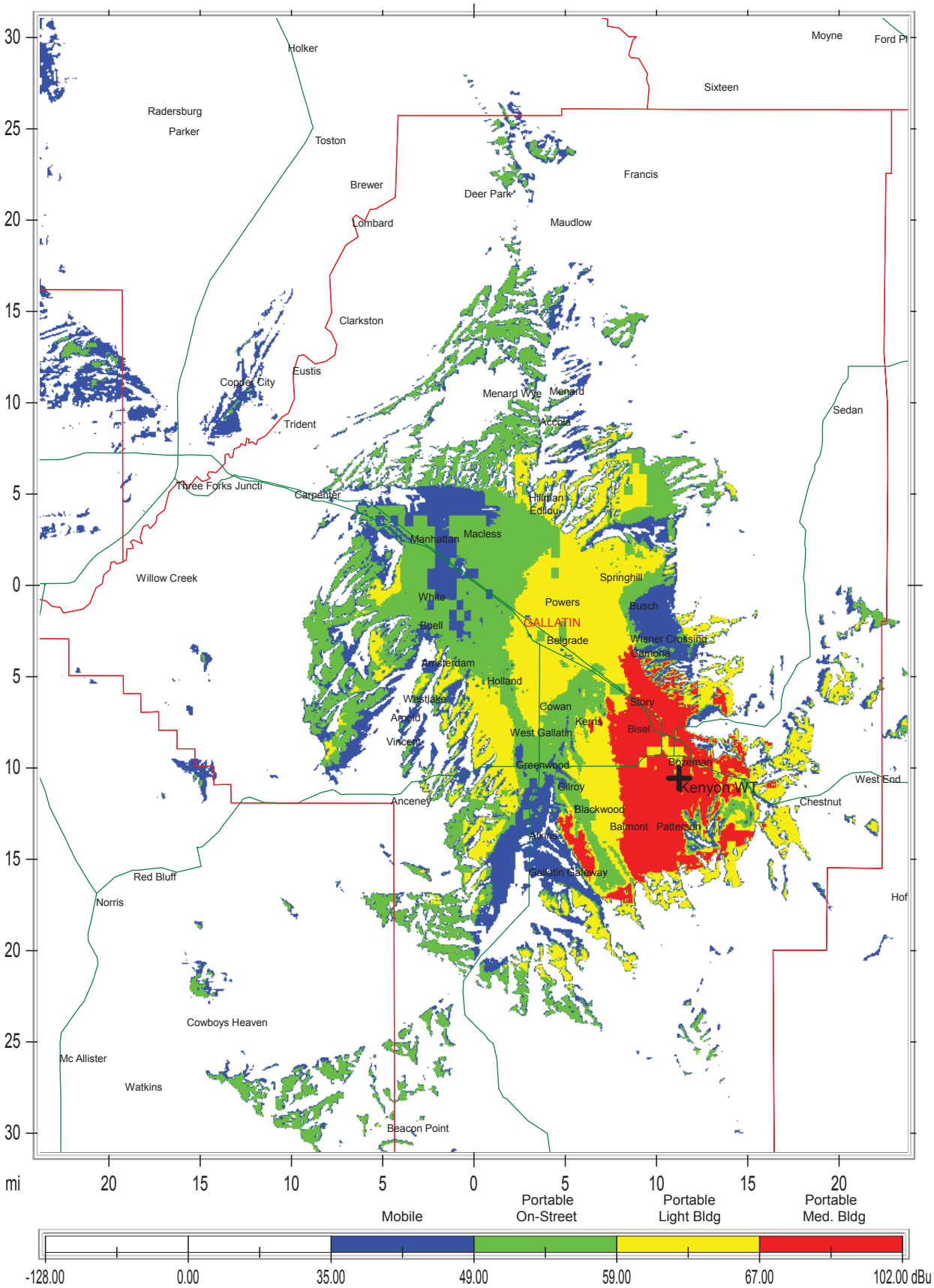
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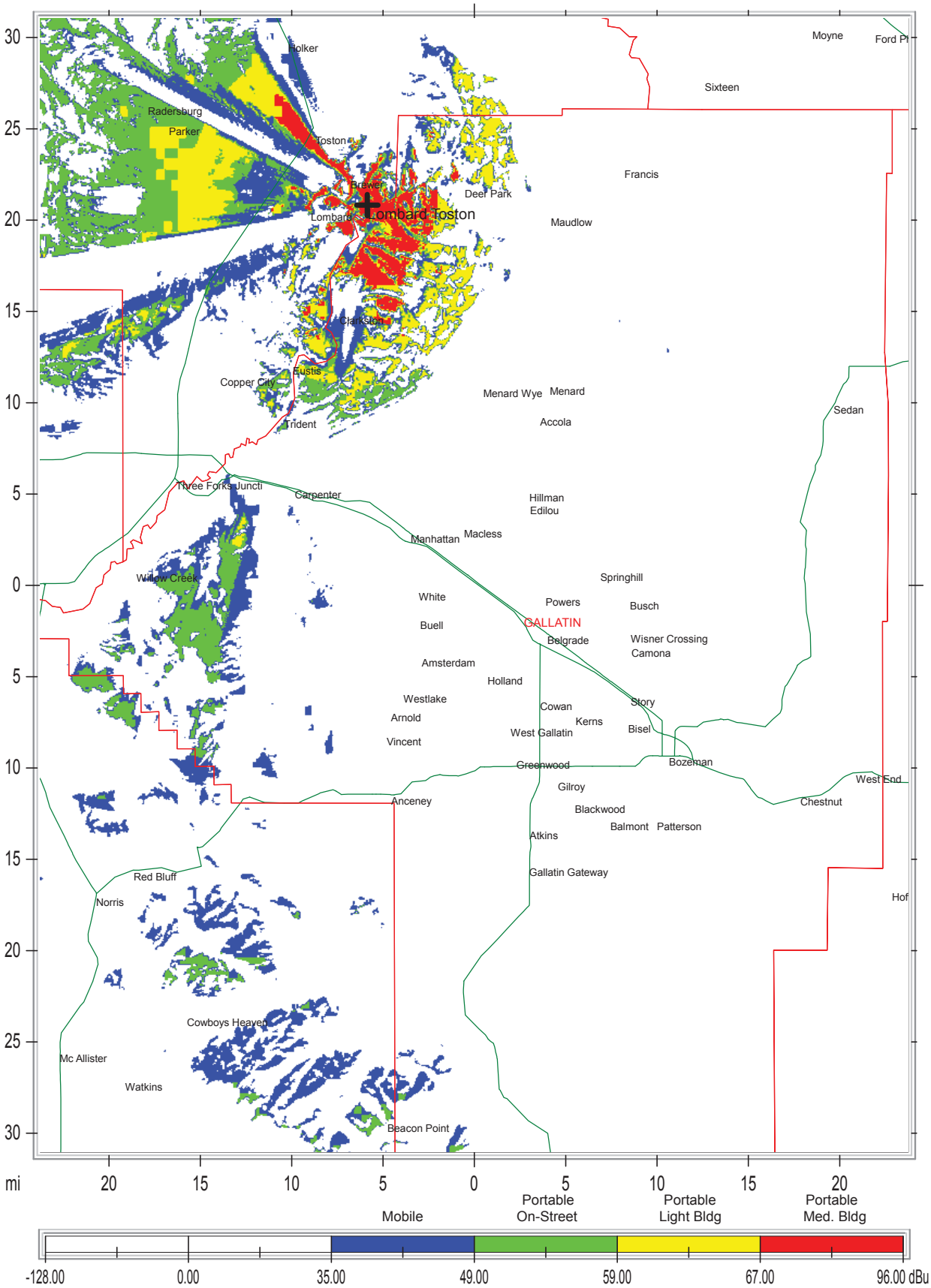
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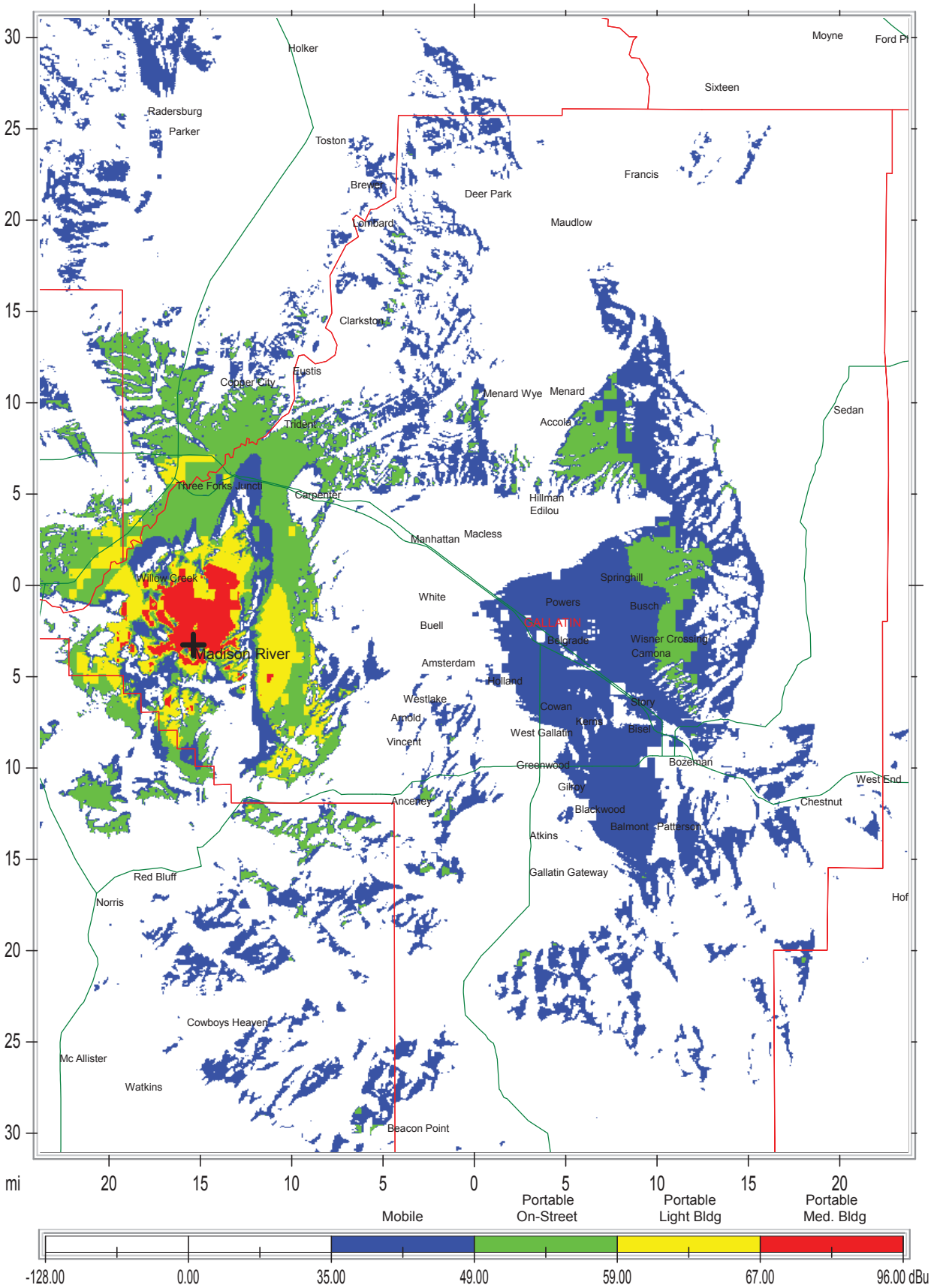
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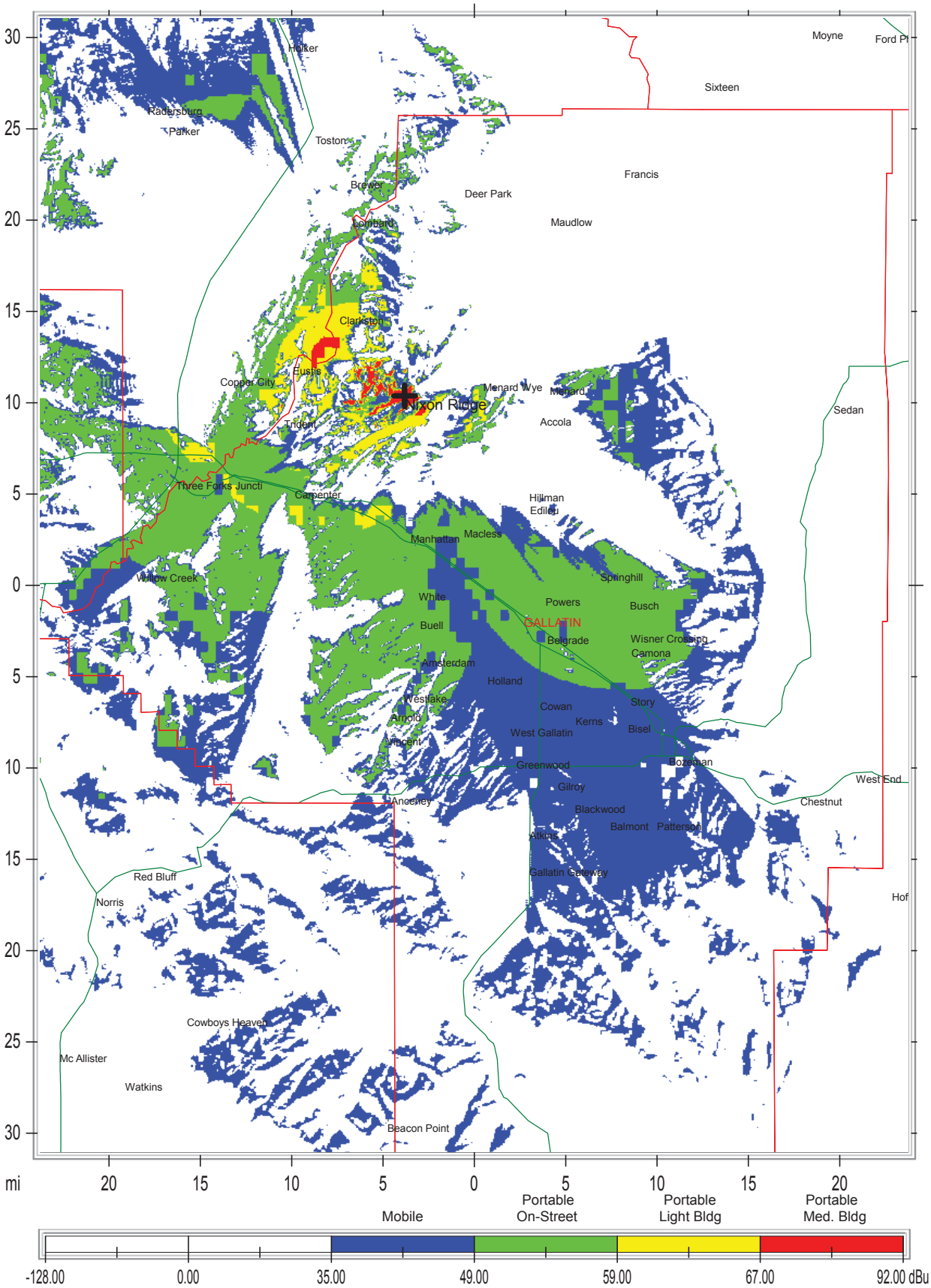
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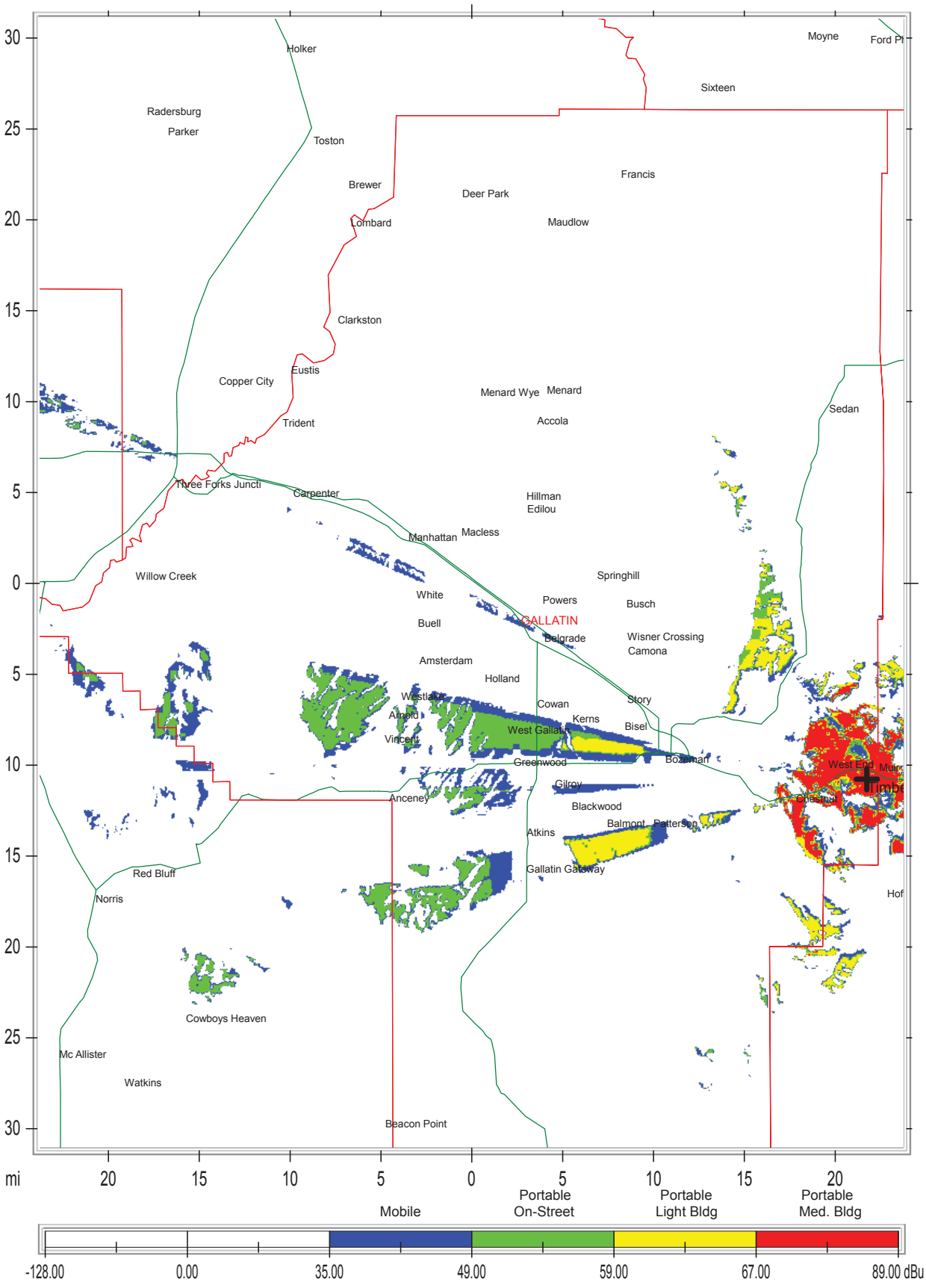
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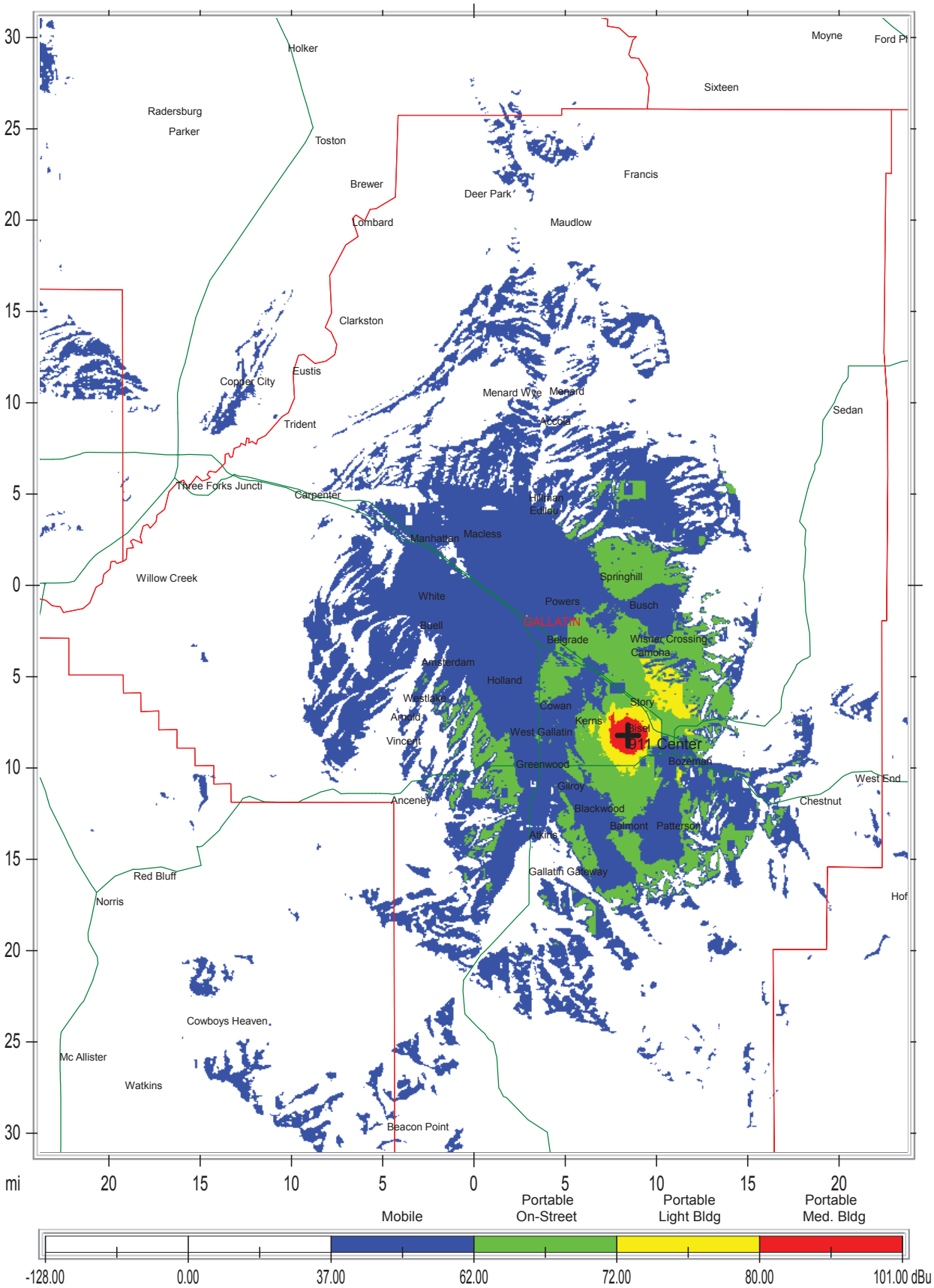
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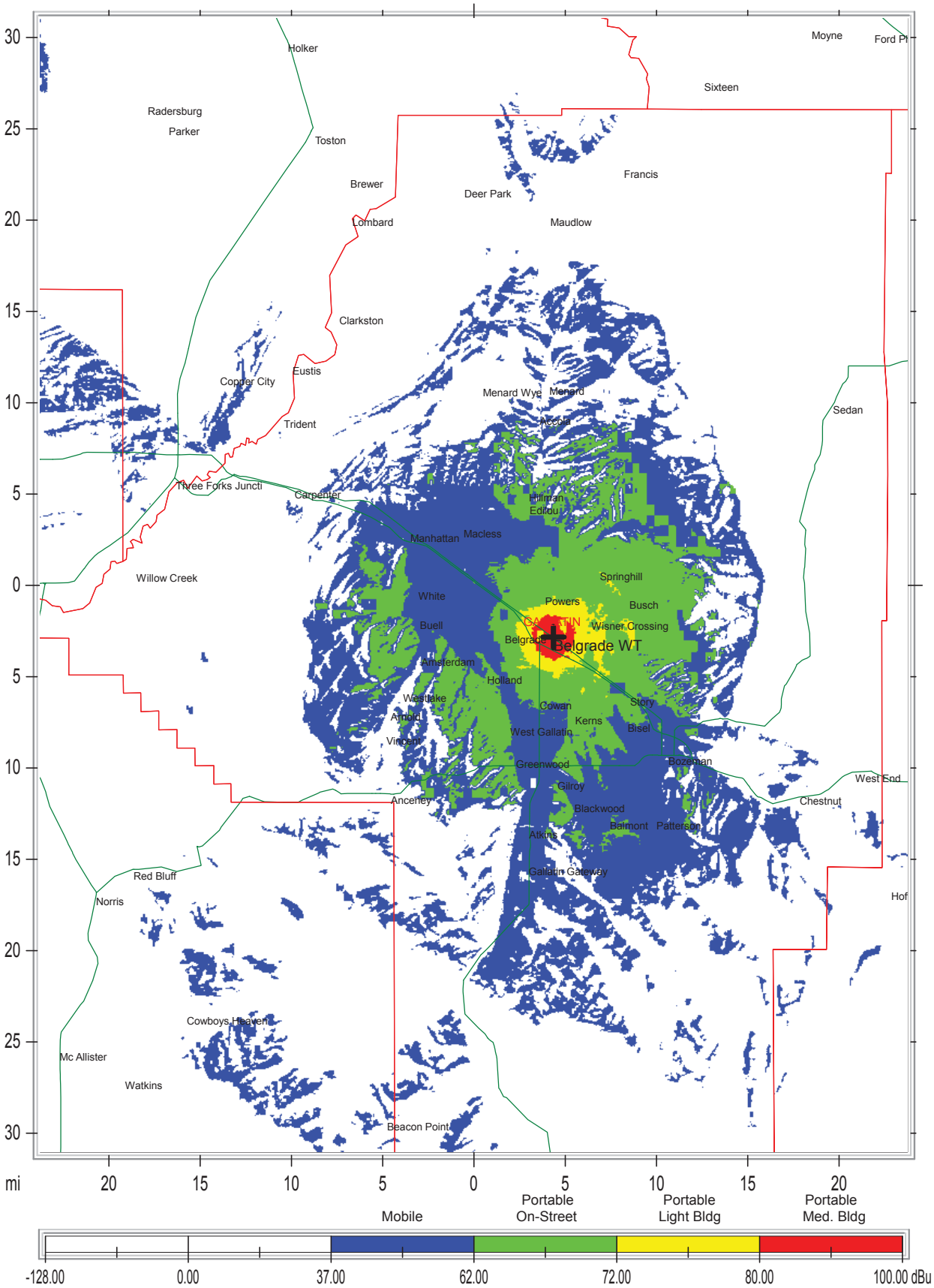
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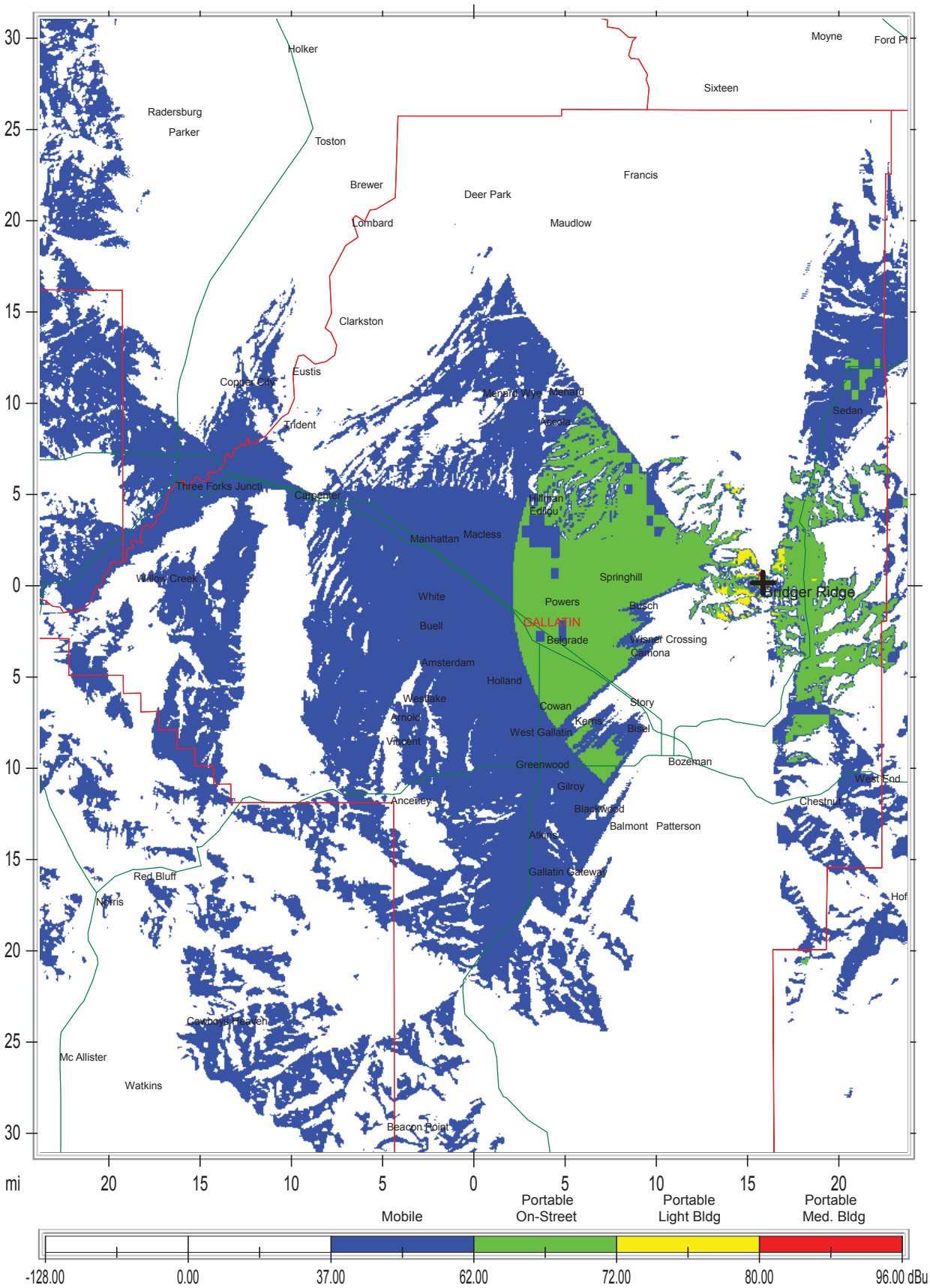
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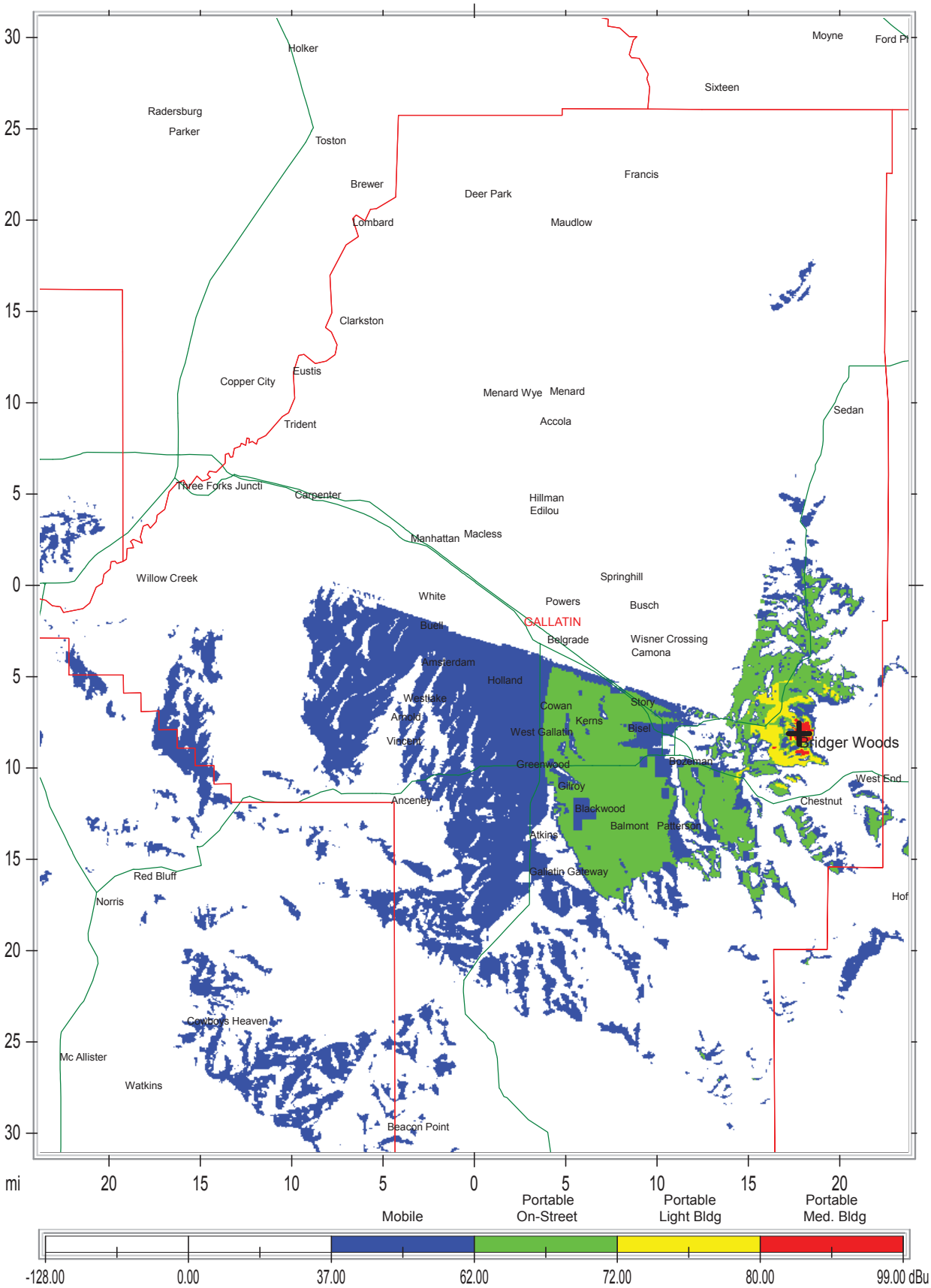
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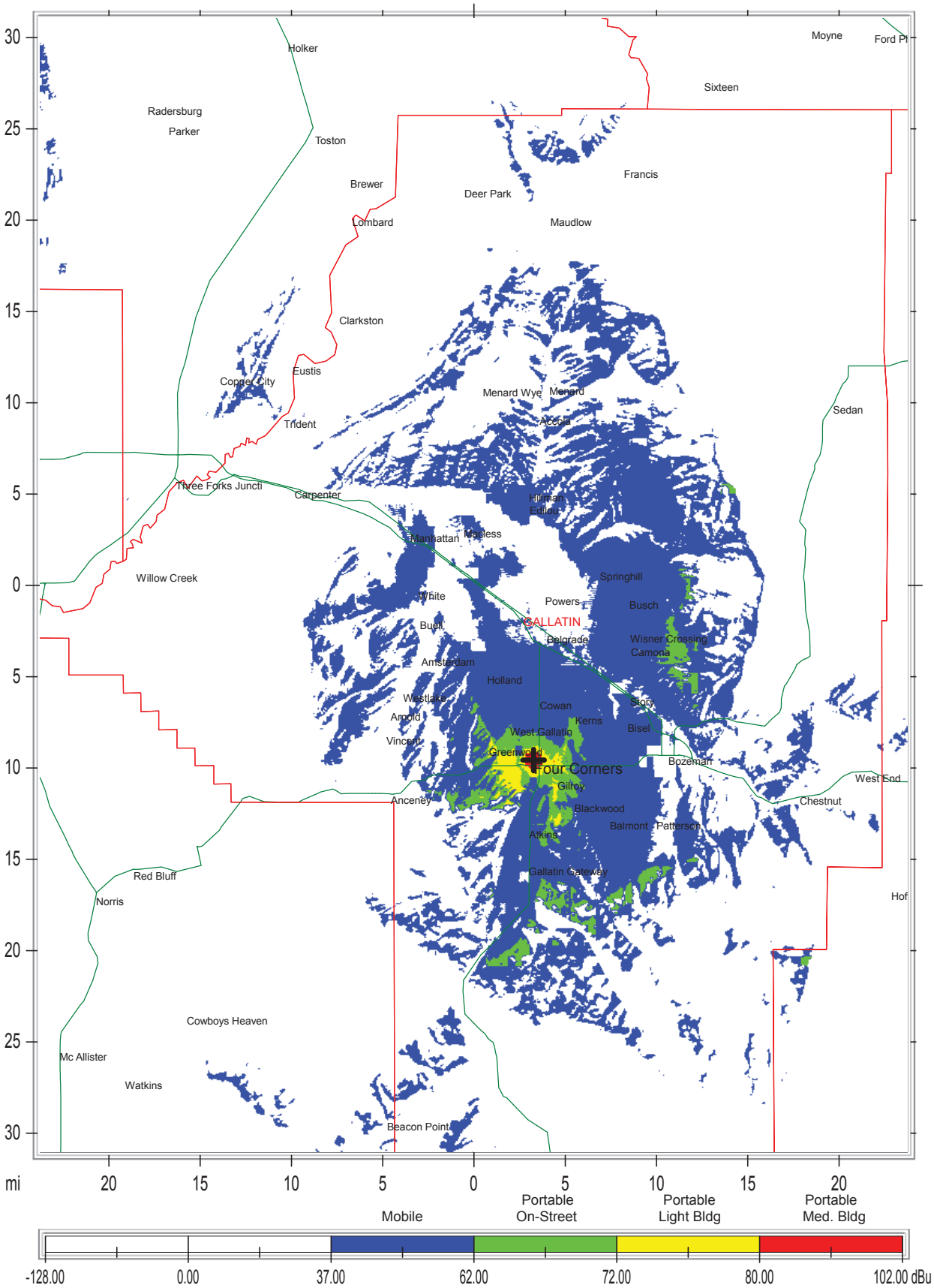
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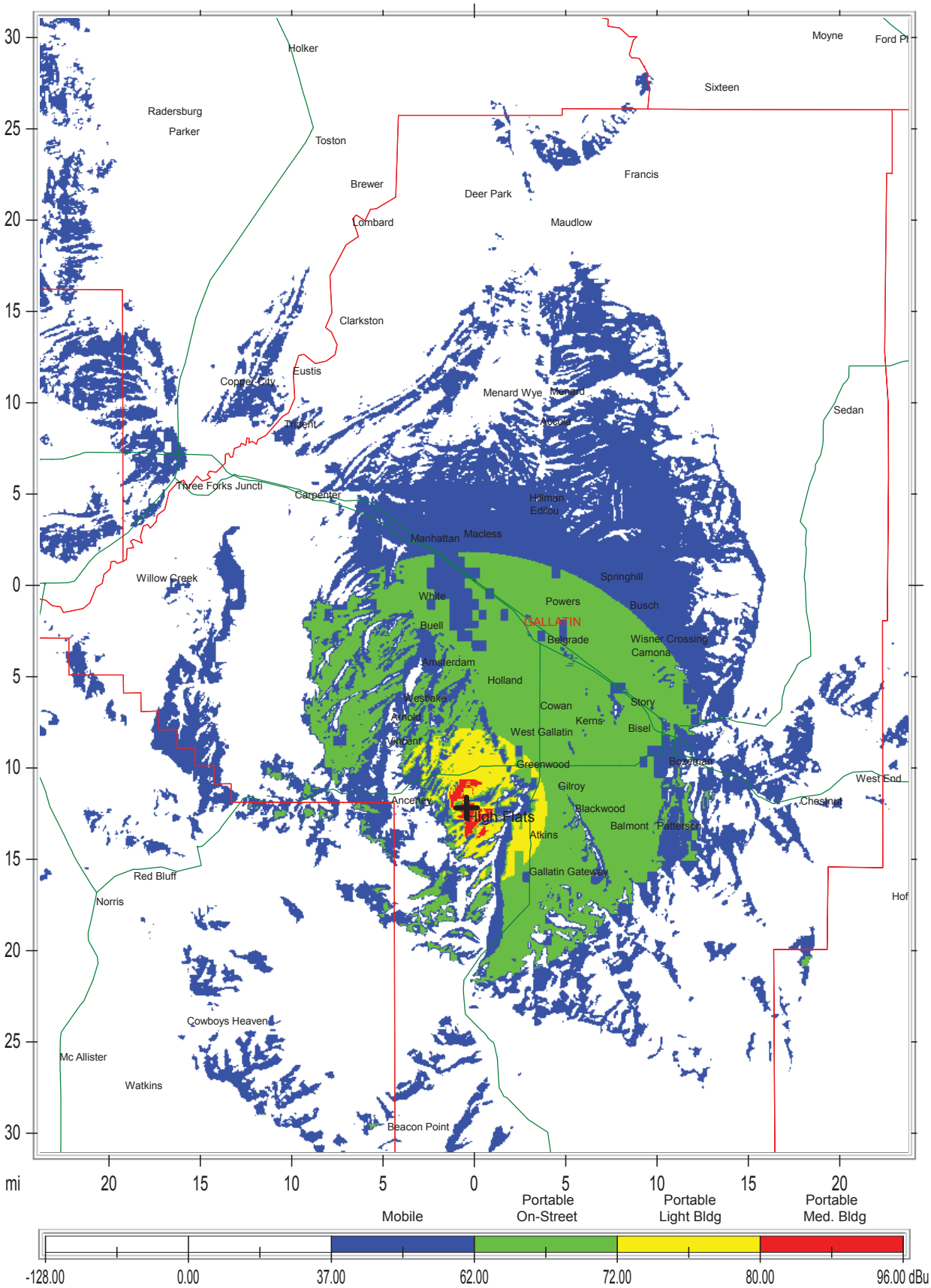
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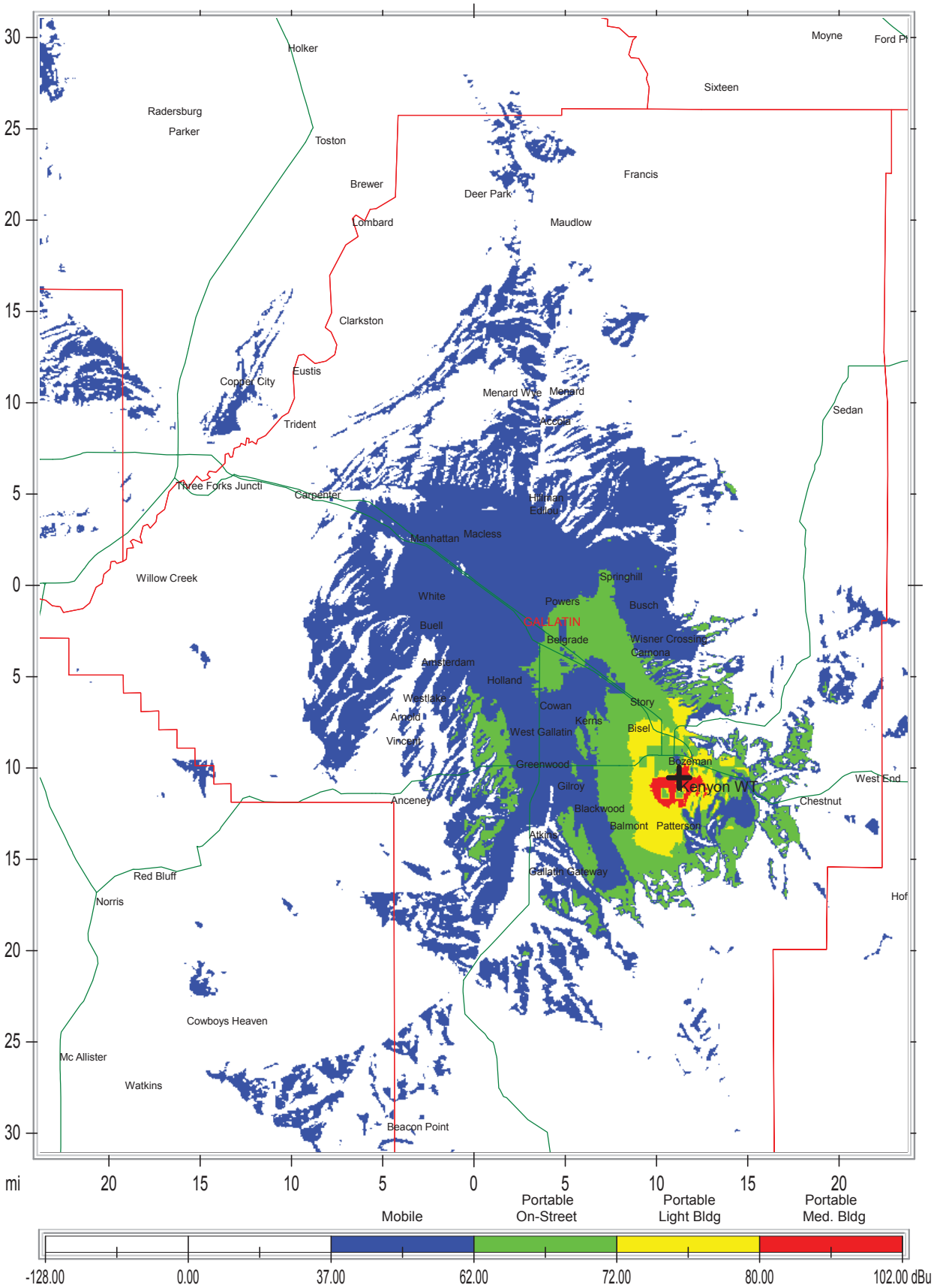
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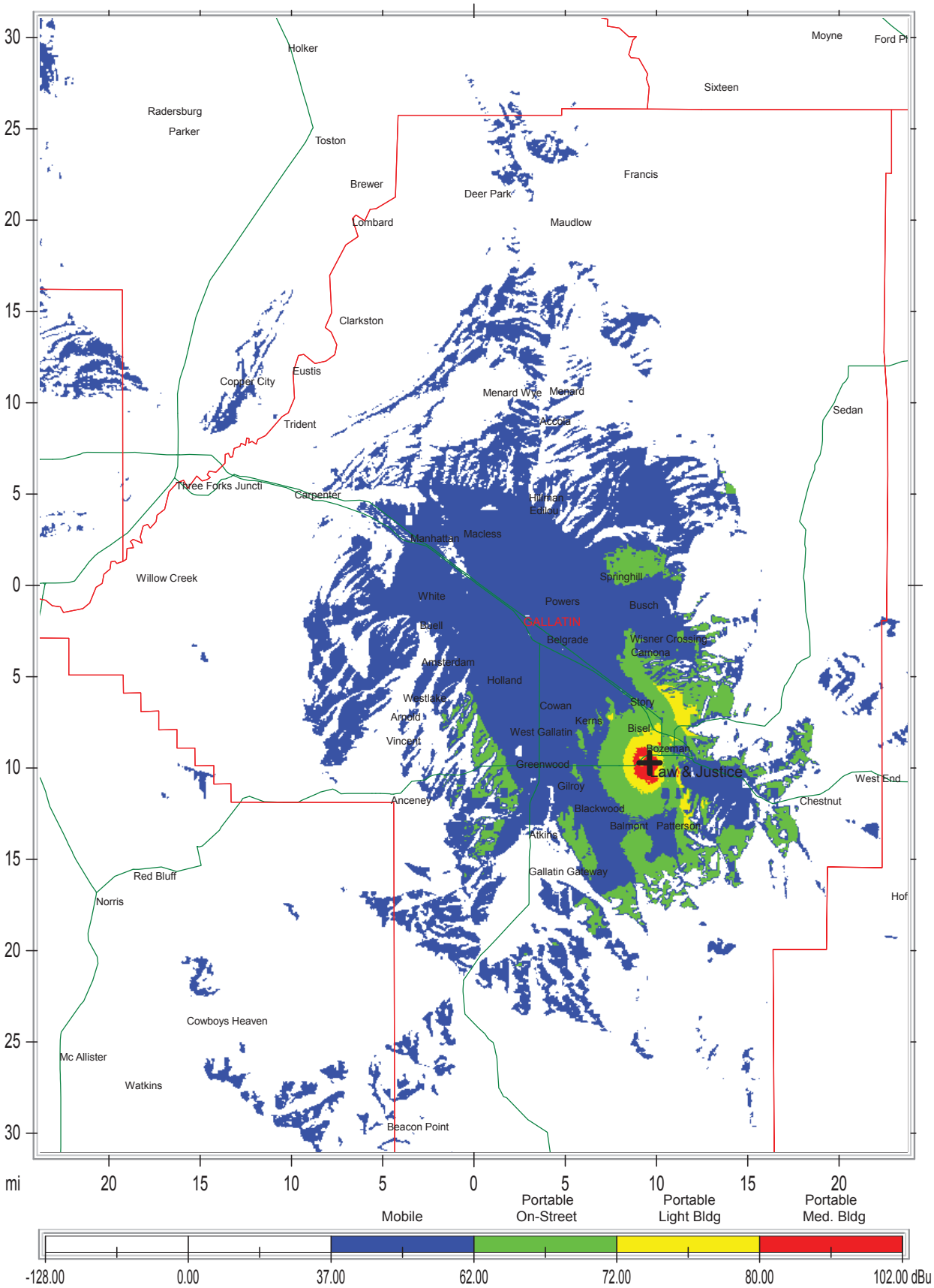
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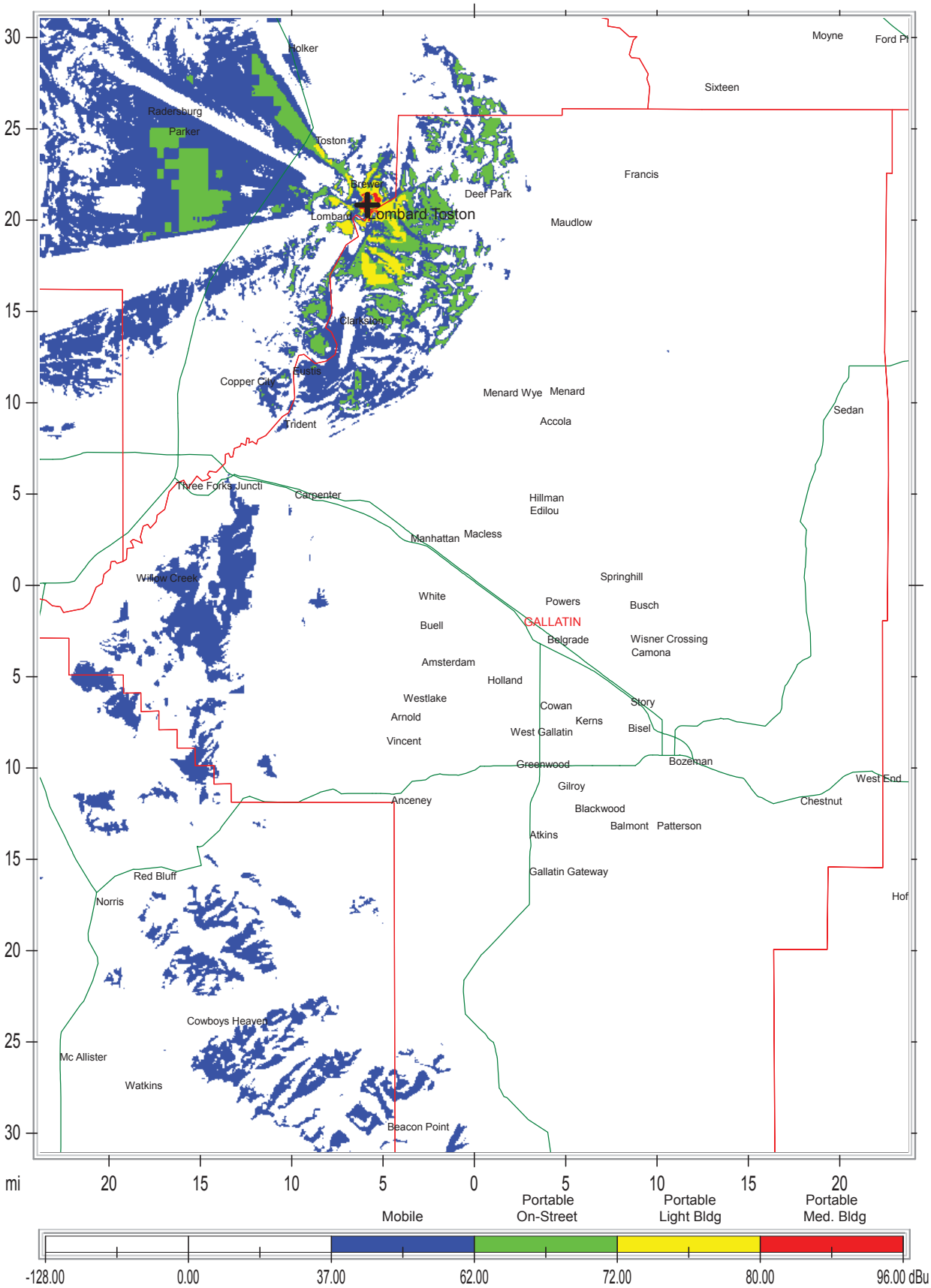
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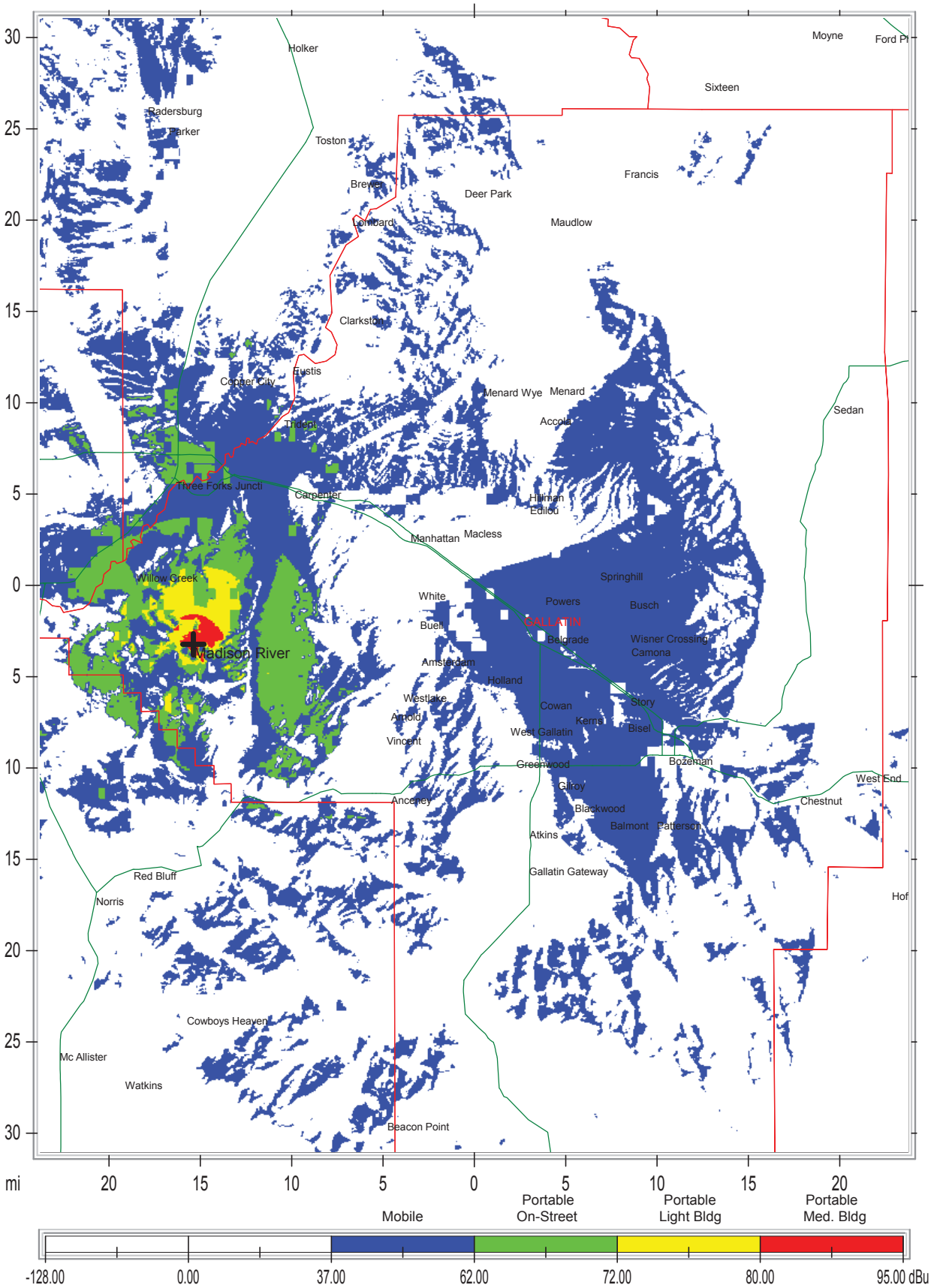
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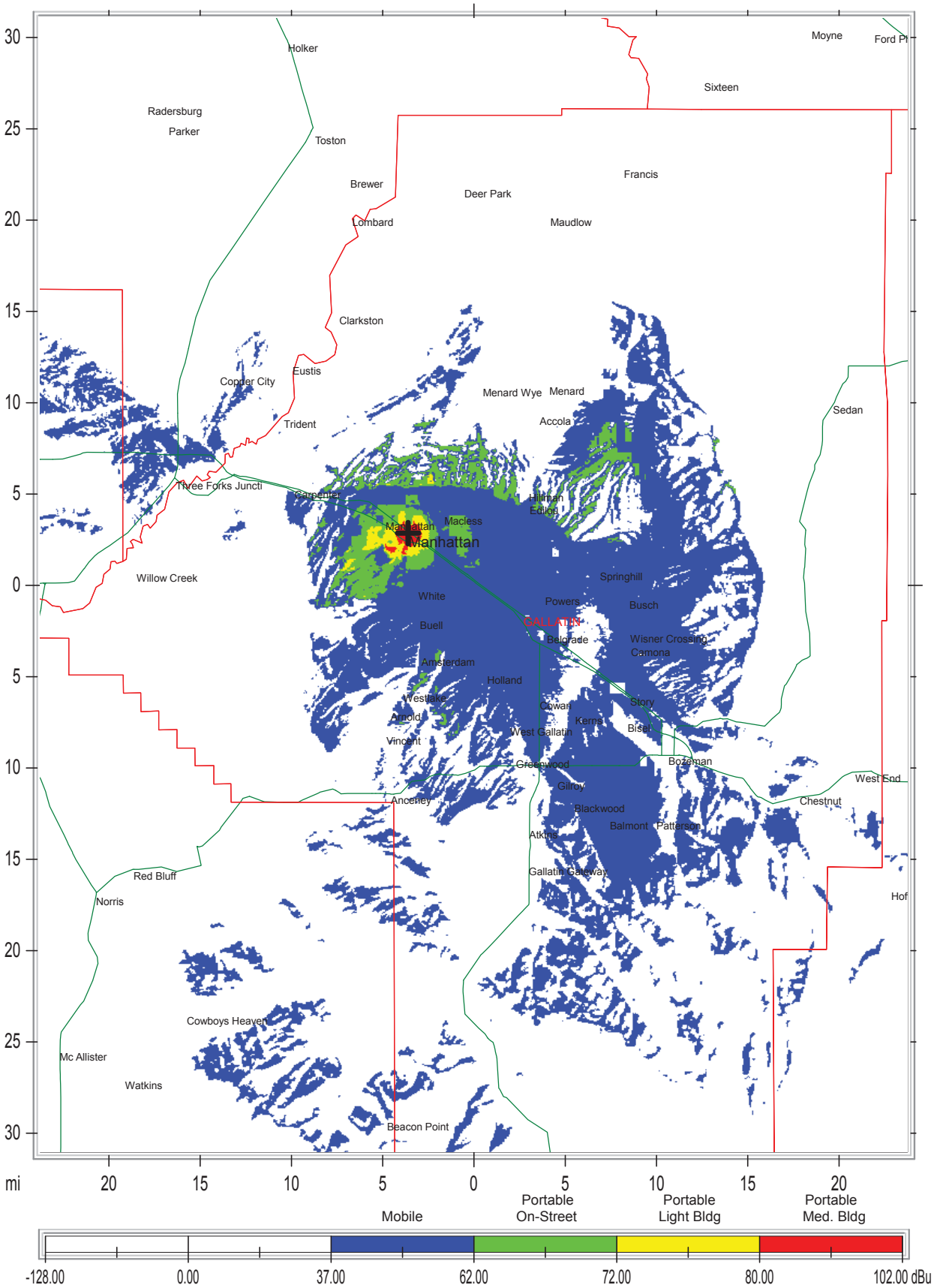
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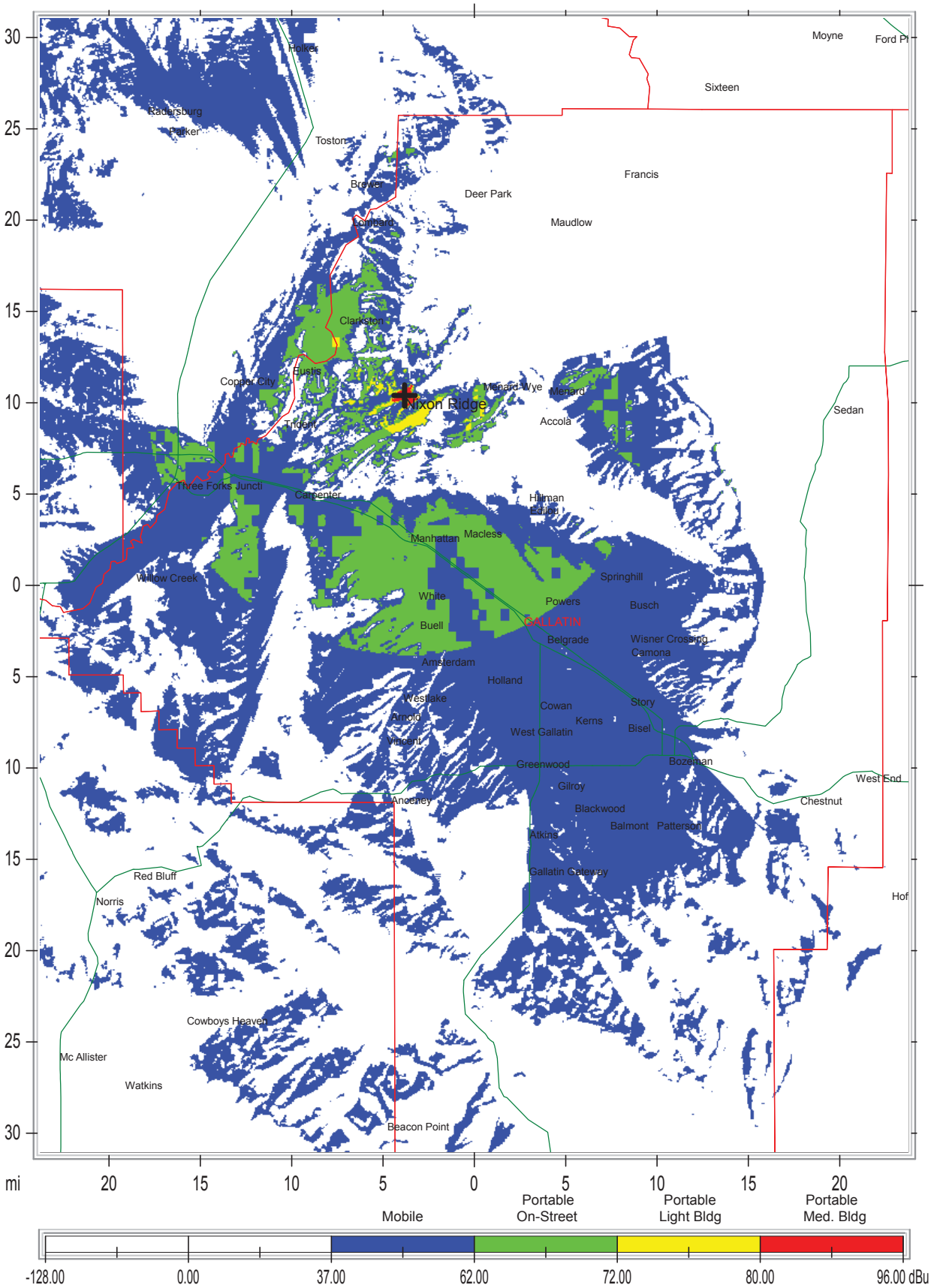
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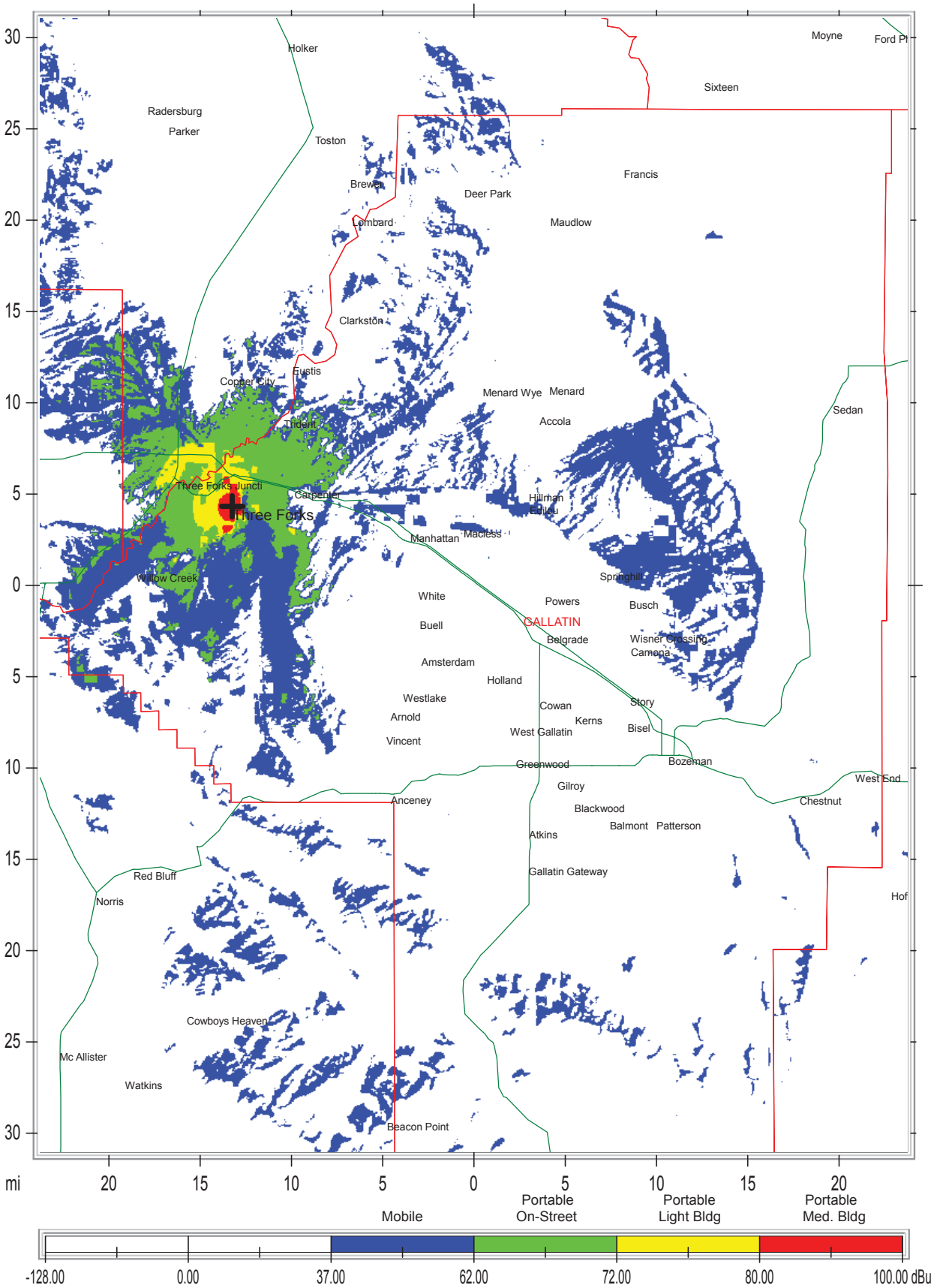
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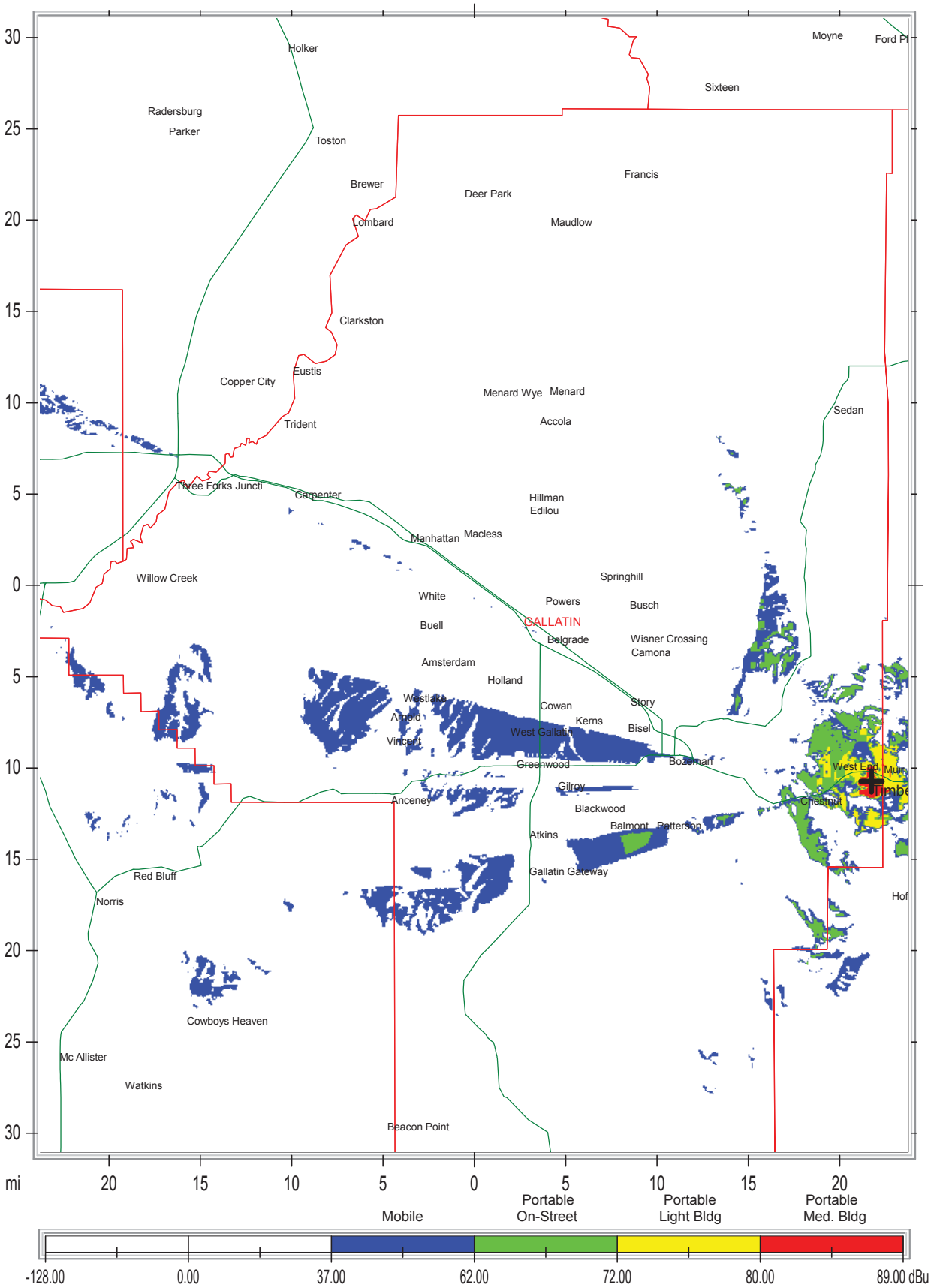
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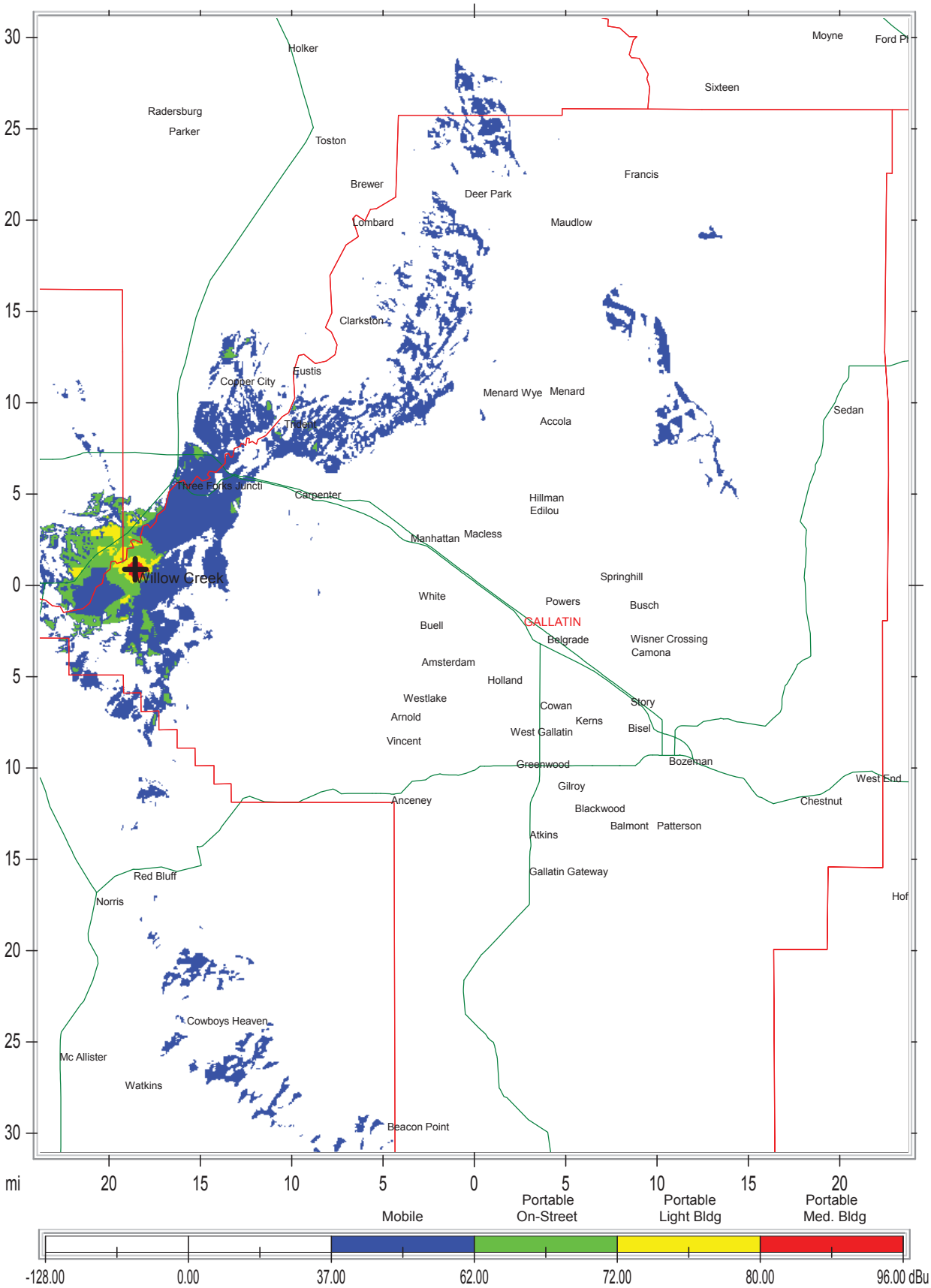
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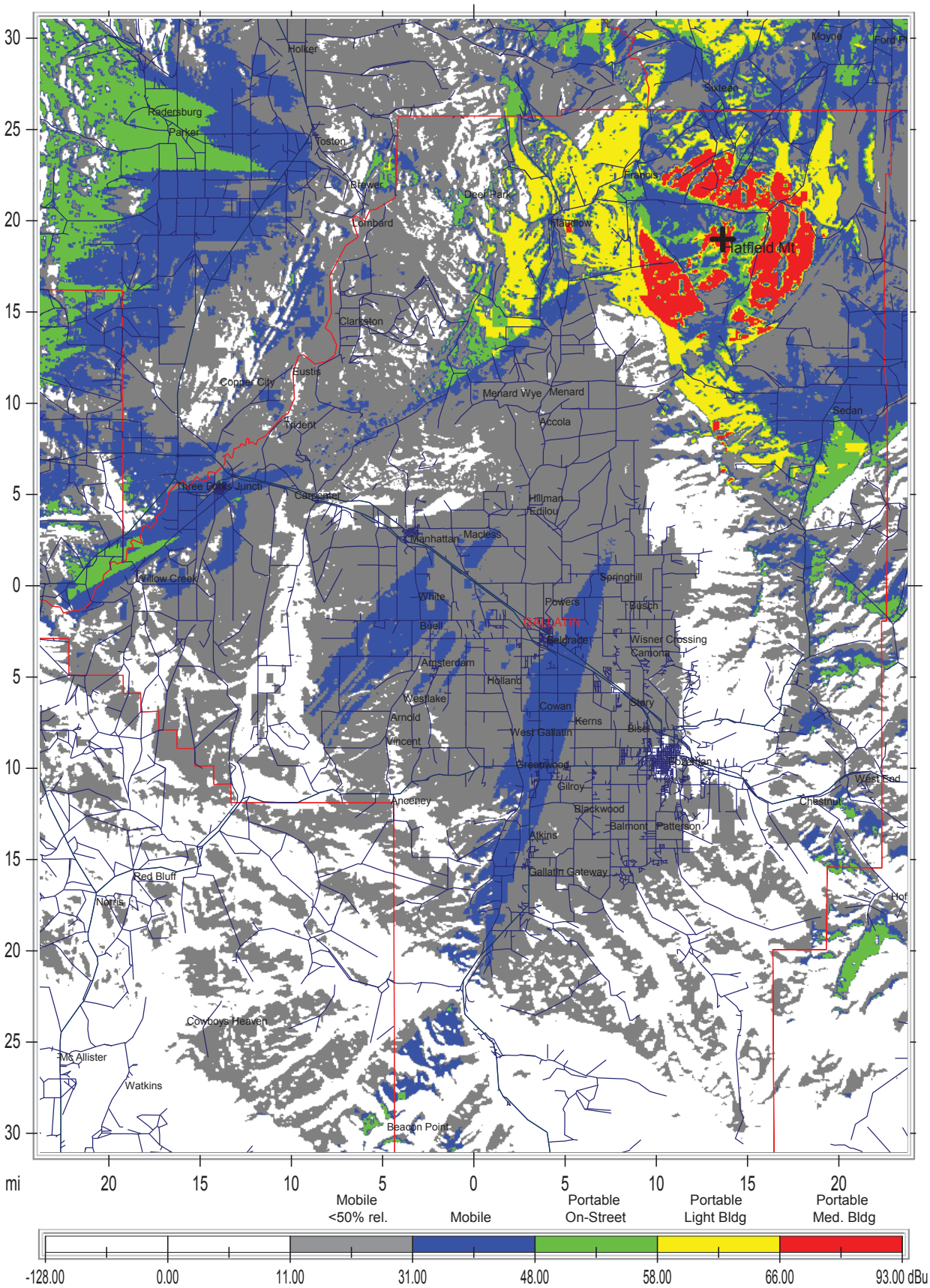
NORTH STANDALONE
TALK-OUT & TALK-IN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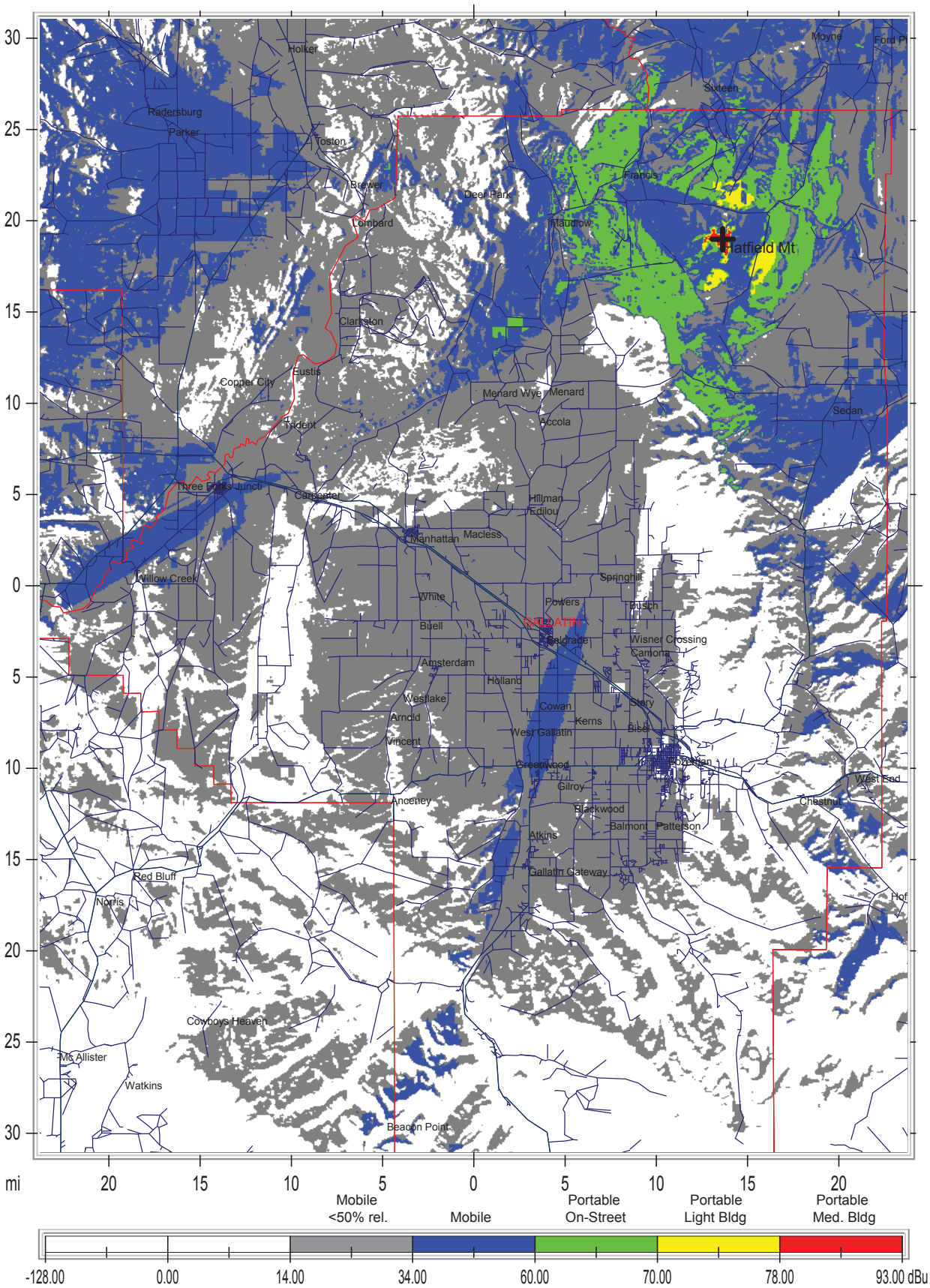
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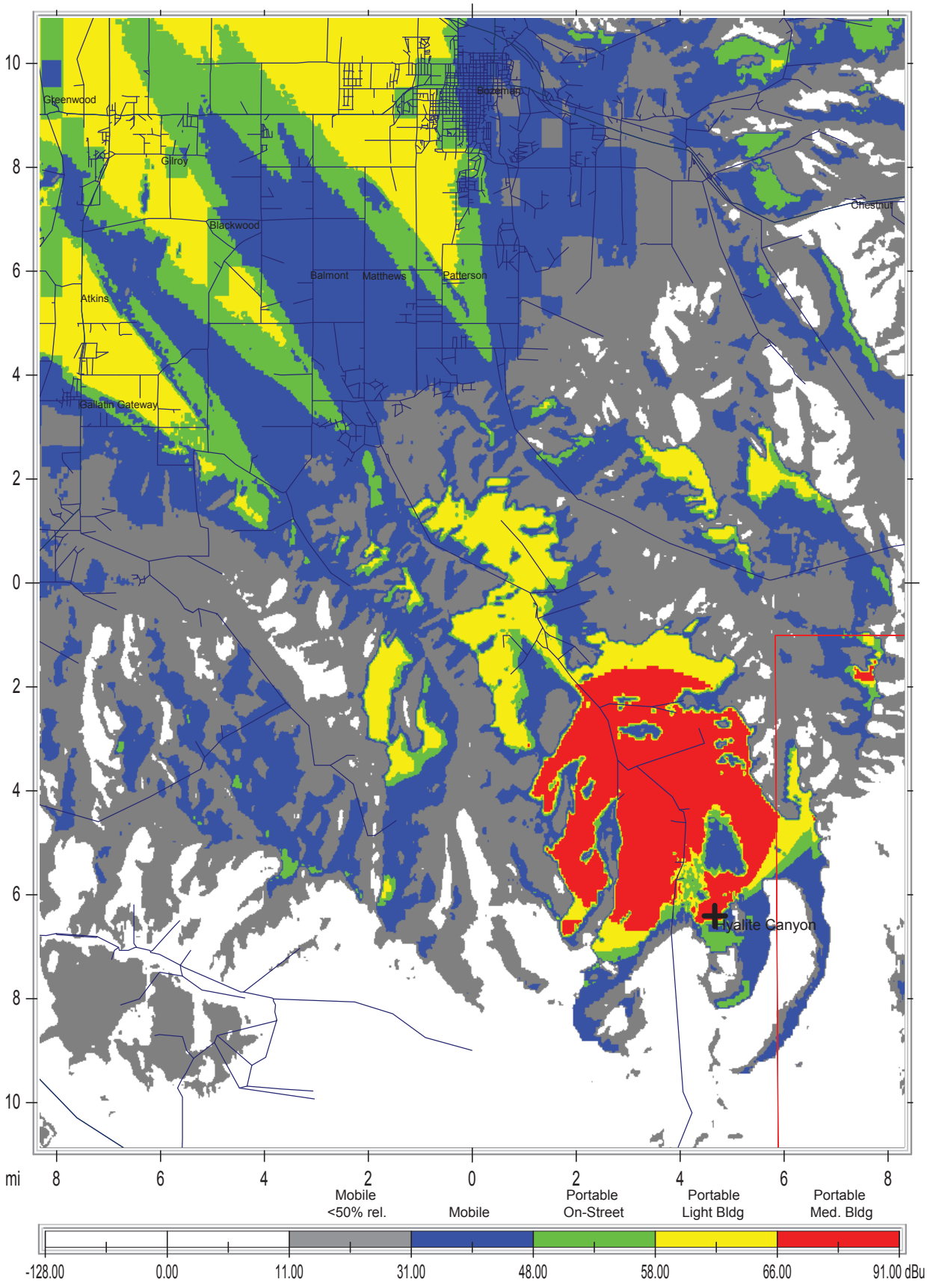
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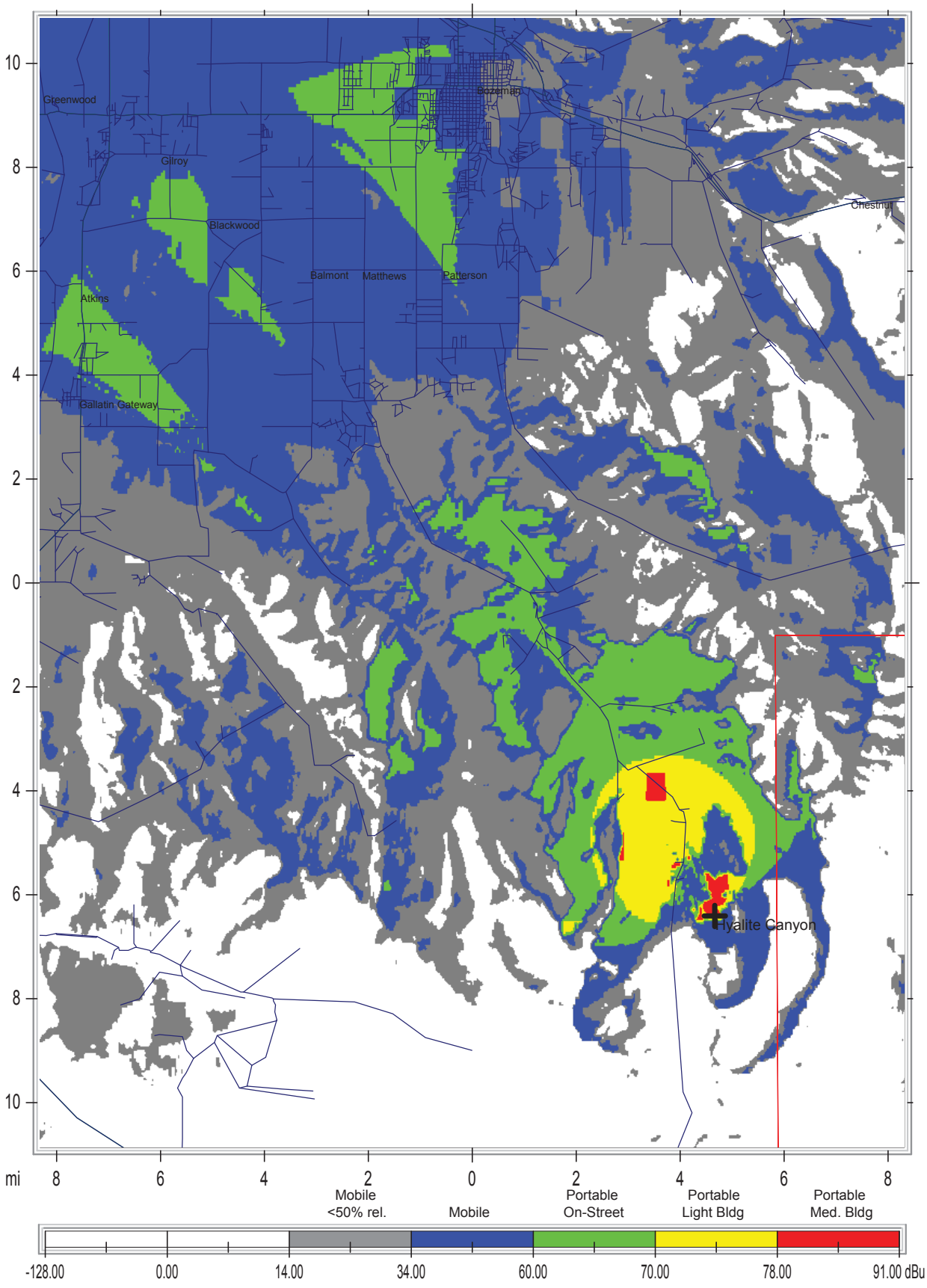
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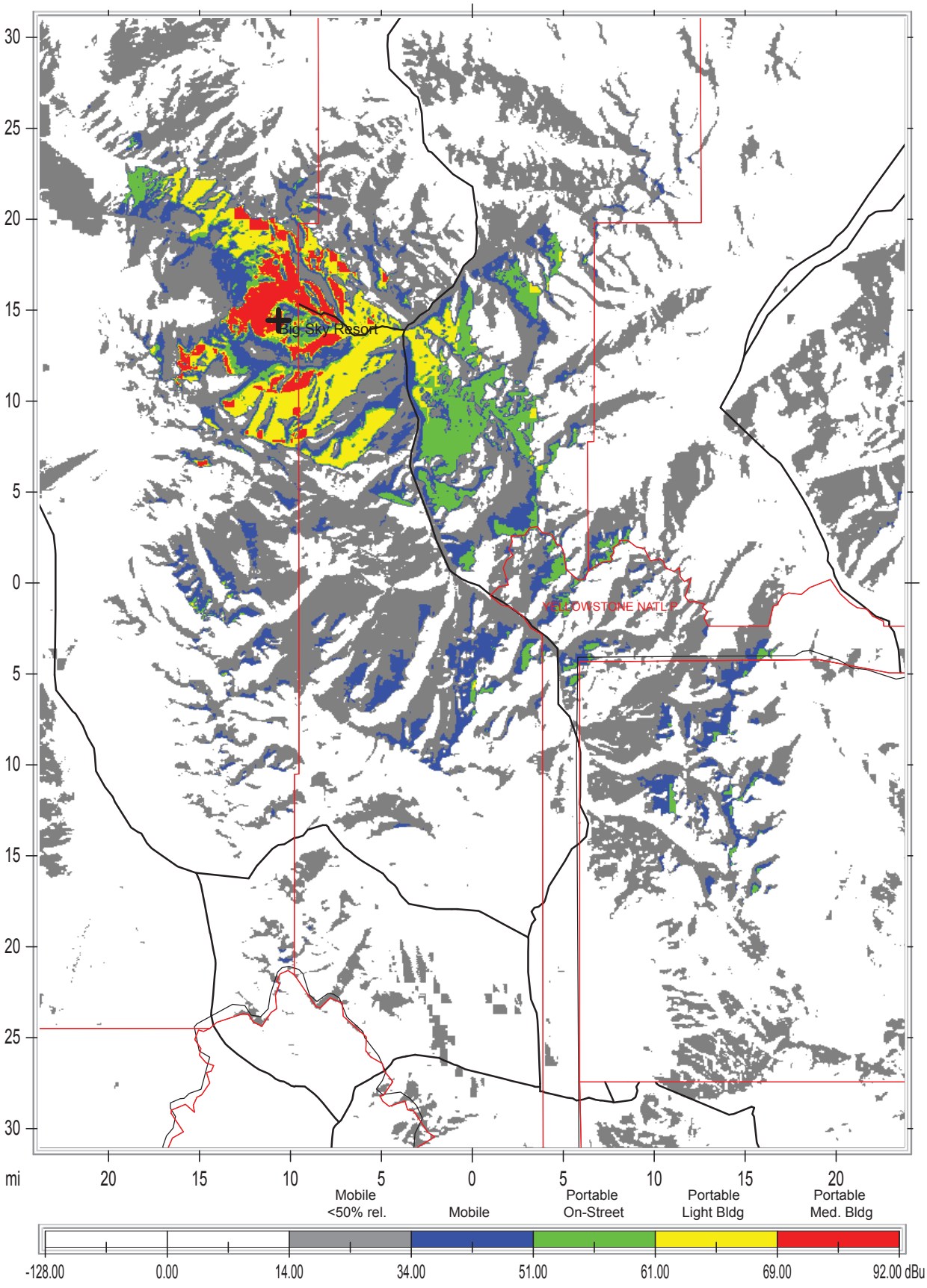
SOUTH MULTICAST TALK-OUT


Big Sky Resort
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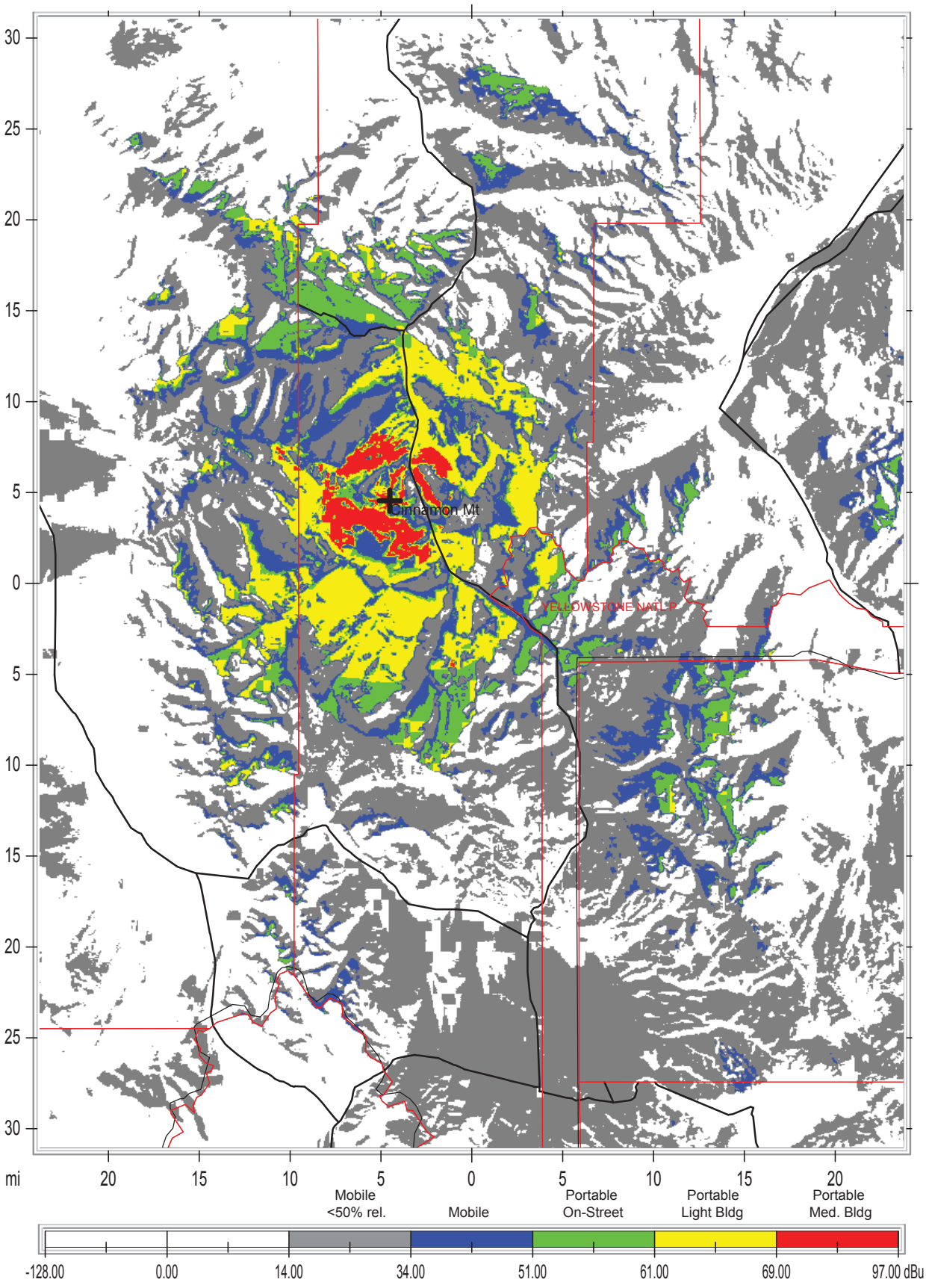
Cinnamon Mt
YELLOWSTONE NAT'L P
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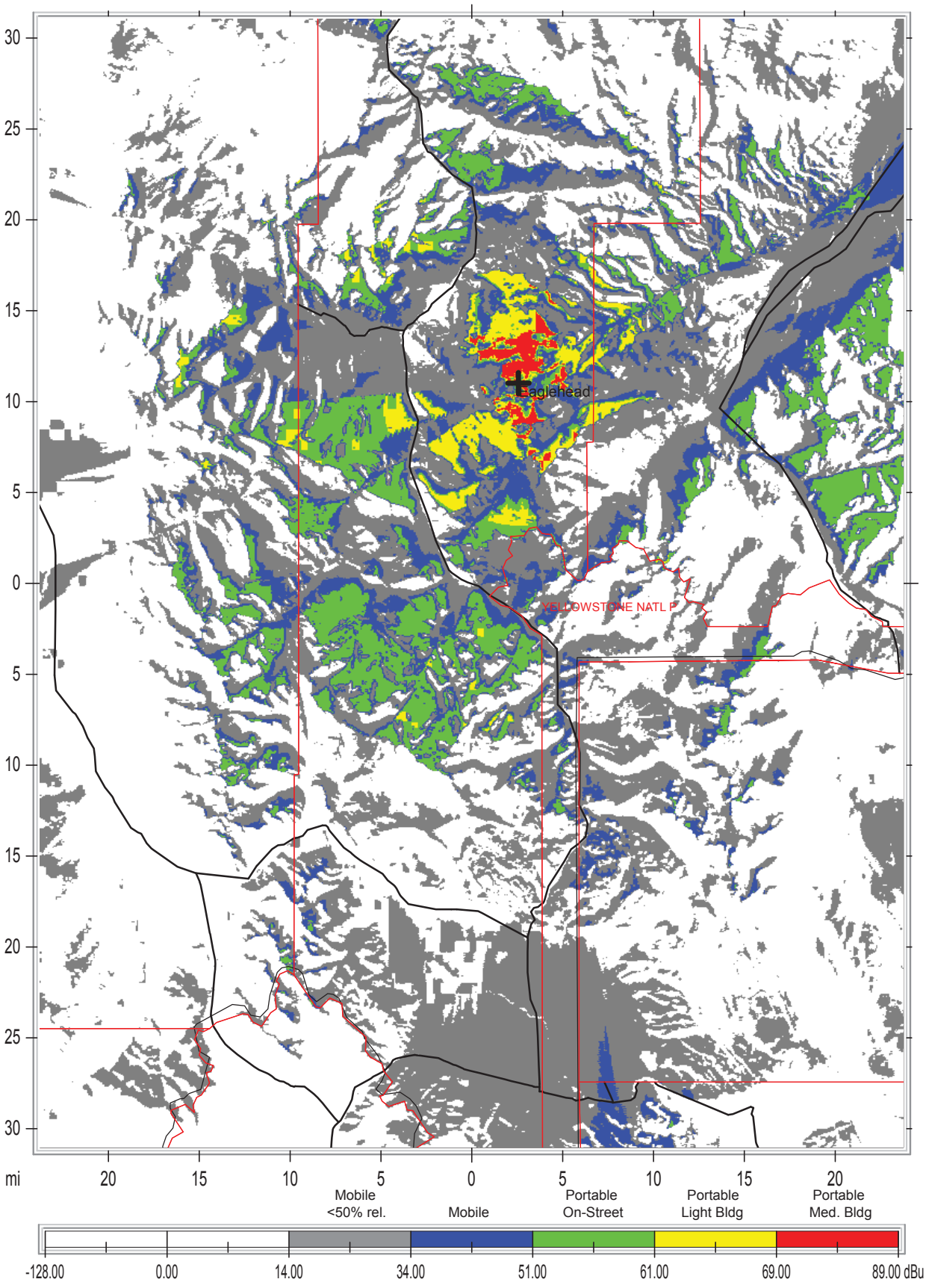
Eaglehead
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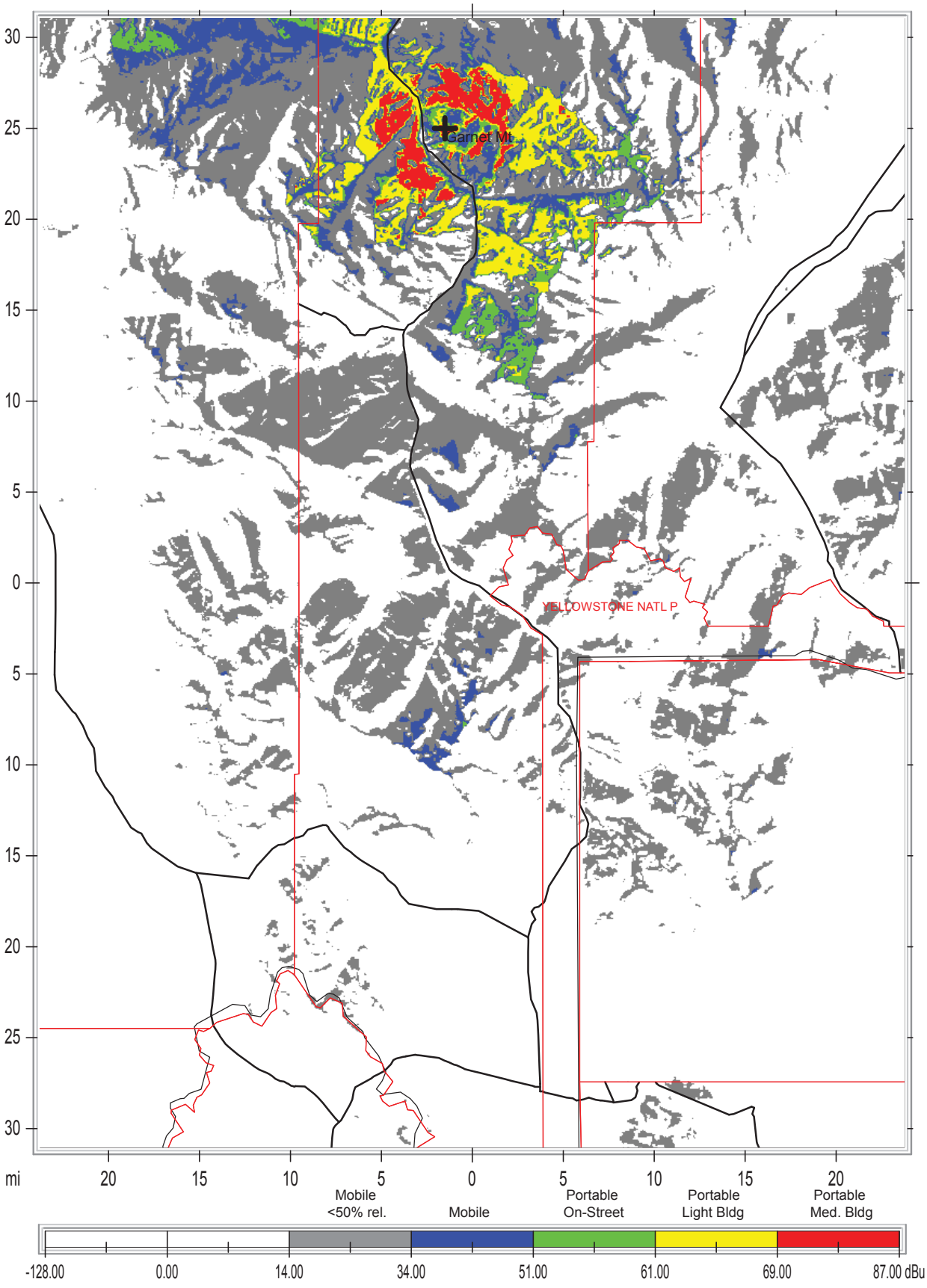
Garnet Mt
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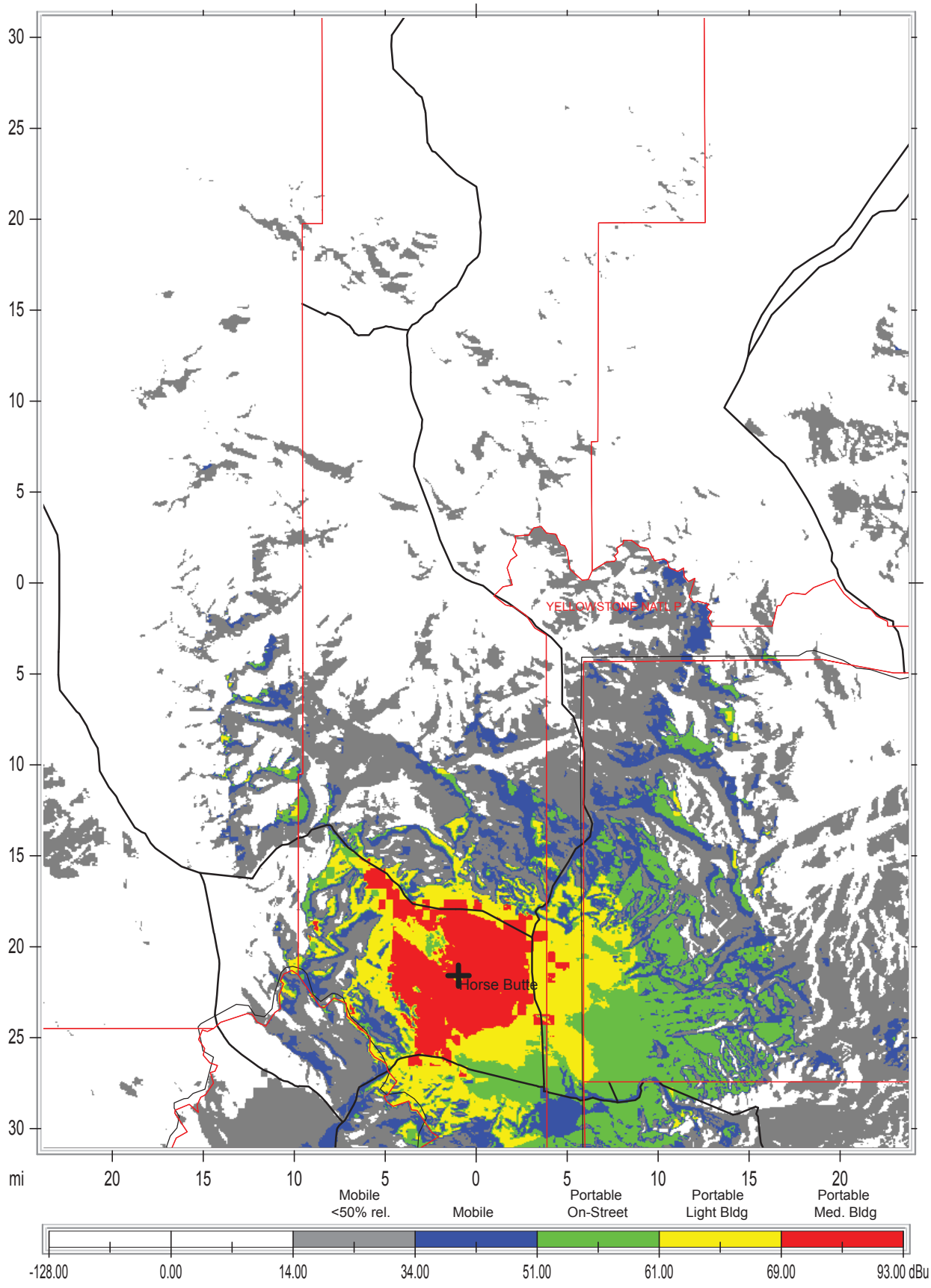
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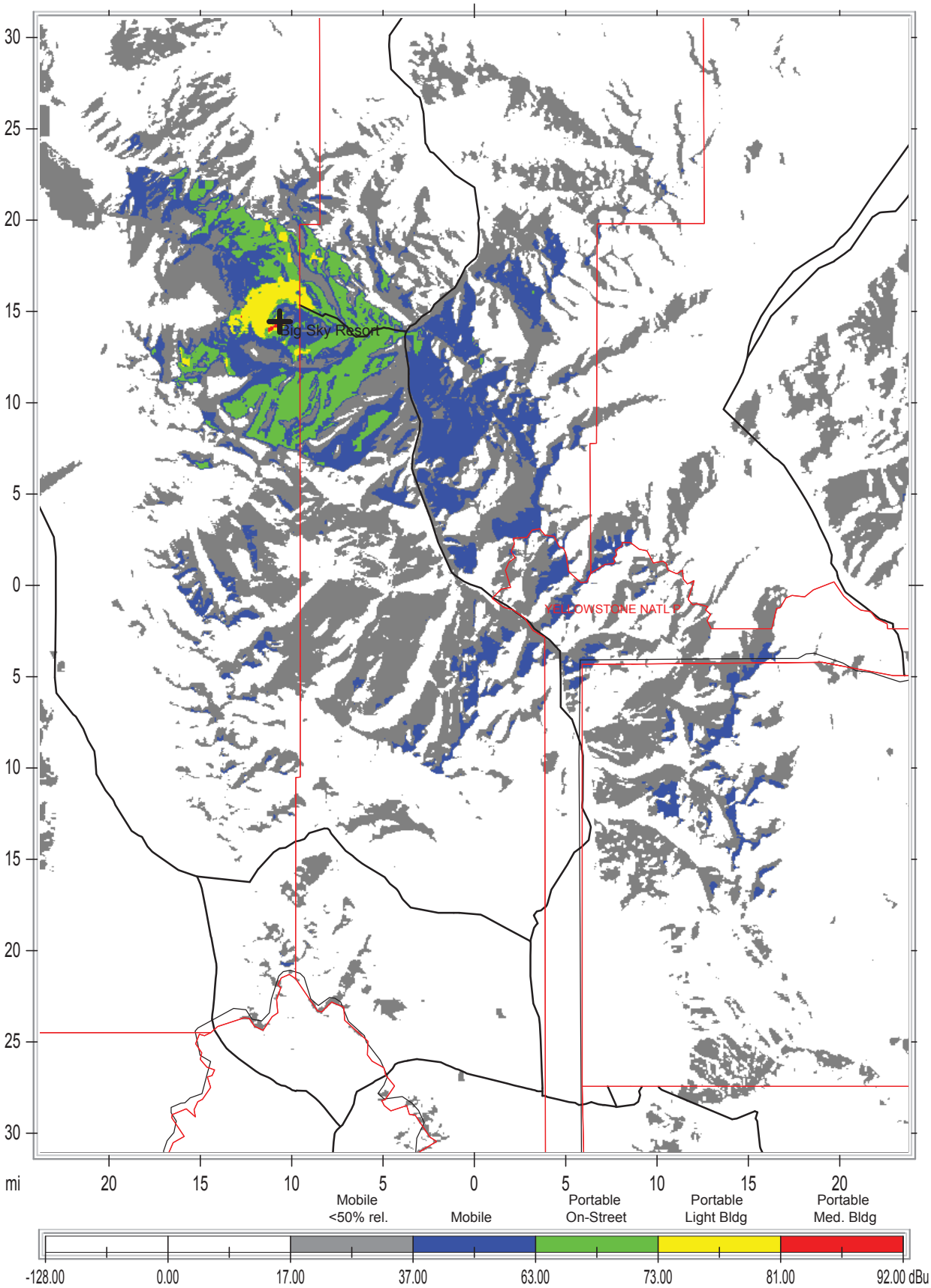
SOUTH MULTICAST TALK-IN


Big Sky Resort
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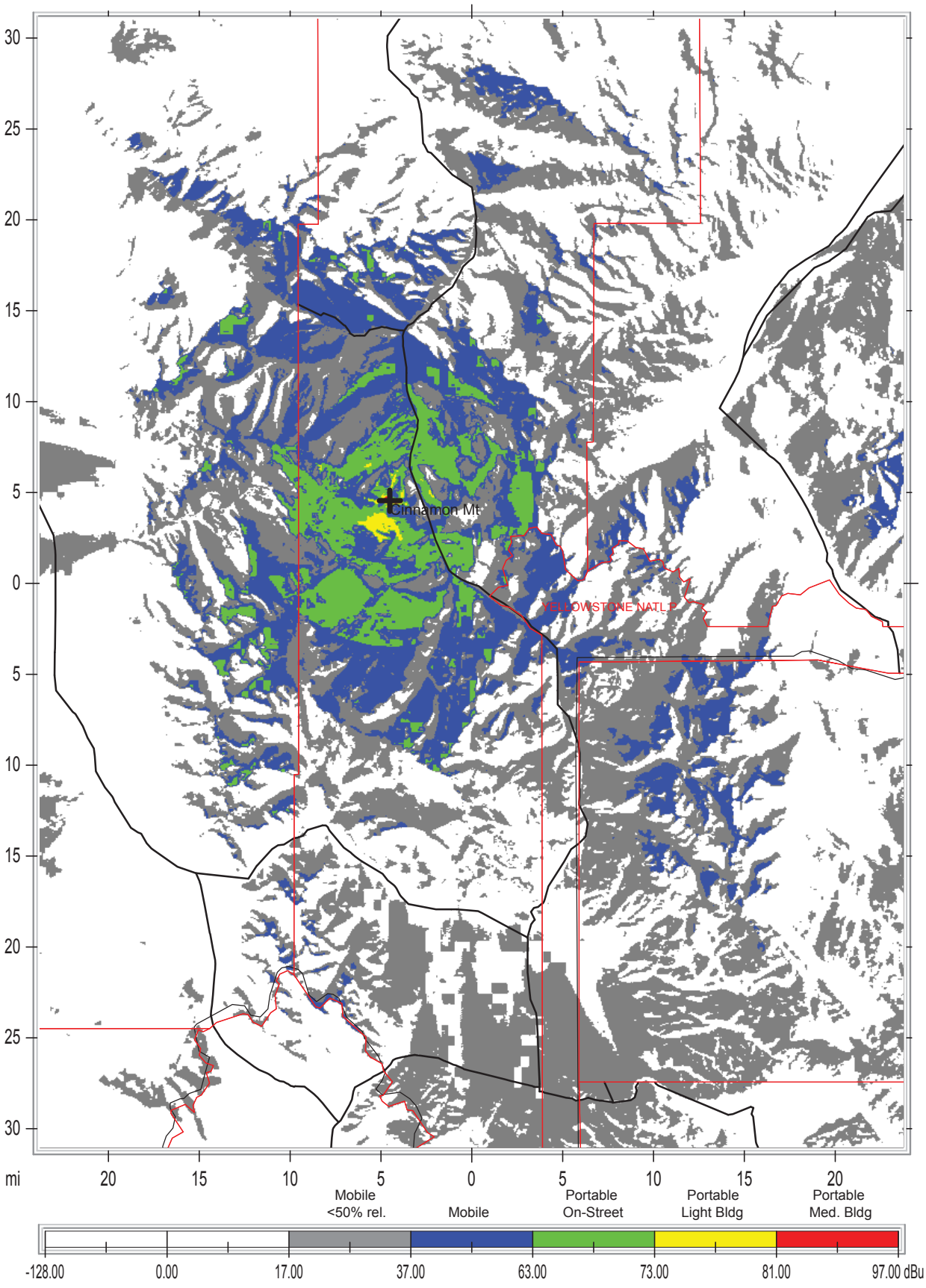
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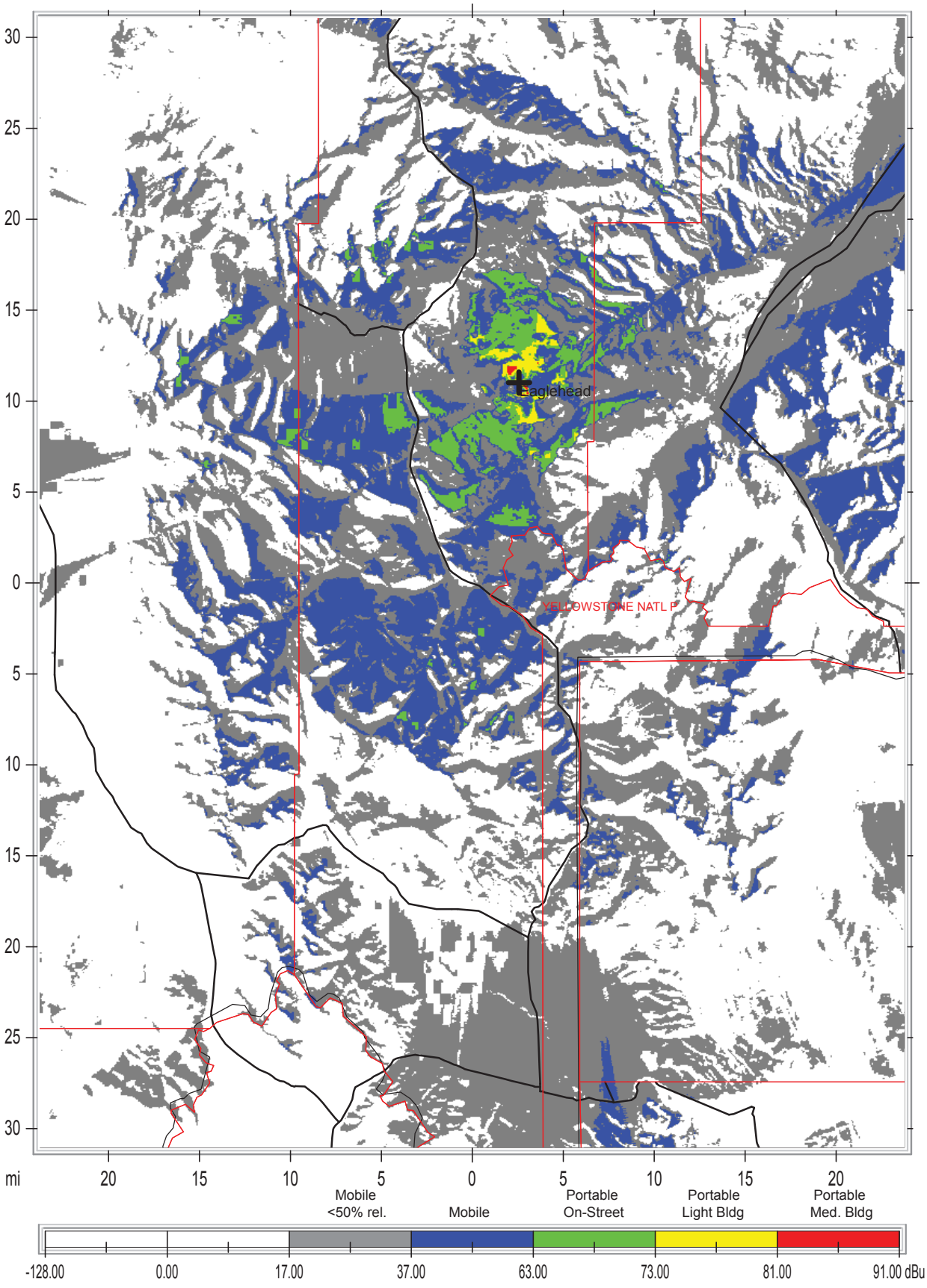
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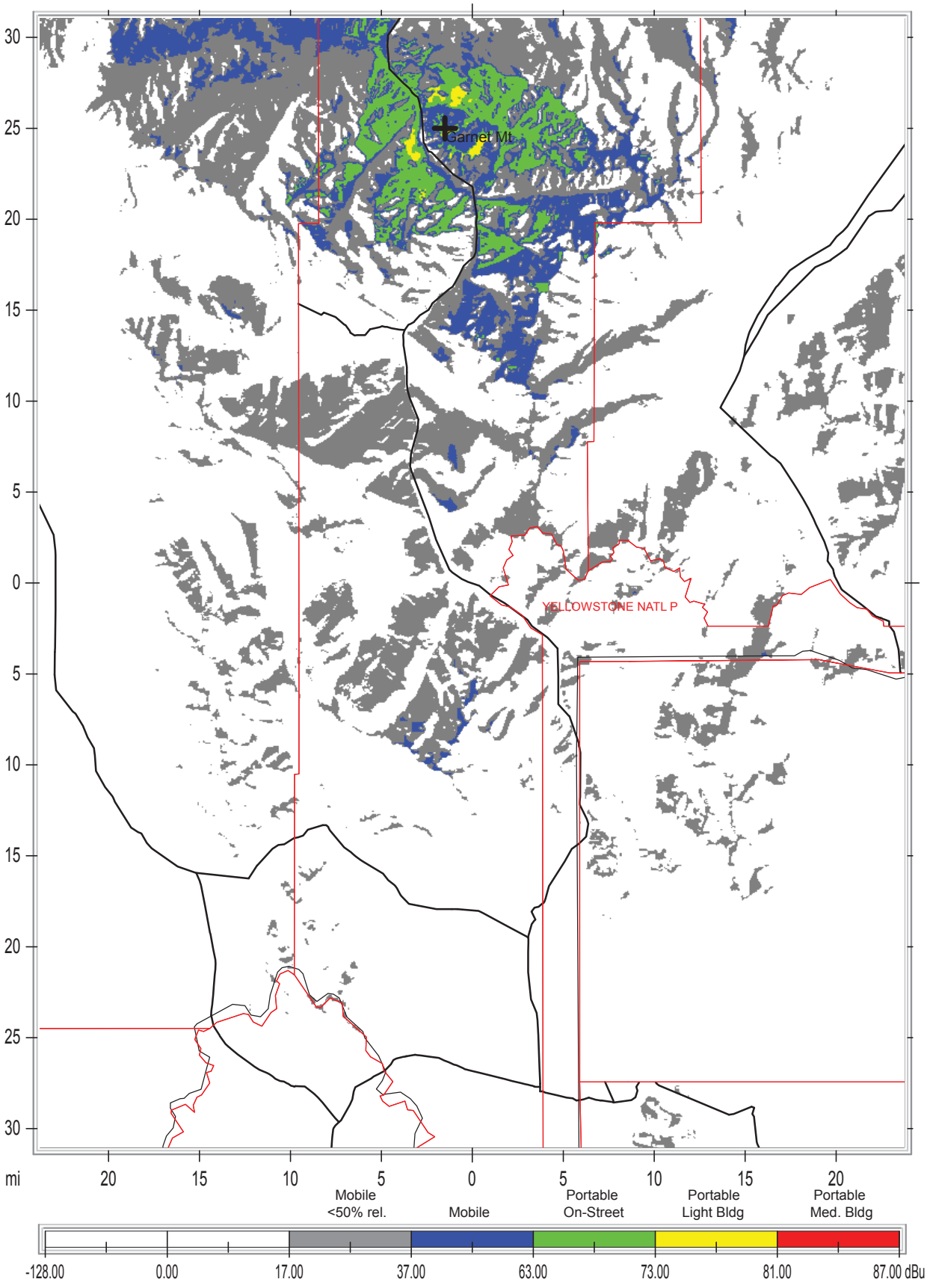
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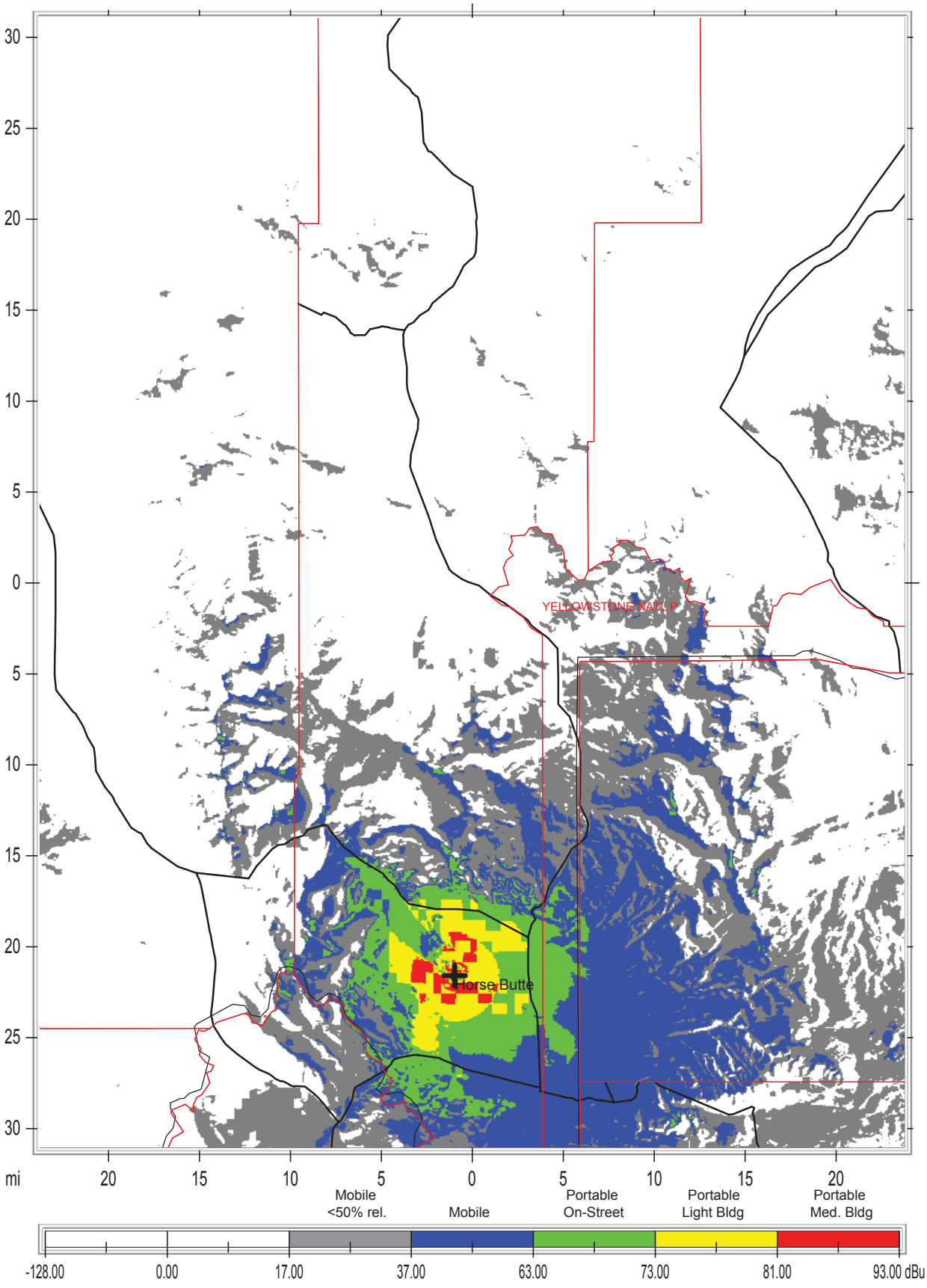
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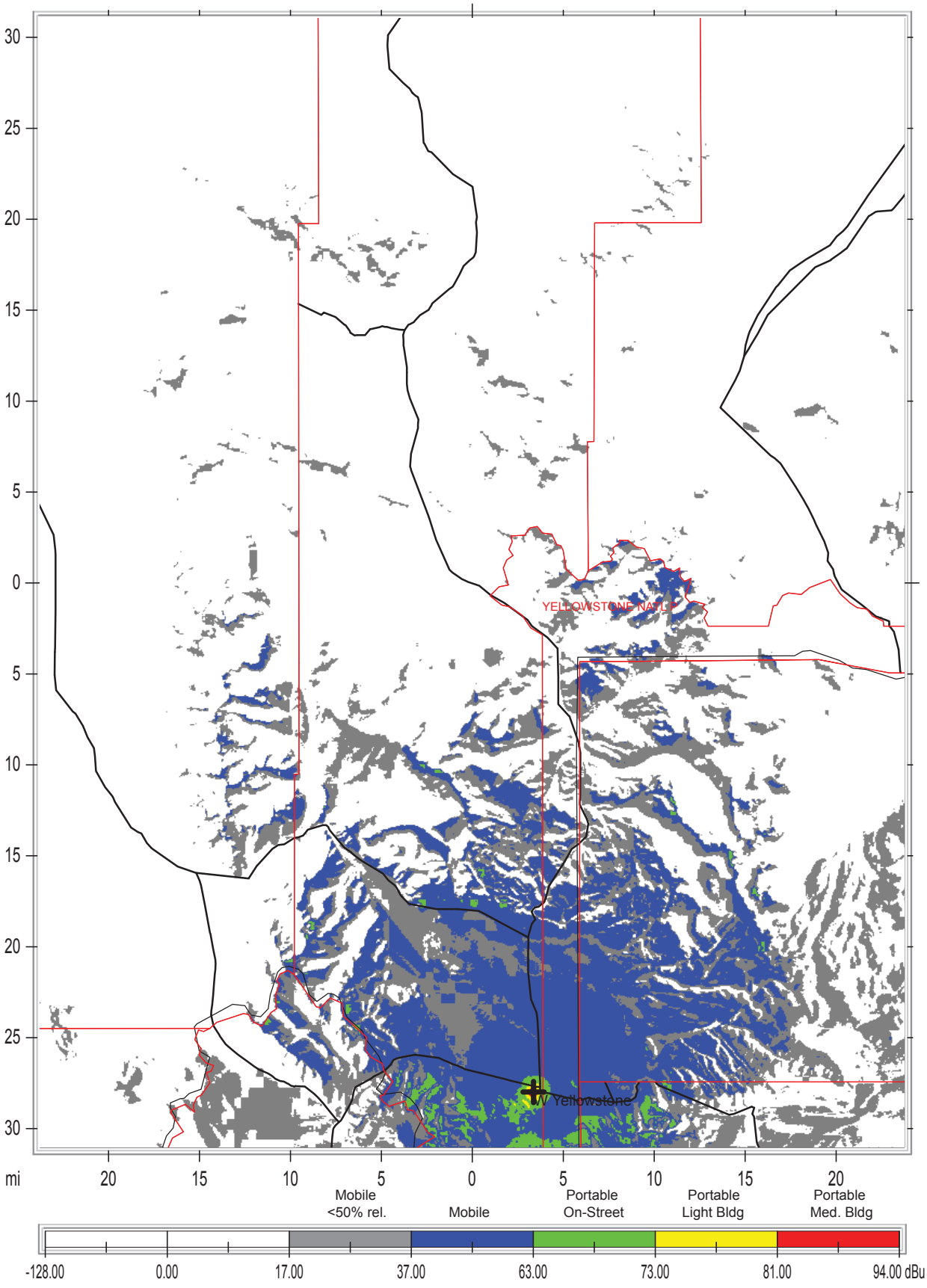
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Final Report

Gallatin County
9-1-1 Radio System Engineering Study
User Needs and Gap Analysis

Prepared for
Gallatin County 9-1-1

Prepared by
Joe Blaschka, Jr., P.E.
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Date Prepared
August 25, 2015

ADCOMM Engineering Company
Bridging the Gap Between Operations and Technology®

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Acronyms and Abbreviations

ADCOMM	ADCOMM Engineering Company
UHF	ultra high frequency
VHF	very high frequency

User Needs and Gap Analysis

Executive Summary

As part of the Gallatin County 9-1-1 Radio System Engineering Study project (the "project"), ADCOMM Engineering Company (ADCOMM) spent considerable time with the users in meetings, interviews, and ride alongs. In addition, ADCOMM reviewed existing documentation and reviewed the system design. This process resulted in a set of user needs that was then compared against the existing system design and performance resulting in the following gap analysis.

When ADCOMM personnel originally met with the users, the first concern voiced was about the poor radio coverage experienced by the public safety users. However, as the discussions continued, there were also concerns about lack of additional channels for command and control and for tactical use over wider areas, interoperability, simplicity of use, growth for the future, and keeping up with technology. While this may seem like a small list, given the size of Gallatin County, it is a significant effort to meet the users' needs.

Over the last few years, there have been some attempts at improvements and some improvements have been made. However, these were often done piecemeal and using low-cost approaches that increased operational complexity. The fire transmitter steering system is an example of one of these approaches. While it does provide some improved coverage, it is difficult to operate and has some significant operational limitations.

The canyon area heading down to West Yellowstone is very rugged and because of the terrain and land ownership the cost of providing improved coverage in that area will be high. However, providing communications in that high traffic area should not simply be ignored. The northern end of the county also has extensive areas where there currently are no communications. While this area is not a high traffic area, some level of communications should be provided.

The user needs and gap analysis is presented in a tabular format to make the direct comparison between options easier.

Introduction

Project Purpose and Scope

In February 2014, ADCOMM was contracted by Gallatin County to perform a radio system study. In general, the purpose of this project was to determine the state of the existing public safety two-way radio communication systems in use by stakeholders in the county, identify the operational needs of the radio systems' users, identify potential technologies and their applicability to a replacement/upgraded radio system, and develop a high-level system design for such a system, followed by solution selection and implementation preparation.

Based on this contract, the project consists of the following phases:

1. **Phase One: Information Gathering and Education.** The deliverables of Phase One are the Current State Report, the Technology Review, and the User Needs and Gap Analysis Report ***(this report)***. The purpose of this phase is to generate information needed by ADCOMM and by stakeholders to fully understand the existing systems, both for comparison purposes and to identify the needs of the systems' users.

2. **Phase Two: Solution Development.** Using the information gathered during Phase One, Solution Development's deliverable is a list of potential solutions, with rough order of magnitude costs, to the challenges faced by Gallatin County's radio systems. The end of Phase Two is a joint meeting to discuss and evaluate each of the potential solutions, with the County decided on one or more potential solutions for further development. Selection of the solution at this stage begins to set the strategic direction.
3. **Phase Three: Strategic Direction and High-Level Design.** During Phase Three, the selected solution is developed further to yield a strategic direction document and a high-level design. The solution will be divided into a series of implementable modules, with estimated costs, implementation time, and impact to the voice systems identified. The High-Level Design will be sufficient to drive the detailed engineering needed as the first step toward acquisition and implementation.
4. **Phase Four: Final Study Report.** The Final Study Report is a combination of all the deliverables created in the project with a summary and explanatory text for use in grant justifications and budget discussions. ADCOMM anticipates an in-person delivery of the final report to Gallatin County decision makers and stakeholders at a combined meeting.
5. **Phase Five: Solution Selection and Implementation Preparation.** Following the Final Study Report release, stakeholders will meet to identify specific solutions for implementation. These solutions will be further developed to produce engineering drawings, detailed system price estimates, and technical specifications for use in procurement and implementation. Solution development will be for voice radio system changes only.

Note that the following are not included in the scope of work for the current project: technical procurement reviews and assistance, vendor selection, technical support during contract negotiations, implementation engineering services, and/or project management.

User Needs and Gap Analysis

The goal of the User Needs and Gap Analysis section of the report is to provide in a clear and concise manner the needs articulated by the users and determine how the existing systems meet those needs. In addition, the final recommended solution is also compared in a table so it can be determined how other options meet those defined needs. ADCOMM does not judge or analyze the user needs other than how they are met by the existing and proposed technologies. However, the needs defined by the users are typical of many if not most other public safety agencies ADCOMM has worked with in both rural and urban settings.

ADCOMM met with the users on four different occasions as well and has had individual interviews with users and management staff.

Overview

Table 1 outlines the user needs and how they are met or not met by the existing system, the Montana State system, a VHF-only solution, and the proposed UHF/VHF combination system.

The basic needs were defined as described below.

Coverage

Radio coverage was the single biggest complaint from the users. There are many areas in the county, in some cases very large areas, where there is neither public safety radio nor cellular

communications, leaving first responders without radio coverage should an emergency occur.[1] The poor coverage is the result of a combination of not enough radio sites, radio sites needed in specific locations, and in and around the greater Bozeman area a very high electrical noise floor that in effect significantly reduces the range of the existing system. In the greater Bozeman and Gallatin Valley area, this noise floor is significant and affects primarily the VHF frequency band that Gallatin County currently uses. Measurements by ADCOMM staff indicated it was pervasive in and around the City of Bozeman and in much of the Gallatin Valley area. This noise is caused by all of the electronic devices that are part of everyday life, and it is fairly common for these levels of noise to exist in urban/suburban areas.

Capacity

The existing system does not have enough capacity to support all of the needs during almost any situation where there are multiple incidents involved or where there is a large-scale incident such as a brush fire.

Growth

The existing system cannot be grown gracefully as the needs of the users change and additional capacity is required to accommodate the growth. There are not adequate VHF frequencies to accommodate additional growth, and the existing infrastructure was implemented in a piecemeal fashion, which does not support graceful growth in the future.

Reliability

The existing system reliability has improved over the last few years with some improvements that have been made. However, the system has little redundancy so when there is a major failure critical portions of the system may not function. Reliability encompasses all of the components of a radio system with critical components made redundant or with some type of back-up process or system available. For example, portions of the existing system use microwave frequencies that are affected by rainfall, which causes the loss of the links when there is heavy rainfall.

Interoperability

Interoperability is critical. This is interoperability between Gallatin County first responders as well as with public safety personnel from surrounding jurisdictions and the Montana Highway Patrol. The State of Montana has an extensive system and approach for using VHF channels to provide interoperability for mutual aid. These are known as the "color" channels and are simplex channels that can be used anywhere in the state. Any system implemented would need to maintain interoperability. In addition, the current Gallatin County system operates on VHF frequencies and some users, primarily law enforcement, have purchased radios that are compatible with the State of Montana VHF trunked radio system.

Ease of Use

First responders rely on their radio system when in an emergency situation or responding to an emergency. A law enforcement officer should not have to change his radio channel during a pursuit because the channel he was on where the pursuit started does not provide coverage where the pursuit is headed. A fire apparatus driver, negotiating a winding road should not have to be looking at her radio to see if she is on the right channel for this part of the county.

[1] For some longer term emergencies, portable repeaters can be deployed for local communications, but these do not allow communications back to dispatch.

Ease of radio use becomes even more critical when units are operating out of their normal operational area and may not be familiar with how the radio system operates.

This same thought applies to dispatch as well. Dispatchers who have to try to "find" officers by selecting different radio channels or sites have their efficiency significantly reduced allowing them to support a far smaller number of users. In addition, a dispatcher can only have one audio source in their headset at a time.[2] All other audio is routed to their speakers. If officers are operating on multiple sites that are heard on the speakers instead of the dispatcher's headset, then the probability increases that the dispatcher may not hear that officer when they call. Having too much audio in the speakers also raises the overall noise level in the dispatch center making it hard for other dispatchers to hear the channels they are monitoring.

Encryption and Other Advanced Features

Law enforcement expressed a desire to have encryption available for use at times when critical information must be passed between units or with dispatch that should not be intercepted by the general public and certainly not by criminals with scanner receivers. Modern systems can also provide features such as status messaging where a unit could press a button on their radio and dispatch could receive status updates such as in service, en route, clear, etc. Some of these features are add-ons that do not affect the basic system design and others are an integral part of the system and must be designed in from the start.

User Needs and Gap Analysis Matrix

The following matrix outlines the defined user needs and ability of each of the compared systems to meet those needs.

Summary

The users' needs are similar to what is found across the public safety service. As Gallatin County continues to grow, needs such as additional capacity and good coverage will continue to grow in importance. Given the long lead time to fund and build a new radio system, any new system should look out into the future so when the new system comes online it is sized and designed to meet the needs of the future not of the past.

The existing system is clearly not meeting the needs of the users. Gallatin County is rapidly growing, placing more demands on public safety responders who in turn place a greater demand on the radio infrastructure and dispatch. At this time, the only approach that can meet the existing needs and have the ability to expand in the future is a mixed band system using both VHF and UHF frequencies.

[2] This is known as the "selected" audio and is the way radio consoles are designed. The selected audio can come from only one source. All other audio is called the "unselected" audio and is routed to speakers on the console.

TABLE 1
User Needs and How They are Met or Not Met by the Existing System

User Need	Existing System Gaps	Montana State System Gaps	VHF-Only System	UHF/VHF System
Coverage	The existing system has mobile coverage gaps in large portions of the County, particularly in the northern and southern portions of the County. While the northern portion is scarcely populated or traveled, the southern canyon area to Yellowstone is heavily traveled. There are many places where there is little or no mobile coverage. In Gallatin Valley, mobile coverage is better but there are many areas where portable radio coverage is poor to non-existent, even in the more urban/suburban areas. In addition, the different channels and systems have different levels of coverage making channel selection more difficult because certain channels do not work in certain portions of the county.	The Montana State system has mobile coverage gaps in large portions of the County, particularly in the northern and southern portions of the County. While the northern portion is scarcely populated or traveled, the southern canyon area to Yellowstone is heavily traveled. There are many places where there is little or no mobile coverage. In Gallatin Valley, mobile coverage is better but there are many areas where portable radio coverage is poor to non-existent, even in the more urban areas. Portable coverage around the Bozeman area is worse than with the existing Gallatin County system.	A VHF-only system could be developed to provide excellent coverage over the Gallatin Valley and Bozeman areas. The high noise floor would require additional sites to overcome the noise. A more critical factor is the lack of radio channels at VHF to provide capacity, which will be discussed below. Providing good coverage to VHF portables is difficult because the VHF portable radio does not have an effective antenna.	The use of UHF in the Gallatin Valley and Bozeman areas provides improved performance because UHF is less affected by the high noise floor and the portable radio antenna at UHF is much more effective. However UHF does not cover as well in the mountain areas so VHF would remain in use in the extreme northern end of the county and the canyon areas. Users would need to use dual band radios for communications in those areas.
Capacity	The existing system has limited capacity due to the limited number of channels that can be used over a wide area or have connections with dispatch.	The Montana State system has additional channels that can be used in areas where they provide radio coverage. However, their system is significantly capacity limited should a major event occur that involves state responders. In addition, because their system uses VHF, there are limited channels available for them to expand their system to provide additional capacity.	A VHF-only system would be limited in capacity because there are a very limited number of VHF channels available.	A combination UHF/VHF system would use UHF channels in the Gallatin Valley and Bozeman areas where the need is the greatest for additional channels due to the rapid growth in the area. There are more than enough UHF channels available for public safety. This would then allow the existing Gallatin VHF channels to be reused in the canyon and northern county areas.

TABLE 1 (cont.)
User Needs and How They are Met or Not Met by the Existing System

User Need	Existing System Gaps	Montana State System Gaps	VHF-Only System	UHF/VHF System
Reliability	The reliability of the existing system has improved due to recent equipment improvements. However, currently a major rain storm causes many of the interconnecting microwave links to fail leaving dispatch disconnected from the rest of the network. In addition, there are areas where the failure of a single base station can leave an area without communications.	The reliability of the State system has been going down due to the age of the equipment and the lack of funding for maintenance. In some cases, elements of the system have remained unrepaired for months.	An all-VHF radio system can be designed with the required reliability and redundancy to meet the needs of the users.	A combination VHF/UHF radio system can be designed with the required reliability and redundancy to meet the needs of the users.
Growth	The existing system has little or no capacity to handle additional traffic.	The State system has limited ability to expand and grow due to frequency limitations and the significant cost to expand due to the nature of a trunking system.	A VHF-only system would have limited ability to grow because of the limited VHF frequency availability.	A combination VHF/UHF system would have the capability to grow in the future because there are a significant number of UHF frequencies available.
Interoperability	The existing system uses VHF frequencies that have excellent interoperability with the rest of the state and federal users.	The Montana State system uses VHF frequencies so the mobiles and portables have excellent interoperability. Because the Montana system is a trunked radio system, users cannot operate on it unless their radio equipment is trunking capable and their equipment is authorized on the system. This limits interoperability.	A totally VHF system would have excellent interoperability with the rest of the state and federal users.	A combination UHF/VHF system using dual-band VHF/UHF radios would have unit-to-unit interoperability and the portions of the system that are VHF would have interoperability with other state and federal users. The section of the system that has UHF infrastructure would require VHF channels be patched into the UHF system to support the ability of the non-UHF users to intercommunicate using the system infrastructure.

TABLE 1 (cont.)
User Needs and How They are Met or Not Met by the Existing System

User Need	Existing System Gaps	Montana State System Gaps	VHF-Only System	UHF/VHF System
Encryption	The existing system does not support encryption.	The Montana State system used Project 25 digital technology and is compatible with encryption.	A totally VHF system if designed and implemented as a Project 25 digital system would support encryption. If it was designed as an analog system, it would not support encryption.	A VHF/UHF system if designed and implemented as a Project 25 digital system would support encryption. If it was designed as an analog system, it would not support encryption.
Advanced Features	The existing system does not support advanced features.	The Montana State system could support advanced features if the additional software and hardware was purchased for the system. Given the size of the system this could be very expensive.	A totally VHF system if designed and implemented as a Project 25 digital system would support advanced features. If it was designed as an analog system, it would not support encryption.	A combination VHF/UHF system if designed and implemented as a Project 25 digital system would support advanced features. If it was designed as an analog system, it would not support encryption.
Cost	Lowest cost.	Very high cost if expanded to meet the needs of the needs of the users within the frequency limitations available. In addition, the existing users that do not have VHF P25 trunking capable radios would have to purchase them. This also has the highest potential ongoing costs depending on what the State does with the system.	Medium cost as most of the existing user radio equipment could be reused. Also, medium cost because the ability to build an adequate system is limited by the number of VHF frequencies available.	High cost because all of the user radios need to be replaced as well as the radio system infrastructure. The user radios will need to be replaced with dual-band radios that are more expensive than single band radios.