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Noise Impact Assessment for Outdoor Activities

Oro Valley Church of the Nazarene

Prepared for

Oro Valley Church of the Nazarene

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R. 2, April 5, 2022

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1. Summary

This report is a preliminary assessment of the community noise impact of amplified speech and music at the proposed activity fields and amphitheater at the Oro Valley Church of the Nazarene on Calle Concordia with respect to Section 25.1 of the Oro Valley Zoning Code. Recommendations for a sound wall, setbacks for loudspeaker placement, and hours of operation are provided.

1.1 Revisions

- R. 2 : April 5, 2022
  - Fix inconsistent setbacks in Section 3.2.3
- R. 1 : February 26, 2022
  - Add analysis of amphitheater
    - general recommendation of sound wall or band shell
    - recommended sound pressure level limit at back of seating
  - Clarification of loudspeaker using during sports events
  - Specification of additional setbacks for outdoor services on activity fields
- R. 0 : December 15, 2021
  - Original release

2. Site Summary

2.1 Proposed Site Development

The Oro Valley Church of the Nazarene is located at 500 West Calle Concordia in Oro Valley. This noise impact study will focus on the planned expansion of outdoor activities in the northern portion of the property. These will consist of an activity field used for sports and occasional church services and a small amphitheater near the east property line.

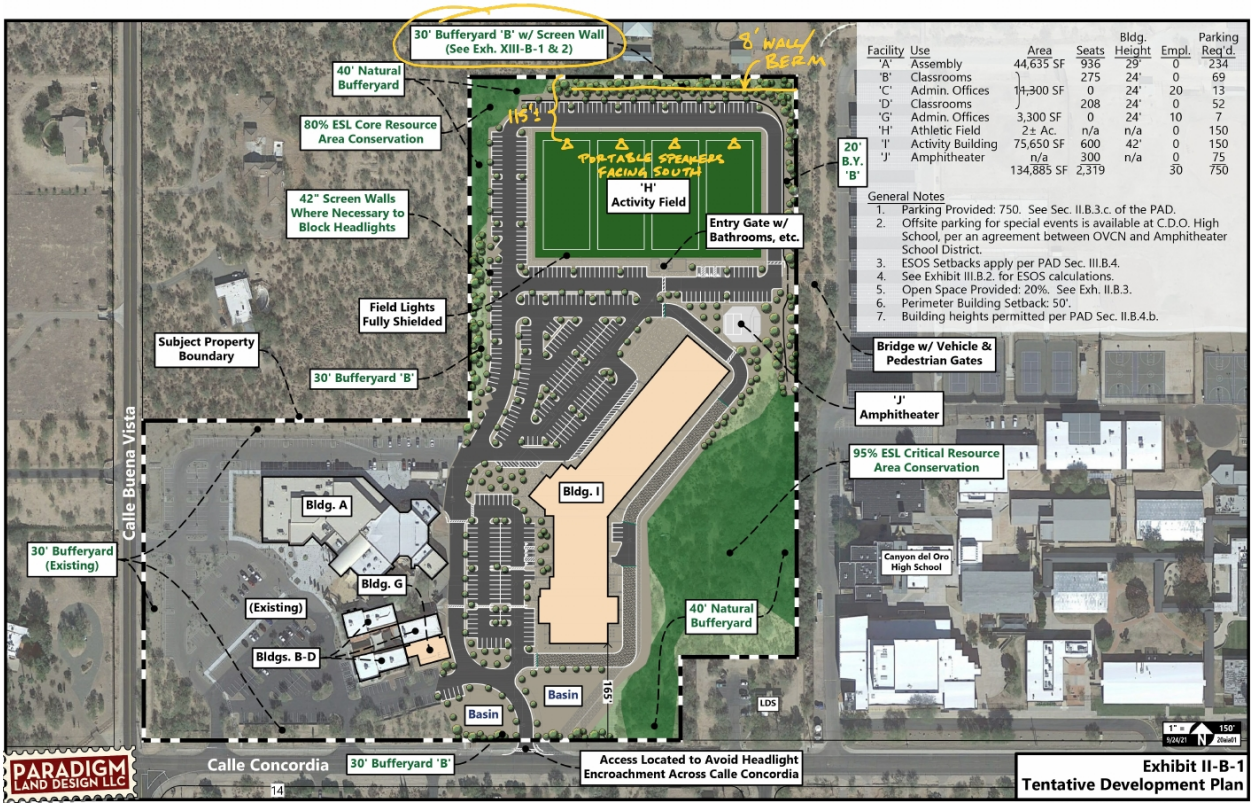

Figure 2.1. Outdoor Activities Expansion Plan

2.2 Area Summary

The land uses surrounding the church are shown in Figure 2.2. To the north and west are single family homes. To the east is the Canyon Del Oro High School. Across Calle Concordia and Calle Buena Vista are single family homes.

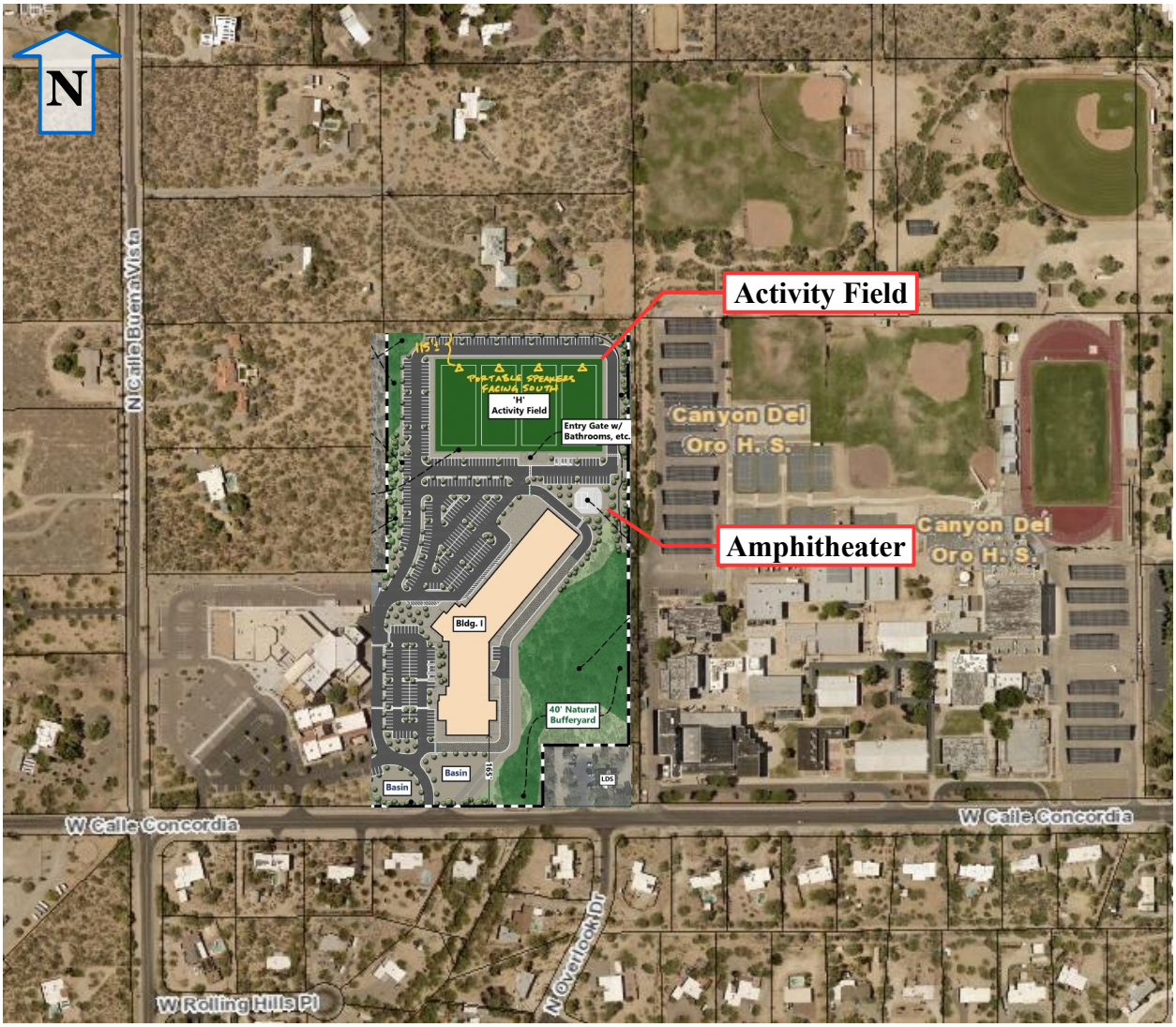

Figure 2.2. Proposed Site and Surrounding Area

The area has a slight slope to the south southwest. This is not expected to have a noticeable effect sound propagation.

2.3 Zoning

Zoning in the area is shown in Figure 2.3 [Pima County ArcGIS Online <https://pimamaps.pima.gov/geoapps/main>]. All properties adjacent to the church are zoned single family residential.

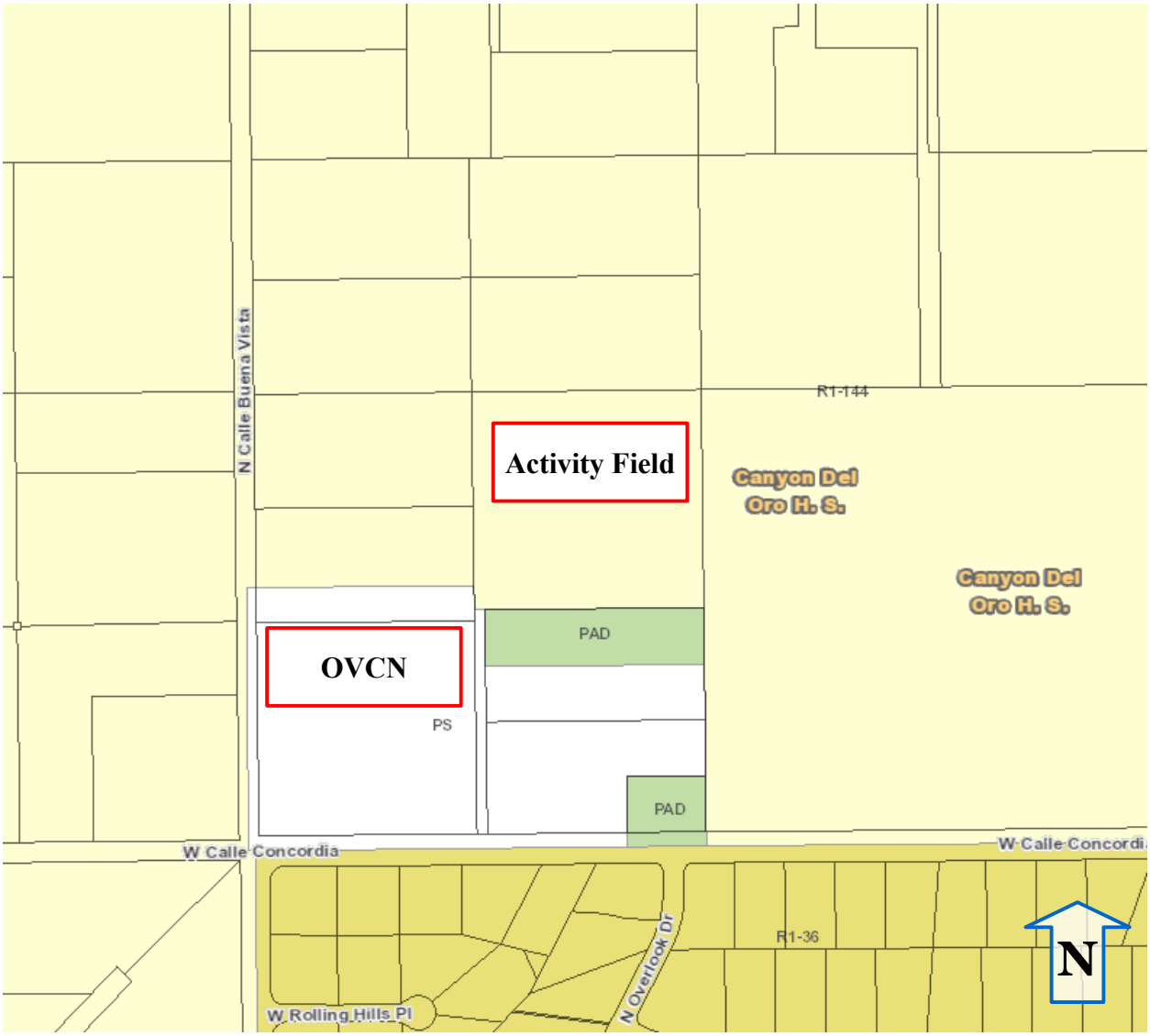

Figure 2.3. Zoning

2.4 Sound Sources

2.4.1 Activity Field

The activity field will be used for team practices, practice events, skills trials, and games. The field is subdividable for practices. Church services may be held on the field as well. Bleachers for spectators are not planned for the field.

A portable sound system will be used for sporting events and services. There will be no play by play announcements during games. The portable speakers will be used intermittently for instructing people where to go and for coaches to communicate with players during practices. Other sound sources may include whistles used by referees and coaches.

2.4.2 Amphitheater

A small amphitheater, about 4,600 square feet, is planned on the east side of the property. There are no specific site plans available at this stage in the design, but expected uses include weddings, sunrise services, musical concerts, and events for youth.

3. Site Plan Analysis

3.1 Methodology

The acoustical site model has been constructed using the iNoise package version 2021.0 developed by DGMR. The sound propagation model is ISO 9613. This software conforms with the ISO/TR 17534-3 quality standard for implementing the ISO 9613 Part 2 outdoor sound propagation model.

3.2 Sound Sources

3.2.1 Portable Loudspeaker System

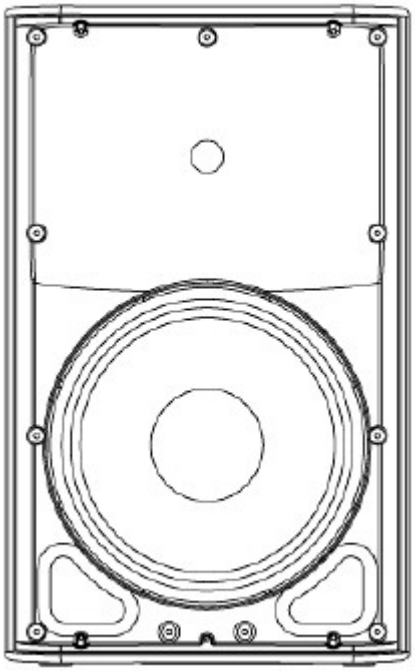

Figure 3.1. QSC K10 2-way Loudspeaker

Sound reinforcement for the activity fields will be a set of portable loudspeakers similar to the QCS K10. These are 2-way cabinets with 90° conical horns mounted on stands at head height. Rear projection for the horns is assumed to be 12 dB less than on the forward speaker axis.

3.2.2 Sports Activities

In this use case, team practices will be held on all four fields. Coaches will use four loudspeakers placed at the north end of each field facing south to communicate with players. The total playing area is approximately 90,900 square feet (10,650 m^2). Figure 3.2 shows the locations of the loudspeakers, whistles, and area covered by players. Loudspeakers will be located on the grassy area of the field.

With two, 11 player teams on each field there will be 0.0104 players per square meter. If one person on each team is speaking at any given time the speech activity ratio for each speaker will be 0.0909. Table 3.1 shows the octave band and A weighted sound power levels per square meter of playing area on the activity fields. The acoustical model uses the loud vocal effort sound power level spectrum.

Coaches will speak through the loudspeakers and are expected to be speaking 10% of the time. The speech spectrum used in the acoustical model is the ANSI S3.5 normal effort speech spectrum shown in Table 3.1. The loudspeaker levels have been adjusted in the acoustical model to produce 62 dBA at the opposite end of the field.

All equivalent-continuous levels used in the acoustical model for speech activities include a 5.0 dBA adjustment for regular impulsive sound as required by the Oro Valley Zoning Code. The typical difference in maximum exponential time weighted level and equivalent-continuous level is about 10.8 dBA. Therefore, for the speech activities above, the limiting criterion for code compliance will be the equivalent-continuous sound pressure level.

Figure 3.2. Sound Source Locations for Sports Activities

ANSI S3.5 Standard Speech Spectrum Level (PWL, DI = 2)										
Center Frequency (Hz)	**31**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**A-wgt**
Normal			56.0	64.8	67.0	62.0	56.7	51.4	44.9	67.1
Raised			57.4	68.3	72.8	70.5	65.1	59.2	49.5	74.3
Loud			58.9	72.4	78.2	78.6	74.1	67.4	55.8	81.8
Shout			54.4	74.4	83.2	87.1	84.0	77.0	65.2	90.1
Speech/music adjustment			5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Single Source Adjusted PWL										
Normal			61.0	69.8	72.0	67.0	61.7	56.4	49.9	72.1
Raised			62.4	73.3	77.8	75.5	70.1	64.2	54.5	79.3
Loud			63.9	77.4	83.2	83.6	79.1	72.4	60.8	86.8
Shout			59.4	79.4	88.2	92.1	89.0	82.0	70.2	95.1
Density (persons/m^2)			0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Active ratio			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PWL correction (dB)			-30.2	-30.2	-30.2	-30.2	-30.2	-30.2	-30.2	-30.2
Adjusted PWL per m^2										
Normal			30.8	39.5	41.7	36.7	31.4	26.1	19.7	41.9
Raised			32.2	43.1	47.5	45.2	39.9	34.0	24.3	49.0
Loud			33.6	47.2	53.0	53.4	48.9	42.1	30.5	56.5
Shout			29.1	49.2	58.0	61.9	58.8	51.7	40.0	64.9

Table 3.1. Unweighted Octave Band ANSI S3.5 Standard Speech Spectra for Sports

Other sound sources include whistles. The worst case scenario will be locations on the north and west sidelines of the fields. Measurement of a safety whistle found a maximum exponential time weighted sound pressure level of 105.0 dBA in the 4,000 Hz octave band at 1.0 meter from the source. The main concern here will be the maximum exponential time weighted sound pressure level as the equivalent-continuous level will be small due to the short duration and intermittent use of these devices.

3.2.3 Outdoor Services

A typical outdoor service is expected to have 300 to 400 people in attendance. Row seating at 8 square feet per person with an 8 foot wide center aisle and 10 feet from the loudspeakers to the first row will require a coverage area of 70 by 70 feet. Two main loudspeakers will be placed at the front of the seating area facing south. With the audience seated near the center of the fields, a 200 foot buffer is achievable from the loudspeakers to the property line. See Figure 3.3.

Recommended setbacks from the west and east property lines are 200 feet and 250 feet respectively for the loudspeakers and seating area. In regard to houses across Calle Concordia, the outdoor services should be located on the activity fields.

Figure 3.3. Loudspeaker Placement for Outdoor Services

	ANSI S3.5 Standard Speech Spectrum Level (PWL, DI = 2)								
Center Frequency (Hz)	**31**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**A-wgt**
Normal			56.0	64.8	67.0	62.0	56.7	51.4	44.9	67.1
Raised			57.4	68.3	72.8	70.5	65.1	59.2	49.5	74.3
Loud			58.9	72.4	78.2	78.6	74.1	67.4	55.8	81.8
Shout			54.4	74.4	83.2	87.1	84.0	77.0	65.2	90.1
Calibrate to 65 dBA at back of seating			34.9	34.9	34.9	34.9	34.9	34.9	34.9	
Leq										
Activity factor			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Speech/music adjustment			5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Total Leq Adjustment			39.9	39.9	39.9	39.9	39.9	39.9	39.9	

Table 3.2. Unweighted Octave Band ANSI S3.5 Standard Speech Spectra for Services

The acoustical model uses the normal effort speech spectrum in Table 3.2 with the loudspeaker gain adjusted to produce 65 dBA at the back of the seating area. Since the speech during the services will be mostly continuous, the activity factor adjustment is 0.0 dBA.

If music will be part of the services, the one minute octave band limits need to be considered. For music the unweighted 63 Hz octave band will typically be about 7 dB higher than the A-weighted sound level.

3.2.4 Amphitheater

The amphitheater is expected to be used for a variety of events. The use case with the highest expected impact on neighboring properties will be music concerts. Loudspeakers are expected to be located at the front of the stage on either side. Elevation drawings for the amphitheater are not available. It is assumed that the main PA speakers will be 6 feet above the height of the stage and subwoofers will be at stage level.

The acoustical spectrum produced by the loudspeakers is the same as that used in the analysis of the outdoor services on the activity fields. The sound power level, however, has been reduced for the size of the amphitheater and to meet low frequency sound pressure level limits at the east property line.

3.3 Sound Pressure Level Contour Maps

Sound pressure level contours in the figures below are displayed in 5 dBA increments. The legend identifying the map symbols is in Figure 3.4. All sound pressure levels are A-weighted unless otherwise noted. Sound walls are labeled as barriers in the iNoise software. The height of the contour grid points is 5 feet above grade.

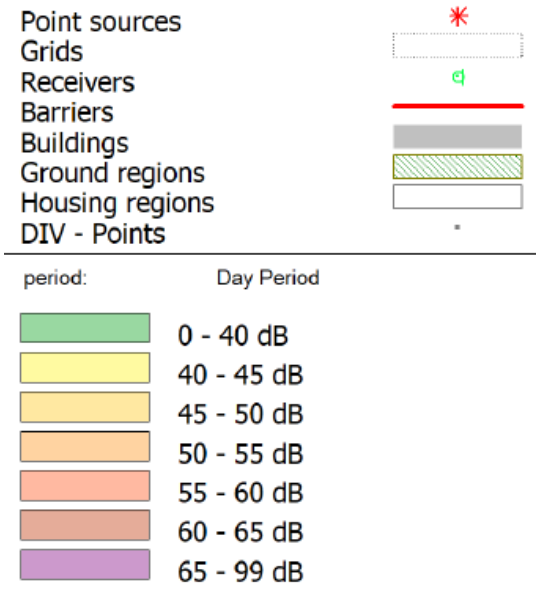

Figure 3.4. Legend for Sound Pressure Level Contour Maps

3.4 The Model Space

Figure 3.5 gives an overview of the acoustical model. A set of field points has been selected to better quantify the sound pressure levels expected at specific locations. These are listed in Table 3.3. Since a sound wall is planned for installation near the property line, two field points have been added on each of the three adjacent residential parcels: one at the property line (PL) and one at the pool area (Pool) as indicated in the table.

Location	Land Use	Height Above Grade (ft)
441 W CALLE CONCORDIA	Single Family	5
9360 N CALLE BUENA VISTA - PL	Single Family	5
9360 N CALLE BUENA VISTA - Pool	Single Family	5
9370 N CALLE BUENA VISTA - PL	Single Family	5
9370 N CALLE BUENA VISTA - Pool	Single Family	5
9382 N CALLE BUENA VISTA - PL	Single Family	5
9382 N CALLE BUENA VISTA - Pool	Single Family	5

Table 3.3. Field Points

Figure 3.5. Acoustical Model View for Activity Fields

Ground types in the model are asphalt and natural desert (default) having ISO 9613 ground factors of 0.1 and 0.3 respectively. The activity fields have ISO 9613 ground factor 1.0 for friable soil. Buildings on the Church property have been included in the model with facade reflection coefficients of 0.8.

An 8 foot high sound wall is also included in the acoustical model shielding the adjacent residential properties to the north and west of the activity fields. This is shown in red in Figure 3.5.

A view of the model used for the amphitheater is shown in Figure 3.6. Loudspeakers are placed at either side of the stage. A calibration point is located at the back of the seating area. A sound wall or band shell will be needed to shield the adjacent school from the subwoofers. the height of the wall is 8 feet.

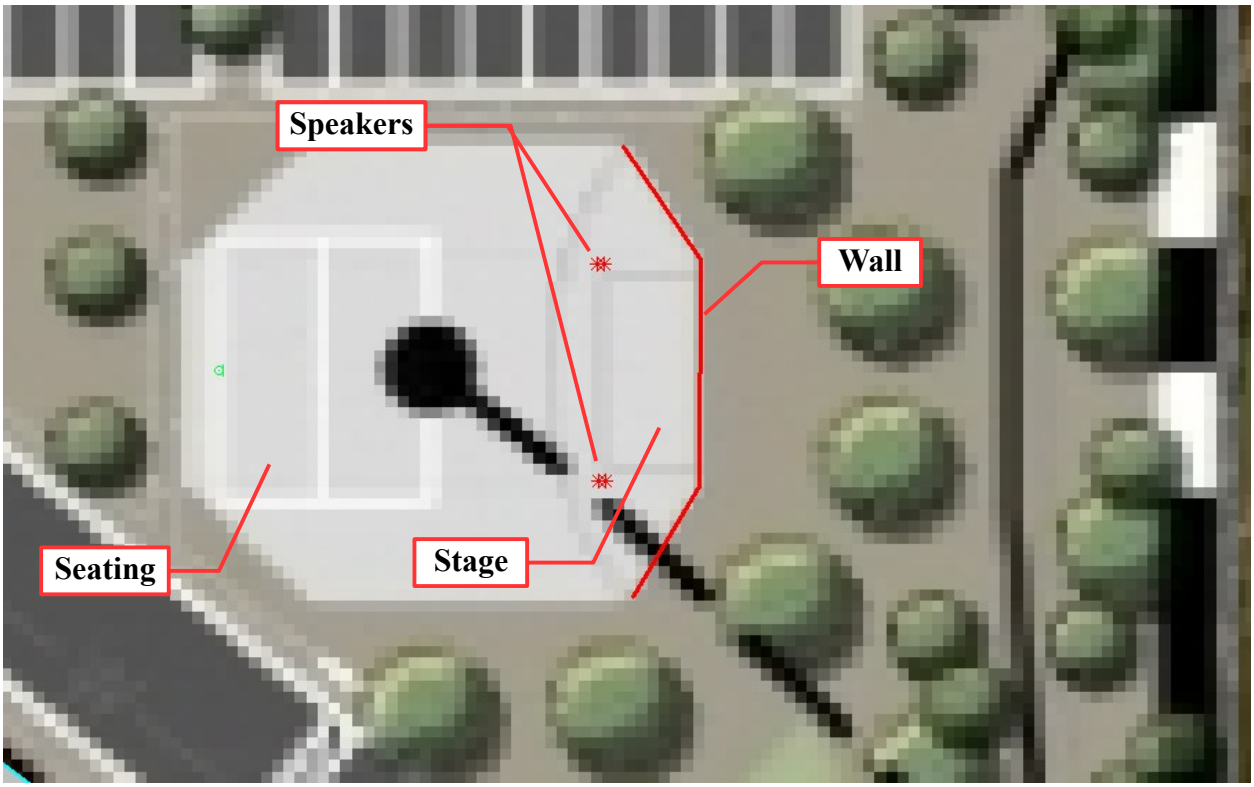

Figure 3.6. Acoustical Model View for Amphitheater

3.5 Use Cases

3.5.1 Sports

For the sports activities use case, sound pressure level contours for the A-weighted equivalent-continuous sound pressure levels (LAeq) are shown in Figure 3.7 and for the maximum fast exponential time weighted sound pressure levels (LAFmax) in Figure 3.8. The results for the corresponding field points are shown in Tables 3.4 and 3.5.

Speech, whistles, and the other activities in this use case do not produce significant amounts of low frequency acoustical energy. The one minute octave band sound pressure levels are therefore not a limiting factor for code compliance.

The results for this use case indicate that it will comply with the Oro Valley Zoning Code in regard to noise for daytime and evening operation (7:00 am to 10:00 pm), but the LAeq may cause an issue for the adjacent residential property to the north after 10:00 pm. The sports activities meet the 65 dBA LAeq and 85 dBA LAFmax requirements for the adjacent to school to the east.

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
441 W CALLE CONCORDIA	Single Family	5	43.4	55	no	50	no	45	no
9360 N CALLE BUENA VISTA - PL	Single Family	5	44.1	55	no	50	no	45	no
9360 N CALLE BUENA VISTA - Pool	Single Family	5	40.3	55	no	50	no	45	no
9370 N CALLE BUENA VISTA - PL	Single Family	5	43.1	55	no	50	no	45	no
9370 N CALLE BUENA VISTA - Pool	Single Family	5	39.5	55	no	50	no	45	no
9382 N CALLE BUENA VISTA - PL	Single Family	5	48.0	55	no	50	no	45	yes
9382 N CALLE BUENA VISTA - Pool	Single Family	5	43.7	55	no	50	no	45	no

Table 3.4. LAeq Code Compliance for Sports Activities

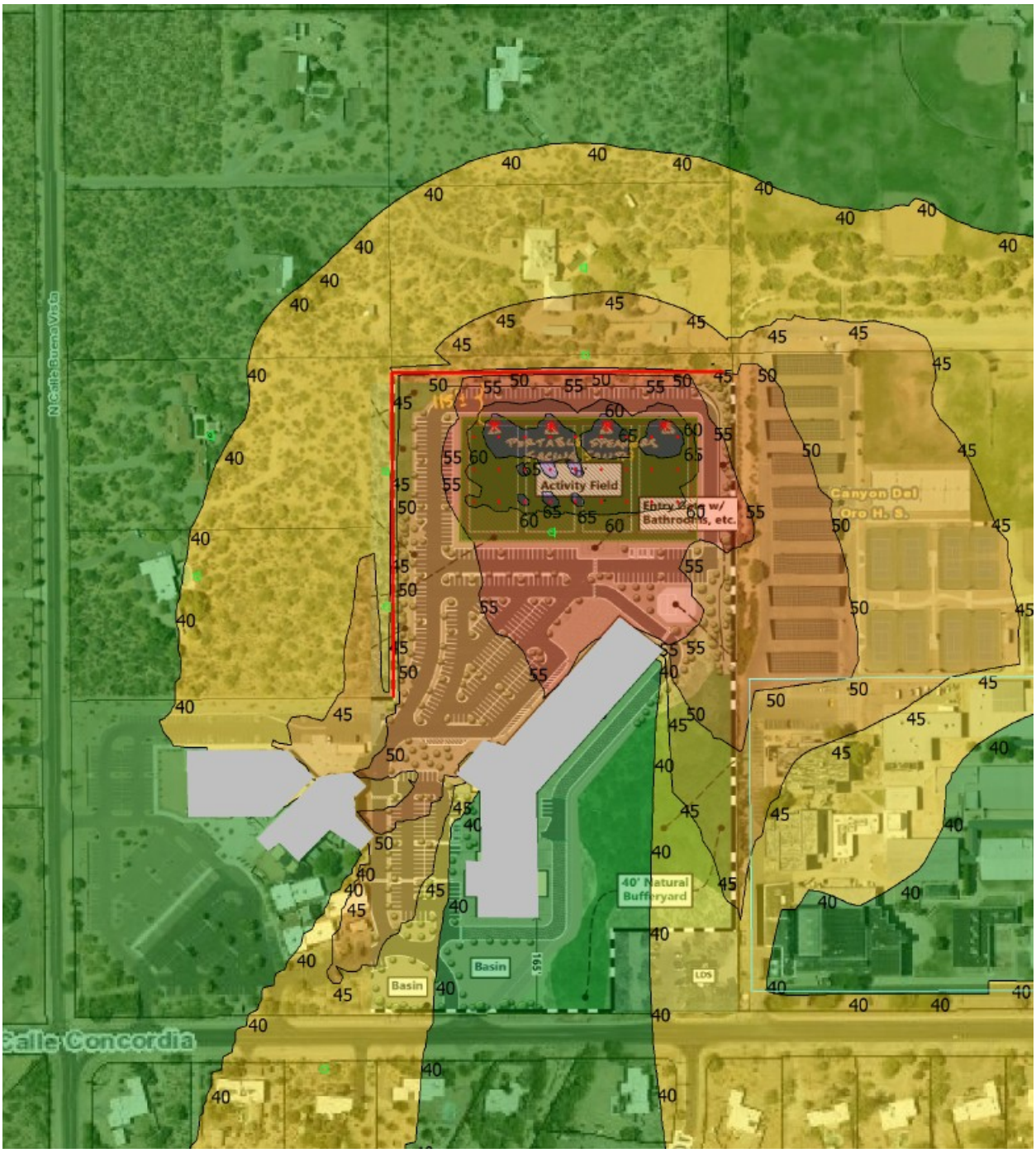

Figure 3.7. Adjusted LAeq Sound Pressure Level Contours for Sports Activities

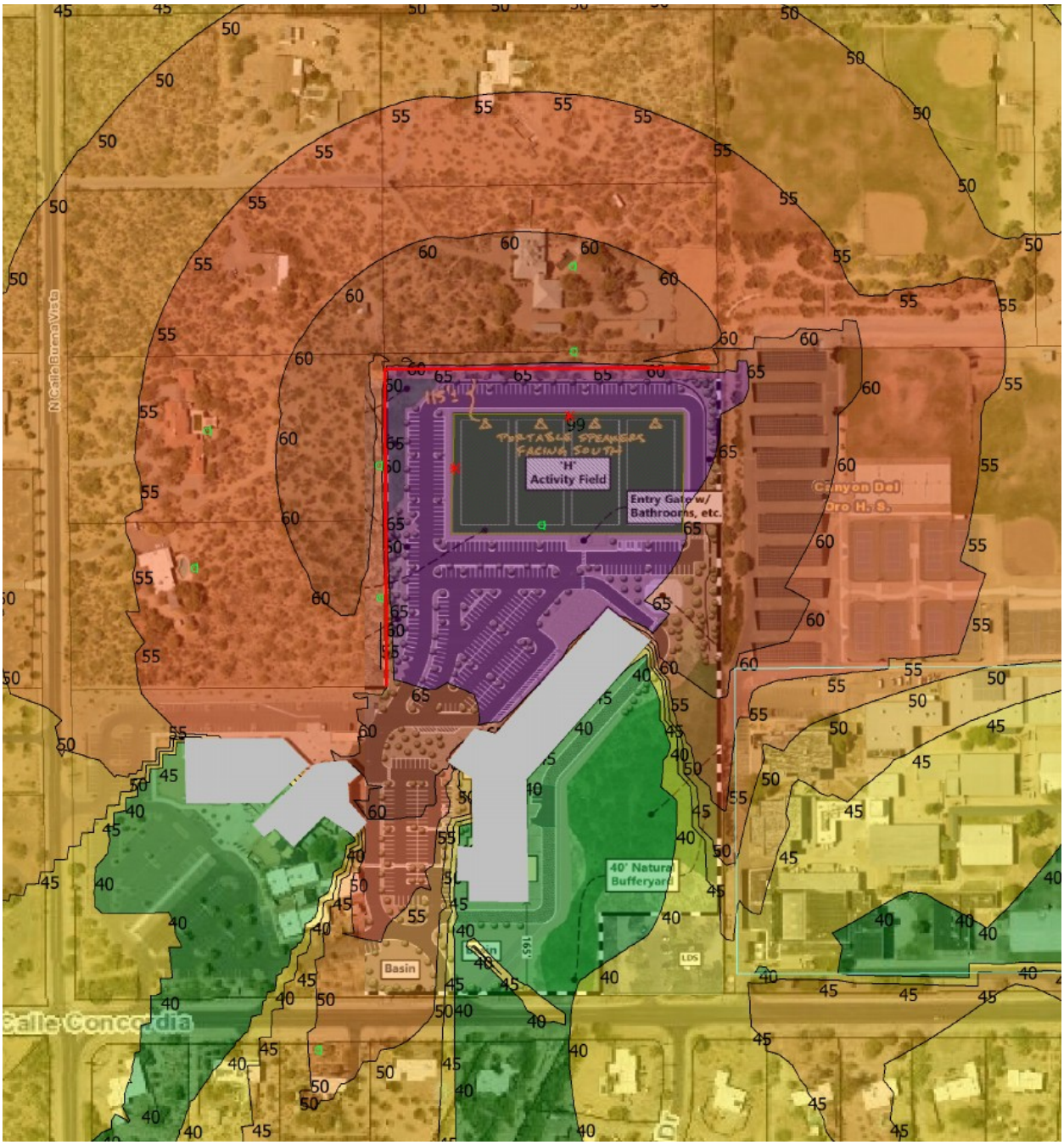

Figure 3.8. LAFmax Sound Pressure Level Contours for Sports Activities

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
441 W CALLE CONCORDIA	Single Family	5	51.6	75	no	70	no	65	no
9360 N CALLE BUENA VISTA - PL	Single Family	5	55.8	75	no	70	no	65	no
9360 N CALLE BUENA VISTA - Pool	Single Family	5	56.3	75	no	70	no	65	no
9370 N CALLE BUENA VISTA - PL	Single Family	5	59.5	75	no	70	no	65	no
9370 N CALLE BUENA VISTA - Pool	Single Family	5	57.4	75	no	70	no	65	no
9382 N CALLE BUENA VISTA - PL	Single Family	5	64.1	75	no	70	no	65	no
9382 N CALLE BUENA VISTA - Pool	Single Family	5	61.1	75	no	70	no	65	no

Table 3.5. LAFmax Code Compliance for Sports Activities

3.5.2 Outdoor Services

For the outdoor services, sound pressure level contours for the A-weighted equivalent-continuous sound pressure levels (LAeq) are shown in Figure 3.9. 63 Hz octave band sound pressure levels are shown in Figure 3.10. The results for the corresponding field points are shown in Tables 3.6 and 3.7.

In this use case, live amplified music may occasionally be part of the services producing sound in the 31.5 and 63 Hz octave bands. The results indicate that locating the seating for the services near the center of the activity fields will comply with the Oro Valley Zoning Code in regard to noise for daytime and evening operation (7:00 am to 10:00 pm), but the LAeq may cause an issue for the adjacent residential property to the west after 10:00 pm. The outdoor services meet the 65 dBA LAeq and 70 dB one minute octave band requirements for the adjacent to school to the east.

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
441 W CALLE CONCORDIA	Single Family	5	45.6	55	no	50	no	45	yes
9360 N CALLE BUENA VISTA - PL	Single Family	5	46.0	55	no	50	no	45	yes
9360 N CALLE BUENA VISTA - Pool	Single Family	5	43.4	55	no	50	no	45	no
9370 N CALLE BUENA VISTA - PL	Single Family	5	42.7	55	no	50	no	45	no
9370 N CALLE BUENA VISTA - Pool	Single Family	5	39.9	55	no	50	no	45	no
9382 N CALLE BUENA VISTA - PL	Single Family	5	42.8	55	no	50	no	45	no
9382 N CALLE BUENA VISTA - Pool	Single Family	5	41.5	55	no	50	no	45	no

Table 3.6. LAeq Code Compliance for Outdoor Services

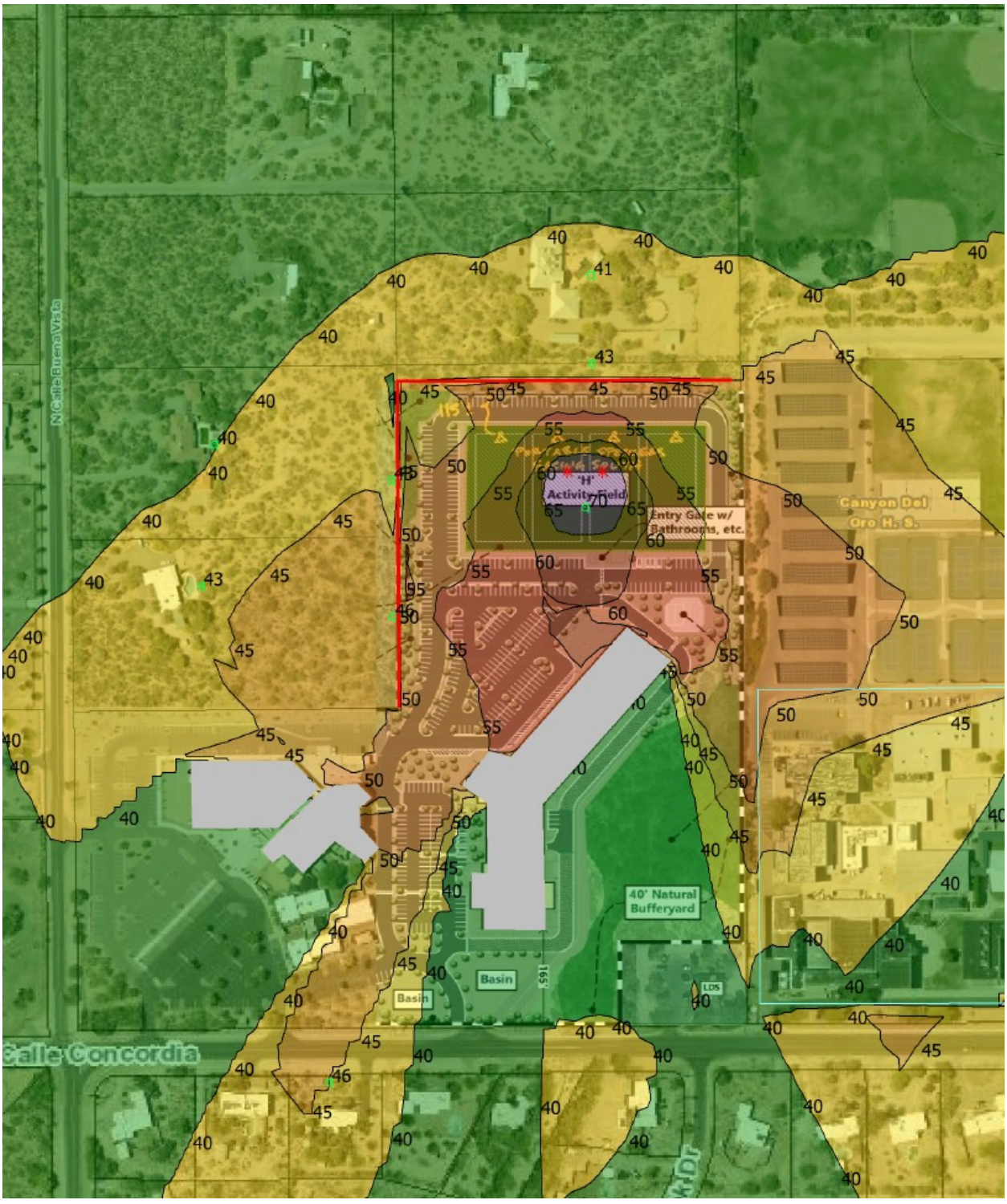

Figure 3.9. Adjusted LAeq Sound Pressure Level Contours for Outdoor Services

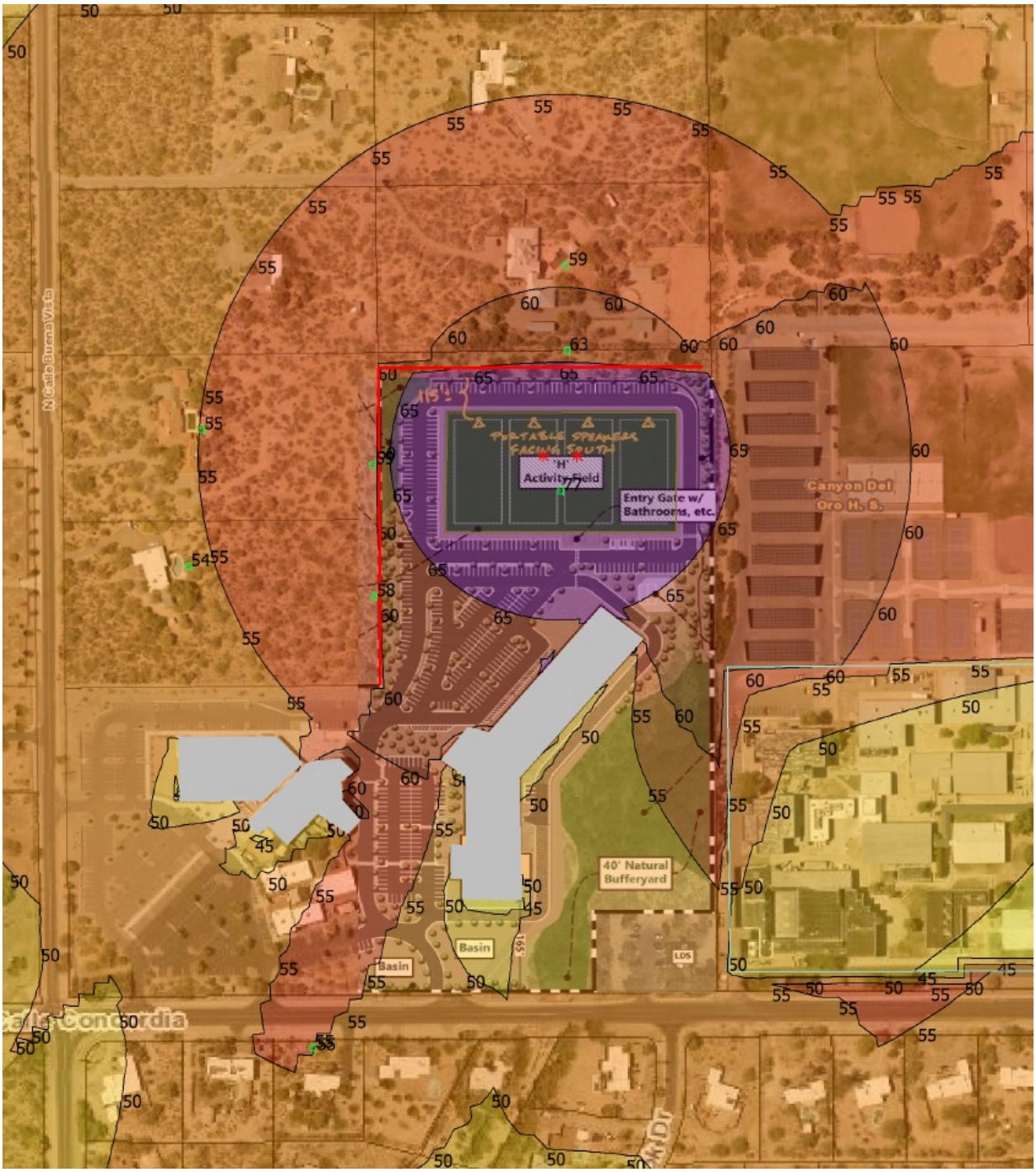

Figure 3.10. 63 Hz Octave Band Sound Pressure Level Contours for Outdoor Services

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
441 W CALLE CONCORDIA	Single Family	5	54.6	65	no	65	no	65	no
9360 N CALLE BUENA VISTA - PL	Single Family	5	57.7	65	no	65	no	65	no
9360 N CALLE BUENA VISTA - Pool	Single Family	5	54.5	65	no	65	no	65	no
9370 N CALLE BUENA VISTA - PL	Single Family	5	59.1	65	no	65	no	65	no
9370 N CALLE BUENA VISTA - Pool	Single Family	5	55.0	65	no	65	no	65	no
9382 N CALLE BUENA VISTA - PL	Single Family	5	63.5	65	no	65	no	65	no
9382 N CALLE BUENA VISTA - Pool	Single Family	5	59.3	65	no	65	no	65	no

Table 3.7. 63 Hz Octave Band Code Compliance for Outdoor Services

3.5.3 Amphitheater

The sound wall on the north and west sides of the activity fields also shields the homes on these sides from the amphitheater. In order to meet the low frequency sound pressure level limit at the east property line, an 8 foot wall or band shell will be needed on the east side of the amphitheater. The sound pressure level at the back of the amphitheater was set at 72 dBA for this analysis. The results are shown in the tables and figures below.

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
441 W CALLE CONCORDIA	Single Family	5	26.7	55	no	50	no	45	no
9360 N CALLE BUENA VISTA - PL	Single Family	5	43.8	55	no	50	no	45	no
9360 N CALLE BUENA VISTA - Pool	Single Family	5	42.9	55	no	50	no	45	no
9370 N CALLE BUENA VISTA - PL	Single Family	5	42.9	55	no	50	no	45	no
9370 N CALLE BUENA VISTA - Pool	Single Family	5	42.3	55	no	50	no	45	no
9382 N CALLE BUENA VISTA - PL	Single Family	5	40.9	55	no	50	no	45	no
9382 N CALLE BUENA VISTA - Pool	Single Family	5	39.9	55	no	50	no	45	no

Table 3.8. LAeq Code Compliance for Amphitheater

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
441 W CALLE CONCORDIA	Single Family	5	42.8	65	no	65	no	65	no
9360 N CALLE BUENA VISTA - PL	Single Family	5	51.7	65	no	65	no	65	no
9360 N CALLE BUENA VISTA - Pool	Single Family	5	48.2	65	no	65	no	65	no
9370 N CALLE BUENA VISTA - PL	Single Family	5	51.0	65	no	65	no	65	no
9370 N CALLE BUENA VISTA - Pool	Single Family	5	48.0	65	no	65	no	65	no
9382 N CALLE BUENA VISTA - PL	Single Family	5	52.9	65	no	65	no	65	no
9382 N CALLE BUENA VISTA - Pool	Single Family	5	50.9	65	no	65	no	65	no

Table 3.9. 63 Hz Octave Band Code Compliance for Amphitheater

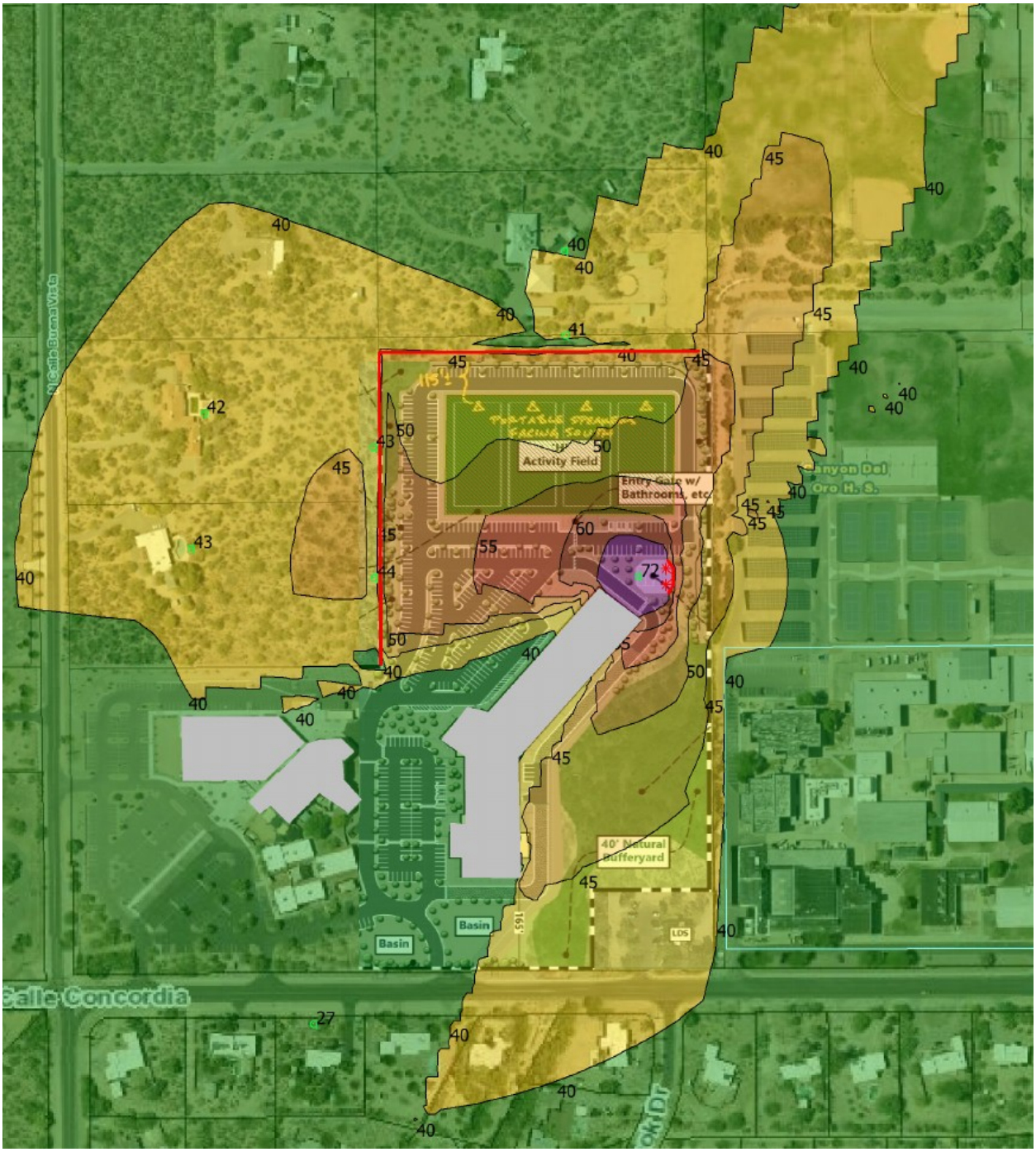

Figure 3.11. Adjusted LAeq Sound Pressure Level Contours for Amphitheater

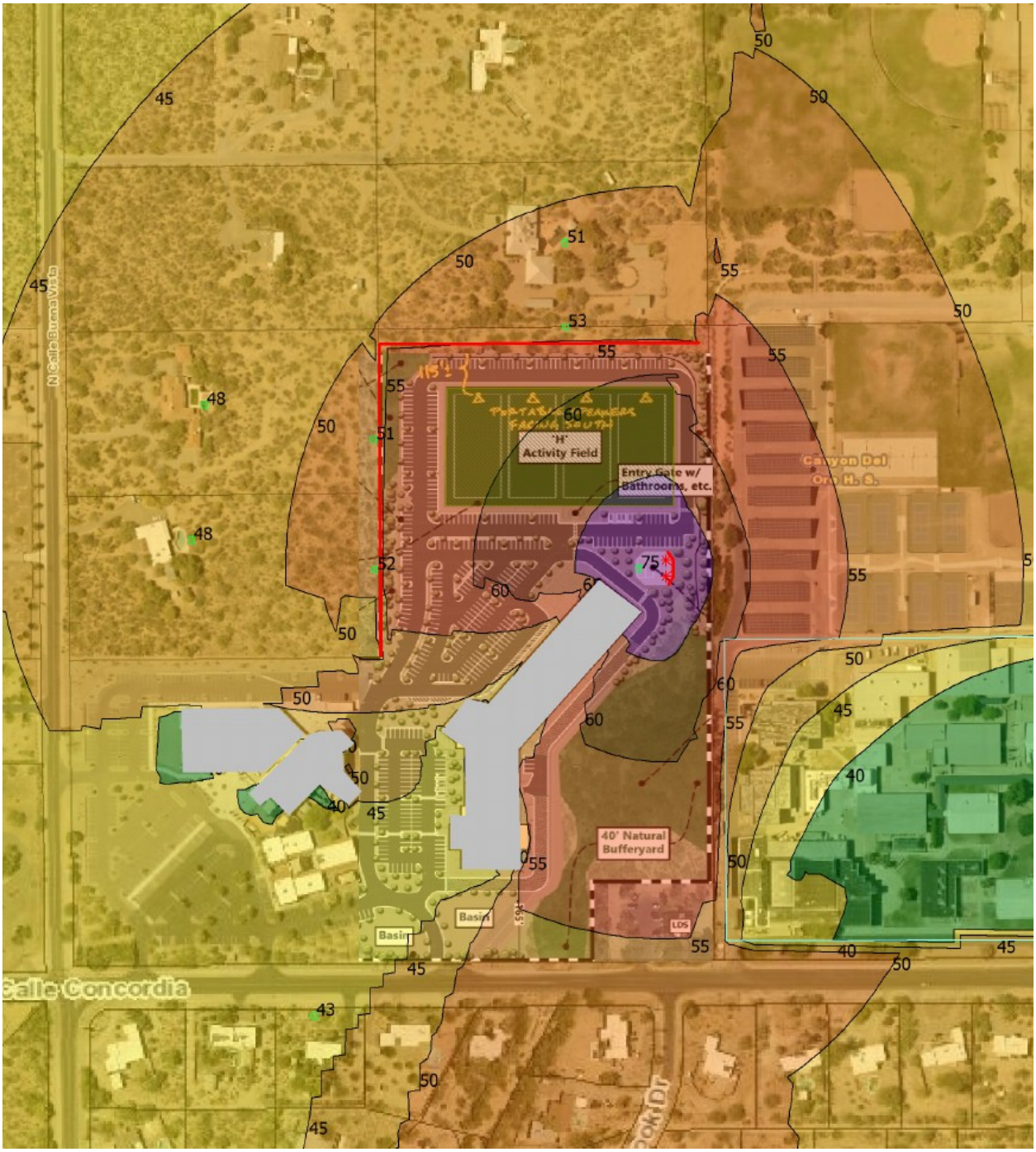

Figure 3.12. 63 Hz Octave Band Sound Pressure Level Contours for Amphitheater

In this configuration, and by limiting the sound pressure level at the back of the seating area as described, the amphitheater is able to meet all zoning regulations for all hours of operation.

4. Conclusions and Recommendations

An ISO 9613 noise assessment has been performed for sports activities and outdoor church services on the activity fields at the Oro Valley Church of the Nazarene. Noise impact on the surrounding properties has been evaluated.

4.1 Sound Walls

4.1.1 Activity Fields

Sound mitigation measures indicated by this analysis include a wall with a height at least 8 feet above the elevation of the activity fields. As shown in Figure 3.5, the wall must extend to the southeast corner of the property at 9360 North Calle Buena Vista and as far east as the curb of the paved drive planned along the east side of the activity fields.

The sound wall is nearly midway between the activity fields and the adjacent houses. Some adjustments may therefore be made in its placement without affecting its acoustical performance. The wall on the west side may be placed closer to the activity fields if needed.

The surface density of the sound wall should be at least 4 lb/ft^2. Any masonry wall will meet this requirement, but other wall or fence systems may also be acceptable. Perforation of the wall should be limited to 1% with no gaps at the bottom. Drainage openings under the wall should not be visible from noise sensitive areas such as the residential properties. One option is to place a low wall or berm in front of the openings. If using a wall, pile earth behind it to absorb and redirect any sound transmitted through the openings.

4.1.2 Amphitheater

The back of the amphitheater will require an 8 foot high sound wall or band shell to meet the Zoning Code requirements for low frequency sound at the adjacent school. No additional mitigation is needed for the south, east, or west. The sound wall or band shell should meet the same construction criteria given in the previous section.

4.2 Activity Fields

4.2.1 Sports Activities

Sound sources included in this analysis were players on the fields, coaches speaking through the portable loudspeakers, and referee whistles. Four loudspeakers were placed at the north end of each playing field facing south to direct sound away from the adjacent residential properties.

This use case was found to comply with the Oro Valley Zoning Code in regard to noise for daytime and evening hours. Amplified speech and music are not recommended between the hours of 10:00 pm and 7:00 am. This analysis assumes a typical conversational sound level from each loudspeaker at about 3/4 of the length of the field. It is the responsibility of the site owners to manage the operation of sound equipment in accordance with the applicable noise codes.

4.2.2 Outdoor Services

Sound sources for this use case included amplified speech and music from two loudspeakers facing south with a seating area for 400 people near the center of the activity fields. A 200 foot setback is recommended from the north property line to the loudspeakers. Recommended setbacks from the west and east property lines are 270 feet and 250 feet respectively for the loudspeakers and seating area. In regard to houses across Calle Concordia, the outdoor services should be located on the activity fields.

This use case was found to comply with the Oro Valley Zoning Code in regard to noise for daytime and evening hours. Amplified speech and music are not recommended between the hours of 10:00 pm and 7:00 am. This analysis assumes a typical conversational sound level at the back of the seating area. It is the responsibility of the site owners to manage the operation of sound equipment in accordance with the applicable noise codes.

4.3 Amphitheater

The use case for the amphitheater located near the east property line next to the planned recreation center building has not been fully defined at this stage of the site planning. The coverage area required for a sound system at this venue is considerably smaller than the activity fields and will therefore require much less sound power. The sound wall recommended for the activity fields will also shield the adjacent residential properties from the amphitheater.

A noise abatement plan for the amphitheater should be prepared at a later design stage to ensure code compliance for the adjacent high school to the east. Preliminary analysis shows that a sound wall or band shell will be sufficient to control low frequency sound traveling to the east.

Appendix

A1. Glossary of Acoustical Terms and Abbreviations

A1.1 Abbreviations

AI: articulation index

ASEL: A-weighted sound exposure level

ASTC: apparent sound transmission class

dB: decibel

DNL: day - night level

FSTC: field sound transmission class

Hz: Hertz

IIC: impact insulation class

kHz: kilohertz

L_{eq}, LA_{eq}, LC_{eq}: equivalent sound pressure level

NC: noise criteria

NIC: noise isolation class

NIPTS: noise induced permanent threshold shift

NR: noise reduction

Pa: Pascal

POE: probable occupant evaluation (see room criteria)

PTS: permanent threshold shift

PWL: sound power level

QAI: quality assessment index (see room criteria)

RC: room criteria

RT_{60}: reverberation time

SEL: sound exposure level

SII: speech interference index

SIL: speech interference level

SLM: sound level meter

SPI: speech privacy index

SPL: sound pressure level

STI: speech transmission index

TTS: temporary threshold shift

A1.2 Terms

A-weighting: see frequency weighting

absorption coefficient: see sound absorption coefficient

acoustical coupler: a cavity of predetermined shape and volume used for the calibration of earphones or microphones in conjunction with a calibrated microphone adapted to measure the sound pressure developed within the cavity

anechoic room: a room whose boundaries absorb practically all of the sound incident thereon, thereby providing essentially freefield conditions

articulation index (AI): a number (ranging from 0 to 1) which is a measure of the intelligibility of speech- the higher the number the greater the intelligibility. This metric has been replaced by the Speech Intelligibility Index (SII) defined in ANSI S3.5.

average sound level: see equivalent continuous sound level

background noise: the total noise from all sound sources other than a particular sound that is of interest

band: a subsection of the frequency spectrum

C-weighting: see frequency weighting

coupler: see acoustical coupler

day-night level (DNL): the 24 hour equivalent (average) A-weighted sound pressure level. A 10 dBA penalty is incurred between the hours of 10:00 PM and 7:00 AM. The DNL system has been adopted by the U.S. Department of Housing and Urban Development, the Department of Defense, and the Federal Aviation Administration.

decibel (dB): a unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is 10 times the common logarithm (base 10) of this ratio.

diffuse field: a sound field which has statistically uniform energy density and in which the directions of propagation of the sound waves are randomly distributed. In a practical sense, the sound pressure levels at all points in the room are nearly the same except near the room

boundaries and a sound wave reaching a given point in the room is equally likely to arrive from all directions.

direct sound: sound which reaches a given location in a direct line from the source without any reflections.

equivalent continuous sound level (L_{eq}): the level of steady sound which, in a stated time period and at a stated location, has the same sound energy as the time varying sound. If frequency weighting is applied, the equivalent continuous sound level may be designated LA_{eq} to indicate A-weighting or LC_{eq} to indicate C-weighting, etc. See also frequency weighting.

field sound transmission class (FSTC): a single number rating similar to sound transmission class (STC), except that the transmission loss values used to derive this class are measured in the field. FSTC ratings are typically lower than STC ratings which are measured under laboratory conditions.

flanking path: A wall or floor/ceiling construction that permits sound to be transmitted along its surface; or any opening, which permits the direct transmission of sound through the air.

freefield: a sound field in which the boundaries have negligible effect over the frequency range of interest.

frequency: the number of times that a waveform repeats itself in a given period of time, usually one second, i.e. the number of cycles per second). Unit: Hz.

frequency weighting: a prescribed frequency dependent attenuation or amplification applied to measured sound data usually intended to better approximate the sensation of loudness in a human listener. For example, A, B, and C weighting approximate the frequency dependent shape of the equal loudness contours for soft, moderate, and loud sounds.

Hertz (Hz): unit of frequency, cycles per second.

impact insulation class (IIC): a single number metric used to compare the effectiveness of floor-ceiling assemblies in providing reduction of impact-generated sounds such as footsteps. This rating is derived from values of normalized impact sound pressure levels in accordance with ASTM E492.

insertion loss: the reduction in sound level at the location of the receiver when a noise reduction measure such as a barrier, attenuator, muffler, etc. is inserted into the transmission path between the source and receiver. Unit: dB.

level: the logarithm of the ratio of a given quantity to the reference quantity of the same kind. Levels represent physical quantities such as sound pressure on a logarithmic scale and are therefore expressed in decibels. Unit: dB.

loudness: that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud. Unit: sone.

masking: the process by which the threshold of hearing for one sound is raised by the presence of another sound.

noise criteria (NC): a single number criteria for the HVAC or mechanical noise level in a room derived from measured octave band data. The octave bands are weighted to de-emphasize low frequencies because the human ear is least sensitive to these frequencies. This metric is not valid for outdoor measurements.

noise induced permanent threshold shift (NIPTS): the permanent hearing loss resulting from noise exposure.

noise isolation class (NIC): a single number rating derived from measured values of noise reduction between two enclosed spaces that are connected by one or more paths. This rating is not adjusted or normalized to a standard reverberation time.

noise reduction (NR): the difference in sound pressure level between any two points along the path of sound propagation, e.g. the difference in level between the interior and exterior of a building where the sound level inside is due only to exterior noise.

octave: the frequency interval between two tones whose frequency ratio is 2.

omnidirectional microphone: a microphone whose response is independent of the direction of the incident sound wave.

Pascal (Pa): a unit of pressure. 1 Pascal = 1 Newton per square meter (1 N / m^2).

permanent threshold shift (PTS): a permanent increase in the threshold of hearing at a given frequency.

point source: a source that radiates sound as if from a single point.

receiver: a person (or persons) or equipment which is affected by sound.

refraction: (1) the phenomenon by which the direction of propagation of a sound wave is changed as a result of a spatial variation is the speed of sound. (2) The angular change in direction of a sound wave as it passes obliquely from one medium to another having different sound speed.

reverberation time (RT_{60}): of an enclosure, for a sound of a given frequency or frequency band, the time that is required for the sound pressure level in the enclosure to decrease by 60 dB after the source has stopped. Unit: second.

room criteria (RC, RC Mark II): an octave band metric for evaluating HVAC noise inside a room. RC is a two dimensional metric consisting of a curve number that is the arithmetic average of the 500, 1000, and 2000 Hz octave band sound pressure levels and a qualitative descriptor identifying the character of the sound spectrum. The descriptor can be (N) for neutral, (LF) for low frequency dominance (rumble), (MF) for midfrequency dominance (roar), and (HF) for high frequency dominance (hiss). In addition, acoustically induced vibration can be designated by (LFV_B) for moderate, but perceptible vibration and (LFV_A) for clearly perceptible vibration. As an example, the maximum RC prerequisite for LEED is designated as RC 37(N) indicating curve number 37 with a neutral spectrum.

Further, two intermediary metrics are used in calculating the room criteria. The quality

assessment index (QAI) is a measure of the deviation from the given RC curve. The probable occupant evaluation (POE) is based on the magnitude of the QAI and can be 'Acceptable,' 'Marginal,' or Objectionable.'

Sabin: a unit of measure of sound absorption; a measure of sound absorption of a surface. It is the equivalent of 1 square foot of a perfectly absorbing surface; a metric Sabin is the equivalent of 1 square meter of a perfectly absorbing surface.

sone: the unit of loudness. One sone is the loudness of a pure tone presented frontally at a frequency of 1000 Hz and a sound pressure level of 40 dB referenced to 20 micropascals.

sound absorption coefficient (α): ideally, the fraction of diffusely incident sound power that is absorbed (or otherwise not reflected) by a material or surface.

sound exposure level (SEL): over a stated time period or event, 10 times the logarithm base 10 of the ratio of the time integral of the sound pressure squared to the product of the reference sound pressure, 20 μPa, squared and the reference time, one second. This quantity is used to characterize single events of short duration where the averaged level (L_{eq}) is inadequate.

sound level meter (SLM): an instrument that is used to measure sound level, with a standard frequency weighting and standard exponentially weighted time averaging.

sound power level (PWL): the total acoustical power emitted from a sound source expressed in decibels relative to 10^{-12} Watts.

sound pressure level (SPL): the acoustical pressure amplitude expressed in decibels relative to 20 micropascals.

sound transmission class (STC): a single number rating used to compare sound insulation properties of walls, floors, ceilings, windows, or doors. See also field sound transmission class.

speech intelligibility index (SII): metric defined under ANSI S3.5 to quantifiy the intelligibility of speech under adverse listening conditions such as noise masking, spectral filtering, and reverberation. The SII is defined for a scale of 0 to 1 where values greater than 0.75 indicate good communication and values below 0.45 indicate generally poor communication conditions.

speech intelligibility test: a procedure that measures the portion of test items (such as syllables, monosyllabic words, or sentences) that are heard correctly.

speech interference level (SIL): an index for assessing the interference effects of noise on the intelligibility of speech, derived from measurements of the background noise level of contiguous octave bands; i.e. the arithmetic average of the octave band sound levels for the bands centered at 500, 1000, 2000, and 4000 Hz (four band method) or the corresponding average for the octave bands centered at 500, 1000, and 2000 Hz (three band method). If other octave bands are used they must be specified. Unit: dB.

speech privacy index (SPI): The SPI is essentially the opposite of the speech intelligibility index and is defined as 1 - SII and usually represented as a percentage. An SPI above 80% is considered normal privacy while an SPI above 95% would meet the requirements of confidential privacy.

speech transmission index (STI): an index for rating the intelligibility of speech that takes both noise and reverberation into account.

temporary threshold shift (TTS): a temporary increase in the threshold of hearing at a given frequency.

threshold of hearing: for a given listener, the minimum sound pressure level of a specified sound that is capable of evoking an auditory sensation. The sound reaching the ears from other sources is assumed negligible.

transducer: a device designed to receive an input signal of a given kind and to furnish an output signal of a different kind in such a manner that the desired characteristics of the input signal appear in the output signal. For example, a microphone takes an acoustic pressure as an input and produces an electrical voltage as an output that is direct proportion to the instantaneous acoustic pressure amplitude. Other common examples in noise measurement would be a loudspeaker, accelerometer, or laser Doppler vibrometer (LDV).

transmission loss: the reduction in sound level from one side of a partition to the other.

wavelength: the distance a sound wave travels in the time it takes to complete one cycle.

weighting: see frequency weighting

A2. General Acoustics

Sound Pressure Level (SPL)

Sound is small, rapidly varying perturbations of atmospheric pressure with respect to the slowly changing ambient pressure. The ambient pressure is measured with a barometer while the small acoustic perturbations are measured with a microphone.

The unit of sound pressure is the Pascal (Pa). However, due to the wide range of acoustic amplitudes that can be heard by the human ear, sound pressure is normally expressed on a logarithmic scale having units of decibels (dB). Sound pressure expressed this way is known as the sound pressure level (SPL) and has the following relation to sound pressure.

$$SPL = 20 \log_{10}\left(\frac{p}{p_{ref}}\right) \qquad \text{(A2.1)}$$

Here p is the sound pressure in Pascals. p_{ref} is a reference pressure, the threshold of hearing at 1000 Hertz (Hz), 20 x 10^{-6} Pa.

A-Weighting

The above formulation of SPL is a purely physical quantity. Due to the nonlinear and frequency dependent characteristics of the human ear it does not always correlate well with the perception of loudness. To improve the correlation for noise assessment purposes, a frequency weighting is often applied called A-weighting. The A-weighting function is based on listening tests in which human subjects adjusted tones throughout a range of frequencies to have equal loudness compared to a tone having an SPL of 40 dB at 1000 Hz. Figure A2.1 shows equal loudness contours according to ISO 226.

Thus applying A-weighting to measured sound pressures more closely represents the frequency response of the human ear for low to moderate amplitude sound. Sound pressure levels that have been A-weighted are denoted by the symbol, dBA. Figure A2.2 shows the A frequency weighting and several other common weightings.

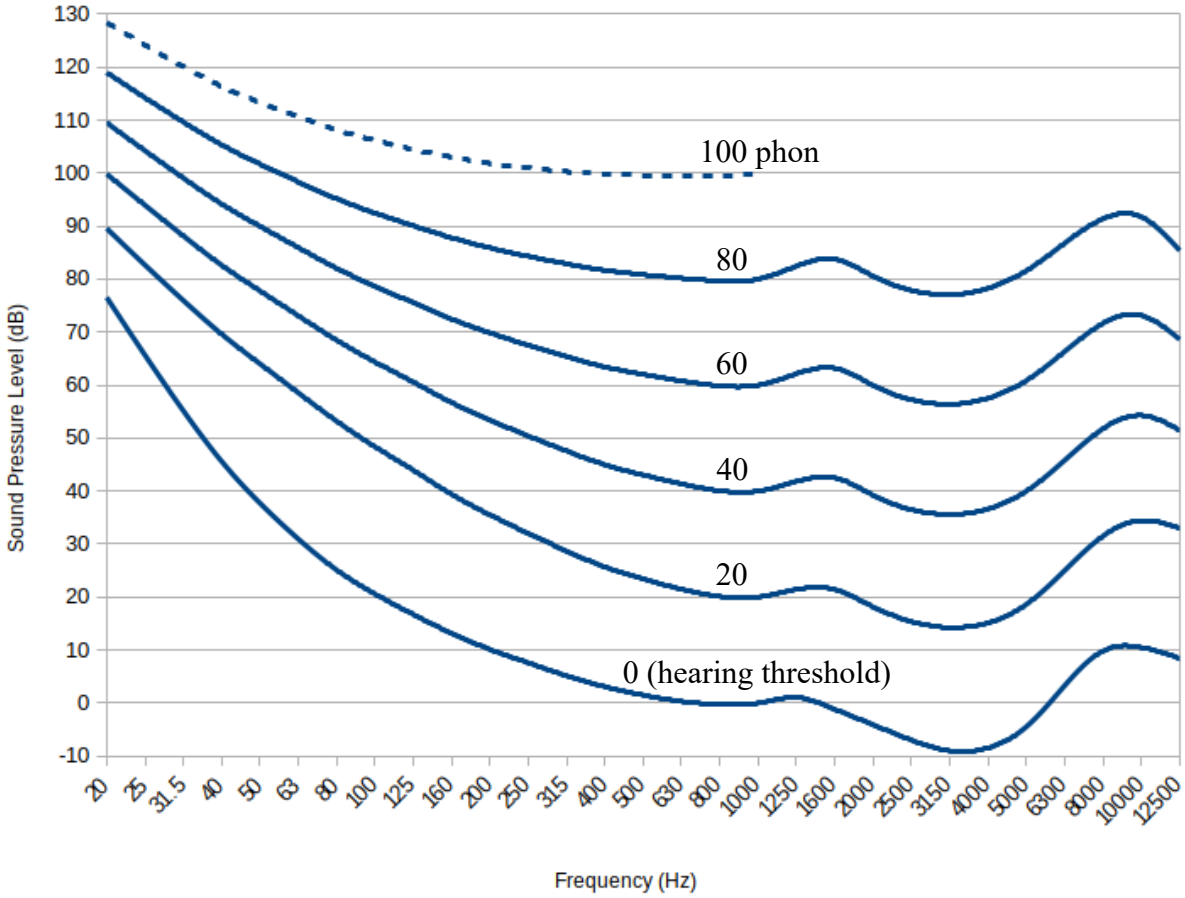

Figure A2.1. ISO 226 Equal Loudness Contours

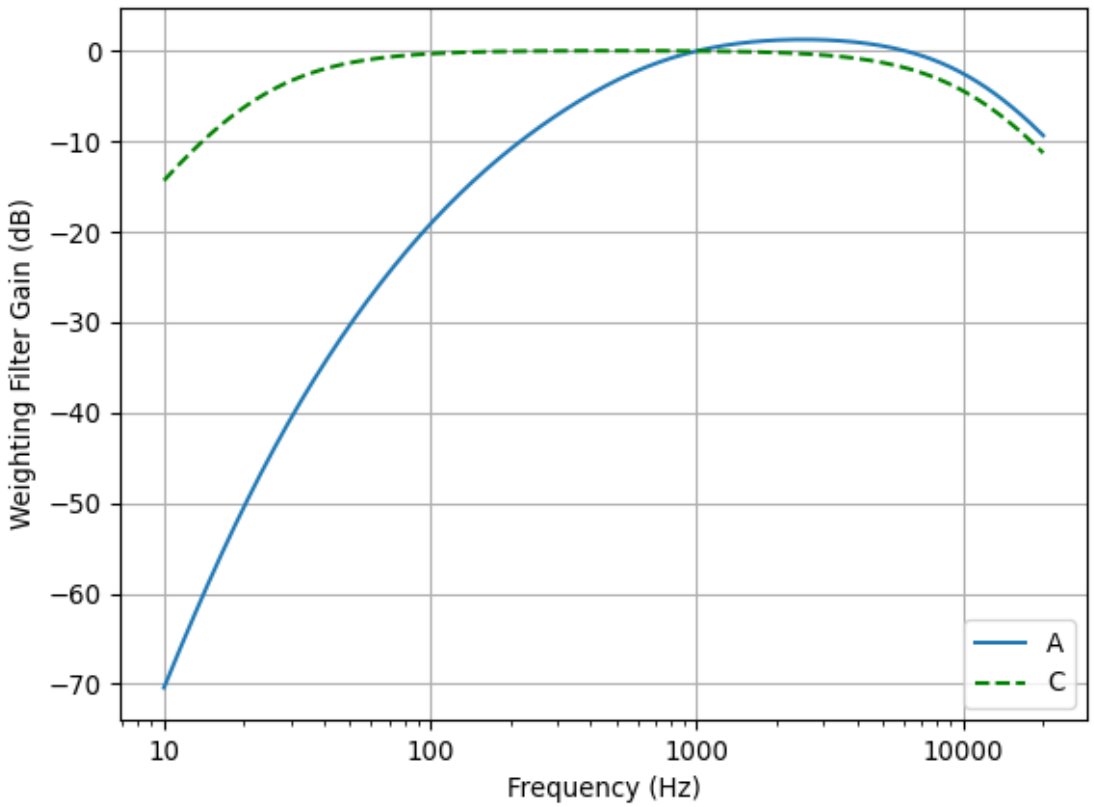

Figure A2.2. Frequency Weighting Filter Curves

The Perception of Sound

The most basic descriptions of sound are loudness (amplitude) and pitch (frequency). The frequency range of human hearing is roughly 20 to 20,000 Hz, although most people can not hear this full range because high frequencies are lost as a natural part of aging and other factors such as illness and exposure to high levels of noise that may cause permanent hearing loss.

Amplitude Attenuation with Distance

Sound originating from a small point source will spread spherically in all directions, absent any nearby surfaces. The conservation of energy requires the sound pressure spreading out from such a source to decrease by half with each doubling of distance. This is known as the inverse square law and is demonstrated in Table A2.1 and Figure A2.3.

Distance from Source (ft)	SPL (dBA)	SPL Loss Relative to 10 ft
10	90	
20	84	6
40	78	12
80	72	18
160	66	24
320	60	30

Table A2.1. Decrease of SPL with Distance Due to Spherical Spreading

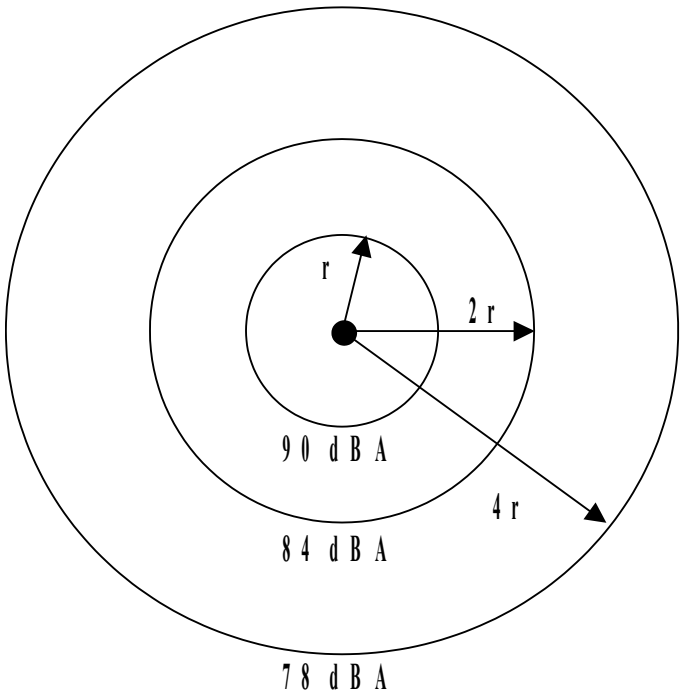

Figure A2.3. Decrease of SPL with Distance Due to Spherical Spreading

Adding Decibels

Summing the contributions from multiple sound sources to obtain the total SPL is *not* done simply by adding the decibel levels because SPL is a logarithmic quantity.

Imagine a fan produces a moderate SPL of 65 dBA at 6 feet. If a second identical fan were turned on the resulting SPL would not be 130 dBA. This would be equivalent to a commercial jetliner taking off at close range.

The correct method of adding the SPL from each source is to sum the acoustic power produced by each source. This implies that each time the number of sources having equal SPL is doubled, the SPL will increase by 3 dBA. Therefore, in the example with two fans, the correct total SPL would be 68 dBA. More examples with multiple sources producing equal SPL are shown in Figure A2.4.

65 dBA + 65 dBA $\neq$ 130 dBA **WRONG** (A2.2)

65 dBA + 65 dBA = 68 dBA **RIGHT** (A2.3)

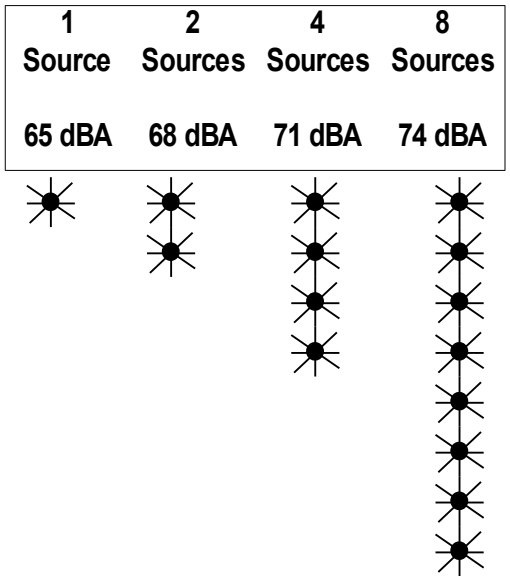

Figure A2.4. Total SPL from Multiple Sources with Equal SPL Output

Further Reading

Bruel and Kjaer, "Measuring Sound." Covers topics in this appendix in more detail. Available on the Bruel and Kjaer website, www.bkhome.com. Find this and other primers under the library section of the site.

Cyril M. Harris, Ed. Handbook of Acoustical Measurements and Noise Control, 3rd Edition. Acoustical Society of America, Melville, NY, 1998.