APPENDICES

APPENDIX A – EQUATIONS USED IN EXPOSURE ASSESSMENT

Source. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Interim Final (1989)

Inhalation of air pollutants. The equation used to calculate intake for exposure by inhalation is:

$$Intake = \frac{(C)(IR)(EF)(ED)}{(BW)(AT)}$$

Intake is the number of micrograms of pollutant inhaled per kilogram of receptor body mass per day

C is the concentration of the pollutant in air, in micrograms per cubic meter

IR is the inhalation rate, which is taken to be 20 cubic meters per day

EF is the exposure frequency, which was taken to be 365 days per year

ED is the exposure duration, which varied

BW is the body weight of the receptor, which was taken to be 70 kilograms

AT is the averaging time; when calculating cancer risk this is taken to be 70 years, when calculating threat of non-cancer effects this is taken to be the same as the ED.

Ingestion of pollutants in soil. The equation used to calculate intake for exposure by ingestion of contaminated soil is:

$$Intake = \frac{(C)(IR)(CF)(FI)(EF)(ED)}{(BW)(AT)}$$

Intake is the number of milligrams of pollutant ingested per kilogram of body mass per day.

C is the concentration of the pollutant in the soil, in units of milligrams of pollutant per kilogram of soil

IR is the soil ingestion rate, which is taken to be 100 milligrams per day

CF is a conversion factor of 1 kilogram per 1,000,000 milligrams

FI is the fraction of ingested soil that is contaminated, which is assumed (protectively) to be 1

EF, *ED*, *BW*, and *AT* are as described above, for air pollutants

APPENDIX B – GAUSSIAN PLUME MODEL

Sources.

Air Pollution Modeling by Paolo Zannetti (Van Nostrand Reinhold, 1990)

Fundamentals of Air Pollution, 3rd edition by Richard W. Boubel, Donald L. Fox, D. Bruce Turner, and Arthur C. Stern (Academic Press, 1994)

Chemical Fate and Transport in the Environment, 2nd edition by Harold F. Hemond and Elizabeth J. Fechner-Levy

Equations. The Gaussian plume model is described by the following equation:

$$C(x, y, z) = \frac{Q g_1 g_2}{2\pi u \sigma_y \sigma_z}$$

where

C is the pollutant concentration at a location defined by coordinate (*x,y,z*)

x is the distance directly downwind of the pollutant source

y is the distance along a horizontal axis perpendicular to the wind direction

z is the distance above the ground surface

Q is the pollutant emission rate in grams per second

g_1 is the horizontal Gaussian distribution factor (i.e., applicable to the *y* direction)

g_2 is the vertical Gaussian distribution factor (i.e., applicable to the *z* direction)

u is the wind speed in meters per second

σ_y is the standard deviation of the horizontal distribution of the pollutant, in meters

σ_z is the standard deviation of the vertical distribution of the pollutant, in meters

The standard deviations were calculated using the Briggs formulae for rural settings:

	σ_y	σ_z
Stability class A	$0.22x(1 + 0.0001x)^{-1/2}$	$0.20x$
Stability class B	$0.16x(1 + 0.0001x)^{-1/2}$	$0.12x$
Stability class C	$0.11x(1 + 0.0001x)^{-1/2}$	$0.08x(1 + 0.0002x)^{-1/2}$
Stability class D	$0.08x(1 + 0.0001x)^{-1/2}$	$0.06x(1 + 0.0015x)^{-1/2}$
Stability class E	$0.06x(1 + 0.0001x)^{-1/2}$	$0.03x(1 + 0.0003x)^{-1}$
Stability class F	$0.04x(1 + 0.0001x)^{-1/2}$	$0.016x(1 + 0.0003x)^{-1}$

The Gaussian distribution factors were calculated using:

$$g_1 = \exp\left[-\frac{y^2}{2\sigma_y^2}\right]$$

$$g_2 = \exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]$$

H is the effective stack height, which in this case is taken to be the distance above the ground at which the pollutant emission occurs.

Appendix C - Determination of Wind Speed for Use in Gaussian Plume Model

The data shown below were determined using the wind roses shown in the *Garfield County Ambient Air Quality Study, June 2005-May 2007* , Section 4

Daytime, Percent of Time Wind Is in Each Velocity Range (m/s)

Silt-Bell

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	5	3.5	4	3	4	5	5	11	5	6.5	9	10	8	8.5	7	7.5	61.2
2.0 - 4.0	1	1	1	2	1	1	2	5	1.5	1	1	2	2	2.5	3	2.5	17.7
4.0 - 6.0						0.5	1	1.5	1	1	1	1	2	3	2	1.5	9.3
6.0 - 8.0								0.5	1	1	1	1	1	1.5	1		4.8
8.0 - 10.0												1	1	1			1.8
Total																	94.8

Silt-Cox

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	6	4	7.5	8.5	10	5	10	9	11	9	10	11.5	10	5	5.5	3	75
2.0 - 4.0	1	1	1	1	1.5	1	1.5	1	1.5	1.5	3	5	4.5	2	2	1	17.7
4.0 - 6.0	1				0.5		0.5	0.5	1	1	1	1	1		1	0.5	5.4
6.0 - 8.0																	0
8.0 - 10.0																	0
Total																	98.1

Silt-Daley

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	15	6	4.5	2.5	3	3	5	6	6.5	12	11.5	6	8	8	7	10	68.4
2.0 - 4.0	5.5	2	1	0.5	1	0.5	1	2.5	1.5	2	1.5	1	2	2	2	3	17.4
4.0 - 6.0	1	0.5	0.25				1	2	1.5	2	2	1.5	1	0.5	0.5	1	8.85
6.0 - 8.0							0.3	1	0.5	1	1	0.5	0.25				2.7
8.0 - 10.0										0.25	0.75						0.6
Total																	97.95

Parachute

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	6	5	8	15	15.5	10	4	5.5	4	6	6	12	7.5	4	4	5.5	70.8
2.0 - 4.0	2	1.5	1	2	2.5	1.5	0.5	0.5		1	2	7	5.5	3	3	2.5	21.3
4.0 - 6.0	1	0.5	0.25									1	1	1	1.5	2	4.95
6.0 - 8.0																	0
8.0 - 10.0																	0
Total																	97.05

Newcastle-Library

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	3	5	9	8	12	12	6.5	5	5.5	9	14	13	7	5	4	3.5	72.9
2.0 - 4.0		0.5	2	2	4	4	1.5	1	2	3	8	6	2.5	1.5	1	0.5	23.7
4.0 - 6.0					0.25	0.25				0.25	1	1	1	0.5			2.55
6.0 - 8.0																	0
8.0 - 10.0																	0
Total																	99.15

Daytime Average for All 5 Sites

(m/s)	Total
0 - 2.0	69.7
2.0 - 4.0	19.6
4.0 - 6.0	6.2
6.0 - 8.0	1.5
8.0 - 10.0	0.5
Total	97.4

Daytime Average for All 5 Sites, Converted to Pasquill Wind Categories

(m/s)	Total
0 - 2	69.7
2 - 3	9.8
3 - 5	12.9
5 - 6	3.1
>6	2.0
Total	97.5

When it was necessary to "split" wind speed categories from the Garfield County wind roses, half the percent occurrence in the wind rose category was allocated to each of the Pasquill categories.

Daytime Average for All 5 Sites, Converted to Pasquill Wind Categories

(m/s)	Adjusted to total 100%	Total
0 - 2		70.7
2 - 3		10.8
3 - 5		13.4
5 - 6		3.1
>6		2.0
Total		100.0

The percent occurrence of each wind speed range was determined by allocating the proportions determined from the wind roses across a total of 100%.

Nightime, Percent of Time Wind Is in Each Velocity Range (m/s)

Silt-Bell

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0						2	3	8	2	1.5	1	1	2	2.5	0.5	0.5	43.2
2.0 - 4.0						1	2	8	1.5	1	1	1					27.9
4.0 - 6.0							1	5	1	0.5	0.5	0.25					14.85
6.0 - 8.0								1									1.8
8.0 - 10.0																	0
Total																	87.75

Silt-Cox

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	9	7	16	16.5	12.5	4.5	3	2	2	2	2	3	4	3	4.5	3	75.2
2.0 - 4.0	1	0.5	3	4.5	4.5	1	1		1	0.5	0.5	1	1	1	1	1	18
4.0 - 6.0	1	0.25	0.25	0.5	0.5	0.25					0.25	0.25	0.25		0.25	0.5	3.4
6.0 - 8.0	0.25																0.2
8.0 - 10.0																	0
Total																	96.8

Silt-Daley

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	1		1.5		1.25	1	3	7	8	17	12	4	3	2	1.5		62.25
2.0 - 4.0	1					1	2	4.5	3	4	2.5	1	1	1		2	23
4.0 - 6.0	0.5						1	3	2	1	1	0.25					8.75
6.0 - 8.0								0.5	0.25	1							1.75
8.0 - 10.0																	
Total																	95.75

Parachute

(m/s)	0°	23°	45°	68°	90°	113°	135°	158°	180°	203°	225°	248°	270°	293°	315°	338°	Total
0 - 2.0	13	13	11	16.5	13	6	2	2	2	4	2.5	7	6	5	9	14	75.6
2.0 - 4.0	7	4	2	1	1	0.5					0.5	1.5	1.5	1.5	3	7	18.3

Nighttime Average for All 5 Sites, Converted to Pasquill Wind Categories

(m/s)	Total
0 - 2	69.5
2 - 3	9.4
3 - 5	12.5
5 - 6	3.2
>6	
Total	94.6

When it was necessary to "split" wind speed categories from the Garfield County wind roses, half the percent occurrence in the wind rose category was allocated to each of the Pasquill categories.

Nighttime Average for All 5 Sites, Converted to Pasquill Wind Categories

(m/s)		Total
0 - 2	Adjusted to total 100%	70.0
2 - 3		11.4
3 - 5		14.4
5 - 6		4.3
>6		
Total		100.0

The percent occurrence of each wind speed range was determined by allocating the proportions determined from the wind roses across a total of 100%.

Nighttime Average for All 5 Sites, Converted to Pasquill Wind Categories

(m/s)	Total
0 - 2	69.5
2 - 3	9.4
3 - 5	12.5
5 - 6	3.2
>6	
Total	94.6

When it was necessary to "split" wind speed categories from the Garfield County wind roses, half the percent occurrence in the wind rose category was allocated to each of the Pasquill categories.

Nighttime Average for All 5 Sites, Converted to Pasquill Wind Categories

(m/s)		Total
0 - 2	Adjusted to total 100%	70.0
2 - 3		11.4
3 - 5		14.4
5 - 6		4.3
>6		
Total		100.0

The percent occurrence of each wind speed range was determined by allocating the proportions determined from the wind roses across a total of 100%.

APPENDIX D – MOST FREQUENT WIND DIRECTIONS

Based on wind roses shown in the Garfield County Ambient Air Quality Monitoring Study, June 2005-May 2007

Nighttime, maximum percent of time wind blows in one direction

Silt-Bell		40%	
Silt-Cox		18%	
Silt-Daley	24%		Average of these 5 sites = 21%
Parachute	14%		
Newcastle-Library	11%		

All hours, maximum percent of time wind blows in one direction

Silt-Bell		26%	
Silt-Cox		12%	
Silt-Daley	17%		Average of these 5 sites = 15%
Parachute	11%		
Newcastle-Library	10%		

APPENDIX E - DURATION OF TIME SUN IS IN EACH INSOLATION CATEGORY

Columns B and C: Time when sun rises above 60 deg and sets below 60 deg (24 hr time) for Rifle, Colorado
Source: http://www.susdesign.com/sunangle/
Column D: Duration for sun above 60 deg (hr:min)
Columns F through H and J through L are analogous, except for 35 deg and 15 deg, respectively

Column:	B	C	D	F	G	H	J	K	L
2007		GMT-6 MDT 60 degrees			GMT-7 MST 35 degrees			GMT-7 MST 15 degrees	
1-Jan							9:15	15:11	5:56
2-Jan							9:15	15:12	5:57
9-Jan							9:13	15:20	6:07
16-Jan							9:09	15:30	6:21
23-Jan							9:02	15:41	6:39
30-Jan							8:54	15:52	6:58
6-Feb				12:20	12:28	0:08	8:45	16:03	7:18
10-Feb				11:34	13:14	1:40	8:33	16:09	7:36
17-Feb				10:59	13:48	2:49	8:28	16:19	7:51
24-Feb				10:34	14:12	3:38	8:16	16:29	8:13
3-Mar				10:12	14:31	4:19	8:04	16:39	8:35
10-Mar				9:53	14:46	4:53	7:52	16:47	8:55
17-Mar				9:36	15:00	5:24	7:41	16:55	9:14
24-Mar				9:20	15:11	5:51	7:29	17:03	9:34
31-Mar				9:06	15:21	6:15	7:17	17:10	9:53
7-Apr				8:53	15:30	6:37	7:07	17:17	10:10
14-Apr	13:04	13:15	0:11	8:42	15:38	6:56	6:56	17:23	10:27
19-Apr	12:22	13:55	1:33	8:34	15:43	7:09	6:49	17:28	10:39
26-Apr	11:58	14:16	2:18	8:25	15:50	7:25	6:41	17:34	10:53
3-May	11:42	14:30	2:48	8:17	15:56	7:39	6:33	17:40	11:07
10-May	11:31	14:41	3:10	8:10	16:01	7:51	6:26	17:46	11:20
17-May	11:22	14:49	3:27	8:05	16:06	8:01	6:21	17:51	11:30
24-May	11:16	14:56	3:40	8:01	16:11	8:10	6:16	17:56	11:40
31-May	11:13	15:02	3:49	7:59	16:15	8:16	6:14	18:01	11:47
7-Jun	11:11	15:06	3:55	7:58	16:19	8:21	6:12	18:04	11:52
14-Jun	11:10	15:09	3:59	7:58	16:22	8:24	6:12	18:07	11:55
21-Jun	11:11	15:11	4:00	7:59	16:25	8:26	6:13	18:09	11:56
28-Jun	11:13	15:12	3:59	8:01	16:24	8:23	6:15	18:10	11:55
4-Jul	11:16	15:12	3:56	8:03	16:24	8:21	6:17	18:10	11:53
11-Jul	11:20	15:10	3:50	8:06	16:23	8:17	6:21	18:08	11:47
18-Jul	11:25	15:06	3:41	8:10	16:21	8:11	6:25	18:05	11:40
25-Jul	11:32	15:00	3:28	8:15	16:17	8:02	6:30	18:01	11:31
1-Aug	11:40	14:51	3:11	8:20	16:12	7:52	6:35	17:56	11:21
8-Aug	11:49	14:41	2:52	8:25	16:05	7:40	6:41	17:49	11:08

15-Aug	12:03	14:25	2:22	8:30	15:57	7:27	6:46	17:41	10:55
22-Aug	12:22	14:02	1:40	8:37	15:47	7:10	6:52	17:32	10:40
28-Aug	13:06	13:15	0:09	8:42	15:28	6:46	6:57	17:24	10:27
4-Sep				8:50	15:27	6:37	7:03	17:13	10:10
11-Sep				8:58	15:13	6:15	7:09	17:02	9:53
18-Sep				9:07	14:59	5:52	7:16	16:51	9:35
25-Sep				9:18	14:43	5:25	7:23	16:39	9:16
2-Oct				9:31	14:26	4:55	7:30	16:26	8:56
9-Oct				9:46	14:07	4:21	7:38	16:14	8:36
16-Oct				10:03	13:46	3:43	7:47	16:02	8:15
23-Oct				10:26	13:21	2:55	7:56	15:50	7:54
30-Oct				10:57	12:48	1:51	8:06	15:39	7:33
3-Nov				11:30	12:16	0:46	8:12	15:32	7:20
10-Nov							8:23	15:23	7:00
17-Nov							8:34	15:15	6:41
24-Nov							8:44	15:08	6:24
1-Dec							8:54	15:03	6:09
8-Dec							9:02	15:00	5:58
15-Dec							9:09	15:00	5:51
22-Dec							9:13	15:03	5:50
29-Dec							9:15	15:08	5:53
31-Dec							9:15	15:10	5:55

Column Y is number of days centered around the date given on each line (duration of period represented by that date)
Columns V,W,X are the hours given in R,S,T multiplied by the number of days in column Y
Columns Z,AA,AB show total number of hours over each month that sun is in each angle range
Total of each column (Z,AA,AB) is total number of hours in year that sun is in each angle range

	V	W	X	Y	Z	AA	AB
2007							
	>60 deg	35 to 60 deg	15 to 35 deg		> 60 deg	35-60	15-35
1-Jan			5.93	1	0.0	0.0	198.4
2-Jan			23.80	4			
9-Jan			42.82	7			
16-Jan			44.45	7			
23-Jan			46.55	7			
30-Jan			48.77	7			
6-Feb		0.40	43.00	6	0.0	58.2	158.2
10-Feb		8.33	29.67	5			
17-Feb		19.72	35.23	7			
24-Feb		25.43	32.08	7			
3-Mar		30.22	29.87	7	0.0	163.8	121.2
10-Mar		34.18	28.23	7			
17-Mar		37.80	26.83	7			
24-Mar		40.95	26.02	7			
31-Mar		43.75	25.43	7			
7-Apr		46.32	24.85	7	27.4	181.0	105.6
14-Apr	0.73	47.25	24.62	7			
19-Apr	7.75	28.00	17.50	5			
26-Apr	16.10	35.82	24.27	7			
3-May	19.60	33.95	24.27	7	104.1	143.2	108.2
10-May	22.17	32.78	24.38	7			
17-May	24.15	31.97	24.38	7			
24-May	25.67	31.50	24.50	7			
31-May	26.72	31.15	24.62	7			
7-Jun	27.42	31.03	24.62	7	118.7	132.7	105.5
14-Jun	27.88	30.92	24.62	7			
21-Jun	28.00	31.03	24.50	7			
28-Jun	27.88	30.80	24.73	7			
4-Jul	23.60	26.50	21.20	6	114.0	139.6	108.5
11-Jul	26.83	31.15	24.50	7			
18-Jul	25.78	31.50	24.38	7			
25-Jul	24.27	31.97	24.38	7			
1-Aug	22.28	32.78	24.38	7	61.9	166.1	109.1
8-Aug	20.07	33.60	24.27	7			

15-Aug	16.57	35.58	24.27	7			
22-Aug	11.67	38.50	24.50	7			
28-Aug	0.90	39.70	22.10	6			
4-Sep		46.32	24.85	7	0.0	178.9	111.3
11-Sep		43.75	25.43	7			
18-Sep		41.07	26.02	7			
25-Sep		37.92	26.95	7			
2-Oct		34.42	28.12	7	0.0	110.7	145.0
9-Oct		30.45	29.75	7			
16-Oct		26.02	31.73	7			
23-Oct		20.42	34.88	7			
30-Oct		9.25	28.50	5			
3-Nov		4.60	39.40	6	0.0	4.6	198.4
10-Nov			49.00	7			
17-Nov			46.78	7			
24-Nov			44.80	7			
1-Dec			43.05	7	0.0	0.0	183.5
8-Dec			41.77	7			
15-Dec			40.95	7			
22-Dec			40.83	7			
29-Dec			23.53	4			
31-Dec			11.83	2			
Total	426	1279	1653	365	426	1279	1653

APPENDIX F - FRACTION OF MONTH REPORTED AS CLEAR, PARTLY CLOUDY, OR CLOUDY

(Approximation based on National Weather Service data for Grand Junction, Communication from J. Daniels of Grand Junction office)

	Mean no. of days with			Fraction of month in category		
	Clear	P Cloudy	Cloudy	Clear	P Cloudy	Cloudy
Jan	9.1	7.0	14.8	0.29	0.23	0.48
Feb	7.6	7.4	13.3	0.26	0.26	0.48
Mar	8.0	8.6	14.4	0.26	0.28	0.46
Apr	7.9	9.4	12.7	0.26	0.31	0.42
May	9.6	10.7	10.7	0.31	0.35	0.34
Jun	14.9	9.4	5.7	0.50	0.31	0.19
Jul	13.7	11.2	5.5	0.45	0.37	0.18
Aug	13.1	11.2	6.1	0.43	0.37	0.20
Sep	16.0	8.1	5.3	0.54	0.28	0.18
Oct	14.7	7.6	8.0	0.49	0.25	0.26
Nov	10.4	7.4	11.6	0.35	0.25	0.40
Dec	9.6	7.6	13.1	0.32	0.25	0.43

Sample calculation of fraction of month for clear sky in January:
(no. of days clear) / (sum of clear, partly cloudy, cloudy) =
(9.1) / (9.1 + 7.0 + 14.8) = 0.29

In units of oktas (octants of sky):

"Clear" corresponds to 0-2 okta of cloud coverage
"Partly cloudy" corresponds to 3-6 okta of cloud coverage
"Cloudy" corresponds to 7-8 okta of cloud coverage

(From www.worldweather.org/oktas.htm)

APPENDIX G - OCCURRENCE OF EACH AIR STABILITY CLASS IN TYPICAL YEAR

Source of Pasquill stability class definitions:

	(from Appendix F) **Fraction of month in category**			**Cloud cover redefined to match Pasquill night stability classes**		
	Clear	P Cloudy	Cloudy	<= 0.4	>= 0.5	overcast
	0-2 okta	3-6 okta	7-8 okta	0-3 okta	4-6 okta	7-8 okta
Jan	0.29	0.23	0.48	0.35	0.17	0.48
Feb	0.26	0.26	0.48	0.33	0.20	0.48
Mar	0.26	0.28	0.46	0.33	0.21	0.46
Apr	0.26	0.31	0.42	0.34	0.23	0.42
May	0.31	0.35	0.34	0.40	0.26	0.34
Jun	0.50	0.31	0.19	0.58	0.23	0.19
Jul	0.45	0.37	0.18	0.54	0.28	0.18
Aug	0.43	0.37	0.20	0.52	0.28	0.20
Sep	0.54	0.28	0.18	0.61	0.21	0.18
Oct	0.49	0.25	0.26	0.55	0.19	0.26
Nov	0.35	0.25	0.40	0.41	0.19	0.40
Dec	0.32	0.25	0.43	0.38	0.19	0.43

Pasquill stability classes during night are based on cloud cover categories of less than or equal to 0.4 cloud cover, greater than or equal to 0.5 cloud cover, and overcast. Because okta refers to an octant, or one-eighth of the sky, 4 okta corresponds to a cloud cover of 0.5. One-third of the 3-6 okta category from Appendix F was moved into the 0-3 okta category; the rest of the 3-6 okta category became the 4-6 okta category.

APPENDIX H. CALCULATION OF POLLUTANT CONCENTRATIONS IN AIR

Calculation of pollutant concentrations for unit emission rate (1 gram per second)

Emission rate (Q) = 1 gram/second
Gaussian model using Briggs sigmas
Stability category **A** (very unstable conditions), rural setting

Using Gaussian plume equation given in Appendix B
Effective height of emission point assumed to be 3 meters.
Chose z = 2 m as the approximate height above ground of inhalation.

downwind distance (m)	sigma-y	sigma-z	y	g-1	H	z	g-2	Pollutant concentration (micrograms/cubic meter) *1 m/s wind*	*2.5 m/s wind*
25	5.49E+00	5.00E+00	0	1.00E+00	3	2	1.80E+00	10417.3	4166.9
50	1.10E+01	1.00E+01	0	1.00E+00	3	2	2.40E+00	3488.2	1395.3
75	1.64E+01	1.50E+01	0	1.00E+00	3	2	2.57E+00	1658.5	663.4
100	2.19E+01	2.00E+01	0	1.00E+00	3	2	2.63E+00	957.0	382.8
125	2.73E+01	2.50E+01	0	1.00E+00	3	2	2.66E+00	620.3	248.1
150	3.28E+01	3.00E+01	0	1.00E+00	3	2	2.68E+00	434.0	173.6
175	3.82E+01	3.50E+01	0	1.00E+00	3	2	2.69E+00	320.5	128.2
200	4.36E+01	4.00E+01	0	1.00E+00	3	2	2.70E+00	246.3	98.5
250	5.43E+01	5.00E+01	0	1.00E+00	3	2	2.70E+00	158.4	63.4
300	6.50E+01	6.00E+01	0	1.00E+00	3	2	2.71E+00	110.5	44.2
350	7.57E+01	7.00E+01	0	1.00E+00	3	2	2.71E+00	81.4	32.6
400	8.63E+01	8.00E+01	0	1.00E+00	3	2	2.71E+00	62.5	25.0
500	1.07E+02	1.00E+02	0	1.00E+00	3	2	2.71E+00	40.2	16.1
600	1.28E+02	1.20E+02	0	1.00E+00	3	2	2.72E+00	28.1	11.2
700	1.49E+02	1.40E+02	0	1.00E+00	3	2	2.72E+00	20.7	8.3
800	1.69E+02	1.60E+02	0	1.00E+00	3	2	2.72E+00	16.0	6.4
900	1.90E+02	1.80E+02	0	1.00E+00	3	2	2.72E+00	12.7	5.1
1000	2.10E+02	2.00E+02	0	1.00E+00	3	2	2.72E+00	10.3	4.1
1100	2.30E+02	2.20E+02	0	1.00E+00	3	2	2.72E+00	8.6	3.4
1200	2.49E+02	2.40E+02	0	1.00E+00	3	2	2.72E+00	7.2	2.9
1300	2.69E+02	2.60E+02	0	1.00E+00	3	2	2.72E+00	6.2	2.5
1400	2.88E+02	2.80E+02	0	1.00E+00	3	2	2.72E+00	5.4	2.1
1500	3.08E+02	3.00E+02	0	1.00E+00	3	2	2.72E+00	4.7	1.9
1600	3.27E+02	3.20E+02	0	1.00E+00	3	2	2.72E+00	4.1	1.7
3200	6.13E+02	6.40E+02	0	1.00E+00	3	2	2.72E+00	1.1	0.4
4800	8.68E+02	9.60E+02	0	1.00E+00	3	2	2.72E+00	0.5	0.2

APPENDIX IA - BENZENE, TOLUENE, AND m,p-XYLENE CONCENTRATIONS DURING FLOW BACK

Calculated by multiplying the concentrations for a 1 gram/second emission rate (from Appendix H) by the emission rates shown below.

BENZENE

Flow back with no gas recovery
Benzene emission rate (Q) = 0.076 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	273.4
50	254.0
75	170.6
100	122.0
125	85.8
150	65.2
175	52.4
200	43.7
250	32.8
300	25.9
350	20.8
400	17.2
500	12.3
600	9.3
700	7.3
800	5.9
900	4.8
1000	4.1
1100	3.5
1200	3.0
1300	2.7
1400	2.4
1500	2.1
1600	1.9
3200	0.7
4800	0.4

BENZENE

Flow back with 93%
Benzene emission r

downwind distance (m)
25
50
75
100
125
150
175
200
250
300
350
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
3200
4800

TOLUENE

Flow back with no gas recovery
Toluene emission rate (Q) = 0.076 grams/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	273.4
50	254.0
75	170.6
100	122.0
125	85.8
150	65.2
175	52.4
200	43.7
250	32.8
300	25.9
350	20.8
400	17.2
500	12.3
600	9.3
700	7.3
800	5.9
900	4.8
1000	4.1
1100	3.5
1200	3.0
1300	2.7
1400	2.4
1500	2.1
1600	1.9
3200	0.7
4800	0.4

XYLENE

Flow back with no gas recovery
Toluene emission rate (Q) = 0.076 grams/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	273.4
50	254.0
75	170.6
100	122.0
125	85.8
150	65.2
175	52.4
200	43.7
250	32.8
300	25.9
350	20.8
400	17.2
500	12.3
600	9.3
700	7.3
800	5.9
900	4.8
1000	4.1
1100	3.5
1200	3.0
1300	2.7
1400	2.4
1500	2.1
1600	1.9
3200	0.7
4800	0.4

Typical natural gas from the Piceance Basin has a BTEX (benzene, toluene, ethylbenzene, xylenes) content of about 0.04% by volume and 0.15% by weight. Of this, benzene is about 0.01% by volume and 0.05% by weight. Most of the remaining BTEX is toluene and xylenes. During flow back, the average flow of natural gas is about 700,000 standard cubic feet (scf) per day.
(Personal communication, R. Matar, Williams Companies)

Assume that the non-benzene part of the BTEX is split evenly in terms of weight percent between toluene and xylenes.

If 700,000 scf of natural gas is released per day, and benzene is 0.01% by volume, then there are 70 scf of benzene released per day.

The molar volume of an ideal gas at 0 C (273 K) is 22.4 liters/mole.
Convє (22.4 L/mol)(288.6/273) = 23.7 L/mol at 60 F

Because 1 cubic foot = 28.32 L, every mole of gas is 23.7 L or 0.837 cubic feet.
Then 70 scf per day of benzene is equivalent to (70)/(0.837) or
83.6 moles of benzene per day.

1 mole of benzene is 78 g, so the mass of benzene emitted per day is 6,520 grams.
The emission rate for benzene is thus 0.076 grams per second.

Assuming that the weight percents of toluene and xylenes are the same as the weight percent for benzene, the emission rate for these compounds is also 0.076 grams per second.

An average of 93% of the gas is recovered during green completions. (Personal communication, R. Matar, Williams Companies)

This means that the emission rate becomes 0.0053 grams per second, which is 0.07 times the emission rate for uncontrolled flow back of 0.076 grams per second.

BENZENE

Flow back with 93% recovery of gas
Benzene emission rate (Q) = 0.0053 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	19.1
50	17.7
75	11.9
100	8.5
125	6.0
150	4.5
175	3.7
200	3.1
250	2.3
300	1.8
350	1.5
400	1.2
500	0.9
600	0.6
700	0.5
800	0.4
900	0.3
1000	0.3
1100	0.2
1200	0.2
1300	0.2
1400	0.2
1500	0.1
1600	0.1
3200	0.0
4800	0.0

TOLUENE

Flow back with 93% recovery of gas
Toluene emission rate (Q) = 0.0053 grams/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	19.1
50	17.7
75	11.9
100	8.5
125	6.0
150	4.5
175	3.7
200	3.1
250	2.3
300	1.8
350	1.5
400	1.2
500	0.9
600	0.6
700	0.5
800	0.4
900	0.3
1000	0.3
1100	0.2
1200	0.2
1300	0.2
1400	0.2
1500	0.1
1600	0.1
3200	0.0
4800	0.0

XYLENE

Flow back with 93% recovery of gas
Toluene emission rate (Q) = 0.0053 grams/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	19.1
50	17.7
75	11.9
100	8.5
125	6.0
150	4.5
175	3.7
200	3.1
250	2.3
300	1.8
350	1.5
400	1.2
500	0.9
600	0.6
700	0.5
800	0.4
900	0.3
1000	0.3
1100	0.2
1200	0.2
1300	0.2
1400	0.2
1500	0.1
1600	0.1
3200	0.0
4800	0.0

APPENDIX IB- BENZENE, TOLUENE, AND m,p-XYLENE CONCENTRATIONS FROM GLYCOL DEHYDRATION EMISSIONS

Calculated by multiplying the concentrations for a 1 gram/second emission rate (from Appendix H) by the emission rates shown below.

BENZENE

Operation of wellhead glycol dehyration units
Benzene emission rate (Q) = 0.0036 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	12.9
50	12.0
75	8.1
100	5.8
125	4.1
150	3.1
175	2.5
200	2.1
250	1.6
300	1.2
350	1.0
400	0.8
500	0.6
600	0.4
700	0.3
800	0.3
900	0.2
1000	0.2
1100	0.2
1200	0.1
1300	0.1
1400	0.1
1500	0.1
1600	0.1
3200	0.0
4800	0.0

TOLUENE

Operation of wellhead glycol dehyration units
Toluene emission rate (Q) = 0.01 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	36.0
50	33.4
75	22.4
100	16.0
125	11.3
150	8.6
175	6.9
200	5.8
250	4.3
300	3.4
350	2.7
400	2.3
500	1.6
600	1.2
700	1.0
800	0.8
900	0.6
1000	0.5
1100	0.5
1200	0.4
1300	0.4
1400	0.3
1500	0.3
1600	0.3
3200	0.1
4800	0.1

XYLENE

Operation of wellhead glycol dehyration units
Toluene emission rate (Q) = 0.01 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	36.0
50	33.4
75	22.4
100	16.0
125	11.3
150	8.6
175	6.9
200	5.8
250	4.3
300	3.4
350	2.7
400	2.3
500	1.6
600	1.2
700	1.0
800	0.8
900	0.6
1000	0.5
1100	0.5
1200	0.4
1300	0.4
1400	0.3
1500	0.3
1600	0.3
3200	0.1
4800	0.1

The worst-case emissions from wellhead glycol dehydration units is 2.5 tons per year of VOCs. Total BTEX is about one-third of this 2.5 tons per year, with benzene emissions being 250 lbs per year.
(Personal communication, R. Matar, Williams Companies)

2.5 tons per year is equivalent to 5,000 lbs per year.
One-third of this is 1,666 lbs per year.
Thus, non-benzene BTEX is 1,666 lbs per year minus 250 lbs per year, or 1,416 lbs per year.

Assuming that this 1,416 lbs per year is split evenly between toluene and xylenes, then each is emitted at a rate of 708 lbs per year.

Convert benzene emissions of 250 lbs per year to grams per second:
(250 lbs/yr)(454 g/lb)/[(365 days/yr)(86,400 seconds/day)] = 0.0036 g/s

Convert toluene, xylene emissions of 708 lbs per year to grams per second:
(708 lbs/yr)(454 g/lb)/[(365 days/yr)(86,400 s/d)] = 0.01 g/s

APPENDIX IC - BENZENE, TOLUENE, AND m,p-XYLENE CONCENTRATIONS FROM CONDENSATE TANK EMISSIONS

Calculated by multiplying the concentrations for a 1 gram/second emission rate (from Appendix H) by the emission rates shown below.

BENZENE

Condensate tanks emitting 20 tpy VOCs
Benzene emission rate (Q) = 0.0081 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	29.1
50	27.1
75	18.2
100	13.0
125	9.1
150	6.9
175	5.6
200	4.7
250	3.5
300	2.8
350	2.2
400	1.8
500	1.3
600	1.0
700	0.8
800	0.6
900	0.5
1000	0.4
1100	0.4
1200	0.3
1300	0.3
1400	0.3
1500	0.2
1600	0.2
3200	0.1
4800	0.0

TOLUENE

Condensate tanks emitting 20 tpy VOCs
Toluene emission rate (Q) = 0.039 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	140.3
50	130.4
75	87.5
100	62.6
125	44.0
150	33.4
175	26.9
200	22.5
250	16.9
300	13.3
350	10.7
400	8.8
500	6.3
600	4.8
700	3.7
800	3.0
900	2.5
1000	2.1
1100	1.8
1200	1.6
1300	1.4
1400	1.2
1500	1.1
1600	1.0
3200	0.4
4800	0.2

XYLENE

Condensate tanks emitting 20 tpy VOCs
Toluene emission rate (Q) = 0.044 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	140.3
50	130.4
75	87.5
100	62.6
125	44.0
150	33.4
175	26.9
200	22.5
250	16.9
300	13.3
350	10.7
400	8.8
500	6.3
600	4.8
700	3.7
800	3.0
900	2.5
1000	2.1
1100	1.8
1200	1.6
1300	1.4
1400	1.2
1500	1.1
1600	1.0
3200	0.4
4800	0.2

Convert VOC emission rate of 20 tons per year to grams per second (g/s):
(20 tons VOC/yr)(2000 lb/ton)(1 yr/365 d)(1 d/86,400 s)(0.454 kg/1 lb) =
0.00058 kg/s = 0.58 g/s VOC emission rate

Typical condensate is 1% by volume benzene, 4% by volume toluene, and 4% by volume xylenes.
Average molecular weight of condensate is 55 lbs per lb mol.
(Personal communication, R. Matar, Williams Companies)

Must convert % by volume to % by mass for each component of interest.
Benzene: molecular weight = 78
(0.01)(78/55) = 0.014 or 1.4% by weight
Toluene: molecular weight = 92
(0.04)(92/55) = 0.067 or 6.7% by weight
Xylenes: molecular weight = 106
(0.04)(106/55) = 0.77 or 7.7% by weight

Calculate emission rate for each component of interest
Benzene: (0.014)(0.58 g/s) = 0.0081 g/s
Toluene: (0.067)(0.58 g/s) = 0.039 g/s
Xylenes: (0.077)(0.58 g/s) = 0.044 g/s

An average of 98% of the condensate emissions are recovered when combustors are used. (Personal communication, R. Matar, Williams Companies)

This means that the emission rate becomes 0.00016 grams per second, which is 0.02 times the emission rate for uncontrolled condensate emissions at rate of 0.0081 grams per second.

BENZENE

Condensate tanks with 98% removal of VOCs emitted at 20 tpy
Benzene emission rate (Q) = 0.00016 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	0.6
50	0.5
75	0.4
100	0.3
125	0.2
150	0.1
175	0.1
200	0.1
250	0.1
300	0.1
350	0.0
400	0.0
500	0.0
600	0.0
700	0.0
800	0.0
900	0.0
1000	0.0
1100	0.0
1200	0.0
1300	0.0
1400	0.0
1500	0.0
1600	0.0
3200	0.0
4800	0.0

TOLUENE

Condensate tanks with 98% removal of VOCs emitted at 20 tpy
Toluene emission rate (Q) = 0.00078 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	2.8
50	2.6
75	1.8
100	1.3
125	0.9
150	0.7
175	0.5
200	0.4
250	0.3
300	0.3
350	0.2
400	0.2
500	0.1
600	0.1
700	0.1
800	0.1
900	0.0
1000	0.0
1100	0.0
1200	0.0
1300	0.0
1400	0.0
1500	0.0
1600	0.0
3200	0.0
4800	0.0

XYLENE

Condensate tanks with 98% removal of VOCs emitted at 20 tpy
Toluene emission rate (Q) = 0.00088 gram/second

downwind distance (m)	concentration (micrograms/cubic meter)
25	2.8
50	2.6
75	1.8
100	1.3
125	0.9
150	0.7
175	0.5
200	0.4
250	0.3
300	0.3
350	0.2
400	0.2
500	0.1
600	0.1
700	0.1
800	0.1
900	0.0
1000	0.0
1100	0.0
1200	0.0
1300	0.0
1400	0.0
1500	0.0
1600	0.0
3200	0.0
4800	0.0

APPENDIX J - RISK ASSESSMENT OF TOTAL PETROLEUM HYDROCARBON RESIDUE IN SOIL AT 1,000 MG/KG

Benzene, toluene, xylenes concentrations

Assume that the material spilled was condensate.

From Appendix G,

benzene is 1.2 weight percent of the condensate
toluene is 6.7 weight percent of the condensate
xylenes are 7.7 weight percent of the condensate

Then for a residual total concentration of 1,000 milligrams per kilogram,

benzene is 12 mg/kg
toluene is 67 mg/kg
xylenes are 77 mg/kg

Cancer risk for benzene

Concentration = 12 mg/kg
Summary intake factor for reasonable maximum residential exposure, ingestion of carcinogen = 0.0000016
Cancer potency factor for ingestion = 0.055

Cancer risk = (concentration)(summary intake factor)(cancer potency factor) =
(12)(0.0000016)(0.055) = 0.000001 or one in one million

Non-cancer threat for benzene, toluene, xylenes

Concentration = 12 mg/kg, 67 mg/kg, and 77 mg/kg respectively
Summary intake factor for reasonable maximum residential exposure, ingestion of non-carcinogen = 0.0000037
Chronic oral reference dose =

- 0.004 for benzene
- 0.08 for toluene
- 0.2 for xylenes

Hazard quotient HQ = (concentration)(summary intake factor)/(reference dose)

Benzene: (12)(0.0000037)/(0.004) = 0.011
Toluene: (67)(0.0000037)/(0.08) = 0.0031
Xylenes: (77)(0.0000037)/(0.2) = 0.0014

Hazard index = sum of HQ's = 0.016

- ***APPENDIX K – CAUSES OF DEATH BY COUNTY, 2003-2006***
  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX L – CAUSES OF DEATH BY RACE/ETHNICITY FOR GARFIELD COUNTY RESIDENTS, 2006***
  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX M – CANCER INCIDENCE AND MORTALITY RATES BY COUNTY FOR 1992 THROUGH 2005***
  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX N – SEXUALLY TRANSMITTED DISEASES RATES BY COUNTY, 2000-2007***
  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX O –COLORADO HOSPITAL ASSOCIATION UTILIZATION DATA – 2000-2007***
  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX P –ROCKY MOUNTAIN HEALTH PLANS (RMHP) MEMBER DATA FOR HEALTH PLAN USAGE – 2000-2007***
  Primary Data Available Upon Request through Garfield County Public Health

ER Data Groupings (used for emergency room data from all sources)

Accident, Injury and Trauma

- Accidents caused by cutting and piercing instruments or objects
- Caught accidentally in or between objects
- Concussion
- Contusion of face, scalp, and neck except eye(s)
- Contusion of lower limb and of other and unspecified sites
- Contusion of trunk
- Contusion of upper limb
- Fall on or from stairs or steps
- Fall on same level from slipping, tripping or stumbling
- Foreign body accidentally entering eye and adnexa
- Fracture of one or more phalanges of hand
- Fracture of radius and ulna
- Fracture of rib(s), sternum, larynx, and trachea
- Injury, other and unspecified
- Open wound of elbow, forearm, and wrist
- Open wound of finger(s)
- Open wound of hand except finger(s) alone
- Open wound of knee, leg (except thigh), and ankle
- Other and unspecified environmental and accidental causes
- Other and unspecified fall
- Other fall from one level to another
- Other injury caused by animals
- Other open wound of head
- Overexertion and strenuous movements
- Sprains and strains of ankle and foot
- Sprains and strains of knee and leg
- Sprains and strains of other and unspecified parts of back
- Sprains and strains of shoulder and upper arm
- Sprains and strains of wrist and hand
- Striking against or struck accidentally by objects or persons
- Struck accidentally by falling object
- Superficial injury of elbow, forearm, and wrist
- Superficial injury of eye and adnexa
- Superficial injury of face, neck, and scalp except eye
- Vehicular accident/Place of occurrence

Respiratory condition

- Acute bronchitis and bronchiolitis
- Acute sinusitis
- Acute upper respiratory infections of multiple or unspecified sites
- Asthma

- Bronchitis, not specified as acute or chronic
- Chronic bronchitis
- Chronic sinusitis
- Pneumonia, organism unspecified
- Symptoms involving respiratory system and other chest symptoms

Ear, Nose and Throat (ENT)
- Acute laryngitis and tracheitis
- Acute pharyngitis
- Acute tonsillitis
- Diseases of esophagus
- Other disorders of ear
- Suppurative and unspecified otitis media
- Symptoms involving head and neck

Infection – Other
- Bacterial infection in conditions classified and of unspecified site
- Other cellulites and abscess
- Streptococcal sore throat and scarlet fever
- Viral and chlamydial infection in conditions classified elsewhere and of unspecified site

Gastrointestinal and Urinary
- Calculus of kidney and ureter
- Cystitis
- Functional digestive disorder, not elsewhere classified
- Infections of kidney
- Other and unspecified noninfectious gastroenteritis and colitis
- Other disorders of urethra and urinary tract
- Other symptoms involving abdomen and pelvis
- Symptoms involving digestive system
- Symptoms involving urinary system

Cardiac
- Cardiac dysthythmias
- Heart failure
- Defined descriptions and complications of heart disease
- Other forms of chronic ischemic heart disease

Dental
- Diseases of hard tissues of teeth
- Gingival and periodontal diseases

Mental Health

- Depressive disorder, not elsewhere classified
- Neurotic disorders
- Alcohol dependence syndrome
- Nondependent abuse of drugs

Endocrine

- Diabetes mellitus
- Disorders of fluid, electrolyte, and acid-base balance
- Essential hypertension
- Nonspecific abnormal results of function studies

Eye

- Disorders of conjunctiva
- Other disorders of eye

Neurological

- Migraine/headache
- Other and unspecified disorders of back

Pregnancy/Gynecological

- Other complications of pregnancy, not elsewhere classified
- Pain and other symptoms associated with female genital organs

Skin/Allergy

- Symptoms involving skin and other integumentary tissue
- Urticaria

Other

- Certain adverse effects not elsewhere classified
- General symptoms
- Nonspecific findings on examination of blood
- Other disorders of soft tissues
- Other and unspecified disorders of joint
- Persons encountering health services for specific procedures, not carried out

- ***APPENDIX Q –GRAND RIVER HOSPITAL DISTRICT EMERGENCY ROOM ADMISSIONS – 2004-2006***

  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX R – VALLEY VIEW HOSPITAL EMERGENCY ROOM ADMISSIONS, 2004-2006***

  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX S –ST. MARY'S HOSPITAL "CAREFLIGHT" DATA***

  Primary Data Available Upon Request through Garfield County Public Health

- ***APPENDIX T – HOUSEHOLD SURVEY INSTRUMENT AND OTHER DOCUMENTS***

  Primary Data Available Upon Request through Garfield County Public Health

Garfield County Health Study
Focus Group Questions

1. How would you rate the health of people in Garfield County and/or your community relative to the health of people in other Colorado communities or other communities in which you've lived? Note: I am simply asking for your perception, based on your own experience.

2. What do you consider to be the priority health-related issues in your community? Note: I am using the term, health, in the context of not only specific physical ailments, but also the broader concept of "well-being".

3. Who is most affected by health issues in your community? Are there particular age or demographic groups that are more at risk or have more health problems?

4. To what environmental or societal factors (if any) would you attribute any of the priority health issues that you've identified in your community?

5. What health issues concern <u>you</u> the most? (Question asked of each participant individually)

- ***APPENDIX U – HOUSEHOLD SURVEY DATA ANALYSIS AND OUTCOMES***
  Primary Data Available Upon Request through Garfield County Public Health