Appendix E10

Open Pit – Weather Studies

MEMORANDUM

To: Jim Gray, GR Technical Services
From: W. Scott Dunbar
Date: May 20, 2010
Subject: Simulation of KSM Storm Production Scenarios

Introduction

The proposed KSM mine will use a fleet of shovels and haul trucks to transport ore and waste. Severe snow storms will impair the traction of the trucks on the haul roads which will naturally affect production. The loss of production will manifest itself by shovels stopping operation, the number of shovels out of operation depending on the duration of the severe storm. In extreme cases, all shovels may shut down. It will take time to return the roads to passable conditions so that in addition to the actual storm duration, there is a recovery period.

The following describes a simulation study which used climate and weather data together with a loss of production and recovery model to estimate the expected number of hours of low production during any one year.

Production Scenarios during a Severe Storm

Severe storms are considered those storms with daily precipitation depths greater than 10 mm[1]. Severe storms can seriously affect production in the mine and a recovery period is required after a severe storm for scraping and snow removal to re-surface the haul roads.

The KSM mine will operate in various stages, each with different production levels of ore and waste. Between 33 and 55 trucks will be operating in the later stages. However, in most stages six shovels will be operating and, although the number of operating trucks will decrease during and after a severe snow storm, the loss of production scenarios are defined by the number of operating shovels. Five operation levels (or scenarios) are assumed:

Operation Level	Duration D (hrs)	Description
L1	na	Normal snow season operation (derated for snow)
L2	$D \leq 6$	5 shovels, 2 scrapers, 2 graders
L3	$6 < D \leq 12$	4 shovels, 4 scrapers
L4	$12 < D \leq 18$	2 shovels, 6 scrapers
L5	$D > 18$	0 shovels (Full pit shutdown, mill fed from stockpile)

Level 1 is normal snow season operation with the equipment derated for snow. Each six hours of a severe snow storm is assumed to lead to six hours of recovery time during which haul roads are cleared of snow. Thus, in Level 2 a severe storm lasting six hours or less occurs causing one

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[1] Snowfall is assumed to have a snow-water equivalence of 10%, so that 1 mm of recorded precipitation becomes 1 cm of snowfall. The air temperature determines the mode of precipitation. In the case of severe precipitation events, it is believed that snow or mixed rain and snow are equally likely modes of precipitation.

shovel to shut down and requiring two scrapers and two graders to clear haul roads for a six hour period to return to Level 1. In Level 3, a severe storm lasting between six and 12 hours occurs causing another shovel to shut down and requiring four scrapers to clear haul roads for a 12 hour period to return to Level 1. In Level 4, a severe storm lasting 12 to 18 hours would cause two more shovels to shut down and lead to 18 hours of road clearing using six scrapers. Full pit shutdown would result from a severe storm lasting 18 hours or more so that the roads cannot be kept open and visibility becomes limited. The mill would be fed from the stockpile.

The operating levels are illustrated in Figure 1.

For the purpose of this study, it is assumed that the KSM snow fleet of graders and scrapers is adequate to clear the haul roads during the recovery periods required to return to Level 1. Future studies will look more closely at equipment productivities to match the snow fleet to the recovery times.

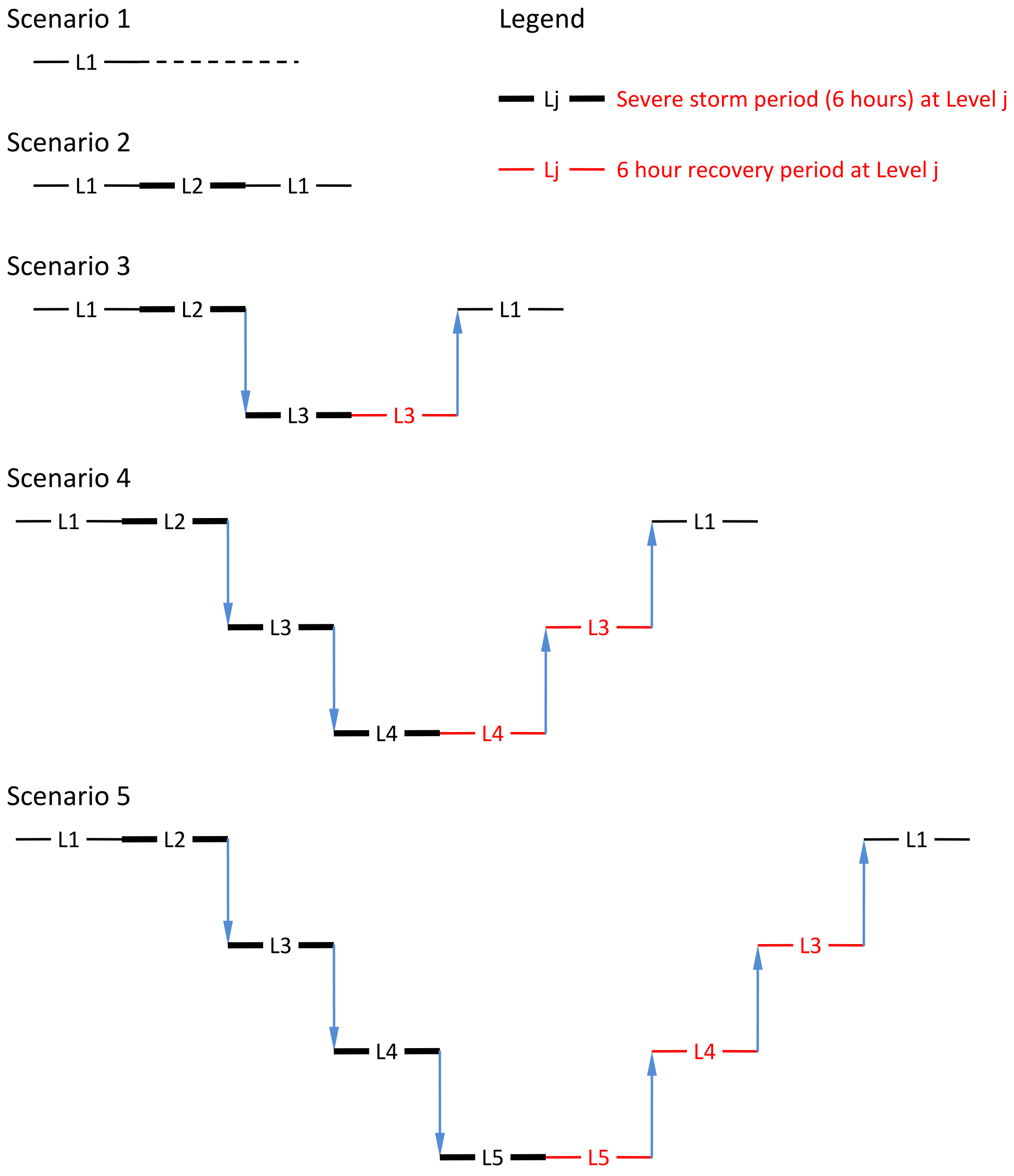

Figure 1 Production operation levels for different severe storm durations

Severe Storm Characteristics

Two characteristics of severe storms are of interest: their frequency and their duration. Estimates of both have been obtained from analysis of available weather data recorded at the KSM site and at the Galore Creek mine site about 100 km to the northwest.

Severe Storm Frequency

Prevailing temperature dictates whether precipitation falls as rain or snow. Generally if the average daily temperature is below 1°C, the precipitation falls as snow (perhaps mixed rain and snow at temperatures near 1°C). Available weather data from the KSM site, obtained from the British Columbia Ministry of Water, Land and Air Protection, show that the five month (150 day) period from November to March is when average daily temperatures are below 1°C. Thus the frequency of severe snow storms during that period is of interest.

Obtaining storm frequency (or average return period) from the available data at the KSM site proved difficult. Data were recorded at two sites during the period January to November 2009. One site was at Sulphurets Creek at an elevation of 880m; the other was at Teigen Creek (Plant site) at an elevation of 1085m. Instruments at both sites malfunctioned or did not function during this period. Thus the average daily temperatures mentioned above were available from the Teigen Creek site and some precipitation information could be obtained from the Sulphurets Creek site.

Compared to results from Galore Creek [2], the daily precipitation data from Sulphurets Creek suggested that KSM is drier so that the severe storm frequency would be smaller than at Galore Creek. However, there are not really enough data to make a definitive conclusion or comparison – 2009 could have been a dry year and the Galore Creek results were based on data recorded during 2004 and 2005.

Given this situation, the simplest assumption was to assume that the average return period of severe snow storms is the same as that at Galore Creek which is 20 days. The expected number of storms during November to March, 150 days, is therefore 7.5; 8 is assumed.

Severe Storm Duration

Between summer 2004 and the end of 2005, 37 severe storms were recorded by the Galore Creek weather station [1]. The dates and durations are listed in Table 1 below. The minimum duration is 4.5 hours and the maximum is 24 hours. The average duration is 15.1 hours. Figure 2 shows a histogram of the duration data.

Table 1

Dates and Durations of Severe Storms
Galore Creek Weather Station 2004-2005

Date	Duration (hrs)	Date	Duration (hrs)	Date	Duration (hrs)
Nov-20-2004	15.75	Jan-18-2005	24	Mar-10-2005	22
Nov-21-2004	4.75	Jan-19-2005	8.5	Nov-08-2005	18
Dec-02-2004	20.5	Jan-22-2005	15	Nov-09-2005	12.5
Dec-15-2004	7.25	Jan-23-2005	11.5	Nov-17-2005	19.25
Dec-16-2004	19.25	Jan-26-2005	21.5	Nov-18-2005	6.5
Dec-18-2004	24	Jan-27-2005	24	Nov-19-2005	17
Dec-19-2004	6.25	Jan-30-2005	15	Nov-20-2005	11.5
Dec-23-2004	11	Feb-01-2005	16.5	Nov-21-2005	16.25
Dec-24-2004	10.75	Feb-11-2005	23.5	Dec-08-2005	22
Dec-28-2004	14.75	Feb-23-2005	14	Dec-09-2005	10.5
Jan-06-2005	13	Mar-03-2005	11.5	Dec-10-2005	7
Jan-17-2005	24	Mar-08-2005	16	Dec-11-2005	19
				Dec-21-2005	4.5

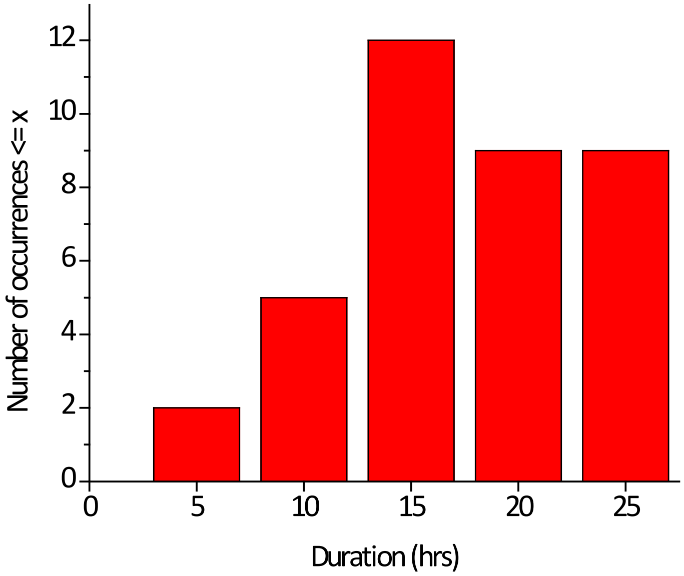

Figure 2 Histogram of observed storm durations

There are two ways to use these duration data in the simulation. One is to assume a continuous distribution that approximates the histogram. This might be a trapezoid with coordinates

[(4.5,0), (10,h), (24,h),(24,0)]

where h is adjusted so that the area of the trapezoid is equal to one (h = 0.0597). However, the problem with this is that a simulated duration may be only a small amount more than the maximum duration corresponding to a particular level and this small extra amount of duration will lead to a six hour recovery period. This seems conservative. For this reason, the 37 data were re-sampled (sampling with replacement) during the simulation. This also leads to additional recovery periods (e.g., 6.25 hours is 15 minutes of Level 3 operation but leads to six hours recovery) but not as much as if the distribution were assumed continuous.

Simulation Results

The simulation is done to estimate the expected number of hours of operation and recovery for each of Levels 2 to 5, during the storm season (November to March, 150 days) when it is assumed that 8 severe storms will occur. The simulation proceeds as follows:

1) For each of the 8 storms randomly sample a duration from the list of 37 durations.
2) Determine the amount of storm operation time and recovery time at each level.
3) Sum the storm operation and recovery time for each level.

Steps 1 to 3 are repeated many times, 2000 times in this case. The result is 2000 “trials” of time at each level for the storm season. The average sum of the 2000 trials at each level is assumed to represent the expected time at that level for any particular storm season. The standard deviation of the The simulation was performed using an Excel add-in called XLSim. [3]

The results of the simulation are shown in Table 2.

Table 2
Results of Simulation
Expected Hours at Each Level during Storm Season

	Level 2	Level 3	Level 4	Level 5
Average (hrs)	47.4	84.6	55.8	26.2
Standard deviation (hrs)	0.9	8.5	14.9	13.6

Discussion

The expected hours of Level 2, 47.4 hours, means that every severe storm of the expected 8 storms will impose at least six hours of a Level 2 scenario (47.4/8 ~ 6). There is about 3.5 days of Level 3 and 2.3 days of Level 4. The expected Level 5 (shutdown) duration is about one day, but given the standard deviation this could vary between 0.5 days to 1.5 days.

These results are very sensitive to the number of severe storms that occur during the November to March period. The average return period is assumed to be 20 days leading to about 8 severe storms during the period. Updated and complete records of precipitation data from the site should be used to improve this estimate. It is relatively easy to re-run the model.

Another important assumption is the amount of recovery time required to return to Level 1 operation. As mentioned above, future studies will look more closely at equipment productivities to match the snow fleet to the assumed recovery times. The actual recovery times could also vary depending on the snow conditions (e.g., its moisture content), the current haul road configuration, and on the experience and training of the scraper and grader operators.

References

[1] March 16, 2006. Memorandum to GR Technical Services from Rescan Environmental Ltd. *Update to Storm Analysis for Galore Creek*

[2] March 7, 2006. Memorandum to GR Technical Services from Rescan Environmental Ltd. *Storm Analysis for Galore Creek*

[3] XLSim, Version 2.10e. Commercial edition. Analycorp Inc. www.analycorp.com

Memorandum

Refer to File No.: \\10.38.1.4\new\868 Seabridge\868-004-02 Meteorology\Working Folder\Extreme visibility & SWE for MMTS\Memorandum - extreme weather information for MMTS - 19.11.10_FINAL.doc

DATE: 19 November 2010
TO: Matthew Erickson – Moose Mountain Technical Services
FROM: Dan Jarratt, P.Eng, Tim Ihle
CC: Greg McKillop, Tom Sharp
SUBJECT: KSM Project Extreme Visibility and Winter Precipitation for Mine Planning

1. Introduction

This memorandum has been prepared in response to a request from Moose Mountain Technical Services (MMTS) on Friday 22nd October 2010. MMTS requested additional detailed data on extreme weather situations at the KSM Project site, including horizontal visibility and snow water equivalent (SWE). This information is required to help MMTS predict when mine production is to be slowed or stopped due to extreme weather conditions and associated safety concerns.

Specifically, this memorandum provides data for the following extreme weather situations:

1. Horizontal visibility less than 1 km; and
2. SWE greater than 0.01 m over a 24 hr period.

The following analysis of these data provides information on frequency, duration and severity of these extreme situations. The analysis has been undertaken using relevant available field data. The analysis does not include a comprehensive review of all regional precipitation (as snowfall) data and as a result the precipitation estimates should be used with caution. The estimates will not be used for engineering design of water management structures.

2. Horizontal Visibility

Horizontal visibility (also known as meteorological optical range) is the greatest distance that a large dark object can be seen and recognized against a light sky background. As light propagates through the atmosphere it is attenuated by absorption and scattering from particles in the air (fog, snow, dust, etc). These particles (also known as obstructions to vision) limit horizontal visibility.

2.1 Methodology

A Sentry Visibility Sensor is installed at the KSM Project site at the Mitchell meteorological station. This sensor is based on the principle of forward scattering. The forward scatter of infrared light is measured between a transmitter and a receiver. The received signal strength is inversely proportional to the visibility and the resulting signal is converted to visibility in units of kilometres (km). Visibility readings are taken over the last five minutes of each hour around the clock. The sensors use "look down" geometry to reduce window contamination and clogging from blowing snow. The sensor's windows use anti-dew heaters and thermostatically controlled external hood heaters for protection in cold and wet weather conditions. Sentry Visibility Sensors have a maximum and minimum range of 16 km and 0.03 km respectively.

2.2 Results

With the exception of a three day period from 24 November 2009 to 26 November 2009, continual hourly horizontal visibility data was available from 8 October 2009 through to 18 August 2010 at the time of writing. Horizontal visibility was less than 1 km for a total of 113 hrs over this ten month data acquisition period. This corresponds to the horizontal visibility being less than 1 km approximately 1.5 % of the time.

Figure 1 shows the monthly distribution of when horizontal visibility is less than 1 km. Poor horizontal visibility (less than 1 km) is most common in the month of March, with a noticeable total of 47 hrs. Poor horizontal visibility events were measured in November through July with monthly totals less than 15 hrs. Although no data were available for the month of September, and a full months worth of data was not recorded for August or October, it appears that these three months rarely experience horizontal visibility values less than 1 km.

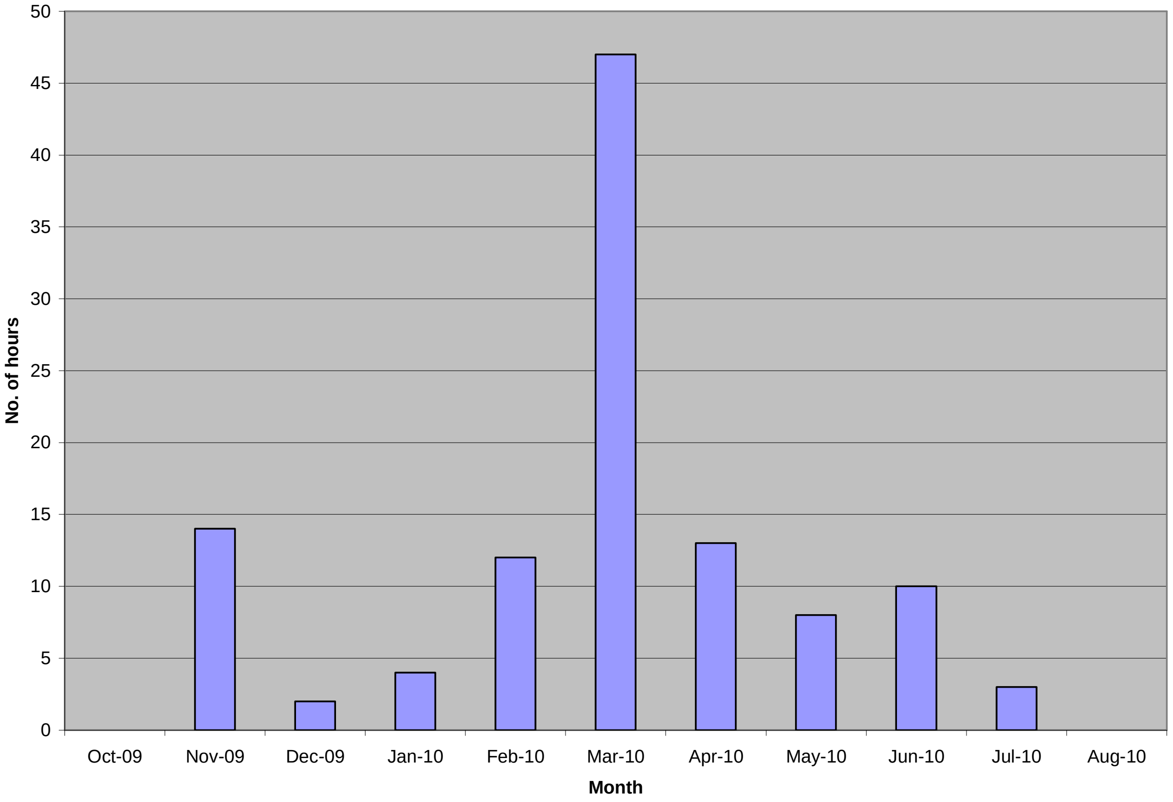

Figure 1: Time of year visibility is less than 1 km.

Figure 2 shows the hourly distribution of when horizontal visibility is less than 1 km. The graph shows that poor horizontal visibility is experienced throughout the day. There is a subtle trend where poor visibility appears to be less likely in the middle of the night and the middle of the day.

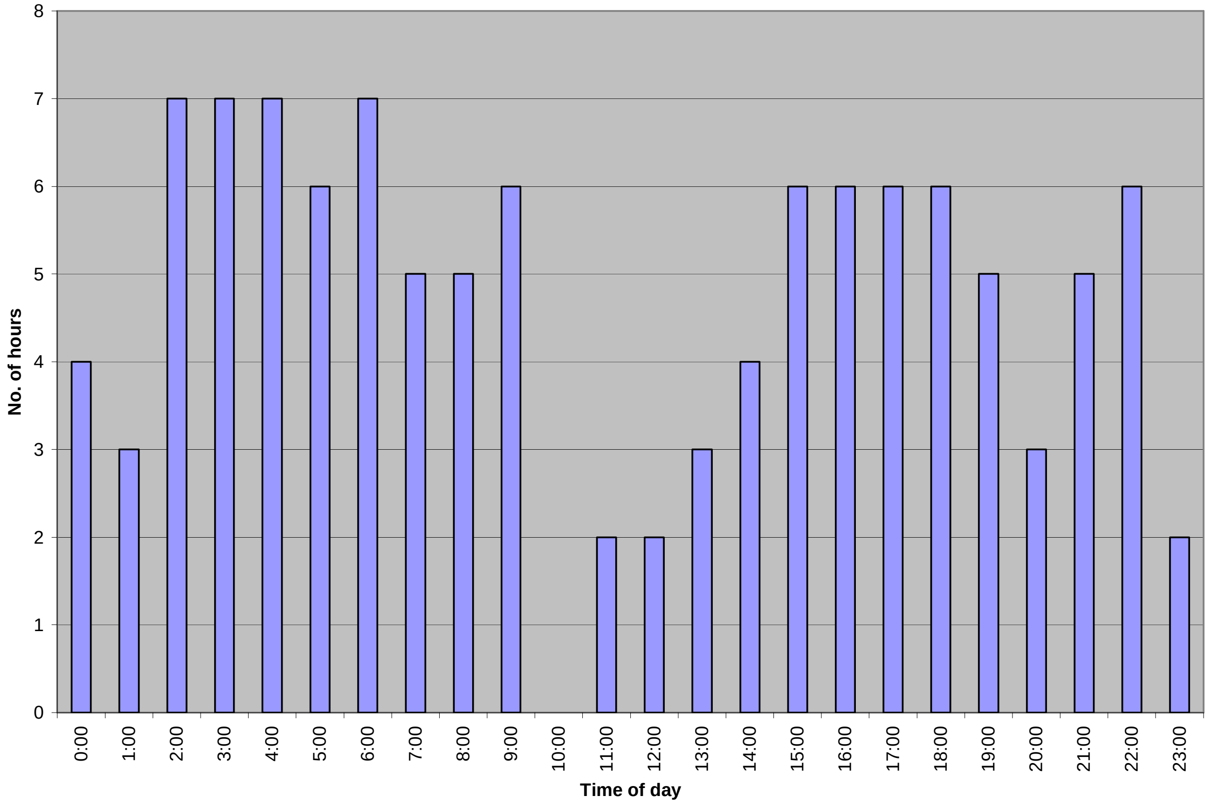

Figure 2: Time of day visibility is less than 1 km.

Figure 3 shows the duration of the events when horizontal visibility was less than 1 km. Poor horizontal visibility events are experienced at the site from one to six consecutive hours. The hourly events are most common, meaning that during a poor horizontal visibility event conditions will normally clear up within an hour after which the horizontal visibility is greater than 1 km. More importantly, however, the Figure 3 demonstrates that poor horizontal visibility can remain for longer, extending for up to six consecutive hours.

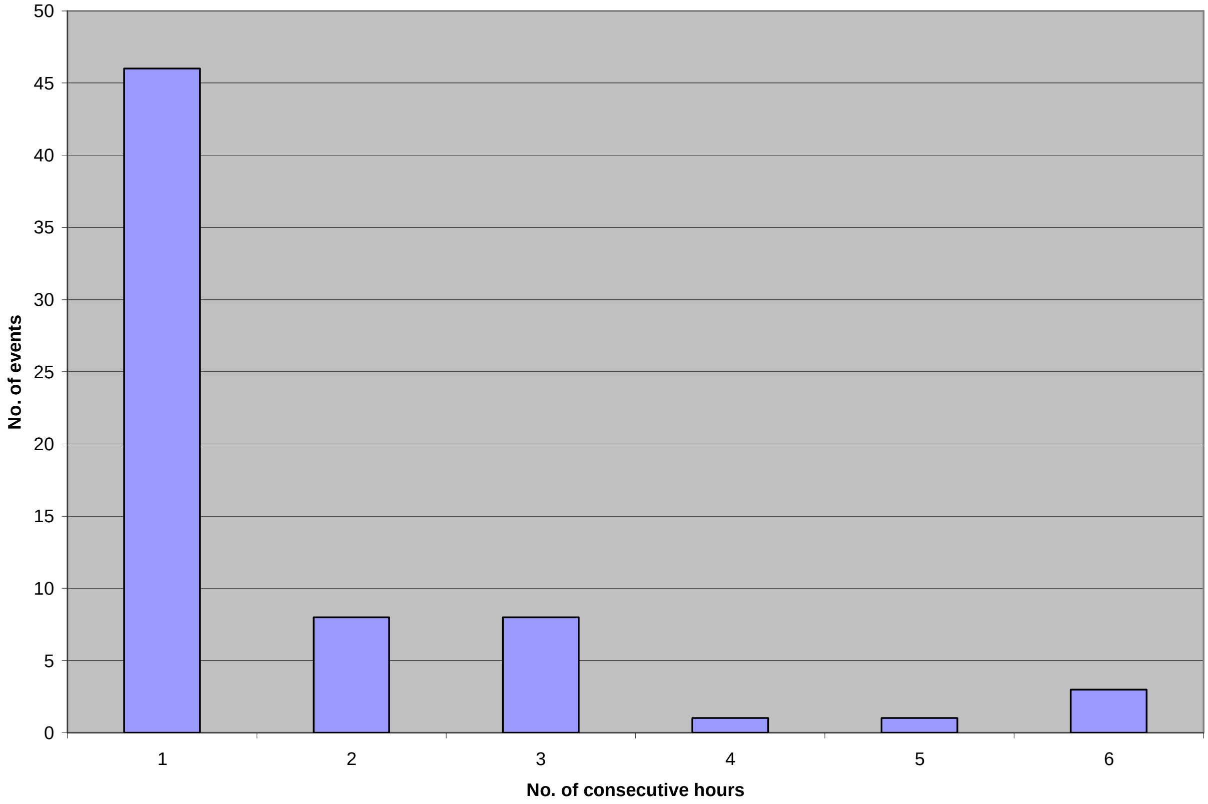

Figure 3: Consecutive hour events where visibility is less than 1km.

3. Snow Water Equivalent

Extreme snowfall analysis is rarely conducted because in terms of hydrology, snow only becomes important when it melts (Hogg and Carr, 1985). In addition, it should be noted that the severity of snow storms is as much controlled by wind and snow drift as by snowfall amount. This alludes to the difficulty in conducting extreme snowfall analysis and the questionable validity of the results. Nevertheless it was of interest to examine the extreme snowfall events.

3.1 Methodology

This SWE analysis relies on the snowfall data recorded by the snow pillow installed at the Sulphurets Creek meteorological station. A snow pillow is a large sac on the ground surface filled with glycol (anti-freeze). When snow falls on the sac the pressure within it increases. This pressure is recorded by a sensor, which is connected to a data logger. The data logger automatically converts the hourly pressure readings to millimetres of SWE.

3.2 Results

The snow pillow hourly data were analysed for the winter months of 2009 only (January to May and October to December). Additional years of data are available and could be assessed if necessary. The total SWE over a consecutive 24 hr period exceeded 0.01 m a total of 1,656 hrs of the year, which included 118 separate events with durations spanning anywhere from 1 hr to 110 hrs. Figure 4 shows the monthly distribution of extreme SWE hours over the year. January has the highest frequency of extreme SWE hours.

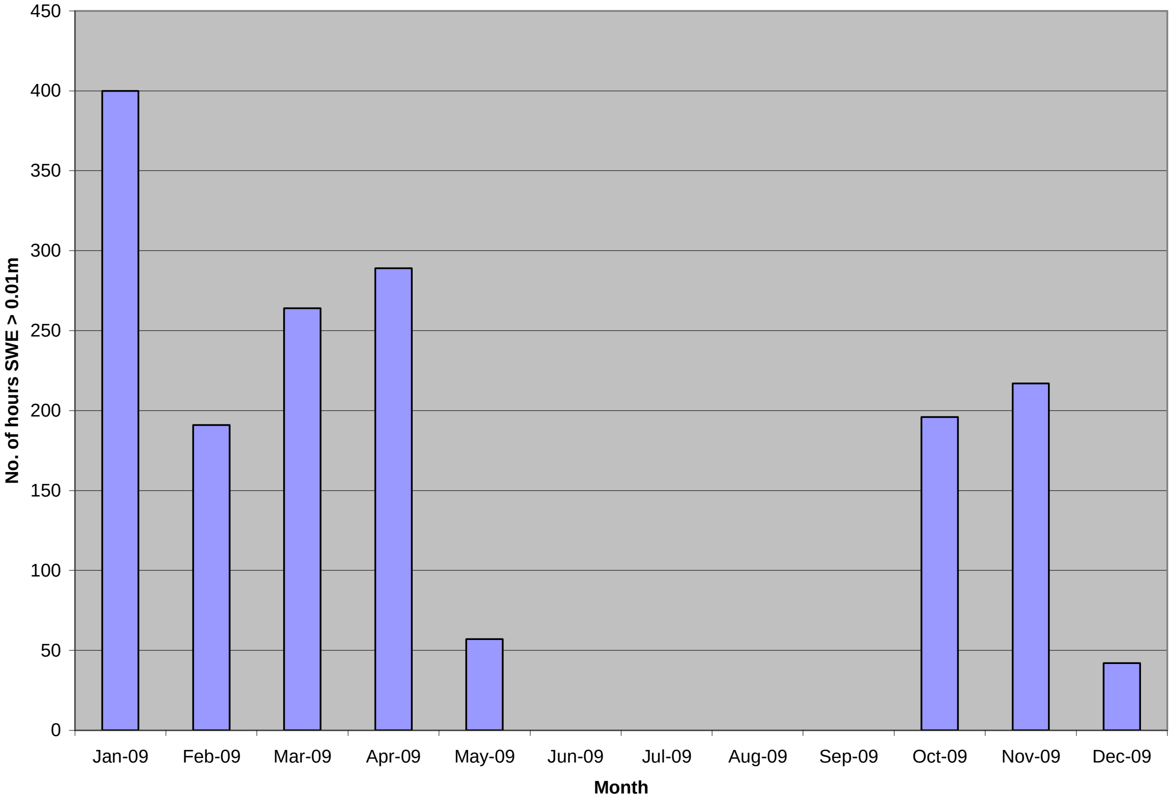

Figure 4: Time of year SWE exceeds 0.01 m over 24 consecutive hours.

Table 1 below shows the severity of snowfall events in terms of SWE magnitude. It highlights that the SWE extreme weather criteria of greater than 0.01m in a 24 hr consecutive period is frequently exceeded, with nearly 20% of the 2009 full year experiencing such conditions. Figure 5 plots the snowfall intensities for the winter months only (January to May and October to December).

Table 1: 2009 snowfall intensity (SWE) distribution at Sulphurets Creek Meteorological Station.

SWE 24 hr Total	**> 0.010m**	**0.000m - 0.005m**	**0.005m - 0.010m**	**0.010m - 0.015m**	**0.015m - 0.020m**	**0.020m - 0.025m**	**0.025m - 0.030m**	**> 0.030m**
Total hours	**1,656**	1,093	3,058	1,065	324	121	24	122
% hours (winter)	**28.5**	18.9	52.6	18.3	5.6	2.1	0.4	2.1

SWE 24 hr Total	**> 0.010m**	**0.000m - 0.005m**	**0.005m - 0.010m**	**0.010m - 0.015m**	**0.015m - 0.020m**	**0.020m - 0.025m**	**0.025m - 0.030m**	**> 0.030m**
% hours (full year)	**19.0**	46.0	35.0	12.2	3.7	1.4	0.3	1.4

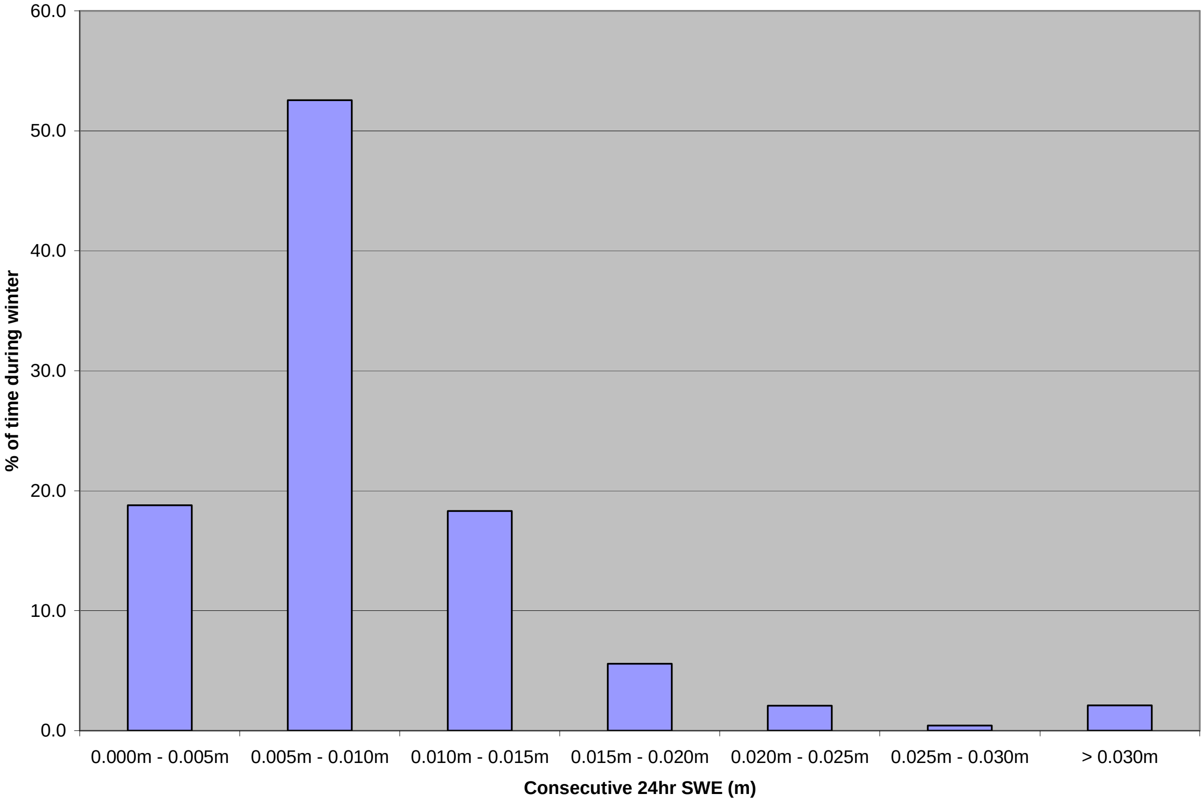

Figure 5: Snowfall intensity (SWE) distribution during the winter months of 2009.

The BC Ministry of Environment operates regional snow pillows throughout the province. The closest of these to the KSM Project site is at Pulpit Lake (Station ID 4A09P, elevation 1,331 m), which is approximately 245 km northeast of the KSM Project Sulphurets Creek meteorological station. The elevation of the Sulphurets Creek snow pillow is 880 m. The Pulpit Lake station has daily SWE data from October 1989 through to September 2009. These records show that snowfall accumulation in 2009 was well above average over this recording period and is therefore an appropriate year for assessing extreme weather conditions in terms of SWE.

Figure 6 shows the duration of events where the extreme weather SWE criterion (accumulation of SWE greater than 0.01 m over 24 consecutive hours) was exceeded during 2009. This information is broken down per month and presented in Figures 7 – 14 to gain a better understanding of the temporal nature of the events. The figures illustrate that shorter duration events are most common, with a one hour event (i.e., the cumulative total snowfall for the preceding 24 hrs exceeds 0.01 m of SWE and after one additional hour the rolling 24 hr total drops back below 0.01 m of SWE) being most likely. However, the data also show that it is not rare for events to extend for a couple of days at a time. The longest duration an event lasted for during 2009 was 110 hrs, experienced in the month of April.

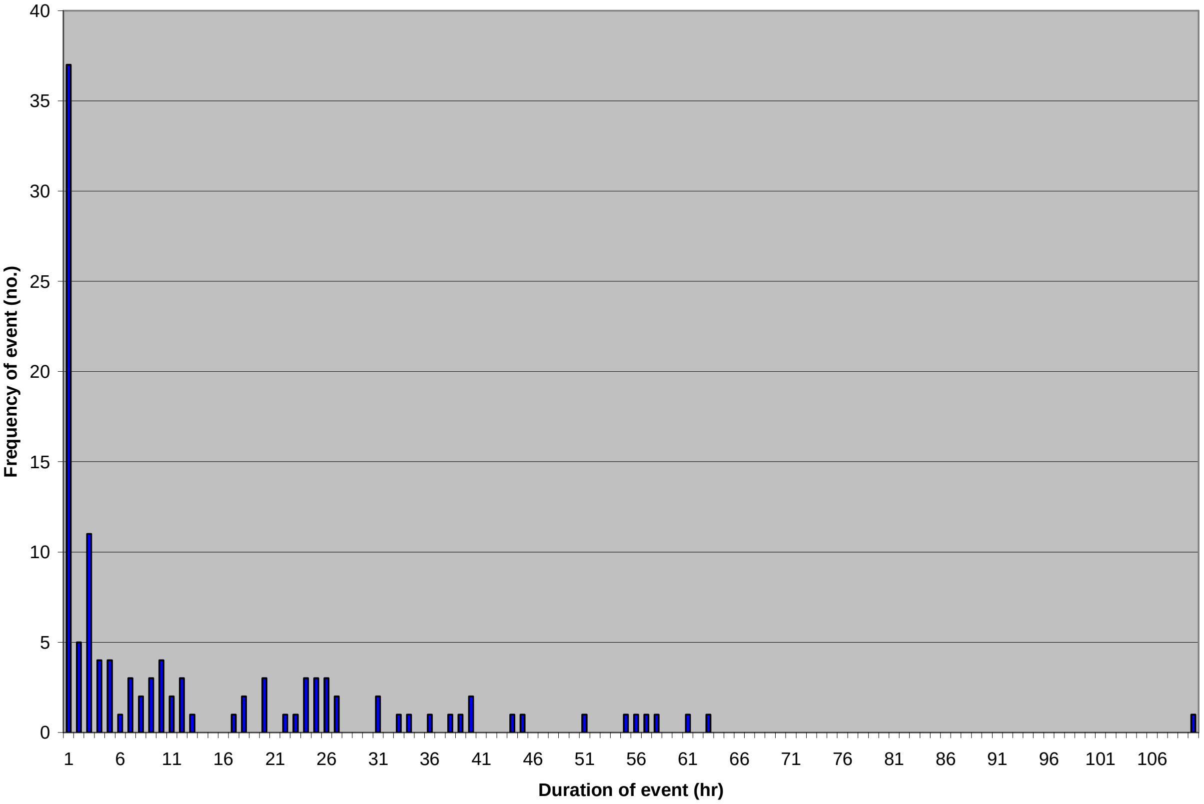

Figure 6: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

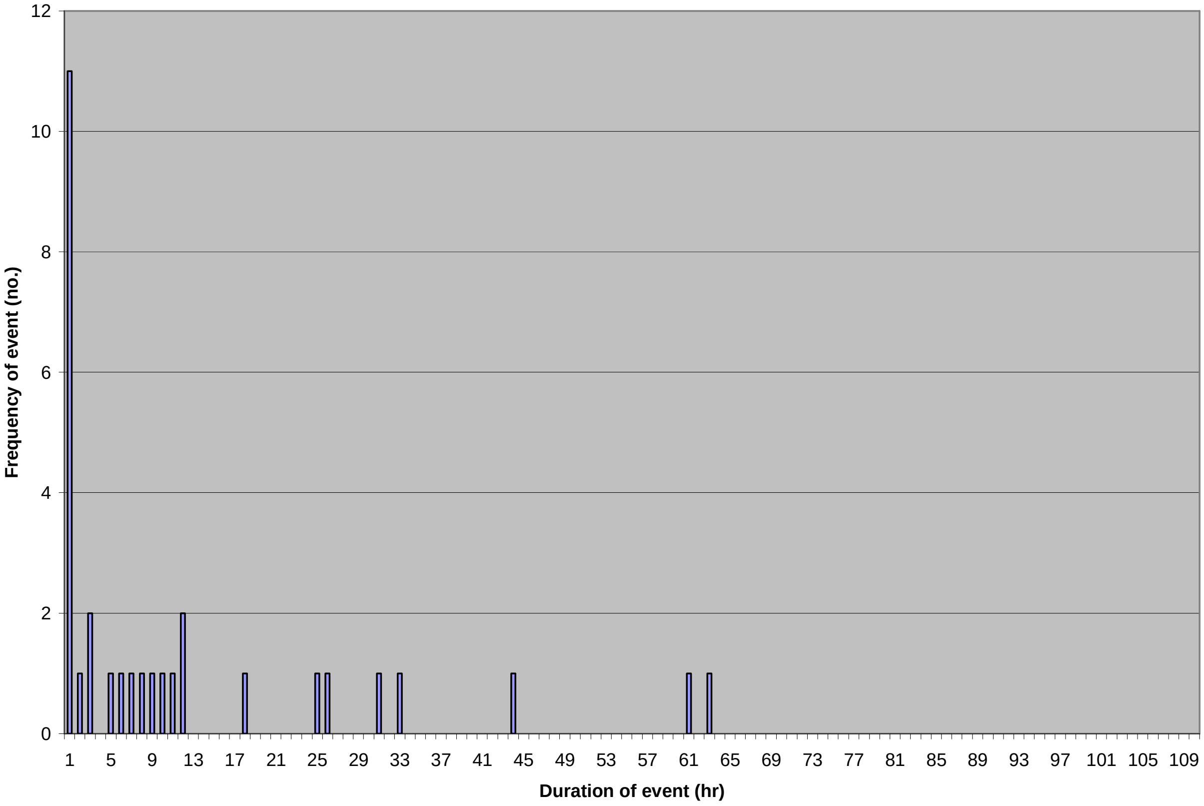

Figure 7: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - January 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In January 2009, the SWE criterion was exceeded for a total of **400 hrs** during **31 separate events**. Seven of these events exceeded a whole day (24 hrs), while two of these events lasted more than two and a half days. The majority of the events were experienced in under a 10 hour period.

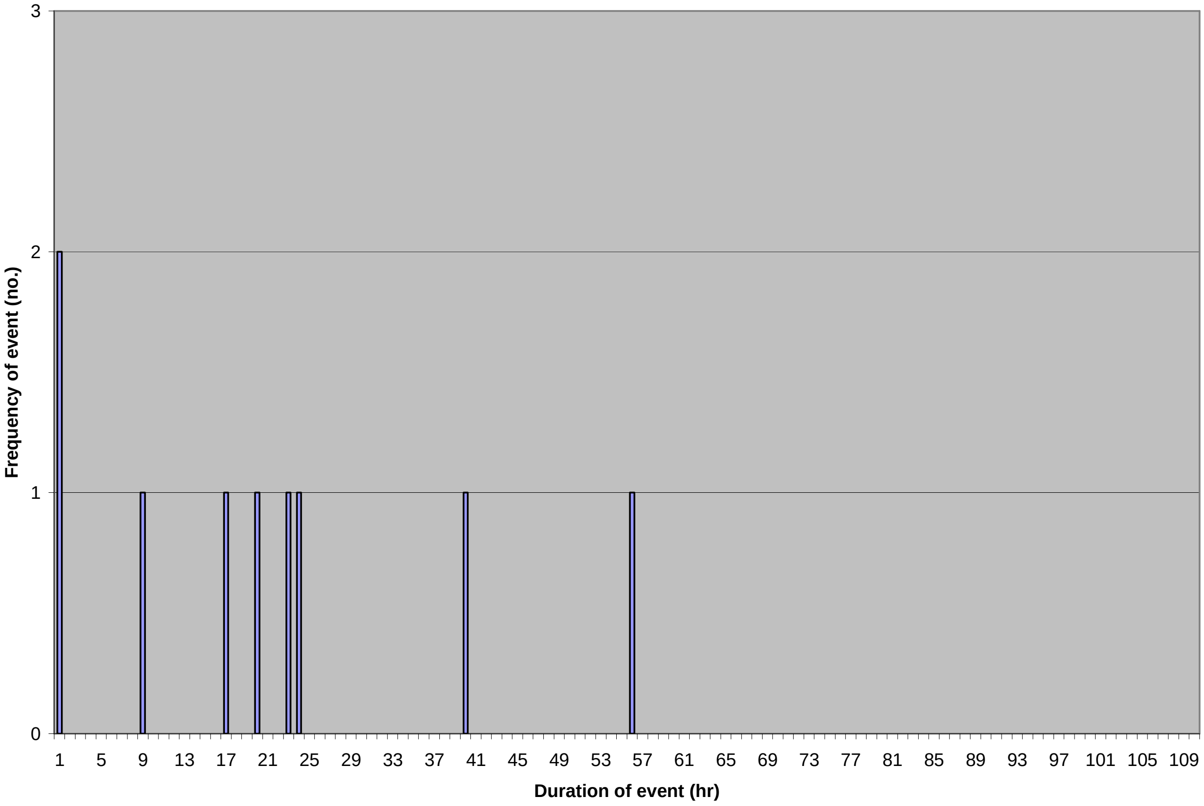

Figure 8: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - February 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In February 2009, the SWE criterion was exceeded for a total of **191 hrs** during **9 separate events**. Three of these events lasted a whole day (24 hrs) or more, with one of these events lasting more than two days.

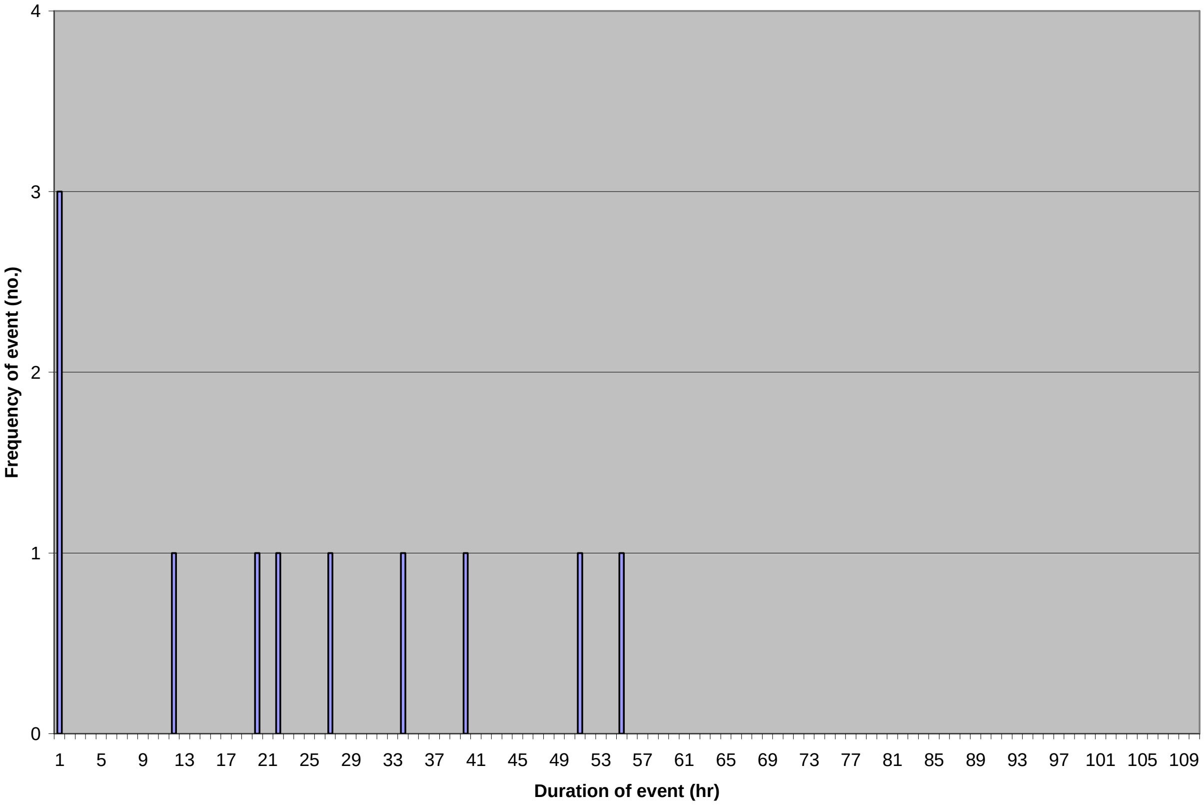

Figure 9: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - March 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In March 2009, the SWE criterion was exceeded for a total of **264 hrs** during **11 separate events**. Five of these events exceeded a whole day (24 hrs), while two of these events lasted more than two days.

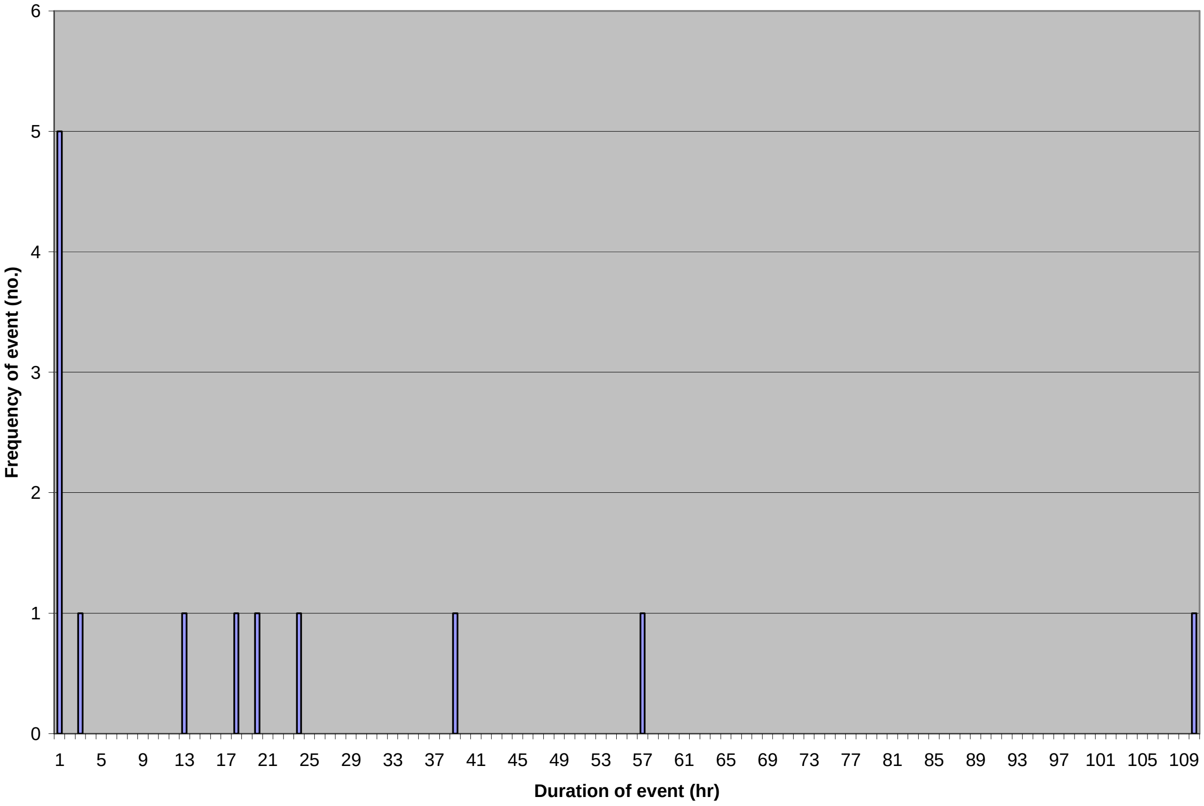

Figure 10: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - April 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In April 2009, the SWE criterion was exceeded for a total of **289 hrs** during **13 separate events**. Four of these events lasted a whole day (24 hrs) or more, while one of these events lasted for 110 hrs (the maximum recorded during 2009).

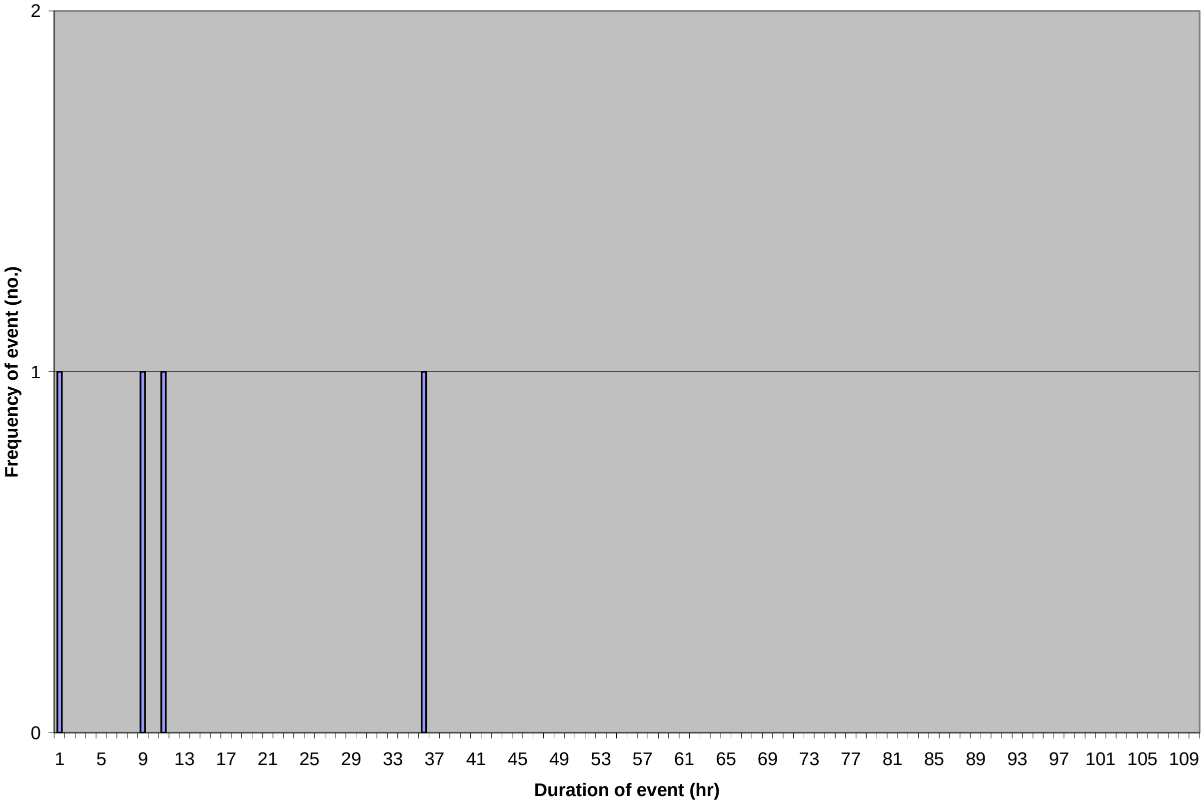

Figure 11: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - May 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In May 2009, the SWE criterion was exceeded for a total of **57 hrs** during **4 separate events**. One event exceeded a whole day (24 hrs).

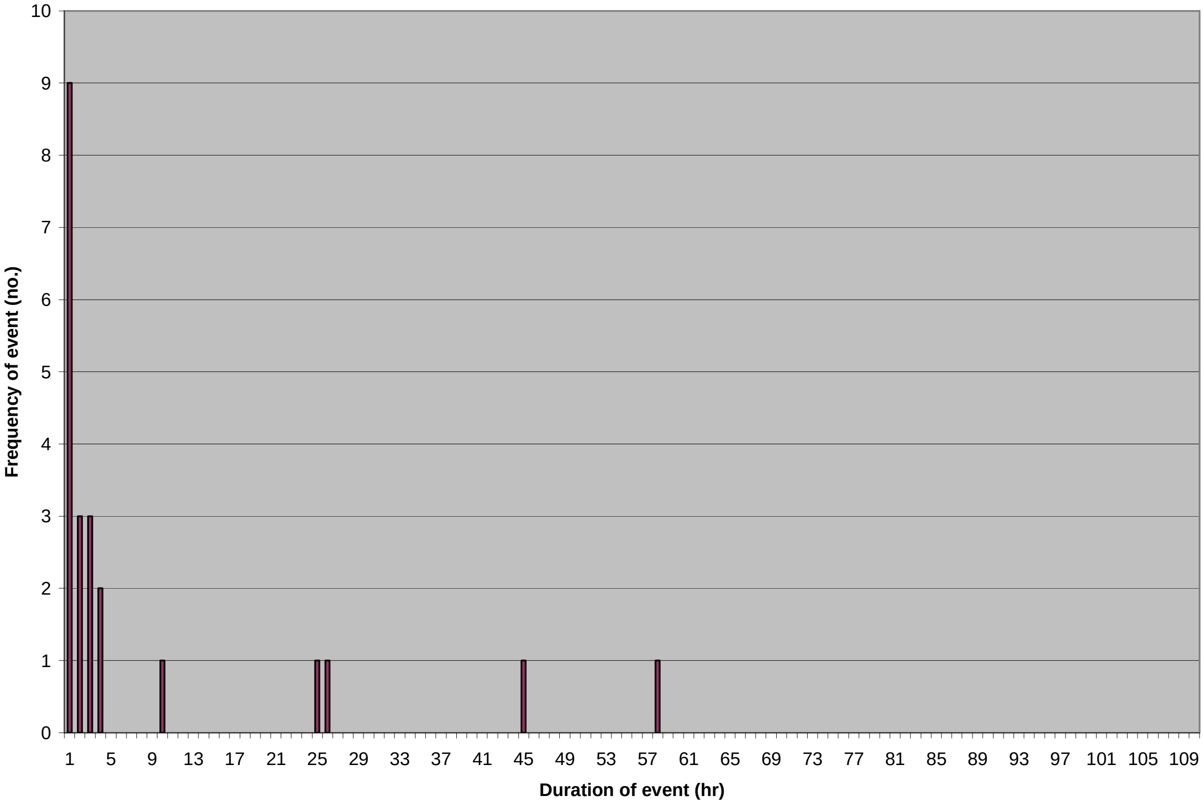

Figure 12: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - October 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In October 2009, the SWE criterion was exceeded for a total of **196 hrs** during **22 separate events**. Four of these events exceeded a whole day (24 hrs), while one of these events lasted more than two days. The majority of the events were experienced in under a 5 hour period.

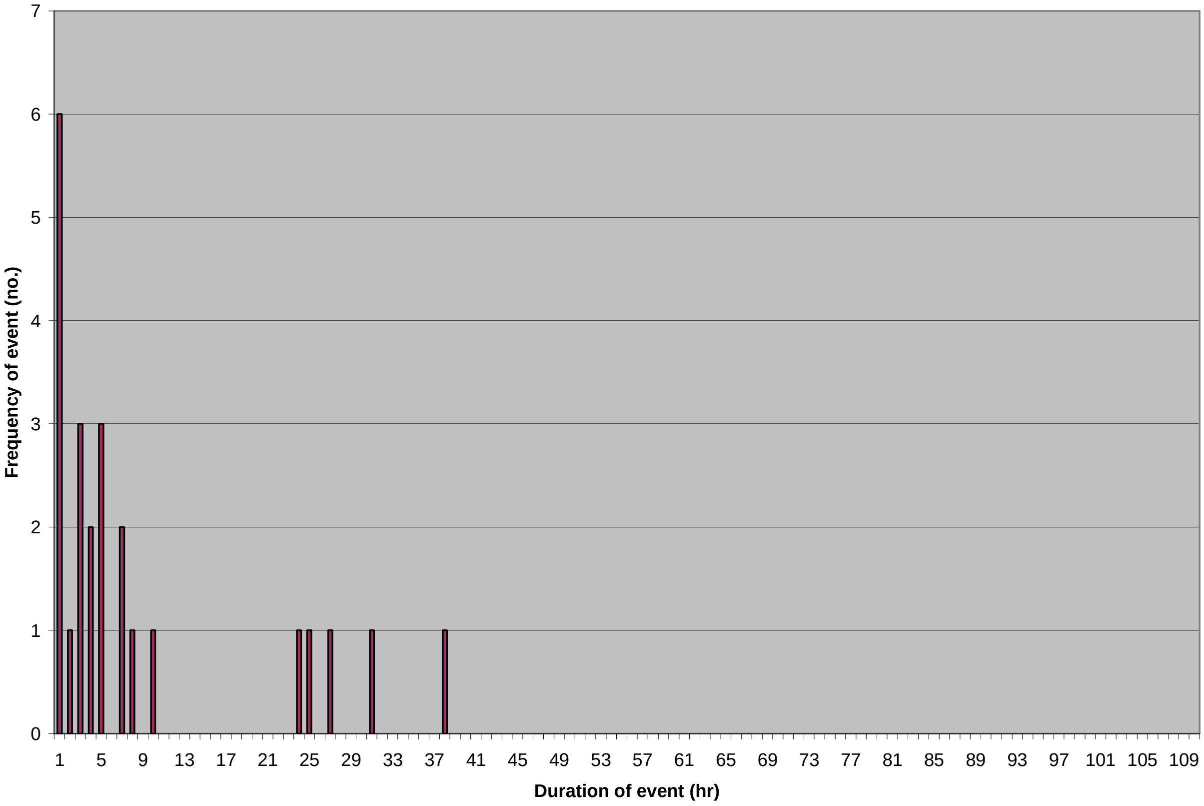

Figure 13: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - November 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In November 2009, the SWE criterion was exceeded for a total of **217 hrs** during **24 separate events**. Five of these events lasted a whole day (24 hrs) or more. The majority of the events were experienced in under a 10 hour period.

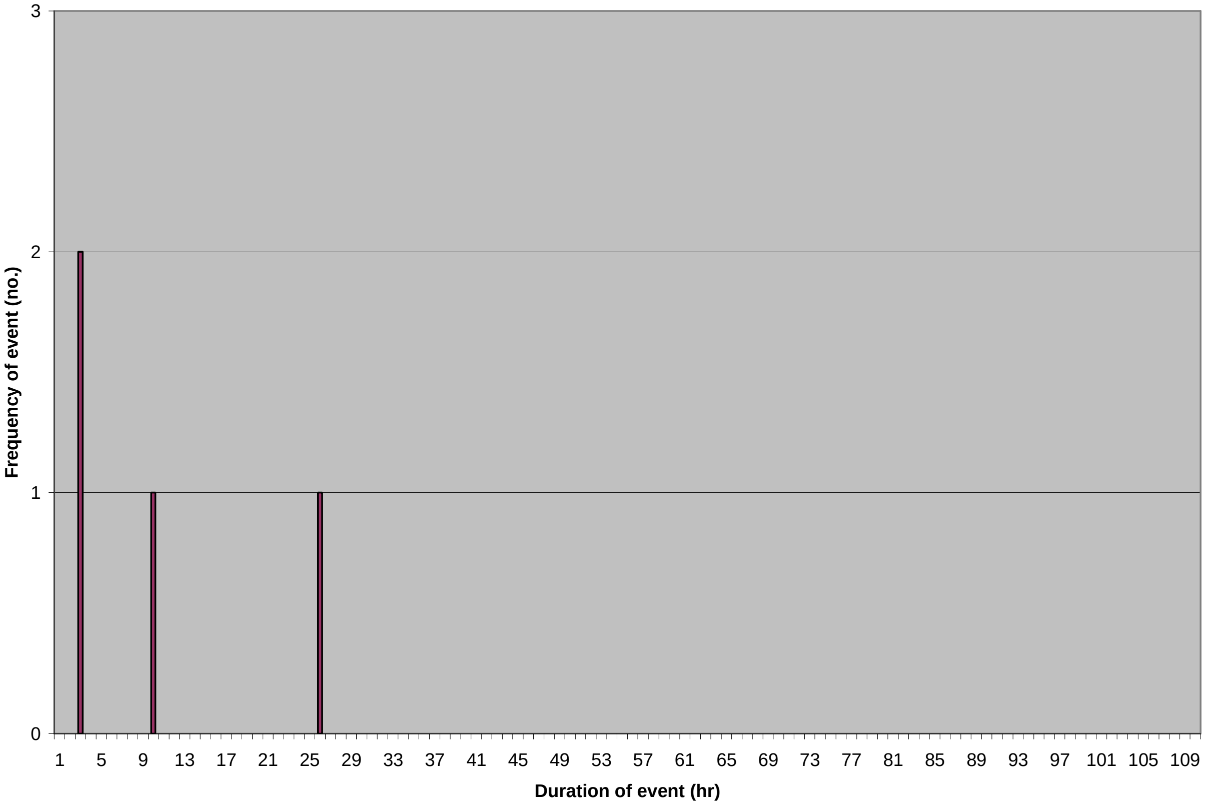

Figure 14: Total Snow Water Equivalent events greater than 0.01m over a consecutive 24hr period - December 2009.

Note: The duration of the events represented in the figure do not account for the consecutive 24 hr period where SWE accumulation exceeded 0.01m. Instead the event durations reflect the period of time after which the 24 hr rolling accumulation remained greater than 0.01m.

In December 2009, the SWE criterion was exceeded for a total of **42 hrs** during **4 separate events**. One of these events exceeded a whole day (24 hrs).

Unlike the severity of a rainfall event where it can be adequately characterized by the total depth of rainfall, snowfall severity is influenced by total snowfall depth, but also snowdrift from high wind velocities. The minimum wind velocity at which snow will drift is approximately 4.5m/s (DeGaetano and O'Rourke, 2003). In terms of snow distribution, wind will preferentially move freshly fallen snow from open areas to more sheltered areas, such as depressions, tree lines, and the lee-side of raised topography or man-made structures. This should also be considered when assessing daily snowfall accumulations at any specific location. The Sulphurets snow pillow is located in a sheltered site that is not prone to drifting. Generally the area around the Sulphurets snow pillow is forested, which reduces surface wind speeds that in turn reduce the likelihood of snow being redistributed towards the snow pillow.

4. Conclusion

The estimated total annual hours when horizontal visibility is less than the extreme weather criteria of 1 km is 113 hours, with the worst month being March. The estimated total annual hours when SWE exceeds the extreme weather criteria of 0.01 m is 1,656 hours, with the worst month being January.

As an aside, but certainly noteworthy for this memorandum, wind speeds of less than 8.0 m/s do not significantly affect visibility during snowfall (Matsuzawa et al., 2005), while blizzard conditions require sustained wind speeds of at least 11.0 m/s (Lawson, 2003).

References

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