Appendix L
Noise and Vibration Analysis Methods

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Acronyms and Abbreviations

Board	Surface Transportation Board
CadnaA®	Computer-Aided Noise Abatement
C.F.R.	Code of Federal Regulations
dB	decibel
dBA	A-weighted decibel
DNL	day-night average noise level
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
Hz	Hertz
Leq	level equivalent
OEA	Office of Environmental Analysis
PPV	peak particle velocity
RMS	root-mean-square
UDOT	Utah Department of Transportation
VdB	root-mean-square vibration velocity

Introduction

This appendix describes the methods and equations that the Surface Transportation Board's (Board's) Office of Environmental Analysis (OEA) used to estimate and analyze the potential effects of noise and vibration from construction and operation of the proposed rail line.

For the noise analysis, OEA evaluated whether the construction and operation of the proposed rail line would result in a 3 A-weighted decibel (dBA)[1] or greater increase in noise levels and whether railroad noise levels (due to wayside noise and locomotive warning horn) would equal or exceed a 65 day-night average noise level (DNL),[2] consistent with the Board's environmental regulations at 49 Code of Federal Regulations (C.F.R.) § 1105.7e(6). OEA also assessed whether vibration from construction and operation of the proposed rail line would cause impacts.

If the estimated increased noise level at a location exceeded either of the thresholds for noise, OEA identified (using aerial photographs) and counted the number of affected noise-sensitive receptors (such as residences, schools, libraries, retirement communities, churches, and nursing homes) and quantified the noise increase. OEA implemented the thresholds separately to determine an upper bound of the area of potential noise impact. Noise research indicates that both thresholds must be met or exceeded to cause an adverse noise impact (Board 1998a; Coate 1999). That is, noise levels would have to be equal to or greater than 65 DNL and increase by 3 dBA or more to result in an adverse noise impact. OEA used the Computer-Aided Noise Abatement (CadnaA®), an internationally accepted environmental noise computer program, and wayside and horn reference levels from previous studies to generate noise contours, which are delineated on a map to show the DNL values. The overall noise model results are sensitive to horn noise, locomotive and rail car noise, train length, and train speed.

OEA incorporated digital terrain modeling as part of the advanced noise modeling techniques, using topographic contours. Because much of the terrain in the study area is steep and/or hilly, the shielding effects[3] of topography are an important aspect of modeling for this study area.

Construction Noise and Vibration Analysis Methods

OEA used the Federal Transit Administration (FTA) general assessment method (2006) to evaluate noise impacts from rail construction. OEA based the construction noise impact assessment on FTA methods (2006), known as the General Assessment construction noise guidelines, shown in Table L-1.

[1] A-weighted decibel (dBA) is a measure of noise level used to compare noise from various sources. A-weighting approximates the frequency response of human hearing.

[2] Day-night average noise level (DNL or Ldn) is the energy average of dBA sound level over a 24-hour period; it includes a 10-decibel adjustment factor for noise between 10:00 p.m. and 7:00 a.m. to account for the greater sensitivity of most people to noise during the night. The effect of nighttime adjustment is that one nighttime event, such as a train passing by between 10:00 p.m. and 7:00 a.m., is equivalent to 10 similar events during the daytime.

[3] Large obstacles, such as hills or intervening terrain, between a receptor and train noise source can cause acoustic shielding resulting in reduced noise levels. For example, if the line-of-sight between a noise source and receptor were completely blocked by an obstacle, a 5-dBA or more reduction in noise level would result.

OEA estimated the combined noise level for general construction equipment at the receptor nearest each Action Alternative and compared the noise level with the assessment criteria.

Table L-1. Federal Transit Administration General Assessment Construction Noise Guidelines

	1-hour L_{eq} (dBA)[a]	
Land Use	**Day**	**Night**
Residential	90	80
Commercial	100	100
Industrial	100	100

Notes:
L_{eq} = level equivalent; dBA = A-weighted decibels

OEA used the FTA General Assessment to evaluate construction noise because the details of the construction schedule for the proposed rail line are not yet known. The method calls for estimating combined noise levels from the two noisiest pieces of construction equipment and determining locations at which their operation would exceed the noise guidelines in Table L-2.

Construction vibration levels are estimated according to the following equation.

$PPV_{equipment} = PPV_{ref}$ x (25/D)1.5

Where:

$PPV_{equipment}$ = The peak particle velocity in inches per second of the equipment adjusted for distance

PPV_{ref} = The reference vibration level in inches per second at 25 feet

D = The distance from the equipment to the receptor

Estimated construction vibration levels are then compared with the building damage criterion.

Rail Line Operation Noise Analysis Methods

Railroad operation noise is composed of diesel locomotive engine and wheel/rail noise (collectively referred to as wayside noise) as well as locomotive warning horns sounding at at-grade rail/roadway crossings.

Wayside Noise Models

Wayside noise refers to all noise generated by rail cars and locomotives (but not including horn noise) and is primarily a function of train speed, train length, and number of locomotives. Based on information provided by the Coalition, OEA's noise analysis used a train composition of eight locomotives and trains with 113 cars. OEA assumed that each of the eight locomotives would be 76 feet long, rail cars would be 60 feet long, and the overall train length would be approximately 7,403 feet. Typical operating speed of the trains would be 15 miles per hour.

OEA used noise measurements from past noise studies (Board 1998a, 1998b) as the basis for the wayside noise level projections for the proposed rail line.

OEA used the following basic equation for the wayside noise model.

$$SEL_{cars} = L_{eqref} + 10\log(T_{passby}) + 30\log(S/S_{ref})$$

OEA used the following equation for locomotives, which can be modeled as moving monopole point sources.

$$SEL_{locos} = SEL_{ref} + 10\log(N_{locos}) - 10\log(S/S_{ref})$$

OEA computed the total train sound exposure level by logarithmically adding SEL_{locos} and SEL_{cars}.

$$DNL_{100'} = SEL + 10\log(N_d + 10*N_n) - 49.4$$

$$DNL = DNL_{100'} + 15\log(100/D)$$

The 10log(x) term in the previous equations can be used to determine the increase (or decrease) in train noise level associated with changes in traffic volumes assuming that the other factors affecting noise (speed, train consist and length, time of day, and number of locomotives) are equivalent. The change in noise level associated with two different traffic volumes would be as follows.

$$\text{Delta (dB)} = 10\log(N_2/N_1)$$

Where: N_1 and N_2 are two different traffic volumes (trains/day)

For example, if rail traffic doubled, the increase in noise level would be 10log(2) = 3 decibels (dB).

Table L-2 lists the parameters that apply to the above equations.

Table L-2. Noise Parameters used in Equations

Parameter	Description
SEL_{cars}	Sound exposure level of railcars (dBA)
L_{eqref}	Level equivalent of railcar
T_{passby}	Train passby time, in seconds
S	Train speed, in miles per hour
S_{ref}	Reference train speed
SEL_{locos}	Sound exposure level of locomotive
SEL_{ref}	Reference sound exposure level of locomotive
DNL	Day-night average noise level
N_{locos}	Number of locomotives
Nd	Number of trains during daytime
N_n	Number of trains during nighttime
D	Distance from tracks, in feet

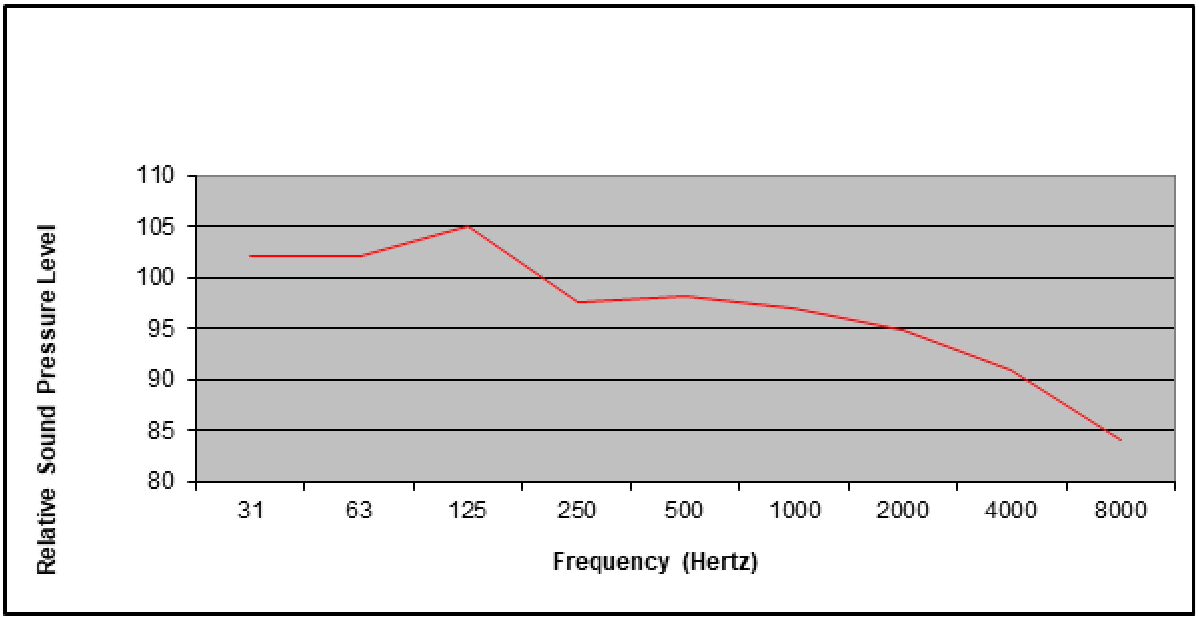
Table L-3 shows the reference wayside noise levels OEA used in the analysis and Figure L-1 shows the wayside noise frequency spectrum used in the calculations.

Table L-3. Reference Wayside Noise Levels

Description	Average Level (dBA)
Locomotive SEL (40 miles per hour at 100 feet)	95
Railcar L_{eq}	82

Notes:
Source: Board 1998a, 1998b
dBA = A-weighted decibels; SEL = sound exposure level; L_{eq} = level equivalent

Figure L-1. Wayside Noise Spectrum



Source: Board 2002

Horn Noise Models

Freight train horn noise levels can vary for various reasons, including the manner in which an engineer sounds the horn. Consequently, it is important to determine horn noise reference levels based on a large sample size. OEA used data on horn noise compiled by the Federal Railroad Administration (FRA) (1999). A substantial amount of horn noise data are available from the *Draft Environmental Impact Statement, Proposed Rule for the Use of Locomotive Horns at Highway-Rail Grade Crossings* (FRA 1999), hereafter referred to as the 1999 FRA Draft EIS.

The FRA data indicate that horn noise levels increase from the point at which the horn is sounded at 0.25 mile from the grade crossing to when it stops sounding at the grade crossing. In the first 0.125-mile segment, the energy average sound exposure level measured at a distance of 100 feet from the tracks was found to be 107 dBA, and in the second 0.125-mile segment, found to be 110 dBA. The 1999 FRA Draft EIS simplified the horn noise contour shape as a five-sided polygon, when it is actually a teardrop shape. The *Final Environmental Impact Statement, Construction and Operation of a Rail Line from the Bayport Loop in Harris County, Texas* (Board 2003) discusses this subject in detail. OEA used the more accurate teardrop contour shape for this analysis. The attenuation or drop-off rate of horn noise is assumed to be 4.5 dBA per doubling of distance away from the tracks (FRA 1999).

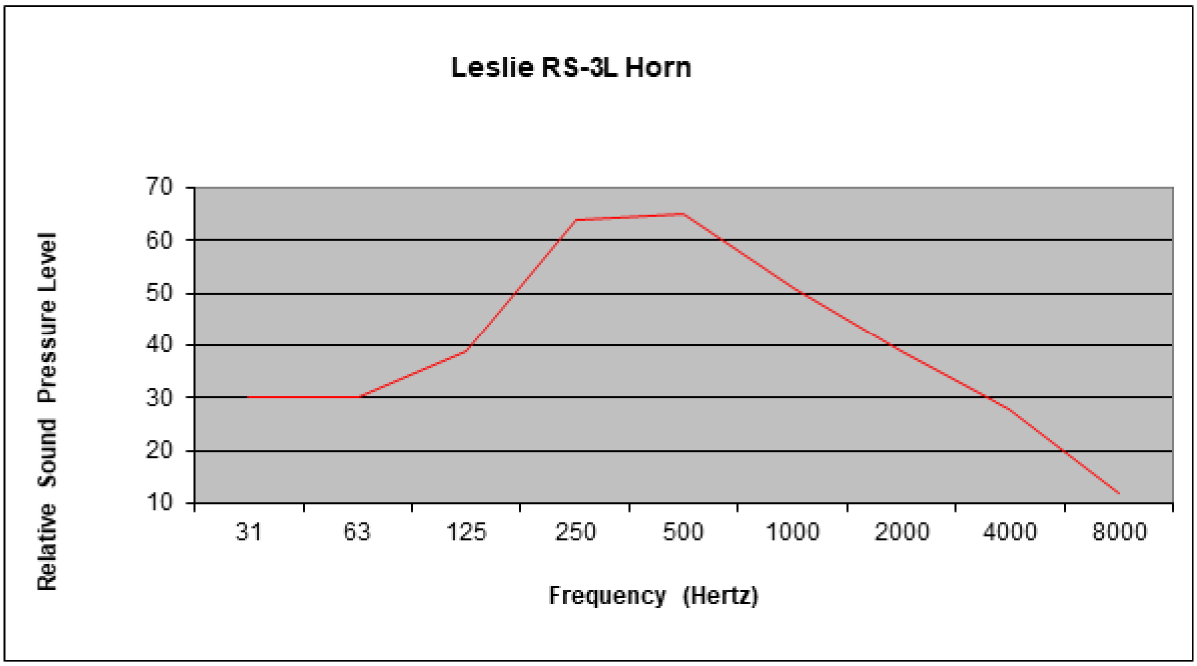
Table L-4 lists the reference horn noise levels OEA used in this analysis, and Figure L-2 shows the horn noise spectrum used in the calculations.

Table L-4. Reference Horn Noise Levels

Description	Average Level (dBA)
Horn SEL 1st 0.25 mile	110
Horn SEL 2nd 0.25 mile	107

Notes:
Source: FRA 1999
dBA = A-weighted decibels; SEL = sound exposure level

Figure L-2. Horn Noise Spectrum



Source: Board 2002

Rail Line Operation Vibration Analysis Methods

OEA based the vibration assessment methods on FTA methods (FTA 2006). Vibration level due to train passbys is approximately proportional to:

$V = 20 \times \log(\text{speed}/\text{speed}_{ref})$

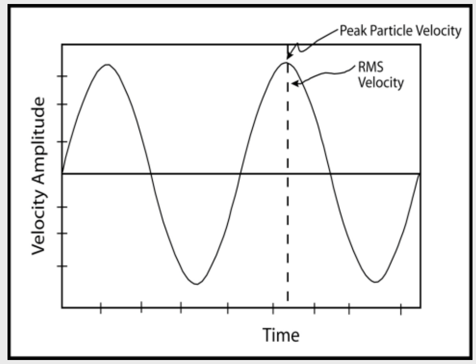
Where:

V = The ground-borne vibration velocity

Speed = The train speed

speed_{ref} = The reference speed of the train relative to its corresponding vibration level

OEA used this equation to adjust FTA's published ground-borne vibration levels for train speed and estimated vibration levels at receptor locations based on their distance from the proposed rail line.



Peak particle velocity (PPV) is an instantaneous positive or negative peak of a vibration signal, measured as a distance per time.

Root-mean-square (RMS) velocity (VdB) is a measure of ground vibration in decibels used to compare vibration from various sources.

There are two ground-vibration impacts of general concern: annoyance to humans and damage to buildings. In special cases, activities that are highly sensitive to vibration, such as microelectronics fabrication facilities, are evaluated separately. Two measurements correspond to human annoyance and building damage for evaluating ground vibration: peak particle velocity (PPV) and root-mean square (RMS) velocity. PPV is the maximum instantaneous positive or negative peak of the vibration signal, measured as a distance per time (such as millimeters or inches per second). This measurement has been used historically to evaluate shock-wave-type vibrations from actions like blasting, pile driving, and mining activities, and their relationship to building damage. RMS velocity is an average, or smoothed, vibration amplitude, commonly measured over 1-second intervals. It is expressed on a log scale in decibels (VdB) referenced to 0.000001 x 10-6 inch per second, which is not to be confused with noise decibels. It is more suitable for addressing human annoyance and characterizing background vibration conditions because it better represents the response time of humans to ground vibration signals.

Mitigation Analysis

Table L-5 shows the receptors in the study area that would be adversely affected by locomotive horn noise at grade crossings or by wayside noise. This distinction is important because there are different noise-reduction strategies for horn noise and wayside noise. The number of affected receptors is shown for the high rail traffic scenario[4] of 10.52 train passbys per day.

[4] The Coalition estimates that rail traffic on the proposed rail line could range from as few as 3.68 trains per day, on average (low rail traffic scenario), to as many as 10.52 trains per day, on average (high rail traffic scenario), depending on future market conditions, including future demand for crude oil produced in the Uinta Basin.

Table L-5. Receptors within the Project Study Area 65 DNL +3 dBA Contours

Receptor ID	Indian Canyon Alternative	Wells Draw Alternative	Whitmore Park Alternative
R-02	X	X	--
R-08	X	--	X
R-10	X	--	X
R-11	X	--	--
R-12	X	--	--
R-13	X	--	--
Total in 65 DNL	**6**	**1**	**2**

All of the receptors in Table L-5 are within the wayside noise contour; therefore, horn noise mitigation strategies would not be necessary.

The following sections discuss various types of noise mitigation techniques that could be applied to the receptors listed in Table L-5.

Building Sound Insulation

Building sound insulation refers to improving the noise attenuation characteristics of a building envelope in order to reduce the intrusion of outdoor noise into the building. Sound insulation treatments usually involve improving the sound insulation characteristics of windows and doors, which is where noise usually enters a building.

To provide building sound insulation, windows and doors can be replaced with special acoustical windows and doors with high values for sound transmission classification. Split-system or central air conditioning may need to be installed so that windows do not need to be opened. Additional insulation can be provided by sealing or relocating vents and, in some cases, acoustically reinforcing walls and ceilings. Sound insulation of a building typically reduces the inside noise level by about 10 dB. Noise levels outside the structure are not affected.

Both wayside and horn noise can be mitigated by building sound insulation. However, the sound insulation requirements relative to the low frequency content of locomotive engine noise may be greater than that for horn noise.

Building sound insulation costs vary depending various factors, such as overall size of the building and the number of windows and doors. A recent survey of international airport sound insulation programs shows an average cost of $40,000 per house. However, aircraft sound insulation strategies can differ from those implemented for rail projects. A recent Santa Clara Valley Transportation Authority transit project cited average insulation costs of $26,000 per building.

Wayside Noise Mitigation

Wayside noise mitigation options include noise barriers and/or building sound insulation. Noise barriers can be effective when the barrier substantially blocks the line-of-sight between a receptor and train noise sources (wheel/rail interface, locomotive engine, and exhaust opening). Since train noise can pass over the top and around the ends of the barrier, both noise barrier height and length are factors in determining potential noise barrier performance.

In addition to its physical dimensions, the extent to which a noise barrier protects a certain number of residences is also important. For example, if a noise barrier's cost was substantially greater than the value of the protected residence(s), the barrier may not be cost-efficient. Utah Department of Transportation (UDOT) evaluates the cost effectiveness of noise barriers based on the following cost effectiveness index.

$$\text{Cost Effectiveness Index} = \frac{Total\ Barrier\ Cost}{dBA \times D.U.}$$

Where dBA = average noise reduction of benefitted receptors (dBA)

D.U. = Number of benefitted receptors (≥ 5 dBA improvement)

A typical planning value is $35 per square foot to estimate the costs of noise barriers. The cutoff for determining barrier feasibility is a cost-effectiveness index of $30,000 or less.

Locomotive Warning Horn Mitigation

Because locomotive warning horns are intentionally noisy to warn motorists of oncoming trains, reducing the noise level of warning horns is not an option. Noise barriers at grade crossings are generally not feasible because large openings are necessitated by cross streets. In addition, noise barriers create safety concerns because they can interfere with adequate sight lines between trains and motorists. Furthermore, locomotive horns are located high up on the locomotive, thus requiring very tall noise barriers to achieve noise-level reductions at receptor locations. As stated previously, building sound insulation can be employed to reduce horn noise inside of a building.

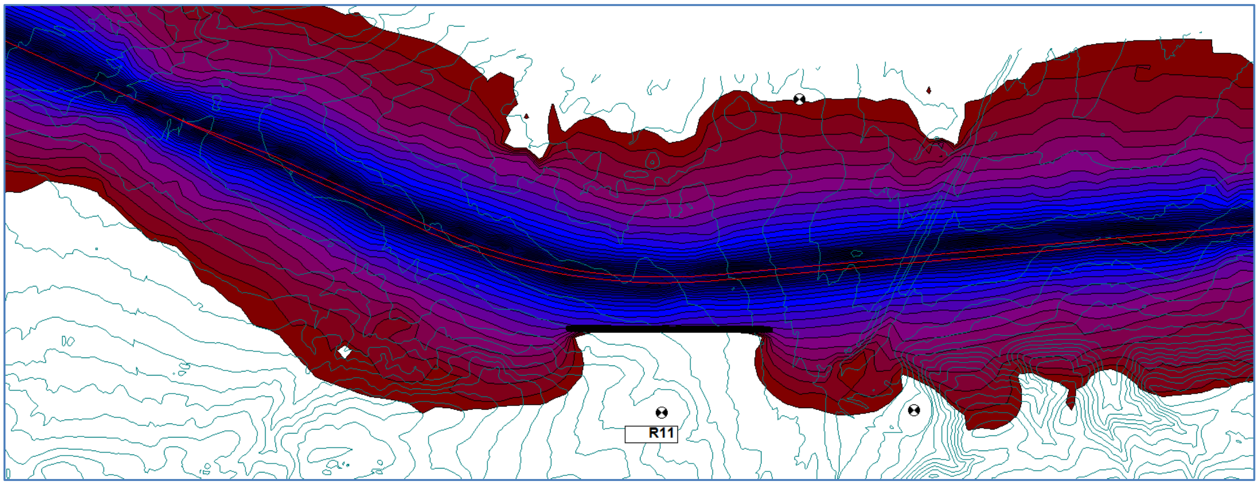
While some success in reducing noise has been found by replacing locomotive horn sounding with stationary warning horns at grade crossings (which generally have a smaller noise footprint than a locomotive horn), many communities have successfully reduced horn noise by implementing the FRA Quiet Zone program. FRA's final Train Horn Rule (9 C.F.R. Part 222) presents the requirements of a Quiet Zone and supplementary safety measures to mitigate the risks of not sounding train horns.

For the proposed rail line, locomotive horn noise would likely be audible in the project study area, but all of the receptors within the 65 DNL noise contour would be affected by wayside noise; therefore, OEA did not analyze mitigation for horn noise in the project study area.

Noise Barrier Analysis

To demonstrate the feasibility of noise barriers for the proposed rail line, OEA used CADN/A® software to model a noise barrier along a certain portion of the Indian Canyon Alternative. Figure L-3 shows a noise barrier 155 meters long and 7.6 meters tall to reduce noise levels at receptor R11. It is evident from the noise contour that the barrier would reduce train noise levels at this location.

Figure L-3. Example Noise Barrier Acoustic Model



The modeled reduction in noise level (or "insertion loss") is 5.1 dBA. Assuming a $35 per square foot cost, this noise barrier would cost approximately $444,964. The cost/(dBA x dwelling units) would be $87,248. One of the reasons that this cost is so high is because this barrier would only protect one receptor. This issue applies to all the receptors in Table L-5.

This example analysis shows that noise barriers may not be a reasonable and feasible option for the proposed rail line.

Downline Noise Analysis

OEA used information on train composition, frequency, length, and speed provided by the Coalition for project-related rail traffic and information from multiple sources, as described in Appendix C, *Downline Analysis Study Area and Train Characteristics*, for rail traffic on the existing rail lines in the downline study area.

Using the equations in the previous sections, Table L-6 shows calculated increases in noise levels along existing downline rail lines. These increases are a function of existing and proposed rail line train volumes, speeds, and specific train composition. In general, noise level increases greater than 3 dBA would be noticeable depending on several factors including a receptor's proximity to the rail line.

Table L-6. Downline Rail Noise Analysis Results

Object ID	Rail Line Segment	Railroad	Passenger Count[a]	Baseline Freight (trains per day)	High Rail Traffic Scenario (trains per day)	Total dB increase	Avg. Train Speed (mph)	Transit Speed (mph)
124	Denver East/North	UP	0	25	8.4	3.2	15	N/A
114	Denver East/North	UP	0	25	8.4	3.2	15	N/A
132	Denver Eastbound	UP	0	10	1.1	1.3	15	N/A
287	Denver Eastbound	UP	0	3	1.1	3.6	11	N/A
286	Denver Eastbound	UP	0	3	1.1	3.6	15	N/A
55	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
56	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
57	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
61	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
62	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
63	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
64	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
65	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
58	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
346	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
347	Denver Eastbound	RTDC	146	3	1.1	1.1	27.5	45
332	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
331	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
344	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
342	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
340	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
339	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
338	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
336	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
335	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
334	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
333	Denver Eastbound	UP	0	4	1.1	1.0	36.5	N/A
365	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
362	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
359	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
357	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
358	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
356	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
352	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A

Object ID	Rail Line Segment	Railroad	Passenger Count[a]	Baseline Freight (trains per day)	High Rail Traffic Scenario (trains per day)	Total dB increase	Avg. Train Speed (mph)	Transit Speed (mph)
353	Denver Eastbound	UP	0	3	1.1	1.0	36.5	N/A
50	Kyune to Denver	UP	2	6	9.5	4.5	22.5	N/A
49	Kyune to Denver	UP	2	6	9.5	4.5	22.5	N/A
48	Kyune to Denver	UP	2	10	9.5	3.8	22.5	N/A
34	Kyune to Denver	UP	2	6	9.5	4.8	40	N/A
33	Kyune to Denver	UP	2	6	9.5	5.0	37.5	N/A
32	Kyune to Denver	UP	2	6	9.5	5.4	32.5	N/A
30	Kyune to Denver	UP	2	6	9.5	5.4	32.5	N/A
29	Kyune to Denver	UP	2	6	9.5	5.4	32.5	N/A
28	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
6	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
26	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
23	Kyune to Denver	UP	2	6	9.5	4.8	41	N/A
45	Kyune to Denver	UP	2	6	9.5	4.7	42.5	N/A
43	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
42	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
41	Kyune to Denver	UP	2	6	9.5	6.0	26	N/A
11	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
9	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
8	Kyune to Denver	UP	2	6	9.5	4.8	41	N/A
20	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
21	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
19	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
16	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
17	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
164	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
147	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
146	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
145	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
143	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
142	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
141	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
197	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
195	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
194	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A

Object ID	Rail Line Segment	Railroad	Passenger Count[a]	Baseline Freight (trains per day)	High Rail Traffic Scenario (trains per day)	Total dB increase	Avg. Train Speed (mph)	Transit Speed (mph)
184	Kyune to Denver	UP	2	6	9.5	4.5	45	N/A
283	Kyune to Denver	UP	0	0	9.5	N/A	7.5	N/A
272	Kyune to Denver	UP	0	0	9.5	N/A	7.5	N/A
270	Kyune to Denver	UP	2	9	9.5	4.9	27.5	N/A
269	Kyune to Denver	UP	2	9	9.5	4.9	27.5	N/A
266	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
263	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
262	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
259	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
258	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
255	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
252	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
251	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
250	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
249	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
247	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
248	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
245	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
246	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
96	Kyune to Denver	UP	2	9	9.5	5.0	26	N/A
94	Kyune to Denver	UP	2	9	9.5	4.7	30	N/A
89	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
189	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
238	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
237	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
236	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
235	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
231	Kyune to Denver	UP	2	9	9.5	4.7	30	N/A
208	Kyune to Denver	UP	2	9	9.5	5.3	22.5	N/A
322	Kyune to Denver	UP	2	9	9.5	5.3	22.5	N/A
319	Kyune to Denver	UP	2	9	9.5	4.7	30	N/A
307	Kyune to Denver	UP	2	9	9.5	3.4	52.5	N/A
306	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
303	Kyune to Denver	UP	2	9	9.5	3.4	52.5	N/A
301	Kyune to Denver	UP	2	9	9.5	3.4	52.5	N/A

Object ID	Rail Line Segment	Railroad	Passenger Count[a]	Baseline Freight (trains per day)	High Rail Traffic Scenario (trains per day)	Total dB increase	Avg. Train Speed (mph)	Transit Speed (mph)
181	Kyune to Denver	UP	2	9	9.5	3.9	40	N/A
299	Kyune to Denver	UP	2	9	9.5	5.0	26	N/A
296	Kyune to Denver	UP	2	9	9.5	3.7	45	N/A
290	Kyune to Denver	UP	2	9	9.5	3.8	42.5	N/A
108	Kyune to Denver	UP	2	9	9.5	3.8	42.5	N/A
109	Kyune to Denver	UP	2	9	9.5	5.7	18.5	N/A
106	Kyune to Denver	UP	2	9	9.5	3.9	41	N/A
84	Kyune to Denver	UP	2	9	9.5	5.1	25	N/A
82	Kyune to Denver	UP	2	9	9.5	4.3	35	N/A
176	Kyune to Denver	UP	2	9	9.5	4.7	30	N/A
177	Kyune to Denver	UP	2	9	9.5	3.4	52.5	N/A
76	Kyune to Denver	UP	2	9	9.5	5.1	25	N/A
171	Kyune to Denver	UP	2	9	9.5	5.7	18.5	N/A
98	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
71	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
70	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
69	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
72	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
68	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
120	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
118	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
186	Kyune to Denver	UP	2	9	9.5	4.4	33.5	N/A
110	Kyune to Denver	RTDC	134	9	9.5	4.4	33.5	38
111	Kyune to Denver	RTDC	134	9	9.5	4.4	33.5	38
278	Denver Northbound	UP	0	10	7.3	4.5	26	N/A
280	Denver Northbound	UP	0	10	7.3	4.5	26	N/A
281	Denver Northbound	UP	0	10	7.3	4.5	26	N/A
329	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
88	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
420	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
421	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
448	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
423	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
424	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
412	Denver Northbound	UP	0	10	7.3	3.3	45	N/A

Object ID	Rail Line Segment	Railroad	Passenger Count[a]	Baseline Freight (trains per day)	High Rail Traffic Scenario (trains per day)	Total dB increase	Avg. Train Speed (mph)	Transit Speed (mph)
529	Denver Northbound	UP		0	7.3	N/A	0	N/A
414	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
415	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
416	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
417	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
418	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
419	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
425	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
426	Denver Northbound	UP	0	10	7.3	3.5	40	N/A
427	Denver Northbound	UP	0	10	7.3	3.5	40	N/A
525	Denver Northbound	UP	0	10	7.3	3.5	40	N/A
447	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
433	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
450	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
434	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
436	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
437	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
438	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
439	Denver Northbound	UP	0	10	7.3	3.7	37.5	N/A
440	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
441	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
443	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
444	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
451	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
445	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
428	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
526	Denver Northbound	UP	0	0	7.3	N/A	0	N/A
429	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
449	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
432	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
466	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
467	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
468	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
471	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
470	Denver Northbound	UP	0	10	7.3	3.3	45	N/A

Object ID	Rail Line Segment	Railroad	Passenger Count[a]	Baseline Freight (trains per day)	High Rail Traffic Scenario (trains per day)	Total dB increase	Avg. Train Speed (mph)	Transit Speed (mph)
469	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
527	Denver Northbound	UP		0	7.3	N/A	0	N/A
472	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
474	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
475	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
476	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
477	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
478	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
479	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
480	Denver Northbound	UP	0	10	7.3	3.3	45	N/A
481	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
482	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
483	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
484	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
519	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
486	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
487	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
488	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
489	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
490	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
491	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
497	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
493	Denver Northbound	UP	0	14	7.3	2.9	37.5	N/A
494	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
495	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
496	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
528	Denver Northbound	UP	--	0	7.3	N/A	0	N/A
499	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
498	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
500	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
501	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
502	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
503	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
504	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
505	Denver Northbound	UP	0	14	7.3	2.6	45	N/A

Object ID	Rail Line Segment	Railroad	Passenger Count[a]	Baseline Freight (trains per day)	High Rail Traffic Scenario (trains per day)	Total dB increase	Avg. Train Speed (mph)	Transit Speed (mph)
515	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
516	Denver Northbound	UP	0	12	7.3	2.9	45	N/A
517	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
518	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
507	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
514	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
513	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
512	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
511	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
509	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
508	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
506	Denver Northbound	UP	0	14	7.3	2.6	45	N/A
59	Denver Southbound	DRIR	0	0	1.1	N/A	5.5	N/A
60	Denver Southbound	DRIR	0	0	1.1	N/A	5.5	N/A
66	Denver Southbound	DRIR	0	0	1.1	N/A	5.5	N/A
131	Denver Southbound	BNSF	0	38	1.1	0.4	10.5	N/A
168	Denver Southbound	BNSF	0	38	1.1	0.4	15.5	N/A
167	Denver Southbound	BNSF	0	38	1.1	0.4	15.5	N/A
129	Denver Southbound	BNSF	0	38	1.1	0.4	15.5	N/A
128	Denver Southbound	BNSF	0	38	1.1	0.4	15.5	N/A
127	Denver Southbound	BNSF	0	38	1.1	0.4	15.5	N/A
375	Denver Southbound	UP	0	20	1.1	0.5	33.5	N/A
371	Denver Southbound	UP	0	20	1.1	0.5	33.5	N/A
372	Denver Southbound	UP	0	20	1.1	0.6	26	N/A
373	Denver Southbound	UP	0	20	1.1	0.6	26	N/A
401	Denver Southbound	BNSF	0	20	1.1	0.5	33.5	N/A
400	Denver Southbound	BNSF	0	20	1.1	0.5	33.5	N/A
399	Denver Southbound	BNSF	0	20	1.1	0.5	33.5	N/A
398	Denver Southbound	BNSF	0	20	1.1	0.5	33.5	N/A
397	Denver Southbound	BNSF	0	20	1.1	0.5	33.5	N/A
404	Denver Southbound	BNSF	0	20	1.1	0.5	33.5	N/A

Notes:

[a] Counts include baseline transit and/or Amtrak.

dB = decibel; mph = miles per hour; UP = Union Pacific Railroad; RTDC = Regional Transportation District Commuter; DRIR = Denver Rock Island Railroad; BNSF = BNSF Railway; N/A = not applicable

Noise Contour Mapping

Figure L-4, Figure L-5, and Figure L-6 show the modeled 65 DNL noise contours and +3 dBA contours for the entire study area for each of the Action Alternatives. The +3 dBA contours generally are large when ambient sound levels are low. Since ambient sound levels vary in the study area, the size of these contours also vary depending on local ambient sound measurement data.

Figure L-4. Indian Canyon Alternative Noise Contours, Sheet Index

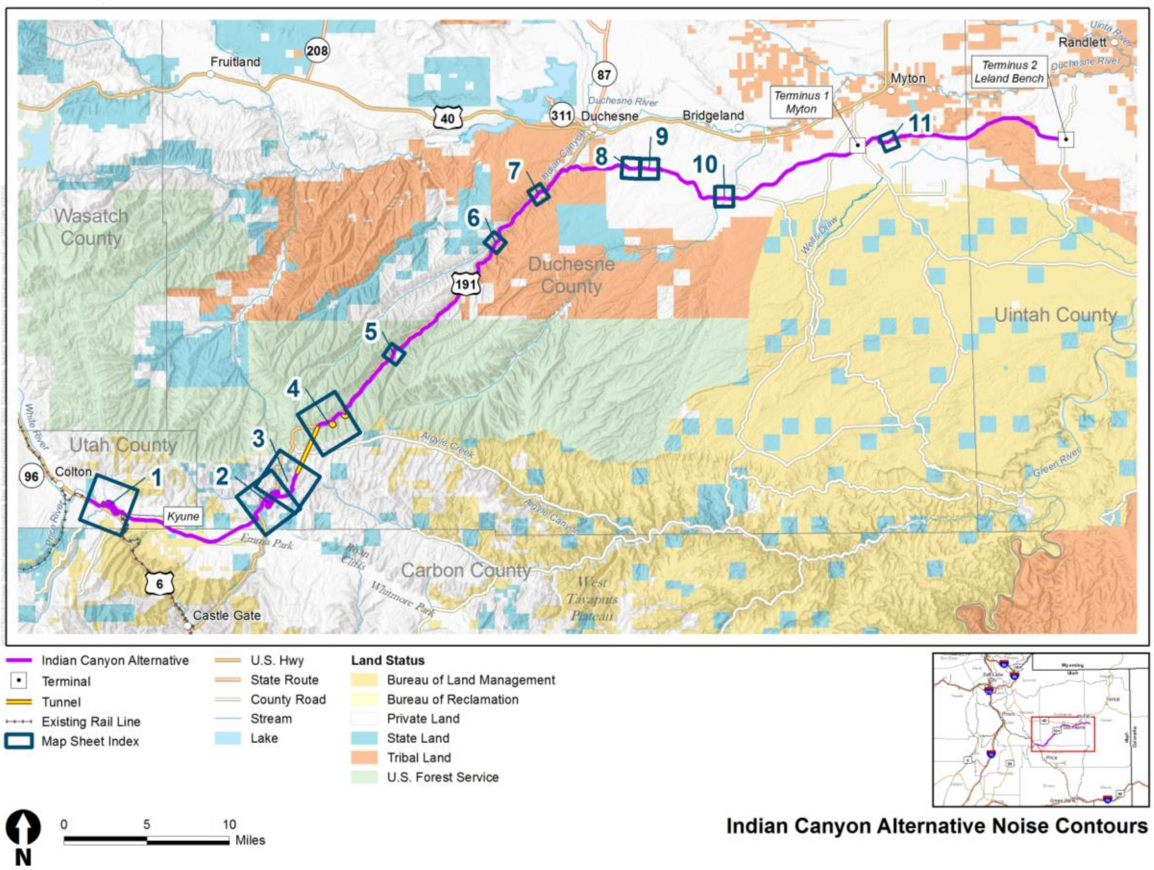


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 1 of 11

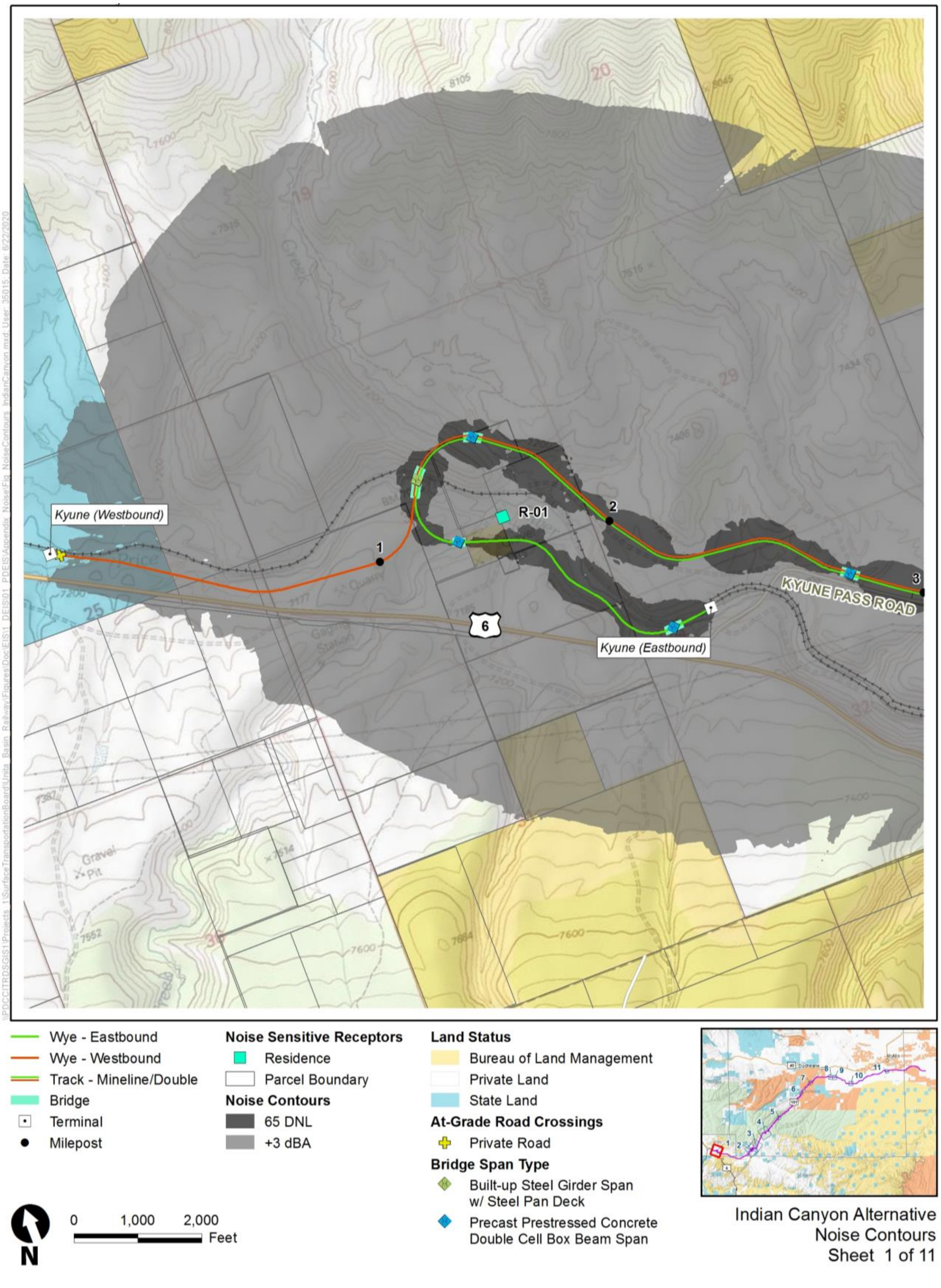


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 2 of 11

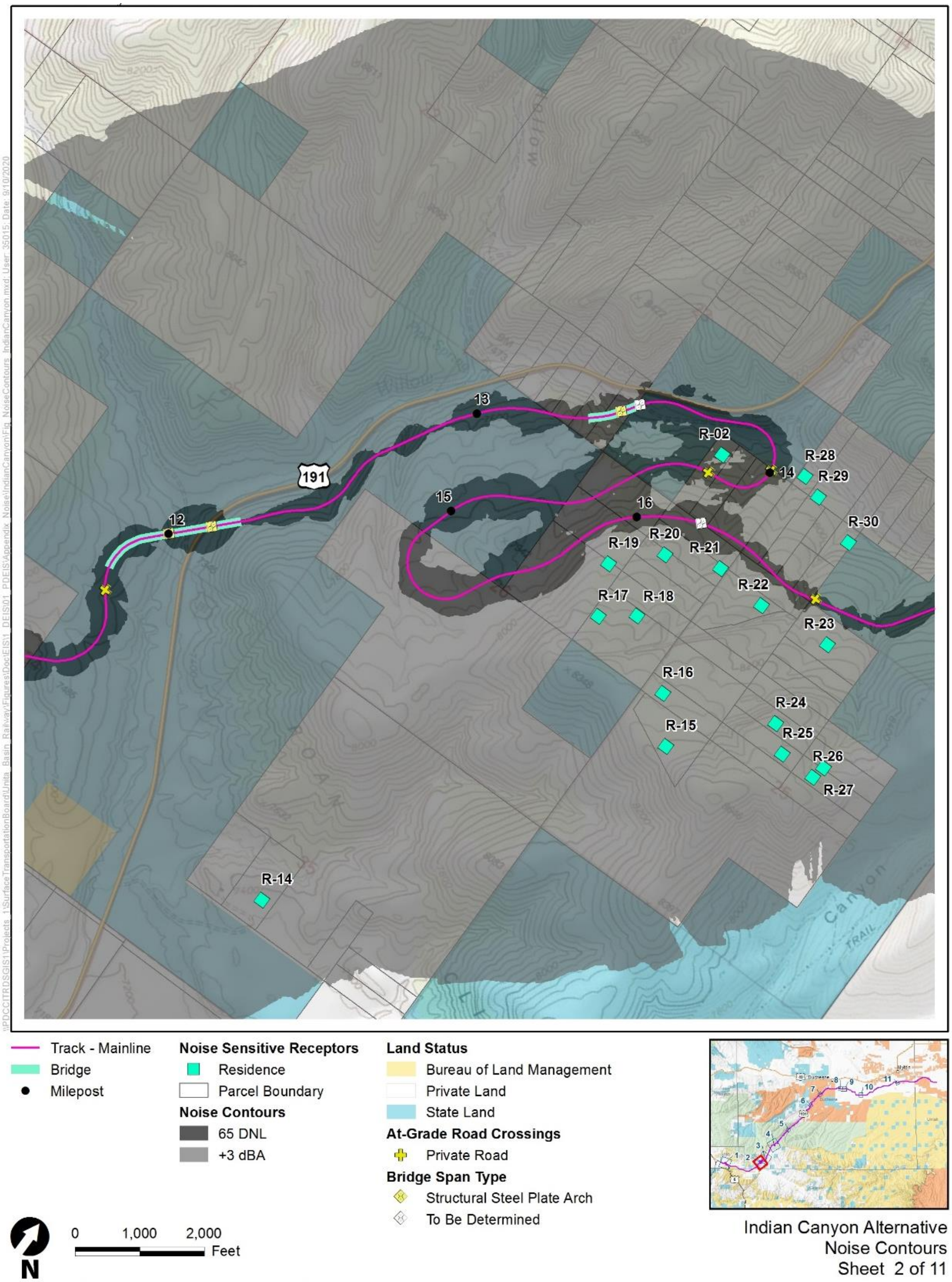


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 3 of 11

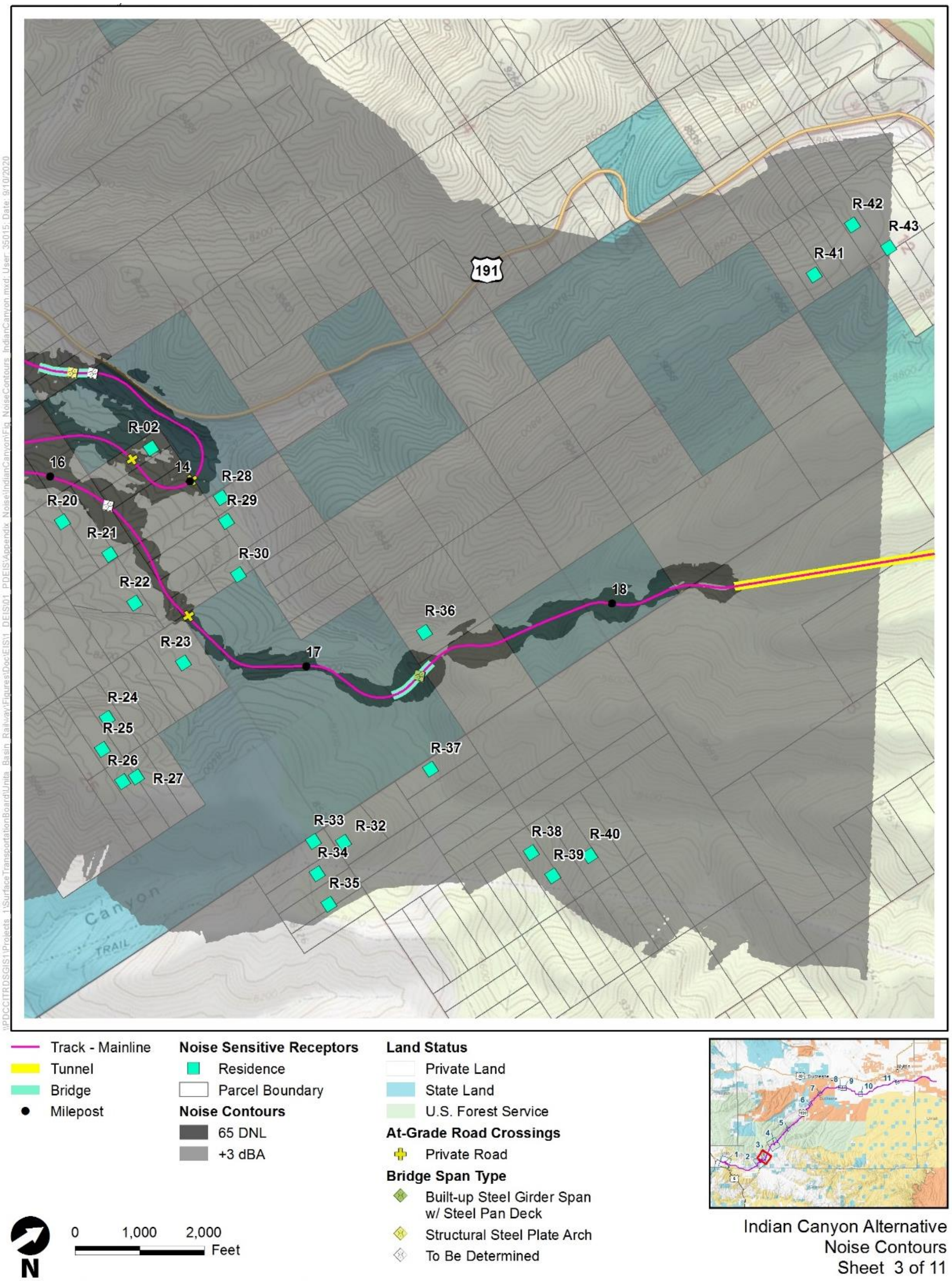


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 4 of 11

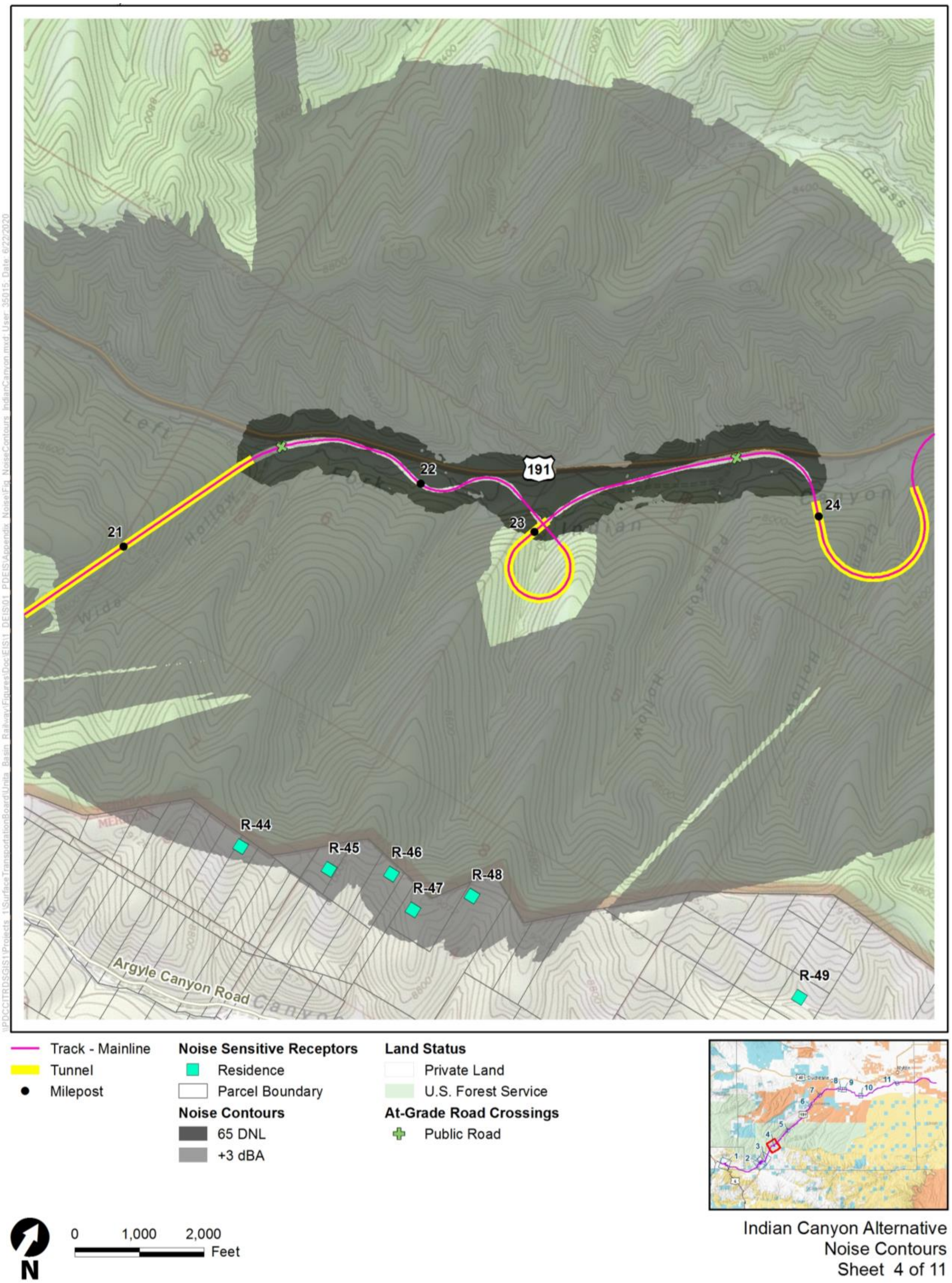


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 5 of 11

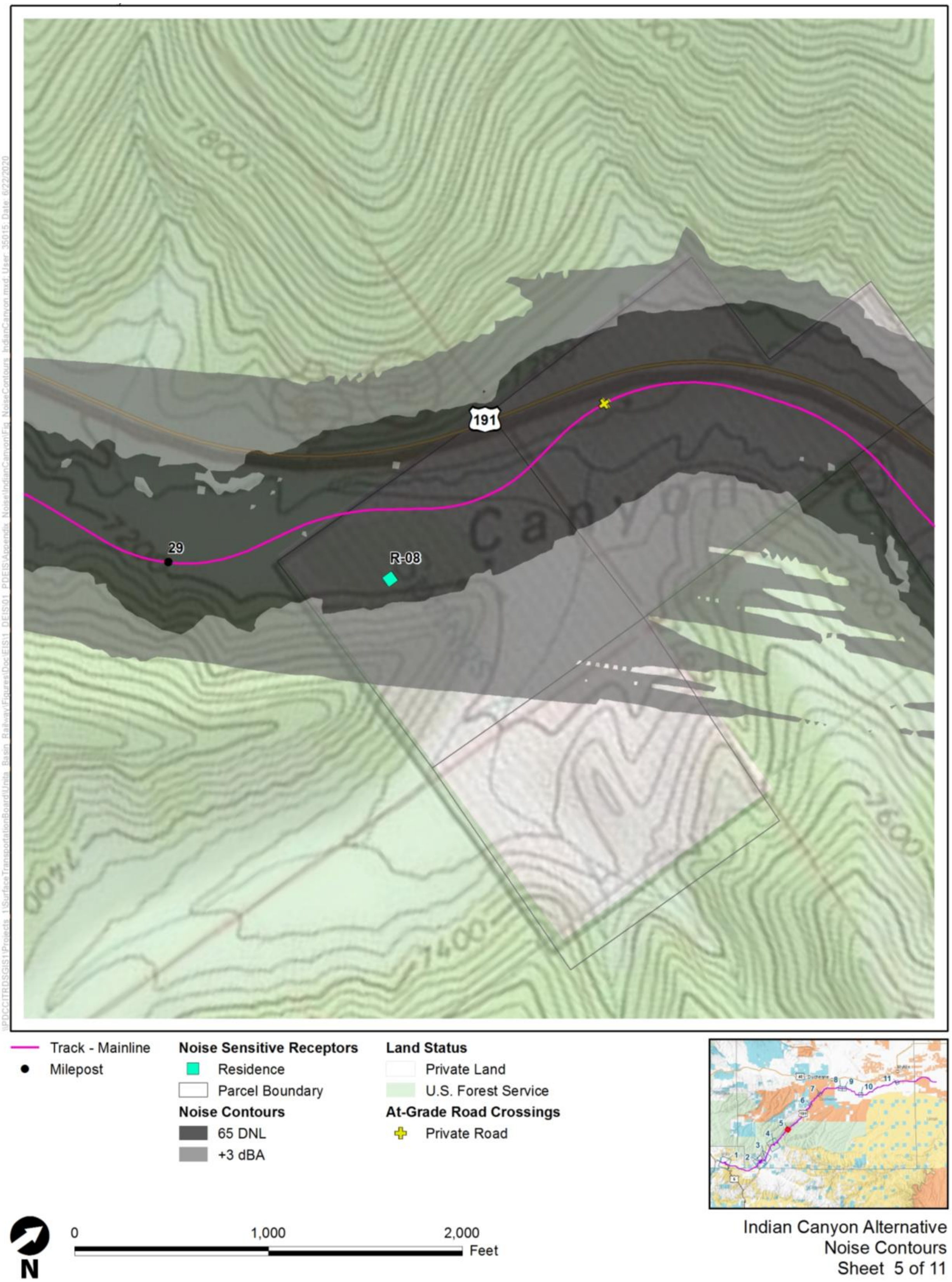


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 6 of 11

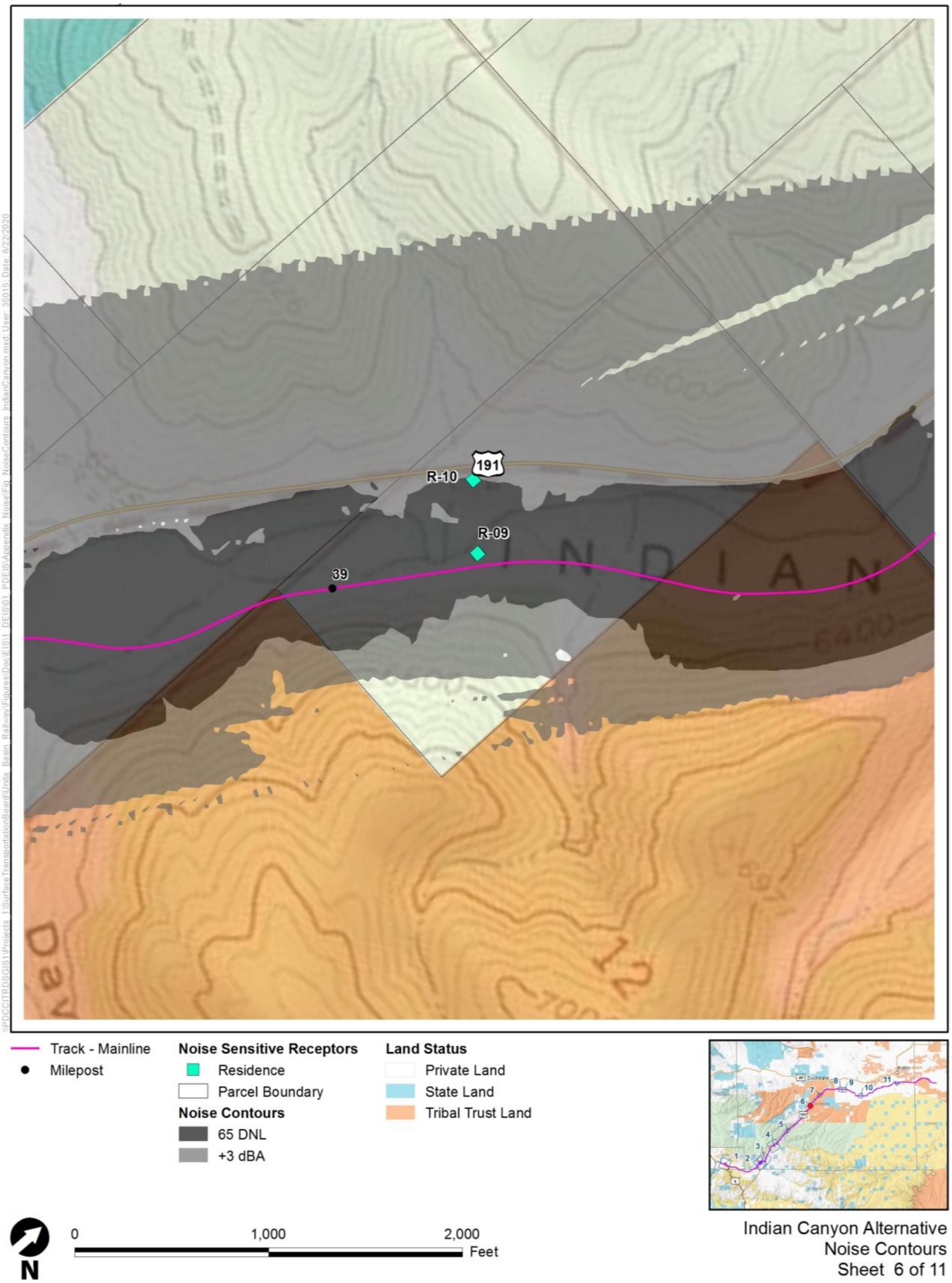


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 7 of 11

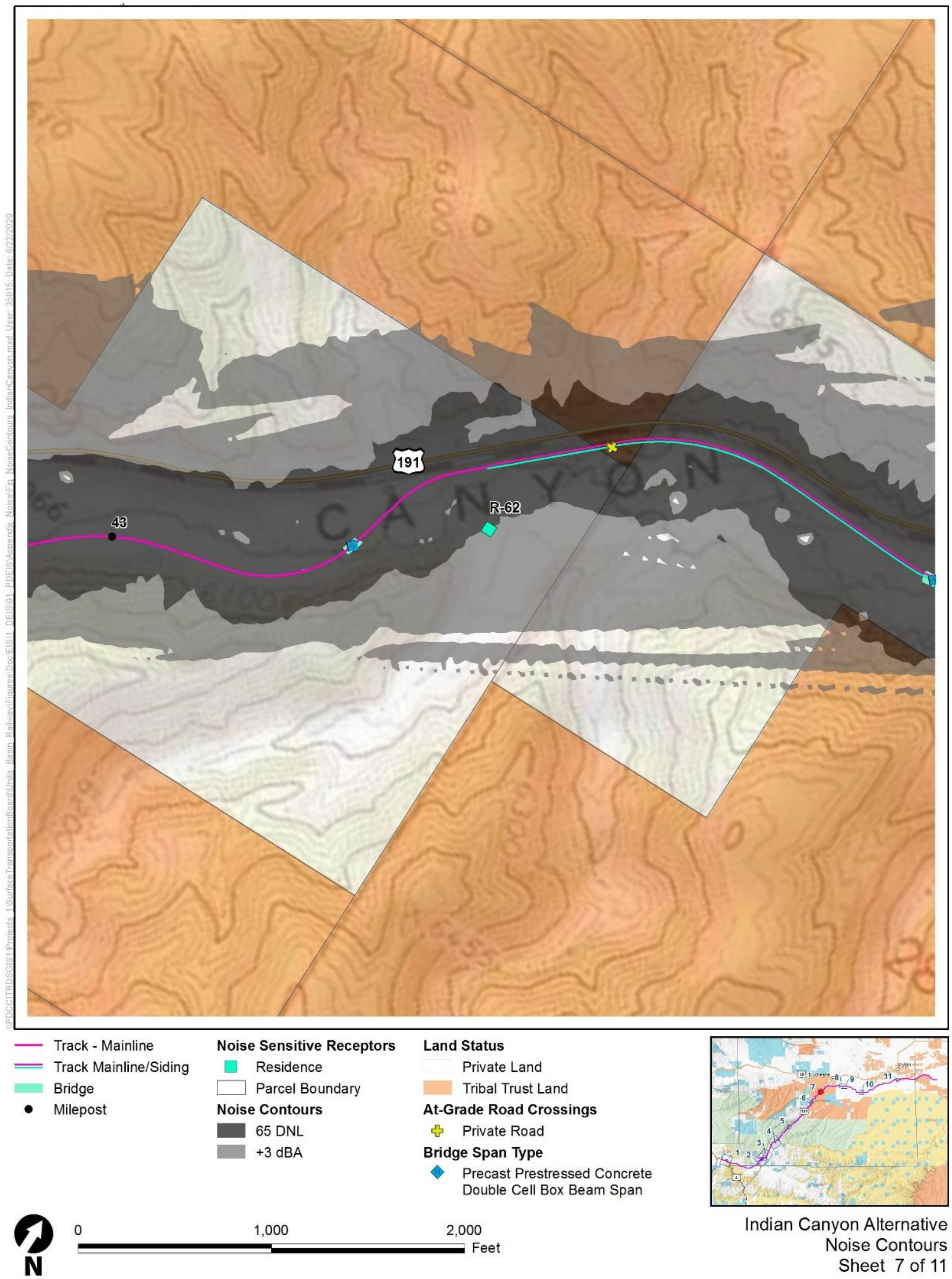


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 8 of 11

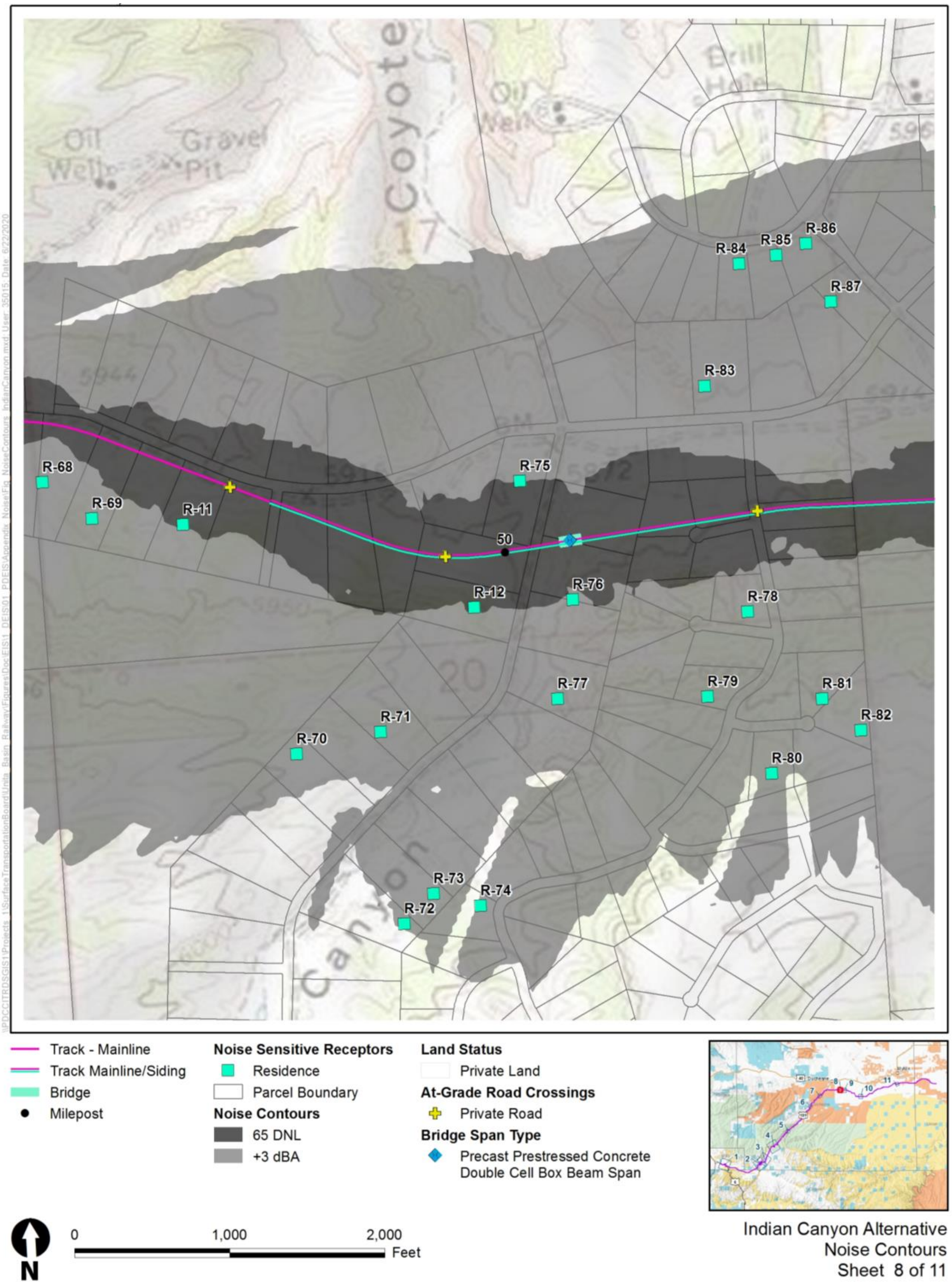
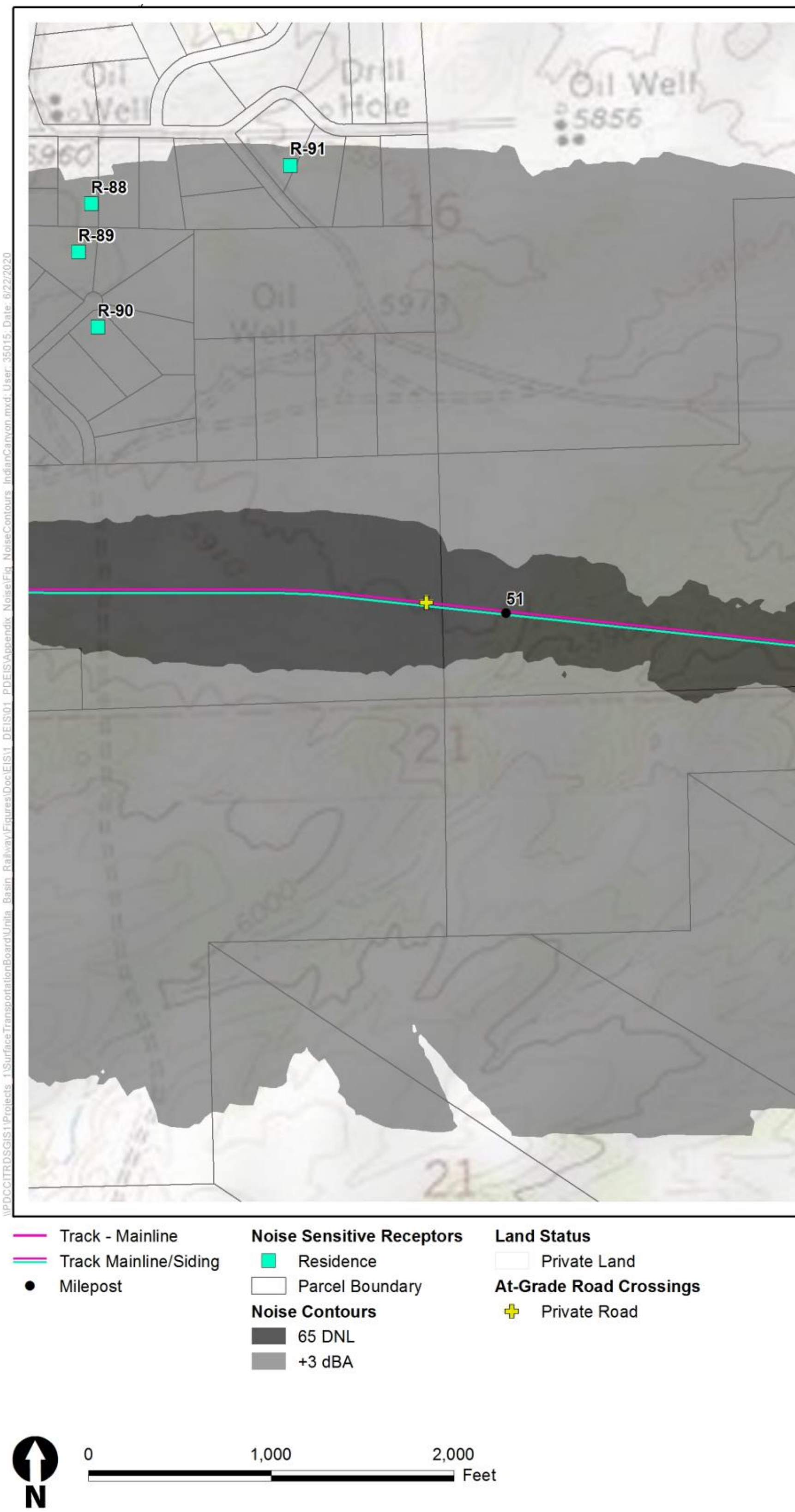


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 9 of 11



Indian Canyon Alternative
Noise Contours
Sheet 9 of 11

Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 10 of 11

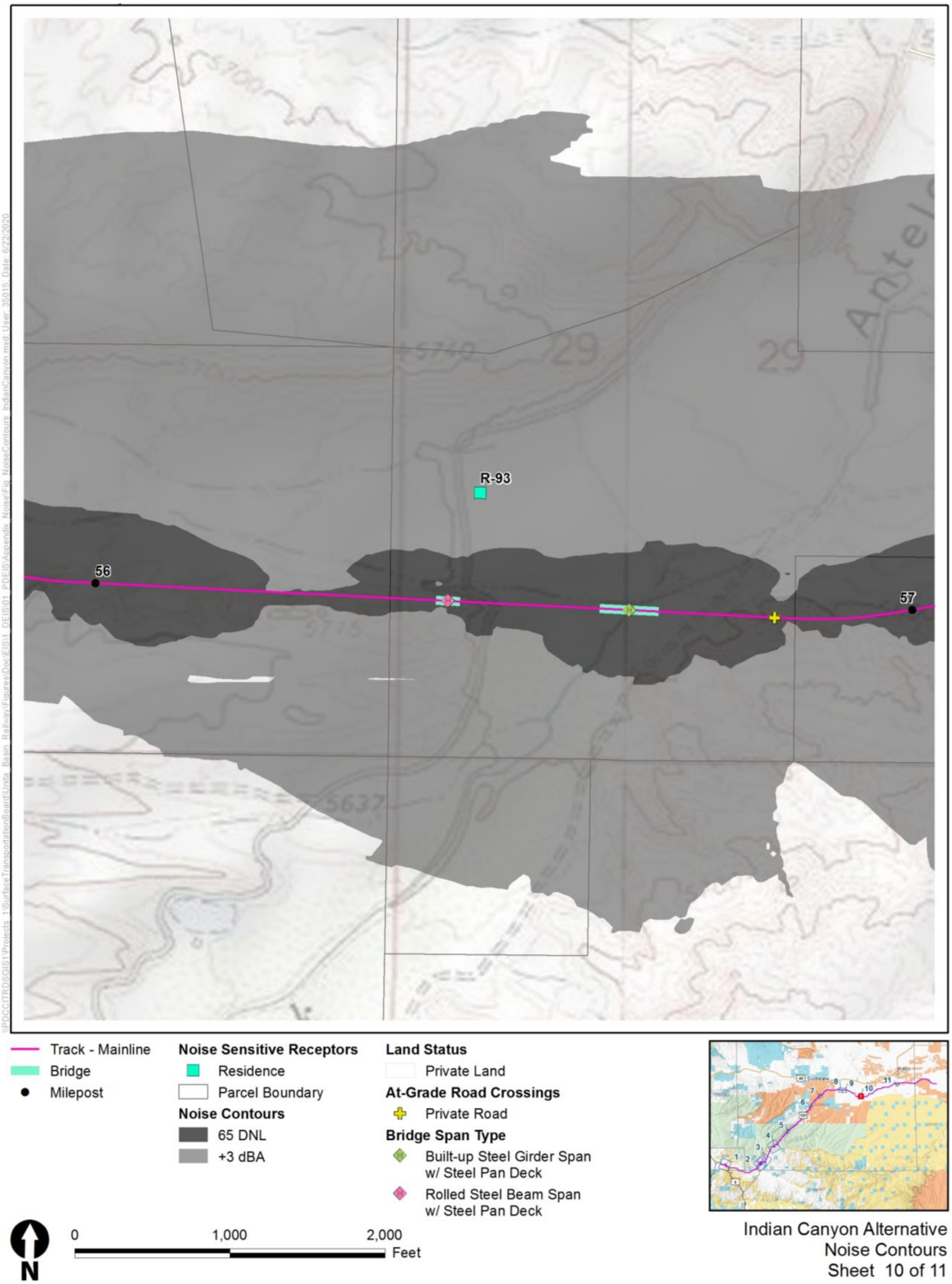


Figure L-4. Indian Canyon Alternative Noise Contours, Sheet 11 of 11

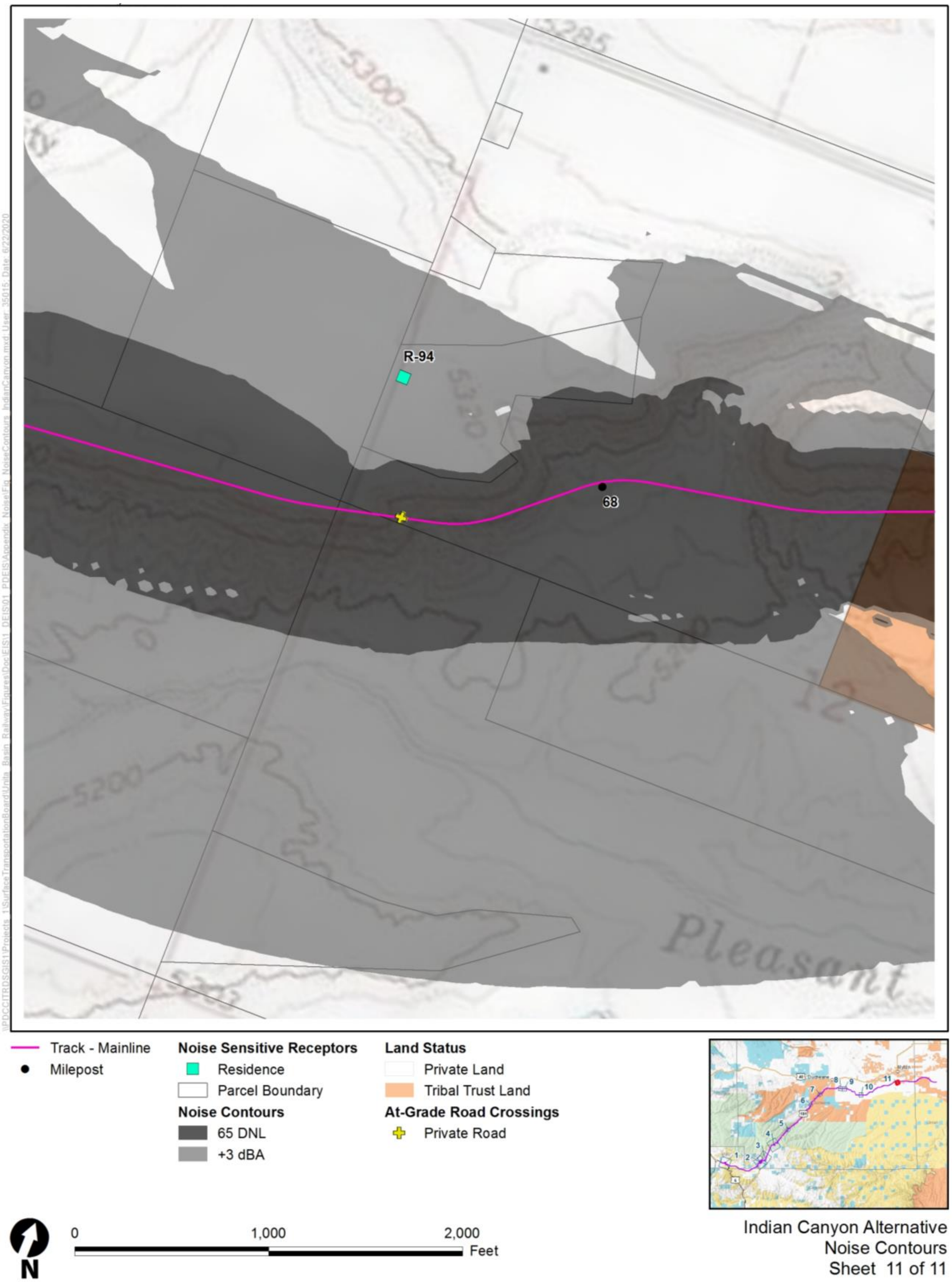


Figure L-5. Wells Draw Alternative Noise Contours, Sheet Index

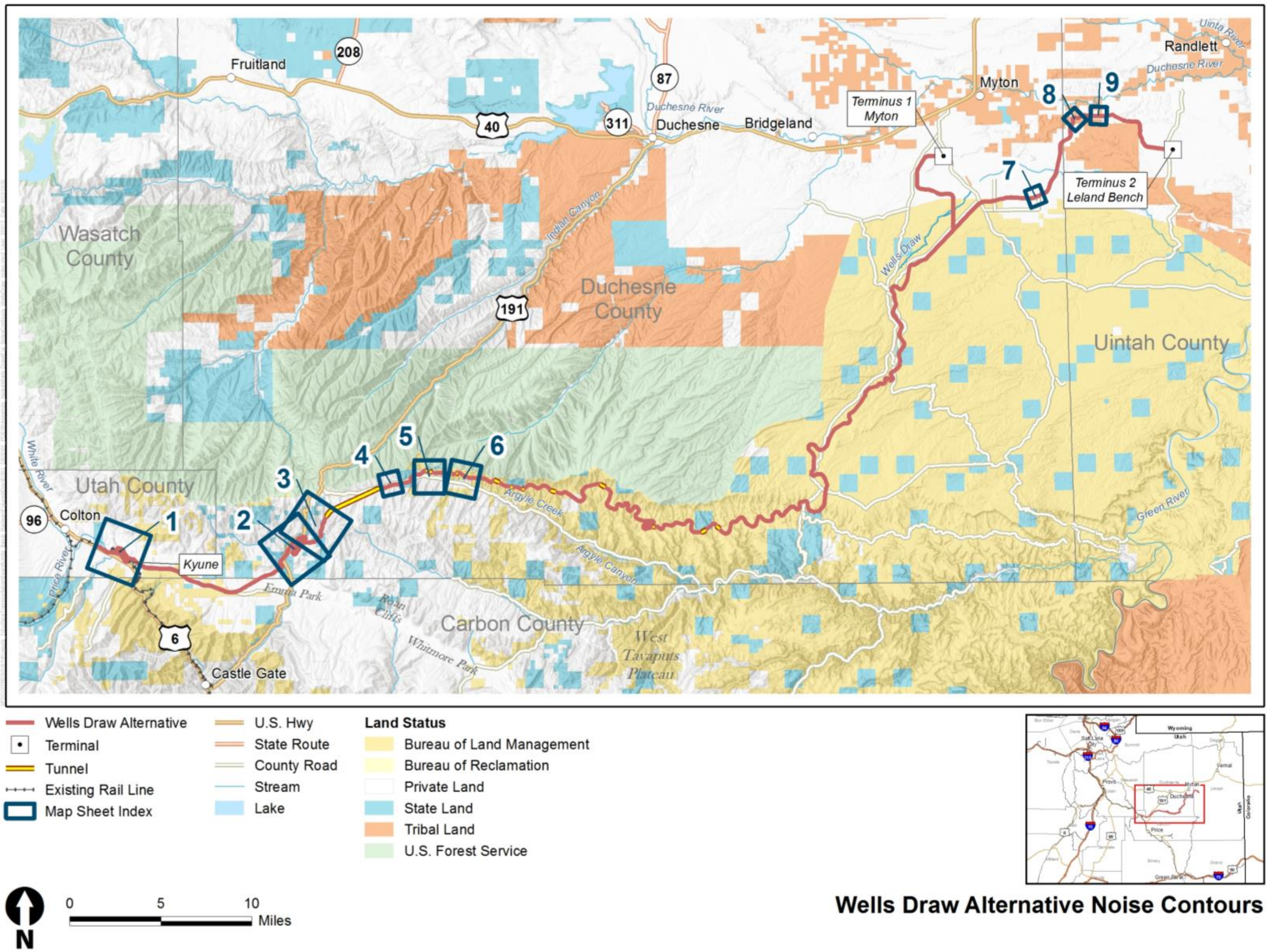


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 1 of 9

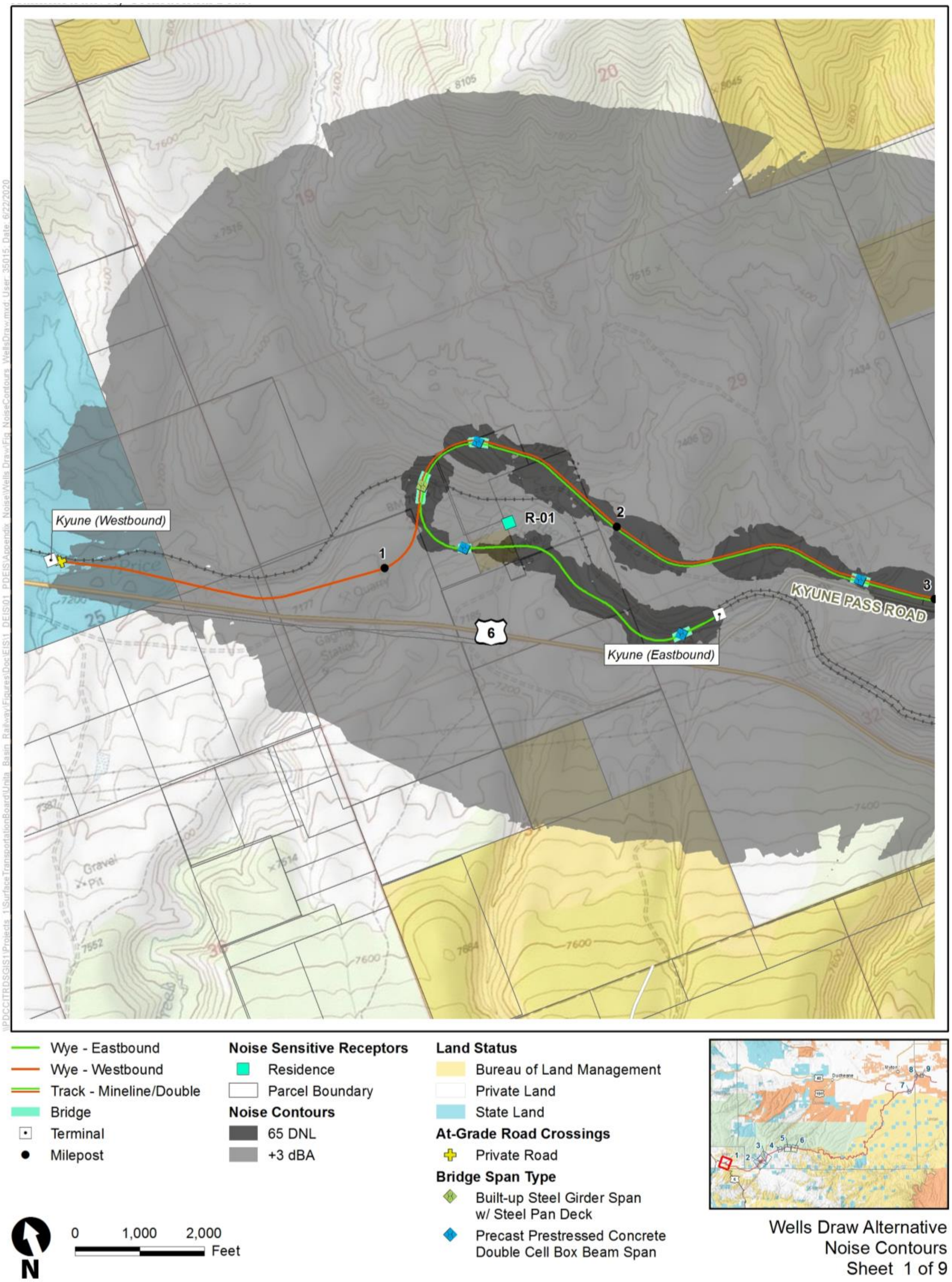


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 2 of 9

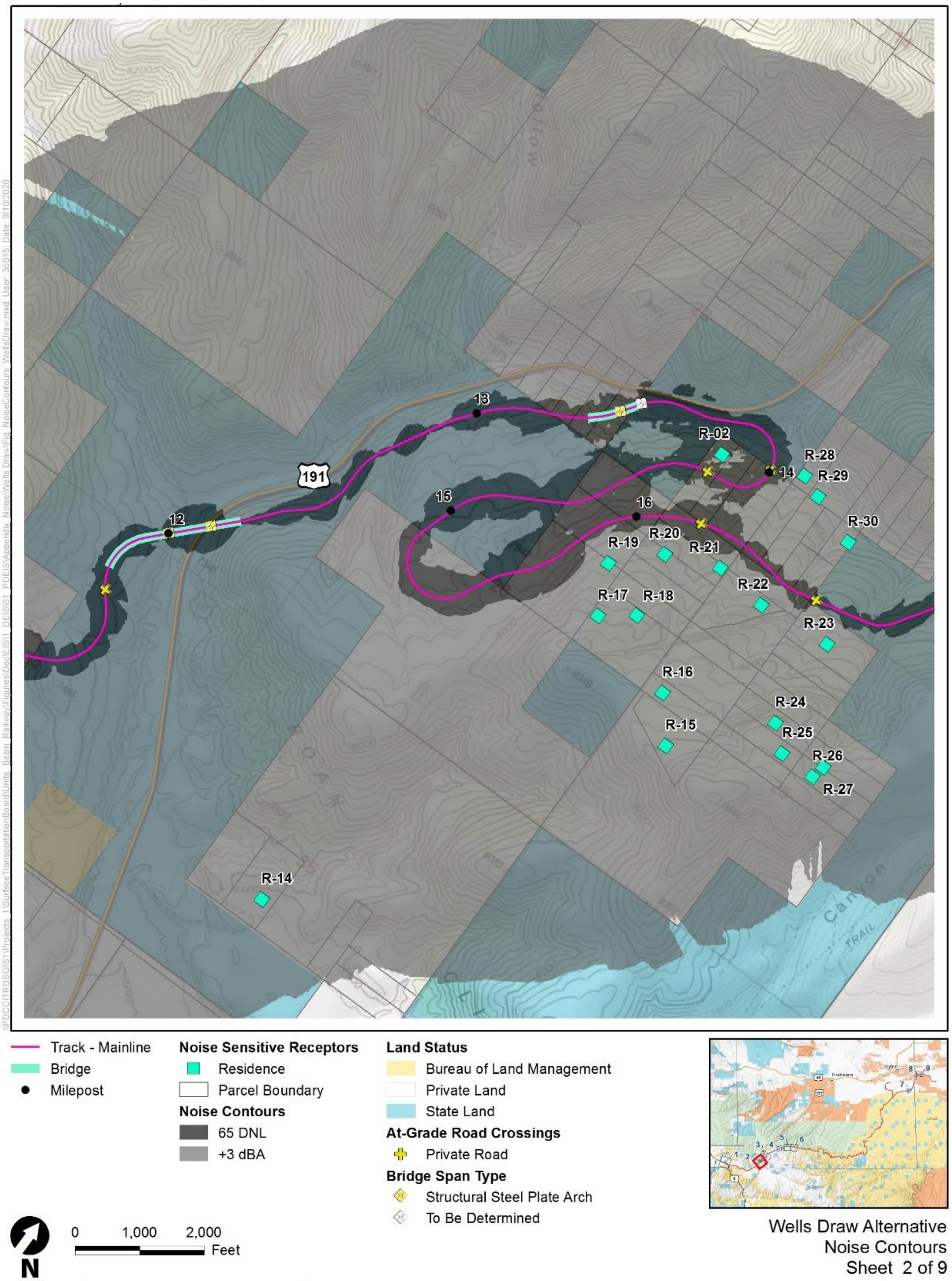


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 3 of 9

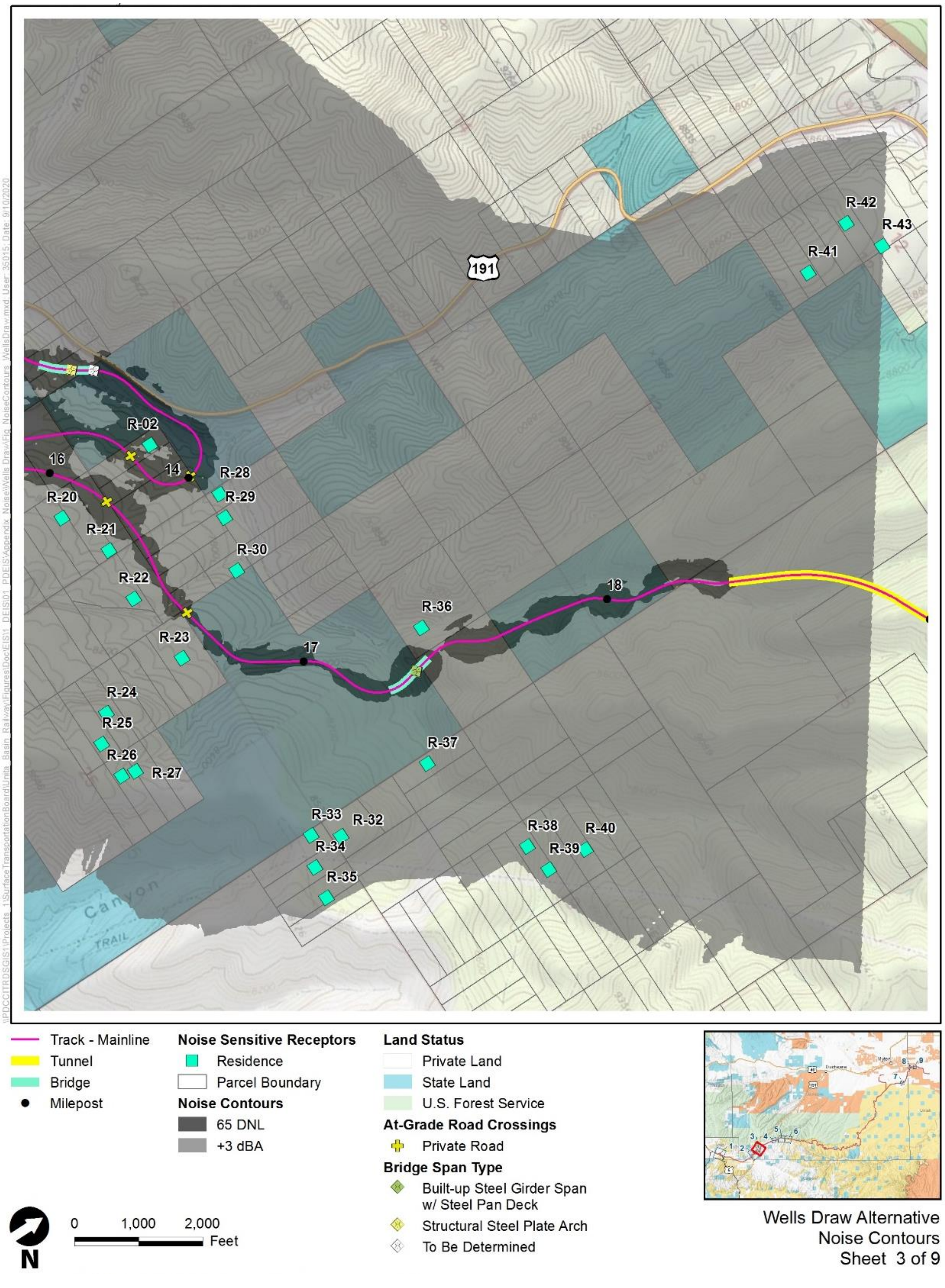


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 4 of 9

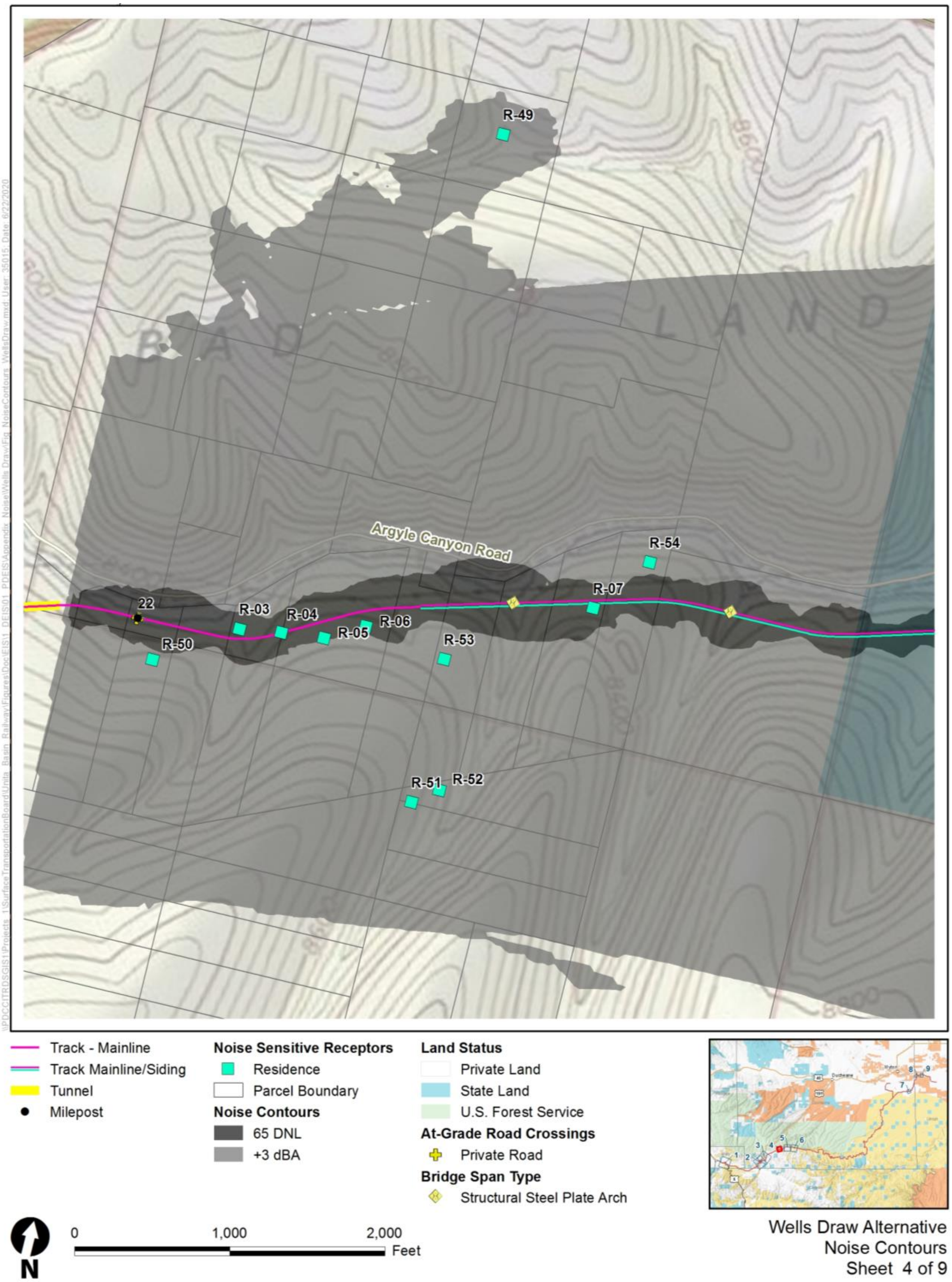


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 5 of 9

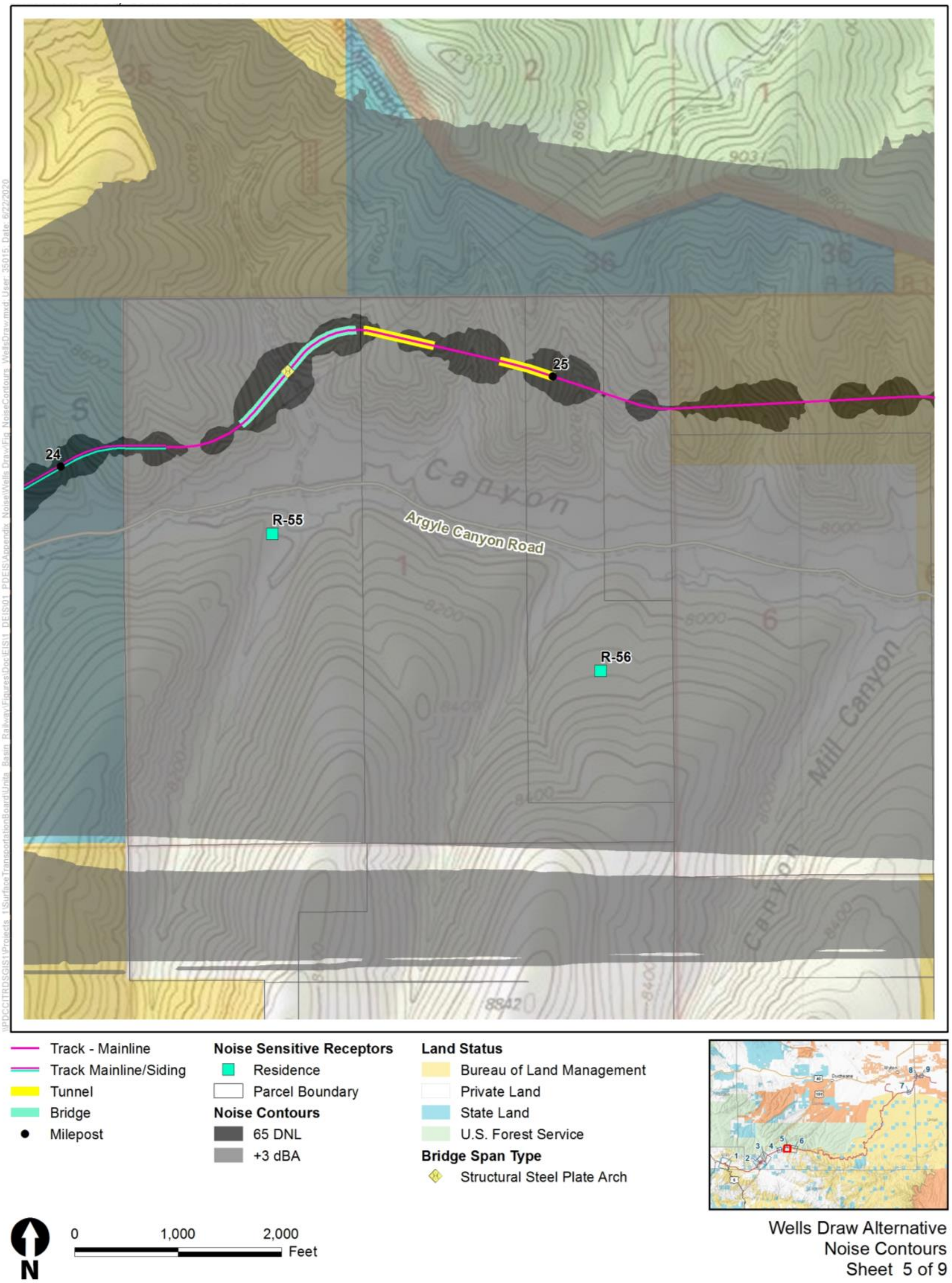


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 6 of 9

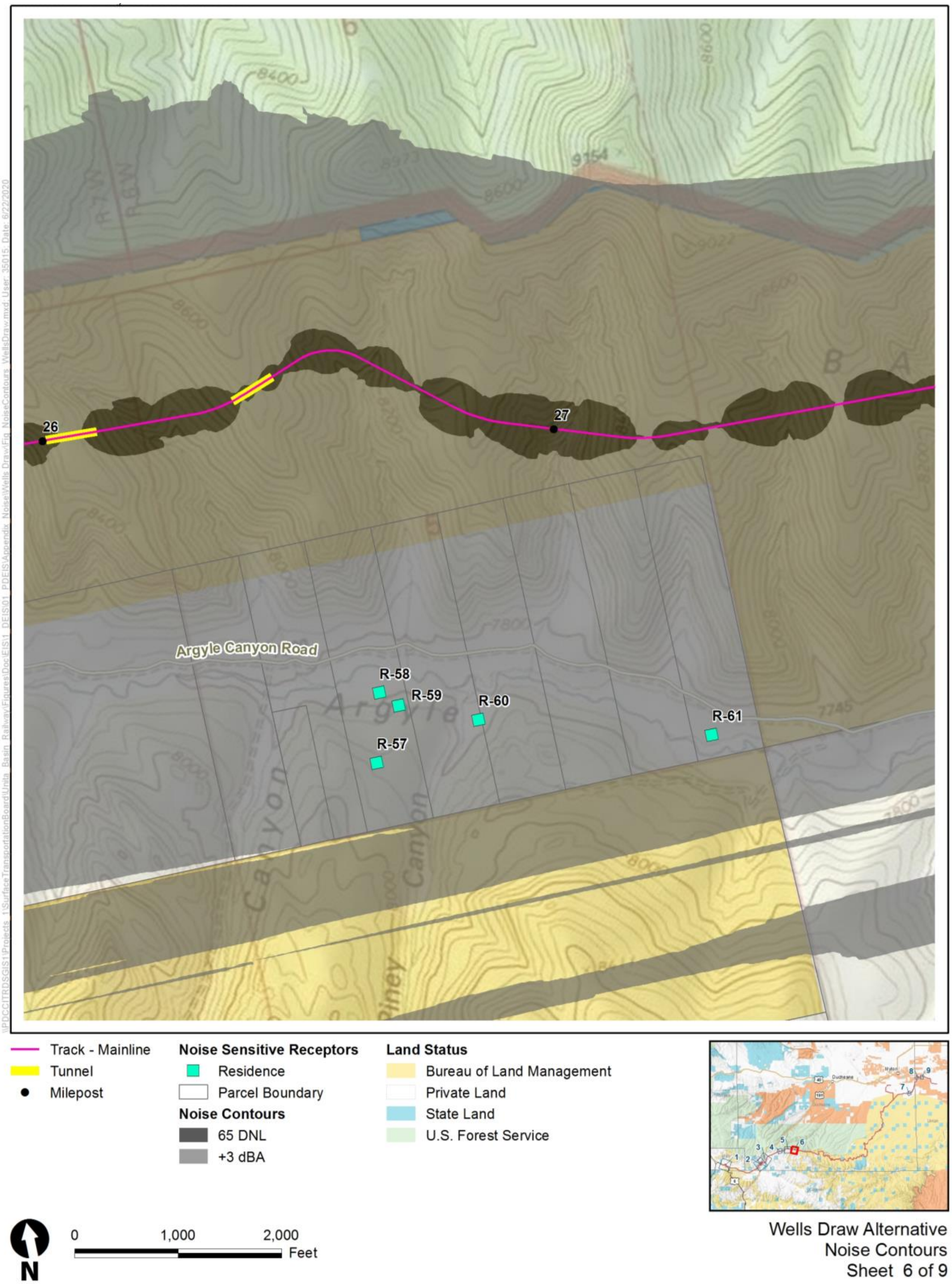


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 7 of 9

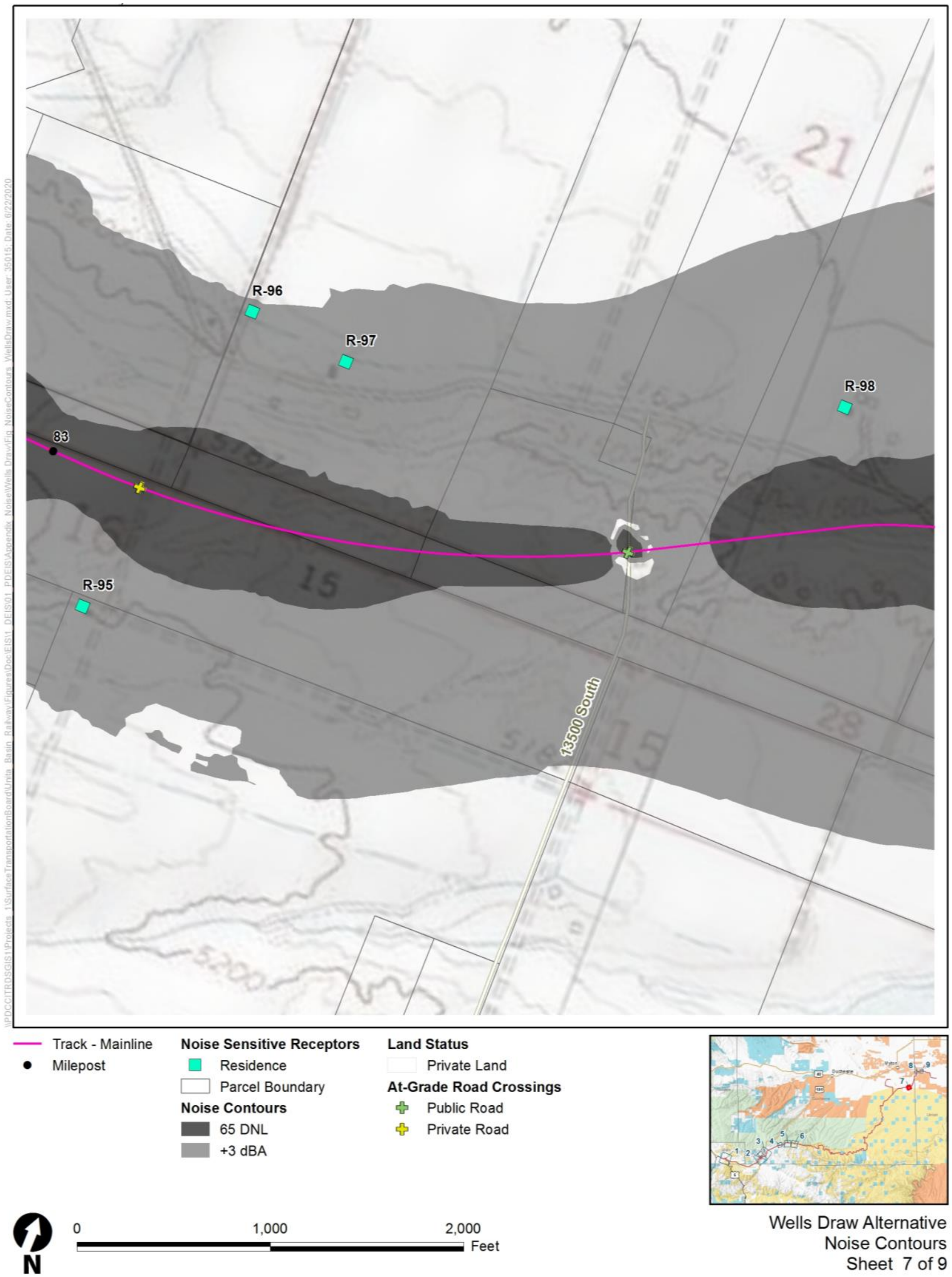


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 8 of 9

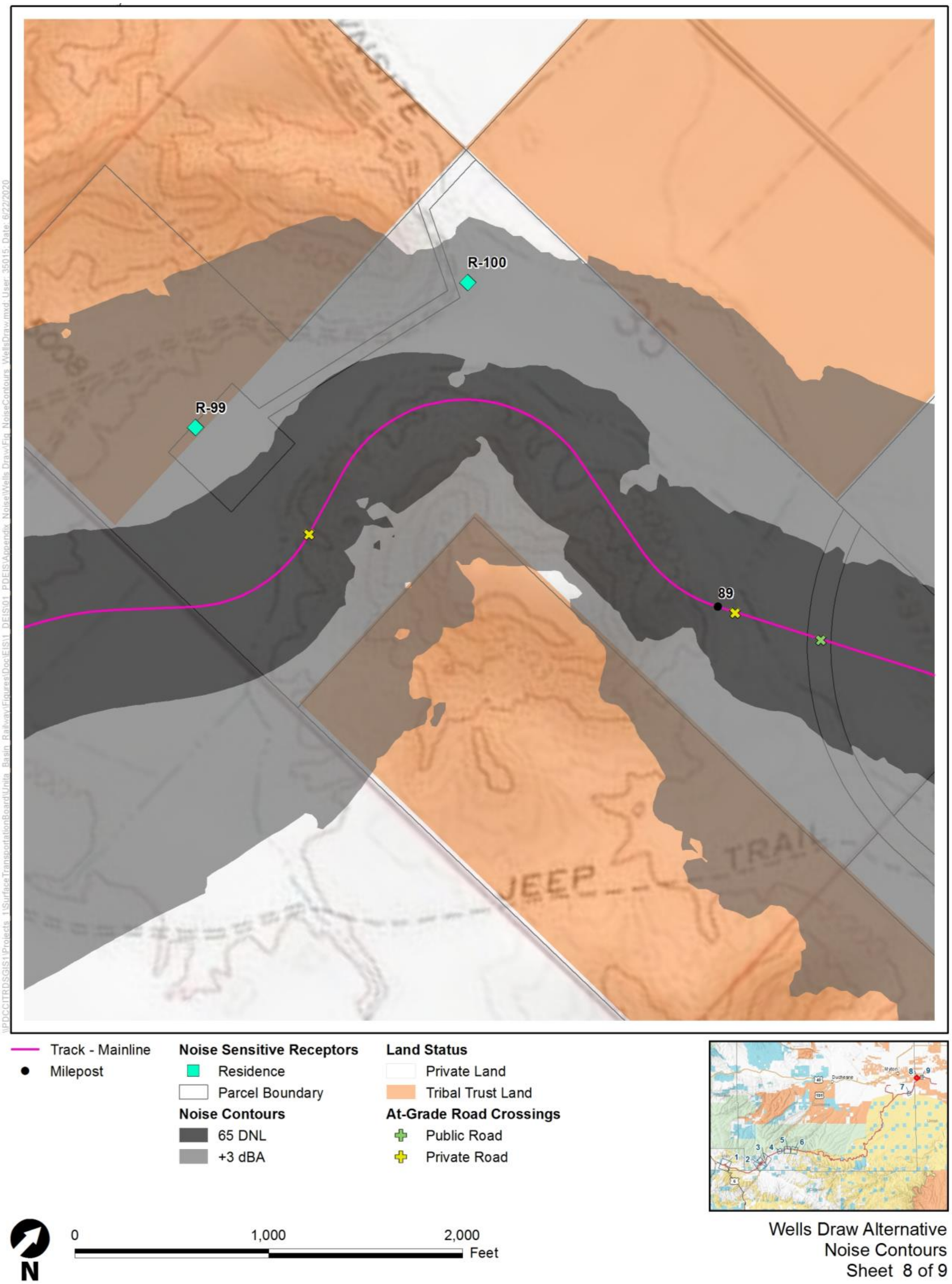


Figure L-5. Wells Draw Alternative Noise Contours, Sheet 9 of 9

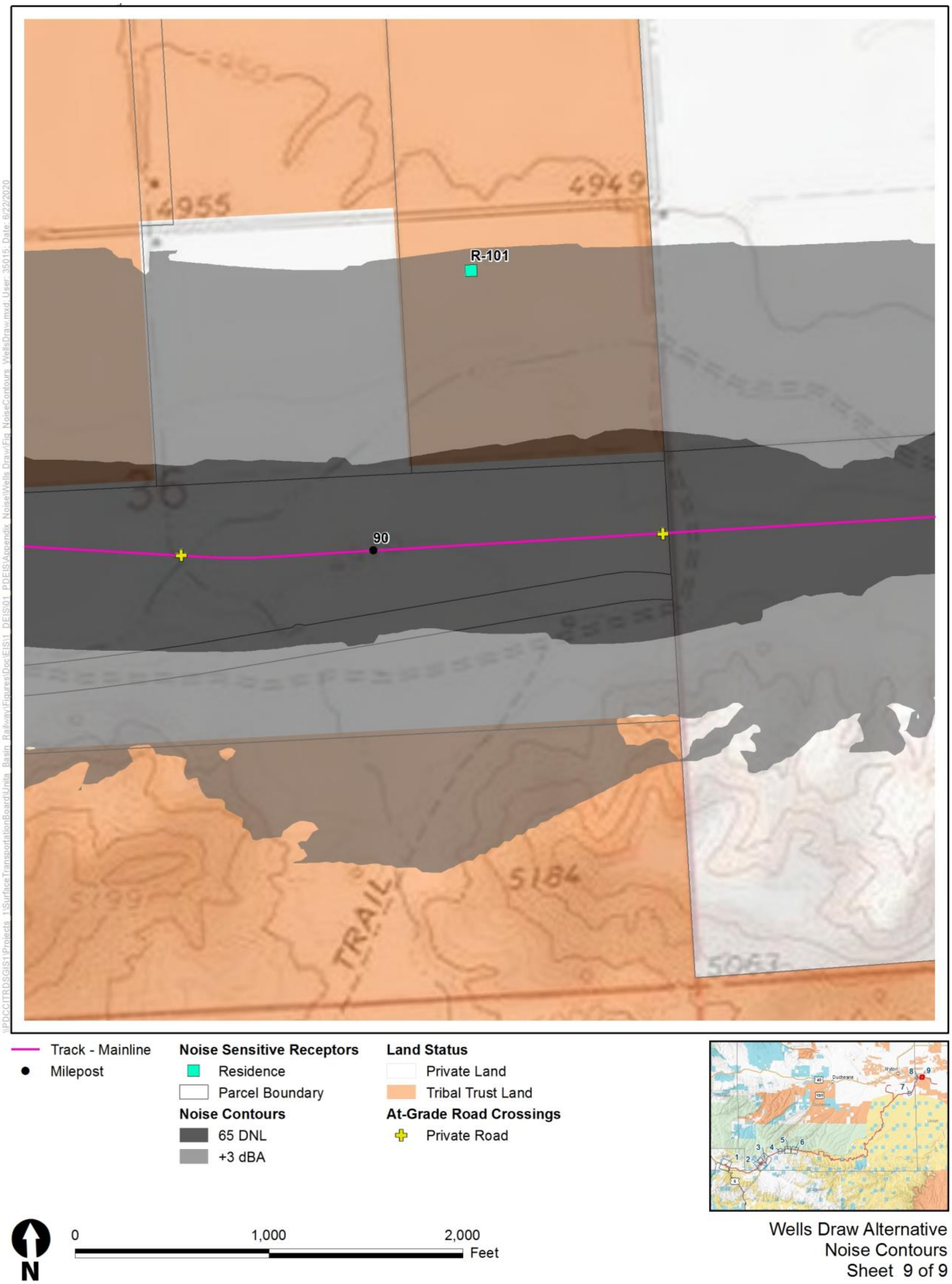


Figure L-6. Whitmore Park Alternative Noise Contours, Sheet Index

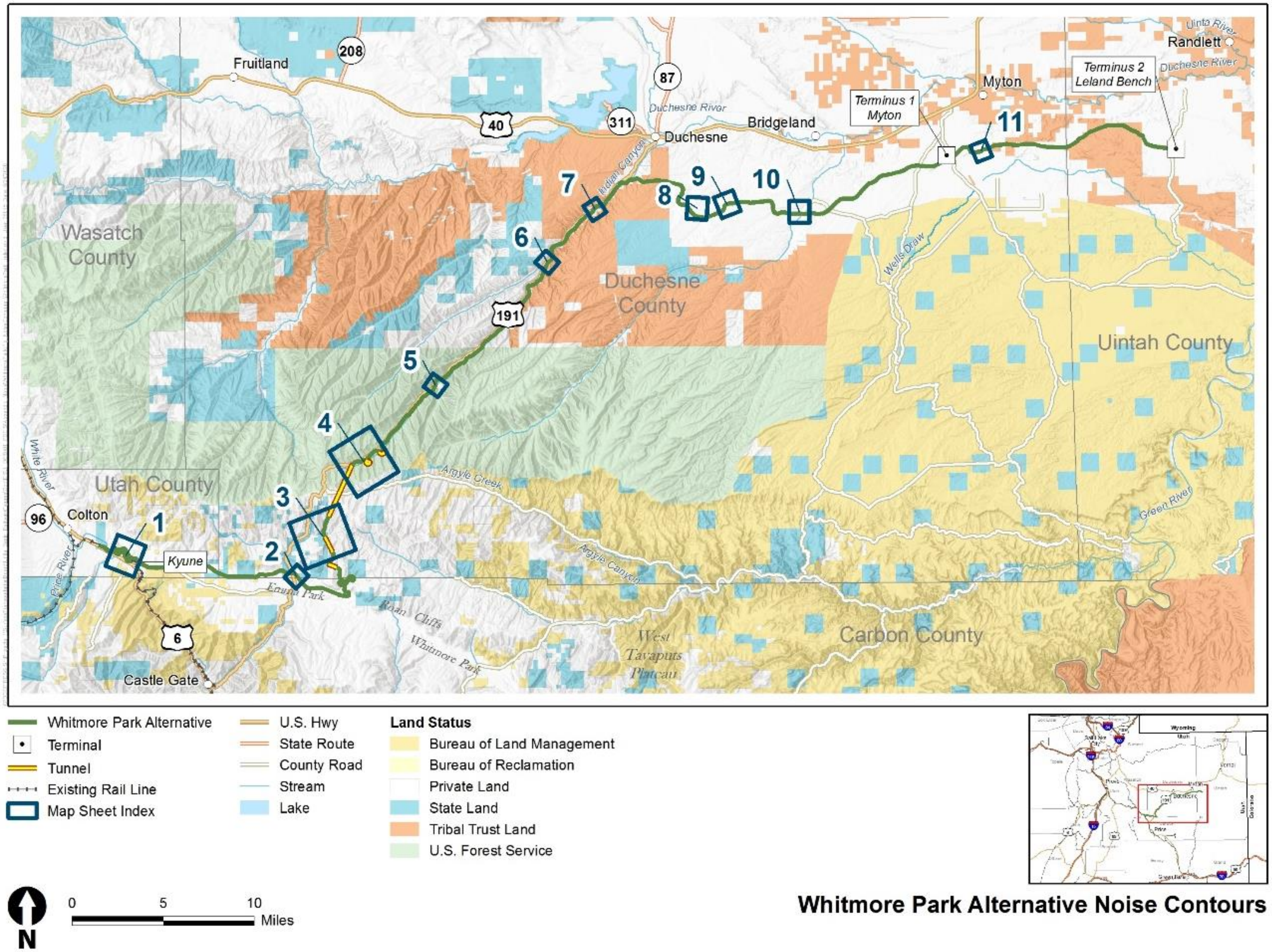


Figure L-7. Whitmore Park Alternative Noise Contours, Sheet 1 of 11

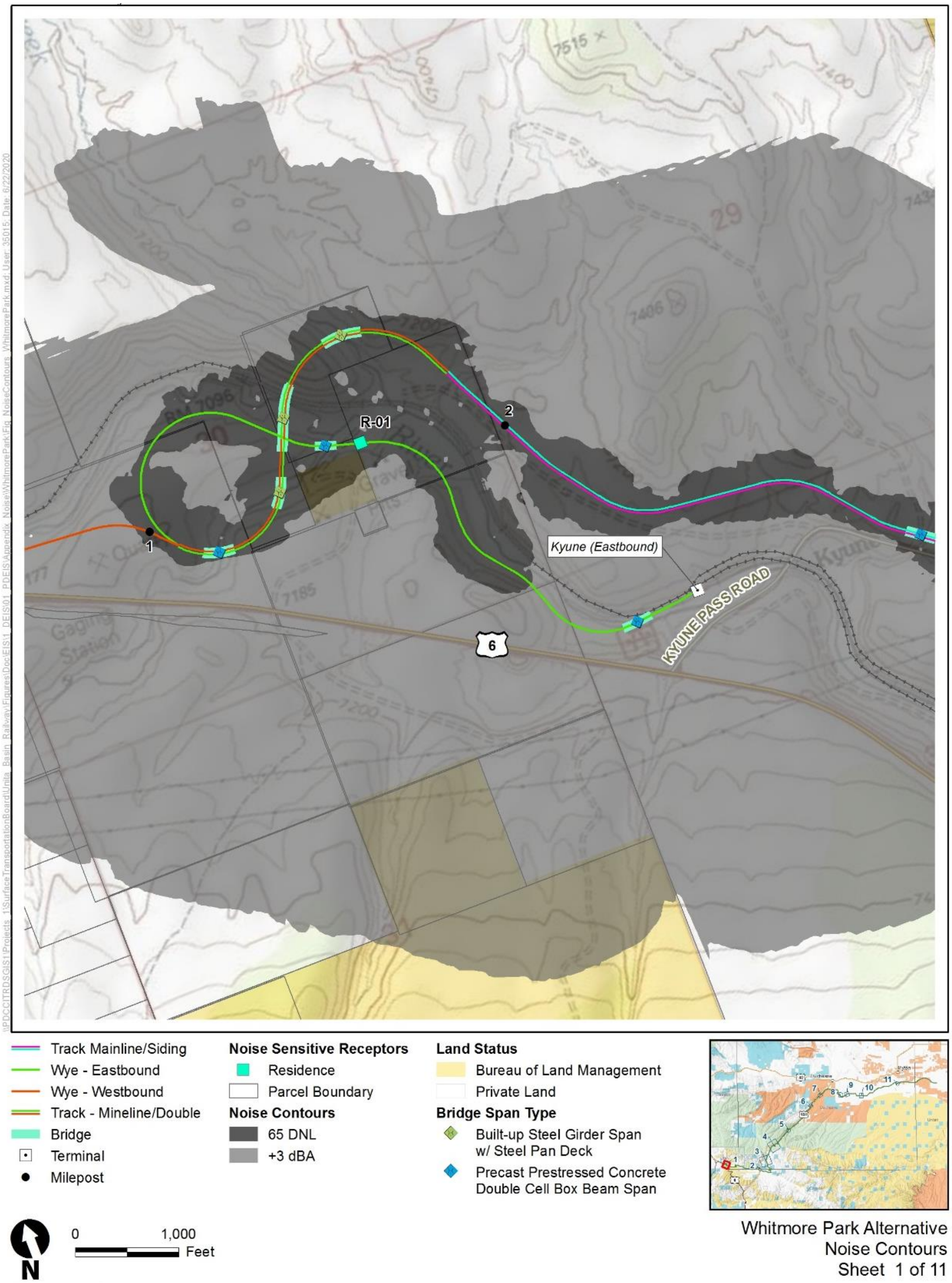


Figure L-8. Whitmore Park Alternative Noise Contours, Sheet 2 of 11

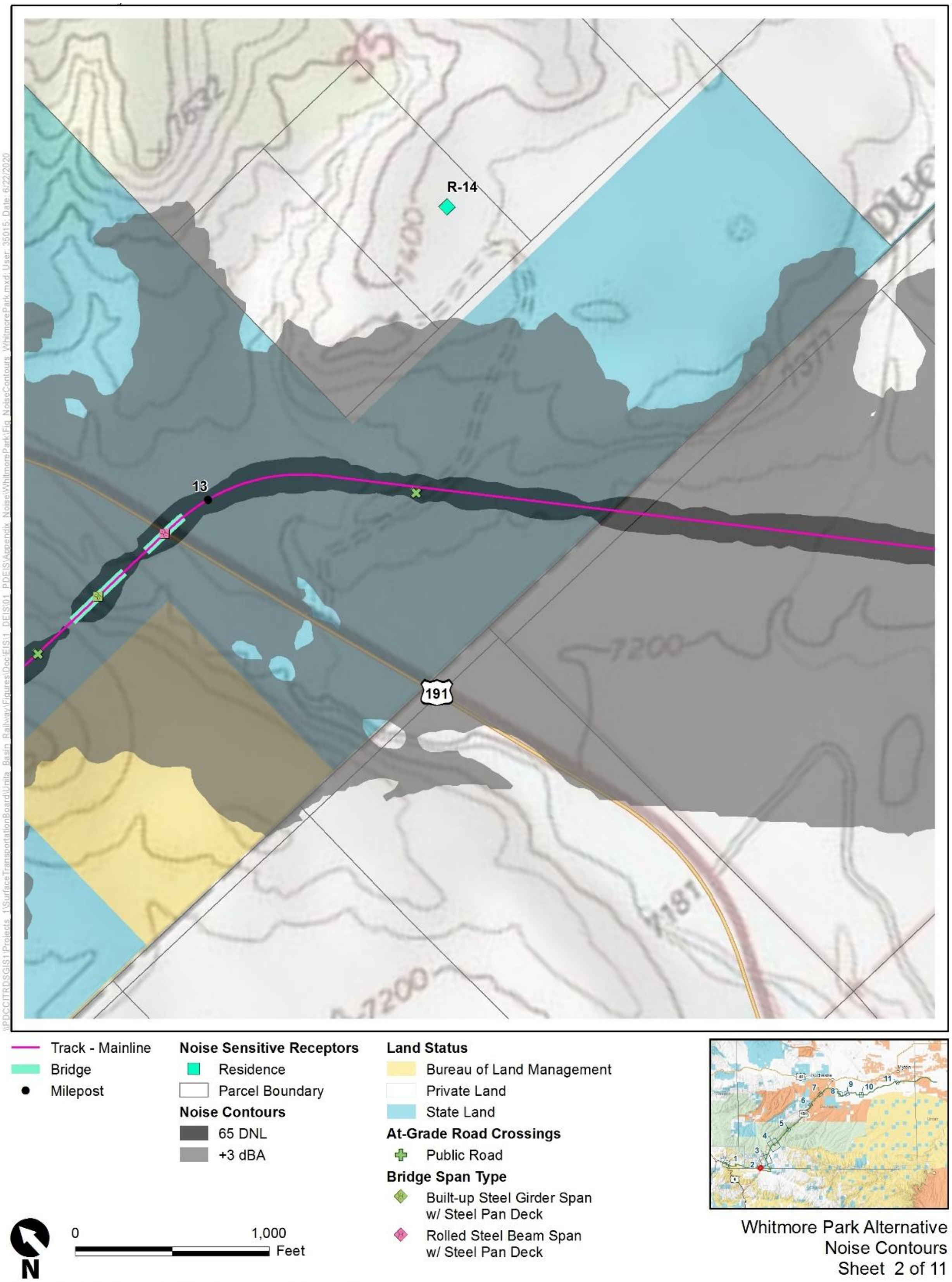


Figure L-9. Whitmore Park Alternative Noise Contours, Sheet 3 of 11

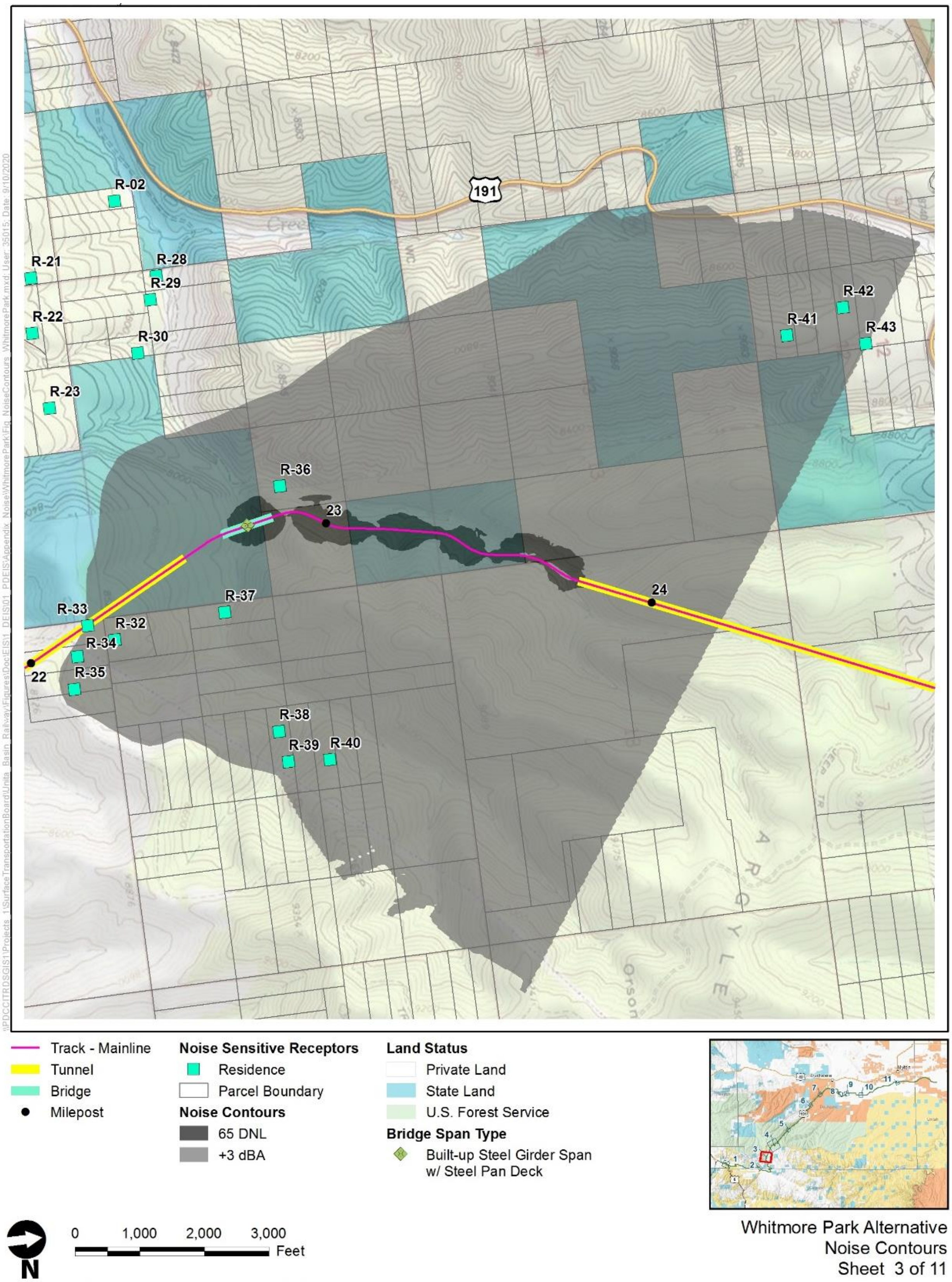


Figure L-10. Whitmore Park Alternative Noise Contours, Sheet 4 of 11

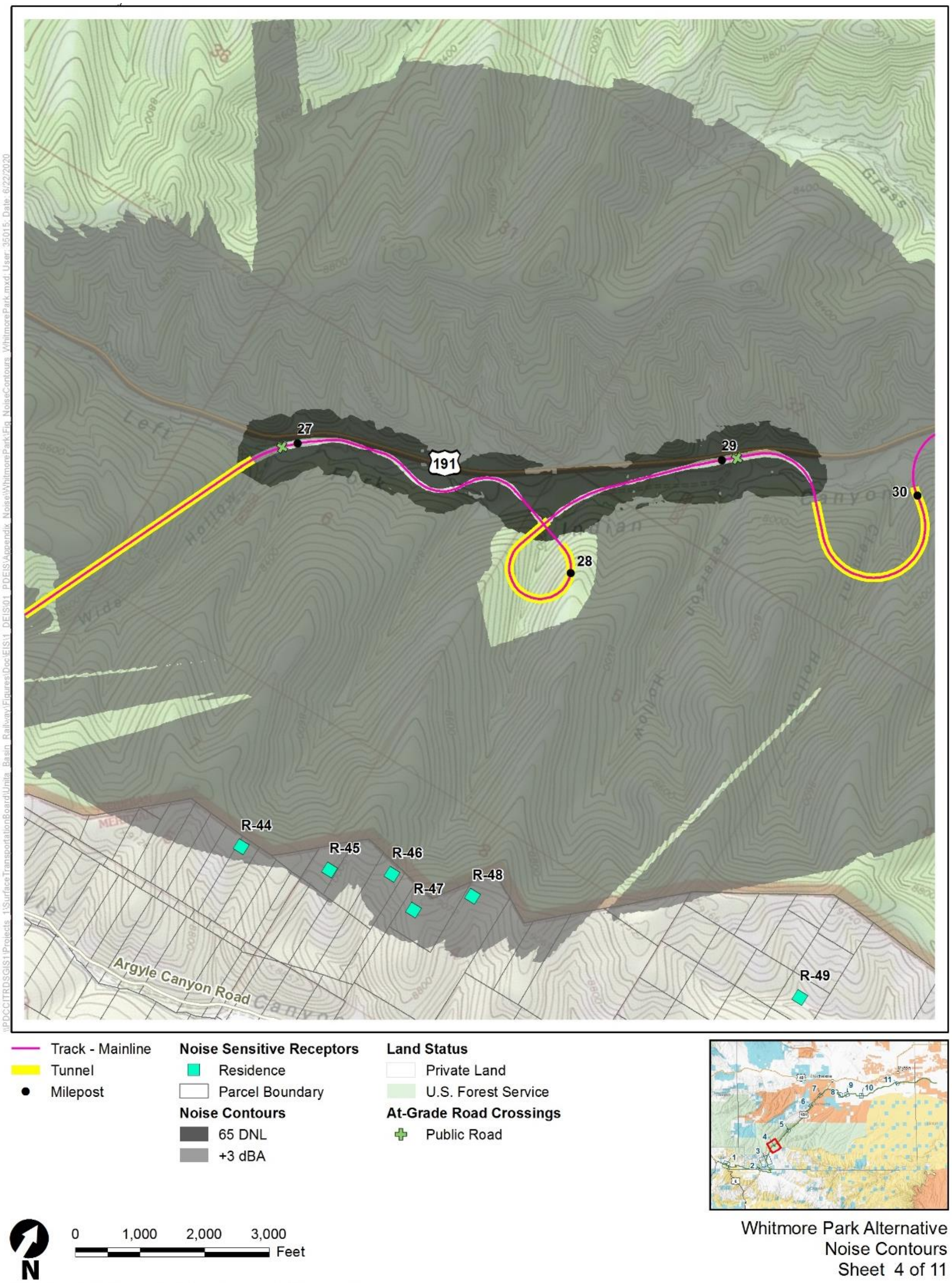


Figure L-11. Whitmore Park Alternative Noise Contours, Sheet 5 of 11

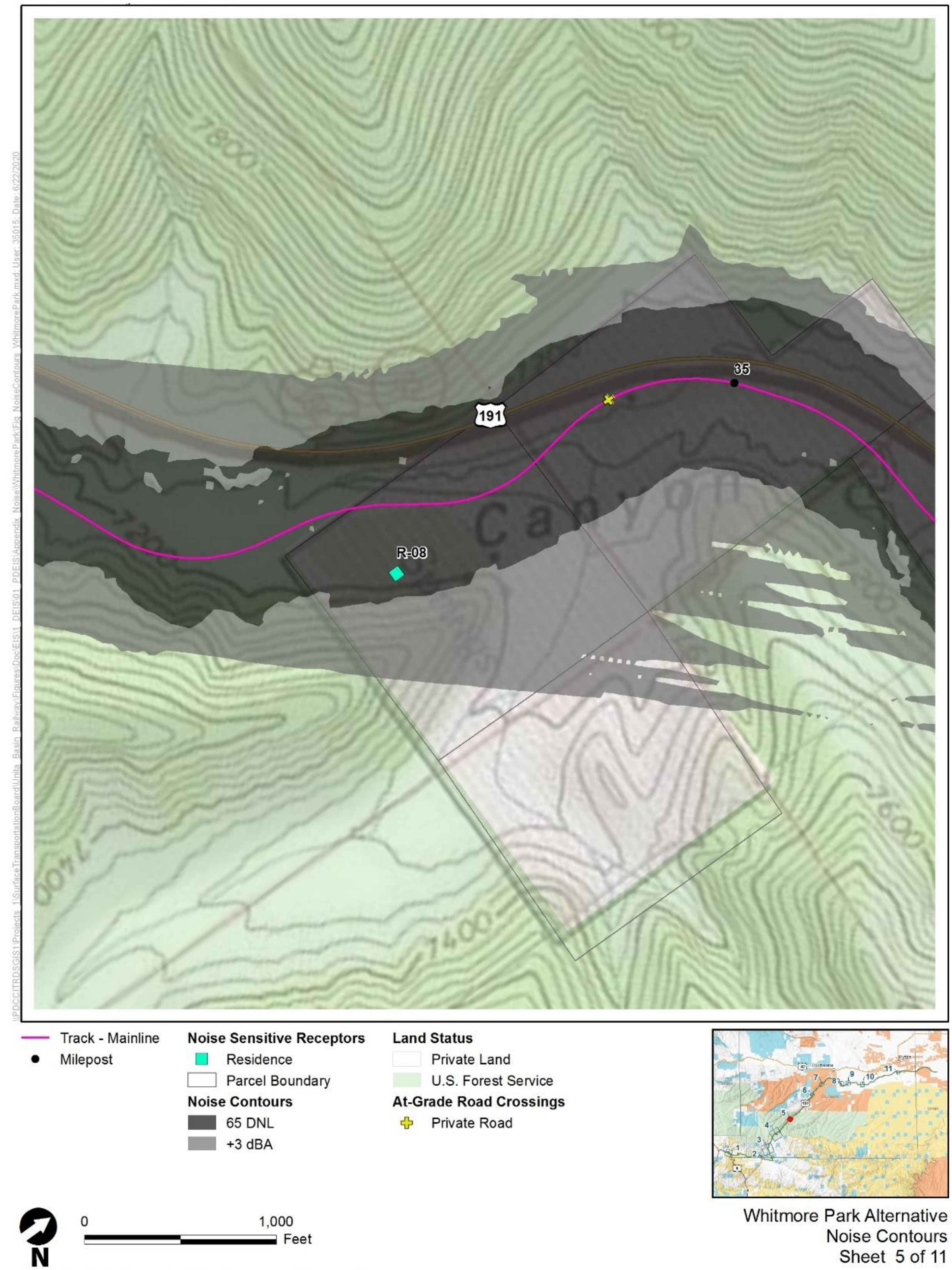


Figure L-12. Whitmore Park Alternative Noise Contours, Sheet 6 of 11

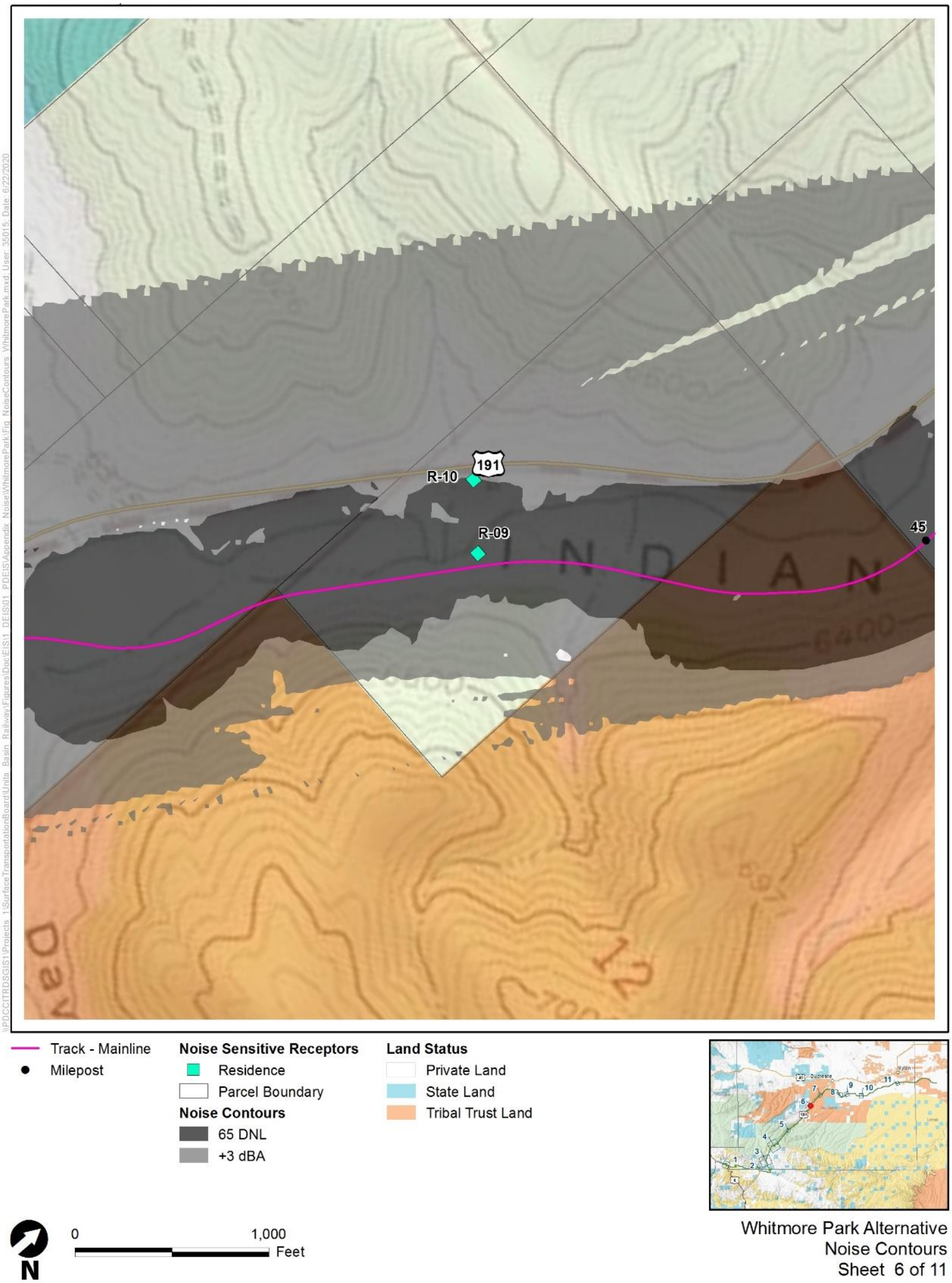


Figure L-13. Whitmore Park Alternative Noise Contours, Sheet 7 of 11

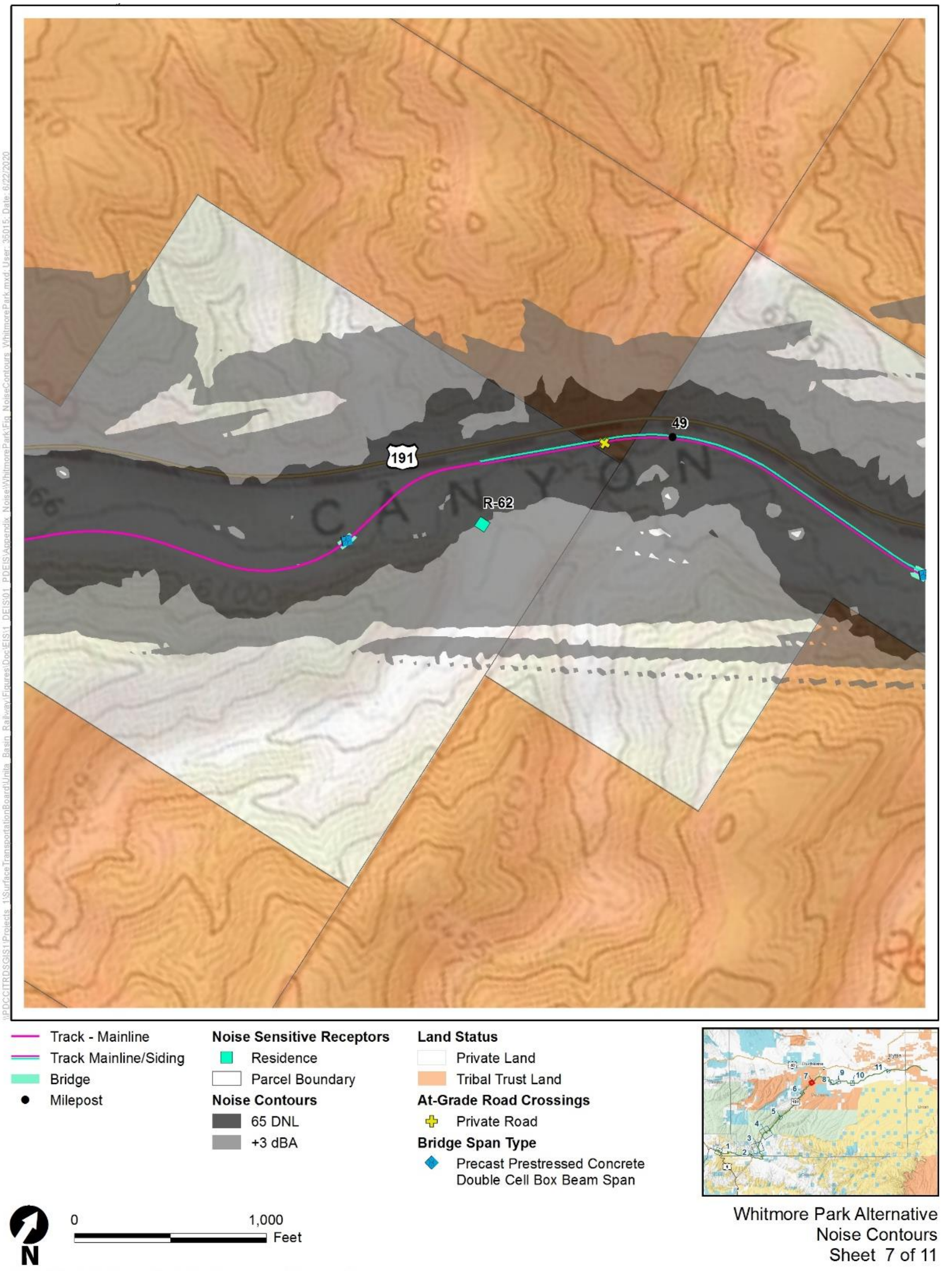


Figure L-14. Whitmore Park Alternative Noise Contours, Sheet 8 of 11

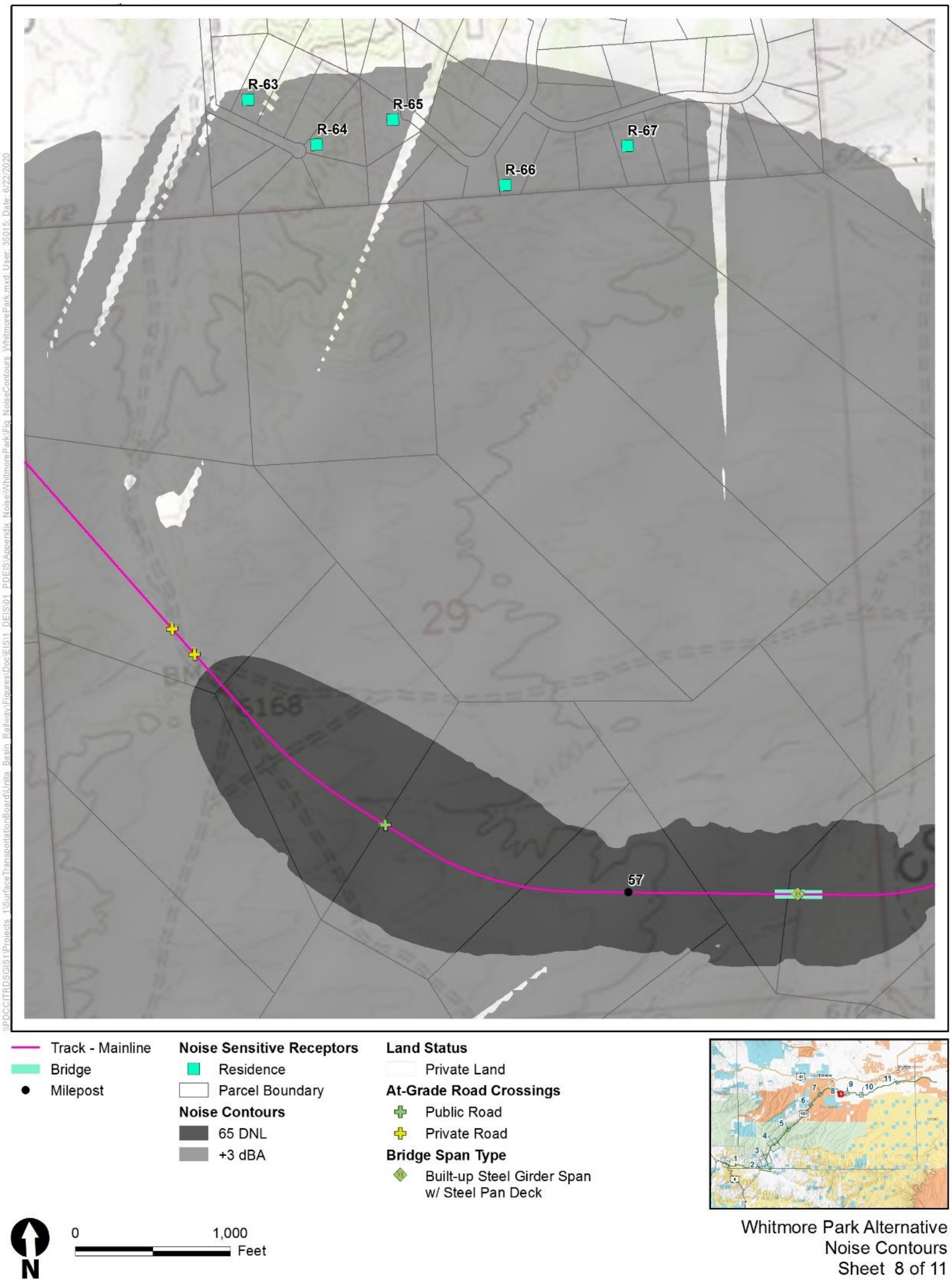


Figure L-15. Whitmore Park Alternative Noise Contours, Sheet 9 of 11

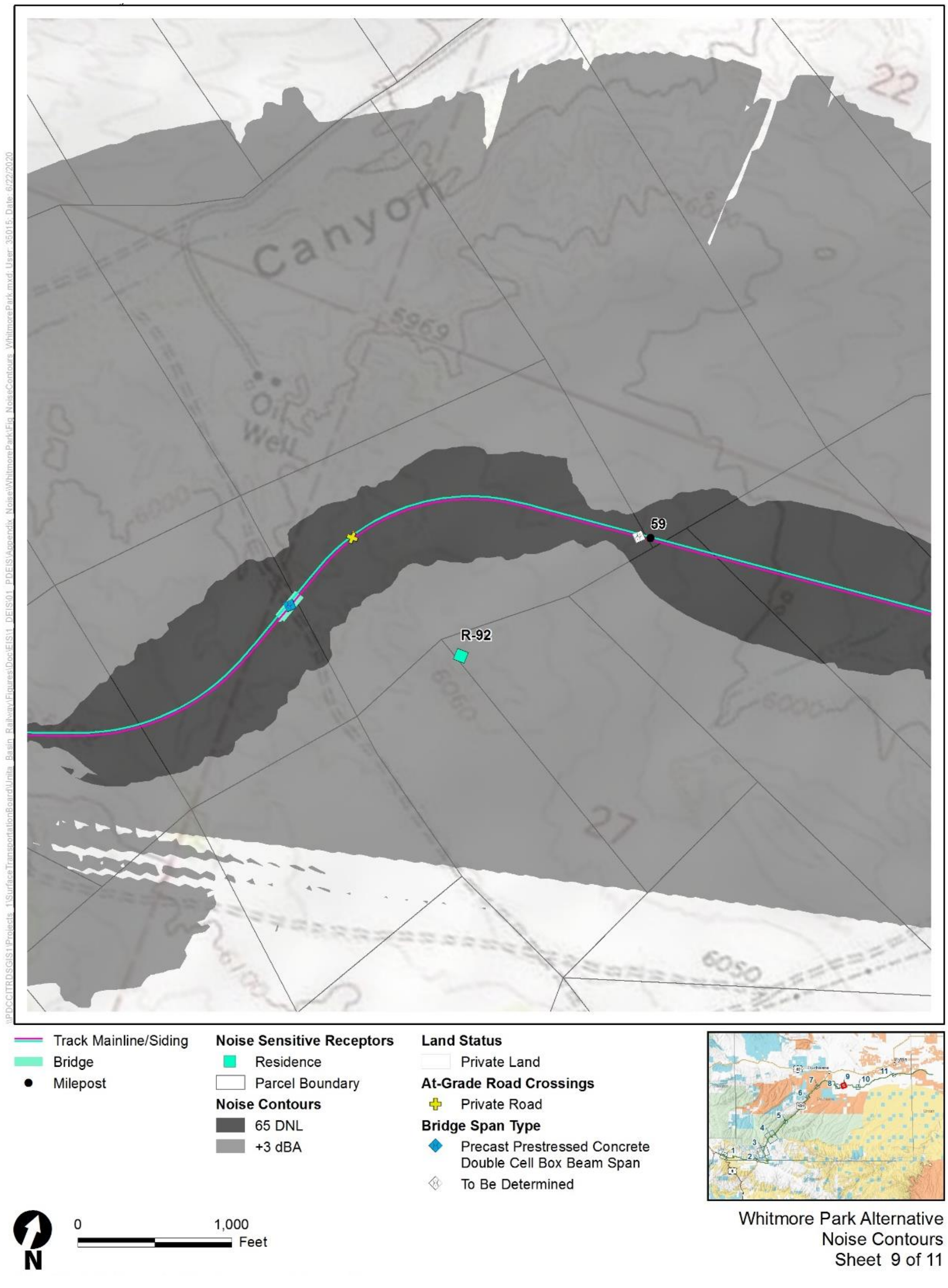


Figure L-16. Whitmore Park Alternative Noise Contours, Sheet 10 of 11

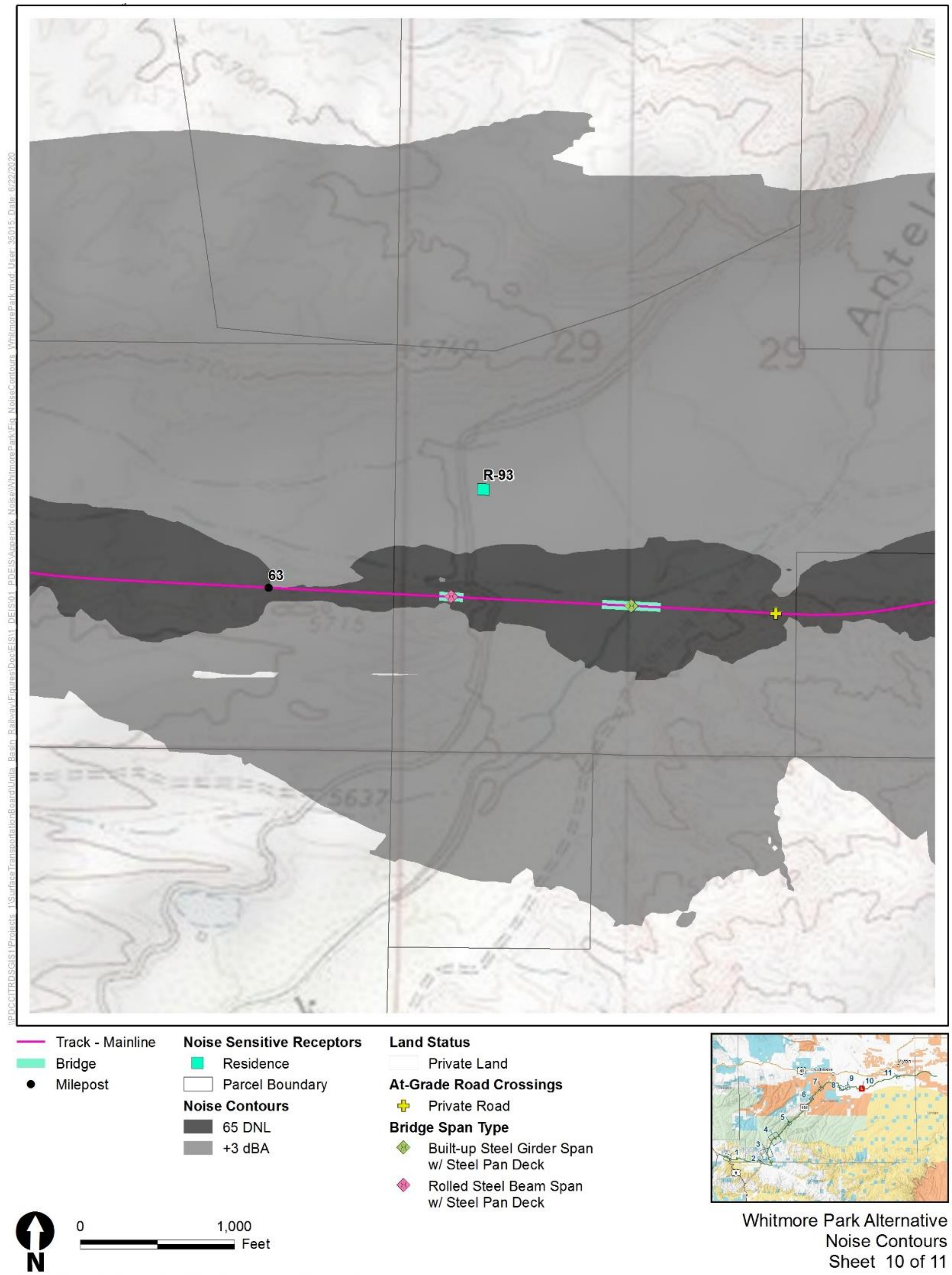
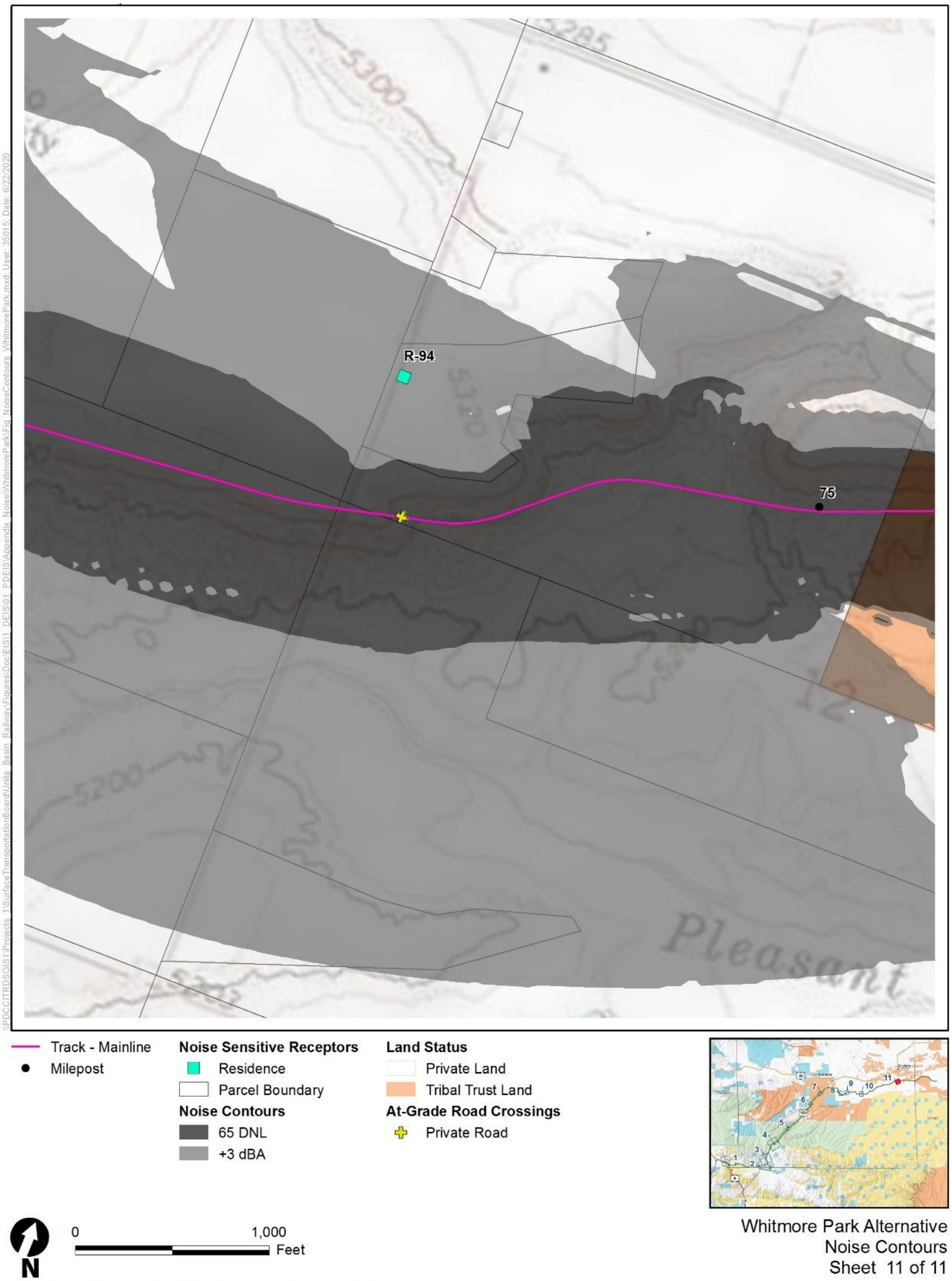


Figure L-17. Whitmore Park Alternative Noise Contours, Sheet 11 of 11



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Glossary

Ambient noise	The sum of all noise (from human and naturally occurring sources) at a specific location over a specific time is called ambient noise.
Day-night average sound level	The energy average of A-weighted decibel sound levels over 24 hours, which includes a 10-decibel adjustment factor for noise between 10 p.m. and 7 a.m. to account for the greater sensitivity of most people to noise during the night. The effect of nighttime adjustment is that 1 nighttime event, such as a train passing by between 10 p.m. and 7 a.m., is equivalent to 10 similar events during the daytime.
Decibel (dB)	A standard unit for measuring sound pressure levels based on a reference sound pressure of 0.0002 dyne per square centimeter. This is nominally the lowest sound pressure that people can hear.
Decibel, A-weighted (dBA)	A measure of noise level used to compare noise from various sources. A-weighting approximates the frequency response of the human ear.
Hertz (Hz)	A unit of frequency equal to one cycle per second.

Peak particle velocity (PPV)	The maximum instantaneous positive or negative peak of the vibration signal, measured as a distance per unit time (such as millimeters or inches per second). This measurement has been used historically to evaluate shock-wave type vibrations from actions like blasting, pile driving, and mining activities, and their relationship to building damage.
Root-mean-square vibration velocity (VdB)	An average or smoothed vibration amplitude, commonly measured over 1-second intervals. It is expressed on a log scale in decibels (VdB) referenced to 0.000001 inch per second and is not to be confused with noise decibels.