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Memo

To: Kami Ballard, Resolution Copper **Date:** September 07, 2018

From: Alfredo Rodrigues, Wood

CC: Buddy Ledger, Wood

Ref: Resolution Copper Underground to Surface Conveyor System

Re: Blasting Monitoring Review Memorandum

1. INTRODUCTION

Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited (hereinafter referred to as Wood), formerly known as Amec Foster Wheeler, at the request of Resolution Copper (Resolution) has prepared this memorandum reviewing the blasting monitoring data as part of the proposed underground inclined ore conveyor and tunnel at the Resolution Copper facility in Superior Arizona.

This memorandum specifically deals with the assessment of the model used in the Vibration Impact Assessment prepared by Wood in July 2018 [1].

2. MONITORING OF BLASTING VIBRATIONS

2.1. Introduction

This memorandum presents data collected during vibration monitoring from blasting conducted on-site during the East Plant Blasting at 4,000 level. Data was collected by Tetra Tech and was transmitted to Wood on June 2018[1].

Data received included the following information:

- Peak Particle Velocity (PPV) collected on-site for three orthogonal axis;
- PPV was recorded in intervals of 1-minute for the entire monitoring period; and

[1] Email from Mr. Kevin Fowler from Tetra Tech on June 11, 2018.

- Blasting schedule at East Plant – 4,000 Level.

The monitoring setup also included for the recording of full waveform in case the PPV exceeded a level of 0.01 in/s. As this level was never exceeded the equipment did not record any waveform data.

The monitoring location was conducted at ground level. Blasting occurred at approximately 4,000 ft below ground surface and with an horizontal offset of approximately 100 ft from monitoring location.

2.2. Limits Considered

The effects of vibration from blasting on structures and human annoyance are discussed in the U.S. Dept. of the Interior, Bureau of Mines (USBM) Report of Investigations RI 8507 [2]. RI 8507 concludes that safe levels of blasting vibrations for residential type structures at low frequencies (< 40 Hz) are below 0.5 in/sec and at high frequencies (≥ 40 Hz) are below 2 in/sec. These levels relate to the effects on building structures and the probability of damage. The criteria presented in the main text of RI 8507 is further expanded in Appendix B of the same document. The purpose of Appendix B was to eliminate the sharp discontinuity in the peak particle velocity criteria at 40 Hz by introducing displacement constraints. Appendix B of RI 8507 defines the safe levels of blasting vibrations for residential type structures as 0.1884 in/sec at 1 Hz, increasing to 0.5 in/sec at 2.7 Hz, remaining at 0.5 in/sec up to 10 Hz, increasing to 2 in/sec at 40 Hz and remaining at 2 in/sec up to 100 Hz.

2.3. Monitoring Period

Monitoring data provided include the periods from January 30, 2018 to March 19, 2018, in which 29 blasting events were reported. Table 1 presents a summary of blasting events assessed.

Table 1: Provided Schedule of Blasting

Date	Time	Date	Time	Date	Time
30/01/2018	2:25:00 AM	15/02/2018	1:10:00 AM	08/03/2018	1:30:00 AM
30/01/2018	10:55:00 AM	18/02/2018	4:25:00 PM	08/03/2018	10:00:00 PM
31/01/2018	9:15:00 PM	25/02/2018	10:55:00 AM	09/03/2018	3:30:00 PM
02/02/2018	10:50:00 PM	26/02/2018	7:10:00 PM	11/03/2018	9:05:00 PM
03/02/2018	9:55:00 PM	28/02/2018	11:10:00 PM	16/03/2018	5:40:00 AM
04/02/2018	12:05:00 PM	01/03/2018	10:48:00 PM	16/03/2018	5:30:00 PM
06/02/2018	2:55:00 PM	02/03/2018	9:52:00 PM	17/03/2018	5:35:00 PM
07/02/2018	11:20:00 AM	05/03/2018	9:00:00 PM	18/03/2018	7:00:00 AM
10/02/2018	9:30:00 PM	06/03/2018	3:30:00 PM	19/03/2018	5:35:00 PM
12/02/2018	8:40:00 PM	07/03/2018	12:25:00 AM		

2.4. Monitoring Results

The monitoring results provided includes PPV measured in 1-minute intervals. Monitoring was continuous and does not only reflect the blasting but environmental vibrations as well. The results are presented in graphical form for every day of monitoring in Appendix A. Table 2 summarizes the PPV results for the blasting events.

Table 2: Monitoring Results per Blasting Event

Date	Time	Measured PPV [in/s]		
		Transverse	Vertical	Longitudinal
30/01/2018	2:25	0.0022	0.0025	0.0028
30/01/2018	10:55	0.0022	0.0034	0.0025
31/01/2018	21:15	0.0019	0.0028	0.0025
02/02/2018	22:50	0.0022	0.0025	0.0022
03/02/2018	21:55	0.0022	0.0025	0.0025
04/02/2018	12:05	0.0031	0.0040	0.0034
06/02/2018	14:55	0.0034	0.0040	0.0040
07/02/2018	11:20	0.0022	0.0034	0.0022
10/02/2018	21:30	0.0019	0.0028	0.0019
12/02/2018	20:40	0.0028	0.0022	0.0031
15/02/2018	1:10	0.0028	0.0019	0.0037
18/02/2018	16:25	0.0022	0.0034	0.0022
25/02/2018	10:55	0.0025	0.0022	0.0025
26/02/2018	19:10	0.0019	0.0028	0.0019
28/02/2018	23:10	0.0047	0.0025	0.0053
01/03/2018	22:48	0.0028	0.0019	0.0037
02/03/2018	21:52	0.0022	0.0028	0.0022
05/03/2018	21:00	0.0028	0.0025	0.0028
06/03/2018	15:30	0.0025	0.0034	0.0031
07/03/2018	0:25	0.0022	0.0022	0.0025
08/03/2018	1:30	0.0022	0.0025	0.0028
08/03/2018	22:00	0.0019	0.0025	0.0025
09/03/2018	15:30	0.0034	0.0040	0.0040
11/03/2018	21:05	0.0025	0.0022	0.0022
16/03/2018	5:40	0.0034	0.0019	0.0043
16/03/2018	17:30	0.0025	0.0031	0.0025

Date	Time	Measured PPV [in/s]		
		Transverse	Vertical	Longitudinal
17/03/2018	17:35	0.0022	0.0028	0.0025
18/03/2018	7:00	0.0037	0.0019	0.0037
19/03/2018	17:35	0.0022	0.0025	0.0022

2.5. Analysis of Results

The vibration levels presented in Table 2 show very small values for the blasting events. A review of the plots in Appendix A shows that the blasting events are similar in magnitude as the background vibration levels. As such, a statistical analysis was conducted to better analyse these vibration events in context of the overall vibration levels.

The data for each day of monitoring and the blasting events is presented in boxplots - Figure 2, Figure 3 and Figure 4. Boxplots allow for a description of the sample and make no representation or assumptions regarding the population. Figure 1 shows a representation of the elements of the boxplot and how they relate to the statistical levels of the sample.

Figure 1: Boxplot Data Representation

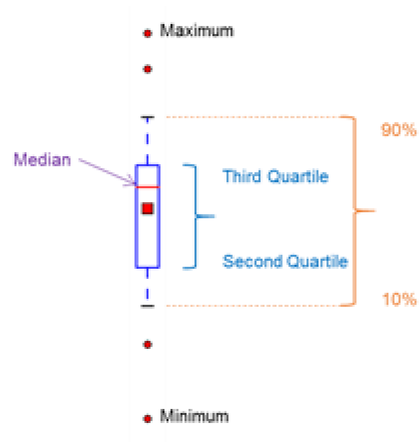


Figure 2: Statistical Review of Vertical Axis Vibration

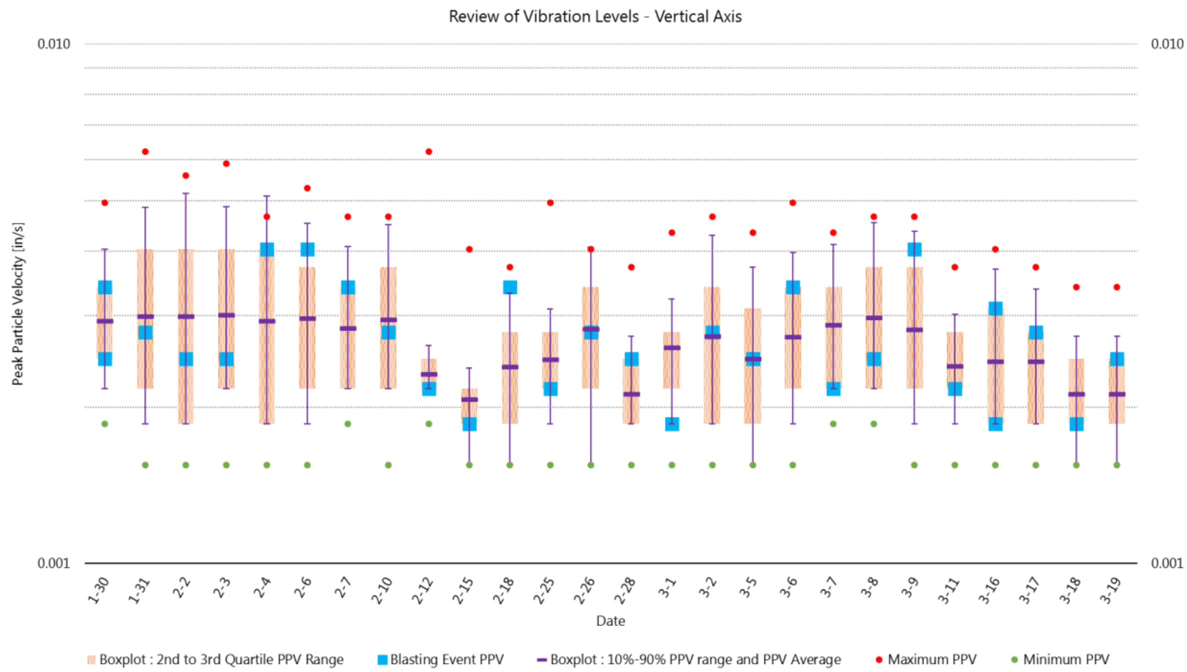


Figure 3: Statistical Review of Transverse Axis Vibration

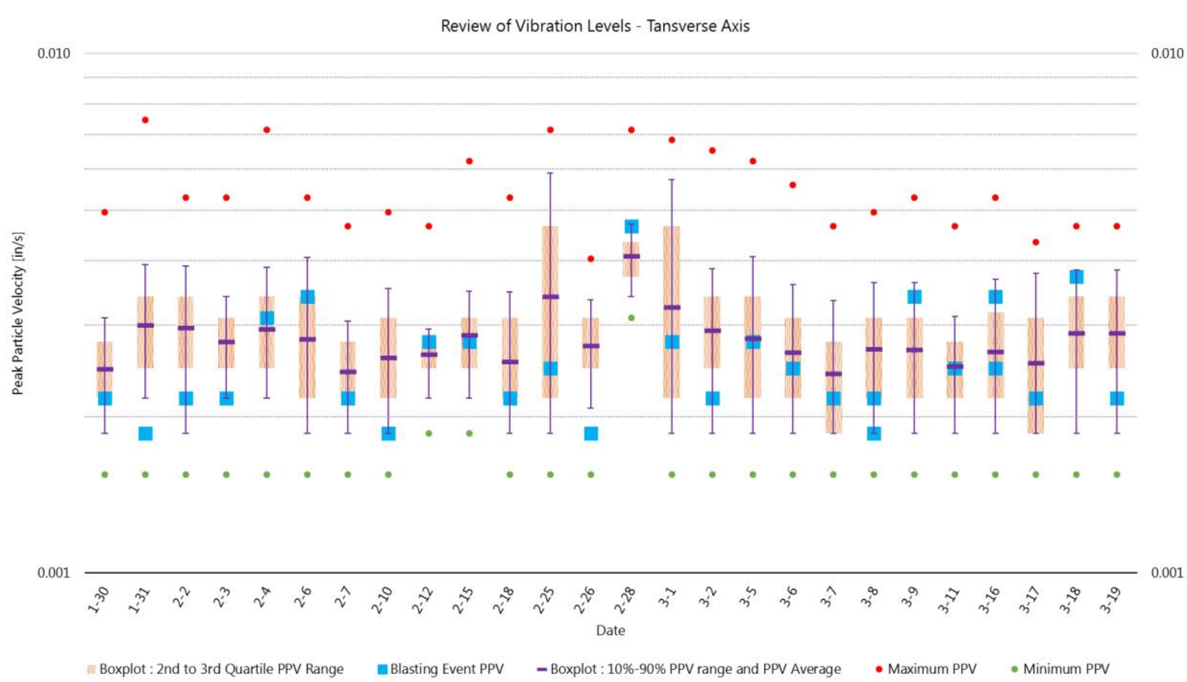
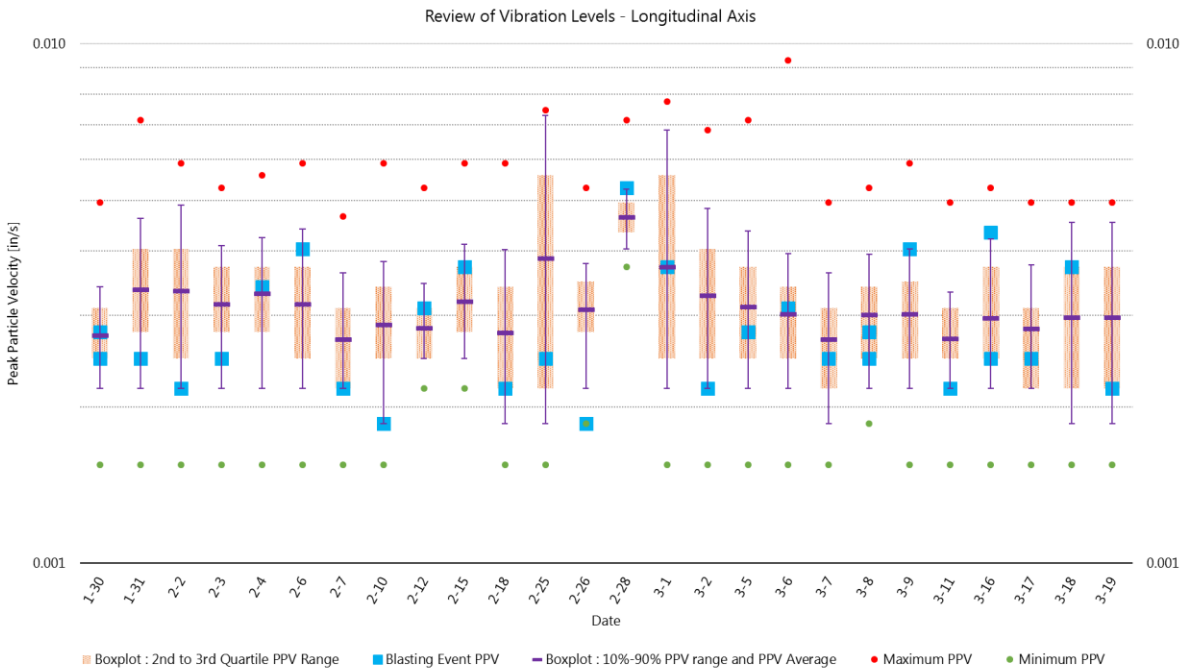


Figure 4: Statistical Review of Longitudinal Axis Vibration



2.6. Interpretation of Results

Based on all the results presented in Appendix A and summarized in Figure 2, Figure 3 and Figure 4, the following conclusions can be derived:

1. The blasting monitoring results show that PPV during blasting periods are very small. The PPV never exceeds 0.01 in/s;
2. The blasting monitoring results show that PPV outside blasting periods, ambient vibration levels vibrations, are also very small. The PPV never exceeded 0.01 in/s;
3. The blasting events never exceeded the trigger level for recording of waveform information;
4. The blasting vibration levels are buried in the ambient vibration levels, meaning that the PPV from blasting events are not high enough for a clear distinction between blasting events and ambient vibration levels; and
5. The monitoring data, if we were to consider that the peaks recorded are from blasting, are well within limits for safe blasting in building structures.

3. BLASTING CALCULATIONS

3.1. Sizing of Blasting Events

Blasting data was provided by Rio Tinto[2] for the blasting at East Plant at 4,000 level. Blasting was conducted with an average loading of 225 lbs of explosives[3] distributed in a patterned hole system composed of approximately 50-60 holes.

In order to estimate the maximum charge per delay Rio Tinto also provided with an average timing on the average round with the number of delays used per round on a 66-hole drift round. This is presented in Table 3.

Table 3: Provided Timing for Blasting

Timing [ms]	# Holes
0	2
1	2
2	4
3	4
4	4

Timing [ms]	# Holes
5	5
6	4
7	8
8	8
9	8

Timing [ms]	# Holes
10	9
11	4
12	4

For calculations purposes Bulletin 656 [3] established a minimum delay interval of 9 milliseconds (ms) for scaled distance calculations. As such the maximum number of holes blasted in any 9 ms presented in Table 3 was considered. This yields that a total of 54 holes were blasted within a 9 ms interval, considering a equally distributed explosive over all the holes, in average it was considered that blasting at the East Plant at 4,000 level was 163 lbs of explosives.

3.2. Modeling Results

Ground vibration levels from blasting can be estimated using the USBM Bulletin 656 [3] methodology. The USBM methodology for predicting ground vibration uses the equivalent weight of Trinitrotoluene explosive (kg TNTe) as the input variable. Utilizing receptor location data, tunnel alignment data and the vibration criteria; the predictive model can be used to establish the upper limit for explosive loading per delay in terms of kg of TNTe.

Appendix B presents a generic calculation table for vibration impacts. It presents estimated PPV values based on slant distance from blasting to receptor and the equivalent weight of Trinitrotoluene explosive (kg TNTe).

[2] Email from Andy Bravence at Rio Tinto on May 28, 2018 and June 13, 2018.
[3] Considered to have relative effectiveness factor (R.E. factor) of 0.7 relative to Trinitrotoluene equivalent explosive (TNTe) weight.

Based on the inputs presented for the blasting:

- Approximate depth of blasting – 4,000 ft and an horizontal set-back of approximately 100 ft, the slant distance is approximately 4,001 ft; and
- With a weight of blasting power per delay of 163 lbs, which equates to approximately 114 lbs of equivalent TNT[4] or equivalently approximately 52 kg TNTe.

Based on the above, the model used in the Vibration Impact Assessment, would result in a PPV of approximately 0.06 in/s.

The monitoring results presented in Table 2 are summarized in Table 4 for the periods that include blasting events.

Table 4: Summary of Monitoring Results for Blasting Events

Metric	Measured PPV [in/s]		
	Transverse	Vertical	Longitudinal
Maximum	0.005	0.004	0.005
Average	0.003	0.003	0.003
Minimum	0.002	0.002	0.002

Based on the results presented it can be stated that the model used Vibration Impact Assessment for modeling of vibration levels from blasting events is conservative.

[4] Considered to have relative effectiveness factor (R.E. factor) of 0.7 relative to Trinitrotoluene equivalent explosive (TNTe) weight.

4. LIMITATIONS

This Memorandum was prepared exclusively for Resolution Copper for the specific application addressed herein. The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in Wood's services and based on:

- Information available at the time of preparation;
- Data supplied by outside sources; and
- The assumptions, conditions and qualifications set forth in the report.

This Memorandum is intended to be used by Resolution Copper only, subject to the terms and conditions of its contract with Wood. Any other use of, or reliance on, this report by a third party other than those expressly noted in this report is at that party's sole risk. This report has been prepared in accordance with generally accepted engineering practice. No other warranty, expressed or implied, is made.

5. CLOSURE

This memorandum presents the review of existing blasting vibration monitoring results and compares those results with the proposed model for the Vibration Impact Assessment.

Should you have any questions regarding this memorandum, please do not hesitate to contact the undersigned.

Sincerely,

Wood Environment & Infrastructure Solutions
a Division of Wood Canada Limited

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6. REFERENCES

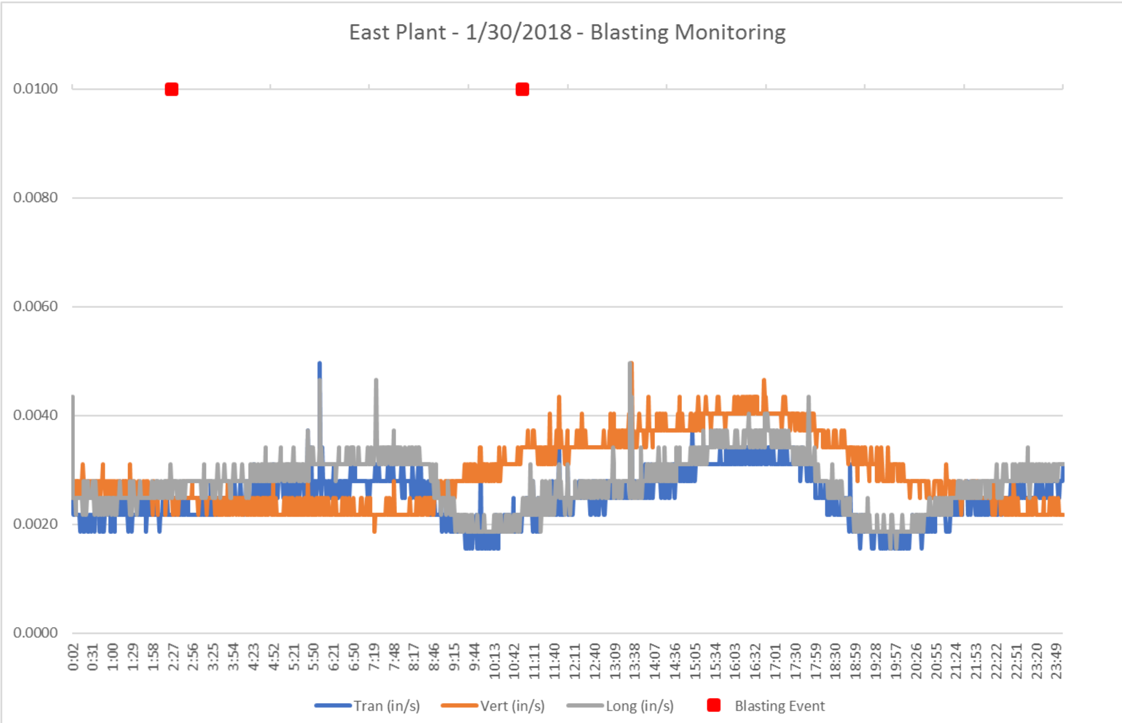
[1] Wood Environment & Infrastructure Solutions, "Resolution Copper Underground to Surface Conveyor System - Vibration Impact Assessment Report," July 2018.

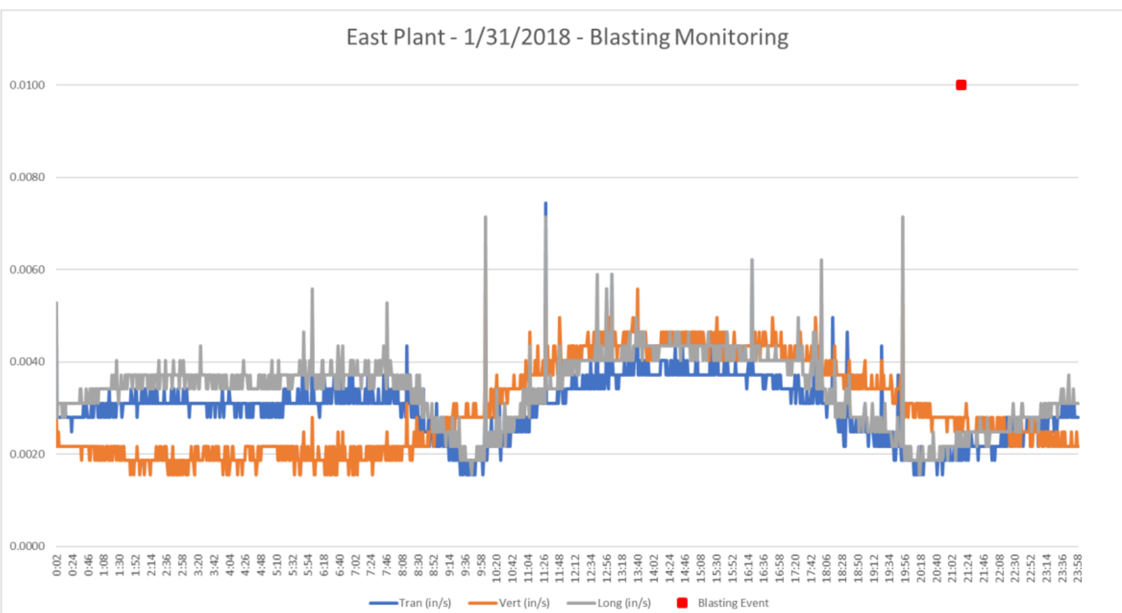
[2] D. E. Siskind, M. S. Stagg, J. W. Kopp and C. H. Dowding, "Structure response and damage produced by ground vibration from surface mine blasting.," U.S. Dept. of the Interior, Bureau of Mines, Washington, D.C., R8507, 1980.

[3] H. R. Nicholls, C. F. Johnson and W. I. Duvall, "Bulletin 656 - Blasting Vibrations and Their Effect on Structures," U.S. Dept. of the Interior, Bureau of Mines, Washington, D.C., 1971.

Appendix A

Monitoring Results Plots


East Plant - 1/30/2018 - Blasting Monitoring
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
0:02 0:31 1:00 1:29 1:58 2:27 2:56 3:25 3:54 4:23 4:52 5:21 5:50 6:21 6:50 7:19 7:48 8:17 8:46 9:15 9:44 10:13 10:42 11:11 11:40 12:11 12:40 13:09 13:38 14:07 14:36 15:05 15:34 16:03 16:32 17:01 17:30 17:59 18:30 18:59 19:28 19:57 20:26 20:55 21:24 21:53 22:22 22:51 23:20 23:49
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 1/31/2018 - Blasting Monitoring
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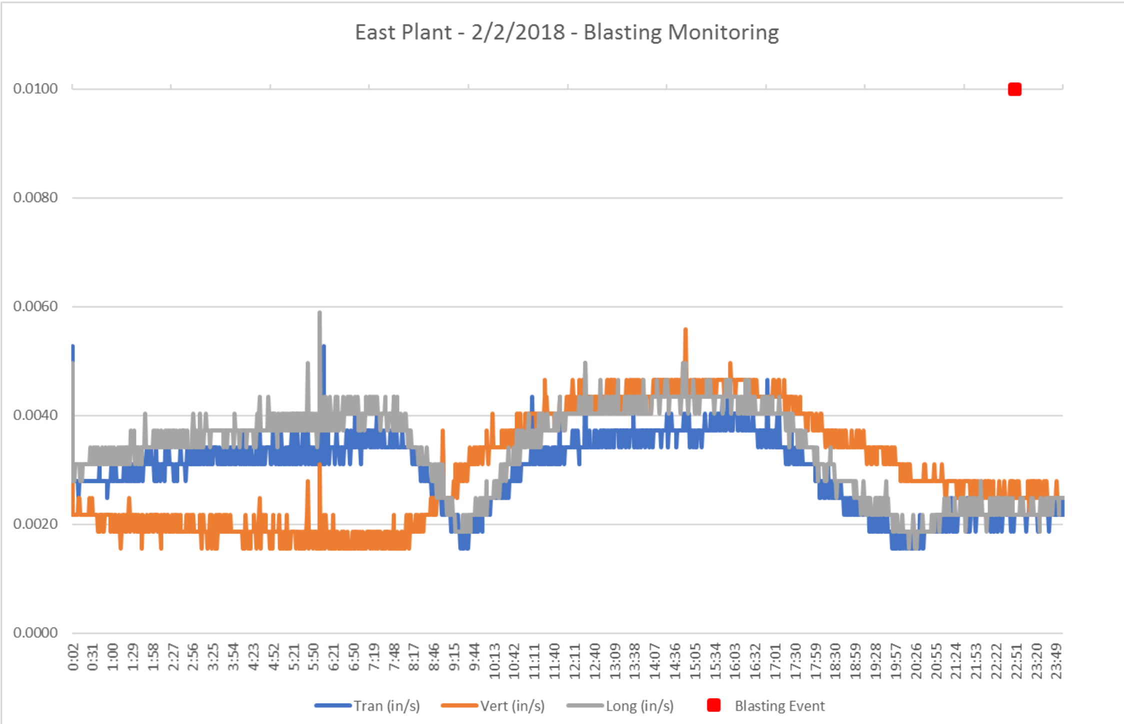
0.0060
0.0040
0.0020
0.0000
0:02 0:24 0:46 1:08 1:30 1:52 2:14 2:36 2:58 3:20 3:42 4:04 4:26 4:48 5:10 5:32 5:54 6:18 6:40 7:02 7:24 7:46 8:08 8:30 8:52 9:14 9:36 9:58 10:20 10:42 11:04 11:26 11:48 12:12 12:34 12:56 13:18 13:40 14:02 14:24 14:46 15:08 15:30 15:52 16:14 16:36 16:58 17:20 17:42 18:06 18:28 18:50 19:12 19:34 19:56 20:18 20:40 21:02 21:24 21:46 22:08 22:30 22:52 23:14 23:36 23:58
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event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0.0060
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0.0020
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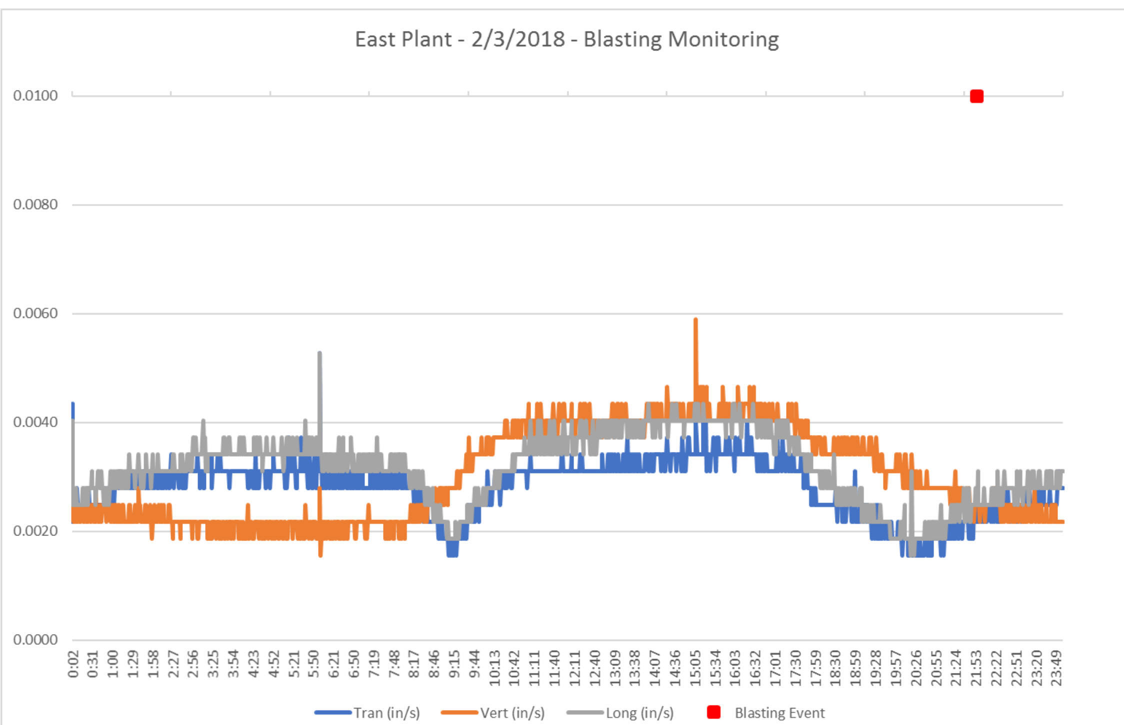
0:02 0:31 1:00 1:29 1:58 2:27 2:56 3:25 3:54 4:23 4:52 5:21 5:50 6:21 6:50 7:19 7:48 8:17 8:46 9:15 9:44 10:13 10:42 11:11 11:40 12:11 12:40 13:09 13:38 14:07 14:36 15:05 15:34 16:03 16:32 17:01 17:30 17:59 18:30 18:59 19:28 19:57 20:26 20:55 21:24 21:53 22:22 22:51 23:20 23:49
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event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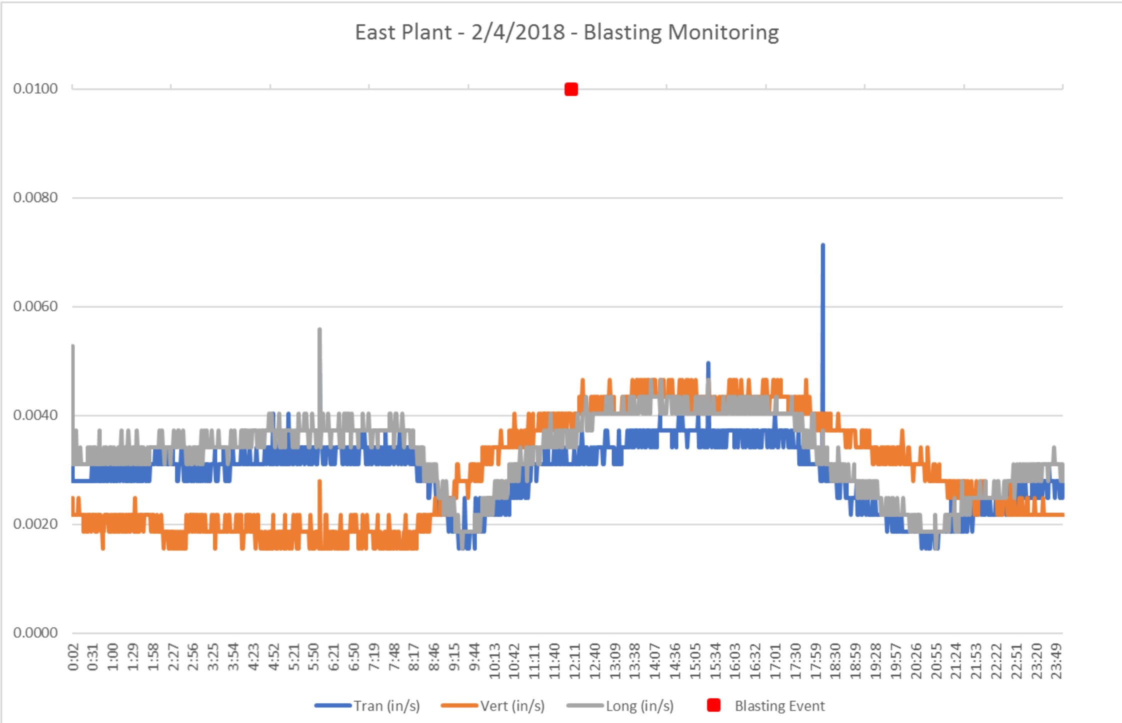
0.0000
0:02 0:31 1:00 1:29 1:58 2:27 2:56 3:25 3:54 4:23 4:52 5:21 5:50 6:21 6:50 7:19 7:48 8:17 8:46 9:15 9:44 10:13 10:42 11:11 11:40 12:11 12:40 13:09 13:38 14:07 14:36 15:05 15:34 16:03 16:32 17:01 17:30 17:59 18:30 18:59 19:28 19:57 20:26 20:55 21:24 21:53 22:22 22:51 23:20 23:49
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event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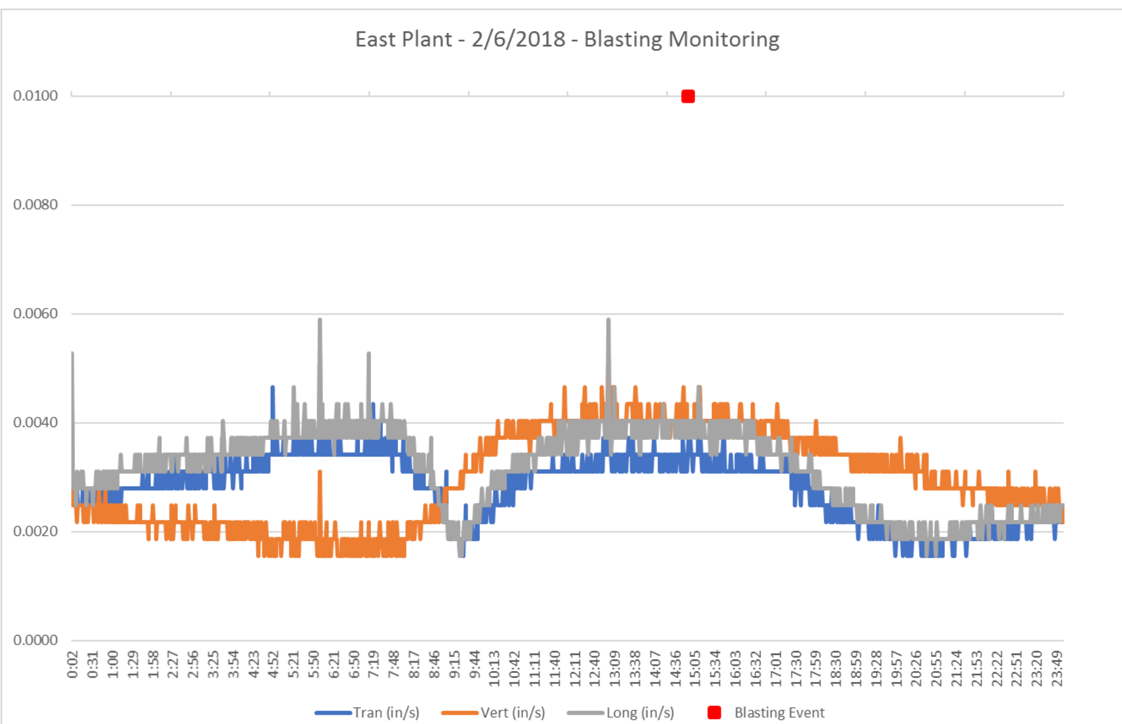
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 2/6/2018 - Blasting Monitoring
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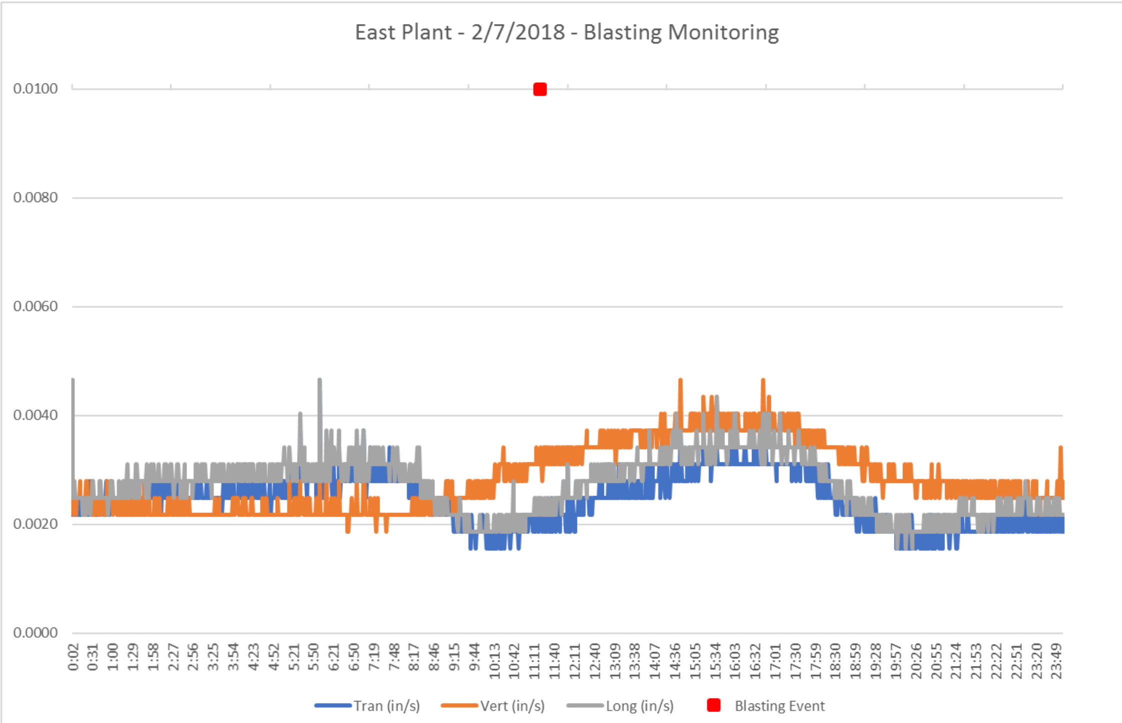
Vert (in/s)
Long (in/s)
Blasting Event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0.0080
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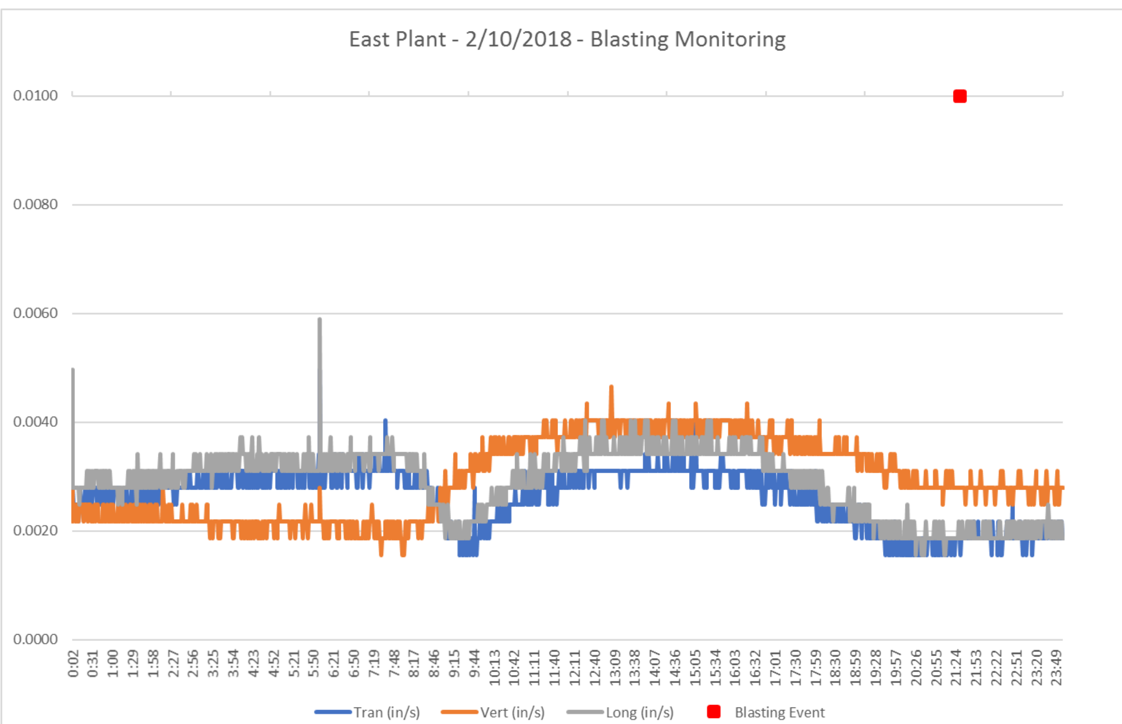
0.0000
0:02 0:31 1:00 1:29 1:58 2:27 2:56 3:25 3:54 4:23 4:52 5:21 5:50 6:21 6:50 7:19 7:48 8:17 8:46 9:15 9:44 10:13 10:42 11:11 11:40 12:11 12:40 13:09 13:38 14:07 14:36 15:05 15:34 16:03 16:32 17:01 17:30 17:59 18:30 18:59 19:28 19:57 20:26 20:55 21:24 21:53 22:22 22:51 23:20 23:49
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event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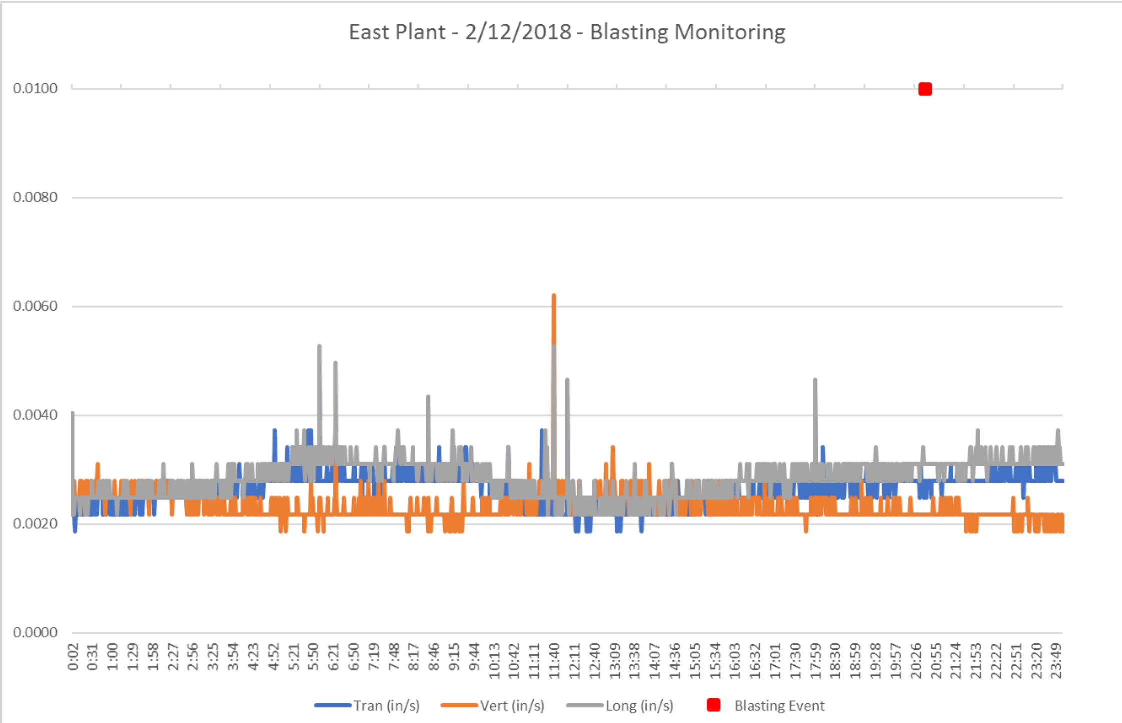
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event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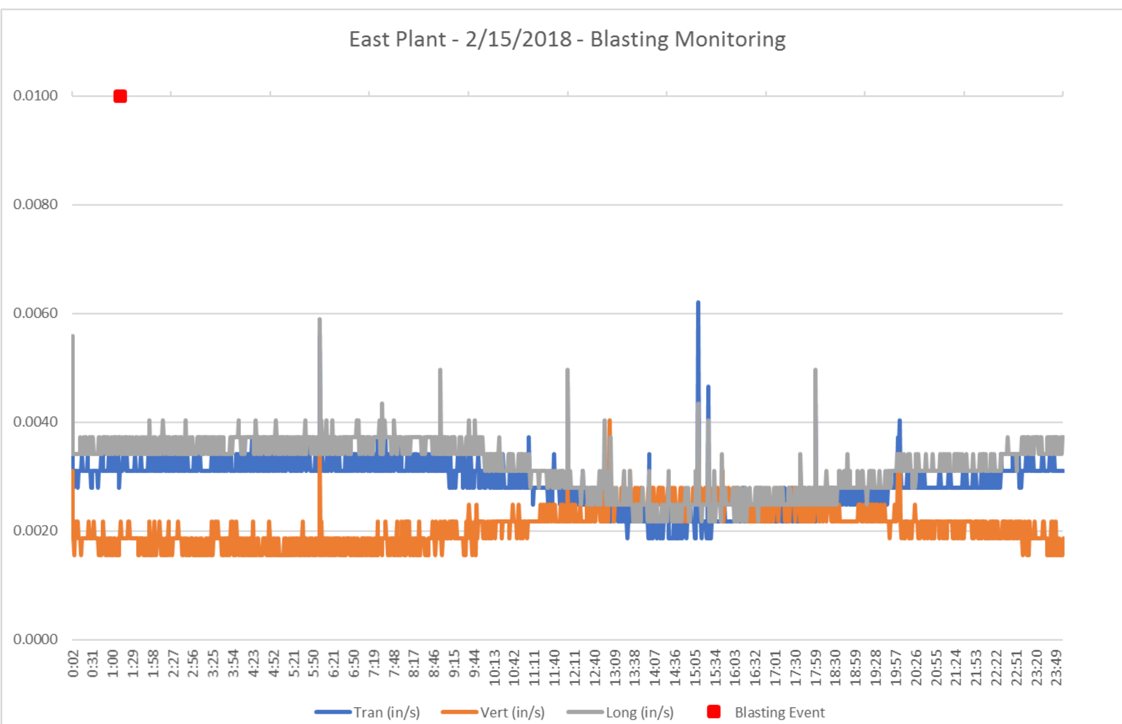
Vert (in/s)
Long (in/s)
Blasting Event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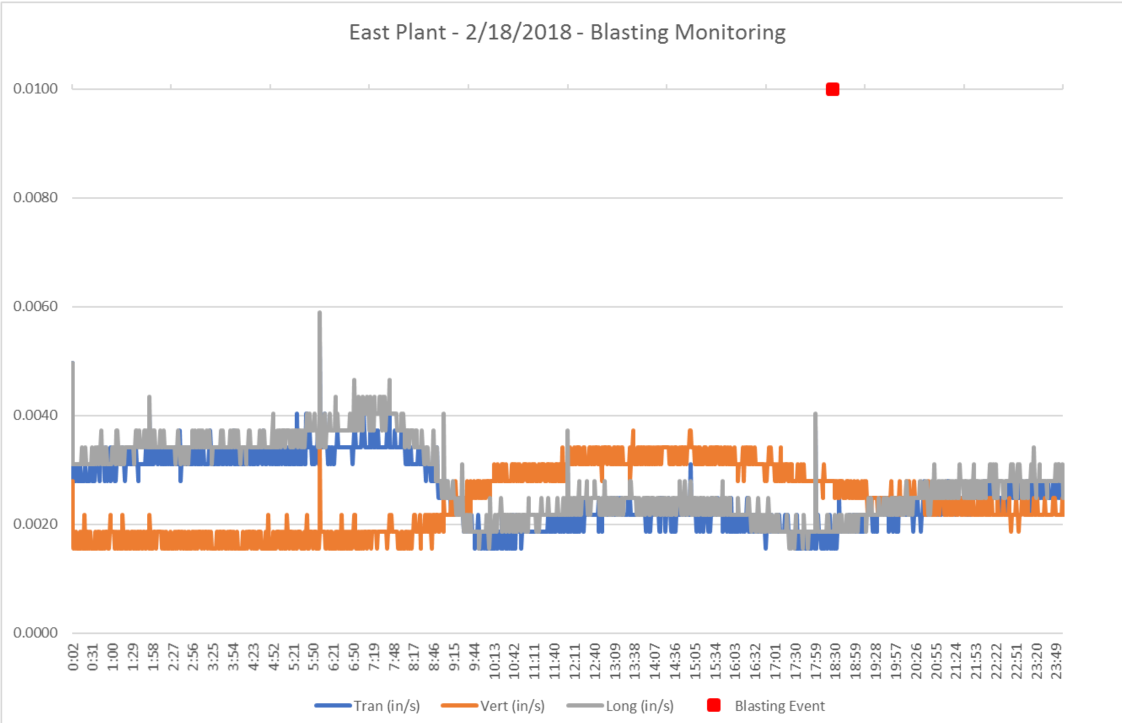
Long (in/s)
Blasting Event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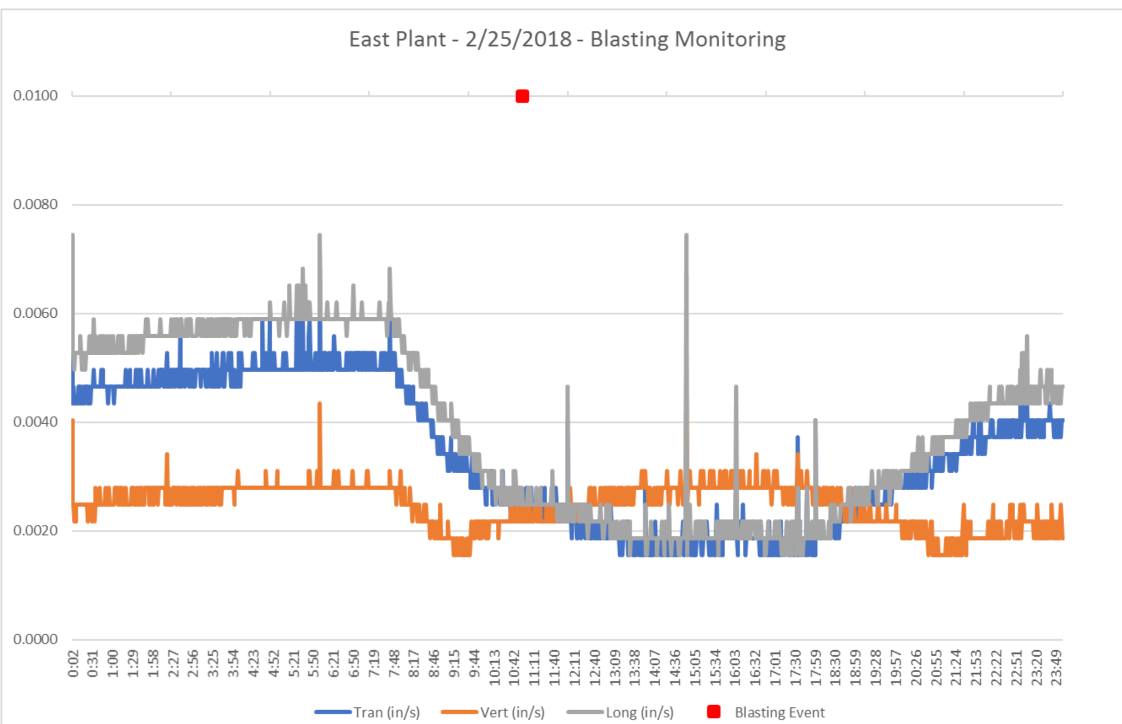
Vert (in/s)
Long (in/s)
Blasting Event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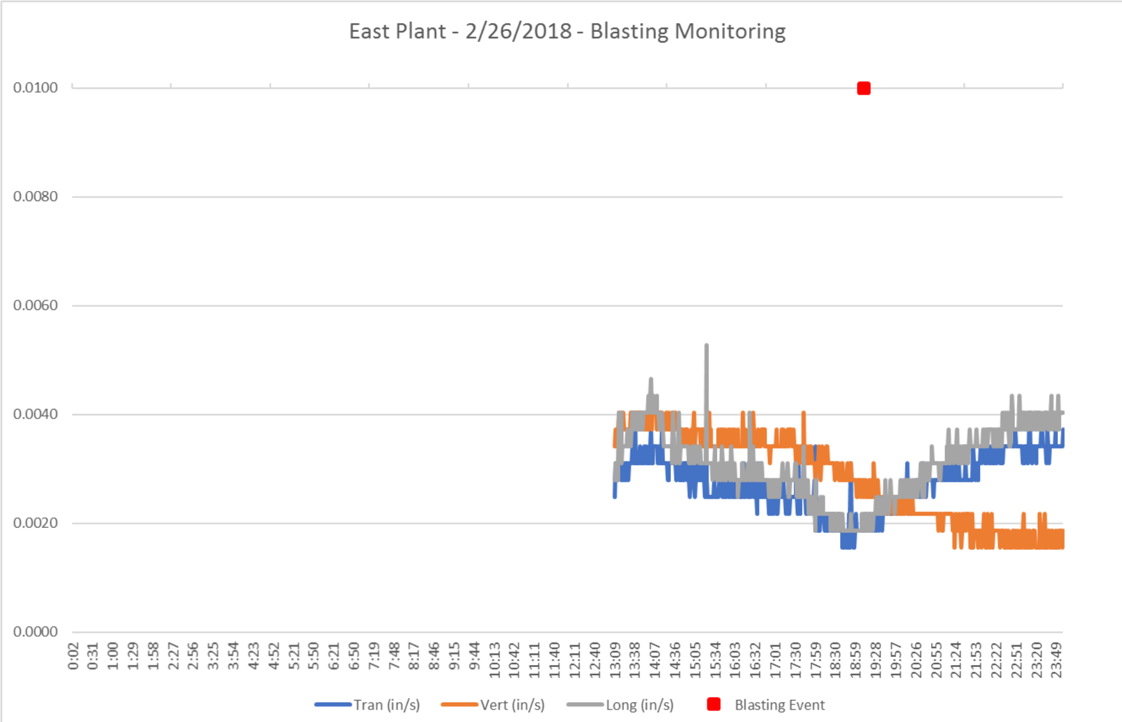
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event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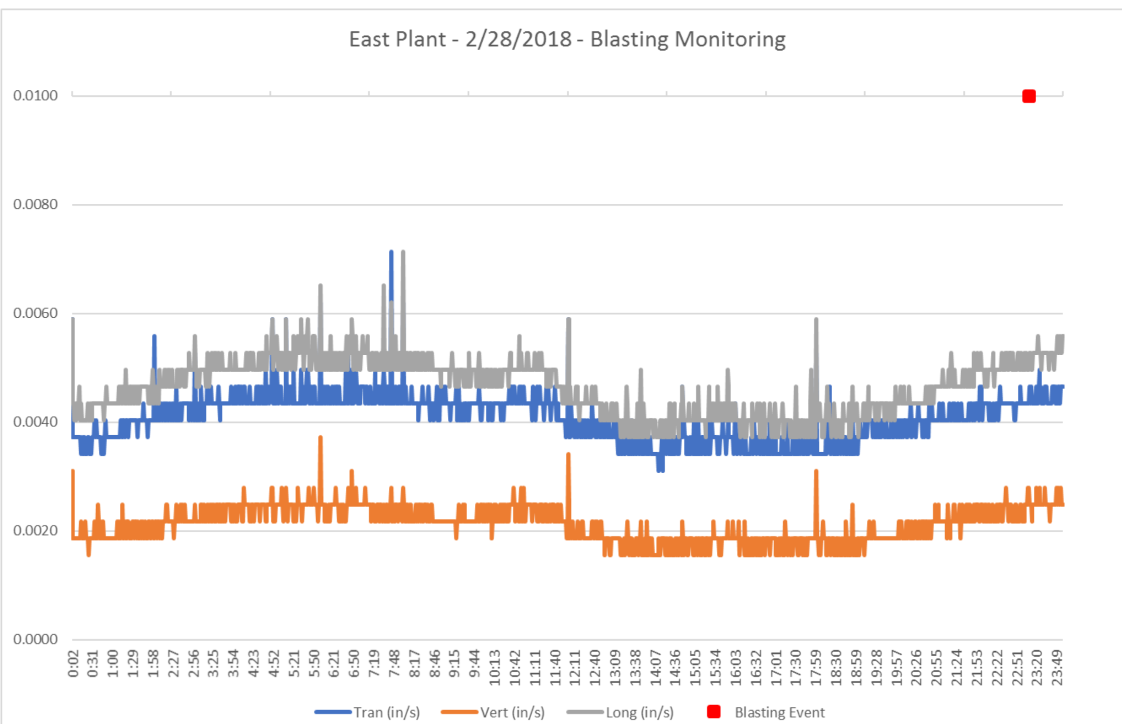
0.0020
0.0000
0:02
23:49
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event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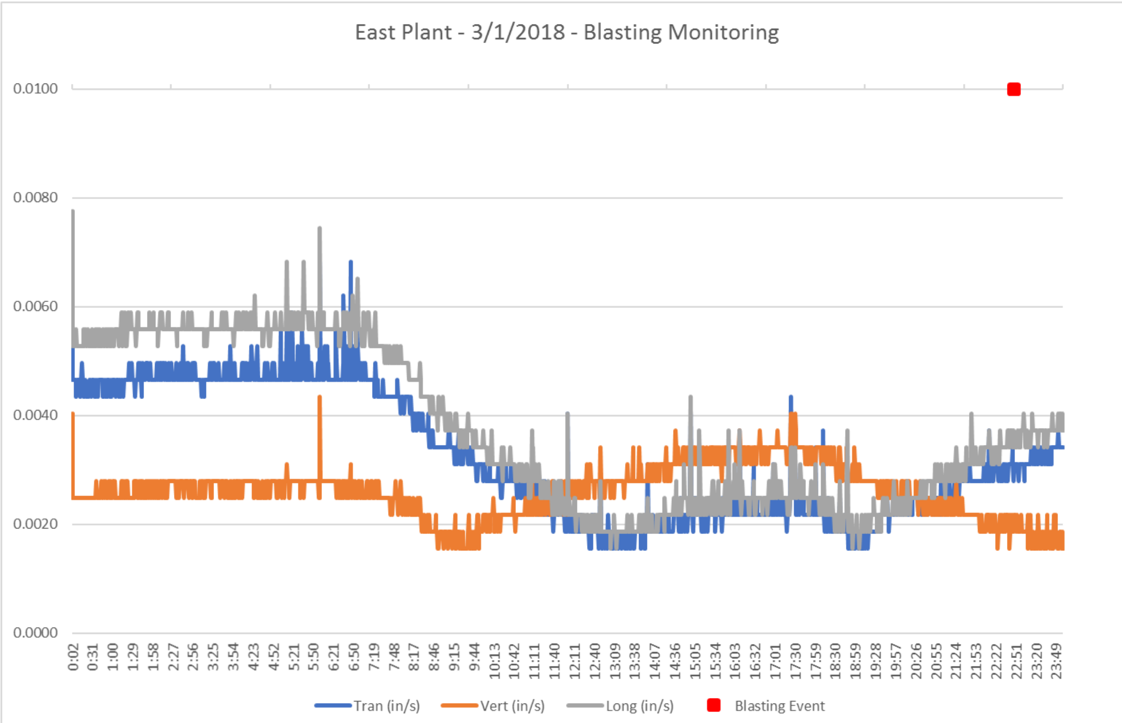
0.0020
0.0000
0:02
23:49
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/1/2018 - Blasting Monitoring
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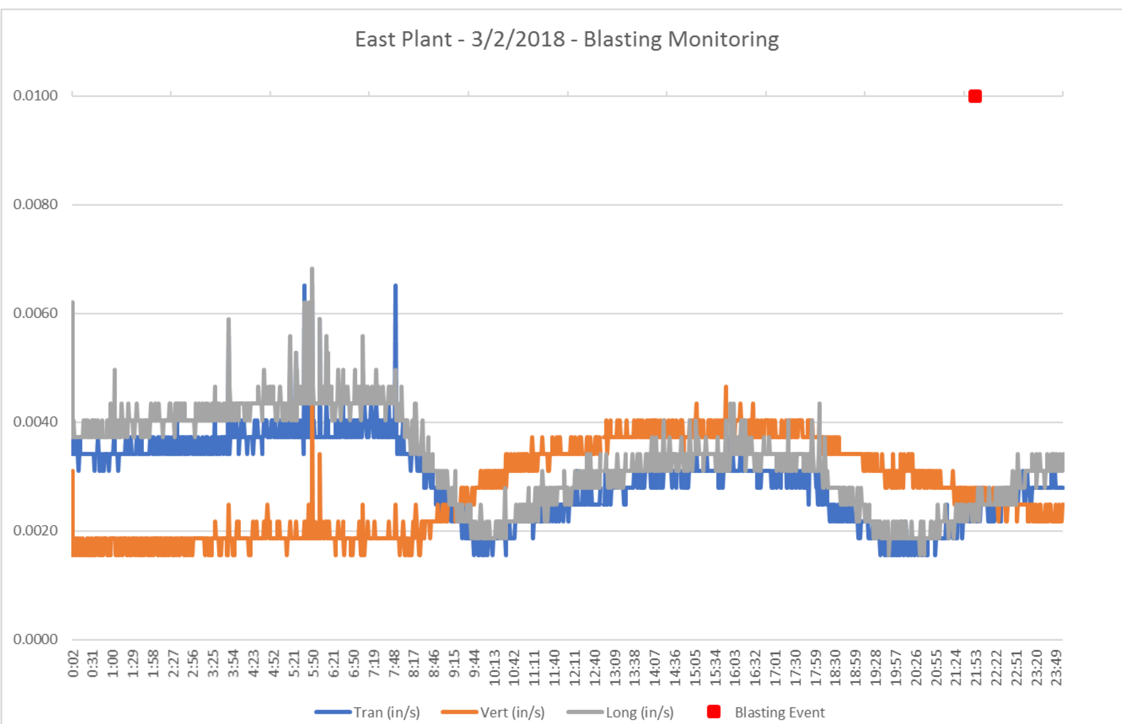
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/2/2018 - Blasting Monitoring
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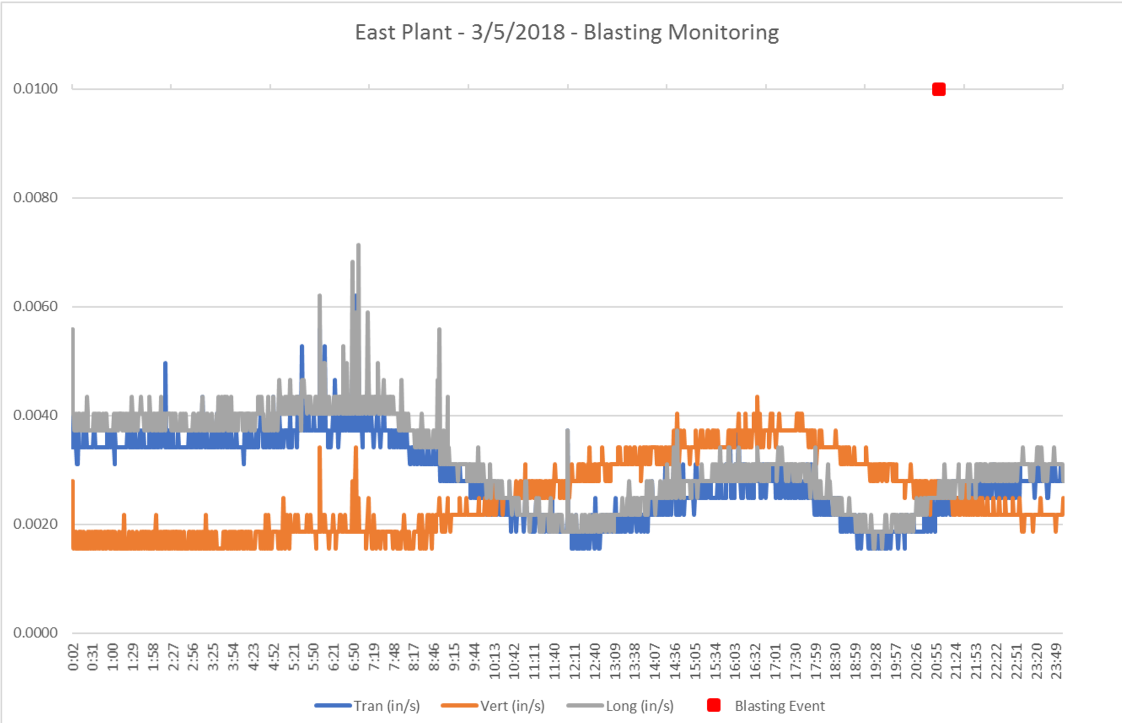
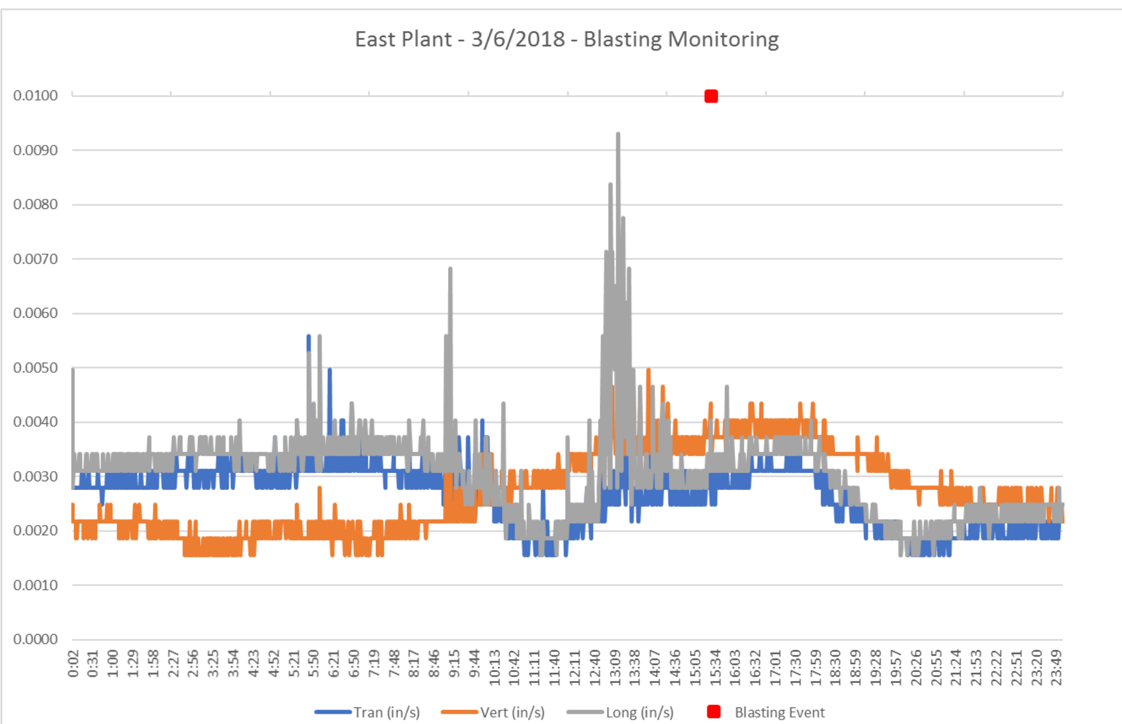
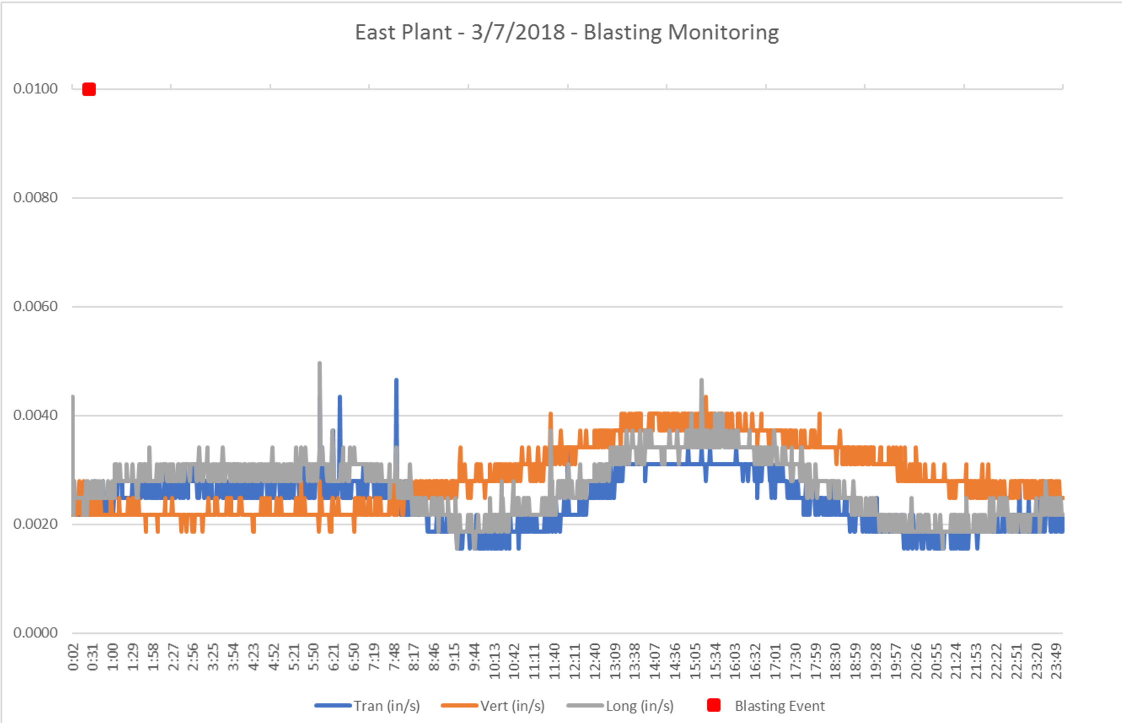
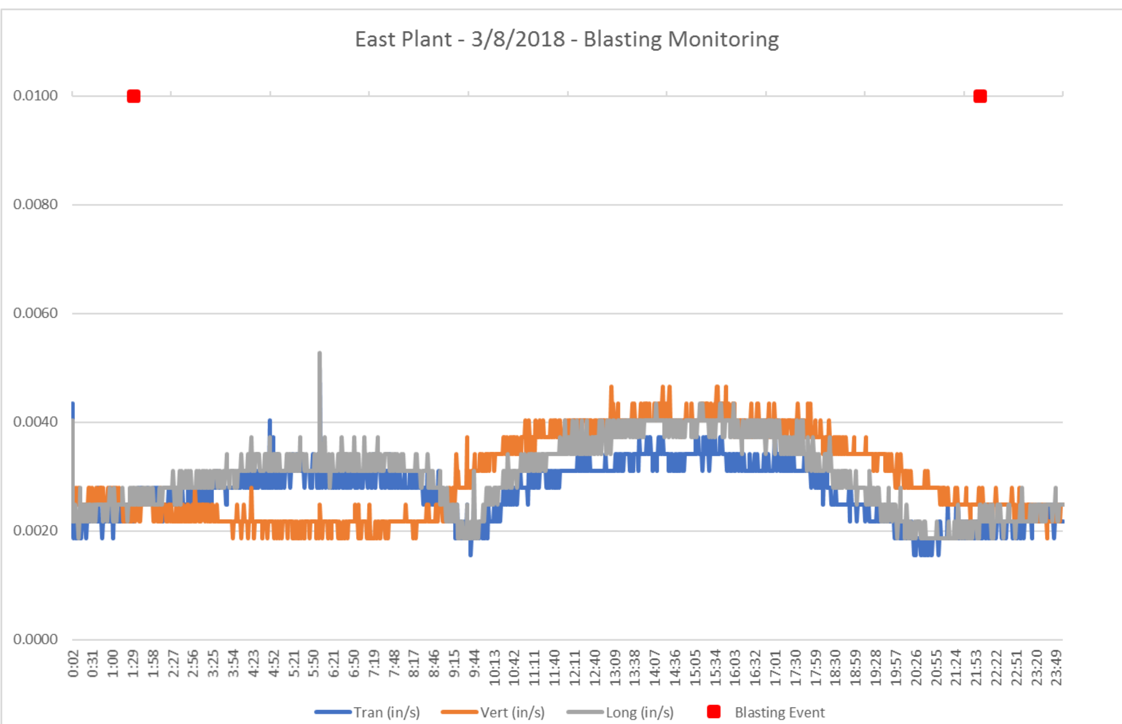
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/5/2018 - Blasting Monitoring
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/6/2018 - Blasting Monitoring
0.0100
0.0090
0.0080
0.0070
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/7/2018 - Blasting Monitoring
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/8/2018 - Blasting Monitoring
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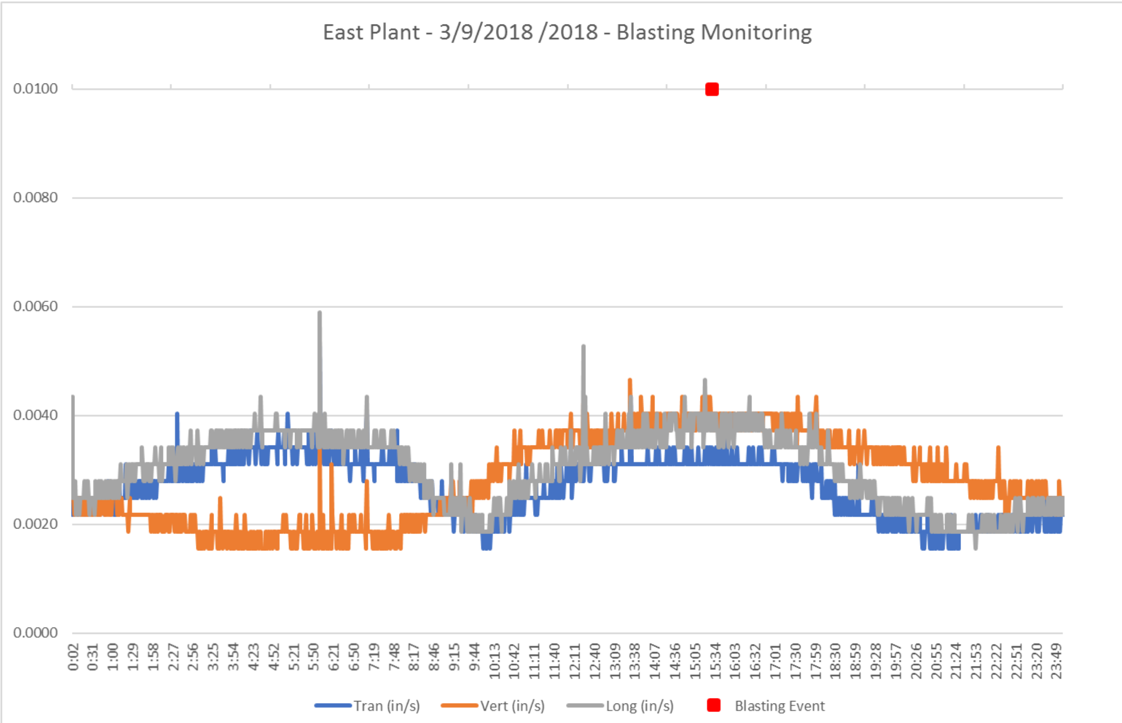
0.0080
0.0060
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/9/2018 /2018 - Blasting Monitoring
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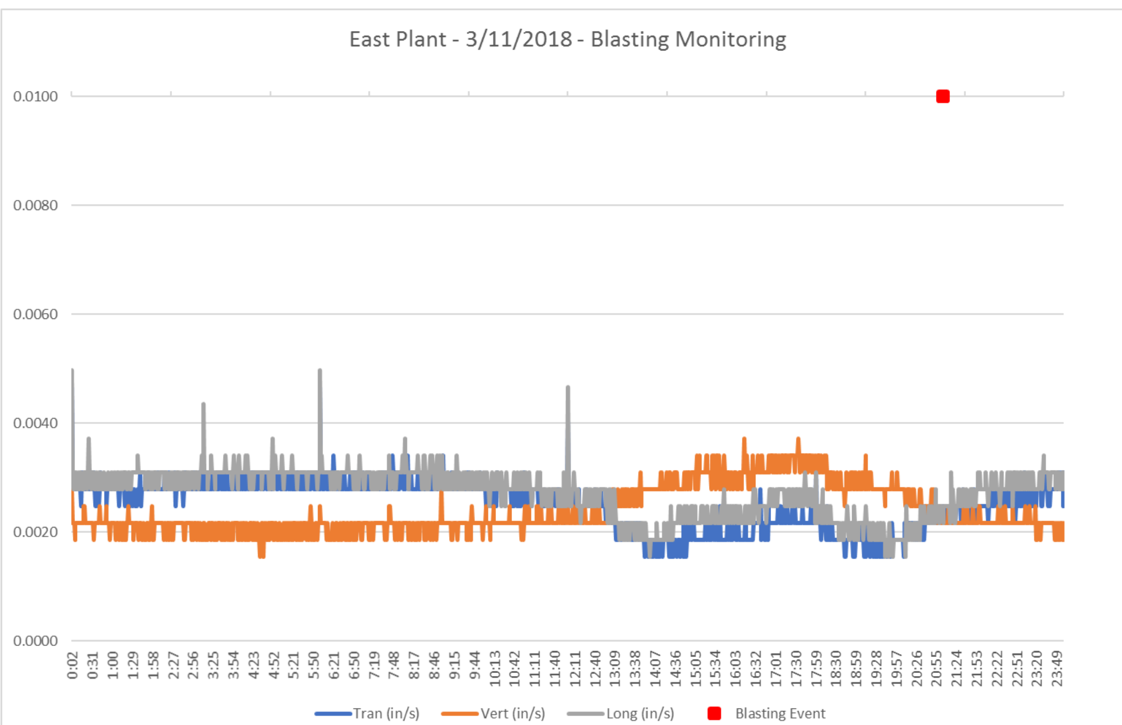
0.0060
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/11/2018 - Blasting Monitoring
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0.0060
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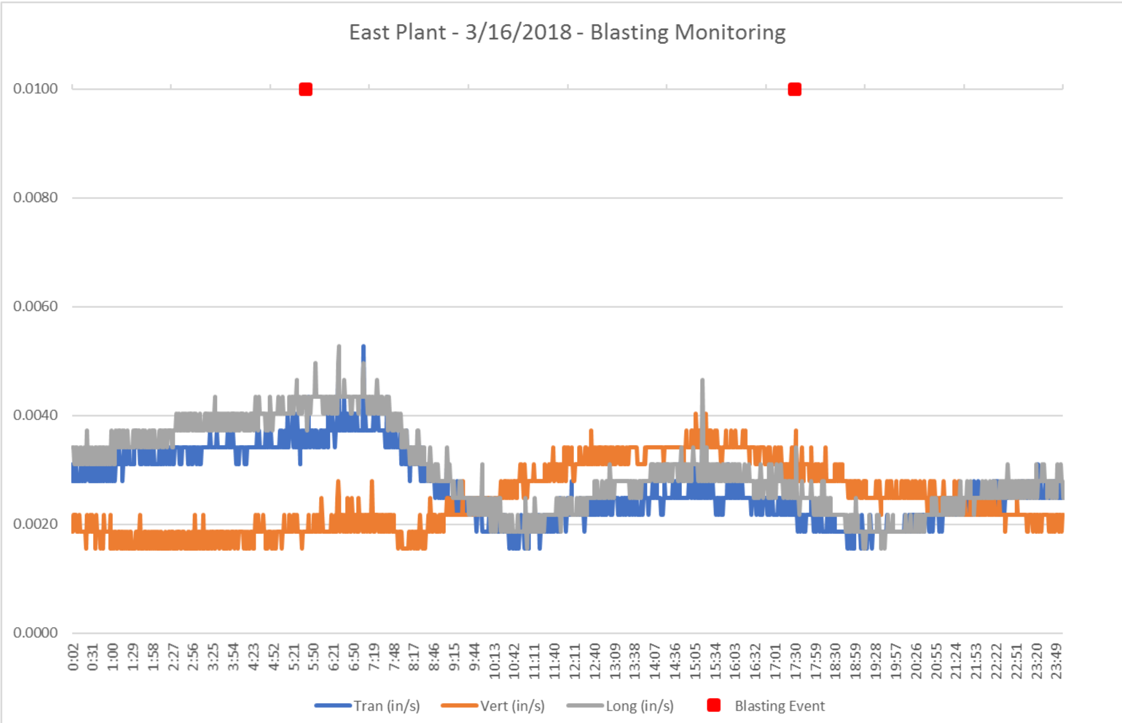
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/16/2018 - Blasting Monitoring
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0.0040
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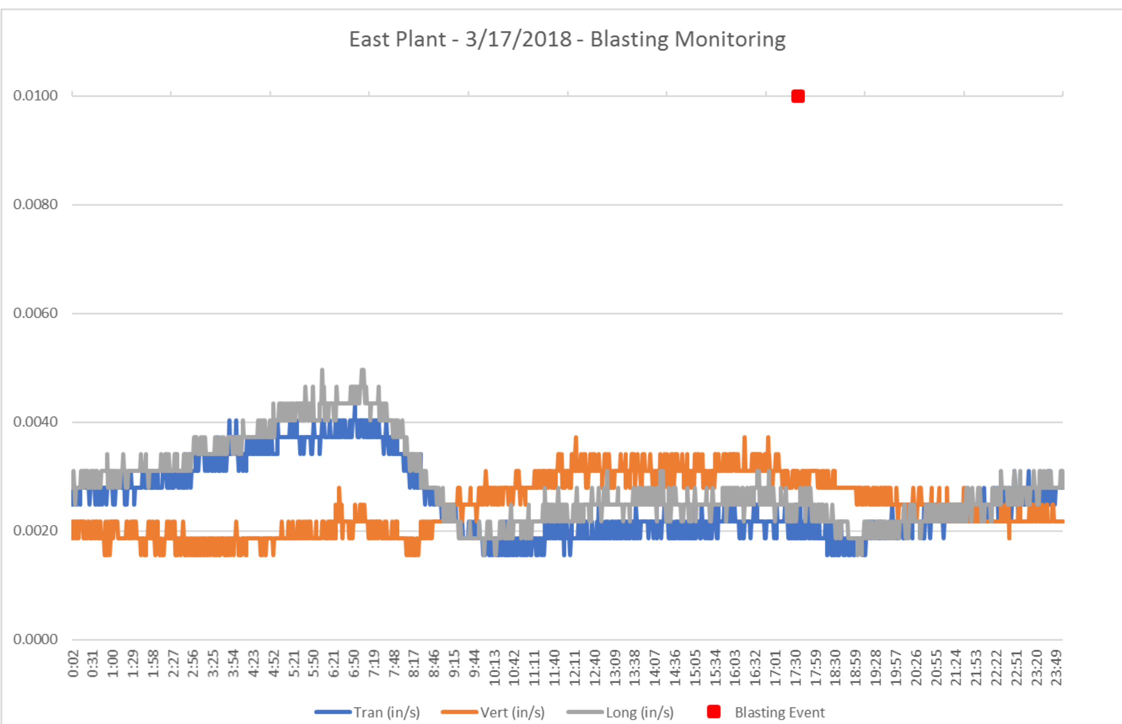
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/17/2018 - Blasting Monitoring
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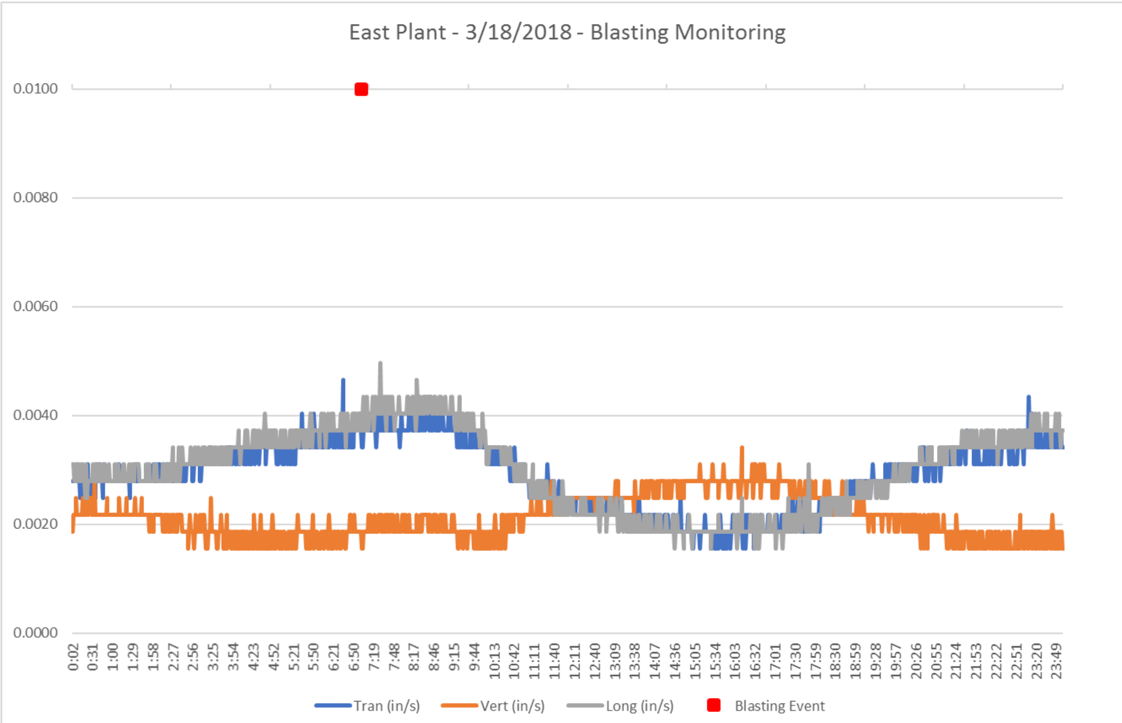
0.0080
0.0060
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/18/2018 - Blasting Monitoring
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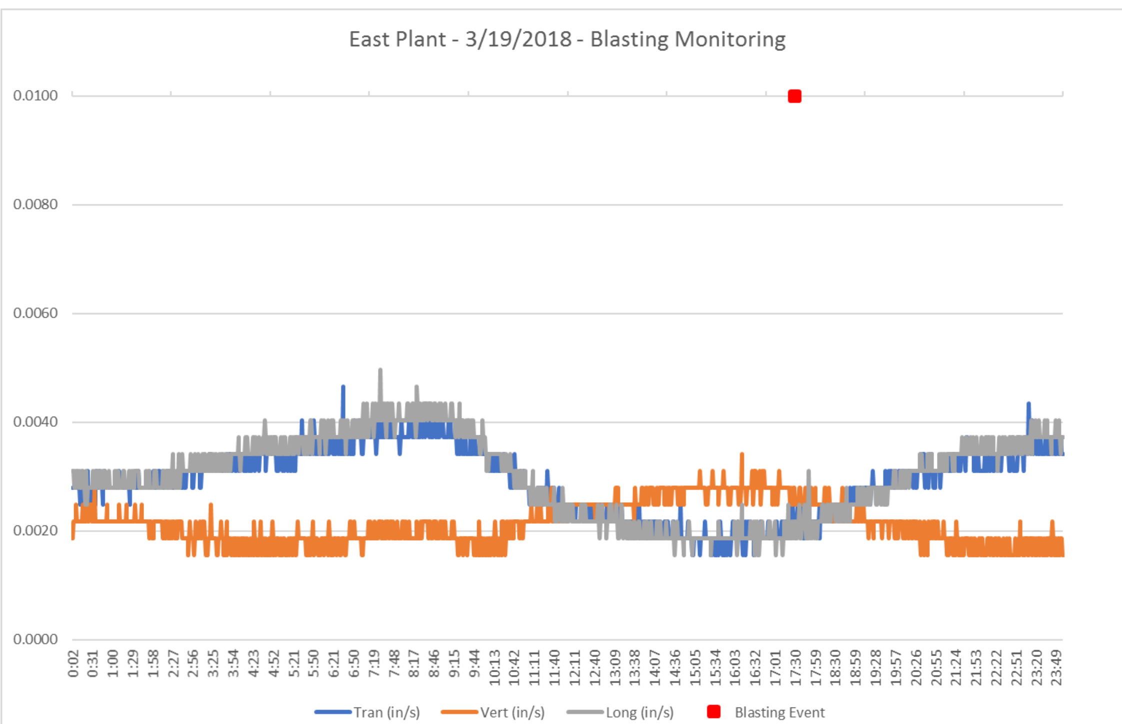
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event


East Plant - 3/19/2018 - Blasting Monitoring
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
Tran (in/s)
Vert (in/s)
Long (in/s)
Blasting Event

Appendix B

Calculation Results

USBM Blasting Calculation Sheet

Project Name: Resolution Copper

Scope of Work: Tailings Conveyor/Tunnel

Calculation: Specified Slant Distance - Output Blast Load

Calculation Identidier: Generic Table for Blasting

Inputs

Site Constant	k	**5000**
Site Exponent	e	**1.6**

Blast Planning Table

Estimation of Peak Particle Velocity in in/s
based on distance to blast and Weight of explosive charge (in kg TNTe) per delay

Slant Distance (Blast to Receptor)		W [kg TNTe]									
feet	**metres**	**5**	**10**	**15**	**20**	**40**	**50**	**100**	**150**	**200**	**250**
200	60	1.02	1.78	2.46	3.09	5.38	6.44	11.20	15.49	19.50	23.31
400	121	0.34	0.58	0.80	1.01	1.76	2.10	3.65	5.05	6.35	7.59
600	182	0.18	0.31	0.42	0.53	0.92	1.09	1.90	2.63	3.31	3.95
800	243	0.11	0.19	0.27	0.33	0.58	0.69	1.20	1.66	2.08	2.49
1000	304	0.08	0.14	0.19	0.24	0.41	0.48	0.84	1.16	1.46	1.74
1200	365	0.06	0.10	0.14	0.18	0.30	0.36	0.63	0.87	1.09	1.30
1400	426	0.05	0.08	0.11	0.14	0.24	0.28	0.49	0.68	0.85	1.02
1600	487	0.04	0.07	0.09	0.11	0.19	0.23	0.40	0.55	0.69	0.82
1800	548	0.03	0.06	0.08	0.09	0.16	0.19	0.33	0.45	0.57	0.68
2000	609	0.03	0.05	0.07	0.08	0.14	0.16	0.28	0.38	0.48	0.58
2500	762	0.02	0.04	0.05	0.06	0.10	0.12	0.20	0.27	0.34	0.40
3000	914	0.02	0.03	0.04	0.04	0.07	0.09	0.15	0.20	0.25	0.30
4000	1219	0.01	0.02	0.02	0.03	0.05	0.06	0.10	0.13	0.16	0.19

References

P. Linehan and J. F. Wiss, "Vibration and Air Blast Noise From Surface Coal Mine Blasting," AIME Transactions, vol. 272, 1982

R. Nicholls, C. F. Johnson and W. I. Duvall, "Bulletin 656 - Blasting Vibrations and Their Effect on Structures," U.S. Dept. of the Interior, Bureau of Mines, Washington, 1971

TC180802

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September 7, 2018

Ms. Mary Rasmussen
US Forest Service
Supervisor's Office
2324 East McDowell Road
Phoenix, AZ 85006-2496

Subject: Resolution Copper Mining, LLC – Mine Plan of Operations and Land Exchange – Response to Data Request, Noise and Vibration Analysis, May 23, 2018

Dear Ms. Rasmussen,

In response to the Noise and Vibration Monitoring call on May 23, 2018, the following report has been completed for your review and consideration:

- Resolution Copper Blasting Monitoring Review Memorandum, Wood Environment & Infrastructure Solutions, September 2018

Should you have any questions or require further information please contact me.

Sincerely,

Vicky Peacey

Vicky Peacey
Senior Manager, Permitting and Approvals; Resolution Copper Company, as Manager of Resolution Copper Mining, LLC

Cc: Ms. Kami Ballard; Environmental & Permitting Advisor; Resolution Copper Company
Ms. Mary Morissette; Senior Environmental Specialist; Resolution Copper Company

Attachments:
- Resolution Copper Blasting Monitoring Review Memorandum, Wood Environment & Infrastructure Solutions, September 2018