Hagler Bailly Pakistan

Noise Modeling of Tbilisi-Rustavi Highway (Section 2)

Draft Report

HBP Ref.: D7V04TRR

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Asian Development Bank (ADB)

Manila, Philippines

Acronyms

ADB	Asian Development Bank
dBA	A-weighted Sound Pressure Level in decibel
DEM	Digital Elevation Model
EHS	Environmental, Health, and Safety
FHWA	Federal Highway Authority
HTV	Heavy Transport Vehicle
IEE	Initial Environment Examination
IFC	International Finance Corporation
km	kilometer
km/h	kilometers per hour
LARP	Land Acquisition and Resettlement Plan
LTV	Light Transport Vehicle
m	meter
m^2	square meter
mb	Millibar

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1. Executive Summary

1. The Asian Development Bank (ADB) is assisting the Government of Georgia in upgrading the Tbilisi-Rustavi Highway. The total length of the road is 17.4 kilometer (km) which is being constructed in three sections. Section 1 and 3 are already constructed while the construction of the 6.8 km Section 2 is to commence soon. A 3.65 km segment of Section 2 will be a new road, bypassing the existing alignment of the Tbilisi-Rustavi Highway. The proposed new alignment of the road passes very close to some buildings. The residents of the buildings have expressed the concern to ADB that the noise levels of the traffic on the new road will be unacceptable and will have adverse effect on the quality of life.

2. This report assesses the noise from the proposed new segment of the Section 2, particularly its western portion where the buildings are near the proposed alignment and from where the concerns originated. The assessment includes:

- A baseline noise survey;
- Predicted future noise levels under 'without mitigation' and mitigation scenarios; and
- Cost comparison.

1.1 Noise Criteria

3. The noise guidelines of the International Finance Corporation (IFC) is used for assessing the impacts of noise. The criteria specifies that noise levels measured at noise receptors must not be 3 dBA greater than the background noise levels or exceed 55 dBA during the day or 45 dBA during the night in residential areas.

1.2 Receptors

4. The residential buildings located between the existing alignment of the Tbilisi-Rustavi Highway and proposed alignment along the Mtkvari River are considered as the receptors for this study. The buildings located south of the existing road are also exposed to traffic noise from the existing highways—Tbilisi-Rustavi Highway and the Marneuli Highway. However, the realignment of the Tbilisi-Rustavi Highway will reduce their exposure to traffic noise and will have a positive effect.

1.3 Baseline Noise Level Measurement

5. Noise levels at 15 different locations were measured. The results indicate that the noise levels on the river side of the apartments are within the acceptable limit whereas those facing the existing Tbilisi-Rustavi Highway are considerably high. The results are presented in **Figure 1-1**. Daytime averages are calculated for 7 am to 10 pm and nighttime for 10 pm to 7 am according to IFC Environmental, Health, and Safety (EHS) guidelines.

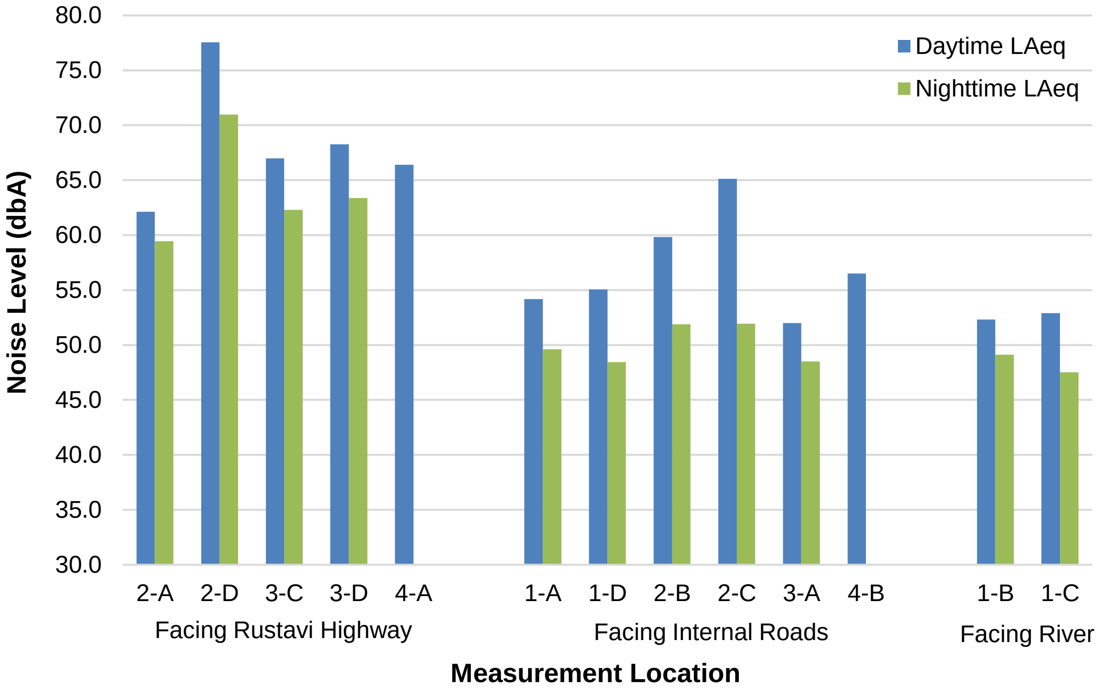


Figure 1-1: Noise Level Sampling Results

6. For receptors facing Rustavi Highway, the daytime and nighttime noise levels exceeded the IFC Guidelines values by 13 dBA and 19 dBA, respectively. For receptors facing internal roads, the daytime noise levels for half the receptors were within the IFC Guidelines values, whereas the nighttime noise levels exceeded the IFC guidelines by 4 to 7 dBA. For receptors facing the Mtkvari River, the daytime noise levels were in compliance whereas the nighttime noise levels exceeded the IFC guidelines values by 2 to 4 dBA.

1.4 Noise Model

7. The noise model, SoundPLAN Essential Version 4.0 by Braunstein + Berndt GmbH / SoundPLAN International LLC was used to model the noise impact. The model results were verified by making an independent field measurement and traffic count and comparing with corresponding modeling result. A 3 dimensional view of the model set up is shown in **Figure 1-2**.

8. The following traffic scenarios were used for the assessment:

- **Scenario 1:** Current Baseline or 2017. This was compared with the predicted noise levels of other scenarios to assess the impacts of the road.
- **Scenario 2:** Unmitigated Noise Levels for 2038. As the traffic on the proposed Highway is predicted to increase annually, the assessment covers the entire life of the project, i.e., 20 years following the commissioning of the road.
- **Scenario 3+:** Mitigated Noise Levels for multiple mitigation scenarios

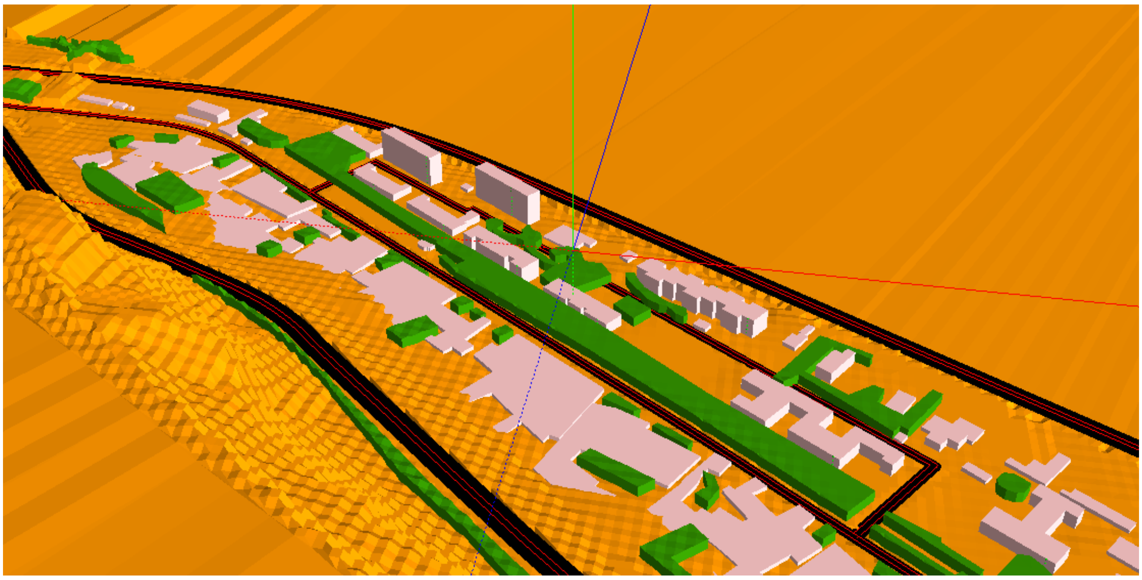


Figure 1-2: 3D View of Model Setup

1.5 Model Outputs

9. The unmitigated noise levels for 2038 traffic (Speed: 80 kilometer per hour (km/h), standard asphalt road, no noise protection) show a significant increase in noise level on the riverside, a decrease in noise level on the existing Tbilisi-Rustavi road, and an increase in buildings between the two rows of buildings.

10. Various mitigation measures were considered to see their possible effectiveness. These include combinations of the following:

- Reduction in traffic speed limit to 60 km/h and 40 km/h
- Noise walls including walls of up to 9 meter (m) height and dual walls (one facing the buildings and one on the median of the road.
- Noise abatement tunnel on selected section of the highway

11. In all 15 different scenarios were modeled (1 baseline, 2 as given in the Initial Environmental Examination (IEE) of the Project, 6 standalone measures, and 6 combinations). The following conclusions are drawn:

- The reduction of traffic speed to 60 km/h from 80 km/h has marginal effect.
- The noise wall suggested in the IEE, including the additional measure of reducing the speed is insufficient as the noise levels of a large number of receptors remain non-compliant.
- The improved road surface is also not viable as it results in only a marginal decrease in the number of receptors with non-compliant noise levels.

12. Four mitigation options were considered technical feasible of which three will require additional measure of relocating some buildings in order to achieve complete compliance.

1.6 Final Mitigation Options

13. Four mitigation options are selected as follows:

- **W** (Noise wall with maximum height of 8 m). In this two noise walls are recommended, one 6-m high, 988 m long wall and the second 8-m high 640-m long wall. These wall will not achieve complete abatement and will therefore require relocation of 5 buildings. A typical wall is shown in **Figure 1-3**.
- **W′** (Noise wall with maximum height of 9 m). In this three noise walls are recommended—one 6-m high, 1,120 m long, the second 8-m high 240 m long and the third 9-m high 268 m long. These walls will not achieve complete abatement and will therefore require relocation of 4 buildings**.** It may be noted that the optimization of the noise wall is done following the removal of the four buildings.
- **W + IRS** (Noise wall with improved road surface). One noise wall and improved road surface is recommended. The noise wall will be 5 m high and 1,628 m long. Thus its area will be about 26% less than that of previous option (noise wall only). The improved road surface will require replacing the standard asphalt with porous asphalt to reduce noise at source on 1.6 km of the road surface. Like the previous option, this option will also require relocation of 4 buildings.
- **W + T** (Noise wall with tunnel). One tunnel and a noise wall is recommended. The tunnel will stretch to a length of 560 m and will cover both carriageways. Its height will be 5 m, which is the same as that of the tunnel under the railway line. Two noise walls are recommended, one 5-m high, 880 m long wall and the second 8-m high and 188 m long wall. Example of typical noise tunnels is shown in **Figures 1-4**.

Figure 1-3: A Typical Transparent Noise Wall

Figure 1-4: A Typical Tunnel Noise Barrier

1.7 Mitigation Cost

14. In **Table 1-1**, the total estimated cost of the three mitigation scenarios is presented. The cost of the three options is comparable, between 14 to 16.0 million USD.

15. The Study has demonstrated that it is possible to mitigate the adverse noise impact by selecting one of the proposed options. The cost provided is based on estimates which are obtained from various published sources. A 20-25% variation from the actual cost is likely. Given this, the decision on which option to take shall also take into account other factors. These may include the social cost of relocation. The overall improvement in environmental quality of the Study Area as a result of potential conversion of the evacuated land to park or amenities.

1.8 Construction Noise

16. The inherent variability in construction noise makes it very difficult to predict. Nevertheless, a reasonable prediction of the scale of noise levels can be made by simulating various deployment configuration for the equipment.

17. In this report, the construction noise has been predicted using the approach proposed by the FHWA, however, the model SoundPlan has been used as it allows assessing the impact and effectiveness of noise barriers.

18. The construction activity has been divided into six stages, excavation, clearing for formation of embankment, structure erection, earth-filling for formation of embankment, laying of sub-base and base, and pavement of asphalt layers. The typical equipment deployed in each stage is used to model the noise levels during the day.

19. The predicted noise levels at the buildings near the construction zone are high and exceed the IFC noise standards for most of the receptors. Introduction of 3-m noise barrier, helps to reduce the noise at the receptors. The impact is significant for the lower floors but is nearly ineffective for the upper floors, Floor 4 and above. For this reason, noise barriers of various height have been proposed along the construction zone. In addition, other mitigation, monitoring and management measurers have been suggested.

Table 1-1: Details of Mitigation Options

Mitigation Options		Noise Wall	Tunnel	Improved Road Surface	Relocation [a]	Total Cost
W	Basis	Area: 11,048 m^2 Unit Cost: USD 475/m^2			Hotel: USD 600,000 Apartments #8, #V, #12VG and #16A/B: USD 9,900,000	
	Estimated Cost	USD 5.25 million			USD 10.5 million	**USD 15.75 million**
W'	Basis	Area: 11,052 m^2 Unit Cost: USD 475/m^2			Apartments #8, #V, #12VG and #16A/B: USD 9,900,000	
	Estimated Cost	USD 5.25 million			USD 9.90 million	**USD 15.15 million**
W + IRS	Basis	Area: 8,140 m^2 Unit Cost: USD 475/m^2		Area: 26,048 m2 Unit Cost USD5.5/m^2	Apartments #8, #V, #12VG and #16A/B: USD 9,900,000	
	Estimated Cost	USD 3.867 million		USD 0.143 million	USD 9.90 million	**USD 13.91 million**
W + T	Basis	Area: 5,944 m^2 Unit Cost: USD 475/m^2	Length 560 m Unit Cost: USD 22,500/m^2			
	Estimated Cost	USD 2.823 million	USD 12.60 million			**USD 15.42 million**

a If the single-story building Apartment #12 VG and 16A/B is included an additional USD 0.3 million will be required.

2. Introduction

20. The Asian Development Bank (ADB) is assisting the Government of Georgia in upgrading the Tbilisi-Rustavi Highway (**Figure 2-1**). The total length of the road is 17.4 km which is being constructed in three sections. Section 1 and 3 are already constructed while the construction of the 6.8 km Section 2 is to commence soon (**Figure 2-2**). A 3.65 km segment of Section 2 will be a new road, bypassing the existing alignment of the Tbilisi-Rustavi Highway. The proposed new alignment of the road passes very close to some buildings. The residents of the buildings have expressed the concern to ADB that the noise levels of the traffic on the new road will be unacceptable and will have adverse effect on the quality of life.

21. ADB acquired the services of Hagler Bailly Pakistan (Pvt.) Limited to undertake an assessment of the noise from the proposed new segment of the Section 2, particularly its western portion where the buildings are near the proposed alignment and from where the concerns originated.

2.1 Scope of Work

22. The noise assessment is to be carried out for the portion of the proposed Highway from where the concerns were raised. This is the realigned western segment of Section 2 (the "Project"). This area is designated as the Study Area in this report (**Figure 2-1**). The scope of work of the assignment included the following:

- Undertake a baseline survey within the Study Area to document the current levels of noise;
- Model the future noise levels due to the proposed Highway in the Study Area under 'without mitigation' and various mitigation scenarios to comply with the noise criteria; and
- Compare the scenarios for their cost and technical feasibility.

23. As the traffic on the proposed Highway is predicted to increase annually, the compliance to the noise criteria is to be demonstrated for the life of the Project, i.e., 20 years following the commissioning of the Project (2038).

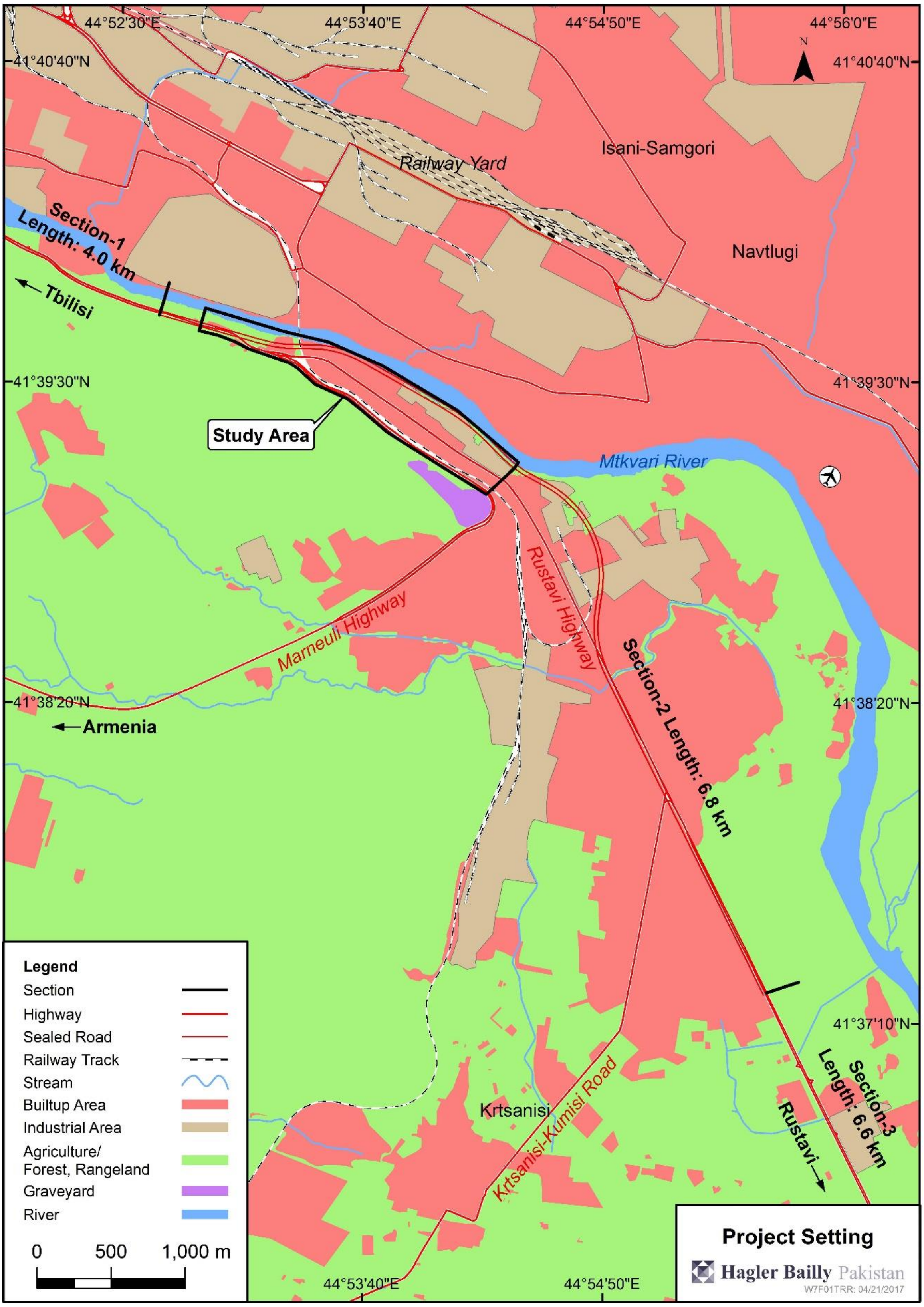


Figure 2-1: Project Setting

The Completed Section 1

The Existing Section 2

The Completed Section 3

Figure 2-2: The Tbilisi-Rustavi Highway

2.2 Noise Criteria

24. The noise guidelines of the International Finance Corporation (IFC) is to be used for assessing the impacts of noise. The criteria specifies that noise levels measured at noise receptors must not be 3 dBA greater than the background noise levels, or exceed the noise levels depicted in **Table 2-1**.

Table 2-1: Noise Level Sampling Results

Receptor	Noise Level Guideline (dBA)	
	Daytime (07:00 - 22:00)	**Nighttime (22:00 - 07:00)**
Residential; institutional; educational	55	45
Industrial; commercial	70	70

Source: International Finance Corporation, General Environmental, Health, and Safety (EHS) Guidelines, Environmental Noise Management. April 2007

2.3 The Proposed Project

25. The proposed Project site is located in the suburban area of Tbilisi. Residential buildings are located on both sides of the existing highway. The new alignment of the Highway will follow the Mtkvari River side and will be partly constructed within the river bed. It will be 4-lane divided highway with a total width of 29.5 meters.

2.4 Receptors

26. The residential buildings located between the existing alignment of the Tbilisi-Rustavi Highway and proposed alignment along the Mtkvari River are considered as the receptors for this study. The buildings located south of the existing road are also exposed to traffic noise from the existing highways—Tbilisi-Rustavi Highway and the Marneuli Highway. However, the realignment of the Tbilisi-Rustavi Highway will reduce their exposure to traffic noise and will have a positive effect.

27. The key receptors considered in this study are shown in **Figure 2-3**. There are over 100 buildings of different sizes in the Study Area. Of these several small buildings fall within the proposed right-of-way (see “LARP” boundary in **Figure 2-3**), and will be removed. Of the remaining buildings, some representative buildings have been selected for assessment.

28. The cross section of the highway near Apartment #12 VG is shown in **Figure 2-4**.

2.5 Assessment Methodology

29. The steps followed in this assessment are as follows:

Step 1: Measure the existing noise levels at various receptors. The sampling sites were selected to be representative. The consideration in selection included a) spatial distribution, i.e., all areas must be covered; b) elevation, i.e., from ground level to the highest floor level (9 stories) must be included; and c) direction with respect to noise source, i.e., receptors facing the existing road, the river and the internal road must be included.

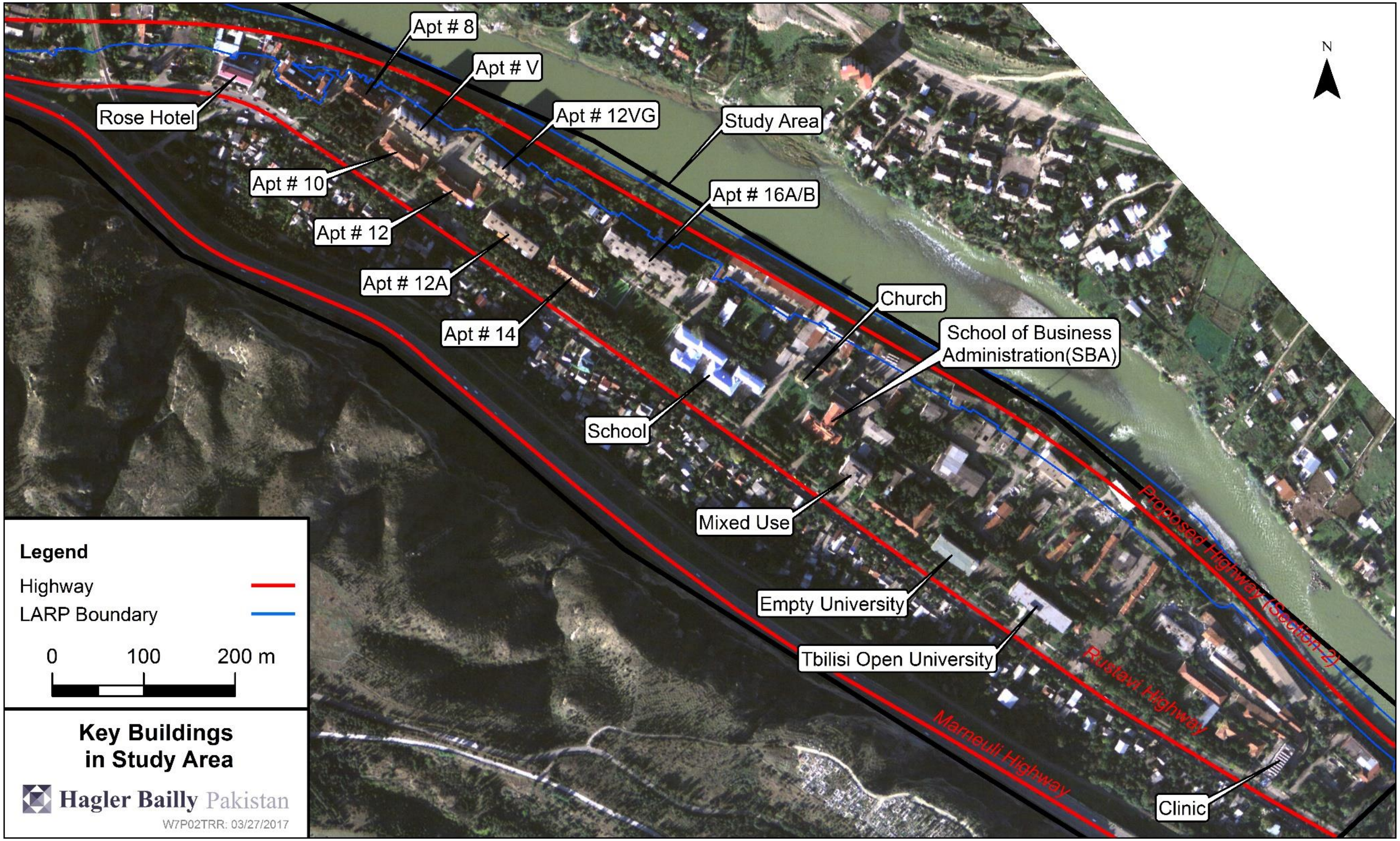


Figure 2-3: Key Buildings in Study Area

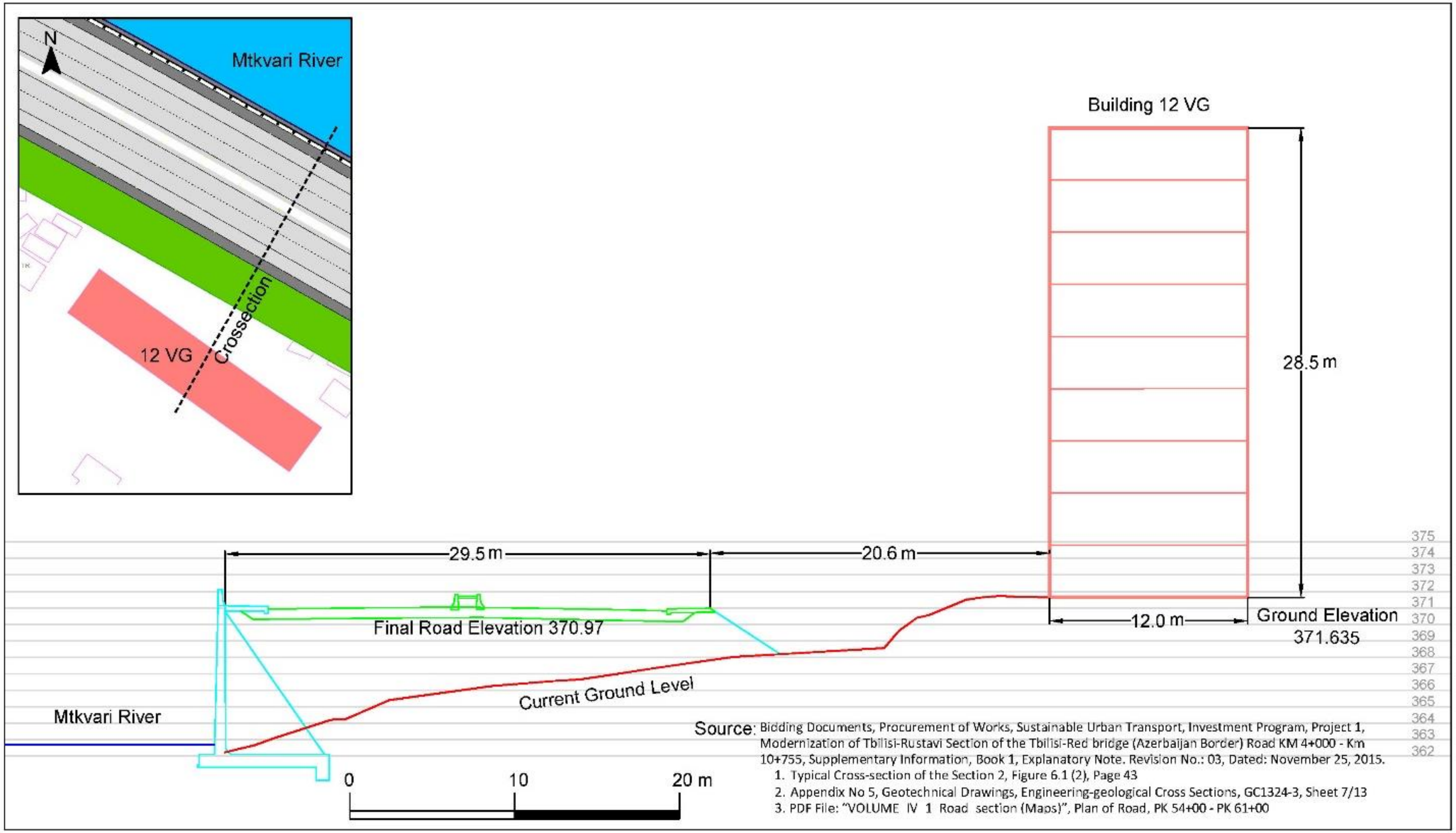


Figure 2-4: Cross Section of the Proposed Highway

Step 2: Undertake a noise measurement for calibration/quality assurance purpose. In this exercise, the traffic noise at four locations, between 8 and 150 m from the existing highway, were measured simultaneously. The noise from the counted highway traffic was modelled and compared with the observed data. A reasonably good agreement was found which gave confidence in the modeling.

Step 3: The existing baseline noise level was determined by modeling the current traffic volume, as reported in the feasibility study. The modeled levels are not expected to be exactly the same as the measured levels as the traffic volume on the day of measurement may not be identical to the reported average traffic volume. However, a reasonable good agreement was found.

Step 4: The individual receptors for modeling were identified. Representative receptors were selected to ensure spatial distribution in the Study Area, both horizontally and vertically. The receptors include various floors of buildings shown **Figure 2-3**. Further, both receptors facing the existing highway and the river were selected. In all 132 receptors were selected.

Step 5: The 'without mitigation' noise levels for each receptor in 2038 (20 years after commissioning of the Highway) was predicted.

Step 6: Various mitigation measures were identified. These included a) change in road pavement type, b) reduction in speed, c) erection of noise wall, and d) installation of noise tunnels. The impact of each one of these measures on noise reduction was assessed individually and in combination. Based on this exercise three different scenarios were selected which resulted in reduction of noise to the acceptable levels.

Step 7: For the selected scenarios complete modeling including the noise levels for 2018 and 2028 were modeled.

Step 8: Finally, the cost for each scenarios was estimated.

2.6 Glossary of Terms

A – Weighting	An internationally standardized frequency weighting which approximates the frequency response of the human ear and gives an objective reading, which therefore agrees with the subjective human response to that sound.
dB(A)	Sound Pressure Level in decibel which has been A-weighted, or filtered, to match the response of the human ear.
Decibel (db)	A logarithmic scale for sound corresponding to a multiple of 10 of the threshold of hearing.
Leq	The value of the average A-weighted sound pressure level measured continuously within a reference time interval, which have the same mean-square sound pressure as a sound under consideration whose level varies with time.
Noise	Sound which a listener does not wish to hear (unwanted sounds).

Sound Level	The level of the frequency weighted and time weighted sound pressure as determined by a sound level meter.
Sound pressure level	Of a sound, 20 times the logarithm to the base 10 of the ratio of the RMS sound pressure level to the reference sound pressure level. International values for the reference sound pressure level are 20 micropascals in air and 100 millipascals in water. SPL is reported as Lp in dB (not weighted) or in various other weightings.

3. Baseline Noise Level Measurement

30. Noise levels at 15 different locations were measured. The results indicate that the noise levels on the river side of the apartments are generally within the acceptable limit whereas those facing the existing Tbilisi-Rustavi Highway are considerably high.

3.1 Methodology

31. To determine the baseline noise levels, measurements were taken at representative sensitive receptors. These include twelve apartments where 24-hour noise levels were recorded and two locations near the school present in the vicinity where 4-hour measurements were taken during working hours of the school. These locations are described in **Table 3-1** and shown in **Figure 3-1**.

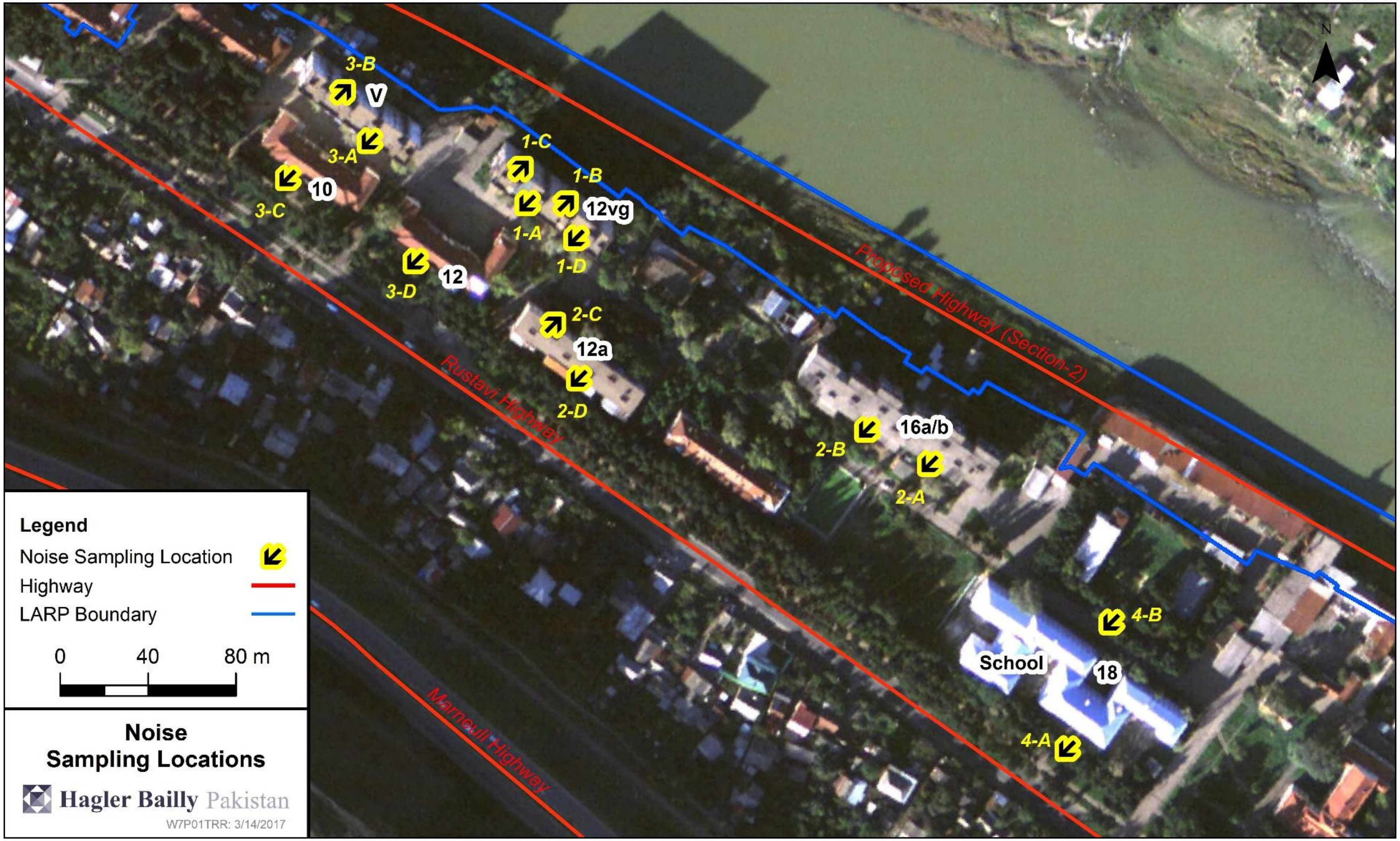
32. The survey was conducted from March 3 to March 6, 2017 using four Cirrus Research plc.'s sound level meters, Model CR:1720. The instrument meets the International standards IEC 61672-1:2002, IEC 660651:1979, IEC 60804:2001, IEC 61260:1995, IEC 60942:1997, IEC 61252:1993, ANSI S1.4-1983, ANSI S1.11-1986, and ANSI S1.43-1997 where applicable. The instruments have a resolution of 0.1 dB.

33. The meter were calibrated at the start and end of measurement at each site, using Cirrus Research plc.'s acoustic calibrator, Model CR:514. The instruments were mounted on tripods and a wind shield was used in all measurements. Photographs of the sampling locations are shown in **Figure 3-2**.

Table 3-1: Noise Level Sampling Locations

ID	Location				Date and time of Survey
	Building	Floor	Facing	Coordinates	
1-A	12 VG	Rooftop (above 9th floor)	Rustavi Highway and internal roads	44° 53' 40.7" E 41° 39' 32.6" N	Start: Mar 2, 10:22 am End: Mar 3, 11:36 am
1-B	12 VG	9th floor	Mtkvari River	44° 53' 41.4" E 41° 39' 32.6" N	Start: Mar 2, 10:32 am End: Mar 3, 11:30 am
1-C	12 VG	2nd	Mtkvari River	44° 53' 40.5" E 41° 39' 33.1" N	Start: Mar 2, 10:44 am End: Mar 3, 11:49 am
1-D	12 VG	1st	Rustavi Highway and internal roads	44° 53' 41.6" E 41° 39' 32.1" N	Start: Mar 2, 11:03 am End: Mar 3, 11:45 am
2-A	16 A/B	5th	Rustavi Highway and internal roads	44° 53' 48.6" E 41° 39' 28.7" N	Start: Mar 3, 12:25 pm End: Mar 4, 1:30 pm
2-B	16 A/B	1st	Rustavi Highway and internal roads	44° 53' 47.4" E 41° 39' 29.3" N	Start: Mar 3, 12:41 pm End: Mar 4, 1:11 pm
2-C	12a	2nd	Mtkvari River and internal roads	44° 53' 41.1" E 41° 39' 30.8" N	Start: Mar 3, 1:24 pm End: Mar 4, 1:21 pm
2-D	12a	3rd	Rustavi Highway and internal roads	44° 53' 41.7" E 41° 39' 30.0" N	Start: Mar 3, 1:11 pm End: Mar 4, 1:17 pm
3-A	V	5th	Rustavi Highway and internal roads	44° 53' 37.6" E 41° 39' 33.5" N	Start: Mar 4, 2:05 pm End: Mar 5, 1:57 pm

ID	Location				Date and time of Survey
	Building	**Floor**	**Facing**	**Coordinates**	
3-B	V	3rd	Mtkvari River	44° 53' 37.0" E 41° 39' 34.2" N	Start: Mar 4, 2:39 pm End: Mar 5, 1:55 pm
3-C	10	2nd	Rustavi Highway	44° 53' 35.9" E 41° 39' 33.0" N	Start: Mar 4, 3:37 pm End: Mar 5, 2:03 pm
3-D	12	2nd	Rustavi Highway	44° 53' 38.5" E 41° 39' 31.7" N	Start: Mar 4, 3:55 pm End: Mar 5, 2:09 pm
4-A	School	Open air	Rustavi Highway	44° 53' 51.3" E 41° 39' 24.5" N	Start: Mar 6, 9:08 am End: Mar 6, 12:54 pm
4-B	School	Open air	Internal roads	44° 53' 52.2" E 41° 39' 26.4" N	Start: Mar 6, 9:17 am End: Mar 6, 12:58 pm



Arrow indicates direction of microphone

Figure 3-1: Noise Level Sampling Locations


Sound meter at 1-A


Sound meter at 1-B


Sound meter at 1-C


Sound meter at 1-D


Sound meter at 2-A


Sound meter at 2-B


Sound meter at 2-C


Sound meter at 2-D

Sound meter at 3-A

Sound meter at 3-C

Sound meter at 3-D

Sound meter at 4-A

Sound meter at 4-B

Figure 3-2: Noise Level Sampling Photographs

3.2 Results

34. The sampling sites can be categorized into three categories. The results are discussed accordingly.

3.2.1 Locations Facing Rustavi Highway

35. The noise levels were highest in buildings directly facing the Rustavi Highway. Noise levels during both the daytime (between 62.1 to 77.6 dBA, with an average of 68.3 dBA) and nighttime (between 59.5 to 71.0 dBA, with an average of 64.1 dBA) did not comply with the IFC noise guidelines (see **Table 2-1**). On an average, the daytime and nighttime noise levels exceeded the by 13 dBA and 19 dBA, respectively.

3.2.2 Locations Facing Internal Roads

36. The noise levels were lower in buildings shielded from the Rustavi Highway by other buildings. Daytime noise levels (between 52.0 to 65.1 dBA, with an average of 57.1

dBA) were in compliance at 3 of the 6 measurement locations whereas, the nighttime noise levels (between 48.5 to 51.9 dBA, with an average of 50.1 dBA) did not comply with IFC noise guidelines and the non-compliance was within 3.5 to 6.9 dBA.

3.2.3 Locations Facing the Mtkvari River

37. The noise levels were low here characterized by the lowest L_{10} readings of 50.5 and 51.5 dBA. L_{10} is used to indicate anthropogenic noise influence in the area. The daytime noise levels (between 52.3 and 52.9, with an average of 52.6 dBA) were in compliance with IFC noise guidelines whereas, the nighttime noise levels (between 47.5 and 49.1, with an average of 48.3 dBA) did not comply with the IFC noise guidelines and the non-compliance was within 2.5 to 4.1 dBA.

38. The complete results are presented in **Table 3-2** and are plotted in **Figure 3-3**. Daytime averages are calculated for 7 am to 10pm and nighttime for 10 pm to 7 am according to IFC-EHS guidelines. Reported sound levels are on the A scale, which covers the full audio range and is relatable to human hearing.

Table 3-2: Noise Level Sampling Results

	L_{10}	L_{50}	L_{90}	24 hour L_{eq}	Daytime L_{eq}	Nighttime L_{eq}
Facing Rustavi Highway						
2-A	63.8	60.4	51.8	61.3	62.1	59.5
2-D	79.6	73.2	61.2	76.1	77.6	71.0
3-C	68.8	64.9	54.8	65.6	67.0	62.3
3-D	68.9	64.6	54.6	66.9	68.3	63.4
4-A	69.1	65.3	59.7		66.4	
Facing Internal Roads						
1-A	55.6	52.5	46.8	53.0	54.2	49.6
1-D	54.4	49.0	40.7	53.5	55.0	48.4
2-B	59.3	55.0	45.6	58.2	59.8	51.9
2-C	58.8	52.2	46.0	63.2	65.1	51.9
3-A	53.5	50.3	44.4	51.0	52.0	48.5
4-B	56.2	49.0	46.5		56.5	
Facing Mtkvari River						
1-B	51.5	49.1	47.7	51.4	52.3	49.1
1-C	50.5	47.3	45.4	51.6	52.9	47.5
3-B	59.4	53.0	48.8	56.3	56.5	55.8

Note: Measured values at location 3-B were discarded as the wind speed was very high. Other locations on the same day were shaded by the buildings.

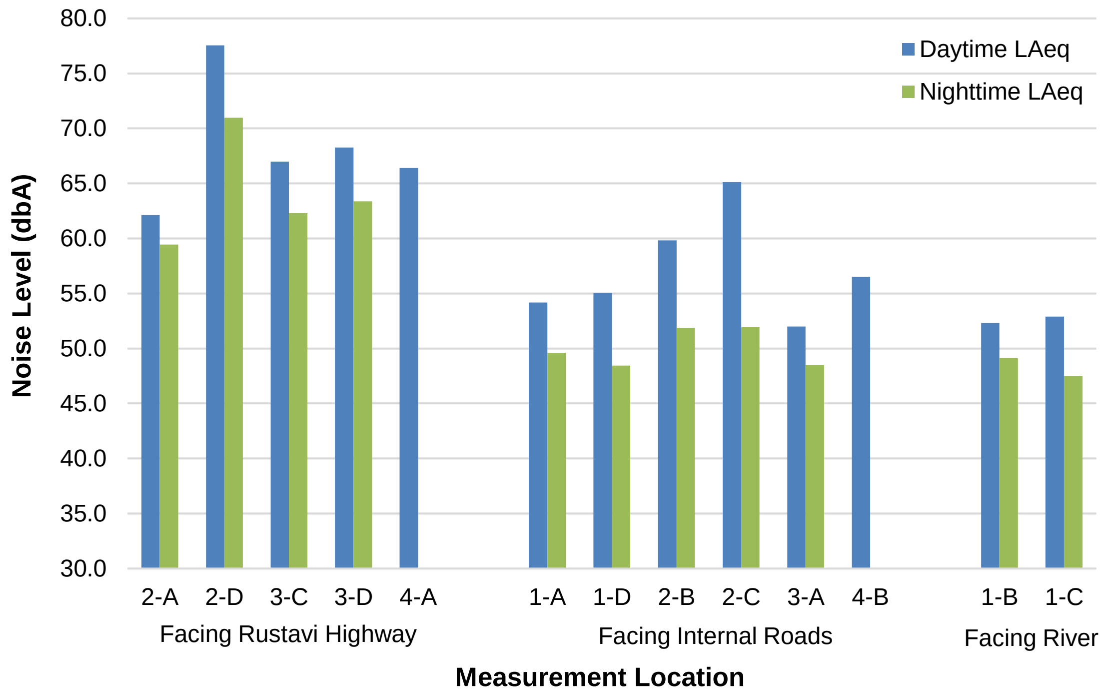


Figure 3-3: Noise Level Sampling Results

4. Model Development and Methodology

39. The impact on noise levels due to the proposed road was determined by modelling the noise generated by the motor vehicles on this road.

40. The noise model, SoundPLAN Essential Version 4.0 by Braunstein + Berndt GmbH / SoundPLAN International LLC was used. The model is capable of modeling noise levels in three-dimensions.

4.1 Model Verification

41. Verification of the model comprised of checking whether the measured and modelled noise levels of known amounts of traffic were similar and adjustments made if required. A relatively flat and open area was selected on the existing Tbilisi-Rustavi Highway. It was made sure that there were no other major noise sources in the vicinity. Four noise meters were installed at a distance of 8 m, 50 m, 100 m and 150 m from the Rustavi Highway, respectively. The weather meter was also installed simultaneously.

42. Noise levels were measured for 4.5 hours in four different intervals. For each interval the corresponding traffic count on the road was also carried out. Photographs of the measurement locations are shown in **Figure 4-1**.

43. Modelling for the traffic volume counted was carried out and compared with the results with measured noise levels. The results of the exercise is presented in **Table 4-1**. The average traffic speed was estimated to be 80 km/hr.

44. It is observed that except for very short distances, where the model appears to underestimate the noise level, a reasonably good agreement is found. The discrepancy is probably due to varying speed of the vehicles.

Sound meter at 8 m from Rustavi Highway

Sound meter at 50 m from Rustavi Highway

Sound meter at 100 m from Rustavi Highway

Sound meter at 150 m from Rustavi Highway

Weather meter at calibration location

Traffic count at calibration location

Figure 4-1: Calibration Exercise Photographs

Table 4-1: Comparison of Measured and Modelled Noise Levels (dBA)

		Measured	Modeled	Difference
Time:1:45 - 2:45; Traffic: LTV:1411 HTV: 78				
Temperature: 9.75C; Relative Humidity: 68.02%; Pressure 984.77 mb, Wind speed calm	8 m	77.2	74.0	3.2
	50 m	63.6	63.2	0.4
	100 m	59.0	58.9	0.1
	150 m	56.7	56.1	0.6
Time: 3:00 - 4:00; Traffic: LTV:1410 HTV: 75				
Temperature: 9.75C, Relative Humidity: 72.28%, Pressure 984.08 mb, Wind speed calm	8 m	77.2	73.9	3.3
	50 m	64.5	63.1	1.4
	100 m	59.2	58.8	0.4
	150 m	57.4	56.0	1.4
Time: 4:00 - 5:00; Traffic: LTV:1862 HTV: 108				
Temperature: 10.20 C, Relative Humidity: 68.14 %, Pressure 983.86 mb, Wind speed calm	8 m	76.9	75.3	1.6
	50 m	63.4	64.5	-1.1
	100 m	59.4	60.2	-0.8
	150 m	56.9	57.4	-0.5
Time: 5:00 - 6:00; Traffic LTV:1614 HTV: 90				
Temperature: 10.04 C, Relative Humidity: 71.58 %, Pressure 983.60 mb, Wind speed calm	8 m	76.9	74.6	2.3
	50 m	64.1	63.8	0.3
	100 m	58.9	59.5	-0.6
	150 m	56.6	56.7	-0.1
Time: 6:00 - 6:30; Traffic: LTV:1141 HTV: 30				
Temperature: 9.87 C, Relative Humidity: 73.76 %, Pressure 983.41 mb, Wind speed calm	8 m	77.0	72.2	4.8
	50 m	63.8	61.4	2.4
	100 m	58.9	57.0	1.9
	150 m	55.2	54.3	0.9
Average: Time 1:45 – 6:30 Traffic: LTV:1488 HTV: 78				
Temperature: 10 C, Relative Humidity: 71 %, Pressure 984 mb, Wind speed calm	8 m	77.0	74.1	2.9
	50 m	63.9	63.3	0.6
	100 m	59.1	59.0	0.1
	150 m	56.6	56.2	0.4

4.2 Model Scenarios

45. The following traffic scenarios were used for the assessment:

- **Scenario 1:** Current Baseline or 2017
- **Scenario 2:** Unmitigated Noise Levels for 2038
- **Scenario 3+:** Mitigated Noise Levels for 2018, 2028,and 2038 (multiple scenarios)

4.3 Model Assumptions and Inputs

46. The following inputs were used to develop the model:

- Estimated traffic projections as obtained from the Bidding Documents of the Project are presented in **Table 4-2.**
- Based on the 19 hour traffic count in the Bidding Documents it was calculated that 92% of LTV (light transport vehicle) and 90% of HTV (heavy transport vehicle) traffic is during day hours. Hourly day and nighttime traffic used in the model is presented in **Table 4-3**.
- 5% of the traffic on the proposed Project road will travel on the current Tbilisi-Rustavi Highway.
- Speed on the roads are assumed to be:
  - i. Marneuli Highway: 80 km/h
  - ii. Current Tbilisi-Rustavi Highway: 60 km/h
- Road Surface for existing roads: Smooth Asphalt
- Road surface for improved road surface option: Porous asphalt, pore>15%/0/8 (results in decrease noise at source by 5dB)
- Road elevation of the proposed road was obtained from the Detailed Design, whereas the elevation of the Marneuli Highway and current Tbilisi-Rustavi Highway were obtained from the 1 m DEM. This is shown in **Figure 4-2.**
- Trees and grassland were assumed as volume attenuation areas, with the average height of trees as 7 m.
- 1-m resolution Digital Elevation Model (DEM) was used.
- Each receptor was separately identified, with location, building height and number of floors
- Building floors were noted during the field survey and an average floor height of 2.8 m (based on field measurements of 3 buildings) was used.
- Weather parameters used were temperature: 13ºC, humidity: 70% and pressure 1013 mb.

47. A 3 dimensional view of the model set up is shown in **Figure 4-3**.

Table 4-2: Traffic on Key Roads as Presented in Detailed Design Report

Scenario	Year	Marneuli Highway		Current Tbilisi-Rustavi Highway		Proposed Project Road	
		LTV	HTV	LTV	HTV	LTV	HTV
Scenario 1	2017	11,340	620	25,304	1,386	0	0
Scenario 2	2018	11,770	646	1,313	72	24,950	1,367
Scenario 3	2028	14,678	805	1,638	90	31,115	1,707
Scenario 4	2038	17,893	982	1,996	110	37,929	2,081

Table 4-3: Calculated Hourly Traffic on Key Roads

Scenario	Marneuli Highway				Current Rustavi Highway				Proposed Project Road			
	Daytime		Nighttime		Daytime		Nighttime		Daytime		Nighttime	
	LTV	HTV	LTV	HTV	LTV	HTV	LTV	HTV	LTV	HTV	LTV	HTV
Scenario 1	696	37	101	7	1,552	83	225	15	0	0	0	0
Scenario 2	722	39	105	7	81	4	12	1	1,530	82	222	15
Scenario 3	900	48	130	9	100	5	15	1	1,908	102	277	19
Scenario 4	1097	59	159	11	122	7	18	1	2,326	125	337	23

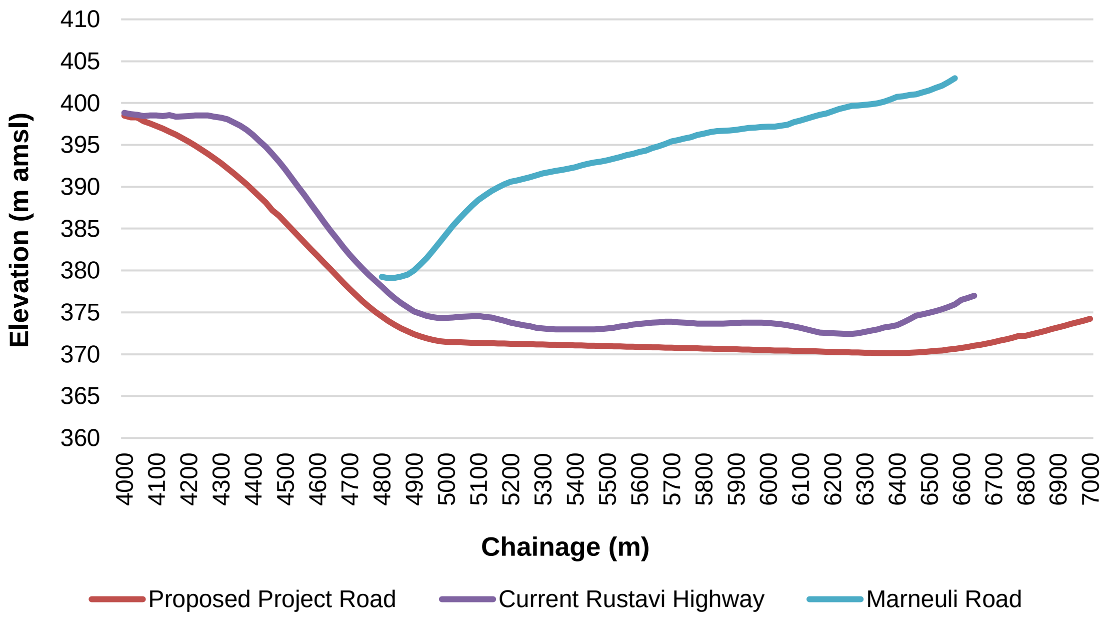


Figure 4-2: Elevation of Key Roads

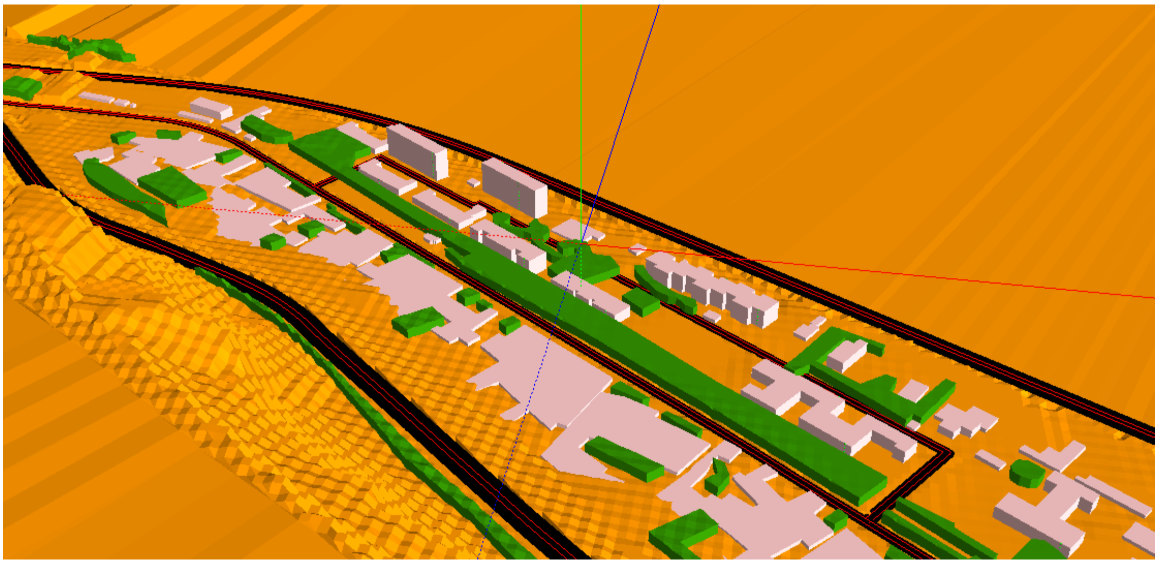


Figure 4-3: 3D View of Model Setup

5. Model Outputs

48. The model output comprises both the noise grid map and noise levels at individual receptors, located on ground or on various floors of the buildings. The results are describes in the chapter.

5.1 The Current Baseline, Scenario 1

49. Grid noise maps for Scenario 1 are presented in **Figure 5-1** and **Figure 5-2**. The following conclusions can be drawn:

- The noise levels at structures along the current Rustavi Highway are exceeding the IFC noise guidelines for both daytime and nighttime (i.e. over 55 dBA during the day and over 45 dBA during the night, as seen from the respective grid noise maps).
- The noise levels at the façade facing the current Rustavi Highway but behind the first row of structures also exceeds the IFC noise guidelines, however, the exceedance is not severe.
- The noise levels at the façade facing away from the current Rustavi Highway and along the Mtkvari River are in compliance with IFC noise guidelines. This is due to the multiple levels of screening that is provided by the buildings between them and the current Rustavi Highway.

50. The results of Scenario 1 or the current baseline as compared to the measured values are shown in **Table 5-1**. Possible reasons for the discrepancies can be:

- Traffic data on the days of measurement could be different from the annual average daily traffic, including both the total and the day and night time distribution.
- Other noise sources such as community noise from local markets, televisions, barking of dogs, horns from cars, and maintenance work may have been included in the measured values.

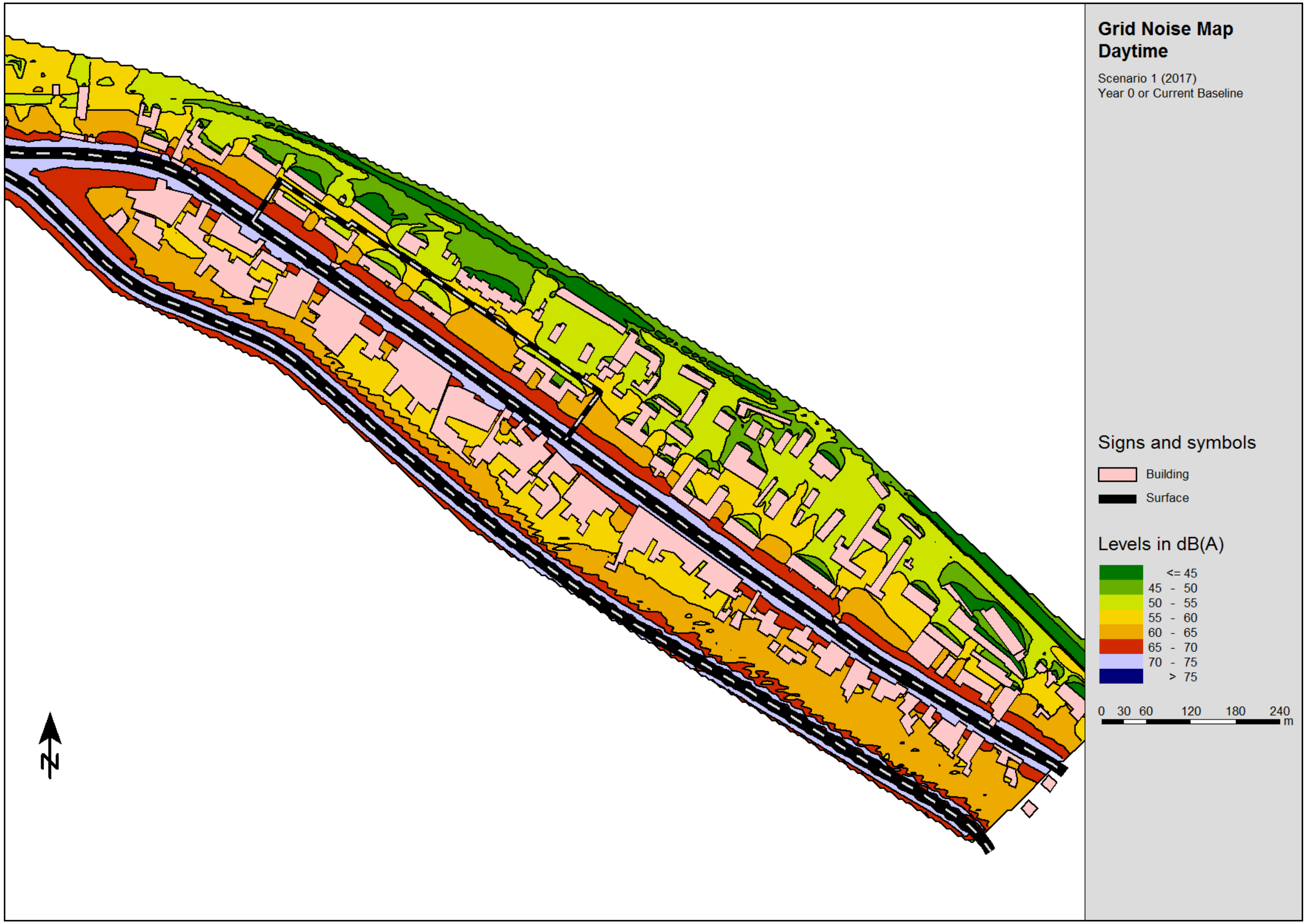


Figure 5-1: Grid Noise Map for Current Baseline (Scenario 1), Daytime Noise Levels

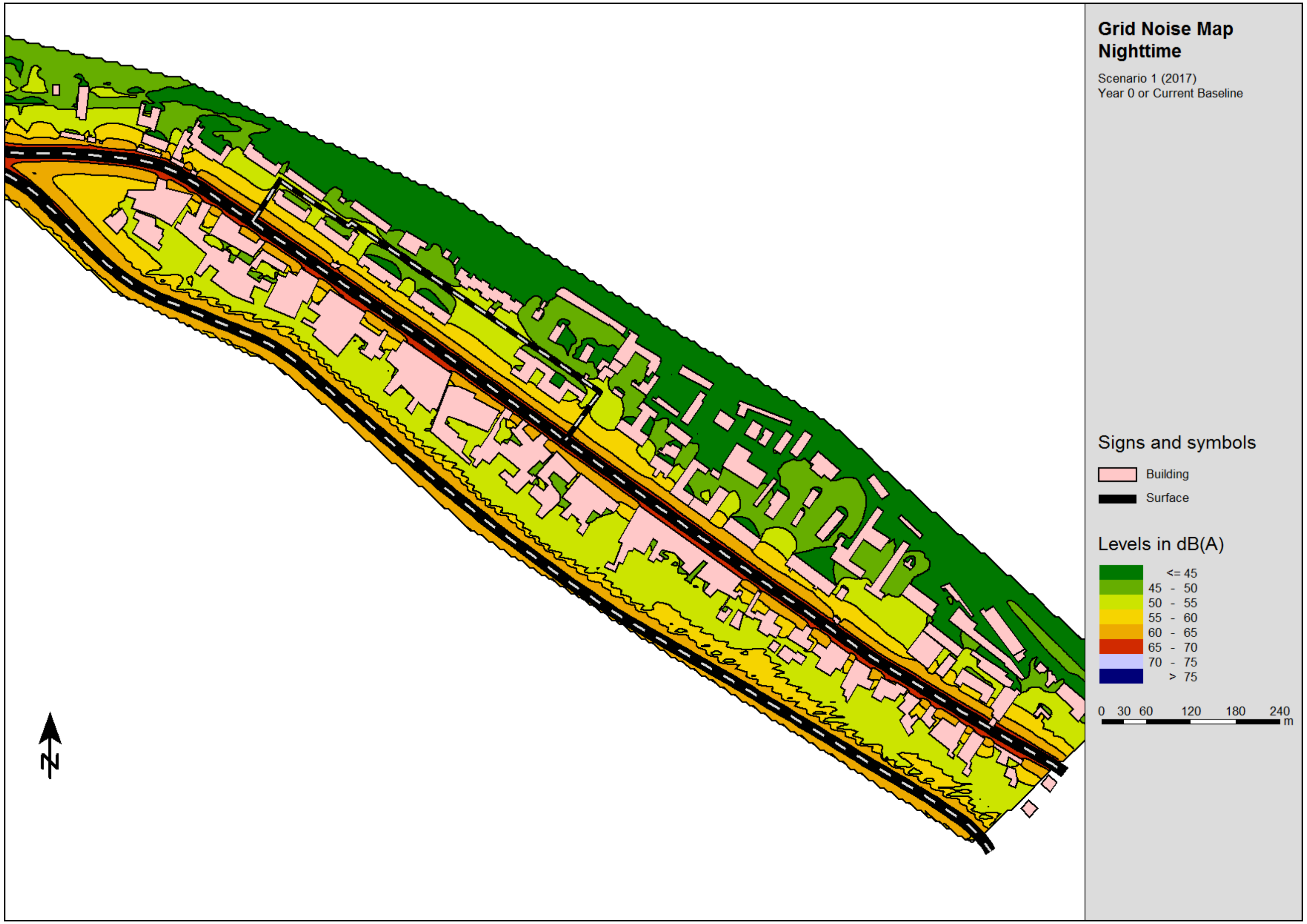


Figure 5-2: Grid Noise Map for Current Baseline (Scenario 1), Nighttime Noise Levels

Table 5-1: Comparison of Measured and Modelled Baseline Noise Levels

	Daytime Leq		**Nighttime Leq**	
	Measured	**Modelled**	**Measured**	**Modelled**
Facing Rustavi Highway				
2-A	62.1	59.8	59.5	52.1
2-D	77.6	66.4	71.0	58.5
3-C	67.0	65.0	62.3	57.2
3-D	68.3	64.1	63.4	56.3
4-A	66.4	63.5		
Facing Internal Roads				
1-A	54.2	61.9	49.6	54.1
1-D	55.0	55.4	48.4	48.1
2-B	59.8	57.3	51.9	49.6
2-C	65.1	49.0	51.9	42.3
3-A	52.0	62.6	48.5	54.9
4-B	56.5	48.4		
Facing Mtkvari River				
1-B	52.3	47.4	49.1	39.5
1-C	52.9	32.2	47.5	24.4
3-B	56.5	34.2	55.8	26.4

5.2 The Unmitigated Noise Levels for 2038, Scenario 2

51. The unmitigated scenario for 2038 traffic is described as follows:

- Speed: 80 km/h
- Pavement: Standard asphalt
- Protection: None

52. Grid noise maps for Scenario 2 are presented in **Figure 5-3** and **Figure 5-4**. Comparison of **Figures 5-3** and **5-4** with **Figures 5-1** and **5-2**, respectively, shows a significant increase of noise level is anticipated in almost all areas if no mitigation measures are introduced.

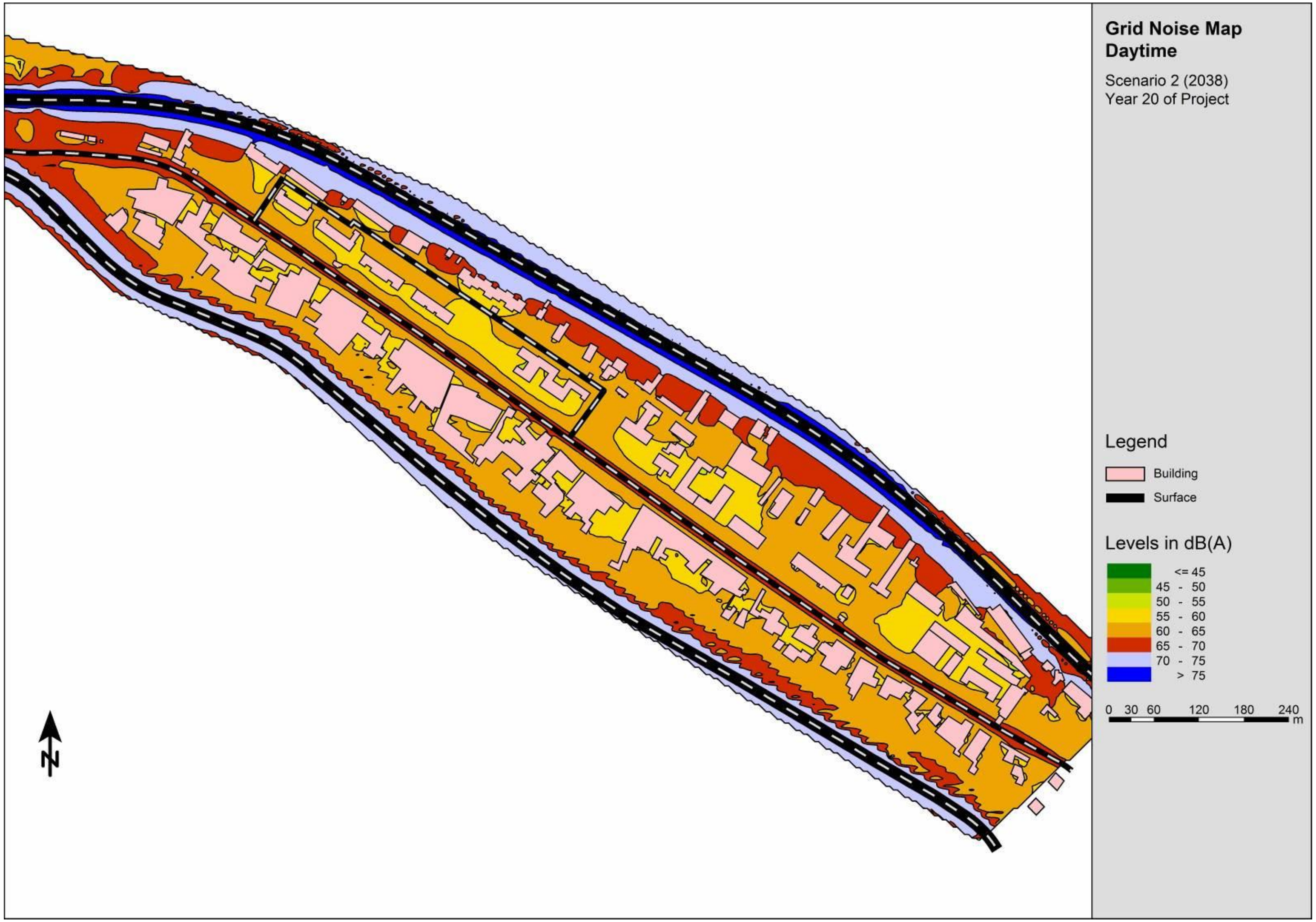


Figure 5-3: Grid Noise Map for Scenario 2, Daytime Noise Levels

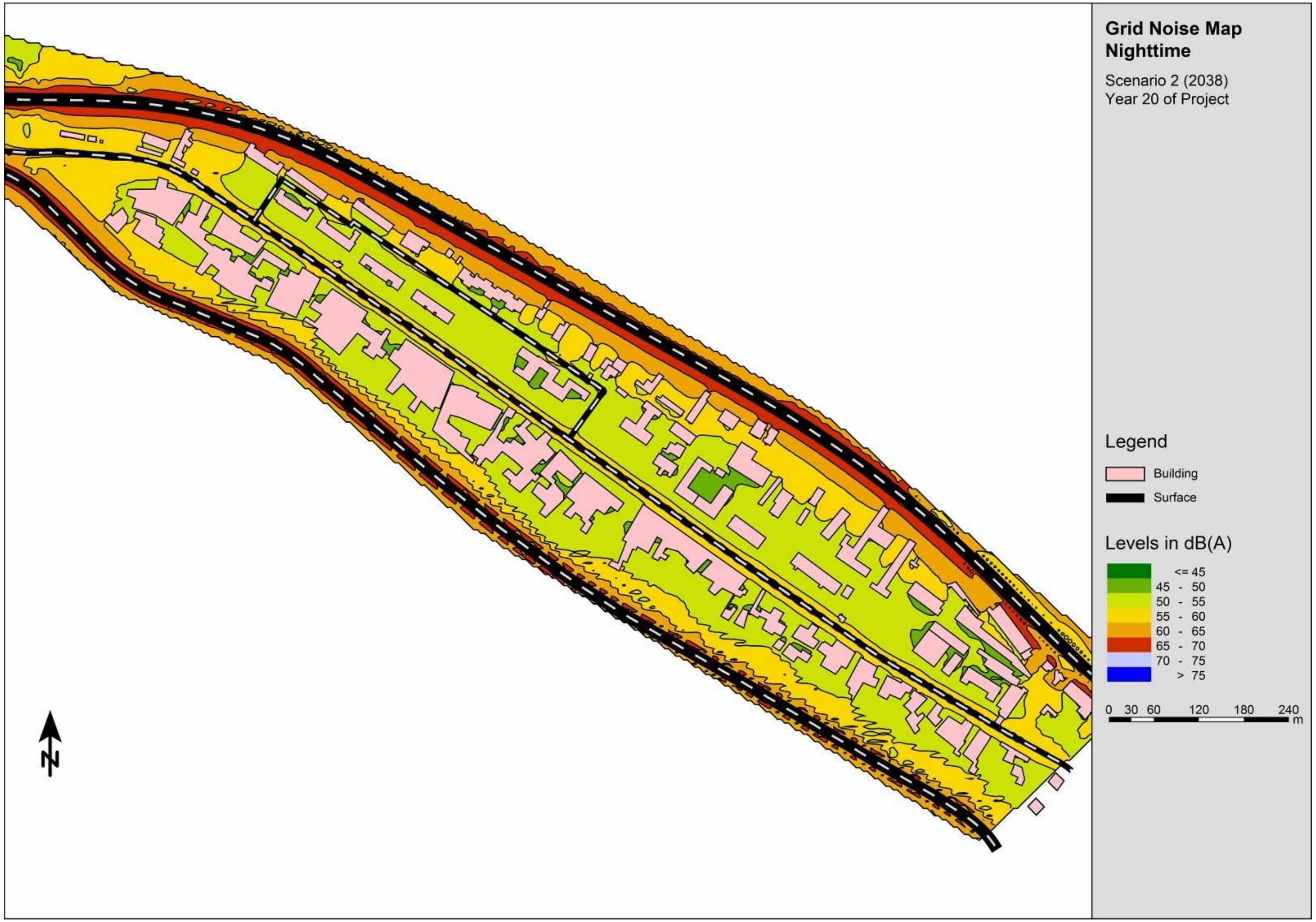


Figure 5-4: Grid Noise Map for Scenario 2, Nighttime Noise Levels

5.3 Impact of Mitigation Measures, Scenarios 3+

53. A large set of mitigation measures were considered to see their possible effectiveness. The mitigation measures considered are summarized in **Table 5-2**. These include combinations of the following:

- **Speed Reduction:** Reduction of speed limit (to 60 km/h and 40 km/h) on Project Road.
- **Noise Wall:** Initially an 8-m noise wall along the road on the side facing the apartments. This was followed by a combination of 3, 5, 8, and 9-m noise walls.
- **Noise Tunnel:** Noise tunnel along high-rise apartments.

Table 5-2: Mitigation Measures Considered

ID	Description	Noise Wall	Speed (km/h)	Road Surface	Tunnel
UM	No mitigation (Base case)	None	80	Smooth asphalt	No
IEE 80	Initial Environmental Examination (IEE) Scenario at 80 km/h	As in IEE (3, 5, and 8 meter combination)	80	Smooth asphalt	No
IEE 60	IEE Scenario at 60 km/h	As in IEE (3, 5, and 8 meter combination)	60	Smooth asphalt	No
SR 60	Speed reduction	None	60	Smooth asphalt	No
SR 40	Speed reduction	None	40	Smooth asphalt	No
IRS	Improved road surface	None	80	Porous asphalt	No
W	Noise wall	8 m	80	Smooth asphalt	No
W’	Noise wall	9 m	80	Smooth asphalt	No
W2	Two noise walls, one on the median and one facing the apartments	8 m	80	Smooth asphalt	No
W2 + SR 60	2 noise walls and reduced speed to 60 km/h	8 m	60	Smooth asphalt	No
W2 + IRS	2 noise walls and improved road surface	8 m	80	Porous asphalt	No
W + IRS	Wall and improved road surface	8 m	80	Porous asphalt	No
W + SR 60	Wall and reduced speed to 60 km/h	8 m	60	Smooth asphalt	No
W + T	Noise wall and tunnel	8 m	80	Smooth asphalt	Yes
W + T + IRS	Noise wall, tunnel, and improved road surface	8 m	80	Porous asphalt	Yes

54. In order to compare the impact of each mitigation measure, a system of rating is used as described in **Table 5-3.** As per the IFC noise guidelines, there are two criteria:

- Final noise level shall not exceed the guidelines values (**Table 2-1**),
- The increase shall not be more than 3 dBA.

Table 5-3: Severity Classification of Compliance with Noise Levels

Project Impact	Magnitude of Change	Final Noise Levels	Rating	
Increase	≥ 3 dBA	Exceeds noise guidelines	**–2**	Unacceptable
Increase	< 3 dBA	Exceeds noise guidelines	**–1**	Acceptable but not preferable
Increase	≥ 3 dBA	Within noise guidelines	**–1**	Acceptable but not preferable
Increase	< 3 dBA	Within noise guidelines	**0**	Neutral
No change	0	Exceeds noise guidelines	**0**	Neutral
No change	0	Within noise guidelines	**0**	Neutral
Decrease	Any amount	Exceeds noise guidelines	**+1**	Good
Decrease	Any amount	Within noise guidelines	**+2**	Very Good

55. Ideally both criteria shall be complied with. Non-compliance with both is considered unacceptable and hence a score of –2. Compliance with one is acceptable but not preferable. A +2 rating is given to receptors where the noise levels after the project will decrease and will comply with the IFC noise guidelines. The decrease will take place due to relocation of highway traffic.

56. The rating is applied to the receptors in each floor of the selected buildings and on both sides of the building. The resulting number of receptors is shown in **Table 5-4**.

Table 5-4: The Receptors for Noise Assessment

Building	Floors								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Apt (#10)	X	X							
Apt (#12 A)	X	X	X	X	X				
Apt (#12 VG)	X	X	X	X	X	X	X	X	X
Apt (#12)	X	X							
Apt (#14)	X	X	X						
Apt (#16 A/B)	X	X	X	X	X				
Apt (#8)	X	X							
Apt (#V)	X	X	X	X	X	X	X	X	X
Church	X	X							

Building	Floors								
	1	2	3	4	5	6	7	8	9
Clinic	X								
Empty University	X	X	X	X					
Mixed Use (1)	X	X	X	X					
Open University	X	X	X	X					
Rose Hotel	X	X	X						
SBA	X	X	X						
School	X	X	X						
Under-construction Apartment	X	X	X	X	X				

Note: All apartments on the same floor of one façade of a building are considered as one receptor. There are two receptors on each floor, one facing southwest (hillside) and one facing northeast (riverside).

57. Using this rating the impact of the mitigation measures (**Table 5-2**) are summarized in **Table 5-5.** The –2 rating indicates a noncompliance with the IFC noise guidelines and is unacceptable. The –1 rating meets only one of the noise criteria. It is thus acceptable but is not preferable. The neutral rating 0 indicates that either there is no change in the noise level or in case of a change it complies with both criteria. The rating +1 indicates that the noise level has reduced for the receptor and +2 indicates that the reduction is such that noise level will come in compliance with the IFC noise guidelines.

58. The following conclusions can be drawn from **Table 5-5**:

- Under the unmitigated condition, noise levels for nearly half of the receptors are noncompliant with the IFC criteria.
- The reduction in speed has marginal effect. There is no benefit of reducing the traffic speed to 60 km/h from 80 km/h as the number of non-compliant receptors remains unchanged. Further reduction to 40 km/h also has marginal benefit as the number of non-compliant receptors remain large.

Table 5-5: Mitigation Options (Year 20 of Project or 2038)

Mitigation	Time Period	Number of Receptors				
		-2	-1	0	+1	+2
UM – Unmitigated	Daytime	61	2	2	60	7
	Nighttime	61	4	0	67	0
As proposed in the IEE						
IEE 80 – As proposed in the IEE (80 km/h)	Daytime	35	23	4	55	15
	Nighttime	46	15	1	69	1
IEE 60 – As proposed in the IEE (60 km/h)	Daytime	35	22	5	55	15
	Nighttime	46	15	1	69	1

Mitigation	Time Period	Number of Receptors				
		-2	-1	0	+1	+2
Stand Alone Measures						
SR 60 – Reduced speed (60 km/h)	Daytime	61	2	2	59	8
	Nighttime	61	4	0	67	0
SR 40 – Reduced speed (40 km/h)	Daytime	50	11	1	53	17
	Nighttime	58	3	1	70	0
IRS – Improved road surface	Daytime	49	12	1	52	18
	Nighttime	57	4	1	67	3
W – Noise wall (8 m)	Daytime	15	26	10	48	33
	Nighttime	21	21	9	64	17
W' – Noise wall (9 m)	Daytime	12	27	11	45	37
	Nighttime	18	21	11	64	18
W2 – 2 Noise walls	Daytime	14	26	11	46	35
	Nighttime	21	20	10	64	17
Combinations						
W2 + SR 60 – 2 Noise walls	Daytime	14	26	11	46	35
	Nighttime	21	20	10	64	17
W2 + IRS – 2 Noise walls	Daytime	10	20	15	43	44
	Nighttime	13	17	15	60	27
W + IRS – Wall and improved road surface	Daytime	10	22	13	43	44
	Nighttime	13	19	12	60	28
W + T – Noise wall and tunnel	Daytime	0	34	11	45	42
	Nighttime	0	35	10	62	25
W + SR 60 – Wall and reduced speed (60 km/h)	Daytime	14	27	10	46	35
	Nighttime	21	21	9	64	17
W + T + IRS – Noise wall, tunnel and improved road surface	Daytime	0	32	11	43	46
	Nighttime	0	32	10	61	29

- The noise wall suggested in the IEE,[1] including the additional measure of reducing the speed is insufficient as the noise levels of a large number of receptors remain non-compliant.
- The improved road surface is also not viable as it results in only a marginal decrease in the number of receptors with non-compliant noise levels.

[1] Initial Environmental Examination, GEO: Sustainable Urban Transport Investment Program – Tranche 3, Tbilisi-Rustavi Urban Road Link (Section 2), Prepared by Municipal Development Fund of Georgia for the Asian Development Bank. December 2015.

- Comparison of the options **W** and **W + SR 60** shows only a marginal difference. Therefore, the latter option is redundant. Similarly, the comparison of options **W + T** and **W + T + IRS** also indicates that the IRS will be an unnecessary measure.
- Comparison of the options **W** (wall with 8 m height) and **W'** (wall with 9 m height) shows a decrease in the noise levels resulting in compliance of some floors.
- Similarly, addition of a second noise wall on the median of the road also has marginal impact whether as a standalone measure (**W2**) or in combination (**W2 + SR 60** and **W2 + IRS**)

59. Therefore, the mitigation options that are likely to be technical feasible are:

- **W** (Noise wall)
- **W + IRS** (Noise wall and improved road surface)
- **W + T** (Noise wall and tunnel)

60. Of these, the first two will require additional measure of relocating some buildings in order to achieve complete compliance.

5.4 Optimization

61. The modeling was initially carried out assuming 8 m high wall throughout the length of the road in the Study Area. This may be over-estimate and therefore unnecessary. A separate option of 9 m wall was also modelled to assess its impact on noise reduction, however, the technical feasibility of such wall is doubtful so it is used only in exceptional conditions. Following the selection of the three options listed above, the size of the noise wall was reduced by 'hit and trial' method. The target was to find the smallest noise wall area that still result in the same level of noise mitigation as listed in **Table 5-5**.

5.5 Final Mitigation Options

62. The details of the mitigation options are described in **Table 5-6.** Three mitigation options are selected as follows:

- **W** (Noise wall with maximum height of 8 m). In this two noise walls are recommended, one 6-m high, 988 m long wall and the second 8-m high 640 m long wall. These wall will not achieve complete abatement and will therefore require relocation of 5 buildings as shown in **Figure 5-6**.
- **W'** (Noise wall with maximum height of 9 m). In this three noise walls are recommended—one 6-m high, 1,120 m long, the second 8-m high 240 m long and the third 9-m high 268 m long. These walls will not achieve complete abatement and will therefore require relocation of 4 buildings as shown in **Figure 5-6.** It may be noted that the optimization of the noise wall is done following the removal of the four buildings.
- **W + IRS** (Noise wall with improved road surface). One noise wall and improved road surface is recommended. The noise wall will be 5 m high and 1,628 m long. Thus its area will be about 26% less than that of previous option (noise wall only). The improved road surface will require replacing the standard asphalt with porous asphalt to reduce noise at source on 1.6 km of the road

surface. Like the previous option, this option will also require relocation of 4 buildings as shown in **Figure 5-7**.

- **W + T** (Noise wall with tunnel). One tunnel and a noise wall is recommended. The tunnel will stretch to a length of 560 m and will cover both carriageways. Its height will be 5 m, which is the same as that of the tunnel under the railway line. Two noise walls are recommended, one 5-m high, 880 m long wall and the second 8-m high and 188 m long wall. The total area of the walls will be about 46% less than that of noise wall only option (**Figure 5-8**).

63. The ground level grid noise maps, for daytime and nighttime, corresponding to the above scenarios are presented in **Figure 5-9** to **Figure 5-14**.

64. Relocation will be required for up to five buildings in three mitigation options (**W**, **W'** and **W + IRS**). The predicted noise levels in 2018, 2028 and 2038 for receptors in the affected buildings are given in **Table 5-7** and **Table 5-8**.

65. As two of the mitigation options required removal of buildings, the model was run again for these option with the buildings remove to assess their impact on noise levels. Although minor changes (less than 3 dBA) resulted in the noise level, the overall pattern remained the same.

Table 5-6: Details of Mitigation Options

Mitigation Options	Wall Dimensions	Tunnel Dimension	Improved Road Surface Dimension	Buildings to be relocated (Building name, land area and number of floor)
W (maximum height of noise wall 8 m)	Wall 1: 988 m × 6 m; Area 5,928 m^2 Wall 2: 640 m × 8 m; Area 5,120 m^2 Total: 11,048 m^2			Rose Hotel, 487 m^2, 3 floors Apt #8, 801 m^2, 2 floors Apt #V, 725 m^2, 9 floors Apt #12VG, 730 m^2, 9 floors Apt #16A/B, 1,629 m^2, 5 floors
W’ (maximum height of noise wall 9 m)	Wall 1: 1,120 m × 6 m; Area 6,720 m^2 Wall 2: 240 m × 8 m; Area 1,920 m^2 Wall 3: 268 m × 9 m; Area 2,412 m^2 Total: 11,052 m^2			Apt #8, 801 m^2, 2 floors Apt #V, 725 m^2, 9 floors Apt #12VG, 730 m^2, 9 floors Apt #16A/B, 1,629 m^2, 5 floors
W + IRS	Wall 1: 1,628 m × 5 m; Area 8,140 m^2		Type: Porous Asphalt Length: 1,628 m Width: 16 m	Apt #8, 801 m^2, 2 floors Apt #V, 725 m^2, 9 floors Apt #12VG, 730 m^2, 9 floors Apt #16A/B, 1,629 m^2, 5 floors
W + T	Wall 1: 880 m × 5 m; Area 4,440 m^2 Wall 2: 188 m × 8 m; Area 1,504 m^2 Total: 5,944 m^2	Length: 560 m Width: 29.5 m Height: 5 m		

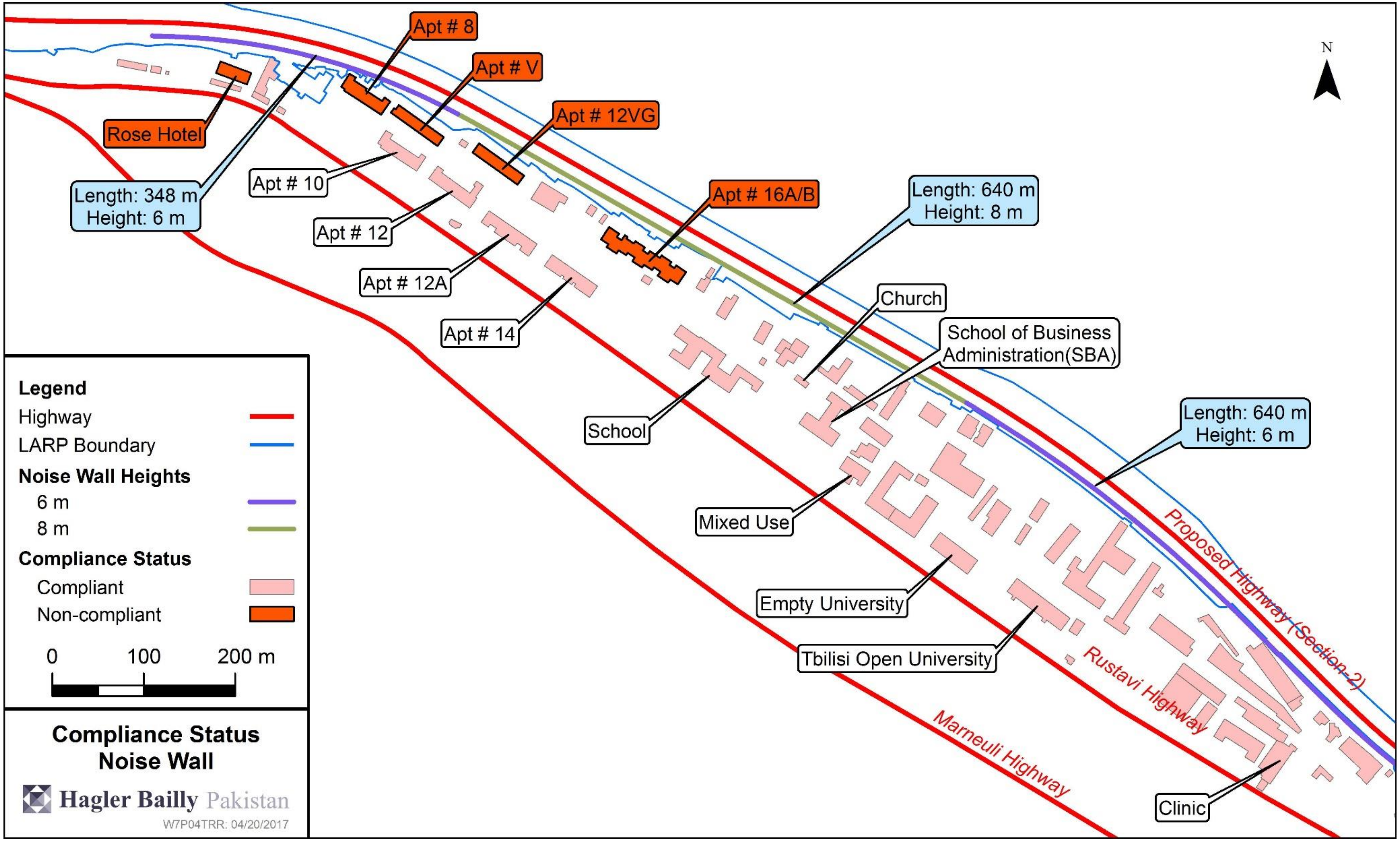


Figure 5-5: Layout and Compliance Status for Noise Wall (Maximum height of 8 m) Mitigation Scenario

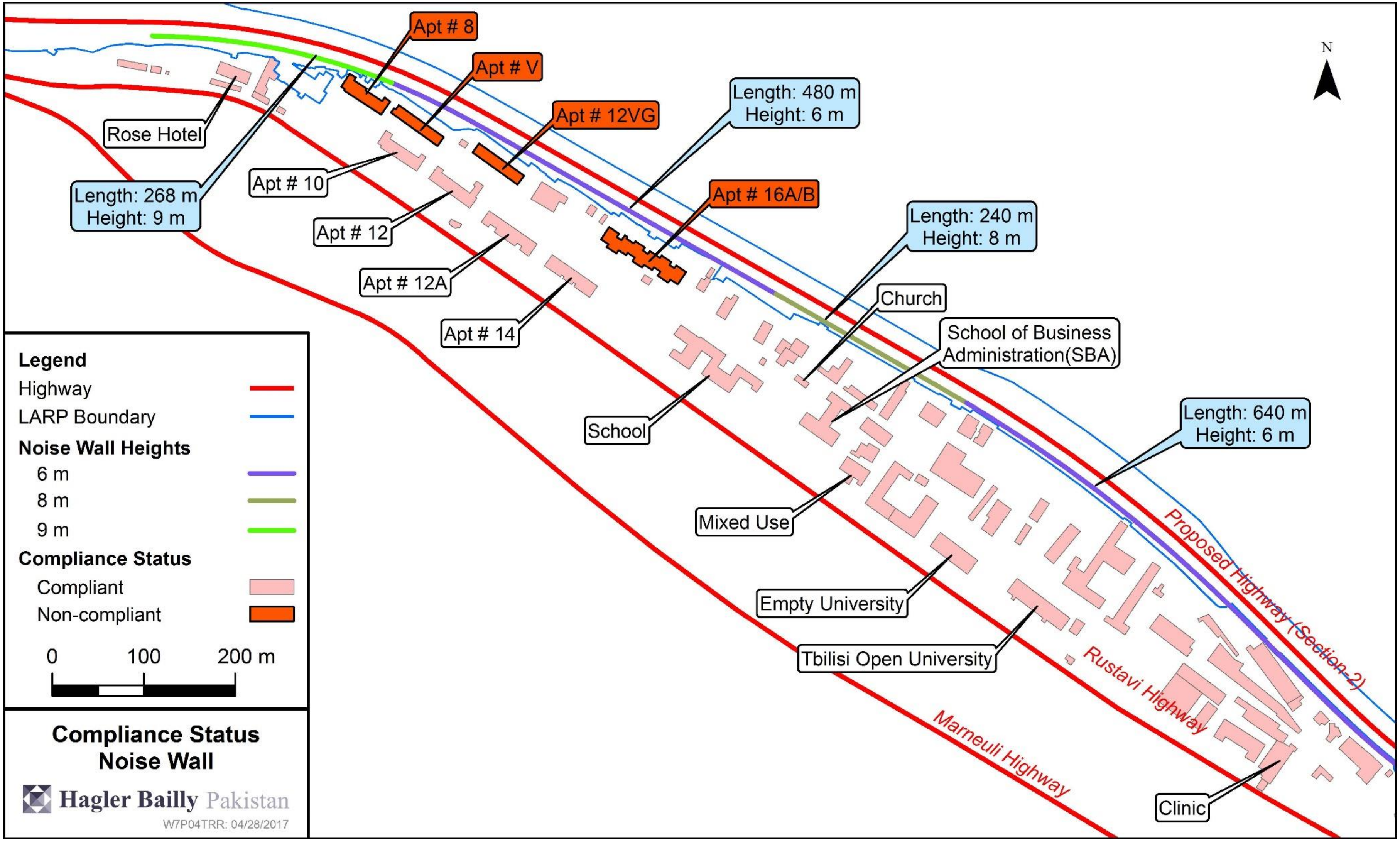


Figure 5-6: Layout and Compliance Status for Noise Wall (Maximum height of 8 m) Mitigation Scenario

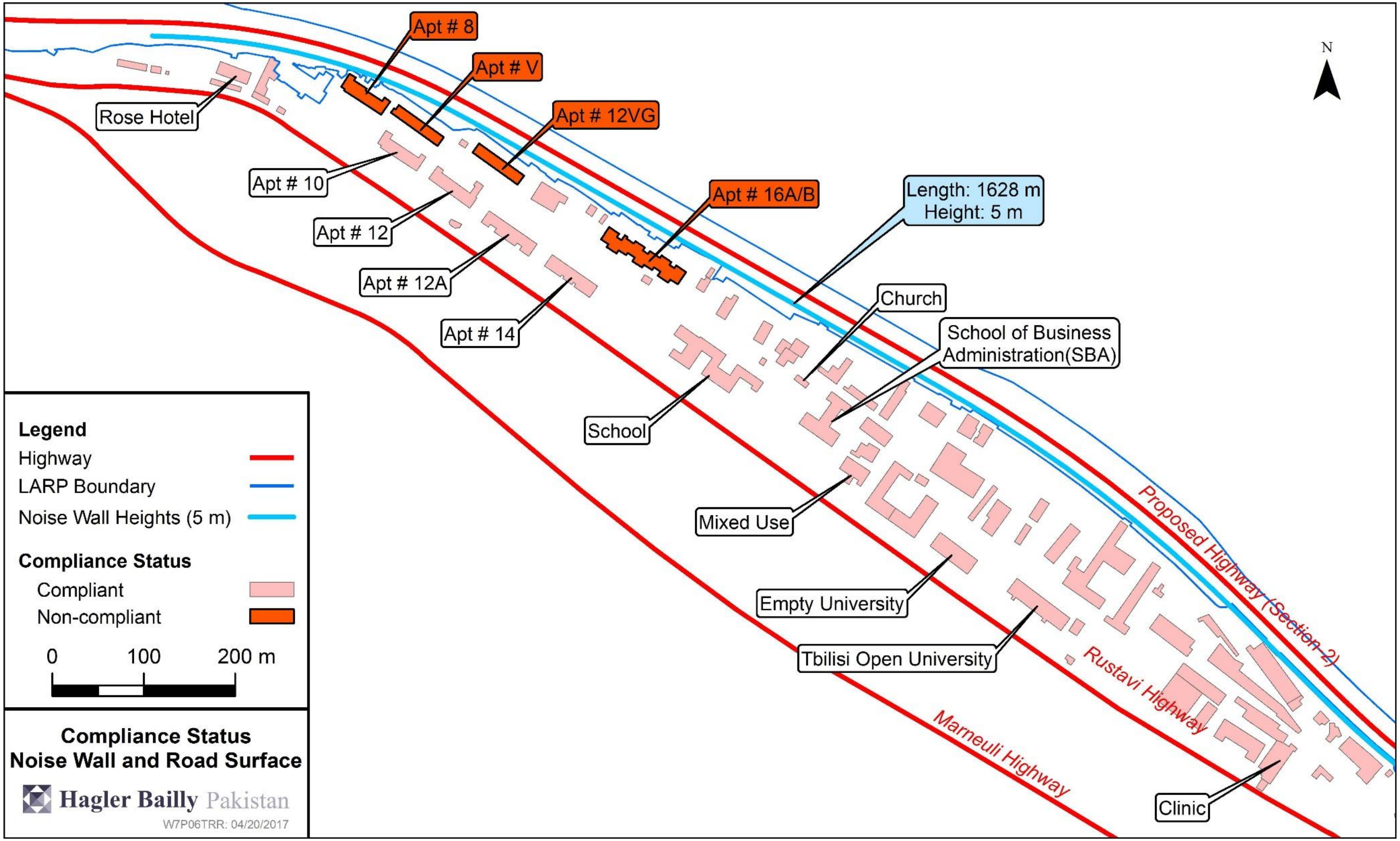


Figure 5-7: Layout and Compliance Status for Noise Wall and Road Surface Mitigation Scenario

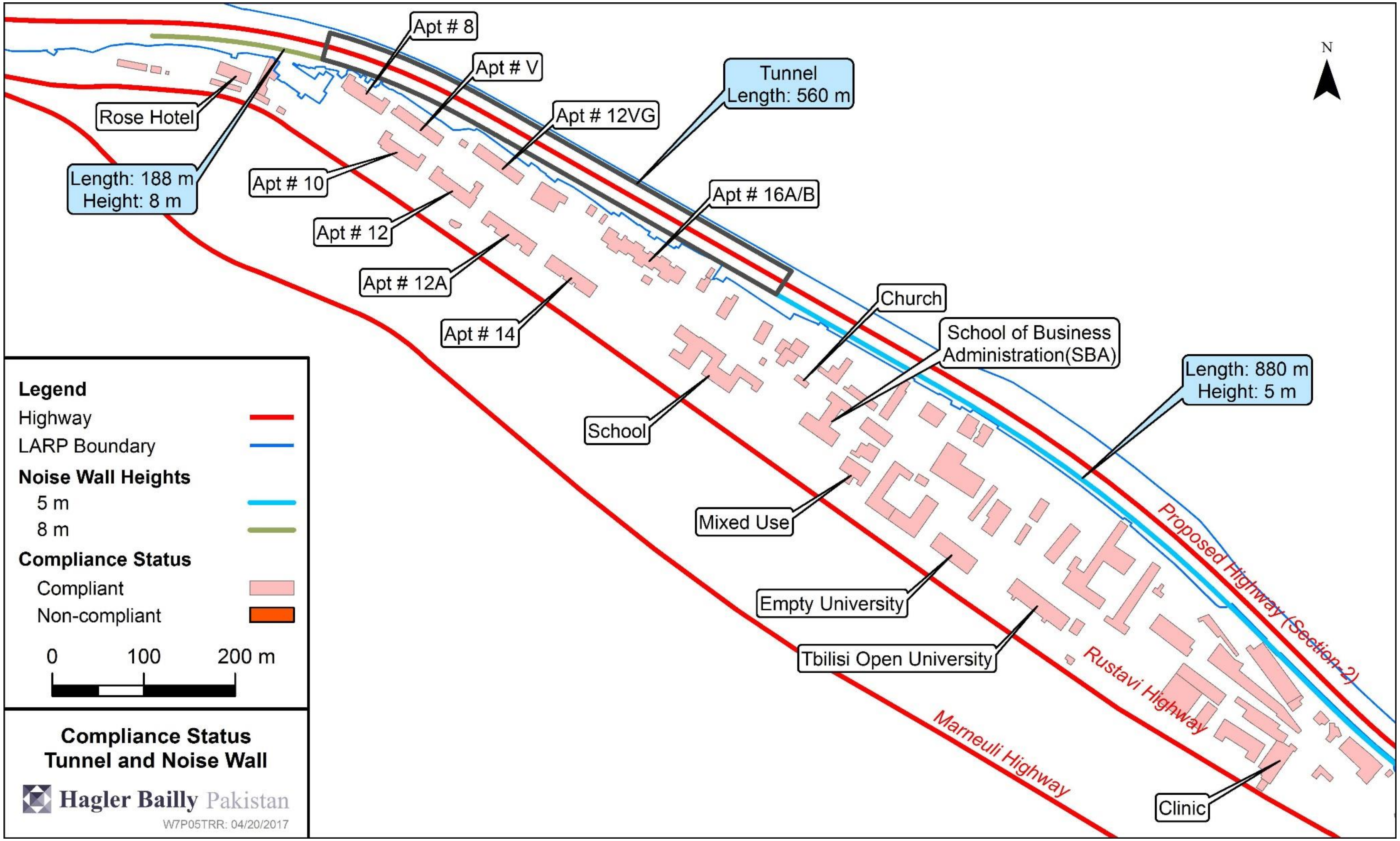


Figure 5-8: Layout and Compliance Status for Noise Wall and Tunnel Mitigation Scenario

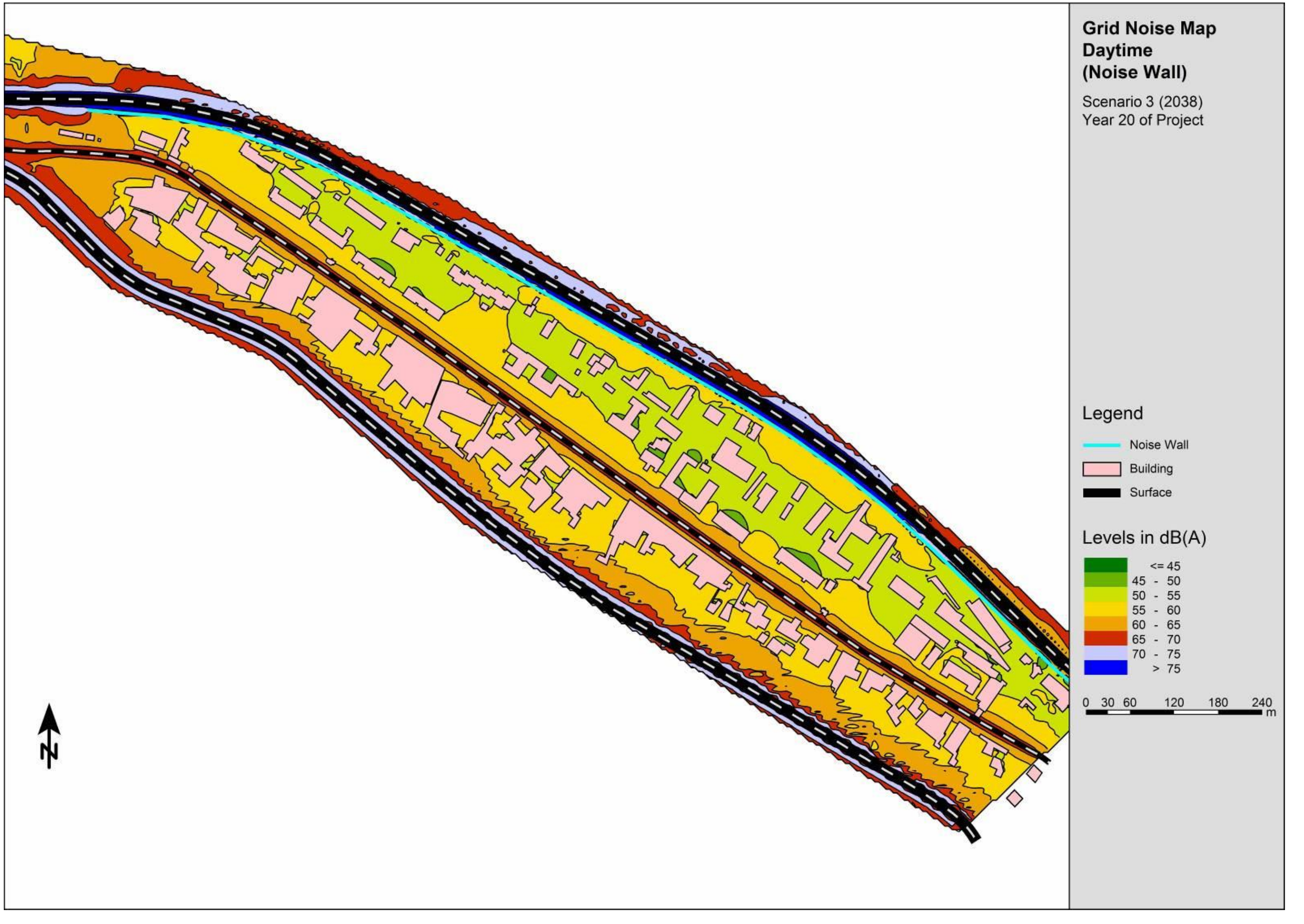


Figure 5-9: Grid Noise Map for Scenario 3 (2038), Daytime Noise Levels (Option W)

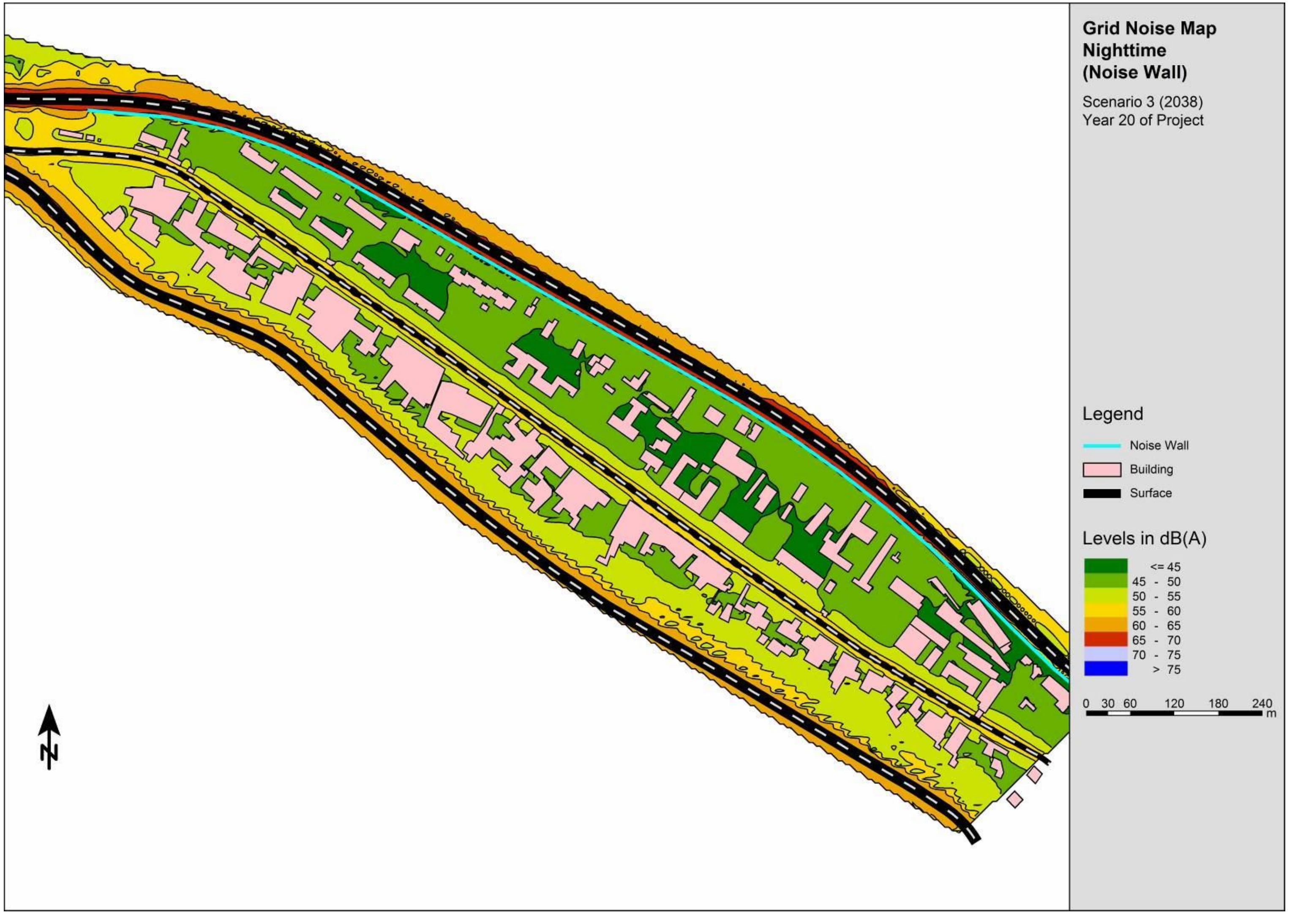


Figure 5-10: Grid Noise Map for Scenario 3 (2038), Nighttime Noise Levels (Option W)

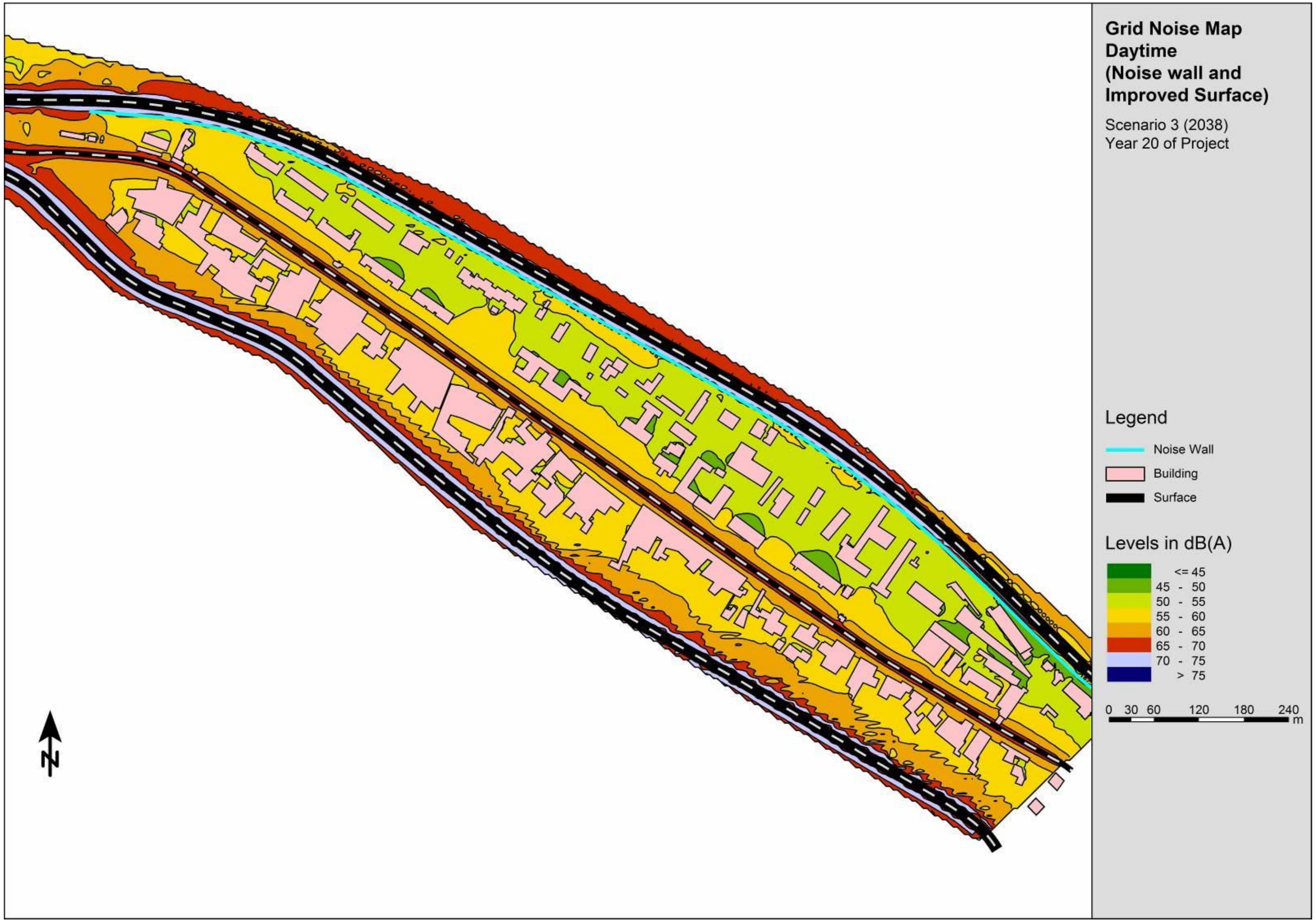


Figure 5-11: Grid Noise Map for Scenario 3 (2038), Daytime Noise Levels (Option W + IRS)

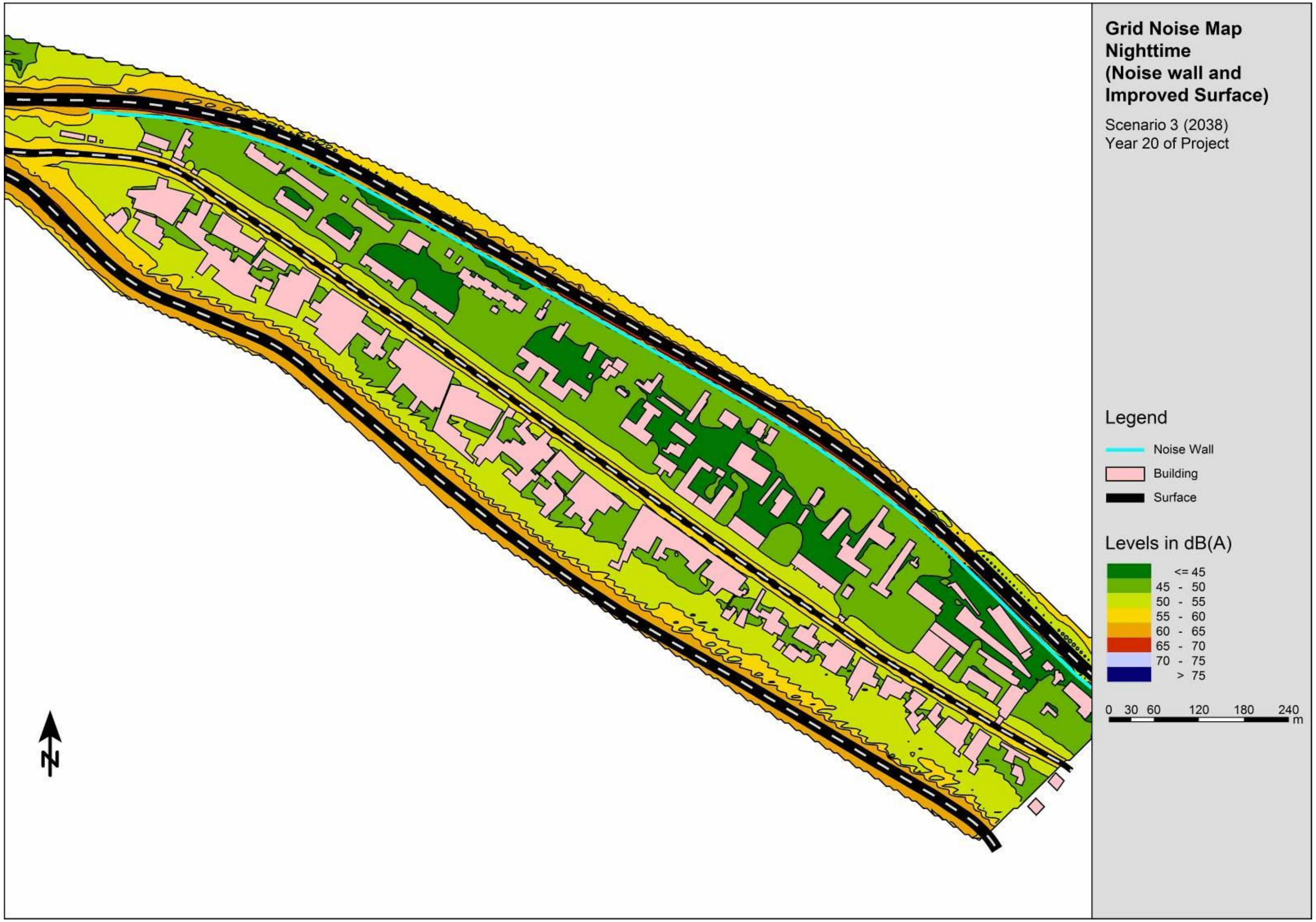


Figure 5-12: Grid Noise Map for Scenario 3 (2038), Nighttime Noise Levels (Option W + IRS)

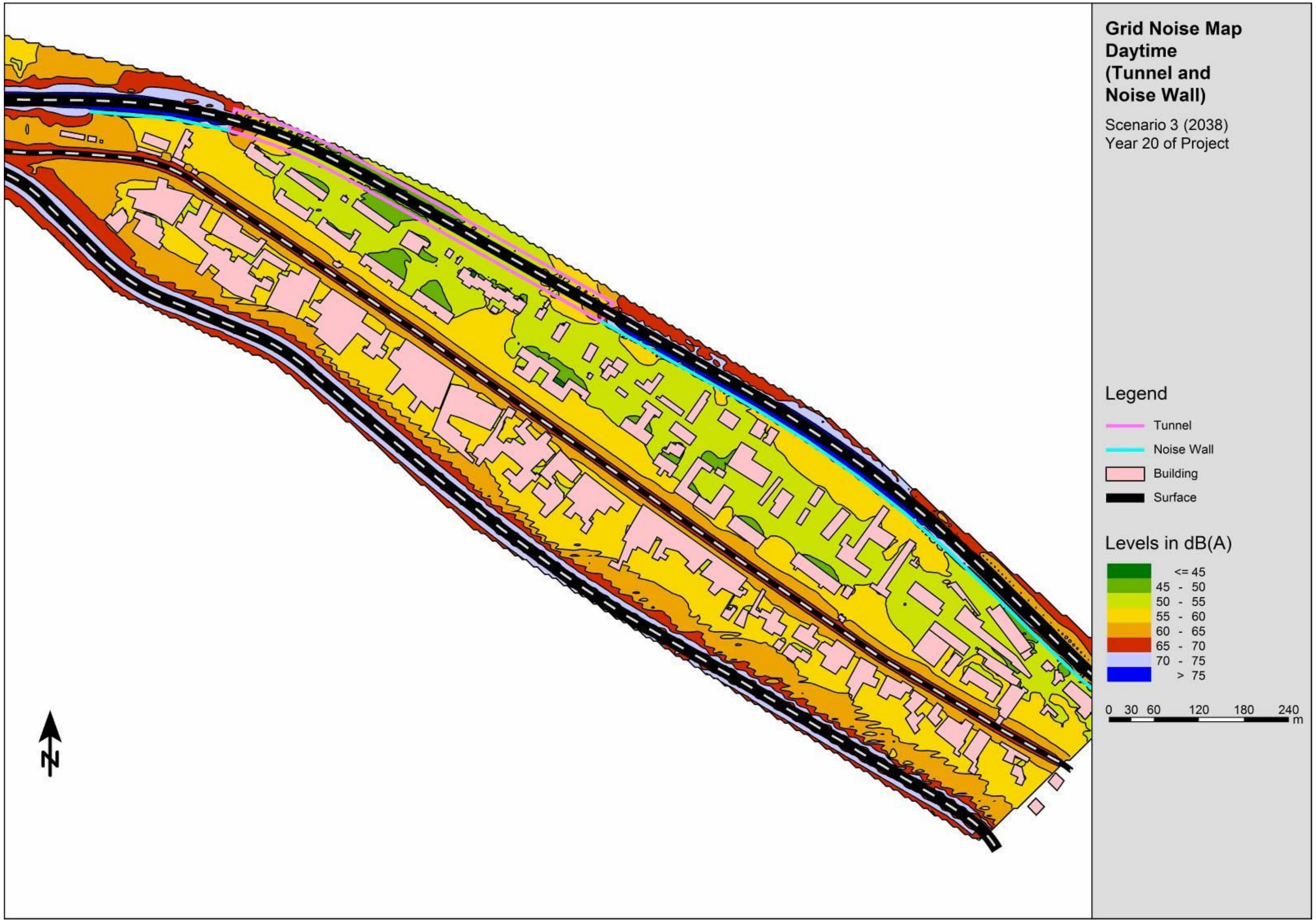


Figure 5-13: Grid Noise Map for Scenario 3 (2038), Daytime Noise Levels (Option W + T)

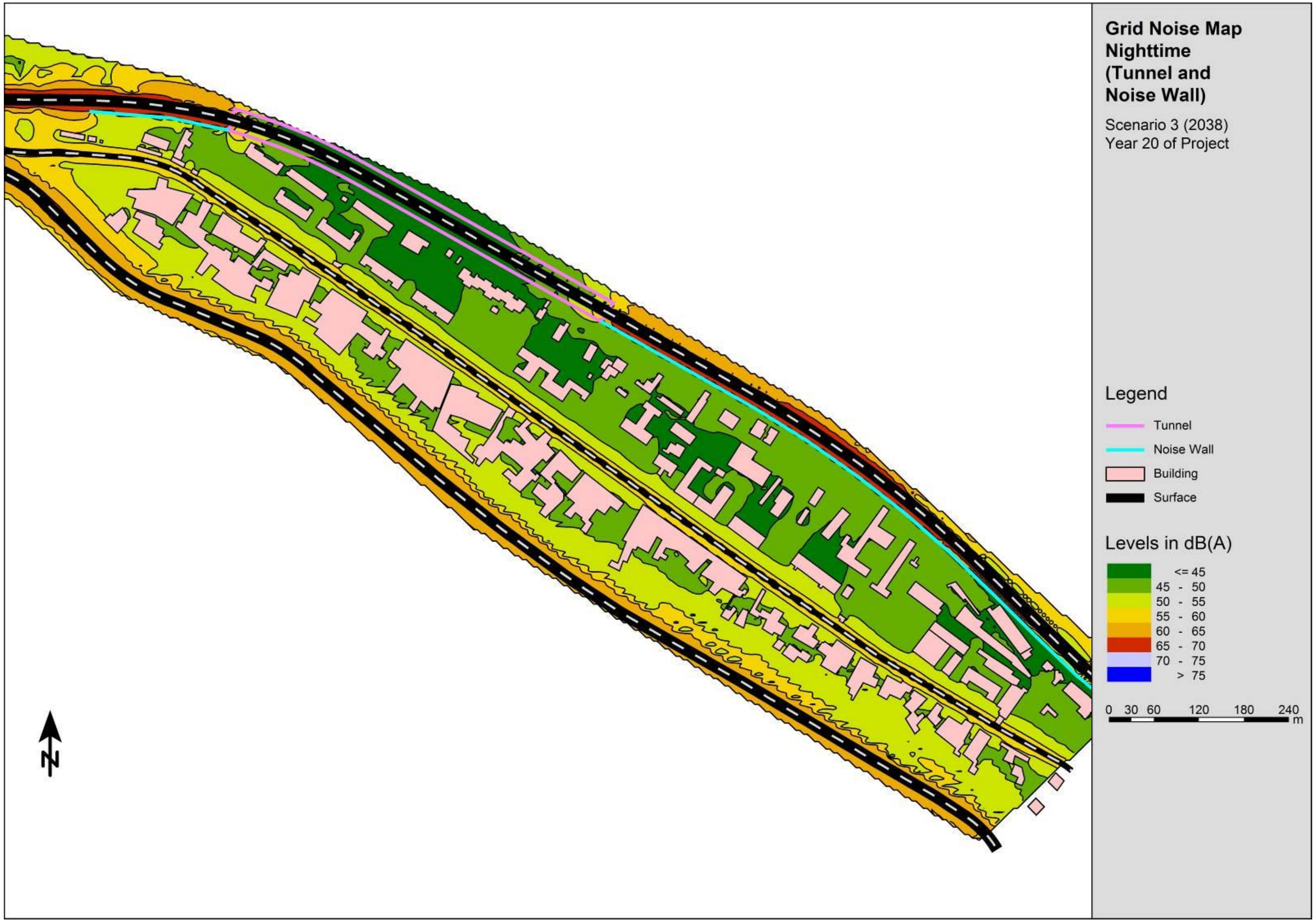


Figure 5-14: Grid Noise Map for Scenario 3 (2038), Nighttime Noise Levels (Option W + T).

Table 5-7: Non-Compliant Buildings for Noise Wall Mitigation Scenario (W)

Building	Face	Floor	Daytime			Nighttime		
			2018	2028	2038	2018	2028	2038
Apt (#12 VG)	Hillside (Southwest)	1	49.9	50.9	51.8	42.1	43.1	43.9
		2	50.7	51.6	52.5	42.9	43.8	44.6
		3	51.4	52.4	53.3	43.7	44.6	45.4
		4	52.1	53.1	54	44.4	45.3	46.1
		5	52.9	53.8	54.8	45.2	46.1	46.8
		6	53.2	54.2	55.1	45.5	46.4	47.1
		7	53.5	54.4	55.4	45.8	46.6	47.4
		8	53.8	54.8	55.7	46.1	47	47.7
		9	54.4	55.4	56.3	46.8	47.6	48.4
	Riverside (Northeast)	1	51	51.9	52.8	43.1	44.1	44.9
		2	52.4	53.3	54.2	44.5	45.5	46.3
		3	54.1	55.1	55.9	46.2	47.2	48
		4	56.7	57.6	58.5	48.8	49.8	50.6
		5	60.3	61.2	62.1	52.4	53.4	54.2
		6	65.1	66	66.9	57.2	58.2	59
		7	66.7	67.7	68.6	58.9	59.9	60.7
		8	66.6	67.5	68.4	58.7	59.7	60.5
		9	66.4	67.4	68.2	58.5	59.5	60.4
Apt (#16 A/B)	Hillside (Southwest)	1	50.8	51.8	52.7	43.1	44	44.8
		2	51.3	52.3	53.2	43.6	44.5	45.3
		3	51.7	52.6	53.5	43.9	44.8	45.6
		4	52	53	53.9	44.3	45.2	46
		5	53.4	54.3	55.2	45.6	46.5	47.3
	Riverside (Northeast)	1	50.2	51.1	52	42.3	43.3	44.1
		2	51.8	52.7	53.6	43.9	44.9	45.7
		3	54	54.9	55.8	46.1	47.1	47.9
		4	56.8	57.7	58.6	48.9	49.9	50.7
		5	59.9	60.9	61.7	52	53	53.9
Apt (#8)	Hillside (Southwest)	1	51.5	52.4	53.4	43.8	44.7	45.4
		2	53.3	54.2	55.2	45.6	46.5	47.2
	Riverside (Northeast)	1	53.1	54	54.9	45.2	46.2	47
		2	55.7	56.7	57.5	47.8	48.8	49.7

Building	Face	Floor	Daytime			Nighttime		
			2018	2028	2038	2018	2028	2038
Apt (#V)	Hillside (Southwest)	1	51	52	52.9	43.2	44.1	44.9
		2	52.7	53.6	54.5	44.9	45.8	46.6
		3	53.3	54.2	55.1	45.5	46.4	47.2
		4	53.7	54.7	55.6	46	46.9	47.6
		5	54.3	55.3	56.2	46.7	47.5	48.2
		6	54.6	55.5	56.5	47	47.8	48.5
		7	55	55.9	56.9	47.4	48.2	48.9
		8	55.3	56.2	57.2	47.7	48.5	49.2
		9	55.8	56.7	57.7	48.2	49	49.7
	Riverside (Northeast)	1	51	51.9	52.8	43.1	44.1	44.9
		2	52.5	53.5	54.3	44.6	45.6	46.5
		3	55.5	56.5	57.4	47.6	48.6	49.5
		4	59.6	60.5	61.4	51.7	52.7	53.5
		5	64.2	65.1	66	56.3	57.3	58.1
		6	65.9	66.9	67.8	58	59	59.9
		7	66	66.9	67.8	58.1	59.1	59.9
		8	66	67	67.9	58.1	59.1	60
		9	65.9	66.9	67.8	58.1	59	59.9

Table 5-8: Non-Compliant Buildings for Noise Wall and Improved Road Surface Mitigation Scenario (W + IRS)

Building	Face	Floor	Day			Night		
			2018	2028	2038	2018	2028	2038
Apt (#12 VG)	Hillside (Southwest)	1	49.7	50.6	51.5	41.9	42.8	43.6
		2	50.4	51.3	52.3	42.6	43.5	44.3
		3	51.3	52.2	53.1	43.5	44.4	45.2
		4	52	52.9	53.8	44.2	45.1	45.9
		5	52.7	53.7	54.6	45	45.9	46.7
		6	53.1	54	55	45.4	46.2	47
		7	53.4	54.4	55.3	45.7	46.6	47.3
		8	53.5	54.4	55.4	45.8	46.7	47.4
		9	54	54.9	55.9	46.3	47.2	47.9
	Riverside (Northeast)	1	51.3	52.3	53.1	43.4	44.4	45.3
		2	54.2	55.1	56	46.3	47.3	48.1

Building	Face	Floor	Day			Night		
			2018	2028	2038	2018	2028	2038
		3	58.3	59.2	60.1	50.4	51.4	52.2
		4	64	64.9	65.8	56.1	57.1	57.9
		5	64	64.9	65.8	56.1	57.1	57.9
		6	63.9	64.8	65.7	56	57	57.8
		7	63.7	64.7	65.6	55.9	56.9	57.7
		8	63.6	64.5	65.4	55.7	56.7	57.5
		9	63.4	64.4	65.3	55.5	56.5	57.4
Apt (#16 A/B)	Hillside (Southwest)	1	50.7	51.7	52.6	43	43.9	44.7
		2	51.2	52.2	53.1	43.5	44.4	45.2
		3	51.6	52.5	53.5	43.8	44.7	45.5
		4	52	52.9	53.8	44.2	45.1	45.9
		5	52.8	53.8	54.7	45.1	46	46.8
	Riverside (Northeast)	1	50.3	51.3	52.2	42.5	43.4	44.3
		2	52.6	53.5	54.4	44.7	45.7	46.5
		3	55.3	56.2	57.1	47.4	48.4	49.2
		4	57.9	58.9	59.8	50.1	51	51.9
		5	61.3	62.3	63.1	53.4	54.4	55.2
Apt (#8)	Hillside (Southwest)	1	50.9	51.8	52.7	43.2	44	44.8
		2	52.6	53.5	54.5	44.9	45.7	46.5
	Riverside (Northeast)	1	52.1	53.1	54	44.3	45.3	46.1
		2	55.7	56.6	57.5	47.8	48.8	49.6
Apt (#V)	Hillside (Southwest)	1	50.6	51.5	52.5	42.8	43.7	44.5
		2	52.3	53.2	54.2	44.5	45.4	46.2
		3	52.8	53.7	54.7	45.1	46	46.7
		4	53.2	54.2	55.1	45.6	46.4	47.1
		5	53.8	54.8	55.8	46.2	47	47.7
		6	54.1	55	56	46.5	47.3	48
		7	54.4	55.4	56.4	46.9	47.6	48.3
		8	54.7	55.7	56.7	47.2	47.9	48.6
		9	55.1	56.1	57	47.6	48.3	49
	Riverside (Northeast)	1	50.2	51.2	52.1	42.3	43.3	44.2
		2	52.9	53.9	54.8	45.1	46	46.9
		3	56.7	57.6	58.5	48.8	49.8	50.6

Building	Face	Floor	Day			Night		
			2018	2028	2038	2018	2028	2038
		4	61.4	62.4	63.3	53.6	54.6	55.4
		5	63.3	64.3	65.1	55.4	56.4	57.3
		6	63.3	64.2	65.1	55.4	56.4	57.2
		7	63.2	64.1	65	55.3	56.3	57.1
		8	63.1	64	64.9	55.2	56.2	57
		9	63	63.9	64.8	55.1	56.1	56.9

6. Mitigation Options

6.1 Noise Wall

66. A noise wall (also called noise barrier or sound barrier) is proposed for the Highway, in all three mitigation options, to reduce the noise levels at the receptors. Noise walls can be made from many different materials. The most common materials are concrete, brick, earthwork, metal (steel or aluminum), wood, or synthetic material such as plastics, PVC, or acrylic. Given the urban setting of the Project, transparent noise walls are recommended.

67. Transparent noise walls are made of acrylic or of polycarbonate.[2] A typical wall is shown in **Figure 6-1**. While the noise abatement properties of transparent walls are comparable to that of the concrete, the transparent material provide the added advantage of aesthetically pleasing.

68. The advantages claimed by one manufacturer includes:[3] increased road safety, long life expectancy, adding extra view to landscapes, and easy installation. One of a risk of transparent noise walls is that birds cannot distinctly see the clear barrier during flight and hence are likely to collide with them. In order to prevent this bird protection designs are available which are recommended for this project.

69. There are practical limit to height of noise walls. Free-standing noise walls reported in Europe are typically 3-5 m high.[4] A 7-m high wall is relatively rare. Higher walls, up to 20 m are reported, but they need elaborate structural support. Therefore, 8 m is considered as the practical limit to long noise walls, while short segments of 9 m are likely to be feasible without incurring significant additional cost on structure.

Figure 6-1: A Typical Transparent Noise Wall

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2 See for example http://www.noisebarriers.org/noisebarrier/transparent-sound-barrier.html

3 Ibid.

4 Based on walls reported in *Noise Barrier Design, Danish and some European Examples*. Danish Road Institute, Report 174, July 2009. http://www.ucprc.ucdavis.edu/pdf/UCPRC-RP-2010-04.pdf

6.2 Noise Tunnel

70. Noise tunnels are effectively noise walls with a roof of similar noise abatement material added to the top. Examples of typical noise tunnels are shown in **Figures 6-2** and **5-3**. Where the sensitive receptors are only on one side of the road, “half-tunnels” are also a possibility.[5] In these, the noise barrier is installed only on one wall and the roof of the tunnel. The structure of the tunnel is made of steel and hence may have considerable weight. As the proposed location of the noise tunnel is partially over the river with its foundation in the river bed, installation of the tunnel may require re-designing and strengthening of the road foundation.

71. Two parallel 573-m long half-tunnels for noise abatement were installed in Warsaw Poland. The height of the tunnel at the center is 7-8 m (**Figure 6-3**) and each tunnel has three driving lanes. The total weight of the steel structure of both tunnels is 1,400 tons. The weight of transparent panel is reported to be about the same.[6] Therefore, the total weight of the structure is about 4,900 kilogram per linear meter. The structure is supported on 300 pile foundation. The tunnel is largely maintenance-free. An inspection is required every few years for structure integrity. The transparent panels require cleaning once in about 3 month.

72. Given that the Tiblisi-Rustavi Highway tunnel will be a single tunnel over 4 driving lanes (plus shoulders, median, and walkways), its total width will be less than the combined width of the two Warsaw tunnels. Using the perimeter length of the tunnel cross section, it is estimated that the weight of the proposed tunnel will be about 3,700 kilogram per linear meter

Figure 6-2: Noise Barrier Tunnel on Route 8 Freeway, Hong Kong

5 See for example, http://www.vistal.pl/en/projects/bridges-our-projects/half-tunnel-noise-barriers-warsaw/

6 Personal communication with Project Manager at Metrostav Poland.

Figure 6-3: "Half-Tunnel" Noise Barrier, Warsaw

6.3 Improved Road Surface

73. Improved Road Surface refers to replacing the conventional asphalt surface of the road with a material that reduces the noise emission from the road traffic. Traffic noise is primarily generated by two sources, the engine noise (which in turn is generated by air intake, exhaust outlet, and movement of mechanical parts) and tire-road surface contact. It is reported that on highways 30 to 80% of the noise radiated from light vehicle and 20 to 60% of noise generated from heavy vehicles comes from tire-road contact.[7]

74. Porous asphalt pavements were developed primarily in the United States in the 1970s in response to regulations requiring reduction in storm water flow from paved surfaces, thereby increase in groundwater recharge. It is a simple technology in which the asphalt is mixed with aggregate to make it porous. The porous asphalt pavement is then underlain with a stone bed that allows the rain water to drain through and infiltrates into the soil. The noise abatement is an added advantage of porous pavement.

75. In the aggregate used to construct porous pavement, fine aggregate material is sieved out and only relatively larger material is used. This means that the aggregate cannot be compacted as finely as regular aggregate material and results in void between the aggregate. The porosity helps in two ways in reducing the noise. At the interface of tire and the road, an air pressure is created because the tire compresses the air between the treads of the tire. The porosity of the road weakens this process as the air 'leaks' out from the pavement voids. In addition, the porous surface also helps in absorbing traffic noise particularly from engine of large vehicles.[8]

76. Information on porous asphalt available from the website of Asphalt Institute (of United States).[9] According to it, single-layer porous asphalt has been implemented in the Netherlands, France and Germany. The single-layer porous asphalt consists of a 30 to 40 mm thick gap-graded mix with 20 to 30 percent air voids. It provides a 3 to 5 dBA noise

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7 https://dge.carnegiescience.edu/SCOPE/SCOPE_24/SCOPE_24_1.12_Lamure.pdf

8 Robert Bernhard. *An Introduction to Tire/Pavement Noise of Asphalt Pavement*. http://www.asphaltroads.org/assets/_control/content/files/anintroductiontotire-pavementnoiseofasphaltpavement.pdf

9 http://asphaltmagazine.com/quiet-asphalta-choice-for-the-future/

reduction. This type mix costs about 10 to 25 percent more than conventional dense-graded asphalt and typically lasts 8 to 10 years.

77. Further, two-layer porous asphalt has been implemented in Denmark, France and Italy and is in the developmental stage in the Netherlands. Two-layer porous asphalt in Denmark is designed to use about an inch of 1/8- or 1/4- inch top size aggregate mix as a filter layer and about 1.75 inches of ½-inch top size aggregate in the lower layer for drainage. Noise reduction with two-layer porous asphalt is 8 or 9 dBA quieter than conventional asphalt mixes and 4 dBA quieter than single-layer porous asphalt. The mix for a two-layer porous asphalt system usually contains an average of 20 percent voids. The typical binder contents are 5.7 to 6.0 percent based on aggregate weight. Construction costs of a two-layer porous asphalt system are typically 25 to 35 percent higher than conventional costs.[10]

78. The modelling of improved road surface option for this assessment uses single layer asphalt option and, therefore, a reduction

6.4 Relocation

79. Relocation is a last resort that is considered for buildings and their residents that will be affected by the Project, i.e., the noise level is likely to increase either by more than 3 dBA or will result in noise levels above 55 dBA during the day and 45 dBA during the night.

[10] Ibid.

7. Mitigation Cost

7.1 Unit Cost

7.1.1 Noises Wall

80. The complete cost for installation of concrete noise wall is about USD 275 per square meter (m^2). The cost of acrylic walls is more expensive. The New Zealand Transport Agency estimates that the acrylic walls are 65% more expensive than the conventional concrete wall.[11] Based on this the estimated cost of acrylic wall is about USD 450 per m^2.

7.1.2 Noise Tunnel

81. The noise abatement material used in the noise tunnels is acrylic, which is also used in the noise wall. As only roof and one wall is to be shielded, about 35 m^2 of wall material will be required for each running meter of tunnel. Using the reported cost of the Warsaw Tunnel (**Section 6.2**) and accounting for the difference in size, it is estimated that the cost of tunnel will be about USD 22,500 per linear meter. This gives a total cost of the 560 m tunnels to be USD 12.6 million. This cost includes the cost of installing additional foundation.

7.1.3 Improved Road Surface

82. The estimated cost of conventional asphalt pavement including the sub-base preparation is estimated from various sources to be USD 22 per square meter[12]. Assuming that the cost of porous asphalt is 25% higher, the incremental cost of this option is USD 5.5 per square meter of paved surface.

7.1.4 Relocation

83. The unit rates in the resettlement plan of the project[13] was used to estimate the resettlement cost of the residential buildings and one commercial buildings. As the plan is more than 2 years old, cost escalation has been added. The total relocation cost of the structures is as follows:

- Four Residential Structure USD 9,900,000
- Rose Hotel USD 600,000
- 'Additional' building USD 300,000

84. There is one single-story building between Apartment No. 12VG and 16A/B. It may be required to relocate all five buildings.

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11 https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/noise-barrier-cost-calculator/

12 For example, http://www.crgov.com/DocumentCenter/Home/View/1481, https://www.wsdot.wa.gov/NR/rdonlyres/A8EE6CB0-46F6-4EE8-95A3-62E9B793F31C/0/CostIndexData.pdf, http://www.barrie.ca/assets/engineering/nov2010/Appendix%20L%20-%20Costs%20per%20metre.pdfhttp://www.shawengineering.com/wp-content/uploads/2013/05/BM-2013-Paving-Project-Bid-Tabulations.pdf,

13 Resettlement Plan: GEO: Sustainable Urban Transport Investment Program — Tranche 3, Tbilisi–Rustavi Urban Link (Section 2 part A). October 2014

7.2 Total Cost

85. In **Table 7-1**, the total estimated cost of the three mitigation scenarios is presented. The cost of the three options is comparable, between 14 to 16.0 million USD.

86. The Study has demonstrated that it is possible to mitigate the adverse noise impact by selecting one of the proposed options. The cost provided is based on estimates which are obtained from various published sources. A 20-25% variation from the actual cost is likely. Given this, the decision on which option to take shall also take into account other factors. These may include the social cost of relocation. The overall improvement in environmental quality of the Study Area as a result of potential conversion of the evacuated land to park or amenities.

87. It may be noted that:

- The cost estimate does not include the cost of redesigning the road, if required, to cater for the tunnel.
- The cost estimate is only the initial capital cost. The maintenance cost for various options are not included.
- A noise wall is already proposed and costed in the IEE. The estimate of noise wall in this study does not discount the cost in the IEE.
- Finally, the option of dual porous layer has not been considered. It reportedly can reduce the noise level by 8-9 dBA at source. However, given the experimental nature of the technology it may not be feasible. If this technology is available, the need for resettlement might be reduced in the Option **W + IRS**.

Table 7-1: Details of Mitigation Options

Mitigation Options		Noise Wall	Tunnel	Improved Road Surface	Relocation [a]	Total Cost
W	Basis	Area: 11,048 m^2 Unit Cost: USD 475/m^2			Hotel: 600,000 USD Apartments #8, #V, #12VG and #16A/B: 9,900,000 USD	
	Estimated Cost	USD 5.25 million			USD 10.5 million	**USD 15.75 million**
W'	Basis	Area: 11,052 m^2 Unit Cost: USD 475/m^2			Apartments #8, #V, #12VG and #16A/B: 9,900,000 USD	
	Estimated Cost	USD 5.25 million			USD 9.90 million	**USD 15.15 million**
W + IRS	Basis	Area: 8,140 m^2 Unit Cost: USD 475/m^2		Area: 26,048 m2 Unit Cost USD5.5/m^2	Apartments #8, #V, #12VG and #16A/B: 9,900,000 USD	
	Estimated Cost	USD 3.867 million		USD 0.143 million	USD 9.90 million	**USD 13.91 million**
W + T	Basis	Area: 5,944 m^2 Unit Cost: USD 475/m^2	Length 560 m Unit Cost: USD 22,500/m^2			
	Estimated Cost	USD 2.823 million	USD 12.60 million			**USD 15.42 million**

a If the single-story building Apartment #12 VG and 16A/B is included an additional USD 0.3 million will be required.

8. Construction Noise Impacts

88. The inherent variability in construction noise makes it very difficult to predict. There are manifold variations:

- Different sets of equipment are deployed in different stages of construction.
- The number of equipment may vary on a daily basis owing to variation in work.
- The equipment are not stationary but move along the construction site.
- The noise of the equipment vary depending on the activity level. In a typical day, its state may vary between powered off (zero noise) to idling (low noise) to full throttle (highest noise) and anywhere between idling and full throttle.
- The noise at source may also vary depending on the manufacturer, age of the equipment, its maintenance condition, and whether noise suppressing shields are installed or not.

89. Nevertheless, a reasonable prediction of the scale of noise levels can be made by simulating various deployment configuration for the equipment. The approach used in this study is described below. This is followed by a discussion of the results and suggested mitigation measures.

8.1 Approach

90. The equipment noise level has been taken from a comprehensive inventory of construction equipment developed by the United States' Federal Highway Authority.[14] The selected list of equipment and their noise specifications is shown in Table 8-1.

91. The information provided in **Table 8-1** include:

- The *acoustical usage factor* assumed for modeling purposes. The acoustical usage factor is the estimate of the fraction of time during each work cycle that a piece of construction equipment is operating at full power i.e., at its loudest condition.
- The maximum noise limit for each piece of equipment provided in manufacturers' specifications, expressed as an L_{max} level in dBA at a reference distance of 50 foot (15 m) from the loudest side of the equipment; and
- The emission level as measured by FHWA at 50 feet (15 m) for each piece of equipment. It is the average of hundreds of emission measurements performed at work sites.

92. FWHA found that the measured noise levels were lower than those in the specification in most case. FHWA, therefore, recommends using the measured noise levels, unless more reliable information specific to the equipment to be used is available.

[14] Federal Highway Authority, Construction Noise Handbook, August 2006, https://www.fhwa.dot.gov/ENVIRONMENT/noise/construction_noise/handbook/handbook09.cfm.

Table 8-1: Equipment Noise Specifications

Equipment	**Acoustical Usage Factor**	**Sound Pressure Level Specified by Manufacturers, L_{max} at 50 ft (15m), dBA**	**Sound Pressure Level Measured by FHWA, L_{max} at 50 ft (15m), dBA**
Concrete Mixer Truck	40%	85	78.8
Crane	16%	85	80.6
Dozer	40%	85	81.7
Dump Truck	40%	84	76.5
Excavator	40%	85	80.7
Front End Loader	40%	80	79.1
Grader	40%	85	
Paver	50%	85	77.2
Pumps	50%	77	80.9
Roller	20%	85	80
Concrete Road Vibrator	40%	76	76
Concrete Pump Truck	20%	82	81
Compressor (air)	40%	80	78

Source: Federal Highway Authority, Construction Noise Handbook, August 2006

93. The construction activity on the road section in Ponichala has been split in to six stages as follows:

- Stage 1: Excavation
- Stage 2: Clearing for formation of embankment
- Stage 3: Structure erection
- Stage 4: Earth filling for formation of embankment
- Stage 5: Laying of sub-base and base
- Stage 6: Pavement of asphalt layers

94. The equipment deployed in each of the above stage in a typical 250 m section of the road is shown in **Table 8-2**. Two configurations have been considered. *Typical configuration* is the one which is expected to prevail most of the time normal construction practices, whereas the *extreme configuration* is likely to occur occasionally, i.e., less than 10% of the time.

Table 8-2: Equipment Deployment in Different Configurations

Equipment	**Stage 1. Excavation**	**Stage 2. Clearing**	**Stage 3. Structure**	**Stage 4. Filling**	**Stage 5. Sub-base and Base**	**Stage 6. Pavement**
Number of Pieces of Equipment Working in Typical Configuration						
Compressor (air)						
Concrete Mixer Truck			1			
Concrete Pump Truck			1			
Concrete Road Vibrator			1			
Crane			1			
Dozer		1				
Dump Truck	1	1		2	2	1
Excavator	1					
Front End Loader	1					
Grader		1		1	1	
Paver						1
Pumps				1		
Roller		1		1	1	1
Number of Pieces of Equipment Working in Extreme Configuration						
Compressor (air)	1		1			
Concrete Mixer Truck			1			1
Concrete Pump Truck			1			
Concrete Road Vibrator			2			
Crane			1			
Dozer	1	1				
Dump Truck	2	2		5	4	3
Excavator	1	1		1		
Front End Loader	1	1		1	1	
Grader		1		1	1	
Paver						1
Pumps		1		1		
Roller		2		2	2	2

95. A 250-m section is selected for noise modeling (see **Figure 8-1**). This is selected as it has apartments very close to the road and may be considered as "worst case". In this section, the noise sources are separately placed at one of the 11 pre-defined locations on the centerline of the road, thus the locations were 25 m apart.

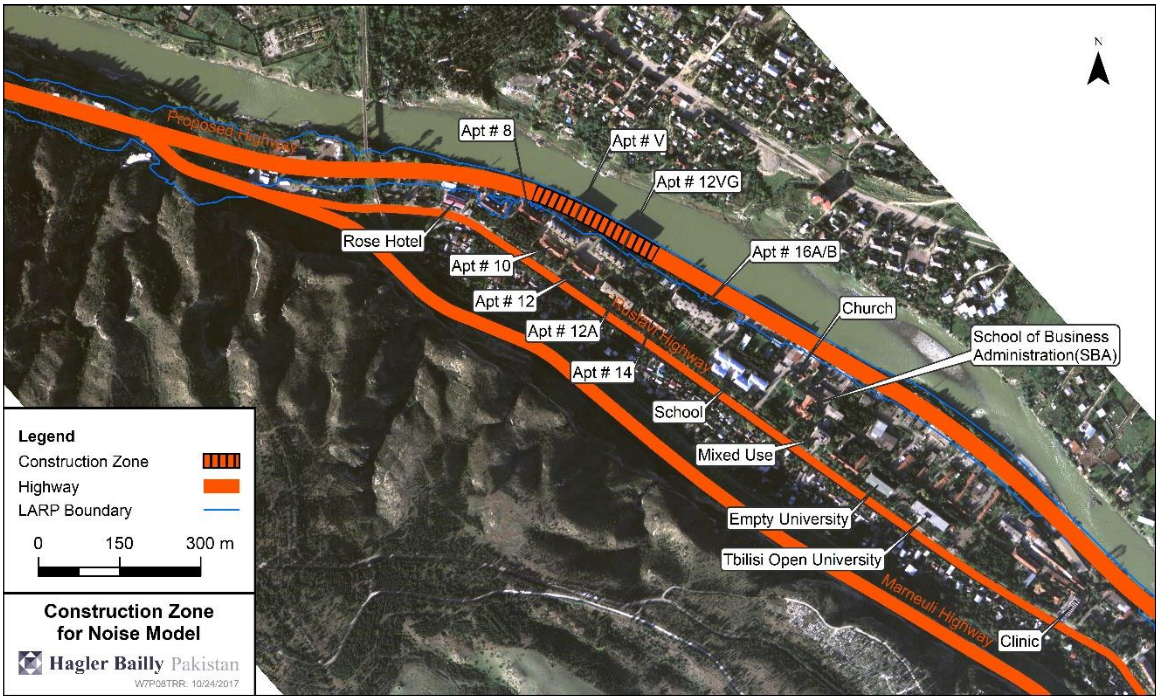

Figure 8-1: Zones for Construction Impact

8.2 Predicted Noise Levels

96. The predicted noise levels for the two proposed configurations at the nearby buildings is shown in **Table 8-3** and **8-4**. The tables also include the results of noise levels with a three-meter high noise wall. Note the noise barrier exceeds beyond the construction zone by at least 250-m on each side of the Following are the observations on the results:

- Generally, the noise levels are high and exceed the IFC standards for most of the receptors in both scenarios.
- Stage 2 and 4 appear to be noisier than the other stages.
- Introduction of 3-m noise barrier, helps to reduce the noise at the receptors. The impact is significant for the lower floors but is nearly ineffective for the upper floors, Floor 4 and above.

Table 8-3: Noise Level for Typical Configuration

	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Stage 6	
Noise Barrier ⇒	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Apt #8 – 1	68.5	60.9	71.4	63	70.2	59.1	77.6	66.0	77.2	67.3	70.5	61.4
Apt #8 – 2	69.6	63.0	71.8	65.3	70.3	61.6	77.7	68.5	77.1	70.4	70.4	64.5
Apt #12 A – 1	53.4	48.9	58.0	53.6	54.6	49.3	56.5	50.9	57.3	52.2	50.8	48.0
Apt #12 A – 2	55.6	50.1	58.6	54.3	55.8	50.9	57.9	51.8	58.1	54.2	51.6	49.0
Apt #12 A – 3	56.6	52.6	58.3	55.1	56.4	51.9	59.0	53.8	58.4	55.1	52.5	50.1
Apt #12 A – 4	57.0	53.4	59.3	55.8	57.6	53.1	60.1	54.8	60.7	56.4	53.2	51.0
Apt #12 A – 5	57.9	55.0	60	57.1	59.3	54.8	60.8	56.3	61.4	57.6	54.9	53.3
Apt #12 VG – 1	66.6	59.1	74.2	63.6	66.9	58.0	69.2	60.5	70.0	62.4	65.6	58.6
Apt #12 VG – 2	67.5	60.8	74.2	65.7	67.9	59.7	69.3	62.1	70.2	64.3	66.2	60.9
Apt #12 VG – 3	67.8	62.5	74.1	68	68.0	61.5	69.4	63.8	70.2	65.9	66.3	62.2
Apt #12 VG – 4	68.1	63.9	74.0	69.5	68.0	63.1	69.6	65.3	70.1	66.2	66.4	62.5
Apt #12 VG – 5	68.4	64.8	73.9	69.9	68.1	63.8	69.7	65.9	70.1	68.9	66.5	65.9
Apt #12 VG – 6	68.5	65.1	73.7	73.2	68.1	64.3	69.6	66.9	70.1	69.8	66.4	66.3
Apt #12 VG – 7	68.4	68.0	73.6	73.6	68.0	67.4	69.5	68.8	70.0	69.8	66.3	66.2
Apt #12 VG – 8	68.4	68.4	73.5	73.4	67.9	67.8	69.4	69.2	69.8	69.7	66.2	66.2
Apt #12 VG – 9	68.4	68.4	73.2	73.2	67.8	67.7	69.4	69.2	69.7	69.7	66.1	66.1
Apt #12 – 1	60.3	54.6	62.7	55.8	57.6	53.5	59.6	53.8	58.8	54.6	57.8	54.4
Apt #12 – 2	61.4	56.5	63.7	57.5	59.0	55.6	60.8	55.9	59.9	56.5	59.0	56.4
Apt #V – 1	71.3	61.6	74.4	64.3	65.0	57.0	71.3	62.8	69.2	63.1	65.6	59.0
Apt #V – 2	72.6	63.4	75.8	66.3	66.1	58.5	72.4	64.3	69.8	64.7	66.7	60.9
Apt #V – 3	73.1	65.4	75.7	68.5	66.5	60.0	73.0	66.0	70.1	66.1	66.7	62.4
Apt #V – 4	73.0	67.3	75.6	70.5	66.5	61.6	73.0	67.6	70.3	66.7	66.8	62.7
Apt #V – 5	72.9	68.2	75.5	70.9	66.6	62.5	73.1	68.7	70.5	67.2	66.8	65.0
Apt #V – 6	72.7	68.6	75.3	72.5	66.6	62.6	73.1	68.8	70.8	69.3	66.8	66.5
Apt #V – 7	72.5	72.0	75.1	74.8	66.7	64.6	73.2	70.3	70.9	70.8	66.8	66.8
Apt #V – 8	72.3	72.3	74.9	74.9	66.6	65.8	73.1	72.4	70.8	70.7	66.7	66.7
Apt #V – 9	72.1	72.1	74.6	74.6	66.5	66.5	72.9	72.9	70.7	70.6	66.6	66.6

Noise levels in db(A)	> 70	65-70	60-65	55-60	≤ 55

Table 8-4: Noise Level for Extreme Configuration

	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Stage 6	
Noise Barrier ⇒	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Apt #8 – 1	73.5	63.0	72.4	64.7	71.2	60.8	78.8	67.5	77.4	67.8	71.4	63.2
Apt #8 – 2	73.8	65.3	72.9	66.9	71.5	63.1	79.0	69.9	77.4	70.8	71.5	66.0
Apt #12 A – 1	55.8	50.1	61.1	55	55.0	49.6	59.0	52.8	57.7	52.4	56.8	51.5
Apt #12 A – 2	57.7	51.8	62.1	56.5	56.6	51.3	60.2	54.0	58.7	54.4	57.9	53.8
Apt #12 A – 3	58.5	53.8	62.3	57.4	57.3	52.8	61.0	55.5	59.0	55.6	58.2	55.2
Apt #12 A – 4	59.3	54.8	63.5	58.5	58.4	53.8	62.2	56.5	61.1	56.8	60.4	56.6
Apt #12 A – 5	60.6	56.2	64.8	59.5	59.9	55.4	63.1	57.7	61.8	58.0	61.2	57.8
Apt #12 VG – 1	71.7	62.0	75.4	65.7	70.0	60.0	72.9	63.5	72.4	64.2	70.9	63.2
Apt #12 VG – 2	72.0	63.8	75.6	67.8	70.5	61.8	73.2	65.2	72.5	66.2	71.3	65.5
Apt #12 VG – 3	72.0	65.9	75.7	69.9	70.5	63.8	73.3	67.0	72.5	67.9	71.3	67.0
Apt #12 VG – 4	72.0	67.5	75.7	71.4	70.4	65.5	73.3	68.6	72.5	68.3	71.3	67.5
Apt #12 VG – 5	72.1	68.1	75.7	71.6	70.4	66.1	73.3	69.2	72.4	70.7	71.3	70.9
Apt #12 VG – 6	72.0	70.5	75.6	74.6	70.3	67.2	73.3	70.0	72.3	72.1	71.2	71.2
Apt #12 VG – 7	71.9	71.6	75.5	75.5	70.2	69.7	73.2	72.6	72.2	72.1	71.0	71.0
Apt #12 VG – 8	71.7	71.7	75.4	75.4	70.0	70.0	73.1	72.9	72.0	71.9	70.9	70.9
Apt #12 VG – 9	71.6	71.5	75.2	75.2	69.9	69.8	72.9	72.8	71.8	71.8	70.7	70.7
Apt #12 – 1	62.7	56.0	65.5	58.1	59.9	54.4	62.1	55.6	61.1	56.3	62.0	56.9
Apt #12 – 2	63.7	57.6	66.4	59.5	61.0	56.3	63.1	57.2	62.0	57.9	62.9	58.5
Apt #V – 1	71.8	62.7	75.9	66.2	68.2	59.6	73.8	64.9	71.3	64.6	68.9	62.4
Apt #V – 2	73.0	64.4	77.2	68.1	69.3	61.1	74.9	66.4	72.2	66.3	70.0	64.3
Apt #V – 3	73.5	66.3	77.3	70.2	69.8	62.8	75.3	68.1	72.4	67.9	70.3	65.9
Apt #V – 4	73.5	68.1	77.2	72.1	69.9	64.5	75.4	69.8	72.5	68.6	70.4	66.2
Apt #V – 5	73.4	68.9	77.1	72.5	69.9	65.5	75.5	71.0	72.6	69.1	70.4	68.0
Apt #V – 6	73.4	69.3	77	74	69.9	65.6	75.5	71.2	72.7	71.7	70.4	70.2
Apt #V – 7	73.2	72.4	76.8	76.5	69.8	67.4	75.4	72.9	72.7	72.7	70.3	70.3
Apt #V – 8	73.1	73.0	76.6	76.5	69.7	69.2	75.3	74.6	72.6	72.6	70.2	70.2
Apt #V – 9	72.9	72.9	76.3	76.3	69.6	69.5	75.1	75.1	72.5	72.4	70.1	70.0

Noise levels in db(A)	> 70	65-70	60-65	55-60	≤ 55

97. To further investigate the mitigation options, the impact of two mitigation measures—increasing the height of noise barrier and reducing the number of equipment—was investigated for Stage 4. The result is shown in **Table 8-5**. It follows that:

- Increasing the height of the barrier by 2 m (from 3 m to 5 m) reduces the noise levels by 2 to 4 dB(A) in the upper floors and by 3 to 5 dB(A) in the lower floors of the nearby high-rise buildings. Temporary noise walls, up to 10 m high are also available.[15] The impact of an 8 m high noise wall was also investigated. It appears that such a noise wall can effectively abate the construction noise generated under typical configuration.

Table 8-5: Impact of Mitigation Measures

	Noise Wall				Number of Pieces of Equipment			
	No	3 m	5 m	8 m	11	5	1	1 with 3 m Wall
Apt #8 – 1	77.6	66.0	62.4	59.5	78.8	77.6	77.0	64.7
Apt #8 – 2	77.7	68.5	63.8	60.6	79.0	77.7	77.0	67.4
Apt #12 A – 1	56.5	50.9	49.8	49.4	59.0	56.5	48.0	47.9
Apt #12 A – 2	57.9	51.8	50.5	50.1	60.2	57.9	49.0	48.9
Apt #12 A – 3	59.0	53.8	52.1	51.5	61.0	59.0	50.2	50.1
Apt #12 A – 4	60.1	54.8	53.0	51.9	62.2	60.1	51.4	51.0
Apt #12 A – 5	60.8	56.3	54.7	53.9	63.1	60.8	53.6	53.3
Apt #12 VG – 1	69.2	60.5	57.2	54.7	72.9	69.2	58.4	54.7
Apt #12 VG – 2	69.3	62.1	58.1	55.2	73.2	69.3	58.7	55.8
Apt #12 VG – 3	69.4	63.8	59.4	55.0	73.3	69.4	59.0	56.6
Apt #12 VG – 4	69.6	65.3	60.8	55.8	73.3	69.6	59.3	57.3
Apt #12 VG – 5	69.7	65.9	62.5	56.8	73.3	69.7	59.6	58.2
Apt #12 VG – 6	69.6	66.9	64.1	57.9	73.3	69.6	59.8	58.4
Apt #12 VG – 7	69.5	68.8	65.2	59.3	73.2	69.5	60.1	58.5
Apt #12 VG – 8	69.4	69.2	65.5	60.6	73.1	69.4	60.2	57.6
Apt #12 VG – 9	69.4	69.2	67.1	62.2	72.9	69.4	60.7	58.4
Apt #12 – 1	59.6	53.8	52.9	52.4	62.1	59.6	51.4	51.3
Apt #12 – 2	60.8	55.9	55.0	54.8	63.1	60.8	54.2	54.1
Apt #V – 1	71.3	62.8	59.2	56.5	73.8	71.3	64.9	58.9
Apt #V – 2	72.4	64.3	60.1	57.2	74.9	72.4	65.5	60.2
Apt #V – 3	73.0	66.0	61.3	57.4	75.3	73.0	66.1	61.5
Apt #V – 4	73.0	67.6	62.8	57.7	75.4	73.0	66.7	62.8
Apt #V – 5	73.1	68.7	64.2	58.6	75.5	73.1	67.2	63.7
Apt #V – 6	73.1	68.8	65.8	59.8	75.5	73.1	67.8	63.9
Apt #V – 7	73.2	70.3	67.3	60.9	75.4	73.2	68.3	64.2
Apt #V – 8	73.1	72.4	68.3	62.1	75.3	73.1	68.3	66.0
Apt #V – 9	72.9	72.9	68.4	63.6	75.1	72.9	68.3	68.2

Noise levels in db(A)	> 70	65-70	60-65	55-60	≤ 55

15 See for example, http://www.drillingnoisecontrol.com/tempwalls.html

- Reducing the number of equipment to a single piece reduces the noise levels at the receptors significantly. However, even under this extreme and unlikely scenario complete compliance with standards cannot be achieved.

8.3 Suggested Mitigation Measures

98. As the alignment of the proposed road is very close to the existing buildings and the construction equipment are typically very noisy, it is anticipated that the construction activity will be a source of nuisance to the community, unless managed properly. A list of mitigation measures are proposed. Given the complexity of the terrain, a single measure is unlikely to be effective. A combination of measures will be required to address these issues. The suggested measures that needs to be considered are as follows:

- **Construction Planning**. Many noise issues can be avoided by planning the construction activities in a manner that minimizes the disturbance to the community. Some suggested measures are:
  - Prefer newer equipment over older equipment as they are generally quieter because of technological advancements, lack of wear and tear, worn out, loose, and damaged components.
  - Locate storage area and vehicle yards in a manner that minimizes the travel time for construction vehicles.
  - Temporary storage shall be located removed from the sensitive receptors.
  - Permanent noise barriers that are planned for the abatement of traffic noise on the highway as part of the project, shall be installed as early as possible. They can possibly be erected simultaneously with Stage 5 of construction (see **Section 8.1**).
  - Pay particular attention to equipment at a particular location. By careful planning, the number of equipment at a particular location at a particular time can be reduced to the extent that compliance with the noise criteria is achieved. It may not be possible for certain type of equipment or certain activities and noise levels may exceed the criteria for certain period of time. In that case, schedule several noisy operations concurrently. This is advantageous because the combined noise levels of several noisy pieces of equipment may not be significantly greater than the level produced if the operations were performed separately. In other words, adding another piece of equipment to an already noisy operation may not be noticeable to the receptors, but running the operation for longer periods will add to the nuisance.
- **Noise Control at Source**. Taking measures to prevent emission of potentially offensive noise, or source control, is, in general, the most effective form of noise mitigation.[16] Some suggested measures are:
  - Avoid using equipment with high intrinsic noise levels (amounts to disallowing old equipment and those with poor maintenance)
  - Install mufflers on air intake and exhaust of all equipment. The mufflers are standard part of equipment, however, the wear and tear results in degradation of their performance and shall be regularly inspected, repaired

[16] Federal Highway Authority. *Construction Noise Handbook*.

and replaced if needed. In addition, availability of additional mufflers for further reduction in noise levels shall be investigated.

- Noise shields, physically attached to the piece of equipment, shall be provided to stationary equipment.
- Provide a regular inspection and maintenance procedure for all pieces of equipment focused on sources of noise and noise control components. This may include, for example, a) cleaning and, if needed, replacement of faulty or damaged mufflers, and b) tightening of loose screws and bolts of metal plates and engine parts to minimize vibration.

- **Equipment Operation Training**. FHWA recognizes that careless or improper operation or inappropriate use of equipment can increase noise levels. Poor loading, unloading, excavation, and hauling techniques are examples of how lack of adequate guidance and training may lead to increased noise levels. It is suggested that:
  - The contractor shall maintain a training plan for all equipment operators that, among other aspects, shall also include techniques for reduction in noise.
  - No operator shall be allowed to operate an equipment, unless he/she has received training on its operation.
- **Temporary Noise Barriers**. Until the permanent noise barriers are installed, temporary noise barriers shall be installed between the apartments and the construction zone. Examples of noise barriers are shown in **Figure 8-2**. Unless by combining other abatement measures it is demonstrated that lower barriers can suffice, the height of the noise barrier shall be (**Figure 8-3**):
  - Chainage 1050 to 1240 (190 m)—Minimum 3 m
  - Chainage 1240 to 1590 (350 m)—Minimum 6 m
  - Chainage 1590 to 1950 (360 m)—Minimum 3 m
- **Night Construction**. Any type of construction activity during the night shall not be allowed.

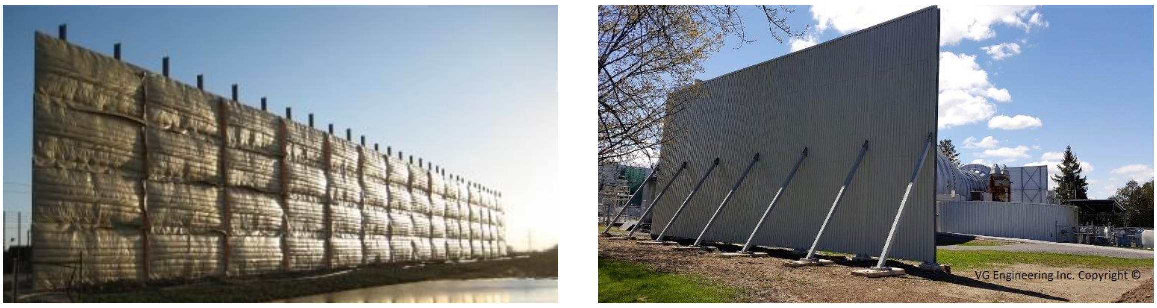

Figure 8-2: Examples of Temporary Nosie Barriers

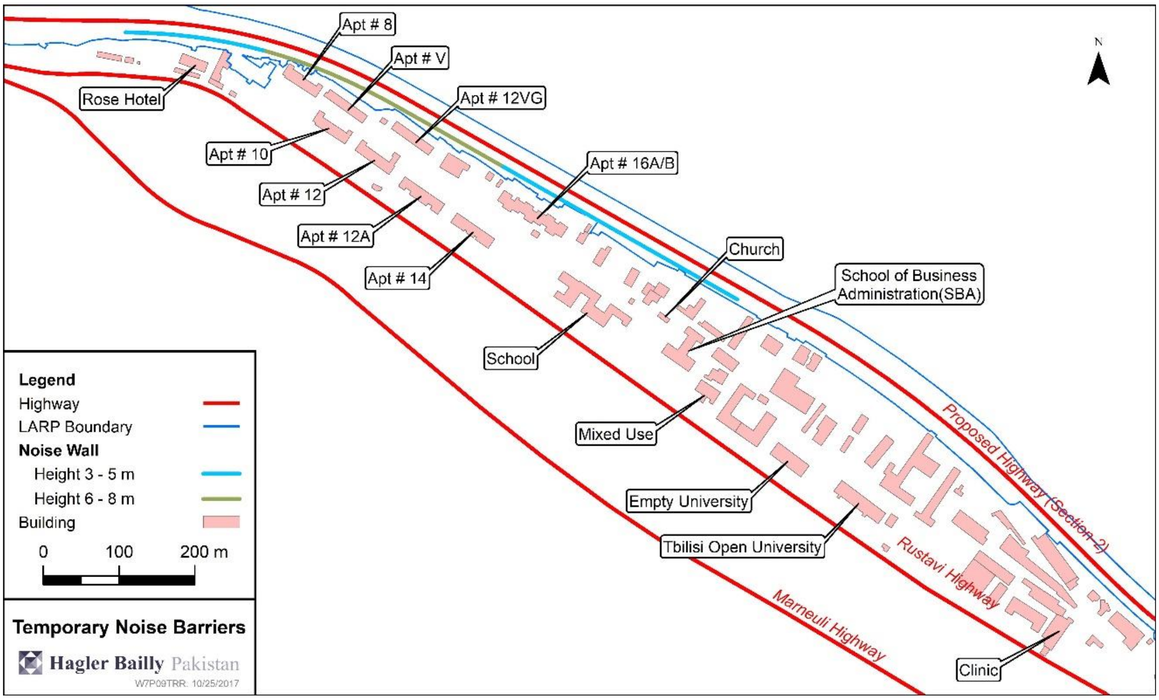

Figure 8-3: Temporary Noise Barriers

8.4 Management and Monitoring Program

99. The noise monitoring program shall be based on a robust management plan. The noise monitoring during construction shall include both monitoring of noise at source and monitoring of noise at receptor. Theses aspects are discussed in this section.

8.4.1 Management

100. An effective noise management program requires well defined goals, appropriate equipment, well-trained staff, written procedures, and clearly defined actions in case the goals are not met. These aspects are discussed below.

- **Procedure.** A written procedure for noise measurement shall be developed and maintained.
    - Sampling location
    - Equipment
    - Sampling Frequency
    - Measurement Protocol
    - Data Analysis
    - Data Reporting
- **Responsibility**. The contractor shall clearly define chain of responsibility to ensure compliance in a timely and proper manner. The top management of the contractor may also have to empower the field staff to take appropriate action, including stoppage of work, in case the goals are not met. The management shall also spell out the consequences in case of repeated non-compliance.
- **Goals**. Well-defined goals may include, for example:

- Meeting the IFC noise criteria x% of time during construction. Where “x%” can be 100%, 95%, 90% or any other value depending on the agreement with the community, project lenders and possibly the Ministry of Environment.
- Minimizing the community complaints and demonstrate reduction in the complaint rates during the life of the project.

- **Staff**. Staff for noise measurement will require the following skills and training:
  - Basic understanding of noise propagation
  - Noise measurement techniques
  - Handling of noise equipment, and
  - Noise data analysis.
- **Equipment**. The contractor shall also provide equipment sufficient to properly monitor noise levels and operations. The noise meters shall:
  - Be Class II rating
  - Meet International standards
  - Have a minimum resolution of 0.1 dB, and
  - Shall have battery life and internal memory to record at least 24 hours of data.

  Additionally, external calibrator, tripods, and back-up power shall be provided.

8.4.2 Monitoring of Noise at Source

101. All equipment, mobile or stationary, employed for construction shall undergo periodic noise testing using a standard measurement protocol. The suggested frequency of testing is as follows:

- Before deployment to construction work.
- Once every three months
- Following any major overhaul

102. A standard measurement protocol shall be used for measurement.[17] The outline of the protocol is as follows:

- While the equipment is being tested, any ancillary equipment which is usually in operation while the equipment is being used must be in operation.
- The equipment must be stationary.
- The measurements must be made where the ambient noise level is at least 10 dB(A) below the noise level being measured.

[17] For example, *Noise Measurement Procedures Manual*. Environment Division. Department of Environment, Parks, Heritage and the Arts, Government of Tasmania. July 2008. http://epa.tas.gov.au/documents/noise_measurement_procedures_manual_2008.pdf or *Measurement of Highway-Related Noise*. Report Number FHWA-PD-96-046. Federal Highway Authority. May 1996. Updated June 2017. https://www.fhwa.dot.gov/Environment/noise/measurement/measure.cfm

- The test site must be in the open air and must comprise a generally flat area of not less than 30 m radius that is free from reflective planes (other than the ground plane) and any obstruction that could significantly affect the test results. The test site surface shall be similar to that of the construction site. It may be covered with concrete, asphalt, firm soil or with a short grass covering, and must be essentially free from any loose acoustically absorbent material such as ice, snow, and ponded water.
- The sound level meter shall be set to A-weighted frequency response and fast time response.
- The microphone must be mounted on a tripod or stand with its nominal axis of maximum sensitivity directed horizontally toward the machine.
- The height of the microphone shall be 1.5 m above ground level.
- The sound level meter shall be placed at a distance of 50 ft (15 m) from the equipment.
- Only the equipment operator and the person carrying out the measurements shall remain within the test site whilst testing is in progress.
- The equipment noise shall be measured both in passive (idling) condition and in active (full throttling) condition. Where appropriate full movement of the major components, such as front-end loader buckets or excavator booms, is required during the test. These cycling movements should be done as far as practical, taking into consideration all relevant safe practices.
- Three sets of sound pressure level measurements, each comprising four measurements representing the front, rear and two sides of the machine must be obtained. Wherever possible the machine to microphone direction must be stepped 90 degrees between each set of measurements.
- The three values at each measurement location are to be arithmetically averaged and the sound pressure level recorded must be the maximum of the four average sound pressure levels.

8.4.3 Monitoring of Noise at Receptor

103. Due to the inherent variability in construction equipment, where they are deployed, the number of equipment deployed a t a given time, and terrain, it is not possible to precisely predict the construction noise levels at a given time and place. Therefore, the key to successful noise management during construction is the ongoing knowledge of noise levels generated by the activities so that time measures can be taken to modify the plans to reduce impacts on the community. The outline of the noise monitoring at receptor is as follows:

- **Monitoring Sites.** Before the start of construction activity, representative sites shall be identified for noise monitoring. The suggested locations are:
  - Rose Hotel
  - Apartment #8
  - Apartment #V (2 Sites)
  - Apartment #12VG (2 sites)
  - Apartment 16A/B

  - School
  - Clinic

- **Placement of Noise Meter**. Noise meters shall be placed in an open window or a balcony facing the construction zone. The pictures in **Figure 3-2** provides examples of proper placement of noise meter. It shall be ensured that there is no local noise source, such as air conditioner, refrigerator, or dog pen, near the site.

- **Duration and Method of Monitoring**. The measurement at each location shall for the duration of the construction activity on a given day. The sampling interval shall not be less than 3 second. The meters shall be calibrated before the start of measurement and subsequently after the completion of measurement.

- **Measurement Frequency**. The measurement frequency will depend on the activity level. Following is the suggested frequency:
  - Once before the start of construction activity
  - Once a fortnight, if the construction activity is within 250 m of the receptor
  - Once a month, if the construction activity is more than 250 m but less than 500 m.

  No monitoring is required if there is no construction activity within 500 m of the receptor.

- **Data Compilation and Analysis**. The data collected shall be analyzed to provide the following information:
  - Duration and timing of construction activity
  - List of equipment (with ID) deployed with their location, timing, and activity level during each hour of the activity
  - The calculated statistics (L_{eq}, L_{90}, L_{10}, and L_{Max}) for each hour of activity tabulated with the activity levels.

8.5 Community Engagement

104. An effective community engagement program is essential for addressing the noise related issues. Such a program provides a mechanism to keep the stakeholders informed throughout the construction phase, is a mean of getting valuable data related to the noise impact, and results in timely feedback from the community on any potential issues. While, the EIA of the project provides the grievance redress mechanism, following specific measures related to noise impacts may be necessary:

- Make an effort to identify and consult those members of the community that will be particularly affected by construction noise. These may not be the most vocal stakeholders and special effort may be required to reach out to them and obtain their feedback.

- The community shall be fully inform about:
  - Schedule of the construction stages
  - Activities in each stage including the number of equipment that will be deployed

  - The proposed noise abatement measures during construction
  - The goals of noise management plan
  - The noise monitoring plan
  - The expected level, duration, and schedule of exceedance
- Community shall be provided with an opportunity to comment and provide input related to purpose and need of management and monitoring. Where community provide alternative schemes those shall be actively considered and, if feasible, adopted.

APPENDIX A: DETAILED RESULTS FOR SELECTED MITIGATION SCENARIOS

Modeling result for predicted 2038 traffic

All values in dBA

Color key:

(dark green)	Baseline (2017): Noise levels above IFC noise guidelines limits Post mitigation (2038): Noise levels reduced and below IFC noise guidelines limits.
(light green)	Baseline (2017): Noise levels above IFC noise guidelines limits Post mitigation (2038): Noise levels reduced however still above IFC noise guidelines limits.
(white)	Either No change in noise level OR the increase is less than 3 dBA and Post mitigation (2038) noise levels below IFC noise guidelines limits
(yellow)	Noise levels increased. The increase is either more than 3 dBA OR Post mitigation (2038) noise levels above IFC noise guidelines limits (only one condition met)
(red)	Noise levels increased. The increase is both more than 3 dBA and Post mitigation (2038) noise levels above IFC noise guidelines limits.

Mitigation Scenarios:

W	Noise wall
W + IRS	Noise wall and improved road surface
W + T	Noise wall and tunnel

Building	Direction	Floor	W		W + IRS		W + T	
			Day	Night	Day	Night	Day	Night
Apt (#10)	Southwest	1	55.8	47.7	55.6	47.5	55.7	47.6
Apt (#10)	Southwest	2	57	48.9	56.8	48.7	56.8	48.7
Apt (#10)	Northeast	1	51.3	43.4	50.8	42.9	50.6	42.7
Apt (#10)	Northeast	2	53.1	45.2	52.6	44.7	52.5	44.7
Apt (#12 A)	Southwest	1	55.5	47.4	55.4	47.3	55.4	47.3
Apt (#12 A)	Southwest	2	57	48.9	57	48.8	57.0	48.9
Apt (#12 A)	Southwest	3	58.1	50	58	49.9	58.1	50.0
Apt (#12 A)	Southwest	4	58.7	50.5	58.6	50.5	58.6	50.5
Apt (#12 A)	Southwest	5	59.1	50.9	59	50.9	59.0	50.8
Apt (#12 A)	Northeast	1	48.6	40.8	48.2	40.4	46.4	38.5
Apt (#12 A)	Northeast	2	49.6	41.7	49.2	41.3	47.3	39.5
Apt (#12 A)	Northeast	3	50.3	42.4	50.1	42.2	48.1	40.2
Apt (#12 A)	Northeast	4	50.9	43	51.1	43.2	48.6	40.8
Apt (#12 A)	Northeast	5	52.2	44.3	52.6	44.7	50.2	42.3

Building	Direction	Floor	W		W + IRS		W + T	
			Day	Night	Day	Night	Day	Night
Apt (#12 VG)	Southwest	1	51.8	43.9	51.5	43.6	51.8	43.9
Apt (#12 VG)	Southwest	2	52.5	44.6	52.3	44.3	52.4	44.5
Apt (#12 VG)	Southwest	3	53.3	45.4	53.1	45.2	53.2	45.3
Apt (#12 VG)	Southwest	4	54	46.1	53.8	45.9	53.9	46.0
Apt (#12 VG)	Southwest	5	54.8	46.8	54.6	46.7	54.6	46.7
Apt (#12 VG)	Southwest	6	55.1	47.1	55	47	54.9	47.0
Apt (#12 VG)	Southwest	7	55.4	47.4	55.3	47.3	55.2	47.3
Apt (#12 VG)	Southwest	8	55.7	47.7	55.4	47.4	55.5	47.6
Apt (#12 VG)	Southwest	9	56.3	48.4	55.9	47.9	55.9	47.9
Apt (#12 VG)	Northeast	1	52.8	44.9	53.1	45.3	45.4	37.6
Apt (#12 VG)	Northeast	2	54.2	46.3	56	48.1	45.5	37.7
Apt (#12 VG)	Northeast	3	55.9	48	60.1	52.2	45.6	37.8
Apt (#12 VG)	Northeast	4	58.5	50.6	65.8	57.9	45.7	37.9
Apt (#12 VG)	Northeast	5	62.1	54.2	65.8	57.9	45.8	38.0
Apt (#12 VG)	Northeast	6	66.9	59	65.7	57.8	45.9	38.1
Apt (#12 VG)	Northeast	7	68.6	60.7	65.6	57.7	46.0	38.2
Apt (#12 VG)	Northeast	8	68.4	60.5	65.4	57.5	46.3	38.5
Apt (#12 VG)	Northeast	9	68.2	60.4	65.3	57.4	48.0	40.2
Apt (#12)	Southwest	1	55.4	47.4	55.3	47.2	55.3	47.3
Apt (#12)	Southwest	2	56.7	48.6	56.5	48.4	56.5	48.5
Apt (#12)	Northeast	1	50.9	43	50	42.1	48.9	41.1
Apt (#12)	Northeast	2	52.5	44.6	52.2	44.3	51.1	43.2
Apt (#14)	Southwest	1	55.6	47.4	55.5	47.4	55.5	47.4
Apt (#14)	Southwest	2	57	48.9	57	48.8	57.0	48.8
Apt (#14)	Southwest	3	58.2	50.1	58.1	50	58.1	50.0
Apt (#14)	Northeast	1	48.8	40.9	48.4	40.5	47.4	39.5
Apt (#14)	Northeast	2	49.8	41.9	49.4	41.5	48.4	40.5
Apt (#14)	Northeast	3	51.7	43.8	51.4	43.5	50.1	42.2
Apt (#16 A/B)	Southwest	1	52.7	44.8	52.6	44.7	52.6	44.6
Apt (#16 A/B)	Southwest	2	53.2	45.3	53.1	45.2	53.1	45.1
Apt (#16 A/B)	Southwest	3	53.5	45.6	53.5	45.5	53.4	45.4
Apt (#16 A/B)	Southwest	4	53.9	46	53.8	45.9	53.7	45.7
Apt (#16 A/B)	Southwest	5	55.2	47.3	54.7	46.8	54.3	46.4

Building	Direction	Floor	W		W + IRS		W + T	
			Day	Night	Day	Night	Day	Night
Apt (#16 A/B)	Northeast	1	52	44.1	52.2	44.3	40.3	32.5
Apt (#16 A/B)	Northeast	2	53.6	45.7	54.4	46.5	41.0	33.2
Apt (#16 A/B)	Northeast	3	55.8	47.9	57.1	49.2	42.2	34.4
Apt (#16 A/B)	Northeast	4	58.6	50.7	59.8	51.9	43.9	36.1
Apt (#16 A/B)	Northeast	5	61.7	53.9	63.1	55.2	50.1	42.2
Apt (#8)	Southwest	1	53.4	45.4	52.7	44.8	52.9	44.9
Apt (#8)	Southwest	2	55.2	47.2	54.5	46.5	54.2	46.2
Apt (#8)	Northeast	1	54.9	47	54	46.1	48.2	40.3
Apt (#8)	Northeast	2	57.5	49.7	57.5	49.6	52.3	44.5
Apt (#V)	Southwest	1	52.9	44.9	52.5	44.5	52.6	44.6
Apt (#V)	Southwest	2	54.5	46.6	54.2	46.2	54.3	46.3
Apt (#V)	Southwest	3	55.1	47.2	54.7	46.7	54.9	47.0
Apt (#V)	Southwest	4	55.6	47.6	55.1	47.1	55.4	47.4
Apt (#V)	Southwest	5	56.2	48.2	55.8	47.7	56.0	48.0
Apt (#V)	Southwest	6	56.5	48.5	56	48	56.3	48.2
Apt (#V)	Southwest	7	56.9	48.9	56.4	48.3	56.6	48.6
Apt (#V)	Southwest	8	57.2	49.2	56.7	48.6	56.9	48.9
Apt (#V)	Southwest	9	57.7	49.7	57	49	57.2	49.2
Apt (#V)	Northeast	1	52.8	44.9	52.1	44.2	45.6	37.7
Apt (#V)	Northeast	2	54.3	46.5	54.8	46.9	46.0	38.1
Apt (#V)	Northeast	3	57.4	49.5	58.5	50.6	46.4	38.6
Apt (#V)	Northeast	4	61.4	53.5	63.3	55.4	46.9	39.0
Apt (#V)	Northeast	5	66	58.1	65.1	57.3	47.4	39.5
Apt (#V)	Northeast	6	67.8	59.9	65.1	57.2	48.0	40.1
Apt (#V)	Northeast	7	67.8	59.9	65	57.1	48.7	40.8
Apt (#V)	Northeast	8	67.9	60	64.9	57	49.4	41.5
Apt (#V)	Northeast	9	67.8	59.9	64.8	56.9	50.8	42.9
Church	Southwest	1	53.8	45.8	53.5	45.6	53.5	45.5
Church	Southwest	2	55.6	47.7	55.6	47.7	55.1	47.2
Church	Northeast	1	51.5	43.7	50.1	42.2	51.0	43.1
Church	Northeast	2	55.5	47.6	55.6	47.7	55.0	47.1
Clinic	Northeast	1	49.7	41.8	47.6	39.7	50.8	42.9
Clinic	Northeast	2	51.6	43.7	49.8	41.9	52.6	44.7

Building	Direction	Floor	W		W + IRS		W + T	
			Day	Night	Day	Night	Day	Night
Empty University	Southwest	1	57.9	49.7	57.8	49.7	57.9	49.7
Empty University	Southwest	2	59	50.8	59	50.8	59.0	50.8
Empty University	Southwest	3	59.4	51.2	59.4	51.2	59.4	51.2
Empty University	Southwest	4	59.7	51.5	59.7	51.5	59.7	51.5
Empty University	Northeast	1	46.7	38.8	45.3	37.3	46.9	39.1
Empty University	Northeast	2	47.5	39.6	46	38.1	47.6	39.8
Empty University	Northeast	3	48.4	40.5	47.4	39.5	48.6	40.8
Empty University	Northeast	4	50	42.1	49.4	41.5	50.2	42.4
Mixed Use (1)	Southwest	1	55.3	47.2	55.2	47.1	55.2	47.1
Mixed Use (1)	Southwest	2	56.4	48.3	56.4	48.3	56.4	48.3
Mixed Use (1)	Southwest	3	57.2	49.1	57.1	49	57.2	49.0
Mixed Use (1)	Southwest	4	58	49.9	58	49.9	58.0	49.9
Mixed Use (1)	Northeast	1	46.1	38.2	45.7	37.8	44.7	36.9
Mixed Use (1)	Northeast	2	47.7	39.8	47.3	39.4	46.4	38.6
Mixed Use (1)	Northeast	3	49	41.1	48.9	41	47.4	39.6
Mixed Use (1)	Northeast	4	50.1	42.2	50.3	42.4	48.3	40.4
Open University	Southwest	1	57.1	49	57.1	49	57.1	49.0
Open University	Southwest	2	58	49.8	58	49.8	58.0	49.8
Open University	Southwest	3	58.5	50.4	58.5	50.4	58.5	50.4
Open University	Southwest	4	58.9	50.8	58.9	50.7	58.9	50.8
Open University	Northeast	1	47.3	39.4	46.1	38.2	47.5	39.6
Open University	Northeast	2	47.9	40	46.9	39.1	48.1	40.3
Open University	Northeast	3	48.7	40.8	47.6	39.7	48.5	40.7
Open University	Northeast	4	50.2	42.3	49.4	41.5	50.1	42.3
Rose Hotel	South	1	55.2	47.3	54.7	46.7	55.1	47.2
Rose Hotel	South	2	59.5	51.4	59.3	51.1	59.4	51.3
Rose Hotel	South	3	60.6	52.4	60.2	52	60.4	52.2
Rose Hotel	North	1	54	46.1	52.7	44.8	52.9	45.0
Rose Hotel	North	2	54.4	46.5	52.3	44.3	52.5	44.6
Rose Hotel	North	3	57	49.1	52.6	44.6	53.0	45.1
SBA	Southwest	1	53.9	45.9	53.8	45.8	53.9	45.9
SBA	Southwest	2	54.9	46.8	54.8	46.7	54.8	46.8
SBA	Southwest	3	56.1	48.1	56	47.9	56.0	48.0

Building	Direction	Floor	W		W + IRS		W + T	
			Day	Night	Day	Night	Day	Night
SBA	Northeast	1	51.5	43.6	49.8	41.9	50.7	42.9
SBA	Northeast	2	51.4	43.5	51.2	43.3	50.2	42.3
SBA	Northeast	3	52.5	44.6	52.7	44.8	51.4	43.6
School	Southwest	1	55.3	47.2	55.2	47.1	55.3	47.1
School	Southwest	2	56.8	48.7	56.7	48.6	56.7	48.6
School	Southwest	3	57.7	49.6	57.6	49.5	57.6	49.5
School	Northeast	1	49.5	41.7	48.9	41	48.1	40.2
School	Northeast	2	50	42.1	49.3	41.4	48.5	40.6
School	Northeast	3	51.7	43.8	51.4	43.6	50.2	42.4
UC Apt	Southwest	1	57.2	49	57.2	49	57.2	49.0
UC Apt	Southwest	2	58.4	50.2	58.3	50.2	58.4	50.2
UC Apt	Southwest	3	58.9	50.8	58.9	50.8	58.9	50.8
UC Apt	Southwest	4	59.4	51.2	59.3	51.2	59.4	51.2
UC Apt	Southwest	5	59.7	51.6	59.7	51.5	59.7	51.6
UC Apt	Northwest	1	52.3	44.4	52.1	44.1	52.3	44.4
UC Apt	Northwest	2	52.5	44.6	52.2	44.3	52.7	44.7
UC Apt	Northwest	3	53.4	45.4	53.2	45.2	53.6	45.7
UC Apt	Northwest	4	54	46	53.8	45.8	54.3	46.4
UC Apt	Northwest	5	54.8	46.8	54.5	46.5	55.2	47.2