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Colorado Front Range Gust Map

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INTRODUCTION

This report describes development of a design level gust wind speed map for the Front Range area of Colorado, Figure 1, which is suitable for adoption for use with the provisions of ASCE 7-02 or ASCE 7-05. Speeds are at 10m height in effective open terrain. The map covers the area from the Wyoming border to south of Denver and from about I-25 west to the Continental Divide. The map uses the concept of equivalent risk that was first adopted in the 1998 version of ASCE 7 and continues in current versions. The reason this map was developed was a lack of knowledge of design level wind speeds for the area and significantly different speeds adopted by various communities along the Front Range. Figure 9 shows the measured speeds used to develop the map contours.

The map is based on gust wind data identified and organized into a suitable database by the Colorado State Climatologist's office under the direction of Nolan Doesken. Funding for the database was organized by the Colorado Chapter of the International Code Council, who assisted by contacting and involving 35 Front Range jurisdictions situated in the special wind region as defined by ASCE 7. The jurisdictions most affected by wind design were able to procure sufficient funding for this project. Jon Peterka of Cermak Peterka Petersen, Inc. (CPP) of Fort Collins analysed the data to develop the map. A technical review by Bill Esterday of CPP assisted in finalizing the map.

High wind speeds in the Front Range area on the plains adjacent to the Rocky Mountains and in the mountains east of the Continental Divide are well known to residents as winter and spring events that are often damaging. The winds are known to occur from roughly the Continental Divide (the line of highest terrain running approximately north to south that divides Pacific Ocean watersheds from Atlantic Ocean watersheds) to approximately I-25 (that runs north-south about 10 miles east of the intersection of the mountains with the plains). The Continental Divide is very close to the plains in the Front Range area resulting in high wind speeds where the mountains and plains intersect.

High winds in the Front Range region are apparently due to two meteorological conditions:

(1) Downslope (known locally as "Chinook") winds are driven by a pressure gradient and act much like a hydraulic jump causing highest winds near the intersection of mountains and plains and in the mountains just west of the plains. Boulder, Colorado, is well known as being highly susceptible to downslope winds. A peak gust wind speed of 147 mph has been measured at the National Center For Atmospheric Research (NCAR) on Table Mesa at the southwest edge of the city of Boulder.

(2) Jet stream winds dip close to mountain-top level causing high wind speeds at higher terrain elevations, peaking near the Continental Divide. A peak gust of 168 mph was measured on Niwot Ridge just east of the Continental Divide west of Boulder.

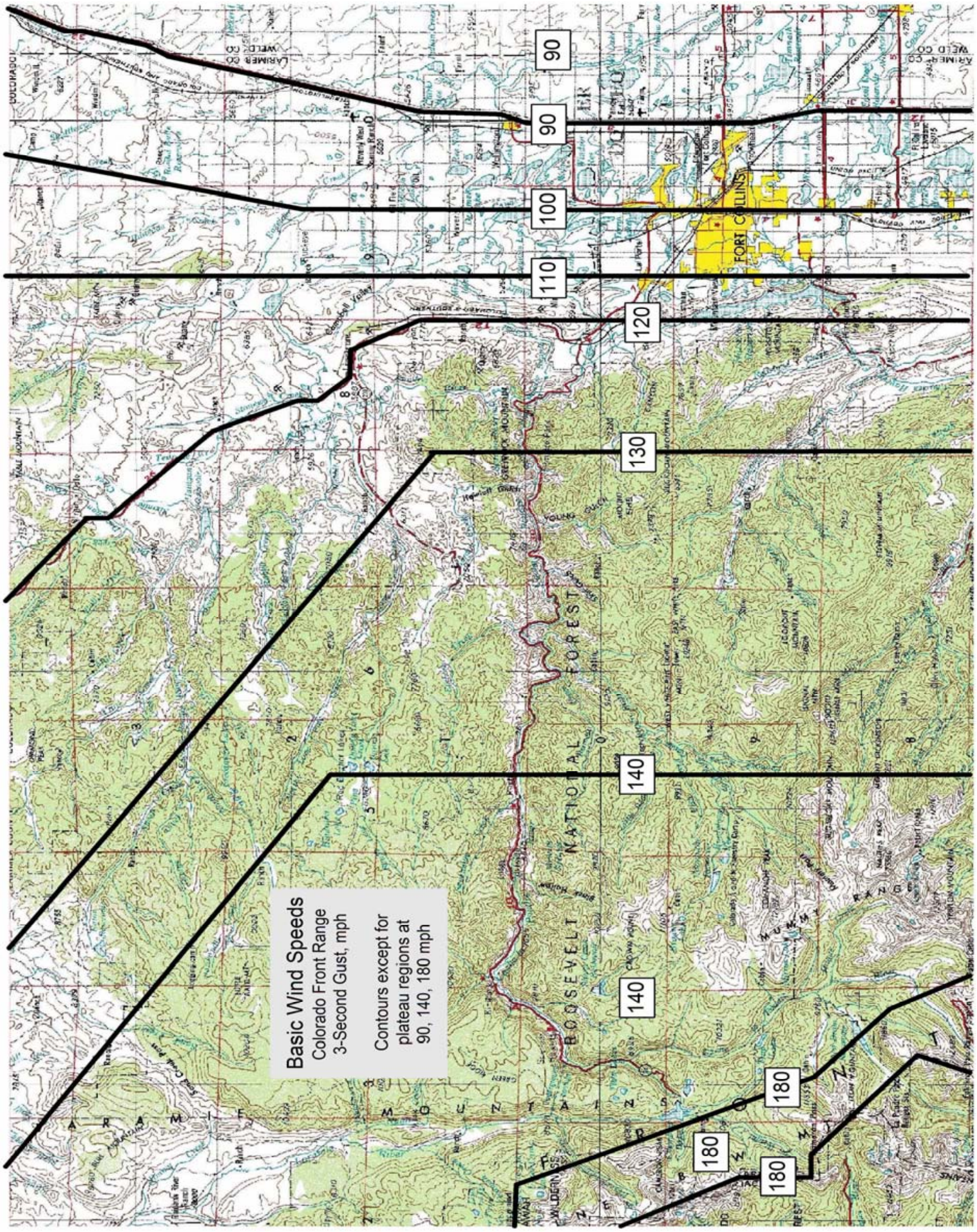

Figure 1 Colorado Front Range Gust Map.

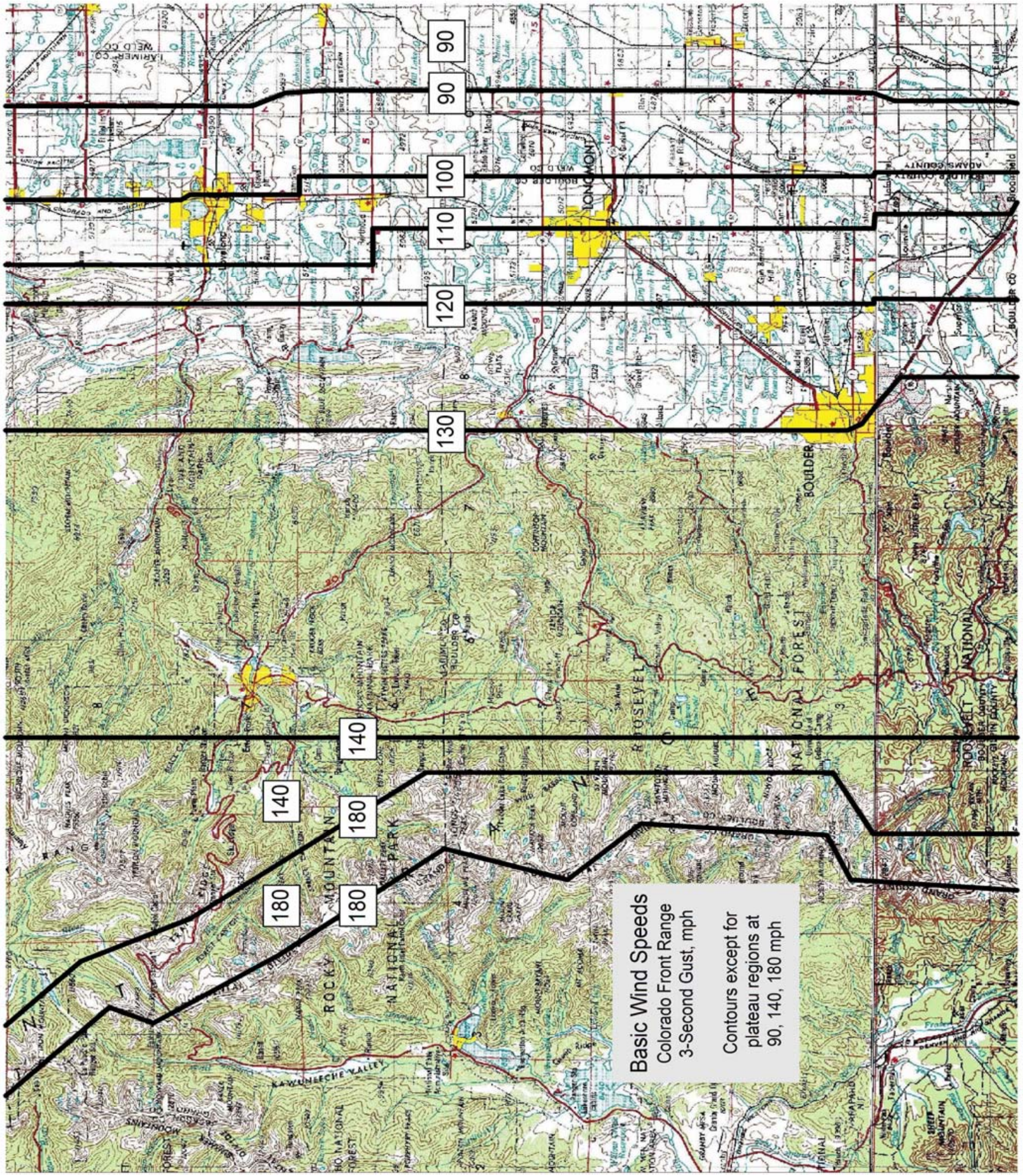

Figure 1 (Continued) Colorado Front Range Gust Map.

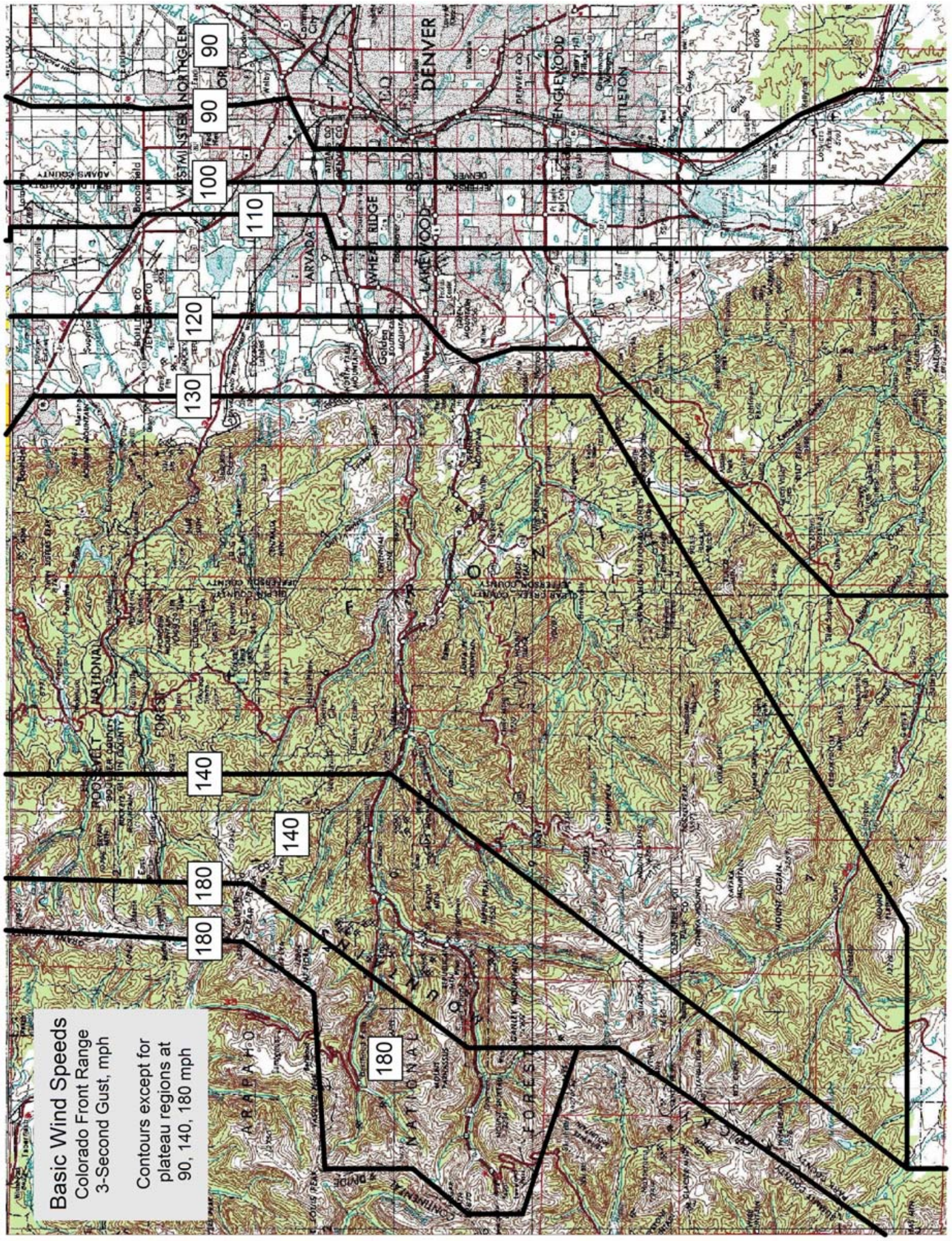

Figure 1 (Continued) Colorado Front Range Gust Map.

THE DATABASE

The database was assembled by student Jim Handy, under the direction of Colorado Assistant State Climatologist Nolan Doesken, during the 2004-2005 school year. The database is contained in an Excel spreadsheet called “Wind Gust Project.xls.” The file contains a page for each data source, including sites supported by government organizations, private data sources by individuals, and records from the publication *Storm Data*. (From the *Storm Data* page at NCDC: “Monthly issues contain a chronological listing, by states, of storm occurrences and unusual weather phenomena. Reports contain information on storm paths, deaths, injuries, and property damage. An "Outstanding storms of the month" section highlights severe weather events with photographs, illustrations, and narratives.”) Each set of data used for this project is discussed individually in the analysis section. In addition to the database from the Colorado State Climatologist’s Office, Cermak Peterka Petersen, Inc. maintains a database of gust wind speeds for use in its wind engineering consulting practice. Data from Denver Stapleton International Airport, Lowry Air Force Base in Denver, Buckley Air Force Base in Denver, and Jeffco Airport southwest of Broomfield were contributed from the CPP database. In addition, data from the Boulder Weather Log (Callahan, 1986) and from NOAA maps of measured high winds published in local newspapers were used.

ANALYSIS OF WIND SPEEDS

Two types of data from the database were used. First were largest yearly gust wind speeds at specific locations over a time period of several (or many) years. Second were individual spot observations of extreme wind speeds obtained from *Storm Data*. The yearly time series data were analysed as single station data using a Type I Extreme Value Distribution to estimate 50 and 500-year recurrence wind speeds. Because of potential differences in wind climatology from station to station, only the three Denver airports (Stapleton, Lowry, Buckley) were analysed as a “superstation” as outlined by Peterka and Shahid (1998). The rest were analysed as single stations. Individual speed reports from Storm Data were used “as is” without further treatment, assuming that a report of sufficient significance to be included in Storm Data has importance for identifying high wind speeds in this region.

A Type I Extreme Value Distribution has been used to define extreme design level wind speeds for non-hurricane speeds in the U.S., Peterka and Shahid (1998). In a typical analysis, yearly maximum gust wind speeds were fitted to

$$P(<U) = 1 - \frac{1}{T} = \exp(-\exp(-\frac{U - U_o}{a})) = \exp(-\exp(-y)) \qquad \text{Eq. 1}$$

in which *P* is the cumulative probability of not exceeding the value *U*, U_0 and *a* are mode and dispersion of the distribution (constants fitted to the data that describe the distribution), *y* is called the “reduced variate,” and *T* is the mean recurrence interval of speed *U*. Taking the natural log of both sides yields

$$y = -\ln[-\ln(1 - \frac{1}{T})] \qquad \text{Eq. 2}$$

that defines the relationship between reduced variate and mean recurrence interval.

From equation 1,

$$U = U_o + ay \qquad \text{Eq. 3}$$

Thus, a set of data that obeys a Type I distribution will plot as a straight line if U is plotted against y, with slope a and intercept U_o.

The database was developed with 4 or 5 highest speeds each year. A method exists to take advantage of this added data (instead of using just the single largest value each year) to provide an improved estimate of the extreme values. This approach was not used here because of simplicity of use of the yearly maximum, and because it was not evident that improved estimates based on short records would be of value. This is due in part to the large variability from station-to-station in small spatial regions.

The measured gust data and Type I Extreme Value fit to the data are shown in the Appendix. A typical fit to the Type I distribution is shown in Figure 2. In this figure, V50 and V500 are 50- and 500-year recurrence speeds from the distribution fit, and T = recurrence interval in years.

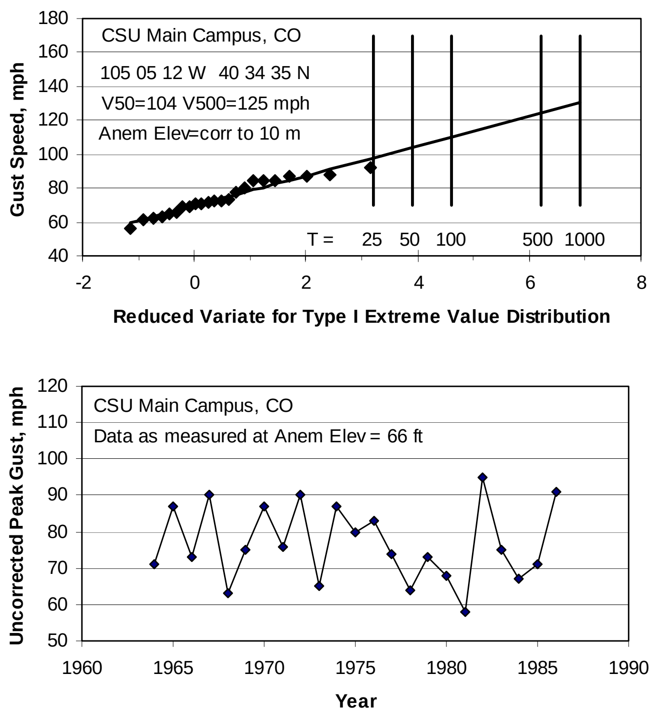

Figure 2. Type I Extreme Value Distribution fit to the Colorado State 1964-1986 record.

A brief discussion of the data and its fit to the probability distribution follows. Where latitude and longitude were not supplied with the data, an estimate was made from a digital topographical map. Where possible and reasonable, corrections to open country were made using an atmospheric boundary layer model as defined by ESDU (1993a, 1993b).

AERC (Figure 3) – Agricultural Engineering Research Center located at the Colorado State University foothills campus west of Overland Trail in Fort Collins. Anemometer is at 2 m above ground in an open field with relatively high grass and a mound of dirt about 1 m high less than 100 ft west of the anemometer. Data was transferred to 10 m using a 0.11 power law (Peterka and Shahid, 1998).

Figure 3. 2m anemometer at AERC.

Figure 4. 10m anemometer at Christman Field.

Bailey – Private anemometer near Bailey southwest of Denver. Height and exposure are unknown. No corrections for exposure were made.

Bonner Peak Ranch – Private anemometer near U.S. 287 north of Fort Collins. No information about the anemometer height or exposure is currently available. No corrections for exposure were made.

Boulder Downtown – Velocities for downtown Boulder were extracted from NOAA maps published in local newspapers at the times of high wind events in the Boulder area from the late 1960's through the early 1980's. Additional data was obtained from the Boulder Weather Log (Callahan, 1986) for the Boulder Camera office location and NCAR. Data were restricted to measurements near Broadway and Arapahoe, extending no further south than Baseline and no further east than the Parkway. Data from the NCAR site are included as a separate location. No information about the anemometer exposures is currently available. No corrections for exposure were made.

Boulder NBS Table Mountain – Data from NOAA maps published in local newspapers at the times of high wind events in the Boulder area from the late 1960's through the early 1980's, located primarily at the National Bureau of Standards site on Table Mountain north of Boulder. Some measurements just southwest of the site were used as well. No information about the anemometer exposure is currently available. No corrections for exposure were made.

Boulder NCAR Table Mesa – Data measured at the National Center for Atmospheric Research located on Table Mesa southwest of Boulder. Data from NOAA maps published in local newspapers at the times of high wind events in the Boulder area from the late 1960's through the early 1980's. Some data was obtained from the Boulder weather Log (Callahan, 1986). No information about the anemometer exposure is currently available. No corrections for exposure were made.

Christman Field (Figure 4) – Located on the Colorado State University foothills campus west of Overland Trail. Anemometer is located on a 10m tower in well-exposed open field. No corrections for exposure were thought necessary to correct to open country.

Coal Creek Canyon (Figure 5) – Private anemometer located at 38 ft above ground and 12 ft above the house rooftop at a personal residence in Coal Creek Canyon. Longitude and latitude were provided with the data. Some acceleration of flow over the house and some shielding by upwind foliage (relative to an open country exposure) may also occur. No corrections for exposure were attempted.

Figure 5. Coal Creek Canyon private anemometer.

Colorado State University Main Campus (Figure 6) – From 1964-1986, the anemometer was at 66 ft. From 1990-2003, the anemometer was at 60 ft on the same shortened tower. An automated anemometer at 10m was active at the same site from 1997-2004. Trees growing west of the site caused an apparent decrease in wind speed as the anemometer was shielded in the wake of the trees. Significant reductions in wind speed that are difficult to quantify for this case are expected downwind of such obstacles (FAA, 1989). Photographs taken in 2005 show that the current anemometer at 10m is well below the height of the shielding trees to the west. The current 10m anemometer is not useful for defining wind speeds for locations other than the site itself. For the gust map, only the 1964-1986 data were used; a correction for the upwind suburban environment, and lack of significant structures close to the anemometer during this period, were accounted for. The correction to 10m in open country was only a few percent.

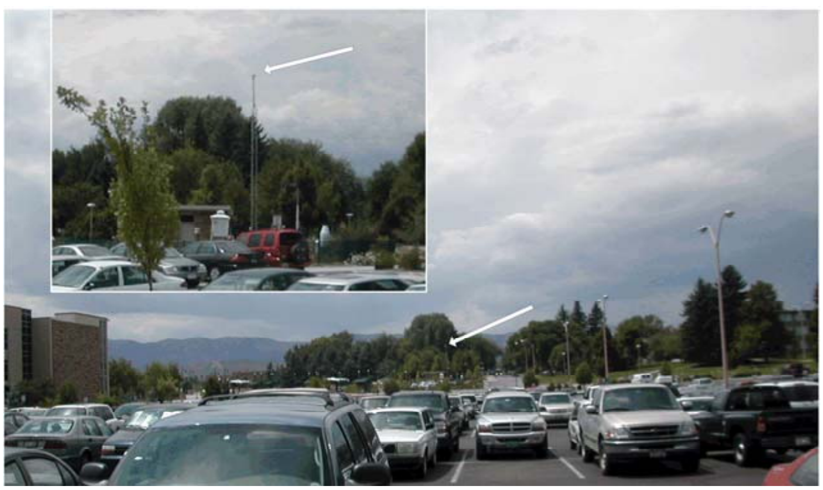

Figure 6. Colorado State University main campus anemometer in 2005, looking west.

In 1999, a measurement of 77 mph was recorded at the 10m anemometer at the automated station. The largest speed for the 60 ft anemometer at the same location the same year was 57 mph. One or the other is not a credible measurement (see the appendix for the two measurement records). The 77 mph speed was ignored by fitting the type I distribution only to the other available years.

Georgetown Lake (Figure 7) – The anemometer is located on the west side of the lake north of Georgetown. The site building may induce some acceleration at the anemometer location. No corrections for exposure were attempted.

Figure 7. Georgetown Lake looking northeast.

Figure 8. Summit View site looking west.

Georgetown South – The details of the location, height and exposure are not known. No corrections for exposure were made. The speeds measured at this location are significantly below those at Georgetown Lake. The lake data was relied upon more heavily in defining speed zones in the map.

Jeffco Airport – The airport anemometer data has been recorded at NCDC since 1982. The data, obtained at an elevation of 20 ft, were corrected to 10m using a 0.11 power law (Peterka and Shahid, 1998). The site is likely to be open country, given that it is on a treeless plain with no structures to the west for almost the entire record.

Mines Peak – This site is on top of a mountain about a mile east of Berthoud pass. There are a number of communications structures on this peak, and the relationship of the anemometer to those structures is not known. No corrections to the data were made.

Niwot Ridge – This set of 3 sites is at an ecological research site. Each of the anemometers has been active intermittently. D-1 is located on top of the east-west oriented ridge 2.6 km east of the north-south ridge defining the Continental Divide at a height above ground of 2m. The Saddle is located somewhat east and a little lower in elevation from D-1 in a saddle between two peaks on the ridge; height above ground is 2m. Both D-1 and Saddle are above timberline and should be reasonably well exposed, although specific local terrain features are not known. Site C-1 is located on the southeast flank of the ridge at lower elevation below timberline. The anemometer height was defined as 0.7m above the general level of the trees. The decrease in wind speed over time at this site may – or may not – indicate that the trees are gradually growing above the anemometer height. No corrections for exposure or anemometer height were made for any of these anemometers.

Red Feather Remote Automated Weather Station (RAWS) – The anemometer is not at the location provided with the data and specified in Table 1. The exposure and height of this anemometer are not known. No correction for exposure or height was made.

Rocky Flats – Measurements were made at this former nuclear processing facility south of Boulder near Highway 93. Exact location of the anemometer, exposure, and height are unknown. The area is a treeless plain, so the only exposure issues would have been structures in the processing facility. No corrections for height or exposure were made.

Rustic – Private anemometer apparently located near the bottom of Cache La Poudre Canyon near the community of Rustic. Height and exposure are unknown. Note that the speeds at Rustic are very similar to those at Red Feather over the time period of Rustic data except for two years, one (1992) in which Red Feather is larger and one (2003) in which Rustic is larger. The difference in design wind speed from these two stations is due primarily to higher speeds measured at Red Feather prior to start of the Rustic record. These two stations may converge to similar design speeds after more years of data collection.

Stapleton – This is a superstation (Peterka and Shahid, 1998) composed of Stapleton International Airport, Lowry Air Force Base, and Buckley Air Force Base. Almost all data represents a location just east of Quebec Street in east Denver. This region appears to be outside the Front Range high wind area. This data was recorded at NCDC and was corrected to open country exposure using a 0.11 power law in height.

Summit View (Figure 8) – This anemometer is at 10m above ground located at 820 Summit View Drive east of Fort Collins and west of I-25. The anemometer is shielded by trees just to the west, and a light suburban area extending west to the heavier suburban area of Fort Collins. The data were corrected to open country assuming a suburban exposure; it is likely that the tree line in Figure 8 provides more sheltering than the assumed typical suburban location (FAA, 1989).

Wind speeds from the Type I Extreme Value Distribution fit are summarized in Table 1. The Colorado State University Main Campus site has been analysed three ways to demonstrate the shielding of recent data. Many sites have estimated locations based on the author's rough knowledge of where these stations might be located. Speeds for both 50- and 500-year recurrence intervals are given. The 500-year speed divided by $\sqrt{1.5}$ is listed since this is the design speed given in the wind map of ASCE 7-02 (and all ASCE 7 wind maps since ASCE 7-98). Table 1 shows that the average ratio $(V500/V50)^2 = 1.45$, is very close to the 1.5 value found for other non-hurricane regions (Peterka and Shahid, 1998). The speeds in the last column were used in formation of the map of Figure 9, and are shown on the map in ovals as speeds without underlines.

The use of a design wind speed represented by $V500/\sqrt{1.5}$ originated from the need to have risk consistent designs across regions with different rates of increase of wind speed with recurrence interval. For example, speeds in hurricane regions increase sufficiently fast that design to the 50-year speed that was the standard procedure prior to ASCE 7-98 produced, in some coastal areas, structures that were vulnerable to damage for a 200-year wind. For areas inland and not in hurricane influence areas, the same structure designed for a 50-year wind was vulnerable to damage at about a 500-year recurrence event. The use of the current design speed eliminates most of that risk differential.

Table 2 shows the recorded maximum wind speeds for stations in Table 1, and the year in which they were measured. Where corrections were made for exposure, the corrected measurement is shown. This information is shown graphically in the appendix as the largest plotted wind speed in the Type I plot. The uncorrected maximum speed is shown in the time series graph in the appendix. The largest gust speeds are 168 mph measured at site D-1 on Niwot ridge near the Continental Divide, and 147 mph at NCAR on elevated Table Mesa just southwest of Boulder.

Wind speeds obtained from Storm Data are shown in Table 3. Only the largest speed recorded or estimated for each location is cited, along with the year. These speeds are shown on the map of Figure 9 as underlined values in ovals. The largest speed is 127 mph on Sugarloaf Mountain; there are at least 3 mountains called sugarloaf (west of Fort Collins, West of Boulder, and southeast of Idaho Springs). The reference in Storm Data did not specify which one, but other high winds cited that day might indicate the one west of Boulder. This speed was not placed on the map because of this uncertainty. Speeds of 125 mph were cited for Buckhorn Mountain west of Fort Collins and a location 6 miles northwest of Masonville, again west of Fort Collins.

Table 1. Summary of Extreme Value Analysis

	Station Name	Location	Record	Years Data	50-yr Spd mph	500-yr Spd mph	(500-yr / 50-yr) ^ 2	500-yr Spd / SQRT(1.50)
1	AERC	# 105 08 12 W 40 35 42 N	1997-2004	6	83	101	1.48	83
2	Bailey	105 19 30 W 39 22 15 N	1995-2004	10	92	122	1.76	100
3	Bonner Peak Ranch	# 105 11 W 40 44 N	1990-2004	15	98	112	1.30	91
4	Boulder - downtown	# 105 15 30 W 40 01 00 N	1963-1980	18	129	160	1.54	131
5	NBS Table Mountain	# 105 15 W 40 07 N	1965-1983	8	126	157	1.57	128
6	NCAR Table Mesa	# 105 16 26 W 39 58 42 N	1967-1983	13	162	189	1.37	154
7	Christman Field	# 105 08 16 W 40 35 26 N	1997-2004	8	84	98	1.38	80
8	Coal Creek Canyon	105 23 28 W 39 52 36 N	1985-2005	21	96	110	1.31	90
9	CSU Main Campus 60 ft*	# 105 05 12 W 40 34 35 N	1964-2003	37	100	122	1.48	100
9a	CSU Main Campus 64-86	# 105 05 12 W 40 34 35 N	1964-1986	23	104	125	1.43	102
9b	CSU Main Campus Auto*	# 105 05 12 W 40 34 35 N	1997-2004	9	70	81	1.34	66
10	Georgetown Lake West	# 105 42 W 39 43 N	2000-2004	5	148	175	1.40	143
11	Georgetown South	# 105 42 W 39 42 N	1995-2004	10	95	116	1.50	95
12	Jeffco Aprt	# 105 07 W 39 54 N	1982-2004	19	116	141	1.50	115
13	Mines Peak	105 45 W 39 48 N	1969-1975	7	149	176	1.30	144
14	Niwot Ridge C-1	# 105 32 W 40 02 N	1966-1986	10	108	129	1.41	105
	SE flank of ridge							
15	Niwot Ridge D-1	# 105 37 01 W 40 03 34 N	1966-2002	27	174	223	1.64	182
	2.6 km E Continental Divide							
16	Niwot Ridge Saddle	# 105 35 28 W 40 03 16 N	1990-2002	10	160	203	1.62	166
	Saddle on Niwot Ridge							
17	Red Feather RAWS	105 34 20 W 40 47 53 N	1988-2004	17	137	172	1.58	140
18	Rocky Flats	# 105 13 W 39 53 N	1963-1977	8	130	154	1.39	126
19	Rustic	# 105 35 W 40 42 N	1992-2003	12	95	104	1.21	85
20	Stapleton - East Denver	Stapleton, Lowry, Buckley	1946-1990	66	80	92	1.34	75
		# 104 53 W 39 46 N						
21	Summit View*	105 01 W 40 35 N	1991-2004	14	84	98	1.35	80
						Average =	1.45	

* = sheltered by upwind trees or buildings
\# = estimated from digital topo map

Some stations are listed with relatively low speeds in comparison to most of the high wind citations. These were included to demonstrate the lack of high winds in certain locations (for example east of the 90 mph contour) less susceptible to downslope winds.

MAP SPEED CONTOURS

Design wind speeds from Table 1, last column and Storm Data individual measurements were placed in ovals on a map of the Front Range, with Type I values not underlined and Storm Data values underlined. Locations for Storm Data citations may be approximate, since the locations in Storm Data are often not specific. Figure 9 shows the data and contours selected to fit the data.

The data set as displayed on the map does not form a continuous and simple set of contours. If exact contours could somehow be known, it is likely that they would be exceedingly detailed and rapidly varying in space, since accelerations and shielding caused by terrain and forests should cause dramatic changes over short distances. As examples, Georgetown has two design gust speeds within a short distance, developed from a Type I analysis, that vary from 95 to 143 mph.

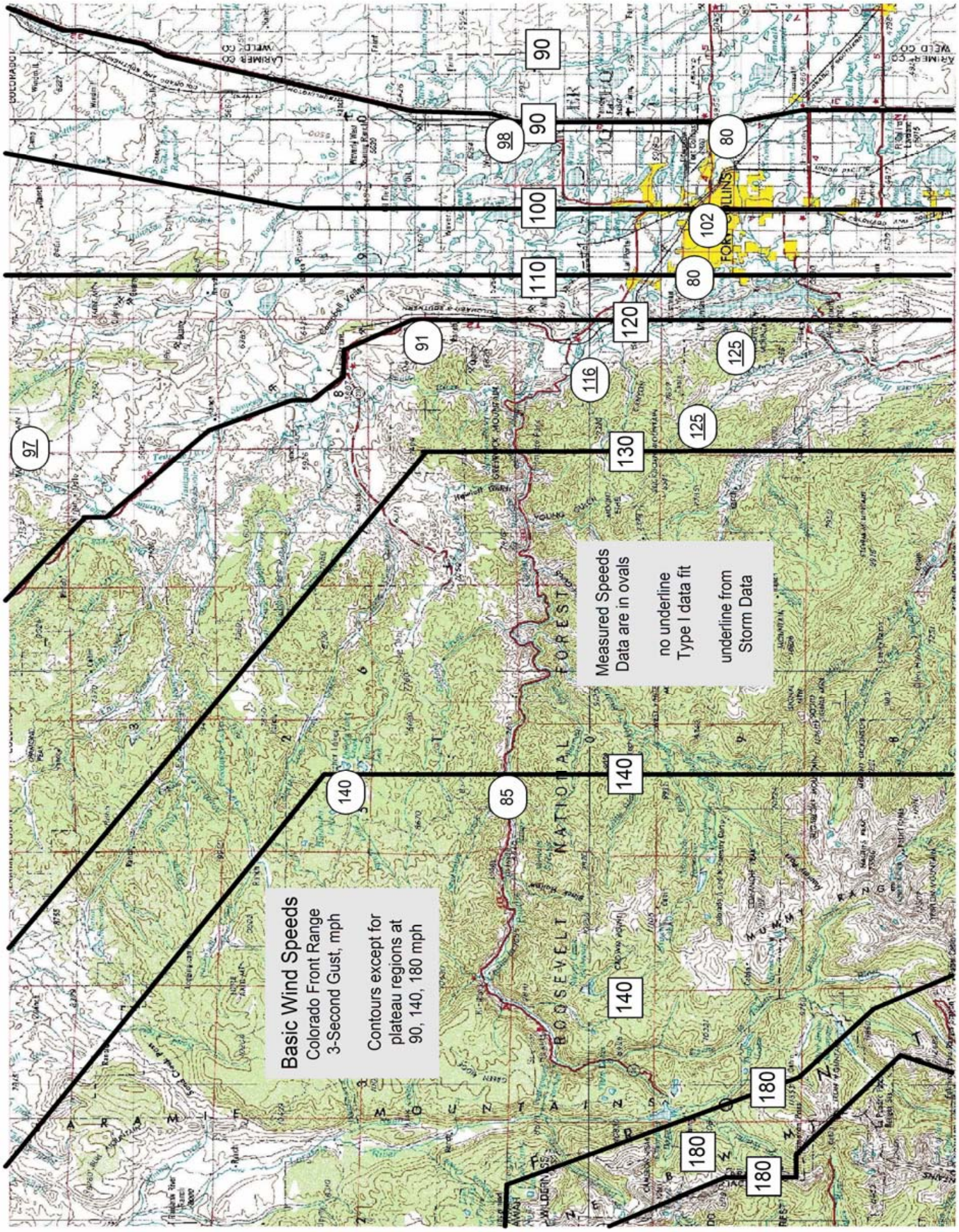

Figure 9 Colorado Front Range Gust Map annotated with measured speeds.

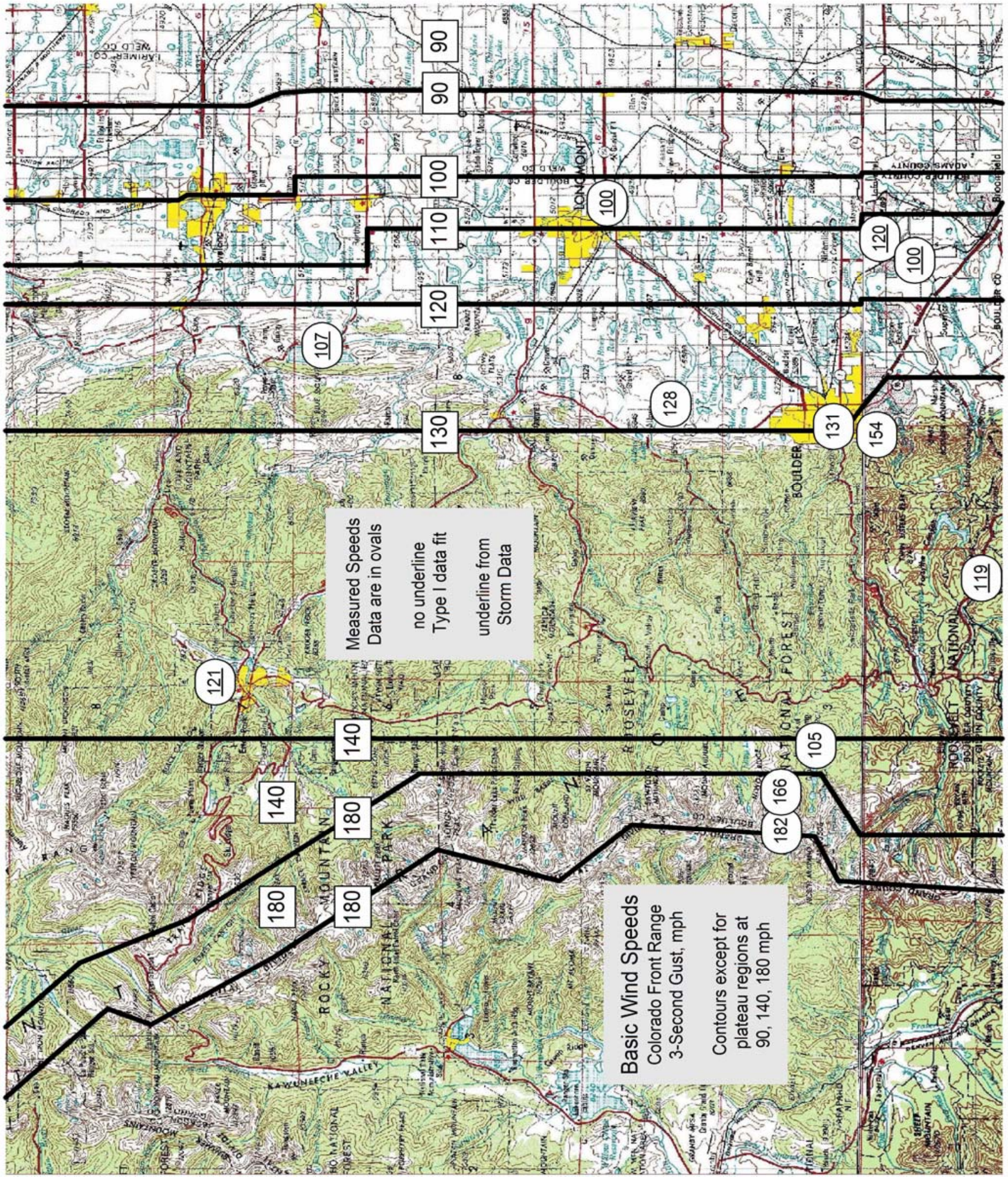

Figure 9 (Continued) Colorado Front Range Gust Map annotated with measured speeds.

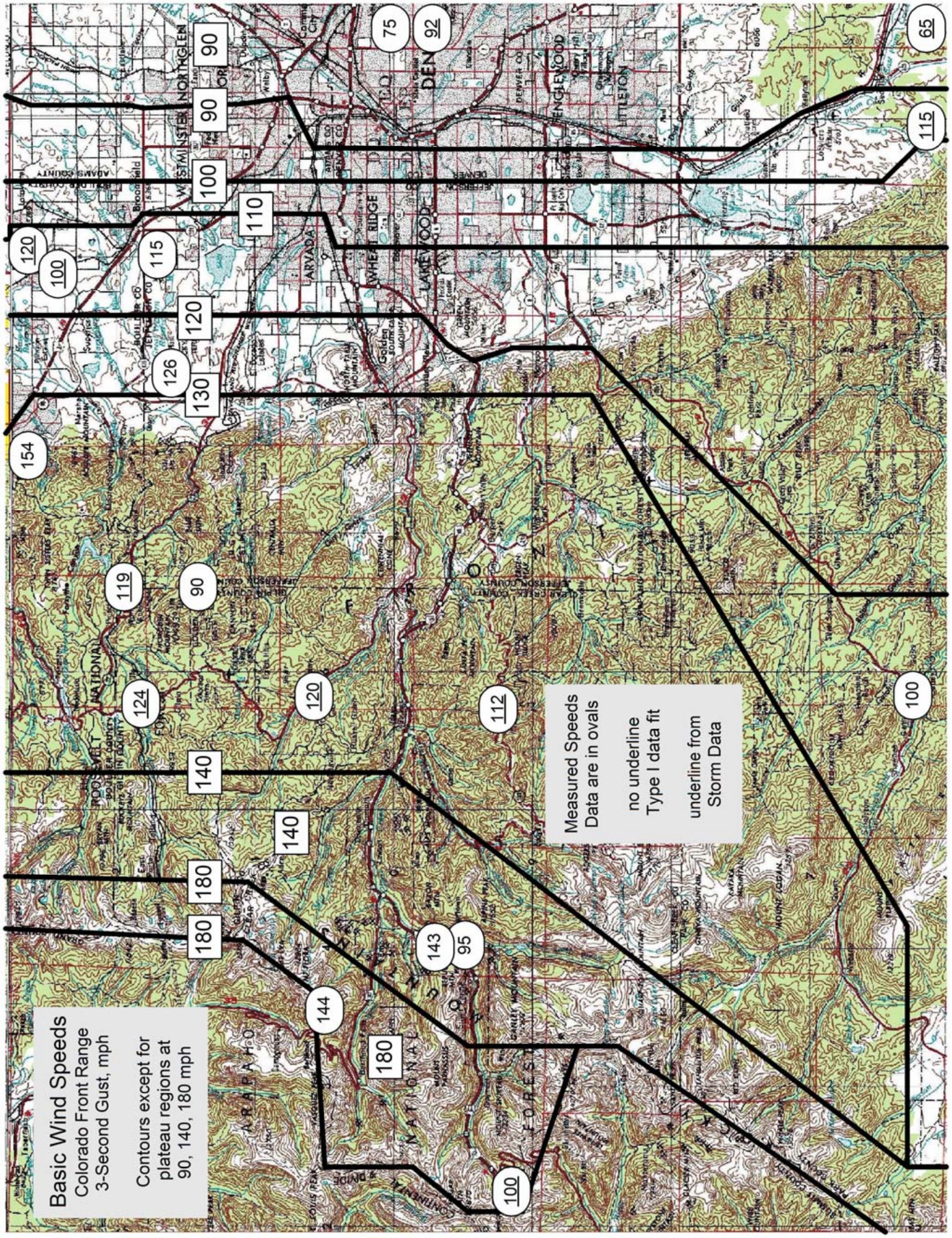

Figure 9 (Continued) Colorado Front Range Gust Map annotated with measured speeds.

Table 2. Maxima in Recorded Data at Stations in Table 1

	Station Name	Gust Speed mph	Year	Years of Record
1	AERC	65 *	2004	6
2	Bailey	72	2000	10
3	Bonner Peak Ranch	91	1999	15
4	Boulder - downtown	120	1978	18
5	NBS Table Mountain	97	1965	8
6	NCAR Table Mesa	147	1971	13
7	Christman Field	73	1999	8
8	Coal Creek Canyon	88	1998	21
9	CSU Main Campus 64-86	98 *	1982	23
10	Georgetown Lake West	123	2004	5
11	Georgetown South	88	1996	10
12	Jeffco Aprt	97 *	1988	19
13	Mines Peak	130	1972	7
14	Niwot Ridge C-1	90	1968	10
15	Niwot Ridge D-1	168	1998	27
16	Niwot Ridge Saddle	136	1996	10
17	Red Feather RAWS	128	1990	17
18	Rocky Flats	110	1977	8
19	Rustic	87	2001	12
20	Stapleton-Lowry	80 *	1964	66
21	Summit View	78 *	1996	14

* = corrected for exposure

After living in a downslope wind region for more than 50 years, including Lakewood and Fort Collins, and being aware of the characteristics of these storms along the Front Range, this author has an understanding of these storms that goes beyond the bare data. The physical characteristics of the storms indicates that areas such as Boulder that have a short distance from Continental Divide to plains should have higher speeds than areas farther from the Divide. Areas south of Denver where the Continental Divide turns sharply west should experience lower wind speeds. Downslope winds are often higher in the foothills west of the mountain-plain interface, but should not continue to increase in speed at higher elevations near the Continental Divide.

The concentration of scientific attention and news reports of high wind speeds in the Boulder area in the late 1960's through the early 1980's, combined with personal experience of the author living in central Fort Collins for 34 years, provides an indication that there may be a decades-long variability in intense downslope winds in the Front Range region. Unfortunately, no one solid meteorological record covers sufficient time to verify this hypothesis. For this reason, there was no attempt to adjust data or wind speed contours for this effect. If the decades-long variability exists with higher downslope speeds in mid 1960's to early 1980's, then the many areas where Storm Data entries began only in the 1990's may have missed earlier higher speed events.

Near the Continental Divide, measurements indicate a higher speed phenomenon that is likely a result of the jet stream dipping to lower elevations as it crosses the mountain range, causing high speeds near the high ridge line. The speeds from this phenomenon would be expected to decrease somewhat at lower elevations.

Table 3. Summary of Data from Storm Data

Selected Storm Data Maximum Gusts

	Station Name	Gust Speed mph	Year
1	Bailey	83	1994
2	Bingham Hill (4 mi NW)	116	1999
3	Blackhawk	120	1996
4	Buckhorn Mtn (10.5 mi NW Masonville)	125	1998
5	Carter Lake	107	1999
6	Castle Rock	65	1996
7	Cherry Creek Reservoir	85	1973
8	Coal Creek Canyon	104	1999
9	Estes Park	121	1995
10	Lafayette	120	1999
11	Larkspur	59	2003
12	Longmont	100	1999
13	Louisville	100	1999
14	Loveland Ski Area	100	1999
15	Masonville (6 mi N)	125	1999
16	Monument (3.5 mi SW)	115	1981
17	Rollinsville	124	1999
18	Squaw Mountain (4 mi S Idaho Spgs)	112	1995
19	Sugarloaf Mtn (which one not specified)	127	1999
20	Virginia Dale (7 mi NE)	97	2000
21	Watkins	92	2000
22	Wellington	98	2000
23	Wondervu (8 mi SW Boulder)	119	1999

Wind speeds may change rapidly over short distances due to terrain and forests. The intent of the contours and zones on the map was to represent speeds as gusts at 10m in open areas without shielding from forests of local terrain. Where local terrain or forests might be expected to locally increase or decrease winds speeds, then appropriate analysis or testing might be used to modify the speeds shown on the map.

Contour boundaries were placed on the map keeping them roughly parallel to the Continental Divide. The highest speeds at the Continental Divide are expected where there is an open valley upwind and amplification over the ridge is maximized. For this reason, the 180 mph zone is restricted to these areas.

CONTOUR WORD DESCRIPTION

To assist in defining the locations of contours, a word description of each speed contour is as follows:

90 mph Contour
Federal Blvd. in Denver, south to U.S. 85 NW of Sedalia, follows 85 SSE to west of Sedalia, then due south. Federal Blvd. in Denver north to I-76, I-76 ENE to I-25, I-25 north to Wyoming line.

100 mph Contour
Sheridan Blvd. at the west edge of Denver due south to a point west of Sedalia, roughly SE to a point near the plains/mountains interface, then south.
Sheridan Blvd. at the west edge of Denver due north along the Boulder County/Adams County line, continuing along the Boulder County/Weld County line to Colorado 60 south of Loveland, west on 60 to U.S. 287, north on 287, leaving 287 in north Fort Collins when 287 turns west, continuing due north to about Buckeye, then roughly NNE to the Wyoming line.

110 mph Contour
Kipling in Lakewood south to map border.
Kipling in Lakewood north to I-76, ENE on I-76 to Wadsworth, Wadsworth north into Broomfield to U.S. 287, NW on 287 following 287 north out of Broomfield, north on 287 through Longmont to CO 56 west of Berthoud, west on 56 to 105^{o} 08’ (near 21 RD), north on this longitude (approximately 21 RD in Loveland and Overland Trail in Fort Collins) to the Wyoming line.

120 mph Contour
SW on I-70 from the intersection of the longitude line 105^{o} 10’ (just east of the I-70 & Colfax interchange) to C-470, south on C470 to U.S. 285, SW along 285 to the Jefferson County Line, south on the Jefferson County line.
North from I-70 on approximately longitude 105^{o} 10’ (just east of the I-70 & Colfax interchange) to Baseline Road east of Boulder, west to 75th street, north on this longitude line (approximately longitude 105^{o} 10.8’) to a point on US 287 SE of The Forks (NW of Fort Collins) where 287 turns west from this longitude, then approximately NW on 287 to the Wyoming line.

130 mph Contour
South from U.S. 36 SE of Boulder along a longitude (105^{o} 14’) approximating the location of Colorado 93 to a point directly west of the intersection of C-470 and U.S. 285, SW to the summit of Mount Blaine (NE of Jefferson in South Park), west to the west edge of South park, then south.
From the intersection of CO 93 and U.S. 6 SE of Boulder, follow 93 NW through Boulder to Broadway, north on Broadway (approximately 105^{o} 17’) to a point north of the Poudre River at latitude 40^{o} 45’, then approximately NW to the Wyoming line.

140 mph Contour
From the intersection of I-70 with longitude 105^{o} 33’, southwest to connect to the 130 mph contour, then south on top of the 130 mph contour.
From the intersection of I-70 with longitude 105^{o} 33’, north on that longitude to a point north of the Red Feather lakes, then approximately NW to the Wyoming line.

180 mph Contour
The west contour follows the Continental Divide.
The east contour follows roughly parallel but east of the Continental Divide.

DISCUSSION

Based on the data presented in this report, there are several observations that can be made about the data.

While wind direction has not been presented explicitly, both recorded wind directions and knowledge of the meteorological events giving rise to this special wind region shows that the higher winds in this region are due to winds from SSW through NNW, roughly 45 degrees to the N/S orientation of the high ridgeline that induces the high speeds. Thus, winds from roughly wind azimuths of 340 through 0 to 200 degrees can use 90 mph peak gust at 10 m in open terrain for design of main wind resisting systems under the provisions of IBC or ASCE 7. Cladding pressure design under IBC or ASCE 7 cannot use this wind speed reduction since the provisions in ASCE 7 do not specify the wind direction giving the highest cladding pressures. Figure 10 illustrates these concepts.

Many of the wind records used in this analysis are short. The Type I Extreme Value Distribution used for this analysis works best for long records of 100 or more years of observation (the standard deviation of prediction error decreases as the inverse of the square root of record length). For shorter records, the likelihood of prediction error increases and is statistically biased to higher wind speeds. This means that predictions using short records are somewhat more likely to predict speeds too high than too low. As more data is acquired in the future at the various stations, it is more likely that contour locations will move slightly to the west than it is that the contours will move slightly to the east. This situation is consistent with good engineering practice of designing for slightly higher loads in the presence of uncertainty. If the conjecture that speeds from the mid 1960's through the early 1980's were higher than subsequent experience due to a possible decades-long variability, the contours as drawn in Figure 1 may not be higher than a longer-term record would indicate due to the predominance of possibly lower wind speeds in 1980's and 1990's data in many of the records.

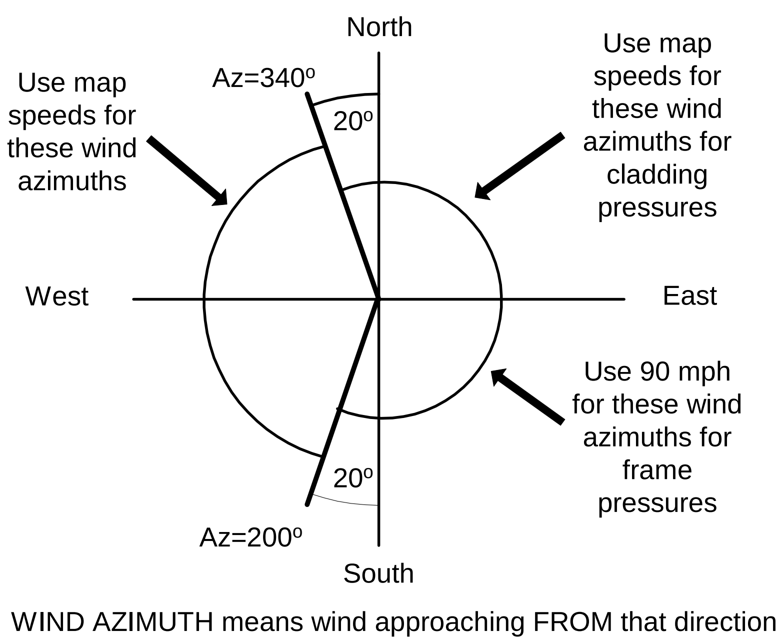

Figure 10. Design speed variation with wind direction

RECOMMENDATIONS FOR THE FUTURE

The lack of long records at the various sites used in this study significantly impacted the ability to accurately place contours on the map of Figure 1. The lack of data in many regions was an even larger impediment to placing contours accurately. In particular, the lack of wind speed data in the suburbs west of Denver and in the mountains made the map preparation more difficult.

It is recommended that communities install one or more anemometers to measure wind speeds and directions in their areas. Anemometer placement should be at least 1.5 to 2 times the heights of typical structures or trees in the area. For suburban areas, this means anemometers at 20 meters (60 ft) or higher. In the mountains, the tree height often dictates anemometer heights of nearly 30 m (100 ft). The author has extensive experience in siting of anemometers to measure wind speeds (as a co-author of the anemometer siting provisions of FAA, 1989) without significant interference of nearby shielding elements such a buildings or trees. This information can be transferred to volunteers who can advise on specific locations.

GUIDE FOR REPRODUCTION

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REFERENCES

ASCE 7-02 (2003), “Minimum Design Loads for Buildings and Other Structures,” *Standard ANSI/ASCE 7–02*, American Society of Civil Engineers and American National Standards Institute, New York.

Callahan, William G. (1986), Boulder Weather Log, Upslope Press, Boulder, Colorado.

ESDU (1993a), Strong winds in the atmospheric boundary layer, Part 1: mean hourly wind speeds, ESDU Report 82026, ESDU International.

ESDU (1993b), Strong winds in the atmospheric boundary layer, Part 2: discrete gust speeds, ESDU Report 83045, ESDU International.

FAA (1989), Siting Guidelines for Low Level Windshear Alert System (LLWAS) Remote Facilities, Appendix 3: Guidelines for Siting Individual LLWAS Anemometers, FAA Order 6560.21A. Appendix 3 prepared by Jon Peterka and Michael Poreh.

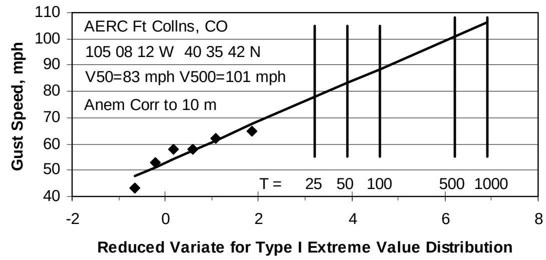
Peterka (1992), "Improved Extreme Wind Prediction for the United States, *Jl Wind Engr. and Ind. Aero.*, Vol. 41, 533-541.

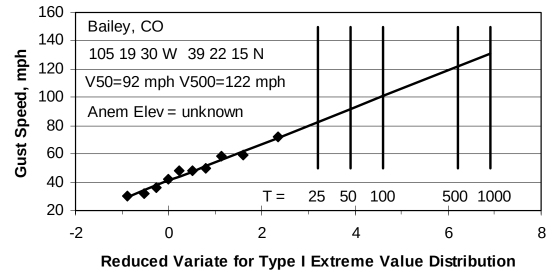
Peterka J.A. and Shahid, S. (1998), "Design gust Wind Speeds for the U.S.," Journal of Structural Engineering, Vol. 124, 207-214.

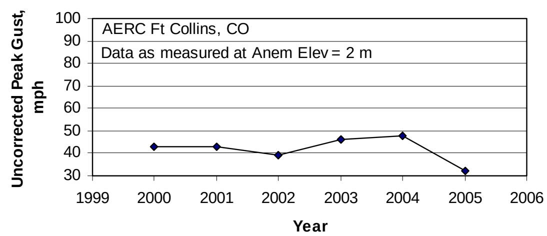
Storm Data, Available monthly from the National Climatic Data Center, Ashville, North Carolina, www.ncdc.noaa.gov.

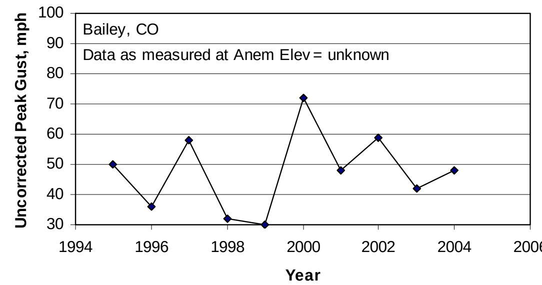
APPENDIX

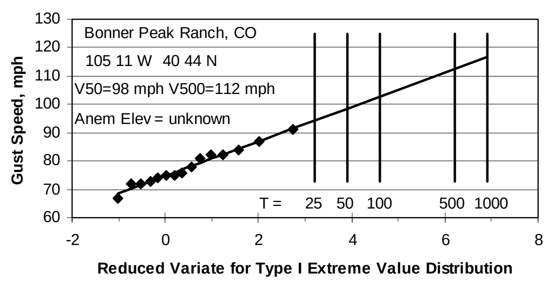
Type I Extreme Value Distribution
And Measured Yearly Maxima
For Each Station

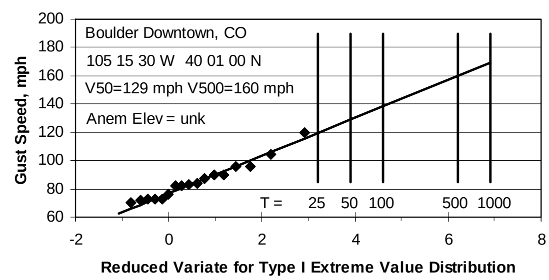

AERC Ft Collns, CO
105 08 12 W 40 35 42 N
V50=83 mph V500=101 mph
Anem Corr to 10 m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

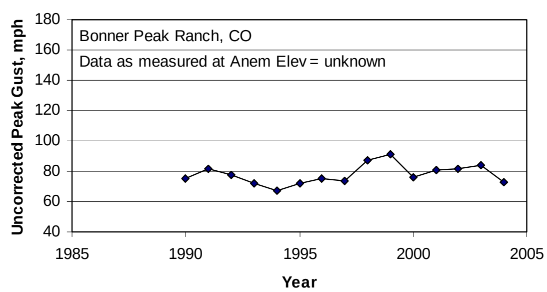

Bailey, CO
105 19 30 W 39 22 15 N
V50=92 mph V500=122 mph
Anem Elev = unknown
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

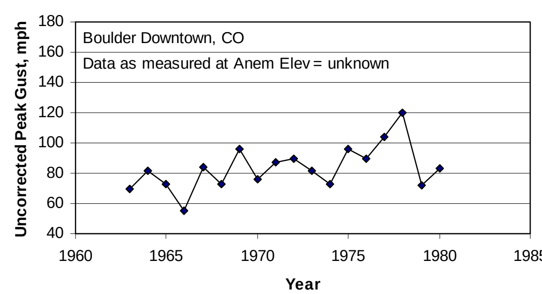

AERC Ft Collins, CO
Data as measured at Anem Elev = 2 m
Uncorrected Peak Gust, mph
Year

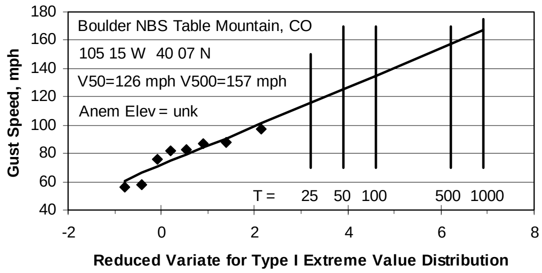

Bailey, CO
Data as measured at Anem Elev = unknown
Uncorrected Peak Gust, mph
Year


Bonner Peak Ranch, CO
105 11 W 40 44 N
V50=98 mph V500=112 mph
Anem Elev = unknown
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution


Boulder Downtown, CO
105 15 30 W 40 01 00 N
V50=129 mph V500=160 mph
Anem Elev = unk
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution


Bonner Peak Ranch, CO
Data as measured at Anem Elev = unknown
Uncorrected Peak Gust, mph
Year


Boulder Downtown, CO
Data as measured at Anem Elev = unknown
Uncorrected Peak Gust, mph
Year


Boulder NBS Table Mountain, CO
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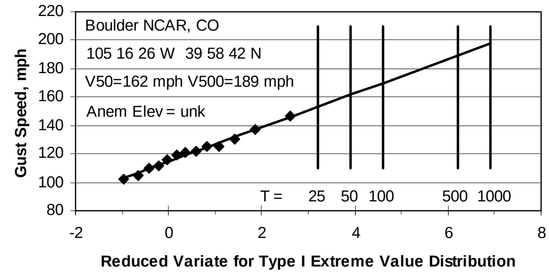
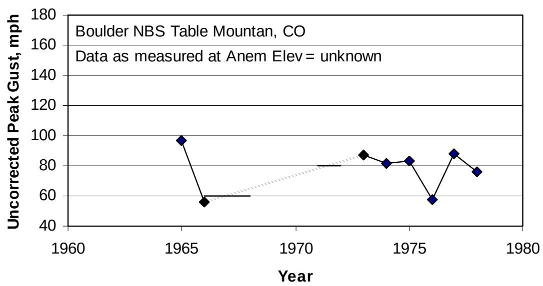
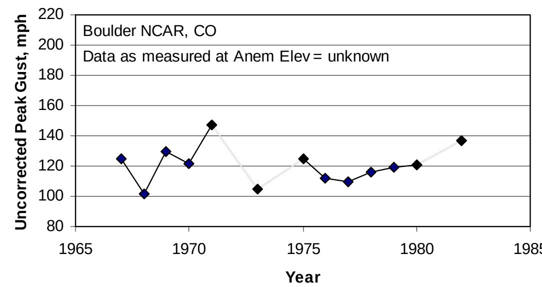
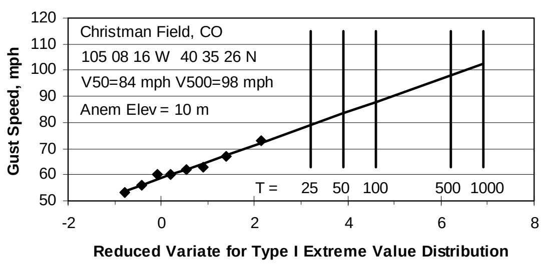
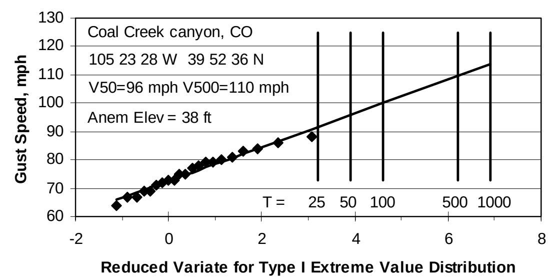
V50=126 mph V500=157 mph
Anem Elev = unk
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

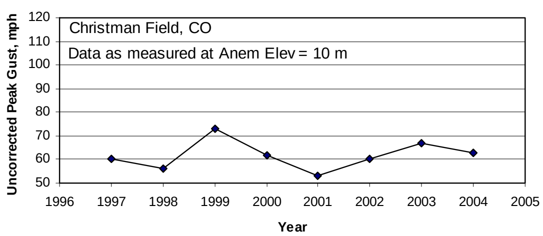

Boulder NCAR, CO
105 16 26 W 39 58 42 N
V50=162 mph V500=189 mph
Anem Elev = unk
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

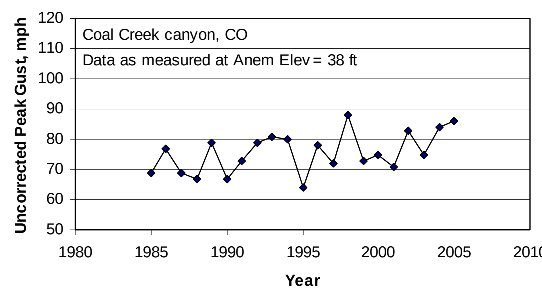

Boulder NBS Table Mountan, CO
Data as measured at Anem Elev = unknown
Uncorrected Peak Gust, mph
Year

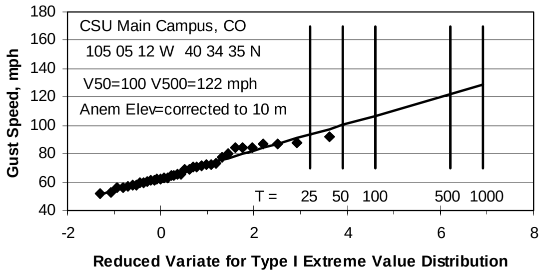

Boulder NCAR, CO
Data as measured at Anem Elev = unknown
Uncorrected Peak Gust, mph
Year

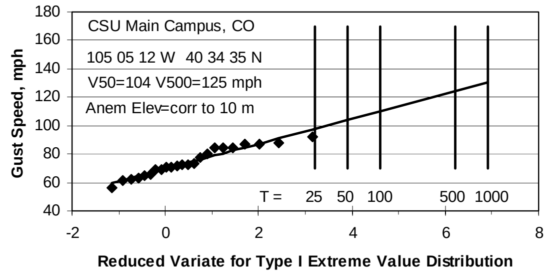

Christman Field, CO
105 08 16 W 40 35 26 N
V50=84 mph V500=98 mph
Anem Elev = 10 m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

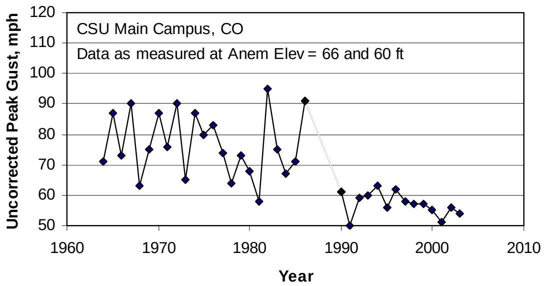

Coal Creek canyon, CO
105 23 28 W 39 52 36 N
V50=96 mph V500=110 mph
Anem Elev = 38 ft
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

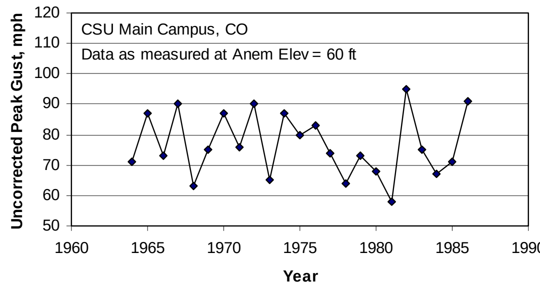

Christman Field, CO
Data as measured at Anem Elev = 10 m
Uncorrected Peak Gust, mph
Year

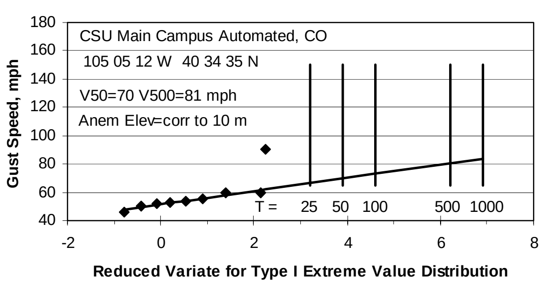

Coal Creek canyon, CO
Data as measured at Anem Elev = 38 ft
Uncorrected Peak Gust, mph
Year

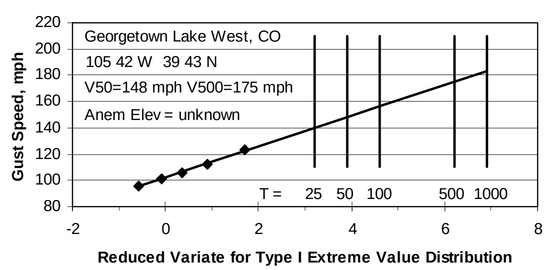

CSU Main Campus, CO
105 05 12 W 40 34 35 N
V50=100 V500=122 mph
Anem Elev=corrected to 10 m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

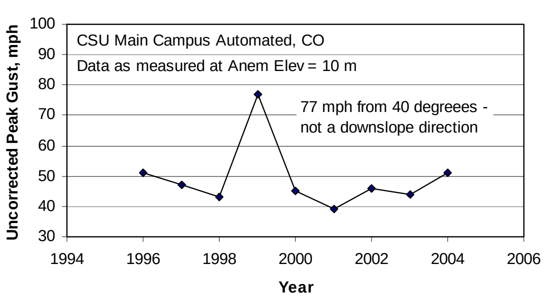

CSU Main Campus, CO
105 05 12 W 40 34 35 N
V50=104 V500=125 mph
Anem Elev=corr to 10 m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

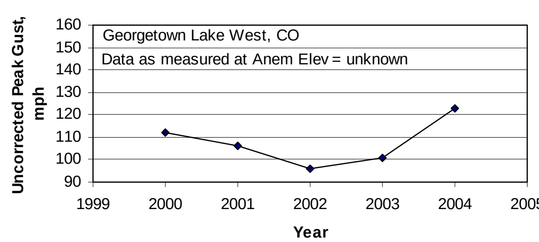

CSU Main Campus, CO
Data as measured at Anem Elev = 66 and 60 ft
Uncorrected Peak Gust, mph
Year

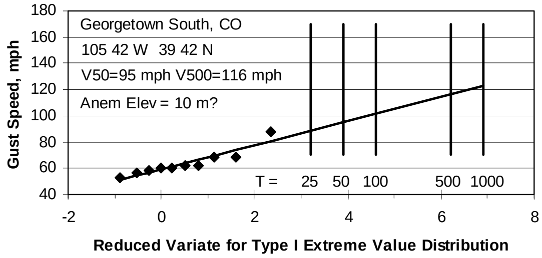

CSU Main Campus, CO
Data as measured at Anem Elev = 60 ft
Uncorrected Peak Gust, mph
Year

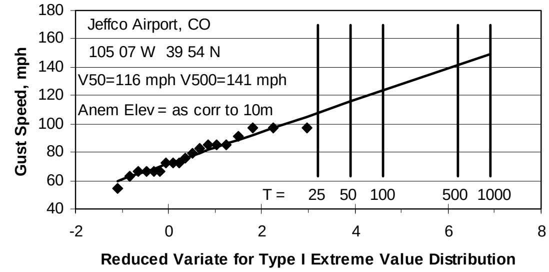

CSU Main Campus Automated, CO
105 05 12 W 40 34 35 N
V50=70 V500=81 mph
Anem Elev=corr to 10 m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

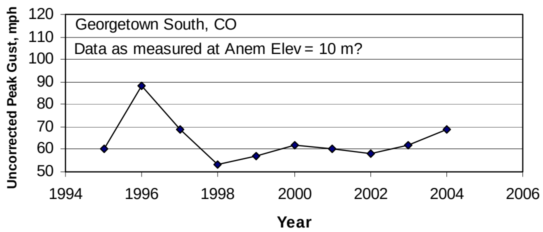

Georgetown Lake West, CO
105 42 W 39 43 N
V50=148 mph V500=175 mph
Anem Elev = unknown
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

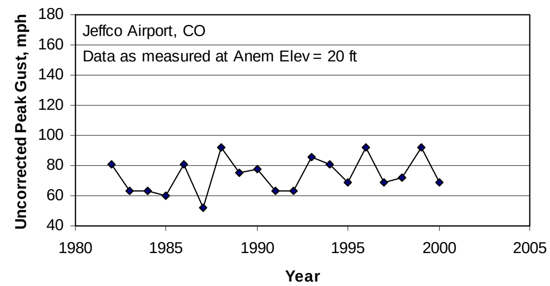

CSU Main Campus Automated, CO
Data as measured at Anem Elev = 10 m
77 mph from 40 degrees -
not a downslope direction
Uncorrected Peak Gust, mph
Year

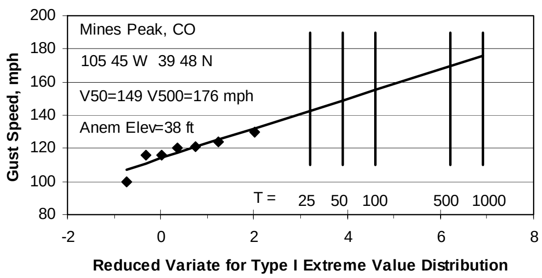

Georgetown Lake West, CO
Data as measured at Anem Elev = unknown
Uncorrected Peak Gust, mph
Year

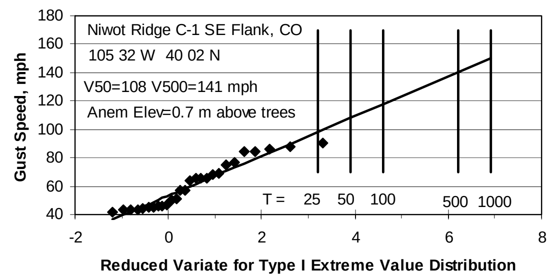

Georgetown South, CO
105 42 W 39 42 N
V50=95 mph V500=116 mph
Anem Elev = 10 m?
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

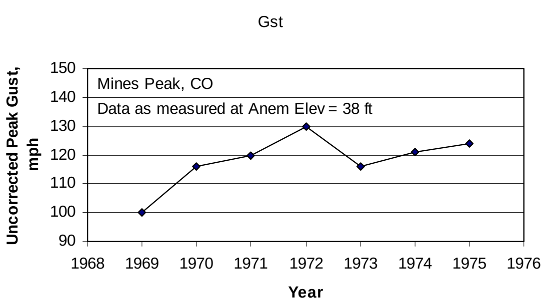

Jeffco Airport, CO
105 07 W 39 54 N
V50=116 mph V500=141 mph
Anem Elev = as corr to 10m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

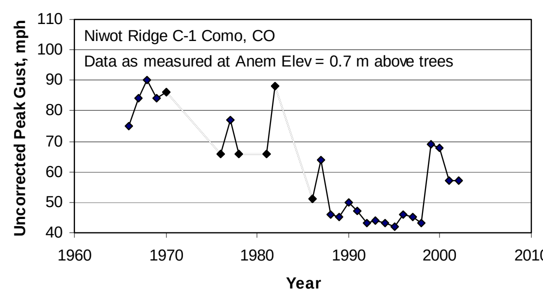

Georgetown South, CO
Data as measured at Anem Elev = 10 m?
Uncorrected Peak Gust, mph
Year

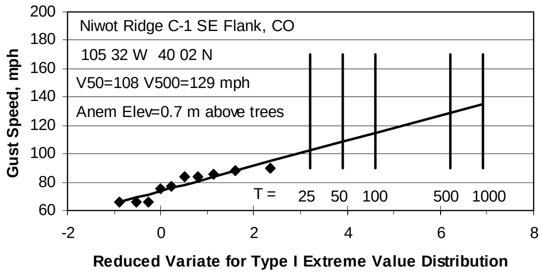

Jeffco Airport, CO
Data as measured at Anem Elev = 20 ft
Uncorrected Peak Gust, mph
Year

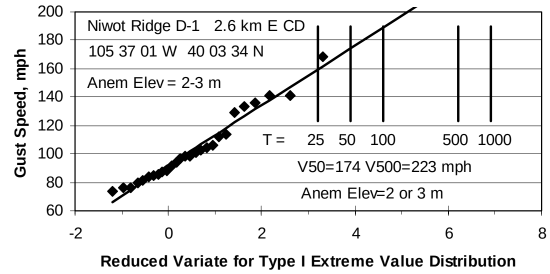

Mines Peak, CO
105 45 W 39 48 N
V50=149 V500=176 mph
Anem Elev=38 ft
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

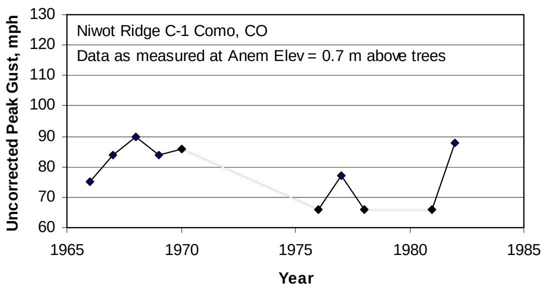

Niwot Ridge C-1 SE Flank, CO
105 32 W 40 02 N
V50=108 V500=141 mph
Anem Elev=0.7 m above trees
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

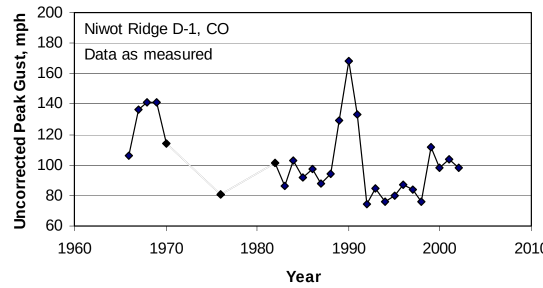

Gst
Mines Peak, CO
Data as measured at Anem Elev = 38 ft
Uncorrected Peak Gust, mph
Year

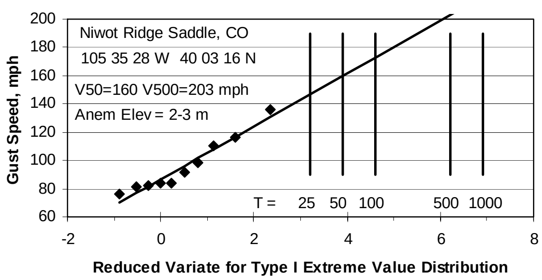

Niwot Ridge C-1 Como, CO
Data as measured at Anem Elev = 0.7 m above trees
Uncorrected Peak Gust, mph
Year

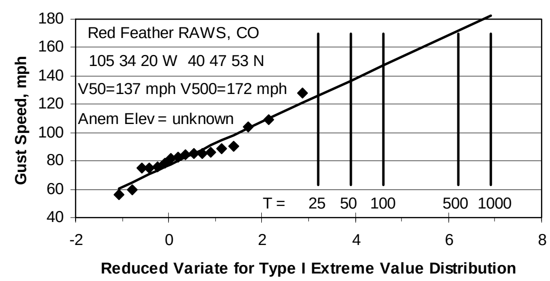

Niwot Ridge C-1 SE Flank, CO
105 32 W 40 02 N
V50=108 V500=129 mph
Anem Elev=0.7 m above trees
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

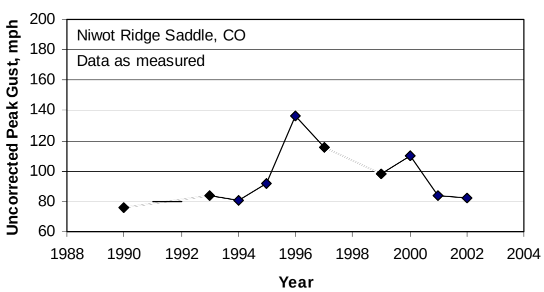

Niwot Ridge D-1 2.6 km E CD
105 37 01 W 40 03 34 N
Anem Elev = 2-3 m
T = 25 50 100 500 1000
V50=174 V500=223 mph
Anem Elev=2 or 3 m
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

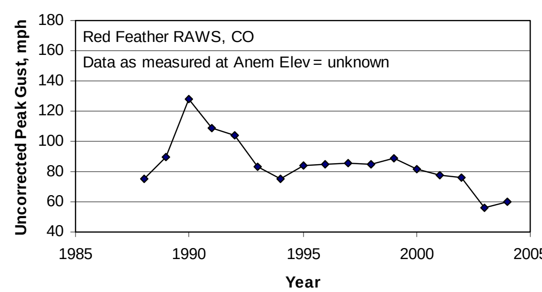

Niwot Ridge C-1 Como, CO
Data as measured at Anem Elev = 0.7 m above trees
Uncorrected Peak Gust, mph
Year

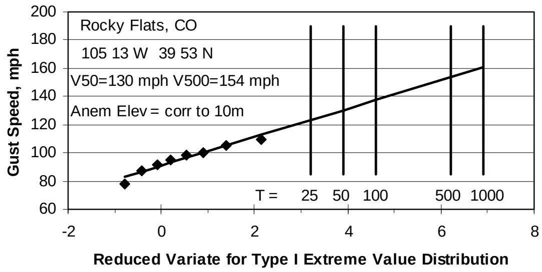

Niwot Ridge D-1, CO
Data as measured
Uncorrected Peak Gust, mph
Year

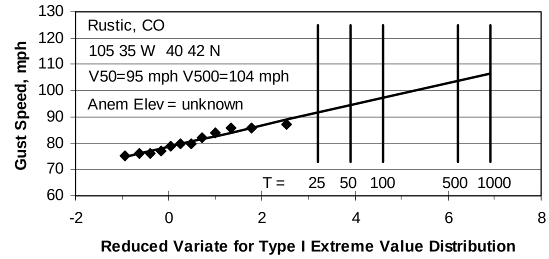

Niwot Ridge Saddle, CO
105 35 28 W 40 03 16 N
V50=160 V500=203 mph
Anem Elev = 2-3 m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

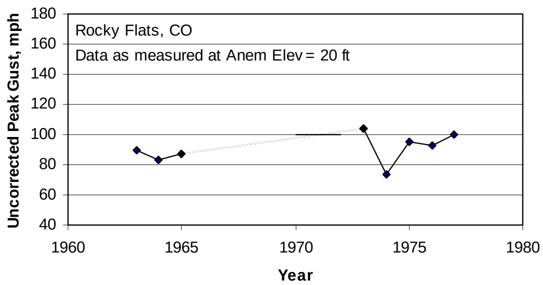

Red Feather RAWS, CO
105 34 20 W 40 47 53 N
V50=137 mph V500=172 mph
Anem Elev = unknown
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

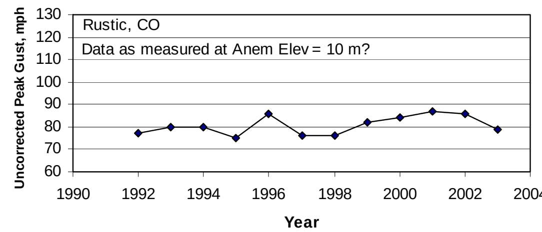

Niwot Ridge Saddle, CO
Data as measured
Uncorrected Peak Gust, mph
Year

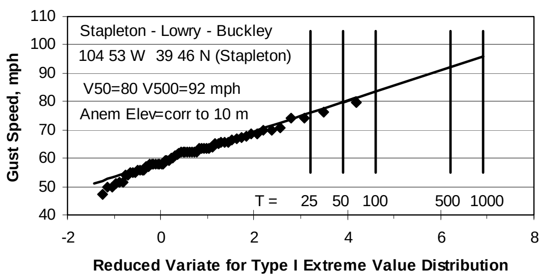

Red Feather RAWS, CO
Data as measured at Anem Elev = unknown
Uncorrected Peak Gust, mph
Year

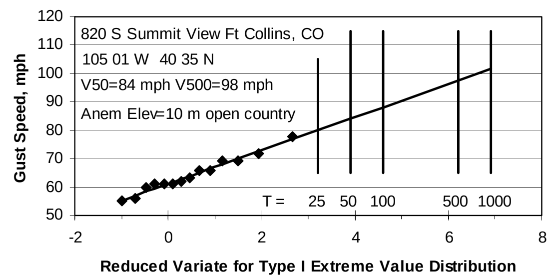

Rocky Flats, CO
105 13 W 39 53 N
V50=130 mph V500=154 mph
Anem Elev = corr to 10m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

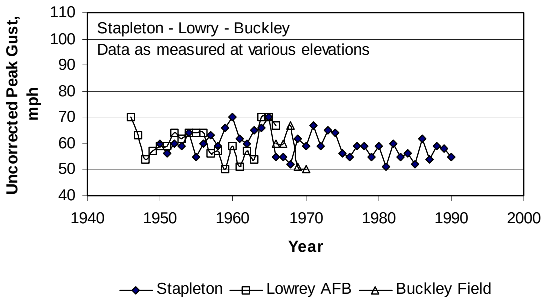

Rustic, CO
105 35 W 40 42 N
V50=95 mph V500=104 mph
Anem Elev = unknown
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution

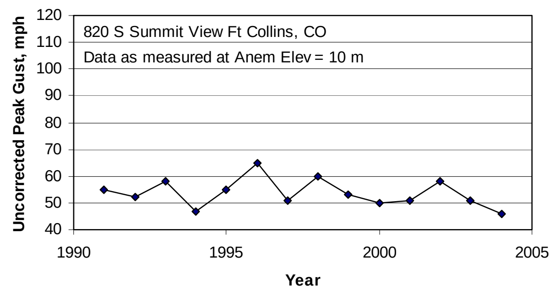

Rocky Flats, CO
Data as measured at Anem Elev = 20 ft
Uncorrected Peak Gust, mph
Year


Rustic, CO
Data as measured at Anem Elev = 10 m?
Uncorrected Peak Gust, mph
Year


Stapleton - Lowry - Buckley
104 53 W 39 46 N (Stapleton)
V50=80 V500=92 mph
Anem Elev=corr to 10 m
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution


820 S Summit View Ft Collins, CO
105 01 W 40 35 N
V50=84 mph V500=98 mph
Anem Elev=10 m open country
T = 25 50 100 500 1000
Gust Speed, mph
Reduced Variate for Type I Extreme Value Distribution


Stapleton - Lowry - Buckley
Data as measured at various elevations
Uncorrected Peak Gust, mph
Year
Stapleton
Lowrey AFB
Buckley Field


820 S Summit View Ft Collins, CO
Data as measured at Anem Elev = 10 m
Uncorrected Peak Gust, mph
Year