FINAL REPORT

On Project 25-34
Supplemental Guidance on the Application of FHWA's Traffic Noise Model (TNM)

APPENDIX H
Ground Zones

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Appendix H Ground Zones

When ground surfaces other than the default ground intervene between roadway and receivers, ground zones are used to model those other ground surfaces. Several questions always arise concerning the location and size of these ground zones:

- **Location:** Are ground zones needed more (1) towards the middle of the propagation path, or (2) towards the ends near the roadway and receivers?
- **General size:** Are ground zones needed for very small patches of non-default ground patches such as suburban sidewalks and driveways?
- **Precise coordinates:** How precisely must ground zone coordinates be input, to achieve reasonably precise sound levels?

This appendix documents a series of TNM sensitivity computations designed to answer these three questions.

H.1 Sensitivity to ground-zone location and size

We first investigated the sound-level effect of ground zones, as a function of their location and size, using the *Automated TNM Sensitivity Tool* (see Section 1 of the Topography Appendix).

For simplicity, we confined our computations to:

- A single at-grade roadway and receivers on flat ground
- A pavement ground zone on default lawn.

In comparison with most other uses of the sensitivity tool on this project, here we are not seeking sound-level sensitivity to small changes in input. Instead, we are seeking sound-level differences *with* and *without* the ground zone. This we do by specifying a very large plus/minus offset increment. In essence, the ground-zone position with the *minus* offset intervenes between roadway and receivers, whereas with the *plus* offset it is out of the way, where it will not influence sound levels.

H.1.1 The input geometry

Figure 1 contains the TNM cross-sectional geometry for these computations, with the plan view just below it. In the cross section, to the left is a TNM roadway and adjacent barrier, with the receivers extending to the right over default lawn.

To the far right in the figure is a pavement ground zone, at its actual input position. Using a large offset value, the sensitivity tool makes two TNM computations: (1) a *minus-offset* computation, which positions the ground zone far to the left (as shown near the barrier), and (2) a *plus-offset* computation, which positions it completely out of the way to the extreme right. As a result of this process, the minus-offset computation is "with" ground zone, while the plus-offset computation is "without" ground zone. So the ΔL_{eq} due to this change in ground-zone position (ΔGZposition) is the sound-level increase due to the ground zone.

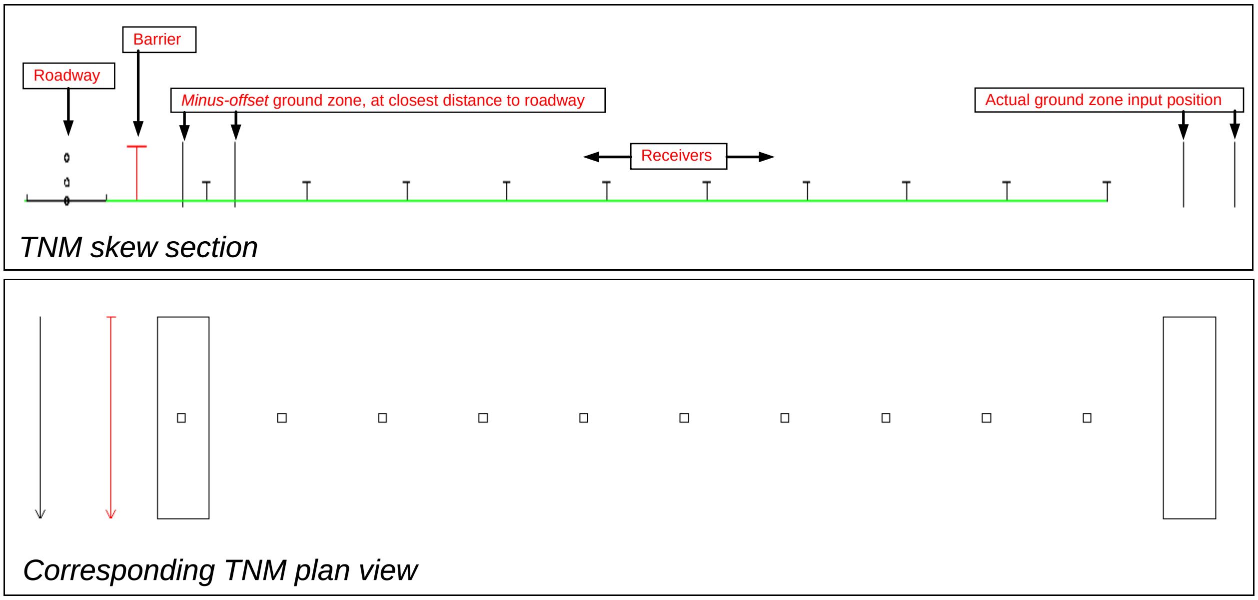

Figure 1 Cross section and plan view for TNM computations

In all, we ran this set of sensitivity tests for the following receivers:

- 10 receiver distances: 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 feet from the near edge of shoulder—all at a 5-foot height.

For the sensitivity computations, we then included:

- 7 ground-zone widths: 12, 25, 50, 75, 100, 150 and 200 feet
- 5 ground-zone (centerline) positions: 50, 150, 250, 350 and 450 feet
- for a total of 35 ground zone width-position combinations. However, some of these combinations would have caused the ground zone to overlap (encompass) the barrier and/or the roadway. So those were extracted from the input sheet before computation, leaving 24 valid width-position combinations.
- 2 barrier heights: 0 and 15 feet
- 3 roadway widths: 40, 50 and 60 feet in synchrony with 3 corresponding roadway centerline positions, to keep the near edge of shoulder unmoved
- 3 traffic conditions: All automobiles, then all medium trucks, then all heavy trucks.

These input values led to (24)(2)(3)(3) equals 432 distinct geometries, each run twice "with" and "without" the ground zone in the propagation path. In turn, these 432 geometries combined with the 10 receivers to produce 4,320 computation combinations.

Figure 2 shows these computation combinations within Excel's Sensitivity Spreadsheet. As seen in the figure:

- Columns 1 and 2 contain the 10 receiver distances, with each receiver at height 5 feet.
- Column 3 contains the distance coordinates of the ground zone's four points, located in its TNM input position (its far right position in Figure 1). These four points vary in synchrony, because their column index is the same. The distance "difference" between these points is the ground-zone width, while the average distance is the ground-zone centroid position. For all four points, the offset parameter is 500 feet.

- Column 4 contains the barrier height at its two end points. These end points vary in synchrony, because their column index is the same.
- Column 5 contains the roadway parameters: End-point positions and corresponding width, in synchrony.
- Column 6 contains the synchronous traffic.

Receivers: Check that Cols B,C on Comps sheet reproduce TNM's receiver order.		Ground Zone Types and Flow Control Devices: If you are entering these here, see the notes below the yellow cells.														
1	2	3	3	3	3	4	4	5	5	5	6	6	6	6	6	6
		GZnY1	GZnY2	GZnY3	GZnY4	BarrHt1	BarrHt2	RdPt1	RdPt2	RdWidth	AUVol	AUSpd	MTVol	MTSpd	HTVol	HTSpd
		TInGround	TInGround	TInGround	TInGround	TInBarr	TInBarr	TInRoad	TInRoad	TInRoad	TInTraf	TInTraf	TInTraf	TInTraf	TInTraf	TInTraf
		K12	K13	K14	K15	T12	T13	K12	K13	F12	I12	J12	K12	L12	M12	N12
		500	500	500	500											
Distance or Height (#s, only)	Height or Distance (#s, only)															
50	5	562	562	538	538	0	0	-20	-20	40	100	50	0	0	0	0
100		575	575	525	525	15	15	-25	-25	50	0	0	100	50	0	0
150		662	662	638	638			-30	-30	60	0	0	0	0	100	50
200		675	675	625	625											
250		701	701	601	601											
300		751	751	551	551											
350		762	762	738	738											
400		775	775	725	725											
450		801	801	701	701											
500		851	851	651	651											
		901	901	601	601											
		951	951	551	551											
		862	862	838	838											
		875	875	825	825											
		901	901	801	801											
		951	951	751	751											
		1001	1001	701	701											
		1051	1051	651	651											
		962	962	938	938											
		975	975	925	925											
		1001	1001	901	901											
		1051	1051	851	851											
		1101	1101	801	801											
		1151	1151	751	751											
4,320	= number of input combinations from above (max = 5,000)															
432	= number of computation loops (ignores number of receivers)															

Figure 2 TNM Input combinations within Excel: With and without ground zones

H.1.2 Resulting dependence on receiver distance

As discussed above, computation results consist of the sound-level increase due to the ground zone, separately for each of the 4,320 combinations of receiver distance, ground-zone location and width, barrier height, roadway width, roadway centerline position, and vehicle type.

Figure 3 plots that computed sound-level increase against receiver distance. As shown, the increase due to the ground zone grows larger with increasing receiver distance. That happens because receivers at larger distances have more soft-ground attenuation to lose, due to the intervening (pavement) ground zone.

The upper bound of these points corresponds to a complete loss of soft-ground attenuation. For the points below that upper bound, the ground zone has not lost all of the soft-ground attenuation either because the ground zone is narrow or because it is centered at an ineffective position between roadway and receiver.

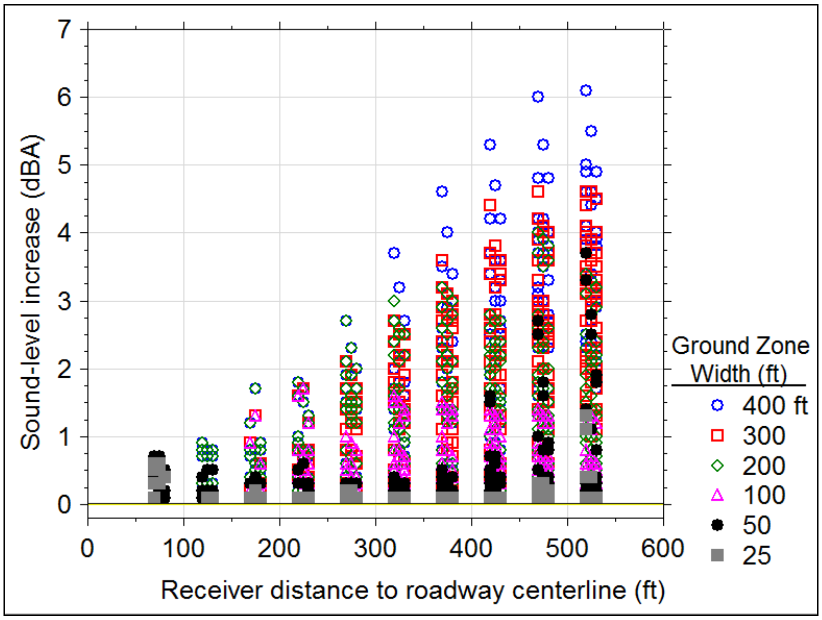

Figure 3 Computed sound-level increases

H.1.3 Resulting dependence upon "bounce" location of the propagation path

To better show the combined effect of ground-zone width and location, we reasoned as follows. We strongly suspect that a ground zone influences sound levels most if the propagation path bounces off the ground within (or very nearby) the ground zone.

To plot this expected effect, we added a "bounce" distance variable to the resulting sensitivity spreadsheet. This variable quantifies (1) how close the bounce point is to the ground-zone boundary and (2) whether that bounce point is inside or outside the ground zone.

Figure 4 shows the computation geometry. In that figure:

- Images below the ground are included only to locate the two bounce points:
  - **Without an** intervening **barrier**, the upper-subsource image bounce point is used.
  - **With an intervening barrier**, the barrier-top image bounce point is used, instead.
- The bounce distance is always measured from the ***closer*** of the two ground-zone boundaries (thereby making it the *shorter* distance to the default-ground surface).
- Bounce distances are plotted ***positive inside*** (and ***negative outside***) the ground zone, to distinguish these two bounce regions.

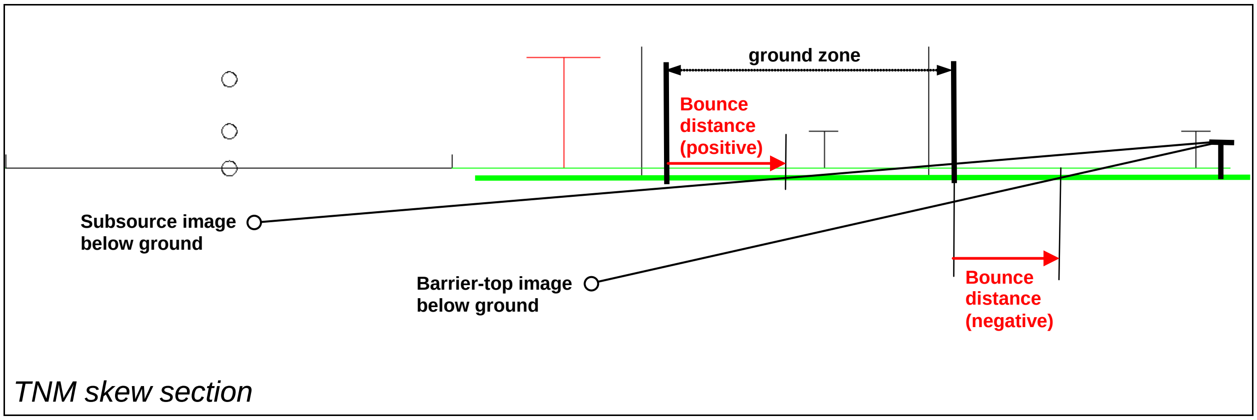

Figure 4 Defining geometry for Bounce Distance (see text for further explanation)

We then investigated several plots for the ground zone's "bounce" dependence. The most informative plot appears as Figure 5.

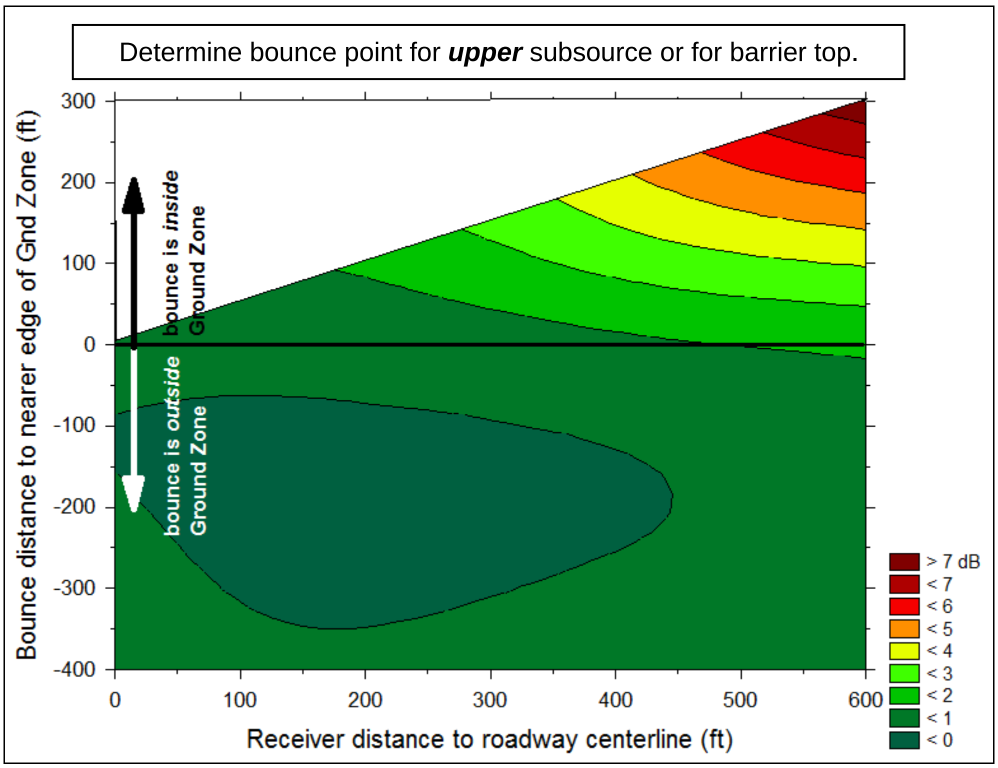

Figure 5 Sound-level increase due to ground zone

In this figure, the contour regions show the effect of the pavement ground zone, as a function of two variables:

- Horizontal variable: The receiver distance to the roadway centerline.
- Vertical variable: The bounce distance to the nearer edge of the ground zones—where the arrows and words within the plot zone are a reminder of that distance's sign convention.

The upper-left portion of the contour plot is blanked out. That is necessary because (1) the ground-zone width cannot be greater than the receiver distance, and therefore (2) the bounce distance (to the nearer ground-zone edge) cannot be greater than *half* the receiver distance.

In the figure, note that the contour key identifies contour *regions*, rather than contour *lines* separating those regions. For example, the fifth entry in the key (for the yellow region) is labeled "< 4 dB." Therefore that region's lower boundary is 3 dB and its upper boundary is 4 dB.

This plot shows only minor sound-level increase when the bounce occurs outside the ground zone.[1] In contrast, when the bounce is inside the ground zone, the sound-level effect increases strongly as the bounce point moves further and further away from the default ground.

H.1.4 Resulting dependence upon ground-zone width and location

We next wish to simplify these results, so the TNM user does not have to determine these bounce points. After several non-informative tries, we settled upon plotting the ground-zone effect as a function of two variables:

- Ground-zone width, as a *percentage* of receiver distance
- Ground-zone centroid distance from the roadway, also as a *percentage* of receiver distance.

These two percentage distances derive from the geometry in Figure 6.

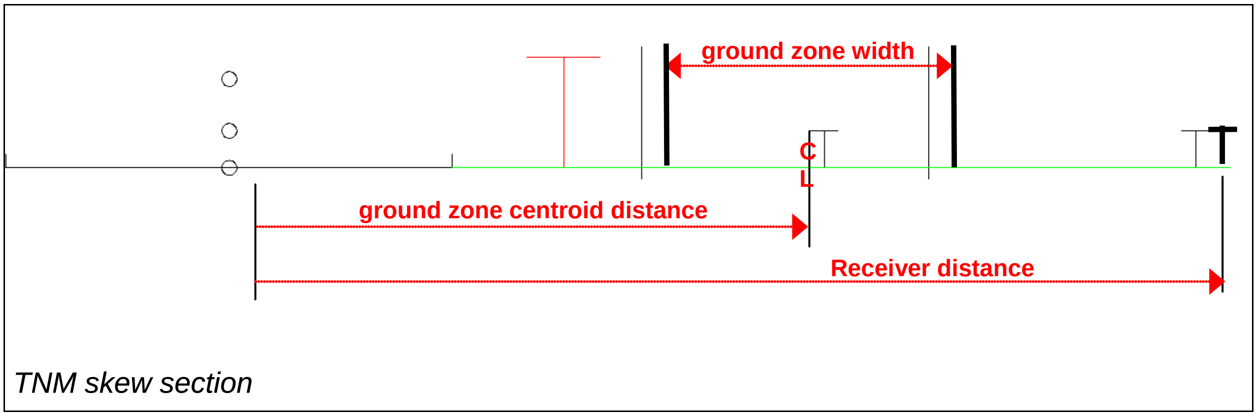

Figure 6 Defining geometry for percentage variables

A contour map of the resulting sound-level increase, against these two variables, appears in Figure 7. In this figure, both the horizontal and vertical parameters are percentages. And so is the contoured sound-level increase a percentage of the "maximum possible increase." That maximum possible increase must be determined by the TNM user. Two options are available: (1) the ground zone can be temporarily enlarged to provide full coverage between roadway and receiver, or (2) the default ground type can be temporarily changed to the ground zone's type.

[1] From the acoustics of the situation, this increase occurs because sound propagates as a spherical wavefront, not as just that wavefront's centerline "ray." So when the wavefront's centerline ray bounces just outside the ground zone, actually a good part of the spherical wavefront hits the ground zone. In effect, the wavefront "spills over," in both directions along the ground, from the ray's geometric reflection point. The acoustics within TNM automatically takes this into account.

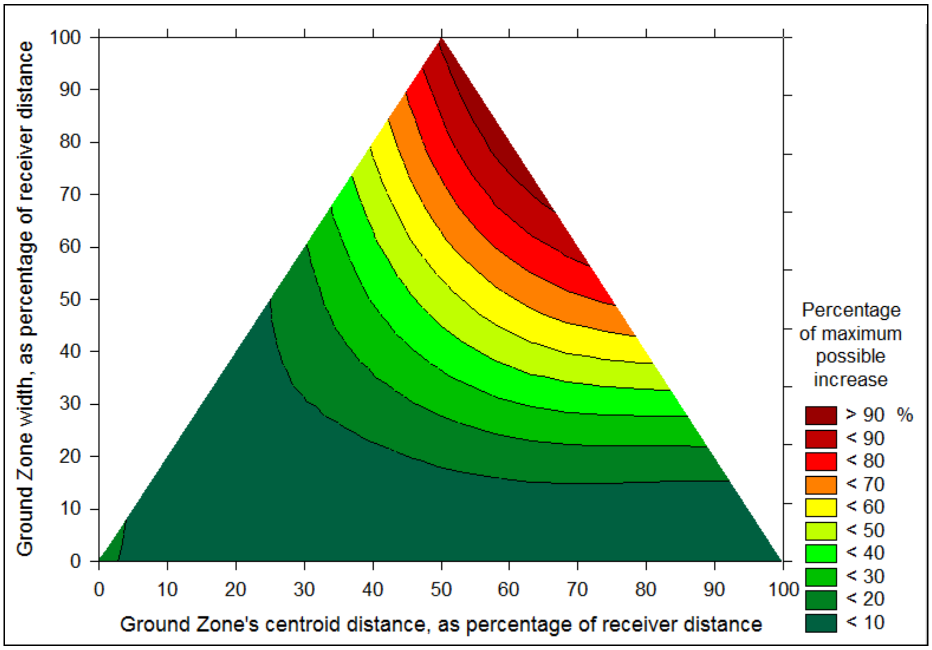

Figure 7 Sound-level increase due to ground zone (as percentage of maximum possible)

As this figure shows, the most effective ground zones are the *wide ones* that are also *located towards the midpoint* (50 percent position) between roadway and receiver.

Note that the contour zones in the figure, however, are not symmetric right and left. Instead, the peak effect occurs more towards the receivers than at the midpoint. That peak's shift towards the receivers happens because the receiver heights are lower than the source heights (heavy-truck subsource and/or barrier top). Those lower receiver heights generally cause the bounce point to lie closer to the receivers than to the roadway.

H.1.5 Implications concerning very small ground zones

In Figure 7, the bottom contour portions (below 20% or so on the vertical axis) pertain to very small ground zones.

For example, when the maximum possible increase is 5 dB, then the contour regions of 10% and 20% correspond to increases of 0.5 and 1.0 dB, respectively. Those two contour zones extend upwards to 20% on the vertical scale. And so for the ground-zone increase to be larger than 1 dB here, the zone would have to cover more than 20% of the distance from source to receiver.

As is obvious from this example, small ground zones are not needed for small patches of non-default ground patches such as suburban sidewalks and driveways.

H.1.6 Generalization to other situations

As stated above, these sensitivity computations assumed a single roadway, flat intervening ground, and a pavement ground zone laid on default lawn. Further, the computations used just a short roadway segment, 100 feet long, instead of a very long roadway. In addition, they included only 5-foot receivers.

To use Figure 7 in more general situations:

- When there are multiple TNM roadways, generally consider only the closest travel lanes.
- When the ground is not flat, use the figure as it is.
- When ground types differ, take that into account when determining the "maximum possible increase." Moreover, when the ground zone is more absorptive than the default ground, substitute "decrease" for "increase" in everything above.
- When the roadway is longer, use the figure to estimate the sound-level increase from just a portion of the roadway that is, the roadway portion affected by the intervening ground zone.
- When receivers are higher than 5 feet, skew the figure's contours towards the roadway somewhat, away from the receivers.

In general, ground zones are needed more towards the middle of the propagation path, in the area where the sound ray bounces off the ground towards the receivers. In general they are needed in this central area, as long as they cover more than 10-to-20 percent of the source-receiver distance.

H.2 Sensitivity test for coordinate precision

H.2.1 The input geometry

For most of the same geometries as above, we conducted sensitivity computations to determine how precisely ground-zone coordinates must be input into TNM. In particular, we computed the combinations shown in Figure 8.

Receivers: Check that Cols B,C on Comps sheet reproduce TNM's receiver order.

Ground Zone Types and Flow Control Devices: If you are entering these here, see the notes below the yellow cells.

1 Distance or Height (#s, only)	2 Height or Distance (#s, only)	3 GZnY1 TInGround K12 5	3 GZnY2 TInGround K13 5	3 GZnY3 TInGround K14	3 GZnY4 TInGround K15	4 BarrHt1 TInBarr T12	4 BarrHt2 TInBarr T13	5 RdPt1 TInRoad K12	5 RdPt2 TInRoad K13	5 RdWidth TInRoad F12	6 AUVol TInTraf I12	6 AUSpd TInTraf J12	6 MTVol TInTraf K12	6 MTSpd TInTraf L12	6 HTVol TInTraf M12	6 HTSpd TInTraf N12
100	5	62	62	38	38	0	0	-20	-20	40	100	50	0	0	0	0
150		75	75	25	25	15	15	-25	-25	50	0	0	100	50	0	0
200		162	162	138	138			-30	-30	60	0	0	0	0	100	50
250		175	175	125	125											
300		201	201	101	101											
350		251	251	51	51											
400		262	262	238	238											
450		275	275	225	225											
		301	301	201	201											
		351	351	151	151											
		401	401	101	101											
		451	451	51	51											
		362	362	338	338											
		375	375	325	325											
		401	401	301	301											
		451	451	251	251											
		501	501	201	201											
		551	551	151	151											
		462	462	438	438											
		475	475	425	425											
		501	501	401	401											
		551	551	351	351											
		601	601	301	301											
		651	651	251	251											

3,456 = number of input combinations from above (max = 5,000)
432 = number of computation loops (ignores number of receivers)

Figure 8 TNM Input combinations within Excel: Sensitivity to ground-zone width

Compared to Figure 2, this current figure shows the ground zones located at their *actual* positions, with their width perturbed higher and lower by 5 feet.

H.2.2 Results

For all these computations, we never obtained more than a 0.3 decibel change due to these 10-foot swings in ground-zone width. This included many situations in which the ground-zone offset changed the ray's "bounce point" from "inside" to "outside" the ground zone, and vice versa.

Because of this, we conclude that sound-level changes caused by ground zones are very *insensitive* to the precise size and location of the zone. For example, it might take a width change of 30 feet to cause a 1-decibel change in the ground zone's effect and then only under the most critical input geometry. High input precision for ground zones is simply never needed.

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