Figure 105: Bridge BRI-2010

Figure 106: Tunnel TUN-2008

601. Many of the road users will be transport vehicles and people moving between urban centers such as Kutaisi and Tbilisi. The impact on them will be short term and limited to the travel time only. Besides, for some of the passengers the landscape may be not familiar, so for them the change will not be crucial. The main impacts will be to the local villagers and tourists, although this portion of the road is not specifically known for its tourist industry.

Management & Mitigation Measures

602. Tree re-planting, as indicated under **Item G.6.1 – Flora**, will go some way to restoring the natural landscape of the area. However, this will not alleviate all of the visual impacts

associated with the elevated interchanges and bridges. Nonetheless, the following mitigation measures are required.

(i) Undertake landscaping after the completion of the activities to match in with surrounding landscape; •and
(ii) Reinstate vegetation according to plans.

Residual Impact Significance

Construction Phase – ***MINOR***

Operational Phase – ***LOW/MEDIUM***

Cut slopes, embankments, concrete bridges and tunnels will have an impact on the landscape within the valley throughout the Project lifecycle. The mitigation measures outlined above may go someway to enhancing the aesthetic value of the Project especially as vegetation grows back around construction zones, and in all likelihood any negative opinion of the new road in terms of visual impact will decrease over time as people get used to the altered landscape.

G.8.7 Noise & Vibration

Potential Construction Vibration Impacts

603. Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position, and can be described in terms either of displacement, velocity or acceleration. Because human sensitivity to vibration typically corresponds best to the amplitude of vibration velocity within the low frequency range of most concern (roughly 5- 100 Hertz), vibration velocity is the preferred measure for evaluating ground-borne vibration from transit projects.

604. Vibration from the construction activities is a cause concern to the community. The effects of vibration varies and depends on the magnitude of the vibration source, the particular ground conditions between the source and receiver, presence of rocks or other large structures in the area. The intensity, duration, frequency and number of occurrences of a vibration all play an important role in both the annoyance levels caused and the strains induced in structures.

605. The effects of vibration includes annoyance, sleep disturbance, and potential damage to structures. The Georgian Standards for vibration are provided in Table 21.

606. The proposed criteria for damage to buildings are shown in Table 80. These are derived from British Standard BS 6472 and are German Standards DIN 4150-3:1999.

Table 80: Criteria for Structural Damage Due to Vibration.

No damage likely	PPV <5mm/s
Cosmetic damage risk	PPV 5 to 15 mm/s
Structural damage risk	PPV > 15 mm/s

607. The following section discusses the issue of vibration under four headings:

(i) General construction
(ii) Tunnel excavation
(iii) Bridge piling
(iv) Trenching.

Table 82: Location and characteristics of tunnels

Tunnel		Carr.	LENGTH	CHAINAGES				Notes	Lithology	Excavation
				START	START UNDERGROUND	END UNDERGROUND	END			
TUN	2001	AT	110.40	0+800,0	0+829,0	0+881,6	0+900,4		Gabbro (higher strength)	Blasting
		TA	113.90	0+793,0			0+906,9	existing		
TUN	2002	AT	186.40	1+129,3	1+135,8	1+309,3	1315.8		Gabbro (higher strength)	Blasting
		-								
TUN	2003	AT	126.30	1+756,7	1+771,4	1+870,9	1+882,9		Gabbro (higher strength)	Blasting
		TA	150.30	1+765,3			1+915,6	existing		
TUN	2004	AT	400.00	2+050			2+450		Gabbro (higher strength)	Blasting
		-								
TUN	2005	AT	311.20	2+837,4	2+854,0	3+133,2	3+148,5		Gabbro (higher strength)	Blasting
		TA	266.00	2+838,6	2+854,0	3+088,4	3+104,6			
TUN	2006	AT	227.40	3+610,5	3+617,0	3+823,4	3+837,9		Granite (lower strength)	Mech excavation
		TA	277.70	3+575,0	3+581,5	3+836,2	3+852,7			
TUN	2007	AT	520.00	4+080			4+600		Granite (lower strength)	Mech excavation
		TA	510.00	4+090			4+600			
TUN	2008	AT	274.90	5+509,5	5+526,0	5+784,4	5+768,9		Granite (lower strength)	Mech excavation
		TA	310.10	5+462,1	5+476,9	5+755,9	5+772,1			
TUN	2009	AT	1300.00	7+220			8+520		Granite (lower strength)	Mech excavation
		TA	1330.00	7+210			8+540			
TUN	2010	AT	710.00	10+320			11+030		Granite (lower strength)	Mech excavation
		TA	660.00	10+330			10+990			
TUN	2011	AT	670.00	11+160			11+830		Granite (lower strength)	Mech excavation
		TA	610.00	11+180			11+790			

612. Tunnel Blasting - In case of blasting, the below tables (**Table 83** and **Table 84***)* (Courtesy of TERROCK Consulting Engineers Blasting-Vibration Course) allow to calculate the vibration level (mm/s) in the soil in accordance to charge and distance.

613. These values do not take into consideration the attenuation effect of the topmost alterated soil but only the propagation in hard rock.

Table 83: Granite (10 mm/s)

VIBRATION LIMIT TABLE
FOR PPV = 10.00 mm/s

SITE LAW CONSTANT = 7927.00
SITE LAW EXPONENT = -1.97

DIST/m	CHARGE/kg
10	0.11
15	0.26
20	0.46
30	1.03
50	2.85
70	5.58
100	11.40
150	25.64
200	45.58
300	102.56
500	284.89
700	558.39
1000	1139.57
1500	2564.04
2000	4558.29
3000	10256.16
5000	28489.31
7000	55839.07

Table 84: Overburden (5 mm/s)

VIBRATION LIMIT TABLE
FOR PPV = 5.00 mm/s

SITE LAW CONSTANT = 2500.00
SITE LAW EXPONENT = -1.60

DIST/m	CHARGE/kg
10	0.04
15	0.10
20	0.17
30	0.38
50	1.06
70	2.07
100	4.23
150	9.52
200	16.92
300	38.07
500	105.74
700	207.24
1000	422.96
1500	951.63
2000	1691.79
3000	3806.54
5000	10573.71
7000	20724.48

*The overburden is the material covering the Granite.

614. All the numerous formula available in the scientific literature refer to the below general formula, with minor modifications:

$$PPV = k\left(\frac{R}{Q^n}\right)^{-b}$$

Where:

PPV = peak particle velocity (mm/s);
k = site constant
R = distance to the point of concern (m);
Q = maximum instantaneous charge weight;
b = rock properties constant;
n = constant that depends on the geometry of the explosive.

615. Recently Kumar et al (2016), have developed a new model which take into consideration many engineering properties of rock to develop a more accurate model to calculate the PPV.

616. The considered parameters are:

(i) unit weight,
(ii) uniaxial compressive strength (UCS)
(iii) and rock quality designation (RQD)

617. For its modernity and recognized higher accuracy, this model has been applied in the Report for the calculation of PPV:

$$PPV = \frac{f_c^{0.642}}{\gamma}\left(\frac{R}{Q^{1/2}}\right)^{-1.463}$$

Where:

PPV = peak particle velocity (mm/s);

f_c = UCS of rock

R = distance to the point of concern (m);

Q = maximum instantaneous charge weight (kg);

γ = unit weight (kN/m^3).

With f_c = 059476RQD+0.00893 RQD^2 for RQD ≤ 75
and f_c= -7.91562 RQD+0.12152 RQD^2 for RQD ≥75

618. RQD (Rock Quality Designation) parameters have been obtained by the engineering Report, whereas for the rock, a density of 2,3 g/cm^3 has been used according to the geomechanical tests.

619. The following parameters have been assumed:
(i) Tunnel section 90 m^2
(ii) Borehole depth: 5m
(iii) Rock blasted per step: 450 m^3
(iv) Powder factor :0,65 (kg/ $m^{3)}$
(v) Max. Istant. Charge: 292.

620. Due to the general type of rock associated to fractures, as seen in the geological sections referring to tunnels; a Powder Factor of 0,6-0,7 has been utilized in the calculations.

621. In accordance to the above formula *above*, the below table can be applied:

Table 85: PPV velocity at different distances from blasting point

Distance from blasting point (m)	Range of Estimated PPV mm/s
50	20-22
60	15-16
70	12-13,5
80	8-9
90	7-7,5
100	5-5,5
110	4

622. According to existing regulations values of 5 mm/s must be considered for building safety. In accordance to that a safe distance of about 100-110 m from blasting point has to

be considered for cosmetic damages and a distance of 60-65 metres for major/structural damages. Tailored blasting techniques optimizing charge load and delay and the presence of overburden, which plays an important role for attenuation, suggest that the distance could be reduced to 80-90 metres in case of 3-5 metres of overburden.

623. In addition, the shallow and poor foundations of the buildings do not allow a good soil-structure coupling with the effect of a further attenuation of the energy transmitted to the building.

624. Tunnelling by mechanical excavation - If tunnelling is made by hammering, (Figure 107) or other means of mechanical excavation, vibration levels could be referred to the ones considered for trenching and also according to the table for TBM (Tunnel Boring Machine) presented in the below table (Figure 108) using as reference the blue dotted line referring to a similar hard rock formation.

Figure 107: Scheme of main direction of propagation of vibrations for tunnelling activities

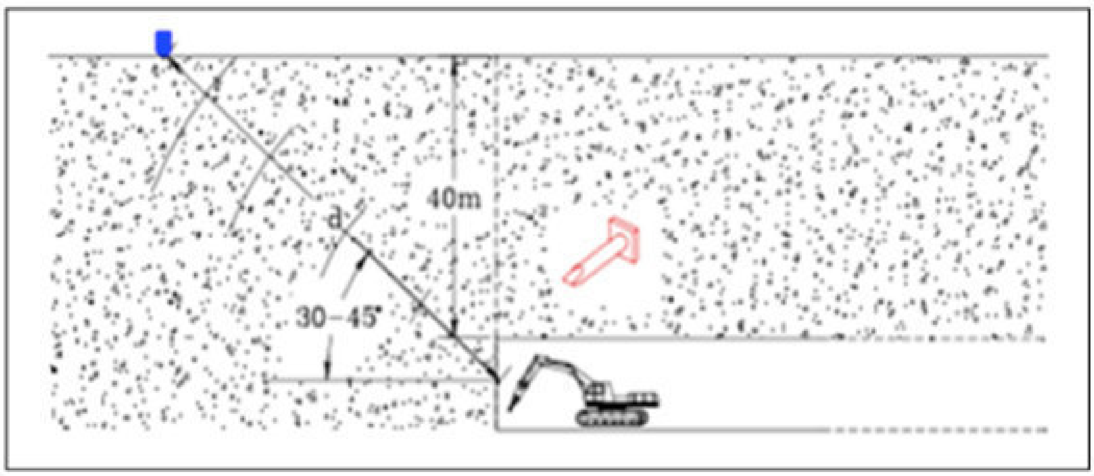
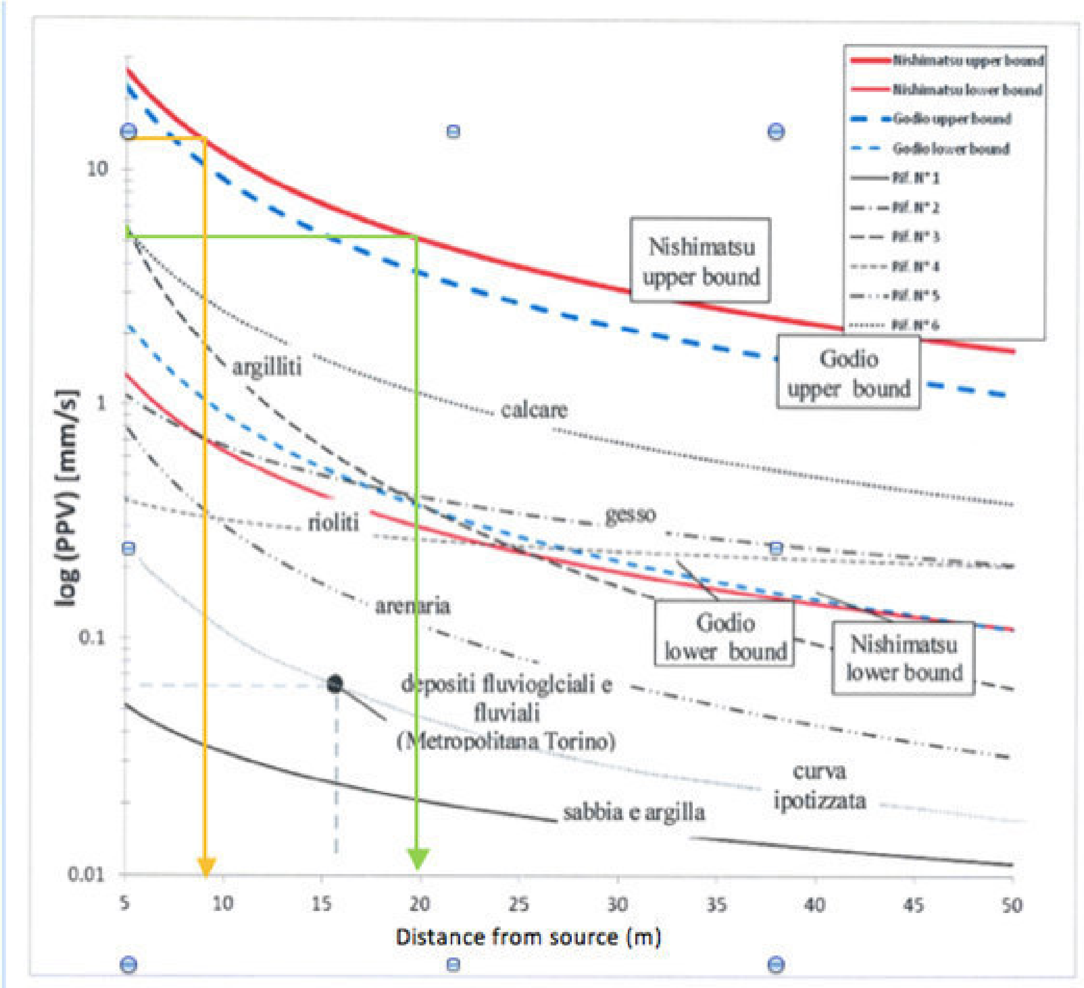


Figure 108: PPV for TBM in different types of rocks (from Italian Railway Co. RFI)



625. As shown by the green line, in accordance to the above table, a safe distance of 20-25 m for PPV value of 5 mm/s can be considered for tunnelling activities by mechanical excavation.

626. According to the yellow line, PPV value of 15 mm/s is reached at less than 10 m from the hammering point.

627. **Piling** - There are several bridges to be constructed, some foundations will directly be built on pits excavated in hard rock, other will be built on piles. Details are presented below.

Table 86: Location and Characteristics of Bridges.

BRIDGES AXIS TA						L. TOT	Lithology	Thickness of the soil or of the overburden	Foundation
BRI	2	1	01	TA	PSC	132.08	Granite (lower strength)	Low	Shallow
BRI	2	1	02	TA	PSC	66.00	Gabbro (higher strength)	Low/Medium	Shallow
BRI	2	1	03	TA	PSC	66.00	Gabbro (higher strength)	Very low	Shallow
BRI	2	1	04	TA	PSC	99.00	Gabbro (higher strength)	Low/Medium	Shallow

BRIDGES AXIS TA						**L. TOT**	**Lithology**	**Thickness of the soil or of the overburden**	**Foundation**
BRI	2	1	05	TA	PSC	99.00	Gabbro (higher strength)	Low	Shallow
BRI	2	1	06	TA	PSC	66.00	Gabbro (higher strength)	Low	Shallow
BRI	2	1	07	TA	PSC	131.65	Gabbro (higher strength)	Medium/High	Shallow/Piles
BRI	2	1	08	TA	PSC	99.00	Gabbro (higher strength)	Very low	Shallow
BRI	2	1	09	TA	PSC	372.00	Gabbro (higher strength)	Low/Medium	Shallow/Piles
BRI	2	1	10	TA	PSC	429.70	Gabbro (higher strength) Tbilisi Granite (lower strength) Argveta	Medium/High	Shallow/Piles
BRI	2	1	11	TA	PSC	132.00	Granite (lower strength)	Medium	Shallow/Piles
BRI	2	1	12	TA	PSC	231.80	Granite (lower strength)	Low/Medium	Shallow/Piles
BRI	2	1	13	TA	STEEL	1296.00	Granite (lower strength)	Medium/High	Piles
BRI	2	1	14	TA	STEEL	462.00	Granite (lower strength)	Medium	Shallow/Piles
BRI	2	1	15	TA	PSC	33.00	Granite (lower strength)	Medium	Shallow/Piles
BRI	2	1	16	TA	STEEL	144.00	Granite (lower strength)	Medium/High	Piles
BRI	2	1	17	TA	PSC	133.70	Granite (lower strength)	Low/Medium	Shallow/Piles
BRI	2	1	18	TA	PSC	165.00	Granite (lower strength)	Medium/High	Piles
BRIDGES AXIS AT						TOT			
BRI	2	1	1	AT	PSC	134.90	Granite (lower strength)	Very low	Shallow
BRI	2	1	2	AT	PSC	99.00	Gabbro (higher strength)	Low	Shallow
BRI	2	1	3	AT	PSC	66.00	Gabbro (higher strength)	Very low	Shallow
BRI	2	1	4	AT	PSC	99.00	Gabbro (higher strength)	Medium	Shallow/Piles
BRI	2	1	5	AT	PSC	99.00	Gabbro (higher strength)	Low	Shallow
BRI	2	1	6	AT	PSC	66.00	Gabbro (higher strength)	Low	Shallow
BRI	2	1	7	AT	PSC	131.55	Gabbro (higher strength)	Medium	Shallow
BRI	2	1	9	AT	PSC	286.35	Gabbro (higher strength)	Medium	Shallow/Piles
BRI	2	1	10	AT	PSC	425.35	Gabbro (higher strength) Tbilisi Granite (lower strength) Argveta	Medium	Piles
BRI	2	1	11	AT	PSC	134.35	Granite (lower strength)	Medium	Shallow/Piles
BRI	2	1	12	AT	PSC	313.45	Granite (lower strength)	Medium	Shallow/Piles
BRI	2	1	13	AT	STEEL	1362.00	Granite (lower strength)	Medium/High	Piles
BRI	2	1	14	AT	STEEL	450.00	Granite (lower strength)	Medium	Shallow/Piles
BRI	2	1	15	AT	PSC	33.00	Granite (lower strength)	Medium	Shallow/Piles

BRIDGES AXIS TA						L. TOT	Lithology	Thickness of the soil or of the overburden	Foundation
BRI	2	1	16	AT	STEEL	144.00	Granite (lower strength)	Medium/High	Piles
BRI	2	1	17	AT	PSC	132.00	Granite (lower strength)	Medium	Shallow/Piles
BRI	2	1	18	AT	PSC	165.00	Granite (lower strength)	Medium/High	Piles

628. Waves emanating from source such as a pile in the ground includes elastic waves in the form of compression waves, shear wave, and surface waves. Compression waves are considered to propagate from the area of the pile toe, expanding outwards over a spherical wave front with a geometric damping coefficient of 1.0. The vertical shear waves emanates from shaft friction and expanding around a conical surface. The waves are shown in Figure 109 and Figure 110.

629. Vibrations generated by friction pile driving can be characterized as a vertical shear wave with a conical wave- front. Therefore, the source can be classified as a point source generating body wave and the travel distance can be estimated as a horizontal distance from the source.

Figure 109: Propagation Ground Vibrations Generated by Piling

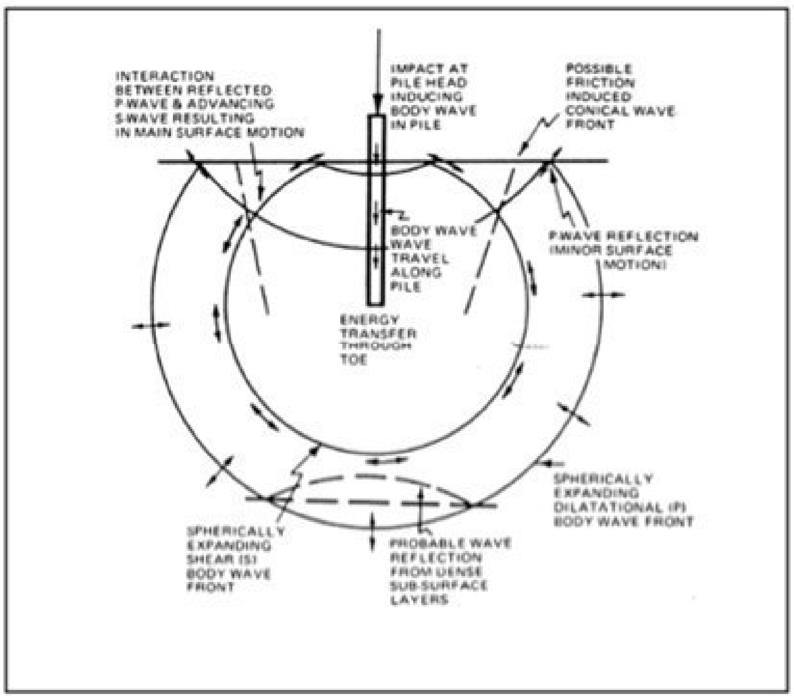


Figure 110: Propagation and Attenuation Characteristics of Various Ground Vibrations

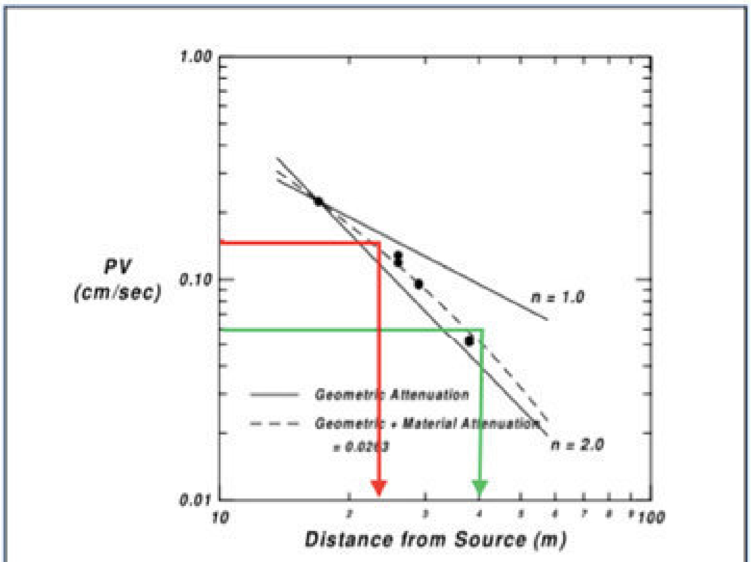


Fig. 12 Attenuation with distance of friction pile driving induced vibration.

630. According to soil characteristics and scientific literature, the PPV=5 Limit (green line) can be set at 40 m, and PPV = 15 mm/s at 20-25 m., those values are in accordance with other tables available in the scientific community.

631. **Surface blasting (trenching and demolition)** - In case of blasting activities of granitic rocks, the below table, (Courtesy of TERROCK Consult. Engineers. Blasting-Vibration Course, modified for editing purposes), provides a useful guide for the calculation of the effects of blasting of rock walls in terms of PPV, Distance and Charge. The safe area, below 5 mm/s, is contained in the green triangle.)

Figure 111: Vibration Estimation for Granite Quarries

Charge Weight per Delay / kg	Distance From Charge / m										
	0.5	1	2	5	10	20	50	100	200	500	1000
0.025	825	211	53.8	8.84	2.26	0.58	0.09	0.02	0.01	0.00	0.00
0.050	1633	417	106	17.5	4.47	1.14	0.19	0.05	0.01	0.00	0.00
0.075	2435	622	159	26.1	6.66	1.70	0.28	0.07	0.02	0.00	0.00
0.100	3233	825	211	34.6	8.84	2.26	0.37	0.09	0.02	0.00	0.00
0.150	4820	1230	314	51.6	13.2	3.37	0.55	0.14	0.04	0.01	0.00
0.250	7972	2035	519	85.4	21.8	5.57	0.92	0.23	0.06	0.01	0.00
0.500	****	4028	1028	169	43.2	11.0	1.81	0.46	0.12	0.02	0.00
0.750	****	6005	1533	252	64.3	16.4	2.70	0.69	0.18	0.03	0.01
1.000	****	7972	2035	335	85.4	21.8	3.59	0.92	0.23	0.04	0.01
1.500	****	****	3034	499	127	32.5	5.35	1.36	0.35	0.06	0.01
2.500	****	****	5018	825	211	53.8	8.84	2.26	0.58	0.09	0.02
5.000	****	****	9932	1633	417	106	17.5	4.47	1.14	0.19	0.05
7.500	****	****	****	2435	622	159	26.1	6.66	1.70	0.28	0.07
10.000	****	****	****	3233	825	211	34.6	8.84	2.26	0.37	0.09
15.000	****	****	****	4820	1230	314	51.6	13.2	3.37	0.55	0.14
25.000	****	****	****	7972	2035	519	85.4	21.8	5.57	0.92	0.23
50.000	****	****	****	****	4028	1028	169	43.2	11.0	1.81	0.46
75.000	****	****	****	****	6005	1533	252	64.3	16.4	2.70	0.69
100.000	****	****	****	****	7972	2035	335	85.4	21.8	3.59	0.92
150.000	****	****	****	****	****	3034	499	127	32.5	5.35	1.36
250.000	****	****	****	****	****	5018	825	211	53.8	8.84	2.26
500.000	****	****	****	****	****	9932	1633	417	106	17.5	4.47

site law exponent = -1.97 site law constant = 7972

632. Calculations have been also done using the EDUMINING Interactive software Blasting Safety - Peak Particle Velocity Thresholds which allow to calculate PPV or distances/level of damages by the insertion of several blasting parameters (indicated in the figures by the red dots).

633. According to the above analysis a conservative safety distance of 60 m should be considered for PPV = 5 mms and about 15 to 20 m for PPV= 15 mm/s.

634. Trenching by mechanical excavation - As seen in the discussion about the tunnelling by mechanical excavation, the effects of hammering are propagating with an angle of about 30-45° respect to the direction of the alignment of the hammer.

635. In this case the propagation of vibrations mainly occurs along the forward direction, with a minimal component of backward ground roll but a large part of energy is backscattered in form of noise.

636. When hammering is selected as demolition technique the rock is in general affected by unconformities of strata/layering which are used as mobilization planes.

637. For this reason there is a certain attenuation of the energy if compared with propagation in competent rock. If the energy of the hammer and the rate of energization are known there are also empiric formula to calculate the transmitted energy. In general these calculations always fits with the provided tables which constitute the base for the evaluation of energy propagation. Once more the presence of overburden and the type of foundations play a important role for the final effects on the buildings.

638. **Findings** - The modeling has analyzed the vibration induced by the excavation, tunneling and trenching activities, its propagation inside the hard rock formation and the attenuation provided by the cushion of alterated/weathered rock and arable/vegetal soil. In addition to that the type of foundations of the buildings, shallow and small, will determine an additional damping factor which is not calculated in the model.

639. Isolines of different colors per type of activity and means of excavation, have been drawn by calculation of the interference at the surface with radial surfaces representing the wave propagation (propagation of vibrations). The propagation for Tunnel Blasting can be represented by a cylinder (formed by the sequence of wave front) set along the tunnel axis to which represents shock waves during the advancement of the tunnel. Each radial plane inside the cylinder has a sequence of parallel (but not equidistant- due to the exponential attenuation) isolines representing different levels of PPV. For that we should imagine a horizontal cylinder having a radius of more than 100 m representing the distribution of PPV with the PPV =5 mm/s occurring at 100 m from the axe of the cylinder (the blasting point). The intersection of the surface morphology with the cylinder at 100m generates the isolines of PPV 5mm; whereas the PPV=15 mm/s are generated by a cylinder with radius of 60m.

640. The same could be represented for piling, but using a vertical cylinder, which represents the wave propagation, having a diameter of 40 m with the limit of 5 mms PPV located at 40 m from insertion point .Where applicable, the attenuation factor of the surface soil has been applied and in this case the isolines gets closer to the point of energization.

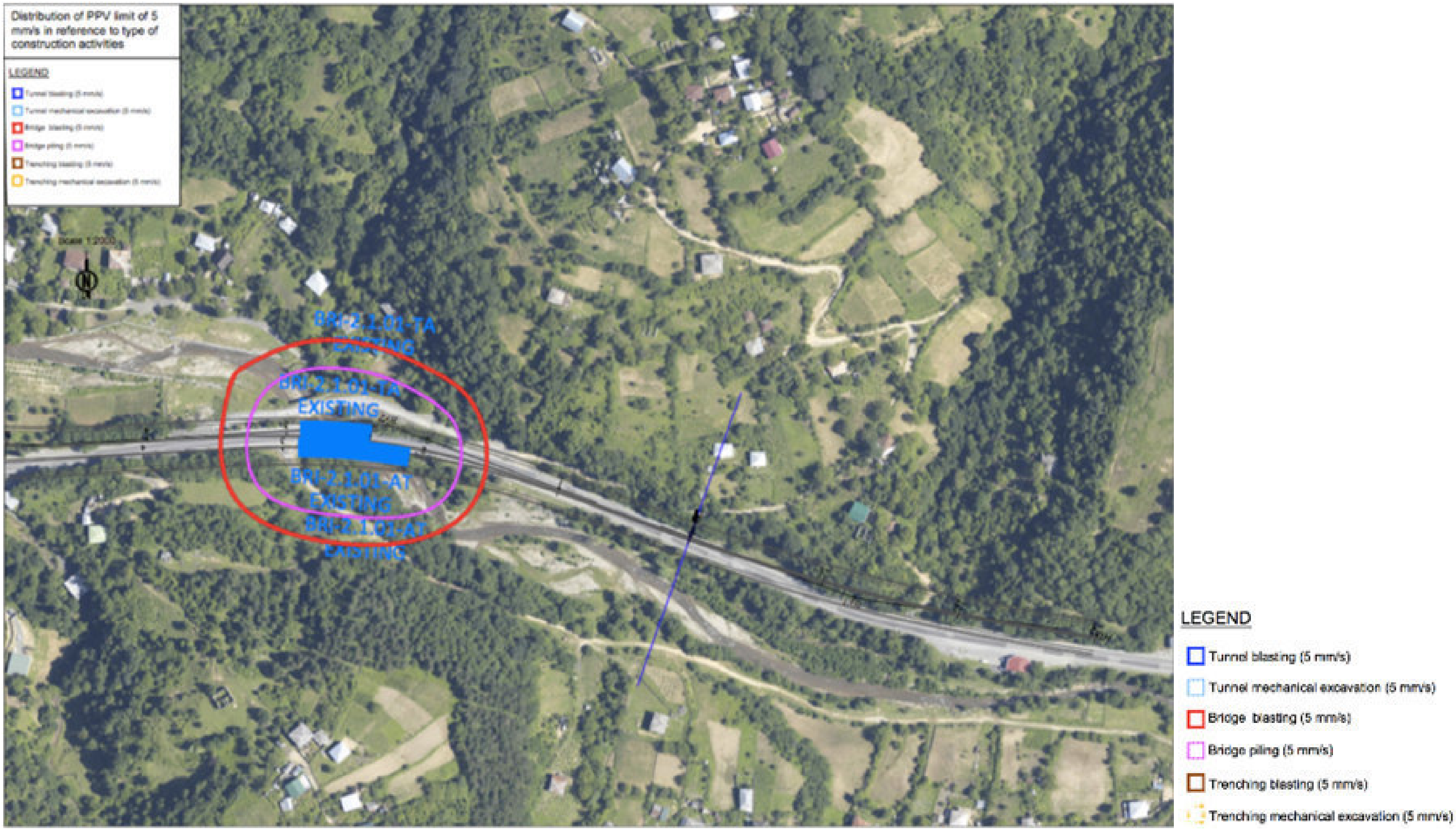


Figure 112: Distribution of PPV Limit of 5 mm/s

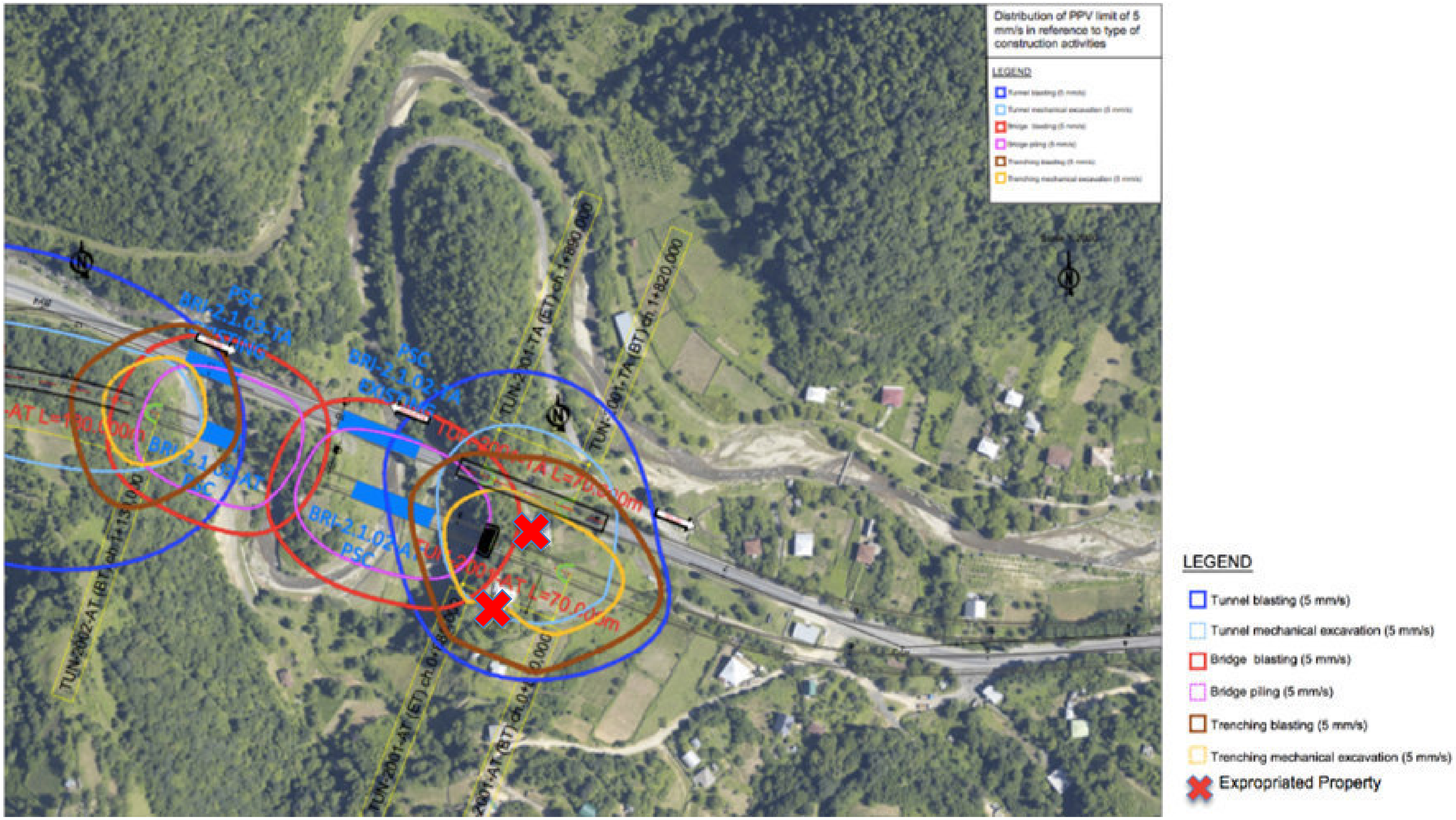


Figure 113: Distribution of PPV Limit of 5 mm/s

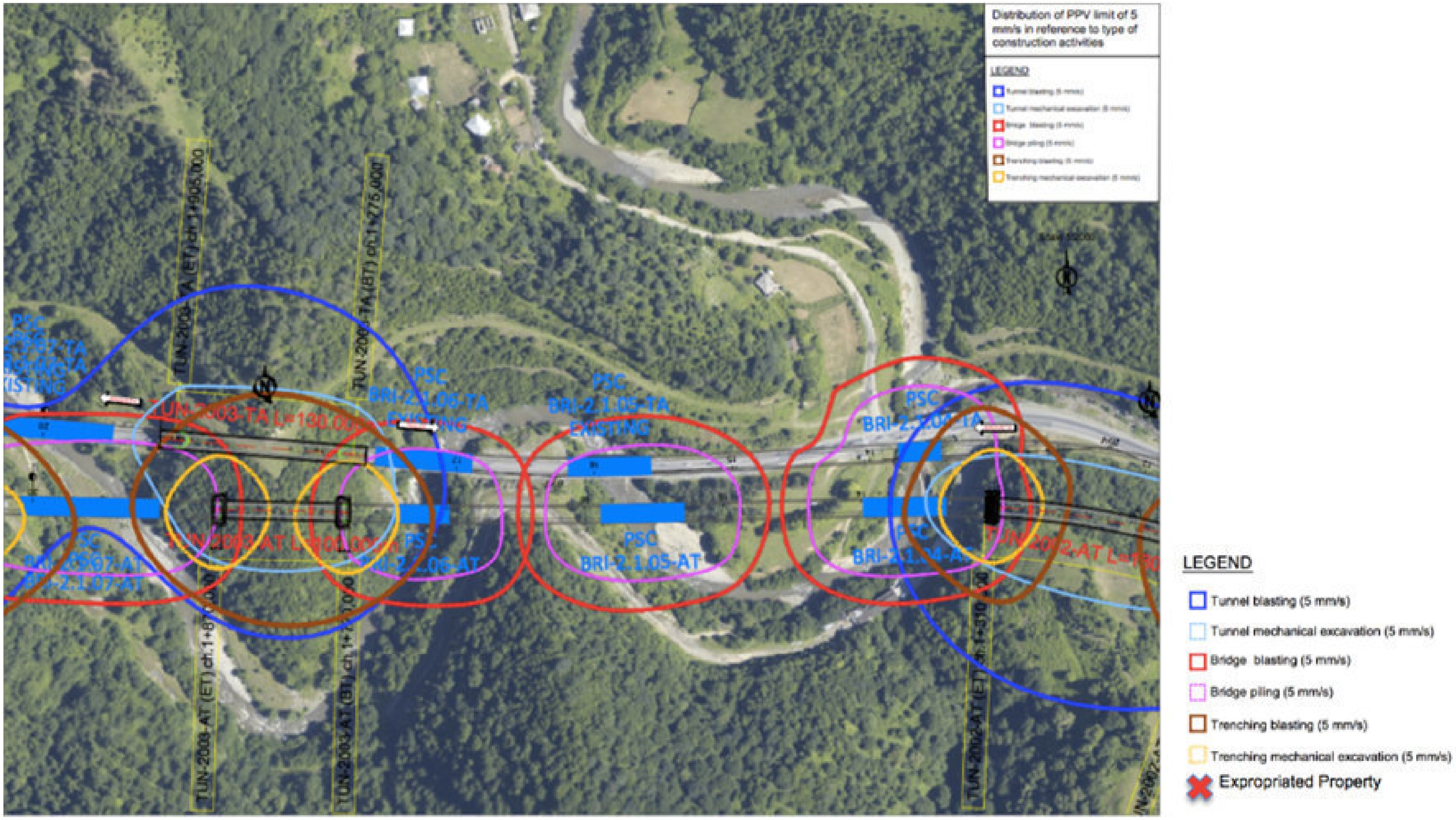


Figure 114: Distribution of PPV Limit of 5 mm/s

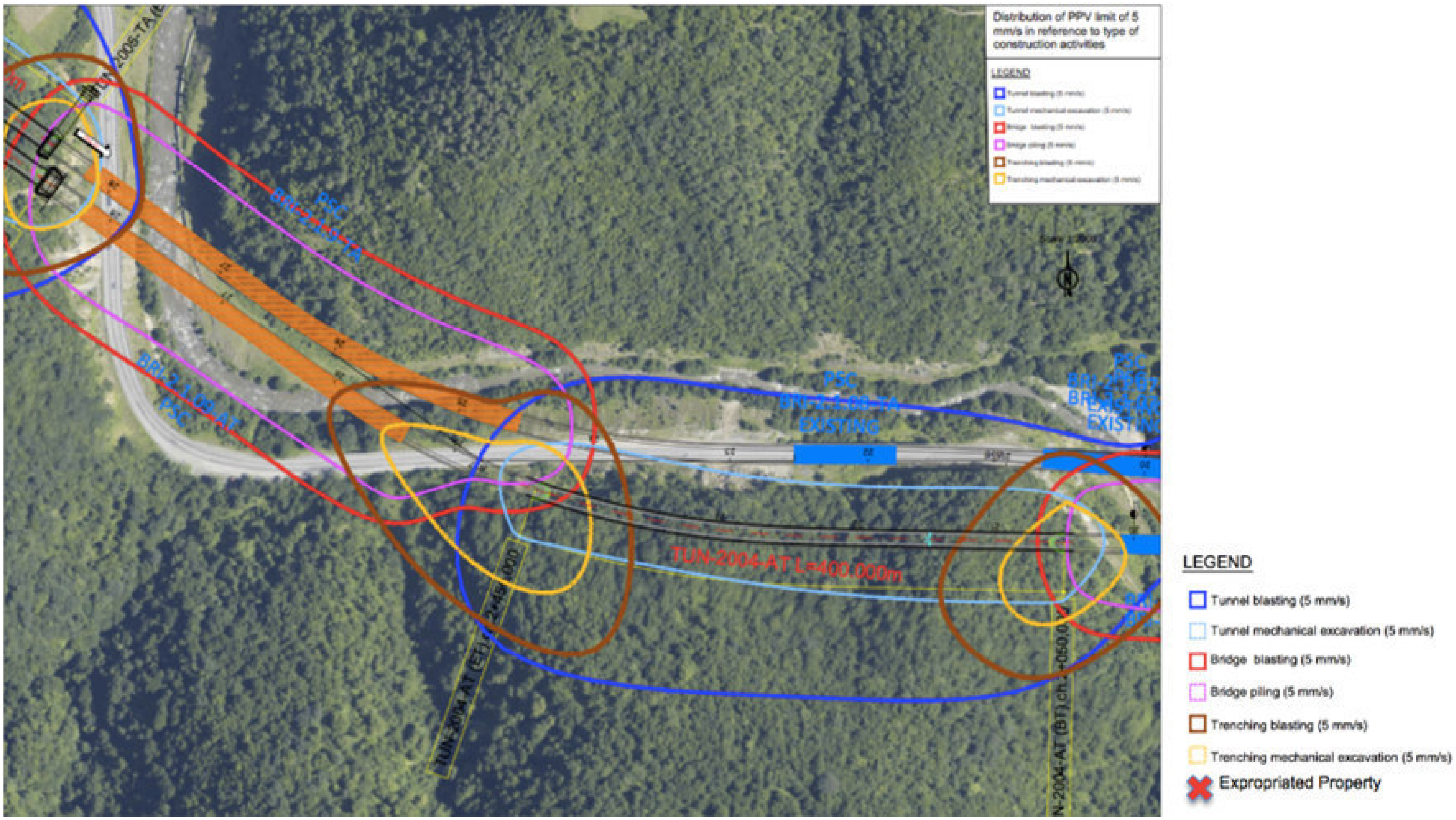


Figure 115: Distribution of PPV Limit of 5 mm/s

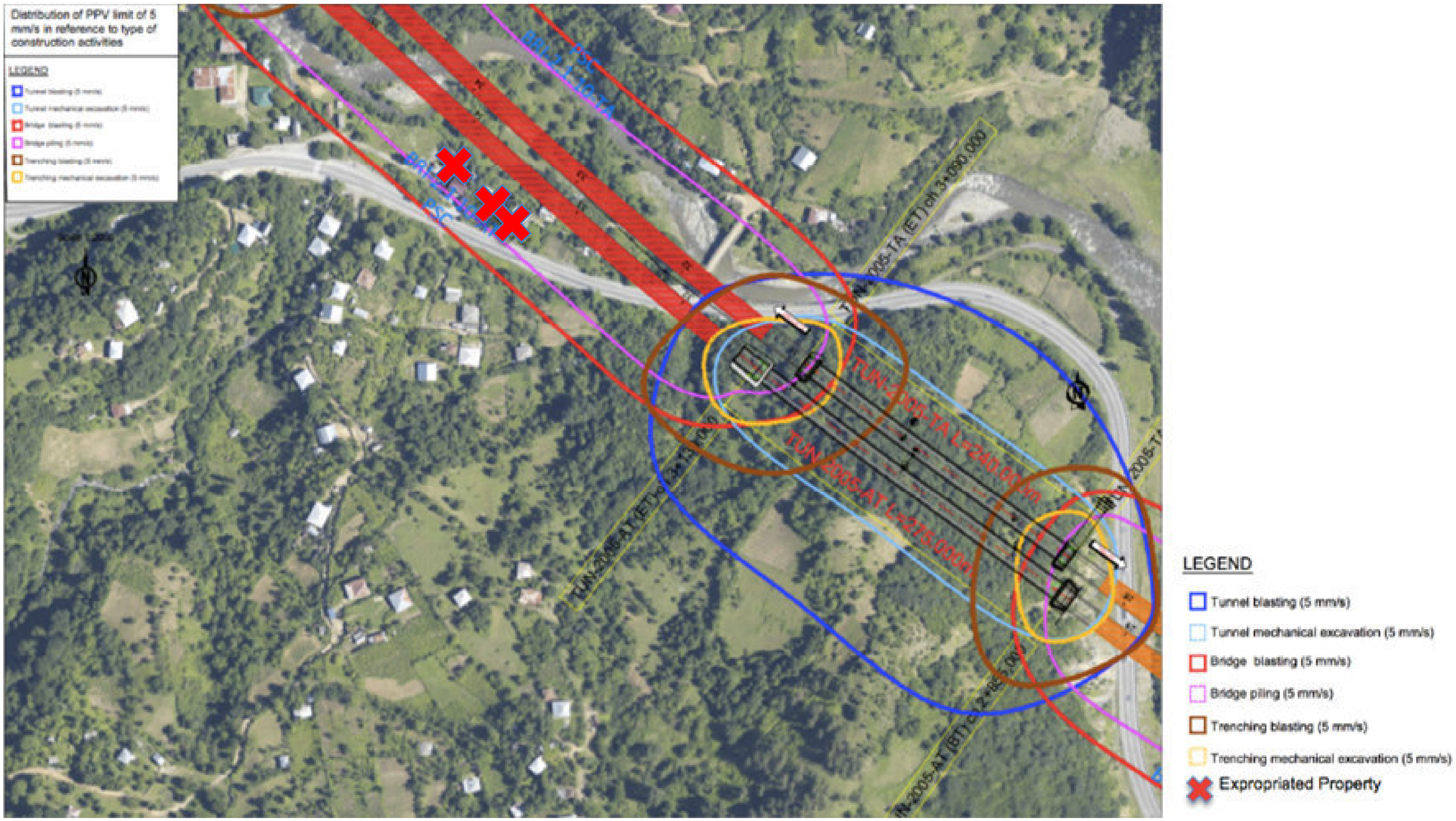


Figure 116: Distribution of PPV Limit of 5 mm/s

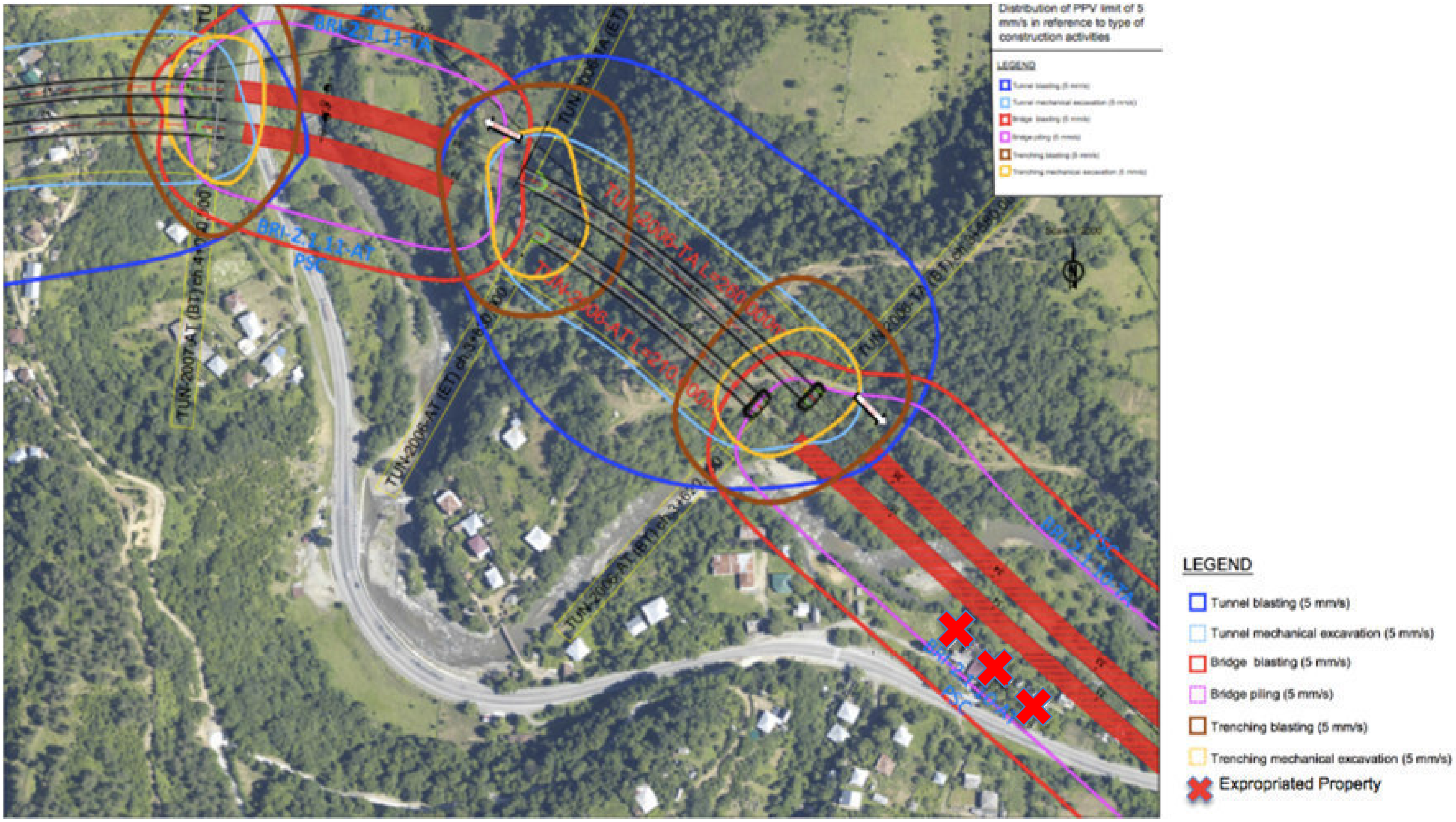


Figure 117: Distribution of PPV Limit of 5 mm/s

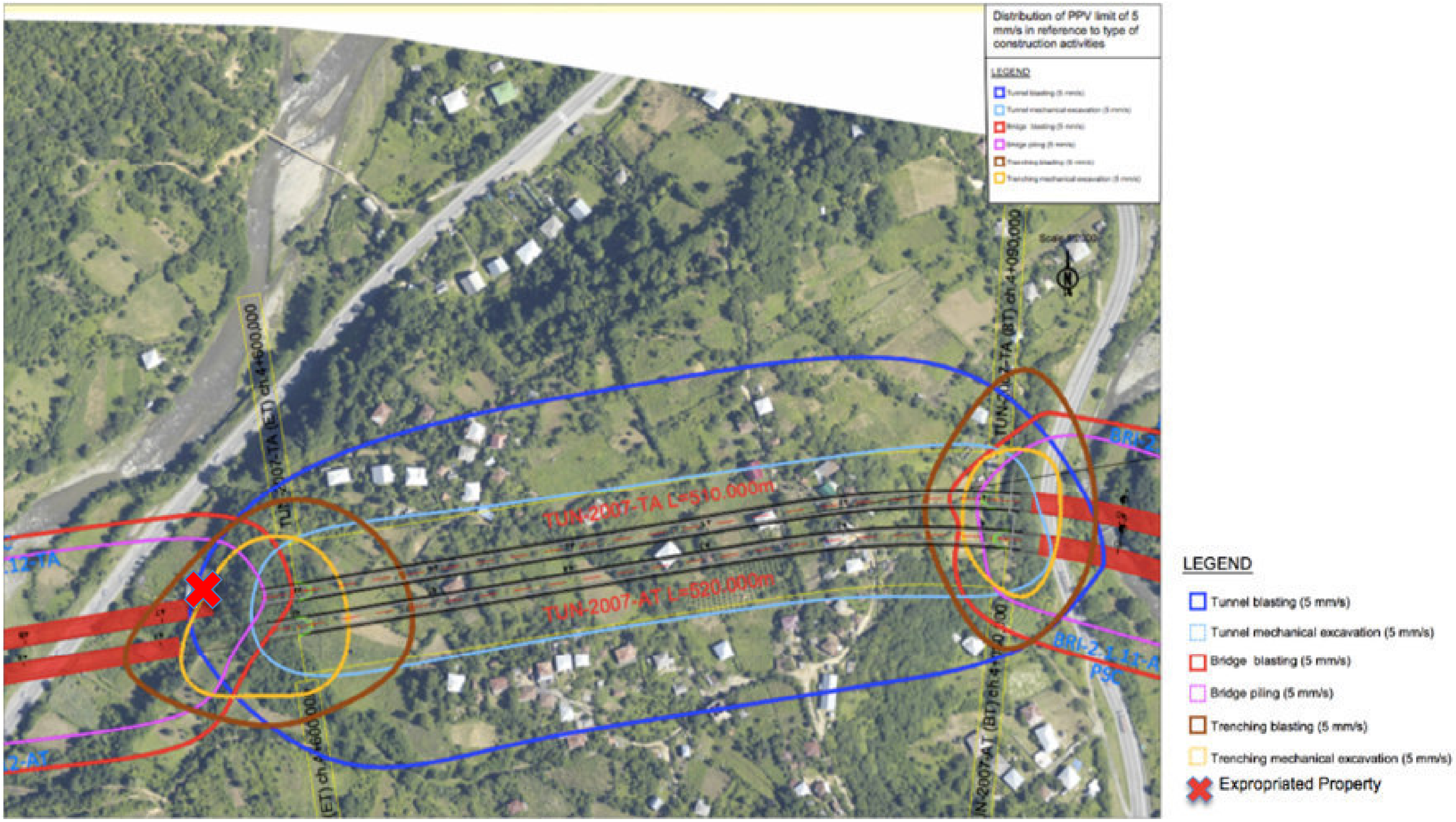


Figure 118: Distribution of PPV Limit of 5 mm/s

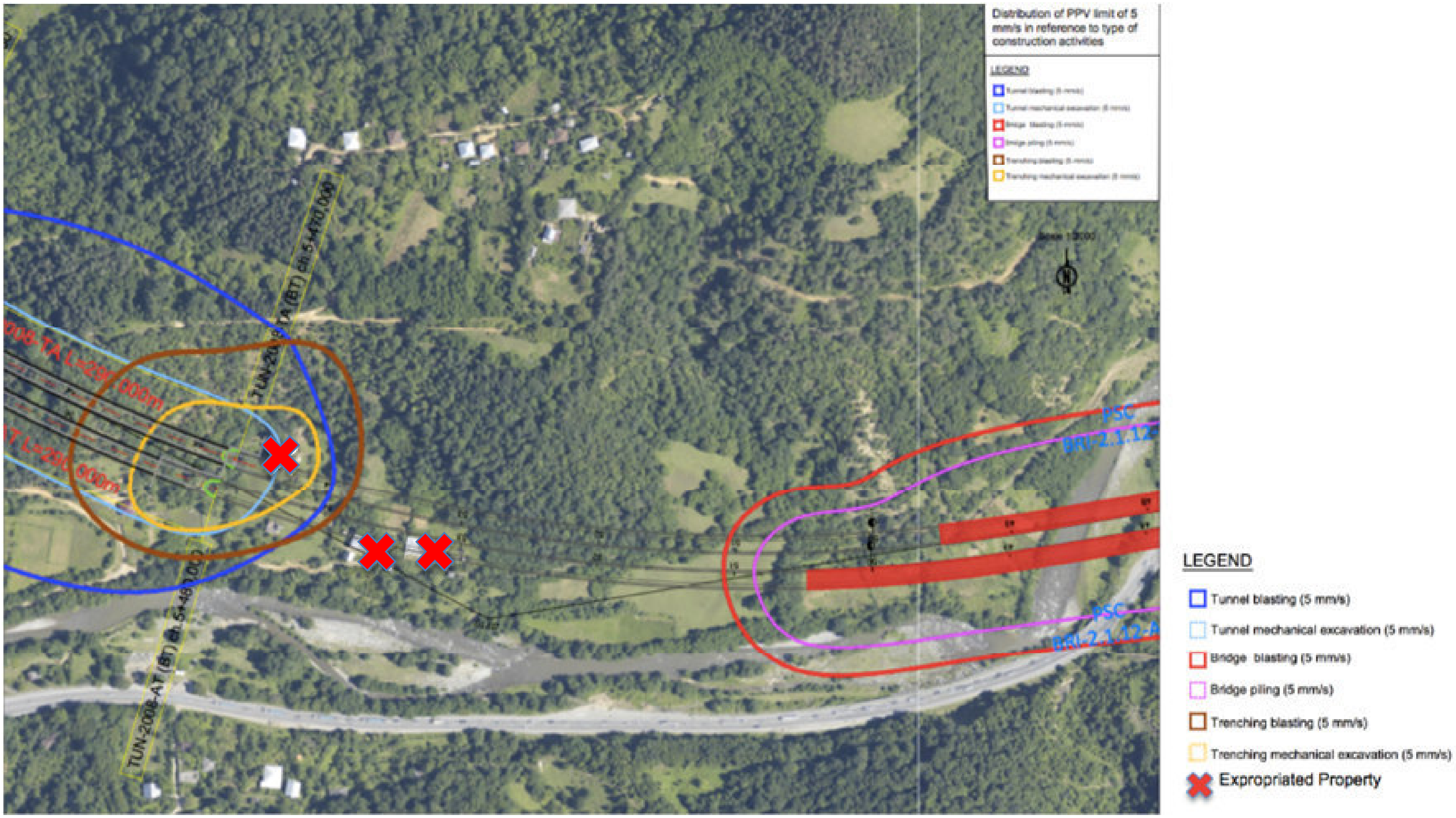


Figure 119: Distribution of PPV Limit of 5 mm/s

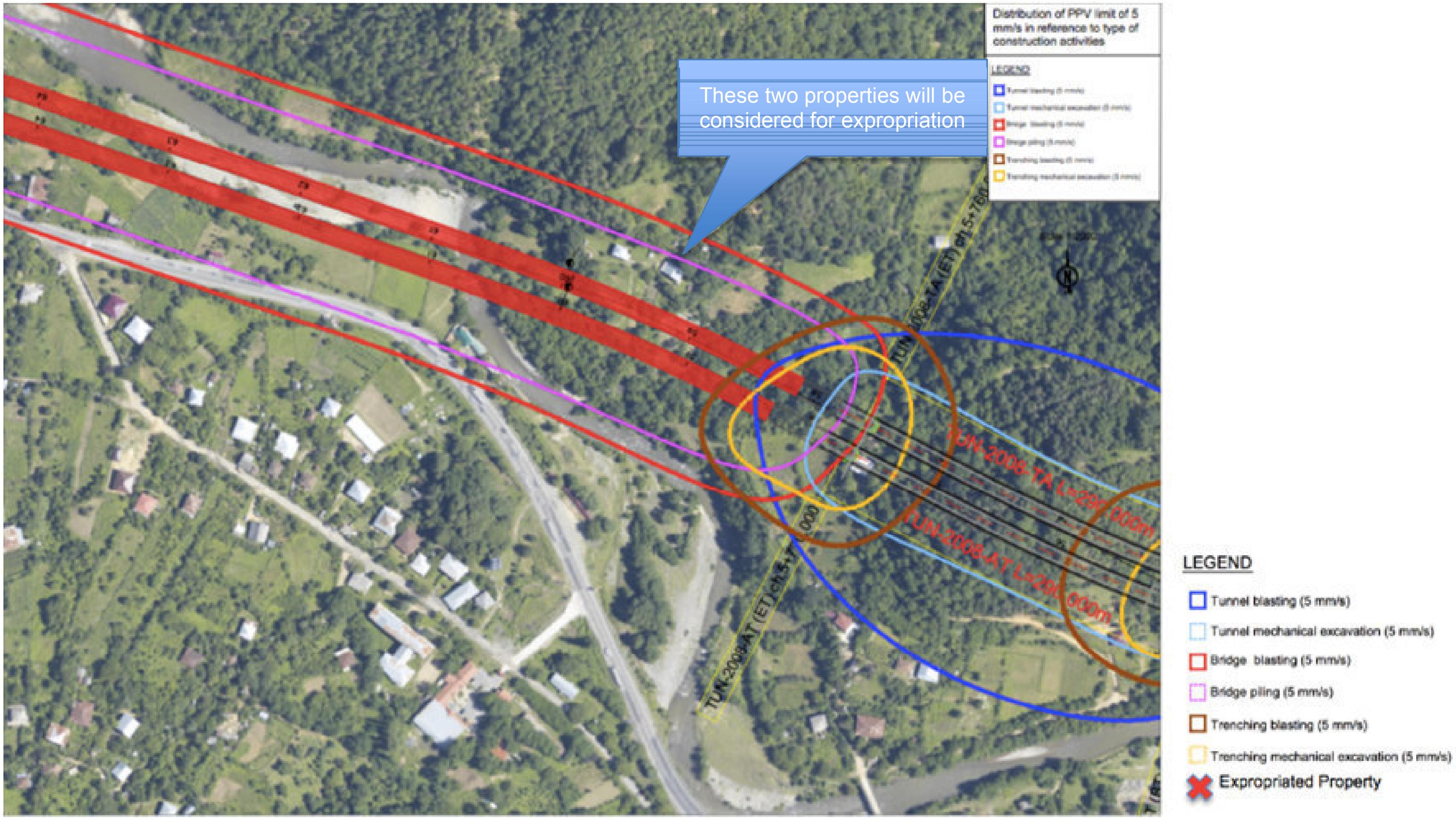


Figure 120: Distribution of PPV Limit of 5 mm/s

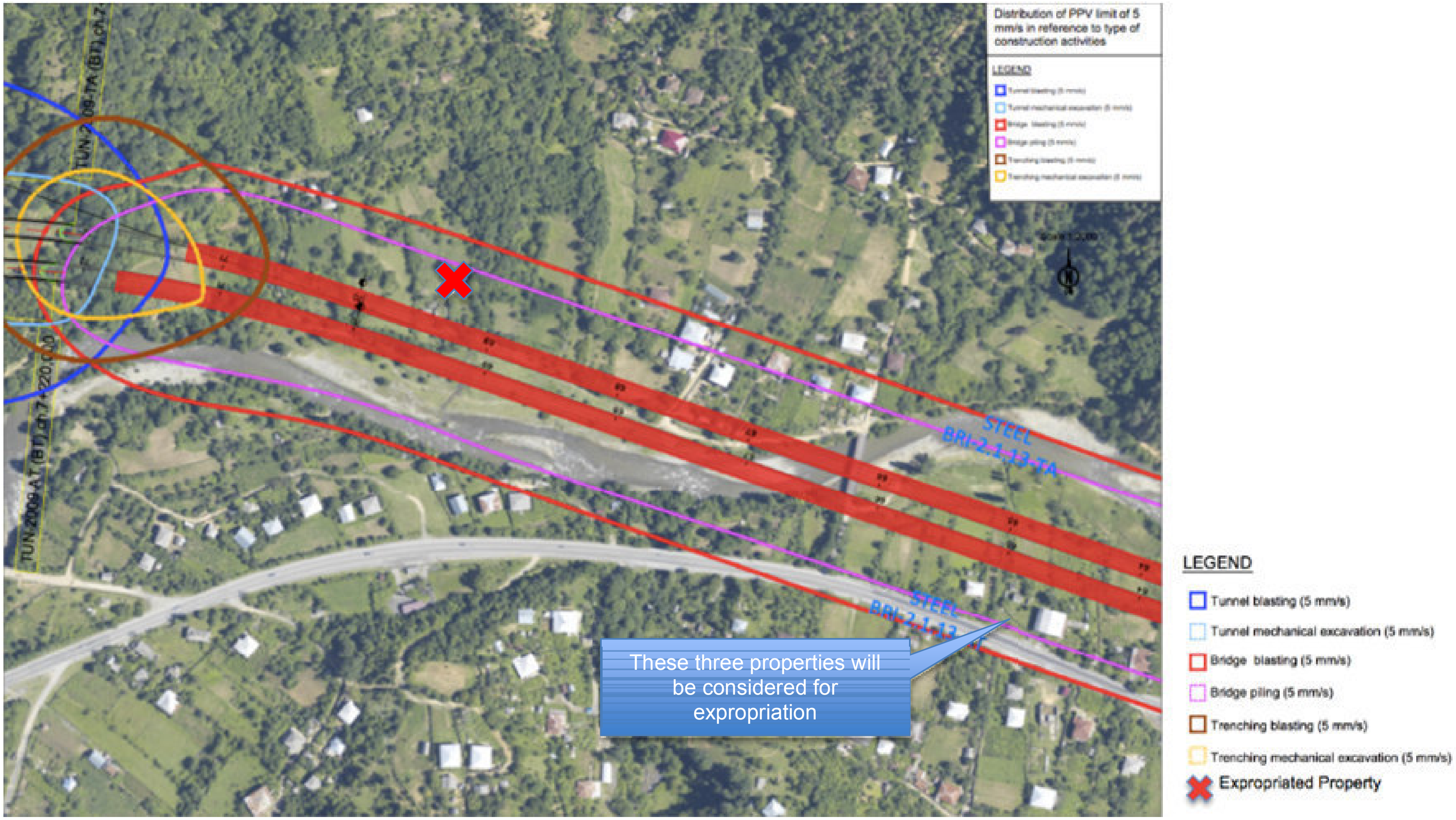


Figure 121: Distribution of PPV Limit of 5 mm/s

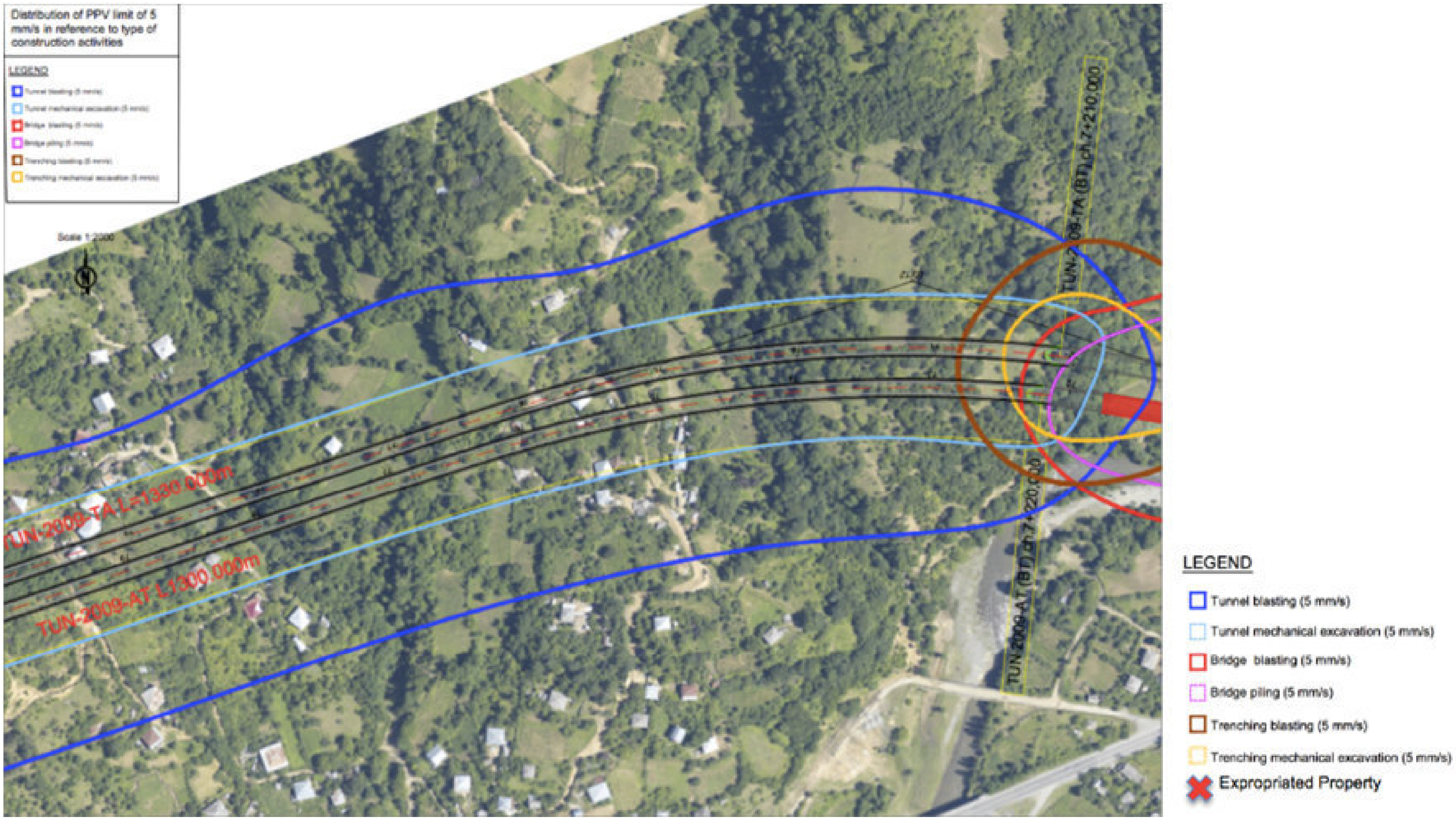


Figure 122: Distribution of PPV Limit of 5 mm/s

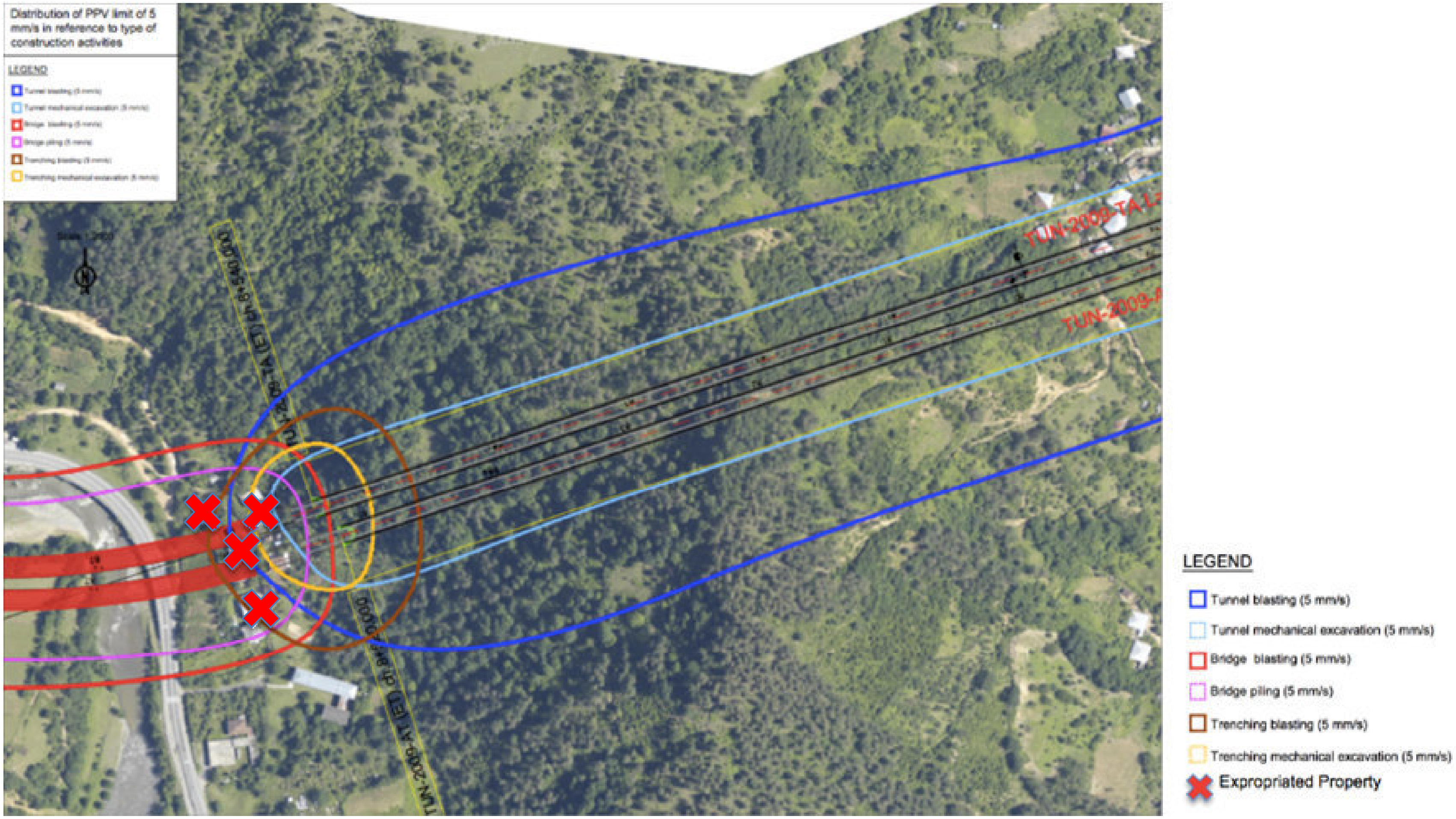


Figure 123: Distribution of PPV Limit of 5 mm/s

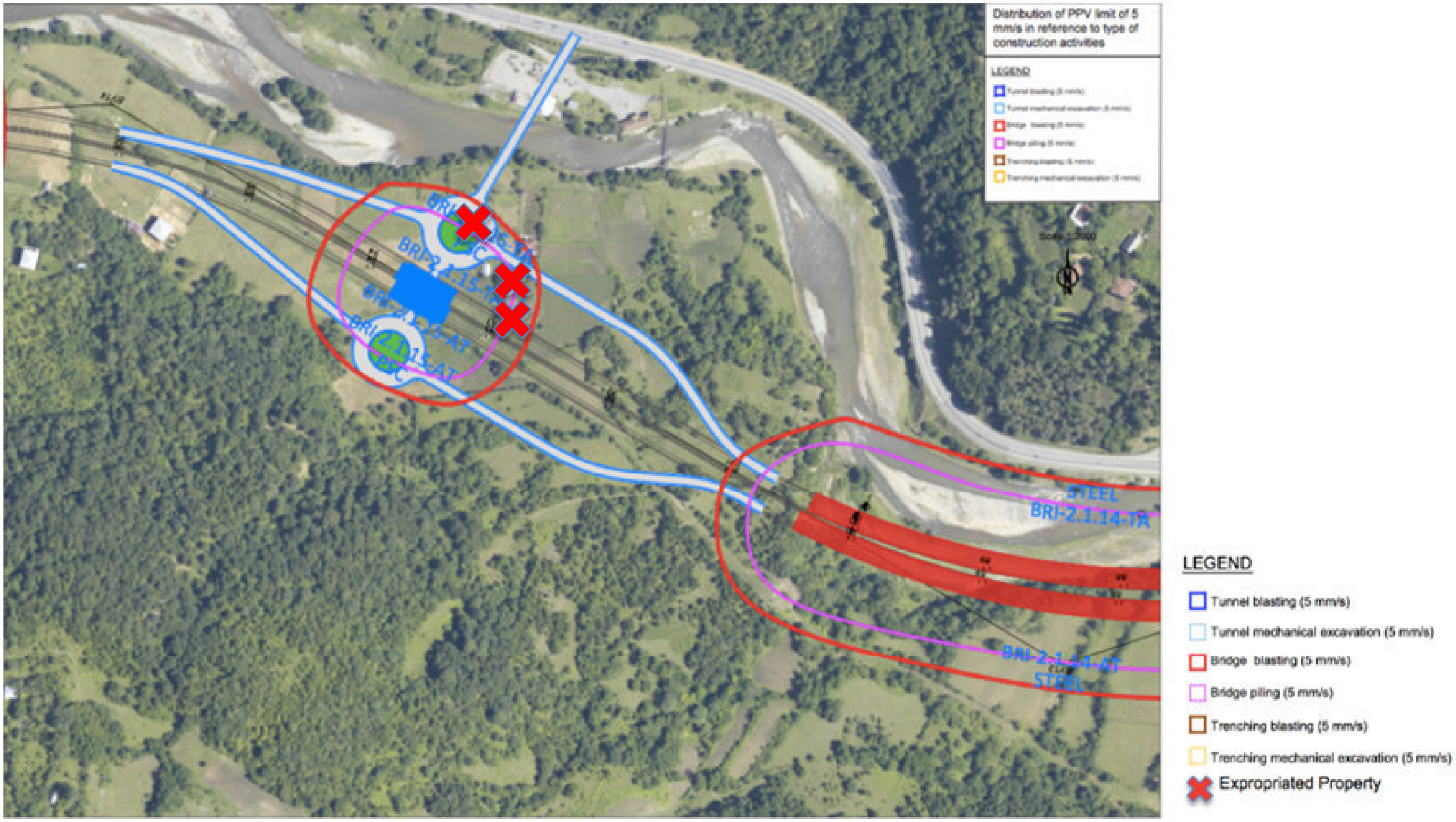


Figure 124: Distribution of PPV Limit of 5 mm/s

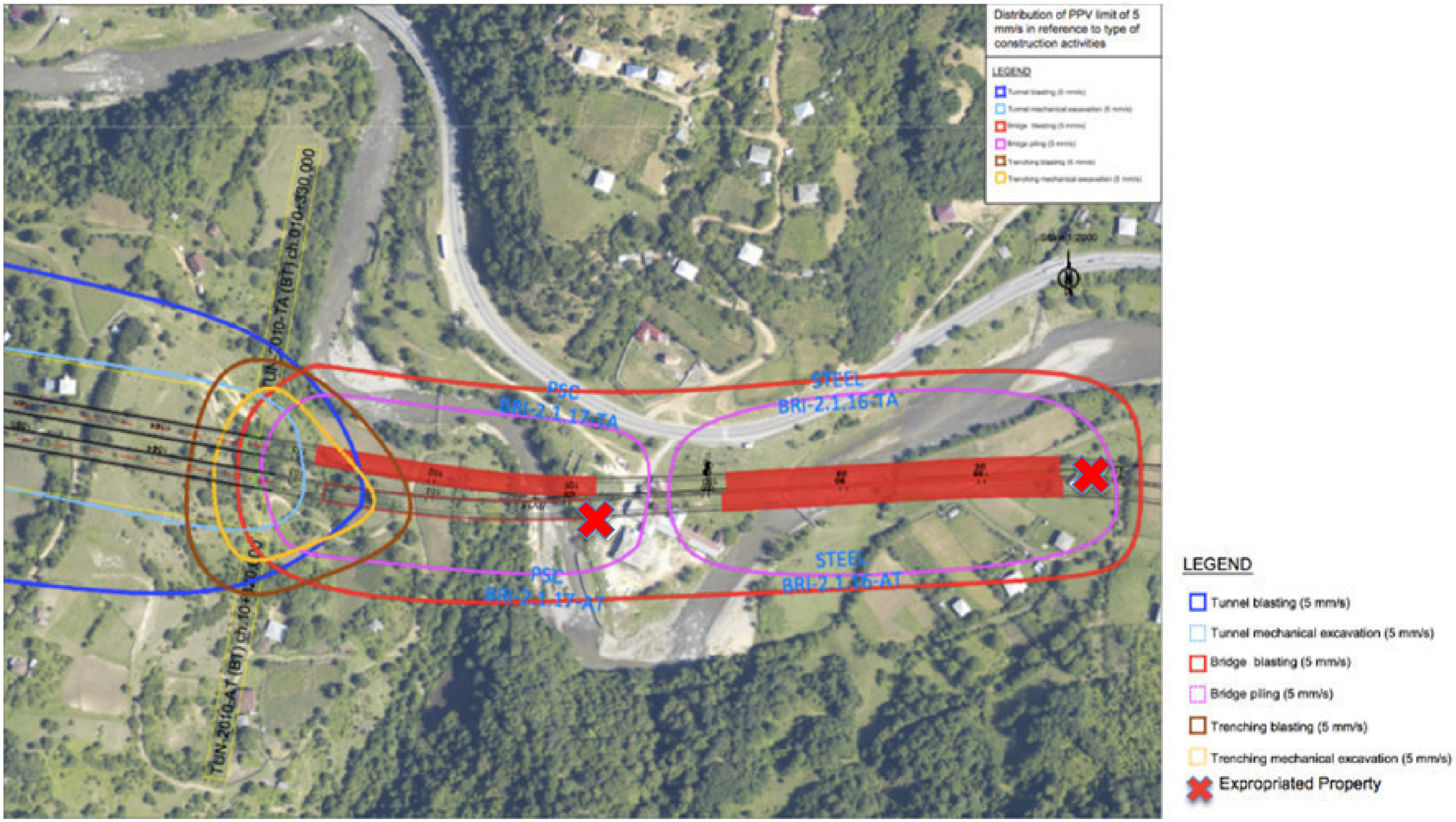


Figure 125: Distribution of PPV Limit of 5 mm/s

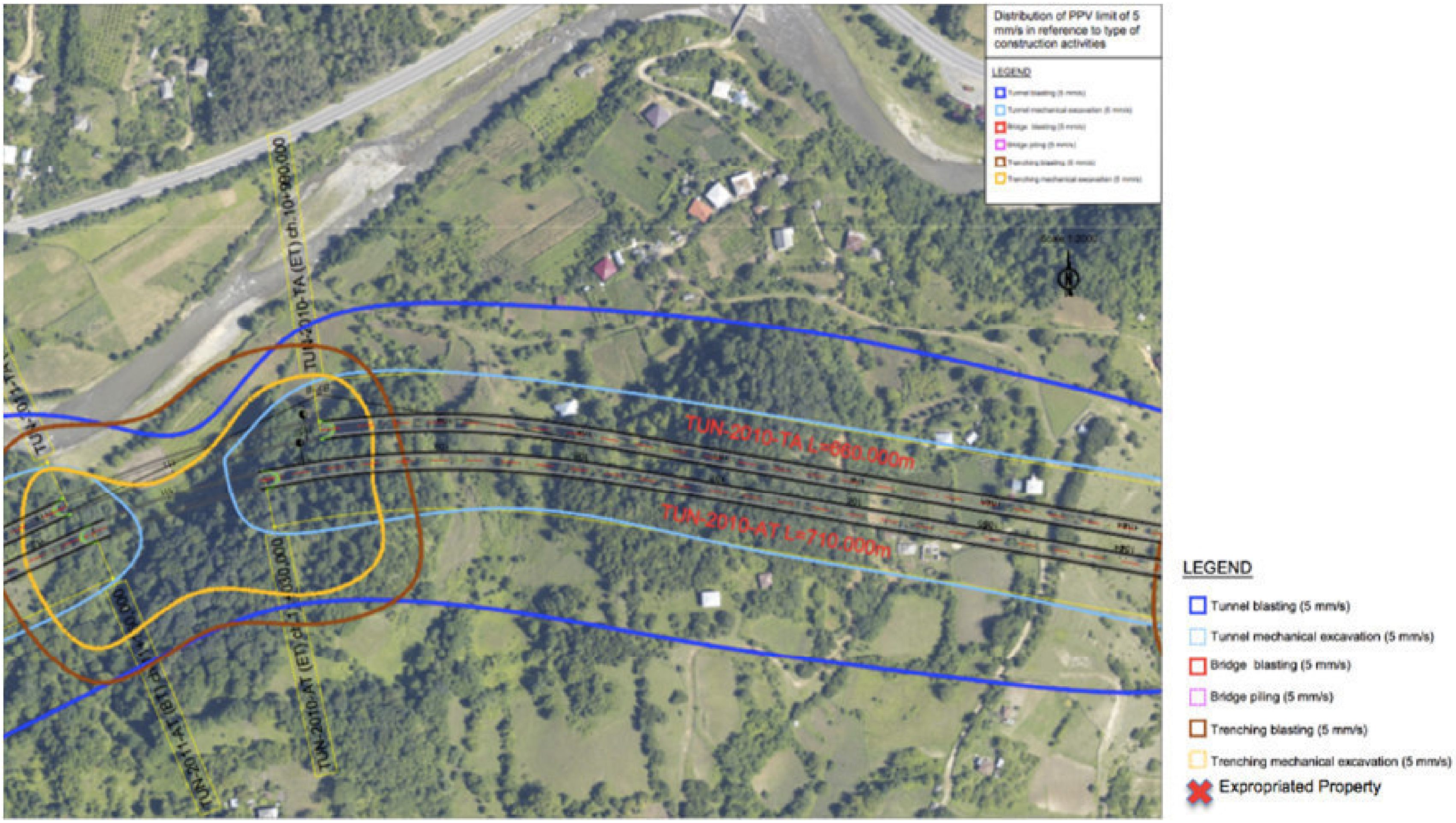


Figure 126: Distribution of PPV Limit of 5 mm/s

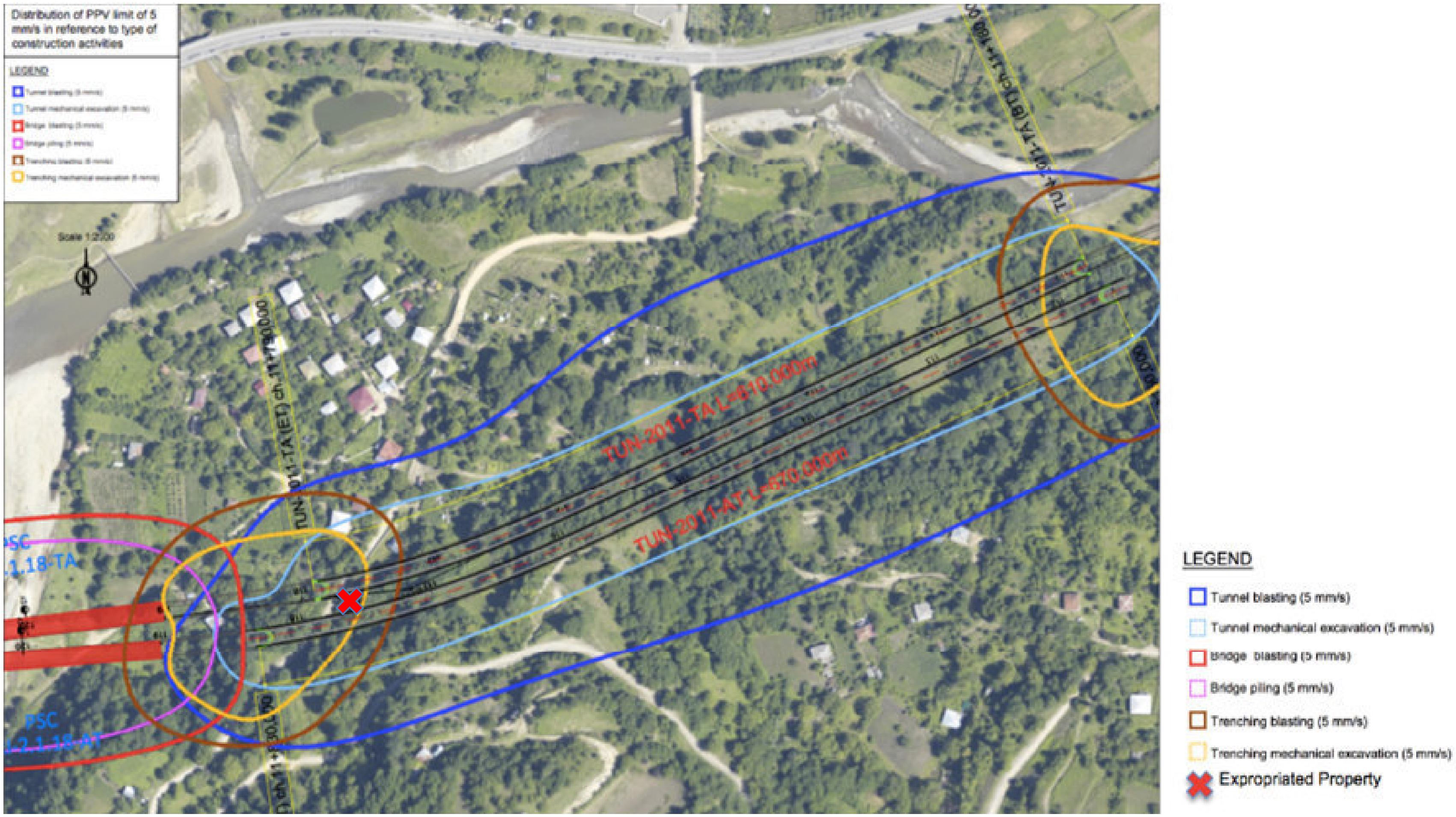


Figure 127: Distribution of PPV Limit of 5 mm/s

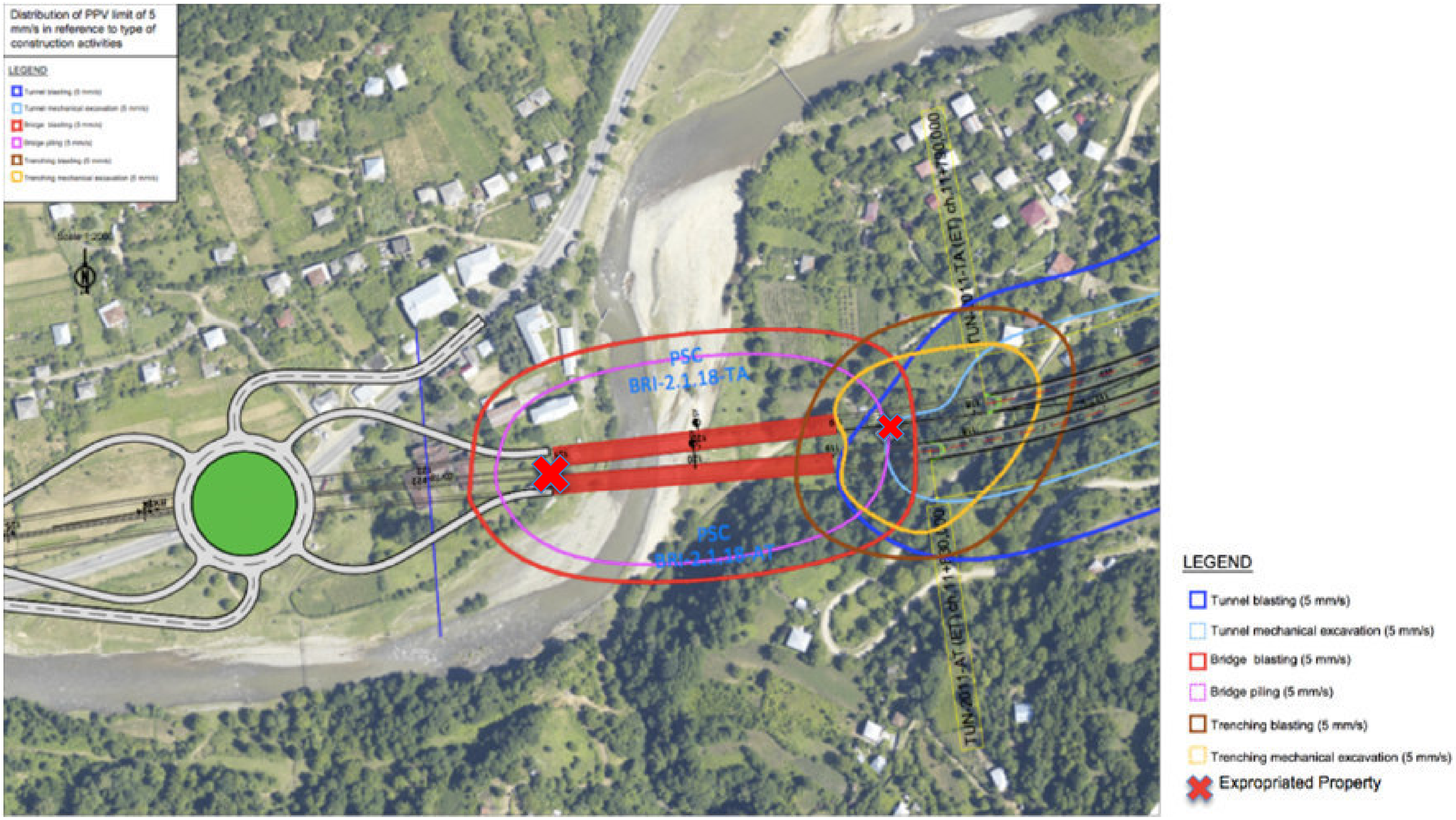


Figure 128: Distribution of PPV Limit of 5 mm/s

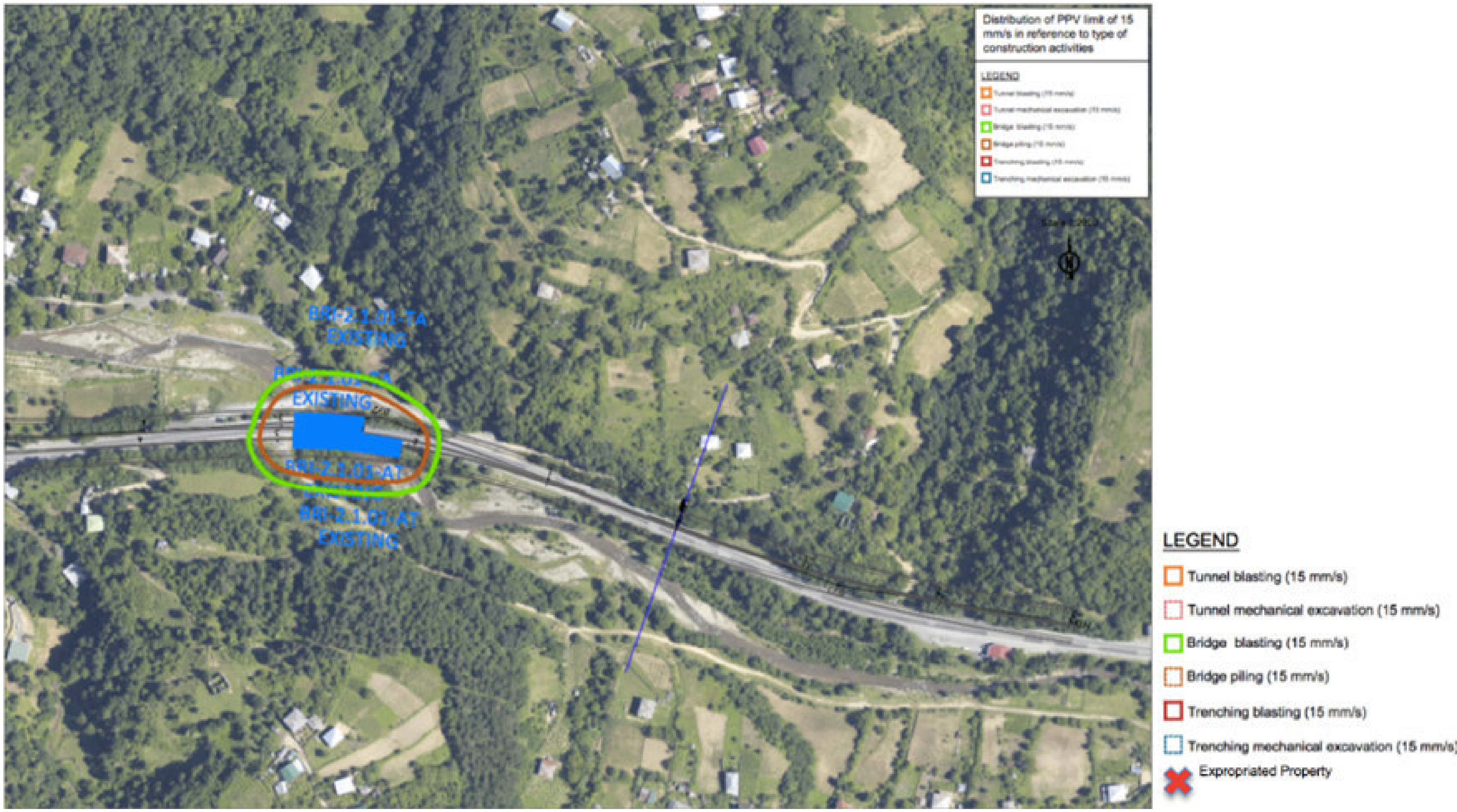


Figure 129: Distribution of PPV Limit of 15 mm/s

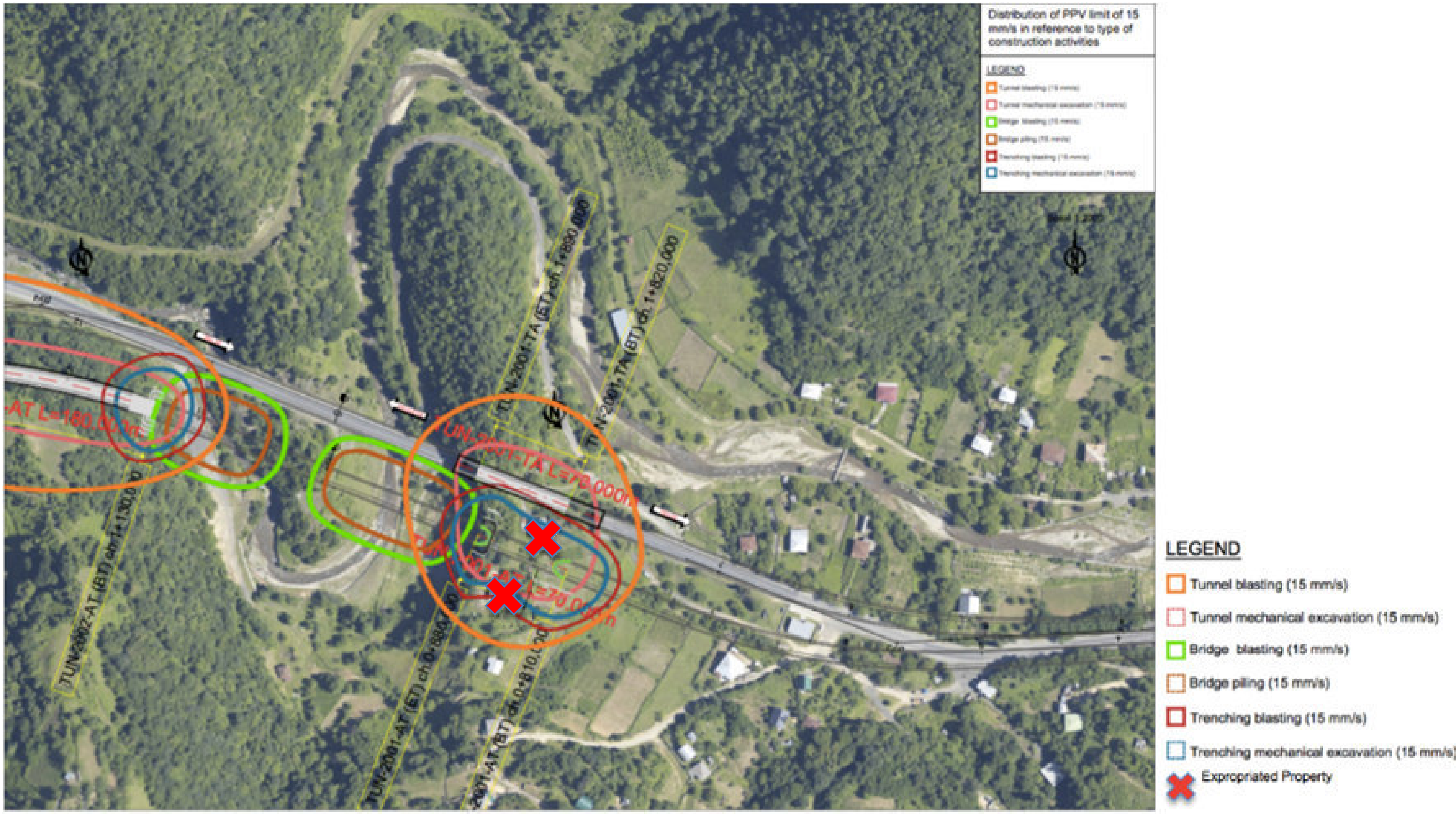


Figure 130: Distribution of PPV Limit of 15 mm/s

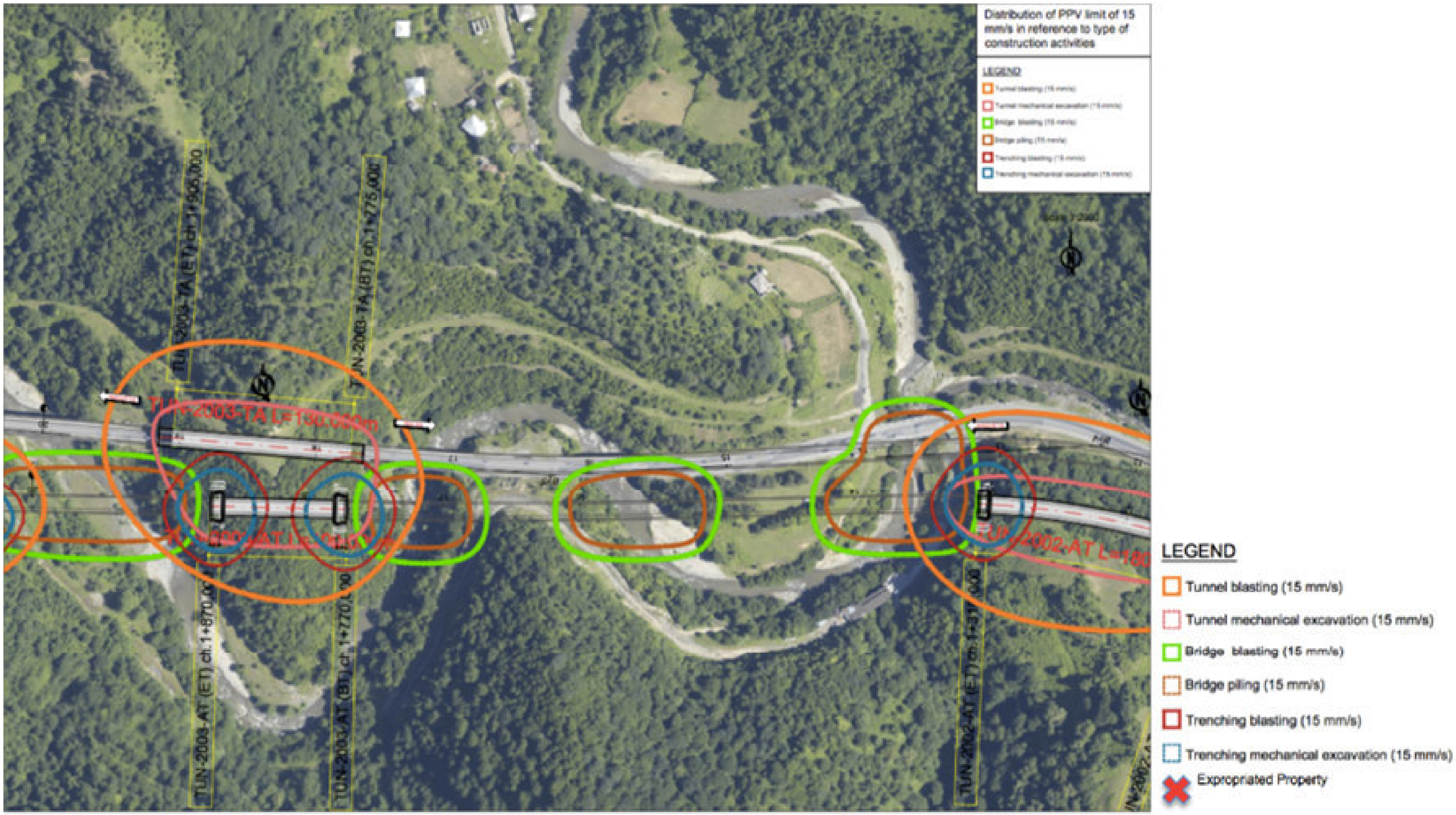


Figure 131: Distribution of PPV Limit of 15 mm/s

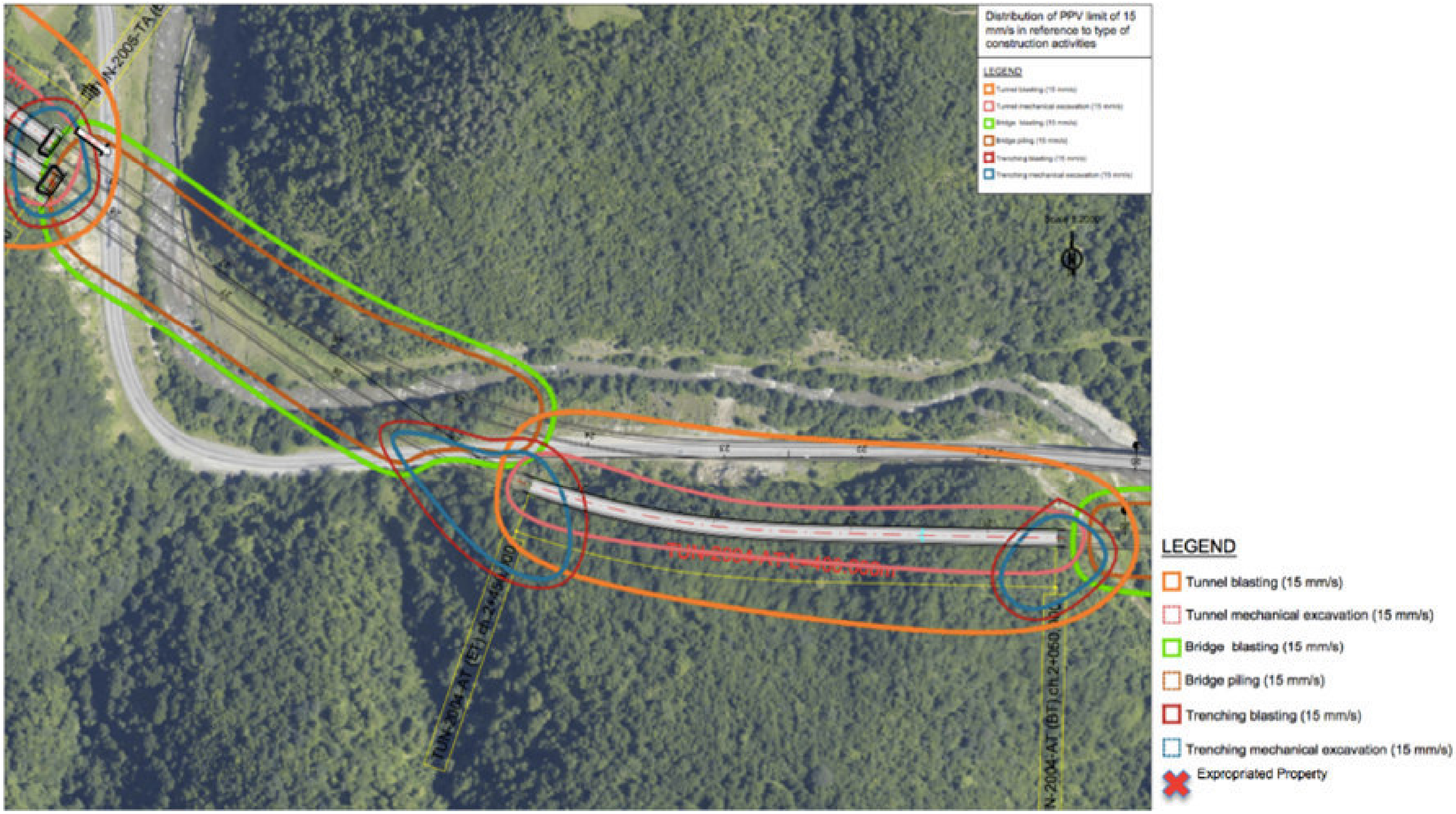


Figure 132: Distribution of PPV Limit of 15 mm/s

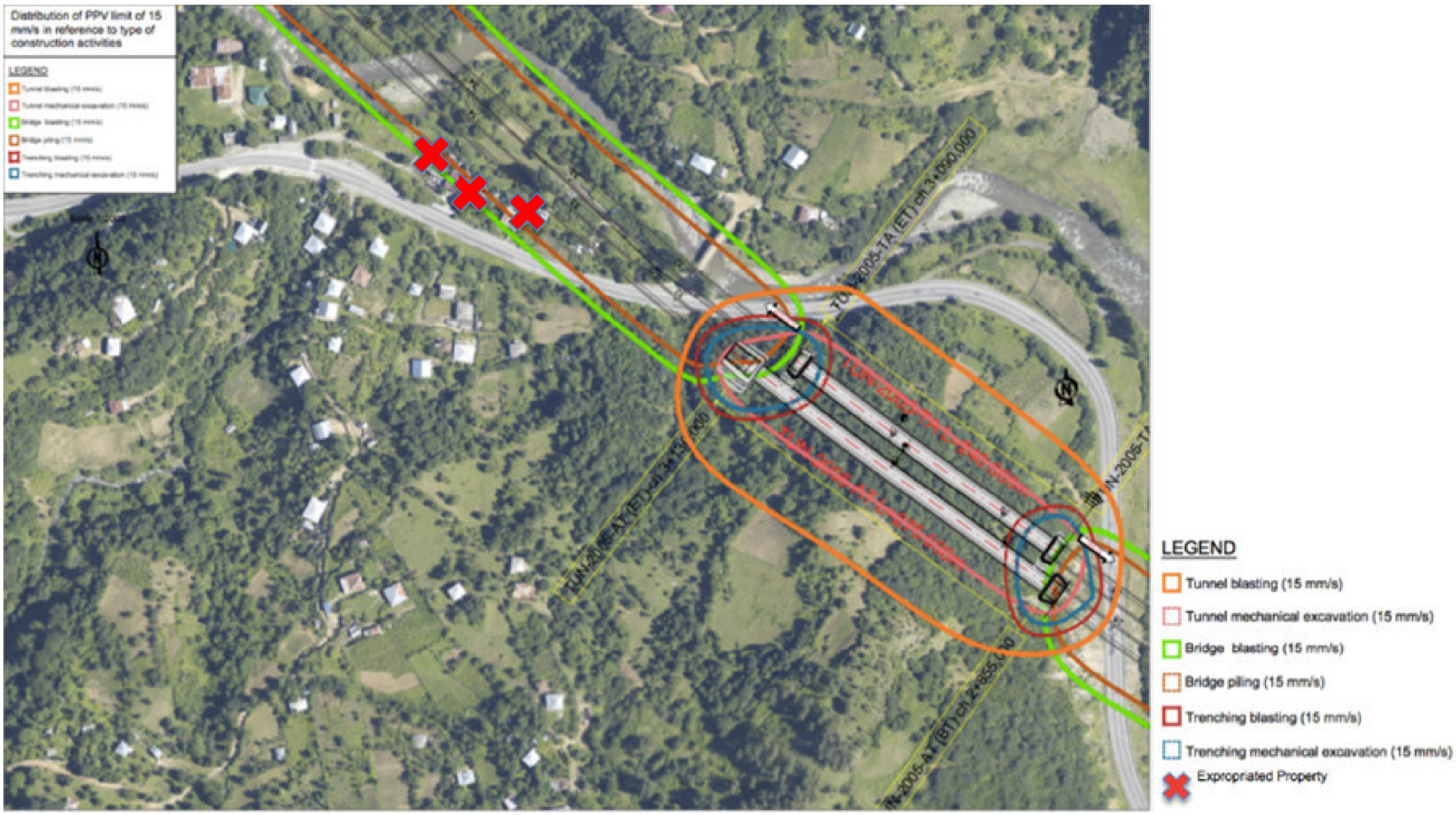


Figure 133: Distribution of PPV Limit of 15 mm/s

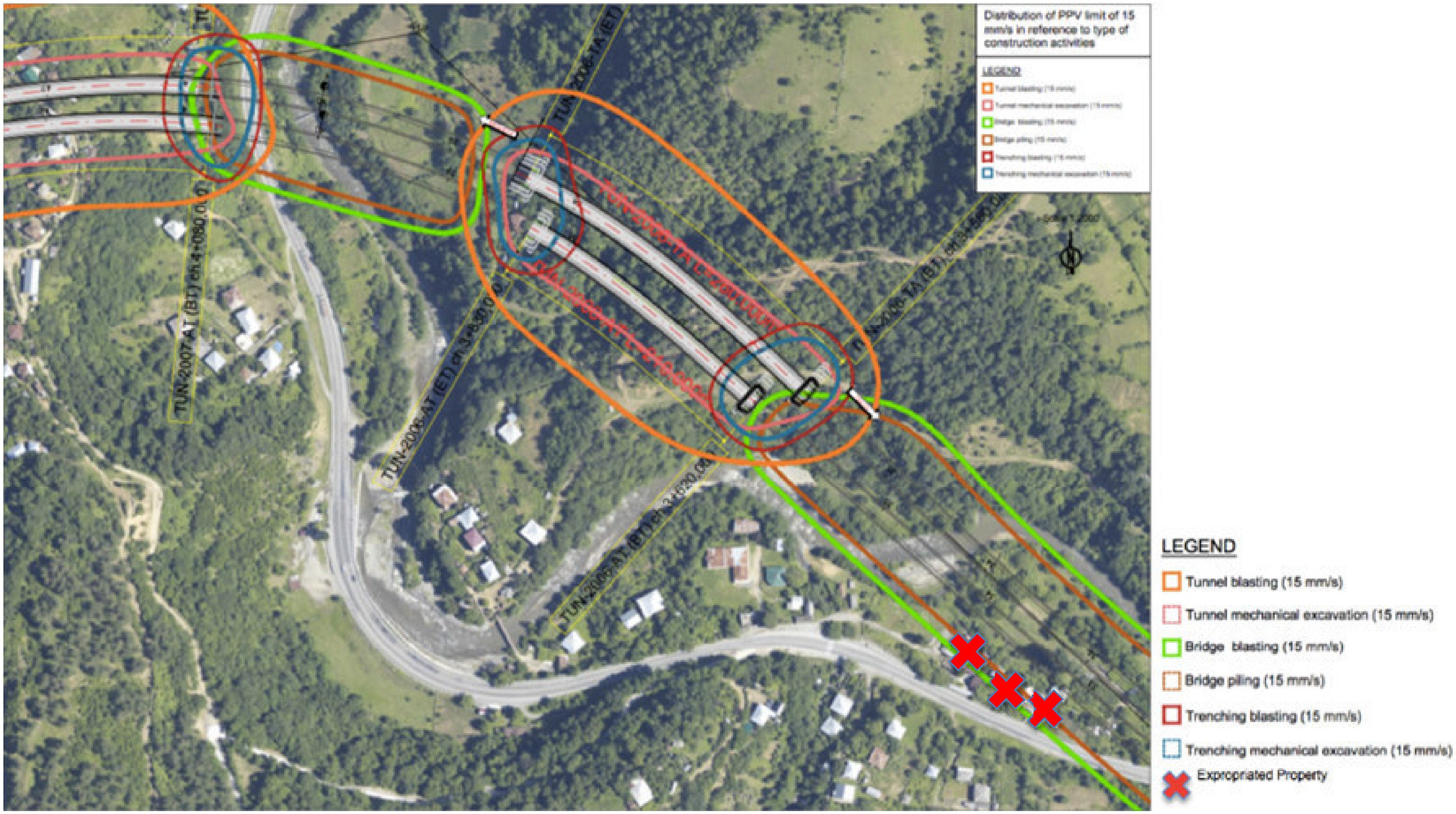


Figure 134: Distribution of PPV Limit of 15 mm/s

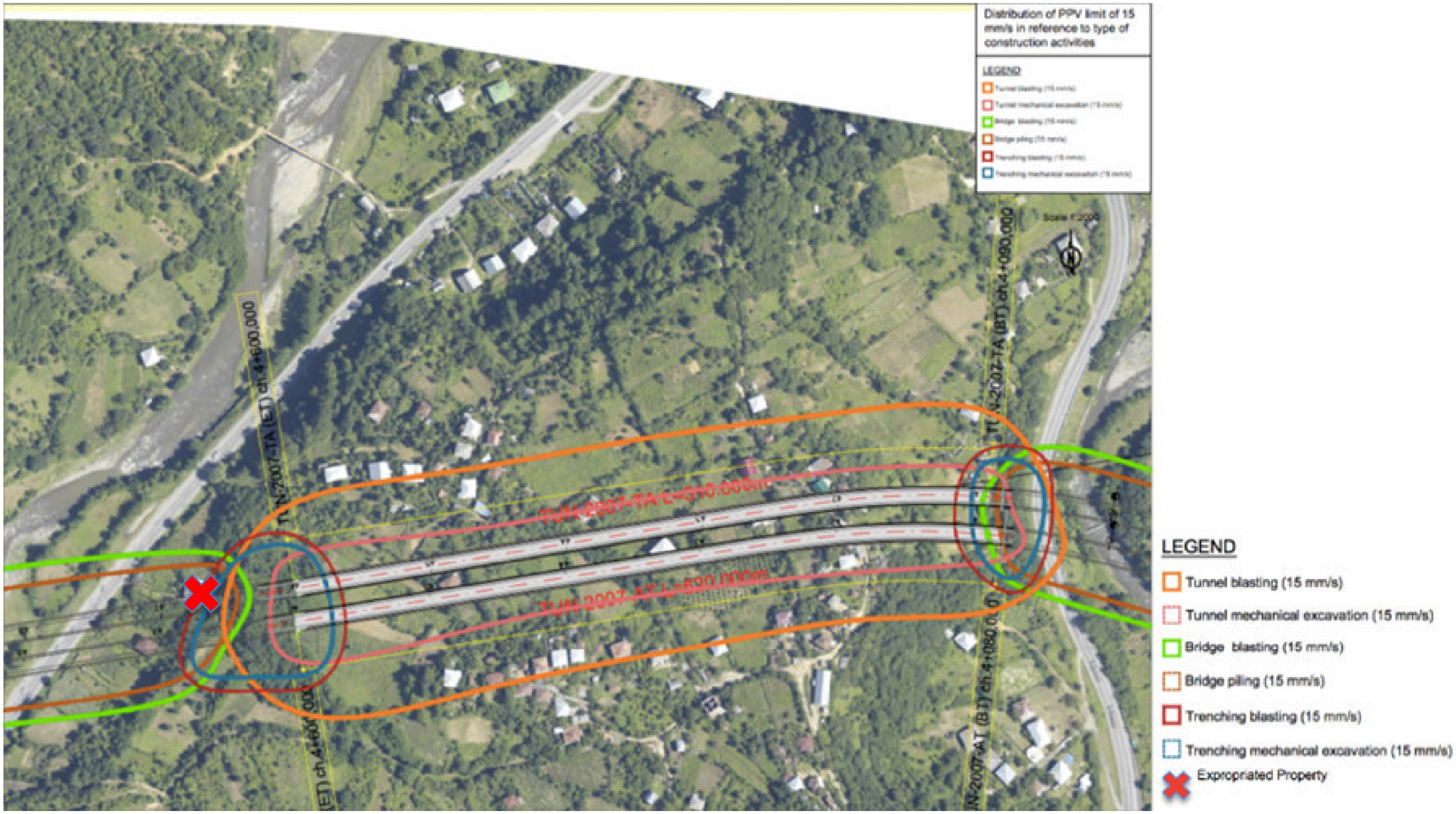


Figure 135: Distribution of PPV Limit of 15 mm/s