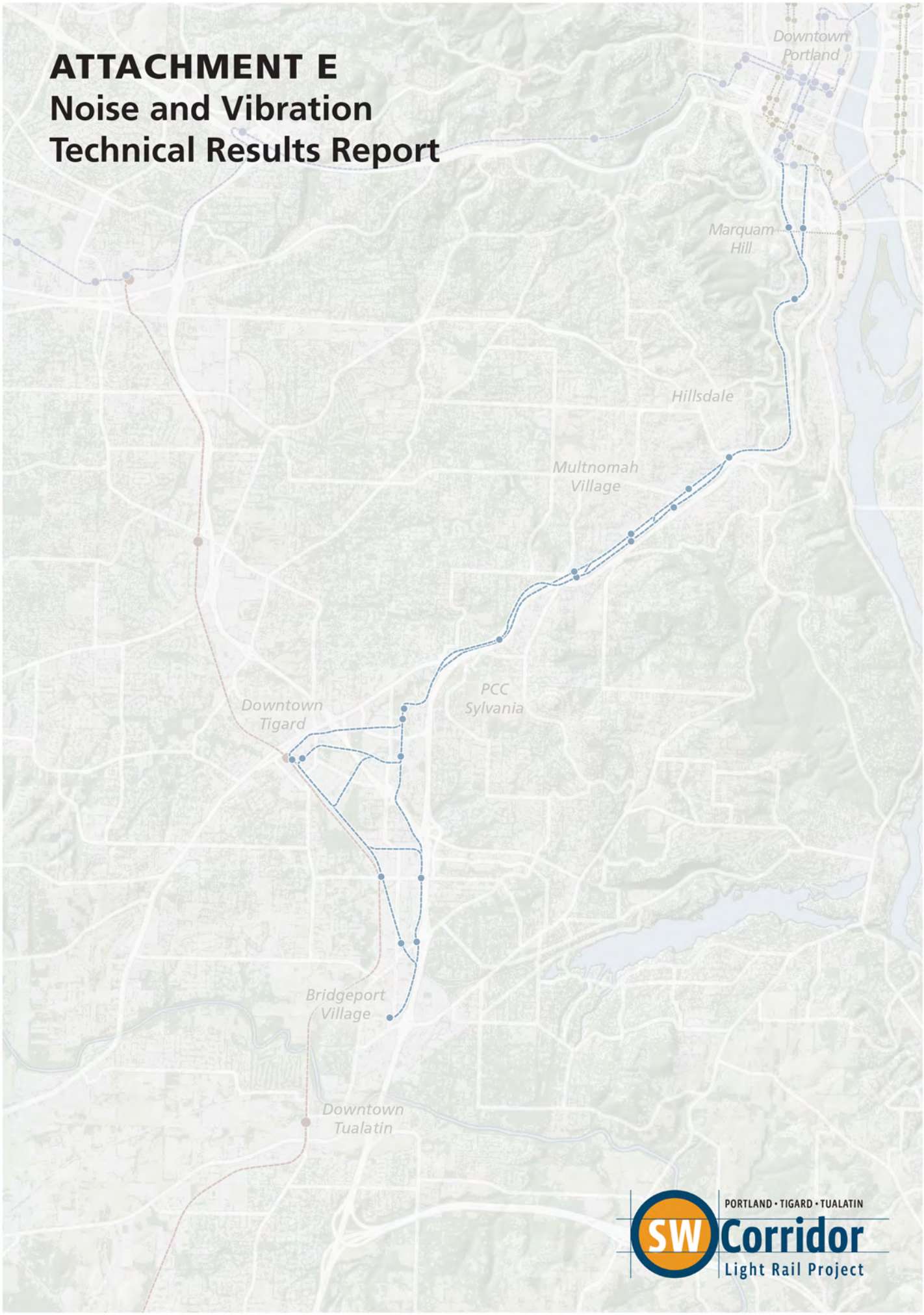
ATTACHMENT E
Noise and Vibration Technical Results Report



PORTLAND • TIGARD • TUALATIN
SW Corridor
Light Rail Project

Southwest Corridor Light Rail Project

Draft Environmental Impact Statement

Noise and Vibration Technical Results Report

November 2017

Prepared for
Metro
Portland, Oregon

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B Detailed Noise Impact Assessment

C Detailed Vibration Impact and Mitigation Assessment

S. SUMMARY OF NOISE AND VIBRATION IMPACTS

The Southwest Corridor Light Rail Project is a proposed 12-mile Metropolitan Area Express (MAX) light rail line serving Southwest Portland, Tigard, Tualatin and the surrounding communities. The project must show compliance with the National Environmental Policy Act, and part of that process is to identify adverse impacts the project could cause, including those related to noise and vibration. This process is also used to identify strategies to avoid, minimize or mitigate those impacts. This section briefly describes the results of the noise and vibration analysis for the project, and complete details are provided in the following chapters.

The noise and vibration analysis was performed for more than 1,400 noise- and vibration-sensitive properties along the project alignments. Under the light rail alternatives, the number and severity of noise impacts depend on the combination of alternatives selected. Many of the impacts are at multi-unit apartments and condominiums, and therefore the number of units with impacts was estimated, and was based on site visits, window counts and unit numbers. The actual number of impacts might be fewer once a more detailed review of these multifamily units is preformed and once any additional structural shielding can be accounted for in the analysis. Therefore, the number of noise impacts presented in this report is a worst case and may be higher than what would actually occur with the project.

There are two full-corridor light rail route configurations: the Through Configuration and the Branched Configuration. Because of the additional trains necessary under the Branched Configuration (Alternatives C5 and C6), full-corridor segment combinations (one alternative from each segment) using those alternatives also have a greater number of total noise impacts in Segments A and B than the number of noise impacts in Segments A and B under the Through Configuration. Two tables provide a summary of the potential noise and vibration impacts: one for the Through Configuration (Table S-1) and one for the Branched Configuration (Table S-2). Note that vibration impacts are based on the maximum pass-by level, and therefore they are the same under both the Through Configuration and the Branched Configuration.

Overall, noise impacts are higher in Segments A and B under the Branched Configuration because of the added trains operating during off-peak hours. The greatest number of impacts occurs in Segment A because of the proximity of receivers to the trackway and the high number of residential uses along the alignment in that segment. The fewest impacts occur in Segment C under Alternatives C3 and C4, because these alternatives miss many of the dense housing areas that have impacts under Alternatives C1 and C2. Impacts in Segment B under the Through Configuration are similar for the various alternatives, with the exception of Alternative B4, which has increased noise impacts due to the higher speeds of the light rail along the sections adjacent to Interstate 5 (I-5).

Under the Branched Configuration, noise impacts are increased under all alternatives in Segments A and B because of the increased off-peak headways. The increases under Alternative A1 are the most notable, with the majority of new impacts occurring at multifamily units located near the alignment. In addition, some of the moderate impacts under the Through Configuration would be in the Federal Transit Administration (FTA) severe category under the Branched Configuration because of the added traffic (see Tables S-1 and S-2).

Table S-1. Summary of Noise and Vibration Impacts by Segment and Alignment for Through Configuration

Light Rail Alternative and Segment	Moderate Noise Impacts	Severe Noise[1] Impacts	Vibration Impacts
Segment A: Inner Portland			
A1: Barbur	293	5	76
A2-BH: Naito Bridgehead	167	1	31
A2-LA: Naito Limited Access	161	1	35
Segment B: Outer Portland			
B1: Barbur	55	0	29
B2: I-5 Barbur TC-60th	49	0	26
B3: I-5 26th-60th	44	0	17
B4: I-5 Custer-60th	80	0	23
Segment C: Tigard and Tualatin			
C1: Ash-I-5	72	15	20
C2: Ash-Railroad	72	15	20
C3: Clinton-I-5	12	0	2
C4: Clinton-Railroad	12	0	2

Source: FTA noise and vibration modeling.

[1] Severe noise impacts are considered significant under the National Environmental Policy Act.

Table S-2. Summary of Noise and Vibration Impacts by Segment and Alignment for Branched Configuration

Light Rail Alternative and Segment	Moderate Noise Impacts	Severe Noise[1] Impacts	Vibration Impacts
Segment A: Inner Portland			
A1: Barbur	353	8	76
A2-BH: Naito Bridgehead	188	4	31
A2-LA: Naito Limited Access	195	4	35
Segment B: Outer Portland			
B1: Barbur	147	1	29
B2: I-5 Barbur TC-60th	115	1	26
B3: I-5 26th-60th	98	1	17
B4: I-5 Custer-60th	140	1	23
Segment C: Tigard and Tualatin			
C5: Ash-I-5 Branched	38	12	21
C6: Wall-I-5 Branched	37	3	20

Source: FTA noise and vibration modeling.

[1] Severe noise impacts are considered significant under the National Environmental Policy Act.

The number of vibration impacts was also greatest in Segment A for the same reasons as given for noise. The same as for noise impacts, the fewest number of vibration impacts occurs under Alternatives C3 and C4, because those alternatives avoid many of the residential areas. The impacts in the table can be summed to provide a project-wide total; for example, a baseline full-corridor light rail, consisting of Alternatives A1, B2 and C1, would have 414 moderate noise impacts, 20 severe noise impacts and 122 vibration impacts.

Noise levels and potential noise impacts for the park and rides and transit centers were also predicted. Noise for simple light rail stations, such as those in Segment A and in other areas along the alignment without park and ride lots, were included in the light rail noise analysis, and therefore those impacts are included with the impacts identified in Tables S-1 and S-2. There are no transit centers or park and rides in Segment A, so no such noise-related impacts were identified in that segment. No noise impacts were identified at the existing Barbur Transit Center (TC) or at the proposed 53rd Park and Ride in Segment B because of the distance from these facilities to noise-sensitive properties. Impacts could potentially occur at the Baylor Park and Ride at residences that were also identified to have light rail noise impacts.

Transit center noise impacts are also predicted under the Tigard TC Ash Station because of the proximity of the bus parking area to a manufactured home park. No noise impacts were predicted for the Tigard TC Clinton or Tigard TC Wall Stations because of the already existing high noise levels at those locations. The southern park and ride options, including the two Bonita Park and Ride options, the two Upper Boones Ferry Park and Ride options, and the Bridgeport Park and Ride, are all sufficiently far from noise-sensitive receivers that no noise impacts were predicted for those locations.

Noise and vibration impacts from the potential operations and maintenance (O&M) facilities options were also included in this analysis. Due to the locations of the Hunziker Full Facility and Hunziker Partial Facility sites, and the locations of the Through 72nd Facility and Branched 72nd Facility sites, which are in established industrial areas, no noise or vibration impacts are predicted. No noise impacts were predicted for either of the two proposed expansions at the existing Ruby Junction O&M Facility, which is also in an established industrial are with no nearby sensitive properties.

The shuttle options for the Portland Community College (PCC) campus—the Barbur TC and Baylor Shuttle and the 53rd Shuttle—would operate in mixed traffic on existing roadways, with service primarily during daytime hours. The limited service on established roadways was predicted to result in no noise impacts. Finally, other project-related features, such as the Marquam Hill connections, bike and pedestrian paths, and other corridor improvements, either do not produce a measureable amount of noise or are in established transportation corridors with high noise levels, and would not result in any new noise impacts.

It currently appears that the majority of the project's noise and vibration impacts could be mitigated using standard mitigation measures. Potential measures for project-related noise impacts could include sound walls (barriers on the light rail guideway or freestanding walls), special trackwork to reduce noise levels at crossovers, and insulation of residential buildings where necessary. Some limited additional noise testing could be performed before finalizing the noise mitigation measures.

Mitigation for vibration impacts could include resilient fasteners, ballast mats, tire-derived aggregate, floating slabs, and special trackwork to reduce vibration at crossovers. Additional vibration testing will be performed to optimize and finalize the vibration mitigation measures.

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1. PROJECT INTRODUCTION, PURPOSE AND NEED

The Southwest Corridor Light Rail Project is a proposed 12-mile MAX light rail line serving Southwest Portland, Tigard, Tualatin and the surrounding communities. After a five-year planning process, the Southwest Corridor Steering Committee has narrowed the potential light rail route to a few alternatives. In addition to the light rail line, the project includes possible investments to improve station access for people walking, biking and driving.

In compliance with the National Environmental Policy Act, a Draft Environmental Impact Statement (EIS) is being prepared to help decision makers understand the environmental consequences of the alternatives under consideration. The Draft EIS will identify the significant positive and adverse impacts the light rail project could have on the built and natural environment, and identify strategies to avoid, minimize or mitigate those impacts.

2. BACKGROUND FOR NOISE AND VIBRATION ASSESSMENTS

This section discusses the fundamentals of the noise and vibration, including human perception, measurement and analysis.

2.1. Noise

What humans perceive as sound is a series of continuous air pressure fluctuations superimposed on the atmospheric pressure that surrounds us. The amplitude of fluctuation is related to the energy carried in a sound wave; the greater the amplitude, the greater the energy, and the louder the sound. The full range of sound pressures encountered in the world is so great that it is more convenient to compress the range by using a logarithmic scale, resulting in the fundamental descriptor used in acoustics—the sound pressure level, which is measured in decibels (dB). When sounds are unpleasant, unwanted, or disturbingly loud, we tend to classify them as noise.

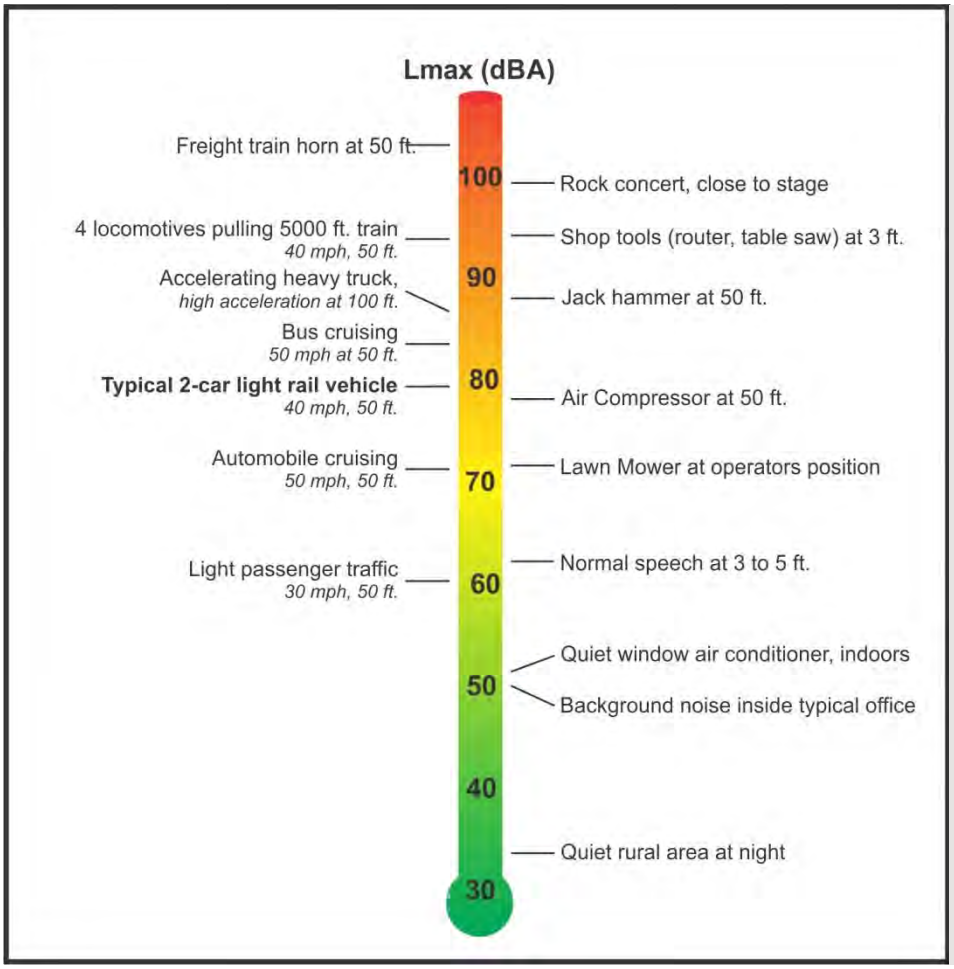
Another aspect of sound is the quality described as its pitch. The pitch of a sound is established by the frequency, which is a measure of how rapidly a sound wave fluctuates. The unit of measurement is cycles per second, called hertz (Hz). When a sound is analyzed, its energy content at individual frequencies is displayed over the frequency range of interest, usually the range of human audibility from 20 Hz to 20,000 Hz. This display is called a frequency spectrum.

Sound is measured using a sound level meter with a microphone designed to respond accurately to all audible frequencies. However, the human hearing system does not respond equally to all frequencies. Low-frequency sounds below about 400 Hz are progressively and severely attenuated (weakened), as are high frequencies above 10,000 Hz. To approximate the way humans interpret sound, a filter circuit with frequency characteristics similar to the human hearing mechanism is built into sound level meters. Measurements with this filter enacted are called A-weighted sound levels, expressed in A-weighted decibels (dBA). Community noise is usually characterized in terms of the A-weighted sound level.

The range of human hearing extends from about 0 dBA for young healthy ears (that have not been exposed to loud noise sources) to about 140 dBA. When sounds exceed 110 dBA, there is a potential for hearing damage, even with relatively short exposures. In quiet suburban areas far from major freeways, the noise levels during the late night hours will drop to about 30 dBA. Outdoor noise levels lower than this only occur in isolated areas where there is a minimal amount of natural noises, such as leaves blowing in the wind, crickets or flowing water.

Another characteristic of environmental noise is that it is constantly changing. The lower average noise levels occur during nighttime hours, when activities are at a minimum, and higher noise levels during daytime hours caused by daily patterns of noise-level fluctuation. For example, noise levels increase when a car approaches, then reach a maximum level as it passes, and decrease as the car moves farther away. In this example, noise levels within a one-minute time frame can range from 45 dBA as the vehicle approaches, increase to 65 dBA as it passes by, and return to 45 dBA as it moves away. Over this measurement period, the ”Lmax” is the maximum level (65 dBA) and the “Lmin” is the lowest level (45 dBA). Figure 2-1 shows a comparison of various noise levels expressed as the maximum sound level (Lmax) in dBA.

Figure 2-1. Typical Maximum Noise Levels



Leq

The Leq is the level of a constant sound for a specified period of time that has the same sound energy as an actual fluctuating noise over the same period of time. The peak-hour Leq is used for all traffic noise analyses and for light rail noise analyses at locations with daytime use, such as schools and libraries.

Ldn

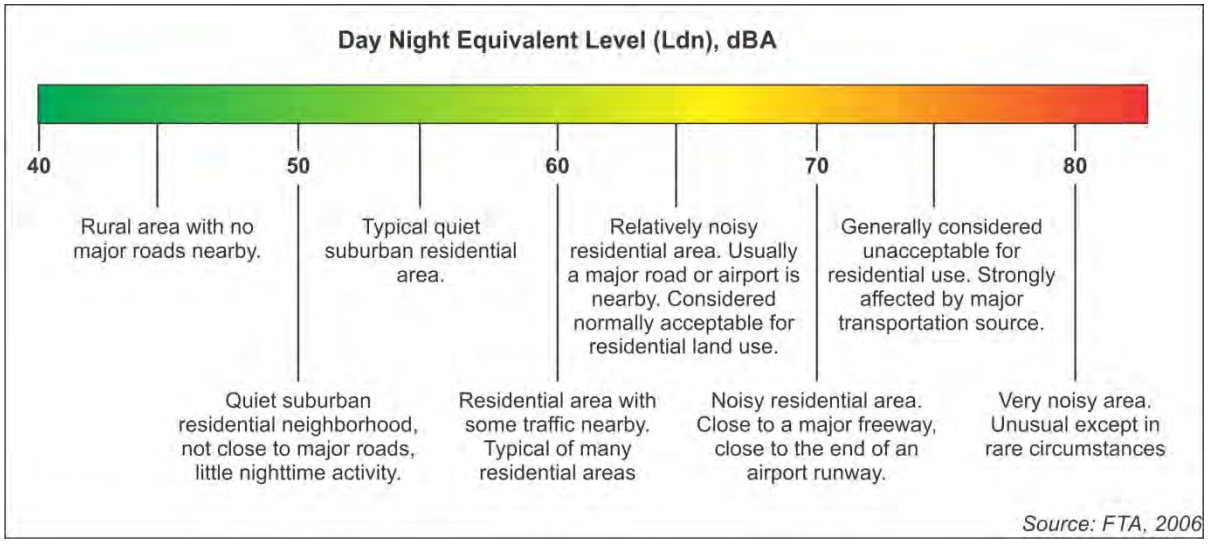
The Ldn is a Leq over a 24-hour period, with 10 dBA added to nighttime sound levels (between 10 p.m. and 7 a.m.) as a penalty to account for the greater sensitivity and lower background sound levels during this time. The Ldn is the primary noise level descriptor for light rail noise at residential land uses.

To account for the variance in loudness over time, most regulations use some form of an equivalent, or energy average, sound pressure level. The most common measurement descriptor is the Leq, which is defined as the energy average noise level, in dBA, for a specific time period (for example, one hour). The Leq can be thought of as the steady sound level that represents the same sound energy as the varying sound levels over a specified time period (typically one hour).

Often the Leq values over a 24-hour period are used to calculate cumulative noise exposure in terms of the day-night equivalent sound level (Ldn), which is defined as the 24-hour Leq but with a 10-dB penalty added to each nighttime hourly Leq (with “nighttime” defined as the period from 10 p.m. to 7 a.m.). The effect of this penalty is that any event during the nighttime is equivalent to 10 events during the daytime. This strongly weighs Ldn toward nighttime noise to reflect that most people are more easily annoyed by noise at night, when background noise is lower and most people are resting. Figure 2-2 shows a range of Ldn noise levels and compatible land uses.

Other noise descriptors, which are used for local noise ordinances, include statistical noise level descriptors, representing the noise level exceeded for a percentage of the measurement period.

Figure 2-2. Ldn Noise Level and Compatible Land Use



Environmental impact assessments for mass transit projects in the United States typically use Ldn to describe the community noise environment at residential locations. Studies of community response to a wide variety of noises indicate that Ldn is a good measure of the noise environment. Most urban and suburban neighborhoods usually have an Ldn in the range of 50 dBA to 70 dBA. An Ldn of 70 dBA is a relatively noisy environment that might be found at buildings on a busy surface street, close to a freeway, or near a busy airport, and would usually be considered unacceptable for residential land use without special measures taken to enhance outdoor-indoor sound insulation. Residential neighborhoods that are not near major sound sources are usually in the range of Ldn 55 dBA to 60 dBA. If there is a freeway or moderately busy arterial nearby or any nighttime noise, Ldn is usually in the range of 60 to 65 dBA.

Ldn is the designated noise metric of choice for many federal agencies, including the Department of Housing and Urban Development (HUD), Federal Aviation Administration (FAA), FTA, and U.S. Environmental Protection Agency. Most federal and state agency criteria for noise impacts are based on some measurement of noise energy. For example, the FAA and HUD use Ldn, and the Federal Highway Administration (FHWA) uses peak-hour Leq. The noise impact criteria applicable to residential areas and included in the 2006 FTA Transit Noise and Vibration Impact Assessment (*FTA Guidance Manual*) (FTA, 2006) use both Leq and Ldn to characterize community noise.

2.2. Vibration

Vibration generated from train operations of the Southwest Corridor Light Rail Project would be transmitted from the tracks through the soil to nearby properties, which is referred to as groundborne vibration. How well the vibration travels from the source to the receiver is a function of the ground propagation characteristics. Areas with efficient propagation characteristics typically have higher number of vibration impacts. Vibration above certain levels can disrupt sensitive operations and cause annoyance to humans within buildings. It is important to note that transit systems rarely produce vibration with sufficient magnitude to cause any structural damage.

When evaluating human response, groundborne vibration is expressed in terms of decibels using the root mean square (RMS) vibration velocity. RMS is defined as the average of the squared amplitude of

the vibration signal. To avoid confusion with sound decibels, the abbreviation VdB is used for vibration decibels. All vibration decibels in this report use a decibel reference of 1 micro-inch per second (μin/sec.).

The potential impacts of light rail transit groundborne vibration are as follows:

- **Perceptible building vibration.** The vibration of the floor or other building surfaces that the occupants feel. Experience shows that the threshold of human perception is around 65 VdB and that vibration that exceeds 75 to 80 VdB is perceived as intrusive and annoying to occupants.

- **Rattle.** The building vibration can cause rattling of items on shelves and hangings on walls, and various rattle and buzzing noises from windows and doors.

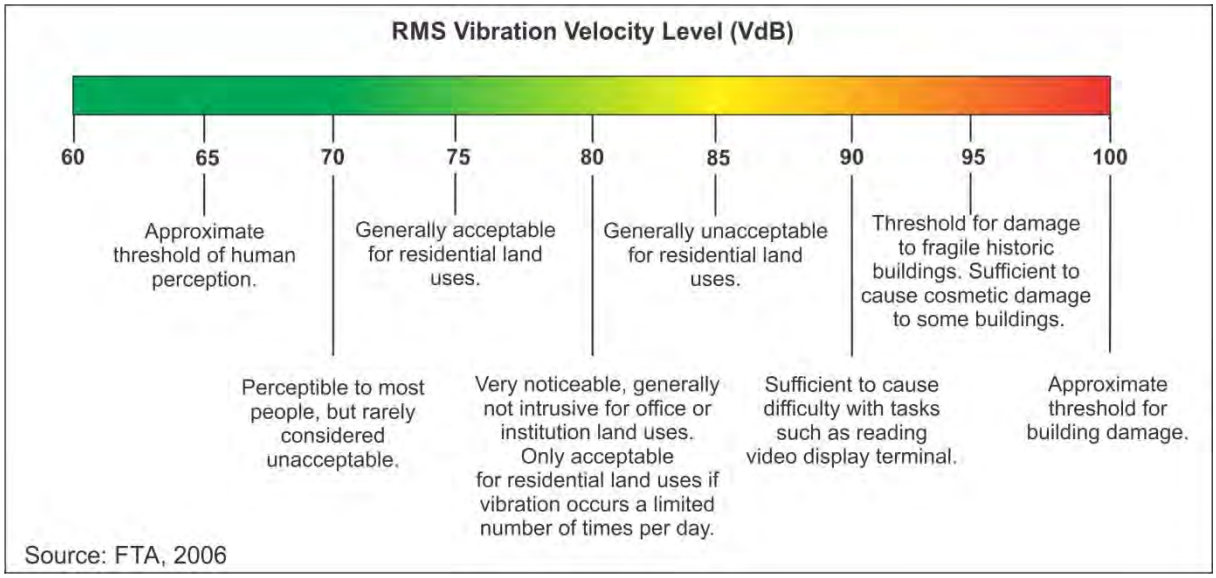
- **Reradiated noise.** The vibration of room surfaces radiates sound waves that are audible to humans (groundborne noise). Groundborne noise sounds like a low-frequency rumble. Usually, for a surface rail system such as the light rail train, the groundborne noise is masked by the normal airborne noise radiated from the transit vehicle and the rails.

- **Damage to building structures.** Although it is conceivable that vibration from a light rail system could damage fragile buildings, the vibration from rail transit systems is one to two orders of magnitude below the most restrictive thresholds for preventing building damage; hence the vibration impact criteria focus on human annoyance, which occurs at much lower amplitudes than does building damage.

Vibration can be measured in terms of displacement, velocity or acceleration. The response of humans, buildings and equipment to vibration is most accurately described using velocity or acceleration. Velocity is the preferred measure for evaluating vibration from transit projects, because it is typically considered to correspond best with human sensitivity. Vibration is expressed in terms of the root-mean-square vibration velocity level in decibels (VdB). The abbreviation VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 2-3 illustrates typical vibration velocity levels for common sources, as well as thresholds for human and structural response to groundborne vibration. As shown, the range of interest is from approximately 50 VdB to 100 VdB (i.e., from imperceptible background vibration to the threshold of damage). The approximate threshold of human perception to vibration is 65 VdB. Humans generally do not find vibration from light rail operations annoying until the vibration exceeds 70 to 75 VdB.

Figure 2-3. Range of Vibration Levels and Acceptability



Although there is relatively little research into human and building response to groundborne vibration, there is substantial experience with vibration from rail systems. In general, the collective experience indicates that:

- It is rare that groundborne vibration from transit systems results in building damage (even minor cosmetic damage); therefore, the primary consideration is whether or not the vibration is intrusive to building occupants or interferes with interior activities or machinery.

- The threshold for human perception is approximately 65 VdB. Vibration levels in the range of 70 to 75 VdB often are noticeable but acceptable. Beyond 80 VdB, vibration levels are considered unacceptable.

- For human annoyance, there is a relationship between the number of daily events and the degree of annoyance caused by groundborne vibration. The FTA Guidance Manual includes an 8-VdB higher impact threshold if there are fewer than 30 events per day and a 3-VdB higher threshold if there are fewer than 70 events per day (FTA, 2006).

Often, when evaluating vibration or noise signals, it is necessary to determine the contribution at different frequencies. The 1/3-octave band spectrum is the most common procedure used to evaluate frequency components of acoustic signals. The term octave is borrowed from music, where it refers to a span of eight notes. An octave consists of three 1/3 octaves. The 1/3-octave band spectrum of a signal is obtained by passing the signal through a bank of filters. Each filter excludes all components except those that are between the upper and lower range of one 1/3-octave band (FTA, 2006). The 1/3-octave band information is also used for the design of mitigation for vibration, because mitigation methods are often selected based on the 1/3-octave bands with the highest levels.

3. PROJECT IMPACT CRITERIA

The following sections provide an overview of the criteria used for evaluating noise and vibration impacts, which are defined by the FTA for transit-related noise and vibration, and by the FHWA for traffic-related noise. Because the Southwest Corridor Light Rail Project will potentially be funded partly by FTA, the FTA methods are the governing methods for the noise and vibration analyses. The FTA noise and vibration analyses are performed based on actual land uses, not zoning designations; therefore, according to the FTA methods, if a residence is located in an area that is zoned commercial, that property is analyzed as a residential land use with nighttime sensitivity to noise.

3.1. FTA Light Rail Noise Criteria

Noise impacts for the project are determined based on the criteria defined in the *FTA Guidance Manual* (FTA, 2006). The FTA noise impact criteria are founded on well-documented research on community reaction to noise and are based on changes in noise exposure rated using a sliding scale. Although more transit noise is allowed in neighborhoods with high levels of existing noise, as existing noise levels increase, smaller increases in total noise exposure are allowed before a noise impact is identified. The FTA noise impact criteria group noise-sensitive land uses into the following three categories:

- **Category 1.** Tracts of land where quiet is an essential element in their intended purposes. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.

- **Category 2.** Residences and buildings where people normally sleep. This category includes residences, hospitals and hotels where nighttime sensitivity is assumed to be of utmost importance.

- **Category 3.** Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.

Ldn is used to characterize noise exposure for residential areas (Category 2). For other noise-sensitive land uses, such as outdoor amphitheaters and school buildings (Categories 1 and 3), the maximum one-hour Leq during the facility's operating period is used. There are two levels of impact included in the FTA criteria. The interpretations of these two levels of impact are:

- **Severe.** Severe noise impacts are considered "significant" according to the usage of this term in National Environmental Policy Act and implementing regulations. Noise mitigation will normally be specified for severe impact areas.

- **Moderate.** In this range, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation. These other factors can include the predicted increase over existing noise levels, the types and number of noise-sensitive land uses affected, existing outdoor/indoor sound insulation, and the cost-effectiveness of mitigating noise to more acceptable levels.

The FTA noise impact criteria are summarized in Figure 3-1. The existing noise level is used to determine the FTA criteria for moderate or severe impacts. As the existing noise level in the overall environment increases, the allowable noise from the transit project is decreased. The Ldn is used to characterize noise exposure for residential areas (Category 2), and the peak one-hour Leq is used to evaluate effects from other noise-sensitive land uses such as schools, libraries and other noise-sensitive daytime uses (Categories 1 and 3) during project operation. There are no FTA impact criteria for commercial uses, such as offices, retail or restaurants.

Figure 3-1. FTA Noise Impact Criteria

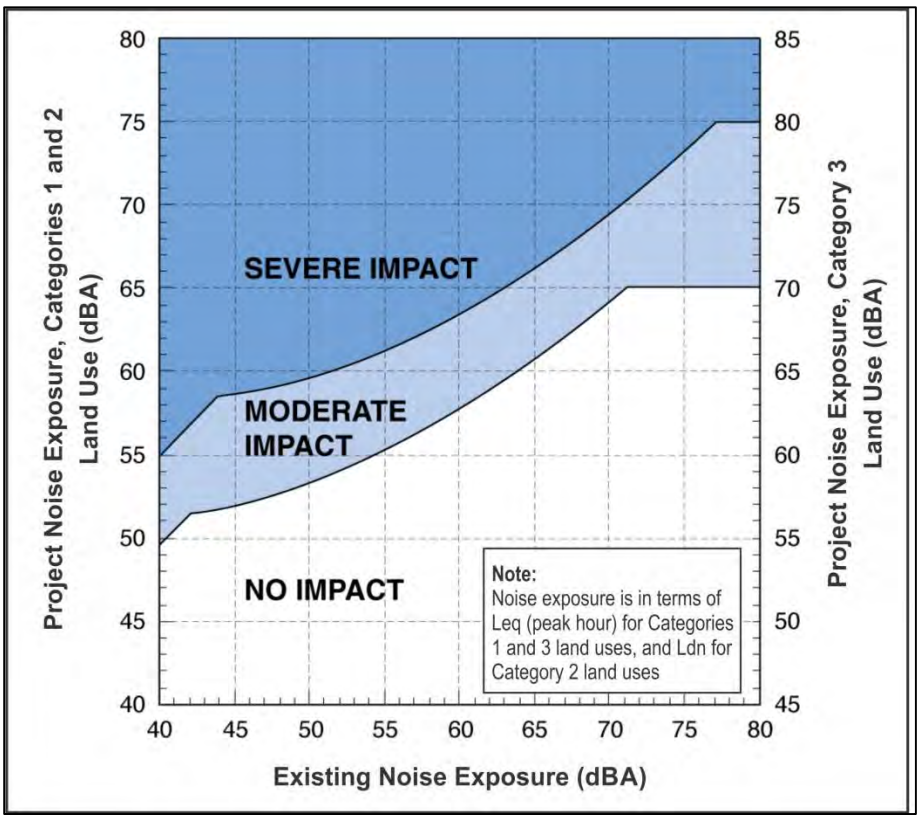


Figure 3-2 expresses the same criteria in terms of the increase in total or cumulative noise that can occur in the overall noise environment before an impact occurs. As shown on Figure 3-2, as existing noise exposure increases, an increasingly smaller increase in noise is permitted before an impact occurs. Table 3-1 provides the FTA noise impact criteria in tabular format.

Figure 3-2. FTA Noise Impact Cumulative Criteria

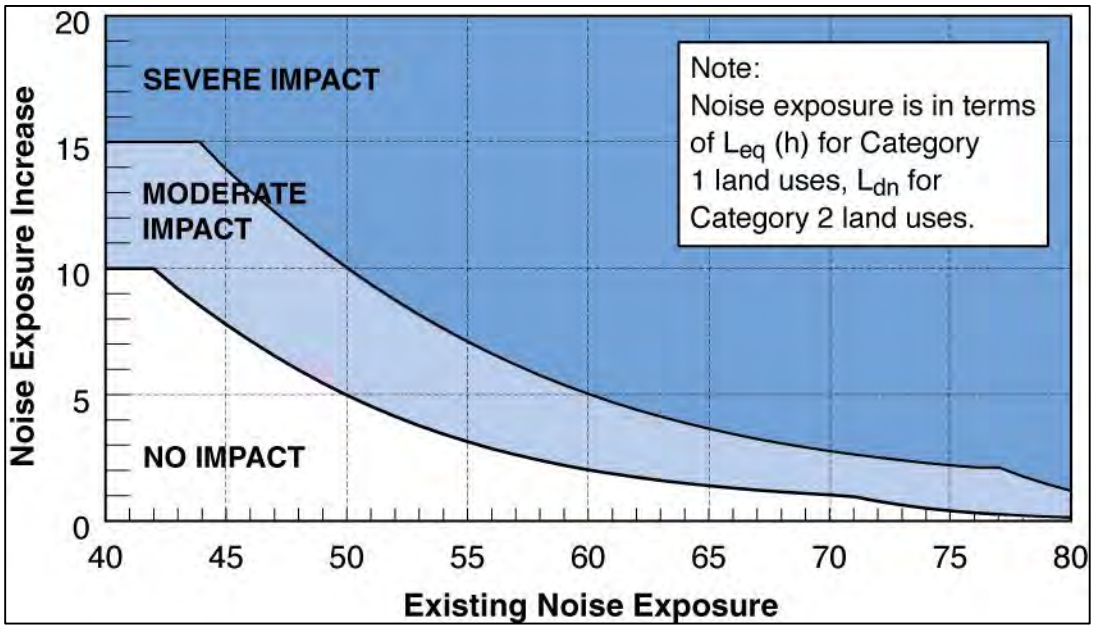


Table 3-1. FTA Noise Impact Criteria

Existing Noise Exposure Ldn or Leq[1]	Project Noise Exposure Impact Thresholds, Ldn or Leq (all noise levels are in dBA)[1]			
	Category 1 or 2 Sites[2]		Category 3 Sites[2]	
	Impact	Severe Impact	Impact	Severe Impact
<43	Ambient + 10	> Ambient + 15	Ambient + 15	> Ambient + 20
43–44	52–58	>58	57–63	>63
45	52–58	>58	57–63	>63
46–47	53–59	>59	58–64	>64
48	53–59	>59	58–64	>64
49-50	54–59	>59	59–64	>64
51	54–60	>60	59–65	>65
52–53	55–60	>60	60–65	>65
54	55–61	>61	60–66	>66
55	56–61	>61	61–66	>66
56	56–62	>62	61–67	>67
57–58	57–62	>62	62–67	>67
59–60	58–63	>63	63–68	>68
61–62	59–64	>64	64–69	>69
63	60–65	>65	65–70	>70
64	61–65	>65	66–70	>70
65	61–66	>66	66–71	>71
66	62–67	>67	67–72	>72
67	63–67	>67	68–72	>72
68	63–68	>68	68–73	>73
69	64–69	>69	69–74	>74
70	65–69	>69	70–74	>74
71	66–70	>70	71–75	>75
72–73	66–71	>71	71–76	>76
74	66–72	>72	71–77	>77
75	66–73	>73	71–78	>78
76–77	66–74	>74	71–79	>79
>77	66–75	>75	71–80	>80

Source: FTA, 2006

1. Ldn is used for land uses where nighttime sensitivity is a factor; peak-hour Leq is used for land use involving only daytime activities. Severe impacts only occur if the predicted levels exceed (>) the values in the appropriate column.
2. Category Definitions:

   Category 1: Buildings or parks where quiet is an essential element of their purpose.

   Category 2: Residences and buildings where people normally sleep. This includes residences, hospitals and hotels where nighttime sensitivity is assumed to be of utmost importance.

   Category 3: Institutional land uses with primarily daytime and evening use. This category includes schools, libraries and churches.

The *FTA Guidance Manual* provides details on how parks are analyzed for noise in Chapter 3, Section 2, Application of Noise Impact Criteria. FTA assumes that parks are a special case, and how they are used and where they are located should be considered when considering whether or not a particular park, or an area in a park, is considered noise-sensitive. Parks that are used for outdoor recreation are typically

not considered noise-sensitive. This includes parks with baseball diamonds, soccer fields, basketball courts, football fields and other active recreation areas.

Parks that are noise-sensitive would be those where quiet is an essential element in their intended purpose or places where it is important to avoid interference with activities such as speech, meditation, and reading. The existing noise levels at a park can provide some indication of the sensitivity of its use. All of the parks along the project corridor were evaluated for consideration under the FTA criteria, and based on the park locations and existing noise levels, none met the requirements for noise sensitivity under the FTA Category 3 criteria.

3.2. Traffic Noise Criteria

The potential for increased exposure to traffic noise was reviewed for noise-sensitive land uses, and those locations with potential increased exposure were identified. Traffic noise exposure could result from the development of new or extended roadways in station areas, or from the removal of buildings, walls or berms that currently provide shielding from traffic noise. Traffic noise modeling will be performed and will use the FHWA Traffic Noise Abatement Criteria once a preferred alternative is selected and adequate design files and traffic data are available.

As required by FTA, the criteria for determining traffic noise impacts associated with the project are taken from the FHWA Procedures for Abatement of Highway Traffic Noise and Construction Noise, Code of Federal Regulations (CFR) Title 23, Part 772 (2010). A traffic noise impact occurs if predicted traffic noise levels approach the criteria levels for specific FHWA land use activity categories or substantially exceed existing noise levels (e.g., a 10-dbA increase). These levels are defined as noise abatement criteria (NAC), and are based on hourly Leq noise levels during the peak traffic noise hour.

The land use activity categories of greatest concern along the project alignments are Types B and C, which include residences, playgrounds, active sports areas, parks, schools, churches, libraries and hospitals. The noise abatement criterion used to determine impacts on this land use is to approach, or exceed, 67 dBA Leq outside of buildings. Under the Oregon Department of Transportation (ODOT) policy, a traffic noise impact occurs if predicted noise levels approach within 2 dB of the NAC; therefore, an impact on Type B or C land uses would occur at 65 dBA Leq. Some commercial uses, including hotels and motels, have a criterion of 71 dBA under the ODOT policy. Many other commercial uses, such as general offices and retail businesses, are not normally considered noise-sensitive. Table 3-2 shows the traffic noise land use types and the corresponding FHWA and ODOT NAC.

Table 3-2. Traffic Noise Impact Criteria

Activity Category[1]	Activity Criteria in Hourly Leq (dBA)		Evaluation Location	Activity Description
	FHWA NAC	ODOT NAC		
A	57	56	Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose
B	67	66	Exterior	Residential (single-family and multifamily units)
C	67	66	Exterior	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, daycare centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails and trail crossings
D	52	51	Interior	Auditoriums, daycare centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools and television studios
E	72	71	Exterior	Hotels, motels, offices, restaurants/bars and other developed lands, properties or activities not included in A–D or F
F	--	--	--	Agriculture, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment and electrical) and warehousing
G	--	--	--	Undeveloped lands that are not permitted

Source: FHWA Procedures for Abatement of Highway Traffic Noise and Construction Noise and WSDOT Traffic Noise Policy and Procedures (23 CFR Subchapter H, Section 772).

[1] Planned and permitted land uses are included under the permitted category.

The FHWA recently clarified the type of noise analysis needed for transit-only projects along federal-aid highways and roadways. Specifically, the FHWA stated that transit-only projects meeting the three criteria below should use the *FTA Guidance Manual* procedures to assess noise associated with the transit project and any highway elements directly affected by the transit project:

1. FTA is the lead agency in the National Environmental Policy Act process. The FHWA's limited participation is as a cooperating agency.
2. The main transportation purpose of the project, as stated in the purpose and need statement of the National Environmental Policy Act document, is transit-related and not highway-related.
3. No federal-aid highway funds are being used to fund the project.

Because all three of the FHWA transit-only project criteria listed above are met by the Southwest Corridor Light Rail Project, the FTA methods were used to assess traffic noise impacts. Complete information on the FHWA guidance can be found on the FHWA website at:

http://www.fhwa.dot.gov/environment/noise/regulations_and_guidance/faq_nois.cfm#A10

3.3. Noise Criteria for Ancillary Facilities and Project Construction

Because the project travels through, or near, several different jurisdictions, all jurisdictions within 500 feet of any potential alignment were reviewed for noise and vibration regulations or ordinances that

have applicability to the project. Applicable local noise ordinances include ordinances from the Cities of Lake Oswego, Portland, Tigard and Tualatin. Also, for noise-sensitive uses in the unincorporated areas of Clackamas and Multnomah counties, county and Oregon State Department of Environmental Quality (DEQ) ordinances and regulations are also included and used as appropriate. These regulations would be applicable to maintenance facilities, power substations and other ancillary facilities in support of system operations. Each of the ordinances is outlined below.

3.3.1. Oregon Department of Environmental Quality Noise Regulations

The Oregon DEQ regulations are found in Oregon Administrative Rule (OAR) 340 Division 35 Noise Control Regulations. Under OAR 340-035-0035 (Noise Control Regulations for Industry and Commerce), industrial or commercial noise sources are subject to the limits specified in Table 3-3 below. The statistical noise levels L01, L10 and L50 refer to the sound pressure levels that occur for 1 percent (0.6 minutes), 10 percent (6 minutes) and 50 percent (30 minutes) in any one-hour period. The DEQ regulations are not applicable to construction noise.

Table 3-3. Oregon DEQ Maximum Allowable Noise Levels from New Industrial and Commercial Sources

Noise Descriptor	Daytime Limits (7 a.m. to 10 p.m.)	Nighttime Limits (10 p.m. to 7 a.m.)
L50	55 dBA	50 dBA
L10	60 dBA	55 dBA
L01	75 dBA	60 dBA

Source: Oregon DEQ

3.3.2. Lake Oswego Noise Control Ordinance

There are several parcels within 350 to 500 feet of the light rail alignments—located along the east side of I-5, south of Oregon Highway 217 (OR-217) and north of the project terminus—that are within the city of Lake Oswego or unincorporated Clackamas County. For the locations in the city of Lake Oswego, ancillary facilities would need to meet applicable ordinances for those areas.

Sections 537 and 539 of Article 34.10 of the Lake Oswego code is specific to noise from ancillary operations. The code restricts noise levels by the time of the day, and also restricts any loud, disturbing or unnecessary noise, but it does not provide any specific decibel levels, making identification of impacts difficult to quantify. However, because the nearest parts of the corridor are across I-5 at distances of 250 to 350 feet or more from the city of Lake Oswego, it is not likely that noise from any ancillary operations would be noticeable at any Lake Oswego residences.

Project construction is exempt from the noise ordinance between 7 a.m. and 6 p.m., Monday through Friday in residential areas, and Monday through Saturday in areas that are not residential. Construction is also exempt on Saturdays between the hours of 8 a.m. and 6 p.m., but prohibited on Sundays. Construction outside of these hours requires a noise variance.

3.3.3. Portland Noise Control Ordinance

Because much of the project alignments are located within the city of Portland, the local noise control ordinance is applicable to the operation of project-related ancillary facilities. The City of Portland Noise Control Ordinance can be found in Chapter 18 of the City of Portland Municipal Code. The City of Portland Noise Control Ordinance defines three classes of property usage and the maximum noise levels allowable for each. For example, the noise caused by a commercial property must be less than 60 dBA at the closest residential property line. The City of Portland Noise Control Ordinance is summarized in Table 3-4.

Table 3-4. Portland Maximum Allowable Noise Levels

Source of Noise	Maximum Allowable Noise Levels		
	Residential and Open Spaces	Commercial	Industrial
Residential and Open Spaces	55 dBA	60 dBA	65 dBA
Commercial	60 dBA	70 dBA	70 dBA
Industrial	65 dBA	70 dBA	75dBA

Source: City of Portland Municipal Code

Between 10 p.m. and 7 a.m., the maximum levels given in Table 3-4 are reduced by 5 dBA. For pure tone and steady state noise, such as constantly running fans, the maximum allowable noise levels shown in Table 3-4 are also reduced by 5 dBA during daytime hours and 10 dBA during nighttime hours.

Construction noise in the city of Portland is limited to 85 dBA Lmax at 50 feet during the hours of 7 a.m. to 6 p.m., Monday through Saturday. Construction outside of those hours would require a noise variance from the city. The 85-dBA daytime limit does not apply to pile drivers, pavement breakers, scrapers, concrete saws and rock drills or haul trucks. Haul trucks and other on-road vehicles are required to have appropriate exhaust mufflers and meet the State of Oregon vehicle requirements.

In addition to the regulations above, the City of Portland restricts pile driving to the hours of 8 a.m. to 6 p.m., Monday through Friday. Pile driving is not allowed during weekends or evening and nighttime hours.

3.3.4. Tigard Noise Control Ordinance

Article V in Title 6 of the Tigard Municipal Code contains a noise nuisance ordinance with maximum noise levels that can be produced by project facilities, such as maintenance bases and power substations, during different times of the day. For example, the noise caused by a project facility at the boundary of a property with a noise-sensitive use must be less than 40 dBA between the nighttime hours of 10 p.m. and 7 a.m., and less than 50 dBA between the daytime hours of 7 a.m. and 10 p.m. For receiving properties that are not noise-sensitive, the noise must be less than 60 dBA during the nighttime hours and less than 75 dBA during the same daytime hours. In addition, the noise caused by a project facility cannot be plainly audible within a noise-sensitive building between the nighttime hours of 10 p.m. and 7 a.m.

Under Section 6.02.450 of the Tigard Municipal Code, sounds caused by regular vehicular traffic upon premises open to the public in compliance with state law are exempt from the ordinance. As a result,

the City of Tigard ordinance will not apply to the project's park and rides. The ordinance also does not apply to construction projects for public facilities within rights of way, pursuant to a noise mitigation plan approved by the city manager. In addition, normal construction activities are exempt from the noise ordinance between the hours of 7 a.m. and 8 p.m., Monday through Saturday. Construction outside of these hours requires a noise variance.

3.3.5. Tualatin Noise Control Ordinance

The City of Tualatin adopted a noise control ordinance as part of the municipal code in 2013. The noise ordinance found in Chapter 6-14 of the municipal code is a nuisance ordinance and includes maximum noise levels that can be produced by project facilities—such as maintenance bases and power substations—during different times of the day. For noise-sensitive properties such as residences, the code limits noise levels to 50 dBA from 10 p.m. to 7 a.m. and 70 dBA from 7 a.m. to 10 p.m. For non-noise-sensitive properties, the levels are 10 dB higher: 60 dBA from 10 p.m. to 7 a.m. and 80 dBA from 7 a.m. to 10 p.m.

Under Section 6-14-060 (5) and (7), noise from facilities that are regulated by federal noise regulations and general traffic on public roadways are exempt from the noise limits provided above. Therefore, noise on public roadways and noise from public transit are exempt from the City of Tualatin noise ordinance. However, noise from maintenance bases and power substations would be required to meet the local regulations, as required by FTA.

For construction noise, the City of Tualatin exempts daily construction activities between the hours of 7 a.m. and 6 p.m., including weekends. Construction outside of these hours requires a noise variance.

3.4. Vibration and Groundborne Noise Impact Criteria

Potential effects of rail transit groundborne noise and vibration include perceptible building vibration, rattle noises, reradiated noise (groundborne noise), and cosmetic or structural damage to buildings. However, vibration caused by light rail operations is typically well below what would cause even minor cosmetic damage to buildings. Vibration caused by construction equipment and activities is evaluated for potential damage to nearby buildings. Therefore, the criteria for building vibration caused by transit operations are primarily concerned with potential annoyance of building occupants.

3.4.1. Transit Operational Vibration Criteria

The FTA vibration impact criteria are based on the maximum indoor vibration level as a train passes. There are no impact criteria for outdoor spaces such as parks. The *FTA Guidance Manual* provides two sets of criteria: one based on the overall vibration velocity level for use in a General Vibration Impact Assessment and one based on the maximum vibration level in any 1/3-octave band (the band maximum level) for use with a Detailed Vibration Assessment. The second set of criteria (the band maximum level) was used for this analysis. An FTA vibration impact exists if the vibration levels meet or exceed both criteria.

Table 3-5 shows the FTA General Assessment criteria for groundborne vibration from rail transit systems. As with the FTA noise criteria, there are three categories of sensitive land uses; however, the category definitions for noise are different than those for vibration. The primary difference is in Category 1. For a noise assessment, Category 1 applies to land uses "…where quiet is an essential

element of their intended purpose." For a vibration assessment, Category 1 applies to "buildings where vibration would interfere with interior operations...," which primarily applies to spaces that house sensitive research and laboratory equipment such as scanning electron microscopes. No FTA Category 1 land uses were identified close enough to the light rail alternatives to be affected by project-generated noise or vibration.

Unlike the FTA noise criteria, the FTA vibration criteria do not incorporate any factor to account for the number of trains per day, with two exceptions: under vibration Categories 2 and 3, for "occasional service," the FTA impact thresholds are 3 VdB higher than for "frequent service," and for "infrequent service," the FTA impact thresholds are 8 VdB higher than for frequent service. Note that since Category 1 is based on operations of equipment (and not human disturbance), a single threshold applies regardless of the number of events. FTA defines occasional service to be between 30 and 70 trains per day, and infrequent service to be less than 30 trains per day. The frequent criteria are applicable to the project, because there would be more than 70 trains per day passing by any one location.

Table 3-5. FTA Impact Thresholds for Groundborne Vibration, General Impact Assessment

Land Use Category	Groundborne Vibration (VdB re 1 micro inch/sec)			Groundborne Noise[1] (dB re 20 micro Pascals)		
	Frequent Events[2]	Occasional Events[3]	Infrequent Events[4]	Frequent Events[2]	Occasional Events[3]	Infrequent Events[4]
Category 1: Buildings where vibration would interfere with interior operations. Typically land uses include vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment, and university research operations.	65	65	65	N/A[5]	N/A[5]	N/A[5]
Category 2: Residences and buildings where people normally sleep.	72	75	80	35	38	43
Category 3: Institutional land uses with primarily daytime uses.	75	78	83	40	43	48

Source: FTA, 2006.

re = reference; micro-inch/sec = micro-inch per second; N/A = not applicable; VdB = vibration decibels

[1] Groundborne noise criteria are not applied to any of the three categories. However, the groundborne noise criteria are applied to special buildings such as concert halls and performing arts centers.

[2] Frequent events are defined as more than 70 vibration events per day.

[3] Occasional events are defined as between 30 and 70 vibration events per day.

[4] Infrequent events are defined as less than 30 vibration events per day.

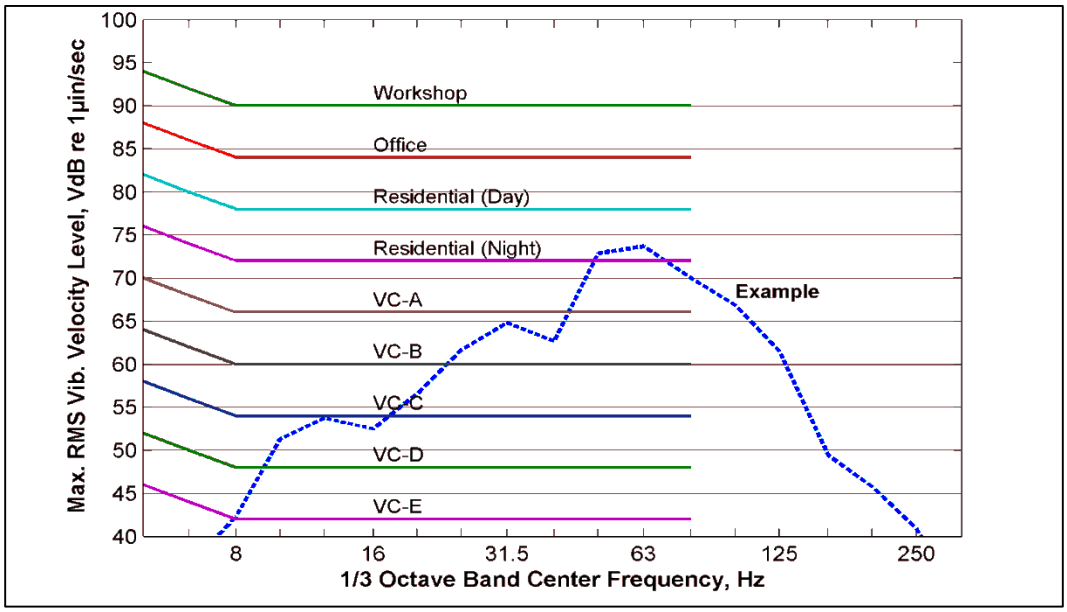
[5] Vibration-sensitive equipment is not sensitive to groundborne noise.

The FTA vibration thresholds do not specifically account for existing vibration. Although roadways located along the light rail alternatives,—especially SW Barbur Boulevard and I-5—have substantial volumes of vehicular traffic, including buses and trucks, it is relatively rare that rubber-tired vehicles generate perceptible ground vibration unless there are irregularities in the roadway surface such as potholes or wide expansion joints.

The refined criteria for use with an FTA Detailed Vibration Assessment are shown on Figure 3-3. For the detailed assessment, the predicted vibration levels in terms of the 1/3-octave band spectra are compared to the curves shown on Figure 3-3 to determine whether there would be impacts and the frequency range over which vibration mitigation would be required. An impact occurs when any spectral values exceed the applicable curve. The FTA interpretation of how each of the curves shown on

Figure 3-3 should be applied is given in Table 3-6. The VC-A through VC-E curves are used to specify acceptable vibration limits for sensitive equipment, such as electron microscopes. Which curve to use depends on the sensitivity of the specific equipment that would be affected. Use of the VC-C curve is adequate to avoid interfering with the operation of most sensitive equipment, with the exception of a few particularly sensitive pieces of equipment such as transmission electron microscopes or atomic force microscopes.

Figure 3-3. FTA Criteria for Detailed Vibration Assessment and Impact Identification



The use of the Detailed Vibration Assessment criteria is illustrated by the example vibration spectrum (the blue dashed line) shown on Figure 3-3. The maximum level of the vibration spectrum exceeds the "residential (night)" curve in the 50- and 63-Hz 1/3-octave bands. For this example, impact would be predicted for residential land uses and vibration mitigation would need to be evaluated, even though all of the 1/3-octave band levels fall below the "residential (day)" curve. Typical sensitive equipment and their appropriate VC curves are listed in Table 3-6. Note that the *FTA Guidance Manual* does not provide a Detailed Vibration Assessment criterion for institutional land uses. However, where the General Assessment threshold is exceeded and the predicted vibration spectrum is available, it is reasonable to apply the residential (day) curve of the Detailed Vibration Assessment criteria to assess impacts. Because institutional land uses are used primarily during the day and the vibration level for annoyance would not be more stringent than residential land uses, this is a valid approach.

The approach used for this vibration analysis is that the General Assessment criteria presented in Table 3-5 were used to screen for potential vibration impacts. The Detailed Assessment criteria were then applied to predict potential impacts and determine whether vibration mitigation would be warranted. The Detailed Assessment curve for the residential (day) was applied for institutional land use, and the residential (night) curve was used for residential land uses.

Table 3-6. Interpretation of Vibration Criteria for Detailed Analysis

Criterion Curves	Maximum Level (VdB)[1]	Description of Uses
Workshop	90	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas.
Office	84	Feelable vibration. Appropriate to offices and non-sensitive areas.
Residential Day	78	Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X).
Residential Night, Operating Rooms	72	Vibration not feelable, but groundborne noise may be audible inside quiet rooms. Suitable for medium-power optical microscope (100X) and other equipment of low sensitivity.
VC-A	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment.
VC-B	60	Adequate for high-power optical microscopes (1,000X), inspection and lithography equipment to 3-micron line widths.
VC-C	54	Appropriate for most lithography and inspection equipment to 1-micron detail size.
VC-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability.
VC-E	42	The most demanding criterion for extremely vibration-sensitive equipment.

Source: FTA, 2006.

[1] Maximum allowed vibration velocity in any 1/3-octave band over the range of 8 to 80 Hz.

There are some buildings, such as concert halls, recording studios and theaters, that can be very sensitive to vibration but do not fit into any of the three categories listed in Table 3-6 or cannot be associated with the curves on Figure 3-3. Because of the sensitivity of these buildings, they usually warrant special attention during the environmental evaluation of a transit project. Table 3-7 gives the FTA criteria for acceptable levels of groundborne vibration and groundborne noise for various categories of special buildings. As of this initial analysis, there were no special use buildings identified near the project alignments.

Table 3-7. Groundborne Noise and Vibration Impact Criteria for Special Buildings

Location	Groundborne Vibration Impact Levels (VdB re 1 micro-inch/sec)	Groundborne Noise Impact Levels (VdB re 1 micro-inch/sec)
Concert Halls	65	25
TV Studios	65	25
Recording Studios	65	25
Auditoriums	72	30
Theaters	72	35

Source: FTA, 2006

3.4.2. Construction Vibration Criteria

Construction vibration, unlike vibration from train operations, has the potential to cause damage to structures that are located very close to high vibration activities. Therefore, the primary concern regarding construction vibration relates to risk of damage. Construction activities with the potential of causing structural damage include impact hammering and pile-driving, and occasionally, soil compacting. The potential risk of damage from construction vibration generally is assessed using peak particle velocity (PPV), which is the maximum vibration velocity amplitude generated by the

construction activity. It is considered the appropriate metric for evaluating the potential for building damage, because PPV is related to the stresses that are experienced by buildings.

The vibration damage risk thresholds for different building categories provided in the *FTA Guidance Manual* (FTA, 2006) are listed below:

- Reinforced concrete, steel or timber: 0.5 inch per second (in./sec) PPV
- Engineered concrete and masonry: 0.3 in./sec PPV
- Non-engineered timber and masonry buildings: 0.2 in./sec PPV
- Buildings extremely susceptible to vibration damage: 0.12 in./sec PPV

The damage risk criterion of 0.5 in./sec PPV is appropriate for single-family and multifamily residences along the project's light rail alternatives alignments, and the criterion of 0.12 in./sec PPV is appropriate for extremely fragile buildings.

The thresholds for daytime human annoyance due to construction vibration are the same as the General Assessment criteria applied for vibration from train operations. The following are the criteria to reduce the potential for intrusive vibration at sensitive receivers. These limits are included for reference only, and they are not intended to be applied to predict impact:

- Annoyance to residential buildings during daytime: 0.016 in./sec PPV (72 VdB)
- Annoyance to daytime sensitive uses at schools, churches and other institutional land uses: 0.022 in./sec PPV (75 VdB)

A general analysis of potential worst-case construction vibration levels was performed. As with the light rail vibration analysis, vibration levels decrease with distance, and areas with efficient propagation, or areas with structures located near construction sites, will have the highest potential for vibration impacts.

4. METHODS AND ASSUMPTIONS FOR NOISE AND VIBRATION ANALYSES

This section summarizes the models used to predict future noise and vibration levels for potential sources of community impacts related to the Southwest Corridor Light Rail Project. These sources include light rail operation, park and rides and transit centers, O&M facility operation, changes in traffic related to the project and construction activities.

4.1. Noise Assumptions and Methods

The noise analysis was performed in accordance with the *FTA Guidance Manual*. Input to the noise analysis includes several critical items associated with the system operations, including number of trains, operational speeds, track type, station locations, park and ride locations, O&M facility sites and the location of special trackwork. The following sections describe the inputs to the noise modeling efforts and how each affects the results of the analysis.

4.1.1. Light Rail Operations

Inputs to the model for the prediction of noise from train operations included train headways, speeds and reference noise levels of the existing fleet of TriMet light rail vehicles. Also included in the modeling were topographical features along the corridor and information on the track type. Noise levels associated with train-mounted warning bells were modeled at station locations. Specifics on the modeling inputs are provided in the following sections.

Noise impacts that would result from the light rail operations were determined through the following approach:

1. A land use survey to identify noise-sensitive receptors, by category (e.g., residences, hotels, hospitals, schools and others—see Section 3.1), that could be affected by the proposed project operations. This process involved site visits and reviewing land-use maps and information. As a starting point, the analysis included all sensitive properties within 350 feet to 500 feet of any of the light rail alternatives alignments.
2. Field noise measurements were used to develop a set of existing ambient sound levels for the noise-sensitive receptors. The existing ambient sound levels and land use were used to determine the noise impact criteria.
3. Projections of light rail noise levels were made based on track type, train speed, number of passenger cars and the distance of the noise-sensitive receptors from tracks. Noise related to bells at stations and special trackwork was included in the analysis.
4. Projections of operational noise levels were compared to the FTA impact thresholds to determine whether a receiver would be affected by light rail operations.
5. Where noise impacts were identified, mitigation measures were considered and followed the *FTA Guidance Manual*.

Reference Noise Levels for TriMet Vehicles

Reference pass-by noise level measurements were performed for the TriMet light rail vehicles operating along the Blue Line near SW Terman Road just west of the Millikan Way MAX Station, along the ballast and tie segment of the alignment. Measurements were performed using the methods

outlined in International Standard (ISO) 3095:2005 (E), *Railway Applications, – Acoustics – Measurement of noise emitted by rail bound vehicles*, Second Edition, 2005-08-15. Measurements were taken during normal revenue service between 8:15 a.m. and 9:35 a.m. on July 14, 2010. Fourteen pass-by measurements were taken, including ten westbound trains and four eastbound trains. Only those pass-by noise readings that were 10 dBA over the ambient noise level, as required for accurate noise measurements, were used to determine the reference level. Speeds for the pass-bys were verified using a radar gun; the average speed was 39 miles per hour (mph).

The noise and speed measurements were used to calculate a reference level for a two-car light rail vehicle operating at 40 mph at a distance of 50 feet. The overall average pass-by noise level normalized to 40 mph and 50 feet was 79.1 dBA. This level was used as the reference level in the noise modeling.

Additional reference measurements are planned, to include specific measurements of the new light rail vehicles received by TriMet since this last measurement was performed. Preliminary testing has shown that the new vehicles produce noise levels that are essentially the same as the existing fleet of vehicles. The additional reference measurements will be used, if necessary, to update the noise model as the project proceeds.

Warning Bells

Train-mounted bells on light rail vehicles would be sounded as a train enters a station and when the train leaves the station. The added noise from these bells was included in the noise model for receivers within 500 feet of any station, transit center or park and ride. There are no other warning bells associated with normal system operations. During emergency situations, such as when pedestrians or vehicles are on the trackway, notably louder bells and/or horns may be used; however, because these are only used in emergency situations, sounding of these warning bells or horns is exempt from noise regulations.

Alignment, Track Types and Special Trackwork

The project design engineers provided plan and profile of the proposed light rail alignment, including the locations of special trackwork such as crossovers and typical speeds The design information provided includes the elevation of the trackway, track base (e.g., at-grade, retained cuts and fills, or elevated on aerial structure), type of track (e.g., ballast and tie, embedded and direct-fixation), and the location and design of the station alternatives. The current design calls for a combination of track types with alignment alternatives at-grade, in retained cuts and fills, on aerial structures using ballast and tie, embedded and direct-fixation track types.

Track crossovers are mechanical devices that enable light rail cars to be guided from one track to another at a junction point. Crossovers have a gap in the rails that is necessary for the flange of the light rail wheels to pass through at the location where the two tracks cross. As a wheel passes through the gap, noise and vibration levels increase. A frog is a rail-crossing structure that allows the train to cross over to another track or continue moving on the same track. A gap is provided on top of the frog so that vehicle wheels can pass regardless of which track is in use. According to the *FTA Guidance Manual* standard frogs can increase noise levels by as much as 8 to 10 dB. Spring-rail frogs and movable-point frogs solve the added noise and vibration problem of standard frogs by closing the gap on the rails.

Flange-bearing frogs, another mitigation option, transfer the vehicle load from the wheel tread to the wheel flange and raise the light rail car up and over the gap, reducing noise and vibration levels. Each of these types of frogs produces noticeably lower noise levels than standard frogs. Depending on the type of crossover and the angle between the crossover and the mainline track, special frogs can reduce noise levels between 4 and 8 dBA compared to a standard frog. The type of frogs used for the Southwest Corridor Light Rail Project would depend on the track type, crossover location and proximity of noise-sensitive properties. A typical crossover is shown in Figure 4-1.

Figure 4-1. Typical Track Crossover

Track corrections used for the analysis are taken from the *FTA Guidance Manual* (FTA, 2006). The corrections used are:

- at-grade ballast and tie track (ballast exposed): 0 dB
- elevated Structure ballast and tie track (ballast exposed): +1 dB
- elevated structure (direct-fixation track): +4 dB
- track crossover (standard): +10 dB at 35 feet, based on measured data during normal operations of similar systems.

Operational Plan

TriMet provided the operational plan for the system, which included the number of cars per train, speeds and headways. The operational plan assumes operations for the year 2035; operations might not be at this level for several years after opening. Further, there are two potential operational plans, one for north of the Beveland Station and for all Through Configuration alternatives (Alternatives C1

Track Types Defined

Continuously Welded Rail: TriMet uses continuously welded rail on all service tracks to prevent the noise and vibration common to butted rail installations.

Ballast and Tie Track: Ballasted track is a track structure consisting of rail, tie plates or fasteners, cross ties, and the ballast or sub-ballast bed supported on a prepared subgrade. The subgrade may be a compacted embankment or fill section, an excavation or cut section, or a bridge structure. Ballast and tie track is generally the standard for light rail transit routes that are constructed on an exclusive right of way.

Direct-fixation Track: Direct-fixation track is a "ballastless" track structure in which the rail is mounted on direct-fixation fasteners that in turn are anchored to an underlying concrete slab. Direct fixation is generally the standard for light rail transit routes constructed on elevated structure. Direct-fixation track is also used for construction of at-grade track under unusual circumstances, such as when there is a relatively short segment of at-grade track between two direct-fixation track structure decks.

Embedded Track: Embedded track can be described as a track structure that is completely encased—except for the tops and gauge sides of the rails—within pavement. Embedded track is generally the standard for light rail transit routes constructed within public streets, pedestrian/transit malls or any area where rubber-tired traffic must operate.

(Source: Transportation Research Board, 2012)

through C4), and a second that is only applicable under the two Branched Configurations (Alternatives C5 and C6).

Base operational plan for the Through Configurations:

- Peak Hours (7 a.m. to 9 a.m. and 3 p.m. to 6:30 p.m.): 6.7-minute headways
- Off-peak Hours (5 a.m. to 7 a.m., 9 a.m. to 3 p.m., and 6:30 p.m. to 1 a.m.): 12-minute headways

Base operational plan for the Branched Configurations:

- Peak Hours: Union Station to Beveland Station (7 a.m. to 9 a.m. and 3 p.m. to 6:30 p.m.): 6.7-minute headways
- Peak Hours: Beveland Station to Tigard Transit Center (7 a.m. to 9 a.m. and 3 p.m. to 6:30 p.m.): 12-minute headways
- Peak Hours: Beveland Station to Bridgeport Station (7 a.m. to 9 a.m. and 3 p.m. to 6:30 p.m.): 15-minute headways
- Off-peak Hours: Union Station to Beveland Station (5 a.m. to 7 a.m., 9 a.m. to 3 p.m., and 6:30 p.m. to 1 a.m.): 8.6-minute headways
- Off-peak Hours: Beveland Station to Tigard Transit Center (5 a.m. to 7 a.m., 9 a.m. to 3 p.m., and 6:30 p.m. to 1 a.m.): 15-minute headways
- Off-peak Hours: Beveland Station to Bridgeport Station (5 a.m. to 7 a.m., 9 a.m. to 3 p.m., and 6:30 p.m. to 1 a.m.): 20-minute headways

Because the Branched Configuration (Alternatives C5 and C6) will require more trains during the off-peak periods, these alternatives have a higher number of impacts in Segments A and B. The additional light rail traffic in Segments A and B also increases the project noise levels and impacts in these two segments compared to the Through Configurations.

Wheel Squeal

Wheel squeal is caused by the oscillation of the wheel against the rail on curved sections of rail. Measured wheel squeal noise levels at several different locations on the TriMet system and other similar systems can produce maximum wheel squeal noise levels of 75 dBA to 90 dBA at 50 feet. The actual noise level will depend on many factors, including the radius and condition of the tracks. During winter months, when there is frequent rain, the level of squeal can be dramatically reduced, because the damp rails tend to reduce the level of squeal.

Research into methods of reducing wheel squeal noise, including using non-oil-based lubricants (such as water, described above) and friction modifiers, has found that such methods effectively reduce or eliminate wheel squeal. The lubricants can be applied by personnel working trackside or by an automated applicator. Wheel squeal is not included in the noise model; however, all curves with a radius of 300 feet or less that are located in noise-sensitive areas have been identified and will be considered for lubrication to mitigate any potential for wheel squeal.

4.1.2. Transit Center, Park and Ride, and Station Noise

Operational noise levels from buses and vehicles accessing newly constructed parking at park and ride stations and transit centers were calculated using the methods outlined in the *FTA Guidance Manual* (FTA, 2006). Future bus and passenger traffic volumes for the new park and ride facilities are based on the predicted maximum number of parking spots and hourly bus operation throughout the day, evening and nighttime hours at each facility.

4.1.3. O&M Facilities Noise

Noise and vibration from operations of the O&M facilities were modeled using the methods described in the *FTA Guidance Manual*. The noise impact assessment includes the analysis of noise from general maintenance operations, cleaning of trains, arrival and departure of trains, vehicle movement in the yard and ancillary equipment, including power substation. All alternatives would involve construction and operation of storage tracks, offices and an enclosed light rail vehicles maintenance building containing service bays for light rail vehicles. All alternatives also assume some expansion at the existing Ruby Junction maintenance facility, and a review of potential noise impacts near that facility was conducted. The analysis used reference noise levels for operation of a maintenance base taken from the *FTA Guidance Manual*. The operational analysis assumes that the O&M facility would operate 24 hours per day.

4.1.4. Traffic Noise

The potential to create or increase exposure to traffic noise as a result of the transit project was evaluated qualitatively. As defined in FHWA noise abatement policy (FHWA, 2011), changes in the traffic noise environment could occur if the project creates new roadways or alters existing roadways in relation to noise-sensitive properties, or changes the pathway for traffic noise by removing or altering barriers (buildings, berms or walls) that currently provide some level of shielding from traffic noise.

Once a final alignment is selected, locations where the project could result in increased traffic noise will be modeled using the methods defined by the FHWA and ODOT. Sites with traffic noise impacts that are related to the project will be considered for noise mitigation. A review of potential areas that could meet the criteria for a traffic noise analysis is provided in Section 6, Noise Impacts.

4.2. Vibration Assumptions and Methods

Localized geologic conditions such as soil stiffness, soil layering and depth to bedrock have a strong effect on groundborne vibration. However, it is difficult to obtain information on subsurface conditions in sufficient detail so that computer models can be used to accurately predict ground vibration. As a result, most detailed predictions of ground vibration are based largely on empirical methods that involve measuring vibration propagation in the soil. Based on this fact and on the results of this analysis, additional vibration propagation measurements will be taken as the project design is updated to further refine the analysis and better determine the project mitigation.

The predictions of groundborne vibration for this analysis follow the Detailed Vibration Assessment procedure of the *FTA Guidance Manual* (2006). This is an entirely empirical method based on testing of the vibration propagation characteristics of the soil and measurements of the vibration characteristics of a similar train vehicle. The quantity derived from propagation tests is referred to as the Line Source Transfer Mobility (LSTM). The LSTM is used with the Force Density Level (FDL), a measure of how much vibration energy trains generate, to predict the vibration energy received by the sensitive receivers.

Vibration propagation results from measurements along the Portland-Milwaukie Light Rail Project line were used in this assessment, because measurements from the project corridor will be taken in the future as the project design is updated. Because data from a different project corridor were substituted for project-specific data in this analysis, the FTA's General Vibration Assessment criteria were applied instead of the Detailed Vibration Assessment criteria to account for the additional uncertainty.

The predicted vibration level (Lv = FDL + LSTM) also includes site-specific adjustments, such as speed, special trackwork, coupling loss, floor amplification and other factors. The result, Lv, is compared to the regulatory limits discussed in Section 3.4. A +5-dB safety factor was also included in all predicted levels. Therefore, this is a worst-case analysis, and the data produced are being used to determine appropriate propagation testing sites. The following sections provide more detail on the analysis and measured data from other TriMet projects used in this analysis.

4.2.1. Line Source Transfer Mobility

Transfer mobility indicates how easily vibration travels through the soil. A high transfer mobility indicates that there is little attenuation (or reduction) as vibration travels through the soil. The measured transfer mobility function for different impact points are combined using numerical integration to derive an equivalent Line Source Transfer Mobility, or LSTM, at each measurement site. The LSTM quantifies how vibration from a line source, such as a train, propagates through the soil. A vibration propagation test is used to measure the LSTM.

A schematic of the at-grade vibration propagation test is shown in Figure 4-2. A drop hammer is used at 11 different positions to create a "line of impacts" over the approximate length of a light rail vehicle. Accelerometers extend perpendicular to the line of impacts to measure the vibration from the drop hammer.

Each of the 11 impact positions yields a point-source transfer mobility. Numerically integrating the 11 point-source transfer mobilities yields the LSTM. Each accelerometer yields its own LSTM at a different distance, which can be fit to an LSTM-versus-logarithm (distance) curve to predict LSTM as a function of distance.

Basic Relationship Used for the Vibration Predictions

Lv = FDL + LSTM

where:

Lv = Train vibration velocity measured at the ground surface

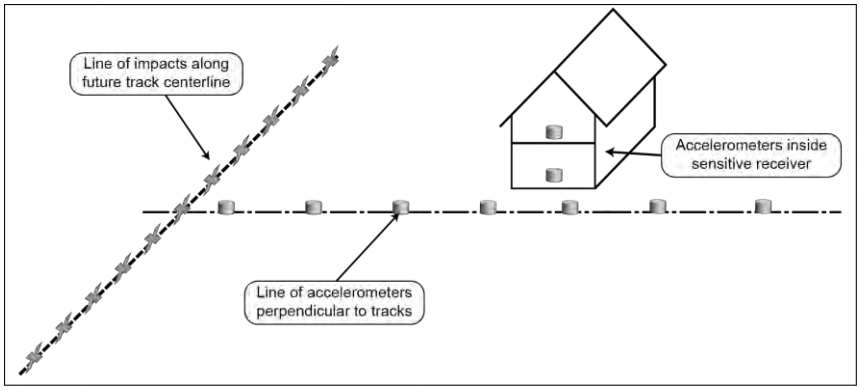
LSTM = Measured line source transfer mobility

FDL = Force density level or function that characterizes the vibration forces generated by the train and track

(All quantities are expressed in decibels using a consistent set of decibel reference values)

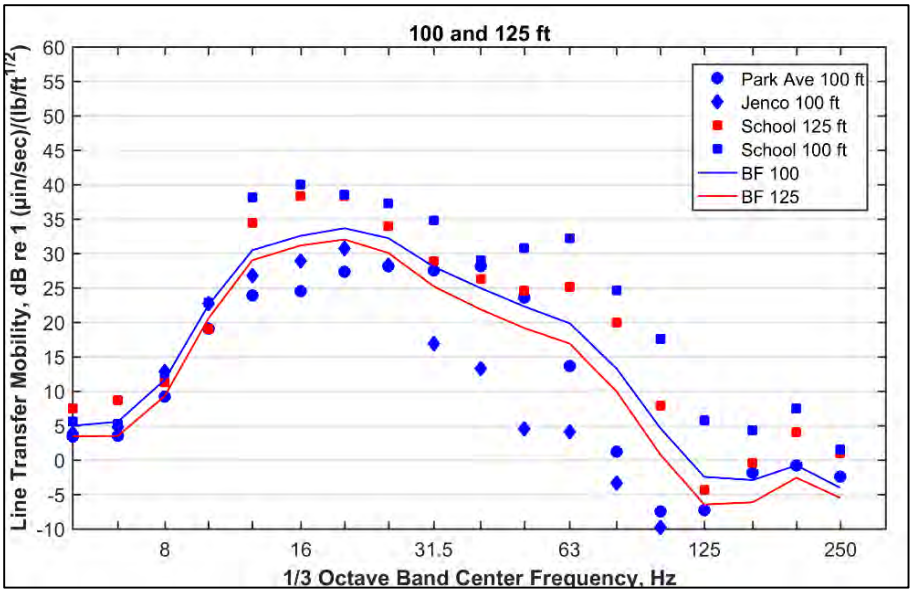
(Source: FTA, 2006)

Figure 4-2. Schematic of At-grade Vibration Propagation Test



For this assessment, the LSTM data from previous measurements that were made for the Portland-Milwaukie Light Rail Project were applied. The LSTM was measured at two sites in March 2008, and an additional five sites in July 2010 (South/North Transit Corridor Final EIS, 2010). The measurements included both indoor and outdoor accelerometer locations, but for this analysis only the outdoor accelerometer locations were considered. The data from the seven measurement sites were used to create a best-fit curve of LSTM-vs-log (distance) for each 1/3-octave band. The best-fit coefficients are shown on Figure 4-3.

Figure 4-3. Best-fit LSTM Lines at Different Distances: Supporting Data Shown for Reference



Key observations from the LSTM data are:

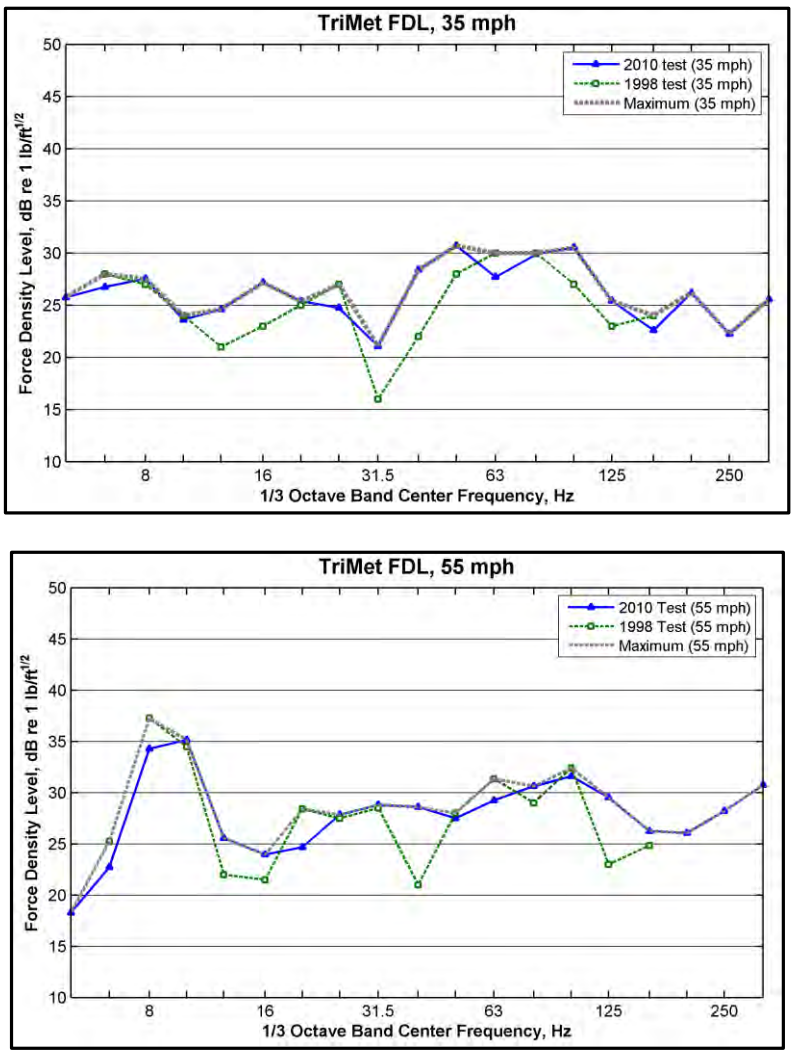
- The LSTM measured at the Portland Waldorf School preformed as part of the Milwaukie Light Rail project shows much higher LSTM levels than the other measurement sites.
- A +5-dB safety factor is included in the predictions to account for uncertainty, including the variations seen in the measured LSTM data.

- LSTM measurements should be completed in the project corridor for the Southwest Corridor Light Rail Project once a preferred alignment is selected in order to reduce the uncertainty in the prediction model.

4.2.2. Force Density Level

FDL is derived by measuring Lv and LSTM at a site where light rail is already in operation and calculating the FDL using the equation: Lv = FDL + LSTM. Previous FDL measurements by TriMet were performed in 1998 (South/North Corridor Project Draft EIS, 1998) and 2010 (South/North Corridor Project Final EIS, 2010). The 1998 measurements included embedded rail, and those results are used for the embedded rail predictions in this report. Both the 1998 and 2010 measurements included measurements on ballast and tie track. A comparison of the FDLs for ballast and tie track at two different speeds is shown in Figure 4-4.

Figure 4-4. TriMet-measured FDL at Different Speeds

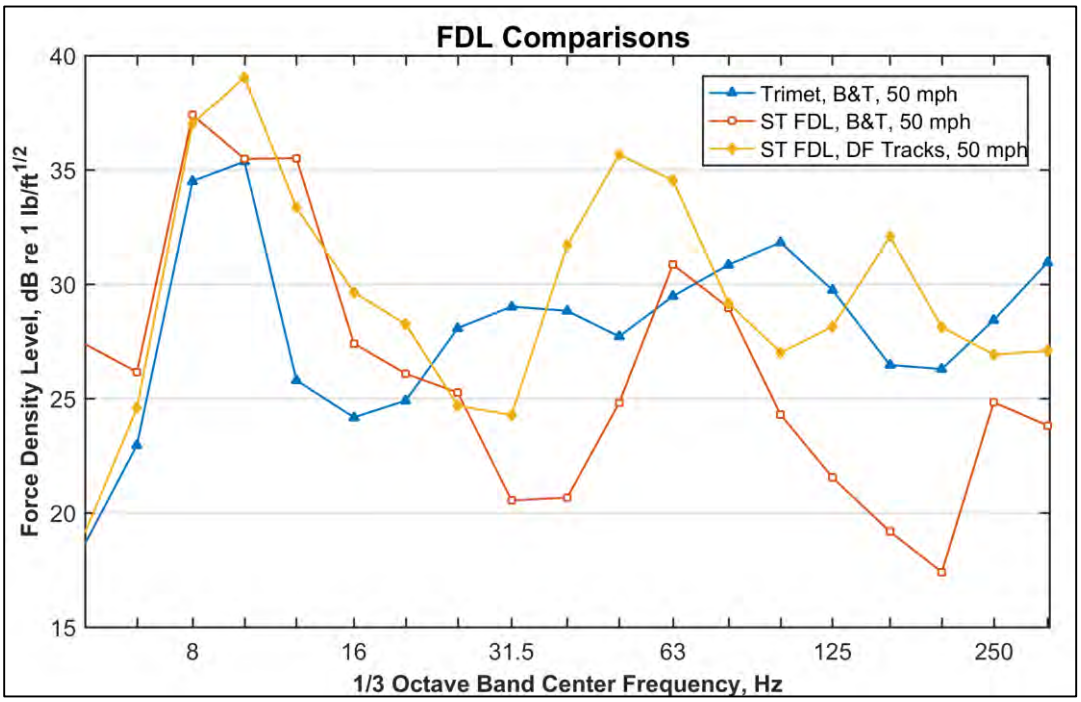


The 1998 and 2010 FDLs show similar trends, although the 2010 FDLs tend to be higher than the 1998 FDLs. The FDLs for comparable speeds are within 2 to 5 dB at most frequencies. The differences between the FDLs are likely a result of the different measurement sites and different track conditions.

A composite maximum FDL was determined by taking the maximum value at each frequency band for each speed. This composite maximum FDL has been used for the predictions for ballast and tie track presented in this report to ensure that predictions do not underestimate the vibration of passing trains.

There is no FDL data from TriMet for direct-fixation track. Data from Sound Transit in Seattle was used to calculate a correction factor between ballast and tie and direct-fixation track types. Direct-fixation track typically has a higher FDL than ballast and tie track. The difference between the Sound Transit direct-fixation and ballast and tie FDLs was added to the TriMet maximum ballast and tie data to estimate a direction-fixation FDL. A comparison of Sound Transit direct-fixation and ballast and tie FDLs to the TriMet ballast and tie FDL is shown in Figure 4-5.

Figure 4-5. Comparison of TriMet and Sound Transit FDLs for Ballast and Tie and Direct-fixation Track Types



Note: B&T = ballast and tie, ST = Sound Transit, DF = direct-fixation.

4.2.3. Model Adjustments for Lv Predictions

After determining the FDL and LSTM discussed in the previous sections, the following adjustments were incorporated into the prediction model to estimate vibration levels in occupied spaces of buildings:

- **Special Trackwork.** The additional vibration at special trackwork was accounted for by adding 10 dB to the predicted vibration levels when the special trackwork frog would be located less than 225 feet from a sensitive receiver.

- **Theoretical Coupling Loss and Floor Amplification.** For lightweight wood-frame structures, the *FTA Guidance Manual* suggests +6 dB for floor amplification and –2 dB per floor for floor-to-floor attenuation up to five floors above grade, as well as a –5 dB adjustment for coupling loss. Combining the adjustment factors for a wood-frame structure such as a residence, there is −5 dB for the coupling loss, +6 dB for floor amplification and an additional −1 to −2 dB for each floor above the grade level. This leads to a net adjustment of between –1 dB to +1 dB for the vibration inside a typical residence. Therefore, no adjustment is applied to account for coupling loss and floor amplification in the prediction model for small single-story residences. For larger buildings, the *FTA Guidance Manual* suggests up to a −10 dB coupling loss adjustment. At this time, detailed information on all buildings near the potential light rail alternatives alignments is not available, so no coupling loss is applied for larger buildings. This is a conservative assumption.

- **Safety Factor.:** It is not feasible to consider each receiver individually without additional measurements. A safety factor of +5 dB was added to each 1/3-octave band to account for uncertainties in the LSTM and building response. This is a conservative approach, ensuring that in most cases the predicted vibration levels are higher than what would occur after the project is operational.

- **Future Measurement Sites.** The data are also being used to develop a set of measurement locations for detailed propagation testing once the project moves forward with a preferred alternative.

5. AFFECTED ENVIRONMENT

This section summarizes existing land uses along the project corridor, as well as existing measured noise and estimates of existing vibration levels. The study area for the project was determined through a combination of on-site visits, review of aerial maps, and information from the project team. The study area included all noise- and vibration-sensitive properties that could have a noise or vibration impact from project operations. In general, the study used the FTA-recommended distance of 350 feet from the light rail alignment as a starting point for the study. Figure 5-1 shows the study area, along with the monitored noise levels discussed in Section 5.2 below.

5.1. Land Use

Details on the land use throughout the project corridor can be found in the Section 3.2 in Draft Environmental Impact Statement. A summary of the land use as related to the FTA criteria is provided by segment in the following sections.

5.1.1. Segment A Land Use

Land use in Segment A consists of single-family and multifamily residences, hotels (FTA Category 2), a school, park lands (FTA Category 3) and commercial uses that are not considered noise-sensitive under FTA criteria. At the northern end of Segment A, near the connection to the existing light rail system, Category 2 land use includes multifamily residences along SW Lincoln Street and two hotels. Under Alternative A1, the alignment continues along SW Barbur Boulevard, where land use includes residential, parks, commercial and some undeveloped lands. The portion of the Alternative A1 alignment along SW Barbur Boulevard from Interstate 405 (I-405) to the merge with Alternative A2 is mainly multifamily residential to the east of the alignment, and single-family residential to the west of the alignment. Also included in this area is the Cedarwood Waldorf School on SW 2nd Avenue and Lair Hill Park, which is between SW Hooker Street and SW Woods Street. The Congregation Ahavath Achim Synagogue is also located in this area, but it would be displaced under Alternative A1.

Under Alternative A2, land use includes a hotel and several multifamily apartments and condominiums north of I-405. The Helfgott Research Institute at the National University of Natural Medicine is located adjacent to Alternative A2 at 2220 SW 1st Avenue; although this site is not likely to be noise-sensitive, it may be sensitive to vibration. South of I-405 to the connection to Alternative A1 at SW Lane Street, land use is primarily residential, with several commercial businesses and a power substation. Schools near the Alternative A2 alignment include the International School on SW Sherman Street, the Cedarwood Waldorf School on SW 2nd Avenue, and the National University of Natural Medicine on SW Porter Street. The Heritage Tree Park is located south of SW Gaines Street, near the connection to SW Barbur Boulevard.

South of SW Lane Street, where Alternatives A1 and A2 merge, land use is the same for all Segment A alternatives. South of the merger, to SW Hamilton Street, land use includes single-family and multifamily residences and several commercial uses. South of SW Hamilton Street, noise-sensitive land uses include single-family and multifamily residential mixed in with several parks and open undeveloped spaces. The Tabernacle Seventh-day Adventist Church is adjacent to SW Barbur Boulevard on SW Condor Way, and nearby parks include the Marquam Nature Park, the Terwilliger Boulevard Parkway, and the George Himes City Park near the connection to Segment B.

5.1.2. Segment B Land Use

Land use in Segment B begins as residential, changing to commercial and mixed use along SW Barbur Boulevard. North of SW Terwilliger Boulevard, land use to the west of the alignment is primarily single-family residential. On the east side of the alignment, land use begins as single-family and transitions to multifamily residential closer to the SW Terwilliger Boulevard overpass. Other sensitive uses north of SW Terwilliger Boulevard include Fulton Park, Fulton Park Community Center and the PDX Church.

Land use varies between SW Terwilliger Boulevard and SW 26th Avenue, starting with commercial and transitioning to single-family and multifamily residential along the west side of the alignment, and mixed commercial and residential along the east side. There are several single-family and multifamily units located between SW Barbur Boulevard and I-5, including some that would be displaced under Alternative B4. Other noise-sensitive uses in this area include Burlingame Park and the Capitol Hill Elementary School, both of which are located east of I-5.

Between SW 26th Avenue and SW Capitol Highway, land use is primarily single-family and multifamily residential to the west of the alignment and commercial to the east. Other sensitive land use in this area includes Sumner College, Good Shepherd Lutheran Church, Little Lambs Preschool/Daycare, a nursing home and several hotels. East of I-5, land use is mainly residential with the exception of the Oregon Department of Transportation maintenance facility, located just northeast of the Barbur Transit Center. There are also several hotels in this part of the segment. Land use on the west side of I-5, near the elevated light rail crossing of I-5, is also mainly residential. The last portion of Segment B on the west side of I-5 includes single-family residences on SW 64th Avenue and all along the east side of I-5.

5.1.3. Segment C Land Use

Land use in Segment C near SW Baylor Street includes a group of single-family residences south of SW Atlanta Street and SW Dartmouth Street. Under Alternatives C1 and C2 and the Branched Configuration (Alternatives C5 and C6), the alignment will also be along a group of residences located east and west of SW 72nd Avenue, just north of SW Beveland Street. Westside Sleep Center is located on SW Beveland Street near the transition to the elevated section over OR-217. The only other residences in this area are a few single-family residences south of SW Beveland Street that are affected only under Alternatives C5 and C6.

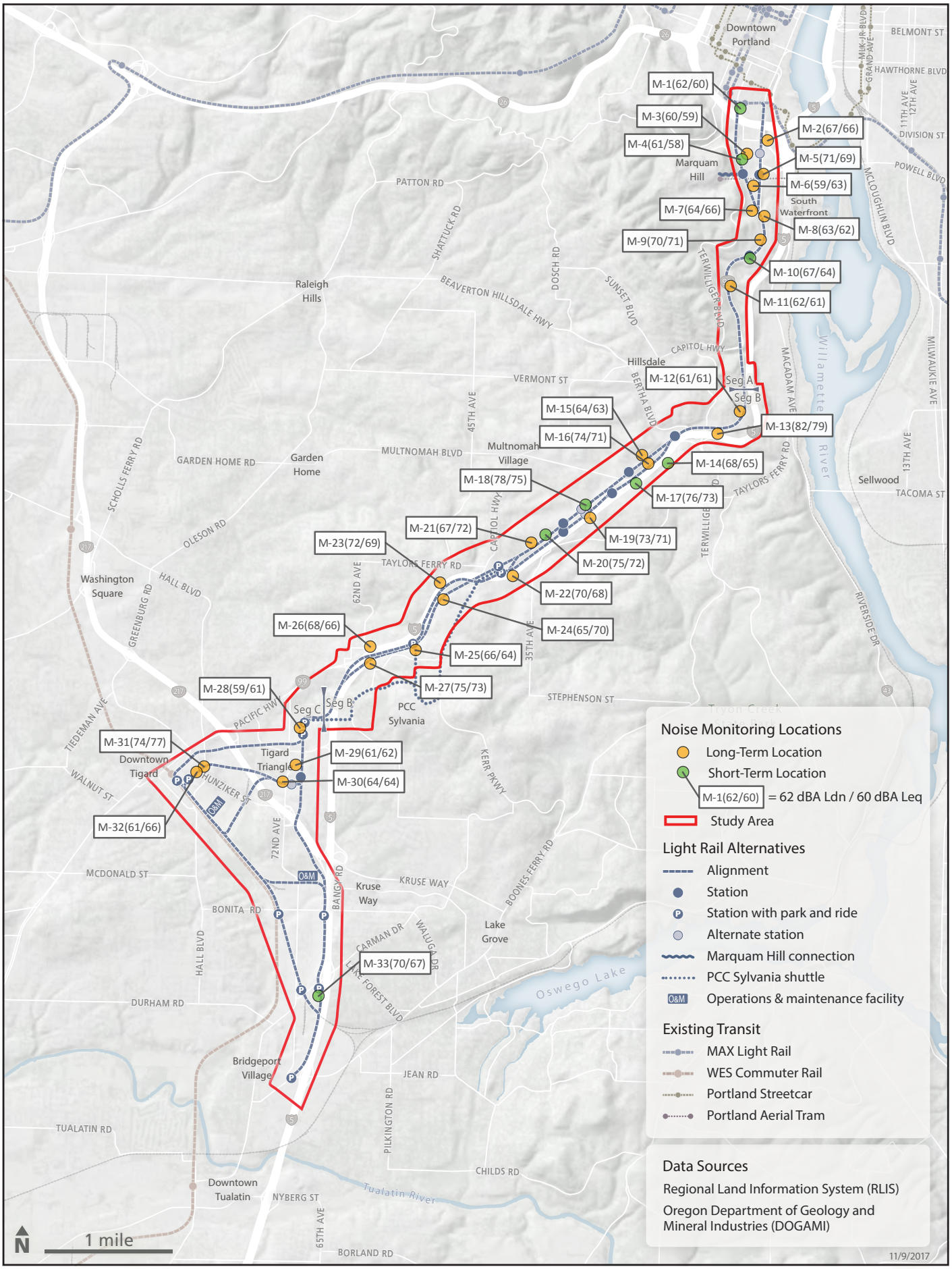
Land use west of OR-217, to the Westside Express Service (WES) Commuter Rail line, includes single-family and multifamily residences along SW Knoll Drive, SW Hall Boulevard, and in the downtown area along SW Ash Avenue, SW Scoffins Street, and SW Commercial Street. There is a manufactured home park between SW Commercial and SW Scoffins Streets, north of SW Ash Avenue. Other uses are commercial and light to heavy industrial.

The southern end of Segment C is primarily commercial and industrial for all of the alignment alternatives. Sensitive uses identified south of downtown Tigard for the Through Configuration and south of SW Hampton Street for the Branched Configuration include Courtyard by Marriott, Holiday Inn Express and Extended Stay America. Sensitive uses east of I-5 include Phoenix Inn Suites and some single-family residences and multifamily units that are more than 250 to 300 feet from the alignment on the opposite side of I-5.

5.2. Existing Ambient Noise Level Measurements

Noise measurements were taken at 33 selected locations along the project corridor. The 33 sites included 11 sites in Segment A, 16 sites in Segment B and 6 sites in Segment C. Eight of the 33 sites were short-term measurement sites with 30-minute measurements. The remaining 25 sites were long-term monitoring sites where measurements were taken for approximately 48 hours at each location. Monitoring site selection was based on several factors, including the site's ability to represent multiple noise-sensitive receivers in a specific area, to provide information on traffic noise levels, and to provide a detailed understanding of the existing noise levels throughout the project corridor. Using this measured data, standard acoustical propagation characteristics, area maps and local shielding, the measured noise levels were used to calculate and predict the Ldn noise levels for Category 2 uses and the peak-hour noise level in Leq for Category 3 land uses. Figure 5-1 provides a corridor-wide view, general study area, noise monitoring sites and measured noise levels. Noise measurement results are provided in the following sections, and detailed photos of each monitoring site are provided in Appendix A.

Figure 5-1. Noise Monitoring Sites



5.2.1. Segment A: Inner Portland Existing Noise Environment

The measured Ldn in Segment A ranged from 59 to 71 dBA, with the highest levels near I-5/I-405, the Ross Island Bridge and adjacent to SW Barbur Boulevard. Noise levels are dominated by traffic on the interstate highway and nearby major arterial roadways. Typical peak hourly Leq noise levels in Segment A ranged from 58 to 71 dBA. A summary of the measured noise levels for Segment A are provided in Table 5-1, and the sites are shown on the vicinity map in Figure 5-1.

The highest measured noise level in Segment A was at site M-5 on SW Water Avenue, close to the access roadways to the Ross Island Bridge, where the 24-hour Ldn was 71 dBA and the Leq was 69 dBA. Other sites with high noise levels include site M-2, also affected by the Ross Island Bridge traffic, and site M-9, on SW Bancroft Street adjacent to SW Barbur Boulevard. All other measurement sites have existing Ldn levels of 60 to 64 dBA, which is typical for a dense urban area.

Table 5-1. Segment A Measured Noise Levels

Site Number[1]	Address[1]	FTA Land Use Category[2]	Type[3]	Ldn[4] (dBA)	Leq[5] (dBA)
Segment A: Inner Portland					
M-1	310 SW Lincoln St. (University Hotel)	Cat 2	Short-Term	62	60
M-2	2637 SW Water Ave.	Cat 2	Long-Term	67	66
M-3	2909 SW 2nd Ave.	Cat 2	Long-Term	60	59
M-4	3037 SW 2nd Ave. (Lair Hill Park)	Cat 3	Short-Term	61	58
M-5	3213 SW Water Ave.	Cat 2	Long-Term	71	69
M-6	3404 SW 1st Ave.	Cat 2	Long-Term	59	63
M-7	SW Condor Way at SW Lane St.	Cat 2	Long-Term	64	66
M-8	3840 SW Water Ave.	Cat 2	Long-Term	63	62
M-9	015 SW Bancroft St.	Cat 2	Long-Term	70	71
M-10	26 SW Condor Way (Church)	Cat 3	Short-Term	67	64
M-11	5055 SW Slavin Rd.	Cat 2	Long-Term	62	61

[1] Sites for Segment A are shown on Figure 5-1.
[2] The FTA Land Use Categories are described in Section 3.1.
[3] Type of measurement: Short-term measurements are 30 minutes and long-term monitoring/measurements are approximately 48 hours.
[4] The Ldn is used for FTA Category 2 land use and is a 24-hour Leq with the 10 dB penalty for nighttime noise between 10 p.m. and 7 a.m.
[5] Peak-hour Leq.

5.2.2. Segment B: Outer Portland Existing Noise Environment

Noise levels in Segment B are dominated by traffic on I-5 and SW Barbur Boulevard, and were notably higher than those in many locations in Segment A because of the proximity of many monitoring sites and noise-sensitive properties to I-5 and SW Barbur Boulevard. The Ldn noise levels in this segment ranged from 61 dBA to 82 dBA Ldn, and peak hourly Leq ranged from 61 dBA to 79 dBA Leq. A summary of the measured noise levels for Segment B are provided in Table 5-2, and the sites are shown on the vicinity map in Figure 5-1.

Noise levels in the residential area west of SW Barbur Boulevard at the start of Segment B were measured at the dead end of SW Nevada Street, just west of SW Barbur Boulevard (site M-12). Because topographical conditions shield these homes from traffic noise, the Ldn was only 61 dBA and was the lowest measured Ldn in Segment B. The highest level in Segment B, which was also the highest level

measured along the entire corridor, was measured at site M-13, which is located adjacent to I-5 near SW Terwilliger Boulevard.

For the alternatives along SW Barbur Boulevard, noise levels for receivers near the roadway range from 75 dBA to 78 dBA Ldn. Noise levels at receivers with some structural shielding from the roadway ranged from 67 dBA to 64 dBA Ldn. Along the I-5 alignments, noise levels ranged from 78 dBA to 74 dBA Ldn. The noise level at Burlingame Park (site M-14) was 65 dBA Leq, and noise levels near the elevated alignments over I-5 up to the connection to Segment C ranged from 68 dBA to 75 dBA Ldn. The measured Leq noise level at Capitol Hill Elementary School was 73 dBA at 12:30 p.m.

Table 5-2. Segment B Measured Noise Levels

Site Number[1]	Address[1]	FTA Land Use Category[2]	Type[3]	Ldn[4] (dBA)	Leq[5] (dBA)
Segment B: Outer Portland					
M-12	110 SW Nevada St.	Cat 2	Long-Term	61	61
M-13	7436 SW 5th Ave.	Cat 2	Long-Term	82	79
M-14	SW Falcon St. at SW 11th Ave. (Burlingame Park)	Cat 3	Short-Term	68	65
M-15	1705 SW Moss St.	Cat 2	Long-Term	64	63
M-16	1624 SW Evans S.t	Cat 2	Long-Term	74	71
M-17	Capitol Hill Elementary School	Cat 3	Short-Term	76	73
M-18	8715 SW Barbur Blvd. (Budget Lodge)	Cat 2	Long-Term	78	75
M-19	8928 SW 26th Ave.	Cat 2	Long-Term	73	71
M-20	3405 SW Alice St. (Church)	Cat 3	Short-Term	75	72
M-21	9347 SW 35th Ave.	Cat 2	Long-Term	67	72
M-22	3724 SW Evelyn St.	Cat 2	Long-Term	70	68
M-23	10030 SW 49th Ct.	Cat 2	Long-Term	72	69
M-24	4735 SW Luradel St.	Cat 2	Long-Term	65	70
M-25	11133 SW 53rd Ave.	Cat 2	Long-Term	66	64
M-26	11048 SW 60th Ave.	Cat 2	Long-Term	68	66
M-27	11394 SW Barbur Blvd.	Cat 2	Long-Term	75	73

[1] Sites for Segment B are shown on Figure 5-1.

[2] FTA Land Use Categories are described in Section 3.1.

[3] Type of measurement: Short-term measurements are 30 minutes and long-term monitoring/measurements are approximately 48 hours.

[4] The Ldn is used for FTA Category 2 land use and is a 24-hour Leq with the 10 dB penalty for nighttime noise between 10 p.m. and 7 a.m.

[5] Peak hour Leq.

5.2.3. Segment C: Tigard and Tualatin Existing Noise Environment

Overall, noise levels in Segment C ranged from 59 dBA to 74 dBA, with the higher noise levels at hotels near I-5 and along SW Hall Boulevard near the Tigard City Center. The typical daytime Leq noise levels ranged from 54 dBA to 77 dBA Leq. A summary of the measured noise levels for Segment C is provided in Table 5-3, and the sites are shown on the vicinity map in Figure 5-1.

Noise levels were lowest near the connection to Segment B near SW Baylor Street and SW Elmhurst Street, where the Ldn ranged from 59 dBA to 61 dBA. The Ldn was slightly higher near SW 72nd Avenue, at 64 dBA. Noise levels along SW Hall Boulevard (site M-31) were the highest, with an Ldn of 74 dBA, while noise levels were lower near the residences along SW Ash Avenue and SW Scoffins

Street, with an Ldn of 61 dBA (site M-32). In the southern end of the segment, the alignments are either in industrial areas or along I-5, where the Ldn was 70 dBA.

Table 5-3. Segment C Measured Noise Levels

Site Number[1]	Address[1]	FTA Land Use[2]	Type[3]	Ldn[4] (dBA)	Leq[5] (dBA)
Segment C: Tigard and Tualatin					
M-28	7040 SW Baylor St.	Cat 2	Long-Term	59	61
M-29	7105 SW Elmhurst St.	Cat 2	Long-Term	61	62
M-30	12465 SW 72nd Ave.	Cat 2	Long-Term	64	64
M-31	12280 SW Hall Blvd.	Cat 2	Long-Term	74	77
M-32	SW Scoffins St. at SW Ash Ave.	Cat 2	Long-Term	61	66
M-33	15700 SW Upper Boones Ferry Rd.	Cat 2	Short-Term	70	67

[1] Sites for Segment C are shown on Figure 5-1.

[2] FTA Land Use Categories are described in Section 3.1.

[3] Type of measurement: Short-term measurements are 30 minutes and long-term monitoring/measurements are approximately 48 hours.

[4] The Ldn is used for FTA Category 2 land use and is a 24-hour Leq with the 10 dB penalty for nighttime noise between 10 p.m. and 7 a.m.

[5] Peak-hour Leq.

5.3. Vibration

Existing vibration levels along the potential light rail alternatives alignments are dominated primarily by heavy truck traffic on public roadways. Typical vibration levels for these vehicles range from 45 VdB for smooth roadways to 65 VdB for rough roadways or roads with large potholes. There are two locations in the project corridor where rail traffic is likely the dominant vibration source. First, in Segment A, along SW Lincoln Street, the existing light rail would be a major source of vibration; however, testing has shown that vibration levels in nearby residences are below the 72 VdB criterion. The second location with rail traffic is near the Tigard City Center, where the WES Commuter Rail service runs. Vibration levels from heavy rail, such as the WES, could produce short-term maximum vibration levels above 72 VdB for sites located near the tracks.

For this analysis, the measured data from a previous TriMet project were used for vibration projections. To ensure that all potential vibration impacts were identified, a +5 VdB safety factor was included in the analysis. As the project moves forward, additional vibration testing will be performed at select sites identified through this analysis in order to verify vibration impacts and aid in the design of vibration mitigation measures. Information on the measured vibration data used in this analysis was provided in Section 3.4, Vibration and Groundborne Noise Impact Criteria.

6. NOISE IMPACT ANALYSIS

This section summarizes and identifies locations where noise levels are predicted to exceed the FTA impact criteria. Noise sources in this analysis include light rail operational noise, station noise, and noise from maintenance facilities and other ancillary facility operations. Additional information on the technical assessment of impacts, including maps of all impacts, are provided in Appendices B and C.

6.1. No-Build Alternative

With the No-Build Alternative, noise levels in the project corridor would continue to be dominated by transportation-related noise sources other than light rail, including cars, trucks and, in Tigard, the WES Commuter Rail. Other noise sources could include miscellaneous industrial activities, commercial activities and local construction projects. With the N-Build Alternative, there would be no light rail project and therefore no light rail-related noise.

6.2. Full Corridor

Table 6-1 summarizes the projected full-corridor noise impacts for the Through Configuration routes and provides a range of impacts for various alignment alternatives. Total noise impacts for a baseline full-corridor set of alternatives were predicted using Alternatives A1, B2 and C1. Two additional full-corridor noise impact summaries were projected using alternatives to provide the minimum and maximum number of potential noise impacts.

Table 6-1. Summary of Potential Full-corridor Noise Impacts for Through Configuration Routes

Light Rail Alternatives Combined	Moderate Noise	Severe Noise	Total Noise Impacts
Baseline Full-corridor Through: A1, B2 and C1			
A1: Barbur	293	5	298
B2: I-5 Barbur TC-60th	49	0	49
C1: Ash-I-5	72	15	87
Baseline Full-corridor Total	**414**	**20**	**434**
Full-corridor Through Fewest Noise Impacts: A2-LA, B3 and C3/C4			
A2-LA: Naito Limited Access	173	1	174
B3: I-5 26th-60th	44	0	44
C3: Clinton-I-5/ C4: Clinton-Railroad	12	0	12
Full-corridor Fewest Total	**229**	**1**	**230**
Full-corridor Through Greatest Noise Impacts: A1, B4 and C1/C2			
A1: Barbur	293	5	298
B4: I-5 Custer-60th	80	0	80
C1: Ash-I-5/C2: Ash-Railroad	72	15	87
Full-corridor Greatest Total	**445**	**20**	**465**

Source: FTA noise modeling.

Table 6-2 is similar to Table 6-1, except the full-corridor alternatives are for the Branched Configuration routes. The increased number of impacts in Segments A and B dominate the total impacts under the Branched Configuration. Details on impacts by segment are provided in the following sections.

Table 6-2. Summary of Potential Full-corridor Noise Impacts for Branched Configuration Routes

Light Rail Alternatives Combined	Moderate Noise	Severe Noise	Total Noise Impacts
Full-corridor Branched Fewest Noise Impacts: A2-BH, B3 and C6			
A2-BH: Naito Bridgehead	188	4	192
B3: I-5 26th-60th	98	1	99
C6: Wall and I-5 Branched	37	3	40
Full-corridor Fewest Total	**323**	**8**	**331**
Full-corridor Branched Greatest Noise Impacts: A1, B1 and C5			
A1: Barbur	353	8	361
B4: I-5 Custer-60th	147	1	148
C5: Ash and I-5 Branched	38	12	50
Full-corridor Greatest Total	**538**	**21**	**559**

Source: FTA noise modeling.

6.3. Light Rail Alternatives (by Segment)

This section provides a summary of the number of predicted noise impacts from each of the light rail alternatives without mitigation. There were more than 1,400 units evaluated for noise impacts. Each unit represents an individual single-family residence, apartment or condominium, or hotel room in the case of residences, or buildings in the case of schools, churches or hospitals. The actual number of units evaluated could vary slightly based on alternative and design options because of the large number of multifamily apartments, condominiums and hotel rooms, range of alignments and varying displacements.

Finally, even though the light rail alignments in Segments A and B are identical under the Through and Branched configurations, the number of noise impacts with the Branched Configuration is greater. The increase in the number and severity of noise impacts is due to the increased headways during off-peak hours required to maintain service levels south of the Beveland Station. Details on the headways for the Through and Branched Configurations are provided in Section 4.1.1. Appendix B has complete tables of the noise analysis, including addresses, land use, existing noise levels, FTA criteria and project noise levels.

6.3.1. Segment A: Inner Portland

Alternative A1 in Segment A has the highest level of noise impacts of all alignment alternatives in all segments because of the large number of multifamily units along SW Barbur Boulevard. Table 6-3 provides a summary by alternative for the Through and Branched configurations in Segment A. Figures 6-1 through 6-6 show the light rail alignment and the location of impacts for each alternative under the Through and Branched configurations.

Table 6-3. Summary of Segment A Noise Impacts

Alternative and Configuration	Moderate Noise	Severe Noise	Total Noise Impacts
Through Configuration Noise Impacts			
A1: Barbur (Fig. 6-1)	293	5	298
A2-BH: Naito Bridgehead (Fig. 6-2)	179	1	180
A2-LA: Naito Limited Access (Fig. 6-3)	173	1	174
Branched Configuration Noise Impacts			
A1: Barbur (Fig. 6-4)	353	8	361
A2-BH: Naito Bridgehead (Fig. 6-5)	188	4	192
A2-LA: Naito Limited Access (Fig. 6-6)	195	4	199

Source: FTA noise modeling.

In the northern end of the alignment, moderate noise impacts occur under Alternative A1 along the entire segment from the downtown connection to the connection to Segment B. Impacts were identified at several rooms at the University Place Hotel & Conference Center because of a nearby crossover. Impacts were also identified along both side of SW Barbur Boulevard from the crossing of I-405 continuing to SW Hamilton Street.

Under Alternative A2, noise impacts at the northern begin along SW Naito Parkway just south of SW Kelly Avenue, and occur along the alignment at many receivers directly adjacent to the corridor to the connection with Alternative A1 near SW Abernethy Street. Light-rail-related impacts are slightly higher under Alternative A2-BH, because it would have fewer displacements along SW Naito Parkway between SW Hooker Street and SW Curry Street.

South of SW Hamilton Street, Alternatives A1 and A2 have the same impacts, with moderate impacts occurring at several multifamily units and a group of single-family residences located at the connection to Segment B along SW 2nd Avenue.

Severe noise impacts in Segment A include four units near SW Condor Avenue and SW Pennoyer Street under Alternative A1 only. An additional severe impact was also identified under Alternatives A1 and A2 on SW Hamilton Street at SW Barbur Boulevard. All other noise impacts in Segment A were in the moderate category.

Marquam Hill Connection Options

None of the Marquam Hill connection options are predicted to have any long-term noise impacts. It is assumed that any elevator systems will be installed such that drive motors and ancillary operating equipment will be contained in housings and will not cause any noise impacts.

Figure 6-1. A1: Barbur Noise Impacts, Through Configuration

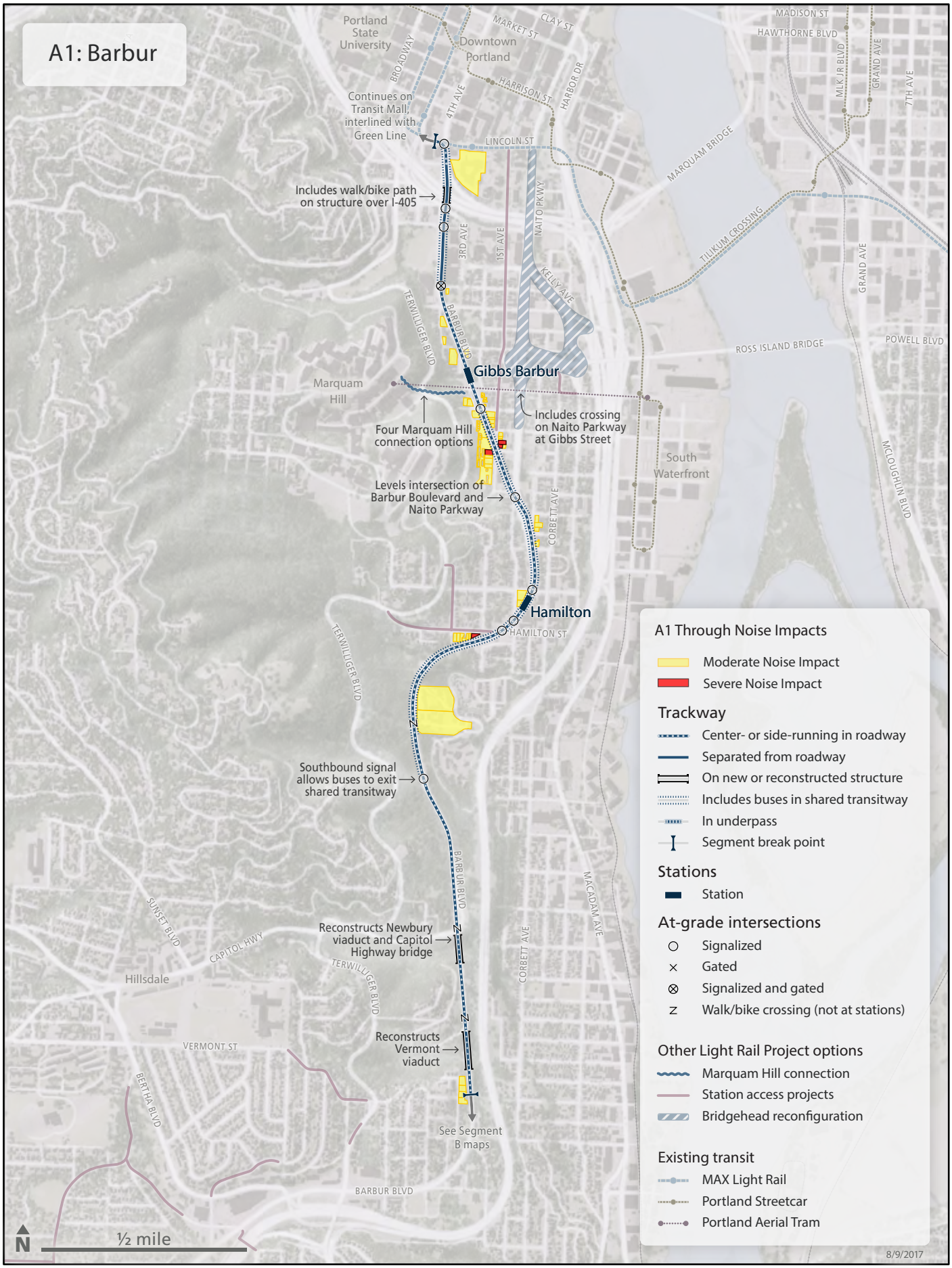


Figure 6-2. A2-BH: Naito with Bridgehead Reconfiguration Noise Impacts, Through Configuration

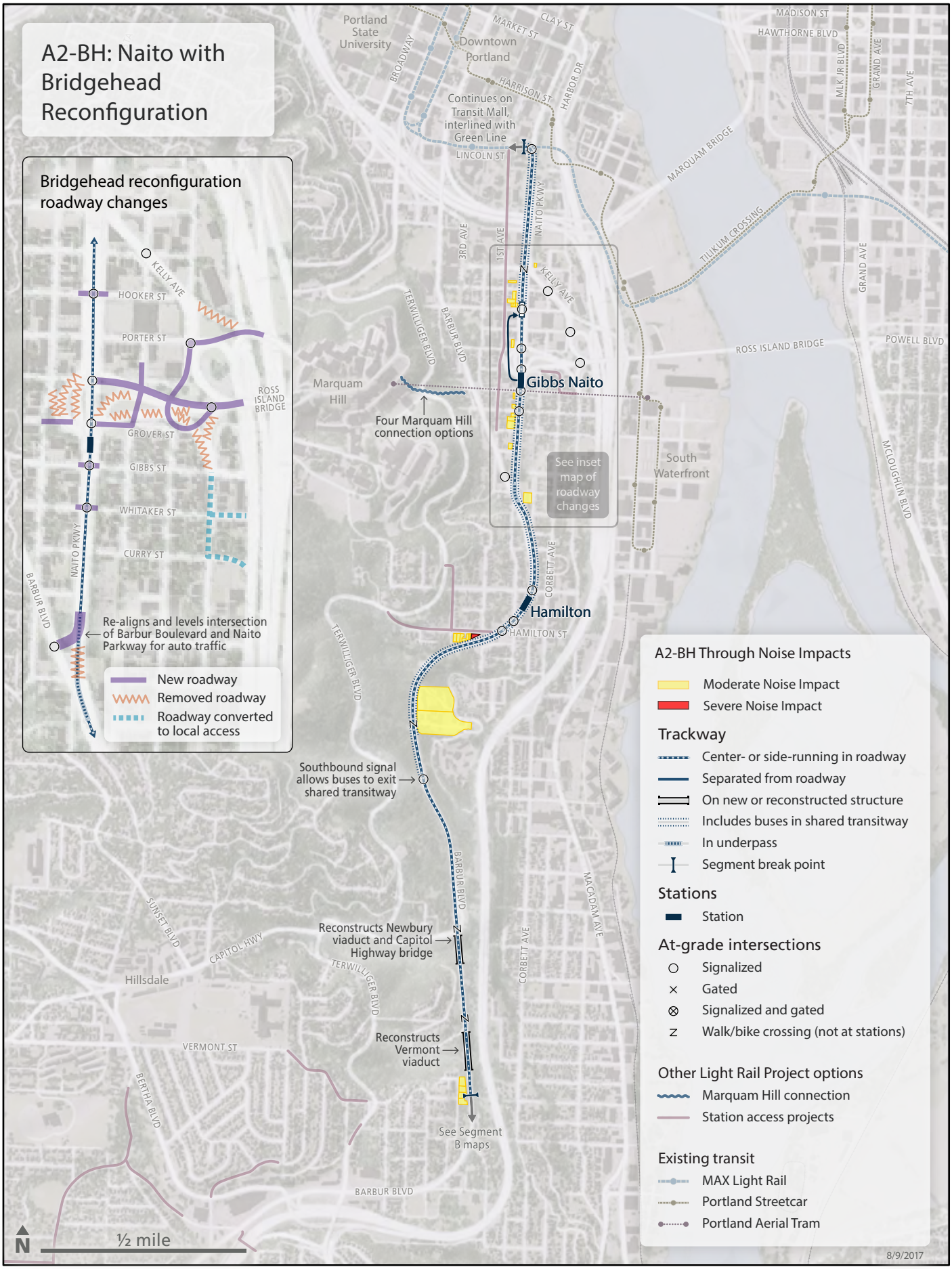


Figure 6-3. A2-LA: Naito with Limited Access Noise Impacts, Through Configuration

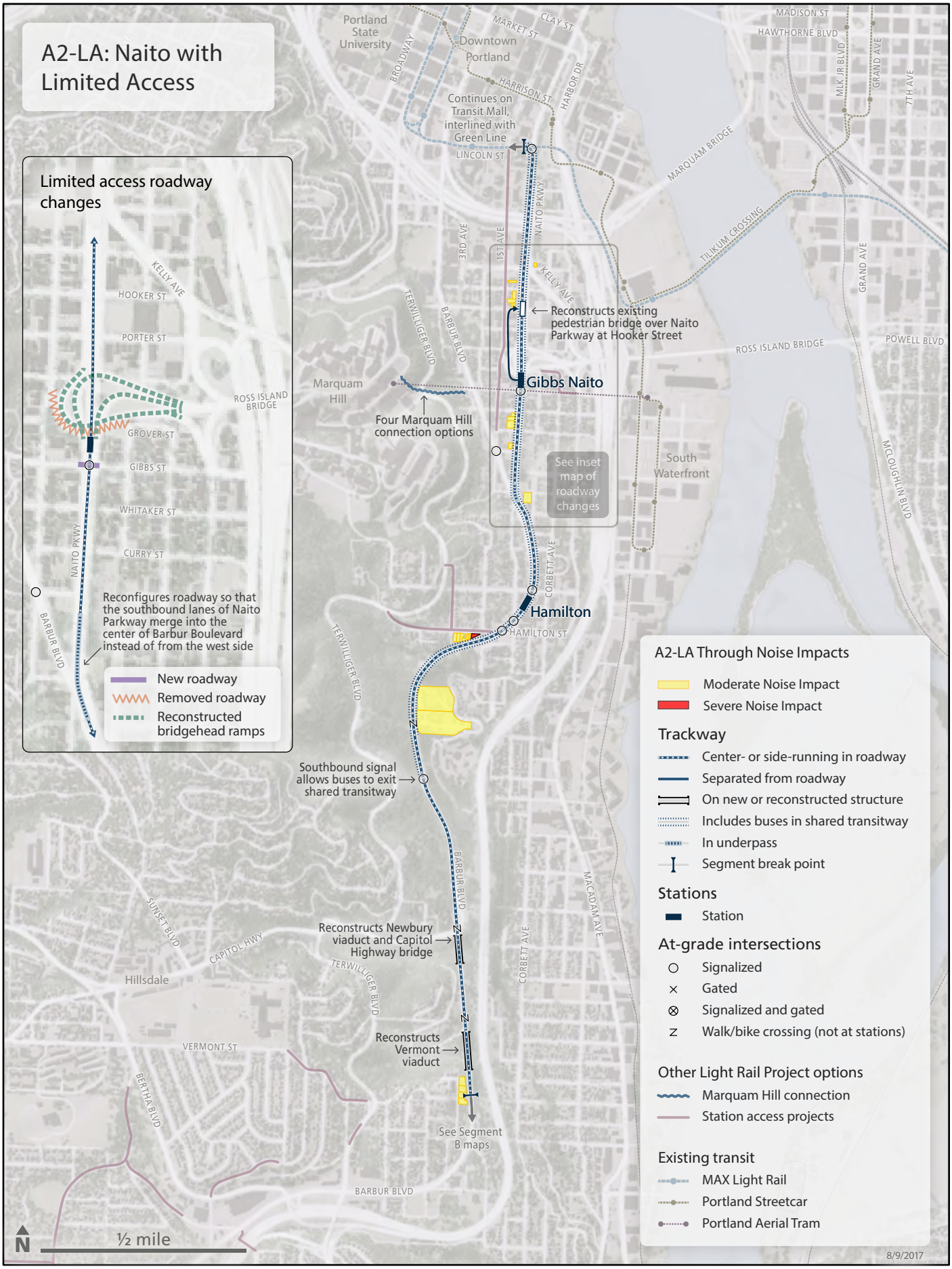


Figure 6-4. A1: Barbur Noise Impacts, Branched Configuration

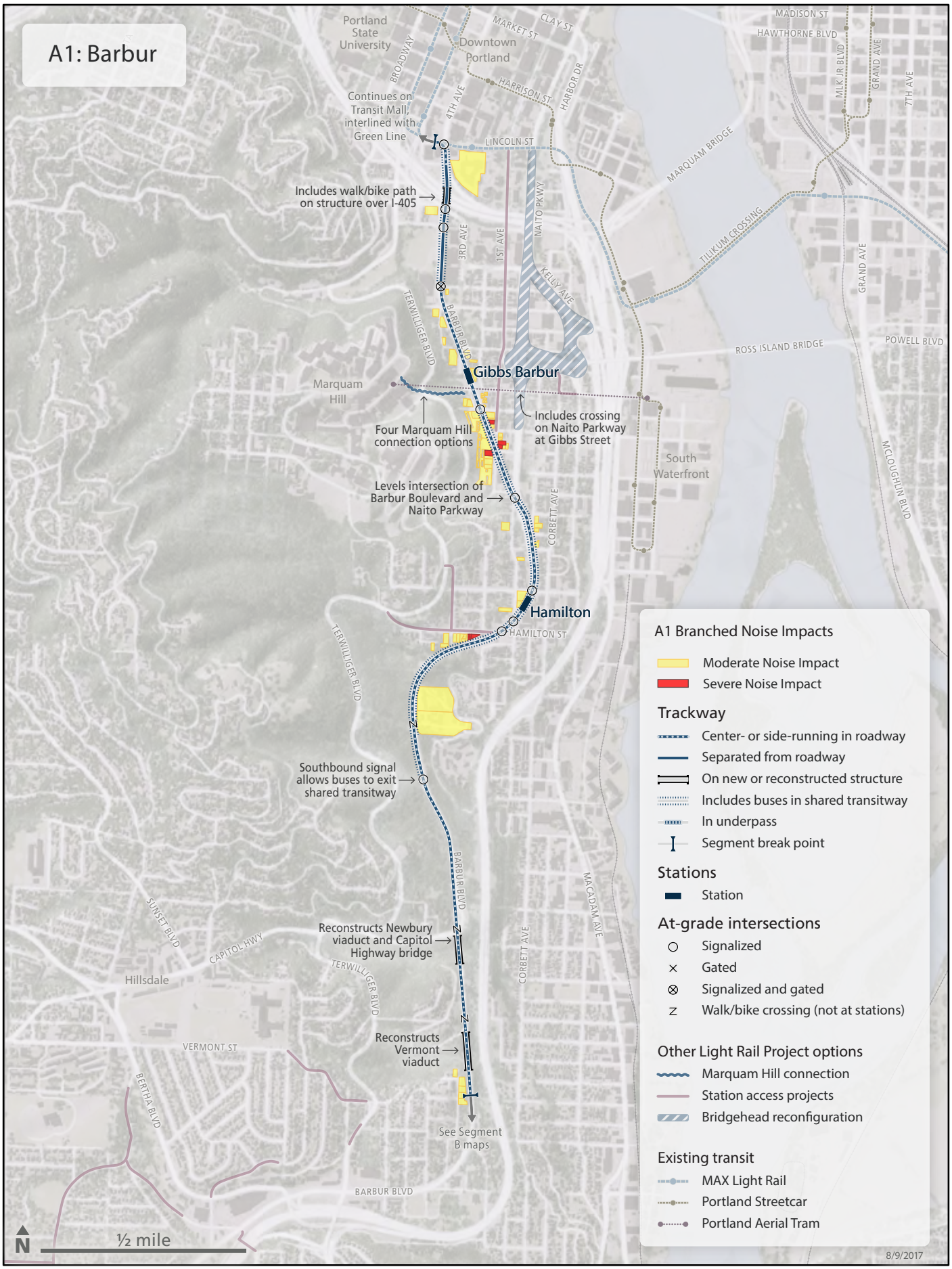


Figure 6-5. A2-BH: Naito with Bridgehead Reconfiguration Noise Impacts, Branched Configuration

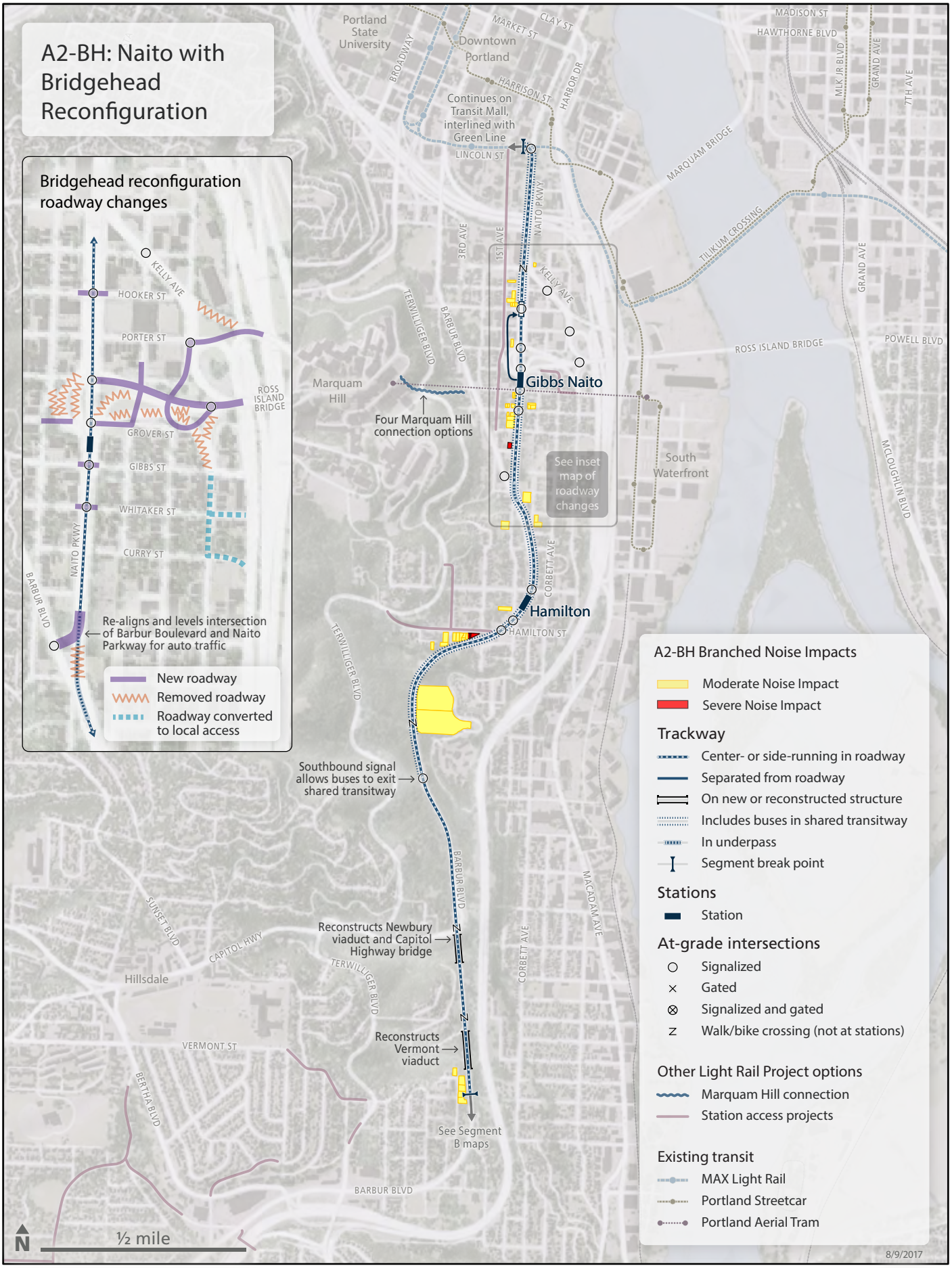
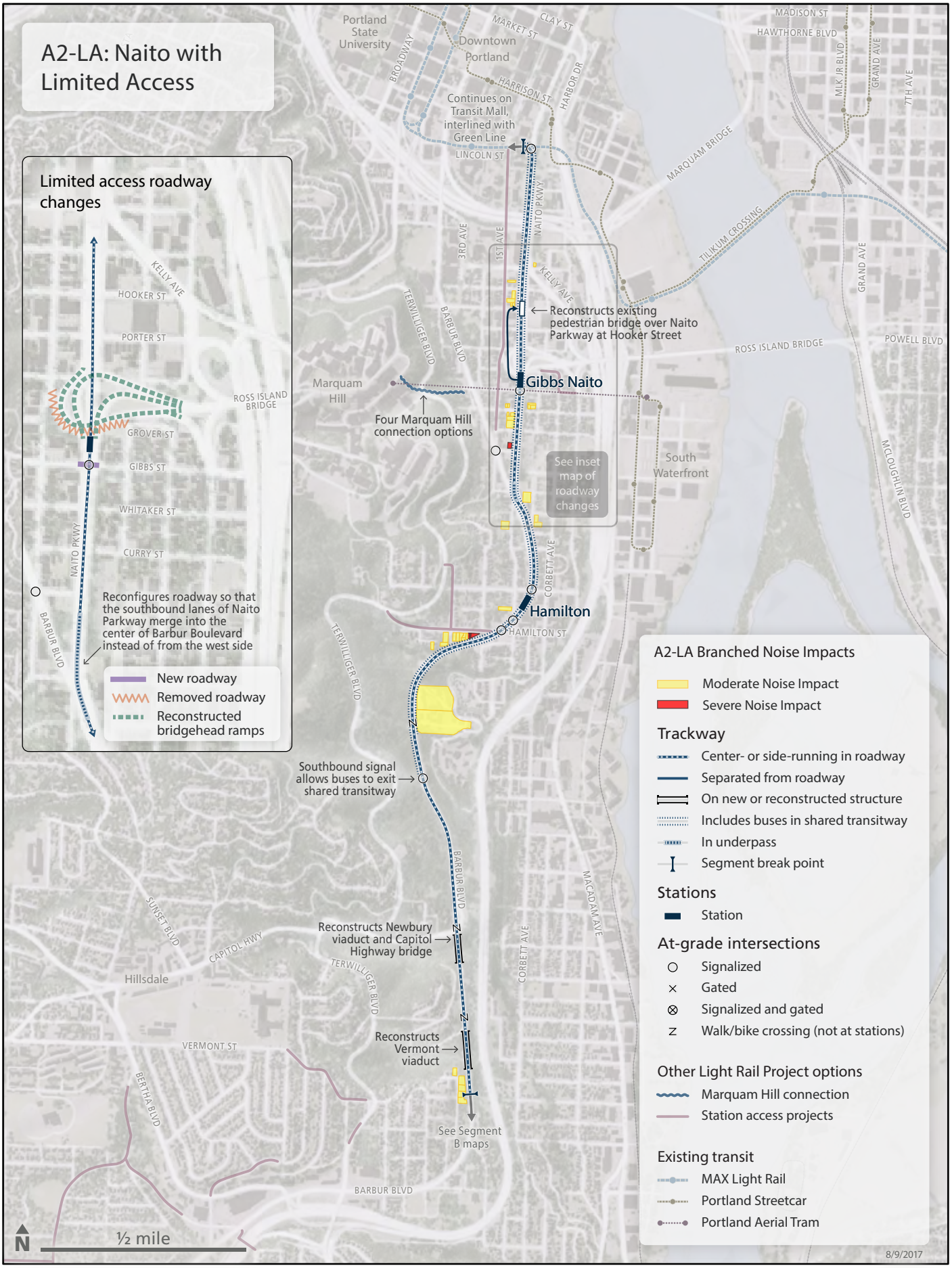


Figure 6-6. A2-LA: Naito with Limited Access Noise Impacts, Branched Configuration



6.3.2. Segment B: Outer Portland

Segment B also has a large number of multifamily residences, with many located adjacent to the alignment. As in Segment A, the increased light rail operations during off-peak hours results in increased impacts under the Branched Configuration. Table 6-4 provides a summary of the impacts by alternative in Segment B. Figures 6-7 through 6-14 show the light rail alignment and the location of impacts for each alternative under the Through and Branched configurations.

Table 6-4. Summary of Segment B Noise Impacts

Alternative and Configuration	Moderate Noise	Severe Noise	Total Noise Impacts
Through Configuration Noise Impacts			
B1: Barbur (Fig. 6-7)	55	0	55
B2: I-5 Barbur TC-60th (Fig. 6-8)	49	0	49
B3: I-5 26th-60th (Fig. 6-9)	44	0	44
B4: I-5 Custer-60th (Fig. 6-10)	80	0	80
Branched Configuration Noise Impacts			
B1: Barbur (Fig. 6-11)	147	1	148
B2: I-5 Barbur TC-60th (Fig. 6-12)	115	1	116
B3: I-5 26th-60th (Fig. 6-13)	98	1	99
B4: I-5 Custer-60th (Fig. 6-14)	140	1	141

Source: FTA noise modeling.

All four of the Segment B alternatives are the same from the connection to Segment A to just south of SW Terwilliger Boulevard. Moderate noise impacts were identified starting at the connection to Segment A at homes along SW 2nd Avenue.

Under Alternative B1, there are only a few additional impacts at multifamily units south of SW Terwilliger Boulevard and north of the Barbur Transit Center. The remaining noise impacts under Alternative B1 occur along the section where the alignment crosses over I-5 on an elevated structure to connect to Segment C. There are no severe impacts under Alternative B1.

Noise impacts under Alternative B2 are the same as under Alternative B1 north of the Barbur Transit Center. South of the Barbur Transit Center, where the alignment crosses over I-5 on a structure, there are several moderate impacts at homes located along SW Wilbur Street, east of I-5. Alternative B2 noise impacts also occur at homes adjacent to a crossover near SW 55th Avenue and at multifamily residences located west of I-5 at the alignment just before the connection to Segment C. There are no severe impacts under Alternative B2.

Noise impacts under Alternative B3 are similar to those under Alternative B2, although some impacts that occur near SW 26th Way under Alternative B2 do not occur under Alternative B3 because of the transition of the alignment over to I-5. Conversely, under Alternative B3 additional noise impacts were identified at select rooms at the Capitol Hill Hotel, which is displaced under Alternatives B1 and B2. South of the Barbur Transit Center, noise impacts are the same as under Alternative B2. As with Alternative B2, there are no severe impacts under Alternative B3.

Alternative B4 has the most impacts of the Segment B alignment alternatives because of the increased speed of the light rail vehicles and the proximity to residences along the alignment from SW Terwilliger

Boulevard to the Barbur Transit Center. The majority of the additional Alternative B4 impacts occur in the part of the alignment where it transitions to I-5 from SW Barbur Boulevard south of the Custer Station and north of the Capitol Hill Hotel. In addition to impacts at the hotel, moderate noise impacts were also identified at several single-family and multifamily residences along SW Hume Street, SW Troy Street, SW Moss Street and SW Evens Street. Even though these locations have high existing noise levels from traffic on I-5, the elevated alignment and high speed results in multiple moderate noise impacts in this area. South of the Barbur Transit Center, impacts under Alternative B4 are the same as under Alternative B2. As with the other Segment B alternatives, there are no severe impacts under Alternative B4.

Figure 6-7. B1: Barbur Noise Impacts, Through Configuration

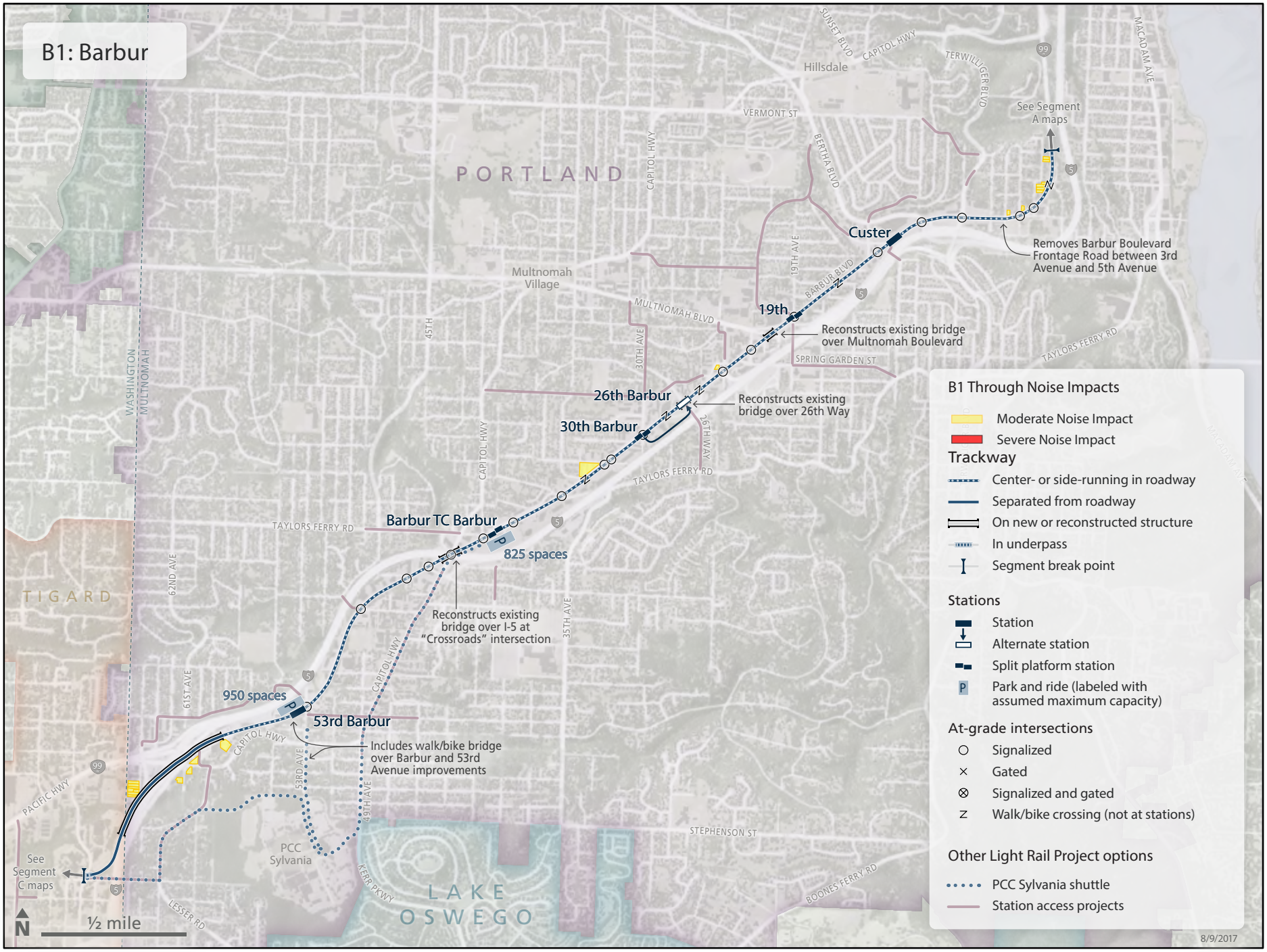


Figure 6-8. B2: I-5 Barbur TC to 60th Noise Impacts, Through Configuration

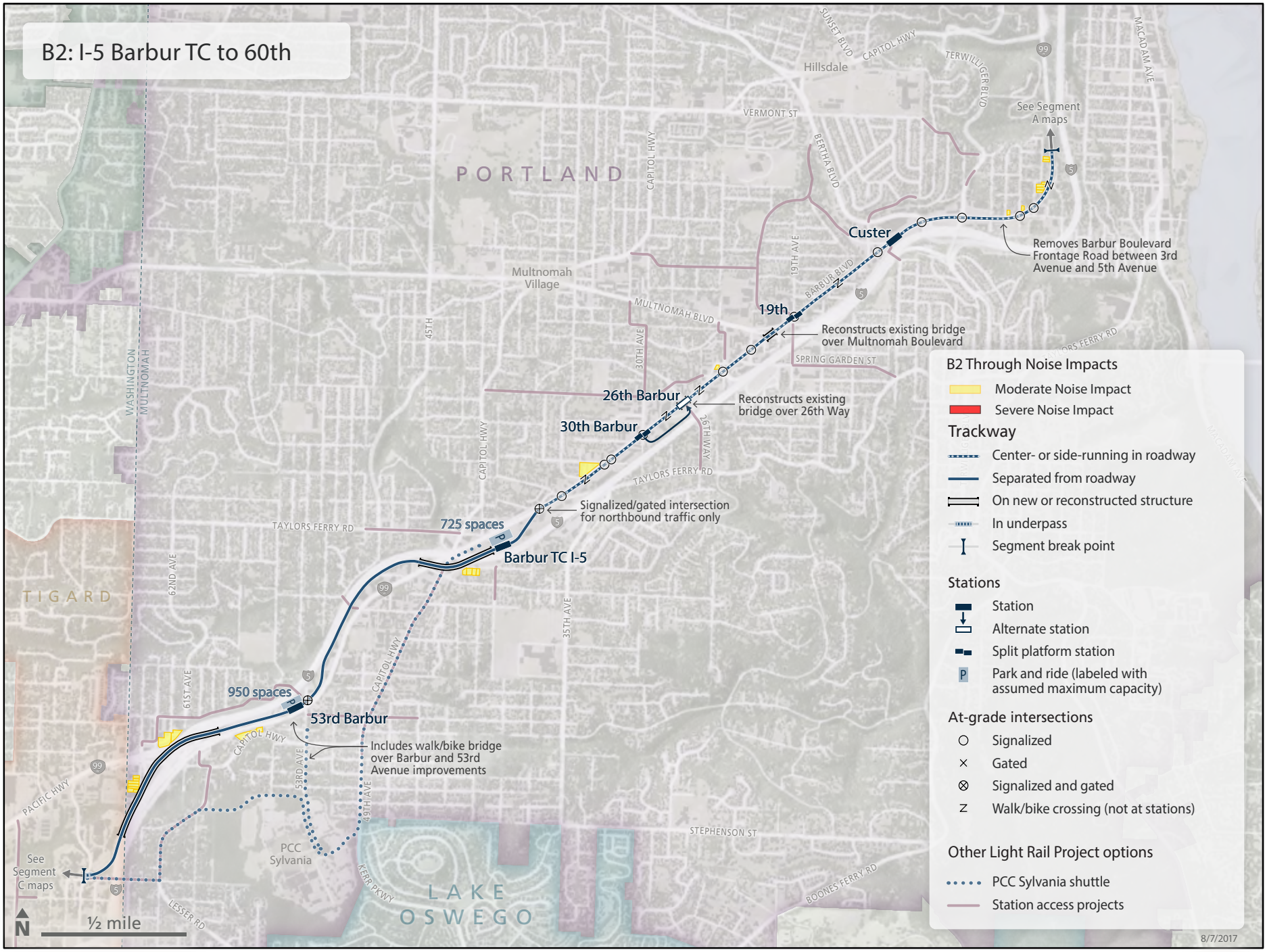


Figure 6-9. B3: I-5 26th to 60th Noise Impacts, Through Configuration

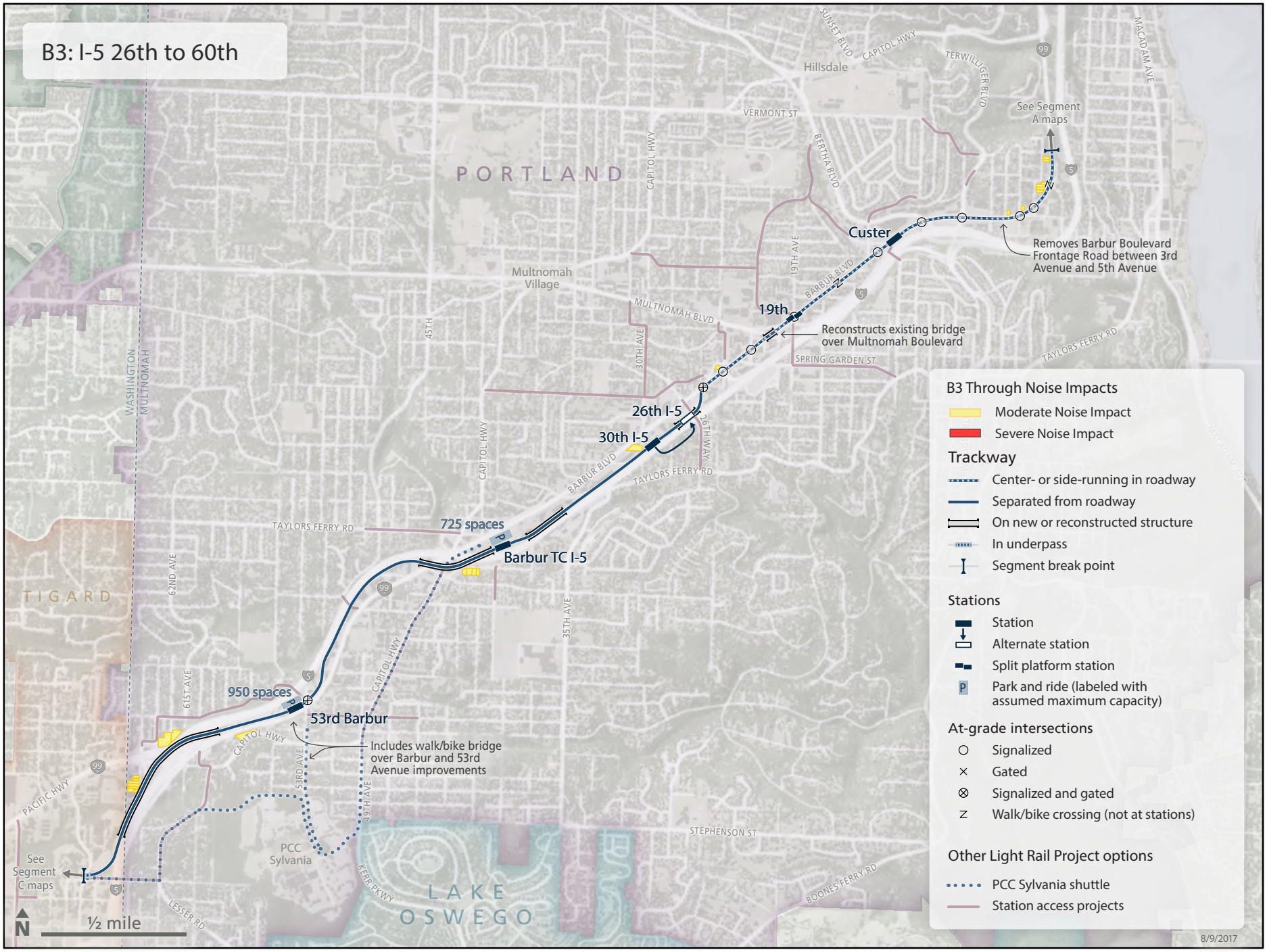


Figure 6-10. B4: I-5 Custer to 60th Noise Impacts, Through Configuration

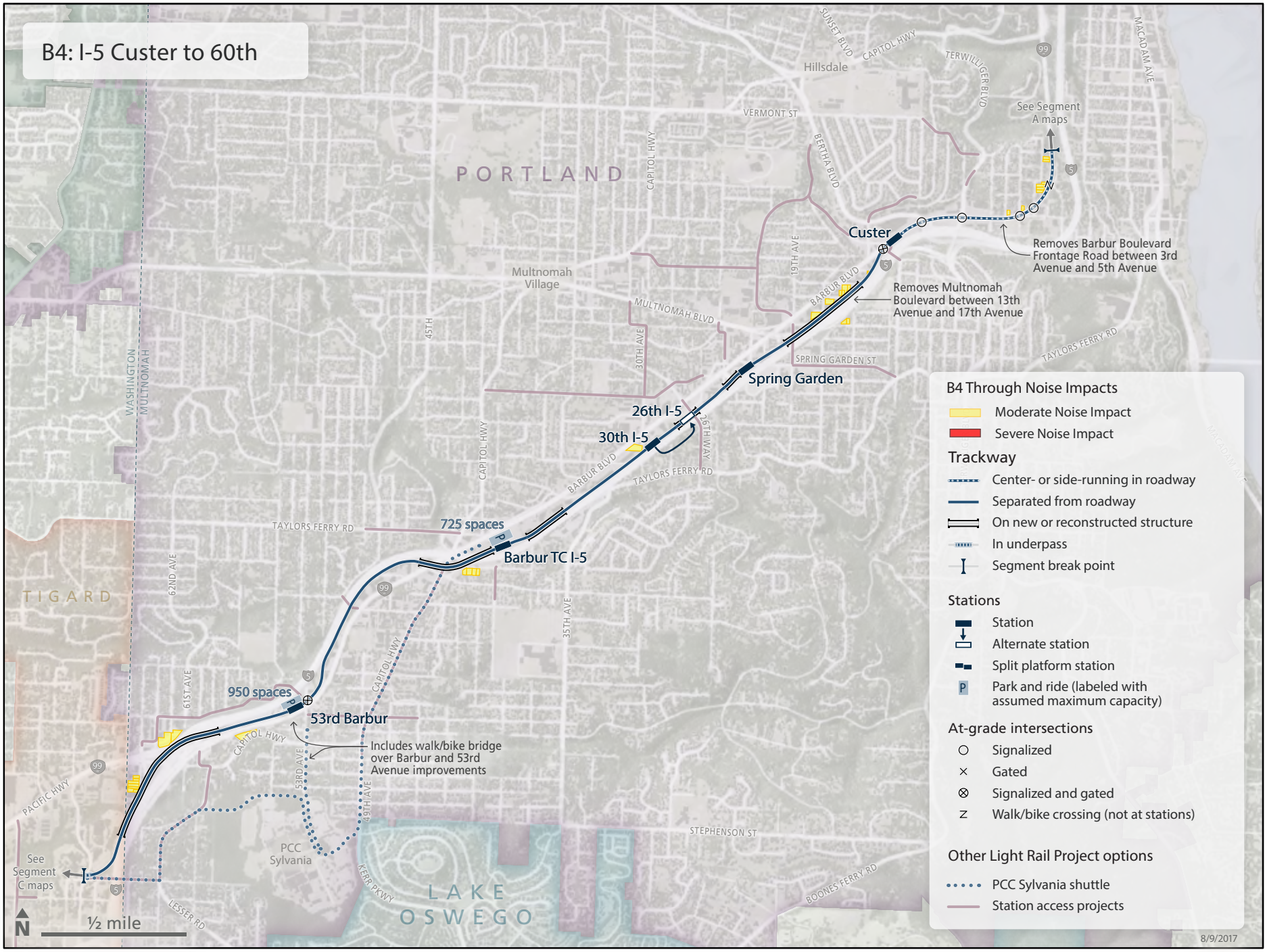


Figure 6-11. B1: Barbur Noise Impacts, Branched Configuration

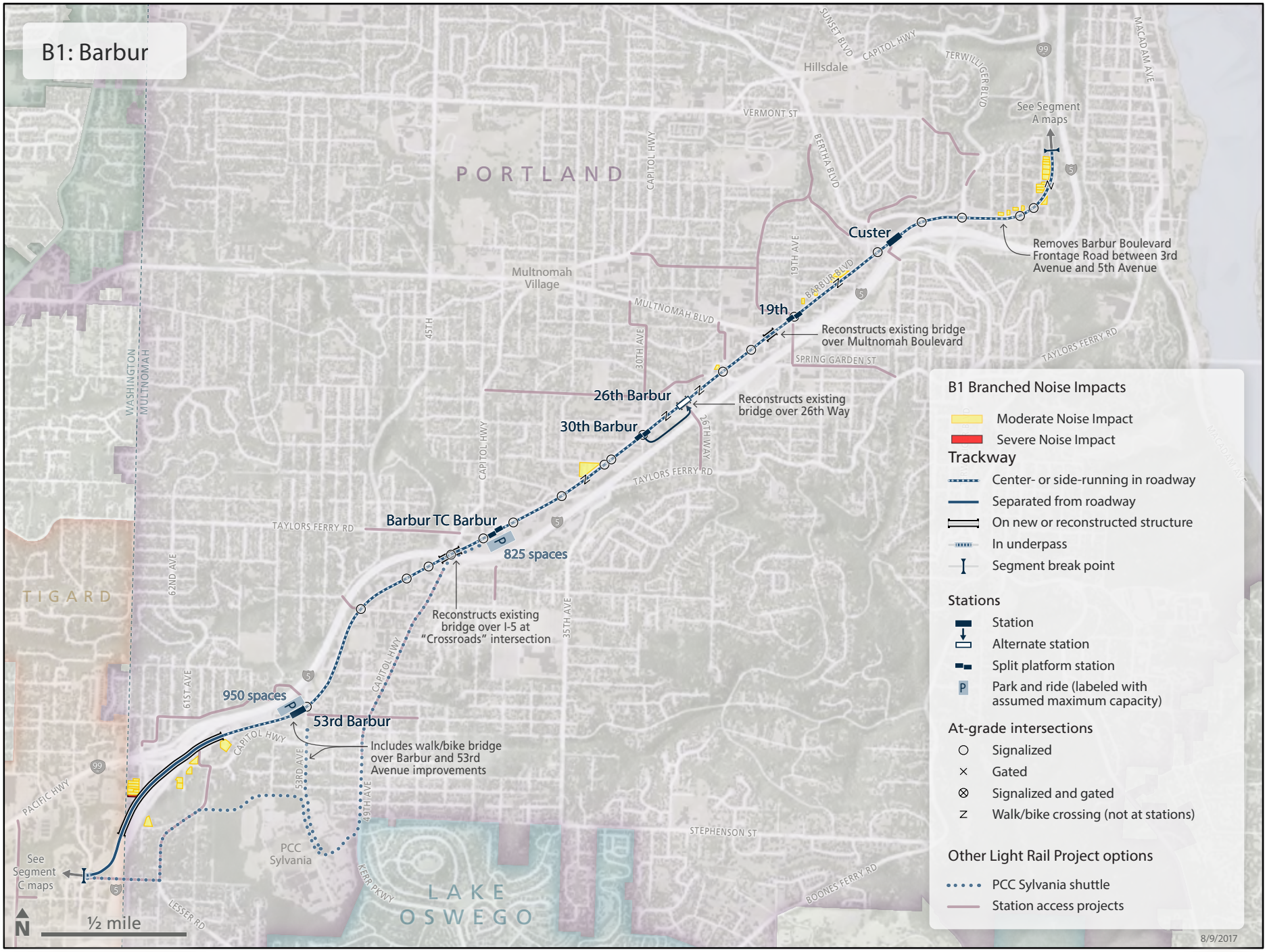


Figure 6-12. B2: I-5 Barbur TC to 60th Noise Impacts, Branched Configuration

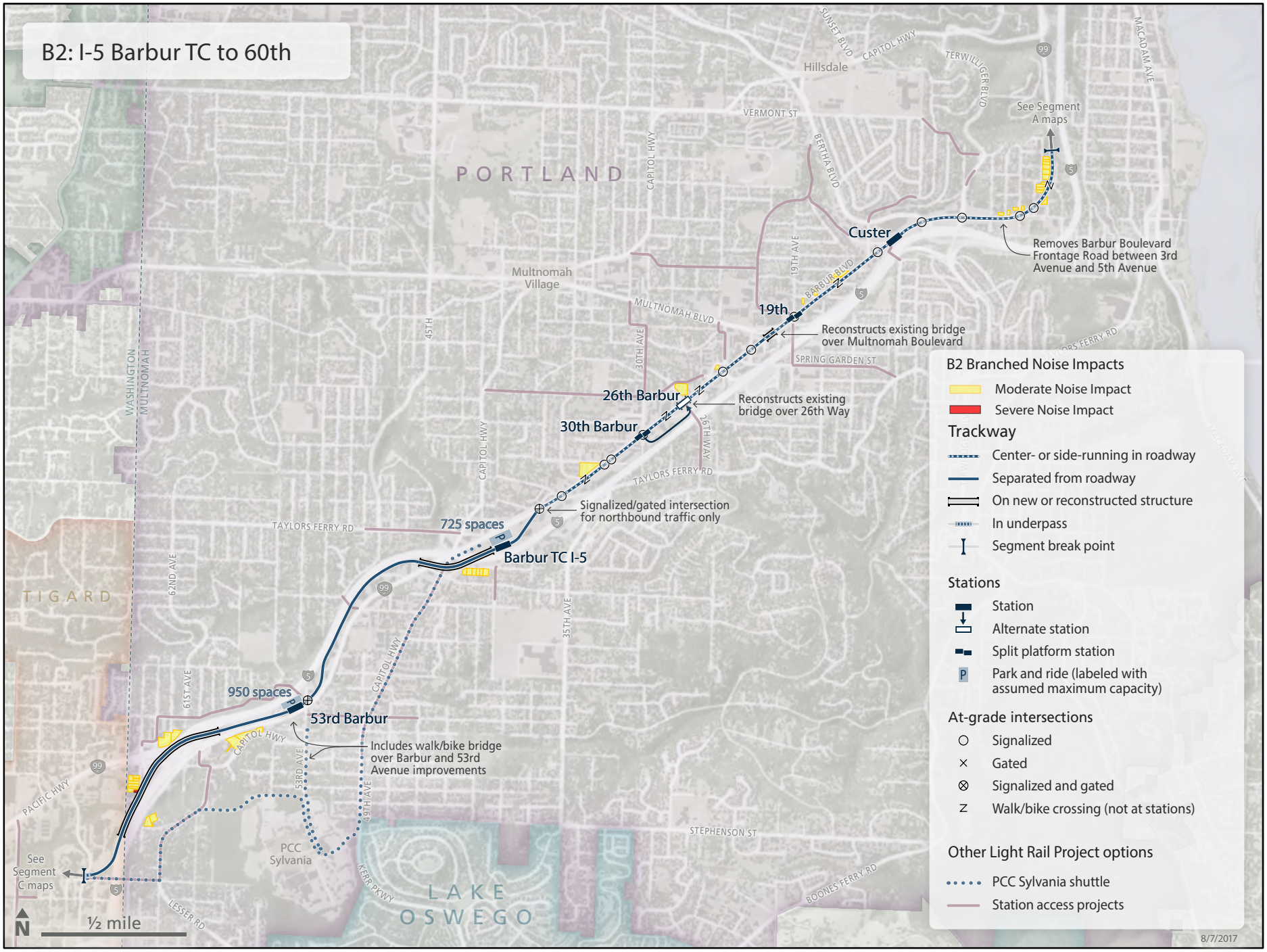


Figure 6-13. B3: I-5 26th to 60th Noise Impacts, Branched Configuration

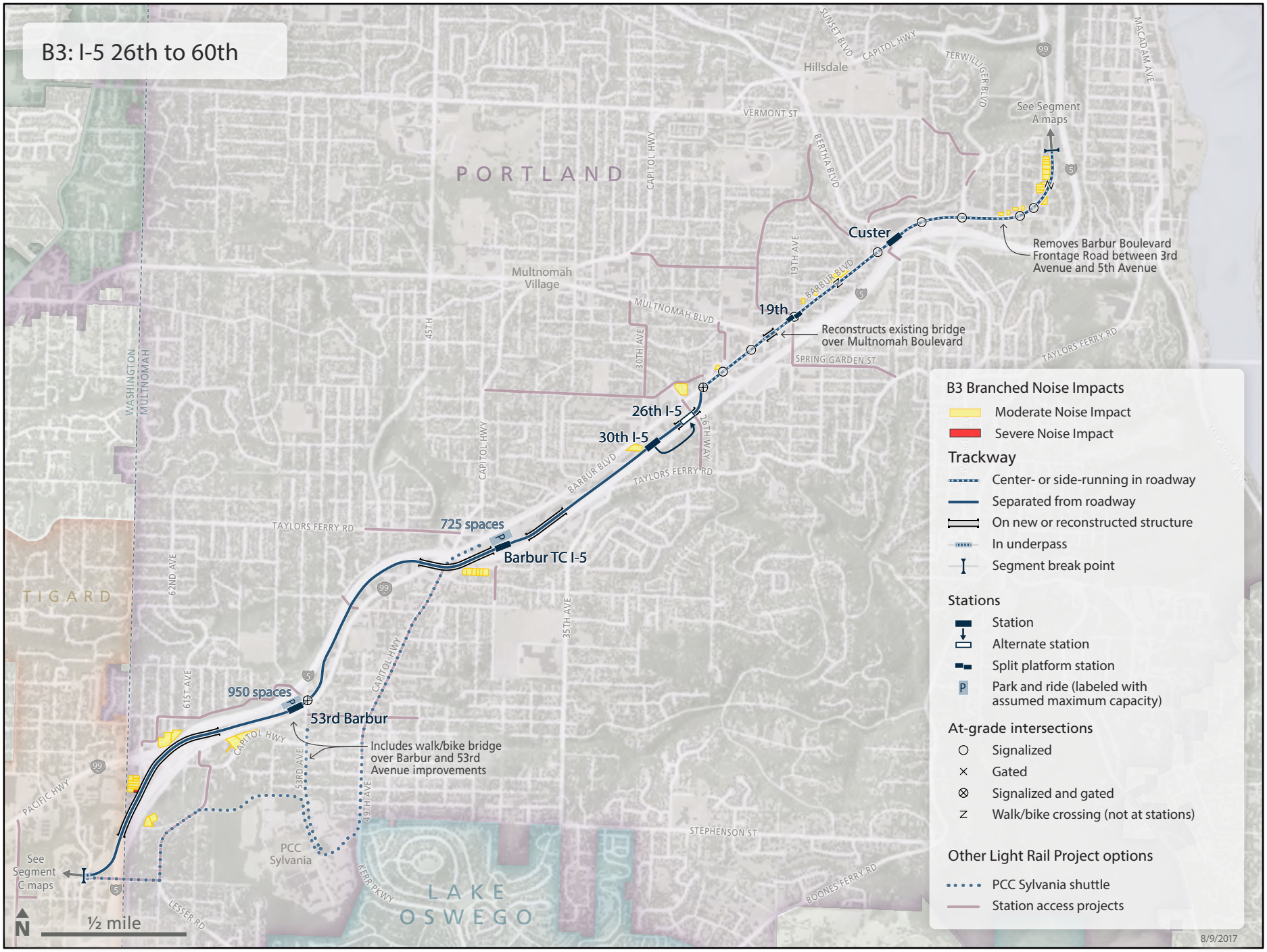
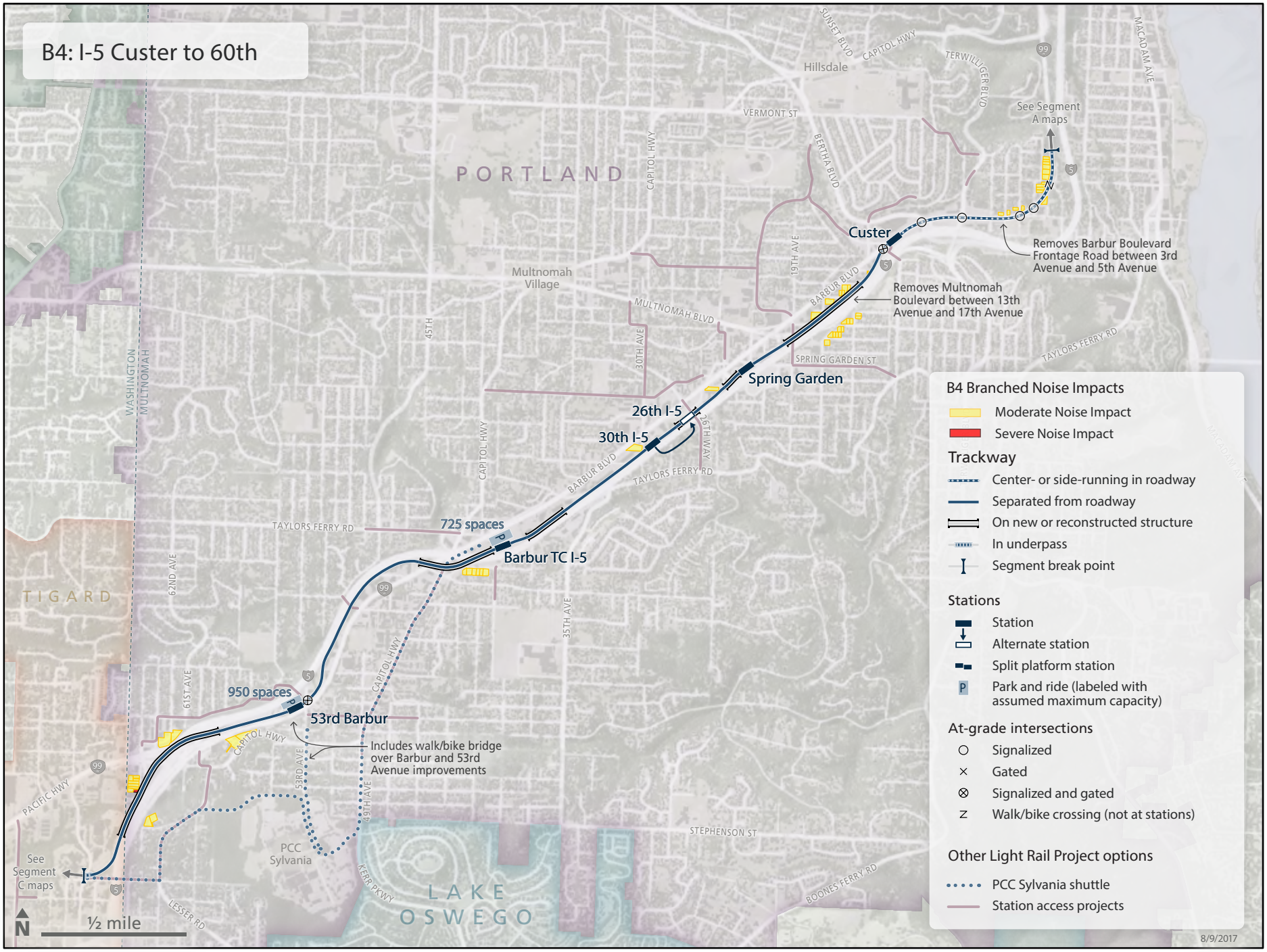


Figure 6-14. B4: I-5 Custer to 60th Noise Impacts, Branched Configuration



6.3.3. Segment C: Tigard and Tualatin

In Segment C, the majority of noise impacts occur at residences south of SW Atlanta Street and east of SW 72nd Avenue, and at multifamily units and a manufactured home park near downtown Tigard. The alternatives with the highest number of impacts are Alternatives C1 and C2, because the alignments for these alternatives are near several multifamily residences. Table 6-5 provides a summary of noise impacts for the Segment C alternatives.

Table 6-5. Summary of Segment C Noise Impacts

Alternative and Configuration	Moderate Noise	Severe Noise	Total Noise Impacts
Through Configuration Noise Impacts			
C1: Ash-I-5 (Fig. 6-15)	72	15	87
C2: Ash-Railroad (Fig. 6-16)	72	15	87
C3: Clinton-I-5 (Fig. 6-17)	12	0	12
C4: Clinton-Railroad (Fig. 6-18)	12	0	12
Branched Configuration Noise Impacts			
C5: Ash-I-5 Branched (Fig. 6-19)	38	12	50
C6: Wall-I-5 Branched (Fig. 6-20)	37	3	40

Source: FTA noise modeling.

Under Alternative C1 (Through Configuration), multiple noise impacts are predicted between the Baylor Park and Ride and SW Beveland Street. Impacts in the severe category were identified near a crossover at SW Clinton Street and SW 70th Avenue, and also at the start of the elevated structure over OR-217. Additional potential severe impacts are predicted at the closest apartments in the downtown Tigard area on SW Ash Street. Additional moderate noise impacts under Alternative C1 were identified along the alignment near SW Knoll Drive, SW Hall Boulevard, SW Scoffins Street and to the north of SW Ash Street; some of these impacts are caused by a crossover. Once the alignment departs the downtown Tigard area and continues to I-5 and the project terminus, there are no more noise impacts, because land use is primarily commercial and industrial, with the exception of some hotels, none of which were identified as having noise impacts.

Noise impacts under Alternative C2, which is also the Through Configuration, are the same as those under Alternative C1. The alignment change from Alternative C1 south of downtown Tigard along the WES corridor has no noise impacts, because there are no noise-sensitive receivers near the alignment.

Noise impacts under Alternatives C3 and C4 with the Through Configuration are the same, with most impacts occurring near the Baylor Park and Ride, east of SW 72nd Avenue. The only other impacts under Alternatives C3 and C4 occur in downtown Tigard at a manufactured home park; these impacts are caused in part by a nearby crossover. All of the noise impacts under Alternatives C3 and C4 are in the moderate category.

With the Branched Configuration, noise impacts under Alternatives C5 and C6 are the same south of the Baylor Park and Ride and east of SW 72nd Avenue. This area is where many of the noise impacts occur, including severe impacts due to a set of crossovers—one on SW 70th Avenue and a second on SW Beveland Street. Additional noise impacts under Alternative C5 occur at several multifamily units near downtown Tigard, including severe impacts due to the proximity of the alignment to an apartment building. The only other impact that occurs under Alternatives C5 and C6 is to the Extended Stay

America Hotel. Finally, Alternative C6 has slightly fewer impacts than Alternative C6, because the Alternative C6 alignment remains outside the downtown Tigard area and follows the WES corridor to serve the Tigard downtown area.

Figures 6-15 through 6-18 show the light rail alignment and the location of impacts for Alternatives C1 through C4 under the Through Configuration. Figures 6-19 and 6-20 show the light rail alignment and the location of impacts for Alternatives C5 and C6 under the Branched Configuration.

Figure 6-15. C1: Ash to I-5 Noise Impacts, Through Configuration

Figure 6-16. C2: Ash to Railroad Noise Impacts, Through Configuration

Figure 6-17. C3: Clinton to I-5 Noise Impacts, Through Configuration

Figure 6-18. C4: Clinton to Railroad Noise Impacts, Through Configuration

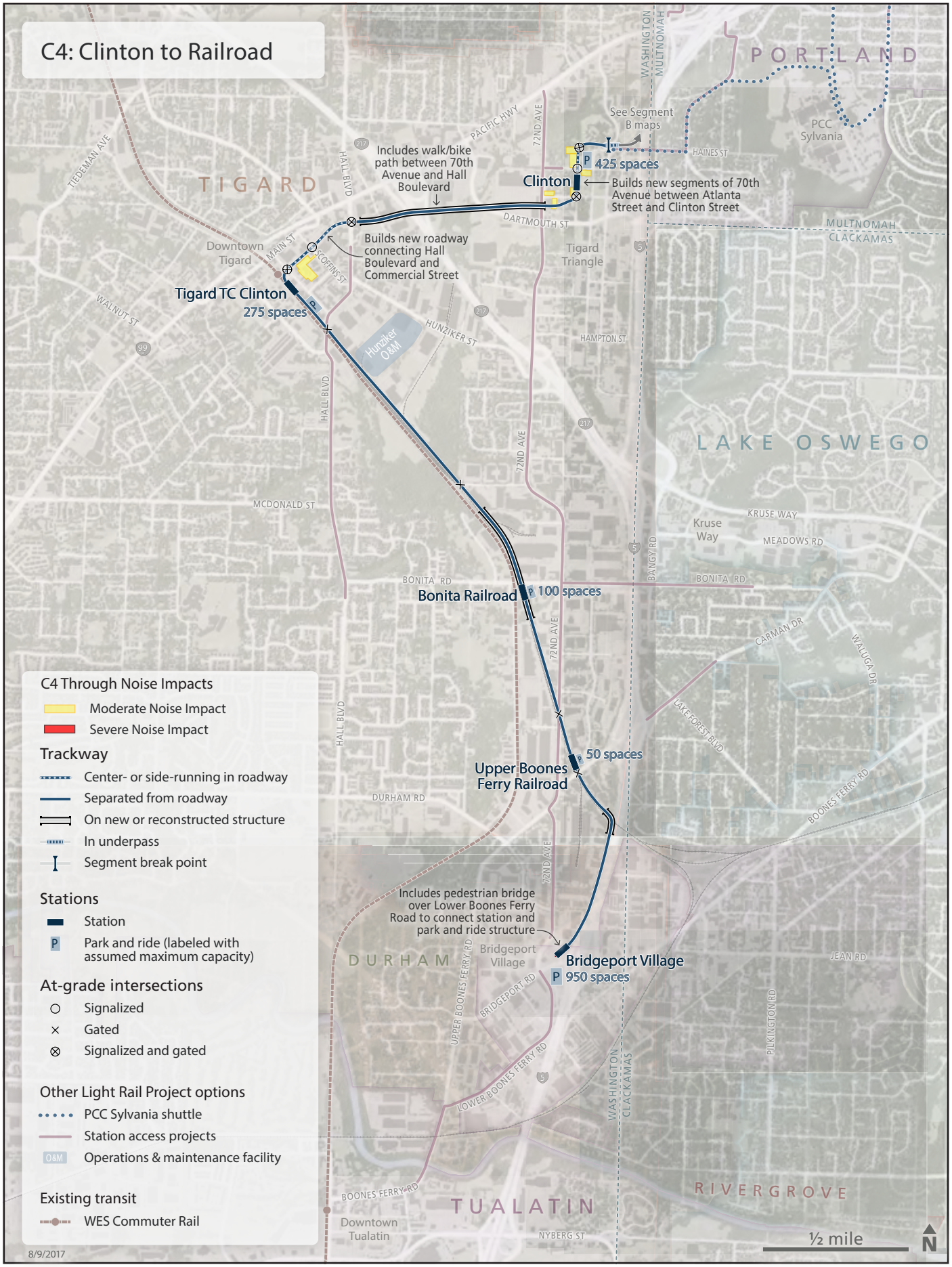


Figure 6-19. C5: Ash and I-5 Branched Configuration Noise Impacts

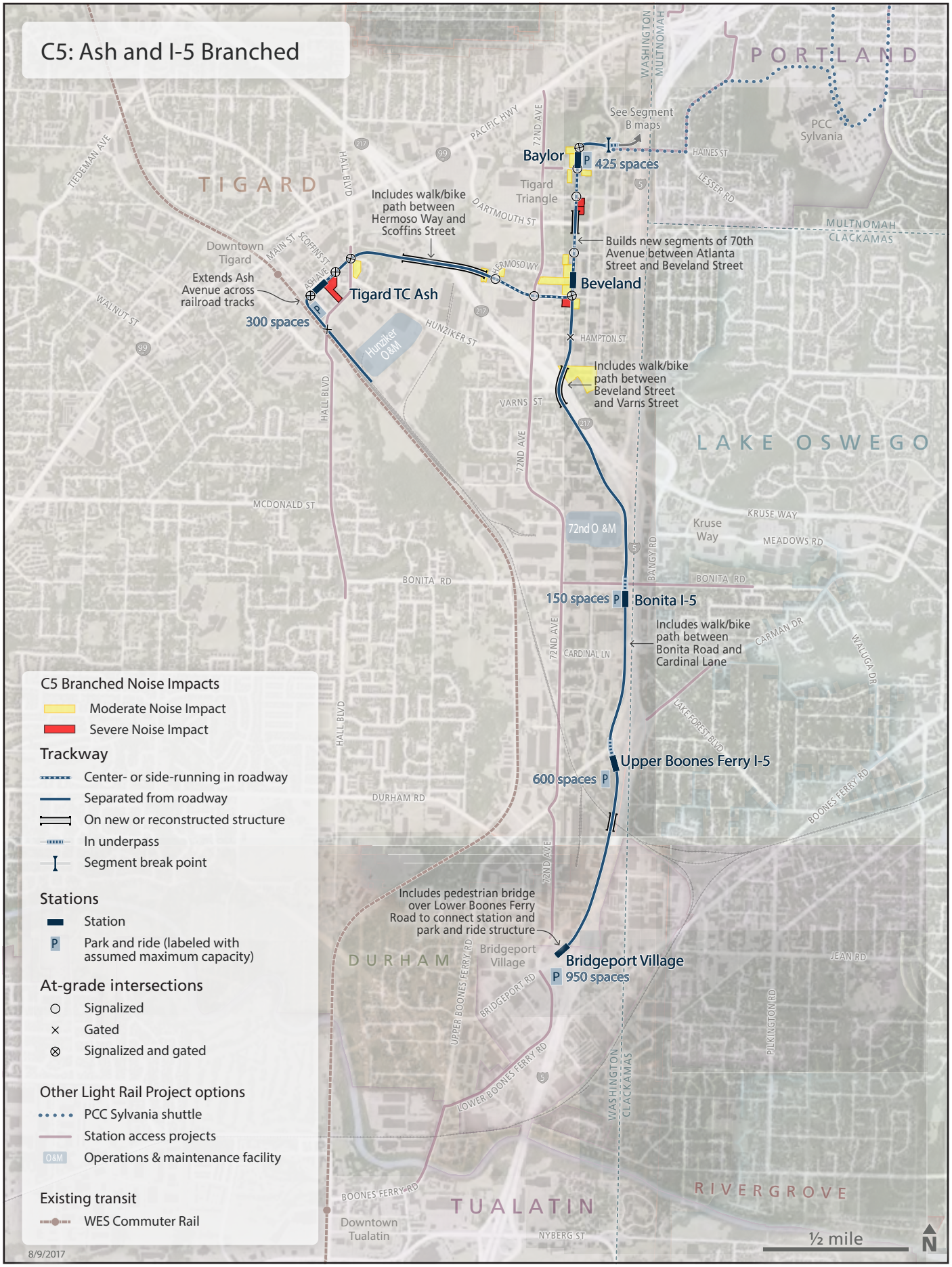


Figure 6-20. C6: Wall and I-5 Branched Configuration Noise Impacts

6.4. Wheel Squeal

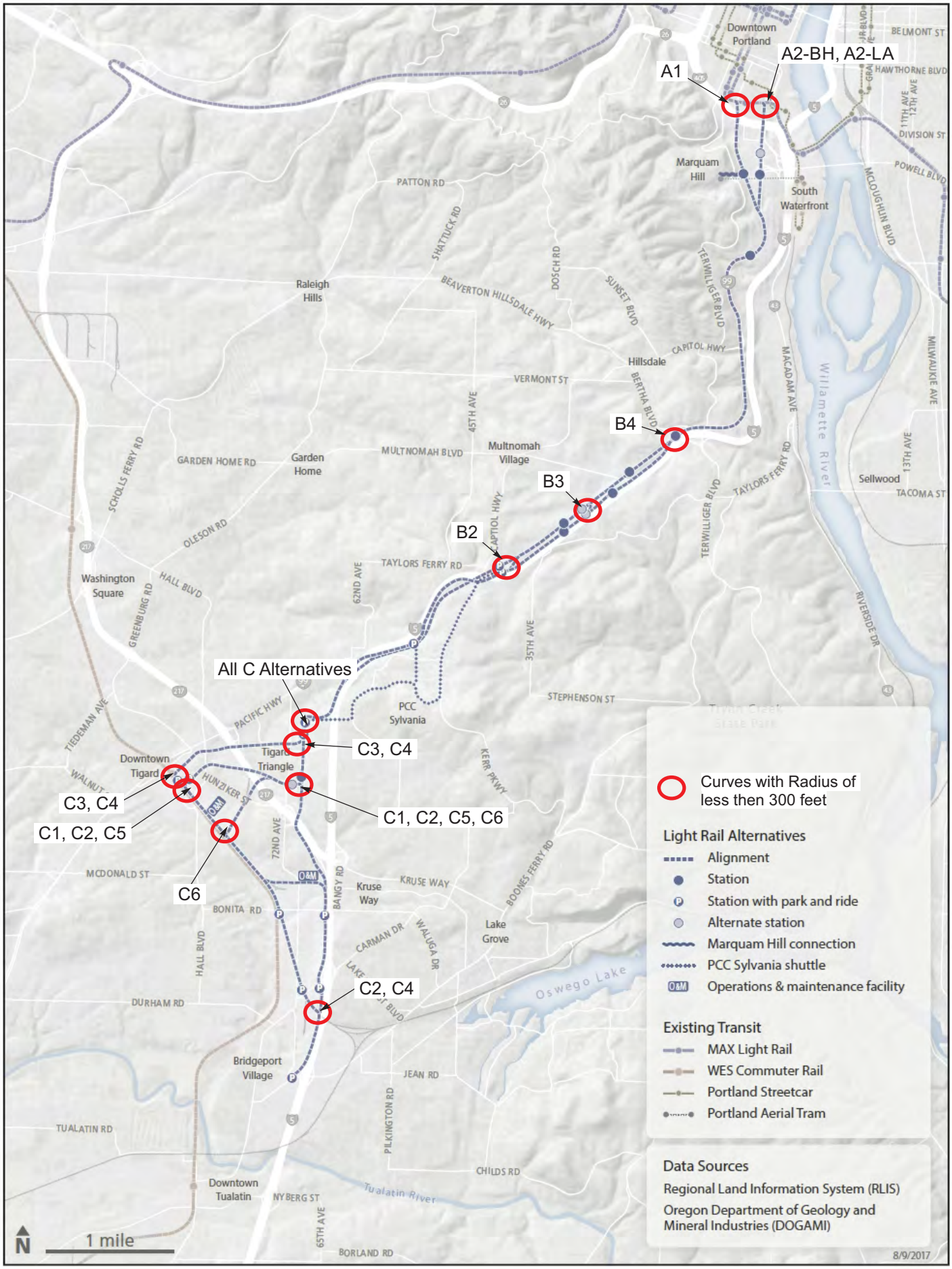
Each of the light rail alternatives was examined for curves with a radius of 300 feet or less. Curves of this radius have the potential for wheel squeal, which occurs as the light rail travels around the curve. Typically, wheel squeal can be mitigated by a trackside lubrication system, and therefore all curves with a potential for squeal were identified. Table 6-6 lists all of the tight-radius curves that will be considered for lubrication, and the sites are identified on Figure 6-21.

Table 6-6. Tight-radius Curves with the Potential for Wheel Squeal

Light Rail Alternative	Location	Curve Radius (feet)
Segment A: Inner Portland		
A1: Barbur	SW Lincoln St. at SW 4th Ave.	110
A2-BH: Naito Bridgehead	SW Lincoln St. at SW Naito Pkwy.	95
A2-LA: Naito Limited Access	SW Lincoln St. at SW Naito Pkwy.	95
Segment B: Outer Portland		
B1: Barbur	None	--
B2: I-5 Barbur TC-60th	Barbur Transit Center	250
B3: I-5 26th-60th	SW Barbur Blvd. at SW 26th Ave.	150
B4: I-5 Custer-60th	SW Barbur Blvd. at SW Custer St.	300
Segment C: Tigard and Tualatin		
C1: Ash-I-5	SW Atlanta St. at SW 7th Ave. SW 70th Ave. at SW Beveland St. SW Ash Ave. at SW Commercial St.	100 100 150
C2: Ash-Railroad	SW Atlanta St. at SW 7th Ave. SW 70th Ave. at SW Beveland St. SW Ash Ave. at SW Commercial St. At I-5 transition	100 100 150 200
C3: Clinton-I-5	SW Atlanta St. at SW 7th Ave. SW 70th Ave. at SW Clinton St. SW Commercial St. north of SW Ash Ave.	100 100 100
C4: Clinton-Railroad	SW Atlanta St. at SW 70th Ave. SW 70th Ave. at SW Clinton St. SW Commercial St. north of SW Ash Ave. At railroad corridor to I-5 transition	100 100 100 200
C5: Ash-I-5 Branched	SW Atlanta St. at SW 70th Ave. SW 70th Ave. at SW Beveland St. SW Ash Ave. at SW Commercial St.	100 100 150
C6: Wall-I-5 Branched	SW Atlanta St. at SW 70th Ave. SW 70th Ave. at SW Beveland St. SW Wall St. at SW Commercial St.	100 100 134

Source: Project design drawings.

Figure 6-21. Tight-radius Curves with the Potential for Wheel Squeal



6.5. Traffic Noise Impacts

Under FTA criteria, traffic noise impacts are considered for locations where the proposed project includes new roads, substantial alterations to existing roads or removal of shielding that would increase potential traffic noise exposure to sensitive receivers.

In Segment A, these types of noise impacts occur at some locations along SW Barbur Boulevard and SW Naito Parkway and, under Alternative A2-BH, at the access to the Ross Island Bridge.

In Segment B there are some displacements along SW Barbur Boulevard, and between SW Barbur Boulevard and I-5 under Alternatives B3 and B4, where increased traffic noise levels could occur due to the removal of shielding. There are no major roadway realignments that would trigger a traffic noise study in Segment B. In Segment C, the major concern for traffic noise is the removal of shielding and construction of new roads for access to station locations near the downtown core and SW Hall Boulevard, where noise levels are already above the traffic noise criteria.

Other project improvements, including traffic safety and access improvements, bicycle lanes and pedestrian access improvements are not normally considered for traffic noise analysis unless they also involve the removal of existing shielding and thereby increase traffic noise level to above the criteria.

6.6. O&M Facilities

Noise and vibration impacts from the potential O&M facilities options were also included in this analysis. The Hunziker Full Facility and Hunziker Partial Facility sites are in established industrial areas. The nearest noise-sensitive receivers are well over 500 feet away and are well shielded from facility operations. Therefore, no noise impacts are predicted from either of the Hunziker Facility options.

The Through 72nd Facility and Branched 72nd Facility sites, which are also in established industrial areas, have no noise impacts identified. The only nearby noise-sensitive property for either of these two O&M facilities options is a hotel that is across I-5, approximately 350 feet away, where noise will continue to be dominated by traffic along I-5.

Many of the O&M facilities in Segment C also include a proposed expansion at the existing Ruby Junction Operations and Maintenance Facility. The Ruby Junction facility is in an established industrial area with no sensitive properties within 500 to 600 feet. Each of the potential expansions was reviewed, and none was found to have a potential for increased noise at any nearby noise-sensitive property.

6.7. Other Ancillary Facilities

Noise from other project-related activities would include noise from power substations and general system maintenance. All power substations will be contained in buildings that acoustically shield the noisy equipment from nearby noise-sensitive properties. In addition, general system maintenance will be performed in accordance with the local jurisdiction noise ordinances, and therefore, no noise impacts related to ancillary activities are predicted.

7. VIBRATION IMPACT ANALYSIS

This section summarizes and identifies locations where vibration levels are predicted to exceed the FTA impact criteria. Additional information on the technical assessment of vibration impacts is provided in Appendix C.

7.1. No-Build Alternative

With the No-Build Alternative, vibration levels in the project corridor would continue to be dominated by other transportation-related vibration sources, primarily heavy trucks and, in Tigard, the WES Commuter Rail. Other vibration sources could include miscellaneous industrial activities and local construction projects. With the No-Build Alternative, there would be no light rail project, and therefore no light-rail-related vibration.

7.2. Full Corridor

Table 7-1 summarizes the projected vibration impacts by alignment alternative and also includes a range of impacts associated with the various alignments. Baseline full-corridor vibration impacts were predicted using Alternatives A1, B2 and C1. The low and high ends of this range can reflect a combination of alternatives to capture the minimum and maximum potential impacts. It is important to note that unlike the noise analysis, the vibration analysis uses the maximum pass-by vibration level in VdB; therefore, vibration impacts are the same under both the Through Configuration and the Branched Configuration.

Table 7-1. Summary of Potential Full-corridor Vibration Impacts

Light Rail Alternatives Combined	Segment Impacts	Total Vibration Impacts
Baseline Full Corridor: A1, B2 and C1		
A1: Barbur	76	76
B2: I-5 Barbur TC-60th	26	26
C1: Ash-I-5	20	20
Baseline Full-corridor Total		**122**
Full-corridor Fewest Vibration Impacts: A2-LA, B3 and C3/C4		
A2-BH: Naito Bridgehead	31	31
B3: I-5 26th-60th	17	17
C3: Clinton-I-5/ C4: Clinton-Railroad	2	2
Full-corridor Fewest Vibration Impacts Total		**50**
Full-corridor Greatest Vibration Impacts: A1, B4 and C1/C2		
A1: Barbur	76	76
B1: Barbur	29	29
C5: Ash-I-5 Branched	21	21
Full-corridor Greatest Vibration Impacts Total		**126**

Source: FTA vibration modeling.

7.3. Light Rail Alternatives (by Segment)

This section provides a summary of the number of predicted vibration impacts from each of the light rail alternatives, without mitigation. Details of the analysis methods and projected vibration impacts for each individual alignment alternative are provided in Appendix C.

7.3.1. Segment A: Inner Portland

Alternative A1 of Segment A has the highest number of vibration impacts of the light rail alternatives. Table 7-2 summarizes the predicted vibration impacts for Segment A.

Table 7-2. Summary of Segment A Vibration Impacts

Vibration Impacts by Alternative	Impacts
A1: Barbur	76
A2-BH: Naito Bridgehead	31
A2-LA: Naito Limited Access	35

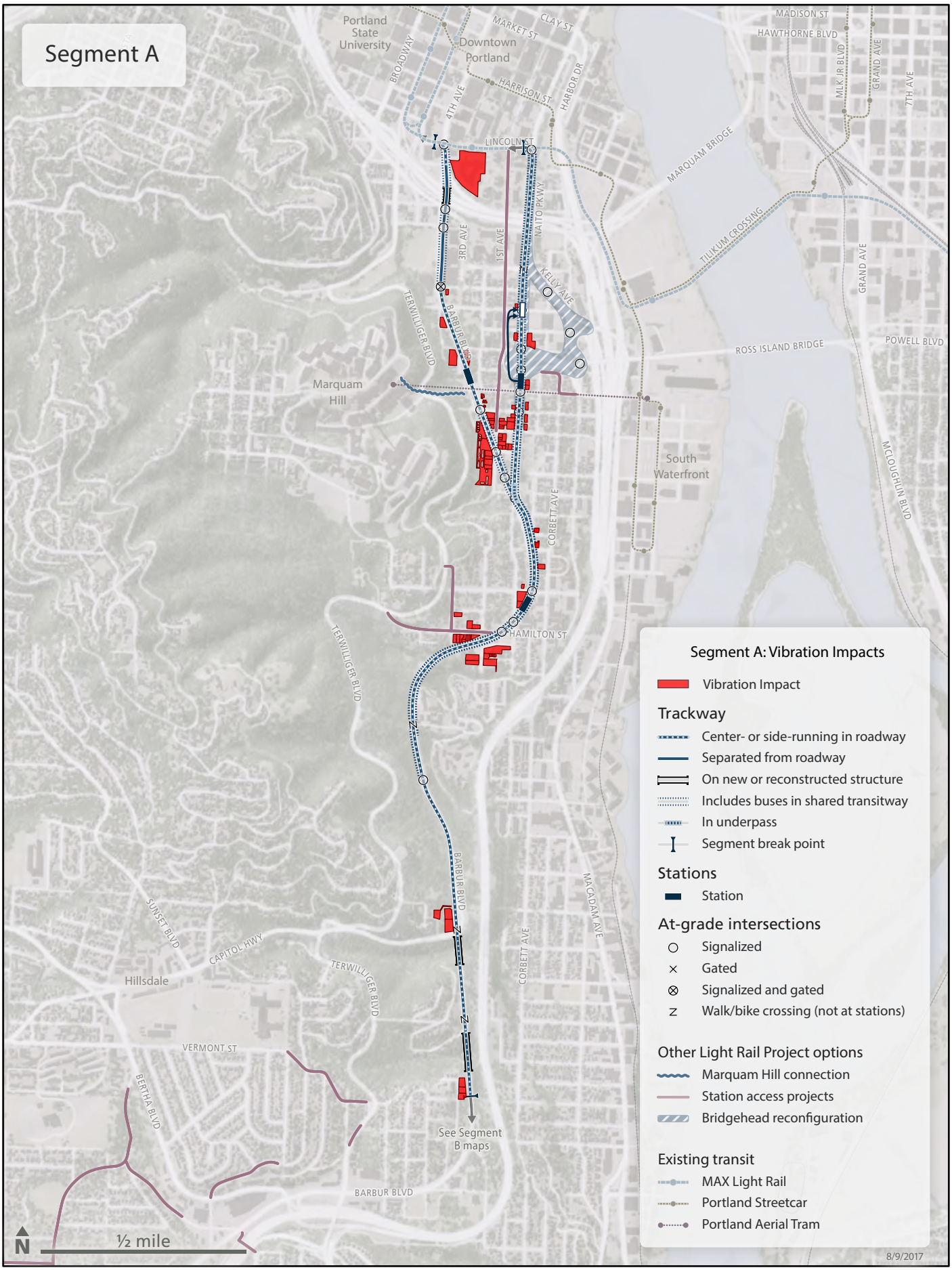
Source: FTA vibration modeling.

Like the noise impacts under Alternative A, the northernmost impact is at the University Place Hotel & Conference Center because of a nearby crossover. Additional vibration impacts were identified along both sides of SW Barbur Boulevard, with the southernmost impacts occurring at a group of single-family residences located at the connection of Segment A and Segment B, along SW 2nd Avenue.

Alternatives A2-BH and A2-LA have similar vibration impacts, with variations between the two occurring primarily because of displacements along SW Naito Parkway under Alternative A2-LA. Alternatives A2-BH and A2-LA have a lower number of impacts than Alternative A1 because there are a lower number of vibration-sensitive uses along SW Naito Parkway than along SW Barbur Boulevard. South of SW Hamilton Street, Alternative A1 and Alternatives A2-BH and A2-LA have the same vibration impacts, including the southernmost group of single-family residences located at the connection to Segment B, along SW 2nd Avenue.

Figure 7-1 shows the Segment A light rail alternatives and the location of vibration impacts for all three of the alternatives. This information will be used in the selection of vibration propagation test sites to aid in the development of vibration mitigation measures.

Figure 7-1. Segment A Potential Vibration Impacts



7.3.2. Segment B: Outer Portland

All four of the Segment B light rail alternatives have the same vibration impacts along SW Barbur Boulevard from the connection of Segment A and Segment B to just south of SW Terwilliger Boulevard. Vibration impacts were identified starting at the beginning of Segment B along SW 2nd Avenue. Table 7-3 summarizes the predicted vibration impacts for Segment B.

Table 7-3. Summary of Segment B Vibration Impacts

Vibration Impacts by Alternative	Impacts
B1: Barbur	29
B2: I-5 Barbur TC-60th	26
B3: I-5 26th-60th	17
B4: I-5 Custer-60th	23

Source: FTA vibration modeling.

Alternative B1, with the highest total number of vibration impacts in this segment, continues along SW Barbur Boulevard and has vibration impacts at several structures located adjacent to the alignment along SW Barbur Boulevard. Three of the vibration impacts between SW Terwilliger Boulevard and the Barbur Transit Center are because of the proximity to a crossover. Additional vibration impacts under Alterative B1 occur at the southern end of the alignment, just before the elevated structure over I-5. Impacts in this area are partially a result of the high speed of the light rail south of SW 53rd Avenue.

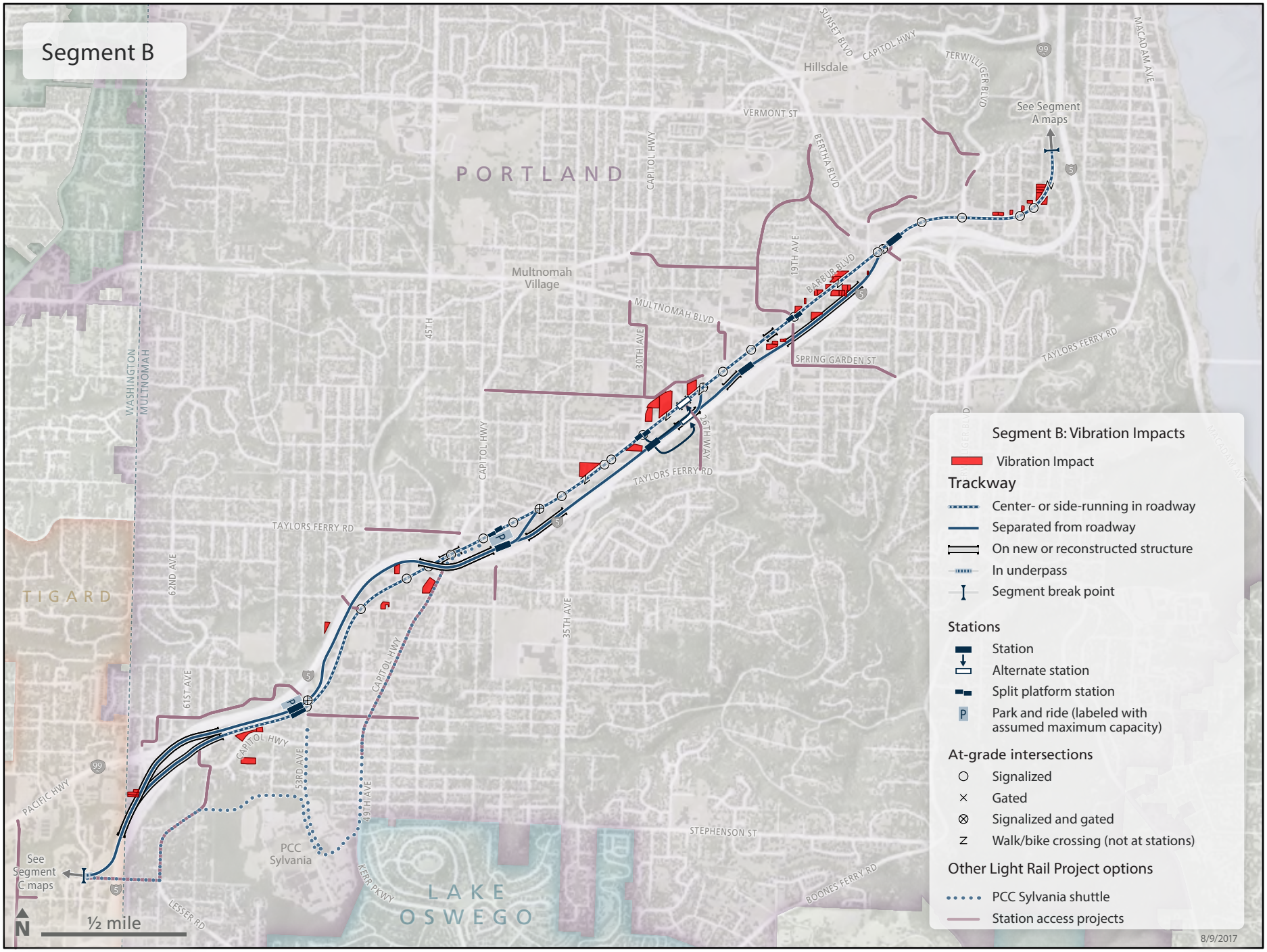
Vibration impacts under Alternative B2 are essentially the same as under Alternative B1 until south of the Barbur Transit Center, where the two alternatives follow different alignments, resulting in slightly fewer total vibration impacts under Alternative B2 than under Alternative B1. Alternative B2 has several vibration impacts along I-5 and also at the south end of the alignment east of I-5, just before the elevated structure. An additional vibration impact was also identified west of I-5 along SW 64th Avenue, where the alignment transitions back to an at-grade alignment.

Vibration impacts under Alternative B3 are the same as under Alternative B2 north of SW 24th Avenue and south of the Barbur Transit Center. Alternative B3 has no vibration impacts between SW 24th Avenue and the Barbur Transit Center, with the exception of one hotel that is displaced under Alternative B2 but has a vibration impact under Alternative B3.

Under Alternative B4, there are several additional vibration impacts between SW 13th Avenue and SW 26th Avenue that only occur with this alternative. South of SW 26th Avenue, the impacts are the same as under Alternatives B2 and B3. Overall, however, Alternative B4 has fewer total vibration impacts than Alternative B2, because its alignment bypasses SW Barbur Boulevard north of the Barbur Transit Center, where many of the Alternative B2 vibration impacts occur.

Figure 7-2 shows the Segment B light rail alternatives and the location of vibration impacts for all four of them. As described previously, this information will be used in the selection of vibration propagation test sites to aid in the development of vibration mitigation measures.

Figure 7-2. Segment B Potential Vibration Impacts



7.3.3. Segment C: Tigard and Tualatin

The majority of vibration impacts in Segment C occur in the northern part of the alignment, where it is in proximity to several residences. Vibration impacts under Alternatives C1, C2, C5 and C6 are similar, and much higher than those under Alternatives C3 and C4, which are notably farther from many residences. Table 7-4 summarizes the predicted vibration impacts for Segment C.

Table 7-4. Summary of Segment C Vibration Impacts

Vibration Impacts by Alternative	Impacts
C1: Ash-I-5	20
C2: Ash-Railroad	20
C3: Clinton-I-5	2
C4: Clinton-Railroad	2
C5: Ash-I-5 Branched	21
C6: Wall-I-5 Branched	20

Source: FTA vibration modeling.

Under Alternatives C1 and C2, the vibration impacts are identical, with impacts occurring south of the Baylor Park and Ride and again in the Tigard City Center. Alternatives C3 and C4 also have identical vibration impacts, with two impacts a result of their proximity to a crossover in downtown Tigard.

Vibration impacts under Alternative C5 are almost identical to those under Alternatives C1 and C2, with the exception of a displacement and additional vibration impacts occurring along the southbound alignment, including impacts to one single-family residence and the Extended Stay America Hotel. It is important to remember that the vibration impacts are determined by the maximum pass-by vibration level, and therefore the Branched Configuration (branching of the light rail traffic—with half of the trips to Tigard and half to Bridgeport Village) has no effect on vibration impacts.

Finally, vibration impacts under Alternative C6 are almost the same as those under Alternative C5; Alternative C6 has one fewer impact because of the alignment transition to the south en route to the Tigard downtown area. Figure 7-3 shows the Segment C light rail alternatives and the location of vibration impacts.

Figure 7-3. Segment C Potential Vibration Impacts

7.4. O&M Facilities

Vibration impacts from the potential O&M facilities options were also included in this analysis, and none of the O&M facilities options was found to have a potential for increased vibration at any nearby vibration-sensitive property.

7.5. Other Ancillary Facilities

Vibration from other project-related activities was reviewed, and none of these activities was found to have a potential for increased vibration at any nearby vibration-sensitive property.

8. CONSTRUCTION IMPACTS – NOISE AND VIBRATION

Project construction would occur throughout the Southwest Corridor Light Rail Project corridor. To aid in quantifying noise and vibration impacts related to project construction, a general assessment of construction noise and vibration levels was performed as described by FTA.

8.1. Construction Noise Regulatory Information

Under FTA regulations, local noise ordinances and regulations govern noise from project construction. Because the light rail line would go through or near several different jurisdictions, all jurisdictions within 500 feet of any potential alignment or project feature were reviewed for regulations or ordinances that have applicability to project noise (see Section 3.3). Regulations and ordinances that are applicable to project construction include those from the cities of Lake Oswego, Portland, Tigard and Tualatin. Each of these jurisdictions has periods when most construction activities are exempt. General exemptions for construction during daytime hours by jurisdiction are:

- 7 a.m. to 6 p.m. in Lake Oswego
- 7 a.m. to 6 p.m. in Portland
- 7 a.m. to 8 p.m. in Tigard
- 7 a.m. to 6 p.m. in Tualatin.

Any proposed construction outside the hours listed above would require a noise variance from the local jurisdiction. Noise variances typically limit noise levels and construction times depending on the land use in the area and the type of construction.

8.2. Construction Noise

The construction noise analysis considers the temporary noise impacts that construction would cause along the project corridor. The contractor would be required to adhere to local ordinances regulating noise, as described above. These impacts would end when project construction was completed.

Noise related to construction would result from the operation of heavy equipment needed to construct various project components, including the light rail trackway, structures, park and ride facilities, O&M facilities and stations.

Project construction would involve the use of construction equipment typically used for transportation construction projects. Table 8-1 lists the typical equipment used for this type of project, the activities it would be used for and the corresponding maximum noise levels that would be produced when measured at 50 feet from the sources under normal use.

Table 8-1. Summary of Construction Equipment and Typical Maximum Noise Levels

Equipment	Typical Use	Lmax (dBA)
Air Compressor	Pneumatic tools and general maintenance (all phases)	81
Backhoe	General construction and yard work	80
Ballast Equalizer	Track installation	82
Ballast Tamper	Track installation	83
Compactor	Soil compaction	82
Concrete Mixer	Concrete mixing and delivery	85
Concrete Pump	Pumping concrete	82
Concrete Vibrator	Concrete compacting	76
Crane, Derrick	General construction and materials handling	88
Crane, Mobile	Materials handling: removal and replacement	83
Dozer	General construction use	85
Generator	General construction use and night work	81
Grader	General construction use	85
Impact Wrench	General construction use	85
Jack Hammer	Pavement removal	88
Loader	General construction and materials handling	85
Paver	Roadway paving	89
Pile-driver (Impact)	Structures and support	101
Pile-driver (Sonic)	Structures and support	96
Pneumatic Tool	General construction use	85
Pump	Staging area work and hauling materials	76
Rail Saw	Materials handling: general hauling	90
Rock Drill	General construction and demolition	98
Roller	Soil compaction	74
Saw	Concrete removal and utilities access	76
Scarifier	Surface preparation	83
Scraper	General construction use	89
Shovel	General construction use	82
Spike Driver	Track installation	77
Tie Cutter	Track installation	84
Tie Handler	Track installation	80
Tie Inserter	Track installation	85
Truck	General project work	88

Source: FTA, 2006.

8.2.1. Construction Phases and Noise Levels

Noise related to construction varies greatly depending on the type of construction activity, the duration of the activity, the distance between the receiver and the source, and the topographical conditions between the source and receiver. In general, noise levels produced for this project will be similar to noise produced for most major transportation projects. As provided in the *FTA Guidance Manual* (2006), typical construction noise levels were predicted using the FHWA *Roadway Construction Noise Model* (RCNM) (FHWA, 2006). These predictions use reference noise levels from typical construction equipment and account for typical equipment operation, including typical noise levels when equipment carries a load and typical operational times. The actual noise levels expected during construction would

generally be lower than those presented, because it is unlikely that all of the equipment would be running at once at a given site.

Construction of the Southwest Corridor Light Rail Project would require several construction phases. Table 8-2 provides a summary of the major construction phases and shows worst-case noise levels for each of these phases as measured at a distance of 50 feet from the construction site. This estimate uses reference noise levels from typical construction equipment and accounts for typical equipment operation. The actual noise levels expected during construction would generally be lower than those presented in the table, because it is unlikely that all equipment would be running at once at a given site.

Table 8-2. Summary of Construction Phases and Noise Levels

Construction Phase	Equipment	Lm (dBA)[1]	Leq (dBA)[2]
Demolition, site preparation and utilities relocation	Air compressors, backhoe, concrete pumps, crane, excavator, forklifts, haul trucks, loader, pumps, power plants, service trucks, tractor-trailers, utility trucks, vibratory equipment	94	87
Structure construction, track installation and paving	Air compressors, backhoe, cement mixers, concrete pumps, crane, forklifts, haul trucks, loader, pavers, pumps, power plants, service trucks, tractor-trailers, utility trucks, vibratory equipment, welders	94	88
Miscellaneous activities	Air compressors, backhoe, crane, forklifts, haul trucks, loader, pumps, service trucks, tractor-trailers, utility trucks, welders	91	83

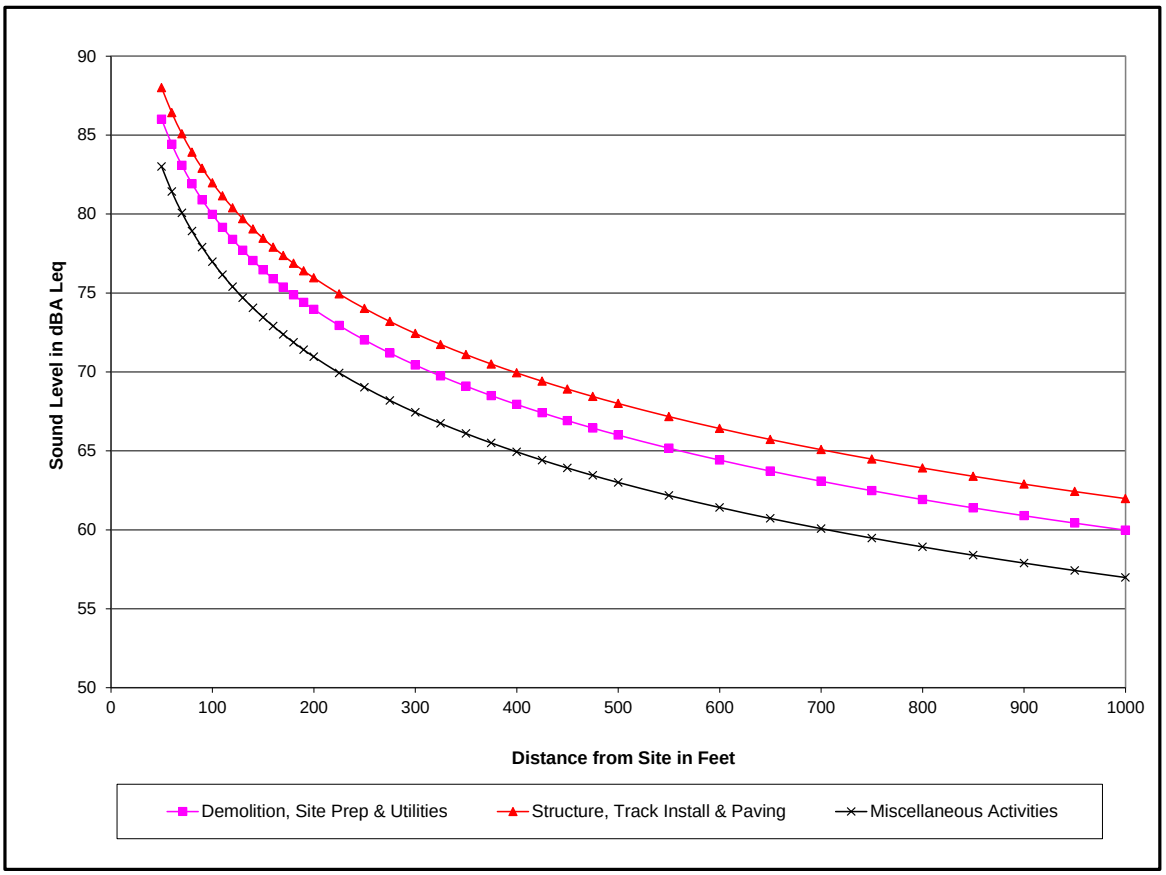
Source: Michael Minor & Associates, Inc. modeling of construction noise using the FHWA Roadway Construction Noise Model (FHWA, 2006).

[1] Lm is approximately equal to the Lmax, or the loudest one-second period.

[2] The Leq is for a typical worst-case hour of active construction.

Using the information in Table 8-2, typical construction noise levels were projected by distance from the project work area. Figure 8-1 is a graph of construction noise level versus distance for each of the three phases described in Table 8-2, assuming a reduction of 6 dB per doubling of distance. Because this projection of the construction noise levels assumes a direct line of sight to the construction activity, the actual noise levels would likely be lower, and sites with shielding from the construction site could have noise levels substantially lower than those presented. A discussion of each of the phases, as well as of pile-driving activities, is provided below.

Figure 8-1. Maximum Noise Level Versus Distance for Typical Construction Phases



Demolition, Site Preparation and Utilities Relocation

Major noise-producing equipment in use during the site preparation stage of light rail construction would include saw cutters, concrete pumps, cranes, excavators, haul trucks, loaders, tractor-trailers and vibratory equipment. Maximum noise levels could reach 82 dBA to 88 dBA at the nearest residences (i.e., within 50 to 100 feet) for normal construction activities during this phase. Other less notable noise-producing equipment expected to be used during this phase would be backhoes, air compressors, forklifts, pumps, power plants, service trucks and utility trucks.

Structures Construction, Track Installation and Paving

The loudest noise sources in use during construction of elevated structures would include cement mixers, concrete pumps, cranes, pavers, haul trucks and tractor-trailers. The cement mixers, cranes and concrete pumps would be required for construction of the light rail superstructure. The pavers and haul trucks would be used to provide the final surface on the trackway during other phases of construction. Maximum noise levels would range from 82 dBA to 88 dBA at 50 feet.

Miscellaneous Activities

Following heavy construction, general construction would still be required, such as installation of guideway railing, signage, and communication and power systems, as well as other miscellaneous activities. These less intensive activities are not expected to produce noise levels above 80 dBA at 50

feet except during rare occasions, and even then only for short periods of time, when combined maximum noise levels could reach 86 dBA Lmax at 50 feet.

Pile-driving

For areas with elevated structures, or occasionally for shoring up weak soils, driving of support piles or sheet piles may be required. Workers would install piles using a standard pile-driver, which produces an impact noise up to 105 dBA. If pile-driving occurs near residential areas, alternative methods for pile installation could be considered, such driving the piles using an auger instead of an impact driver. In addition, any pile-driving would be subject to the regulatory requirements of the local jurisdiction.

8.3. Construction Vibration

Construction-related vibration levels depend greatly on the construction equipment and methods in use. Major sources of construction vibration include impact pile-drivers, large track-mounted jackhammers used for demolition (hoe-rams) and vibratory rollers used for compacting soils. Construction has the potential to affect vibration-sensitive equipment, produce rumbling and in rare circumstances cause damage to buildings. In general, construction vibrations are assessed where prolonged annoyance or damage could be expected.

Complete details of construction methods for building the project were not available at the time this report was written. The major pieces of high-vibration construction equipment likely to be used in this project are listed in Table 8-3. The table provides typical vibration levels in peak particle velocity, or PPV, and in VdB for comparison, both at a distance of 25 feet. Vibration levels from construction are typically reduced with increased distance from the site, and could still be detectable at several hundred feet from the site, depending on the activity and soil propagation characteristics.

Table 8-3. Summary of Typical Construction Vibration Levels at 25 Feet

Equipment	Conditions (if applicable)	PPV at 256 feet (in./sec)	Approximate VdB at 25 feet
Pile-driver (impact)	Upper Range	1.518	112
	Typical	0.644	104
Pile-driver (sonic)	Upper Range	0.734	105
	Typical	0.170	93
Slurry wall construction	Range depends on soil	0.008 – 0.202	66 – 94
Vibratory roller	Typical	0.210	94
Hoe ram (track jackhammer)	Typical	0.089	87
Large bulldozer	Typical	0.089	87
Loaded trucks	Typical	0.076	86
Jackhammer	Typical	0.035	79
Small bulldozer	Typical	0.003	58

Source: FTA,2006.

For most other construction activities, the vibration generated would be minimal. Most activities would be far enough away from any buildings that there would be no impacts. Occasionally, however, vibration from construction could be noticeable at sites along the project work areas.

9. POTENTIAL MITIGATION MEASURES

9.1. Operational Noise

TriMet is committed to maintaining a quiet and effective transit system. This commitment includes using state-of-the-art vehicles equipped with wheel skirts, periodic rail grinding or replacement, wheel truing or replacement, vehicle maintenance and operator training, all of which help to reduce noise levels along transit corridors. For noise impacts that would still exist after these source noise treatments, potential noise mitigation measures that are consistent with the FTA requirements would be considered. During final design, all of the potential impacts and mitigation measures would be reviewed for confirmation. During preliminary and final design, if it is discovered that mitigation could be achieved by a less costly means or if the detailed analysis shows no impact, then a mitigation measure may be eliminated or modified.

The potential mitigation options available for noise would primarily be sound walls. Sound walls would be proposed where they can be feasibly and reasonably constructed. Sound walls would be located along the side of the guideway structure for elevated profiles, and on the ground for at-grade or cut profiles. Sound walls are a preferred noise mitigation measure, because they are effective at reducing noise before it arrives at the receiver.

Another potential mitigation measure is special trackwork, which includes movable point or spring rail frogs, which eliminate the gap between tracks at crossovers that causes noise and vibration at these locations.

When source mitigation measures or sound walls are infeasible or not entirely effective at reducing noise levels below the FTA impact criteria, residential sound insulation might be evaluated and implemented for affected properties, in cases where the existing building does not already achieve a sufficient exterior-to-interior reduction of noise levels. Most new buildings have good exterior-to-interior noise reduction, and additional sound insulation might not be necessary.

Noise mitigation for the park and rides includes station design and sound walls. Station design can include designing the parking garages with short noise barriers, and modifying the entrances and exits to place them away from nearby noise-sensitive properties. In addition, noise barriers can be placed between the station and the noise-sensitive properties, reducing noise levels and eliminating noise impacts. Most, if not all, noise impacts could be mitigated through the use of noise mitigation measures.

9.2. Operational Vibration

Vibration impacts that exceed FTA criteria would be mitigated when the mitigation measures were determined to be reasonable and feasible. The locations requiring mitigation would be refined during the preliminary and final design processes. Because there are locations where the alignment would be close to buildings, mitigation of some impacts could be difficult. As the design is further developed, vibration propagation testing will be performed and used to further refine the impacts and design mitigation measures.

Mitigation could include the use of **high compliance direct fixation fasteners** to provide vibration isolation between rails and concrete slabs. These fasteners include a resilient element between the rail and concrete to provide greater vibration isolation than standard rail fasteners.

For at-grade segments, where ballast and tie track is used, there are two potential forms of vibration mitigation. The most common form is the use of **ballast mats**, which consist of a pad made of rubber or rubberlike material placed on an asphalt or concrete base with the normal ballast, ties and rail on top. The reduction in vibration provided by a ballast mat is strongly dependent on the vibration frequency content, and the design and support of the mat. A relatively new form of vibration mitigation for ballast and tie installations includes the use of **tire-derived aggregate** instead of the standard ballast. Tire-derived aggregate consists of shredded tires wrapped with filter fabric that is added to the base below the track ties.

In extreme cases, as for sites that have very high levels of vibration or vibration impacts near sensitive equipment, a **floating slab** can be used. A floating slab is an isolated slab of concrete with rail attached to the top of the slab and provides very high levels of vibration reduction. Floating slabs are expensive to construct and must be designed following detailed testing of the soil and affected property, and are normally reserved for research laboratories and other areas with high vibration sensitivity.

To mitigate vibration impacts related to the added vibration from track crossovers, **special trackwork** could be employed. Special trackwork includes movable point or spring rail frogs, which eliminate the gap between tracks at crossovers that causes increased vibration.

As project design is refined, and a preferred alignment is selected, additional vibration propagation measurements will be performed and used to revise the analysis, and update the number and severity of vibration impacts. This additional information will also be used to develop vibration mitigation measures, which are dependent on the soil propagation characteristics, distance from the tracks to the affected structure and type of structure affected. With vibration mitigation measures, most, if not all, vibration impacts could be mitigated such that they would be below the FTA criteria.

9.3. Construction Noise

Construction noise impacts can be reduced with operational methods and scheduling, equipment choice and acoustical treatments. In locations where noise barriers are installed with the project, construction of the barriers early in the construction process as practical could also help to reduce noise from the ongoing construction activities. Project construction noise would also meet the local noise-control regulations. Any potential nighttime construction would control noise levels by applying noise-level limits established through the variance process, and would use noise-control measures where necessary. The contractor would have the flexibility of either prohibiting certain noise-generating activities during nighttime hours or providing additional noise-control measures to meet these noise limits. Noise-control for nighttime or daytime work could include the following measures, as necessary, to meet required noise limits:

- install construction site sound walls by noise-sensitive receivers
- during nighttime work, use smart backup alarms that automatically adjust or lower the alarm level or tone based on the background noise level
- use low-noise emission equipment
- implement noise-deadening measures for truck loading and operations
- conduct monitoring and maintenance of equipment to meet noise limits
- use lined or covered storage bins, conveyors and chutes with sound-deadening material
- use acoustic enclosures, shields or shrouds for equipment and facilities

- install high-grade engine exhaust silencers and engine-casing sound insulation
- prohibit nighttime aboveground jack-hammering and impact pile-driving
- minimize the use of generators or use whisper-quiet generators to power equipment
- limit the use of public address systems
- use movable noise barriers at the source of the construction noise
- focus on pile-driving mitigation measures that limit the time of day the activity can occur.

9.4. Construction Vibration

Measures to minimize short-term annoyance from construction vibration include the use of alternative methods with less vibration, such as drilled shafts in place of driven piles, or the use of static roller compactors rather than vibratory roller compactors. Activities with potential for short-term annoyance could also be restricted to shorter periods and daytime hours, when vibrations and noise are less noticeable. Other construction vibration-related mitigation could include the following as part of the project specifications:

- **Preconstruction survey.** Before construction begins, a survey of buildings directly adjacent to the alignment and fragile structures within approximately 200 feet of the alignment should be completed. The survey should include foundation inspections and photographs, and should be expanded for fragile or sensitive structures.

- **Vibration limits.** Construction vibration specification should limit construction vibration to a maximum of 0.5 in./sec at the foundation of structures adjacent to the alignment, with fragile or sensitive structures limited to 0.12 in./sec. The use of high-vibration construction equipment should be limited near sensitive receivers such as residences, schools and hospitals.

- **Vibration monitoring.** Vibration monitoring should occur at any buildings that the preconstruction survey identifies as very fragile and where the lowest construction vibration limit is applicable. Where pile-driving is employed near fragile structures, test piles should be monitored before starting production pile-driving to make sure that vibration will not damage the structure.

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