Appendix II

Table of contents: **Engineering Dynamics Inc.**

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NOISE ASSESSMENT

KING II COAL MINE

HESPERUS, LAPLATA COUNTY COLORADO

NOVEMBER 2013

Prepared by: Howard N. McGregor

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EXECUTIVE SUMMARY

In response to concerns regarding the noise emission emitted by above ground processing and mine ventilation equipment, a noise assessment was conducted by Engineering Dynamics Inc. personnel during the month of February 2013. Two types of noise measurements were conducted and analyzed.

1. Close-in noise measurements were taken around the mine ventilation fan which takes outside air and feeds it into the mine. These measurements involved measuring the tonal properties of the noise so that the significant frequency components of the fan noise could be determined. The measurement data showed that the fan noise was predominately that caused by the rotational speed of the fan and occurred at the frequency of the fan blades, very similar to that of the noise coming from the intake of an aircraft jet engine but not as high in pitch but lower in frequency, more like a humming sound.

2. At five of the eight sites, the measurement duration was about twenty hours while at the remaining three sites, the measurement duration was about four hundred fifty hours. At seven of the sites the noise monitors were set to measure and record the "C" weighted sound levels per the requirements of COGCC. At Site 1 located at the intersection of the mine access road and CR120, the noise monitor was set to measure and record the "A" weighted sound levels per that section of CRS 25-12 that addresses motor vehicle noise especially trucks.

   All of the measured noise levels at the sites were well in compliance with the State of Colorado Noise Law or that of COGCC. However, it should be pointed out that compliance with the laws or regulations does not assure that the noise will be inaudible during moments of silence, that is; no traffic, wind noise or other anthropogenic noise (anthropogenic means, man-made).

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I. FOREWORD

This noise assessment report was prepared for the King II Coal Mine, by Engineering Dynamics Inc. under the direction of Joe Bowden, Senior Scientist and Partner, CDS Environmental Services, LLC.

This report addresses the noise emissions associated with the mine ventilation fan at the King II Coal Mine. The mine is located at 6473 County Road 120, Hesperus, Colorado 81326.

Drawing and maps necessary for the preparation of this Noise Assessment Report were provided to Engineering Dynamics Inc. by CDS Environmental Services, LLC.

Noise measurements were taken at a total of eight locations, herein referred to as Sites; five sites for a duration of about twenty hours and three sites for a duration of 451 hours.

Engineering Dynamics Inc. has prepared noise impact assessment analyses and reports for the surface and underground mining industry since 1972. All of the work report herein was performed by Mr. McGregor or under his direct supervision. Howard N. McGregor is a registered professional engineer licensed to practice engineering in the State of Colorado, License Number 3928, obtained by examination.

II. APPLICABLE NOISE LAWS, REGULATIONS AND ORDINANCES

A. Community Noise

Community noise has been addressed by the Federal Government starting with the U. S. Environmental Protection Agency, (EPA) "Noise Control Act of 1972". In concert with that act, state and local governments have enacted laws or ordinances regulating noise emission levels. Furthermore, these laws clearly define measurement methodology and decibel limits in scientific terms. Some laws do, however, include subjective assessments which are outside of rigorous scientific evaluation and for this reason can be highly variable. Subjective assessments or considerations will not be addressed in this report.

B. State of Colorado Noise Law

Section 25-12-103. Maximum Permissible Noise Levels

§(1) Every activity to which this article is applicable shall be conducted in a manner so that any noise produced is not objectionable due to intermittence, beat frequency, or shrillness. Sound levels of noise radiating from a property line at a distance of twenty-five feet or more therefrom in excess of the dB(A) established for the following time periods and zones shall constitute prima facie evidence that such noise is a public nuisance.

Maximum Allowable Noise Levels		
Zone	7am to next 7pm	7pm to next 7am
Residential	55 dB(A)	50 dB(A)
Commercial	60 dB(A)	55 dB(A)
Light Industrial	70 dB(A)	65 dB(A)
Industrial	80 dB(A)	75 dB(A)

§(2) In the hours between 7:00am and the next 7:00pm, the noise levels permitted in subsection (1) of this section may be increased by ten dB(A) for a period of not-to-exceed fifteen minutes in any one-hour period. This paragraph in the State of Colorado Noise Law has been interpreted to mean that this 10 dB increase can occur once and only once during the daytime hours of 7:00am to 7:00pm and never during the nighttime hours.

§(3)Periodic, impulsive or shrill noises shall be considered a public nuisance when such noises are at a sound level of five dB(A) less than those listed in subsection § (1) of this section.

Examples

Periodic – pile drivers, impact wrenches, punch presses jack hammers and compaction equipment.

Impulsive – firearm, fireworks, blasting high pressure venting

Shrill – sirens, metal forming, warning devices.

§(5)Construction projects shall be subject to the maximum permissible noise levels specified for industrial zones for the period within which construction is to be completed pursuant to any applicable construction permit issued by proper authority or, if no time limitation is imposed, for a reasonable period of time for completion of project. This section of the law has been interpreted to include mine development as construction. Such construction would include access roads, top soil removal and storage, set up of stationary equipment such as crushers, screens and engine generators, installation of utilities and construction of earthen noise barrier berms.

Section 25-12-104 Action to Abate

The entire section was amended in 2008 and made effective on August 5, 2008. The last sentence of this section now reads:

The court may stay the effect of any order issued under this section for such time as is reasonably necessary for the defendant to come into compliance with the provisions of this article

C LaPlata County

LaPlata County has no noise ordinance or regulation and relies upon the State of Colorado Noise Law; CRS 25-12 and the Colorado Oil and Gas Conservation Commission Regulations (Section 802).

D. Colorado Oil and Gas Conservation Commission (COGCC)

The COGCC regulations are not applicable to surface or underground mines. However, LaPlata County Planning Department has adopted a portion of COGCC regulation 802 which read as follows.

In situations where the compliant or Commission onsite inspection indicates that low frequency noise is a component of the problem, the Commission shall obtain a sound level measurement twenty-five (25)

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feet from the exterior wall of the residence or occupied structure nearest to the noise source, using a noise meter calibrated to the dB© scale. If this reading exceeds 65 dB©, the Commission shall require the operator to obtain a low frequency noise impact analysis by a qualified sound expert, including identification of any reasonable control measures available to mitigate such low frequency noise impact. Such study shall be provided to the Commission for consideration and possible action.

It is assumed that LaPlata County has considered that low frequency noise is a factor in the noise emissions from the King II ventilation fan and has recommended that the noise measurements conducted by E. D. I. be done using the C weighting, rather than the A weighting, which is commonly done. It will be shown in this report that the fan noise is not low frequency but rather mid-frequency having a peak at 313 Hz compared to heat exchanger cooling fans, typical in the gas industry, having a low frequency noise emission at 40 Hz.

E. U. S. Environmental Protection Agency (EPA)

The EPA has established guidelines for noise levels in sensitive areas, suggesting that the average acceptable outdoor residential level to be 55 dB(A) or less. See U. S. Environmental Protection Agency, March 1974, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety", NTIS No. 50/9-74-004, Washington D. C. Government Printing Office, commonly referred to as "the levels document".

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III. MEASUREMENT INSTRUMENTS, METHODOLOGY and OTHER EFFECTS

A. Equipment Inventory

1. Short Term Noise Monitors

All of the short term noise monitors were Quest Model M-39 instruments. These instruments are fitted with a high quality laboratory microphone. The acoustical signal from the microphone is converted into a numerical decibel value which is then stored in the instruments' computer memory where the information can be downloaded at a later date. The detailed setting of each instrument is presented at the top of the instrument data download sheet.

The data download time history presentation shows the average decibel value for each and every one (1) minute interval over the entire measurement time, shown as the "run time" at the top of the first download sheet for each instrument.

2. Long Term Noise Monitors

The three long term monitors were Quest Model 2900 instruments. These instruments are fitted with high quality laboratory microphones. These units function just like the M-39 units described above except they have much larger memories and therefore can run for much longer time periods; hundreds of hours as compared to twenty-four hours. The data download sheets for these three instruments are also included in this report. Run time for each of the three instruments was 451 hours.

B. Atmospheric Absorption of Sound

The effect of atmospheric absorption of the noise emitting from a rock drill or any other equipment at 100 ft. is insignificant and is an order of magnitude less than other factors such as terrain and wind. Atmospheric absorption is dependent upon humidity, temperature and the spectral characteristics of the noise source, that is; at low frequency there is very little atmospheric absorption of sound whilest at high frequencies the atmospheric absorption is substantial being as much as 40 dB per 1000 ft. This frequency dependent absorption of sound explains why the low frequency noise from a railroad diesel/electric engine can be heard at great distances, while the noise from the engine air brakes cannot be heard. Most mining equipment such as rock drills have a noise spectrum that is low frequency in its nature. The atmospheric absorption of sound increases very rapidly with increasing frequency. Rock drill noise is made up mostly of engine fan and exhaust noise which is low frequency. An approximate calculation of the atmospheric absorption of rock drill noise can be obtained by using 250 Hz as the frequency of the noise emission.

A complete presentation on atmospheric absorption including data tables is in ANSI SI.26-1995 (R 2009). Contrary to popular belief the greatest effect of the atmosphere in the absorption of sound is at high air temperatures and relatively low humidity, so the greatest reduction in sound due to absorption in the atmosphere is on hot dry days.

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IV. MEASUREMENT RESULTS WITH COMMENTS

A. Short Duration Noise Monitors

Site 1 – Location: At the intersection of the mine access road and CR120, 100 ft to the left of the haul road and about 50 ft. from the centerline of CR120. The noise monitor at this location was set to A-weighting because truck noise limit in CRS 25-12 specifies the north limits in A-weighted dB, all other sites were C-weighted as requested by LaPlata County Planning Department Staff.

Run Dates: 2/14/13
Run Time: 22:10
Meter, s/n 0023
Weighting: A

Noise Statistics					
Exceedance Level – Percentiles					
01	10	50	90	AVG	MIN
67	53	46	38	55.2	35.6

Site 2 – Location: Residence at 515 CR120, Randy Randg, in driveway area next to bird house mounted on tree.
Run Dates: Run Dates: 2/14/13
Run Time: 22:40
Meter, s/n 0027
Weighting: C

Noise Statistics					
Exceedance Level – Percentiles					
01	10	50	90	AVG	MIN
80	67	50	35	67.6	32.6

Site 3 – Location: At the Vista deOro entrance arch, 500 Sand Ridge Ct., on metal gate next to archway.
Run Dates: 2/14/13
Run Time: 21:54
Meter, s/n 0026
Weighting: C

Noise Statistics					
Exceedance Level – Percentiles					
01	10	50	90	AVG	MIN
79	68	50	36	66.5	33.3

Site 4 – Location: At 595 Sand Ridge Ct., J. C. Coyne, in front yard. An air compressor located in the garage at the rear of the residence was audible.

Run Dates: 2/14/13
Run Time: 21:25
Meter, s/n 0029
Weighting: C

Noise Statistics					
Exceedance Level – Percentiles					
01	10	50	90	AVG	MIN
73	62	48	37	61	33

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Site 5 – Location: Near front of hay barn at northern most portion of Vista deOro
Run Dates: 2/14/13
Run Time:20:48
Meter, s/n 0031
Weighting: C

Noise Statistics					
Exceedance Level – Percentiles					
01	10	50	90	AVG	MIN
76	62	43	35	63.7	33

B. Long Duration Noise Monitors

Site 6 – Location: Rear of home on patio, 500 Sand Ridge Ct.
Run Dates: 2/14/13 to 3/5/13
Run Time:451:58
Meter, s/n 0046
Weighting: C

Noise Statistics					
Exceedance Level – Percentiles					
05	10	50	90	AVG	MIN
63.4	58.9	42.5	37.2	57.0	35.4

Site 7 – Location: 650 Sand ridge Ct.
Run Dates: 2/14/13 to 3/5/13
Run Time:451:33
Meter, s/n 001
Weighting: C

Noise Statistics					
Exceedance Level – Percentiles					
05	10	50	90	AVG	MIN
69.2	63.5	39.4	33.9	61.8	30.8

Site 8 – Location: Front of hay barn at ranch
Run Dates: 2/14/13 to 3/5/13
Run Time:449:39
Meter, s/n 0021
Weighting: C

Noise Statistics					
Exceedance Level – Percentiles					
05	10	50	90	AVG	MIN
59.8	54.8	40.7	35.6	54.2	31.7

The large decibel difference between the average and minimum value is that the average is an average of the equivalent energy values. A 3 dB difference between two decibel numbers is a two to one difference in the energy between the two. Another way of looking at the situation is to recognize that decibels are a logarithmic measure of sound and cannot be mathematically manipulated using common arithmetic so, 50 dB(A) plus 50 dB(A) equals 53 dB(A) assuming the two noise sources are uncorrelated.

C Ventilation Fan Spectral Data

Figures 1 through 5 present the ⅓ octave and the overall A and C weighting noise levels at several locations around the intake air ventilation fan. During these measurements the fan was running at normal speed and airflow. The fan is an Air Jet Corporation, Model 84 inch, X-5300-C, 300hp electric motor drive. It can be seen in Figures 1 through 4 that there are two significant peaks in the ⅓ octave values; one at 20 Hz and one at 315 Hz. The 20 Hz peak occurs at the rotational speed of the fan that is 1179 rpm. The 315 Hz peak is the frequency of the fan blade, that is 16 blade times1179 rpm equals 314 Hz. The fan blade noise component at 315 Hz can be reduced by the use of a commercially available intake silencer. The noise component at 20 Hz may be caused by motor/fan unbalance and would require field balancing of the motor/fan assembly. This balancing work would require the fan to be stopped while balance weights were added to determine the angular location of the unbalance and amount of unbalance and whether or not the unbalance is simple single plane (static unbalance) or unbalance in both the motor and fan assembly (dynamic multi-plane unbalance). The installation of corrective balance weights would take several hours so, it would be preferred to first determine if the 20 Hz noise is caused by unbalance of the motor/fan or not. This can be determined without shutting the ventilation fan down, that is; accelerometers can be installed while the fan is running.

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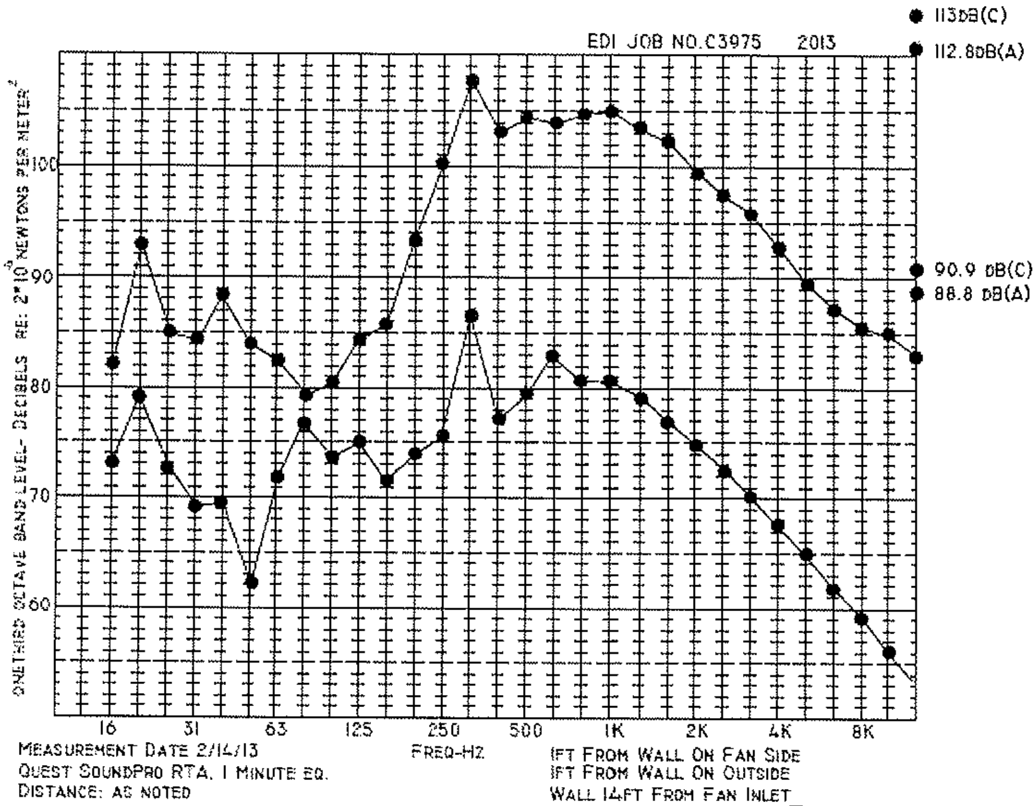

FIGURE - 1

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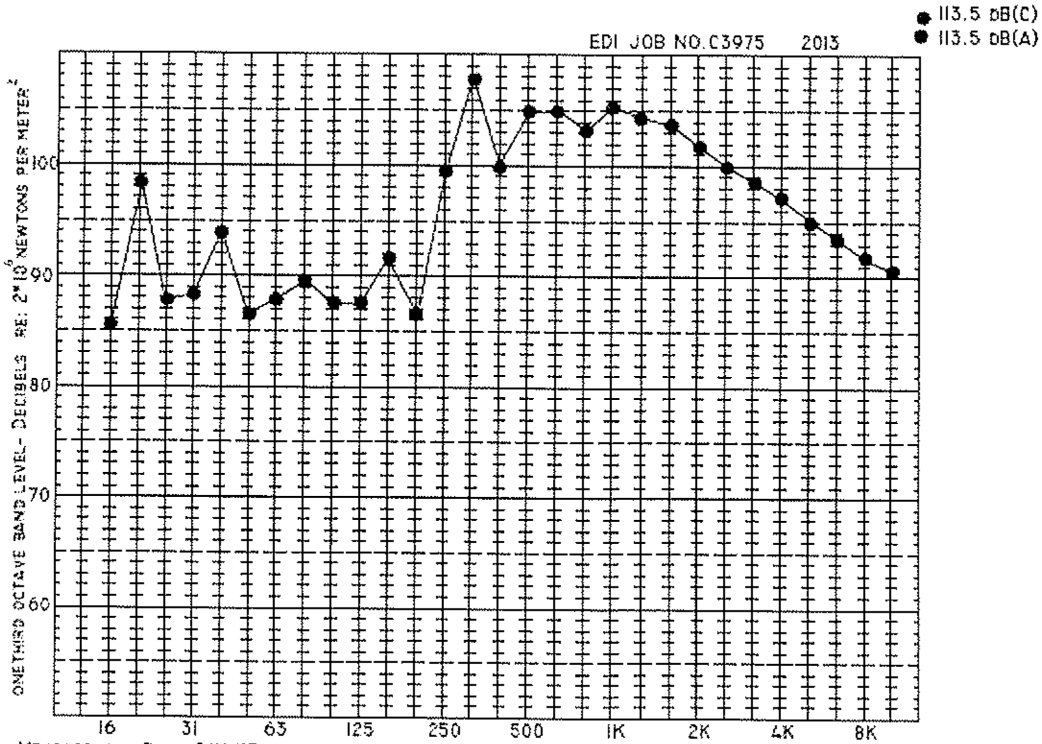

MEASUREMENT DATE 2/14/13
QUEST SOUNDPRO RTA, 1 MINUTE EQ.
DISTANCE: AS NOTED

KING II VENTILATION FAN
4FT-2IN FROM LEFT SIDE OF FAN

FIGURE - 2

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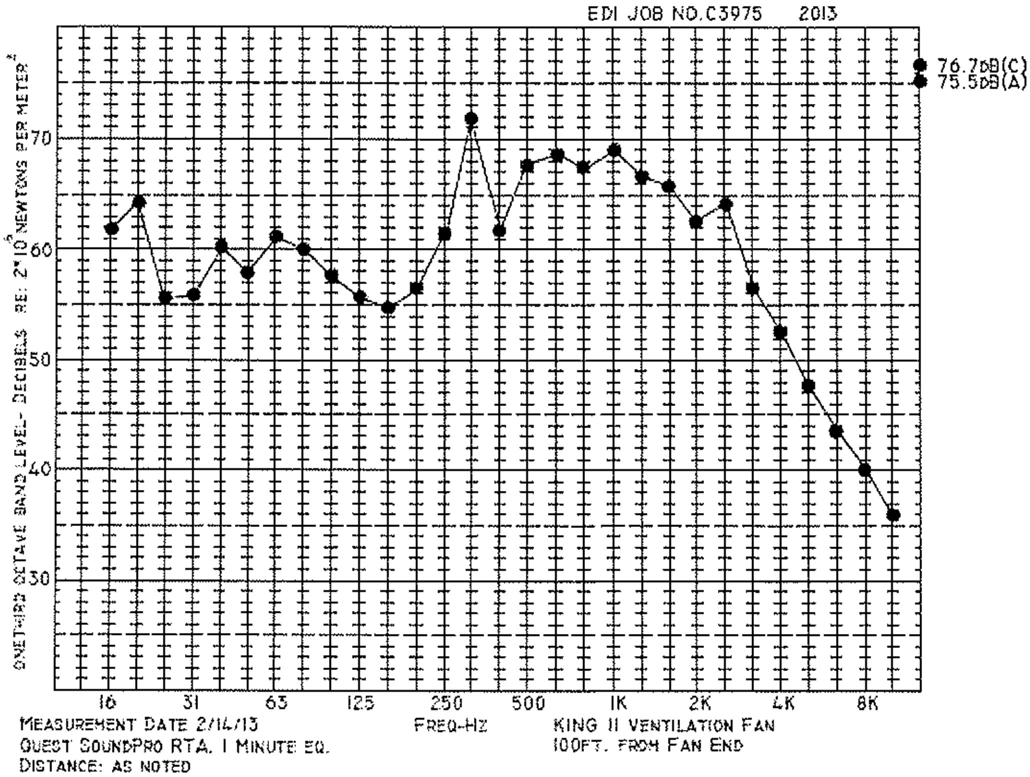

FIGURE - 3

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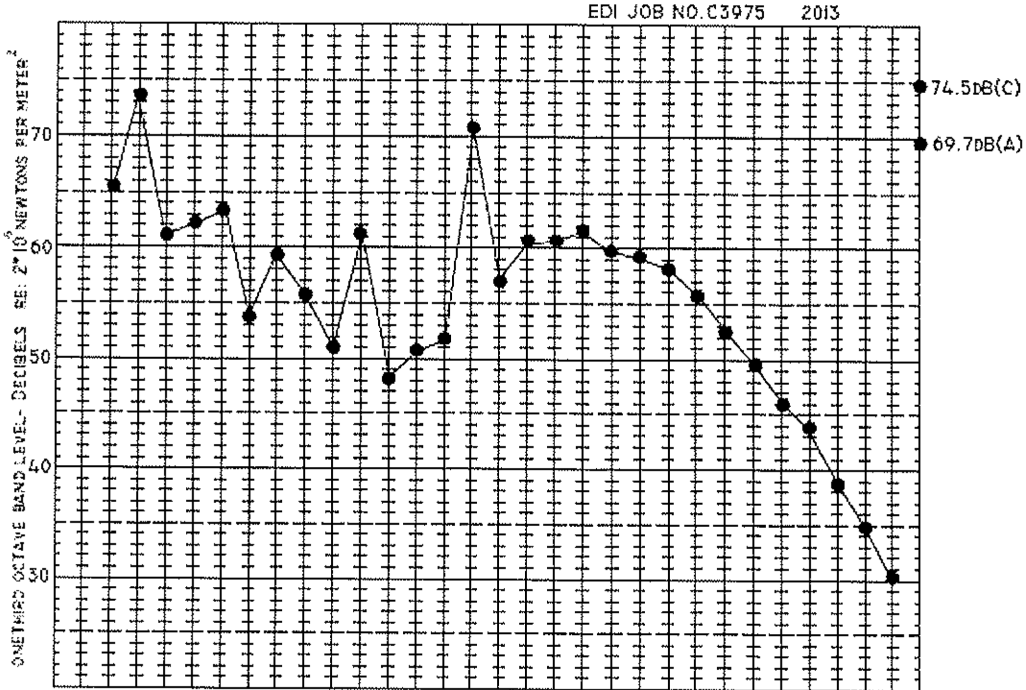

MEASUREMENT DATE 2/14/13
QUEST SOUNDPRO RTA, 1 MINUTE EQ.
DISTANCE: AS NOTED

KING II VENTILATION FAN
100FT. TO THE LEFT OF FAN END
NEXT TO BUILDING DOWN HILL

FIGURE - 4

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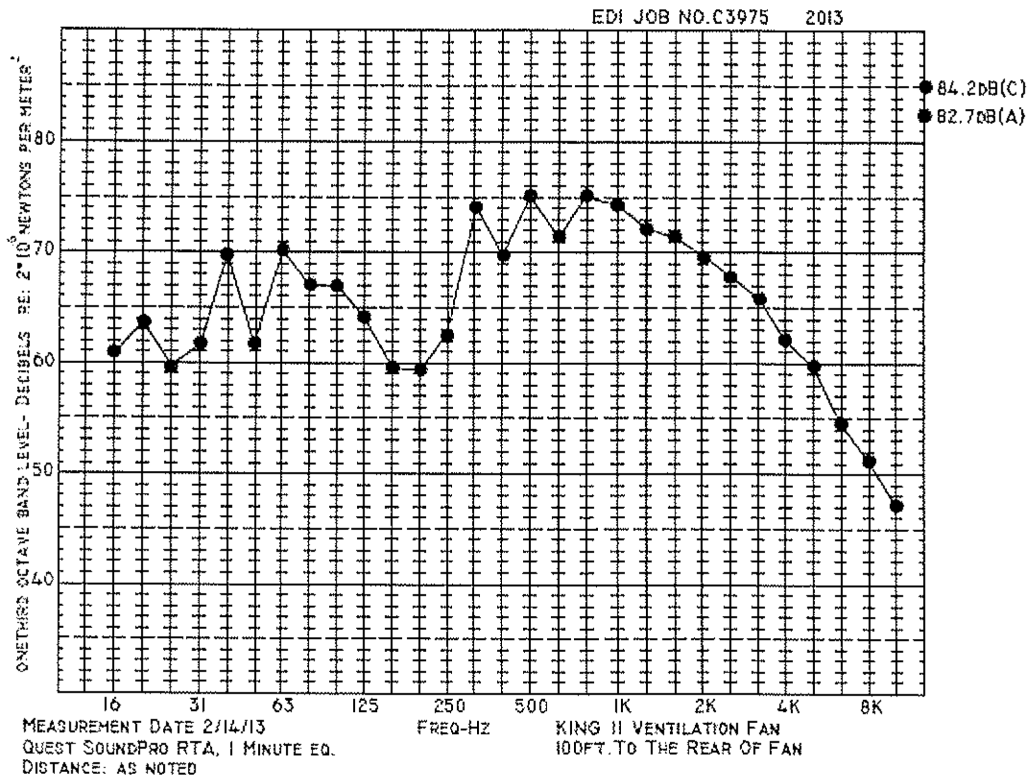

FIGURE - 5

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V. FINDINGS and TIME HISTORY – GRAPHICAL PRESENTATIONS.

A. General

The King II coal mine ventilation fan runs continuously and the noise emission at the eight measurements sites do not exceed the limits in the Colorado Noise Law, CRS 25-12 and those of the Colorado Oil and Gas Conservation Commission; COGCC. All of the noise measurements conducted were C-weighted as requested by the LaPlata County Planning Department except for one site where the noise environment was mainly due to haul trucks going to and from the King II coal mine. This was at the junction of the mine access road and LaPlata County Road 120. Also, included in this section are detailed "Time History" graphs for each measurement location; Time History Graphs 1 through 8. Presented on each graph is the recorded one-minute average dB(A) value. These graphs clearly show when the noise level is at a minimum value and when there are periods of wind and anthropogenic noise; a fancy word for man-made. It can be seen on all of the graphs except Site 1, where haul truck noise was the dominant noise source that when wind and anthropogenic noise is eliminated that the average noise level is well below the COGCC noise limit of 65 dB(A) adjacent to occupied structures. The State of Colorado residential noise limit of 55 dB(A) daytime and 50 dB(A) residential noise limits are not exceeded.

B. Site Specific

1. Site 1 (Graph 1)
   The measurements at Site 1 were A-weighted decibel values so they could be compared with CRS 25-12-106 (1) §(d) which limits the A-weighting noise level to 86 dB(A) at 50 ft. This would include haul trucks on CR120 as they were arriving and departing the King II Coal Mine access road. The measurements show that during the entire measurement interval of 22 hours there was only one event that occurred at 2:54 on Thursday, February 14 and that momentary level was 89.2 dB(A) from an unknown source.
2. Site 2 (Graph 2)
   This site and all of the Sites except Site 1 were set to record the C-weighted decibel level as required by LaPlata County Planning Department. A maximum level of 96 dB(C) occurred at 11:19 on Friday, February 15, 2013. The duration of the 96 dB(C) noise was less than one minute, 13 percent of the total 22 hour measurement interval time exceeded 65 dB(C) and this exceedance can be attributed to wind and vehicle noise. When these noise events were not present the noise level was 35 dB(C) or lower.
3. Site 3 (Graph 3)
   At 11:23 on Friday the 15th, a maximum noise event occurred and was probably caused when the noise monitor was physically moved from the area, just prior to end of run shut down. 16 percent of the total measurement interval of 21 hours, the noise level exceeded 65 dB(C) and this occurred during removal and shut-down of the noise monitor.
4. Site 4 (Graph 4)
   At 21:25 on Thursday, February 14th, a maximum noise level of 88.8 dB(C) occurred at the end of the 21 hour measurement interval while the noise monitor was being shut down. 8% of the time the noise level was greater than 65 dB(C) and can be attributed to wind and vehicle noise.
5. Site 5 (Graph 5)
   At 11:37 on Friday the 14th of February a noise event of 91.5 dB(C) occurred and can be attributed to the handling of the noise monitor as it was being removed from the site and shut down. 8% of the time the noise level was greater than65 dB(C).
6. Site 6 (Graph 6)
   This site was one of the three sites that ran for an extended period of time; from February 14 to March 5, 2013. The total number of one-minute average A-weighted decibels was 27,060. A maximum noise level of 80 dB(A) occurred at 13:30 on February 24 and a minimum level of 35.4 dB(A) occurred on February 16, 2013. The average noise level over the entire 451 hours was 57 dB(A).
7. Site 7 (Graph 7)
   The total run time at Site 7 was 451 hours from February 14 to March 5, 2013. A maximum noise level of 81.5 dB(A) occurred on February 21 and a minimum level of 30.8 occurred on February 16, 2013. The average noise level over the entire 451 hours was 61.8 dB(A).

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8. Site 8 (Graph 8)
The total run time at Site 8 was 449 hours from February 14th to March 5, 2013. A maximum noise level of 81.1 dB(A) occurred on February 24 at 9:28 and a minimum noise level of 31.7 dB(A) occurred on February 16 at midnight. The average noise level over the entire 449 hours was 54.2 dB(A).

C. Audibility
Audibility of noise emission is not addressed in the State of Colorado Noise Law or the Colorado Oil and Gas Conservation Commission regulations. These noise limits are addressed in a manner very similar to speed limits, either one is over the speed limit or under the speed limit. A noise value can be measured using scientific instruments, not by subjective assessments, which can be subjected to significant error. The same is true for environmental noise, the decibel level can be lower than the law or regulation but it can still be audible and considered to be objectionable by the receptor that is by nearby or even distance residents. One way to resolve this situation is by the use of noise mitigation methods. In the case of the King II Coal Mine, mitigation will be accomplished by using a silencer attached to the ventilation fan air intake. Such silencers are currently in use at numerous coal mines in the U. S.

Once the intake silencer has been installed, noise measurements will be taken at the same locations where the ⅓ octave plots are presented in Figures 1 through 5. The new ⅓ octave data point will be put on these figures to show the actual reduction in noise.

D. Background Noise
Background noise is that noise caused by other noise sources that are not associated with the noise source under consideration, in this case the King II Coal Mine. During the noise measurements at several sites the background noise consisted of the following:

- Wind noise
- Wind gusts
- Nearby traffic on CR120, mine access road and Sandy Ridge Road
- Aircraft approaching and departing LaPlata County Airport (DRO).
- Barking dogs
- Resident's motor vehicles on driveways
- Outdoor activities of residents

A common descriptor for these types of noises that are man-made is anthropogenic noise sources.

Distance noise sources are profoundly affected by terrain and atmospheric conditions. In general, they do not, especially at great distances, that is, distances greater than one mile, follow the classical inverse square law, which states that every time you double the distance from a noise source the level of the sound reduces by 6 dB. This all means that the noise from a distance noise source such as from the King II Mine can be easily estimated, although the value will be on the high side.

A formal technical description of background or residential noise is presented in American National Standards Institute (ANSI)document ANSI S12.9 defines the L_{90} as a measure of the background or residual noise level in a specific environment or at a specific location in that environment. The L_{90} exceedance levels at the eight measurement sites are:

Site 1	38 dB(A)	page 18
Site 2	35 dB(C)	page 18
Site 3	36 dB(C)	page 19
Site 4	37 dB(C)	page 19
Site 5	35 dB(C)	page 20
Site 6	37.2 dB(C)	page 20
Site 7	33.9 dB(C)	page 21
Site 8	35.6 dB(C)	page 21

It can be seen that the measured L_{90} exceedance value correlates well with the time history presentations in Graphs 1 through 8 and according to the definition of Background Noise in ANSI S12.9 the noise from the King II Coal Mine is less than 33.9 dB(C)/37.2 dB(C).

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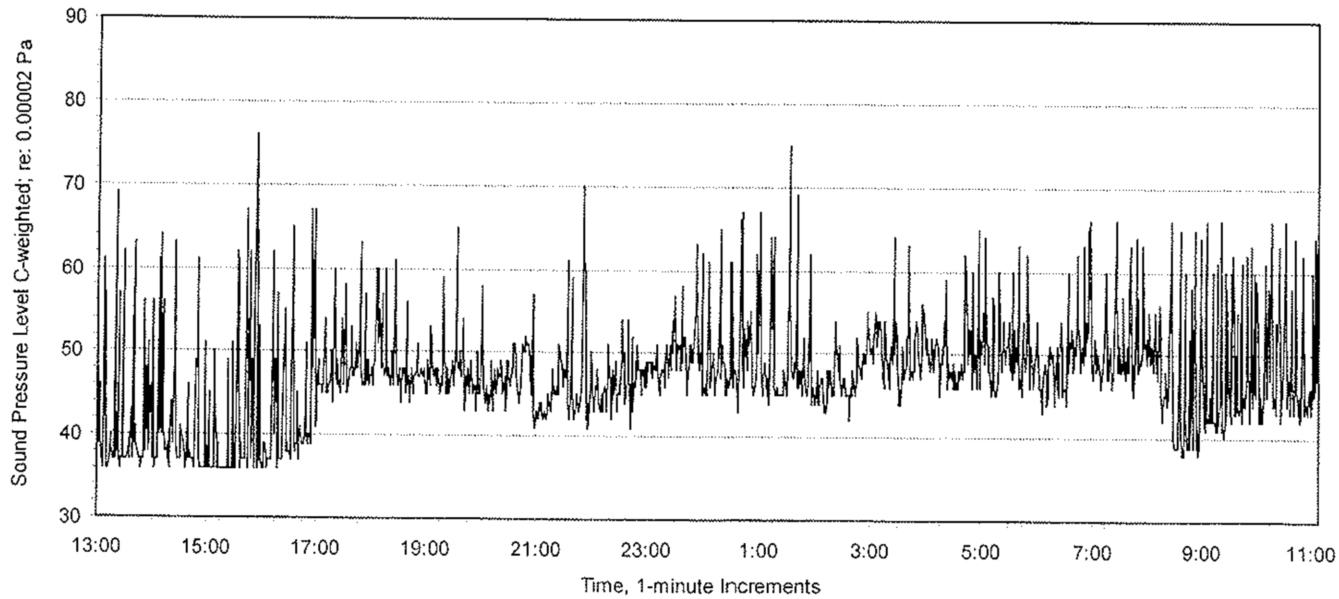
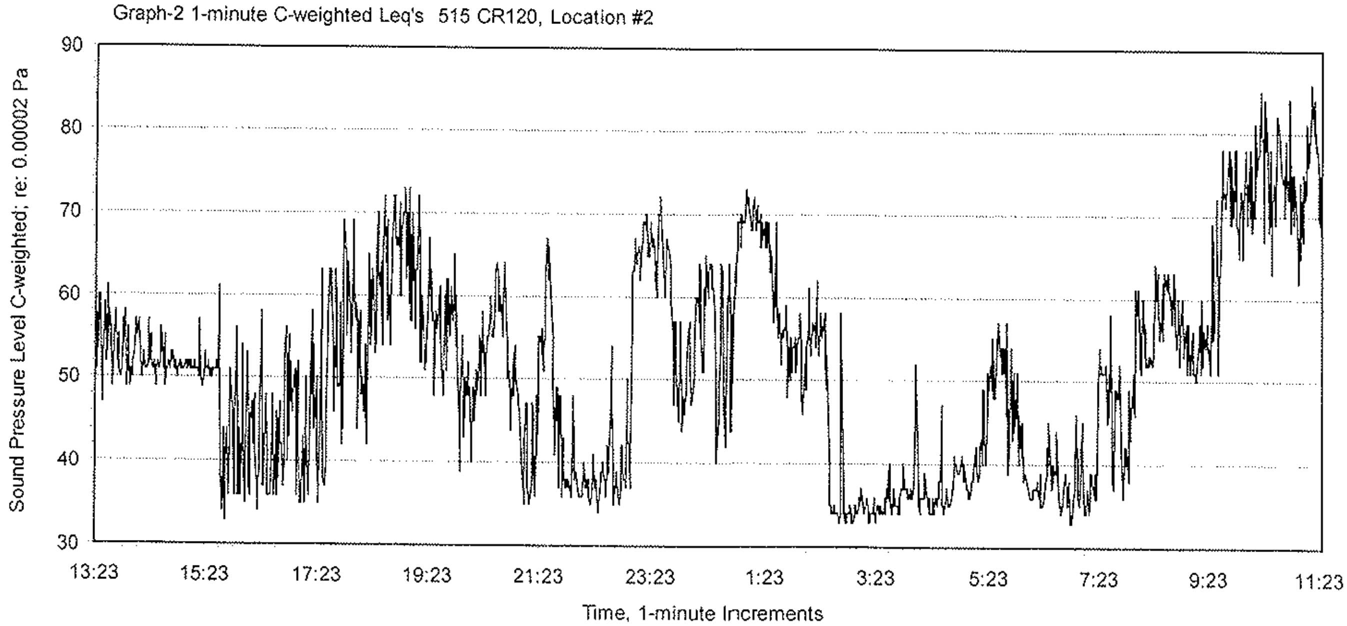
Graph-1: 1-minute A-weighted Leq's Haul Road and CR120, Site#1



Graph-2 1-minute C-weighted Leq's 515 CR120, Location #2



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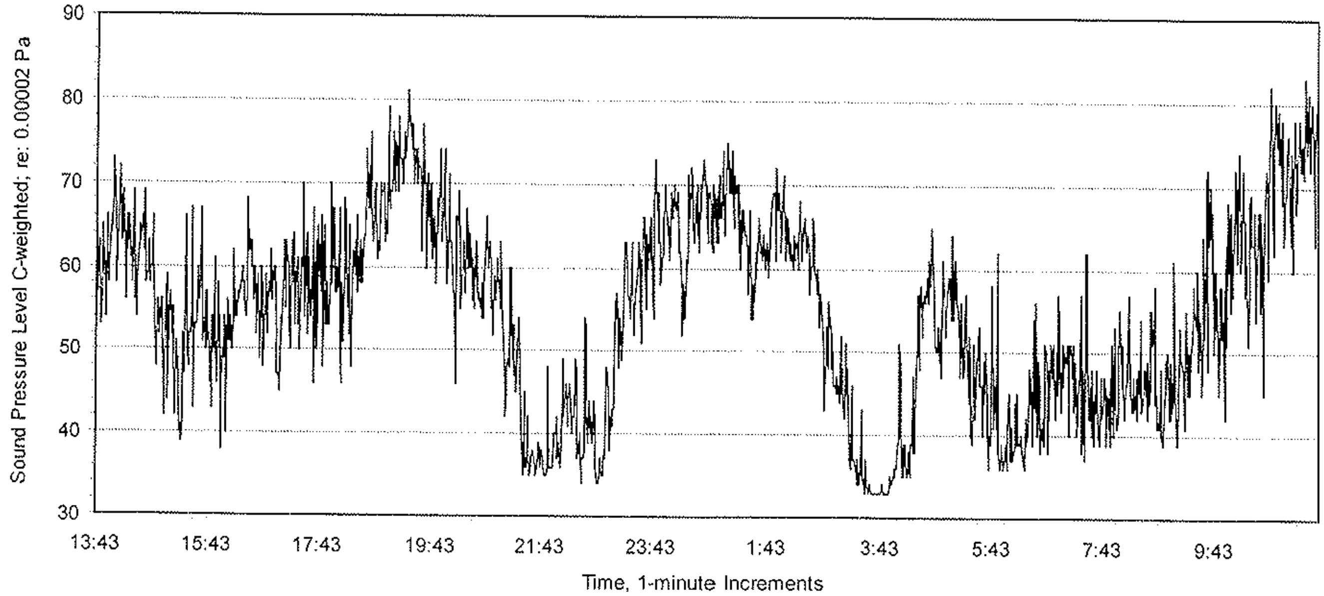
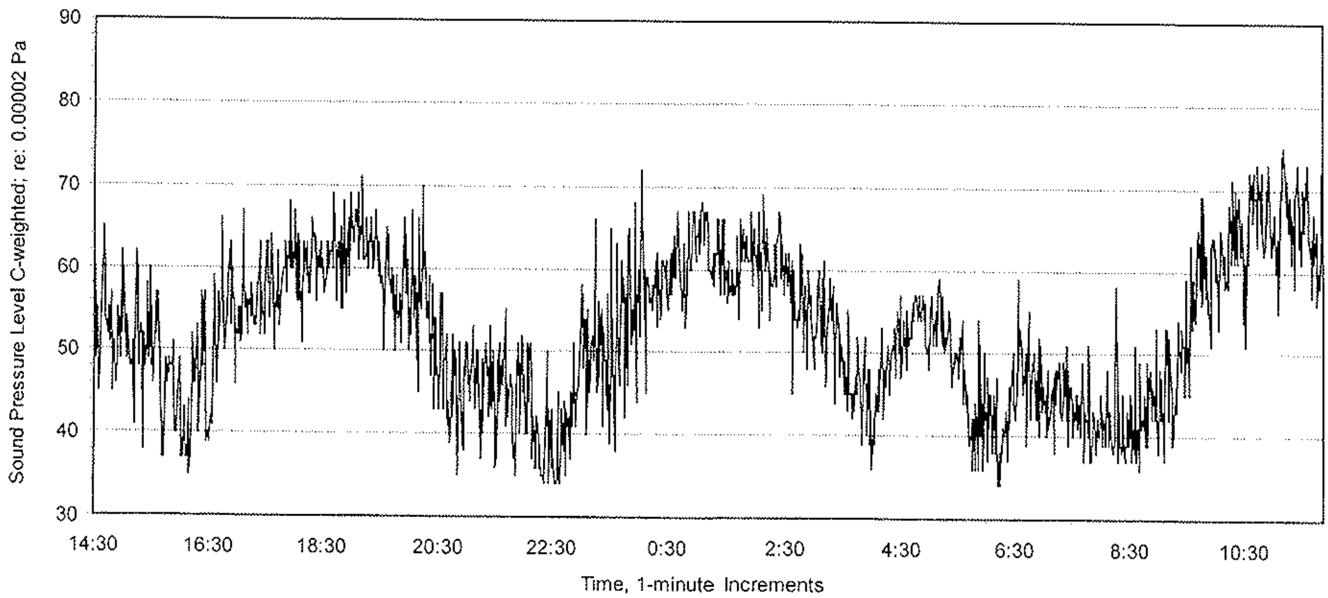
Graph-3: 1-minute C-weighted Leq's At Entrance to Vista de Oro 500 Sand Ridge Ct., Location #3



Graph-4: 1-minute C-weighted Leq's 595 Sand Ridge, Site #4



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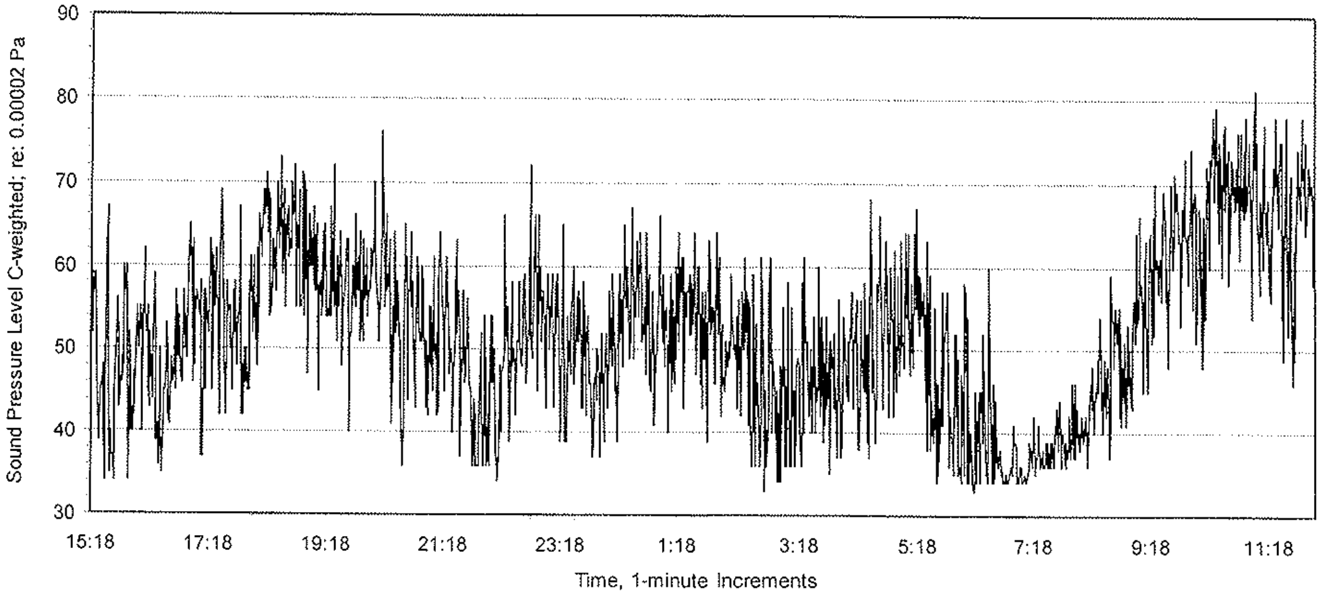
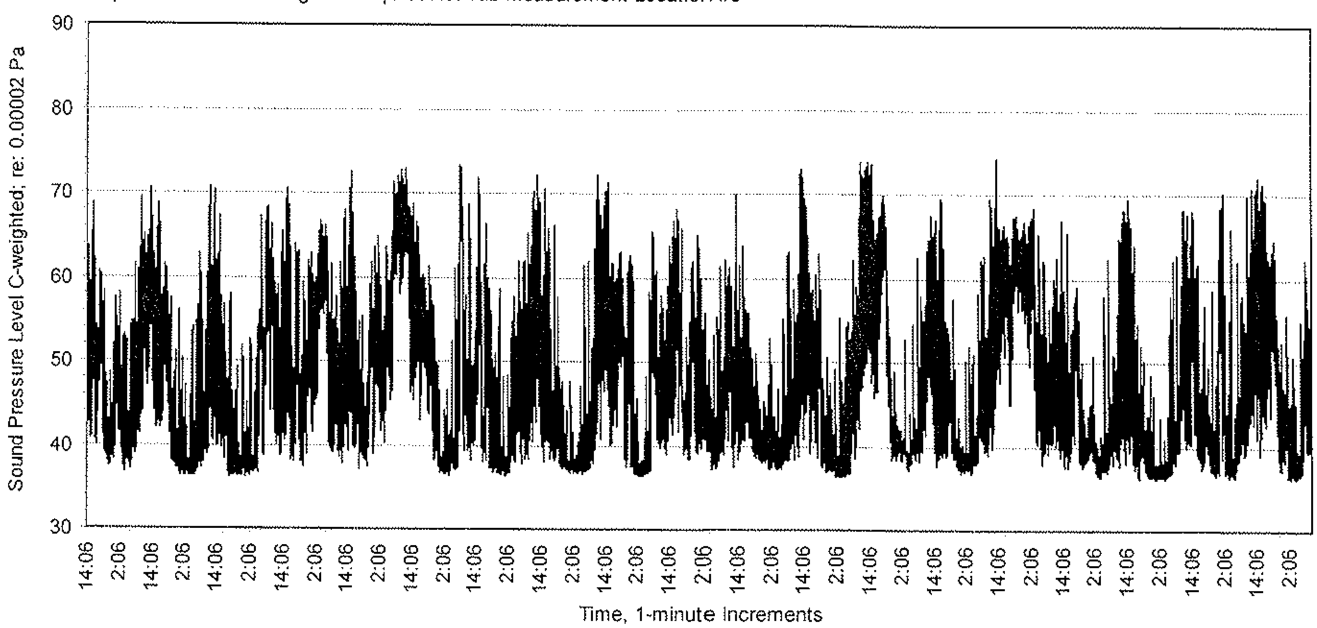
Graph-5: 1-minute C-weighted Leq's Lot23 , Site #5



Graph-6: 1-minute C-weighted Leq's at Hot Tub Measurement Location #6



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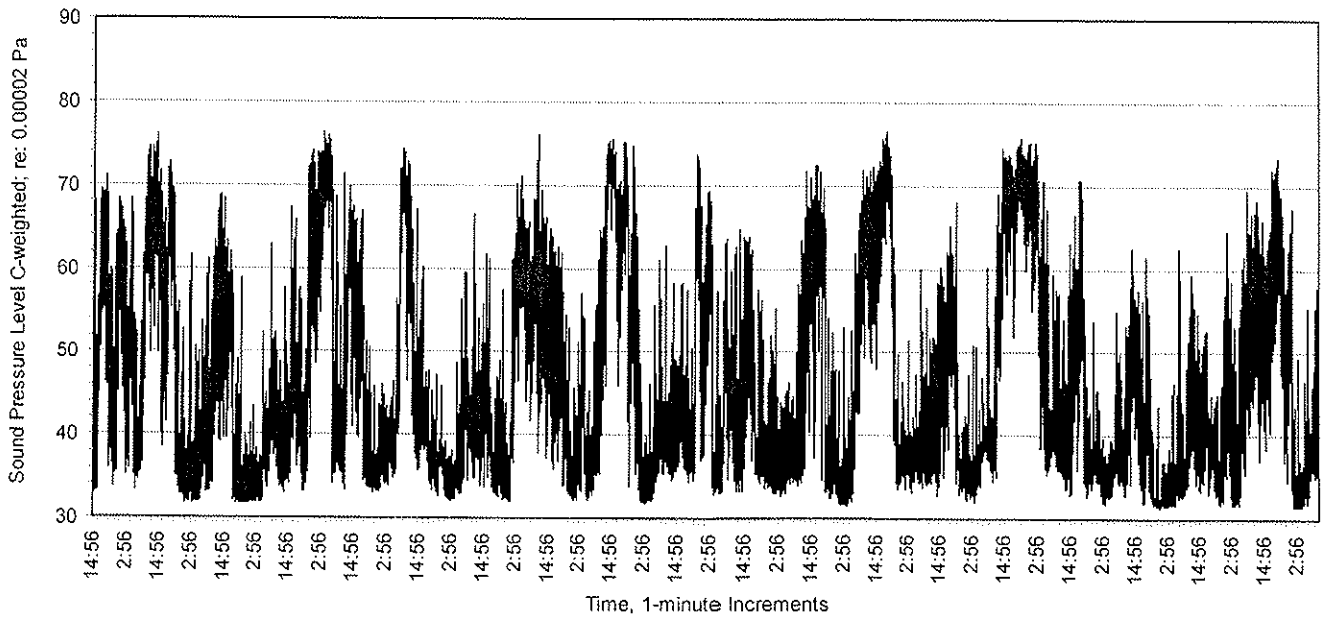
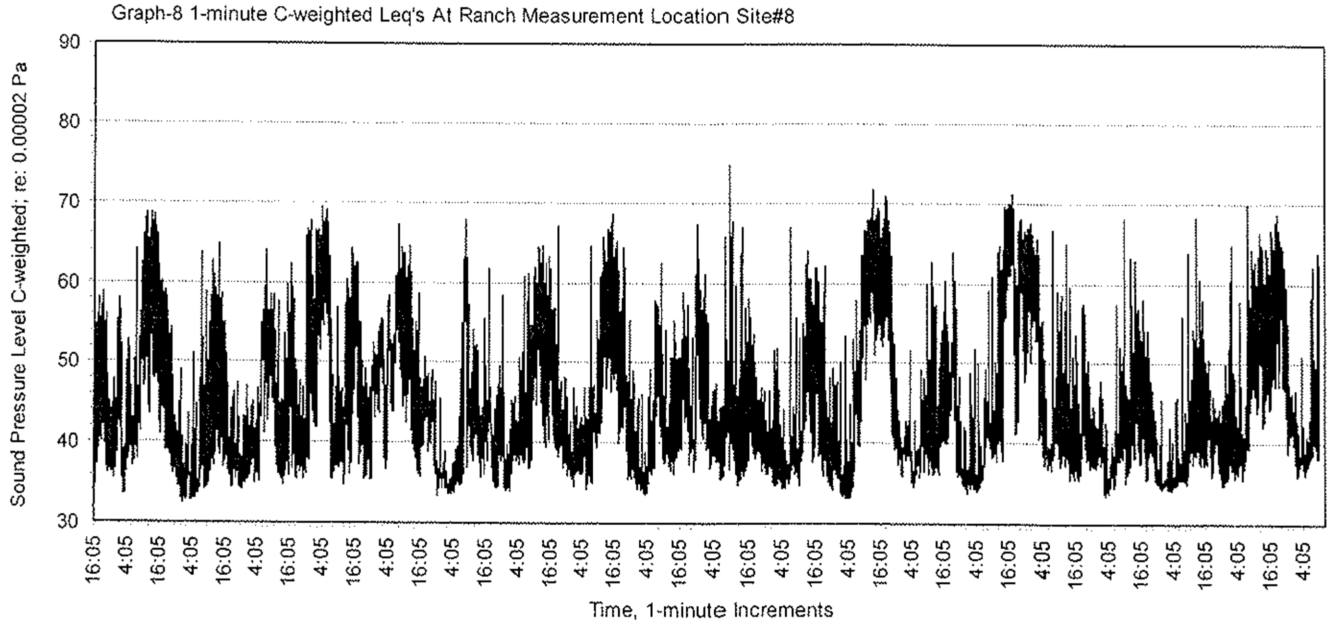
Graph-7 1-minute C-weighted Leq's at Fence 650 Sand Ridge Measurement Location #7



Graph-8 1-minute C-weighted Leq's At Ranch Measurement Location Site#8



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Sound Source

Volume 1/Issue 4 February 2005

A– AND C –WEIGHTED NOISE MEASUREMENTS

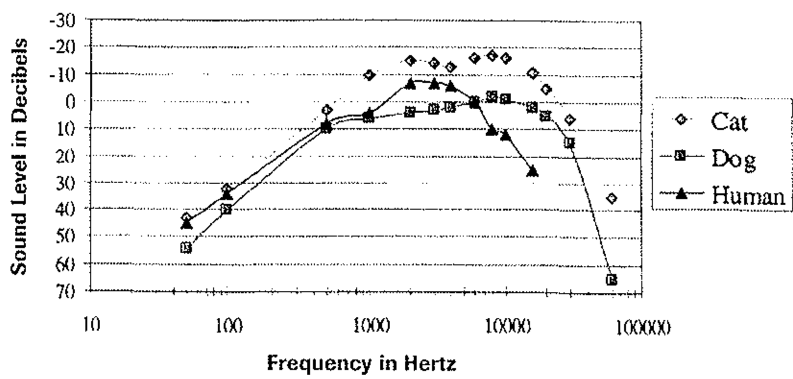
Hearing protector literature makes reference to A-weighted and C-weighted noise measurements. What are A-weightings and C-weightings?

The A-weightings and C-weightings refer to different sensitivity scales for noise measurement. For example, we've heard it said that animals have better hearing sensitivity than humans. This increased sensitivity is true not only for the ***intensity*** of a sound (a cat can hear sounds that are much quieter than humans can hear), but also for the ***frequency*** of a sound (a high-pitched dog whistle is easily heard by a dog, but is beyond the frequency range perceived by humans, even though it is quite loud). So hearing sensitivity must be measured not only in *intensity*, but also in terms of *frequency*.

To display these measurements of hearing sensitivity, we use a scale showing frequency on the horizontal axis (measured in hertz), and intensity on the vertical axis (measured in decibels). The curves in Figure 1, for example, show the measured hearing sensitivity for a cat and dog compared with a human.

Note in this figure that humans have hearing that is most sensitive for soft tones in the mid-to high frequencies of the chart, but less sensitive in the low frequencies; that is, hearing for soft tones "drops off" in the lows. Researchers in the 1930s discovered that this loudness sensitivity curve for soft tones was not the same for loud tones. In fact, at very loud tones, the sensitivity of the human ear has difficulty distinguishing differences in loudness between a low-frequency 80 Hz tone and a high-frequency 4,000 Hz tone – to the human ear, they sound about equally loud. Thus, in high noise levels, the loudness sensitivity of the ear is quite "flat."

Figure 1. **Hearing Sensitivity at Threshold**

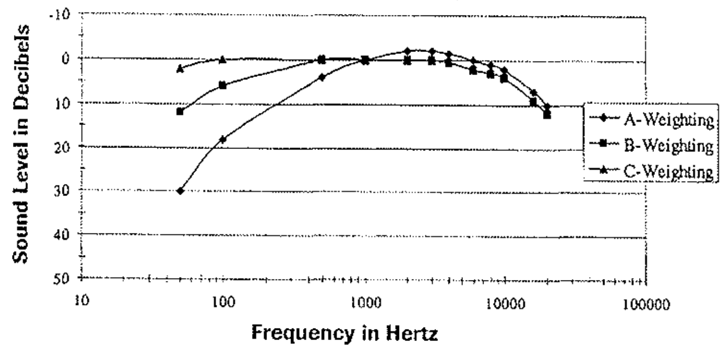


(Area under the lines represents sounds that are audible)

In the development of sound level meters over the years, manufacturers have built in these different response curves (see Figure 2), and named them the A-, B-, and C-weighting scales:

The C-weighting scale was originally designed to be the best predictor of the ear's sensitivity to tones at high noise levels. Why, then, are noise measurements for hearing conservation almost always measured in dBA? Because the ear's loudness sensitivity for tones is not the same as the ears' damage risk for noise. Even though the low frequencies and high frequencies are perceived as being equally loud at high sound levels, much of the low frequency noise is actually being filtered out by the ear, making it less likely to cause damage. The A-weighting scale in a sound level meter replicates this filtering process of the human ear.

Figure 2. **A-, B- and C-Weighting Curves**



A-Weighting	Follows the frequency sensitivity of the human ear at low levels. This is the most commonly used weighting scale, as it also predicts quite well the damage risk of the ear. Sound level meters set to the A-weighting scale will filter out much of the low-frequency noise they measure, similar to the response of the human ear. Noise measurements made with the A-weighting scale are designated dBA.
B-Weighting	Follows the frequency sensitivity of the human ear at moderate levels, used in the past for predicting performance of loudspeakers and stereos, but not industrial noise.
C-Weighting	Follows the frequency sensitivity of the human ear at very high noise levels. The C-weighting scale is quite flat, and therefore includes much more of the low-frequency range of sounds than the A and B scales.

Several of hearing conservation's key documents (including OSHA's Hearing Conservation Amendment, and EPA's labeling requirements for hearing protectors) rely on dBC in determining noise exposures. Today, however, nearly all noise measurements for hearing conservation are measured in dBA, resulting in misapplications and errors when figuring attenuation from hearing protectors. OSHA has attempted to bridge the difference between C and A-weightings with the following advice:

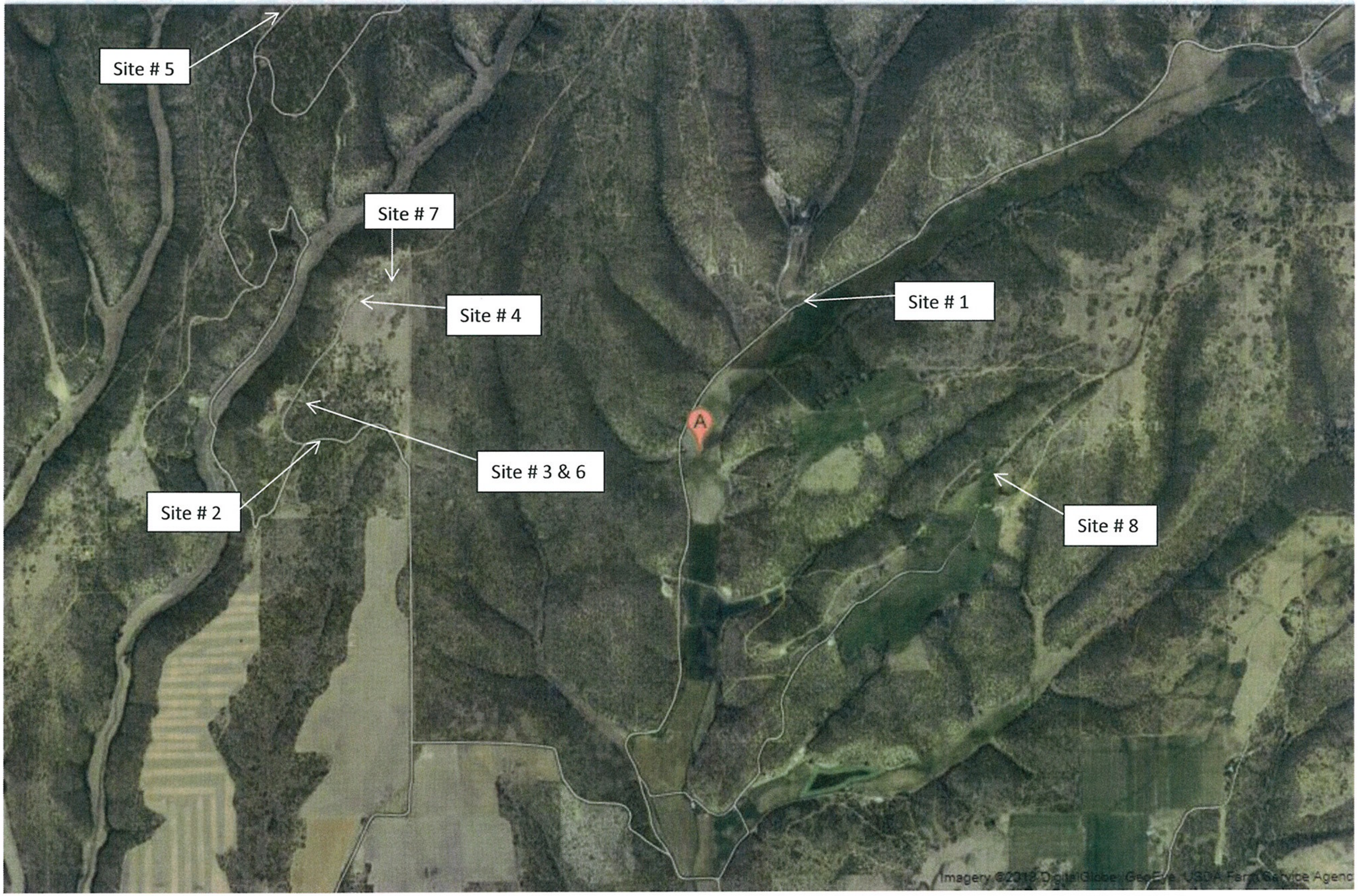
If your industrial noise measurements are in dBC, subtract the NRR of the hearing protector from the dBC noise measure to determine the protected noise level for the worker.

EXAMPLE	Noise Level	105 dBC
	Hearing Protector	25 NRR
	Protected Noise Level	80 dB

If your industrial noise measurements are in dBA, subtract 7 from the NRR of the hearing protector as an error cushion for C-A differences, then subtract the resulting lower NRR from the dBA noise measure to determine the protected noise level for the worker.

EXAMPLE	Noise Level	105 dBA
	Hearing Protector	25 NRR – 7 dB = 18 NRR
	Protected Noise Level	87 dB

-- *Brad Witt, MA, CCC-A*
Audiology & Regulatory Affairs Manager
Bacou-Dalloz™ Hearing Safety Group



Location of sound (noise) measurement sites

Appendix I

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To:	Mr. Joe Bowden, PhD CDS Environmental Services LLC P.O. Box 4124 Durango, CO 81302
Date:	January 16, 2013
Subject:	GCC Energy – King II Mine GROUND MOTION STUDIES La Plata County, Colorado January 8, 2013

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Matheson Mining Consultants, Inc.

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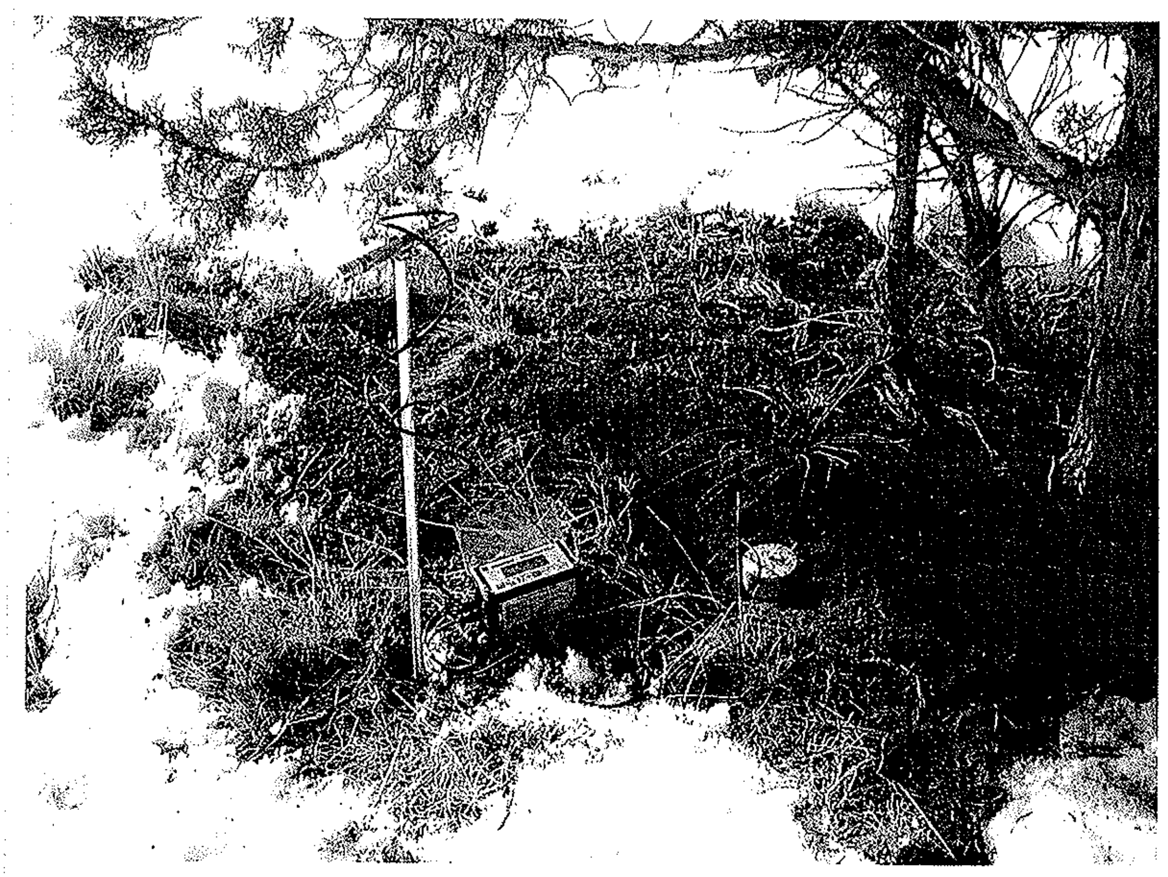
GCC ENERGY – KING II MINE

GROUND MOTION STUDIES REPORT

La Plata County, Colorado
January 8, 2013

SUMMARY

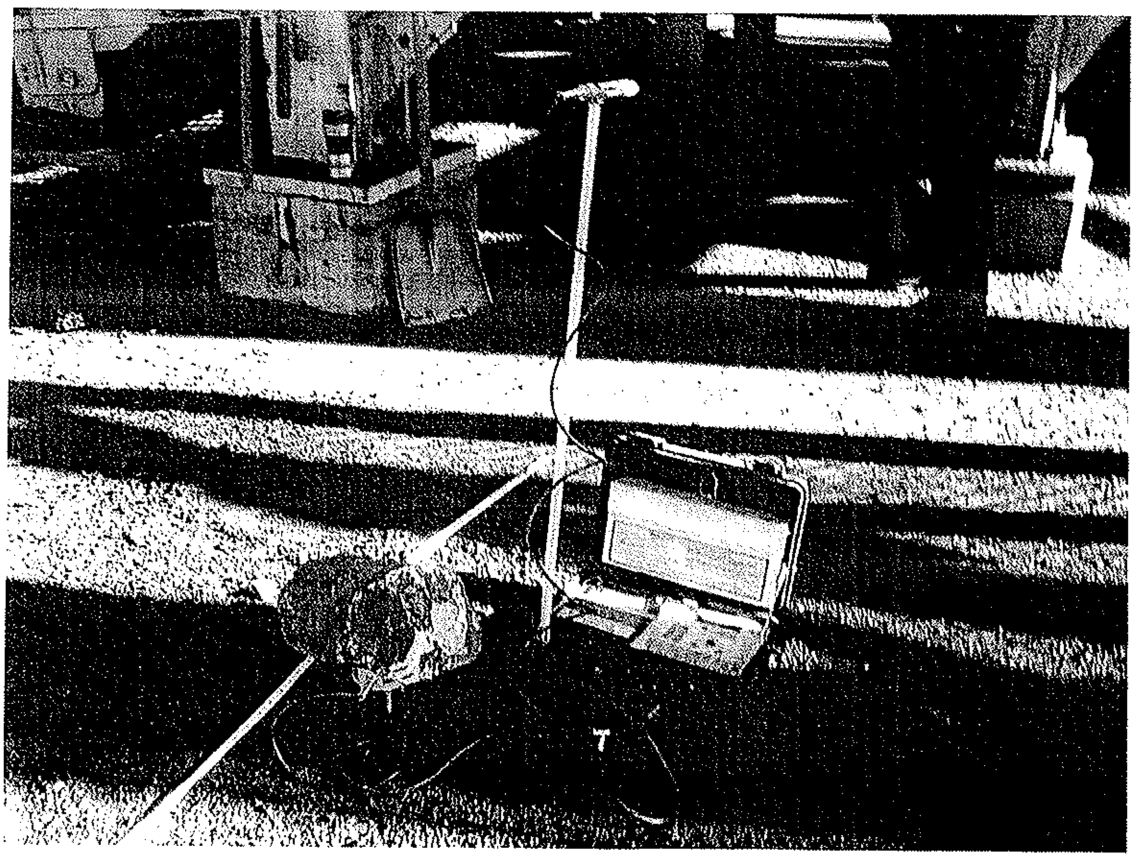
Matheson Mining Consultants, Inc. (MMC) was retained by GCC Energy to investigate ground motion concerns at the Map ID # 8 & 9 residences. Potential ground motion sources at the mine including the fan and screen were studied and ground motion was monitored between the residences for a period of 5.5 hours on January 8, 2013.



Seismograph Setup Between Map ID # 8 & 9 *Residences*

MMC recommends adherence with the United States Bureau of Mines (USBM) and/or the Office of Surface Mining Reclamation and Enforcement (OSMRE) Variable Frequency versus Particle Velocity criteria (Figure 4). Above 4 Hz, 0.50 to 2.00 inches per second (ips) is allowed, depending on dominant frequency (the threshold level for possible damage to plaster-on-lath). Adherence to these criteria provides a maximum level of liability protection. Documented cases of structural damage have never been observed in any structure, historic, exceptionally fragile, residential, or commercial, at particle velocities greater than those recommended in the USBM and OSMRE standards.

The threshold of human perception is around 0.030 ips. Oil and gas wells, pipelines, water wells, and fiber optic cables can withstand significantly higher levels and a level of 2.00 ips on these engineered structures is conservative. Bell Labs states that a limit of 4.00 ips is safe for their fiber optic cable and U.S. Bureau of Mines states that a limit of 4.92 ips is safe for a pipeline of any age or construction material and that this level is also appropriate for oil, gas, and water wells. Ten inches per second is considered a safe level for concrete.



Acquiring Ground Motion Data near the Screen.

There was no discernible ground motion recorded between residences during the 5.5 hour monitoring period on January 8, 2013. All ground motion levels recorded near the mine fan, screen and conveyors were low level and will not be transmitted beyond the immediate vicinity.

INTRODUCTION

The ground motion is measured in terms of peak particle velocity and is a combination of body and surface waves (Figure 1)[1]. The body waves attenuate more rapidly with distance from the vibration source than the surface waves. Body waves spread spherically, whereas the surface waves expand in two dimensions. The principal cause of ground motion attenuation with distance is due to simple geometric spreading. As the ground motion wave train spreads outwards from the energy source, the medium's individual particles are set in retrograde elliptical motion about their rest positions. The wave is generated as each particle transmits energy to the next particle. Some energy loss occurs with each transmission of energy from one particle to the next, which is also a cause of ground motion attenuation with distance. The ground motion is a complex wave train consisting of many different wave types (Figure 2)[1]. As the body waves impinge upon the surface, they are converted to surface waves. Body waves may also be reflected and refracted to the surface to become converted to surface waves. As the surface wave spreads out, the various components of the wave train have different particle motions, travel at different velocities, and have different geometric constraints.

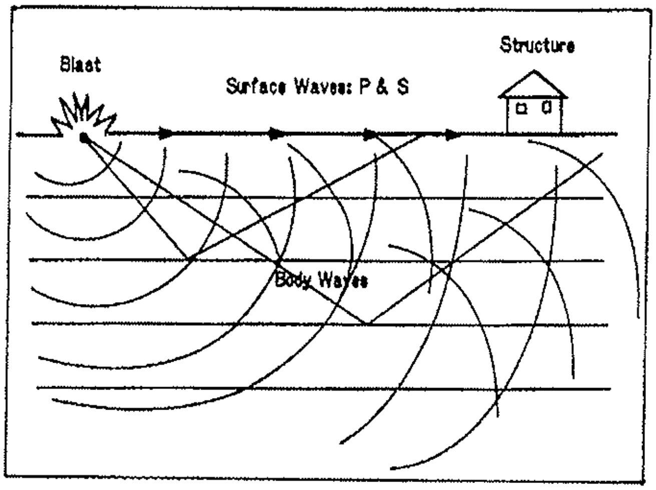


Figure 1 - Surface and Body Waves

Particle velocity has been determined to be the most significant single parameter, in terms of the potential for damage (as opposed to acceleration or displacement). Furthermore, the peak particle velocity found on any of the three geophone channels is the parameter used, rather than the resultant vector sum particle velocity. All research has been done and all regulations have been written in terms of peak particle velocity (PPV). Using the PPV instead of the vector sum allows for easier, more consistent comparison of values. A true resultant velocity could be calculated from the peak measurements for all three components if they occurred at the same instant of time. In addition, there is variability in how different seismograph manufacturers calculate the vector sum. Some actually calculate a pseudo resultant sum. These models take the peak levels on all three channels, regardless of where they individually occurred in time, to calculate the vector sum.

[1] Rosenthal, M.F., and G.L. Morlock. Blasting Guidance Manual. U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, March, 1987, p.11.

[1] Ibid., p. 12.

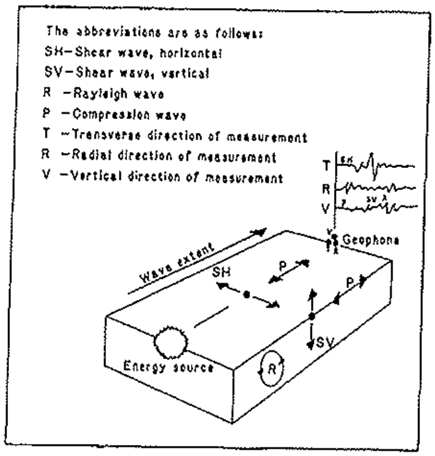


Figure 2 - Types of Ground Motion Waves

Since the 1920's or earlier, ground vibrations have been studied extensively to determine their potential for damage to various structures and construction materials. Blasting activities are among the most common sources of ground motion, have therefore been studied the most, and have thus prompted the ordinances and regulations that are in place. At the present time, the only federal regulation that pertains to ground motion is from the OSMRE. This regulation was written to protect residential structures. Complaints of damage to residences were, and are, the most common form of complaint resulting from the perception of ground motion.

INSTRUMENTATION

Vibration records were collected using Instantel Minimate Plus and Blastmate III seismographs. Each seismograph records particle velocity digitally in the frequency range of 1.5 to 250 Hertz. Each event is measured in three orthogonal channels of ground motion: vertical, longitudinal, and transverse. Zero-crossings of each of the three waveform components are calculated to determine frequency response.

An excerpt from the Blastmate III User's Manual is attached as part of Appendix I and describes the specifications and function of the instrumentation, and record processing.

An independent party using shake table, piston phone, and electronics traceable to the National Institute of Science and Technology has calibrated the instruments within the past year. Copies of the Calibration Certificates for the instrument, microphone and geophone are also included in Appendix I.

The microphone measures air overpressure in dBL. Air overpressures are typically produced from blasting activities and much of the energy is beneath the range of human hearing.

It is not possible to alter the vibration recordings or file names in any way, other than the ability to add post event notes. For security reasons, the instrument and software manufacturer (Instantel) will not release any of the programming code to any outside interests for any reason.

A self-test (on board calibration) was performed at each monitor location after setting up the instrument. The instrument also performs a self-test when it is put into monitor mode (this was disabled in instrument BA10185, but manual self-tests were performed).

METHOD

The energy sources at the mine that were studied were the screen and the fan. Readings were also taken near a mine office trailer to quantify perceptible motion in the trailer (window screens also vibrated). A seismograph was set up between the Map ID # 8 & 9 residences for a five and a half hour period from 10:25 am until 3:56 pm. MMC met with both home owners prior to setting up the monitor seismograph to discuss their vibration perceptions.

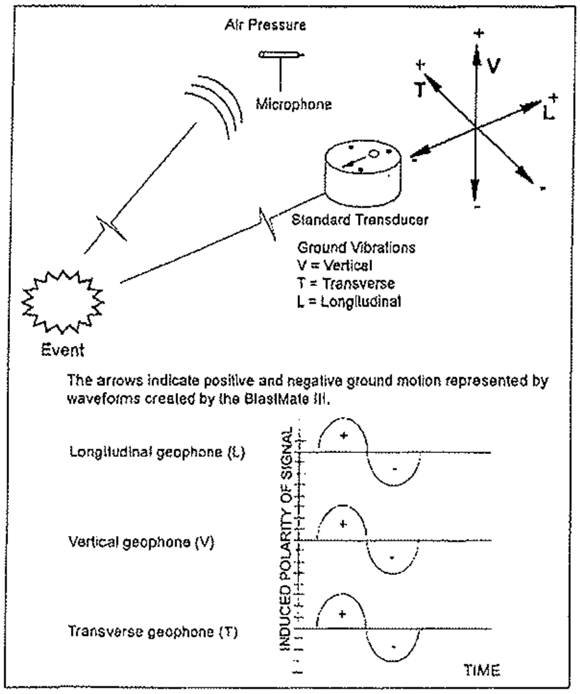


Figure 3 - Event Monitoring

The Map ID # 9 residence is located at see Last page of this report and the Map ID # 8 residence is located at see last page of this report.

Study and monitor locations were recorded using a handheld GPS and are found in Appendix III. The coordinate for the surface location above the underground mining on January 8, 2013 was provided by the mine and was 37° 15' 53.13" N 108° 08' 15.73" W. A monitor location identifier was assigned to each monitor location. A location identifier Of J08B1 indicates instrument B was used here on January 8, 2013 and this was the first monitor location on this day. Instrument A was BA10185 and Instrument B was BE10051.

Maps showing the locations of underground mining, the monitor location between the Map ID #9 and Map ID #8 residences, and the study locations at the mine are found in Appendix II. Ground distances from the monitor location between residences to the surface location above underground mining was 9,785 feet, to the mine fan was 7,628 feet, and to the mine screen was 8,349 feet (Google Earth).

Figure 3 shows an excerpt from the Blastmate III user's manual and illustrates how the geophone was oriented relative to the energy source. Surface material was removed as necessary to get a good solid geophone plant at all recording locations. Geophone plants were problematic for the screen study. Geophone spikes were removed and a large rock was used to couple the geophone to the earth.

Both instruments were set in sensitive mode with trigger levels set at or near to the minimum of 0.005 ips.

RESULTS

MMC recommends adherence to the USBM and the OSMRE variable particle velocity vs. frequency criteria for non-damage to plaster-on-lath, considered the most fragile of construction materials. Residential structures are most prone to damage as a result of vibration energy within the frequency range of 4-12 hertz. Within this range, a 0.50 inch per second maximum particle velocity is recommended to preclude "threshold" damage to the plaster-on-wood lath interior portions of older structures. The government regulations are designed to provide positive protection against damage to private and public property, and therefore, these regulations are as conservative as possible.

Above 12 hertz, the allowable vibration increases as the frequency increases, up to 40 hertz. Above 40 hertz, a constant 2.0 ips is recommended to protect the interior walls and ceilings of structures, regardless of construction material. A graphic representation of the USBM recommended criteria is shown in Figure 4.

However, complaints from residents often begin at levels of 0.25 ips or lower. Oil and gas wells, pipelines, and fiber optic cables can withstand significantly higher levels and a level of 2.00 ips on these engineered structures is conservative. For example, Bell Labs states that a limit of 4.00 ips is safe for their fiber optic cable and the USBM states that a limit of 4.92 ips is safe for a pipeline of any age or construction material.

The USBM and OSMRE variable particle velocity vs. frequency criteria is plotted on each vibration event report. The upper line represents the threshold level for possible sheetrock damage, while the lower, dashed line represents the threshold level for possible plaster-on-lath damage.

Map ID # 8/9 Residence Monitoring

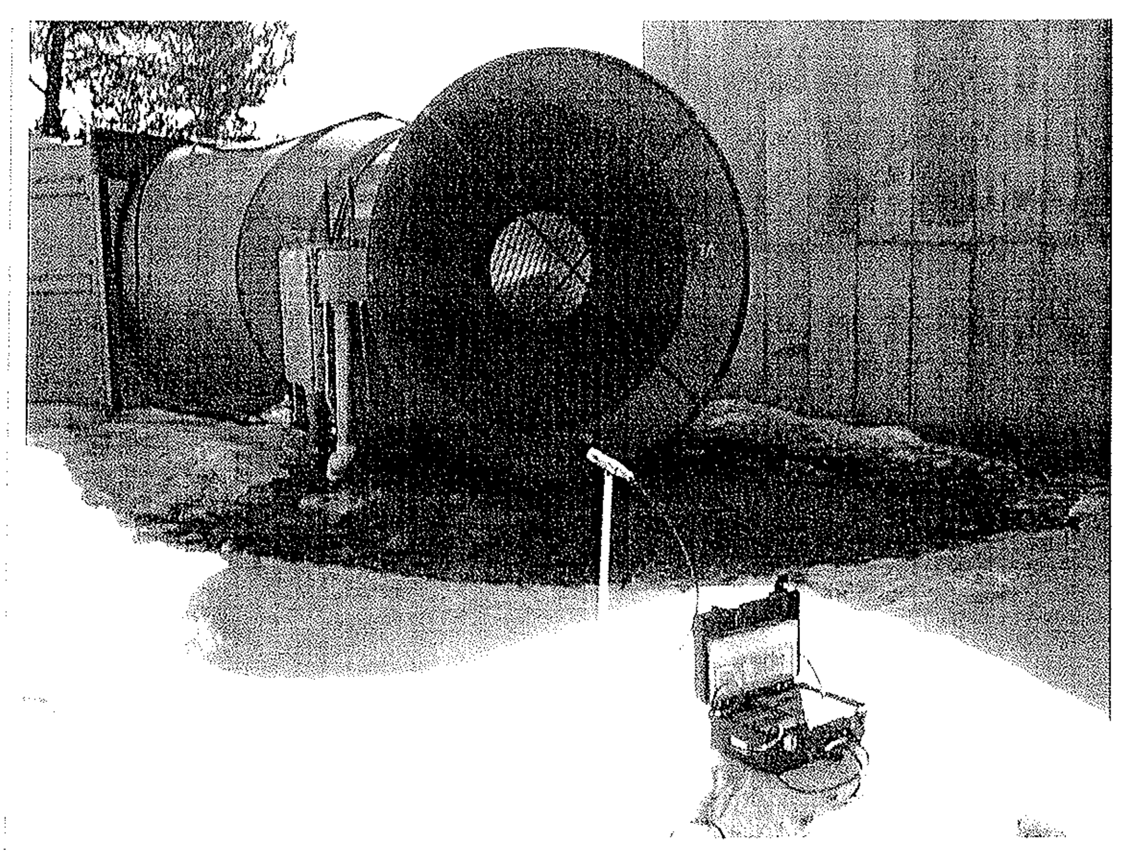
Prior to setting up the seismograph, MMC met with both residents to discuss their vibration perceptions. Map ID # 8 reported repeated misalignment of two pictures in his residence as evidence of ground motion. Both residents reported additional concerns (other than ground motion) that included the presence of the mine, noise from the mine (particularly when the wind is out of the east, and backup alarms on equipment), and truck traffic. Both residents reported experiencing vibrations that are steady-state and that are not impulsive, discrete events. This ground motion was perceived the most in evenings and at night when the activity level of the residents was low and was also more noticeable when outside on the patio during the summer. These perceived vibrations have been present since the mine began operations. Underground mining is moving north away from the residents.

Field notes and vibration recordings are found in Appendix IV. Forty events were recorded from 10:25 until 15:56 on January 8, 2013. Vibration levels recorded ranged from 0.0050 to 0.0075 ips. However, there was an offset problem with the vertical channel; it was offset approximately +0.004 ips. Background noise levels are around 0.003 ips. There are no discernible waveforms on any of the vibration recordings and it appears all recordings were the result of the offset problem.

Seismograph Location between Map ID # 8 and # 9 *Residences.*

Fan Study

A seismograph was setup twelve feet away from the fan intake and fifteen vibration events were recorded. Field notes and vibration recordings are found in Appendix V. Ground motion ranged from 0.00500 to 0.00562 ips with dominant frequencies ranging from 34 to >100 Hz. The highest air overpressure measured was 112.8 dBL

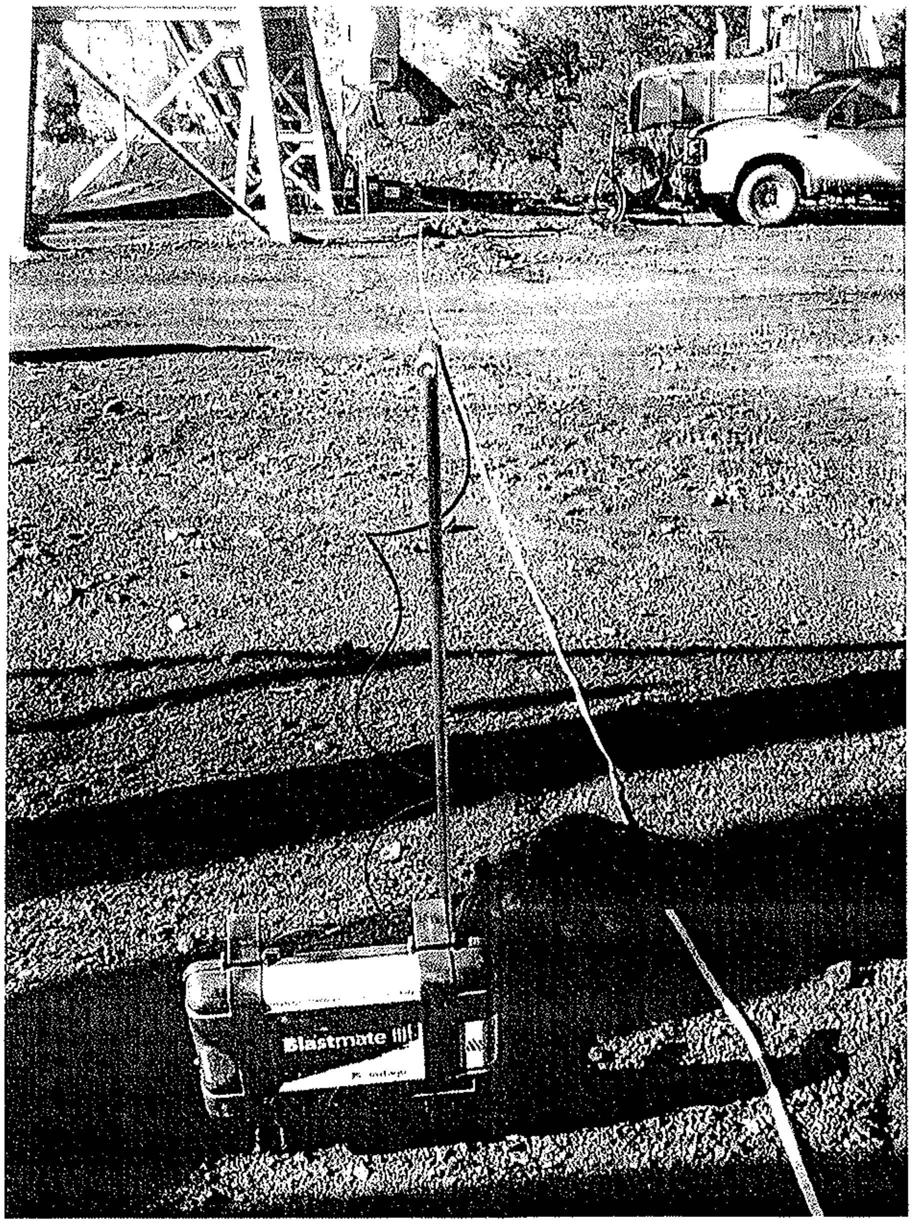


Data Acquisition near the fan.

reduce

Screen Study

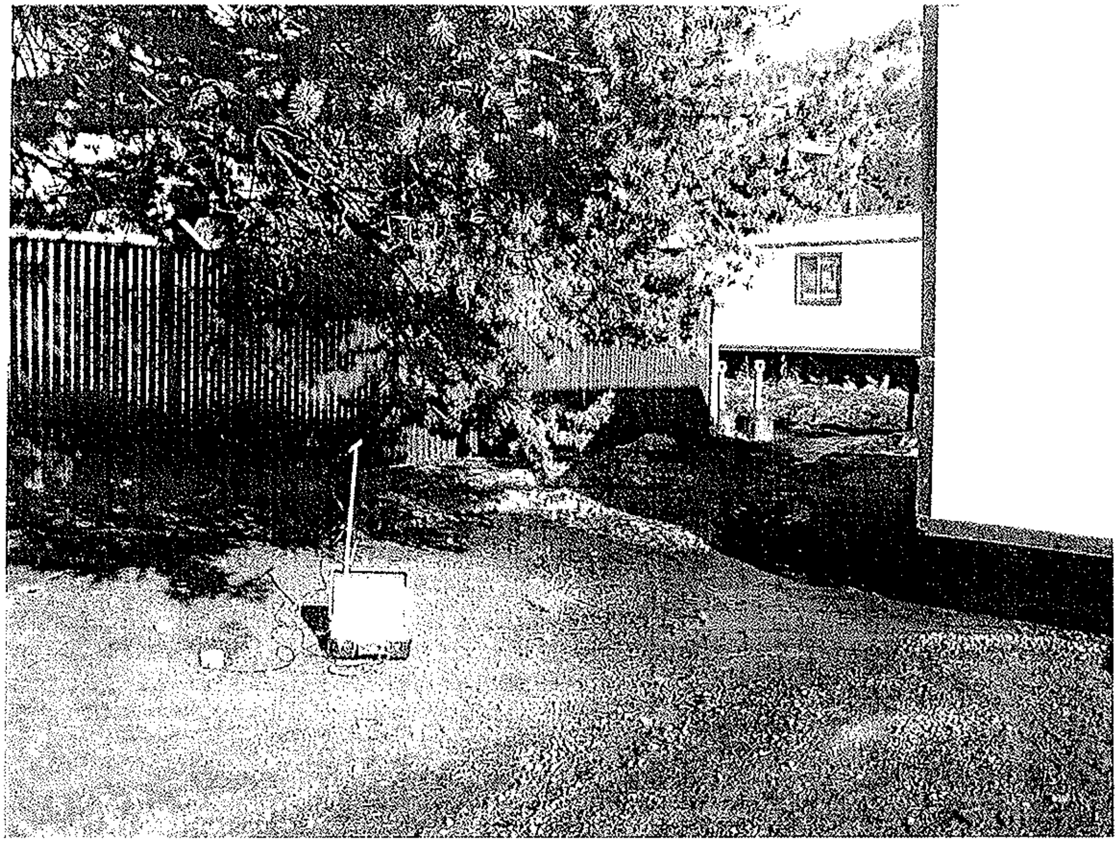
Fifty-one vibration events were recorded at distances of from 0 to 60 feet from the southwest concrete support pad in a west northwest direction along the conveyor from the tipple. Field notes and vibration recordings are found in Appendix VI. Ground motion levels ranged from a high of 0.0431 ips adjacent to the concrete pad to 0.0069 at a distance of 40 feet. At distances greater than approximately 30 feet, the recorded ground motion most likely results from the adjacent conveyor. Recorded air over-pressures ranged from 100 to 112.8 dBL.



Recording Line away from Screen towards Tipple.

Mine Office Trailer Study

Six ground motion events were recorded at a location approximately 10 feet northwest of the northwest corner of the mine office trailer. Field notes and vibration recordings are found in Appendix VII. Ground motion ranged from 0.0075 to 0.0081 ips and air overpressures ranged from 91.5 to 94.0 dBL. The ground motion appears to be induced by conveyors.



Mine Office Study Location.

CONCLUSIONS

There was no discernible ground motion at the recording location between the Map ID # 8 and ID # 9 residences during a 5.5 hour period on January 8, 2013. A longer monitoring period may be helpful in assuaging resident concerns of ground motion effects. All ground motion levels recorded at the mine screen, fan, and conveyors were very low level and will not transmit beyond the immediate vicinity. Sound studies may be helpful in determining potential mine effects on the Map ID # 8 and ID # 9 residences.

RECOMMENDED VIBRATION LIMITS

The following is a discussion of recommended vibration limits including sections on residential, human, pipeline, and water well and aquifer response to ground motion.

The USBM in Report of Investigations 8507 (November 1980) recommends a Variable Particle Velocity versus Frequency standard for assuring non-damage to all structures (see Figure 5). The OSMRE regulations, as outlined in their Blasting Guidance Manual, employ a similar variable particle velocity versus frequency limit. These two standards are the most often quoted limits for ground vibration from blasting operations and are very conservative. Under typical circumstances ground vibrations need to exceed the USBM recommendations or the OSMRE regulations by a considerable amount in order to observe threshold damage such as plaster or drywall cracking or paint flaking. Engineered structures such as pipelines and wells are able to withstand significantly greater peak vibration levels. Human response is often the limiting factor in determining a reasonable ground vibration limit.

MMC recommends adherence with USBM and/or OSMRE Variable Frequency versus Particle Velocity criteria. Adherence to these criteria provides a maximum level of liability protection and is the least restrictive in allowing the highest particle velocities at close distance. Documented cases of structural damage have never been observed in any structure, historic, exceptionally fragile, residential, or commercial, at particle velocities less than those recommended in the USBM and OSMRE standards.

More restrictive ground vibration standards exist internationally, notably the German vibration standards (DIN 4150), Australian standard (CA 23-1967). These restrictive standards are based on prevention of annoyance, not for any technical or damage related justification.

RESIDENTIAL STRUCTURES

Seismological research by the USBM, foreign investigative groups, and individual seismologists has established criteria relating the occurrence of structural damage to certain frequencies and levels of ground motion.

USBM Report of Investigations 8507, "Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting,"[3] states that residential structures are most prone to damage as a result of vibration energy within the frequency range of 4-12 hertz. Within this range, a 0.5-inch per second maximum particle velocity is recommended to preclude 'threshold' damage to the plaster-on-wood lathe interior portions of older structures. The line that separates real from alleged or imagined damage is ill defined. Therefore, it is common to talk in terms of probability or possibility of damage.

In general, very high particle velocities are necessary to cause any damage. Ground motion blast vibration damage is well documented, and the points at which threshold damage can occur are well defined. "Failure can occur to brittle materials such as plaster at particle velocities less than one inch per second at very low frequencies (1.5 to 10 Hz). The majority of failures will not begin to occur, however, until vibration levels exceed 3 to 4 inches per second."[1]

In addition to the threshold level of damage being dependent on peak particle velocity and frequency, it is also dependent on other factors such as: the geography and type of terrain the structure sits on, the type of structure, the height of the structure, the natural frequency of the structure, and the state of repair, or disrepair, of the structure. "...Some of these conditions may combine so that even if actual damage is unlikely below 2 or 3 inches per second, it is nevertheless possible that threshold damage might occur under some conditions at velocities as low as 0.50 to 0.70 inches per second...the (government) regulations are designed to provide positive protection

[3] Siskind, D.E., M.S. Stagg, J.W. Kopp, and C.H. Dowding. Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting, U.S. Bureau of Mines Report of Investigations 8507, p. 1.

[1] Ibid., pp. 31-32.

against damage to private and public property."[1] Therefore, these regulations are as conservative as possible.

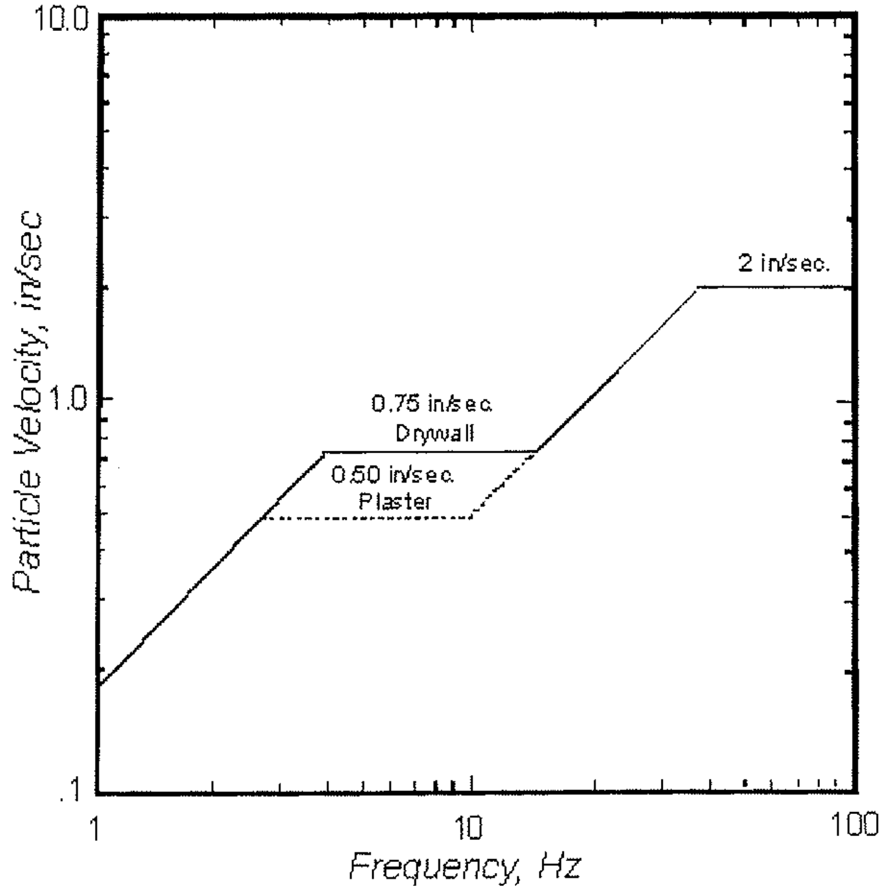


Figure 4: USBM Criteria from RI-8507, November 1980

Threshold damage is defined by the USBM as the loosening of paint; small plaster cracks at joints between construction elements or the lengthening of old plaster cracks. A maximum of 0.75 inch per second is recommended for the protection of modern drywall interior construction. The damage threshold is normally considerably higher for load bearing or other structural portions of a house.

Above 12 hertz, the allowable vibration increases as the frequency increases, up to 40 hertz. Above 40 hertz, a constant 2.0 inches per second level is recommended to protect the interior walls and ceilings of structures, regardless of construction material. A graphic representation of the USBM recommended criteria is shown in Figure 4.[3]

All buildings are characterized by a single natural fundamental frequency. This means that, as with a pendulum or a tuning fork, there is one dominant frequency to which a particular building will respond. The structures fundamental frequency depends primarily upon its height. Tall buildings

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1 Ibid., pp. 31-32.

3 Ibid., p. 7.

are more flexible and respond to low frequencies. Low-rise structures, being stiffer, respond to higher frequencies.

CONCRETE DAMAGE

In order for damage to occur to a concrete pad, the supporting soil must fail. It is therefore nearly impossible to damage concrete with elastic ground vibrations. Nearly all concrete has suffered some form of environmental damage. This is due primarily to initial curing shrinkage and thermal expansion and contraction. Expansive soils (such as clays), erosion, and settlement are also common causes of concrete damage. The peak displacement associated with most surface vibrations is of no consequence to concrete. For example, a shot recently measured by MMC at 1.20 inches per second had a peak displacement of only 0.0146 inches. "Typical deflections in bridge deck, building floors, and highway slabs are often greater by up to a factor of ten...The only known cause of damage to concrete slabs from typical external industrial and construction sources of vibrations comes from very close or intense sources that can directly rupture the concrete, as in the crater zone of a blast."[2]

ENVIRONMENTAL FORCES

Environmental forces that act on structures include both internal and external stresses. Internal stresses include: changes in moisture, changes in temperature, curing of lumber, drying and curing of plaster, stucco, concrete, or adobe; changes in application of internal heat, aging, the loss of coulomb friction, and gravity. External sources include: poorly compacted or expansive soils, poor drainage, water damage, wind, freeze/thaw cycle, and vegetation. Environmental forces are generally static (non-vibratory).

Most environment forces act silently. Therefore, most people are unaware of the large stresses and large strains induced in structures and materials. Many people who feel they have incurred damage from a ground vibration find it difficult to believe the silent environmental forces cause more stress than the vibration they felt and heard. Environmental forces are responsible for on going, time-dependent damage and deterioration to all structures and materials. "A careful study of buildings shows that cracks continue to increase in size and number as the building ages."[2]

Figure 5 shows typical environmental stresses and equivalent ground vibrations. This table is taken from Vibroseis Operations in an Urban Environment by L.L. Oriard. This was derived from information in USBM R.I. 8896, Effects of Repeated Blasting on a Wood-Frame House (Stagg, 1984)[2]. Environmental forces may induce equivalent ground vibrations as high as eight inches per second in a structure.

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[2] Ibid., pp. 353-354.

[2] Ibid., p. 356.

[2] Ibid., p. 358.

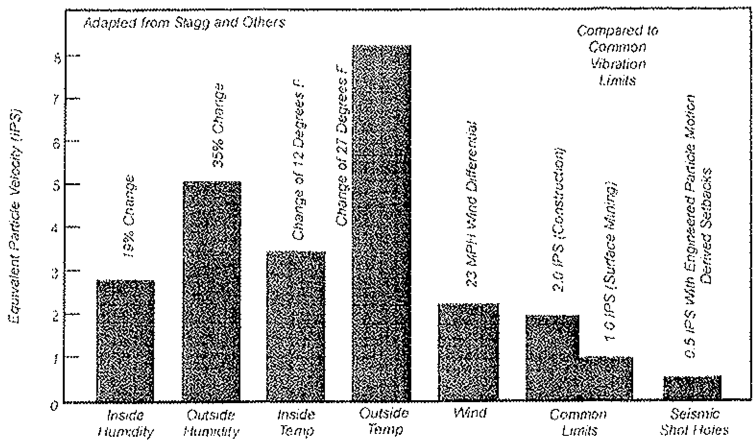

Figure 5: Typical Environmental Stresses & Equivalent Ground Vibrations

EVERYDAY ACTIVITIES

Stresses are also induced in structures as a result of human activities, traffic, and industrial activities. Human activities include door slams, walking, jumping, pounding nails into a wall, etc... These stresses are not as intense as environmentally induced stresses but nevertheless may produce equivalent ground vibrations as high as 2 inches per second. These stresses often account for hairline cracks in plaster and sheetrock around doorways and window frames. Figure 6 shows vibrations from everyday activities and equivalent ground motions and is taken from Vibroseis Operations in an Urban Environment by L.L. Oriard and was also adapted from USBM R.I. 8896, Nicholls, 1971, and others.[3]

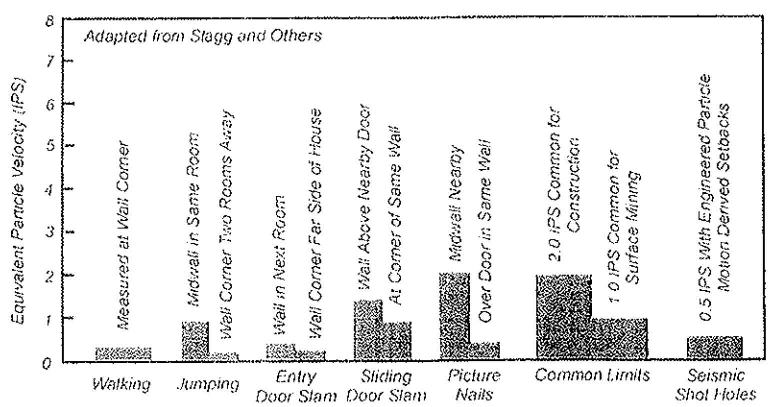

Figure 6: Vibrations for Everyday Activities

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[3] Ibid, p. 359.

CYCLE FATIGUE

There is often a misapprehension by property owners that repeated blasting has a cumulative effect on the structure. USBM study R.I. 8896, Effects of Repeated Blasting on a Wood-frame House is an investigation of this concept. In this study, the USBM built a wood-frame test house in the path of advancing surface coal mining. Structural fatigue and damage were assessed over a two-year period.

The house was subjected to vibrations from 587 production blasts with particle velocities that varied from 0.10 to 6.94 inches per second. Later, the entire house was shaken mechanically to produce fatigue cracking. Failure strain characteristics of construction materials were evaluated as a basis for comparing strains induced by blasting and shaker loading to those induced by weather and household activities.

Cosmetic or hairline cracks 0.01 to 0.10 mm wide occurred during construction of the house and also during periods when no blasts were detonated. The formation of cosmetic cracks increased from 0.3 to 1.0 cracks per week when ground motions exceeded 1.0 in/s. Human activity and changes in temperature and humidity cause strains in walls that were equivalent to those produced by ground motions up to 1.2 in/s. When the entire structure was mechanically shaken, the first crack appeared after 56,000 cycles, the equivalent of 28 years of shaking by blast-generated ground motions of 0.5 in/s twice a day.[4]

HUMAN RESPONSE TO GROUND MOTION

"Vibration levels that are completely safe for structures are annoying and even uncomfortable when viewed subjectively by people."[5] Figure 7 was taken from Bulletin 656 and shows subjective response of the human body to vibratory motion. These limits were based on empirical results for sinusoidal vibration.

According to the OSMRE Blasting Guidance Manual, "Most researchers agree that the threshold of human perception of ground motion is around 0.03 inches per second. Depending on activity, sensitivity, and whether or not the subject knows when the event is to occur, a few humans can sense ground motion...to about 0.01 inches per second.

Although complaints can occur at any level perceptible to humans, they are unusual below 0.08 inches per second or so...At, say, 0.25 inches per second, a level that is eminently safe, and well within OSMRE limits, except below 2 Hz, complaints can be expected."[1] Human reactions to ground motion from blasting can be the limiting factor. Vibration levels can be felt that are considerably lower than those required to produce damage. "Particle velocities of 0.5 in/sec...should be tolerable to about 95% of the people perceiving it as 'distinctly perceptible.'"[1]

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4 Stagg, M.S., D.E. Siskind, M.G. Stevens, and C.H. Dowding. Effects of Repeated Blasting on a Wood Frame House. U.S. Bureau of Mines, Report of Investigations 8896, 1984, p. 1.

5 Nichols, H.R., C.F. Johnson, and W.I. Duvall. Blasting Vibrations and Their Effects on Structures. U.S. Bureau of Mines Bulletin 656, 1971, p. 27.

1 Ibid, p. 34.

1 Ibid, p. 37.

What is annoying to one person may not be annoying to another. Each person perceives movement differently. Factors that can influence how human beings perceive blasting are:

- The frequency content of the blast events.
- The number of events per day or week.
- The time of day. The structure response.
- The condition of the property.
- The degree of activity of the person.
- The state of health of the person.
- The state of mind of the individual.
- The position and attitude of the person, i.e., in bed, working, sitting, inside or outside, etc...
- The local perception of the operation.
- The history of local damage claim payments (including "good neighbor" payments related to claims where liability was denied).

In some cases, regardless of the levels of ground motion experienced, complaints may still arise. "No amount of objective data will convince a person who "feels" strong vibrations that the vibration level as measured was barely perceptible-similarly with noises and air blasts. Personal contact and strong efforts in public relations help alleviate the problem but convince few."[5] In this event, pre-survey inspections, a monitoring program, and good record keeping can be invaluable should matters proceed to the legal arena. In extreme cases, dishonest individuals may see this as an opportunity for repairs or new water well.

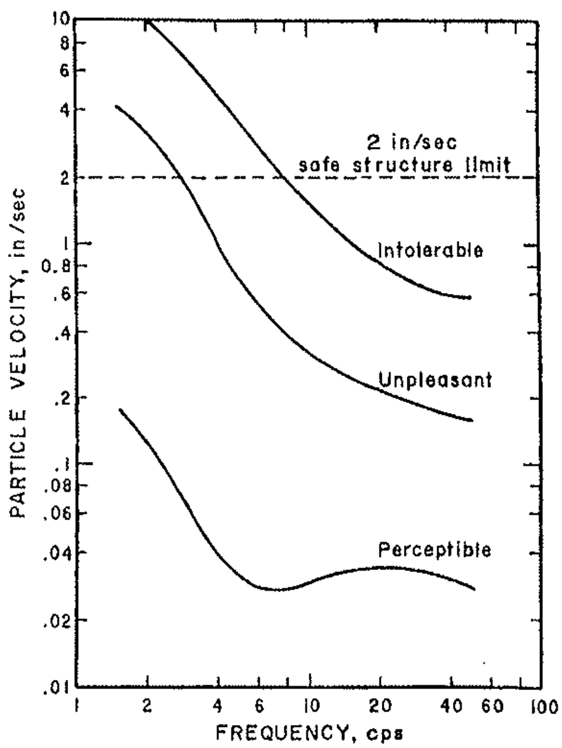

Figure 7: Subjective Response of the Human Body to Vibratory Motion (From USBM Bulletin 656, 1971)

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[5] Ibid, p. 27.

WATER WELLS AND AQUIFERS

Water wells and aquifers exhibit a constrained response when subject to ground vibration. That is to say, they move in concert with the geologic material that surrounds them. In general, this geologic material surrounding the well must be disrupted to cause damage to a water well. In the case of the aquifer, a change in its structure (permeability) would be the necessary affect for it to have undergone changes as a result of blast vibration. Furthermore, the amplitude of the ground motion greatly decreases with depth. Following is general information on hydrology as well as information from studies on shot hole geophysical exploration and surface mine blasting effects on water wells and aquifers.

Hydrology

A groundwater system is a dynamic system where water moves down gradient from a recharge area to a discharge area (i.e., a spring). Normally, ground water moves slowly, the rate ranging from a fraction of an inch per year to a few feet per day. The geology determines the rate of ground-water recharge and movement. Most sedimentary aquifers consist of sandstone, limestone, Tertiary sediments, recent alluvium, or coal seams. Aquifers can also exist in fractured metamorphic rocks and igneous rocks. Hydraulic characteristics of aquifers include porosity, permeability, transmissivity, and the coefficient of storage. These characteristics differ greatly among different rock types.

Porosity is the volume of void space in a unit volume of material (this space can be occupied by water). Permeability is a measure of the capability of a geologic material to transmit water through a unit area. Transmissivity is defined as the permeability times the vertical thickness of the material, usually an aquifer. Coefficient of storage is defined as the volume of water that an aquifer can release from or take into storage per unit surface area, per unit change in head in a line normal to that surface.

Shot-Hole Geophysical Exploration

In "A Study of the Influence of Seismic Shotholes on Groundwater and Aquifers in Eastern Montana,"[6] five widely distributed sites in eastern Montana were chosen and monitored: (1) a 25 pound charge at a 197 foot depth, 150 feet away from the 150 foot deep test well, (2) a 25 pound charge at a 197 foot depth, a 165 foot distance away from the 90 foot deep test well, (3) a 80 pound charge at a 200 foot depth, 400 feet away from an 80 foot deep test well and a 25 pound charge at a depth of 150 feet, 150 feet away from the same test well, (4) a 25 pound charge at a 200 foot depth, 150 feet away from a test well with a 22 foot depth and a test well with a 96 foot depth, and (5) a 25 pound charge at a 200 foot depth, 150 feet away from a 135 foot deep test well and a 207 foot deep test well.

> Pumping tests of existing water wells and specially drilled observation wells, before and at several times after the firing of a seismic shot, revealed no detectable change in the physical properties of the aquifers. Analyses of water samples collected from water wells, observation wells, and test holes, at frequent intervals throughout the study period, showed only the random minor variations expectable in water from shallow aquifers. A few water

[6] Bond, E.W., A Study of the Influence of Seismic Shotholes on Groundwater and Aquifers in Eastern Montana, State of Montana – Montana Bureau of Mines and Geology, Special Publication 67, 1975.

samples from shotholes showed minor temporary increases in some chemical constituents, but these were not enough to affect the use of the water. Water-level measurements during the pumping tests showed that most of the shotholes were virtually sealed through the aquifer within a few months, at most, but tests could not be repeated over a long enough period to determine the final sealing date of all shotholes.

> Any mechanical change in aquifer structure as a result of seismic shooting should be indicated by change in permeability of the aquifer material. None of the aquifer tests conducted at the five test sites showed any change in aquifer structure, although poor efficiency of common well construction was evident...A change in aquifer permeability would require either a change in the packing arrangement of the aquifer material or an alteration of the cement holding the aquifer material together.
>
> Because drill holes for seismic programs average only about 200 feet in depth, multiple aquifers would have relatively small differences in hydrostatic head, and the quality of the waters would probably be similar.[6]

This indicates minimal interflow between aquifers.

In "The Effects of Seismic Blasting on Shallow Water Wells and Aquifers in Western North Dakota,"[7] the results of a literature search, a preliminary investigation, a field investigation, and an experimental investigation are presented. The preliminary investigation involved sending questionnaires to federal, state, county, and city agencies, certified water well contractors, as well as, grazing and environmental groups.

The questionnaires along with a news release resulted in numerous personal letters alleging effects during and after seismic testing. A third of these wells were field investigated. Both old and new wells were investigated. Eighteen wells were less than twenty years old and twenty-five wells were more than twenty years old. This indicates the problem is not restricted to older wells. Effects that were described by owners include long term decline in water quality (over a several year period), an abrupt (over several hours) decline in water quality, and 53 of 76 questionnaires cited decreased yield. In some instances these wells were not pumped wells, but rather were flowing wells. A gradual decline in a flowing well (or spring) is a naturally occurring result of usage.

Few instances of legal action were found during the study's preliminary search. Few people have good or complete records of their wells with respect to production and water quality. This causes difficulties when defending their position. A few respondents claimed to have replaced wells and equipment at their own expense. Also, because of the lack of background information on the wells, it is difficult to draw definitive conclusions regarding changes in water quality and production.

> Pumping tests conducted in a sand and coal aquifer system showed no apparent physical effects when shots were detonated one-quarter mile away from the pumping wells. Shots 500 feet distant resulted in no permanent effects. Shots 100 feet or closer increased the yield from wells finished in the sand aquifer and decreased the yield from the coal aquifer. Fracturing of the poorly indurated sandstone aquifer is suggested as the mechanism for the

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6 Ibid.

7 Beaver, F.W. The Effects of Seismic Blasting on Shallow Water Wells and Aquifers in Western North Dakota, Master's Thesis Submittal, University of North Dakota, 1984.

increase. Collapse of the fractures is suggested as the failure mechanism in the coal aquifer. Well casings remained intact after 25-pound charges were detonated as close as 10 feet from a well screen...

During the pumping tests, no significant long-term chemical or mineralogical equilibrium changes were observed which could be attributed to the blasting.[7]

Surface Mining

The source of these comments is the U.S. Bureau of Mines (USBM) study "Survey of Blasting Effects on Ground Water Supplies in Appalachia."[8] This study relates to coalmine blasting where large per delay explosive weights exceeding 5000 pounds are common. The USBM study included four test sites chosen for geographic and geologic diversity. Maximum resultant particle velocities of up to 5.44 inches per second were recorded at the surface next to the wells.

No direct evidence of change in water quality or well performance was produced by blast vibrations, but removal of down slope support by excavation does cause lateral stress relief which permits the water-bearing fractures to become more open. This additional storage capacity causes the static water level to drop and for well-bore permeability to improve. Static water level recovers if sufficient recharge is available and well performance is improved.

The well continues to perform in the same manner although blast induced round vibrations at the surface may approximate 2.0 inches per second maximum resultant particle velocity, until surface mining approaches to within about 300 feet of the water well.

State agencies and coal companies in Appalachia were contacted to develop a list of reportedly blast damaged wells. Of 36 wells so reported, 24 were investigated in the field but there was no clear evidence that the problem was blast related. In most cases, it was evident that other factors were responsible for changes in well behavior.

Maximum ground vibration levels at the four test wells, measured as close as practical to the well heads, were 2.2, 5.44, 2.14, and .84 inches per second resultant particle velocity. Based on observable change in well conditions immediately after a blast, there was no direct evidence of any significant change as a result of blasting. At three sites, when mining approached within a distance of approximately 300 feet, a fairly abrupt drop in static water level occurred followed by a significant improvement in well performance as indicated by specific capacity. At the fourth site, there was no change.

Measurements made at the bottoms of wells indicated that vibrations were considerably attenuated at depths of 140 to 160 feet.[8]

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7 Ibid.

8 Robertson, D.A., Gould, J.A., Straw, J.A., and M.A. Dayton. Survey of Blasting Effects on Ground Water Supplies in Appalachia, U.S. Bureau of Mines Contract J-0285029, prepared by Philip R. Berger & Associates, 1980.

8 Ibid.

This study found the vibrations at the bottom of an observation well to be between 14 to 68 % as strong as those at the surface (approximately 150 feet deep). The largest effects on vibration attenuation with depth are the geometric relationship between the charge location and the well and the degree of confinement of the shot.

This study quotes another study, "Water Well Design for Earthquake Induced Motions,"[9] a survey of published reports describing the conditions of numerous water wells during and after three major earthquakes. This study involved 350 wells in areas where severe damage to structures occurred. Almost all wells reported to be permanently damaged were in regions of permanent displacement of the surrounding earth, primarily land sliding. Eight wells were destroyed, four were inoperable but reparable, and forty-five wells were damaged but operable. The intensity of the earthquakes in the study were modified Mercalli scale magnitudes VIII, IX, and X.

PIPELINE RESPONSE

Five pipeline sections were studied by the USBM in conjunction with the State of Indiana and AMAX Coal and its consultants in the advance of coal mine overburden blasting (USBM R.I. 9523).[10] These tests were conducted on the highwall of the Minnehaha Mine near Sullivan, Indiana and were designed for testing to failure.

All five pipeline sections were 76 m (249 ft) long. Four sections were welded steel pipe and one section was PVC. The pipeline sections were laid parallel to one another, 3 m (9.8 ft) apart, with 1 m (3.3 ft) depths of burial. They were buried in a clay soil. Each pipeline had three uprights for pressurization and gage access. Following is a summary of the pipeline attributes:

Outside Diameter, cm, (in)	Wall Thickness, mm, (in)	Fill Material	Age	Material Type
Steel:				
16.8, (6.6)	4.78, (.188)	Gas	Used	X-42
32.4, (12.8)	6.35, (.250)	Gas	Used	Grade B
32.4, (12.8)	6.35, (.250)	Gas	New	X-42
50.8, (20.0)	6.63, (.261)	Water	Used	X-56
PVC:				
21.9, (8.6)	8.43, (.332)	Water	Used	SDR26

Steel Pipelines: Initial pressurization 6.2 MPa (900 psi).
PVC Pipeline: Initial pressurization 0.62 MPa (90 psi).

The pipelines were monitored for vibration, strain, and pressure for a period of 6 months while production advanced up to a point 15 m (49 ft) away. 29 productions blasts were measured. The blasts used maximum charge weights per delay of up to 950 kg (2090 pounds) in 31 cm (12.25 inch) diameter holes.

Following the production blasts, a single row of four blast holes was drilled between the pipelines to complete the destructive test. The explosive charge was below the pipes at 5 to 6 m

[9] Nazarian, H.N. Water Well Design for Earthquake Induced Motions. ASCE J. Power Div., V. 99, No. P02, Paper 10176, November 1973, pp. 377-394.

[10] Siskind, D.E., M.S. Stagg, J.E. Wiegand, and D.L. Schulz. Surface Mine Blasting Near Pressurized Transmission Pipelines. U.S. Bureau of Mines, Report of Investigations 9523, 1994, 51 pp.

(16.4 to 19.7 ft) distances. The vibration level measured was greater than 900 mm/s (35.43 in/s), however, this was non-elastic response. The result of the destructive test on each pipeline is as follows: 1) 16.8 cm (6.6 in) diameter steel pipe - severely bent but unbroken, 2) new 32.4 cm (12.8 in) diameter steel pipe - bowed, but unbroken, 3) used 32.4 cm (12.8 in) diameter steel pipe - cleanly broken at the risers, 4) water filled 50.8 cm (20.0 in) diameter steel pipe - uplifted, parted, fell back down, and 5) 22 cm (8.6 in) diameter PVC pipe - came apart at O-rings, but unbroken.

The results of the closest production blast (15 m (49.2 ft) distant from the closest pipeline) resulted in a 635 mm/s (25.00 in/s) measurement at the surface and 234 to 274 mm/s (9.21 to 9.84 in/s) on two instrumented pipelines.

> Analysis found low pipe responses, strains, and calculated stresses from even large blasts. Ground vibration of 120 to 250 mm/s (4.72 to 9.84 in/s) produced worst-case strains that were about 25% of the strains resulting from normal pipeline operations and calculated stresses of only about 10% to 18% of the ultimate tensile strength. No pressurization failures or permanent strains occurred even at vibration amplitudes of 600 mm/s (23.62 in/s)...
>
> ...Although particle velocities of over 600 mm/s (23.62 in/s) were sustained without loss of pipe integrity, it is recommended that 125 mm/s (4.92 in/s) measured at the surface is a safe-level criterion for large surface mine blasts for Grade B or better steel pipelines. The same criterion is recommended for SDR 26 or better PVC pipe...Also, no adjustment is believed needed for pipeline age, assuming the protective coating is intact, unless the pipeline is known to be at higher risk from previous damage or other causes. The same safe-level criterion also appears applicable, at a minimum, to vertical wells and telephone lines.[10]

The primary blasting risk to pipelines appears to be from block motion or from having the pipeline in the actual crater zone. In both cases, permanent strain has occurred in the surrounding geologic material, which is weaker than the pipe.

In the early 1960's work was undertaken by the American Gas Association Pipeline Research Committee to establish limits for charge size (pounds per delay) and distance from a blast to high-pressure gas transmission pipelines. The primary research found that there had been no reported case of pipeline failure due to normal blasting activities. Failures were recorded only when explosives were detonated directly adjacent to a pipeline.

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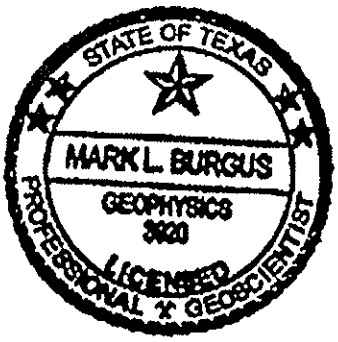
[10] Ibid., pp. 1, 36.

Sincerely,

Mark L. Burgus P.G.,
Texas Registered Geophysicist #3920




Underground Mining Location 1/8/2013
Fan Study Location
Screen Study Location
Mine Office Study Location
Residence Monitor Location
Google earth
Google earth
miles
2
km
3


Fan Study Location
Screen Study Location
Mine Office Study Location
© 2013 Google
Google earth
feet
1000
meters
400

To: Mr. Joe Bowden, PhD
CDS Environmental Services LLC
P.O. Box 4124
Durango, CO 81302

Date: December 11-31, 2014

Subject: GCC Energy – King II Mine
UNDERGROUND MINER GROUND MOTION STUDY
La Plata County, Colorado

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GCC ENERGY – KING II MINE

UNDERGROUND MINER GROUND MOTION STUDY REPORT
La Plata County, Colorado
December 11-31, 2014

SUMMARY

Matheson Mining Consultants, Inc. (MMC) was retained by GCC Energy to investigate potential ground motion at the surface directly above underground miner activities in response to continued perception of ground motion in the Vista de Oro subdivision. This study is in addition to studies performed on January 8, 2013, where potential ground motion was investigated between the Luz and Coyne residences, near the mine fan, screen, and conveyors (please see report: GCC Energy – King II Mine, Ground Motion Studies).

Permanent Monitor Station Location

A portable instrument was set out overnight for an 18 hour period on December 11, 2014 and was located on the surface approximately 300 feet above the underground miner in order to discern if additional local study was necessary. A permanent station was placed on the surface above the center of the underground mining area expected over the course of the next month.

Temporary Seismograph Monitor Station

MMC recommends adherence with the United States Bureau of Mines (USBM) and/or the Office of Surface Mining Reclamation and Enforcement (OSMRE) Variable Frequency versus Particle Velocity criteria (Figure 4). Above 4 Hz, 0.50 to 2.00 inches per second (ips) is allowed, depending on dominant frequency (the threshold level for possible damage to plaster-on-lath). Adherence to these criteria provides a maximum level of liability protection. Documented cases of structural damage have never been observed in any structure, historic, exceptionally fragile, residential, or commercial, at particle velocities greater than those recommended in the USBM and OSMRE standards.

The threshold of human perception is around 0.030 ips. Oil and gas wells, pipelines, water wells, and fiber optic cables can withstand significantly higher levels and a level of 2.00 ips on these engineered structures is conservative. Bell Labs states that a limit of 4.00 ips is safe for their fiber optic cable and U.S. Bureau of Mines states that a limit of 4.92 ips is safe for a pipeline of any age or construction material and that this level is also appropriate for oil, gas, and water wells. Ten inches per second is considered a safe level for concrete.

Any potential ground motion experienced by residents in the Vista de Oro subdivision must be caused by a source other than King II mine activities. No ground motion was detected on the surface directly above underground mining at levels from one fourth to one sixth of what a human can feel. All ground motion levels recorded in the January 8, 2013 studies recorded at the mine screen, fan, and conveyors were very low level and will not transmit beyond the immediate vicinity.

INTRODUCTION

The ground motion is measured in terms of peak particle velocity and is a combination of body and surface waves (Figure 1)[1]. The body waves attenuate more rapidly with distance from the vibration source than the surface waves. Body waves spread spherically, whereas the surface waves expand in two dimensions. The principal cause of ground motion attenuation with distance is due to simple geometric spreading. As the ground motion wave train spreads outwards from the energy source, the medium's individual particles are set in retrograde elliptical motion about their rest positions. The wave is generated as each particle transmits energy to the next particle. Some energy loss occurs with each transmission of energy from one particle to the next, which is also a cause of ground motion attenuation with distance. The ground motion is a complex wave train consisting of many different wave types (Figure 2)[1]. As the body waves impinge upon the surface, they are converted to surface waves. Body waves may also be reflected and refracted to the surface to become converted to surface waves. As the surface wave spreads out, the various components of the wave train have different particle motions, travel at different velocities, and have different geometric constraints.

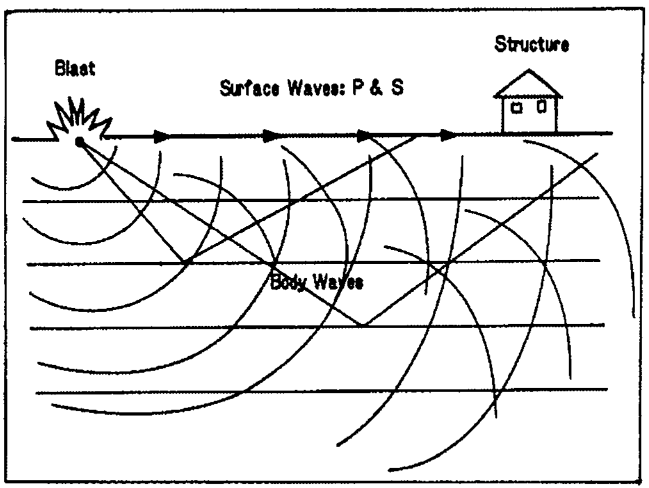


Figure 1 - Surface and Body Waves

Particle velocity has been determined to be the most significant single parameter, in terms of the potential for damage (as opposed to acceleration or displacement). Furthermore, the peak particle velocity found on any of the three geophone channels is the parameter used, rather than the resultant vector sum particle velocity. All research has been done and all regulations have been written in terms of peak particle velocity (PPV). Using the PPV instead of the vector sum allows for easier, more consistent comparison of values. A true resultant velocity could be calculated from the peak measurements for all three components if they occurred at the same instant of time. In addition, there is variability in how different seismograph manufacturers calculate the vector sum. Some actually calculate a pseudo resultant sum. These models take the peak levels on all three channels, regardless of where they individually occurred in time, to calculate the vector sum.

1 Rosenthal, M.F., and G.L. Morlock. Blasting Guidance Manual. U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, March, 1987, p.11.

1 Ibid., p. 12.

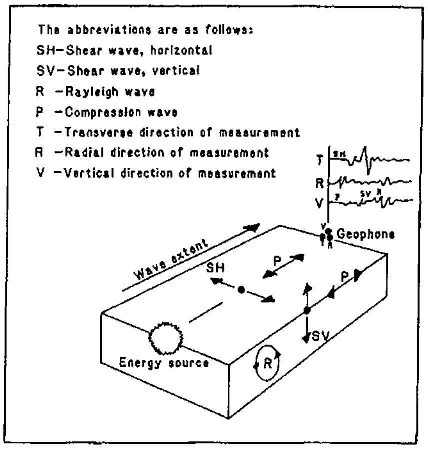


Figure 2 - Types of Ground Motion Waves

Since the 1920's or earlier, ground vibrations have been studied extensively to determine their potential for damage to various structures and construction materials. Blasting activities are among the most common sources of ground motion, have therefore been studied the most, and have thus prompted the ordinances and regulations that are in place. At the present time, the only federal regulation that pertains to ground motion is from the OSMRE. This regulation was written to protect residential structures. Complaints of damage to residences were, and are, the most common form of complaint resulting from the perception of ground motion.

INSTRUMENTATION

Vibration records were collected using an Instantel Minimate Plus and a Blastmate III seismograph. Each seismograph records particle velocity digitally in the frequency range of 1.5 to 250 Hertz. Each event is measured in three orthogonal channels of ground motion: vertical, longitudinal, and transverse. Zero-crossings of each of the three waveform components are calculated to determine frequency response.

An excerpt from the Blastmate III User's Manual is attached as part of Appendix I and describes the specifications and function of the instrumentation, and record processing.

An independent party using shake table and electronics traceable to the National Institute of Science and Technology has calibrated the instruments within the past year. Copies of the Calibration Certificates for the instrument and geophone are also included in Appendix I.

The microphone measures air overpressure in dBL. Air overpressures are typically produced from blasting activities and much of the energy is beneath the range of human hearing. This channel was turned off for the purpose of the study.

It is not possible to alter the vibration recordings or file names in any way, other than the ability to add post event notes. For security reasons, the instrument and software manufacturer (Instantel) will not release any of the programming code to any outside interests for any reason.

A self-test (on board calibration) was performed at each monitor location after setting up the instrument.

METHOD

A portable instrument was set out overnight for an 18 hour period from December 11, 2014 at 17:25 until December 12, 2014 at 12:02 and was located on the surface approximately 300 feet above the underground miner. This instrument was set with the minimum trigger level of 0.005 ips in full waveform mode. If ground motion was detected from the underground miner, additional portable monitoring at various distances would be performed. No ground motion was detected, so additional study with the portable seismograph was not performed. The temporary monitor station was located at a coordinate of N37 16.256 W108 07.370 and was 14,339 feet away from the Luz/Coyne residence monitor location.

A permanent station was placed on the surface above the center of the underground mining area expected over the course of the next month at a coordinate of N37 16.174 W108 07.401. This station was 13,854 feet away from the Luz/Coyne residence monitor location. Cellular service was not available at this location, so remote access was not possible. To conserve memory, the seismograph was set in histogram mode. In histogram mode, the instrument continuously monitors and registers the peak particle velocity for each five minute time period. A test was performed from December 12, 2014 at 9:40 until 11:17. The instrument was then placed back in monitor mode from 11:22 on December 12, 2014 until 6:27 on December 31, 2014, when the unit lost power and exited monitor mode.

An Instantel Blastmate III seismograph was used for portable monitoring and a Minimate Plus seismograph was used in the permanent monitor station

A hand held GPS unit was used to record the monitor locations.

A map showing the locations of underground mining, the monitor location between the Luz and Coyne residences, and the study locations at the mine is found in Appendix II.

Figure 3 shows an excerpt from the Blastmate III user's manual and illustrates how the geophone was oriented relative to the energy source. Surface material was removed as necessary to get a good solid geophone plant at both recording locations.

Both instruments were set in sensitive mode with trigger levels set at the minimum of 0.005 ips.

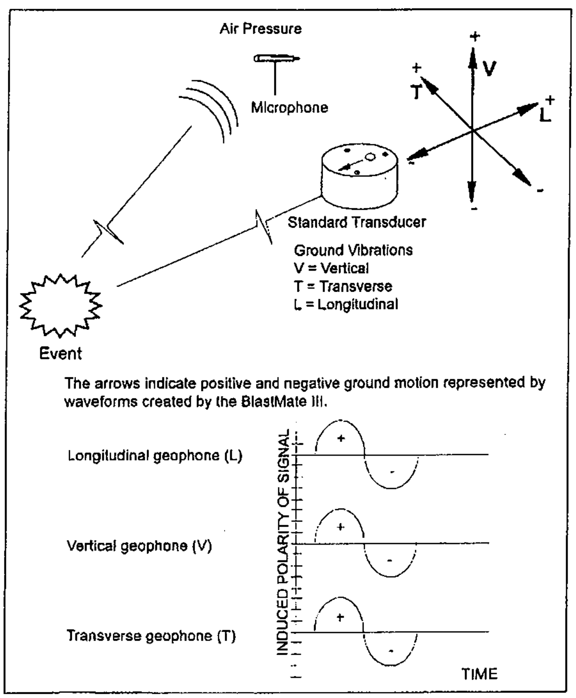
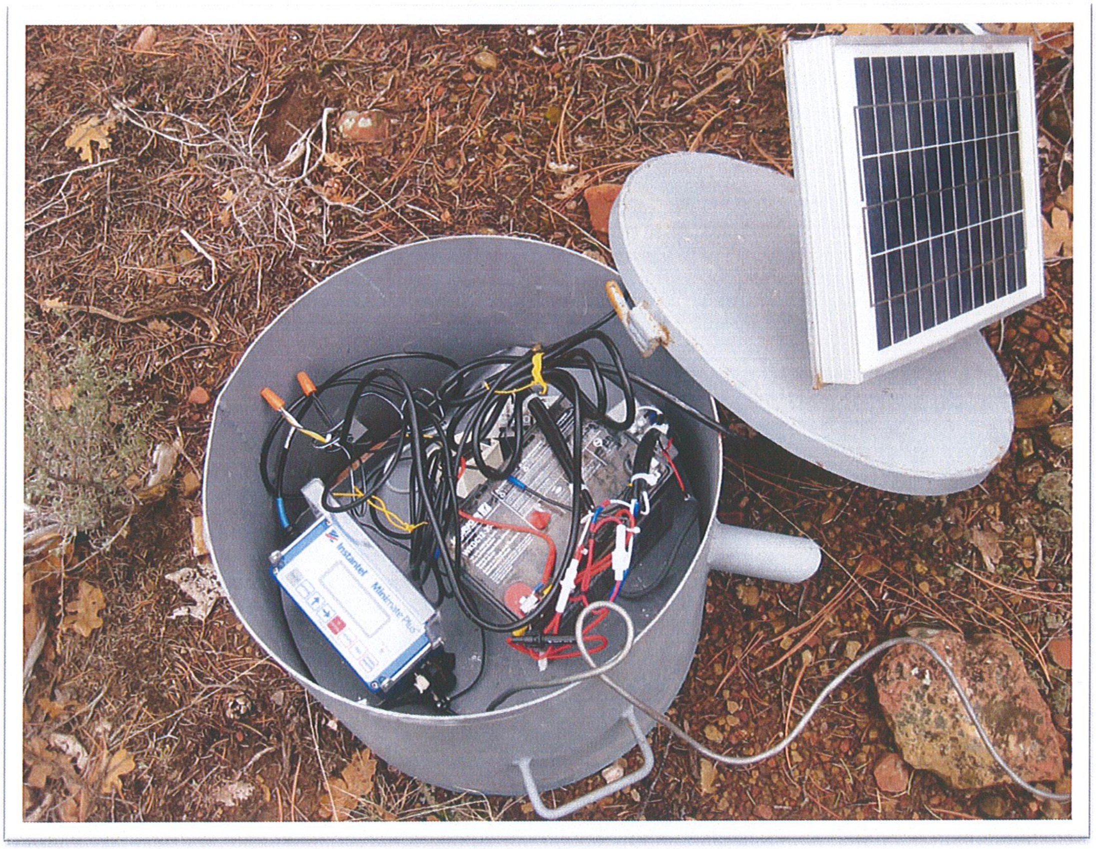


Figure 3 - Event Monitoring



Inside the Permanent Monitor Station

RESULTS

A monitor log showing when the instrument was armed and disarmed, as well as the trigger level and a summary of vibration recordings and vibration recordings for the portable instrument are found in Appendix III. The USBM and OSM variable particle velocity vs. frequency criteria is plotted on each vibration event report. The upper line represents the threshold level for possible sheetrock damage, while the lower, dashed line represents the threshold level for possible plaster-on-lath damage. All recommendations in this report are based on these criteria. Four operator induced vibrations were recorded at the startup on December 11, 2014 and one operator induced event was recorded when the instrument was shut down on December 12, 2014. No other ground motion in excess of 0.005 ips was detected.

A monitor log showing when the permanent station instrument was armed and disarmed and two histogram event reports (one for the test period and one for the December 12 – 31, 2014 time period) are found in Appendix IV. Both histogram records show operator induced (placing the lid back on the housing) ground motion at the beginning of the monitor period. Otherwise all histogram periods show ground motion less than 0.005 ips (background noise level).

CONCLUSIONS

No ground motion was detected on the surface directly above underground mining at levels from one fourth to one sixth of what a human can feel. All ground motion levels recorded in the January 8, 2013 studies recorded at the mine screen, fan, and conveyors were very low level and will not transmit beyond the immediate vicinity. Based on these studies, any perceived ground motion in the Vista de Oro subdivision must be caused by a source other than the King II mine screen, shaker, conveyor belts, or underground miner activity. Any potential ground motion produced by these sources would have to be very large to transmit over the relatively great distances to the subdivision.

RECOMMENDED VIBRATION LIMITS

The following is a discussion of recommended vibration limits including sections on residential, human, pipeline, and water well and aquifer response to ground motion.

The USBM in Report of Investigations 8507 (November 1980) recommends a Variable Particle Velocity versus Frequency standard for assuring non-damage to all structures (see Figure 5). The OSMRE regulations, as outlined in their Blasting Guidance Manual, employ a similar variable particle velocity versus frequency limit. These two standards are the most often quoted limits for ground vibration from blasting operations and are very conservative. Under typical circumstances ground vibrations need to exceed the USBM recommendations or the OSMRE regulations by a considerable amount in order to observe threshold damage such as plaster or drywall cracking or paint flaking. Engineered structures such as pipelines and wells are able to withstand significantly greater peak vibration levels. Human response is often the limiting factor in determining a reasonable ground vibration limit.

MMC recommends adherence with USBM and/or OSMRE Variable Frequency versus Particle Velocity criteria. Adherence to these criteria provides a maximum level of liability protection and is the least restrictive in allowing the highest particle velocities at close distance. Documented cases of structural damage have never been observed in any structure, historic, exceptionally fragile, residential, or commercial, at particle velocities less than those recommended in the USBM and OSMRE standards.

More restrictive ground vibration standards exist internationally, notably the German vibration standards (DIN 4150), Australian standard (CA 23-1967). These restrictive standards are based on prevention of annoyance, not for any technical or damage related justification.

RESIDENTIAL STRUCTURES

Seismological research by the USBM, foreign investigative groups, and individual seismologists has established criteria relating the occurrence of structural damage to certain frequencies and levels of ground motion.

USBM Report of Investigations 8507, "Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting,"[3] states that residential structures are most prone to damage as a result of vibration energy within the frequency range of 4-12 hertz. Within this range, a 0.5-inch per second maximum particle velocity is recommended to preclude 'threshold' damage to the plaster-on-wood lathe interior portions of older structures. The line that separates real from alleged or imagined damage is ill defined. Therefore, it is common to talk in terms of probability or possibility of damage.

In general, very high particle velocities are necessary to cause any damage. Ground motion blast vibration damage is well documented, and the points at which threshold damage can occur are well defined. "Failure can occur to brittle materials such as plaster at particle velocities less than one inch per second at very low frequencies (1.5 to 10 Hz). The majority of failures will not begin to occur, however, until vibration levels exceed 3 to 4 inches per second."[1]

In addition to the threshold level of damage being dependent on peak particle velocity and frequency, it is also dependent on other factors such as: the geography and type of terrain the structure sits on, the type of structure, the height of the structure, the natural frequency of the structure, and the state of repair, or disrepair, of the structure. "...Some of these conditions may combine so that even if actual damage is unlikely below 2 or 3 inches per second, it is nevertheless possible that threshold damage might occur under some conditions at velocities as low as 0.50 to 0.70 inches per second...the (government) regulations are designed to provide positive protection against damage to private and public property."[1] Therefore, these regulations are as conservative as possible.

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[3] Siskind, D.E., M.S. Stagg, J.W. Kopp, and C.H. Dowding. Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting, U.S. Bureau of Mines Report of Investigations 8507, p. 1.

[1] Ibid., pp. 31-32.

[1] Ibid., pp. 31-32.

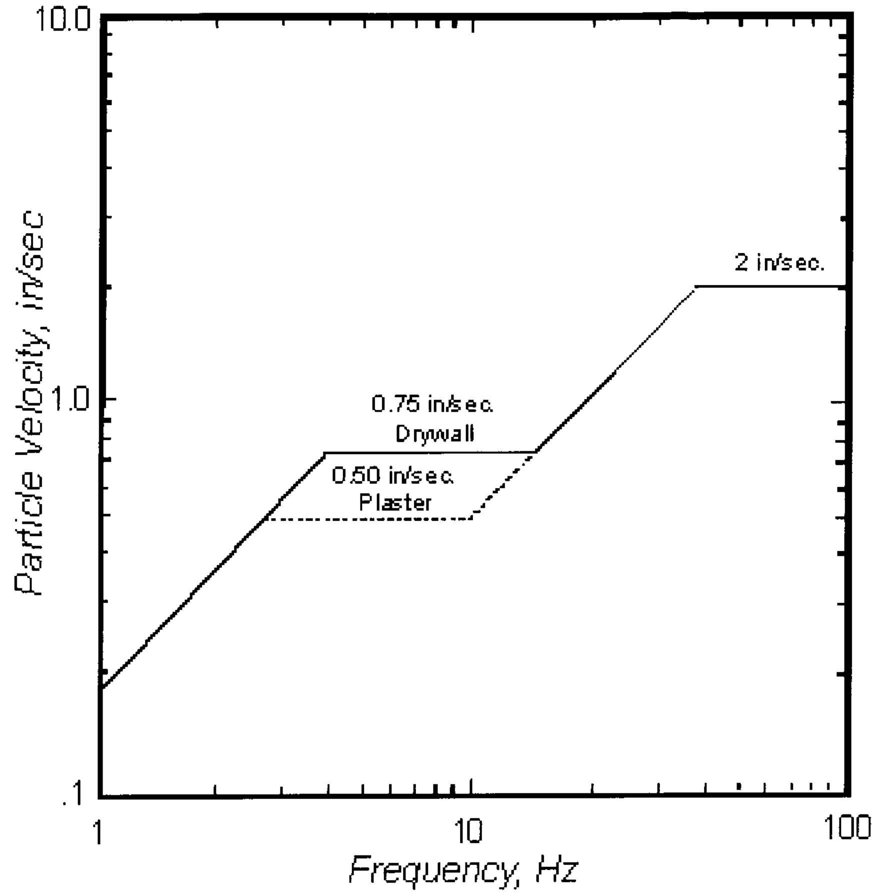

Figure 4: USBM Criteria from RI-8507, November 1980

Threshold damage is defined by the USBM as the loosening of paint; small plaster cracks at joints between construction elements or the lengthening of old plaster cracks. A maximum of 0.75 inch per second is recommended for the protection of modern drywall interior construction. The damage threshold is normally considerably higher for load bearing or other structural portions of a house.

Above 12 hertz, the allowable vibration increases as the frequency increases, up to 40 hertz. Above 40 hertz, a constant 2.0 inches per second level is recommended to protect the interior walls and ceilings of structures, regardless of construction material. A graphic representation of the USBM recommended criteria is shown in Figure 4.[3]

All buildings are characterized by a single natural fundamental frequency. This means that, as with a pendulum or a tuning fork, there is one dominant frequency to which a particular building will respond. The structures fundamental frequency depends primarily upon its height. Tall buildings are more flexible and respond to low frequencies. Low-rise structures, being stiffer, respond to higher frequencies.

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[3] Ibid., p. 7.

CONCRETE DAMAGE

In order for damage to occur to a concrete pad, the supporting soil must fail. It is therefore nearly impossible to damage concrete with elastic ground vibrations. Nearly all concrete has suffered some form of environmental damage. This is due primarily to initial curing shrinkage and thermal expansion and contraction. Expansive soils (such as clays), erosion, and settlement are also common causes of concrete damage. The peak displacement associated with most surface vibrations is of no consequence to concrete. For example, a shot recently measured by MMC at 1.20 inches per second had a peak displacement of only 0.0146 inches. "Typical deflections in bridge deck, building floors, and highway slabs are often greater by up to a factor of ten...The only known cause of damage to concrete slabs from typical external industrial and construction sources of vibrations comes from very close or intense sources that can directly rupture the concrete, as in the crater zone of a blast."[2]

ENVIRONMENTAL FORCES

Environmental forces that act on structures include both internal and external stresses. Internal stresses include: changes in moisture, changes in temperature, curing of lumber, drying and curing of plaster, stucco, concrete, or adobe; changes in application of internal heat, aging, the loss of coulomb friction, and gravity. External sources include: poorly compacted or expansive soils, poor drainage, water damage, wind, freeze/thaw cycle, and vegetation. Environmental forces are generally static (non-vibratory).

Most environment forces act silently. Therefore, most people are unaware of the large stresses and large strains induced in structures and materials. Many people who feel they have incurred damage from a ground vibration find it difficult to believe the silent environmental forces cause more stress than the vibration they felt and heard. Environmental forces are responsible for on going, time-dependent damage and deterioration to all structures and materials. "A careful study of buildings shows that cracks continue to increase in size and number as the building ages."[2]

Figure 5 shows typical environmental stresses and equivalent ground vibrations. This table is taken from Vibroseis Operations in an Urban Environment by L.L. Oriard. This was derived from information in USBM R.I. 8896, Effects of Repeated Blasting on a Wood-Frame House (Stagg, 1984)[2]. Environmental forces may induce equivalent ground vibrations as high as eight inches per second in a structure.

[2] Ibid., pp. 353-354.

[2] Ibid., p. 356.

[2] Ibid., p. 358.

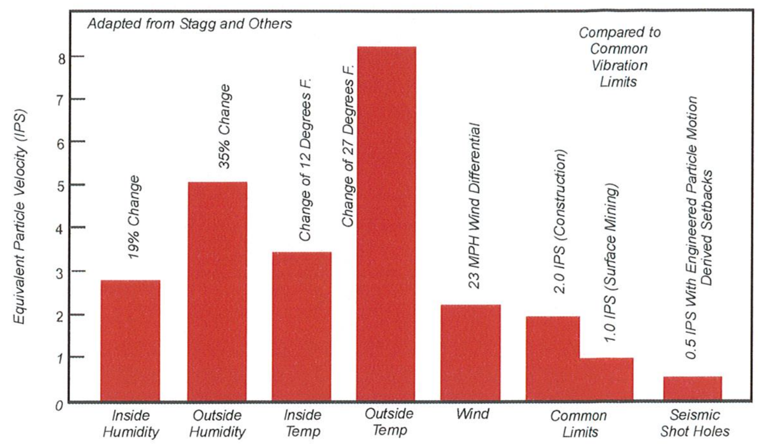

Figure 5: Typical Environmental Stresses & Equivalent Ground Vibrations

EVERYDAY ACTIVITIES

Stresses are also induced in structures as a result of human activities, traffic, and industrial activities. Human activities include door slams, walking, jumping, pounding nails into a wall, etc... These stresses are not as intense as environmentally induced stresses but nevertheless may produce equivalent ground vibrations as high as 2 inches per second. These stresses often account for hairline cracks in plaster and sheetrock around doorways and window frames. Figure 6 shows vibrations from everyday activities and equivalent ground motions and is taken from Vibroseis Operations in an Urban Environment by L.L. Oriard and was also adapted from USBM R.I. 8896, Nicholls, 1971, and others.[3]

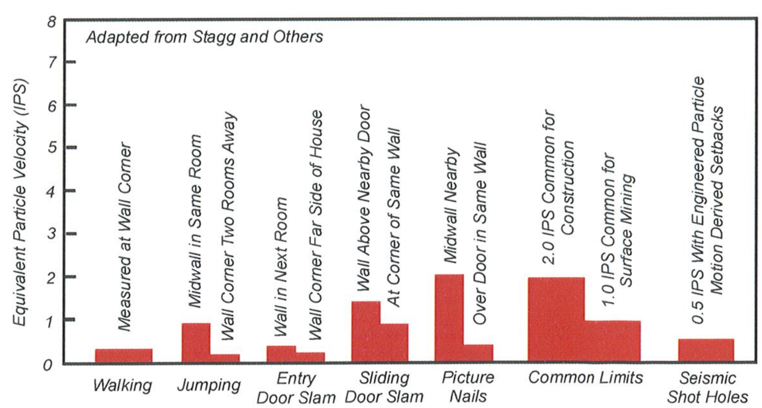

Figure 6: Vibrations for Everyday Activities

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3 Ibid, p. 359.

CYCLE FATIGUE

There is often a misapprehension by property owners that repeated blasting has a cumulative effect on the structure. USBM study R.I. 8896, Effects of Repeated Blasting on a Wood-frame House is an investigation of this concept. In this study, the USBM built a wood-frame test house in the path of advancing surface coal mining. Structural fatigue and damage were assessed over a two-year period.

The house was subjected to vibrations from 587 production blasts with particle velocities that varied from 0.10 to 6.94 inches per second. Later, the entire house was shaken mechanically to produce fatigue cracking. Failure strain characteristics of construction materials were evaluated as a basis for comparing strains induced by blasting and shaker loading to those induced by weather and household activities.

Cosmetic or hairline cracks 0.01 to 0.10 mm wide occurred during construction of the house and also during periods when no blasts were detonated. The formation of cosmetic cracks increased from 0.3 to 1.0 cracks per week when ground motions exceeded 1.0 in/s. Human activity and changes in temperature and humidity cause strains in walls that were equivalent to those produced by ground motions up to 1.2 in/s. When the entire structure was mechanically shaken, the first crack appeared after 56,000 cycles, the equivalent of 28 years of shaking by blast-generated ground motions of 0.5 in/s twice a day.[4]

HUMAN RESPONSE TO GROUND MOTION

"Vibration levels that are completely safe for structures are annoying and even uncomfortable when viewed subjectively by people."[5] Figure 7 was taken from Bulletin 656 and shows subjective response of the human body to vibratory motion. These limits were based on empirical results for sinusoidal vibration.

According to the OSMRE Blasting Guidance Manual, "Most researchers agree that the threshold of human perception of ground motion is around 0.03 inches per second. Depending on activity, sensitivity, and whether or not the subject knows when the event is to occur, a few humans can sense ground motion...to about 0.01 inches per second.

Although complaints can occur at any level perceptible to humans, they are unusual below 0.08 inches per second or so...At, say, 0.25 inches per second, a level that is eminently safe, and well within OSMRE limits, except below 2 Hz, complaints can be expected."[1] Human reactions to ground motion from blasting can be the limiting factor. Vibration levels can be felt that are considerably lower than those required to produce damage. "Particle velocities of 0.5 in/sec...should be tolerable to about 95% of the people perceiving it as 'distinctly perceptible.'"[1]

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4 Stagg, M.S., D.E. Siskind, M.G. Stevens, and C.H. Dowding. Effects of Repeated Blasting on a Wood Frame House. U.S. Bureau of Mines, Report of Investigations 8896, 1984, p. 1.

5 Nichols, H.R., C.F. Johnson, and W.I. Duvall. Blasting Vibrations and Their Effects on Structures. U.S. Bureau of Mines Bulletin 656, 1971, p. 27.

1 Ibid, p. 34.

1 Ibid, p. 37.

What is annoying to one person may not be annoying to another. Each person perceives movement differently. Factors that can influence how human beings perceive blasting are:

- The frequency content of the blast events.
- The number of events per day or week.
- The time of day. The structure response.
- The condition of the property.
- The degree of activity of the person.
- The state of health of the person.
- The state of mind of the individual.
- The position and attitude of the person, i.e., in bed, working, sitting, inside or outside, etc…
- The local perception of the operation.
- The history of local damage claim payments (including "good neighbor" payments related to claims where liability was denied).

In some cases, regardless of the levels of ground motion experienced, complaints may still arise. "No amount of objective data will convince a person who "feels" strong vibrations that the vibration level as measured was barely perceptible-similarly with noises and air blasts. Personal contact and strong efforts in public relations help alleviate the problem but convince few."[5] In this event, pre-survey inspections, a monitoring program, and good record keeping can be invaluable should matters proceed to the legal arena. In extreme cases, dishonest individuals may see this as an opportunity for repairs or new water well.

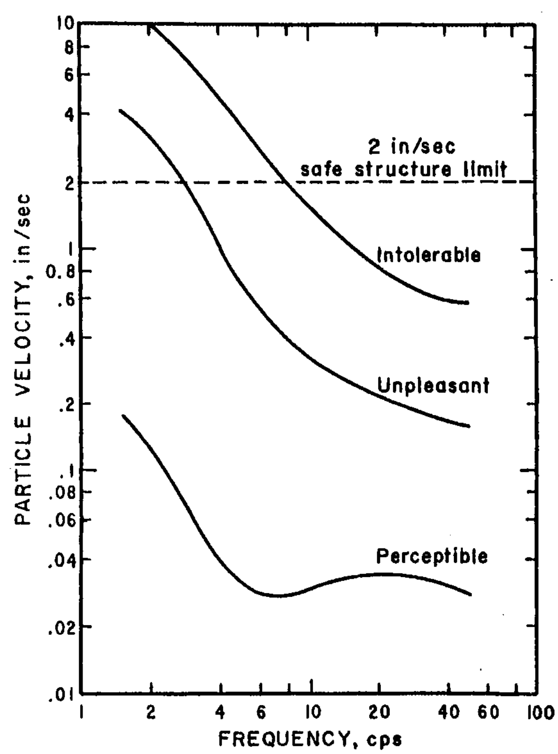

Figure 7: Subjective Response of the Human Body to Vibratory Motion (From USBM Bulletin 656, 1971)

[5] Ibid, p. 27.

WATER WELLS AND AQUIFERS

Water wells and aquifers exhibit a constrained response when subject to ground vibration. That is to say, they move in concert with the geologic material that surrounds them. In general, this geologic material surrounding the well must be disrupted to cause damage to a water well. In the case of the aquifer, a change in its structure (permeability) would be the necessary affect for it to have undergone changes as a result of blast vibration. Furthermore, the amplitude of the ground motion greatly decreases with depth. Following is general information on hydrology as well as information from studies on shot hole geophysical exploration and surface mine blasting effects on water wells and aquifers.

Hydrology

A groundwater system is a dynamic system where water moves down gradient from a recharge area to a discharge area (i.e., a spring). Normally, ground water moves slowly, the rate ranging from a fraction of an inch per year to a few feet per day. The geology determines the rate of ground-water recharge and movement. Most sedimentary aquifers consist of sandstone, limestone, Tertiary sediments, recent alluvium, or coal seams. Aquifers can also exist in fractured metamorphic rocks and igneous rocks. Hydraulic characteristics of aquifers include porosity, permeability, transmissivity, and the coefficient of storage. These characteristics differ greatly among different rock types.

Porosity is the volume of void space in a unit volume of material (this space can be occupied by water). Permeability is a measure of the capability of a geologic material to transmit water through a unit area. Transmissivity is defined as the permeability times the vertical thickness of the material, usually an aquifer. Coefficient of storage is defined as the volume of water that an aquifer can release from or take into storage per unit surface area, per unit change in head in a line normal to that surface.

Shot-Hole Geophysical Exploration

In "A Study of the Influence of Seismic Shotholes on Groundwater and Aquifers in Eastern Montana,"[6] five widely distributed sites in eastern Montana were chosen and monitored: (1) a 25 pound charge at a 197 foot depth, 150 feet away from the 150 foot deep test well, (2) a 25 pound charge at a 197 foot depth, a 165 foot distance away from the 90 foot deep test well, (3) a 80 pound charge at a 200 foot depth, 400 feet away from an 80 foot deep test well and a 25 pound charge at a depth of 150 feet, 150 feet away from the same test well, (4) a 25 pound charge at a 200 foot depth, 150 feet away from a test well with a 22 foot depth and a test well with a 96 foot depth, and (5) a 25 pound charge at a 200 foot depth, 150 feet away from a 135 foot deep test well and a 207 foot deep test well.

> Pumping tests of existing water wells and specially drilled observation wells, before and at several times after the firing of a seismic shot, revealed no detectable change in the physical properties of the aquifers. Analyses of water samples collected from water wells, observation wells, and test holes, at frequent intervals throughout the study period, showed only the random minor variations expectable in water from shallow aquifers. A few water

[6] Bond, E.W., A Study of the Influence of Seismic Shotholes on Groundwater and Aquifers in Eastern Montana, State of Montana – Montana Bureau of Mines and Geology, Special Publication 67, 1975.

samples from shotholes showed minor temporary increases in some chemical constituents, but these were not enough to affect the use of the water. Water-level measurements during the pumping tests showed that most of the shotholes were virtually sealed through the aquifer within a few months, at most, but tests could not be repeated over a long enough period to determine the final sealing date of all shotholes.

> Any mechanical change in aquifer structure as a result of seismic shooting should be indicated by change in permeability of the aquifer material. None of the aquifer tests conducted at the five test sites showed any change in aquifer structure, although poor efficiency of common well construction was evident...A change in aquifer permeability would require either a change in the packing arrangement of the aquifer material or an alteration of the cement holding the aquifer material together.
>
> Because drill holes for seismic programs average only about 200 feet in depth, multiple aquifers would have relatively small differences in hydrostatic head, and the quality of the waters would probably be similar.[6]

This indicates minimal interflow between aquifers.

In "The Effects of Seismic Blasting on Shallow Water Wells and Aquifers in Western North Dakota,"[7] the results of a literature search, a preliminary investigation, a field investigation, and an experimental investigation are presented. The preliminary investigation involved sending questionnaires to federal, state, county, and city agencies, certified water well contractors, as well as, grazing and environmental groups.

The questionnaires along with a news release resulted in numerous personal letters alleging effects during and after seismic testing. A third of these wells were field investigated. Both old and new wells were investigated. Eighteen wells were less than twenty years old and twenty-five wells were more than twenty years old. This indicates the problem is not restricted to older wells. Effects that were described by owners include long term decline in water quality (over a several year period), an abrupt (over several hours) decline in water quality, and 53 of 76 questionnaires cited decreased yield. In some instances these wells were not pumped wells, but rather were flowing wells. A gradual decline in a flowing well (or spring) is a naturally occurring result of usage.

Few instances of legal action were found during the study's preliminary search. Few people have good or complete records of their wells with respect to production and water quality. This causes difficulties when defending their position. A few respondents claimed to have replaced wells and equipment at their own expense. Also, because of the lack of background information on the wells, it is difficult to draw definitive conclusions regarding changes in water quality and production.

> Pumping tests conducted in a sand and coal aquifer system showed no apparent physical effects when shots were detonated one-quarter mile away from the pumping wells. Shots 500 feet distant resulted in no permanent effects. Shots 100 feet or closer increased the yield from wells finished in the sand aquifer and decreased the yield from the coal aquifer. Fracturing of the poorly indurated sandstone aquifer is suggested as the mechanism for the

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6 Ibid.

7 Beaver, F.W. The Effects of Seismic Blasting on Shallow Water Wells and Aquifers in Western North Dakota, Master's Thesis Submittal, University of North Dakota, 1984.

increase. Collapse of the fractures is suggested as the failure mechanism in the coal aquifer. Well casings remained intact after 25-pound charges were detonated as close as 10 feet from a well screen...

During the pumping tests, no significant long-term chemical or mineralogical equilibrium changes were observed which could be attributed to the blasting.[7]

Surface Mining

The source of these comments is the U.S. Bureau of Mines (USBM) study "Survey of Blasting Effects on Ground Water Supplies in Appalachia."[8] This study relates to coalmine blasting where large per delay explosive weights exceeding 5000 pounds are common. The USBM study included four test sites chosen for geographic and geologic diversity. Maximum resultant particle velocities of up to 5.44 inches per second were recorded at the surface next to the wells.

No direct evidence of change in water quality or well performance was produced by blast vibrations, but removal of down slope support by excavation does cause lateral stress relief which permits the water-bearing fractures to become more open. This additional storage capacity causes the static water level to drop and for well-bore permeability to improve. Static water level recovers if sufficient recharge is available and well performance is improved.

The well continues to perform in the same manner although blast induced round vibrations at the surface may approximate 2.0 inches per second maximum resultant particle velocity, until surface mining approaches to within about 300 feet of the water well.

State agencies and coal companies in Appalachia were contacted to develop a list of reportedly blast damaged wells. Of 36 wells so reported, 24 were investigated in the field but there was no clear evidence that the problem was blast related. In most cases, it was evident that other factors were responsible for changes in well behavior.

Maximum ground vibration levels at the four test wells, measured as close as practical to the well heads, were 2.2, 5.44, 2.14, and .84 inches per second resultant particle velocity. Based on observable change in well conditions immediately after a blast, there was no direct evidence of any significant change as a result of blasting. At three sites, when mining approached within a distance of approximately 300 feet, a fairly abrupt drop in static water level occurred followed by a significant improvement in well performance as indicated by specific capacity. At the fourth site, there was no change.

Measurements made at the bottoms of wells indicated that vibrations were considerably attenuated at depths of 140 to 160 feet.[8]

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7 Ibid.

8 Robertson, D.A., Gould, J.A., Straw, J.A., and M.A. Dayton. Survey of Blasting Effects on Ground Water Supplies in Appalachia, U.S. Bureau of Mines Contract J-0285029, prepared by Philip R. Berger & Associates, 1980.

8 Ibid.

This study found the vibrations at the bottom of an observation well to be between 14 to 68 % as strong as those at the surface (approximately 150 feet deep). The largest effects on vibration attenuation with depth are the geometric relationship between the charge location and the well and the degree of confinement of the shot.

This study quotes another study, "Water Well Design for Earthquake Induced Motions,"[9] a survey of published reports describing the conditions of numerous water wells during and after three major earthquakes. This study involved 350 wells in areas where severe damage to structures occurred. Almost all wells reported to be permanently damaged were in regions of permanent displacement of the surrounding earth, primarily land sliding. Eight wells were destroyed, four were inoperable but reparable, and forty-five wells were damaged but operable. The intensity of the earthquakes in the study were modified Mercalli scale magnitudes VIII, IX, and X.

PIPELINE RESPONSE

Five pipeline sections were studied by the USBM in conjunction with the State of Indiana and AMAX Coal and its consultants in the advance of coal mine overburden blasting (USBM R.I. 9523).[10] These tests were conducted on the highwall of the Minnehaha Mine near Sullivan, Indiana and were designed for testing to failure.

All five pipeline sections were 76 m (249 ft) long. Four sections were welded steel pipe and one section was PVC. The pipeline sections were laid parallel to one another, 3 m (9.8 ft) apart, with 1 m (3.3 ft) depths of burial. They were buried in a clay soil. Each pipeline had three uprights for pressurization and gage access. Following is a summary of the pipeline attributes:

Outside Diameter, cm, (in)	Wall Thickness, mm, (in)	Fill Material	Age	Material Type
Steel:				
16.8, (6.6)	4.78, (.188)	Gas	Used	X-42
32.4, (12.8)	6.35, (.250)	Gas	Used	Grade B
32.4, (12.8)	6.35, (.250)	Gas	New	X-42
50.8, (20.0)	6.63, (.261)	Water	Used	X-56
PVC:				
21.9, (8.6)	8.43, (.332)	Water	Used	SDR26

Steel Pipelines: Initial pressurization 6.2 MPa (900 psi).
PVC Pipeline: Initial pressurization 0.62 MPa (90 psi).

The pipelines were monitored for vibration, strain, and pressure for a period of 6 months while production advanced up to a point 15 m (49 ft) away. 29 productions blasts were measured. The blasts used maximum charge weights per delay of up to 950 kg (2090 pounds) in 31 cm (12.25 inch) diameter holes.

Following the production blasts, a single row of four blast holes was drilled between the pipelines to complete the destructive test. The explosive charge was below the pipes at 5 to 6 m

[9] Nazarian, H.N. Water Well Design for Earthquake Induced Motions. ASCE J. Power Div., V. 99, No. P02, Paper 10176, November 1973, pp. 377-394.

[10] Siskind, D.E., M.S. Stagg, J.E. Wiegand, and D.L. Schulz. Surface Mine Blasting Near Pressurized Transmission Pipelines. U.S. Bureau of Mines, Report of Investigations 9523, 1994, 51 pp.

(16.4 to 19.7 ft) distances. The vibration level measured was greater than 900 mm/s (35.43 in/s), however, this was non-elastic response. The result of the destructive test on each pipeline is as follows: 1) 16.8 cm (6.6 in) diameter steel pipe - severely bent but unbroken, 2) new 32.4 cm (12.8 in) diameter steel pipe - bowed, but unbroken, 3) used 32.4 cm (12.8 in) diameter steel pipe - cleanly broken at the risers, 4) water filled 50.8 cm (20.0 in) diameter steel pipe - uplifted, parted, fell back down, and 5) 22 cm (8.6 in) diameter PVC pipe - came apart at O-rings, but unbroken.

The results of the closest production blast (15 m (49.2 ft) distant from the closest pipeline) resulted in a 635 mm/s (25.00 in/s) measurement at the surface and 234 to 274 mm/s (9.21 to 9.84 in/s) on two instrumented pipelines.

> Analysis found low pipe responses, strains, and calculated stresses from even large blasts. Ground vibration of 120 to 250 mm/s (4.72 to 9.84 in/s) produced worst-case strains that were about 25% of the strains resulting from normal pipeline operations and calculated stresses of only about 10% to 18% of the ultimate tensile strength. No pressurization failures or permanent strains occurred even at vibration amplitudes of 600 mm/s (23.62 in/s)...
>
> ...Although particle velocities of over 600 mm/s (23.62 in/s) were sustained without loss of pipe integrity, it is recommended that 125 mm/s (4.92 in/s) measured at the surface is a safe-level criterion for large surface mine blasts for Grade B or better steel pipelines. The same criterion is recommended for SDR 26 or better PVC pipe...Also, no adjustment is believed needed for pipeline age, assuming the protective coating is intact, unless the pipeline is known to be at higher risk from previous damage or other causes. The same safe-level criterion also appears applicable, at a minimum, to vertical wells and telephone lines.[10]

The primary blasting risk to pipelines appears to be from block motion or from having the pipeline in the actual crater zone. In both cases, permanent strain has occurred in the surrounding geologic material, which is weaker than the pipe.

In the early 1960's work was undertaken by the American Gas Association Pipeline Research Committee to establish limits for charge size (pounds per delay) and distance from a blast to high-pressure gas transmission pipelines. The primary research found that there had been no reported case of pipeline failure due to normal blasting activities. Failures were recorded only when explosives were detonated directly adjacent to a pipeline.

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[10] Ibid., pp. 1, 36.

Sincerely,

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