Evaluation of Highway

Noise Mitigation Alternatives

For Vail Colorado

Final Report

October 2005

Prepared for

TOWN OF VAIL

Vail, Colorado

Prepared by

HANKARD ENVIRONMENTAL

ACOUSTICS AND VIBRATION CONSULTING

Fort Collins, Colorado

1.0 Introduction

This report describes the options available to reduce noise from Interstate 70 through Vail Colorado. This study was commissioned by the Town of Vail, which has been investigating the noise issue for many years. There are a number of complexities involved with the implementation of highway noise mitigation measures, including the length of the study area (8 miles), the extreme topography and weather in Vail, Colorado Department of Transportation (CDOT) and Federal Highway Administration (FHWA) regulations, safety and maintenance concerns, aesthetics, and cost. Understanding of the issue is aided by dividing the list of available mitigation measures into three categories: "source", "path", and "receiver". As illustrated in Figure 1-1, the source is traffic traveling on the highway and frontage roads. The path is the land between the highway and adjacent residences and parks. The residences and parks are the receivers. Table 1-1 lists the available highway noise mitigations measures using this categorization.

As described in Section 2, Source Controls reduce the amount of noise that is generated in the first place. As a result, they benefit almost everyone, regardless of location. For example, reducing speeds and/or putting down quiet pavement reduces noise at ALL homes and businesses in Town, versus a wall that benefits only those located directly behind it or thicker windows that only benefit an individual property. The cons of source controls are that each only provides only a few dB of reduction, they are costly, and they require continued cooperation from the public and/or government agencies.

As described in Section 3, Path Controls benefit a given area, such as a neighborhood. For walls and berms, the extent of the benefited area depends on their height and length and on topography. Barriers typically range in height from 3 to 25 feet, and can be hundreds to thousands of feet long. A 15-foot tall wall typically provides 5 to 10 dBA of noise reduction, depending on topography and distance. The cons of building barriers, particularly walls, are aesthetics, cost, and the rigors of CDOT coordination. The most effective path control is a tunnel, which would virtually eliminate highway noise along adjacent stretches. However, ventilation and portal noise would need to be addressed. Building a tunnel is, obviously, a major undertaking with a host of issues associated with it.

Receiver Controls are described in Section 4. For developed properties, these include the construction of solid fences on private property, the rearrangement of outdoor use areas such as patios, and the installation of better windows. Such measures are effective, but only benefit individual properties and are the responsibility of the property owner. For new (re)developments, recommendations are provided regarding how noise can be considered early in the planning and design process as to minimize conflicts in the first place.

A summary of recommended noise mitigation measures is provided in Section 5. In order to effectively mitigate noise in Vail, a number of measures will need to be pursued simultaneously, including speed reduction, pavement changes, barriers, and improvements to the planning processing for proposed (re)developments.

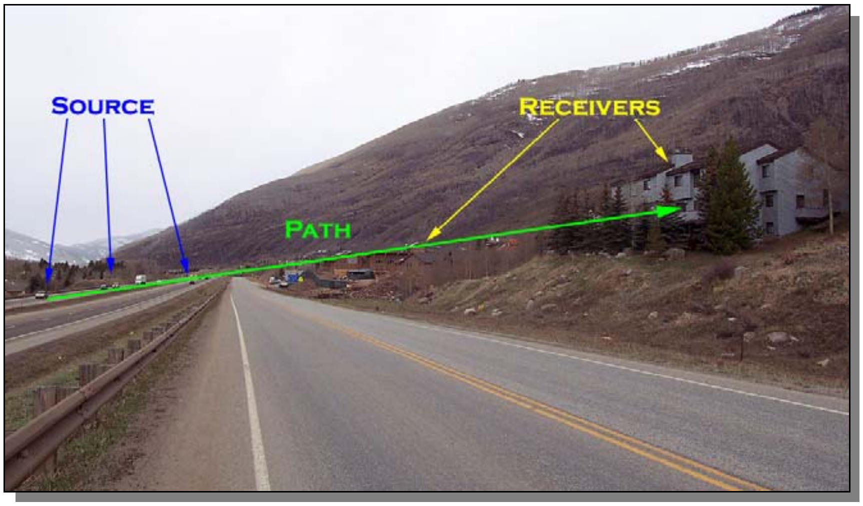


Figure 1-1
Breakdown of Available Highway Noise Mitigation Measures

Table 1-1
Available Highway Noise Mitigation Measures

Source Control Measures	❖ Reduce speeds ❖ Install low-noise pavement ❖ Modify tires, reduce engine/exhaust noise
Path Control Measures	❖ Construct barriers (berms/wall) along highway/frontage roads ❖ Construct tunnel
Receiver Control Measures	❖ Construct barriers (walls, berms) on affected property ❖ Re-arrange existing site use ❖ Acoustically insulate structures ❖ Consider noise in the layout of (re)developments ❖ Consider noise early in the design of buildings within (re)developments

2.0 Source Noise Controls

It is almost always best from a noise-reduction standpoint to mitigate noise at the source, i.e. before it ever gets into the environment. For *cars* traveling at highway speeds, almost all of the noise generated is the result of interaction between tires and the roadway surface. For *trucks* traveling at highways speeds, noise is generated from a combination of the tire-roadway interaction, the engine, and the exhaust. Therefore, available noise reduction measures include:

- Speed reduction
- Changes to pavement type
- Changes tire tread design
- Truck engine and exhaust modifications

Recommendations for the implementation of each of these controls in Vail are provided below. Note that source controls benefit almost all of the receptors in Town. Therefore, they are particularly important to those areas where path and receiver controls are not possible (e.g. for residences located above the highway).

Reduce Speeds on I-70/Frontage Roads

The speed/noise measurements conducted as part of this study indicate that the current speed reduction program has produced a slight reduction in noise levels (~1 dBA). However, it must be noted that the measured data is rather inconclusive due to the complexities involved. Nonetheless, based on known acoustic principals it can be assumed that a 5 mph decrease in speed would result in a noise reduction 0.5 to 1 dBA, and a 10 mph reduction in speed would result in a noise reduction of approximately 1.5 dBA. This assumes that ALL vehicles reduce their speed at ALL times on both I-70 AND the frontage road.

We conducted research in an attempt to locate reports from other states and communities who have implemented speed reduction programs. Most of the information we found related to traffic calming techniques, such as speed bumps. Some of the more relevant data we found was in regard to the effectiveness of photo radar systems. See Attachment B for a summary from the journal US Roads. One thing that is apparent from the literature is that more and more communities are relying on photo radar for speed enforcement, and some reports claim that it is the only way to obtain true, long-lasting speed reduction.

Anecdotally speaking, we believe that in order to produce a continuous, long-term reduction in speed on I-70 of at least 5 mph, a concerted effort of police patrols, signage, and education would need to be implemented. Local and visiting drivers need to know that one doesn't speed through Vail, much as East-coasters know not to speed on I-95 through Connecticut and Coloradoans know not to speed through Empire.

One possible scenario would be one full-time police officer providing 20 hours per week of patrols, "your speed" and other signs at approximately 5 locations (two coming into each end of Town and one somewhere in between), and the existing level of public outreach continued year to year. Responsibility for this lies with the Town of Vail. CDOT coordination would be required for signs, but this is expected to be fairly straightforward. The estimated cost of this is $25k for the signs, $65k per year for the officer, and $5k per year for the education/outreach program. Note that the officer and outreach costs are recurring.

Change Pavement Type on I-70

Research and testing of "low noise" or "quiet" pavements is ongoing in Europe, at the Federal level in the U.S., and within CDOT. The research is aimed at determining if certain concrete and asphalt pavements produce less noise than others, whether or not the reduction lasts over time, and if the "quiet" pavements are as safe and durable as the pavements in use today.

Results from across the U.S. indicate that certain pavements could provide a noise reduction of 2 to 4 dBA versus CDOT's typical Superpave mix, at least initially. There pavements include Stone Mastic Asphalt (SMA), open-graded friction course (OGFC), rubberized, and others such as NovaChip.

CDOT's pavement selection process is based primarily on safety concerns and on the results of a life-cycle cost analysis. In order to be considered, a low noise pavement would need to be shown to be safe, durable, and provide a long lasting noise reduction. A test section of OGFC recently failed on I-70 near the Chief Hosa exit due to safety issues, and is likely out of contention for near-term use in the High Country. However, there was no change in the accident rate at an adjacent SMA test section, which is the most promising mix for Vail. CDOT seems to have a good degree of confidence in SMA, based on the presentation CDOT gave at the pavement noise meeting in Eagle in June. Based on research and testing conducted by CDOT and others, the lowest noise levels are achieved when using a small aggregate size in the mix (3/8" or ½", versus ¾"). We recommend that the Town of Vail continue to work with CDOT to ensure that a small aggregate SMA or Superpave is considered/used for the I-70 overlay that is schedule for Vail in 2007.

Modify Tires, Truck Engines, and Truck Exhausts

These three control measures are discussed together because all are, for the most part, outside the control of the Town of Vail. The Federal Government currently regulates the amount of noise that new cars and trucks emit. The limits were set in concert with feasible mitigation practices. That is, they were specified as not to place undue hardship on vehicle manufacturers. Currently there are no regulations in the U.S. that control tire noise. Europe recently introduced such legislation. Thus Vail's only recourse would be lobbying-type efforts.

Modify Tires

As discussed above for pavement type, it is the interaction of the tires and roadway that generates almost all automobile noise and some of truck noise. Research is ongoing in Europe and the United States to determine the properties of tires that influence noise, and how these properties can be modified. As of this writing, FHWA recently initiated two research efforts aimed at better understanding truck tire/roadway noise, and truck noise in general. In other efforts, a coast-by method for the measurement of tire sound emission has been adopted by several organizations as the standard for measurement of tire sound emissions, including ISO 13325:2003 and UNECE – Transport Division – World Forum for Harmonization of Vehicle Regulations. Regulation No. 51 (Informal Document 4, 35th GRB).

Two test methods are being employed; one using vehicles alone and one using a test trailer. The trailer test is thought to give a result that is more specific to tire noise, while the vehicle test is known to be influenced by vehicle propulsion noise as well. There are provisions in the standard for both passenger cars and trucks. Measurement results are currently being collected by agencies around the world and assembled into a database. It will establish current conditions of tire/road noise emissions. From this standards can be determined. The United States is part of this effort through the Society of Automotive Engineers. The last meeting of the group was in December of 2004.

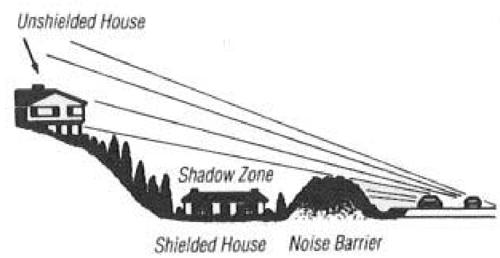
Given that research is just getting underway, it is safe to assume that there are no tire-tread noise regulations on the immediate horizon for the U.S.

Modify Truck Engines and Exhausts

In 2000, the State of Colorado enacted a law requiring all commercial vehicles equipped with an engine brake to have an adequate muffler in constant operation and properly maintained, or face a $500 fine. Inspections are conducted as part of routine safety checks. The Colorado Motor Carriers Association conducted a test in Vail where two identical trucks were driven at highway speeds through Town and applied their engine brake. One truck had a standard muffler, and there was no audible braking noise. The other's muffler was disconnected and a very loud, noticeable braking sound was heard along the highway. The CMCA makes the point that all new trucks have engine brakes, that the brakes are an integral part of the truck and its safety, and that the most prudent course of action is to ensure that proper mufflers are installed and maintained. We agree.

3.0 Path Controls

Once noise is produced by the source, i.e. traffic, it begins to propagate outward. When the propagating sound waves encounter a barrier, some of the sound energy is absorbed by the barrier, some is reflected backward, and some is diffracted over the top of the barrier. A typical 15 foot tall highway noise wall achieves 5 to 10 dBA of reduction at receivers within 300 feet of the wall. Less reduction is obtained at receivers located further than 300 feet or those elevated above the highway. Barriers in use today range in height from 3 feet (i.e. a CDOT Type 7 safety barrier) to 20 feet tall (20 to 30 foot tall walls are uncommon, but do exist). Barriers can be vertical concrete walls, earthen berms, or some combination thereof. A tunnel can be thought of as "the ultimate noise barrier", as it blocks all of the noise (except at portals as discussed below).



The amount of noise reduction that a barrier will achieve is the result of the relationship between the height of the barrier with respect to the surrounding topography, the relative location of all roads and receivers, ground type, and traffic conditions. This situation is very complex in Vail due to the variation in terrain along the length of the study area (8 miles). To analyze barrier effectiveness in Vail, three thorough surveys of the Town and surrounding land use and topography were conducted. Twenty-one areas were identified for analysis, and an aerial view of each is provided in Attachment C. The software model STAMINA, which is relatively accurate and is used by most state and federal agencies, was used to predict the effectiveness of various barrier scenarios for each area. The analysis took into account topography, traffic on the Frontage Roads, receiver elevation, etc.

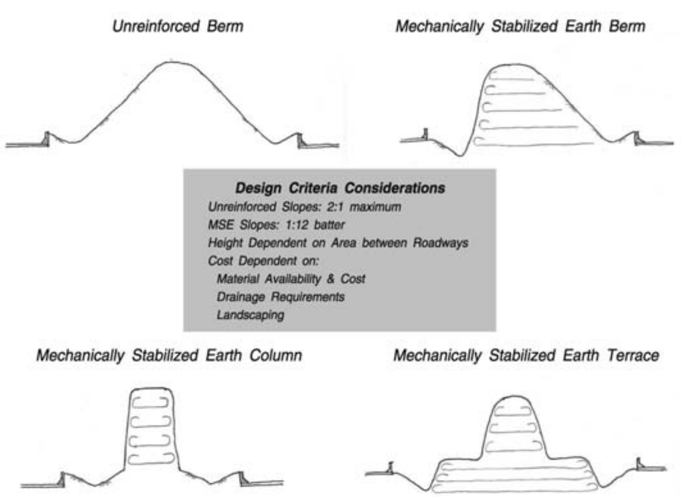
A summary of each barrier type and the areas where each is recommended for consideration is provided below. This is followed by a summary of the recommendations at each area. Detailed noise prediction results are provided in Attachment D.

"Sand Storage Berms"

Over the past few years, the Town of Vail has worked cooperatively with CDOT to construct sand storage berms at a number of locations along I-70. This is a win-win situation, as Vail is desirous of noise mitigation, and CDOT needs a place to dispose of sand. Berms require slopes on each side ranging from 2:1 to 3:1. Therefore, a 15-foot tall berm needs a footprint of 60 to 90 feet. This amount of land area is generally only available in the East Vail area. Sand storage berms are recommended for consideration in Areas G-1, G-4, K-1, L, N, O-1, O-4, and O-5, as shown in the figures in Attachment C.

Solid Safety Barriers

Much of the noise from vehicle traffic comes from the interaction of the tire and the pavement. Therefore, in certain areas where residences are below the elevation of the highway, even a relatively short (height-wise) barrier will provide some noise reduction. CDOT's 3-foot tall Type 7 Solid Safety Rail, which the Department uses regularly on its roadways, would be a logical choice as it meets current safety standards. For those areas where open guardrail currently exists, the Town could consider petitioning CDOT to replace it with solid rail when it is due for major maintenance, and perhaps only pay the cost differential. Alternatively, the Town could petition CDOT to replace existing open rail with solid rail immediately, or install solid rail where none exists currently. In this case it is anticipated that the Town would need to pay the entire cost. Type 7 barrier costs approximately $50 per foot (installed). Sites will require anywhere from 500 to 2,000 linear feet, at a resulting cost of $25k to $100k per site. Aesthetics should also be considered, as Type 7 rail does tend to become chipped and marred over time. Type 7 barriers are recommended for consideration in Areas A, D, and O-2, as shown in the figures in Attachment C.



Steepened Slope Berms

There may be some areas where a 3 to 10 foot tall barrier is needed to provide any significant noise reduction, yet there is not enough room for a berm with the standard slopes of 3:1 or even 2:1, and a concrete wall would be too obtrusive or otherwise infeasible. In these areas, a soil-reinforced steepened earth berm combined with a Type 7 barrier shape on the traffic-side (where necessary) provides a possible solution. Steepened slope berms are recommended for consideration in Areas O-1 and O-2.

Noise Walls

Vertical walls require very little footprint and they provide between 5 and 15 dB of noise reduction. In this sense they are a feasible mitigation option in Vail. The detractions are cost and aesthetics. Depending on the design, a 2,000-foot long, 15-foot tall concrete wall costs approximately $1,000,000. The aesthetics of walls have improved greatly in the past view years. A few sample pictures of walls from Europe, the United States, and Asia are provided in Attachment E.

Based on a number of tours we conducted of the Town, we believe that Areas D and G-1 are the most suitable sites to consider noise walls. As discussed below, the most prudent location for a barrier for each of these areas is within CDOT's right of way. As a result, each wall will need to comply with CDOT's Policy Directive 1900. A synopsis of this and how it applies to Vail is provided below. This is followed by analysis results for each wall.

CDOT Policy Directive 1900
To be constructed within CDOT's right of way, locally sponsored walls need to meet the requirements of CDOT's Policy Directive 1900.0 (effective 12/18/03). This policy states that wall requests are considered appropriate transportation projects provided:

- The wall and all associated costs are locally funded
    - We assumed that Vail would fund the wall or seek non-CDOT funding

- The request is submitted by a local jurisdiction
    - Of which Vail is one

- The request has the support of the area Transportation Planning Region or MPO
    - Vail is within the Intermountain Transportation Planning Region

- There is no other feasible location for the wall off of CDOT's right of way
    - This is true for Areas D and G-1, as described below

- The wall meets the applicable sections of CDOT Noise Analysis and Abatement Guidelines (December 2002)
    - This is true for Areas D and G-1, as described below

- The wall must not impact future transportation alternatives
    - To our knowledge, the I-70 Mountain Corridor PEIS that CDOT is currently conducting does not include any major widening of I-70 in Vail with the exception of Area A

Area D Noise Wall Considerations
Area D consists of relatively densely spaced residences that are located, for the most part, below the elevation of the highway. In this case, the only reasonable location for the wall is on the shoulder of the highway (refer to the line labeled "futMIT D-11" in the Area D figure in Attachment C). The south side of the frontage road is not feasible due to local access and topography. The wall was analyzed for compliance with CDOT's noise guidelines. First, future loudest hour noise levels at front-row residences must equal or exceed 66 dBA. This is true for existing conditions, and levels will be a few dB higher in the future. Second, the wall must achieve at least 5 dB of noise reduction at front row (closest) receptors, and preferably 10 dB (this is difficult and not commonly achieved). STAMINA 2.0 was used to predict the noise reduction at each of the receptors shown in the figure. The model included frontage road traffic, which will not be mitigated by the wall. The model predicts that a 15-foot tall wall would achieve 5 to 6 dB of reduction at front row receptors, and a 20-foot tall wall would achieve 6 to 7 dB of reduction. This meets CDOT guidelines.

CDOT's noise guidelines also require that the wall be predicted to have a cost-benefit index of less than $4,000 per dB of reduction per benefited receptor. A benefited receptor is one where the wall is predicted to achieve at least 3 dB of reduction. CDOT calculates cost by multiplying the area of the wall by a wall construction cost index, which is currently $30 per square foot. Table 3-1 shows the calculations of cost-benefit for both a 15 ft. and 20 ft. tall wall. For the most part both walls meet the criterion. The exact number of benefited receptors may be higher or lower than that used in the analysis, and would need to be refined if this wall is to be pursued.

Table 3-1
Cost-Benefit Calculations For Noise Wall at Area D

	15 Foot Tall Wall	20 Foot Tall Wall
Length	4,100 ft	4,100 ft
Area	61,500 sqft	82,000 sqft
Cost ($30/sqft)	$1,845,000	$2,460,000
Number of Benefited Receptors	100	100
Average Noise Reduction	4.5	6.5
Cost/dB of Reduction/Receptor	$4,100	$3,780

Area G-1 Noise Wall Considerations
Area G-1 consists of relatively densely spaced residences that are elevated slightly above the highway, as shown in the figures in Attachment C. From a pure noise reduction standpoint, the wall (or berm) should be located on the north side of the frontage road. However, there are four access points into the apartments along there, which precludes a barrier. There is an existing berm on the west side of these residences that could be augmented to provide greater noise reduction. Also, we understand that this entire area may be redeveloped. If so, we strongly advocate that noise be considered during planning. One entrance would be preferable, and a berm or wall-berm combination could be built. Refer to Section 5 for more information on noise issues during planning.

This leaves the south side of the frontage road as the only feasible location for the wall, as shown as the line labeled "futMIT C-12" in the Area G-1 figure in Attachment C. The wall was analyzed for compliance with CDOT's noise guidelines. First, future loudest hour noise levels at front-row residences must equal or exceed 66 dBA. This is true for existing conditions, and levels will be a few dB higher in the future. Second, the wall must achieve at least 5 dB of noise reduction at front row (closest) receptors, and preferably 10 dB (this is difficult and not commonly achieved). STAMINA 2.0 was used to predict the noise reduction at each of the receptors shown in the figure. The model included frontage road traffic, which will not be mitigated by the wall. The model predicts that a 15-foot tall wall would achieve 4 to 5 dB of reduction at front row receptors, and a 20-foot tall wall would achieve 6 to 8 dB. Therefore, the wall would need to be at least approximately 18 feet tall to meet the 5 dB reduction criterion at all front row receptors.

CDOT's noise guidelines also require that the wall be predicted to have a cost-benefit of less than $4,000 per dB of reduction per benefited receptor. A benefited receptor is one where the wall is predicted to achieve at least 3 dB of reduction. CDOT calculates cost by multiplying the area of the wall by a wall construction cost index, which is currently $30 per square foot. Table 3-2 shows the calculations of cost-benefit for both a 15 ft. and 20 ft. tall wall. For the most part both walls meet the criterion. The exact number of benefited receptors may be higher or lower than that used in the analysis, and would need to be refined if this wall is to be pursued.

Table 3-2
Cost-Benefit Calculations For Noise Wall at Area G-2

	15 Foot Tall Wall	20 Foot Tall Wall
Length	2,500 ft	2,500 ft
Area	37,500 sqft	50,000 sqft
Cost ($30/sqft)	$562,500	$1,500,000
Number of Benefited Receptors	40	50
Average Noise Reduction	5	7
Cost/dB of Reduction/Receptor	$2,800	$4,300

Tunnel

A tunnel is an extremely effective noise barrier. Highway noise would be *completely* eliminated along both sides of the highway for the length of the tunnel. Noise levels would increase within a few hundred feet of the portals, however this could be treated effectively or the portals could be located in non noise sensitive areas. Noise from ventilation systems would need to be treated, but this too can be accomplished effectively.

There are, of course, many major ramifications to constructing a tunnel, such as CDOT/FHWA approval, funding, maintenance requirements, safety, public opinion, and many others. At the January 5, 2005 Town Council meeting attendees discussed that prior to conducting any sort of in-depth engineering feasibility study, the following issues need to be addressed: public opinion regarding the impact of development over the highway, maximum length of tunnel before staff and facilities are needed, and the ownership of air rights. The recent popularity of public-private partnerships was noted.

Path Mitigation Recommendations By Area

The Town was toured a number of times to determine what form of path treatments, i.e. barriers, might be effective and where. A software model of each area was constructed using STAMINA 2.0. The noise reduction that would be achieved by each of the following barriers was predicted at each site: a 3-foot tall Type 7 rail, 8 and 10-foot tall steepened slope barrier, and 15 and 20 foot tall noise walls. Figures showing the location of each Area under study and the location of the barriers modeled are included in Attachment C. Prediction results are listed in Attachment D. Table 3-3, below, summarizes the analysis results and mitigation recommendations for each area.

Table 3-3 – Path Treatment Analysis Results

Area	Analysis Results and Mitigation Recommendations
A	Type 7 along I-70 predicted to provide 2 dB of reduction at closest residences A 12' tall wall along I-70 is predicted to provide 5 to 8 dB of reduction
B	Not analyzed
C	Berm on private property modeled (C11) and shown to NOT provide significant reduction Barrier along Frontage Road modeled (C12) and shown to NOT provide significant reduction
D	Type 7 along I-70 predicted to provide <1 dB of reduction at closest residences A 15' tall wall along I-70 is predicted to provide 6 dB of reduction (wall site candidate) Short section of Type 7 along Frontage Road (D12) predicted to provide 4 dB of reduction
E	Barriers predicted to NOT provide significant reduction
F	Not analyzed – Good example of proper site planning
G-1	Berm on private property predicted to provide 6 dB of reduction at closest residences A 15' tall wall along I-70 is predicted to provide 6 of reduction (wall site candidate)
G-2	Not analyzed – limited outdoor use
G-3	A 15' tall wall is predicted to provide 5 dB of reduction, but only to a few residences For Sandstone Park, consider a wall along north side of Frontage Road
G-4	Not analyzed – Enhance berms on private property
G-5	Not analyzed – Construct fence along playground if desired
G-6	Not analyzed
I-1	Not analyzed – commercial land use
I-2	Not analyzed – high rise buildings would not benefit from barriers
I-3	Type 7 analyzed, but predicted to achieve only 1 dB of reduction – not recommended
I-4	Type 7 analyzed, but predicted to achieve only 1 dB of reduction – not recommended
I-5	Not analyzed – commercial land use
J-1	Downtown area shielded from I-70 and orientated away – no barriers recommended
J-2	Barriers predicted to NOT provide significant reduction
K-1	Barrier along I-70 NOT recommended Consider small berms and barriers near specific use areas such as the amphitheater
K-2	Barrier along I-70 NOT recommended due to limited benefit
K-3	Residences shielded by existing berm
K-4	Barrier along I-70 NOT recommended due to limited benefit and high cost
L	Consider additional sand storage berming
M-1	Berm constructed at Vail Mountain School (good site planning)
M-2	Low barriers NOT effective at residences
N	Consider additional sand storage berming
O-1	Consider additional berming Consider steepened slope berm
O-2	Consider Type 7 barrier
O-3	Barrier along I-70 NOT recommended due to limited benefit
O-4	Consider berming
O-5	Consider berming

4.0 Receiver Controls

Noise reduction can be achieved by making changes at receiver locations (i.e. residences). For outdoor activities, such as the use of a patio, some sort of a barrier can be erected that blocks the line of sight from the location of the outdoor activity to the highway and/or frontage roads. For indoor activities such as sleeping, mass can be added to walls and better windows installed. For new developments and redevelopments, noise should be considered early in the planning of the layout of a site, and structures should be designed so that interior noise levels are acceptable. The following information is provided for use by residents, planners, builders, etc.

Protecting Outdoor Use Areas With A Barrier

The amount of noise reduction that a barrier will provide is dependent on how well it blocks the line of sight between the source (i.e. the highway and frontage roads) and a receiver (e.g. a residence or park). The following steps should be taken when considering the construction of a barrier to reduce highway noise:

- Determine the area on the property where outdoor use regularly occurs, such as a patio, deck, or lawn.
- Consider if it might be more feasible to move the use area behind an existing structure where it will be shielded from the highway. It is understood that there may be overriding concerns such as view or sun.
- The appropriate height for a barrier is dependent on the relative locations of the outdoor use area in question, the ground where the wall will be placed, and I-70 (and frontage road if applicable). A good way to determine the necessary height is to place poles (e.g. PVC pipe) along the desired/most feasible barrier location. String a line between the poles and raise the line until it just breaks line of sight to the roadways of interest. A wall built to this height will achieve approximately 3 to 5 dB of reduction. This is generally considered the minimum desired reduction. Raise the line so that it is five feet above the minimum height. This will provide approximately 10 dB of noise reduction, which is generally considered very good.
- Wood walls in particular need to be sealed well. A typical one-sided privacy fence consisting of 1″ (nominal) thick slats tacked to horizontal rails is NOT a sufficient noise wall. Placing 1″ thick slats on both sides of the rails is better, but still not completely adequate due to the gaps between the slats. A better method is to place 1″ thick slats on the highway side of the rails, and line the inside (rail side) of these with ¾″ plywood. After installation, listen with one's ear placed close to the wall and caulk any seams where roadway noise is particularly audible. Place additional 1″ thick slats on the inside of the rails for finish if desired.

- Earthen berms are effective noise barriers. The height considerations are the same as those described for walls. Berms require 2:1 slopes at a minimum. Therefore they require more room. Also, they need to be landscaped per Vail's guidelines, and drainage and utilities must also be considered.

- Walls can be made from poured concrete and masonry (brick or block). A minimum thickness of 4" in necessary. See pictures of representative walls in Attachment E.

- Recent advances in noise wall materials have led to a new breed of clear walls. These walls are made from high durability plastics, and are available from a number of sources. This is of particular importance in order to preserve the view.

Reducing Interior Noise Levels At Existing Residences
Reducing highway noise inside a residence should be approached on a "weakest link in the chain" basis. Typically, the weakest link is windows, doors, and other wall penetrations such as stove vents, followed by walls.

- Single pane windows are not effective at reducing noise transmission. Double pane windows should be used at a minimum. The greater the thickness of the glass and the width of the space between the panes the greater the noise reduction. Widows must be well sealed also. Doors should be solid-core, well sealed/gasketed. Widows in the doors should be thick and well sealed, or double paned. Proper sealing of the edge can be difficult, and it is imperative that the door closes tight and uniformly.

- If noise is coming through solid walls mass needs to be added, and the easiest way to do this is typically to add layers of drywall.

Installing Sound Masking Systems
One way of reducing the annoyance of roadway noise is to install a sound masking system either inside or outside the home. A sound masking system can consist of commercially available sound generators, water features, or "white noise" being played over a home "stereo".

Reducing Exterior Noise Impacts In (Re)Developments
Many outdoor use areas such as patios and decks are less than enjoyable when traffic noise makes conversation difficult. It is understood that there are many constraints on the decision of where to put outdoor use areas within a development, such as the availability of land and the desire for a certain view. However, where possible, the following noise considerations should be weighed during the planning of new developments along I-70:

- Increase the distance between the use areas and the highway as much as possible; locate non noise-sensitive uses such as parking lots closer to the highway
- Place buildings between the highway and outdoor use areas, provided that buildings where people will live are properly designed to reduce interior noise (see below)
- Orient buildings such that patios and balconies face away from the highway

Reducing Interior Noise Impacts In (Re)Developments
As always, the best way to minimize noise impacts is to prevent them from occurring the first place. The following is a list of ideas that should be considered early in the design of new structures:

- Place non noise-sensitive areas such as bathrooms, closets, and hallways on the side of the building facing the highway
- Minimize the number of operable doors and windows on the highway side of the building
- Avoid penetrations in the exterior walls facing the highway, such as those needed for vents and plumbing

The Town of Vail has adopted the 2003 International Building Code, which requires exterior walls to exhibit a Sound Transmission Class (STC) of 50. An analysis was conducted where noise levels inside a typical building were calculated using maximum measured highway noise levels and an exterior wall STC of 50. The resulting interior noise levels were less than the Noise Criterion (NC) 30 curve, which defines adequate sleeping and resting noise levels. Therefore, the STC 50 requirement is adequate in Vail.

A second analysis was conducted where interior noise levels were calculated using the sound transmission loss of a typical double-glazed window. Windows are typically the "weakest link in the chain" in terms of how well a wall blocks noise. Again, the resulting interior noise levels were less than the Noise Criterion (NC) 30 curve. Therefore, an exterior wall with a STC 50 rating containing double-glazed windows will adequately reduce noise from I-70.

This, of course, assumes that all doors and windows are closed and are well gasketed, which is the case with most modern components. Care should be taken to ensure a good seal at the bottom of doors using a sweep.

5.0 Summary of Noise Mitigation Recommendations

- Consider implementing a long term speed reduction campaign consisting of "slow down" signs, additional police patrols, and public education/outreach

- Work with CDOT to ensure that some form of low-noise pavement is used for the 2007 overlay of I-70 (perhaps a small aggregate SMA)

- Support the efforts of the State in enforcing truck muffler requirements

- Continue to work with CDOT to construct more sand storage berms, specifically in Areas G-1, G-4, K-1, L, N, O-1, O-4, and O-5, as shown in the figures in Attachment C

- Consider working with CDOT to have Type 7 barriers installed in Areas A, D, O-2, as shown in the figures in Attachment C

- Further analyze the costs and other issues associated with constructing steepened slope berms in Areas O-1 and O-2, as shown in the figures in Attachment C

- If funding for a noise wall is pursued, consider Areas D and G-1

- Continue to consider a tunnel, at least a short one in a critical area, with development above it to offset the cost

- Make "Receiver [Noise] Controls" information contained in this report available to residents, planners, developers, etc.

ATTACHMENT A
RELEVANT NOISE TERMINOLOGY

A-Weighted Sound (dBA) - A-weighting network was developed and is applied to either measured or predicted noise levels to mimic the ear's varying sensitivity to frequency. Resulting noise levels are expressed in dBA. Table A1 shows the A-weighted noise levels of some common noise sources.

TABLE A1
Typical Noise Levels

Noise Source	Noise Level (dBA)
Amplified rock band	115 – 120
Commercial jet takeoff at 200 feet	105 – 115
Community warning siren at 100 feet	95 – 105
Busy urban street	85 – 95
Construction equipment at 50 feet	75 – 85
Freeway traffic at 50 feet	65 – 75
Normal conversation at 6 feet	55 – 65
Typical office interior	45 – 55
Soft radio music	35 – 45
Typical residential interior	25 – 35
Typical whisper at 6 feet	15 – 25
Human breathing	5 – 15
Threshold of hearing	0 – 5

Decibel (dB) – A decibel is one-tenth of a Bel. For sound pressure levels, it is a measure on a logarithmic scale, which indicates the squared ratio of sound pressure to a reference sound pressure.

Equivalent Sound Level (L_{eq}) - The equivalent steady state sound level which in a stated period of time would contain the same acoustical energy as the time-varying sound level during the same period. The time period used for highway noise analysis is one hour. All noise levels described in this report are hourly, A-weighted L_{eq}'s.

Frequency (f) - The number of oscillations per second of a periodic wave sound expressed in units of Hertz (Hz). The value is the reciprocal (1/x) of the period of oscillations in seconds. The human ear is, in general, capable of detecting frequencies between 20 to 20,000 Hertz. The human ear is more sensitive to high frequency sounds than to low frequency sounds.

Noise – Unwanted sound, usually loud or unexpected.

Noise Receptors - Areas in which people are typically located, which include places such as residences, hotels, commercial buildings, parks, etc. Usually, one noise receptor location is used to analyze an area unless the area is quite large and covers various distances from the roadway. The noise receptor is typically located on the façade of a structure that faces the noise source or roadway.

Pascal (Pa) – A unit of pressure (in acoustics, normally RMS sound pressure) equal to one Newton per square meter (N/m2). A reference pressure for a sound pressure level of 0 dB is 20 μPa (20 micro Pascal).

Sound – Caused by pressure fluctuations in the air. The range of sound pressures, which the human ear is capable of detecting, is very large (0.00002 to 200 Pascals). To facilitate easier discussion, sound pressures are described on a decibel (dB) scale.

Sound Absorption – This typically occurs when sound is converted to heat or another form of energy. A common sound absorptive material is fiberglass insulation.

Sound Pressure Level (SPL) – Sound pressure level in dB is equal to $10Log_{10}(p^2/p_o^2)$ where p is the instantaneous sound pressure and p_o is the reference sound pressure of 0.00002 Pa. This results in a scale of 0 dB (threshold of audibility) to 120 dB (threshold of pain).

Sound Reflection – The reflection of sound occurs when an object is able to significantly increase the impedance when compared to the surrounding air. This would require an object to be non-porous and to have enough density, stiffness and thickness.

Sound Transmission Loss (STL or TL) – The conversion of sound energy to another form of energy (usually heat) from one side of a barrier to the other.

ATTACHMENT B
SUMMARY OF PHOTO RADAR STUDIES

[From Auto and Road User Journal, March 17, 1997]

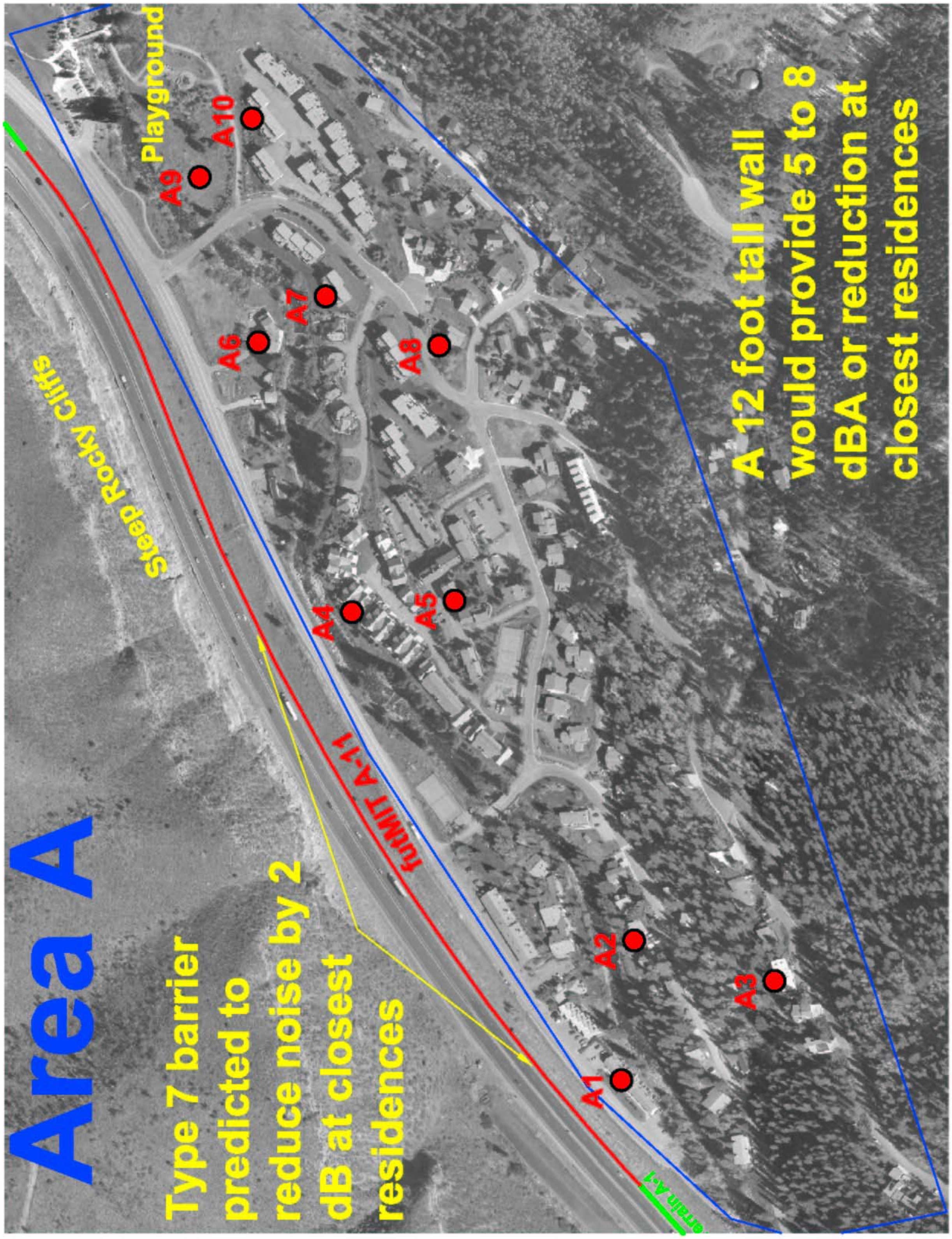
- A 1988 Victoria, B.C. study concluded that photo radar cameras reduced speeds at study sites.
- Two years of data from Victoria, Australia showed that speed reduction at camera sites was greater when media publicity and signs announced the presence of photo radar.
- In Vancouver, B.C. research from a short-term 1994 study indicated that fewer vehicles traveled over the speed limit when photo radar was in place.
- An Arlington, Texas report concluded that the presence of photo radar cameras reduced speeding--the greater the concentration of cameras, the greater the reduction in speeders.
- During a 1990-to-1992 Swedish research project, data showed fewer injury-producing crashes both on test roadway sections monitored by cameras and on control sections of roadways not monitored by cameras. The reductions were greater, however, where there were cameras.
- German statistics compared collisions on the Autobahn in 1977, without photo radar, and in 1978, after the installation of photo radar. Researchers reported increased compliance with speed limits. Moreover, there were only 9 crashes, 7 injuries, and no deaths in 1978 compared with 300 crashes, 80 injuries, and 7 deaths the year before.
- Similarly, Australian statistics from 1992 and 1993 showed photo radar reduced injury-producing collisions on some roadways by as much as 20 percent.
- United States research substantiated the relationship between reduced speed and injury-producing collisions. In 1974, the U.S. instituted national 55-mile-per-hour speed limits. The Transportation Research Board estimated that during 1983 the reduced speed limit saved between 2,000 and 4,000 lives. Interstate highways where states increased the speed limit from 55 to 65 miles per hour experienced a 27.1 percent increase in fatal crashes in 1987, while sections of the interstate where the speed limit remained at 55 miles per hour showed increases of only 0.6 percent. During the same time, the number of motorists driving more than 65 miles per hour increased by 48.2 percent on interstates where the speed limit was 65 miles per hour; interstates where the speed limit was still 55 miles per hour showed an increase of only 9.1 percent. Michigan statistics compared fatalities, serious injuries, and moderate injuries on sections of interstate before and after the change from a 55-mile-per-hour speed limit to 65 miles per hour. Although no significant increase in the number of vehicles involved in crashes resulted, significant increases occurred in the number of fatalities and injuries--showing a relationship between higher speed and severity of crashes.

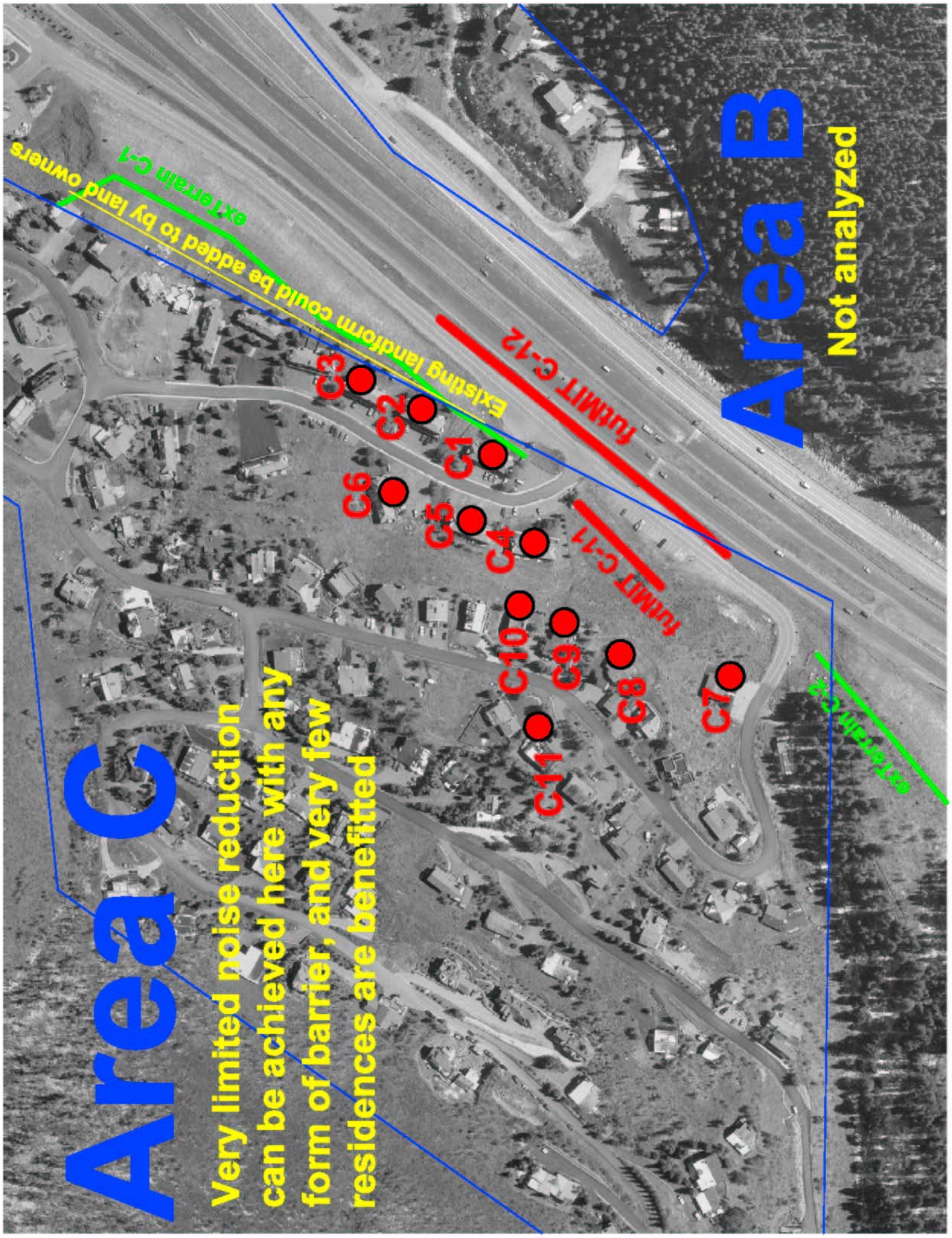
In an eleven-month pilot study, the Province of Ontario is using four portable photo radar units on selected sections of roadway. The MTO created three site pairings to compare data for test sections using photo radar equipment and control sections not using the equipment. Loops embedded in the roadways collected data 24 hours a day and seven days a week on vehicle speeds and sizes. Photo radar vehicles containing radar units, cameras, and Ontario Provincial Police patrolled the test roadways. Baseline data collection took place the end of July 1994.

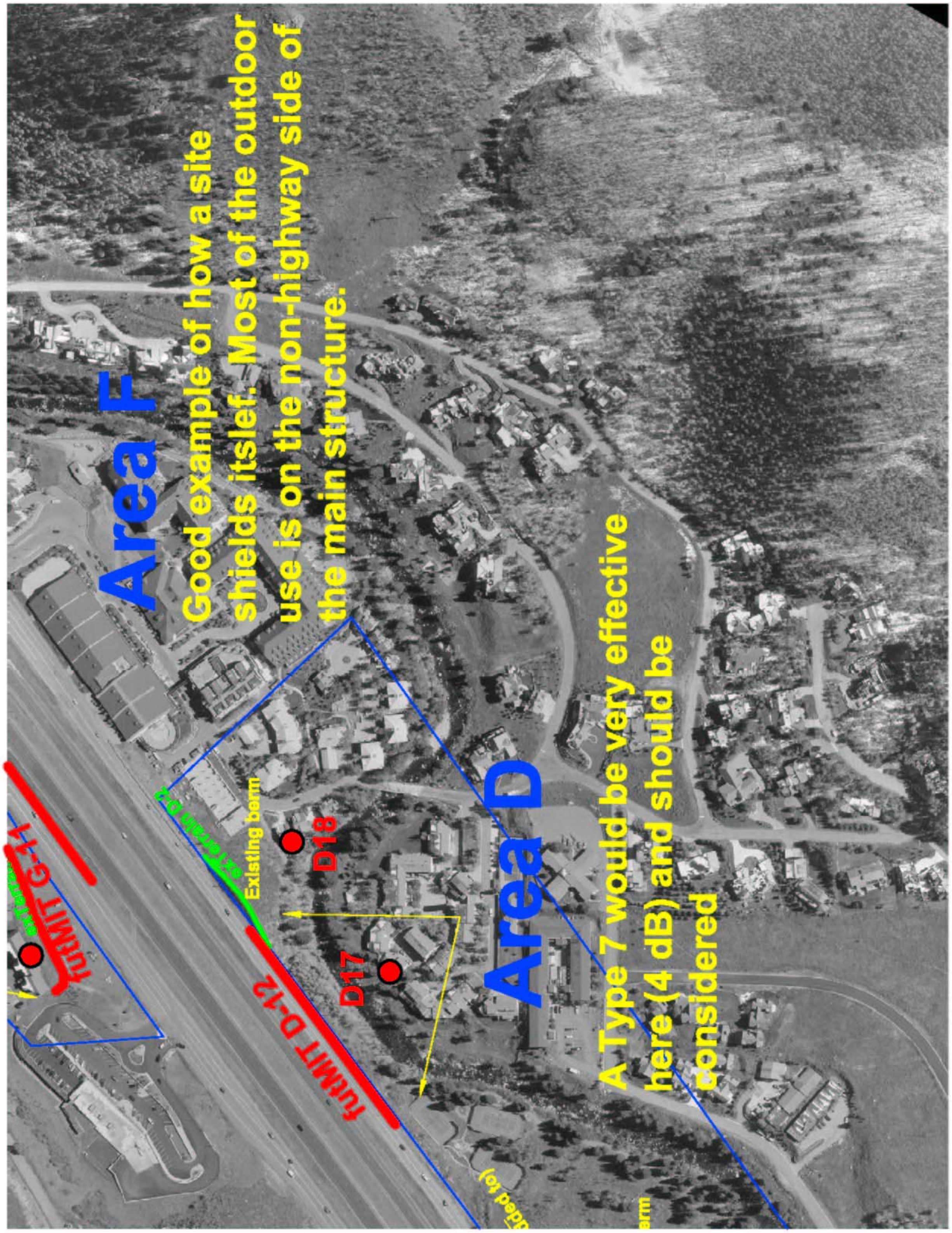
From August 1 through August 14, 1994, signs reading SPEED ENFORCED BY PHOTO RADAR confronted motorists on the test sections; however, enforcement did not begin until August 15. With 18 million vehicles monitored on test roadways and 13 million on control roadways, results showed speed reductions on all roadways. However, the average speed reduction was greater at all test sites when compared with control sites. Data led researchers to several conclusions:

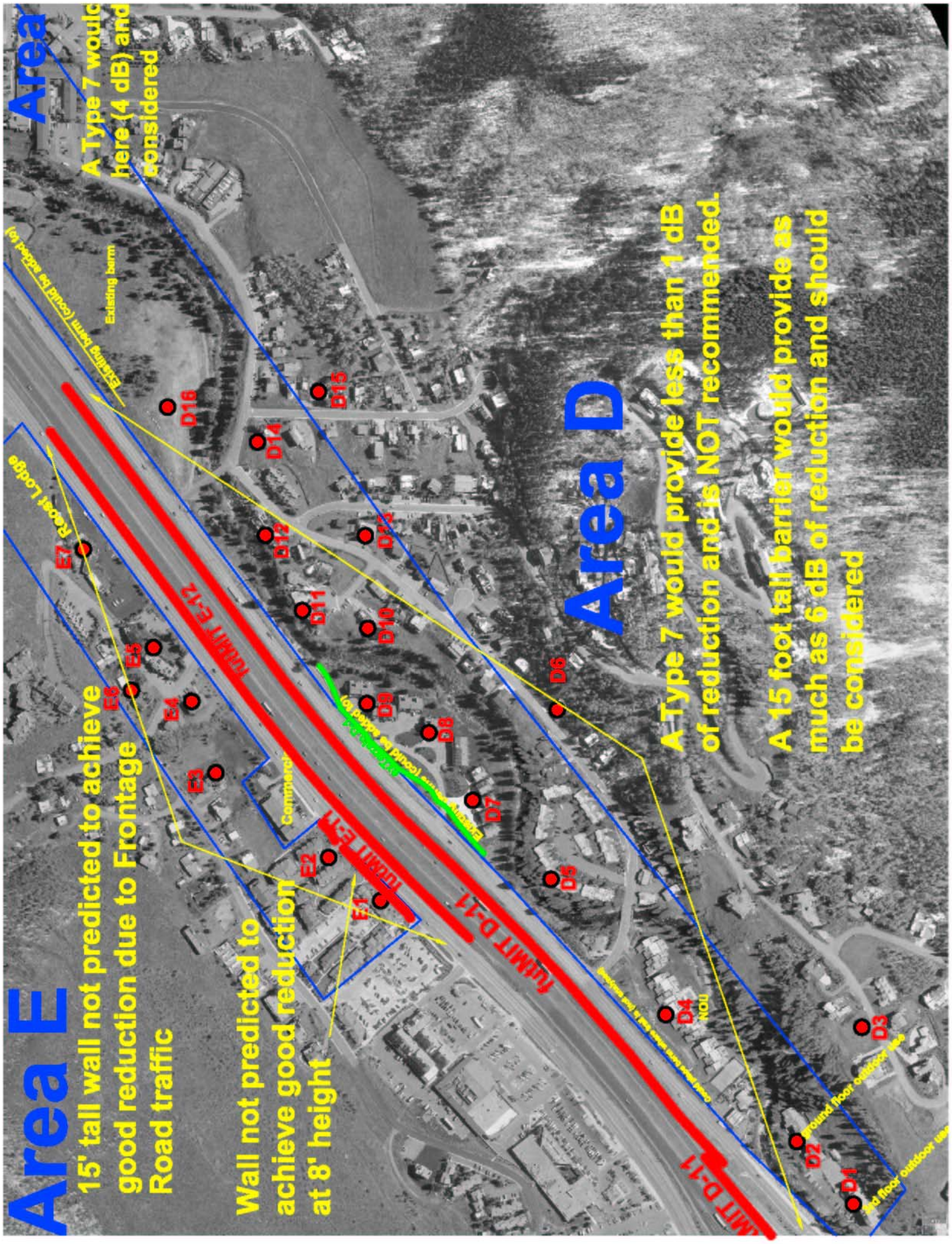
- While the proportion of speeding vehicles decreased at all sites during the test period, decreases were greater at test sites.
- The greatest decreases in the proportion of speeding vehicles at all sites were for vehicles traveling at the highest rates of speed. Again, the largest decreases were at test sites.
- Substantial speed reductions at all sites suggested that media coverage of the use of photo radar at some sites affected the behavior of all drivers. In addition, other ongoing safety initiatives were probably causing speed reductions.
- The greatest speed reductions occurred on the six-lane test section. While daily radio announcements advertised the use of photo radar at the six-lane site, the use of radar at other sites attracted less media attention. These preliminary data seem to support the hypothesis that specific speed enforcement in conjunction with public media campaigns can lower average speeds and the proportion of speeders on provincial highways.
- At least for a short time, the mere presence of signing announcing photo radar reduced speeding--even when cameras were not present.
- When the MTO increased enforcement presence and fully deployed the photo radar units (on December 1, 1994), decreases in speeding on the test roadways became even more significant. The report suggested that drivers were more likely to reduce their speed as they talked to more people who had seen the photo radar units or as they saw units themselves.
- Baseline data showed 62 percent of motorists drove over the speed limit before photo radar enforcement. During the fourth month of enforcement, this figure had dropped to 47 percent at some sites. Over half the total drivers, however, continued to exceed the speed limit--even at the end of the preliminary study period.

ATTACHMENT C
AERIALS VIEWS OF STUDY AREAS

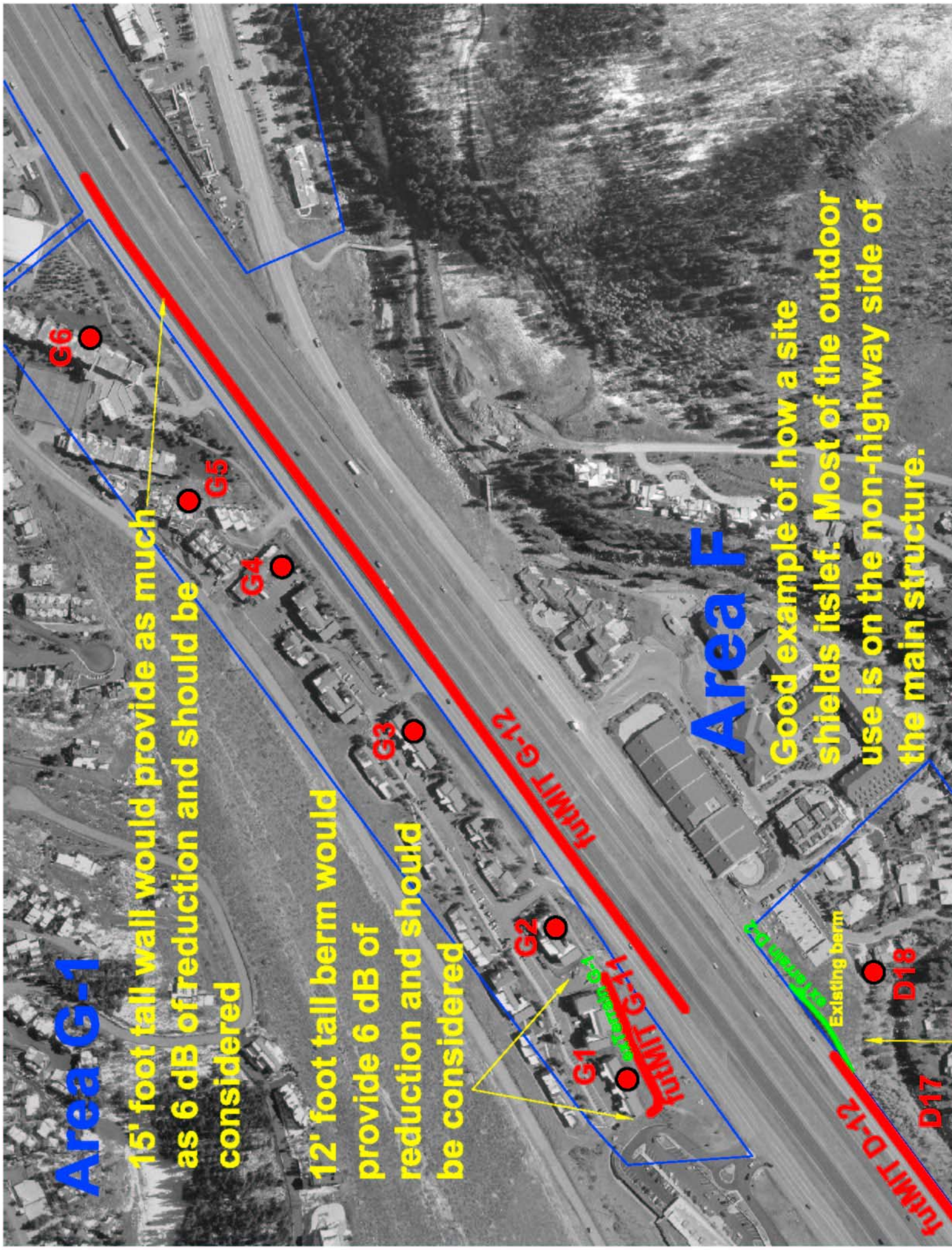

Area A
Type 7 barrier predicted to reduce noise by 2 dB at closest residences
A 12 foot tall wall would provide 5 to 8 dBA or reduction at closest residences
Steep Rocky Cliffs
Playground
futMIT A-1-1
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10


Area B
Not analyzed
Area C
Very limited noise reduction can be achieved here with any form of barrier, and very few residences are benefitted
exTerrain C-1
Existing landform could be added to by land owners
futMIT C-12
futMIT C-11
exTerrain C-2
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11

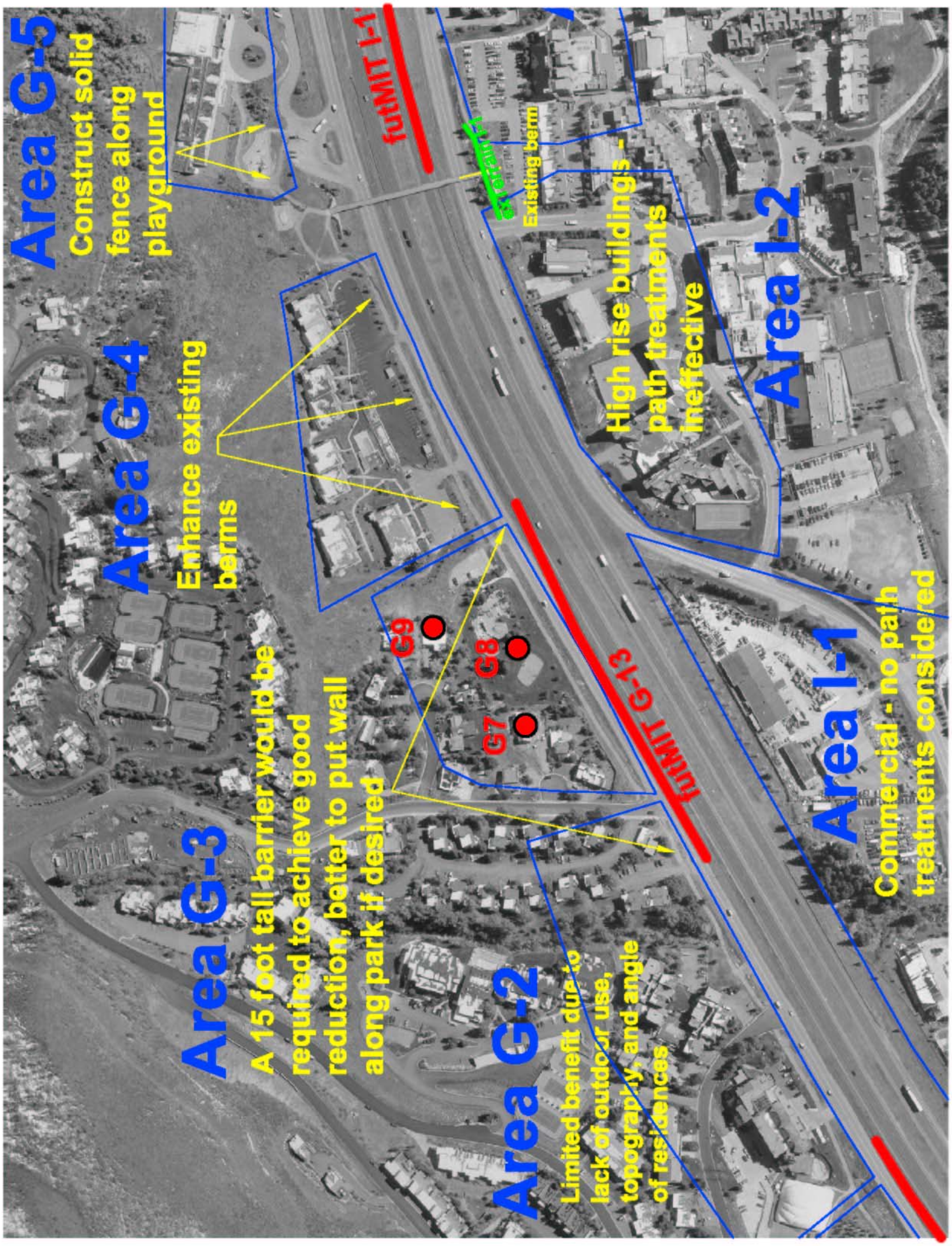

Area F
Good example of how a site shields itslef. Most of the outdoor use is on the non-highway side of the main structure.
Area D
A Type 7 would be very effective here (4 dB) and should be considered
Existing berm
D18
D17



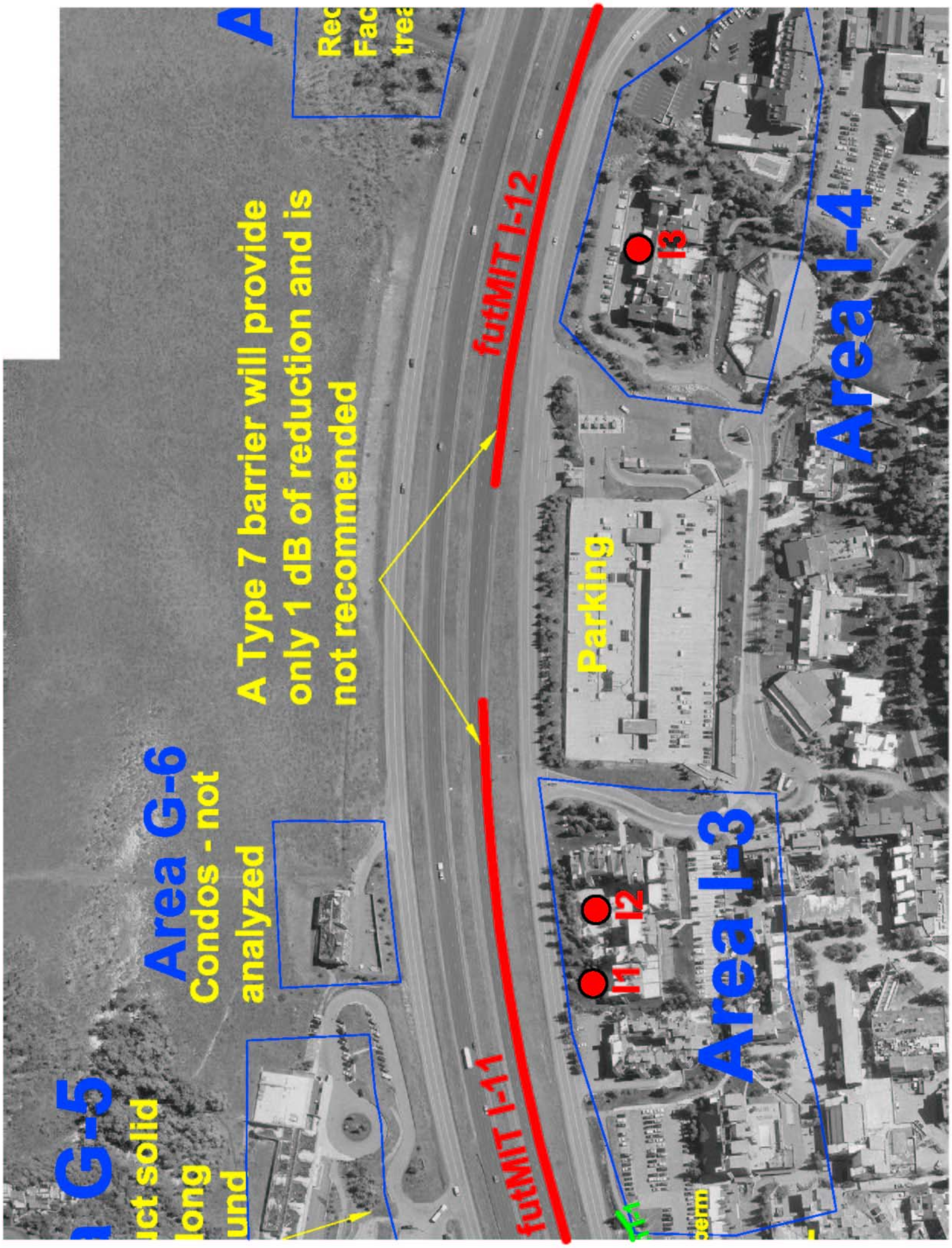
Area E
15' tall wall not predicted to achieve good reduction due to Frontage Road traffic
Wall not predicted to achieve good reduction at 8' height
Area D
A Type 7 would provide less than 1 dB of reduction and is NOT recommended.
A 15 foot tall barrier would provide as much as 6 dB of reduction and should be considered
Existing berm (could be added to)
Existing berm
Commercial
E1
E2
E3
E4
E5
E6
E7
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
D14
D15
D16
2nd floor outdoor use
ground floor outdoor use



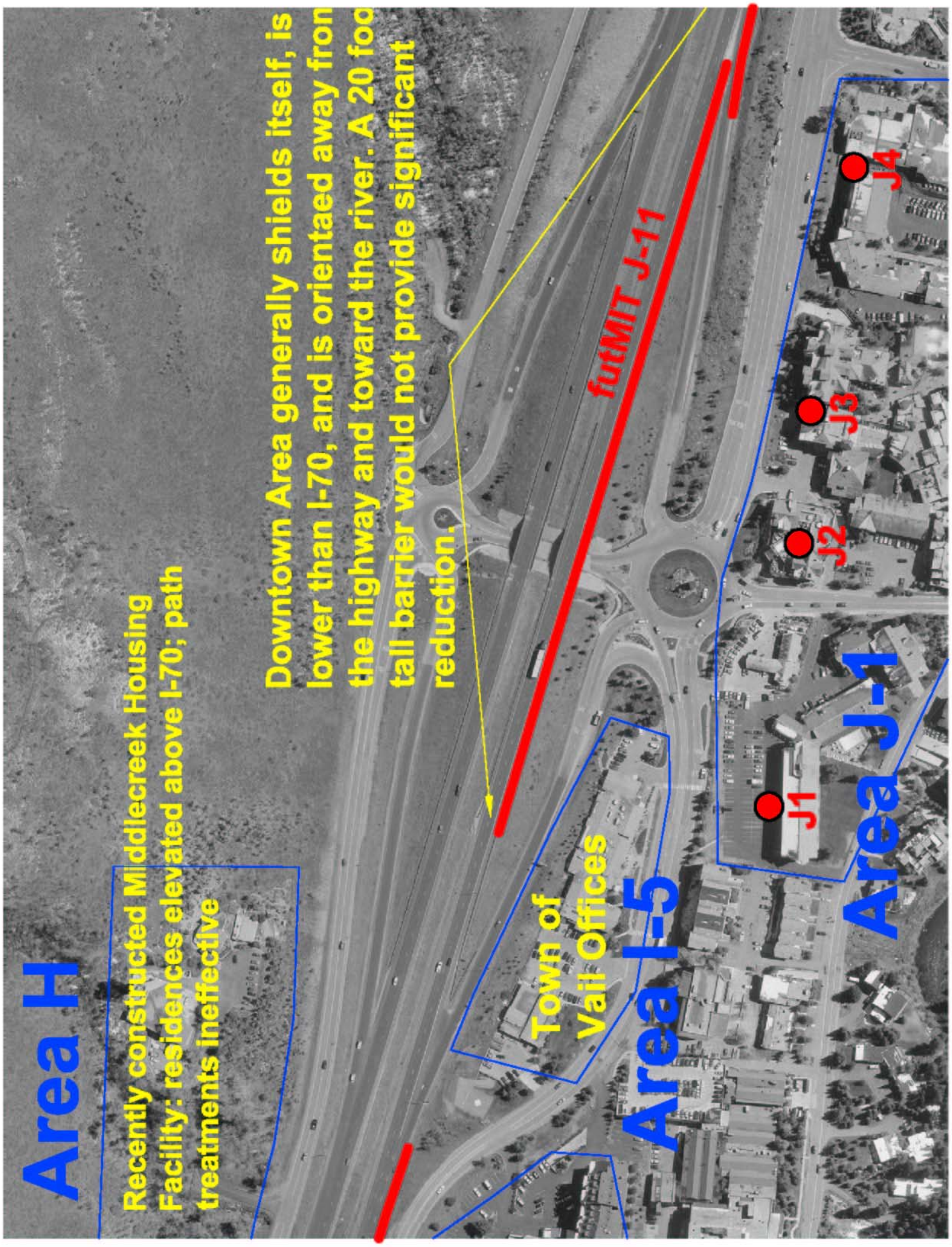
Area G-1
15' foot tall wall would provide as much as 6 dB of reduction and should be considered
12' foot tall berm would provide 6 dB of reduction and should be considered
G1
G2
G3
G4
G5
G6
exTerrain G-1
futMIT G-11
futMIT G-12
Area F
Good example of how a site shields itslef. Most of the outdoor use is on the non-highway side of the main structure.
exTerrain D-2
Existing berm
D17
D18
futMIT D-12



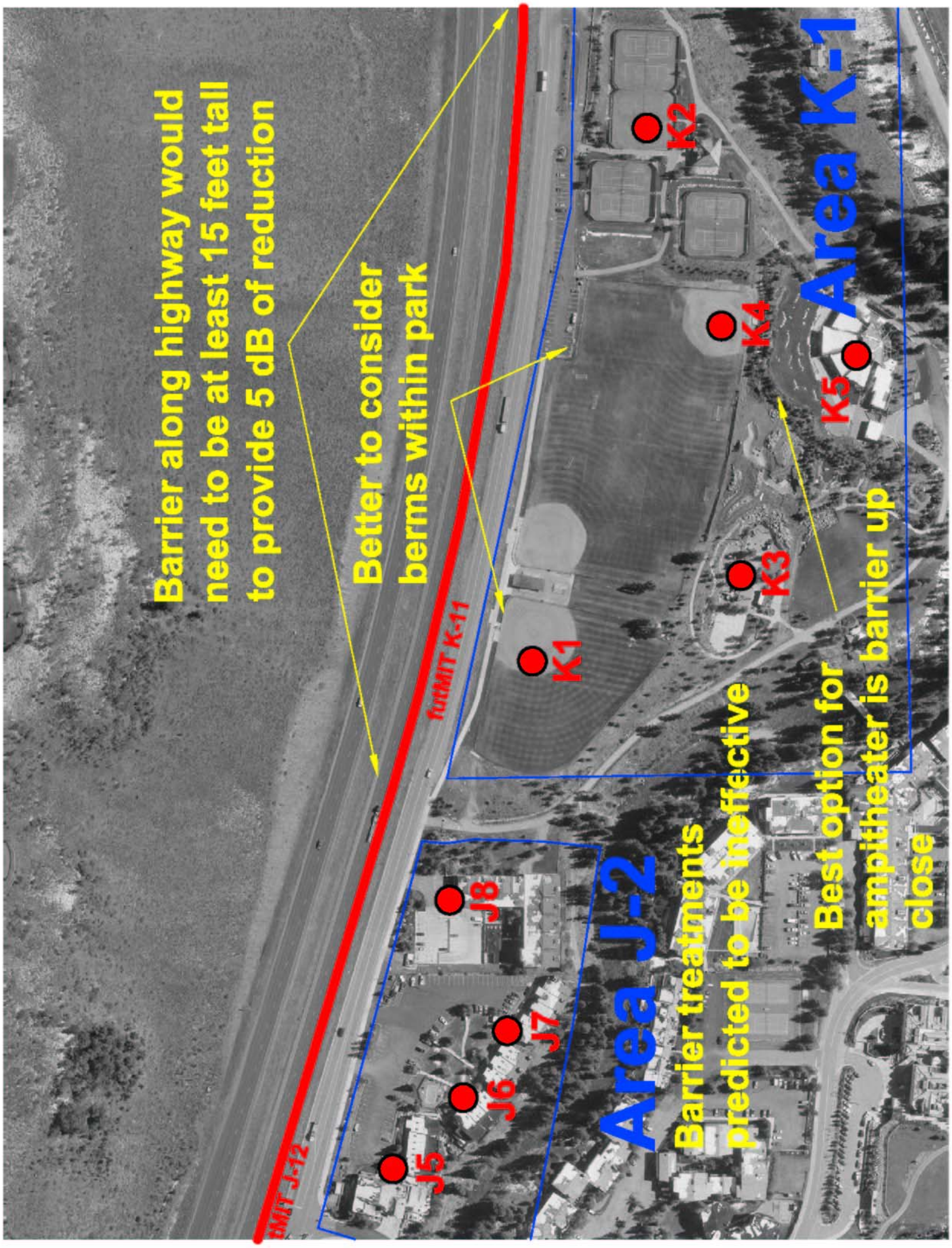
Area G-5
Construct solid fence along playground
futMIT I-1
Existing berm
Area I-2
High rise buildings - path treatments ineffective
Area G-4
Enhance existing berms
G9
G8
G7
futMIT G-13
Area I-1
Commercial - no path treatments considered
Area G-3
A 15 foot tall barrier would be required to achieve good reduction, better to put wall along park if desired
Area G-2
Limited benefit due to lack of outdoor use, topography, and angle of residences

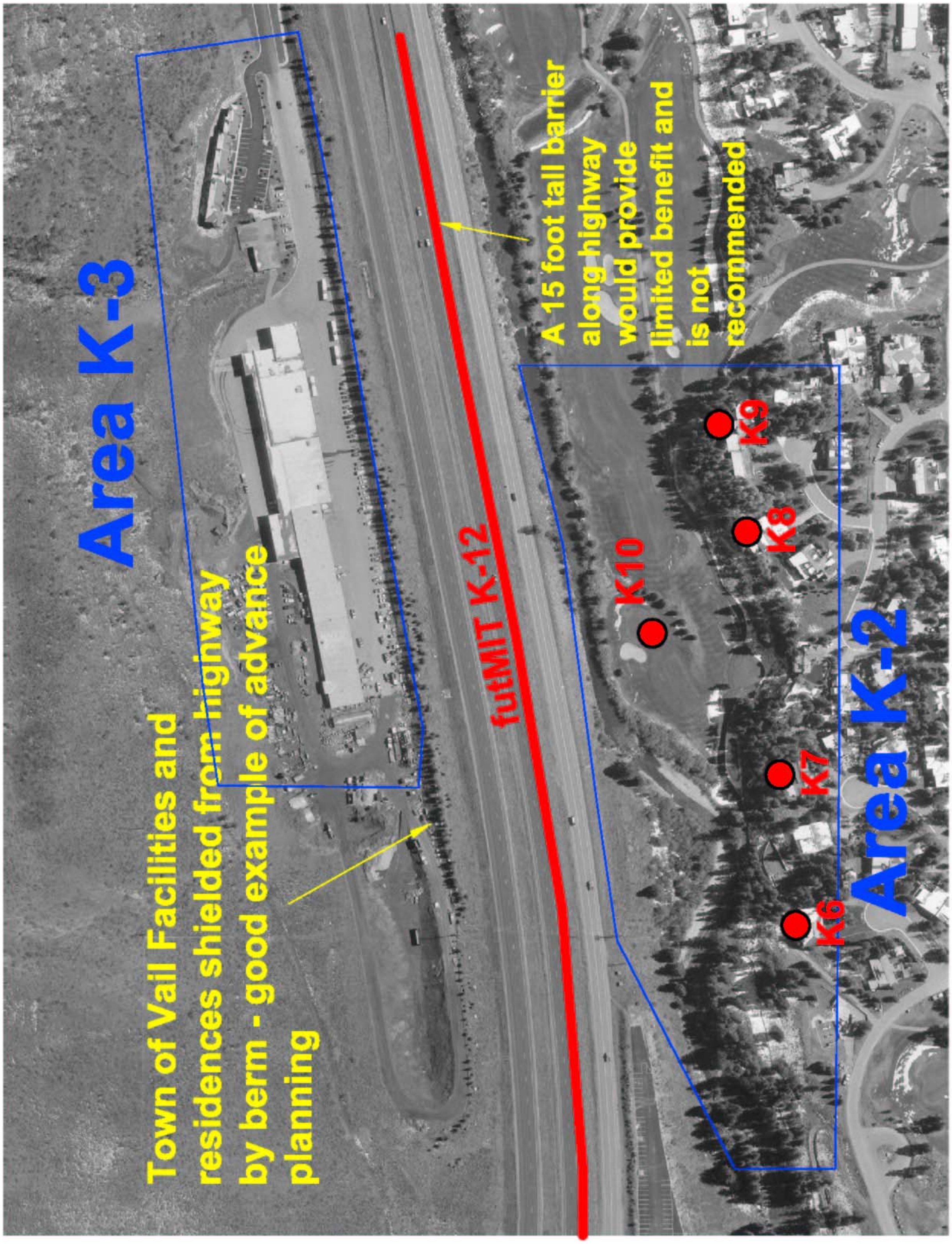


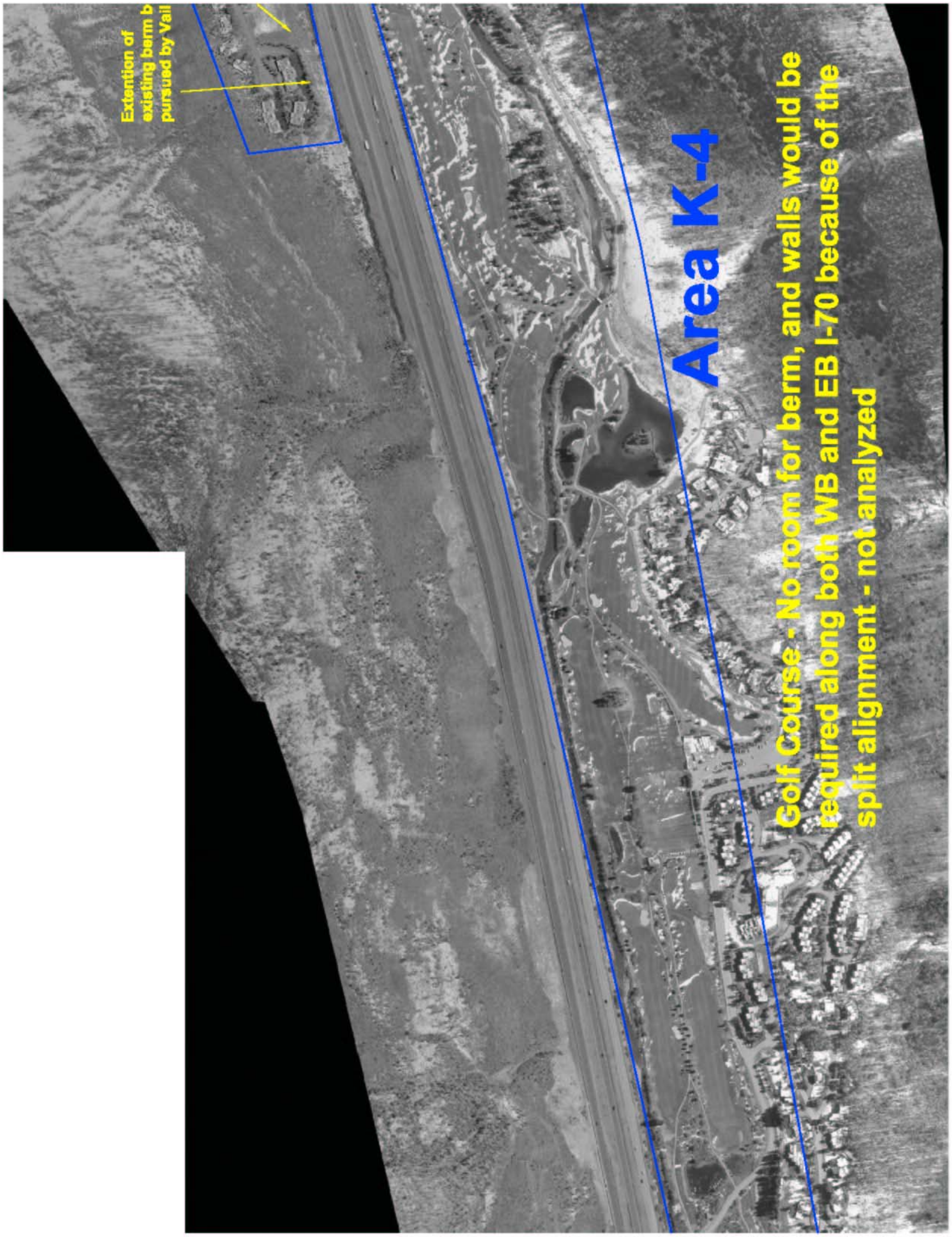
Area G-6
Condos - not
analyzed
A Type 7 barrier will provide
only 1 dB of reduction and is
not recommended
futMIT I-12
futMIT I-11
Parking
Area I-3
Area I-4
I1
I2
I3

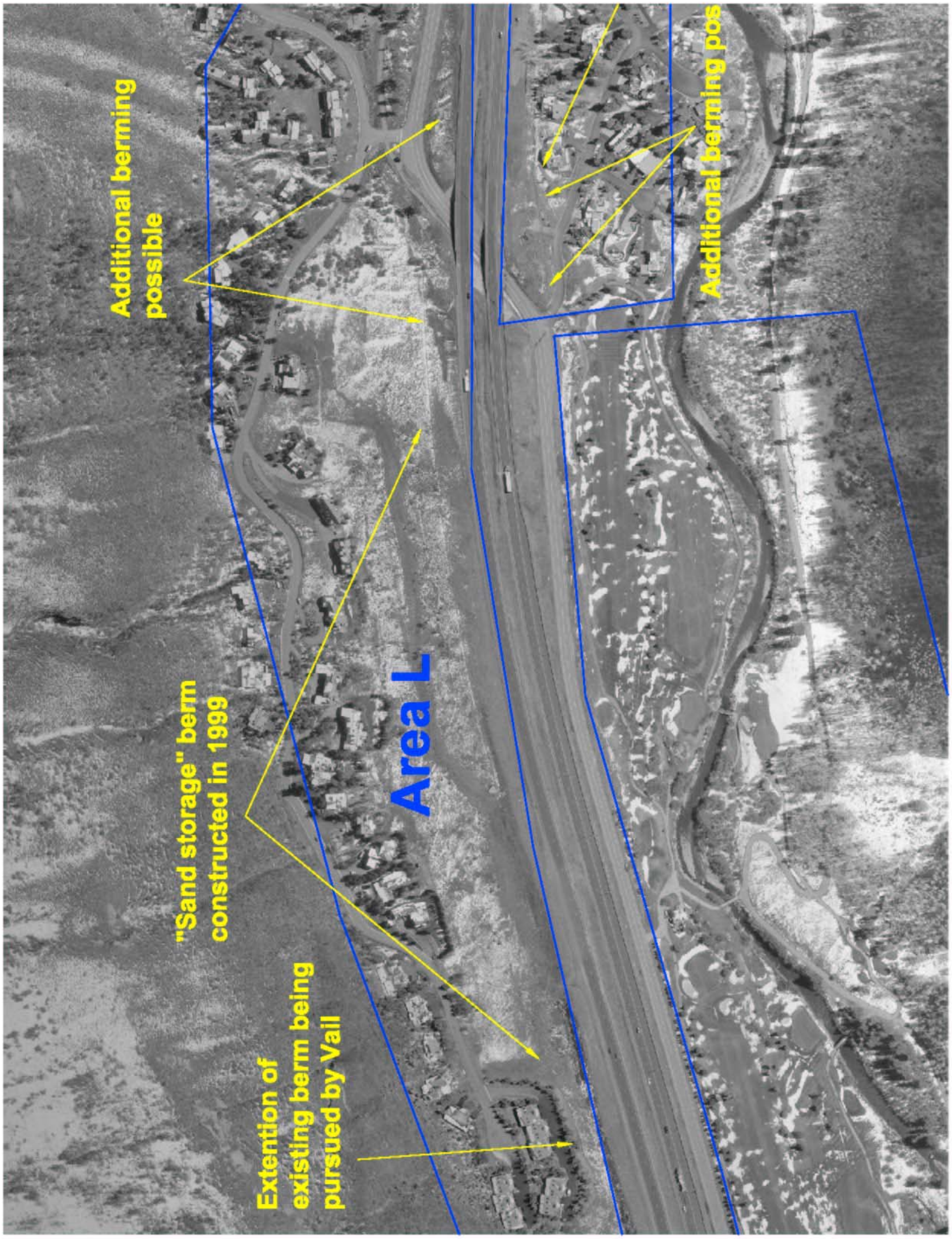


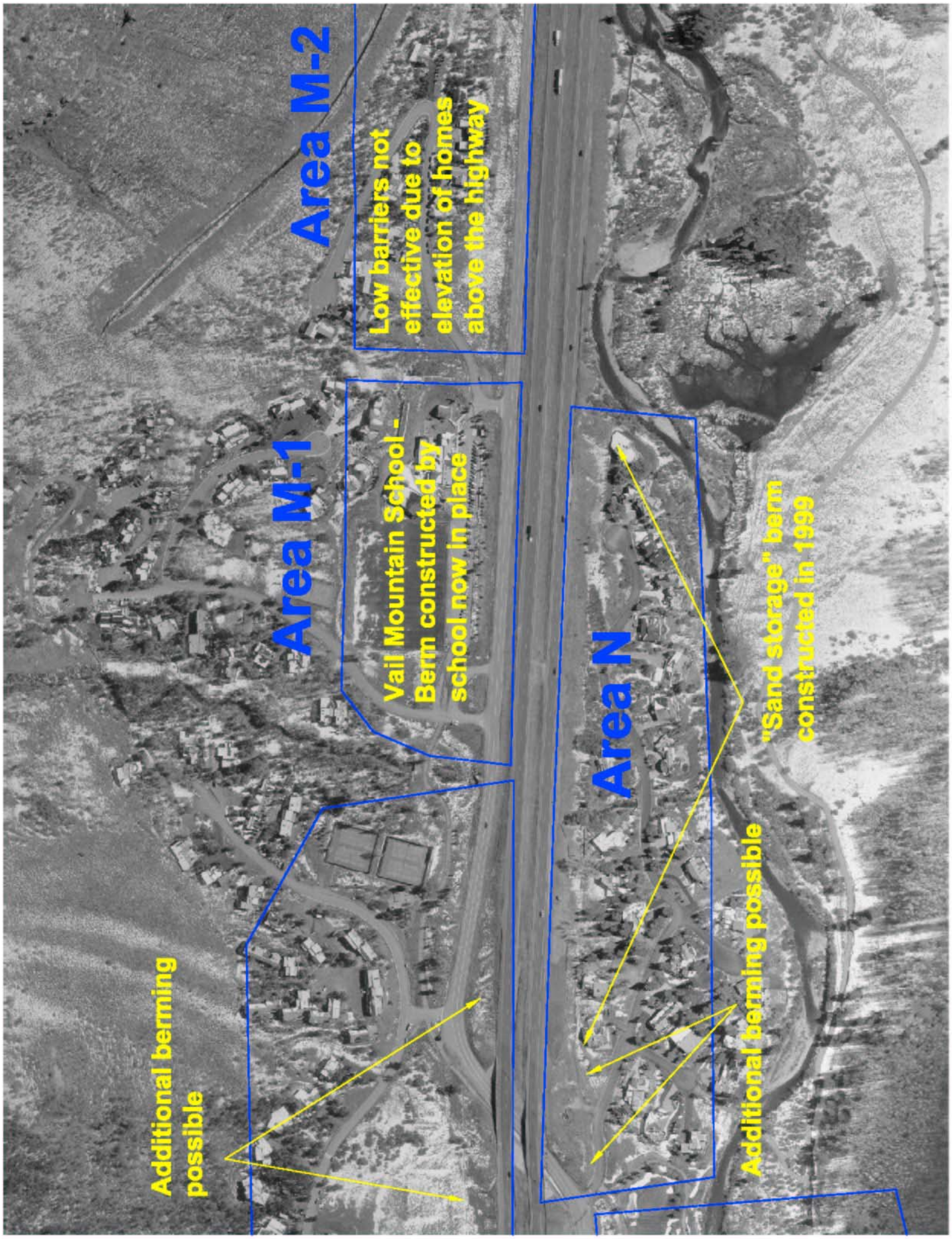
Area H
Recently constructed Middlecreek Housing Facility: residences elevated above I-70; path treatments ineffective
Downtown Area generally shields itself, is lower than I-70, and is orientaed away fron the highway and toward the river. A 20 foo tall barrier would not provide significant reduction.
futMIT J-11
Town of Vail Offices
Area I-5
Area J-1
J1
J2
J3
J4

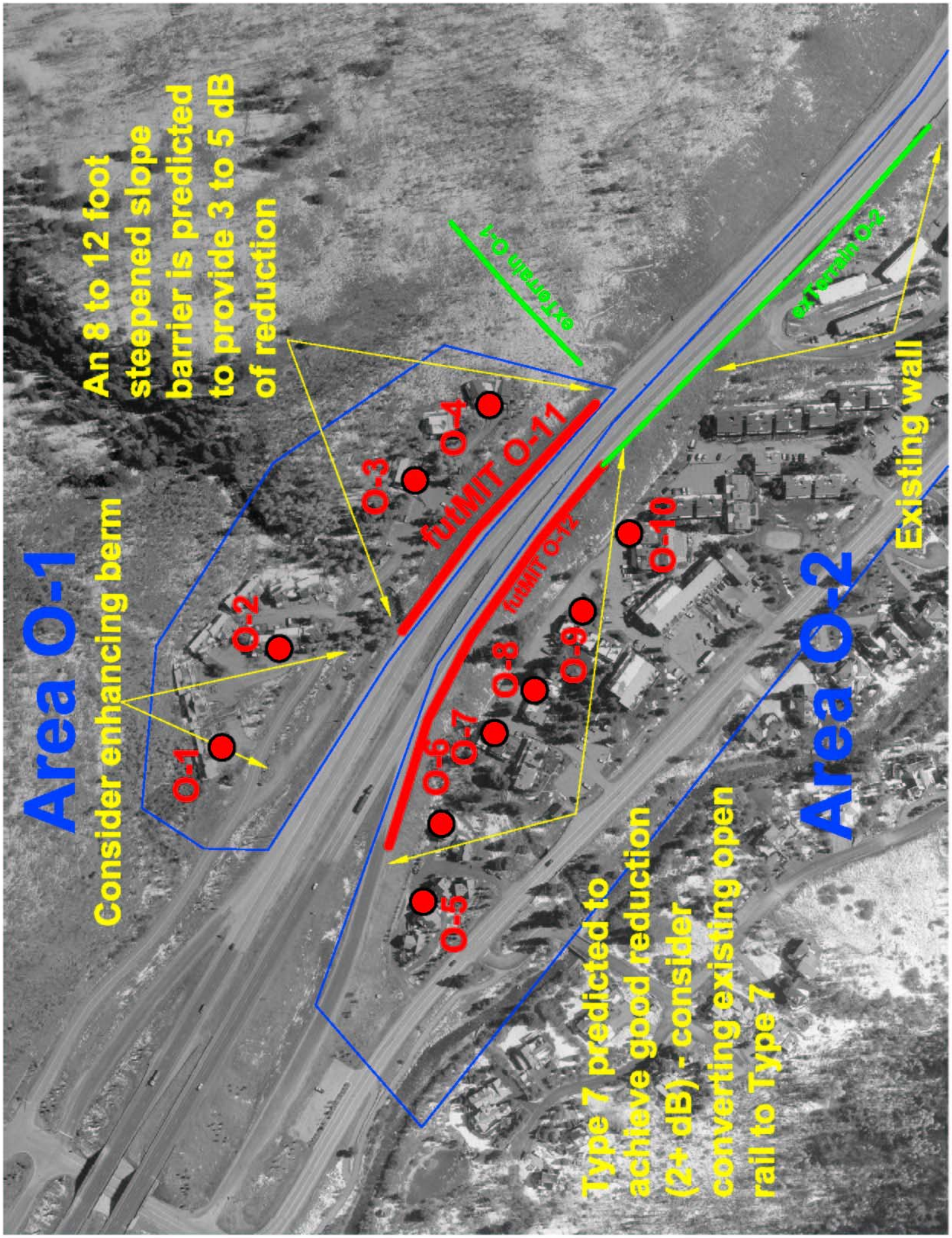

Barrier along highway would need to be at least 15 feet tall to provide 5 dB of reduction
Better to consider berms within park
Barrier treatments predicted to be ineffective
Best option for ampitheater is barrier up close
Area K-1
Area J-2
futMIT K-11
tMIT J-12
K1
K2
K3
K4
K5
J5
J6
J7
J8

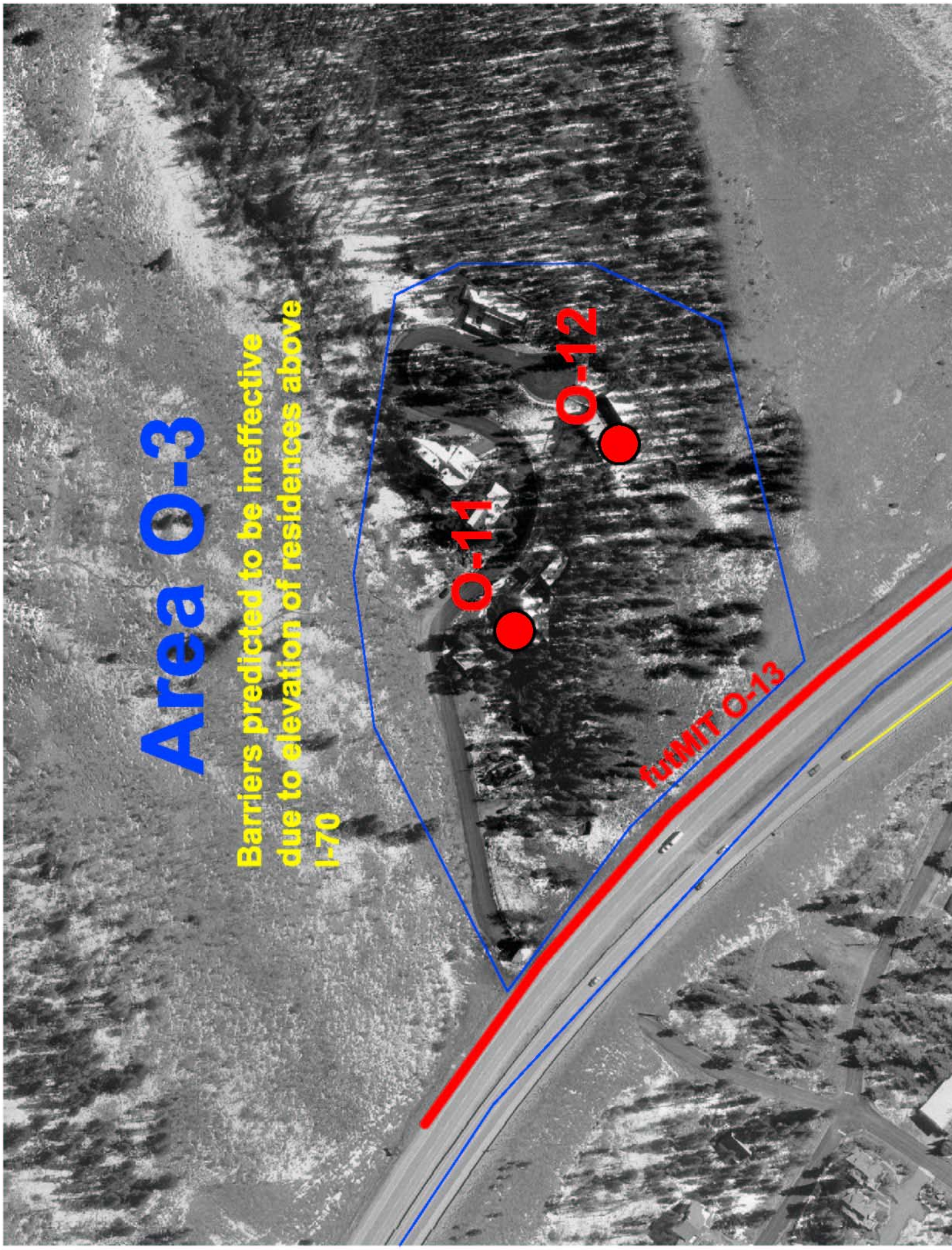

Area K-3
Town of Vail Facilities and residences shielded from highway by berm - good example of advance planning
futMIT K-12
A 15 foot tall barrier along highway would provide limited benefit and is not recommended
K9
K8
K10
K7
K6
Area K-2

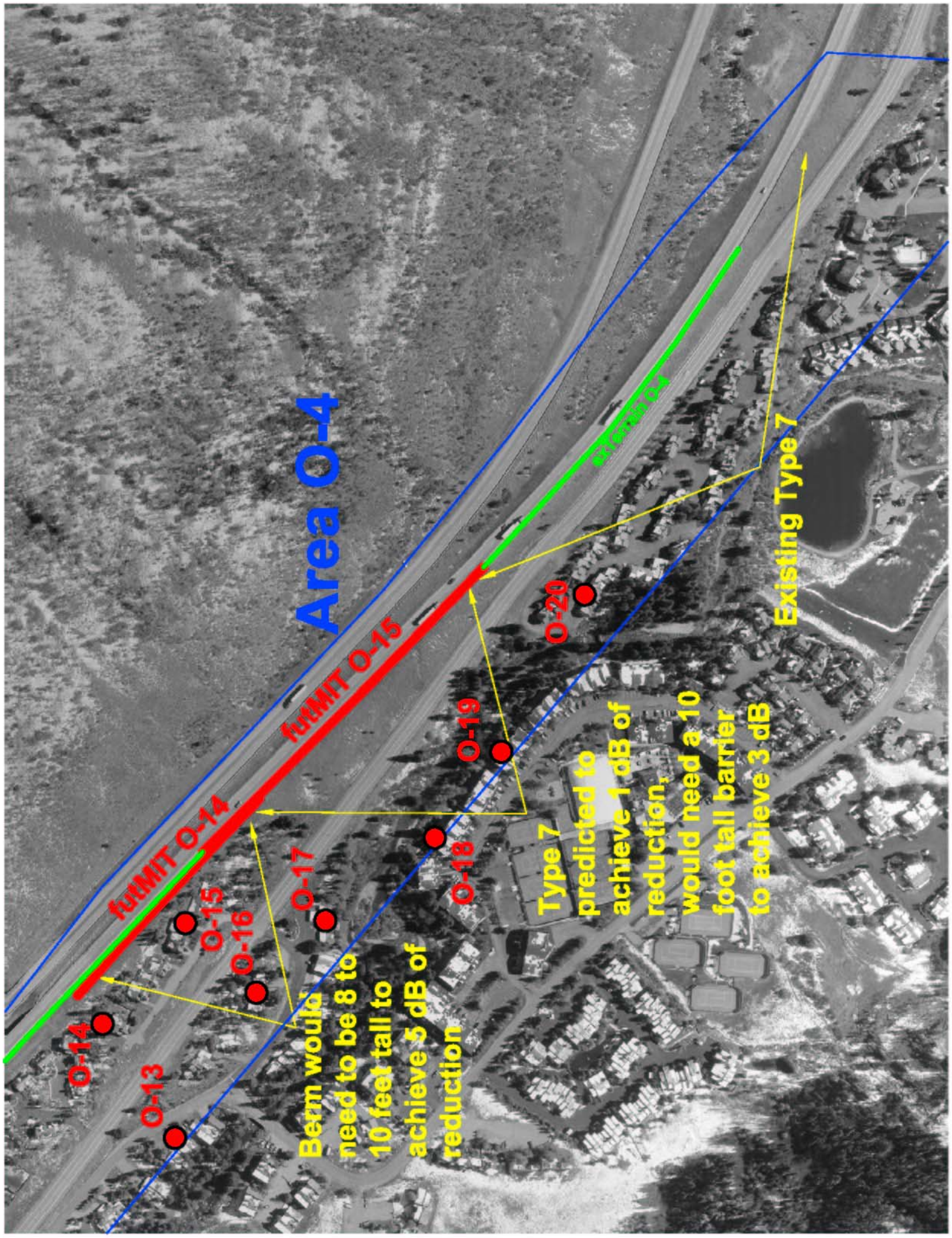

Extention of
existing berm b
pursued by Vail
Area K-4
Golf Course - No room for berm, and walls would be
required along both WB and EB I-70 because of the
split alignment - not analyzed


Additional berming possible
Additional berming pos
"Sand storage" berm constructed in 1999
Area L
Extention of existing berm being pursued by Vail

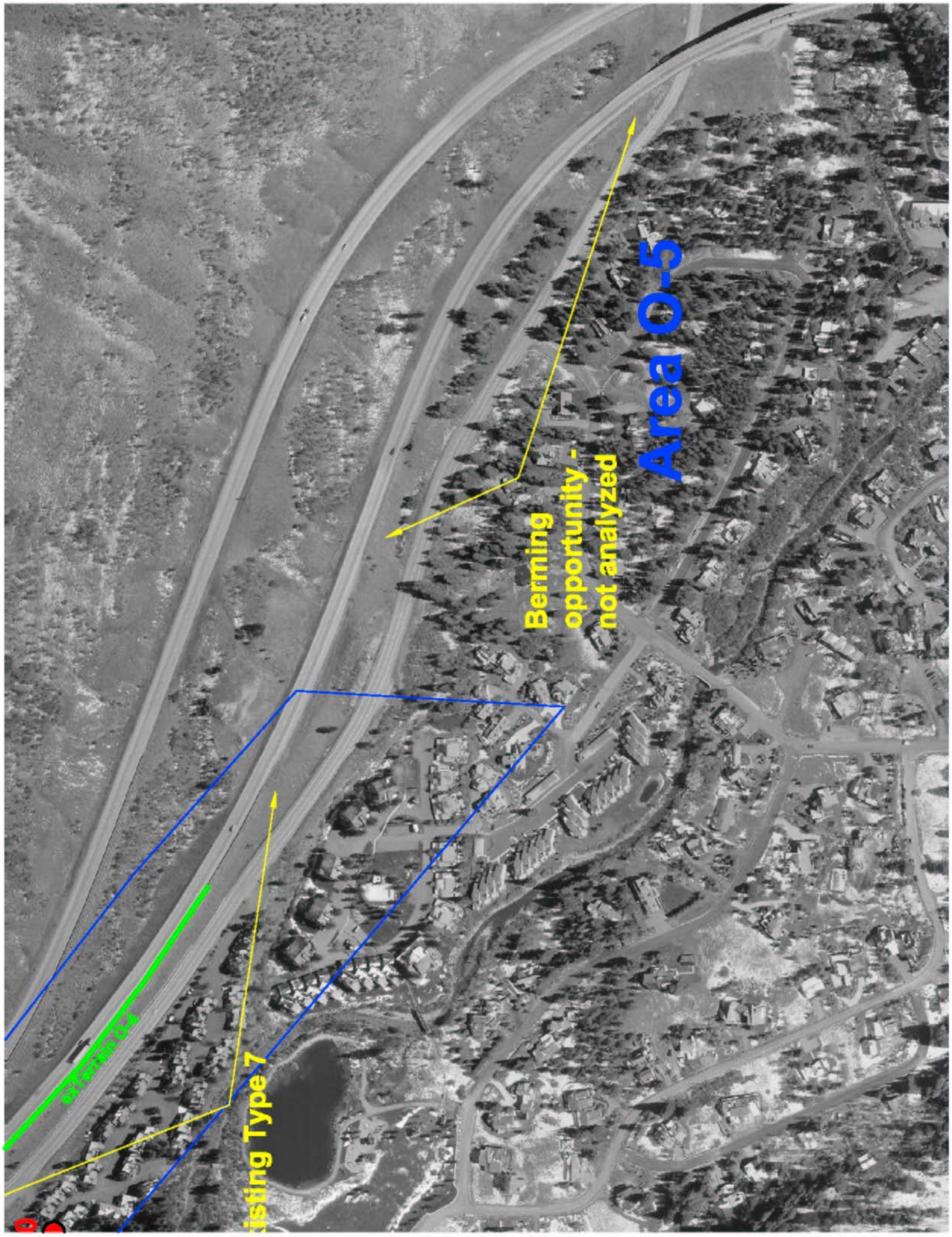

Area M-2
Low barriers not effective due to elevation of homes above the highway
Area M-1
Vail Mountain School - Berm constructed by school now in place
Area N
"Sand storage" berm constructed in 1999
Additional berming possible
Additional berming possible


Area O-1
Consider enhancing berm
An 8 to 12 foot steepened slope barrier is predicted to provide 3 to 5 dB of reduction
exTerrain O-1
exTerrain O-2
Existing wall
futMIT O-11
futMIT O-12
O-1
O-2
O-3
O-4
O-5
O-6
O-7
O-8
O-9
O-10
Area O-2
Type 7 predicted to achieve good reduction (2+ dB) - consider converting existing open rail to Type 7


Area O-3
Barriers predicted to be ineffective due to elevation of residences above I-70
O-11
O-12
futMIT O-13



Area O-4
futMIT O-15
futMIT O-14
O-13
O-14
O-15
O-16
O-17
O-18
O-19
O-20
Existing Type 7
Type 7 predicted to achieve 1 dB of reduction, would need a 10 foot tall barrier to achieve 3 dB
Berm would need to be 8 to 10 feet tall to achieve 5 dB of reduction


Berming
opportunity -
not analyzed
Area O-5
xisting Type 7

ATTACHMENT D
PREDICTED NOISE LEVELS AT EACH STUDY AREA

Mit A-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
A1	64	63	60	59	58	58	2	4	6	6	6
A2	59	59	57	54	53	52	1	3	5	6	7
A3	55	55	55	54	53	52	0	0	1	2	3
A4	64	63	59	56	55	53	2	5	8	10	11
A5	59	58	56	53	51	49	1	2	5	7	10
A6	63	62	59	56	55	53	1	4	7	9	10
A7	58	57	56	53	52	51	1	2	5	6	8
A8	54	54	52	51	49	47	0	2	3	5	7
A9	62	62	60	58	57	57	1	3	5	5	6
A10	60	60	59	57	56	56	1	2	3	4	4

Mit C-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
C1	67	67	67	67	67	67	0	0	0	0	0
C2	62	62	62	62	62	62	0	0	0	0	0
C3	61	61	61	61	61	61	0	0	0	0	0
C4	65	65	65	65	65	64	0	0	0	1	1
C5	61	61	60	60	60	60	0	0	0	0	1
C6	57	57	57	57	57	57	0	0	0	0	0
C7	65	65	65	65	65	65	0	0	0	0	0
C8	64	64	64	64	64	64	0	0	0	0	0
C9	63	63	63	63	63	63	0	0	0	0	0
C10	60	60	60	60	60	60	0	0	0	0	0
C11	57	57	57	57	57	57	0	0	0	0	0

Mit C-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
C1	67	67	66	64	63	60	0	1	3	5	7
C2	62	62	62	62	62	61	0	0	0	0	1
C3	61	61	61	61	61	60	0	0	0	0	1
C4	65	65	65	63	62	60	0	1	2	3	5
C5	61	60	60	58	57	55	0	1	2	4	6
C6	57	57	57	56	55	53	0	0	1	2	4
C7	65	65	65	65	65	65	0	0	0	1	1
C8	64	64	64	63	63	63	0	0	0	0	1
C9	63	63	63	63	63	62	0	0	0	1	2
C10	60	60	60	59	59	58	0	0	1	1	2
C11	57	57	57	57	57	56	0	0	0	0	1

Mit D-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
D1	64	64	63	62	61	61	0	1	2	3	4
D2	65	64	63	61	60	59	1	2	4	5	6
D3	56	56	56	55	55	54	0	0	1	1	2
D4	67	66	64	62	61	60	1	3	5	6	7
D5	66	65	63	61	60	59	1	3	5	6	7
D6	57	56	56	55	54	53	0	1	2	3	4
D7	66	65	64	62	61	59	1	2	4	5	7
D8	65	64	64	62	61	59	0	1	3	4	6
D9	67	67	66	64	62	60	0	2	4	5	7
D10	64	63	63	61	60	58	0	1	2	4	5
D11	67	66	65	63	62	60	1	2	4	5	7
D12	65	65	64	62	61	59	1	2	3	5	6
D13	58	58	57	56	56	55	0	1	1	2	3
D14	62	62	61	61	60	59	0	1	2	2	4
D15	56	56	55	55	55	54	0	1	1	2	2
D16	65	65	64	63	62	61	0	1	2	3	4

Mit D-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
D17	65	60	59	59	58	58	4	5	6	6	6
D18	62	61	61	61	61	61	1	1	1	2	2

Mit E-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
E1	69	69	67	65	62	59	0	2	4	7	10
E2	68	67	66	65	65	64	0	2	3	3	3
E3	65	65	65	65	65	65	0	0	0	0	0
E4	67	67	67	67	67	67	0	0	0	0	0
E5	67	67	67	67	67	67	0	0	0	0	0
E6	61	61	61	61	61	61	0	0	0	0	0
E7	67	67	67	67	67	67	0	0	0	0	0

Mit E-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
E1	69	68	68	66	65	63	0	1	3	4	6
E2	68	67	66	64	63	61	0	2	3	5	6
E3	65	65	64	62	61	58	0	1	3	4	6
E4	67	67	66	64	62	60	0	2	3	5	7
E5	67	67	65	63	62	60	1	2	4	5	7
E6	61	61	59	58	56	54	0	1	3	5	6
E7	67	67	65	63	62	61	1	2	4	5	7

Mit G-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
G1	65	65	62	60	58	57	1	3	6	7	9
G2	68	68	68	68	68	68	0	0	0	0	0
G3	68	68	68	68	68	68	0	0	0	0	0
G4	67	67	67	67	67	67	0	0	0	0	0
G5	65	65	65	65	65	65	0	0	0	0	0
G6	66	66	66	66	66	66	0	0	0	0	0

Mit G-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
G1	65	65	65	65	65	65	0	0	0	1	1
G2	68	68	67	65	64	62	0	1	3	4	6
G3	68	68	67	65	63	61	0	1	3	5	7
G4	67	67	65	63	62	60	1	2	4	6	8
G5	65	65	64	62	61	58	0	1	3	5	7
G6	66	66	65	63	62	60	0	1	3	4	6

Mit G-13

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
G7	65	65	63	62	61	60	1	2	4	5	6
G8	67	67	65	63	62	61	1	2	4	5	6
G9	64	64	63	62	62	61	0	1	2	3	3

Mit I-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
I1	68	67	66	64	64	63	1	3	4	5	5
I2	67	66	65	63	62	62	1	3	4	5	5

Mit I-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
I3	67	66	64	62	62	61	1	3	4	5	6

Mit J-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
J1	62	62	61	61	60	60	0	1	2	2	3
J2	63	63	62	60	59	59	1	2	3	4	5
J3	64	64	63	61	61	60	1	2	3	4	4
J4	65	64	63	61	61	60	1	2	3	4	4

Mit J-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
J5	62	62	62	62	62	62	0	0	0	0	0
J6	63	63	63	63	63	63	0	0	0	0	0
J7	65	65	65	65	65	65	0	0	0	0	0
J8	65	65	65	65	65	65	0	0	0	0	0

Mit K-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
K1	66	65	63	61	60	59	1	3	5	6	7
K2	66	65	64	62	61	59	1	2	3	5	7
K3	60	60	59	57	56	54	1	2	4	5	6
K4	62	62	61	59	58	56	0	1	3	4	6
K5	54	54	53	51	50	49	0	1	3	4	5

Mit K-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
K6	62	62	61	60	59	58	0	1	2	3	4
K7	62	62	61	60	59	57	0	1	2	3	5
K8	62	61	61	60	59	57	0	1	2	3	4
K9	62	61	61	60	59	57	0	1	2	3	5
K10	65	64	62	60	59	57	1	3	5	6	7

Mit O-11

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
O1	66	66	66	66	66	66	0	0	0	0	0
O2	66	66	66	66	66	65	0	0	0	1	1
O3	66	66	63	61	61	60	1	3	5	6	7
O4	67	66	63	62	61	61	1	3	5	5	6

Mit O-12

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
O5	66	66	66	65	65	65	0	1	1	1	1
O6	64	63	62	61	61	60	1	3	3	4	4
O7	65	64	60	58	57	57	2	5	7	8	9
O8	65	63	60	58	57	56	2	5	7	8	9
O9	64	62	59	57	56	56	2	5	7	7	8
O10	61	60	57	56	56	56	2	4	5	5	6

Mit O-13

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
O11	64	63	63	62	60	58	0	1	2	3	5
O12	62	62	62	61	61	60	0	0	1	1	2

Mit O-14

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
O13	62	62	62	61	61	61	0	0	1	1	1
O14	69	68	68	67	67	67	1	1	2	2	2
O15	70	69	66	63	62	60	1	4	6	8	9
O16	63	63	63	62	61	61	0	1	1	2	3
O17	63	63	63	62	62	61	0	1	1	2	2
O18	63	63	62	62	62	62	0	0	0	1	1
O19	63	63	63	63	63	63	0	0	0	0	0
O20	65	65	65	65	64	64	0	0	0	0	0

Mit O-15

	Predicted Noise Levels (dBA)						Predicted Noise Level Reductions (dBA)				
	No Mit	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier	3ft barrier	8ft barrier	12ft barrier	15ft barrier	20ft barrier
O13	62	62	62	62	62	62	0	0	0	0	0
O14	69	69	69	69	69	69	0	0	0	0	0
O15	70	70	69	69	69	69	0	0	0	0	0
O16	63	63	63	63	63	62	0	0	1	1	1
O17	63	63	62	61	61	60	1	1	2	3	3
O18	63	62	61	59	59	58	1	2	3	4	5
O19	63	62	61	59	59	58	1	2	4	4	5
O20	65	64	63	63	63	63	1	1	2	2	2

ATTACHMENT E
NOISE WALL EXAMPLES