



Investigation of contamination flashover as a possible cause for unexplained faults on the Montana Power Company 500kV transmission lines
by Mark Grant Major

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering
Montana State University
© Copyright by Mark Grant Major (1993)

Abstract:

The Montana Power Company 500kV transmission lines located in Eastern and Central Montana encounter a much higher than expected number of unexplained outages in the form of single-phase, self-clearing faults. Research was performed to help determine if dust contamination is a primary cause for these unexplained faults. The wetting of dust contaminated insulator strings by moisture, in the form of dew, light rain or ice, is believed to be the leading cause of unexplained faults worldwide. To facilitate the research, six computerized weather stations were strategically installed along a 100 mile segment of the transmission line route, and unexplained faults were correlated with the meteorological parameters from the nearest weather station locations.

The weather station data loggers, which are mounted on the towers of the 500kV line, measure the ambient air temperature, relative humidity, wind speed and direction, barometric pressure, and precipitation at 15 second intervals. The data loggers also monitor surface temperature and dew sensors on a test insulator.

Since the installation of the weather stations, 19 faults have occurred. The meteorological data surrounding each fault were analyzed through a set of carefully constructed criteria used to ascertain if the conditions present were consistent with contamination flashover. The meteorological data from only one fault appears to be consistent with conditions expected for contamination flashovers. The data surrounding 14 of the faults were not consistent with contamination flashover and 4 faults were deemed inconclusive.

Equivalent Salt Deposit Density (ESDD) sampling was performed to assess the degree of accumulated contamination. Dust samples were taken on test insulator strings mounted halfway up certain towers and insulator strings removed from service. Samples taken during 1992 and 1993 have shown only very light levels of contamination.

Magnetic fault indicators were installed on towers along 35 miles of the line to identify the individual towers on which unexplained faults occur and obtain physical evidence which might help determine the cause of the faults. Since the installation of magnetic fault indicators, the site of one fault has been identified.

INVESTIGATION OF CONTAMINATION FLASHOVER
AS A POSSIBLE CAUSE FOR UNEXPLAINED FAULTS ON
THE MONTANA POWER COMPANY 500kV TRANSMISSION LINES

by

Mark Grant Major

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Electrical Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

November 1993

71378
m2889

ii

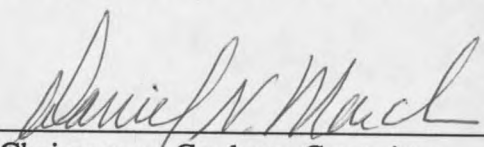
APPROVAL

of a thesis submitted by

Mark Grant Major

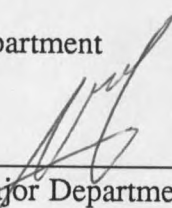
This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

11/29/93
Date


Chairperson, Graduate Committee

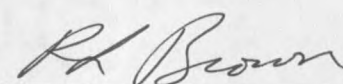
Approved for the Major Department

12/1/93
Date


Head, Major Department

Approved for the College of Graduate Studies

12/12/93
Date

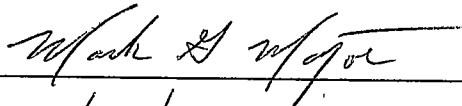

Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature



Date

11/23/93

ACKNOWLEDGEMENTS

Appreciation is extended to the Montana Power Company for providing the financial support to complete this research. I would like to thank Steve Luther, Gene Braun, Benny Buntjer, and Jim Cole. These Montana Power Company personnel have provided invaluable assistance. I would like to especially thank Professor Daniel N. March, the chairperson of my committee, for his encouragement, enthusiasm and invaluable direction. Thanks are also extended to Professor Murari Kejariwal and Harley Leach for their technical assistance; and to Dr. Victor Gerez and Dr. Baldev Thapar for providing guidance based on their professional experience and for their participation and personal interest in the research. I am also sincerely thankful for the assistance Tom Austin provided during the installation of the weather stations and test insulator strings. Appreciation is extended to the following landowners and organizations who have granted permission to cross and install equipment on their land: the Cooney Brothers, Mac White, Phil and Helen Rostad, and Ben Galt. Thanks are bestowed to the Reclamation Research Department, Dr. Frank Munshower, Stuart Jennings, Dennis Neuman, and Dawn Major for providing use of their laboratory and technical assistance in processing ESDD samples. Special thanks are extended to my wife, Dawn Major, for her patience and support throughout my academic career and also for her assistance in the preparation of this thesis. My parents, John and Gretel Major also deserve my sincere gratitude for their encouragement and support.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	x
ABSTRACT	xiii
INTRODUCTION	1
RESEARCH OBJECTIVES	10
LITERATURE REVIEW	11
Leading Causes for Unexplained Faults	11
Physics of Contamination Flashover	12
Sources of Contamination	14
Measuring the Degree of Surface Contamination	15
Tests on Contaminated Insulators	16
Remedies to Contamination Flashover Problems	18
Research Into the Causes of Unexplained Faults	19
METHODS AND EXPERIMENTAL PROCEDURES	23
Analysis of Historical Fault Data	23
Installation of Weather Stations	24
Criteria for Evaluating Weather Data	32
Contamination accumulation	33
Insulator wetting	35
Surface condensation	36
Water impingement by fog or light drizzle	38
Ice formation	40
Algorithm for application of criteria	41
ESDD Sampling	44
Installation of Magnetic Fault Indicators	46

TABLE OF CONTENTS -- Continued

EXPERIMENTAL RESULTS AND DISCUSSION	49
Historical Fault Data Analyses	49
Chronological distribution	49
Position distribution	53
Time of day distribution	55
Weather Data Analyses	59
Fault #1 - 2:43 a.m., August 16, 1992	
102.7 miles west of Broadview	61
Fault #2 - 2:52 p.m., October 1, 1992	
42.5 miles west of Broadview	62
Fault #3 - 12:36 p.m., October 18, 1992	
99.6 miles west of Broadview	62
Fault #4 - 4:17 p.m., October 23, 1992	
117 miles west of Broadview	63
Fault #5 - 11:36 p.m., November 2, 1992	
17.2 miles east of Broadview	64
Fault #6 - 12:08 p.m., February 7, 1993	
93.7 miles west of Broadview	65
Fault #7 - 5:09 p.m., February 23, 1993	
44.9 miles west of Broadview	66
Fault #8 - 9:46 a.m., February 25, 1993	
69.6 miles west of Broadview	67
Fault #9 - 12:19 p.m., April 29, 1993	
42.1 miles west of Broadview	67
Fault #10 - 4:16 p.m., June 5, 1993	
41.8 miles west of Broadview	68
Fault #11 - 5:04 a.m., June 10, 1993	
72.2 miles west of Broadview	69
Fault #12 - 10:16 a.m., June 11, 1993	
44.2 miles west of Broadview	70
Fault #13 - 5:12 a.m., July 1, 1993	
69.1 miles west of Broadview	70
Fault #14 - 4:21 a.m., July 7, 1993	
62.6 miles west of Broadview	71
Fault #15 - 5:17 a.m., July 15, 1993	
94.1 miles west of Broadview	72
Fault #16 - 5:02 a.m., July 20, 1993	
18.4 miles west of Broadview	73

TABLE OF CONTENTS -- Continued

Fault #17 - 1:45 a.m., July 21, 1993	
104.6 miles west of Broadview	74
Fault #18 - 4:46 a.m., July 23, 1993	
18.1 miles east of Broadview	75
Fault #19 - 4:46 p.m., September 6, 1993	
40.5 miles west of Broadview	76
ESDD Samples	77
May 1992	77
April 1993	78
August and September 1993	80
ESDD Samples from test insulator strings	81
Results From Magnetic Fault Indicators	82
SUMMARY AND RECOMMENDATIONS	87
REFERENCES CITED	92
APPENDICES	96
A: LISTING OF UNEXPLAINED FAULTS ON BROADVIEW-TO-TOWNSEND LINES	97
B: PLOTS OF METEOROLOGICAL PARAMETERS SURROUNDING UNEXPLAINED FAULTS	102
C: LOCATION AND METEOROLOGICAL CONDITIONS FOR FAULTS WITHIN WEATHER STATION COVERAGE	179
D: MEAN AND STANDARD DEVIATION FOR TEN DAY PERIODS OF METEOROLOGICAL PARAMETERS RECORDED BY WEATHER STATIONS	184
E: LOCATIONS AND ESDD LEVELS FOR INSULATOR STRINGS SAMPLED	191

LIST OF TABLES

Table		Page
1.	ESDD Classification	15
2.	Description of Weather Station Sites	27
3.	Criteria for Dust Contamination Accumulation	35
4.	Criteria for Surface Condensation	37
5.	Criteria for Fog or Drizzle	39
6.	Criteria for Ice	41
7.	Fault Indicator Coverage Area	47
8.	Chronologically Listed Unexplained Fault Data for Broadview to Townsend Lines for Years 1984-1993	98
9.	Location and Meteorological Data for Faults Within Weather Station Coverage	180
10.	Galt Ranch Mean and Standard Deviation for Ten Day Periods of Meteorological Parameters	185
11.	Rostad Ranch Mean and Standard Deviation for Ten Day Periods of Meteorological Parameters	186
12.	White Ranch Mean and Standard Deviation for Ten Day Periods of Meteorological Parameters	187
13.	Cooney Ranch Mean and Standard Deviation for Ten Day Periods of Meteorological Parameters	188
14.	Golden Valley Mean and Standard Deviation for Ten Day Periods of Meteorological Parameters	189
15.	Broadview Substation Mean and Standard Deviation for Ten Day Periods of Meteorological Parameters	190

LIST OF TABLES -- Continued

Table		Page
16.	Locations of Strings Sampled May 1992	192
17.	ESDD Levels For Strings Sampled May 1992	192
18.	Locations of Strings Sampled April 1993	193
19.	ESDD Levels For Strings Sampled April 1993	193
20.	Locations of Strings Sampled August and September 1993	194
21.	ESDD Levels For Strings Sampled August and September 1993	194
22.	ESDD Levels For #2 Test Insulator at Each Weather Station Site	195

LIST OF FIGURES

Figure		Page
1.	Montana Power Company 500kV Lines	2
2.	Fault Distribution Colstrip to Townsend	3
3.	Guy-wire Supported Towers with "V"-strings	5
4.	Self-supported Towers with "V"-strings	5
5.	Self-supporting Dead-end Towers	6
6.	Dry Band Formation Leading to Flashover Arc	13
7.	Road Map Showing Weather Station Sites	26
8.	Typical Weather Station Configuration	28
9.	Algorithm for Application of Criteria	43
10.	Test Insulator Configuration	45
11.	Road Map Showing Fault Indicator Coverage Area	48
12.	Chronological Fault Distribution, Broadview to Townsend, 1984-1993	50
13.	Yearly Fault Distribution, Broadview to Townsend, 1984-1993	51
14.	Monthly Fault Distribution, Broadview to Townsend, 1984-1993	52
15.	Yearly Position Distribution, Broadview to Townsend, 1984-1993	54
16.	Fault Location Distribution, Broadview to Townsend, 1984-1993	55
17.	Time of Day Distribution, Broadview to Townsend, 1984-1993	56

LIST OF FIGURES -- Continued

Figure		Page
18.	Hour of Day Distribution, Broadview to Townsend, 1984-1993	57
19.	Hour of Day Distribution, June, July and August, Broadview to Townsend, 1984-1993	58
20.	Hour of Day Distribution, August Only, Broadview to Townsend, 1984-1993	58
21.	ESDD for Strings From 500kV Line Removed from Service May 1992	77
22.	ESDD for Strings From 500kV Line Removed from Service April 1993	79
23.	ESDD for Strings From 500kV Line Removed from Service Aug. and Sep. 1993	81
24.	ESDD Levels for Test Strings, #2 Insulator, Sampled August 5, 1993	82
25.	Markings on Tower 40-2	86
26-30	Meteorological Parameters for Fault #1	103-105
31-34	Meteorological Parameters for Fault #2	105-107
35-39	Meteorological Parameters for Fault #3	107-109
40-46	Meteorological Parameters for Fault #4	110-113
47-51	Meteorological Parameters for Fault #5	113-115
52-65	Meteorological Parameters for Fault #6	116-122
66-73	Meteorological Parameters for Fault #7	123-126
74-81	Meteorological Parameters for Fault #8	127-130

LIST OF FIGURES -- Continued

Figure		Page
82-89	Meteorological Parameters for Fault #9	131-134
90-97	Meteorological Parameters for Fault #10	135-138
98-105	Meteorological Parameters for Fault #11	139-142
106-113	Meteorological Parameters for Fault #12	143-146
114-121	Meteorological Parameters for Fault #13	147-150
122-129	Meteorological Parameters for Fault #14	151-154
130-145	Meteorological Parameters for Fault #15	155-162
146-153	Meteorological Parameters for Fault #16	163-166
154-162	Meteorological Parameters for Fault #17	167-170
163-168	Meteorological Parameters for Fault #18	171-174
169-176	Meteorological Parameters for Fault #19	174-178

ABSTRACT

The Montana Power Company 500kV transmission lines located in Eastern and Central Montana encounter a much higher than expected number of unexplained outages in the form of single-phase, self-clearing faults. Research was performed to help determine if dust contamination is a primary cause for these unexplained faults. The wetting of dust contaminated insulator strings by moisture, in the form of dew, light rain or ice, is believed to be the leading cause of unexplained faults worldwide. To facilitate the research, six computerized weather stations were strategically installed along a 100 mile segment of the transmission line route, and unexplained faults were correlated with the meteorological parameters from the nearest weather station locations.

The weather station data loggers, which are mounted on the towers of the 500kV line, measure the ambient air temperature, relative humidity, wind speed and direction, barometric pressure, and precipitation at 15 second intervals. The data loggers also monitor surface temperature and dew sensors on a test insulator.

Since the installation of the weather stations, 19 faults have occurred. The meteorological data surrounding each fault were analyzed through a set of carefully constructed criteria used to ascertain if the conditions present were consistent with contamination flashover. The meteorological data from only one fault appears to be consistent with conditions expected for contamination flashovers. The data surrounding 14 of the faults were not consistent with contamination flashover and 4 faults were deemed inconclusive.

Equivalent Salt Deposit Density (ESDD) sampling was performed to assess the degree of accumulated contamination. Dust samples were taken on test insulator strings mounted halfway up certain towers and insulator strings removed from service. Samples taken during 1992 and 1993 have shown only very light levels of contamination.

Magnetic fault indicators were installed on towers along 35 miles of the line to identify the individual towers on which unexplained faults occur and obtain physical evidence which might help determine the cause of the faults. Since the installation of magnetic fault indicators, the site of one fault has been identified.

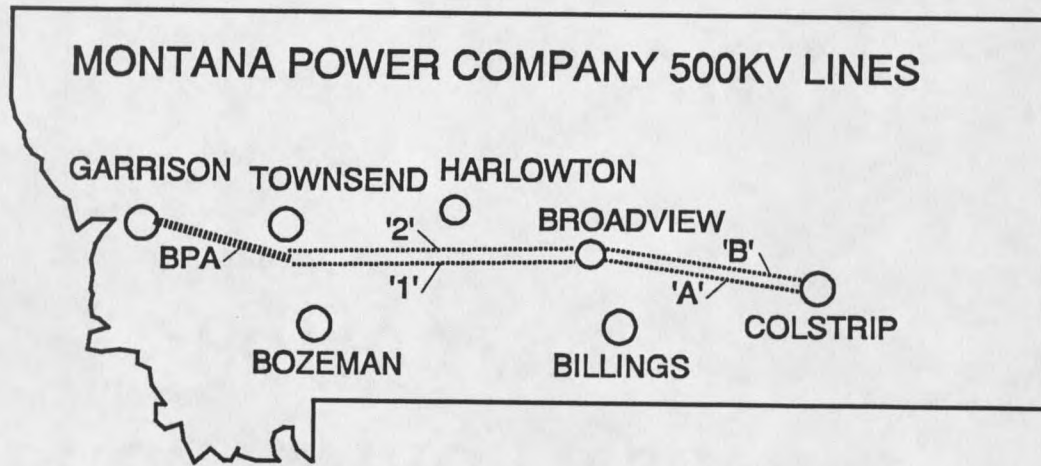
INTRODUCTION

In 1983, construction was completed on a 500kV transmission system running from Colstrip, Montana to Garrison, Montana. The Montana Power Company (MPC) is responsible for the operation and maintenance of the portion of the transmission lines from Colstrip to a transition point near Townsend, Montana. From Townsend to Garrison, the lines are the responsibility of the Bonneville Power Administration (BPA).

The transmission lines for this system have had a much higher than expected number of unexplained faults which almost always take the form of single-phase, self-clearing faults. Though these faults have normally been noncatastrophic, they force the circuit breakers to open and reclose and induce transients into the transmission network, including the Colstrip Generators. Premature equipment wear-out and component failure are of concern to MPC since they impose a financial impact to the utility and affect system reliability. Severe system instability or the loss of synchronization resulting in an interruption of power generation or transmission is a threatening possibility.

The line route is depicted in Figure 1. From Colstrip to Townsend, the transmission system is comprised of a parallel set of 3-phase lines. As shown in Figure 1, these lines are named the A Line and B Line from Colstrip to Broadview and Line 1 and Line 2 from Broadview to Townsend. The electric power is generated at Colstrip, and the lines terminate and continue at two substations: the Broadview Substation and the Garrison Substation. The BPA portion of the lines, which also suffers from a high number of unexplained faults, consists of double-circuit 500kV towers, unlike the MPC portion which is a parallel set of single-circuit towers.

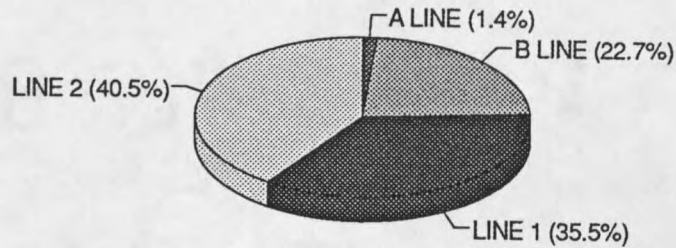
Figure 1



The B Line and Lines 1 and 2 were constructed in 1983. The A Line was converted to a single-circuit 500kV line from a double-circuit 230kV transmission line. The A Line towers and insulator strings were modified to accommodate 500kV power in 1983. This note in the history of the 500kV line's construction is important because the A Line has provided excellent performance with only three unexplained faults to date. At least one of these faults was most likely caused by lightning. As shown in Figure 2, the B Line and Lines 1 and 2 have suffered many faults since the lines were first energized. The B line and Lines 1 and 2 are of identical construction. The Colstrip-to-Broadview lines and the Broadview-to-Garrison lines are approximately 110 and 200 miles long respectively.

Figure 2

FAULT DISTRIBUTION COLSTRIP TO TOWNSEND
221 TOTAL UNEXPLAINED FAULTS



What differentiates the A Line from the other lines is the mechanical construction of the towers and the length of the insulator strings. Although the towers are almost identical in construction, the A Line has larger towers. The minimum air gap between a conductor and a tower on the A Line is 138 inches compared to 116 inches on the B Line and Lines 1 and 2. Furthermore, 25 insulators are present in the insulator strings for the A Line, where only 22 are used on the B Line and Lines 1 and 2. The insulators on all four lines are very similar and made of glass by the Sedivar Company in Carlstadt, New Jersey. The excellent performance of the A Line suggests that the B Line and Lines 1 and 2 are under-insulated. The question at issue is: what instigates the unexplained faults on the B Line and Lines 1 and 2? The research presented in this thesis addressed dust contamination as a possible cause for the faults. When insulator strings contaminated by dust or pollution become wet, they sometimes flashover and

cause a single-phase, self-clearing fault. The contaminants must contain one or more salts and be water-soluble for flashover to occur.

Several types of towers are present along the line route. These towers can be roughly categorized into three types:

- 1) guy-wire-supported towers with "V"-string insulator configurations;
- 2) self supporting towers with "V"-string configurations; and
- 3) self-supporting dead-end towers which use a combination of horizontal tension insulator strings, vertical insulator strings and "V"-string configurations.

Each of these tower types is sketched in Figures 3, 4, and 5. Note that the dimensions shown are only approximate. The first type, those supported by guy-wires, are the most common and are used where horizontal angle changes in the line's topology are not made. The second type are used when special mechanical loading circumstances are present which prevent the use of guy-wires. The self-supporting dead-end towers are used when the line makes a change in horizontal angle and the horizontal tension must be taken up on one or more of the conductor bundles. Lines 1 and 2, between the Broadview Substation and the transition to BPA ownership at Townsend, are supported by a total of 553 towers per line. Approximately 70 of these towers are of the dead-end type, with an average of one dead-end tower every 1.9 miles.

For increased mechanical strength, most of the insulator strings on the 500kV lines use two or four separate parallel strings which are closely spaced.

Figure 3: Guy-wire Supported Towers with "V"-strings

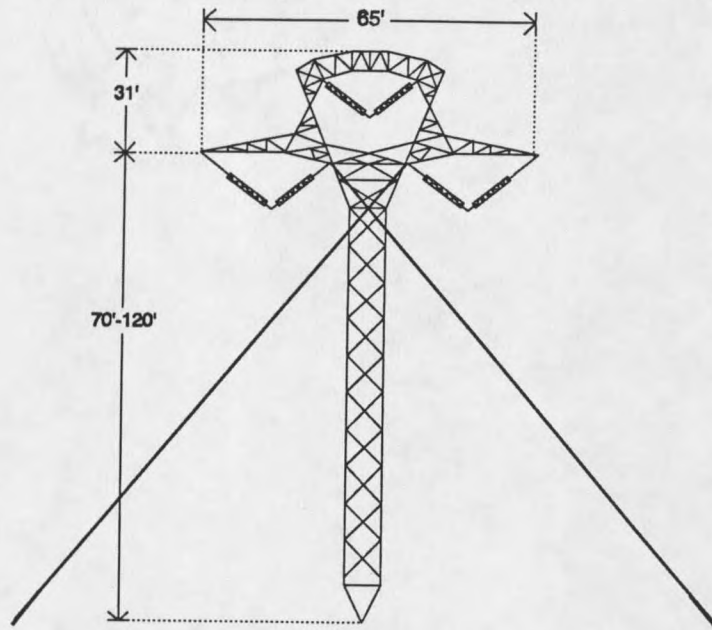


Figure 4: Self-supported Towers with "V"-strings

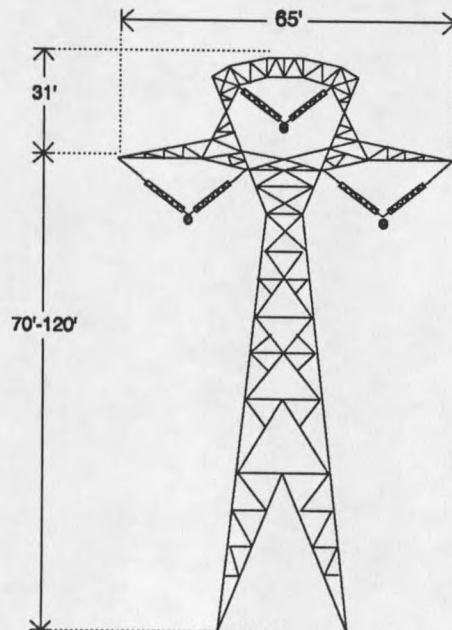
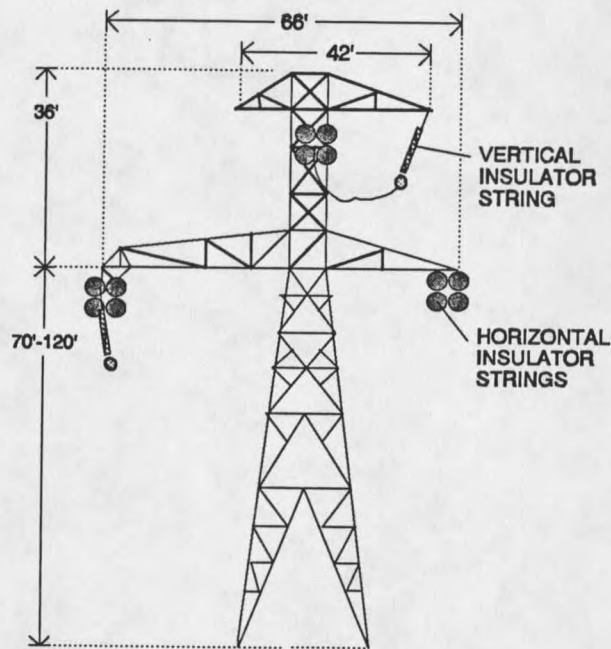


Figure 5: Self-supporting Dead-end Towers



Throughout this thesis, references are made to individual towers which are identified by their particular tower number. The towers between Broadview and Townsend are marked as follows: they are separated numerically into five-mile segments with the first set of digits in a tower number correspond to the mileage from Broadview of the five-mile segment and the second set of digits, separated by a "-" or "/" mark from the first set of digits, indicate the number of spans from the beginning of that particular five-mile segment. For example, Tower 40-0 is the first tower in a segment of towers 40 miles from Broadview and is exactly 40 miles west of Broadview. Tower 40-5 is five spans west of Tower 40-0 and, since each span is approximately 0.25 miles in length, is approximately 41.25 miles west of Broadview. Lines A and B, between

Colstrip and Broadview, are numbered in the same fashion with the numbering beginning at Colstrip.

In the eastern portion of the line route (Colstrip to Broadview), the terrain can be described as semi-arid rangeland with few trees and, with exception of the Yellowstone River which passes under the lines midway between Colstrip and Broadview, no large bodies of water. The central portion of the lines pass over various terrain including semi-arid rangeland, grassland, and a few areas of agricultural activity. Several very small reservoirs are near the lines and a large lake (Canyon Ferry) is present approximately 10 miles north of the MPC-to-BPA transition point. At this transition point, the lines cross the Missouri River. Approximately 75 miles west of the Broadview Substation the lines pass through the Lewis and Clark National Forest, just north of the Crazy Mountains, and between Ringling and Townsend (100 - 130 miles west of the Broadview Substation), the lines pass through a small forested mountain area separating the Gallatin and Helena National Forests. Most of the line between Broadview and Townsend passes over rangeland with few or no trees.

The research into the cause of unexplained faults on this transmission system was endorsed and supported by the Montana Power Company. Prior to approaching the Electrical Engineering Department at Montana State University for assistance in their research efforts, MPC engineers ruled-out switching surges and transients as a primary cause for the unexplained faults. Preliminary research conducted at MSU in 1989-90 investigated lightning as a possible contributor to the fault problem. With few

exceptions (three faults), no correlation between lightning activity and fault occurrence was obtained.

The study outlined in this thesis focused primarily on Lines 1 and 2 between Broadview and Townsend, the lines which have had the greatest number of unexplained faults. The close proximity of Lines 1 and 2 to Bozeman (home of MSU) were also motivators for MSU researchers to concentrate their efforts on these two lines.

Several engineers at other power utility companies were contacted and questioned about their experiences with unexplained transmission line faults. Engineers at Florida Power and Light believe that insulator contamination and birds are to blame for most unexplained faults on their system and have found insulator washing to be the most effective preventative measure. The Ontario Hydro Power Company in Toronto, Canada reported dust contamination from salted roads caused flashovers on their 500kV lines. Ontario Hydro increased the length of their insulator strings from 23 to 27 on a segment of their transmission lines and, surprisingly, observed no significant reduction in unexplained fault incidence. Sierra Pacific Power Company has had similar experiences. On a particular transmission line suspected of having many contamination flashovers in Nevada, five insulators were added to strings 18 insulators long. Initially, a significant reduction in fault activity was observed, however, the fault rate "seems to be increasing" and an engineer for Sierra Pacific Power predicts the rate will equal the original fault rate in the near future. The Minnkota Power Company in Grand Forks, North Dakota reported having too many unexplained faults on their 345kV transmission lines. They felt the cause was either contamination or birds. They have observed significantly fewer

unexplained faults after adding four insulators to each insulator string in 1990. They have not had any faults on their lines in 1993.

Engineers at Sierra Pacific Power, Tucson Electric Power Company, and Pacific Power and Light have used tower-mounted magnetic fault indicators, which permanently display a small red flag after a fault, to identify individual towers on which faults occurred. Physical evidence such as heavy contamination, the presence and position of burn marks, and nests helped the engineers offer opinions as to the cause for faults.

Engineers for the Pacific Gas and Electric Company have the ability to locate faults well on their 500kV transmission lines. Several times they have identified problematic sources of contamination by examining the areas surrounding fault locations. Faults were especially likely when a contamination source was near a body of water.

RESEARCH OBJECTIVES

It has been hypothesized that the excessive number of unexplained faults occurring on the Montana Power Company 500kV transmission lines is a result of the wetting of dust-contaminated insulators flashing over. The research outlined in this paper was performed to test that hypothesis by addressing the following research objectives:

- evaluate historical fault statistics and search out any tendencies which might suggest or be in accordance with contamination flashover theory;
- obtain and analyze meteorological data representative of conditions surrounding faults to ascertain if meteorological conditions during unexplained faults are consistent with those expected for faults instigated by contamination flashovers;
- determine the amount of contamination the MPC 500kV insulator strings accumulate and compare those levels to established industry standards; and
- identify particular towers on which unexplained faults occur to determine which tower configurations are more susceptible to faults and obtain any physical evidence which might suggest the cause of faults.

LITERATURE REVIEW

Leading Causes for Unexplained Faults

Since the advent of high voltage power transmission, unexplained outages due to various causes including insulator contamination, lightning, birds, and switching surges have plagued electrical utilities. Today the problem persists and as Electrical Power Research Institute (EPRI) researchers point out, several transmission line operators in the Western United States (Wyoming, Idaho, Utah, North Dakota, South Dakota, Nevada, Colorado, California, and Washington) are experiencing higher than expected outage rates which commonly take the form of single phase-to-ground, self-clearing faults (Sandhu et al. 1988). Worldwide experience has shown contamination-caused flashovers to be the leading cause for faults on ultrahigh voltage (UHV) transmission lines (Richards and Mauldin 1989). Lightning is also frequently blamed for faults. In a three year study of the English 275kV transmission grid by Sforzini, (1971) lightning was responsible for 72% of recorded faults. In 1965 and 1985 an IEEE Power Engineering Society Working Group conducted surveys on the problem of insulator contamination in the United States and Canada (Nasser et al. 1971, Adler et al. 1993). In addition to contamination and lightning, switching surges, birds, vandalism, and severe storms were also identified as reasons for unexplained faults. Long-term studies in the Former Soviet Union suggest low air pressure in mountainous areas increases the risk of flashover on polluted insulators (Rudakova and Tikhodeev 1989).

Physics of Contamination Flashover

Many studies have been undertaken to gain knowledge about the physics and mechanisms of flashovers on insulators coated with contamination and the ability of various insulators to withstand high voltage when contaminated. Jolly (1972) outlines and categorizes the sequence of events necessary for contamination flashover into four distinctive steps:

- "1) deposition of conducting salts and moisture
- 2) dry band formation
- 3) electrical breakdown of dry band(s)
- 4) propagation of the discharge across the moist film, bridging the insulator."

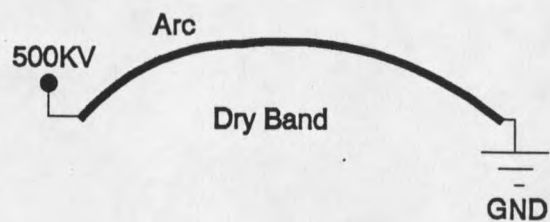
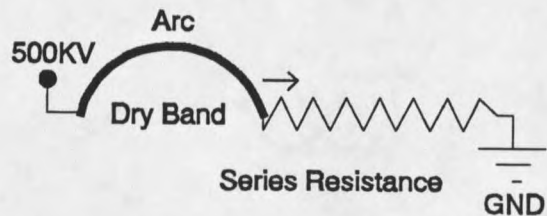
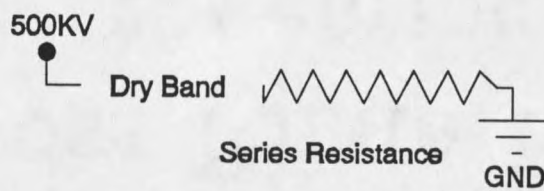
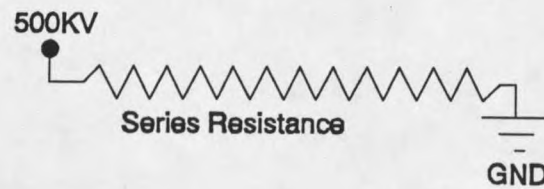
The flashover mechanism of polluted insulation is described in detail by Hampton (1964) who provides a technical description of the "Dry Band Theory" when explaining the process through which a contaminated insulator surface, when wetted, eventually flashes over.

"When the layer of pollution becomes wet, its resistance falls and leakage current flows over the surface of the insulator. The leakage current density is highest at some parts, usually the narrowest, of the insulator. These regions dry more quickly than the rest of the surface and their resistance increases. This causes the power dissipated locally to increase and an unstable condition arises which rapidly leads to the formation of dry bands around the insulator. Discharges across these dry bands usually become extinguished but, exceptionally, may develop into a flashover of the insulator."

The dry band flashover process, assuming a 500kV source, is illustrated in Figure

6. The series resistance in Figure 6 represents the conductive film formed by the wetting of dust contamination on an insulator string.

Figure 6: Dry Band Formation Leading to Flashover Arc



Glowing corona, scintillation, and luminous streamer discharges can be observed by the naked eye during the process as described and photographed by Nasser (1967) in a study of physical properties of electrical discharges across dry bands on contaminated surfaces.

Sources of Contamination

Jolly (1972) indicates the contamination must be in the form of water soluble salts for surface conductivity and any subsequent electrical discharge or flashover to occur. There are numerous sources of such contamination. When individually identified, sea salt was reported as the most troublesome source of contamination, particularly in coastal areas, by a survey conducted by the IEEE Power Engineering Society Working Group (Nasser et al. 1971). Gerez et al. (1982) attributed contamination flashover problems, experienced by Mexican power utilities near Mexico City, to industrial pollution from the city. Long range transported pollution, specifically from the combustion of fossil fuels from Europe, was identified by Fikke et al. (1992) as a source of contamination which caused flashover events in mountain areas of Norway. EPRI researchers (Sandhu et al. 1988) found wind blown dust originating from dry alkaline lake beds to be a significant source of contamination. Road salt, agricultural activity, birds, and naturally occurring dust from local soils are also believed to contribute to insulator contamination (Nasser et al. 1971, Burnham et al. 1993).

Some types of contamination are more threatening than others. The flashover voltage of contaminated insulators is dependent on the salt species present in the contamination. Holt et al. (1975) identified NaCl and NaNO_3 as the most severe salts when a comparison of 8 different species were made. Furthermore, Holt et al. showed that the minimum flashover voltage is obtained when a coating of contamination is uniform. Contamination makeup can be very complex and, in short, the degree of

contamination is dependent on the amount and type of soluble salts and the amount and type of inert substances (Gerez and Talamas 1987, Williams et al. 1973, Holt et al. 1975).

Measuring the Degree of Surface Contamination

Several methods have been proposed for measuring the amount of contamination present on the surface of an insulator. Most electric utilities and UHV researchers have adopted the Equivalent Salt Deposit Density (ESDD) measure for expressing contamination severity levels (Gerez and Talamas 1987, Zedan and Akbar 1985, Naito and Naganawa 1993). To measure the ESDD, the surface contamination is removed and dissolved in distilled water. The conductivity of the water is then measured and the equivalent density of NaCl that would produce the same conductivity for the given surface area is calculated and expressed in mg/cm^2 . Table 1 shows the standard ESDD classification for site severities (Holt et al. 1979).

Table 1: ESDD Classification	
ESDD (mg/cm^2)	SITE SEVERITY
0 - 0.03	VERY LIGHT
0.03 - 0.06	LIGHT
0.06 - 0.1	MODERATE
0.1 - HIGHER	HEAVY

Tests on Contaminated Insulators

Artificially contaminating and testing insulators is an art many researchers have attempted to perfect. Reece et al. (1973) when conducting research for Pacific Gas and Electric provide one such example. A mixture of NaCl, kaolin clay, silica flour, and chalk was applied to insulators using three spray nozzles to independently control the ratios of contamination between the top and bottom insulator surfaces. A carefully controlled cool fog chamber was used to moisten insulators under test. The purpose of the cool fog chamber tests was to provide a comparison of various types of insulators used by the power industry. Fog type high leakage distance insulators performed better than standard bell shaped insulators in their tests.

Other researchers were more concerned with studying conditions found in natural environments where contamination is never comprised of only one salt species, contamination is not uniformly applied, and moisture usually forms in a nonreproducible, nonuniform manner.

Kawai (1967) conducted research on contaminated insulators allowed to become wet under natural conditions.

"After sunset, the temperature fell and the relative humidity started to increase, frequently producing dew, fog or drizzle. When the relative humidity exceeded 80%, salinity on the surface of the porcelain absorbed moisture and the insulation of the porcelain surface was rapidly lost, resulting in flashover."

Kawai also identified meteorological conditions which present the most dangerous situation for contaminated insulators.

"Light rain or fog after several hours of high humidity can be regarded as the worst meteorological condition. Flashover does not necessarily occur during rain or fog, but it does often occur in the high-humidity conditions immediately before the rain or fog."

Karady (1974) studied the effects of various types of fog on contaminated insulators. Both the wetting process and any subsequent washing of the insulators by the fog caused moisture were investigated. In analyzing the hygroscopic behavior of insulator surfaces, he concluded that the cold fog type tests, the type found under natural conditions, resulted in a higher washing rate than either the warm fog or the steam fog tests.

Scores of research publications document various methods for testing insulators under artificially contaminated and wetted conditions. Natural conditions leading to insulator contamination and wetting are not reproducible in a laboratory, therefore relatively little understanding of naturally occurring contamination flashovers, particularly the appropriate meteorological conditions, is known and even less is documented. In comparing the feasibility and practicality of laboratory tests with natural tests, Gerez and Talamas (1987) commented:

"Even though exposing energized insulators in the field is preferable to a laboratory from the point of view of validity, laboratory tests are increasingly used. They are faster, and allow experimentation under controlled conditions. Using field data, the influence of each factor can be analyzed in depth in laboratory experiments."

In spite of their limited ability to simulate real life conditions, laboratory experiments have provided a wealth of information previously unavailable. For example, laboratory research has shown fog-type insulators to be more resistant to contamination flashover even though they tend to accumulate more contamination (Holt

et al. 1979, Claverie and Porcheron 1972). Insulator strings which are suspended vertically also tend to accumulate more contamination than diagonally or horizontally positioned strings (Wahl 1976). Tests have revealed that the contamination flashover voltage on long strings of insulators is a nonlinear function of string length (Schneider and Nicholls 1977); a very important fact for those responsible for designing transmission lines. Designers frequently choose to use multiple strings of insulators, such as the popular double-"V" string, for added mechanical strength, however, Rizk et al. (1975) showed that the use of multiple strings increases the probability of contamination flashover.

Remedies to Contamination Flashover Problems

Several methods have been applied to prevent and, in many cases, eliminate faults on transmission lines subject to high levels of contamination. The most common approaches are listed below (Claverie and Porcheron 1972, Gerez et al. 1982, Holt et al. 1979):

- increase the length of the insulator strings or post insulators;
- replace the conventional insulators by anti-fog insulators;
- cover the insulator surfaces with mineral or silicon grease to delay the formation of the conductive layer;
- wash the insulators periodically; and
- use resistance graded insulators.

The degree of success varies among these treatments and so do the costs. Moran and Powell (1971) performed an economic analysis comparing the above solutions. They suggest the use of insulators with resistance graded glazing which conduct a small leakage current and heat the insulator, preventing the formation of moisture. Few electric utilities have heeded their advice perhaps because of concern over the wasted power and radio frequency interference resistance graded insulators emit. Florida Power and Light Company has found washing insulators to be the most effective means for preventing contamination flashovers (Renowden 1992). Good results were obtained by the application of silicone grease by respondents of the IEEE Working Group Survey (Nasser et al. 1971).

Research Into the Causes of Unexplained Outages

The EPRI publication, "A Joint Utility Investigation of Unexplained Transmission Line Outages" (Sandhu et al. 1988) is a very comprehensive and timely study into the problem of identifying the causes of unexplained faults. This study focused on a set of 345kV transmission lines in western Nevada which were experiencing unacceptably high rates of unexplained outages. These faults were primarily single phase-to-ground faults which were self-clearing and occurred mainly between midnight and 8 a.m.. Two possible causes, which were individually researched, include dust contamination flashover and flashovers caused by bird excrement. The insulator contamination study they conducted involved periodic ESDD sampling, chemical analysis of dust contamination, soil sampling and analysis, live staged tests with both natural and

artificial contamination, and weather monitoring. ESDD levels measured periodically from 1983-1986 ranged from 0.003 to 0.010 mg/cm², which are categorized as "very light" for typical transmission lines. The researchers did observe that contamination levels were "seasonally variable, with highest accumulations during the drier summer and fall months. The chemical analysis of dust samples revealed abundant concentrations of elements which constitute natural conductive salts. Their results indicated that local soils were the largest source of contamination and that "alkaline dust was responsible for a large fraction of the contaminated insulators' surface conductivity."

The research also included staged live tests on Pacific Power and Light Company's Jim Bridger 345kV transmission lines located in Wyoming. These tests were performed on insulator strings suspected of flashing over periodically from contamination. The intention was to cause a fault and prove that, with the appropriate type and amount of moisture, contamination flashovers were probable. In the first staged test, live insulator strings on the transmissions lines were sprayed with clean steam from nozzles mounted on the towers during the night. Scintillation activity, visible to the naked eye, was observed even when natural contamination measured very low. In a second test, the strings were artificially contaminated to a level believed to equal the greatest amount the transmission line would ever accumulate. "Heavy and intense scintillation" was observed and "an electrical arc was observed to occasionally bridge (short) 6 to 8 insulators at a time."

Although they failed at producing a complete flashover, the tests convinced the EPRI researchers that,

"flashovers caused by low-level contamination on the test line are possible when the insulators are exposed to proper wetting conditions, especially after extended periods of dry weather when contamination is allowed to accumulate on the insulators."

The bird study included making aerial and ground surveys and investigating the effectiveness of bird discouragers mounted on a segment of one transmission line. They observed that "eagles, hawks and other large raptors were present in the study area when outages occurred" and "large birds were observed perching on towers in positions where an excrement stream could trigger a fault." Although the researchers did observe a significant shift in bird use away from tower positions equipped with discouragers, they did not observe a significant reduction in the number of faults on those towers.

An analysis of meteorological conditions present during fault occurrences was attempted in the EPRI study. Three significant conclusions were drawn from their research.

- "1) No consistent pattern of weather conditions to individual outages was established.
- 2) Moisture related events that could produce insulator wetting cannot be ruled out in any season. However, it is less likely that summer-time outages were associated with insulator wetting conditions such as dew, fog, frost, etc.
- 3) Field observations made during the study suggest that precipitation and moisture-related events in desert environments are often highly localized. The weather monitoring performed for this study may have been inadequate to characterize accurately the weather environments in the vicinity of the outage locations."

The researchers went on to recommend future weather studies employing more weather stations located at or near the transmission lines. It should be pointed out that

the weather stations used in their study were as far as 60 miles away from outage locations. They recommended using stations equipped with relative humidity and precipitation sensors.

In the 1965 survey conducted by the IEEE Working Group (Nasser et al. 1971), respondents who were confident about fault causes were asked about prevailing weather conditions at the time of trouble. Most respondents indicated that some form of precipitation or moisture was present during fault activity. "It is quite surprising to discover that fog is not the most frequent and severe deteriorating factor, but that drizzle and mist are even worse." With the exception of flashovers caused by sea salt, respondents also usually indicated that no wind was present during the outages. They also found that the season most conducive to contamination flashovers was fall, followed by spring and most troubles were reported to occur during the night and early morning hours.

The literature on the subject of appropriate meteorological conditions which instigate contamination flashovers deserves much greater review. This review, however, is deferred to Methods and Experimental Procedures where the development of the criteria for evaluating weather data is formed and substantiated utilizing findings from published literature addressing meteorological factors related to contamination flashovers.

METHODS AND EXPERIMENTAL PROCEDURES

Analysis of Historical Fault Data

Unexplained fault data on the MPC 500kV transmission lines were obtained for each year of operation (1983-1993). These data include the date and time of each fault, line number, phase, and the estimated location.

These data were analyzed so that any trends or patterns which might suggest or be in accordance with contamination caused faults could be observed. This was accomplished by entering the data into computer spreadsheets and generating graphs and histogram-type plots illustrating statistical distributions of chronological occurrence, position, time of year, time of day, line and phase.

For the data to be consistent with contamination caused faults, the fault activity should be concentrated during the late summer months, when contamination is expected to reach highest levels (Sandhu et al. 1988). Furthermore, contamination flashovers are believed to occur mainly between the hours of midnight and 8 a.m. when dew is most likely to form (Richards and Mauldin 1989). Contamination caused faults would also be expected to occur near sources of dust or pollution such as dirt roads and areas of industrial or agricultural activity. The data were analyzed specifically to search out any of the above tendencies.

Four different systems are used to estimated fault locations. The location of faults during the years 1983 through 1989 were calculated by MPC engineers using an electrical circuit model of the transmission lines and fault current ratios. The measured

fault current at Garrison and Broadview were used to form the fault current ratios for faults between these two substations. In January of 1990, three other fault location systems became available: a Fault Location and Relay (FLARE) system was installed, Schweitzer Engineering Laboratory (SEL) fault location relays were installed, and Bonneville Power Administration (BPA) engineers began estimating fault locations using their own line model, voltage measurements, and fault current ratios. Very few faults of known cause have occurred on the transmission lines and intentional, staged faults have not been performed, therefore, the accuracy of these systems is not known and can only be estimated by evaluating the amount of disagreement between them. The MPC current ratio calculation has been the most reliably available estimation. MPC and MSU engineers have observed failures and erratic behavior by the other three systems. For these reasons, the MPC current ratio calculation was used for analysis of fault location based on historical data.

Installation of Weather Stations

Meteorological data were obtained from weather stations installed at locations along the 500kV transmission line route. Prior to the installation of the weather stations, meteorological data from towns near the lines (Broadview, Harlowton, Martinsdale, and Townsend) were obtained, correlated with fault times, and examined. It was found that the data collected at these towns were inadequate because only daily summaries and statistics were recorded. Furthermore, wind and relative humidity statistics were not recorded. The meteorological conditions at the precise time of faults were needed.

These towns are located as much as 20 miles away from the lines, and, because weather conditions are sometimes very isolated, the meteorological parameters recorded at these towns may not accurately represent conditions present at the transmission lines.

Six sites along the transmission lines between The Broadview Substation and the transition of the lines to BPA ownership near Townsend were carefully chosen for the placement of computerized weather stations. Only this portion of the 500kV lines was chosen because most faults occur on this section and funding limited the number of weather stations to six. If the stations were separated by too great a distance, the meteorological data might not accurately represent the conditions at fault locations along the lines. The sites were chosen to provide easy access to the stations year-round while maintaining fairly even spacing along the line route. Installation of the weather stations was completed August 1, 1992. Figure 7 is a road map showing the approximate position of each weather station (numbered 1-6) along the transmission line route. The weather station equipment were mounted on the actual towers of the 500kV lines and Table 2 provides a listing of the tower numbers and a description of the sites. All of the towers are of the guy-wire support type except for 95-18 which is a self-supporting, "dead-end" tower. See Introduction for tower numbering method.

A set of requirements and specifications were prepared, and the weather stations were purchased through a bid process conducted by the Electrical Engineering Department and the Purchasing Department at Montana State University.

Figure 7: Road Map Showing Weather Station Sites

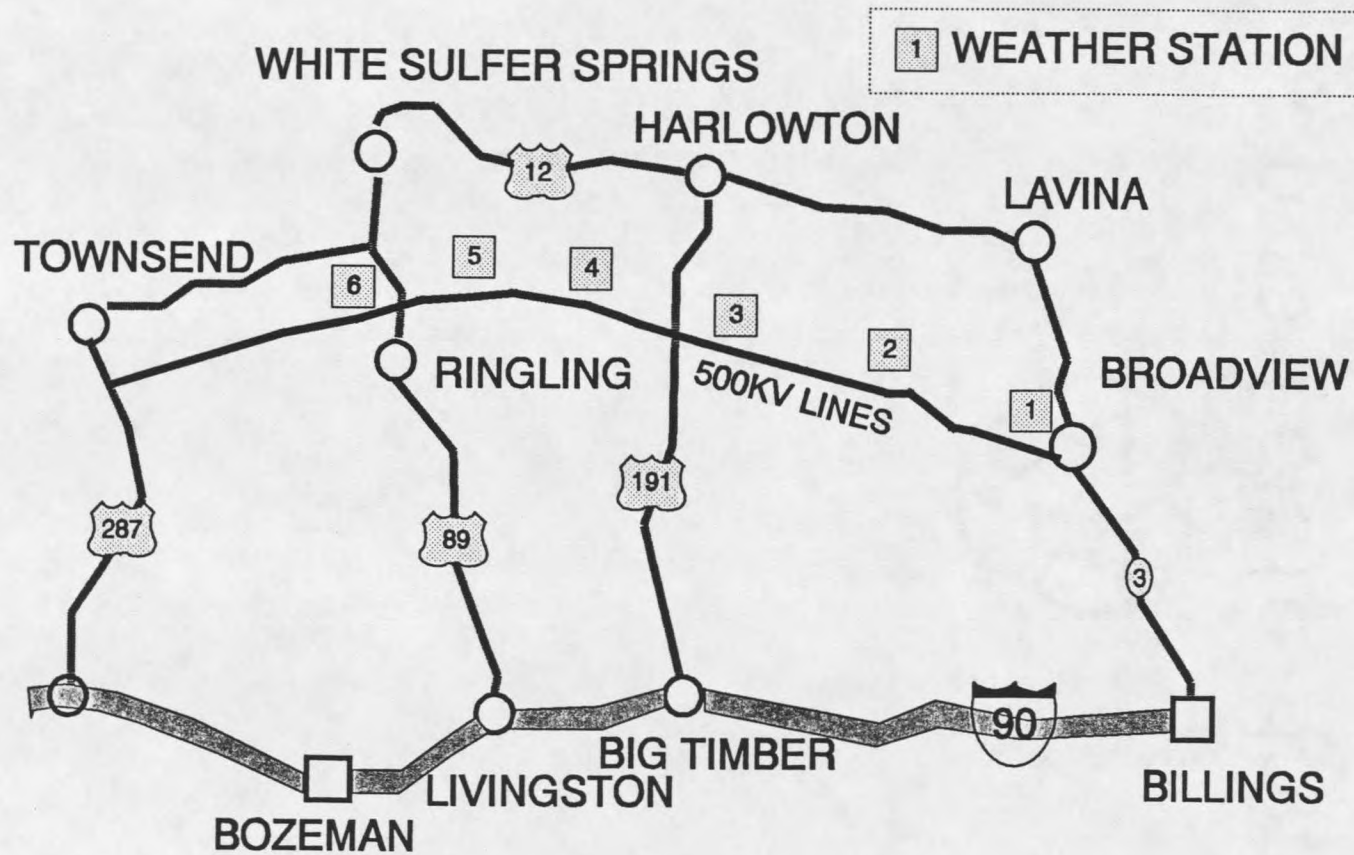


Table 2: Description of Weather Station Sites					
Site	Tower No.	Miles West of Broadview	Location Name	Description of Terrain	Fault Activity
1	0-0 North Line	0	Broadview Substation	Flat and several sections of tall grass.	Area of relatively few faults.
2	20-12 North Line	23	Golden Valley	At bottom of very large valley in wheat fields.	Area of moderate fault activity.
3	45-11 South Line	47.75	Cooney Ranch	On top of small ridge next to dirt road - no farming activity, rangeland.	Area of high fault incidence.
4	60-13 South Line	63.25	White Ranch	Flat and in the middle of several wheat fields.	Area of moderate fault activity.
5	85-18 North Line	89.5	Rostad Ranch	In bottom of narrow valley, next to creek.	Area of low to moderate fault incidence.
6	95-18 South Line	99.5	Galt Ranch	Flat rangeland	Area of moderate to high fault activity.

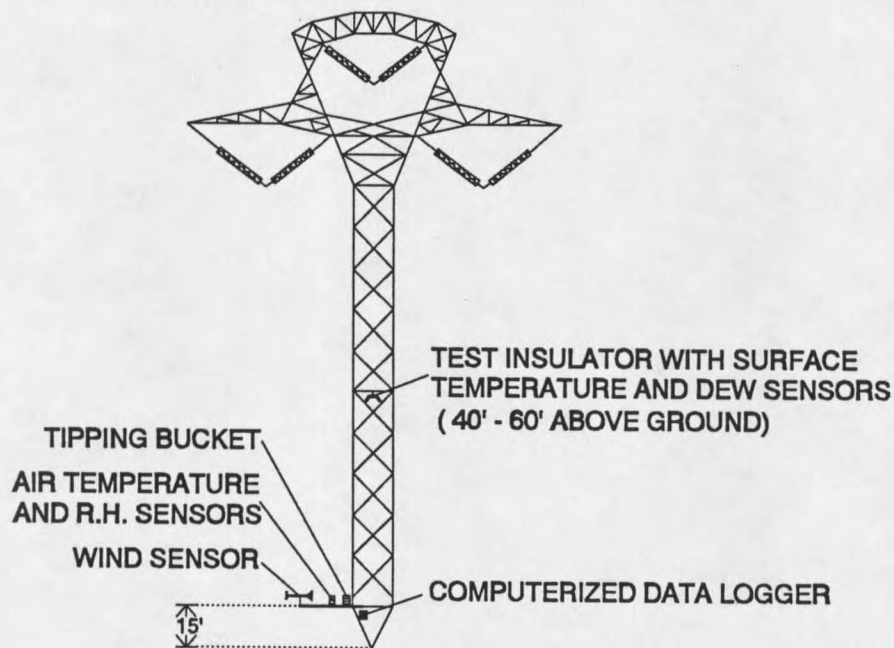
The weather stations were manufactured by Campbell Scientific of Logan, Utah and measure the following parameters:

1. Ambient air temperature.
2. Relative humidity (R.H.).
3. Wind speed and direction.
4. Barometric Pressure.
5. Precipitation from tipping bucket.

6. Surface temperature of a test insulator.
7. Amount of surface moisture present on dew sensors on a test insulator.

Figure 8 is a sketch showing the physical placement of the various weather station components and sensors on a typical tower.

Figure 8: Typical Weather Station Configuration



The specifications and parameters stored to memory for each of the sensors are listed below.

- Ambient air temperature

Range: -31°F to 122°F (-35 to +50°C)

Accuracy: 0.28°F (0.5°C)

Measured every 15 seconds. Averaged and stored at 15 minute intervals.

- Tipping Bucket Precipitation

Range: 0" to 2"

Resolution: 0.01"

Measured every 15 seconds. Totaled at 15 minute intervals.

- Wind velocity

Range: 0 mph to 100 mph

Accuracy: 1 mph

Measured every 15 seconds. Maximum, mean, and minimum stored at 15 minute intervals.

- Wind direction

Range: 0° to 360° (0° is due north.)

Accuracy: 1°

Measured every 15 seconds. Mean and standard deviation stored at 15 minute intervals.

- Relative humidity

Range: 0% to 100 %

Accuracy: 1 %

Measured every 15 seconds. Averaged and stored at 15 minute intervals.

- Barometric pressure

Range: 800 mbar to 1060 mbar

Accuracy: 1 mbar

Measured every 15 seconds. Averaged and stored at 15 minute intervals.

- Test insulator surface temperature

(This sensor is a K-type (Chromega-Alomega) thermocouple bonded to the bottom surface of the test insulator.)

Range: -75°F to 122°F (-59 to +50°C)

Accuracy: 0.28°F 0.5°C

Measured every 15 seconds. Averaged and stored at 15 minute intervals.

- Moisture on test insulator dew sensors (Resistance measurement)

(Two dew sensors were bonded to the test insulator, one on the top of the insulator and one on the bottom. See discussion below on dew sensor characteristics)

Range: 500Ω to 100MΩ (Resistance above 10kΩ indicates dew or other moisture present.)

Accuracy: 10%

Measured every 15 seconds. Averaged and stored at 15 minute intervals.

To detect moisture on the surface of the test insulator, electronic dew sensors were used. These sensors are resistive components specifically designed to detect the presence of dew inside electronic equipment. They are commonly used by video cassette recorder (VCR) manufacturers to prevent user operation and subsequent damage if operation is attempted when moisture is present inside the equipment. The resistance of these sensors, which increases with increasing moisture, normally varies from approximately 500Ω to 100MΩ depending on the level of surface moisture. Several VCR manufacturers were checked and found to use 10kΩ as the threshold which

indicates the presence of moisture. The use of dew sensors to indicate moisture on the surface of a high voltage test insulator was in itself an experiment, for this had never been done. The sensors were periodically inspected and tested and were found to operate correctly and reliably. In addition to detecting wet moisture, they also correctly indicated the presence of frozen moisture such as ice or frost.

Each weather station data logger was equipped with enough electronic memory so that data collection (downloading) to a portable computer could be performed at monthly intervals. The units transferred collected data to a lap-top IBM compatible computer via a standard RS232 computer communication interface. The meteorological data were then converted into standard MS-DOS ASCII format and then entered into a computer spreadsheet allowing the generation of plots and statistical calculations. For final spreadsheet storage, the data were separated into 10-day periods. Each month's data were broken and stored into three files containing weather parameters for 10-day periods. Computer memory limitations necessitated this partitioning of the data.

For each fault that occurred within the weather station coverage area (20 miles east of the Broadview Substation to 120 miles west of the Broadview Substation), the meteorological data from the nearest weather station were analyzed to determine if the data were consistent with conditions expected for contamination caused faults. The next section of this chapter outlines the criteria applied to the meteorological data surrounding each fault.

Criteria for Evaluating Weather Data

The following is a formal method proposed for evaluating the weather data associated with unexplained faults on the MPC 500KV transmission lines. These criteria form a basis by which the weather data for individual faults will be analyzed quantitatively and a subsequent opinion will be offered on whether or not individual faults appear to be caused by the wetting of contaminated insulator strings. These criteria will not be used to make a rigid determination about fault cause, but rather ascertain if the data, originating from a collective analysis of the meteorological parameters surrounding a fault, are consistent with those expected for faults instigated by the wetting of contaminated insulator strings.

A comprehensive review of technical literature on contamination flashover has been made and information gained was applied in the generation of the criteria outlined in this section. It must be understood that the quantitative parameters used to establish the criteria are very subjective. Since natural meteorological conditions are not reproducible in a laboratory, little detail was actually provided by the technical literature and only vague descriptions of appropriate conditions for contamination flashover were given. No quantitative definitions of "low winds", "warm, dry days", or "significant precipitation" were offered.

The criteria presented in this paper form a hypothesis. It is hypothesized that the quantitative criteria outlined constitute the correct and necessary conditions for the meteorological parameters to be consistent with those expected for unexplained faults caused by contamination flashovers.

All theories which explain the mechanisms that produce contamination flashover agree on two conditions that must be present. First, the insulator surfaces must be contaminated by a dust or some other form of pollution containing water soluble salts capable of producing a conductive film when wet. Secondly, the insulator surface must become wet (Richards and Mauldin 1989, Sandhu et al. 1988, Jolly 1972, Kawai 1972, Holt et al. 1979).

Contamination accumulation

The weather stations do not provide any contamination level information. They can, however, indicate when the weather was conducive to the accumulation of dust contamination on insulator strings. Warm and dry days accompanied by at least light winds form what are considered to be prime conditions for the accumulation of dust on insulator strings (Sandhu et al. 1988, Richards and Mauldin 1989, Nasser et al. 1971, Wahl 1976, Lozano et al. 1989, Burnham 1993, Zedan and Akbar 1985). For example, Florida Power and Light Company experienced 114 outages in one day when a humid cold front wetted insulator strings after a month with "no significant rainfall to help clean the insulators of accumulated local contamination" (Burnham 1993). Researchers for Sierra Pacific Power Company noted in their study

"Higher levels of contamination appear to accumulate during the long periods of hot, dry weather in the summer and fall" (Sandhu et al. 1988).

Data presented in a seasonal variation study of contamination in Mexico showed as much as a ten-fold increase in the contamination levels over a three month period of

dry weather, and rain washing of insulators reduced the contamination of insulators by a factor of 10 in only one month (Lozano et al. 1989).

Strong winds are usually considered to increase the likelihood of contaminants being deposited on the insulators by providing a mechanism of transportation for contamination (Sandhu et al. 1988, Holt et al. 1979, Wahl 1976, Rizk et al. 1975); however, they may not always be necessary for dust accumulation on the MPC 500KV lines. During the summer months of 1992, large clouds of dust generated by agricultural equipment were observed rising to and above the level of live insulator strings in fields through which the MPC 500KV lines cross. The wind speed during these observations was very low, estimated at less than 5 m.p.h.. Furthermore, many "dust devils", some higher than the 500KV conductors, were observed during periods of low winds.

To be consistent with conditions necessary for contamination flashover, a fault should occur after periods in which dust has had an opportunity to accumulate (indicated by several warm and dry days with no precipitation or only light rain). Medium or heavy rain (0.1" per hour or greater (Plate 1982)) will be considered sufficient to wash the insulators of contamination. The presence of winds will not be deemed necessary for contamination accumulation preceding faults during the summer months. This forms the first set of criteria, outlined in Table 3, to be used for evaluating the weather data.

Table 3: Criteria for Dust Contamination Accumulation	
INDICATORS	PARAMETERS
Warm day time temperatures	Air temperatures in excess of 40°F each day for five-day period preceding fault
Several dry days with only light precipitation	Tipping bucket registers less than 0.1" per hour for five-day period preceding fault

The criteria in Table 3 are not meant to imply that dust accumulation will occur if these criteria are satisfied. These simply represent the minimum conditions required for dust accumulation to occur, and if these conditions are not met, dust accumulation is unlikely.

Insulator wetting

The data from the weather stations provide very direct methods of checking for the presence of moisture on insulator strings. One must first understand the various ways in which the surface of an insulator can become wet. Surface condensation (dew formation), water impingement (fog or very light drizzle), and ice (including snow) are sources of moisture believed to instigate contamination flashovers (Richards and Mauldin 1989, Nasser et al. 1971, Berger and Chowdhure 1972, Rizk et al. 1975, Naito et al. 1983, Kawai and Milone 1969, Kawai 1970, Fikke et al. 1992).

Rain which causes dripping is not considered to cause contamination flashovers and actually washes some contamination off insulators (Holt et al. 1979, Wahl 1976, Lozano et al. 1989, Kawai 1967, Kawai and Milone 1969).

The weather stations are equipped with tipping buckets which record precipitation, relative humidity sensors, and dew sensors on test insulators indicate the presence of surface moisture.

Surface condensation

"Dew formation on insulators is the major cause of flashover on contaminated insulators" (Richards and Mauldin 1989). In addition to the above quotation, Richards and Mauldin provide a detailed explanation of the complex process through which dew is formed. Dew formation typically occurs at night when the air surrounding an insulator gives up water and deposits this moisture on the insulator surface. This condensation will form on both the top and bottom surface of the insulator. Dew will form if the relative humidity reaches 100% (the air is saturated) or the surface temperature of the insulator is equal to or less than the dew point temperature, which is below the ambient air temperature. As mentioned above, dew normally forms during a clear, still night when the insulator surface temperature drops below the ambient air temperature through a process of radiative cooling (Holt et al. 1979). With regard to the wind, dew forms "especially when the air is calm and there is practically no turbulence" (Hewson 1944). Dew may also form immediately before rain, during a short period of very high humidity (Richards and Mauldin 1989, Kawai et al. 1967, Kawai and Milone 1969).

This forms another set of criteria for collectively evaluating the weather data for indications of dew. The data will be considered consistent with dew-wetted

contamination flashover if there are indications of dew-wetted insulator strings. These indicators include the presence of dew on the test insulators (measured by the top and bottom dew sensors) by which an inference is made that moisture is also present on the live insulators. Another indicator is the insulator temperature dropping to or below the dew point temperature before a fault. Winds should be less than breezy (under 5 m.p.h. (Plate 1982)). Obviously, a high relative humidity near 100% is also a positive indicator of moisture, but it is not necessary for dew. A fault occurring immediately before a precipitation event will be considered consistent with contamination flashover, however, significant precipitation recorded by the weather station preceding and during the fault is not consistent with contamination flashover. Table 4 summarizes the criteria listed above.

Table 4: Criteria for Surface Condensation	
INDICATORS	PARAMETERS
Moisture on top and bottom of test insulator at time of fault	Top and bottom dew sensor readings above 10K Ω
Insulator temperature drops to the dew point temperature before fault	Ambient air temperature and relative humidity used to calculate dew point temperature; test insulator thermocouple temperature must be equal to or below dew point at some time during 6-hour period preceding fault.
Calm or moderate wind speed	Maximum wind speed less than 10 m.p.h.; Mean wind speed less than 5 m.p.h.
No significant precipitation immediately preceding and during time of fault	Tipping bucket registers no more than trace (0.01") for one-hour period preceding fault

The second criterion in Table 4 requires the insulator to drop to the dew point some time during the six hour period preceding a fault. The choice of six hours was somewhat arbitrary. It is possible for an insulator string to become wet by the process of dew formation and then remain wet for several hours. A flashover may not necessarily occur at the moment this moisture forms, but may occur many hours later, after some of the moisture has had an opportunity to evaporate and form a dry band. Six hours was chosen as a sufficient amount of time for this process to take place.

Water impingement by fog or light drizzle

"There is a critical amount of water required on the insulator surface to produce the minimum flashover voltage. The most severe condition requires sufficient quantity and time duration of wetting to dissolve the majority of the conductive contaminant without dripping. Larger amounts of water can wash the insulator while preventing the formation of dry bands. Thus the critical wetting conditions most commonly occur during fog or light misty rain" (Holt 1979).

Although less common along the MPC 500KV line route than dew, fog clouds have been observed during early morning hours in low-lying valleys along the MPC 500KV line route and light drizzle is not uncommon. Fog is "a suspension of very small water droplets in the air" and is a form of moisture impingement on an insulator surface (Byers 1959). "This mechanism, depending on the wind, can wet the undersurfaces of the insulator more effectively than the condensation mechanism" (Holt et al. 1979). Indicators of fog or very light drizzle recorded by the weather stations include high relative humidity, but how high must the relative humidity be? In a study of salt-contaminated insulators, Kawai and Milone (1969) noted that in an area where

dew, fog, and drizzle appeared, the insulation strength of an insulator surface "decreased rapidly" when the relative humidity exceeded 80% due to increased moisture absorption by the salt contaminants. Rizk et al. (1975), concluded in a study of EHV transmission line insulators in the desert that "only relative humidities above about 95% and lasting for at least one hour represent a serious hazard to a contaminated insulator in the desert."

The following indicators must be present to satisfy the criteria for a fault consistent with fog or light drizzle wetted contamination flashover. Both the top and bottom dew sensors must indicate the presence of moisture on the test insulator. The weather station must record no more than a trace of precipitation preceding and at the time of the fault, and the relative humidity must be greater than 70% (a conservative estimate). Table 5 summarizes the fog and drizzle criteria.

Table 5: Criteria for Fog or Drizzle	
INDICATORS	PARAMETERS
Moisture on top and bottom of test insulator	Top and bottom dew sensor readings above 10K Ω
Only trace of precipitation immediately preceding and during time of fault	Tipping bucket registers no more than 0.01" for one-hour period preceding fault
High relative humidity	Relative humidity measurement above 70%

Ice formation

"Ice accretions on insulators may cause a dramatic reduction of the flashover voltage of exposed transmission lines" (Fikke et al. 1992).

Ice, even when hard and dry, has been found to cause flashovers and precontamination of insulators is not required (Kawai 1970). Ice forms when rain or wet snow freezes on the insulator surfaces or dew freezes to form frost. Distribution line outages caused by snow and ice are a common problem during the winter months in Montana; however, MPC engineers and linemen and MSU researchers have not reported ice or snow accumulations on the MPC 500KV line insulators. Of course, this is not sufficient to dismiss snow or ice as a cause for faults on the MPC 500KV lines. The weather parameters must be examined for faults which occur during the winter months, or anytime when conditions warrant insulator icing to be considered a possibility.

Fortunately, the dew sensors indicate the presence of moisture in any form (water, frost, and wet or dry ice) on the test insulator surface. To meet the criteria for ice, the test insulator temperature must be near or below freezing before the fault. An insulator temperature rising from below to above freezing accompanied by continuous moisture on the dew sensors is an indication of melting frost, ice, or snow. The criteria for the presence of ice are listed in Table 6.

Table 6: Criteria for Ice	
INDICATORS	PARAMETERS
Moisture on at least the top surface of test insulator	Top dew sensor reading greater than 10K Ω
Near freezing test insulator temperature before fault	Test insulator thermocouple measures under 35°F during fault or at some time within 2 hour period before fault; (35°F is used because of possible temperature differential between test insulator and live insulators)

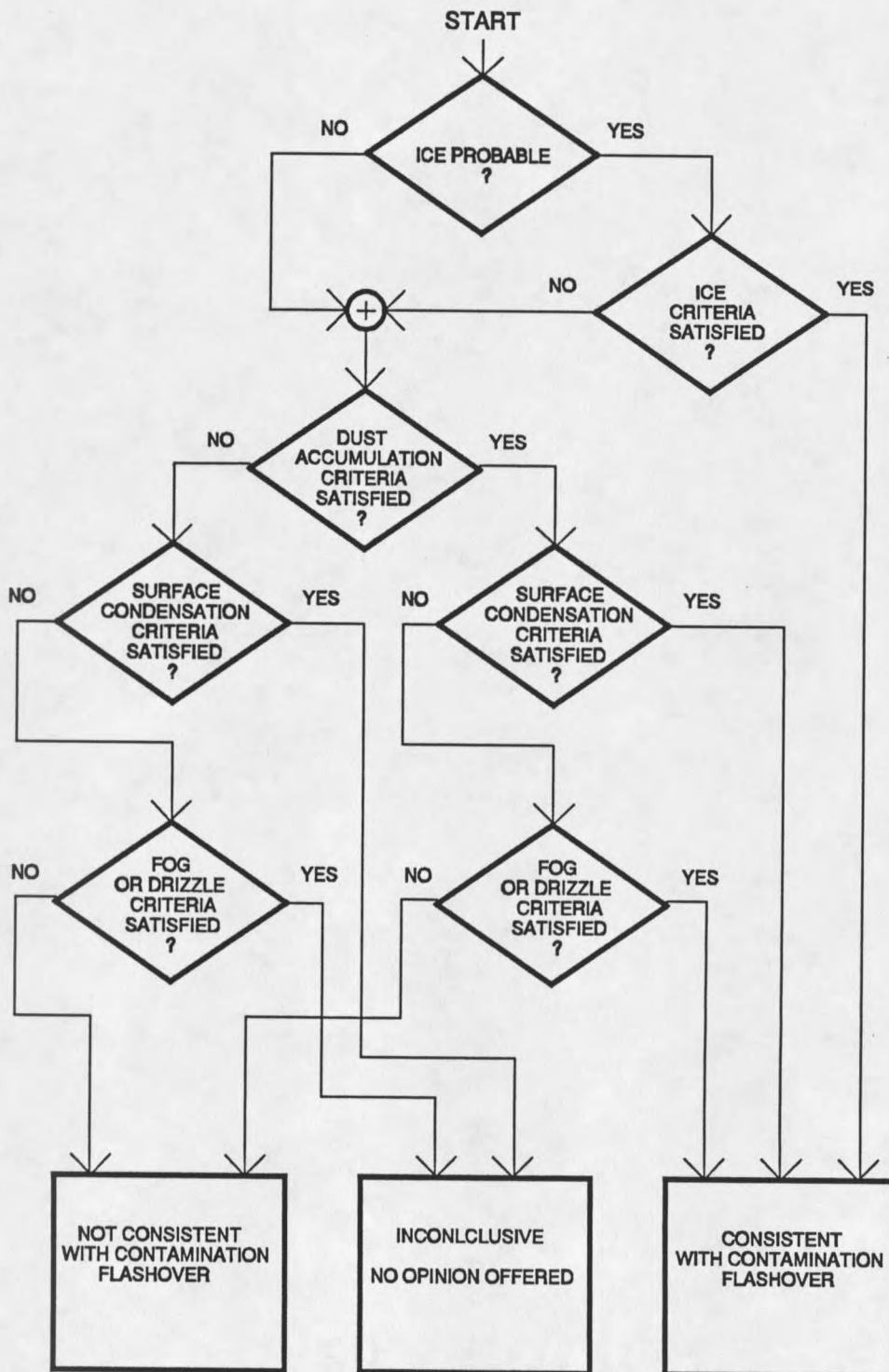
Algorithm for application of criteria

Figure 9 is a logical flow chart describing the application of the above criteria in an algorithm. The first decision block (Is ice probable?) requires information about local conditions obtained by visits to the area or details provided by residents local to the transmission line. The other decision blocks make use of the criteria outlined in Tables 3-6. An inconclusive deduction will result if a fault occurs while the appropriate wetting conditions for contamination flashover exist, but the dust criteria are not satisfied. For example, if a fault occurs after (0-5 days) a heavy rain (intense enough to wash insulators) and the conditions at the time of the fault are consistent with contamination flashover, the outcome will be deemed inconclusive. This implies that information about the long-term accumulated contamination level and the washing ability of rain is too limited to offer an opinion.

The criteria considered above and the algorithm outlined in the flow chart provide a general guideline for evaluating the weather data. In some respects, this guide

may be considered oversimplified because of the complex nature of meteorological conditions and limited information the weather station parameters provide. For example, little is known about the presence or density of cloud cover or the amount of sunlight. The intensity and subsequent washing ability of rain during precipitation is not provided. Only through visiting the area around the transmission lines does knowledge about snow cover or soil moisture become available. The data do not provide a "picture" of storm fronts approaching or leaving an area and no detection of lightning is available at the weather stations. These limitations necessitate the careful examination of all the meteorological parameters surrounding each individual fault and any other knowledge about the area at the time of fault such as agricultural activity, lightning, snow cover, fires, etc. Some exceptions to the above criteria must be allowed under special circumstances when a collective analysis of all the information surrounding a fault suggests a cause that contradicts the criteria given.

Figure 9: Algorithm for Application of Criteria



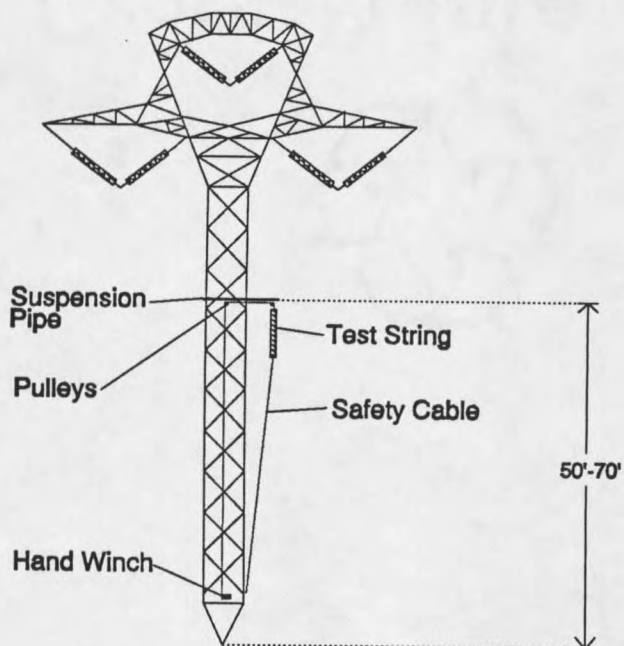
ESDD Sampling

Equivalent Salt Deposit Density (ESDD) sampling was performed on several occasions to determine the degree of contamination present on the 500kV insulators. In May 1992, April 1993 and September 1993, MPC crewmen removed strings of insulators from service, providing the opportunity for ESDD sampling. These strings suffered damage from gunfire and normally several insulators were missing on each string. ESDD sampling was performed on many of the remaining insulators. Each of the strings removed from service had been in place since the line's construction.

In June of 1993, six test strings, each consisting of 15 insulators, were installed on each weather station tower. Each string was suspended with a pulley system and can be lowered to the ground by a hand winch mounted near the base of each tower. Figure 10 shows the mechanical arrangement of the winch, aircraft cable, and insulator string for each site.

The strings were carefully cleaned to remove any contamination at the time of installation. The test strings provide a means for performing periodic sampling allowing insight about seasonal contamination variance. A plan was instituted to sample the test strings every two or three months and obtain statistics on seasonal contaminant accumulation patterns. One insulator from each string was sampled for ESDD on August 5, 1993. That was the only time in which the test strings were sampled before this report was prepared.

Figure 10: Test Insulator Configuration



Procedures devised by the Bonneville Power Administration (BPA) were followed for obtaining dust samples from insulators and calculating ESDD levels (Renner 1991). The following steps summarize the procedure used for each ESDD sample.

1. All surface contamination was removed by wiping with a small piece of sterile gauze dampened with distilled (very low conductivity) water. Rubber gloves were used to avoid contamination by body salts.
2. The surface area for each sample was carefully calculated.
3. Each sample (piece of gauze) was placed in a separate plastic bag which was sealed and marked for identification.

4. Each sample was dissolved in a known volume of distilled water and mixed with a magnetic mixer for at least ten minutes.
5. The conductivity of the solution for each sample was measured with an electric conductivity meter.
6. The temperature of the solution for each sample was measured.
7. The equivalent amount of NaCl that would produce the same conductivity was calculated for each sample. (The conductivity of the distilled water (usually less than 1 micro Siemen) and the temperature of the solution were used as correction factors.)

The calculations were made easy by a computer program provided by BPA engineers.

Installation of Magnetic Fault Indicators

The ability to determine the cause of unexplained faults on the 500kV lines is very dependent on accurate fault location. Finding actual towers on which faults occur would enable an inspection of these towers and the insulator strings on them.

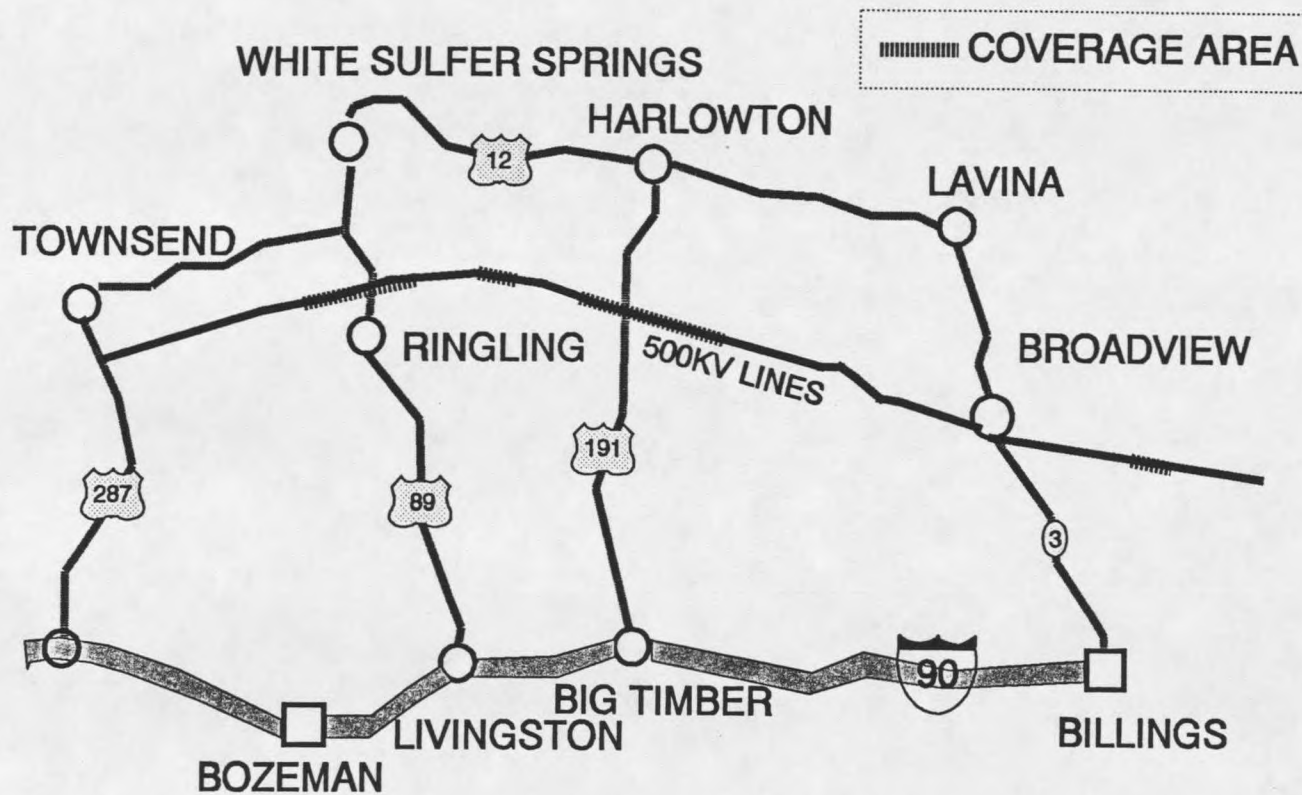
Two methods for estimating the location of faults, the MPC current ratio and the FLARE system, seem to be in fairly close agreement, however, due to old scars on the towers, there can be no certainty about which tower experienced a fault immediately after a fault's location is estimated. Either the line must be cataloged (all burn marks and scars documented) or an alternative method for calibrating the location system has to be found, or, an entirely new way for finding faults has to be considered.

In order to identify individual towers on which faults occur, magnetic type fault indicators were installed. The installation of 280 tower-mounted fault indicators was completed in August of 1993 and approximately 37 miles of the 500kV lines were covered in four separate sections. These are simple devices which clamp to a cable and permanently display a small red flag if the current through the cable exceeds a certain threshold, usually in the range of 100 to 800 amperes. The fault indicators installed on the MPC 500kV lines have a trip rating of 100A and were clamped to a ground cable at the base of each tower in the coverage area.

A listing of the towers equipped with fault indicators is provided in Table 7 and the coverage area is illustrated in Figure 11. The first section, north of Shepherd, is a small section 28 miles east of the Broadview Substation where only the "B" line was equipped. Both lines were equipped in the other three sections west of Broadview.

Table 7: Fault Indicator Coverage Area			
Location	Miles and direction from Broadview Substation	Towers	Miles Covered
North of Shepherd.	27 to 30 (East)	80/5 - 80/18	3
South of Harlowton.	39 to 57 (West)	35/16 - 55/8	18
South of Twodot	62 to 65 (West)	60/9 - 65/0	3
North of Ringling	92 to 105 (West)	90/10 - 105/0	12

Figure 11: Road Map Showing Fault Indicator Coverage Area



EXPERIMENTAL RESULTS AND DISCUSSION

Historical Fault Data Analyses

Fault data provided by The Montana Power Company was entered into a computer spreadsheet to facilitate analysis and the generation of plots showing various fault distributions. This analysis of historical fault data focussed on the section of 500kV lines between the Broadview Substation and Townsend (the Number 1 (south) and Number 2 (north) lines). This section of the transmission route has had the greatest number of unexplained faults. Table 8 in Appendix A is a listing of each recorded fault on this section of the lines for the years 1984 through 1993. This list includes the date, time, julian day of year, estimated location, line number, phase, and phase orientation of each fault. Various statistics based on this listing are presented and discussed in the following sections.

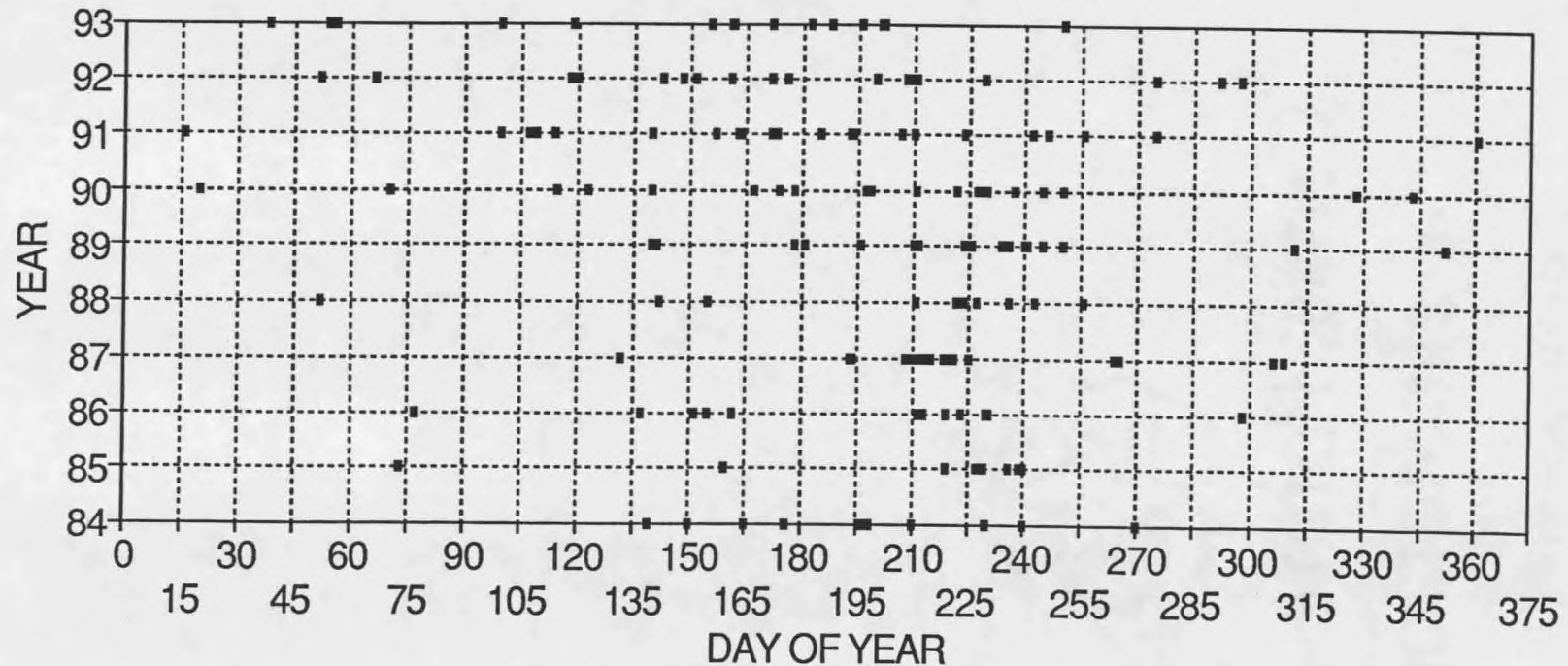
Chronological distribution

Figure 12 is a plot of the chronological distribution of unexplained faults on the section of lines between Broadview and Townsend. Each fault is represented by a small vertical bar. The year and the julian day of the year define the position of each fault mark. There is an apparent tendency for faults to occur mainly during the summer months. Seventy one percent of the faults occurred between days 150 and 250, the months of June, July and August. This trend is consistent with contamination flashover since most contamination caused faults occur during the summer months.

Figure 12

CHRONOLOGICAL FAULT DISTRIBUTION

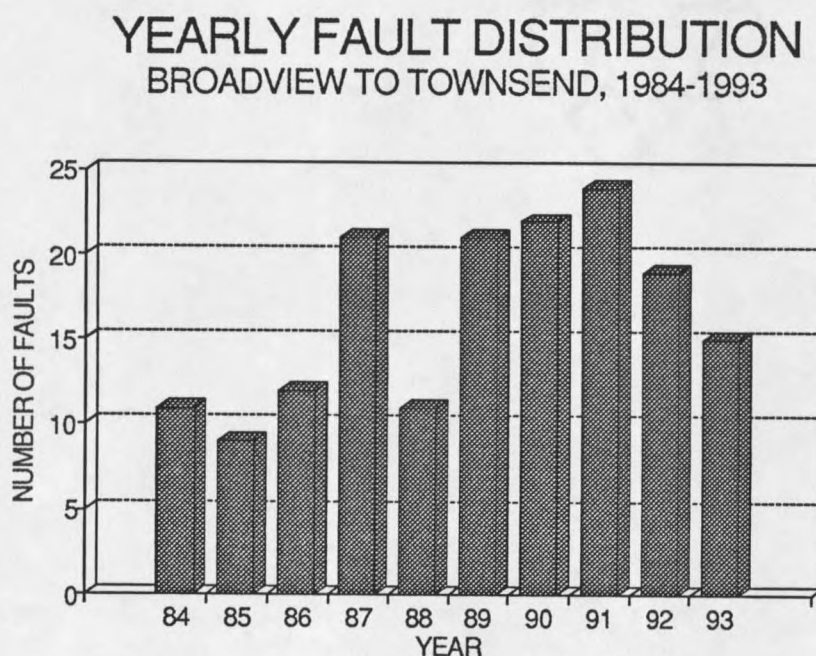
BROADVIEW TO TOWNSEND, 1984-1993



A particularly close concentration of faults occurred in 1987 where 13 faults occurred in an 18-day period during the last week of July and first week of August.

The number of faults on the Broadview-to-Townsend lines per year is shown in Figure 13. It is worth noting that during the first full year of operation, 11 unexplained faults occurred on these lines. If contamination flashover caused these faults, then the time required for problematic contamination accumulation is relatively short and several years of exposure is not needed.

Figure 13



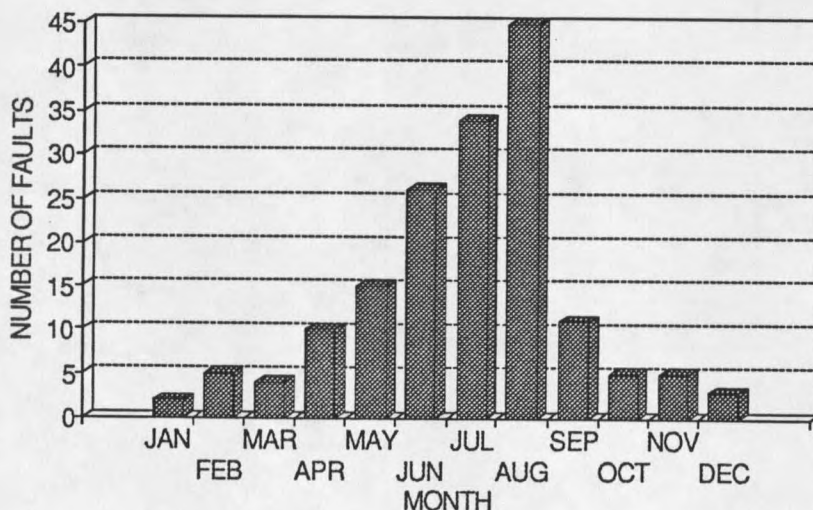
The number of unexplained faults gradually increased each year from 1985 to 1991 with the exception of 1988, when fault activity decreased significantly from the previous year. The year 1988 is when many forests throughout Montana, and most notably, Yellowstone National Park (Approximately 100 miles south of the 500kV

lines), suffered extensive forest fires. It is interesting to observe that fault activity has been decreasing in 1992 and 1993, both considered years of higher-than-normal summertime precipitation.

Figure 14 is the monthly fault distribution for the Broadview-to-Townsend lines. This graph, generated from the 1984-1993 fault data, clearly displays the above mentioned tendency for faults to occur mainly during the summer months. Figure 14 also illustrates a significant increase in fault activity each month from March through August. This too is consistent with contamination flashover theory, since dry summer months provide the best opportunity for contamination levels to increase. However, it is not well understood why there is such a sudden reduction in fault activity for the month of September.

Figure 14

MONTHLY FAULT DISTRIBUTION BROADVIEW TO TOWNSEND, 1984-1993



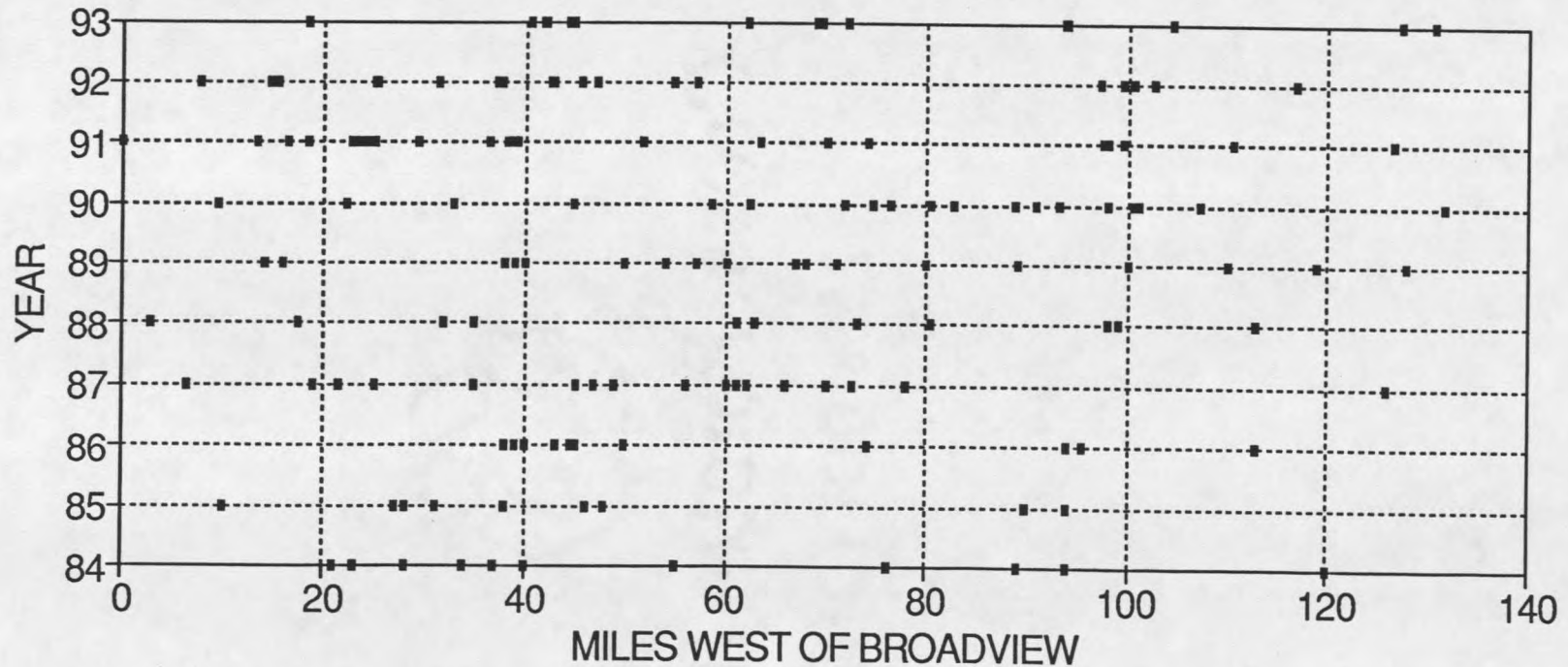
Position distribution

Figure 15 shows the approximate location, in miles from Broadview, for each fault along the Broadview-to-Townsend lines based on the MPC estimated distance. The faults appear to be somewhat randomly distributed along the lines. There is no apparent concentration of faults in any one area which is consistent for every year of operation. Very few faults, however, have occurred near the ends of the lines, 0 and 140 miles west of Broadview. The estimated fault locations were categorized into 10-mile segments and the resulting distribution is shown in Figure 16.

The 10-mile segment with the greatest number of faults (40 to 50 miles west of Broadview) is mostly rangeland with no agricultural activity; however, 4 dirt roads pass under the lines. The second highest peak (90-100 miles west of Broadview) is an area containing several sections of wheat fields. The third highest area of faults is an area of agricultural activity, in a large depression known as the "Big Coulee" (20-30 miles west of Broadview). The segment of least fault activity (130-140 miles west of Broadview) is the final section of the MPC lines where the transition to single, double-circuit towers owned by BPA takes place. This section crosses the Missouri River and the nearby land is used mostly for agricultural purposes. Few faults have occurred in the first 10-mile segment near the Broadview Substation, an area containing both several farming plots and many sections of very tall grass. Another area of little fault activity is the 80-90 mile section directly north of the Crazy Mountains where a five-mile portion of the lines passes through the Lewis and Clark National Forest.

Figure 15

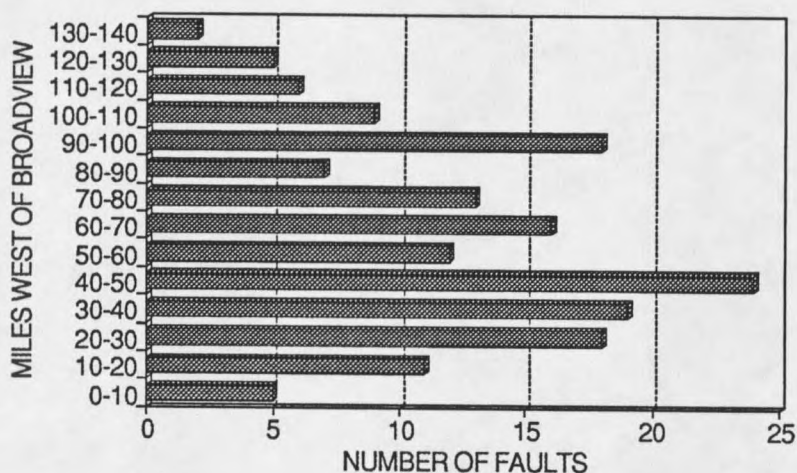
YEARLY POSITION DISTRIBUTION BROADVIEW TO TOWNSEND, 1984-1993



■ UNEXPLAINED FAULT

Figure 16

FAULT LOCATION DISTRIBUTION BROADVIEW TO TOWNSEND, 1984-1993



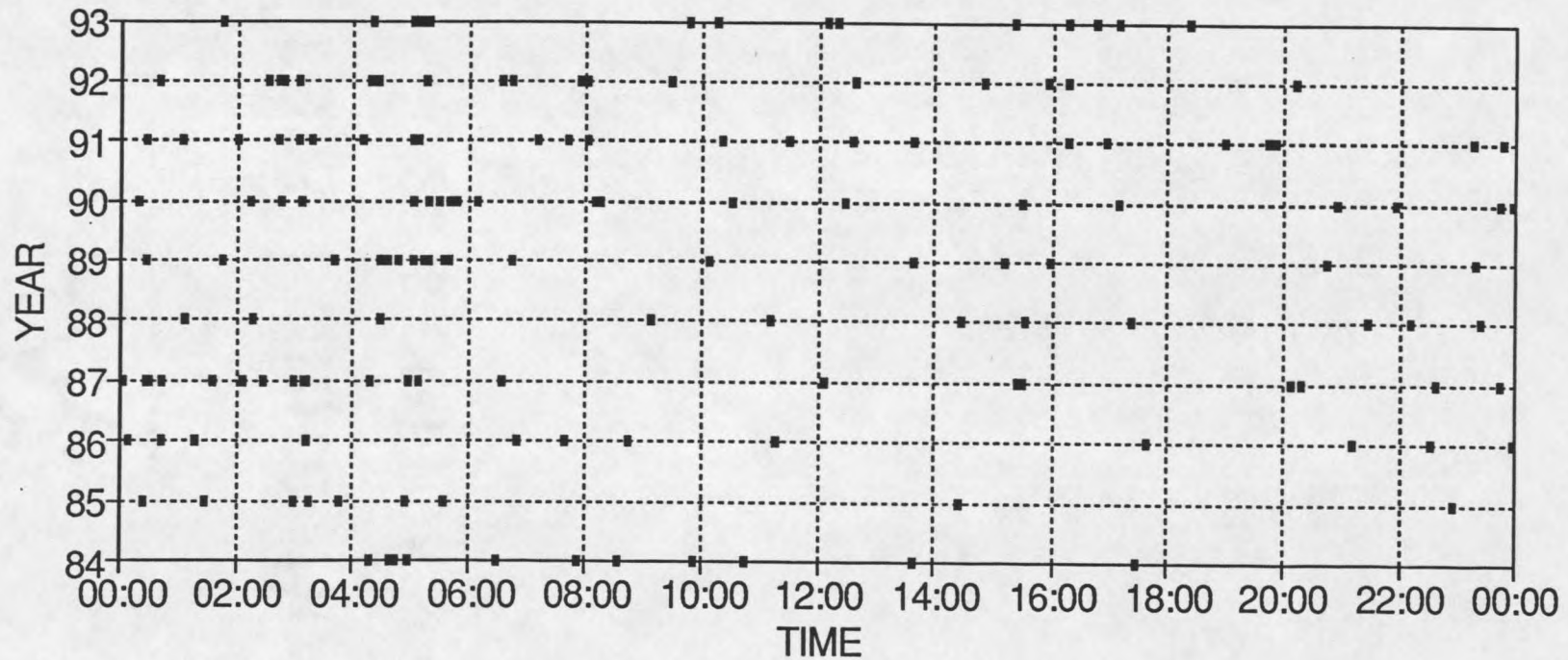
Contamination flashovers usually occur in areas more susceptible to contamination accumulation such as near dirt roads and agricultural activity. There are no trends in the fault location distribution which contradict contamination theory. However, the accuracy of the MPC fault location estimates is limited, therefore, the location distributions should not be used to suggest contamination as a cause of the faults.

Time of day distribution

The yearly time of day fault distribution is plotted in Figure 17. Although the times appear to be somewhat scattered, a trend for the faults to occur mainly during the late evening and early morning hours is apparent and consistent for each year of the operation.

Figure 17

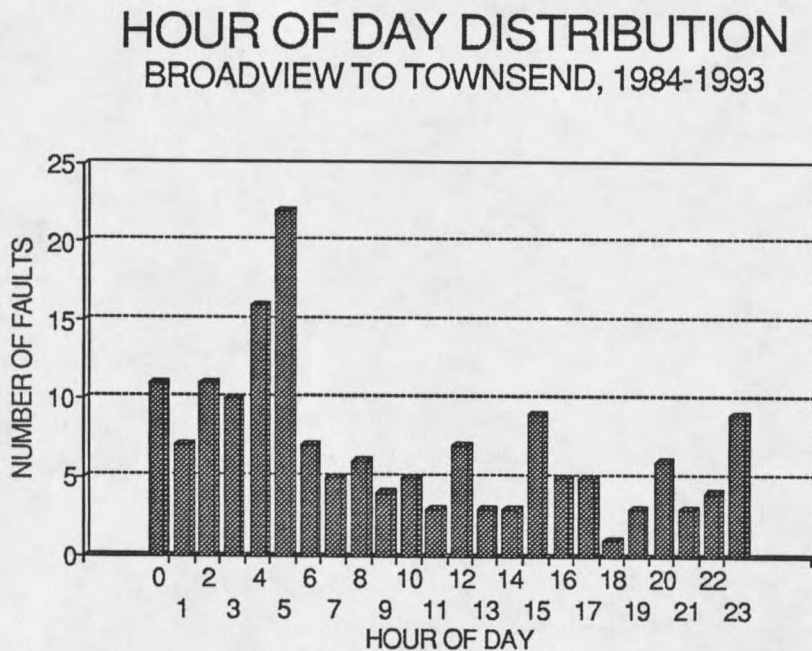
TIME OF DAY DISTRIBUTION BROADVIEW TO TOWNSEND, 1984-1993



■ UNEXPLAINED FAULT

The fault times were categorized hourly and plotted in Figure 18. Sixty seven percent of the faults occurred between the hours of 8 p.m. and 8 a.m. and there is a distinct peak in fault activity during the early morning hours of 4 a.m. to 6 a.m..

Figure 18



Since the fault activity is more prominent during the summer months, the time of day for faults which occurred during the summer was examined. Figure 19 shows the hour of day distribution for faults which occurred during the months of June, July, and August, and Figure 20 is the distribution for the month of August only. Each of these distributions share a common tendency for faults to occur more often during hours of darkness with fewer faults during the late morning and afternoon. These distributions are consistent with contamination flashover theory since the majority of faults have occurred at times when dew formation on insulator surfaces was most likely.

Figure 19

HOUR OF DAY DISTRIBUTION JUNE, JULY AND AUGUST (BV-TN, 1984-1993)

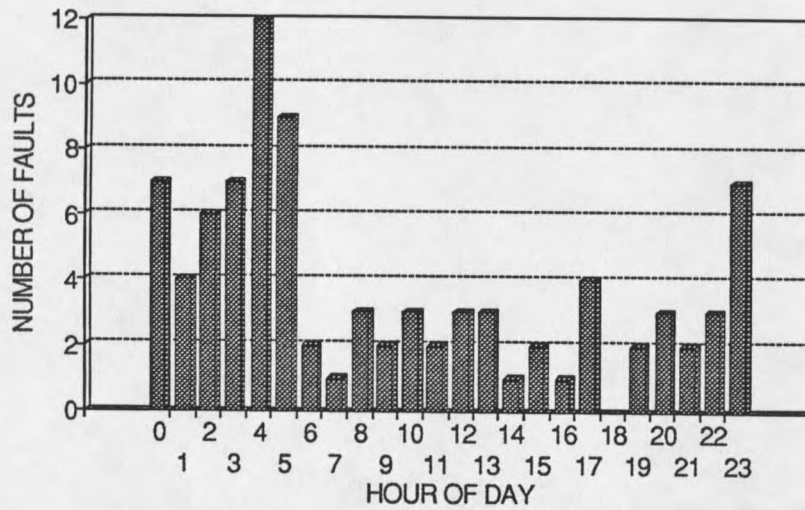
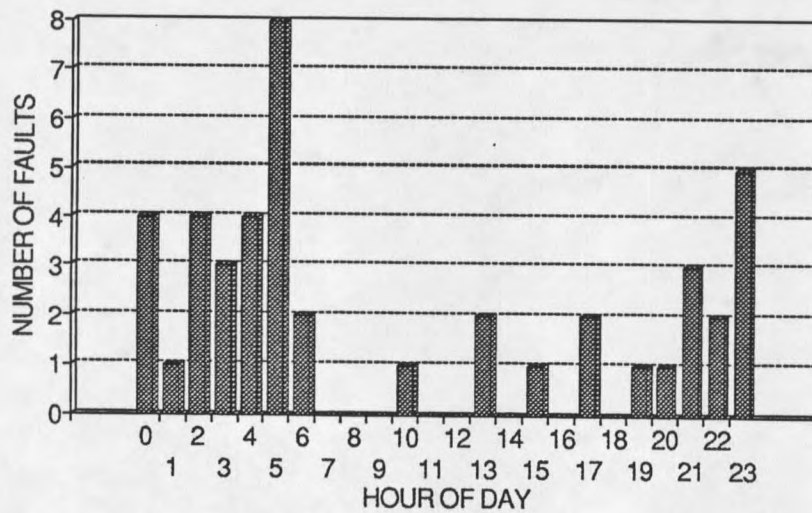


Figure 20

HOUR OF DAY DISTRIBUTION AUGUST ONLY (BV-TN, 1984-1993)



Weather Data Analyses

From the time the weather stations were installed to the time this thesis was prepared, nineteen unexplained faults had occurred within the weather monitoring coverage area. Faults which occurred between 20 miles east of the Broadview Substation to 120 miles west of the Broadview Substation were considered to be within the weather station coverage area.

For each of these nineteen faults, several plots of the meteorological parameters were generated for a six-day period with day six containing a fault. These plots provided a means for collectively analyzing the meteorological data for several days leading up to each fault and closely examining the conditions immediately preceding each fault. These plots are included as Figures 26-176 in Appendix B and graphically illustrate meteorological parameters including air temperature, relative humidity, wind speed, barometric pressure, test insulator temperature, dew sensor resistances, and dew point. When viewing these plots, note that a date mark on the X-axis corresponds to the beginning of a day and the time of each fault is denoted by an asterisk. Where the X-axis is an hourly time scale, international time (military time) is used.

Table 9 in Appendix C is a listing of the estimated locations and meteorological data for each of the nineteen faults. When available, location estimates from each of the four systems (MPC, FLARE, SEL, BPA) were listed. The MPC estimate was normally used to approximate which of the six weather stations was the closest to each fault. When a fault occurred between the Broadview Substation weather station and the Galt Ranch weather station, the meteorological parameters from two or three nearest

weather stations were listed to evaluate any significant differences in the weather conditions. The meteorological parameters listed in Table 9 (Appendix C) were those recorded the 15-minute period in which each fault occurred. The clocks in the weather stations are accurate to within 2 minutes of the MPC system clock. The criteria for evaluating the weather data (developed in Methods and Experimental Procedures) was applied to the meteorological parameters listed in Table 9 and the plots included in Appendix B. The resulting conclusions formed by the application of these criteria are also listed in Table 9.

Appendix D contains six tables, Tables 10-15, each listing the ten-day mean and standard deviation of all meteorological parameters recorded at 15-minute intervals by each weather station. The reason for ten-day partitioning of the data from each weather station was discussed in Methods and Experimental Procedures. Tables 10-15 cover data recorded from August 1, 1992 to September 20, 1993.

The weather stations were installed and operating August 1, 1992, however, the dew sensors and surface thermocouple on the test insulators were not installed in time for Faults 1,2,3, and 5. This prevents direct application of the criteria formed for evaluating the weather data. An opinion about the consistency of the meteorological conditions with contamination flashover was offered based on the meteorological parameters which were available.

The information presented in Appendices B,C, and D were used to make general observations about the weather conditions surrounding each fault, and, through the application of the criteria for evaluating the weather data, determine if the

meteorological conditions appeared to be consistent with those expected for contamination flashover. A case-by-case examination of the meteorological conditions, application of criteria, and any other pertinent information for each individual fault is discussed below.

Fault #1 - 2:43 a.m., August 16, 1992 - 102.7 miles west of Broadview

Figure 26 is a plot of the air temperature and relative humidity for a six day period leading up to, and including, the fault. Figure 26 shows that the relative humidity increased significantly (from 25% to 88%) several hours before the fault and the temperature the evening of August 15 dropped suddenly (from 75°F to 60°F) at approximately 6:00 p.m.. The temperature plot somewhat resembles a sinusoidal pattern between August 11 and 15, with an observable disturbance in that pattern the evening of August 15. Figure 27 reveals that a small amount of precipitation fell the evening of August 15 which could account for the sudden rise in humidity. As seen in Figure 28, a plot of the maximum, mean, and minimum wind speeds, the wind was gusty (peaks in excess of 15 m.p.h.) each afternoon for several days prior to the fault. Figure 29, which is a "blow up" of Figure 28, shows the wind speed from 6:00 p.m. of August 15 to 8:00 a.m. of August 16. Note the peak (22 m.p.h.) in the wind speed which corresponds to the time of precipitation, and, how the wind became very calm (0 m.p.h.), possibly aiding in formation of fog or dew, approximately 30 minutes before the fault occurred. The barometric pressure, plotted in Figure 30, shows low pressure entered the area August 12. The criteria for dust contamination were satisfied since only

light precipitation (maximum rate of 0.03" per hour) fell on the preceding evening.

It is unfortunate that the dew sensors had not been installed in time for this fault, however, the other parameters including the early morning hour, high humidity, low wind, and a trace of precipitation several hours prior to the fault, are consistent with conditions expected for contamination flashover.

Fault #2 - 2:52 p.m., October 1, 1992 - 42.5 miles west of Broadview

Data from Figures 31, 32, and 33 and Table 9 show this fault occurred during a hot (86°F), dry (9% R.H.), and windy (up to 15 m.p.h.) afternoon. No plot of precipitation is given because no precipitation was recorded for the week preceding the fault. This lack of precipitation satisfies the dust criteria, however, the meteorological parameters provide no evidence of moisture around the time of this fault. As shown by Figure 34, the barometric pressure was not changing suddenly around the time of the fault.

The time of day, warm temperature, and very low relative humidity for this fault are not consistent with conditions expected for contamination flashover.

Fault #3 - 12:36 p.m., October 18, 1992 - 99.6 miles west of Broadview

As shown by Figure 35 and Table 9, this fault occurred on a relatively warm and dry afternoon after the air temperature rapidly increased from 28°F to 55°F and the relative humidity dropped from 89% to 37%. Figures 36 and 37 indicate a light breeze averaging 3 m.p.h. at the time of the fault. Figure 38 indicates a trace (0.01") of

precipitation fell 32 hours before the fault on October 17. However, no precipitation was recorded around the time of the fault, therefore the dust criteria were satisfied. The barometric pressure, shown in Figure 39, was falling gradually the afternoon of the fault.

This fault occurred during a warm and dry afternoon, conditions not consistent with those expected for contamination flashover. According to the MPC estimate, this fault occurred within a 1/4 mile to the Galt Ranch weather station, therefore, the parameters recorded by the weather station should accurately reflect the conditions that the line was under at the time of the fault.

Fault #4 - 4:17 p.m., October 23, 1992 - 117 miles west of Broadview

The test insulator thermocouple and dew sensors were operating at the time of this fault. This fault also occurred on a warm and dry afternoon after the air temperature increased from 38 °F to 64°F and the relative humidity dropped from 65% to 24%, as shown by Figure 40. Figures 41 and 42 indicate a moderate breeze up 13 m.p.h. was present the afternoon of the fault. A high pressure system had moved into the area as shown by Figure 43. The resistance of the dew sensors, shown in Figure 44, indicate that the test insulator was dry around the time of the fault (moisture on a dew sensors will cause its resistance to increase above 10kΩ). The surface temperature of the test insulator and the ambient air temperature is plotted in Figures 45 and 46. Figure 46 also includes the dew point temperature. As shown by Figure 46, there was little difference in the insulator and air temperatures around the time of the fault and the insulator did not fall to the dew point any time in a six hour period before the fault.

This indicates that it is highly unlikely any moisture formed on the insulator strings. No plot of precipitation is given because no precipitation was recorded for the week preceding the fault.

The criteria for moisture (surface condensation, fog or drizzle, and ice) are not satisfied, therefore, the weather conditions were not consistent with those expected for contamination flashover.

Fault #5 - 11:36 p.m., November 2, 1992 - 17.2 miles east of Broadview

As illustrated by Figure 47, this fault occurred at night after the air temperature dropped from 42°F to near the freezing mark, 33.2°F, and, the relative humidity increased from 48% to 73% around the time of the fault. Falling snow was reported in Billings (45 miles south of the fault location) the evening of the fault. Figure 48 shows 0.11" precipitation fell 17 hours before the fault. If it was snowing at the time of the fault, the tipping bucket at the weather station may have been frozen and not functioning. Figures 49 and 50 show a strong breeze, up to 25 m.p.h. was recorded at the time of the fault. The barometric pressure, plotted in Figure 51, had risen rapidly from 878 mbars to 887 mbars the afternoon and evening prior to the fault. The test insulator dew sensors and thermocouple were not installed in time for this fault so it is not known if moisture was present on the insulators.

Since the distance between the fault and the weather station was estimated to be 17 miles, it is possible the weather conditions surrounding this fault may have been somewhat different from those recorded by the weather station at the Broadview

Substation. It is suspected that snow or ice formation may have caused this fault, however, no opinion is offered as to the consistency of this fault with contamination flashover. This fault is deemed inconclusive because of the lack of dew sensors, precipitation information (possible frozen tipping bucket), and the 17 mile distance.

Fault #6 - 12:08 p.m., February 7, 1993 - 93.7 miles west of Broadview

According to the MPC estimate, Fault #6 occurred midway between the Galt Ranch weather station and the Rostad Ranch weather station. Therefore, the meteorological data from both weather stations were analyzed. Figures 52 and 53 show that the relative humidity decreased from approximately 64% to 54% and the air temperature increased from approximately 30°F to 38°F before this fault. No precipitation plots are presented because no precipitation was recorded by either weather station for the week preceding this fault. Therefore, the dust accumulation criteria were satisfied. As shown by Figures 54 to 57, both weather stations recorded relatively low wind speeds (usually under 10 m.p.h.) for four days preceding the fault and a light breeze (8 m.p.h. to 12 m.p.h.) at the time of the fault. Figures 58 and 59 show that the barometric pressure was dropping gradually during the four-day period preceding and including the day of the fault. Figures 60 to 63 indicate that the test insulators were warmer than the ambient air during the fault and the test insulators were also at least 15°F above the dew point. The dew sensors (Figures 64 and 65) provide no evidence of moisture on the test insulators preceding or around the time of the fault.

Since no indication of moisture was present at either weather station, the meteorological conditions were not consistent with contamination flashover.

Fault #7 - 5:09 p.m., February 23, 1993 - 44.9 miles west of Broadview

This fault occurred in the evening following a winter day in which the temperature remained below 11°F the entire day (Figure 66). The temperature at the time of the fault was only 3.2°F and the relative humidity was 71%. As shown by Figures 67 and 68, the test insulator was 5°F warmer than the ambient air temperature at the time of the fault, suggesting the sun was probably shining on the insulator, and, the test insulator was 13°F above the dew point. Figure 69 indicates the weather station recorded a trace of precipitation two days before the fault. This may not accurately indicate the time of precipitation since the tipping bucket is not functional in freezing temperatures. As Figures 70 and 71 show, short wind gusts up to 17 m.p.h. were recorded the day of the fault and the wind calmed to under 3 m.p.h. during the fault. Figure 72 indicates a high pressure system had moved into the area during a three-day period before the fault. The dew sensor resistances, shown in Figure 73, show that moisture, probably in the form of frost, ice or snow, was present on the test insulator the night before the fault. However, the insulator had dried out seven hours before the fault.

Since no indication of moisture was present during or shortly preceding the fault, the conditions were not consistent with those expected for contamination flashover.

Fault #8 - 9:46 a.m., February 25, 1993 - 69.6 miles west of Broadview

This fault occurred mid-morning after the air temperature increased from -2°F to 8°F and the relative humidity decreased from 82% to 67% (Figure 74). The sun was probably shining at the time of the fault since, as shown by Figures 75 and 76, the test insulator was warmer than the ambient air by 3°F at the time of the fault and gradually became 15°F warmer than the air two hours after the fault. Figure 77 shows 0.03" of precipitation was recorded two hours after the fault, possibly in the form of melting snow or frost on the tipping bucket. A landowner at the White Ranch, only one mile from the weather station, reported a great deal of melting ice on buildings one hour after the fault. Winds were moderate (4-7 m.p.h.) and the barometric pressure had leveled off to about 836 mbars after rising from 828 mbars the previous day (Figures 78-80). The top dew sensor on the test insulator was defective at the time. The bottom dew sensor indicated moisture on the test insulator during the early morning hours before the fault, however, as Figure 81 shows, the moisture (suspected snow, ice, or frost) had evaporated away two hours before the fault.

Each of the moisture-related criteria were not satisfied. Therefore, the conditions surrounding this fault were not consistent with conditions expected for contamination flashover.

Fault #9 - 12:19 p.m., April 29, 1993 - 42.1 miles west of Broadview

As shown in Figure 82, the temperature was mild (52°F) around noon of April 29 and the relative humidity had dropped from 78% to 43% two hours before this fault.

Figure 83 indicates a trace of precipitation (0.01") fell April 26, three days before the fault. Wind gusts of up to 38 m.p.h. were recorded during the week preceding the fault and 12 to 17 m.p.h. winds were present at the time of the fault (Figures 84 and 85). The barometric pressure, shown in Figure 86, was gradually dropping and was approximately 2 mbars below the April average. The dew sensor resistances, shown in Figure 87, indicate no moisture on the test insulator. The test insulator temperature was above the ambient air temperature during the fault and did not drop to the dew point prior to the fault, as illustrated by Figures 88 and 89.

Since indication of moisture was present during or shortly preceding the fault, the moisture-related criteria were not satisfied and the meteorological conditions were not consistent with those expected for contamination flashover.

Fault #10 - 4:16 p.m., June 5, 1993 - 41.8 miles west of Broadview

Figure 90 indicates this fault occurred 10 hours after light precipitation (0.03"). The relative humidity exceeded 90% during this precipitation. However, the air temperature increased from 47°F to 56°F and the relative humidity decreased to 66% before this fault (Figure 91). The dew sensors indicated moisture on the top and bottom of the test insulator during the 5:00 a.m. rain, and the top sensor indicated moisture again around noon, possibly in the form of very light drizzle (Figure 92). However, both surfaces of the test insulator became dry three hours before the fault. The area was probably cloud covered, since the test insulator remained within 1°F of the ambient air temperature for an eight-hour period preceding the fault (Figures 93 and 94). The wind

speed, plotted in Figures 95 and 96, had peaked at 15 m.p.h. before the fault, however, became calm (0 m.p.h. minimum) 15 minutes before the fault.

The meteorological parameters tend to describe a cloudy day with intermittent light precipitation for this fault. However, since the relative humidity was not exceptionally high and moisture on the test insulator disappeared hours before the fault, the conditions were not consistent with those expected for contamination flashover.

Fault #11 - 5:04 a.m., June 10, 1993 - 72.2 miles west of Broadview

This fault occurred before sunrise on a morning in which the temperature was dropping and the relative humidity was rising as shown by Figure 98. Figures 99 and 100 show a gentle breeze was (0 m.p.h. to 12 m.p.h.) recorded from midnight to the time of the fault. A significant amount of precipitation (approximately 1") was recorded for June 6, 7, and 8 (Figure 101). The rate of precipitation exceeded 0.1" per hour on June 6 and 7, therefore, the dust criteria were not satisfied. The barometric pressure was low during the rain on June 6 and 7, however, it had risen 11 mbars and leveled off June 9 to approximately 839 mbars (Figure 102). The top dew sensor on the test insulator was defective; the bottom dew sensor, which was operating correctly, did not indicate any moisture the morning of the fault as seen in Figure 103. Figures 104 and 105 show that the test insulator did not warm to above the air temperature until about 9:00 a.m., four hours after the fault, suggesting the area was cloud covered. As shown in Figure 105, the test insulator did not cool to the dew point at any time during the night and early morning hours preceding the fault.

Since the dust accumulation criteria and the moisture criteria were not satisfied, the meteorological conditions were not consistent with contamination flashover.

Fault #12 - 10:16 a.m., June 11, 1993 - 44.2 miles west of Broadview

This fault occurred the day after and about 25 miles east of Fault 11. Many of the meteorological conditions which preceded Fault 11 were similar to those for Fault 12 (Figures 106-110). Fault 12 occurred mid-morning when the air temperature was rising (61°F at time of fault) and the relative humidity was rapidly dropping from 85% (around 4:00 a.m.) to 47% at the time of the fault (Figure 106). As in the case of Fault 11, significant precipitation was recorded on June 6 and 7 and the rate exceed 0.1" per hour (Figure 107). Therefore, the dust criteria were not satisfied. The dew sensors indicate the test insulator was dry the morning of this fault (Figure 111). Figures 112 and 113 show the test insulator was 9°F warmer than the ambient air temperature, suggesting the sun was shining on the insulators at the time of the fault. Furthermore, the test insulator temperature was approximately 30°F above the dew point.

As in the case of Fault 11, the dust accumulation criteria and the moisture criteria were not satisfied. Therefore, the meteorological conditions were not consistent with contamination flashover.

Fault #13 - 5:12 a.m., July 1, 1993 - 69.1 miles west of Broadview

Figure 114 illustrates that Fault 13 occurred in the morning when the air temperature (45°F) was near a minimum and the relative humidity was near a maximum

(above 70%). A light breeze, averaging 6 m.p.h., was present at the time of the fault (Figures 115 and 116). Figure 117 shows a significant amount of precipitation was recorded the evening of June 28 and early morning of June 29. The rate of precipitation the morning of June 29 exceeded 0.1" per hour, therefore, the dust accumulation criteria were not met. Figures 118 and 119 indicate the test insulator temperature remained close to the ambient air temperature (within 3°F) and did not cool to the dew point anytime in the early morning hours preceding the fault. The dew sensors indicate that the top surface of the test insulator was wet from approximately 10:00 p.m. the evening of June 30 and remained wet the entire day of July 1 (Figure 121). However, the bottom surface remained dry for the entire period. This suggests very light drizzle wetted only the top surface of the test insulator. Since the bottom surface of the test insulator remained dry, the fog or drizzle criteria were not satisfied.

The dust accumulation criteria and the moisture criteria were not satisfied, therefore, the meteorological conditions were not consistent with contamination flashover.

Fault #14 - 4:21 a.m., July 7, 1993 - 62.6 miles west of Broadview

As shown in Figure 122, Fault 14 occurred during a period of very high humidity (above 90%), while the air temperature (37°F at time of fault) was gradually dropping. Figure 123 indicates heavy rain was recorded July 3, four days prior to this fault. The rate of precipitation exceeded 0.1" per hour, therefore, the dust accumulation criteria were not satisfied. Figure 123 also shows this fault occurred approximately three hours

before a significant precipitation event. A light breeze was recorded during the early morning hours of July 7 and the wind speed suddenly dropped to 0 m.p.h. 15 minutes before the fault (Figures 124 and 125). The top dew sensor indicated moisture the entire morning of July 7 and, interestingly, the bottom dew sensor indicated a sudden rise in moisture moments before this fault, as illustrated by Figure 126. Figures 127 and 128 indicate that the test insulator temperature remained close to the ambient air temperature and did not drop to the dew point any time during the night and early morning hours leading up to this fault. This suggests that the moisture on the top and bottom surfaces of the test insulator was a result of fog or very light drizzle and not surface condensation (dew). The fog or drizzle criteria were satisfied.

Although appropriate wetting conditions consistent with contamination flashover were present, the heavy rain (approximately 1.5") on July 3 should have washed off any significant contamination on the insulator strings. The dust accumulation criteria were not satisfied, however, the fog or drizzle criteria were satisfied. Therefore, the consistency of the meteorological conditions surrounding this fault with contamination flashover were deemed inconclusive.

Fault #15 - 5:17 a.m., July 15, 1993 - 94.1 miles west of Broadview

The location of this fault was estimated to be between the Galt Ranch weather station and the Rostad Ranch weather station. Plots of meteorological parameters from both weather stations were generated and analyzed for this fault. The meteorological conditions for this fault were very similar to those observed for the previous fault, Fault

14 (Figures 130-137). This fault also occurred during the early morning hours when the air temperature was near a minimum and the relative humidity was very high. Heavy precipitation, in excess of 0.2" per hour, was recorded July 12, three days preceding this fault at both weather stations. The wind at both weather stations was very calm the morning of the fault and dropped to 0 m.p.h. for a one-hour period prior to the fault. The dew sensors indicate moisture on the top and bottom surfaces of the test insulators at both weather stations at the time of the fault (Figures 138 and 139). The test insulator temperature at each weather station did not drop to the dew point at any time during the night and early morning hours preceding this fault (Figures 140-143). These parameters suggest the insulator surfaces were wetted by fog or very light drizzle rather than dew. Although appropriate wetting conditions consistent with contamination flashover were also present for this fault, the dust accumulation criteria were not satisfied due to the rain recorded July 12. The consistency of the meteorological conditions surrounding this fault with contamination flashover are also deemed inconclusive.

Fault #16 - 5:02 a.m., July 20, 1993 - 18.4 miles west of Broadview

The meteorological conditions for this fault are also very similar to those observed for the previous two faults (Figures 146-149). This fault also occurred during the early morning hours when the air temperature was near a minimum (42°F) and the relative humidity was very high (92%). Precipitation, in excess of 0.1" per hour, was recorded July 16 and July 17. Around 1:00 a.m., the morning of the fault, a light

drizzle (0.02") was also recorded. The wind was very calm (usually under 5 m.p.h.) the entire morning of the fault. The dew sensors indicate moisture on the top and bottom surfaces of the test insulator at the time of the fault (Figure 150) and the test insulator temperature did not drop to the dew point at any time during the night and early morning hours preceding this fault (Figures 151 and 152). Again, these parameters suggest the insulator surfaces were wetted by fog or very light drizzle rather than dew.

Although appropriate wetting conditions consistent with contamination flashover were also present for this fault, rain recorded July 16 and 17 should have washed the insulator strings. Therefore, the consistency of the meteorological conditions surrounding this fault with contamination flashover are also deemed inconclusive.

Fault #17 - 1:45 a.m., July 21, 1993 - 104.6 miles west of Broadview

Figure 154 shows that the relative humidity was above 70% the early morning hours from midnight to about 5:00 a.m. of July 21 and the temperature (50°F) was dropping at the time of the fault. The weather station recorded a precipitation event July 17, where the rate of precipitation exceeded 0.1" per hour and a light rain, accompanied by a drop in the barometric pressure, was recorded the afternoon before the fault (Figure 155). At the time of the fault, a 10 m.p.h. breeze was present, as shown in Figures 156 and 157, and, as Figure 158 illustrates, both dew sensors on the test insulator indicate the surfaces were dry. The test insulator temperature was close to the air temperature and did not drop to the dew point the evening preceding the fault (Figures 159 and 160).

Since a high rate of precipitation was recorded on July 17, the dust accumulation criteria were not met. Furthermore, no evidence of moisture on the insulator strings was present at the time of the fault. These conditions were not consistent with those expected for contamination flashover.

Fault #18 - 4:46 a.m., July 23, 1993 - 18.1 miles east of Broadview

This fault occurred approximately 18 miles east of the Broadview Substation weather station, and because of this distance, only meteorological parameters from that weather station were examined. This fault occurred during the early morning hours when the air temperature was near a minimum (55°F) and the relative humidity was above 70% (Figure 162). During the evening of July 21, two days before this fault, the weather station recorded significant precipitation in excess of 0.1" per hour (Figure 163). The dust accumulation criteria were not satisfied due to this precipitation. Winds were relatively calm (Figures 164 and 165), averaging less than 5 m.p.h., for the entire morning preceding the fault. Figures 166 through 168 indicate no moisture was present on the test insulator and the test insulator did not drop to the dew point the evening and early morning hours preceding this fault. The barometric pressure sensor at the Broadview Substation weather station was defective at the time of the fault, therefore, a plot of barometric pressure is not included in Appendix B.

The dust accumulation criteria were not met and no evidence of moisture on the insulator strings was present at the time of the fault. These conditions were not consistent with those expected for contamination flashover.

Fault #19 - 4:46 p.m., September 6, 1993 - 40.5 miles west of Broadview

As shown in Figure 169, this fault occurred during a warm (62°F), relatively dry afternoon. The relative humidity dropped from 98% the morning of September 6 to 47% at the fault time. Significant precipitation was recorded during the early morning hours of September 5, the day before the fault. This precipitation exceeded 0.1" per hour (Figure 170), therefore the dust accumulation criteria were not satisfied. The dew sensors (Figure 173) indicate that the test insulator was dry for the entire afternoon in which the fault occurred. The test insulator temperature exceeded the ambient air temperature by 8°F (Figures 174 and 175) suggesting the sun was warming the insulators. A high barometric pressure system was present in the area (Figure 176).

The meteorological conditions were not consistent with conditions expected for a contamination-caused fault.

This fault was unique because the magnetic fault indicators were in place and identified the fault location at 40.8 miles east of the Broadview Substation. Information was obtained during an examination of the fault site and those results are discussed in Results From Magnetic Fault Indicators.

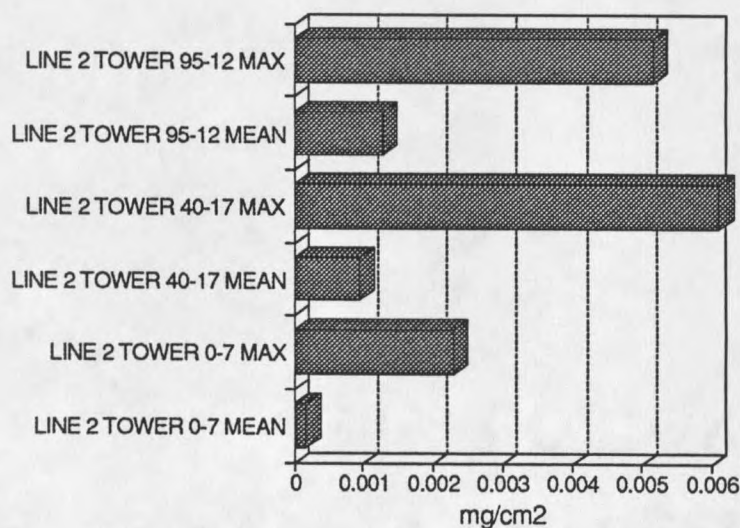
A meteorologist in Harlowton (15 miles north of the fault location) was questioned about the weather conditions and lightning in the area. At 10 a.m., on September 6, the area was covered by heavy clouds. At noon, the clouds were breaking up and by 4 p.m., the sky was partly cloudy. At 8 p.m., it was rated clear. The meteorologist observed no lightning on September 6 and felt there was little chance of lightning in the area at 4:46 p.m., the time of the fault.

ESDD SamplesMay 1992

Insulator strings from three towers along the Broadview-to-Townsend line route were removed for repair by MPC linemen. The linemen were instructed not to touch any surfaces of the glass insulators. The strings were placed in clean containers and delivered to the Electrical Engineering Department at MSU where ESDD measurements were made on the top and bottom surface of each individual insulator. A description of the exact orientation of each string is provided in Table 16 in Appendix E, and the ESDD level of each surface is listed in Table 17 in Appendix E. Figure 21 summarizes the results by showing the mean and maximum ESDD levels measured at each tower.

Figure 21

ESDD FOR STRINGS FROM 500KV LINE
REMOVED FROM SERVICE MAY 1992



Scattered rain showers occurred the week before the strings were removed, and very heavy rain occurred between Bozeman and Columbus a week before the strings were removed. The string from Tower 95-12, which had the highest average ESDD level, was noticeably more contaminated than the other two strings. Perhaps rain was more effective at washing the other two strings.

Although the strings were handled carefully, some contamination probably fell off the insulators during the transportation of the strings from the line to Bozeman. All future samples were taken on site immediately after removal.

The ESDD levels measured for May 1992 are all categorized as very light. Even the highest observed ESDD level would have to be five times higher to be considered light and 16 times higher to be considered moderate. These very light levels were not surprising since the strings were sampled in the spring after rain may have washed off much of the contamination. Much higher levels were expected to accumulate during the late summer months. Unfortunately, MPC was unable to remove any other strings for ESDD sampling from the 500kV lines in 1992.

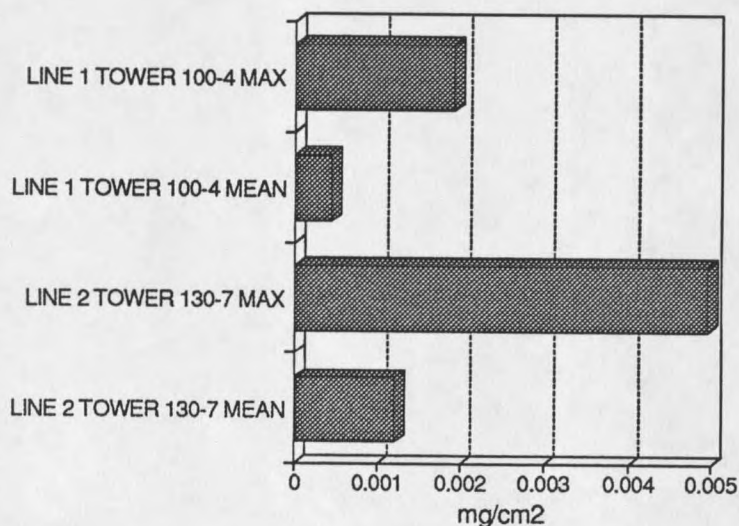
April 1993

On April 20 and 21, five strings of insulators were removed from two towers on the 500KV lines. Four strings were removed from Tower 130-7 near Townsend and one string was removed from Tower 100-4 near Ringling. These strings were removed by MPC linemen to replace several insulators. After being removed, each string was placed on a clean tarp at the tower sight and immediately sampled for ESDD.

Six insulators from each string were sampled: two from the top of the string, two from the center, and two from the bottom. The top and bottom surface of each insulator was sampled. The orientation of each string and the resulting ESDD measurements are listed in Tables 18 and 19 respectively in Appendix E. The results are summarized in Figure 22 which again shows the mean and maximum ESDD measurements for each of the two towers. The levels shown in Figure 22 exclude the bottom surface of the bottom insulator. Corona and very high electric fields usually cause a much higher contamination level on the underside of the insulator closest to the conductor and the ESDD level on the bottom surface of the bottom insulator is not representative of the contamination level of the entire string.

Figure 22

ESDD FOR STRINGS FROM 500KV LINE
REMOVED FROM SERVICE APRIL 1993



The April 1993 ESDD levels were found to be very light. Because these strings were removed in the spring, after periods of rain, it was not surprising to find only very light contamination levels. These ESDD levels are comparable to those measured on the three strings removed from service in May of 1992.

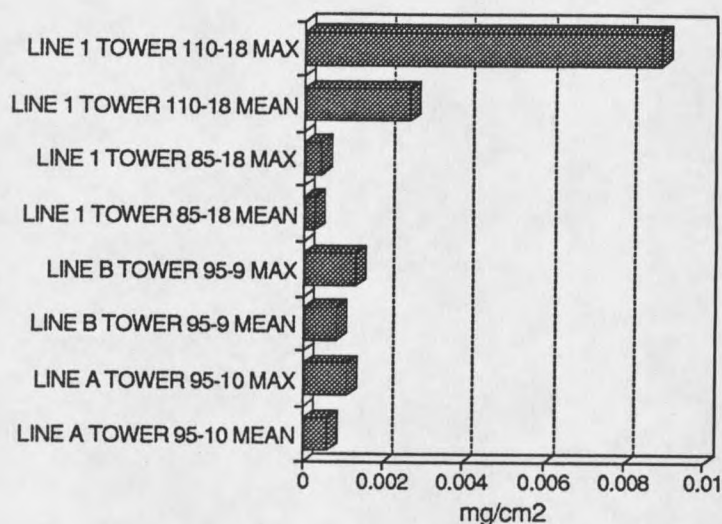
Tower 130-7 is a "dead-end" tower in which some strings were positioned at a 25° angle (angle from vertical), and some were positioned at 65°. During the ESDD sampling, noticeably more dust was observed on strings positioned at 25° than on strings oriented at more horizontal orientations. Vertically positioned insulator strings accumulate more contamination than horizontal strings because rain is more effective at washing horizontally oriented strings.

August and September 1993

During the last week of August and first week of September, 1993, an MPC crew replaced several strings containing damaged insulators on four towers and ESDD samples were taken on five strings. Two strings were from towers on the Colstrip-to-Broadview lines approximately 20 miles east of Broadview. The remaining strings were from towers on the Broadview-to-Townsend lines. Again six insulators from each string were sampled: two from the top of the string, two from the center and two from the bottom. This time the bottom two insulators which were sampled did not include the very bottom insulator next to the conductor. Tables 20 and 21 in Appendix E list the string locations and measured ESDD levels respectively. Figure 23 shows mean and maximum ESDD levels for each tower.

Figure 23

ESDD FOR STRINGS FROM 500KV LINE
REMOVED FROM SERVICE AUG. AND SEP. 1993



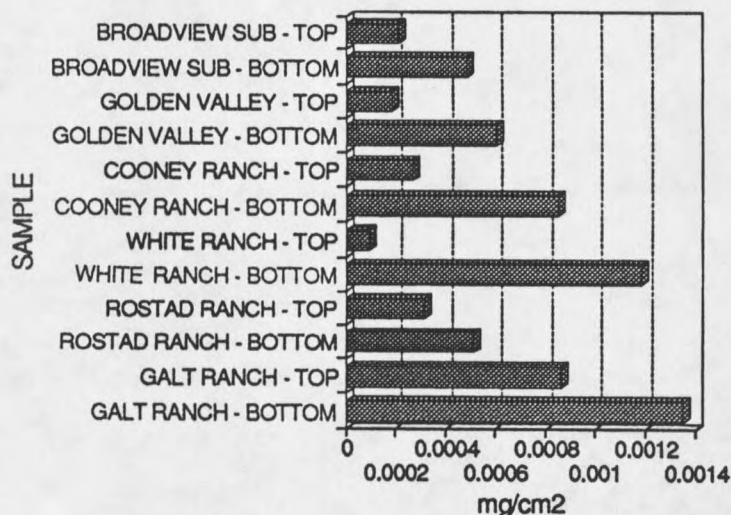
The August and September 1993 ESDD measurements revealed only very light levels of contamination. Normally, higher levels would be expected since these samples were taken during the late summer. However, since much higher than normal amounts of precipitation were observed the summer of 1993 in Montana, these low levels were not surprising.

ESDD samples from test insulator strings

On August 5, 1993, ESDD samples were taken from each of the six test strings which were installed at the weather station sites during the first week of June 1993. Insulator #2 (second from the top) on each string was sampled. The ESDD levels are listed in Table 22 in Appendix E and are illustrated in Figure 24.

Figure 24

ESDD LEVELS FOR TEST STRINGS
#2 INSULATOR, SAMPLED AUGUST 5, 1993



Each of these samples were found to have ultra-light levels of contamination, which is not very surprising since they were suspended only two months during a very rainy summer. Sampling of the test insulators was not repeated before this thesis was prepared, however, continued sampling of these test insulators is planned.

Results From Magnetic Fault Indicators

On Labor Day, September 6, 1993, a fault occurred at 4:46 in the afternoon on Phase A (north phase) of Line #1 (south line) between Broadview and Townsend. The four fault location systems each provided different estimates for the number of miles east of the Broadview Substation. These four estimates are listed below.

- 1) MPC: 43.3 miles
- 2) BPA: 52.0 miles
- 3) FLARE: 41.8 miles
- 4) SEL: 72.0 miles

Magnetic fault indicators were installed on a segment of lines approximately 36 miles to 57 miles west of Broadview. Fault indicators on three Line #1 towers had tripped; Towers 40-1, 40-2 and 40-11. The static shield wires are sectioned-off into approximately 6 mile segments where, at all the towers except the center tower, the static wires are insulated from the towers by small 15kV insulators. At the tower in the center of each six-mile segment, the static wires are connected via a grounding cable to the tower. Each of the towers which had tripped fault indicators are part of the same six-mile shield wire segment. Tower 40-11 happened to be the center, grounded-static-wire tower and Tower 40-1 is the most eastward tower in the segment, separating two shield wire segments. It was anticipated that fault indicators on the grounded-static-wire towers would also trip when faults occurred on other towers in the same shield wire segments, therefore, the actual fault site was one of the two towers which tripped; 40-1 or 40-2. Towers 40-1 and 40-2 are 40.5 and 40.8 miles, respectively, west of the Broadview Substation.

Towers 40-1 and 40-2 were closely examined by MPC linemen and MSU researchers for physical evidence to suggest which tower faulted and why the fault occurred. An examination of Tower 40-1, which is a self-supporting, dead-end tower,

provided no evidence to suggest the fault occurred on that tower; no insulator damage, burn marks, abrasions, or visible contamination were observed.

Tower 40-2 provided much more insight. The underside of the bottom insulator on the northeast insulator string (suspending the A phase) had a large dark area on it, possibly a burn mark or excessive contamination, which was visible from the ground. This black, discolored area covered approximately 30% of the bottom surface area on the bottom insulator. Many bird droppings on the insulators were also visible. Furthermore, the adjacent tower (Tower 40-2 on Line #2), had a very large nest on the end of the south arm, the arm nearest Line #1. At the time the tripped fault indicator was first found on Tower 40-2, a large bird (thought to be a hawk or eagle) was observed to be sitting on the tower. MPC linemen climbed the tower and examined each insulator string suspending the A phase from the above tower arm. From this close vantage point, they observed and photographed several unusual markings on the northeast insulator string and the supporting hardware. In addition to several bird droppings along the insulator string, a discoloration or possible surface fracturing was observed on the underside of several insulators. The top yoke, which is a plate suspending the insulator strings, had a black mark on the upper surface estimated to be about 1/4 inch in diameter. The linemen also reported heavy contamination, burn-like dark markings, and possible glass fracturing on the underside of the bottom insulator. The clevis, which attaches the bottom yoke to the bottom insulator, had many (10 or more) black pit marks and the head of the clevis bolt had a very shiny pockmark approximately one inch in diameter. When an arc terminates on metal, it leaves a shiny

pockmark similar to the one observed on the clevis bolt head. Several dark marks were also present on the bottom metal post of the bottom insulator. Figure 25 is a sketch of Tower 40-2 with a blow-up of the northeast insulator string identifying the position of each of the above mentioned markings.

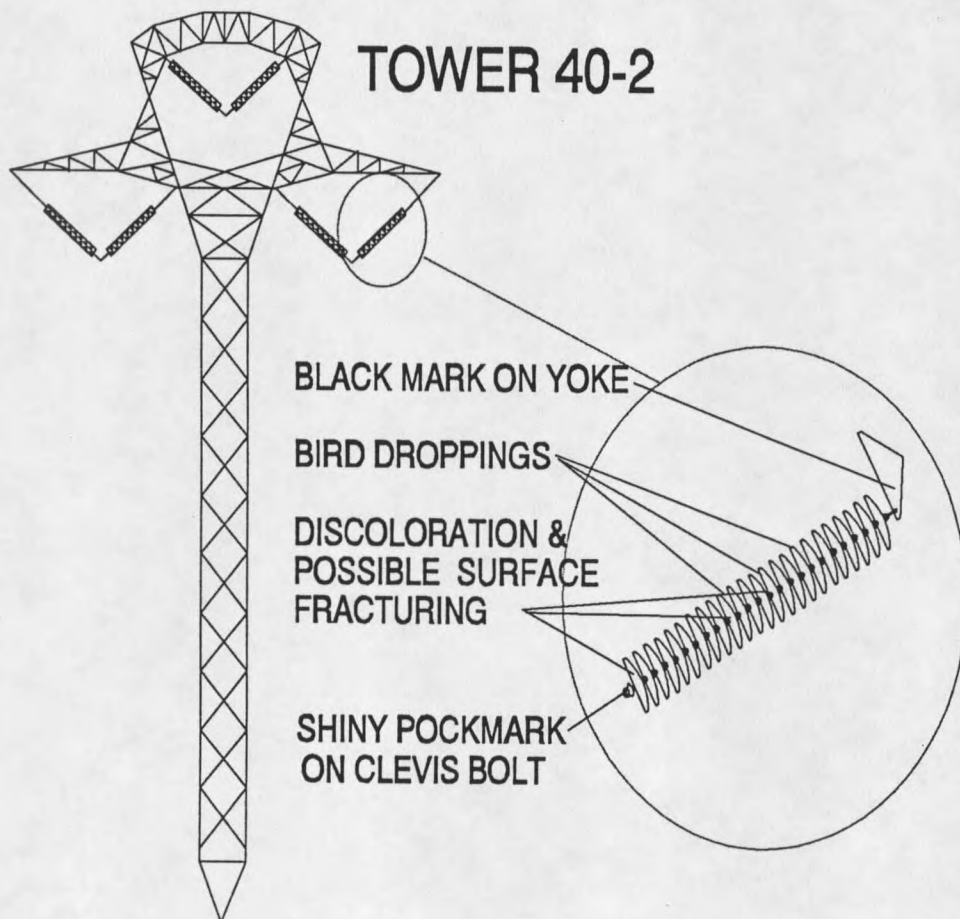
The physical evidence obtained at Tower 40-2 suggests the fault occurred on that tower. The close examination of the towers was performed on September 24, two weeks after the fault. One week after the fault, rain in excess of 1" fell in the area. This rain probably removed any significant contamination which might have been present on the insulators at the time of the fault, therefore, ESDD sampling was not performed. The bright pockmark on the clevis bolt head, the burn-like markings, and possible glass fractures on the underside of the bottom insulator are believed to be the result of the September 6 fault. It is also possible that the markings found on Tower 40-2 were a result of one or more faults prior to September 6.

To be more definitive about fault cause, the insulator string and associated hardware must be more closely inspected. In a separate report to MPC, it was proposed that the insulator string in question be removed in the near future. This would provide an opportunity to examine traces of arcing and discover any possible damage to the insulator string. It was also suggested that linemen inspect the hardware from an insulated fiberglass ladder suspended from the tower arm to provide a bottom-side view of each yoke, clevis, and insulator.

Since the fault is believed to have occurred on Tower 40-2, which is 40.8 miles east of the Broadview Substation, the FLARE and MPC estimates proved to be the two most accurate, missing by only 1 and 2.5 miles, respectively.

The fault discussed above was the only fault to occur within the areas of the line equipped with fault indicators prior to the preparation of this thesis.

Figure 25: Markings on Tower 40-2



SUMMARY AND RECOMMENDATIONS

The historical fault data for the MPC 500kV line segments between the Broadview Substation and Townsend were analyzed to search out any observable trends. These historical fault data exhibit several tendencies which are consistent with trends observed by other power utility companies and engineers who believe contamination flashover is a primary cause for unexplained faults. These tendencies include the increasing rate of fault activity for the summer months, with a peak observed during the month of August, when dust accumulation is believed to be the greatest. The concentration of the faults occurring during the early morning hours, when dew formation is most likely, is also a strong factor which is consistent with contamination flashover theory. The location of faults on this section of the lines do not appear to be uniformly distributed. Contamination-caused faults are expected to occur more often in areas more conducive to dust or pollution accumulation. However, the correlation of high fault incidence areas with high dust accumulation areas was prevented by the limited accuracy of the fault location systems.

It was observed that tendencies in the fault statistics, such as fault location, day of year, and time of day, changed from year to year. These tendencies in fault occurrence might be controlled by changes in factors such as weather patterns, electrical voltage and loading of the lines, bird migration schedules, agricultural activity, and age of the lines. Further historical fault data collection and analysis, in correlation with the collection of information about other parameters such as those listed above, is recommended for the entire life of the 500kV lines.

Meteorological conditions surrounding 19 faults on the MPC 500kV lines between the Broadview Substation and Townsend were obtained by six computerized weather stations located along the line route. These data were analyzed to determine if the meteorological conditions for each fault were consistent with those expected for contamination flashover. Of the nineteen faults, only one appeared to be preceded by weather conditions considered appropriate for contamination flashover. However, it must be pointed out that for this fault, Fault #1 in Results of Weather Data Analyses, the dew sensors and the surface temperature thermocouple on the test insulator were not yet installed. The conclusion that the conditions for Fault #1 were consistent with contamination flashover was based only on the other meteorological parameters which were available. It is possible that if the thermocouple and dew sensors were in place at the time of Fault #1, the conclusion might have been different. Four of the nineteen faults were deemed inconclusive. Fault # 5, on November 2, 1992, was considered inconclusive because the test insulator thermocouple and dew sensors were not installed, the tipping bucket may not have been operating (the air temperature was near freezing), the weather stations were not equipped to measure snowfall, and the fault occurred a long distance (17 miles away) from the nearest weather station. Appropriate wetting conditions for contamination flashover were present for the other three inconclusive faults, however, each were preceded by rainfall (one to five days before fault) thought to be sufficient in amount and intensity to wash the insulator strings of any significant contamination. Fourteen of the nineteen faults were preceded by meteorological conditions considered not consistent with those expected for contamination flashover.

The weather data do not suggest contamination flashover was the primary cause for unexplained faults on the MPC 500kV lines which occurred within the weather monitoring area from Broadview to Townsend.

The Broadview-to-Townsend section of the 500kV lines have been in operation for approximately ten years and have had 165 unexplained faults. The meteorological conditions surrounding only 19 faults which occurred during a 14 month period have been studied. Further weather monitoring and analysis is recommended to provide greater confidence, in a statistical sense, for the results. Though the meteorological data analyzed in this thesis did not support the contamination flashover hypothesis, it is possible that during years of higher fault activity, contamination flashover contributes to a significant percentage of unexplained faults. Meteorological data should be collected and analyzed for several years before these data are used to completely rule out contamination flashover as a major cause for unexplained faults.

ESDD sampling was performed on insulators removed from service May 1992, April 1993, and August and September 1993. ESDD sampling was also conducted August 1993 on one insulator from the test string at each weather station site. Only very light levels of contamination were observed from the ESDD calculations. The highest level encountered on an insulator surface, other than a bottom insulator next to a conductor, was 0.00891 mg/cm^2 . This level is three times less than a level considered to be light and over ten times less than a level considered to be heavy. The ESDD measurements fail to suggest that contamination accumulation on the MPC 500kV lines reach levels considered severe enough to instigate contamination flashovers.

The ESDD samples taken in 1992 and 1993 did not provide a complete overview of the seasonal variation for contamination levels on the MPC 500kV lines. More frequent sampling, year-round, must be performed to obtain this pattern. Further ESDD testing is recommended. Periodic sampling of the test strings located at the weather station sites should continue for several years to provide the needed seasonal variation characteristics and an estimate of the maximum ESDD levels the 500kV insulators accumulate.

To date, only one tower on which a fault occurred has been identified through the use of magnetic fault indicators. This fault was Fault #19 in the Results of Weather Data Analyses and occurred on September 6, 1993. The physical evidence which was obtained through an examination of this tower and the particular insulator string suspected of flashing over were not adequate to identify the fault cause. A nearby nest, and other signs of birds occupying the tower suggest that a bird might have caused the fault, however, the tower was inspected 18 days after the fault. During this time, a heavy rain was recorded in the area and any significant contamination present at the time of the fault may have been removed. Furthermore, this time may have been sufficient for the removal of burn marks or traces of arcing, and the oxidation of any pockmarks or abrasions which were not discovered by the September 24 inspection. The removal and close examination of the insulator string in question has not been performed.

It is recommended that, when possible, towers identified by the magnetic fault indicators be examined immediately after identification and that particular insulator

strings suspected of flashing over be removed to facilitate close inspection and ESDD sampling. The use of magnetic fault indicators to locate towers on which faults occur is recommended to continue for several years. Future location of towers that experience faults may provide physical evidence suggesting the cause for faults and identify the particular tower structures more susceptible to faulting. It is possible that many faults occur on certain individual towers, and, it is also possible that particular tower configurations, such as dead-end towers with vertical insulator strings, are more prone to faults.

In addition to continuing the research outlined in this thesis, it is recommended that other possible causes for the unexplained faults be examined. Many nests were observed during field trips to the lines and evidence of bird use was obtained on Tower 40-2, the tower identified by a magnetic fault indicator. It is possible that birds are causing or contributing to the problem. Furthermore, it is recommended that lightning be re-evaluated as a possible contributor to fault activity. A closer examination of the various electrical characteristics of the transmission lines including voltage versus loading profiles, is recommended.

When compared to the A Line, the B Line and Lines 1 and 2 appear to be under-insulated. It is recommended that research into identifying the cause of the unexplained faults continue prior to extending the length of the insulator strings on the B Line and Lines 1 and 2, since an identification of fault cause will most likely lead to the most economical solution to the problem.

REFERENCES CITED

- Adler, R.B., et al. "An IEEE Survey of U.S. and Canadian Overhead Transmission Outages at 230kV and Above" IEEE Power Engineering Society Paper 93 WM 054-7 PWRD, November 1971.
- Berger, K. and Chowdhure, P. "Behavior of Insulators Under Dew and Fog" Journal of The Franklin Institute, Vol. 294, No. 6, December 1972.
- Burnam, J.T., et al. " FLP's Christmas 1991 Transmission Outages" IEEE Power Engineering Society Paper 93 WM 094-3 PWRD, January 1993.
- Byers, H.R. *General Meteorology* McGraw Hill, New York, N.Y., 1959.
- Claverie, P. and Porcheron, Y. "How to Choose Insulators For Polluted Areas" IEEE Power Engineering Society Paper T 72 554-4, July 1972.
- Fikke, S.M., et al. "Long Range Transported Pollutants and Conductivity of Atmospheric Ice On Insulators" IEEE Power Engineering Society Paper 92 SM 462-2 PWRD, July 1992.
- Gerez, V., et al. "A Model for the Evaluation of Impact on Electric Power Systems by Pollution in Mexico City" IEEE Power Engineering Society Paper 81 WM 207-0 PWR, November 1982.
- Gerez, V. and Talamas, L. "Testing of Contaminated Insulators: Recent Results and Future Problems" International Journal of Energy Systems, Vol. 7 No. 3, 1987.
- Hampton, B.F. "Flashover Mechanism of Polluted Insulation" Proceedings of the Institution Of Electrical Engineers, Vol. 111, No. 5, May 1964.
- Hewson, E.W. *Meteorology Theoretical and Applied* Chapman & Hall LTD., New York, N.Y., 1944.
- Holt, K.C., et al. "Dependence of Flashover Voltage on the Chemical Composition of Multi-component Insulator Surface Contaminants" IEEE Power Engineering Society Paper F 75 482-0, April 1975.
- Holt, K.C., et al. "Application Of Insulators In A Contaminated Environment" IEEE Transactions on Power Apparatus and Systems, Vol.PAS-98, No.5, September 1979.
- Jolly, D.C. "Contamination Flashover, Part 1: Theoretical Aspects" IEEE Power Engineering Society Paper T 72 199-3, January 1972.
- Jolly, D.C. "Contamination Flashover Theory and Insulator Design" Journal of The Franklin Institute, Vol. 294, No. 6, December 1972.

- Karady, G. "The Effect of Fog Parameters on the Testing of Artificially Contaminated Insulators in a Fog Chamber" IEEE Power Engineering Society Paper T 74 454-5, May 1974.
- Kawai, M. "Tests in Japan on the Performance of Salt-Contaminated Insulators in Natural and Artificial Humid Conditions" Proceedings of IEE Vol. 115, No. 1, July 1967.
- Kawai, M. and Milone, D.M. "Tests on Salt-Contaminated Insulators in Artificial and Natural Wet Conditions" IEEE Transactions on Power Apparatus and Systems, Vol. PAS-88, No. 9, September 1969.
- Kawai, M. "AC Flashover Tests at Project UHV on Ice Coated Insulators" IEEE Transactions on Power Apparatus and Systems, Vol. PAS-89, No. 8, November 1970.
- Kawai, M. "Research at Project UHV on the Performance of Contaminated Insulators" Journal of The Franklin Institute, Vol. 294, No. 6, December 1972.
- Lozano, C., et al. "Patterns of Pollution on Insulators: Clustering by Seasonal Variation and Exposure Period" IEEE Transaction on Power Delivery, Vol. 5, No. 1, January 1989.
- Moran, J.H. and Powell, D.G. "Resistance Graded Insulators - the Ultimate Solution to the Contamination Problem?" IEEE Power Engineering Society Paper T72 202-5, November 1971.
- Naito, K., et al. "Influence of Fog Parameters On Withstand Voltage of Contaminated Insulators" IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, No. 3, March 1983.
- Naito, K. and Naganawa, W. "Contamination Flashover and 800-kV Transmission Line Design" The Mexican IEEE Power Engineering Society Paper RVP 92-TRA-03, December 1993.
- Nasser, E. "Some Physical Properties of Electrical Discharges on Contaminated Surfaces" IEEE Transactions on Power Apparatus and Systems, Vol. PAS-87, No. 4, April 1967.
- Nasser, E., et al. "A Survey of the Problem of Insulator Contamination in the United States and Canada - Part 1" IEEE Working Group, IEEE Power Engineering Society Paper 71 TP 133-PWR, January 1971.
- Plate, E. *Engineering Meteorology* Elsevier Scientific Publishing Company, New York, N.Y., 1982.

- Reece, T.A., et al. "P G and E's Cool Fog Tests on Artificially Contaminated Suspension Insulators" IEEE Power Engineering Society Paper T 74 070-9, November 1973.
- Renner, P.E. "BPA Procedure for Measurement of Natural Contamination on Ceramic Insulators" U.S. Department of Energy - Bonneville Power Administration Paper BPA F 5450.05, July 1991
- Renowden, J.D. "December, 1991 Contamination Outage Problems at Florida Power and Light Company" Presented to the Ieee Summer Power Meeting, Juno Beach, Florida, July 1992.
- Richards, C. and Mauldin, T.P. "A System for Preventing Contamination Flashover on Insulators" presented at the IASTED Power High Tech meeting, Valencia, Spain 1989.
- Rizk, F., et al "Laboratory and Field Experiences with EHV Transmission Line Insulators in the Desert" IEEE Transactions on Power Apparatus and Systems, Vol. PAS-94, No. 5, September 1975.
- Rudakova, V.M. and Tikhodeev, N.M. "Influence of Low Air Pressure on Flashover Voltages of Polluted Insulators" IEEE Transactions on Power Delivery, Vol. 4, No. 1, January 1989.
- Sandhu, K. S., et al. "A Joint Utility Investigation of Unexplained Transmission Line Outages" EPRI Publication EL-5735 Research Project 2335-1, May 1988.
- Sforzini, M. "Testing of Polluted Insulators - The present Situation and the Problems of the Future" Journal of The Franklin Institute, Vol. 294, No. 6, December 1972.
- Schneider, H.M. and Nicholls, C.W. "Contamination Flashover Performance of Insulators for UHV" IEEE Power Engineering Society Paper F 77 749-5, April 1977.
- Wahl, H.A. "Design Features of Transmission Line Insulation In Desert-Like Areas" Paper prepared for Norden Insulators LTD. Valbey, Denmark, April 1976.
- Williams, L.J., et al. "Contaminated Insulators - Chemical Dependence of Flashover Voltages and Salt Migration" IEEE Power Engineering Society Paper T 74 069-1, December 1973.
- Zedan, Z.M. and Akbar, M. "Field Measurement of Various Polution Assessment Parameters" Presented at the EPRI/DOE/IEEE Workshop, Los Angeles, California, November 1985.

APPENDICES

APPENDIX A

**LISTING OF UNEXPLAINED FAULTS
ON BROADVIEW-TO-TOWNSEND LINES**

Table 8: Chronologically Listed Unexplained Fault Data
For Broadview to Townsend 500kV Lines For Years 1984-1993

FAULT NUMBER	DATE	TIME	JULIAN DAY	LINE	PHASE	PHASE LOCATION	ESTIMATED MILES WEST OF BROADVIEW
1	18-May-84	04:55	139	1	C	TOP	89
2	29-May-84	07:52	150	1	C	TOP	94
3	13-Jun-84	04:43	165	1	B	SOUTH	76
4	24-Jun-84	09:51	176	1	C	TOP	21
5	14-Jul-84	08:34	196	2	A	TOP	55
6	15-Jul-84	10:45	197	1	C	TOP	40
7	17-Jul-84	04:17	199	2	B	NORTH	23
8	28-Jul-84	04:38	210	1	A	NORTH	37
9	17-Aug-84	17:28	230	1	C	TOP	34
10	27-Aug-84	13:37	240	2	A-C	SOUTH	120
11	26-Sep-84	06:27	270	2	C	SOUTH	28
12	14-Mar-85	14:23	73	1	B	TOP	10
13	09-Jun-85	04:54	160	1	C	TOP	27
14	07-Aug-85	03:47	219	1	C	TOP	94
15	15-Aug-85	03:13	227	1	B	SOUTH	31
16	17-Aug-85	00:23	229	2	B	NORTH	38
17	24-Aug-85	01:26	236	2	C	SOUTH	90
18	27-Aug-85	02:57	239	1	B	SOUTH	28
19	27-Aug-85	22:55	239	1	C	TOP	46
20	28-Aug-85	05:33	240	1	C	TOP	48
21	18-Mar-86	22:30	77	1	B	SOUTH	50
22	17-May-86	08:44	137	2	B	NORTH	40
23	01-Jun-86	17:40	152	2	B	NORTH	74
24	04-Jun-86	11:15	155	2	A	TOP	113
25	11-Jun-86	01:15	162	1	C	TOP	45
26	31-Jul-86	07:39	212	1	C	TOP	38
27	01-Aug-86	03:12	213	2	A	TOP	45
28	07-Aug-86	00:09	219	2	C	SOUTH	43
29	11-Aug-86	06:48	223	1	B	SOUTH	95.5
30	18-Aug-86	23:58	230	2	B	NORTH	94
31	19-Aug-86	00:43	231	2	A	TOP	39
32	25-Oct-86	21:11	298	2	A	TOP	44.5
33	12-May-87	06:33	132	1	C	TOP	19
34	12-Jul-87	12:05	193	2	A	TOP	78
35	13-Jul-87	20:18	194	1	C	TOP	35
36	27-Jul-87	23:45	208	2	B	NORTH	49
37	28-Jul-87	00:30	209	1	B	SOUTH	25
38	28-Jul-87	02:57	209	1	B	SOUTH	25
39	31-Jul-87	00:03	212	2	C	SOUTH	45
40	31-Jul-87	01:34	212	2	C	SOUTH	49
41	31-Jul-87	03:08	212	2	C	SOUTH	49
42	01-Aug-87	04:58	213	1	B	SOUTH	49
43	02-Aug-87	05:08	214	2	B	NORTH	56
44	03-Aug-87	22:37	215	2	A	TOP	21.5
45	06-Aug-87	02:26	218	1	B	SOUTH	72.5
46	07-Aug-87	02:08	219	2	B	NORTH	62
47	08-Aug-87	15:27	220	1	C	TOP	70
48	09-Aug-87	00:42	221	1	B	SOUTH	61
49	13-Aug-87	04:18	225	2	B	NORTH	60
50	21-Sep-87	03:12	264	2	A	TOP	66

Table 8 Continued

FAULT NUMBER	DATE	TIME	JULIAN DAY	LINE	PHASE	PHASE LOCATION	ESTIMATED MILES WEST OF BROADVIEW
51	22-Sep-87	15:31	265	2	B	NORTH	6.5
52	02-Nov-87	00:27	306	2	B	NORTH	47
53	05-Nov-87	20:08	309	2	B	NORTH	126
54	21-Feb-88	15:33	52	1	C	TOP	35
55	21-May-88	11:11	142	1	C	TOP	17.3
56	03-Jun-88	09:07	155	2	A	TOP	73
57	29-Jul-88	14:28	211	1	B	SOUTH	80.5
58	09-Aug-88	23:25	222	1	C	SOUTH	3
59	10-Aug-88	04:28	223	2	A	TOP	113
60	11-Aug-88	22:10	224	2	A	TOP	32
61	14-Aug-88	21:27	227	2	C	SOUTH	63
62	23-Aug-88	17:24	236	2	A	TOP	61
63	30-Aug-88	02:17	243	1	C	TOP	98
64	12-Sep-88	01:05	256	2	B	NORTH	99
65	20-May-89	05:17	140	2	A	TOP	39
66	21-May-89	05:01	141	1	A	NORTH	38
67	21-May-89	05:01	141	1	A	NORTH	40
68	27-Jun-89	01:45	178	2	B	NORTH	57
69	27-Jun-89	15:12	178	2	B	NORTH	57
70	30-Jun-89	03:41	181	1	A	NORTH	14
71	15-Jul-89	04:28	196	2	B	NORTH	80
72	29-Jul-89	04:34	210	2	C	SOUTH	68
73	31-Jul-89	04:46	212	1	C	TOP	54
74	12-Aug-89	05:11	224	1	B	SOUTH	89
75	13-Aug-89	04:29	225	2	B	NORTH	68
76	14-Aug-89	20:45	226	1	A	NORTH	110
77	22-Aug-89	06:45	234	1	C	TOP	16
78	24-Aug-89	05:37	236	2	A	TOP	119
79	28-Aug-89	10:08	240	2	B	NORTH	71
80	29-Aug-89	13:37	241	2	A	TOP	50
81	02-Sep-89	00:26	245	2	B	NORTH	60
82	07-Sep-89	05:33	250	2	A	TOP	68
83	08-Nov-89	15:59	312	1	C	TOP	100
84	08-Nov-89	15:59	312	2	A	TOP	67
85	18-Dec-89	23:20	352	1	B	SOUTH	128
86	20-Jan-90	05:37	20	2	C	SOUTH	131.6
87	11-Mar-90	08:15	70	2	B	NORTH	62.4
88	25-Apr-90	05:18	115	2	B	NORTH	90.9
89	03-May-90	06:09	123	1	B	SOUTH	82.8
90	20-May-90	05:26	140	2	B	NORTH	101.2
91	16-Jun-90	08:11	167	1	C	TOP	80.5
92	23-Jun-90	17:08	174	1	B	SOUTH	74.6
93	23-Jun-90	20:56	174	1	B	TOP	9.4
94	27-Jun-90	02:15	178	1	B	SOUTH	107.2
95	16-Jul-90	03:07	197	1	A	NORTH	76.4
96	18-Jul-90	05:01	199	1	A	NORTH	71.9
97	30-Jul-90	00:19	211	1	B	SOUTH	44.8
98	10-Aug-90	05:28	222	1	C	TOP	32.8
99	10-Aug-90	23:58	222	1	C	TOP	22.2
100	15-Aug-90	05:45	227	2	B	NORTH	98.2

Table 8 Continued

FAULT NUMBER	DATE	TIME	JULIAN DAY	LINE	PHASE	PHASE LOCATION	ESTIMATED MILES WEST OF BROADVIEW
101	17-Aug-90	23:46	229	2	A	TOP	100.5
102	18-Aug-90	05:41	230	2	B	NORTH	93.3
103	25-Aug-90	21:55	237	2	B	NORTH	58.6
104	02-Sep-90	15:31	245	2	A	TOP	93.3
105	07-Sep-90	12:26	250	1	C	TOP	22.1
106	24-Nov-90	02:45	328	1	C	TOP	88.9
107	09-Dec-90	10:31	343	1	A	NORTH	100.8
108	16-Jan-91	16:18	16	1	A	NORTH	0
109	10-Apr-91	03:16	100	1	A	NORTH	126.6
110	17-Apr-91	02:00	107	2	B	NORTH	97.9
111	17-Apr-91	07:42	107	2	C	SOUTH	18.2
112	19-Apr-91	12:34	109	2	C	SOUTH	16.2
113	24-Apr-91	01:03	114	2	A	TOP	23.3
114	20-May-91	05:01	140	2	A	TOP	38.9
115	06-Jun-91	03:03	157	2	B	NORTH	74.2
116	12-Jun-91	11:28	163	1	C	TOP	70.2
117	13-Jun-91	23:15	164	2	B	NORTH	13.4
118	21-Jun-91	04:08	172	2	A	TOP	39.3
119	22-Jun-91	13:38	173	2	B	NORTH	63.4
120	04-Jul-91	02:44	185	2	B	NORTH	24.6
121	12-Jul-91	16:56	193	1	B	SOUTH	29.2
122	13-Jul-91	10:22	194	1	A	NORTH	24
123	26-Jul-91	19:51	207	1	B	SOUTH	99.7
124	29-Jul-91	08:03	210	2	B	NORTH	36.4
125	12-Aug-91	05:07	224	1	C	TOP	38.2
126	30-Aug-91	19:45	242	2	C	SOUTH	110.6
127	30-Aug-91	23:17	242	2	B	NORTH	25
128	03-Sep-91	23:49	246	2	A	TOP	39
129	13-Sep-91	00:27	256	2	C	SOUTH	51.7
130	02-Oct-91	19:00	275	1	B	SOUTH	22.7
131	27-Dec-91	07:10	361	2	B	NORTH	97.5
132	21-Feb-92	09:27	52	2	B	NORTH	45.6
133	06-Mar-92	08:02	66	1	B	NORTH	7.7
134	27-Apr-92	06:44	118	2	B	NORTH	97.3
135	29-Apr-92	20:14	120	1	B	TOP	15.2
136	22-May-92	04:25	143	1	B	SOUTH	54.8
137	22-May-92	07:54	143	1	B	SOUTH	57.1
138	27-May-92	05:14	148	2	B	NORTH	100.5
139	31-May-92	20:13	152	2	C	SOUTH	25.1
140	09-Jun-92	15:55	161	1	A	NORTH	14.5
141	20-Jun-92	00:41	172	1	A	NORTH	42.9
142	24-Jun-92	06:34	176	1	C	TOP	37.3
143	18-Jul-92	03:05	200	1	B	SOUTH	37.6
144	26-Jul-92	02:32	208	2	B	NORTH	47.1
145	28-Jul-92	04:17	210	2	B	NORTH	31.2
146	29-Jul-92	02:48	211	2	A	TOP	25.4
147	16-Aug-92	02:43	229	2	C	SOUTH	102.7
148	01-Oct-92	14:52	275	1	A	NORTH	42.5
149	18-Oct-92	12:36	292	2	A	TOP	99.6
150	23-Oct-92	16:17	297	2	C	SOUTH	117

Table 8 Continued

FAULT NUMBER	DATE	TIME	JULIAN DAY	LINE	PHASE	PHASE LOCATION	ESTIMATED MILES WEST OF BROADVIEW
151	07-Feb-93	12:08	38	1	C	TOP	93.7
152	23-Feb-93	17:09	54	2	A	TOP	44.9
153	25-Feb-93	09:46	56	2	A	TOP	69.6
154	10-Apr-93	15:21	100	2	B	NORTH	130.7
155	29-Apr-93	12:19	119	2	C	SOUTH	42.1
156	05-Jun-93	16:16	156	1	C	TOP	41.8
157	10-Jun-93	05:04	161	1	A	NORTH	72.2
158	11-Jun-93	10:16	162	1	C	TOP	44.2
159	21-Jun-93	18:23	172	1	C	TOP	127.2
160	01-Jul-93	05:12	182	2	C	SOUTH	69.1
161	07-Jul-93	04:21	188	2	B	NORTH	62.2
162	15-Jul-93	05:17	196	1	B	SOUTH	94.1
163	20-Jul-93	05:02	201	1	C	TOP	18.4
164	21-Jul-93	01:45	202	2	C	SOUTH	104.6
165	07-Sep-93	16:46	250	1	A	NORTH	40.5

APPENDIX B

**PLOTS OF METEOROLOGICAL PARAMETERS
SURROUNDING UNEXPLAINED FAULTS**

Figure 26

AIR TEMPERATURE AND RELATIVE HUMIDITY AT GALT RANCH

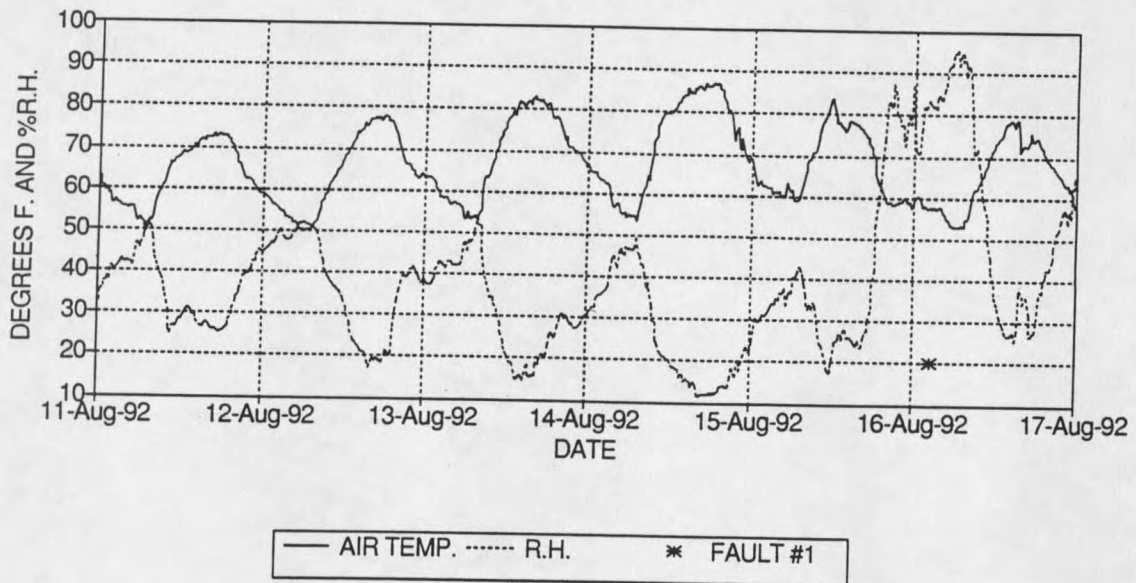


Figure 27

PRECIPITATION AT GALT RANCH

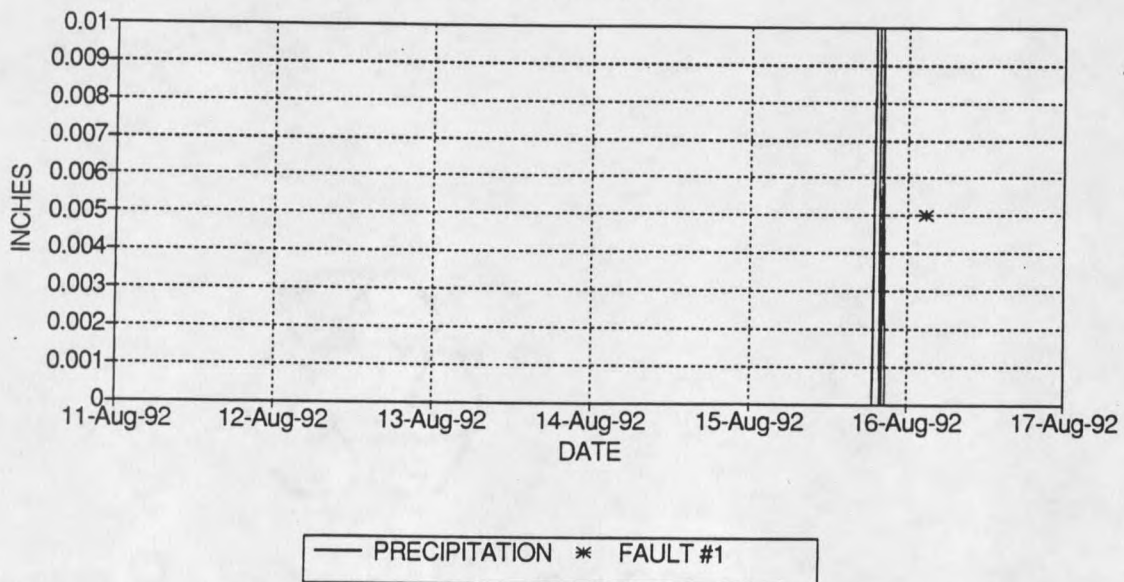


Figure 28

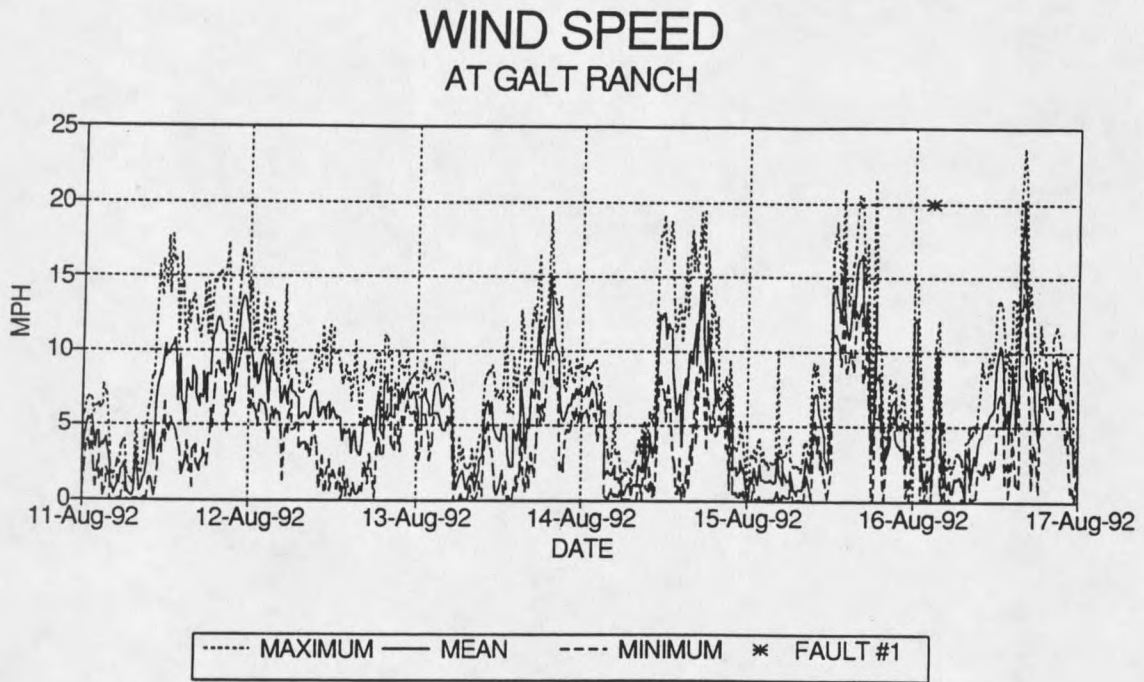


Figure 29

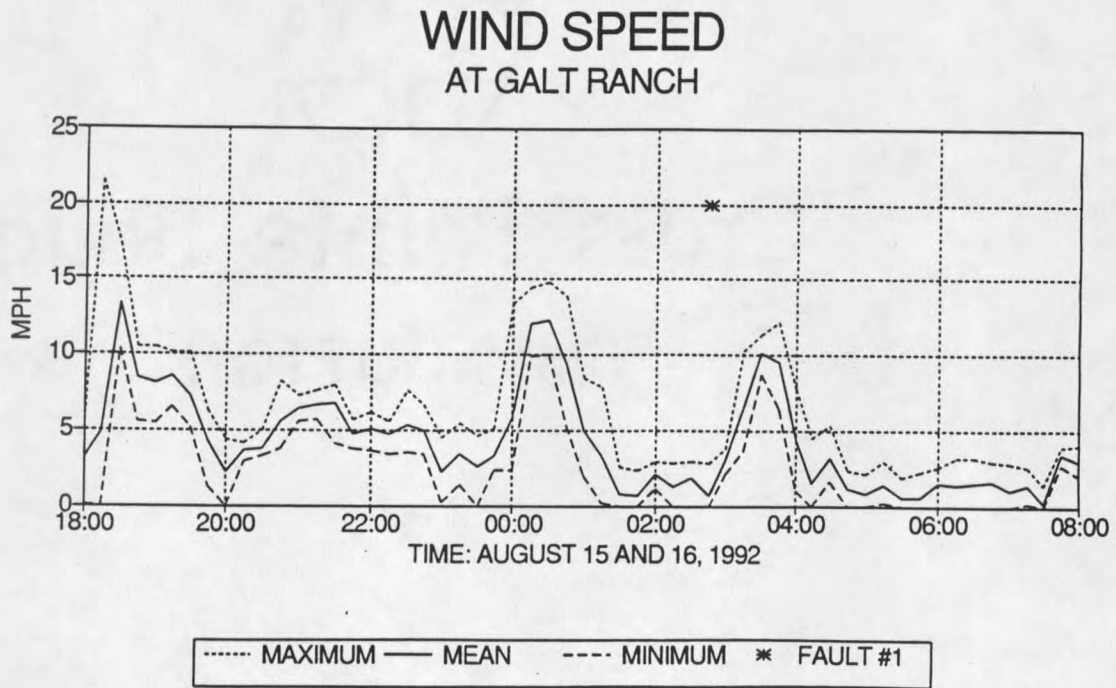


Figure 30

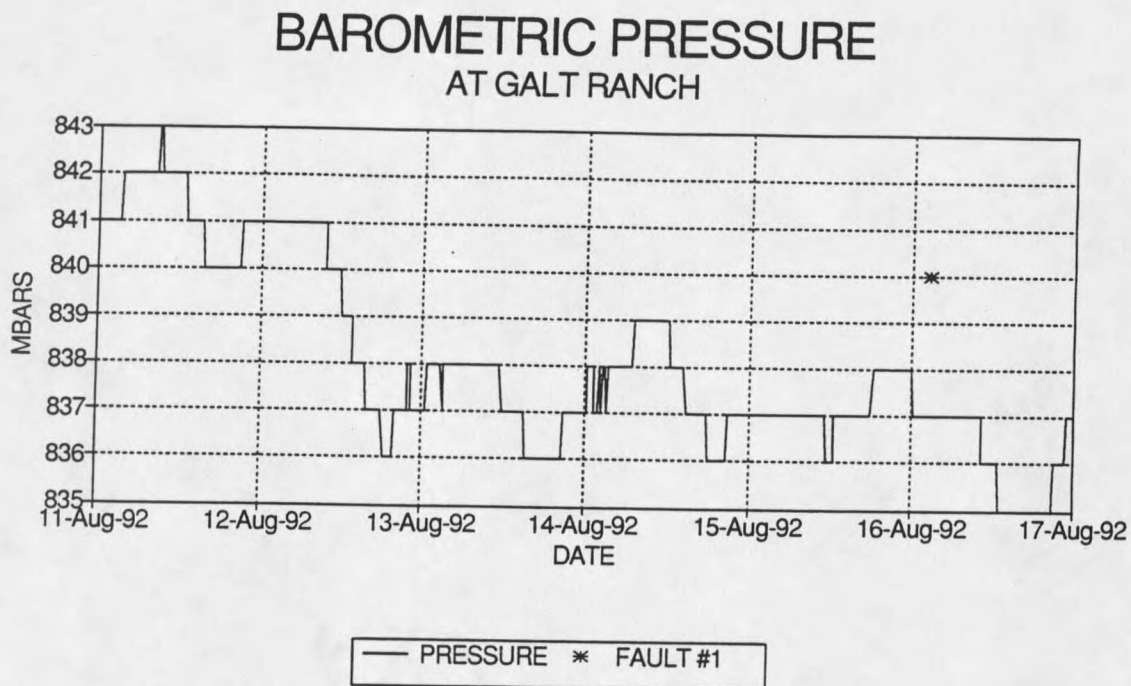


Figure 31

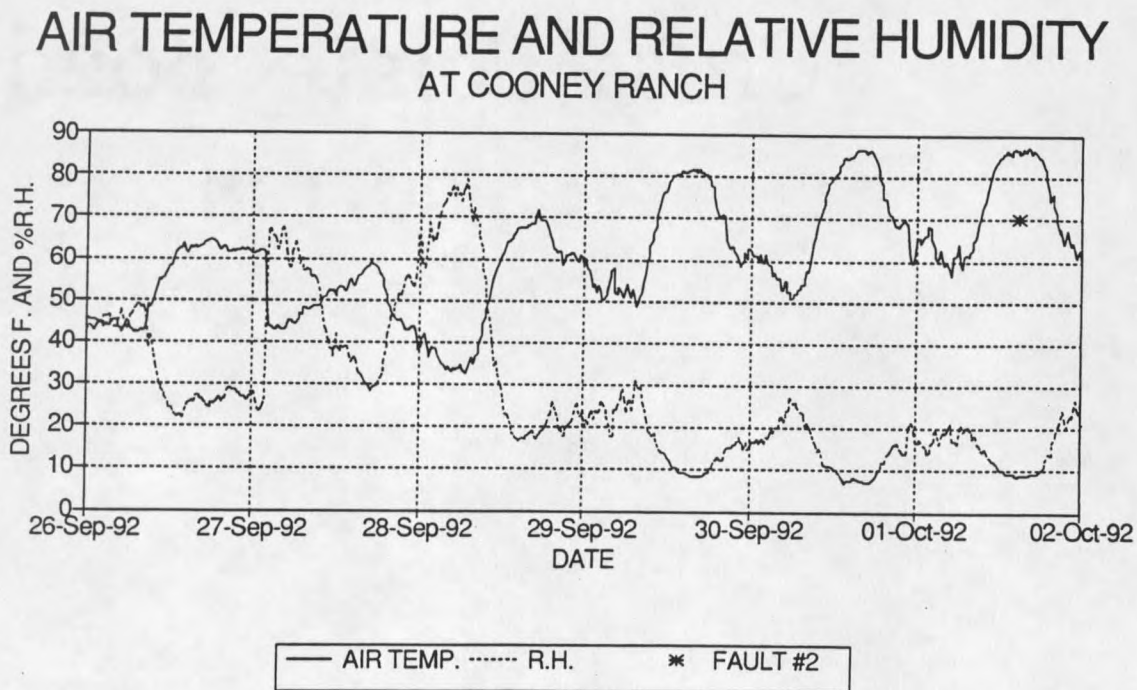


Figure 32

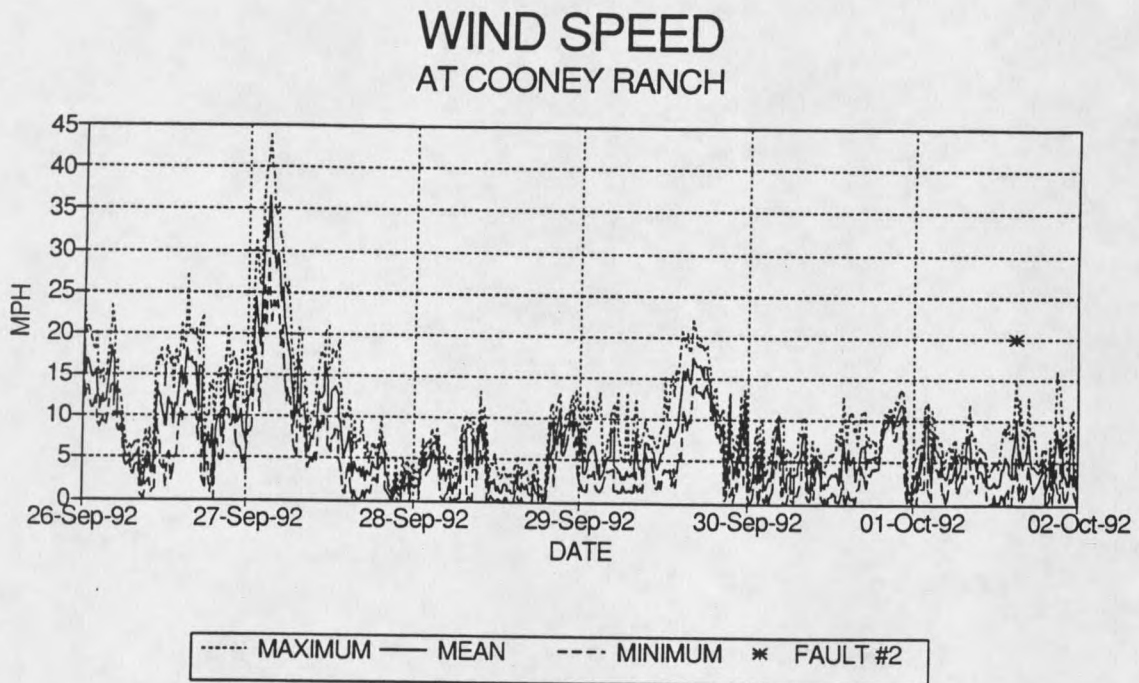


Figure 33

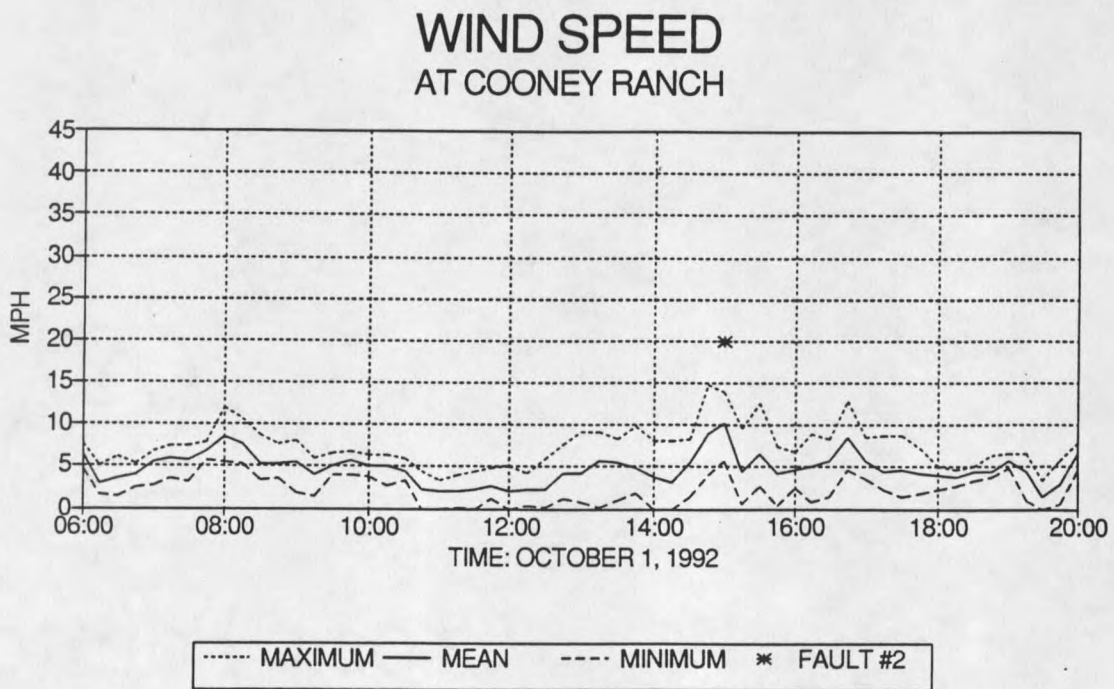


Figure 34

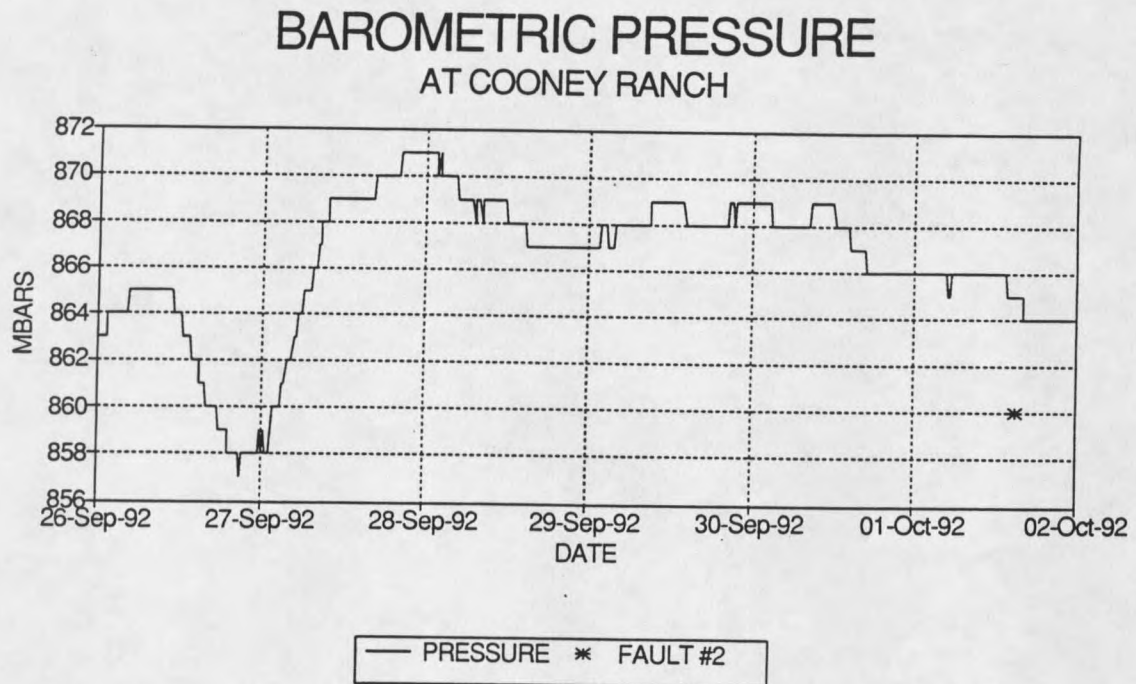


Figure 35

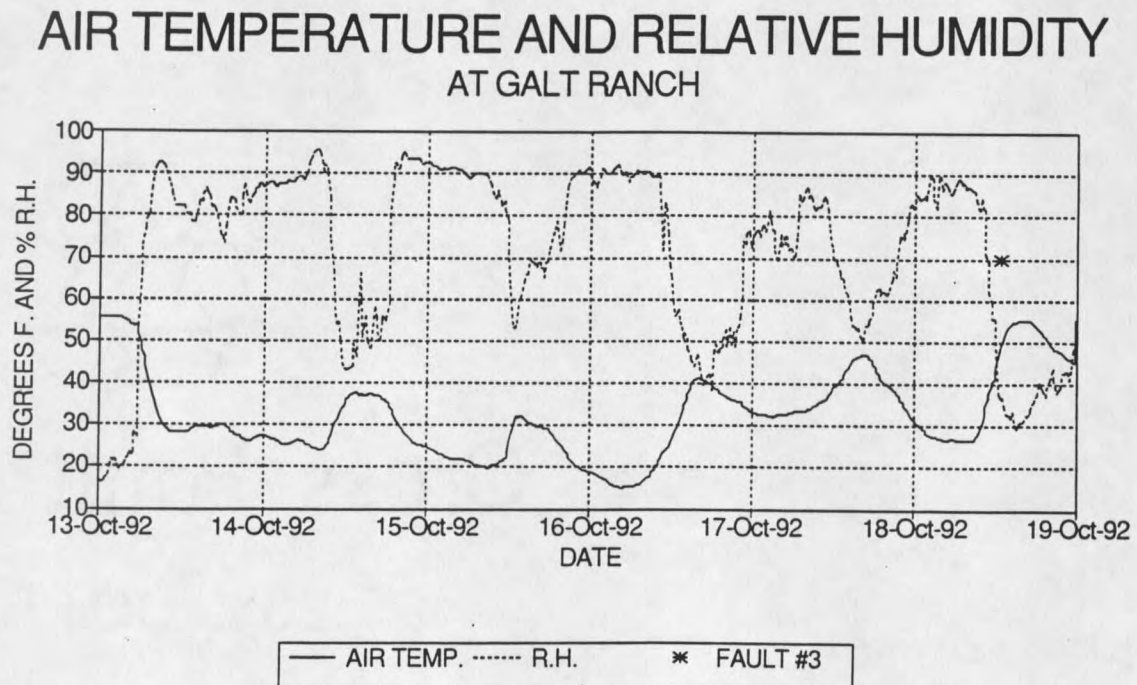


Figure 36

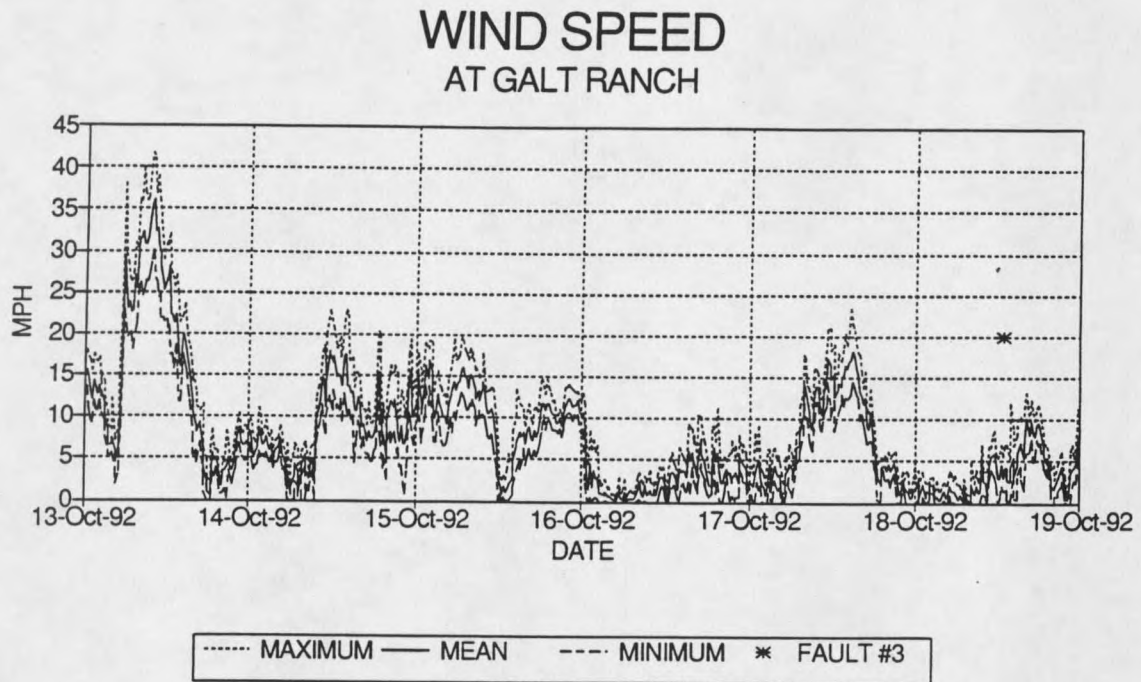


Figure 37

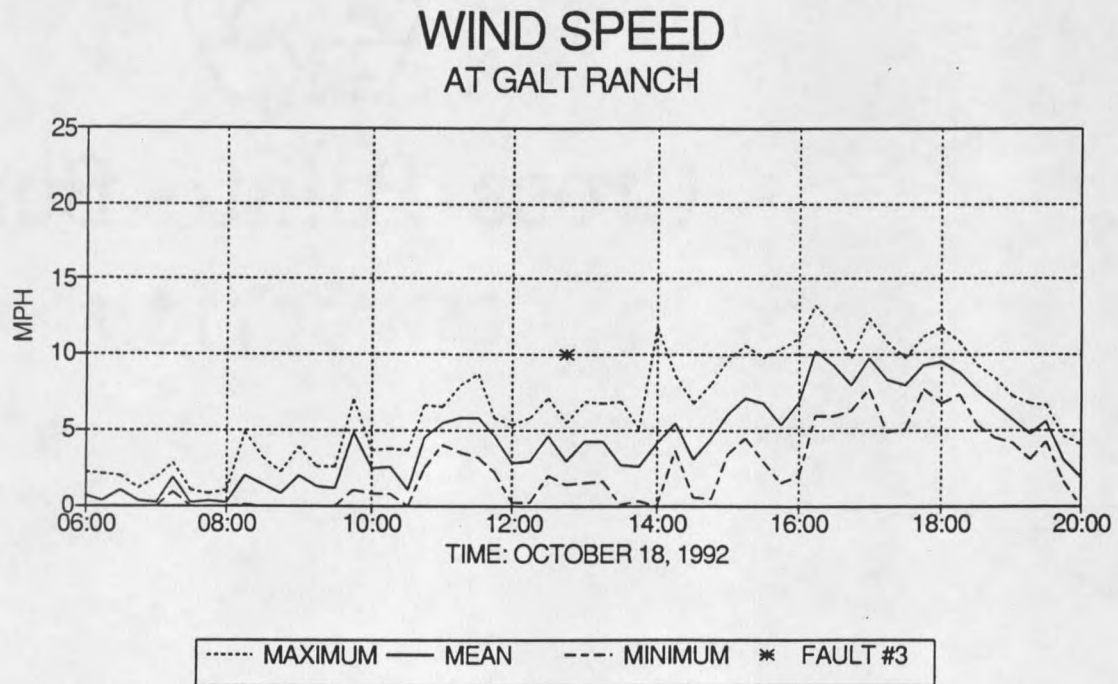
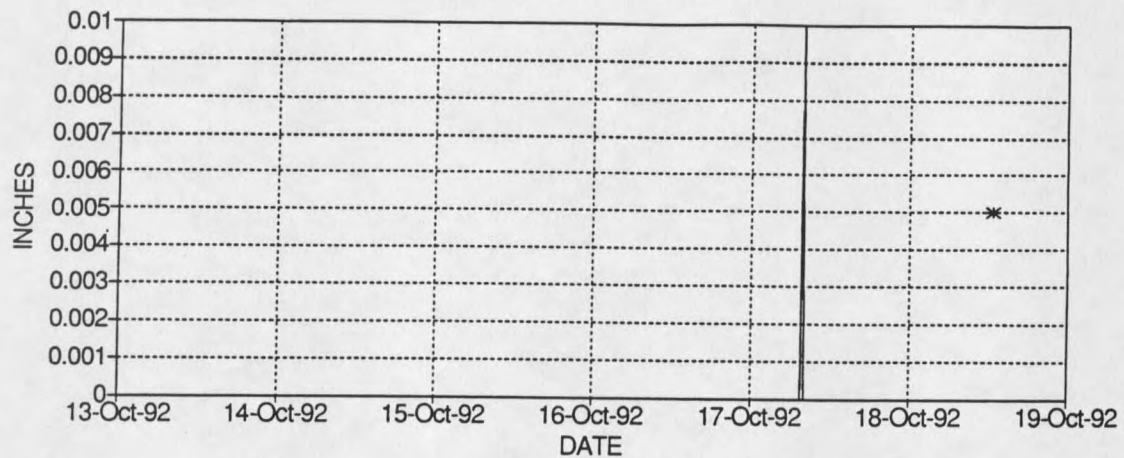


Figure 38

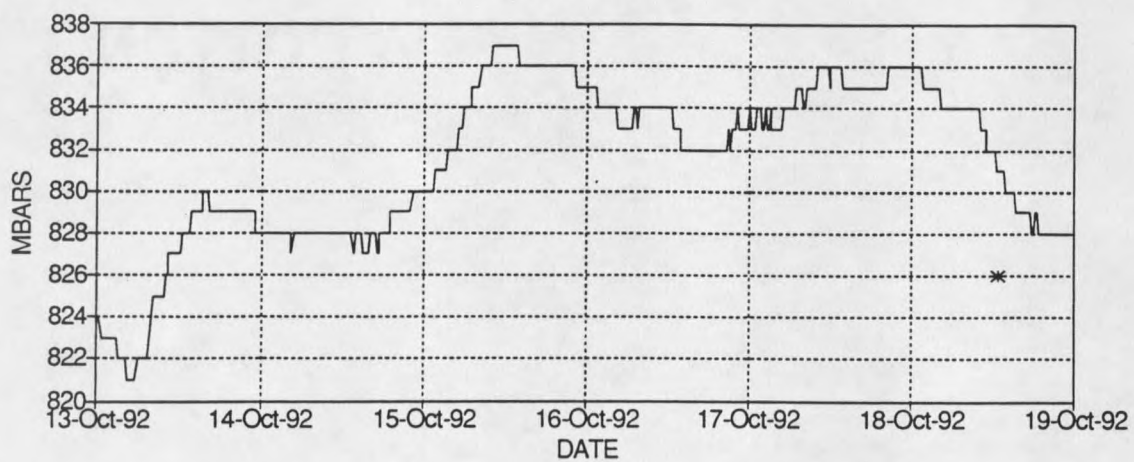
PRECIPITATION AT GALT RANCH



— PRECIPITATION * FAULT #3

Figure 39

BAROMETRIC PRESSURE AT GALT RANCH



— PRESSURE * FAULT #3

Figure 40

AIR TEMPERATURE AND RELATIVE HUMIDITY AT GALT RANCH

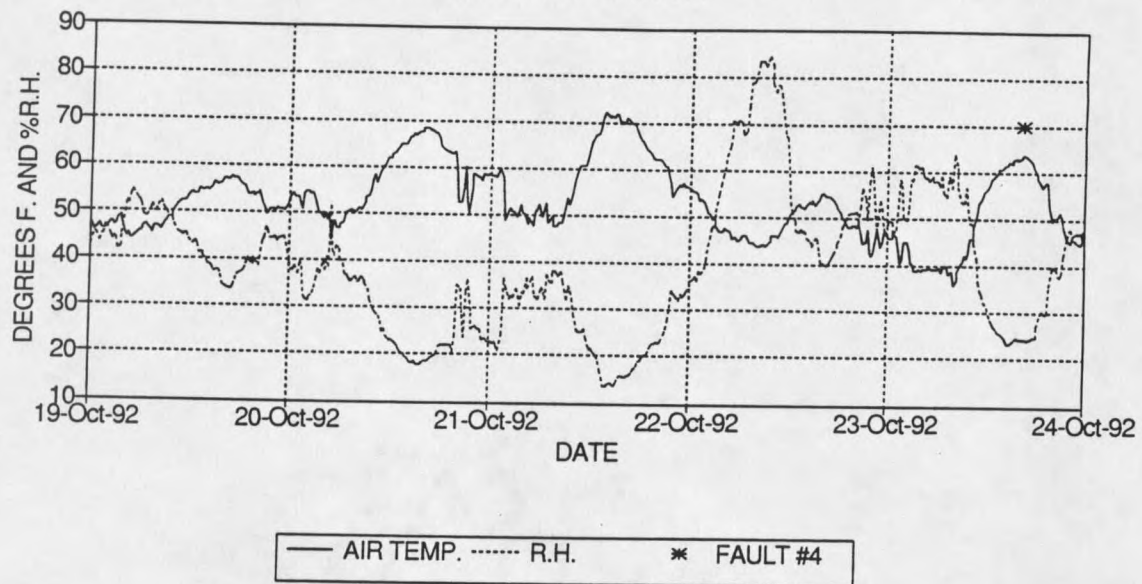


Figure 41

WIND SPEED AT GALT RANCH

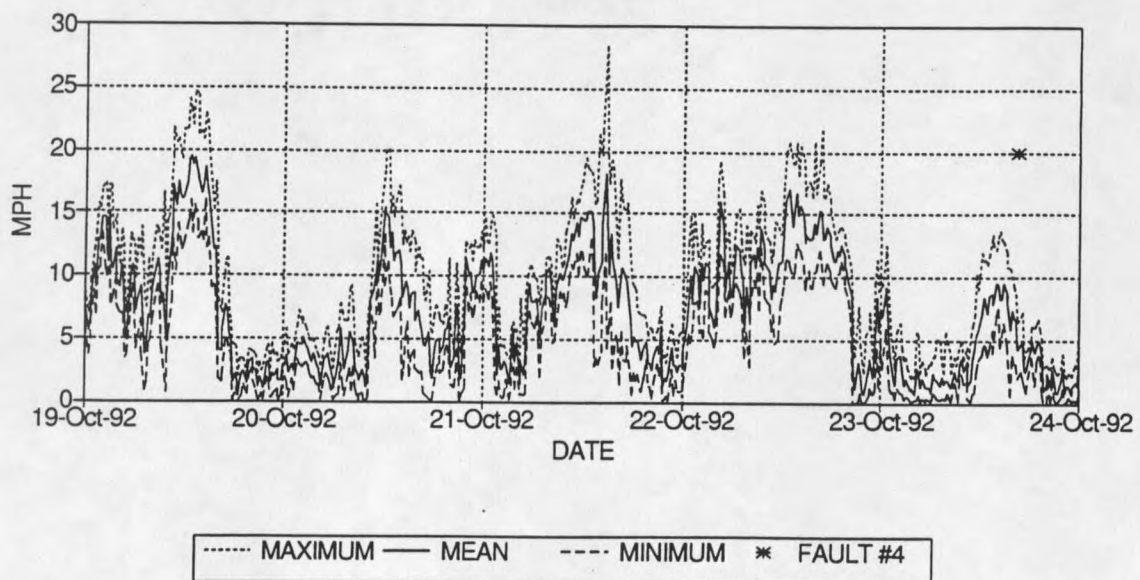


Figure 42

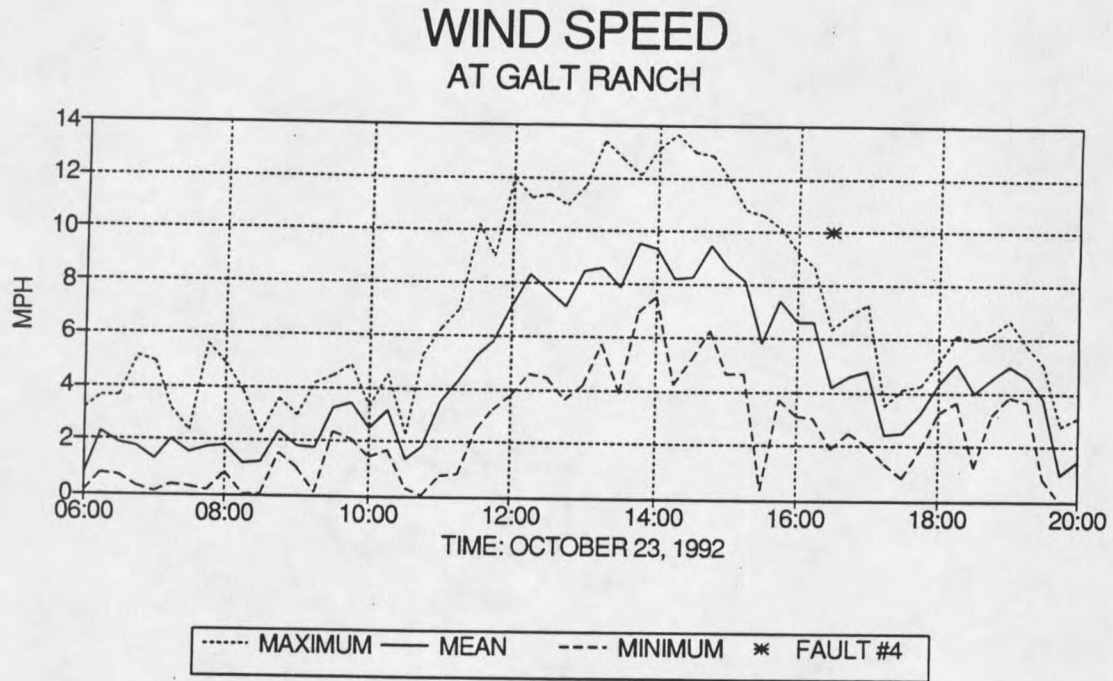


Figure 43

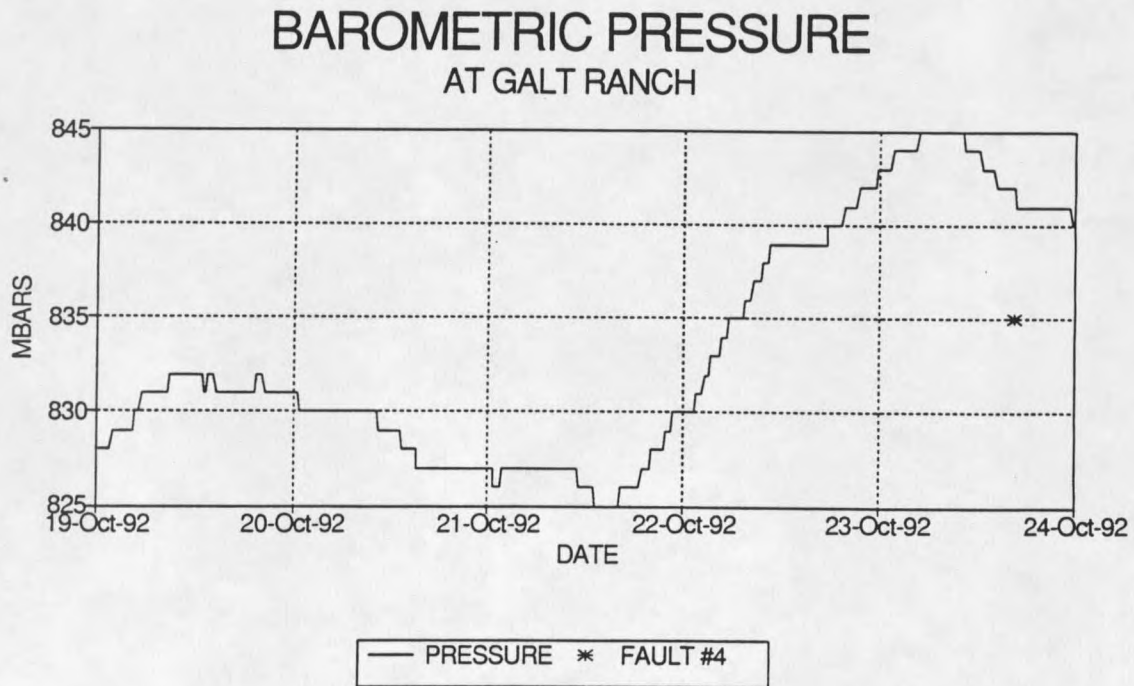


Figure 44

DEW SENSOR RESISTANCES AT GALT RANCH

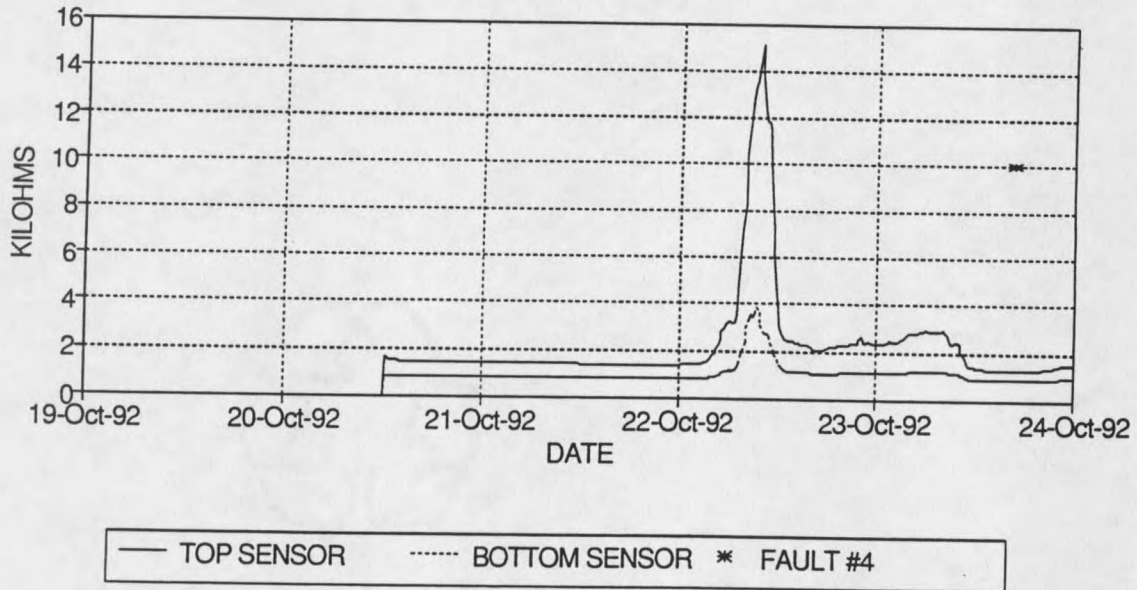


Figure 45

INSULATOR AND AIR TEMPERATURES AT GALT RANCH

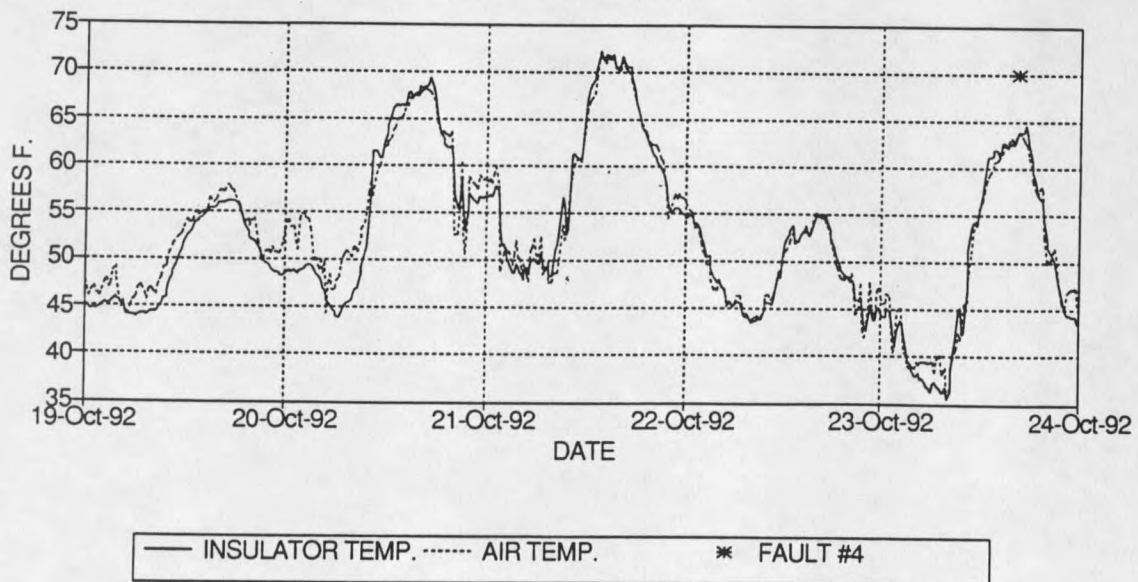


Figure 46

INSULATOR, AIR & DEW POINT TEMPERATURES AT GALT RANCH

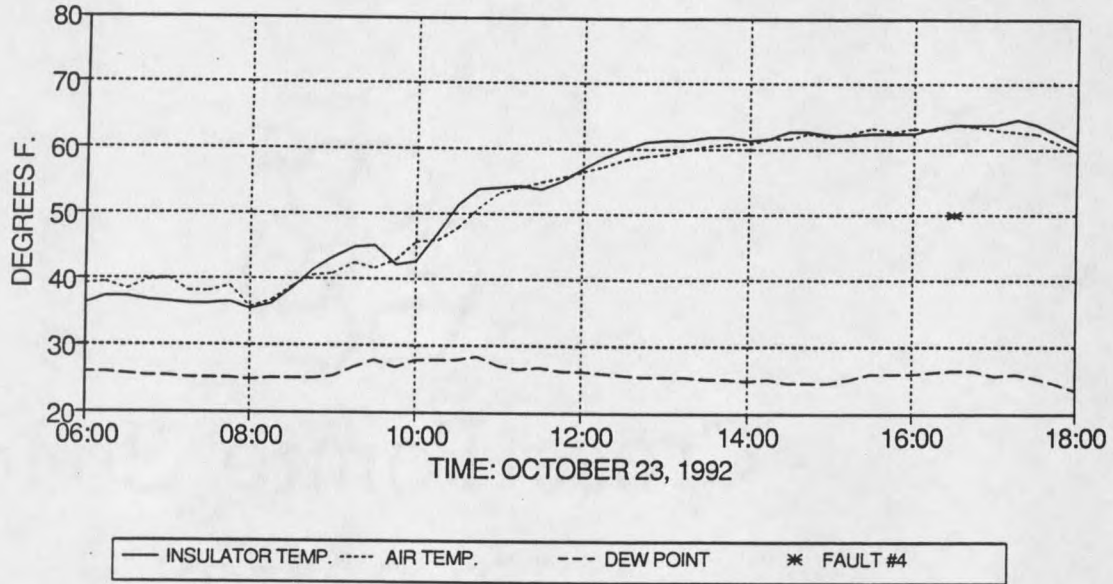


Figure 47

AIR TEMPERATURE AND RELATIVE HUMIDITY AT BROADVIEW SUBSTATION

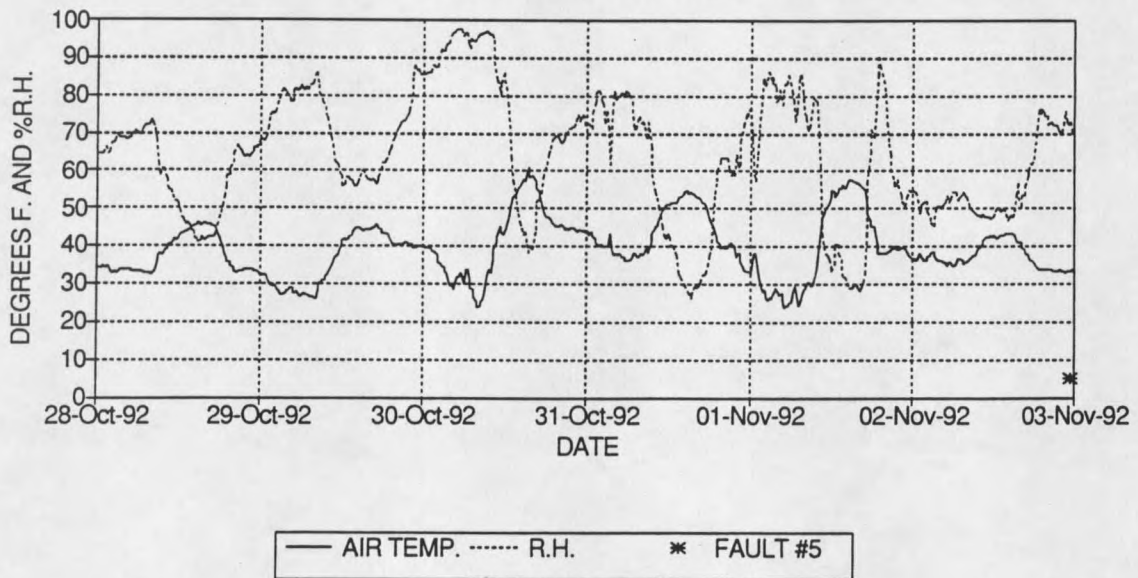


Figure 48

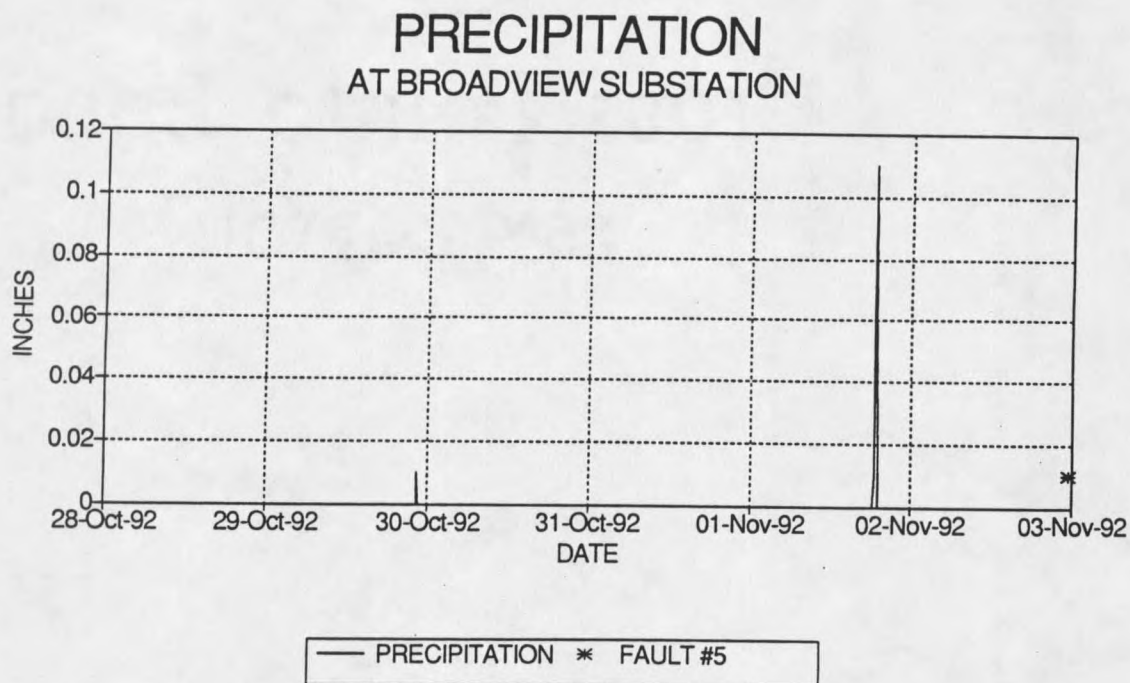


Figure 49

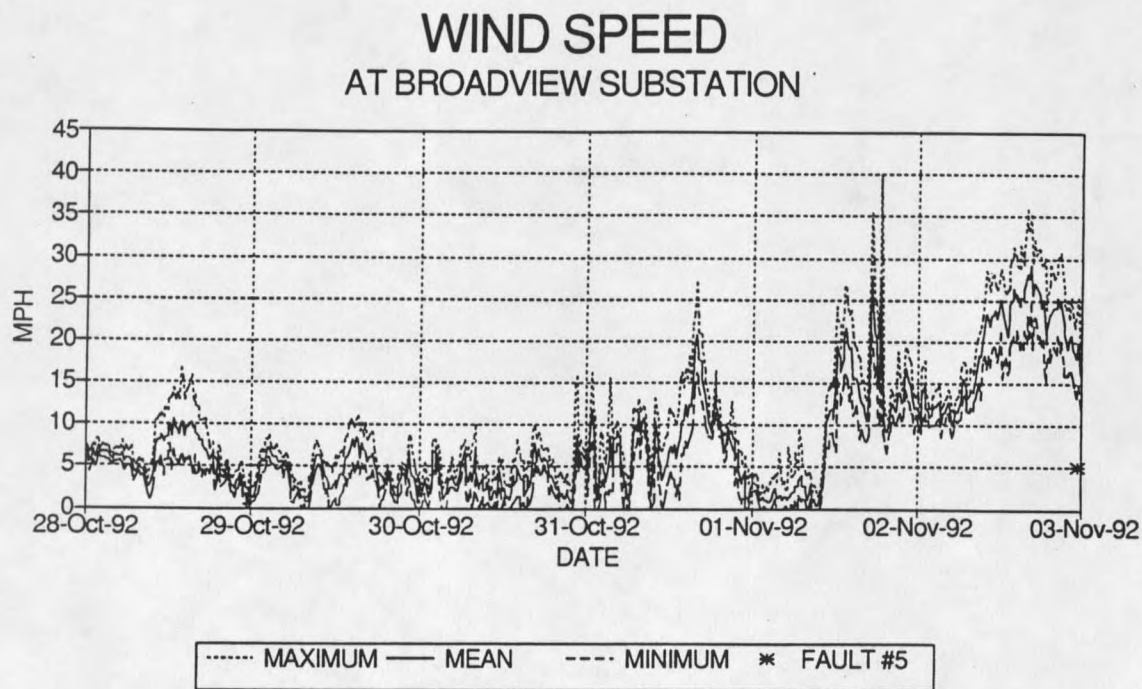


Figure 50

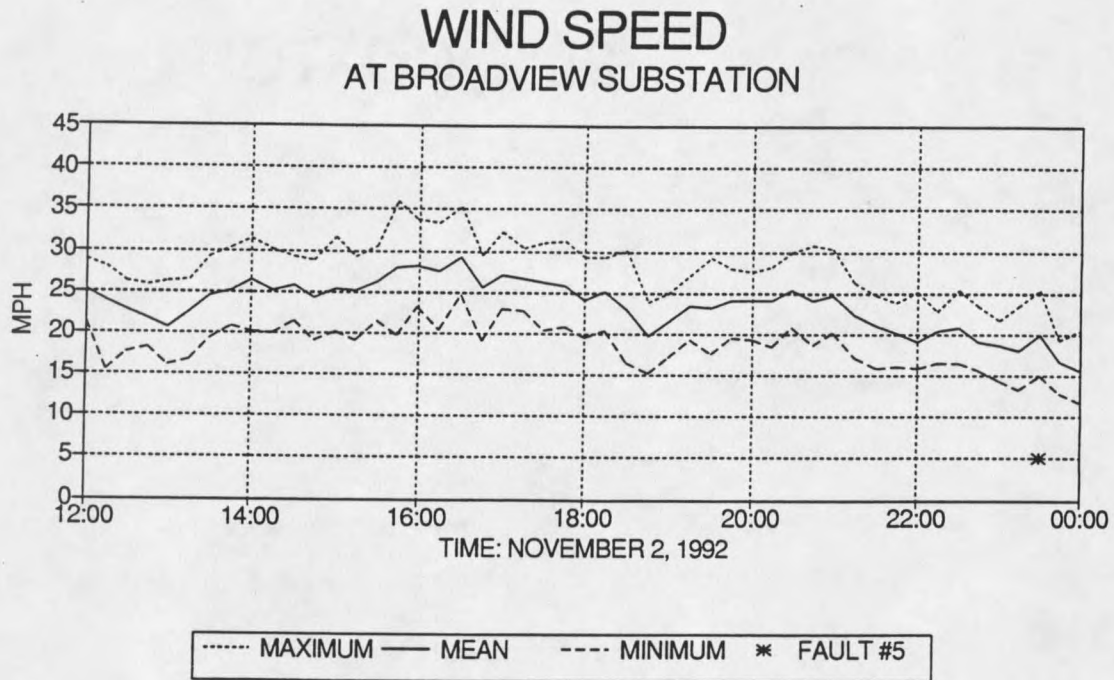


Figure 51

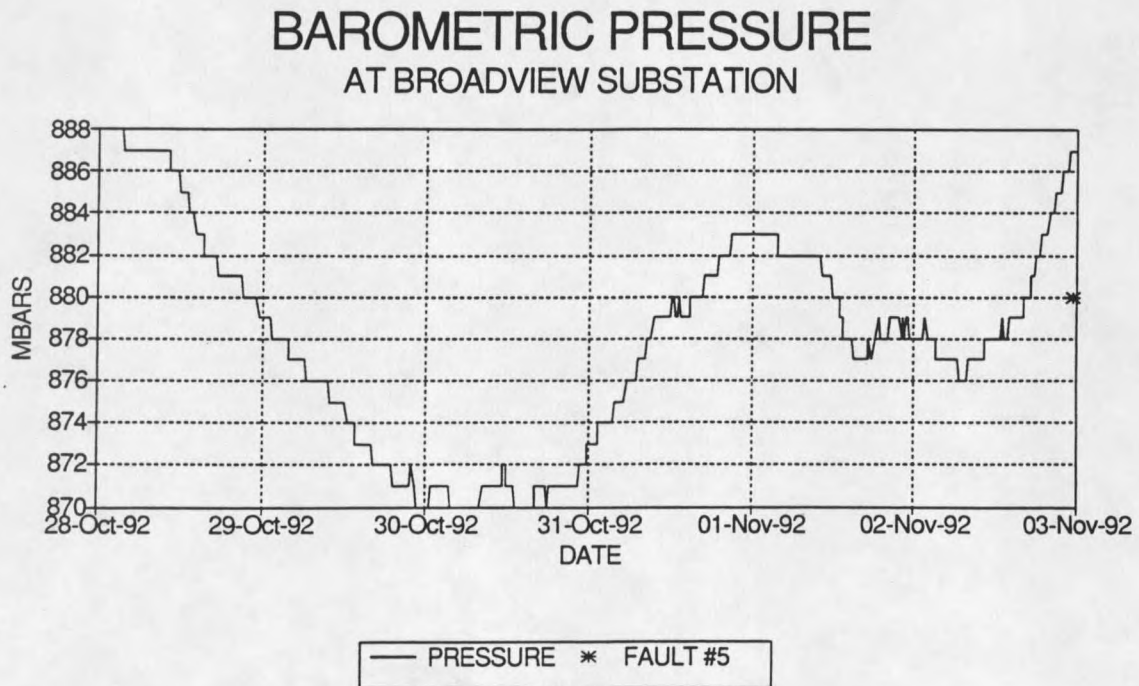


Figure 52

AIR TEMPERATURE AND RELATIVE HUMIDITY AT GALT RANCH

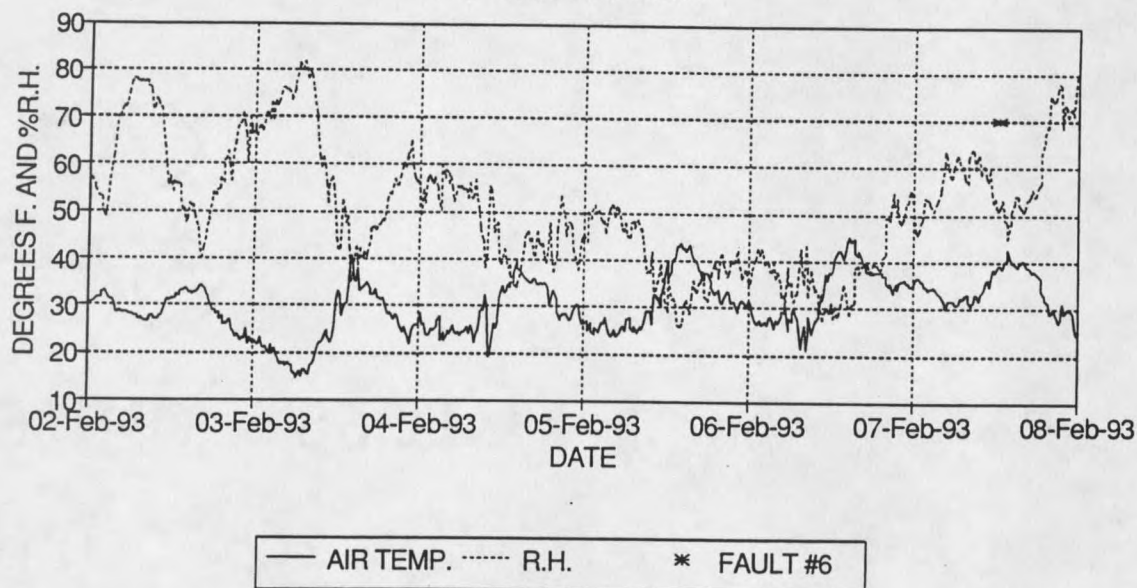


Figure 53

AIR TEMPERATURE AND RELATIVE HUMIDITY AT ROSTAD RANCH

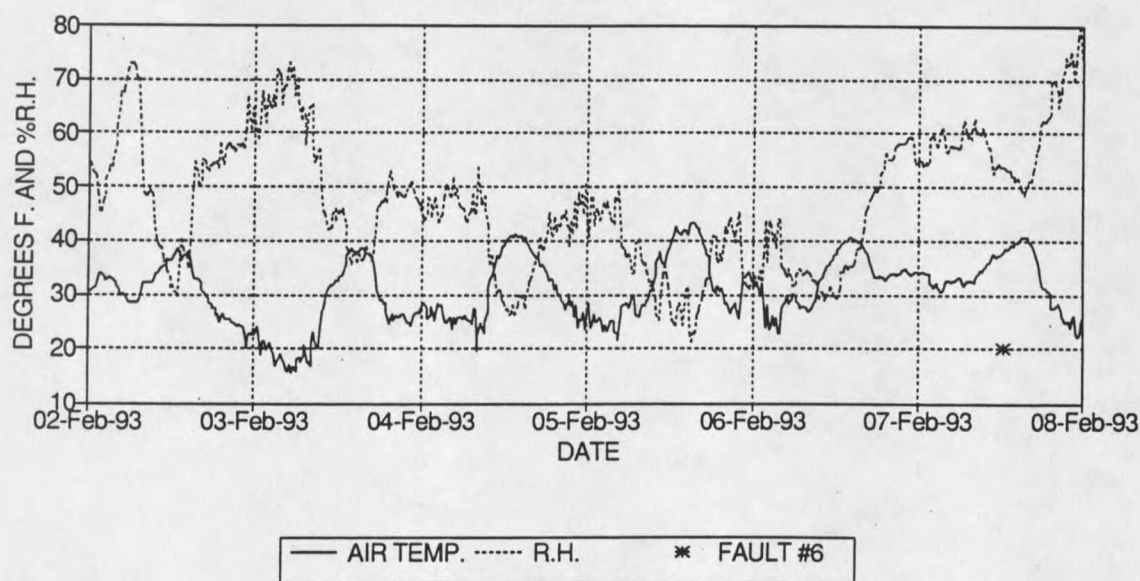
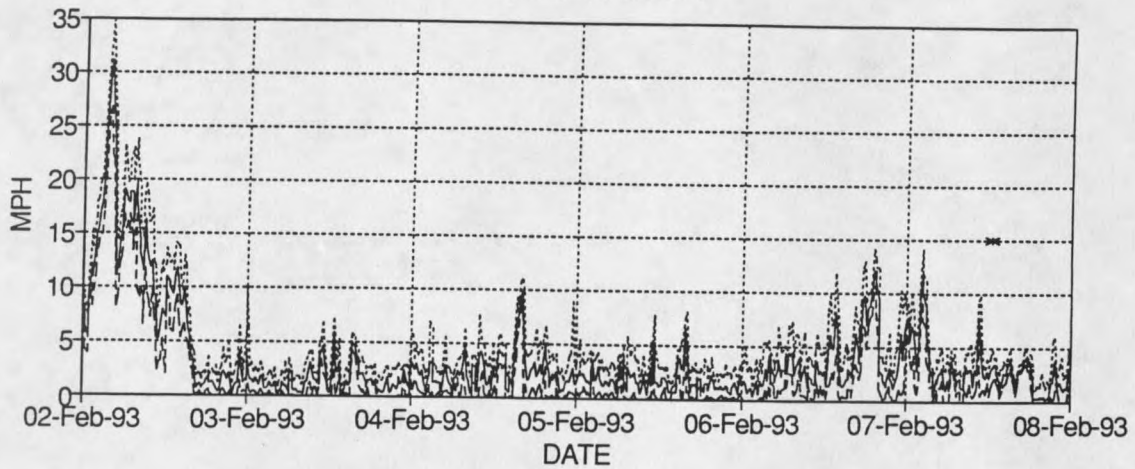


Figure 54

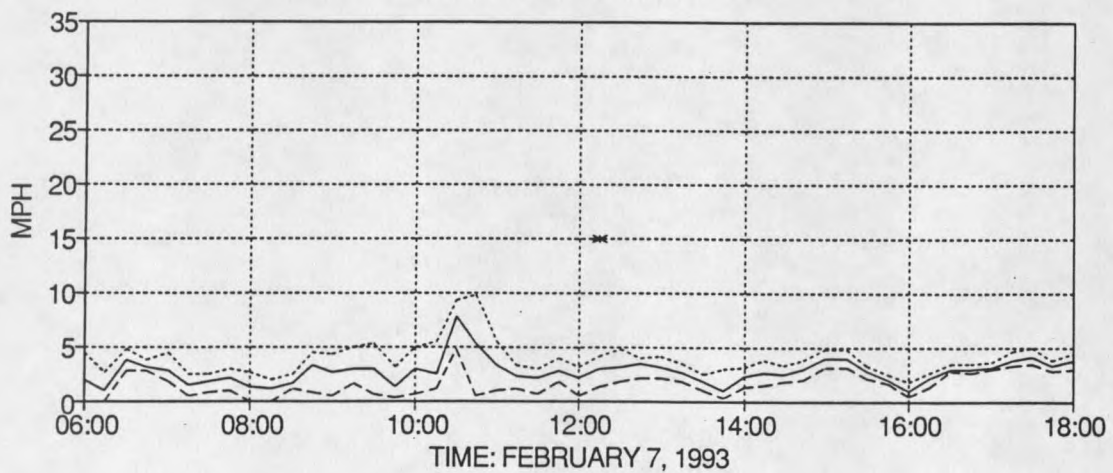
WIND SPEED AT GALT RANCH



..... MAXIMUM — MEAN ---- MINIMUM * FAULT #6

Figure 55

WIND SPEED AT GALT RANCH



..... MAXIMUM — MEAN ---- MINIMUM * FAULT #6

Figure 56

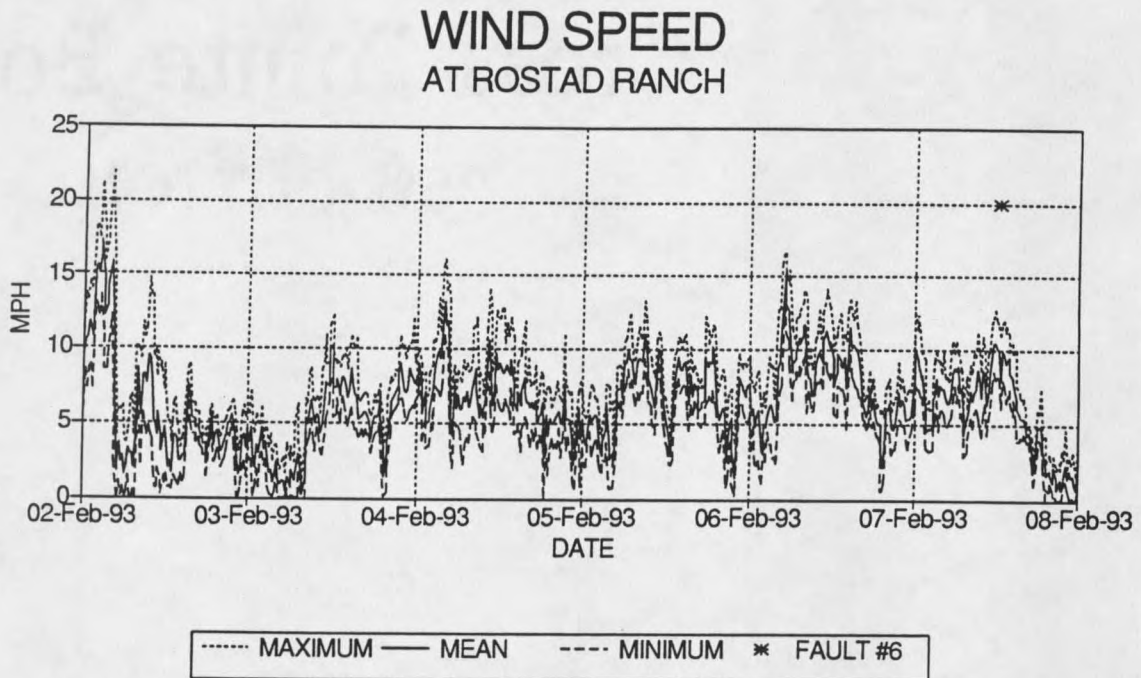


Figure 57

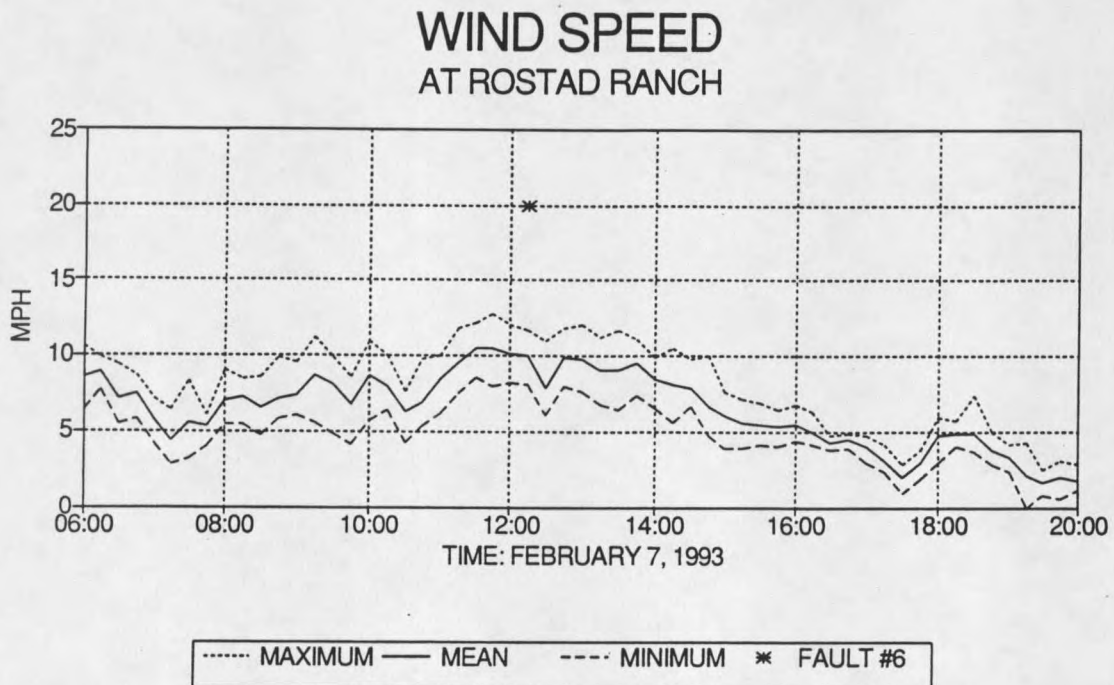


Figure 58

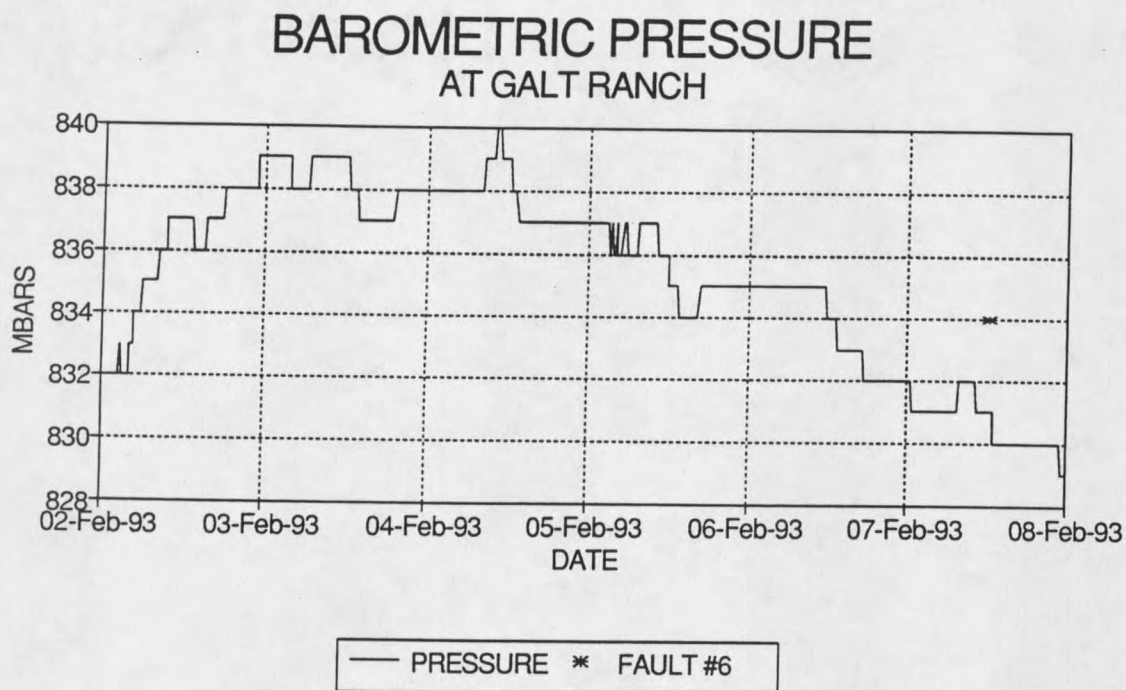


Figure 59

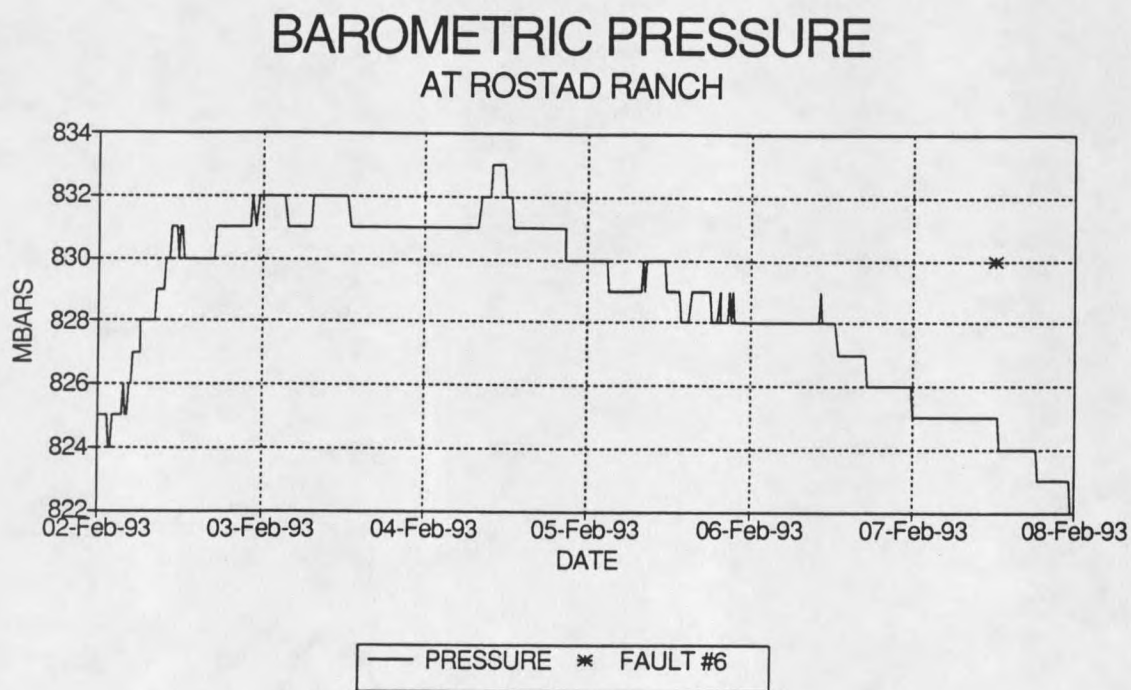


Figure 60

INSULATOR AND AIR TEMPERATURES AT GALT RANCH

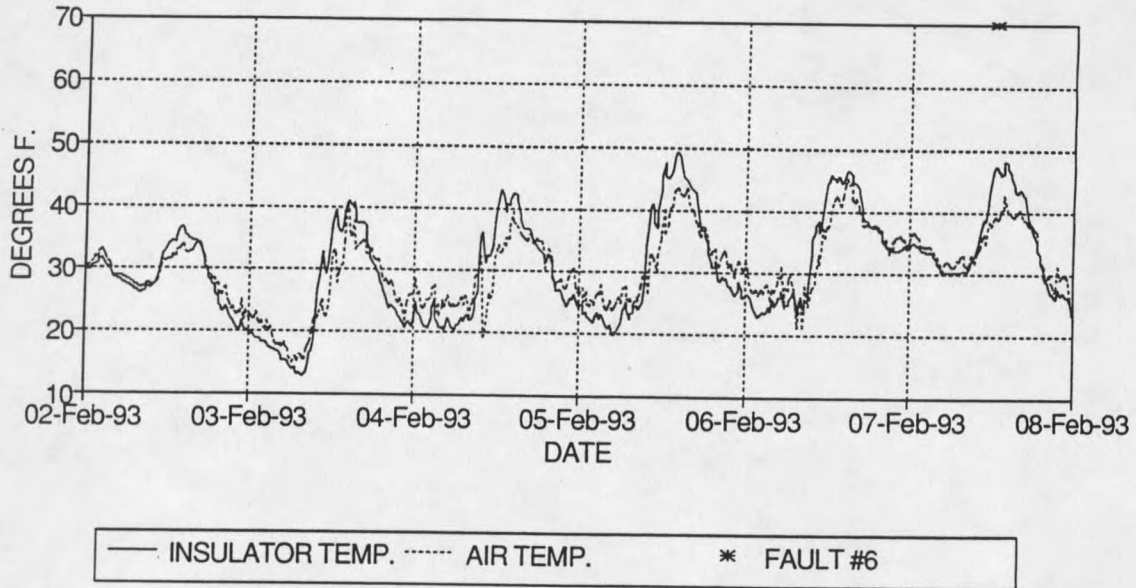


Figure 61

INSULATOR, AIR & DEW POINT TEMPERATURES AT GALT RANCH

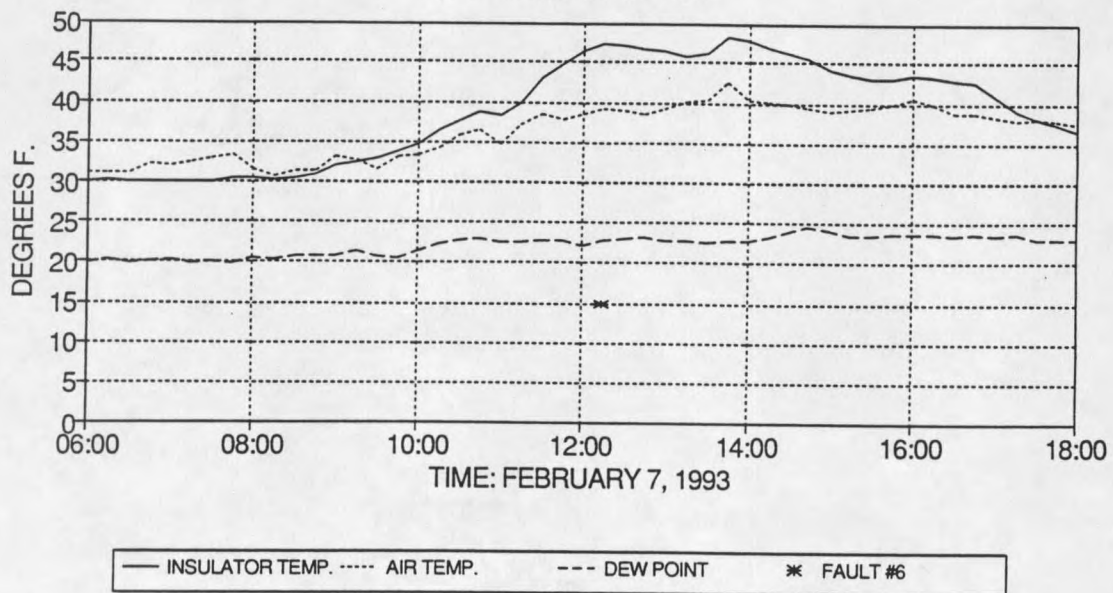


Figure 62

INSULATOR AND AIR TEMPERATURES AT ROSTAD RANCH

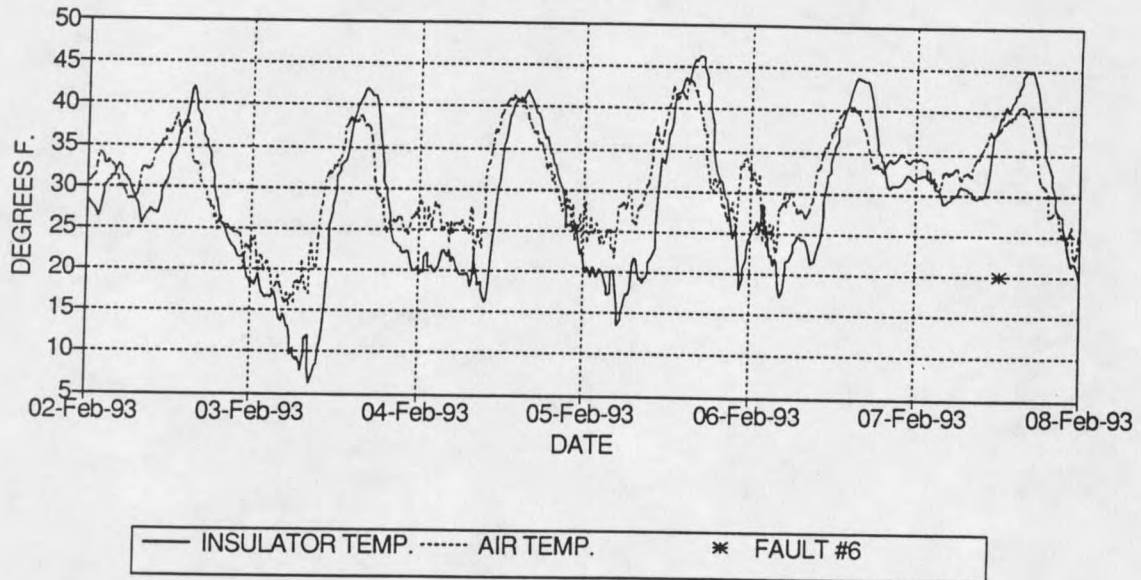


Figure 63

INSULATOR, AIR & DEW POINT TEMPERATURES AT ROSTAD RANCH

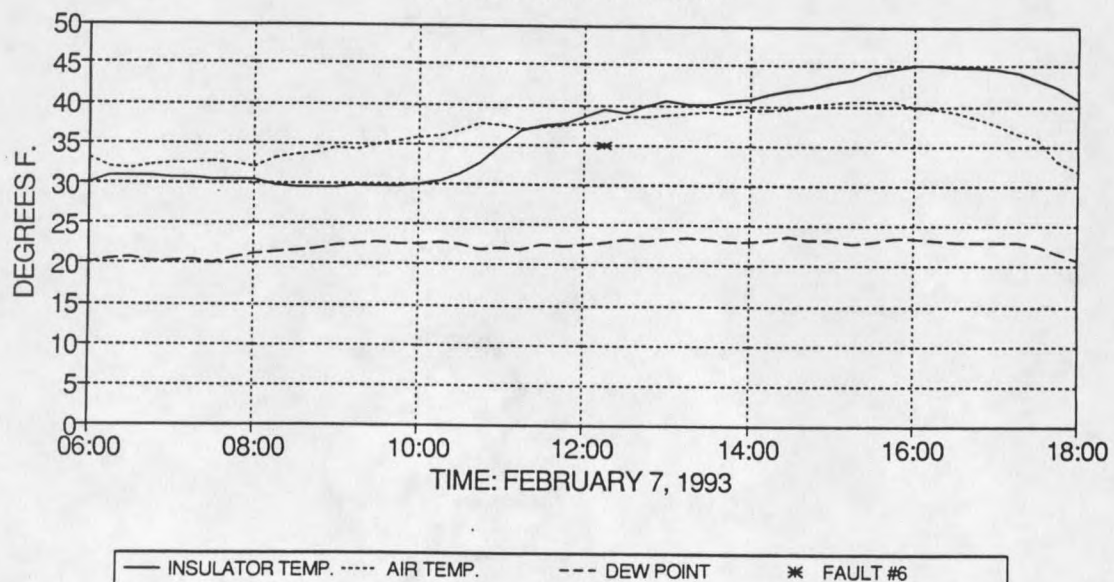


Figure 64

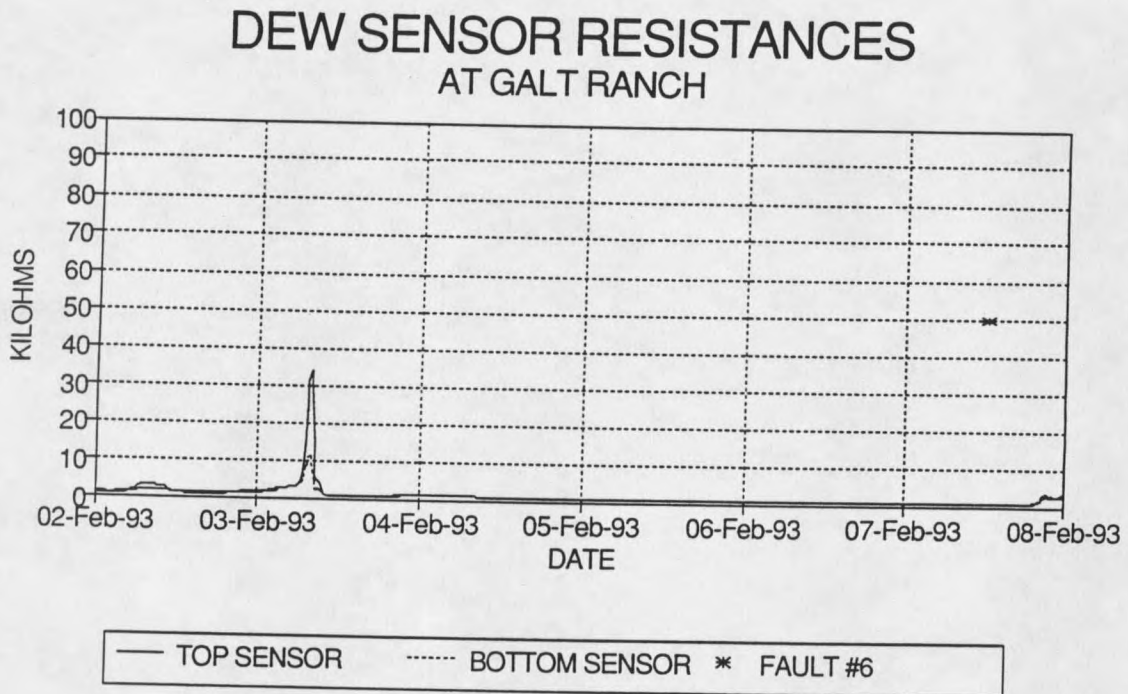


Figure 65

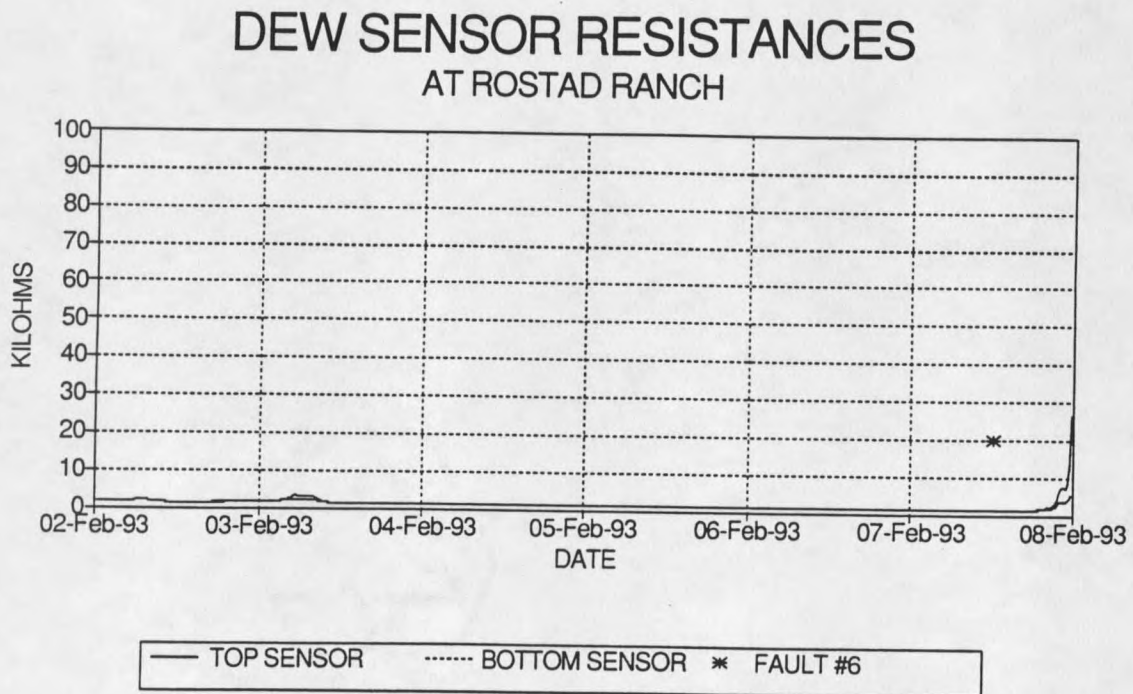


Figure 66

AIR TEMPERATURE AND RELATIVE HUMIDITY AT COONEY RANCH

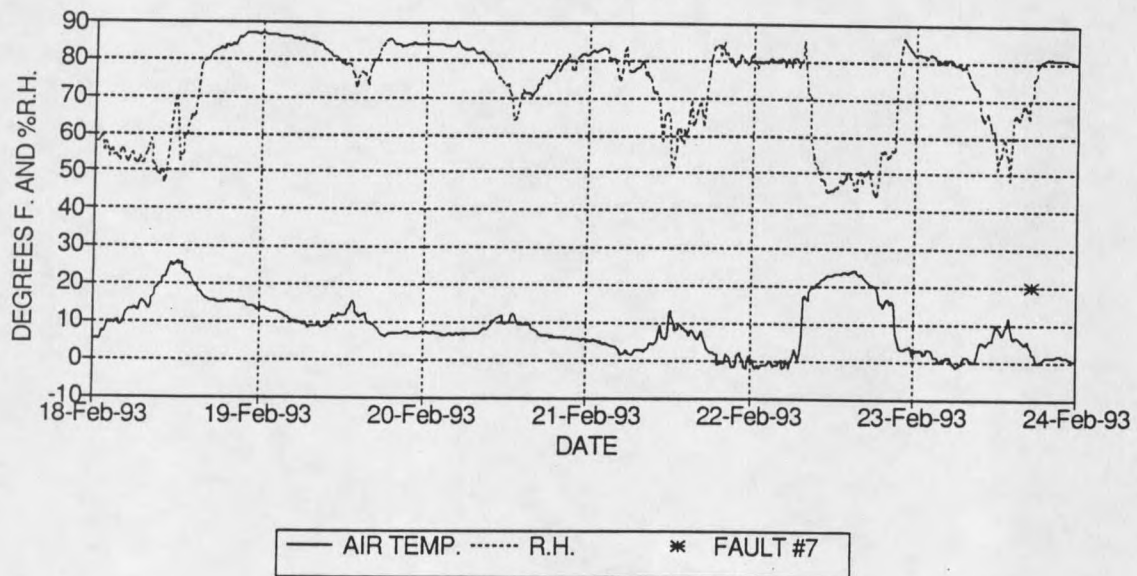


Figure 67

INSULATOR AND AIR TEMPERATURES AT COONEY RANCH

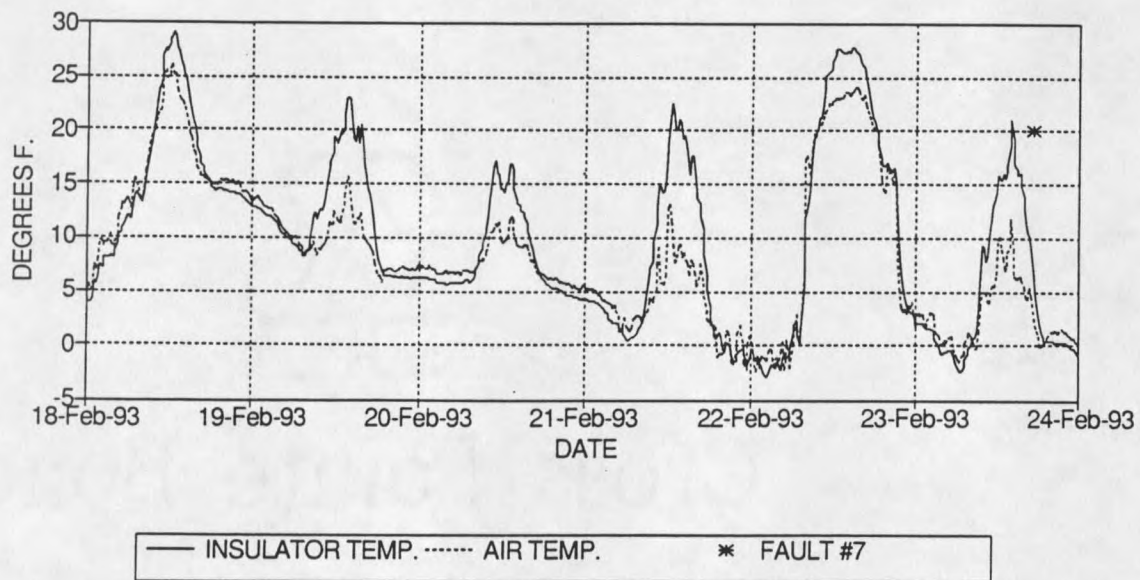


Figure 68

INSULATOR, AIR & DEW POINT TEMPERATURES AT COONEY RANCH

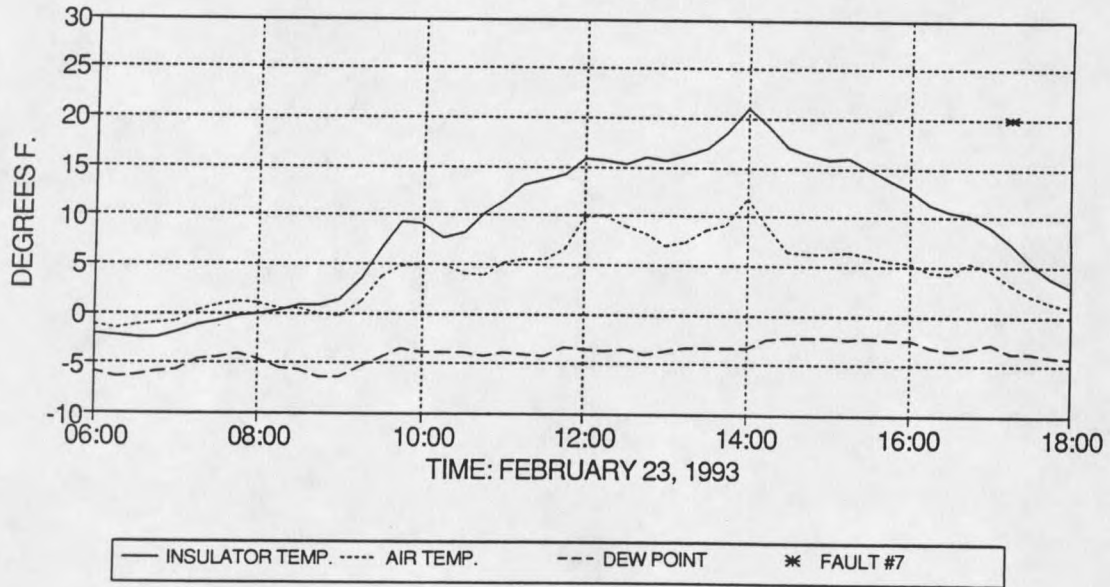


Figure 69

PRECIPITATION AT COONEY RANCH

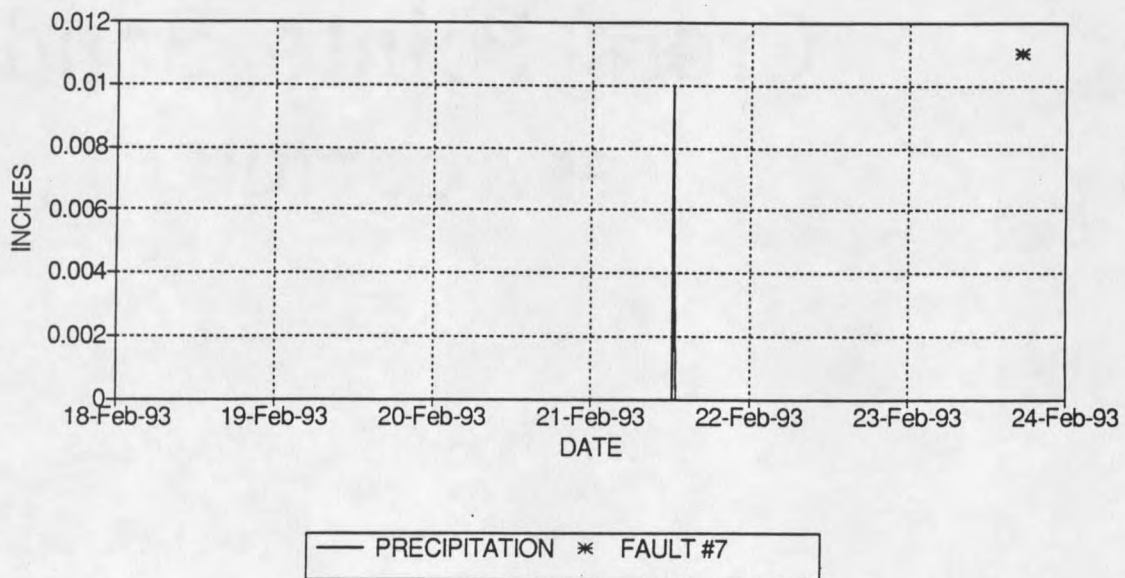


Figure 70

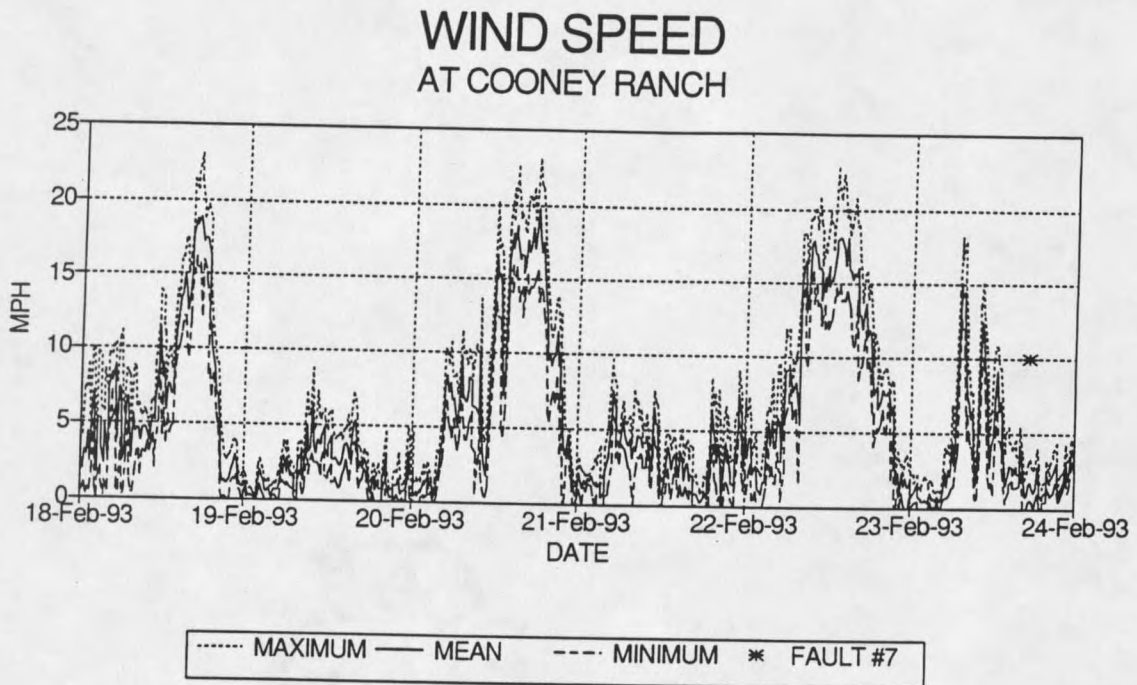


Figure 71

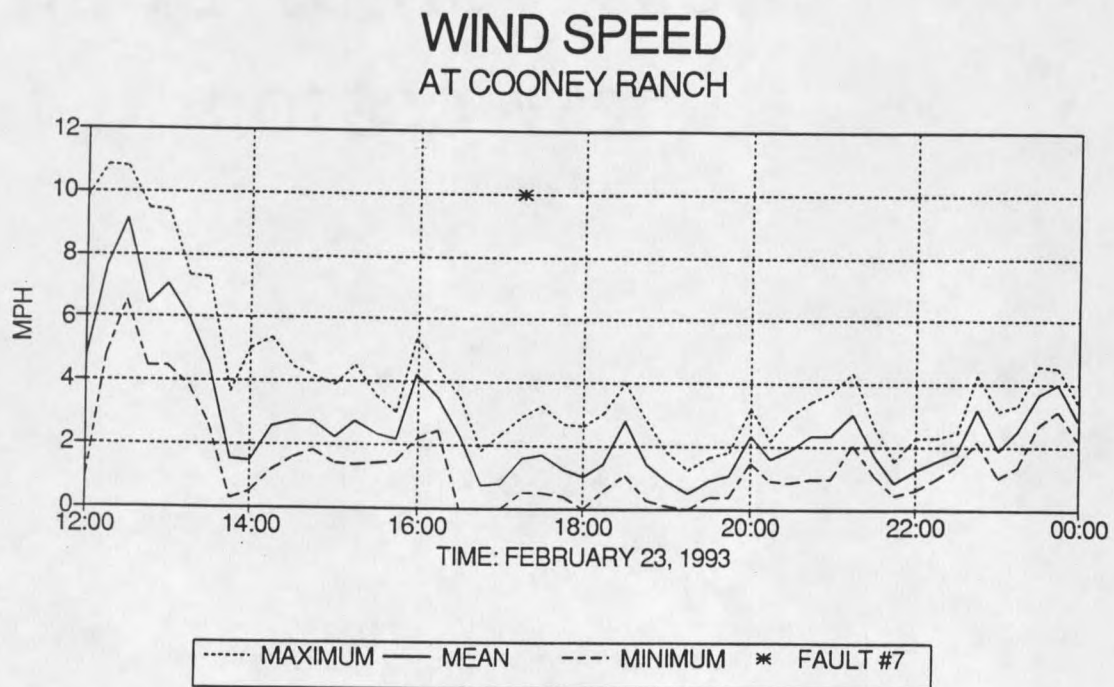


Figure 72

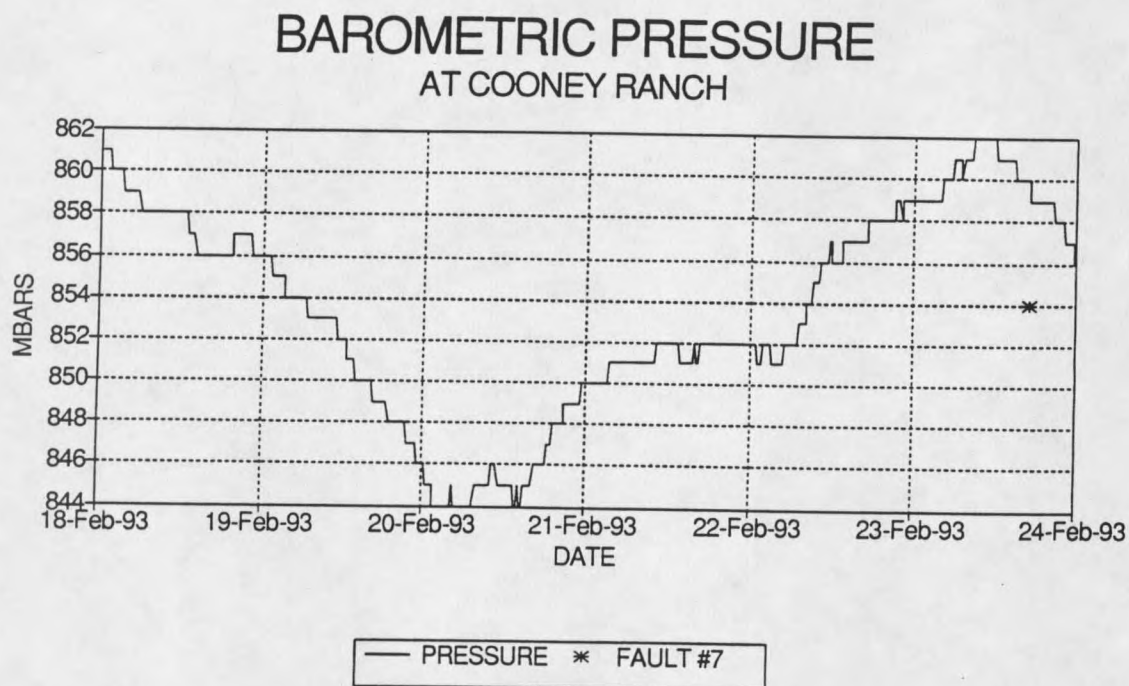


Figure 73

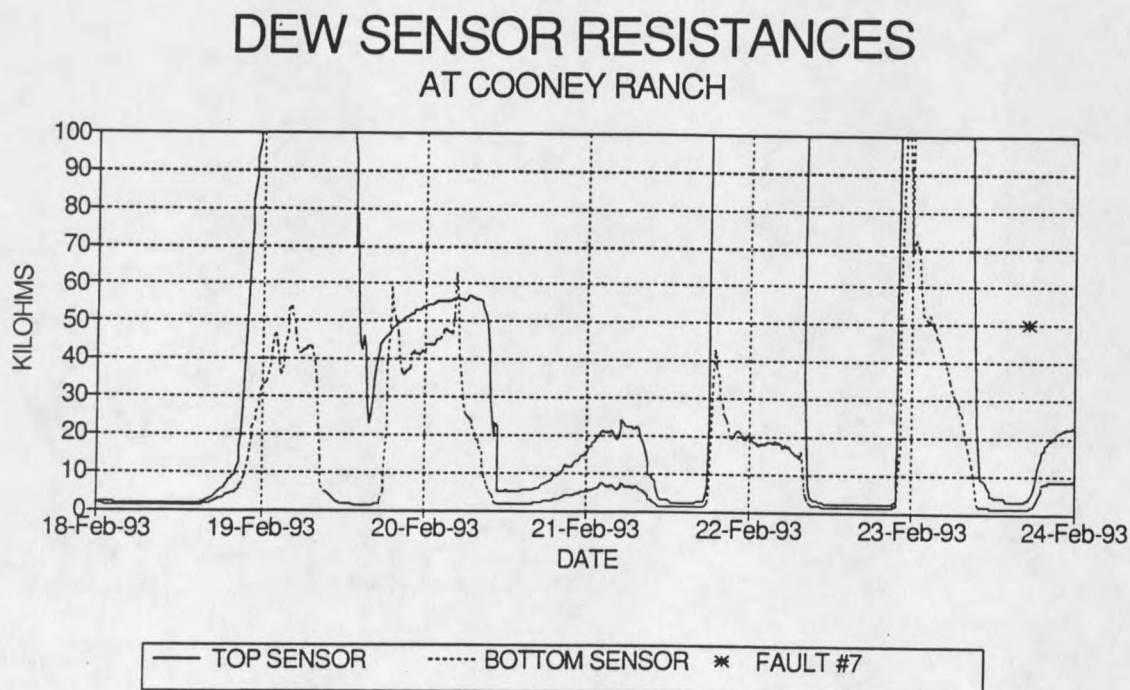


Figure 74

AIR TEMPERATURE AND RELATIVE HUMIDITY AT WHITE RANCH

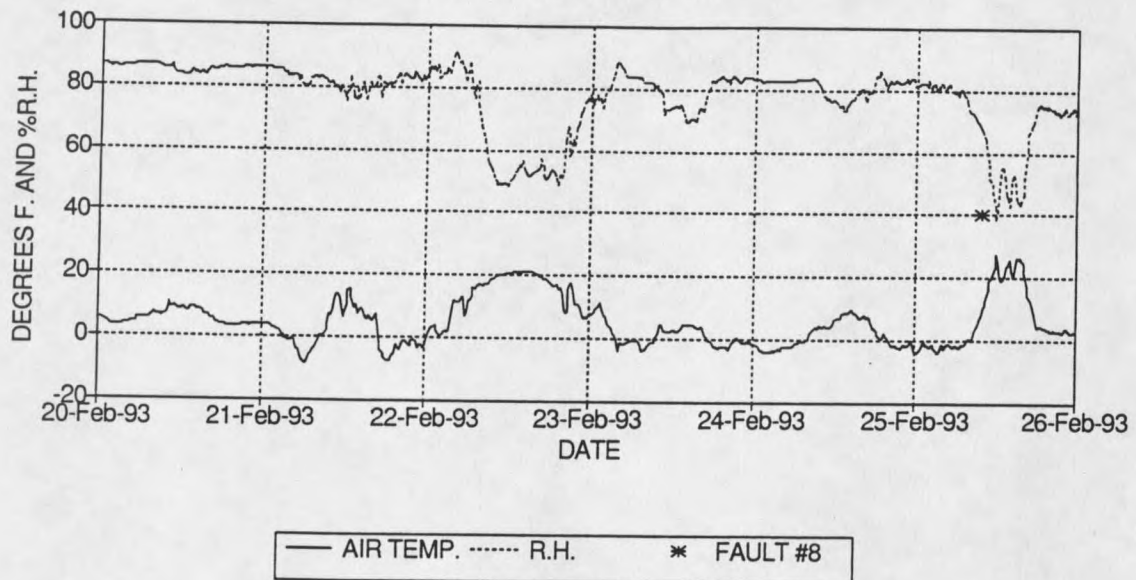


Figure 75

INSULATOR AND AIR TEMPERATURES AT WHITE RANCH

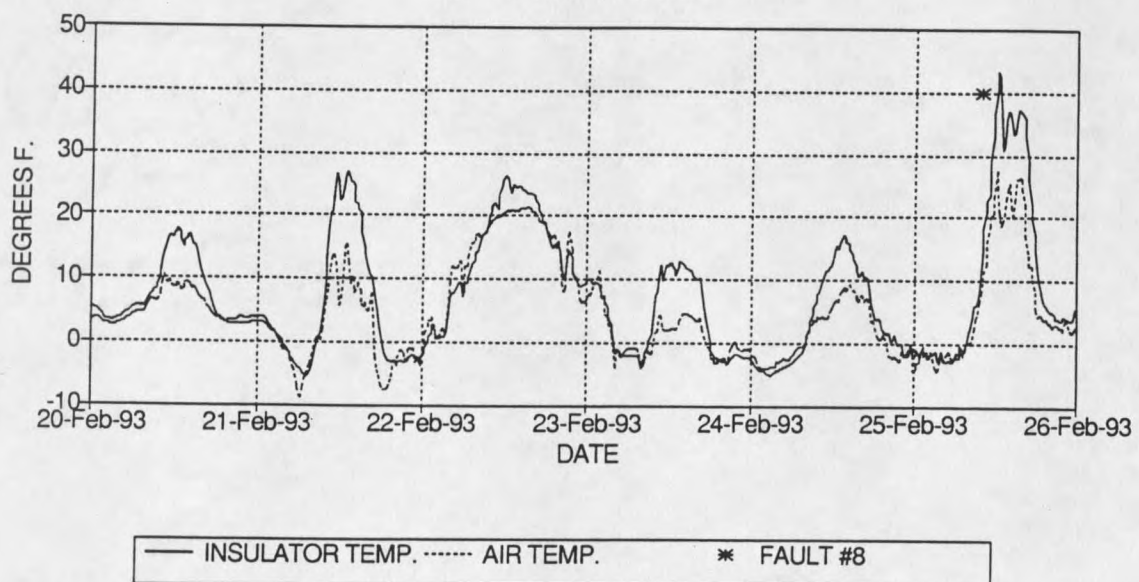


Figure 76

INSULATOR, AIR & DEW POINT TEMPERATURES AT WHITE RANCH

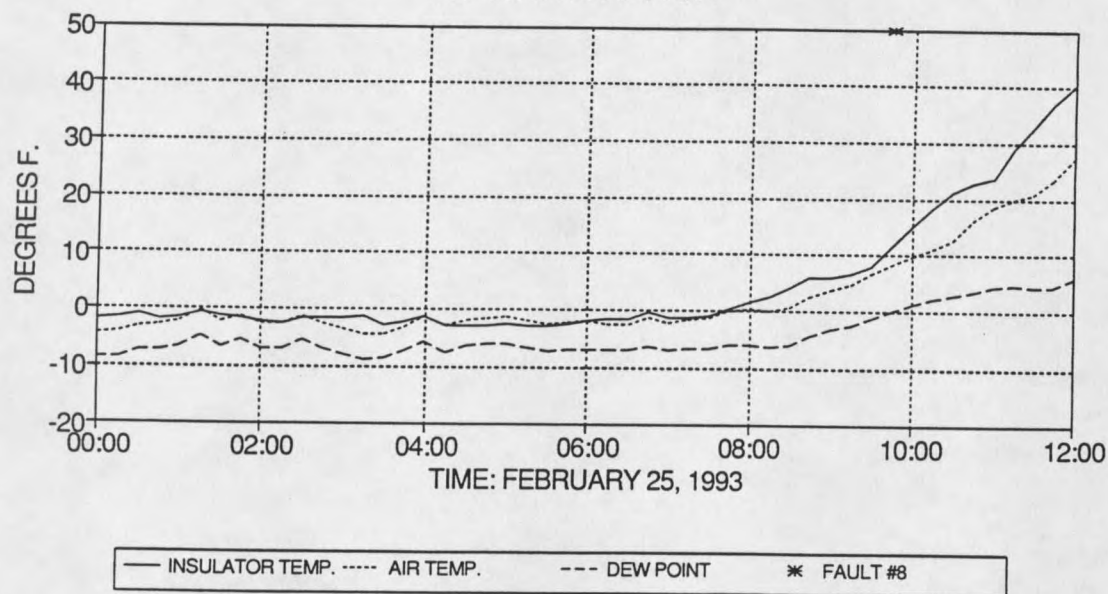


Figure 77

PRECIPITATION AT WHITE RANCH

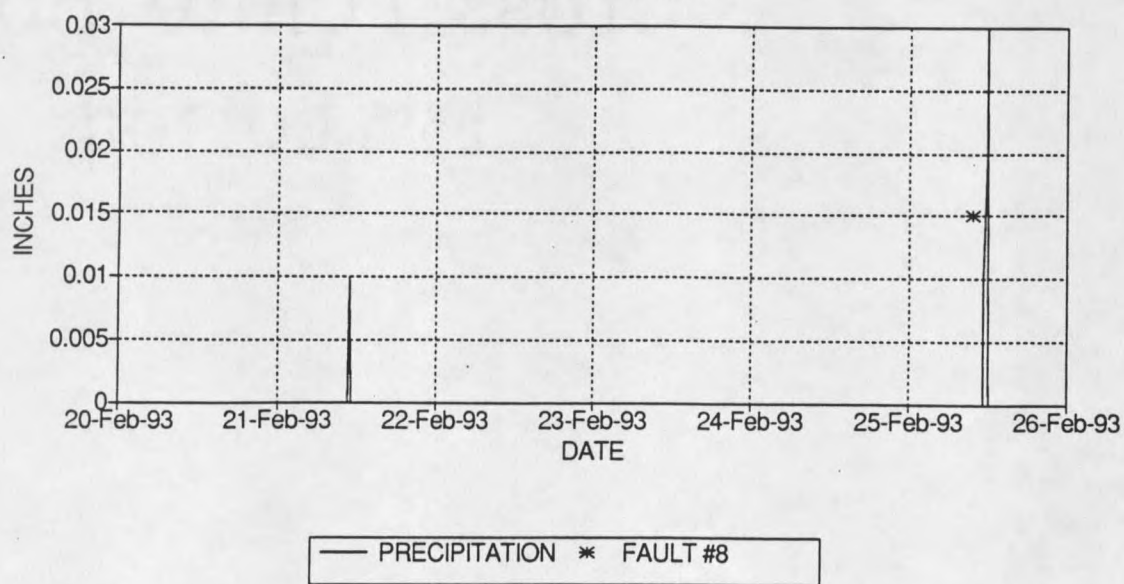


Figure 78

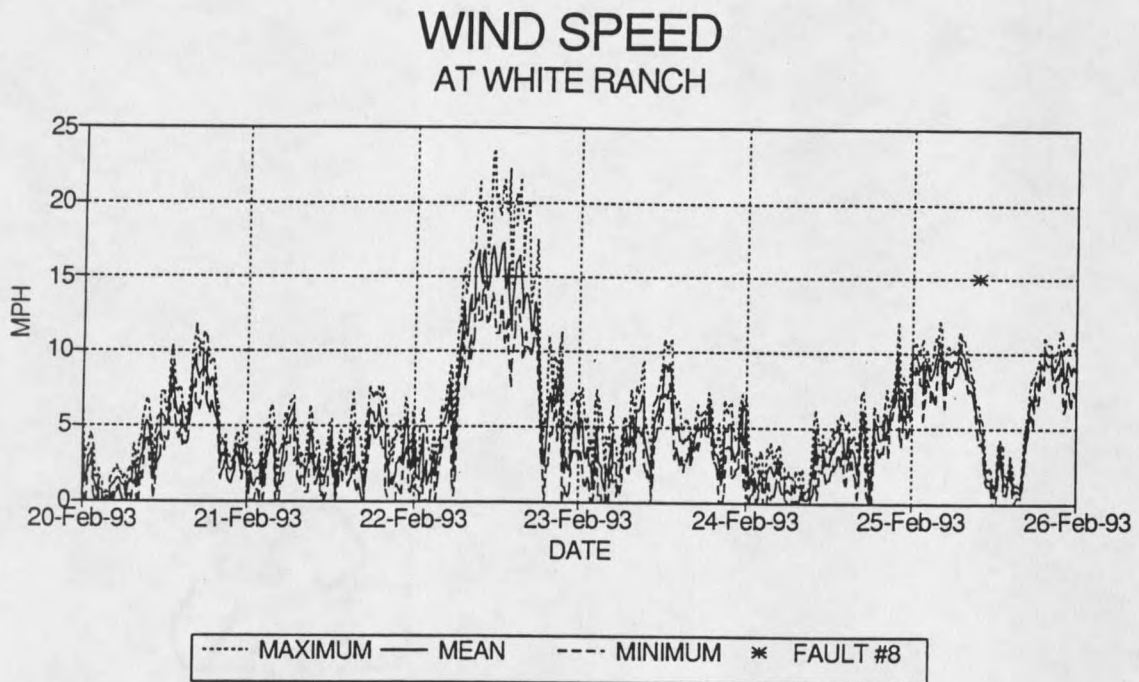


Figure 79

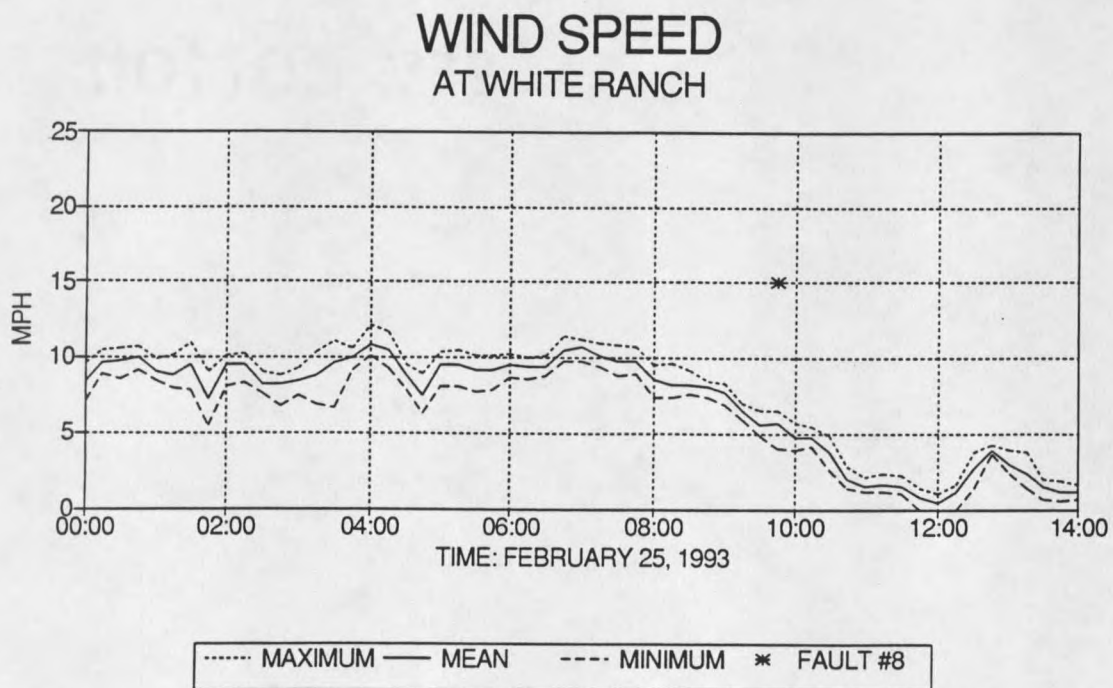


Figure 80

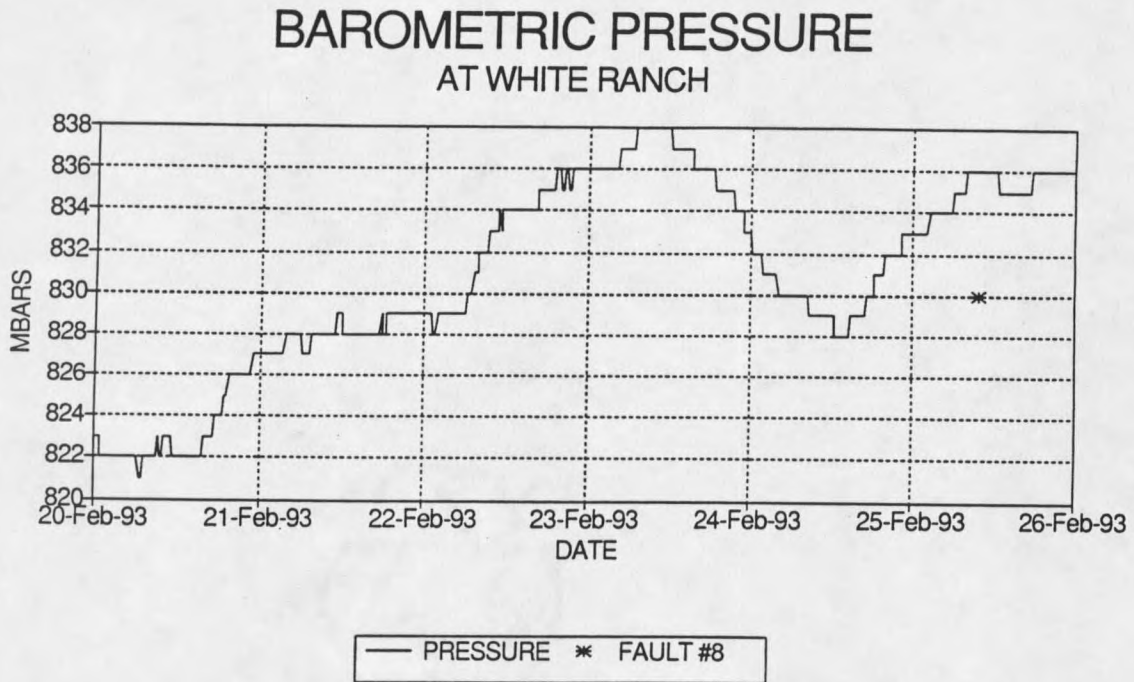


Figure 81

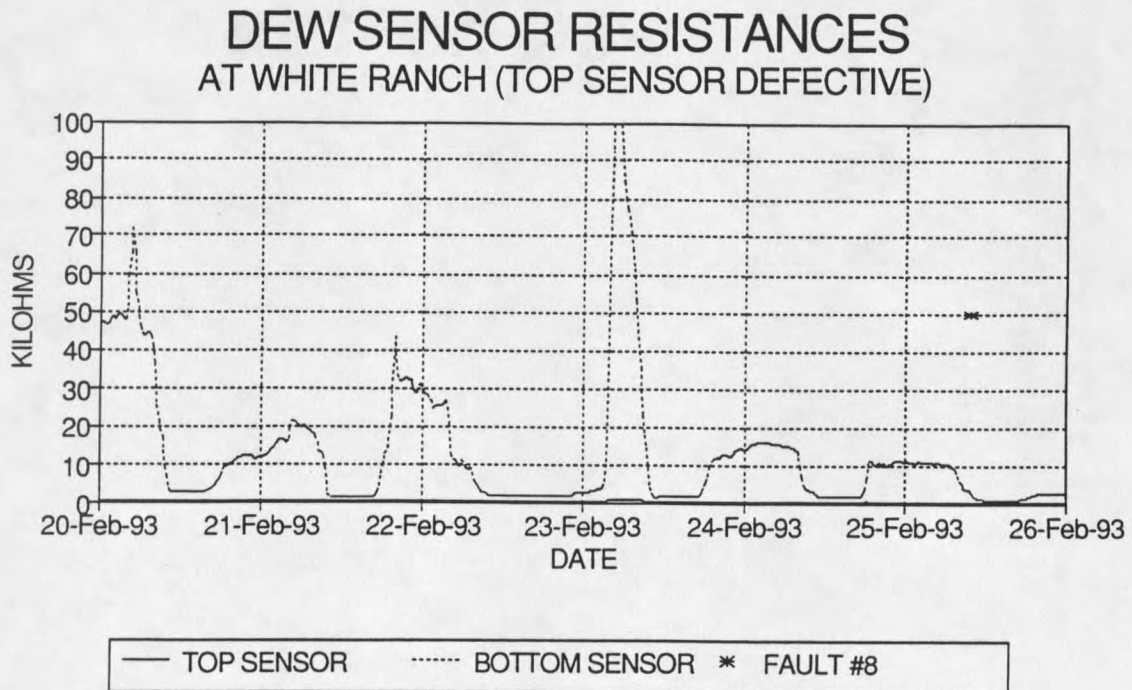


Figure 82

AIR TEMPERATURE AND RELATIVE HUMIDITY AT COONEY RANCH

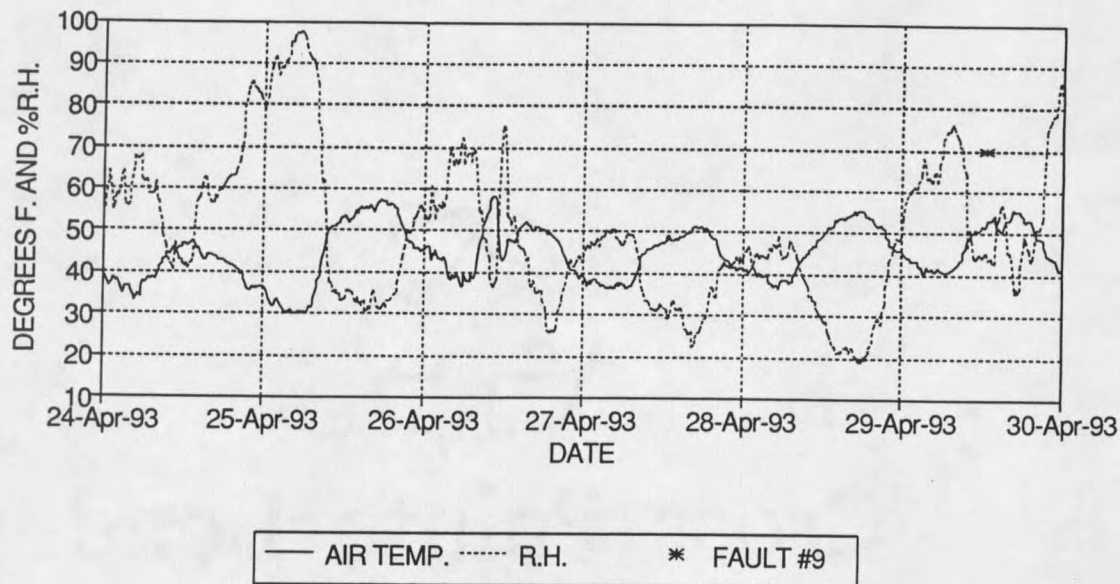


Figure 83

PRECIPITATION AT COONEY RANCH

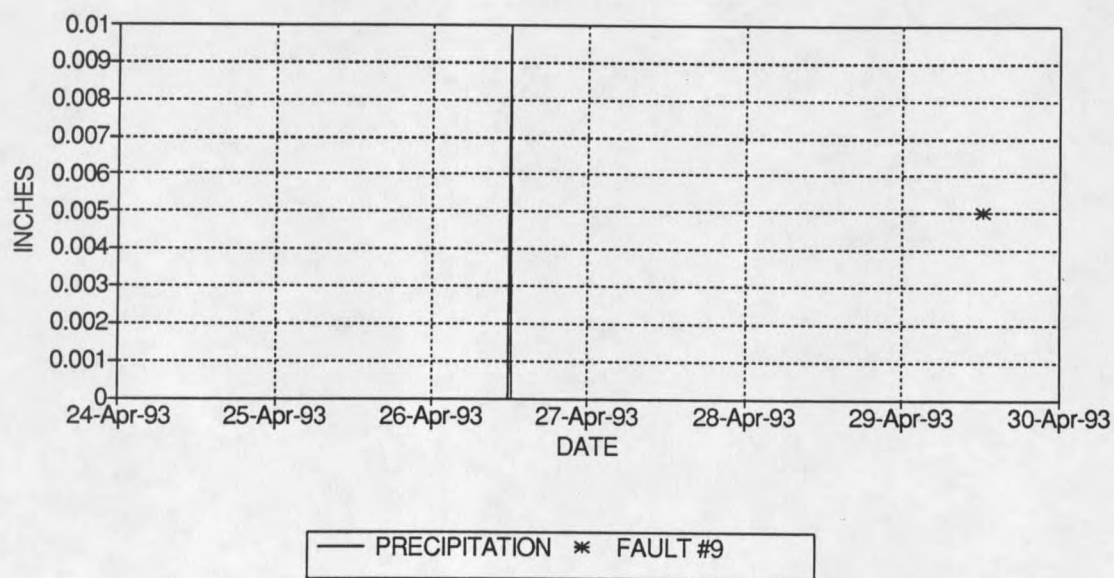


Figure 84

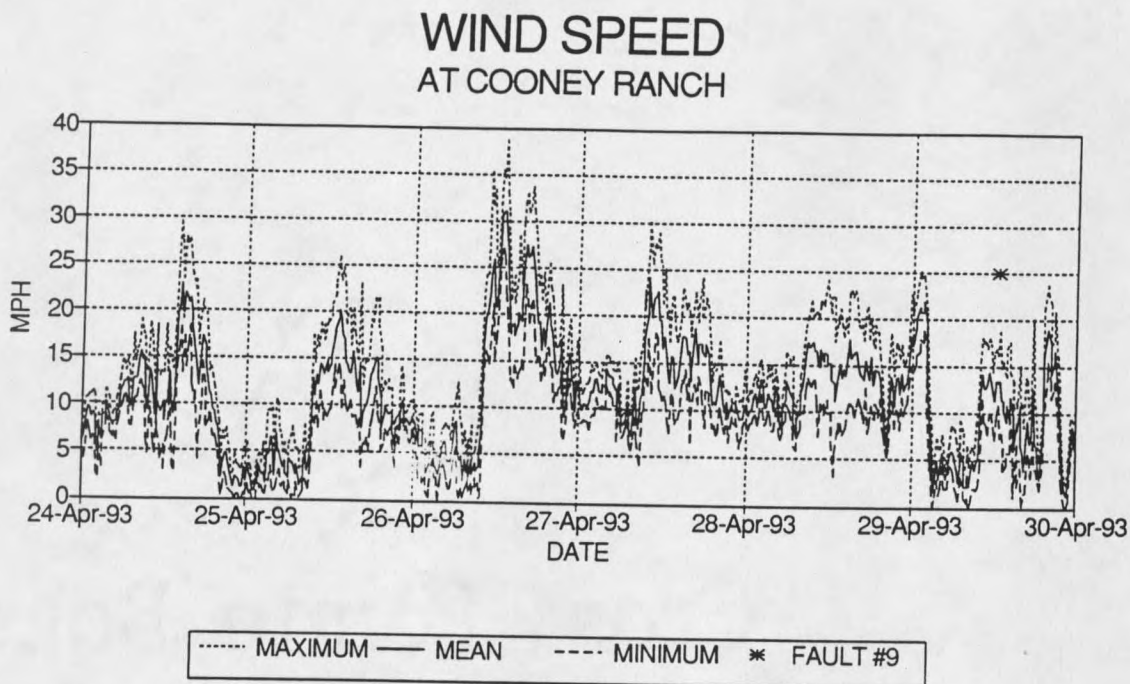


Figure 85

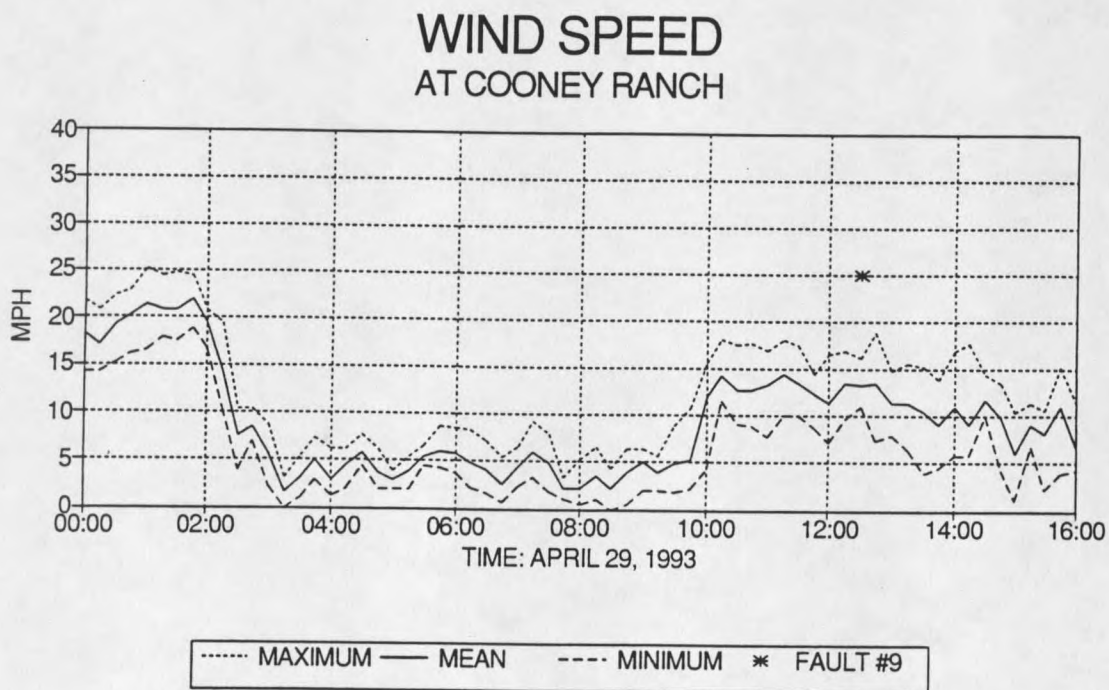


Figure 86

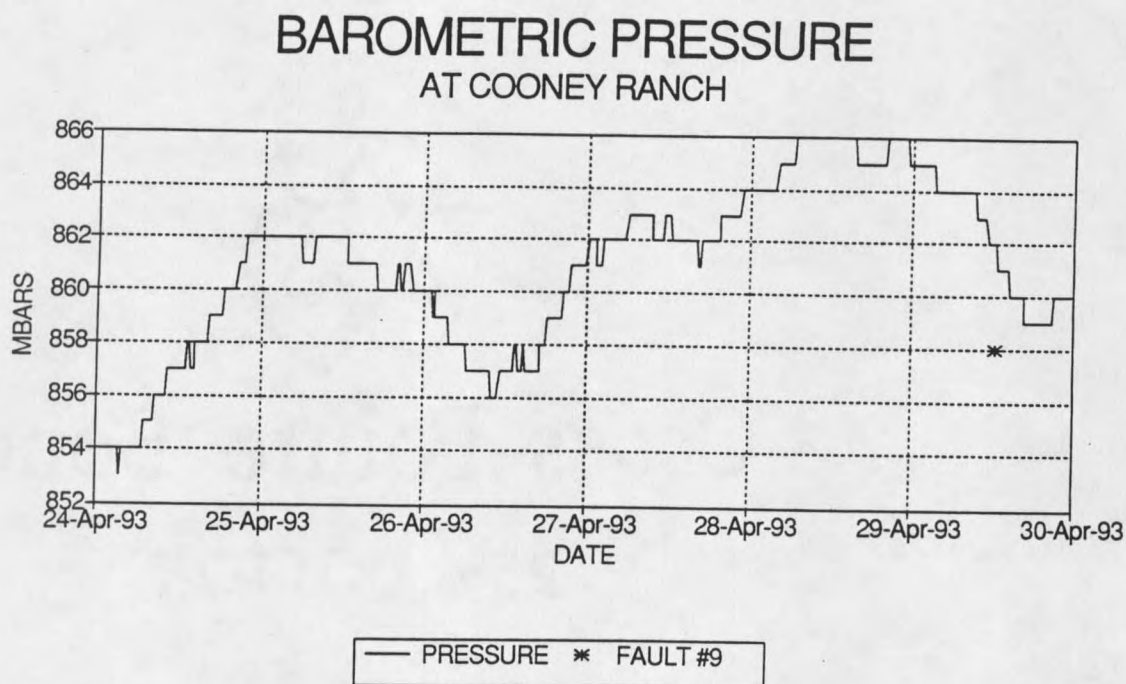


Figure 87

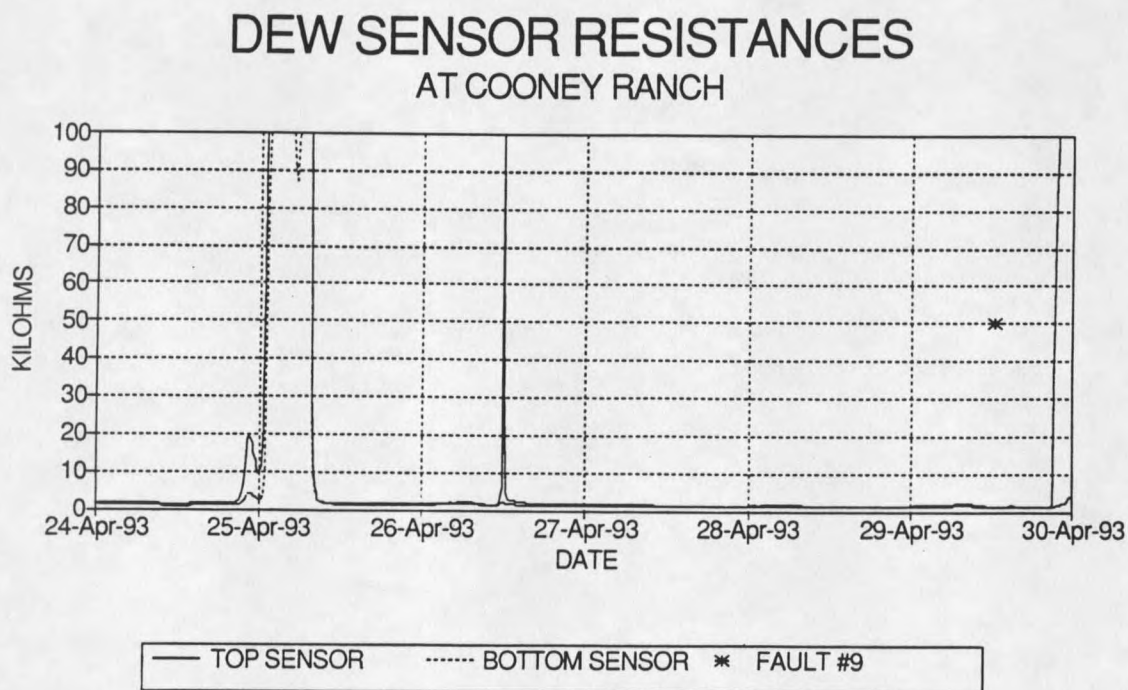


Figure 88

INSULATOR AND AIR TEMPERATURES AT COONEY RANCH

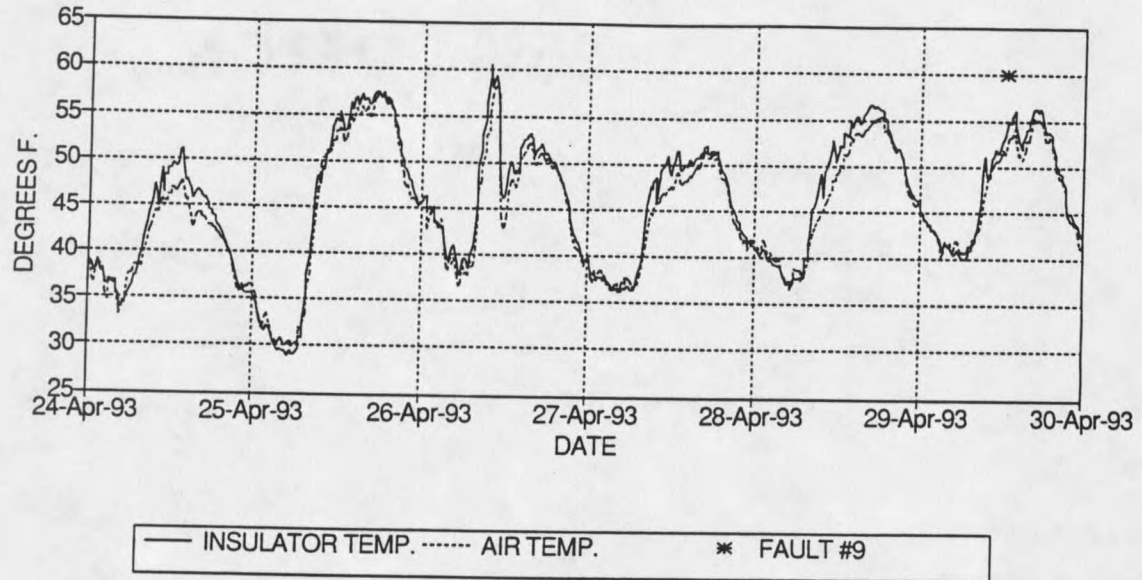


Figure 89

INSULATOR, AIR & DEW POINT TEMPERATURES AT COONEY RANCH

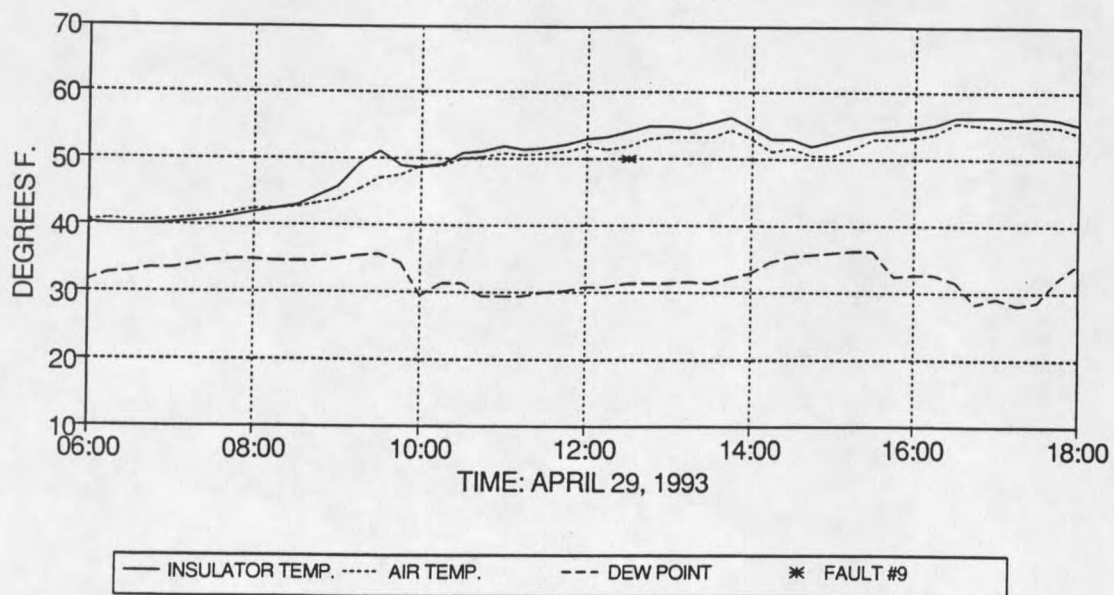


Figure 90

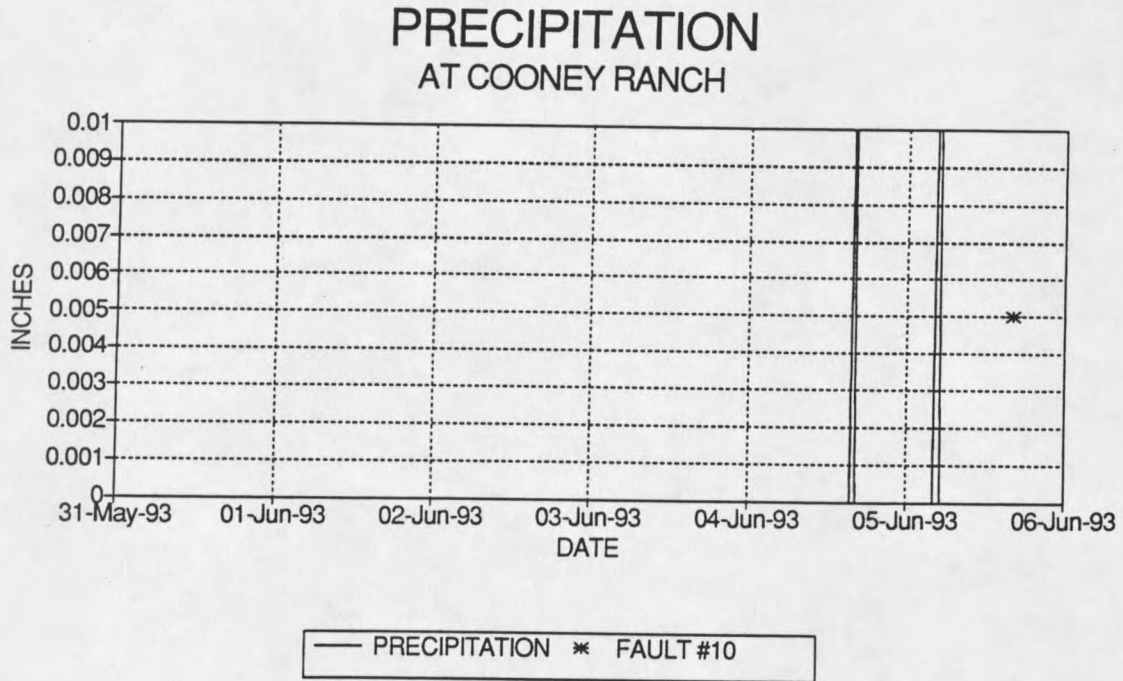


Figure 91

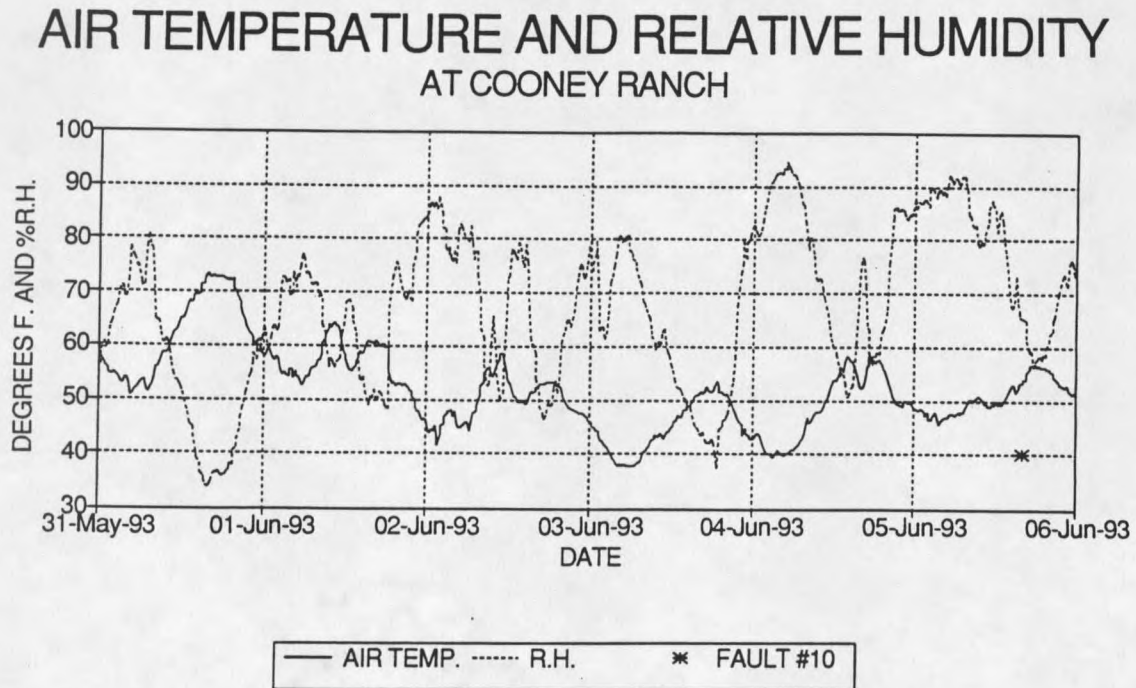


Figure 92

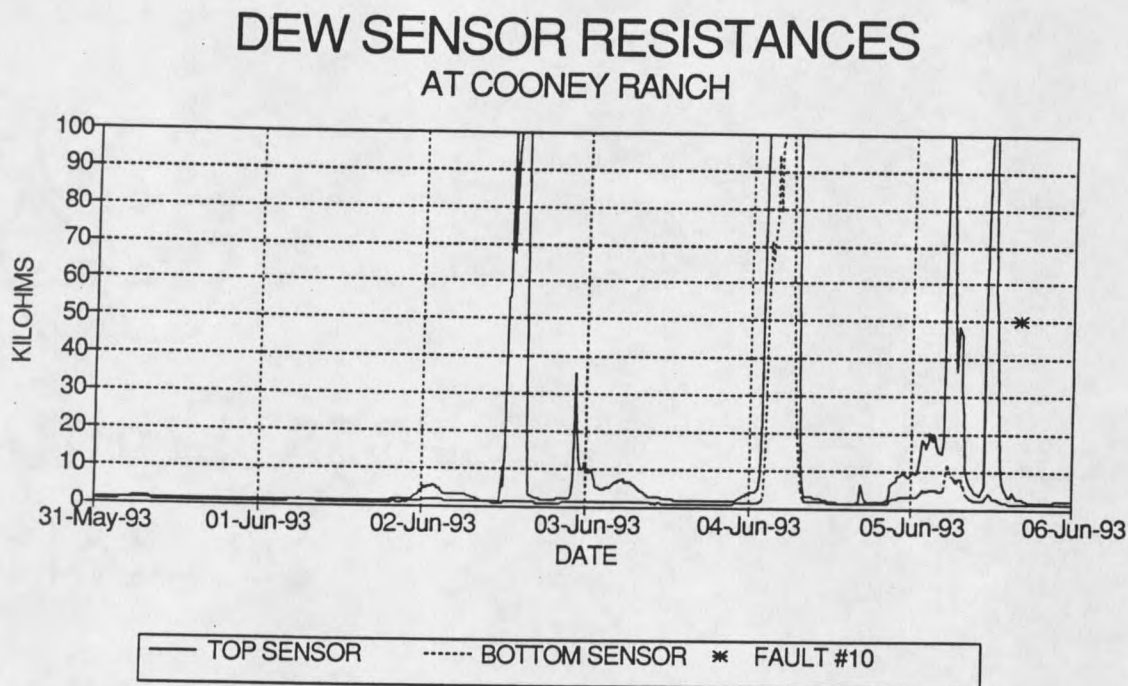


Figure 93

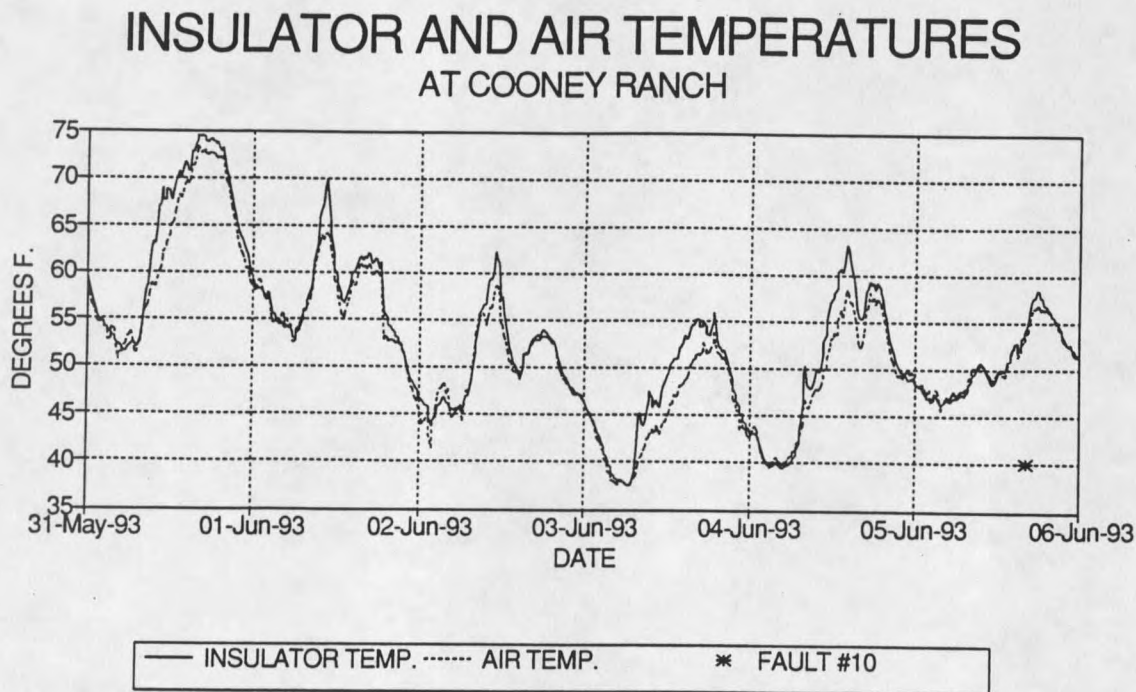


Figure 94

INSULATOR, AIR & DEW POINT TEMPERATURES AT COONEY RANCH

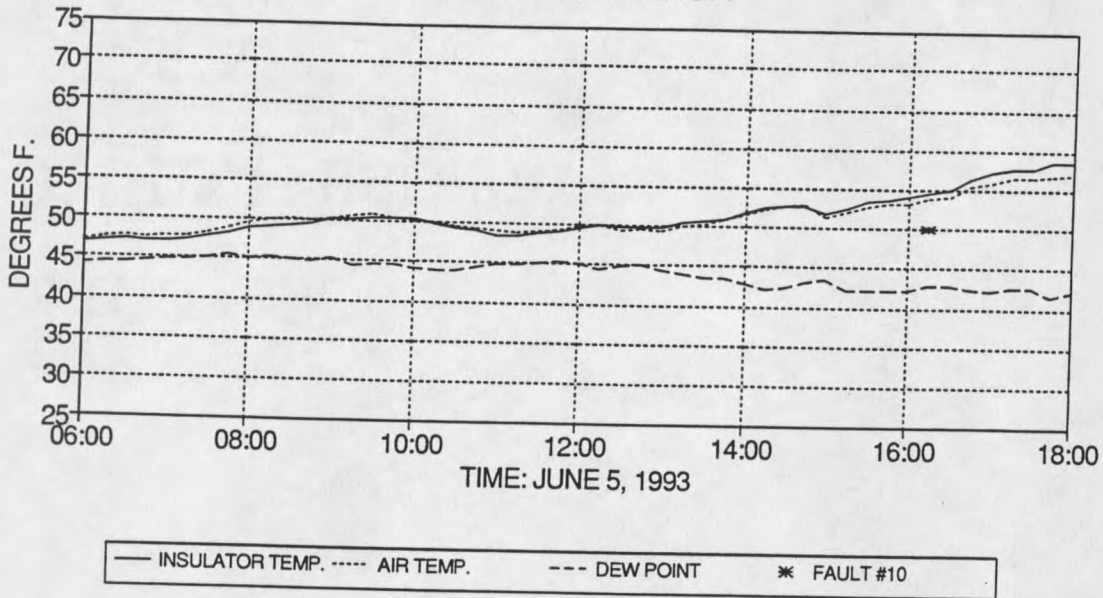


Figure 95

WIND SPEED AT COONEY RANCH

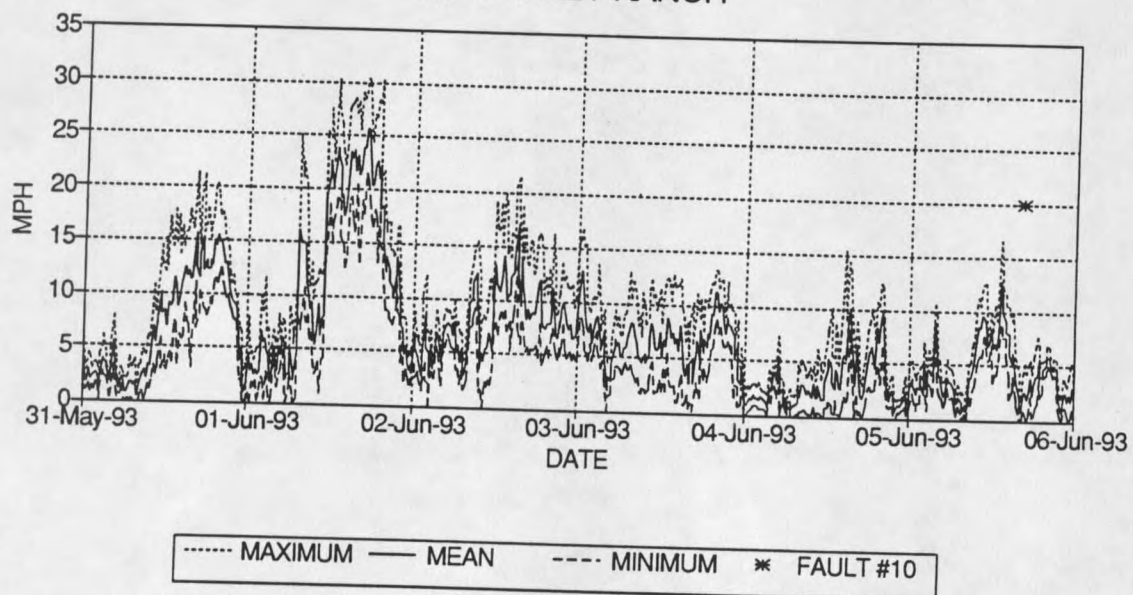


Figure 96

WIND SPEED AT COONEY RANCH

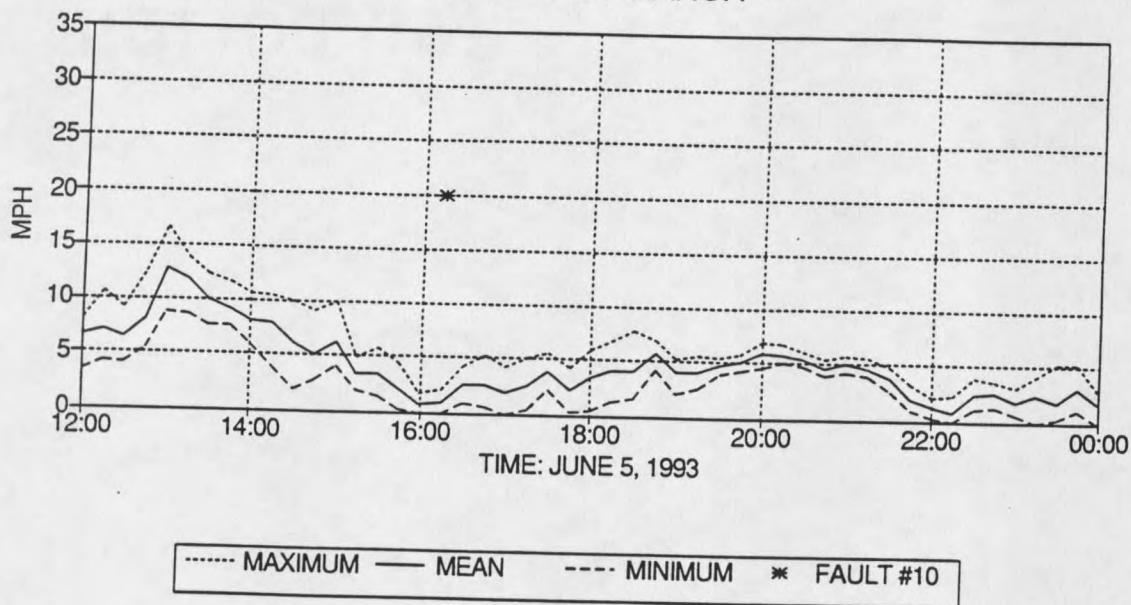


Figure 97

BAROMETRIC PRESSURE AT COONEY RANCH

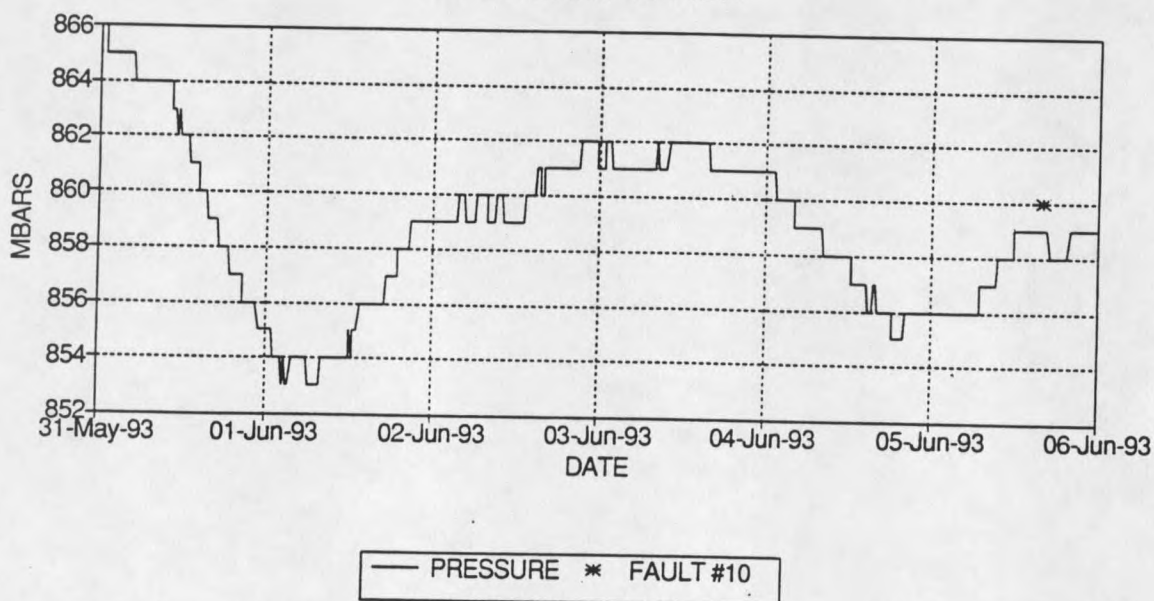


Figure 98

AIR TEMPERATURE AND RELATIVE HUMIDITY AT WHITE RANCH

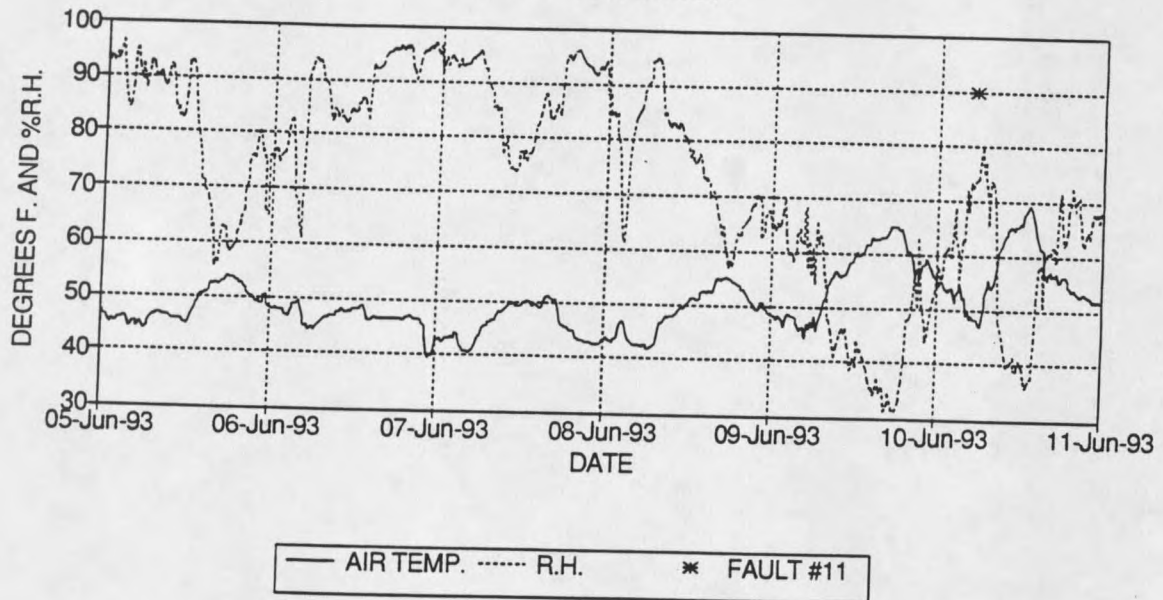


Figure 99

WIND SPEED AT WHITE RANCH

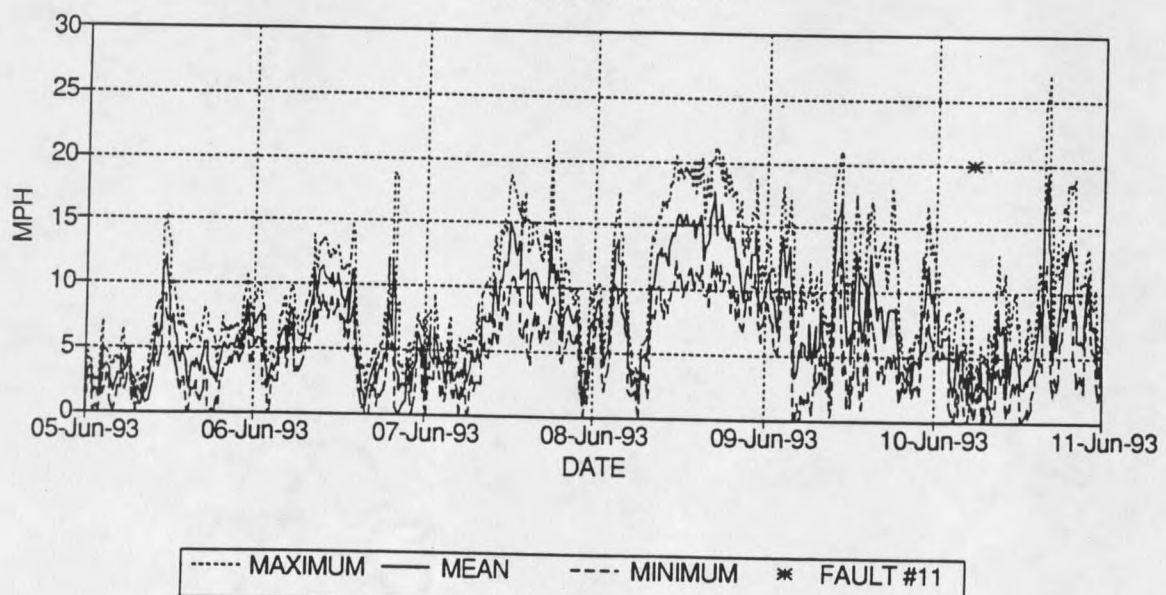


Figure 100

WIND SPEED AT WHITE RANCH

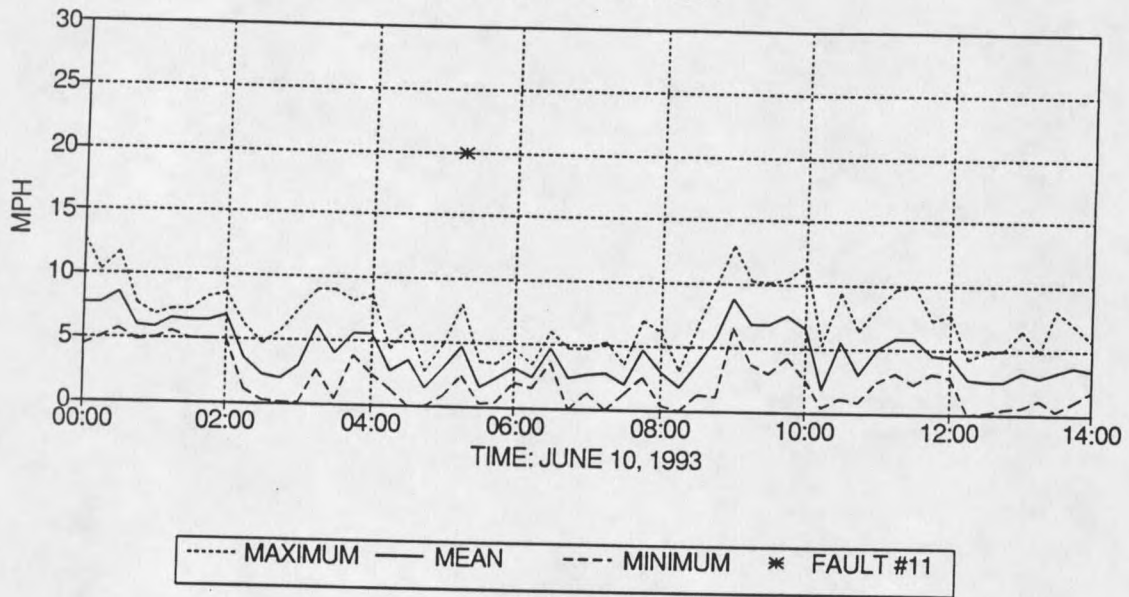


Figure 101

PRECIPITATION AT WHITE RANCH

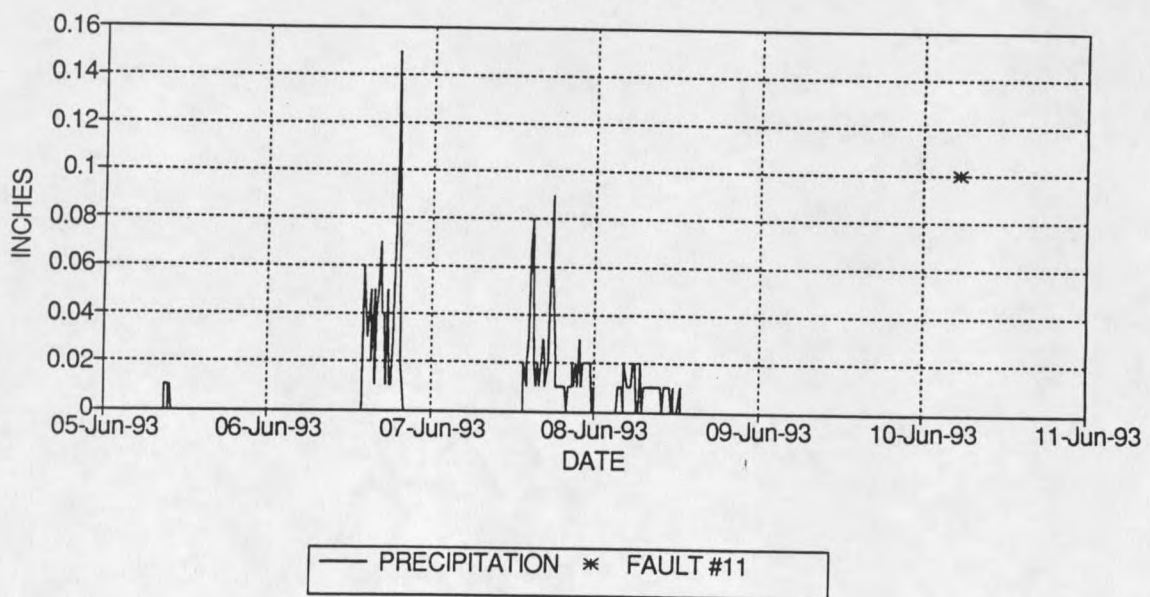


Figure 102

BAROMETRIC PRESSURE AT WHITE RANCH

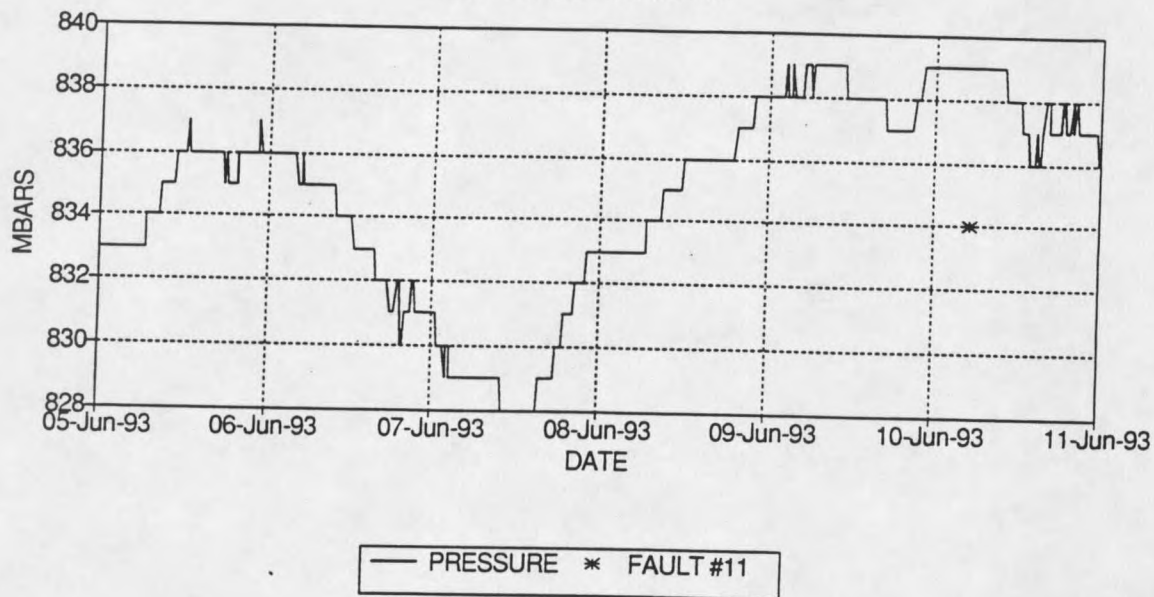


Figure 103

DEW SENSOR RESISTANCES AT WHITE RANCH

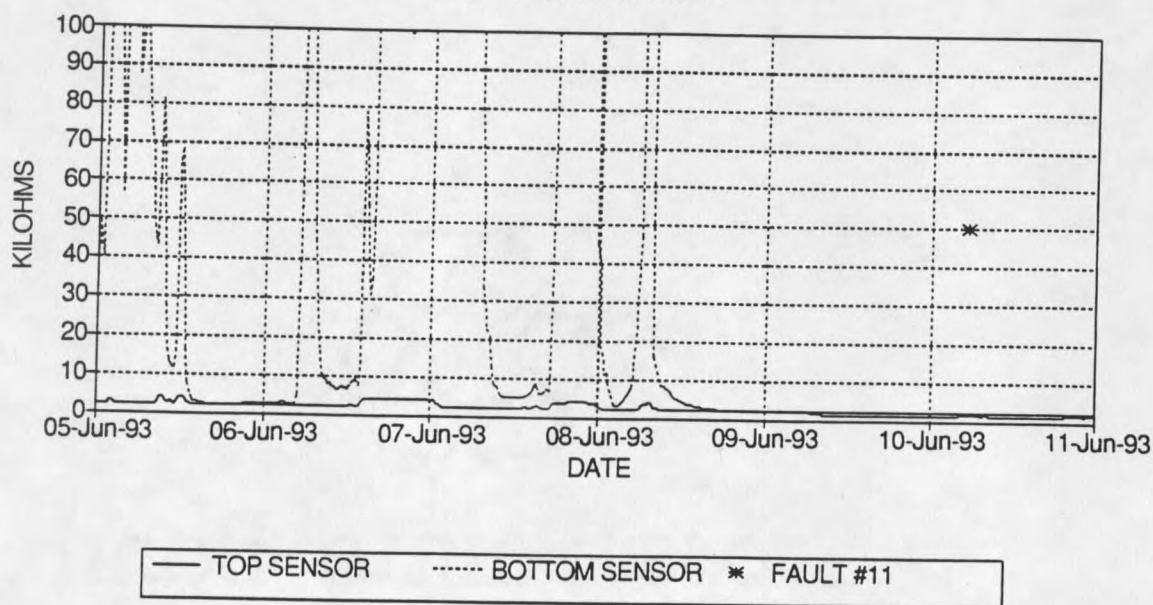


Figure 104

INSULATOR AND AIR TEMPERATURES AT WHITE RANCH

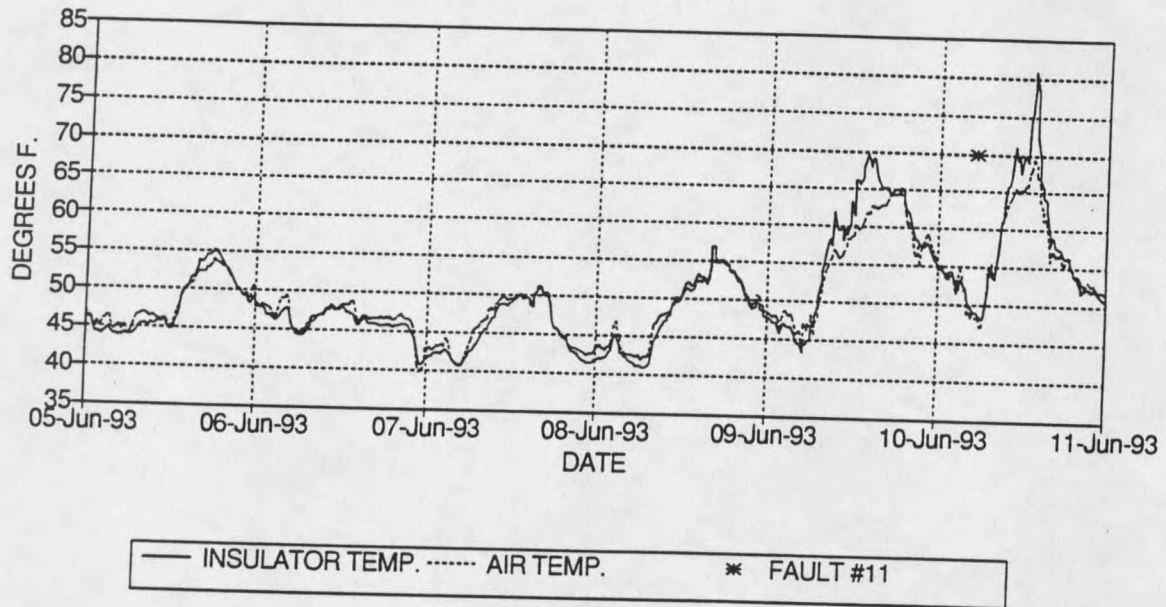


Figure 105

INSULATOR, AIR & DEW POINT TEMPERATURES AT WHITE RANCH

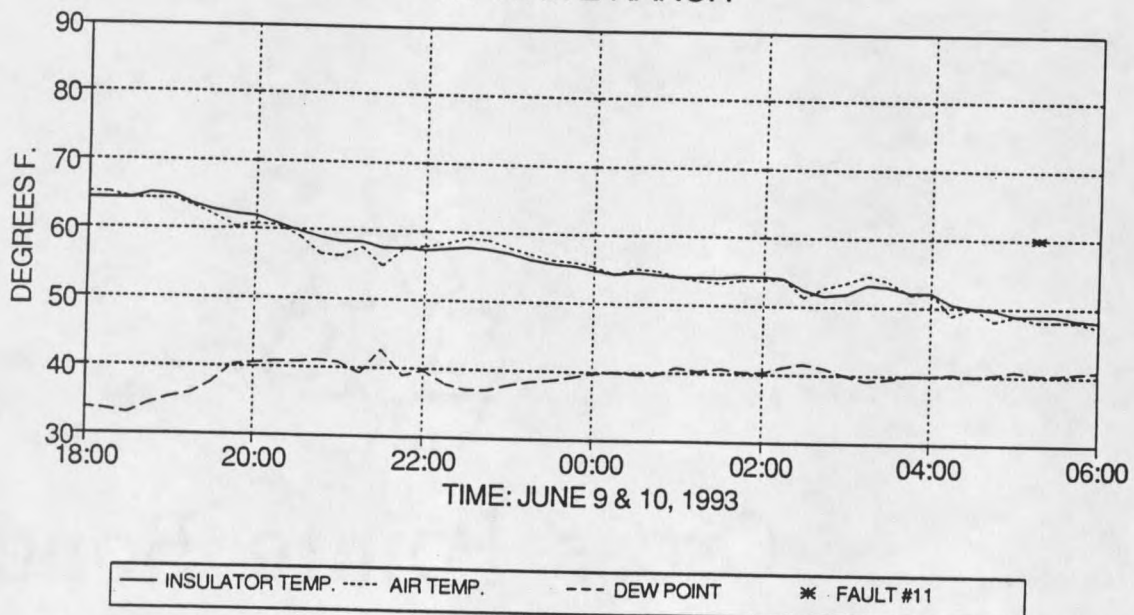


Figure 106

AIR TEMPERATURE AND RELATIVE HUMIDITY AT COONEY RANCH

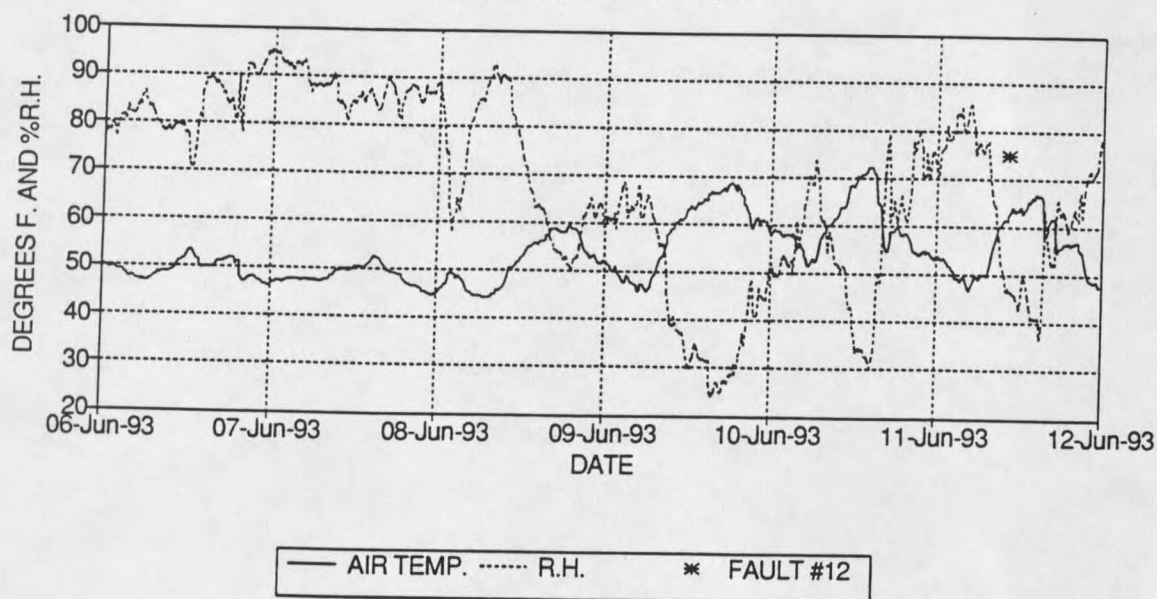


Figure 107

PRECIPITATION AT COONEY RANCH

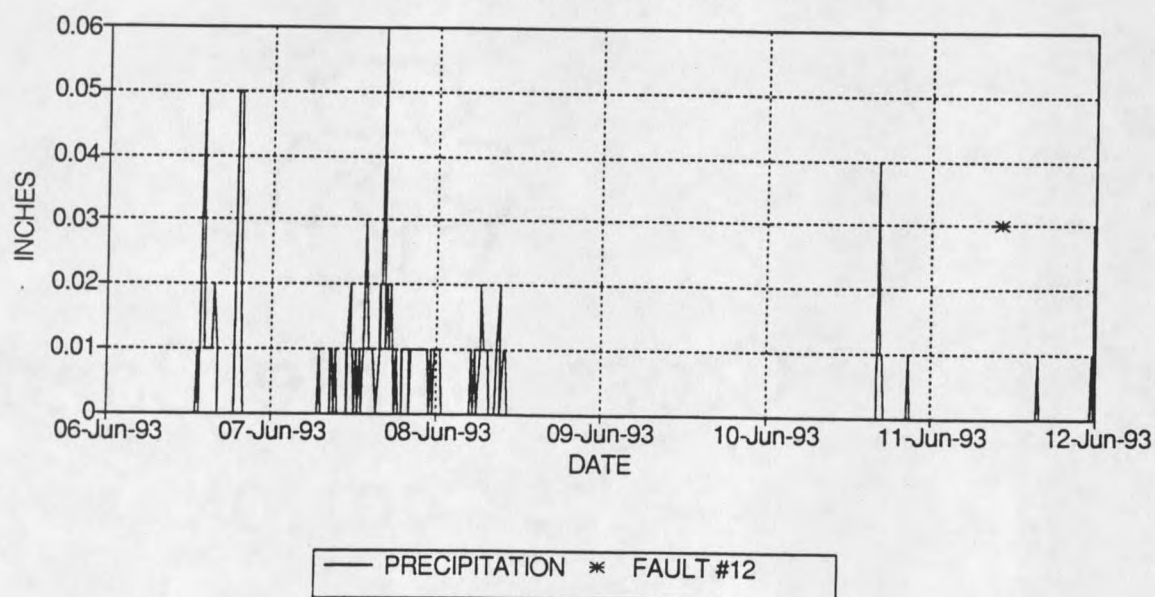


Figure 108

WIND SPEED AT COONEY RANCH

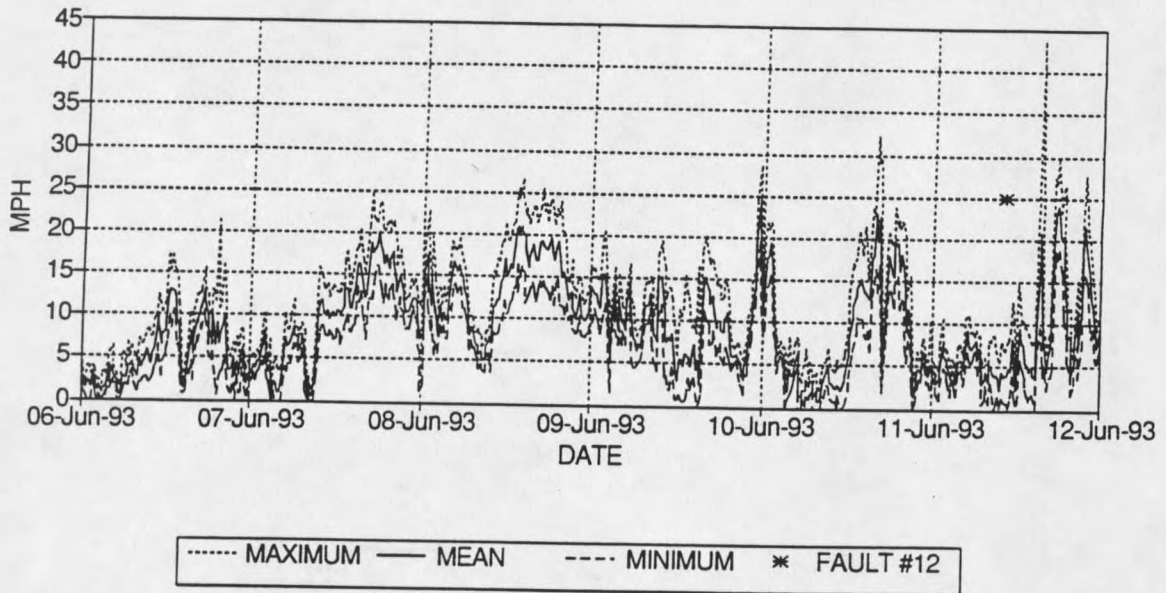


Figure 109

WIND SPEED AT COONEY RANCH

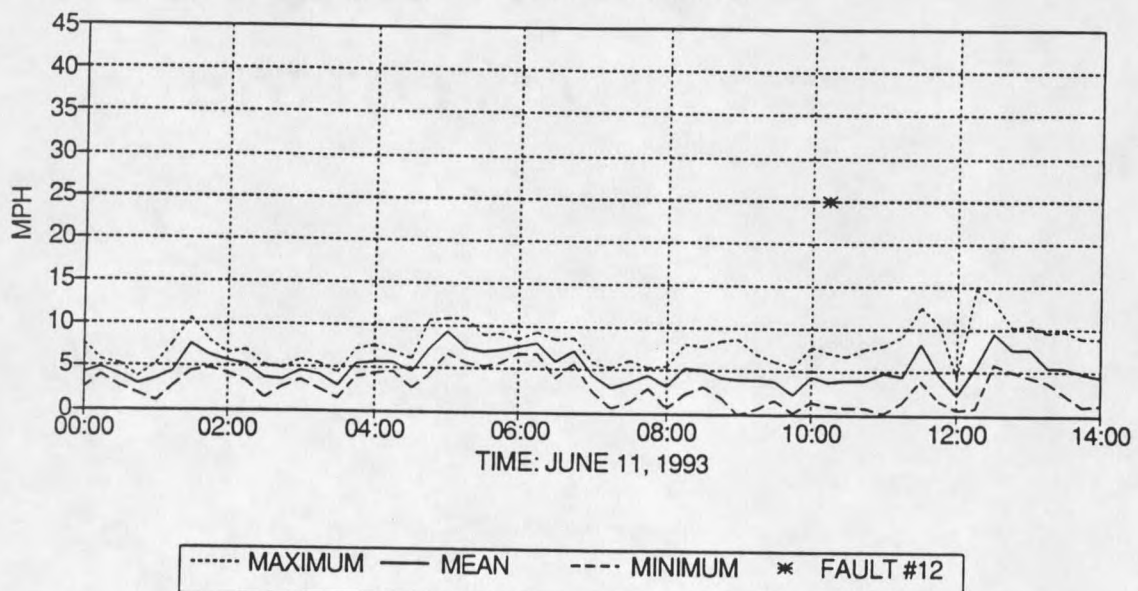


Figure 110

BAROMETRIC PRESSURE AT COONEY RANCH

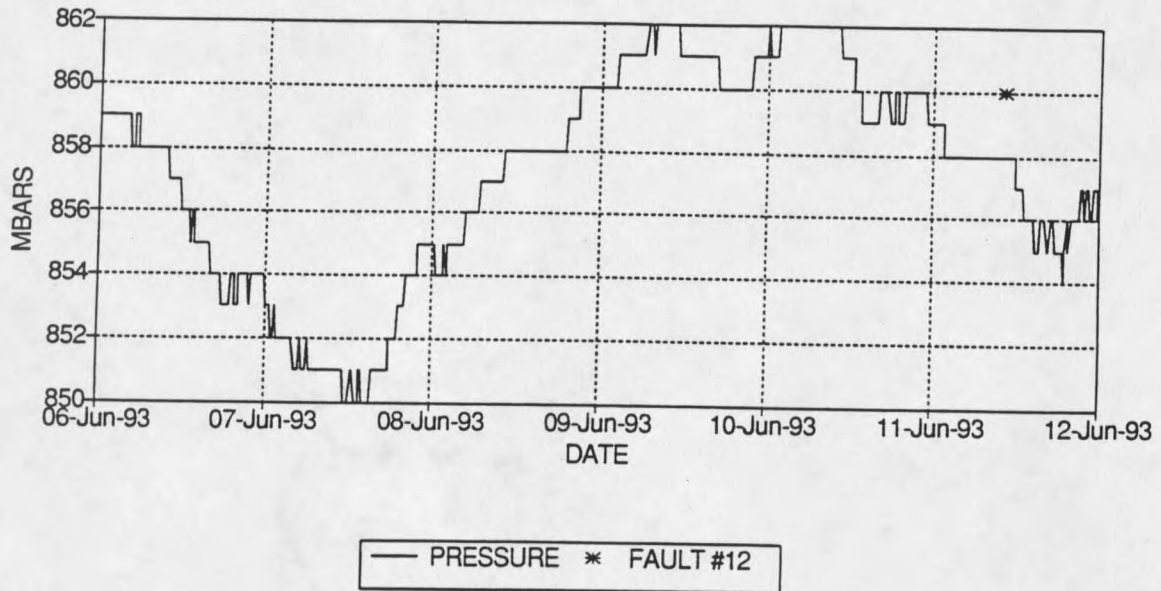


Figure 111

DEW SENSOR RESISTANCES AT COONEY RANCH

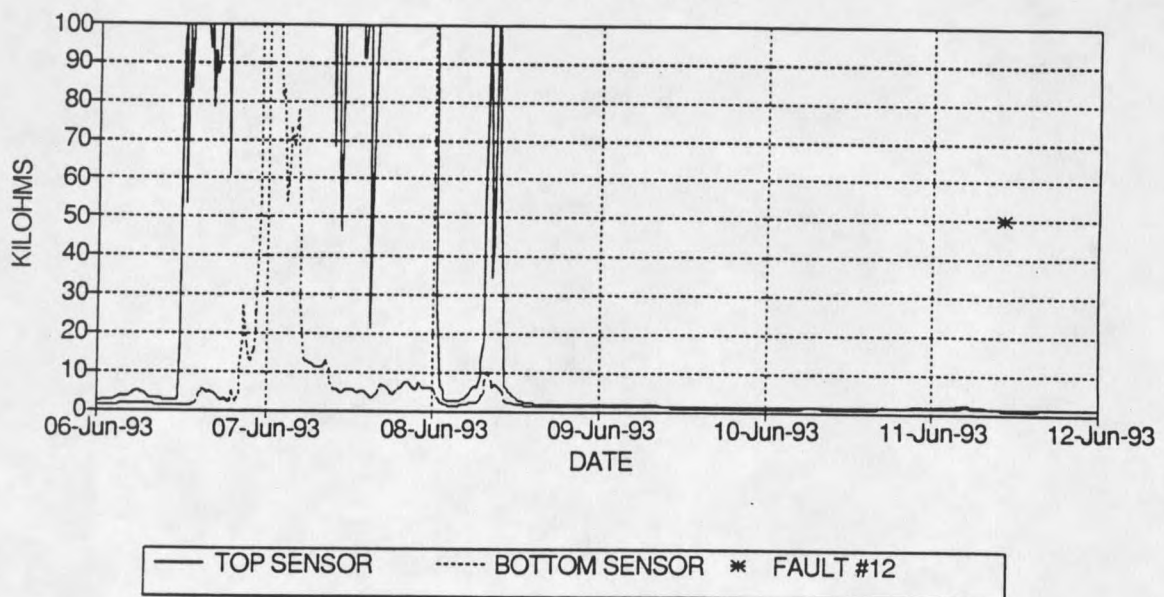


Figure 112

INSULATOR AND AIR TEMPERATURES AT COONEY RANCH

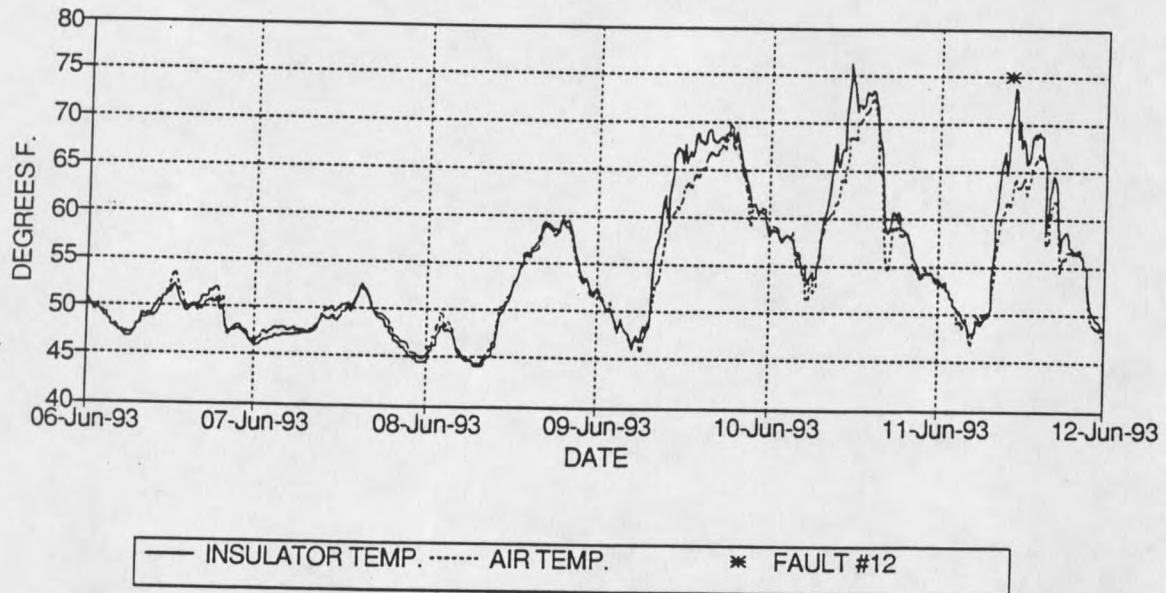


Figure 113

INSULATOR, AIR & DEW POINT TEMPERATURES AT COONEY RANCH

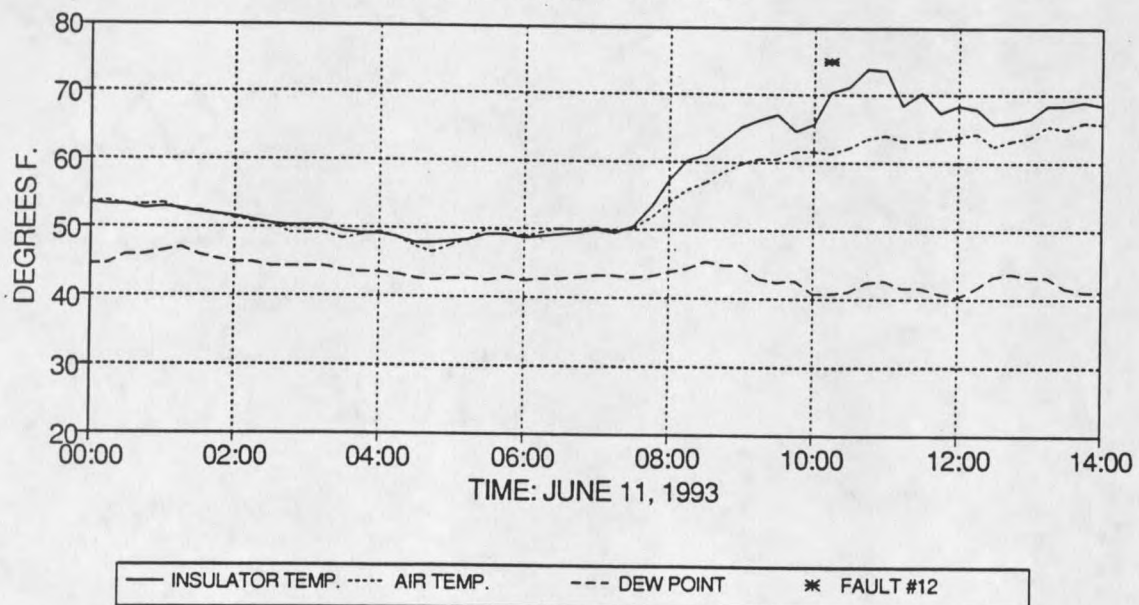


Figure 114

AIR TEMPERATURE AND RELATIVE HUMIDITY AT WHITE RANCH

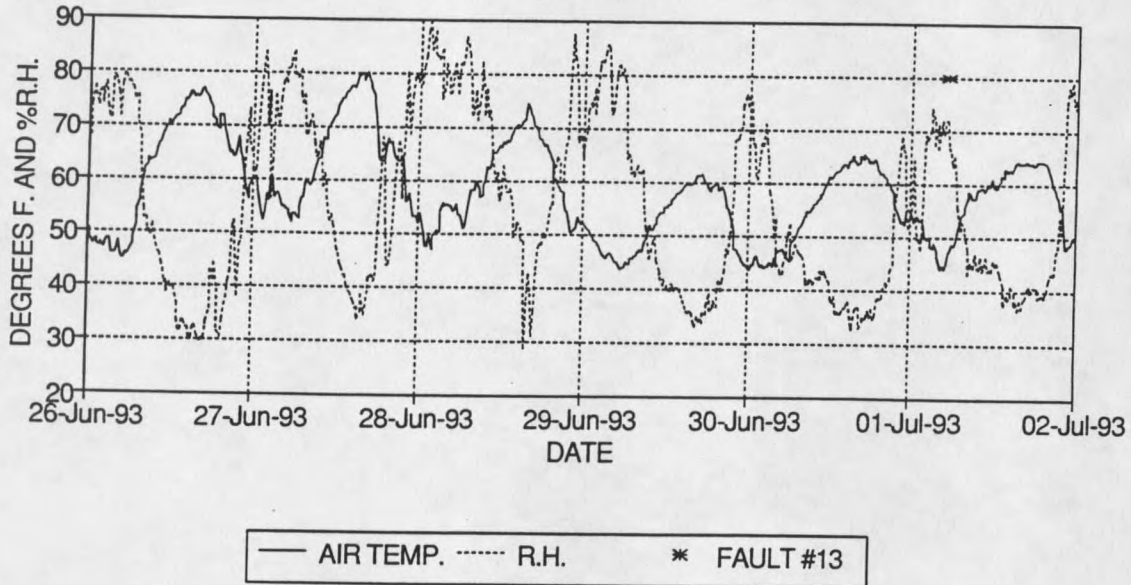


Figure 115

WIND SPEED AT WHITE RANCH

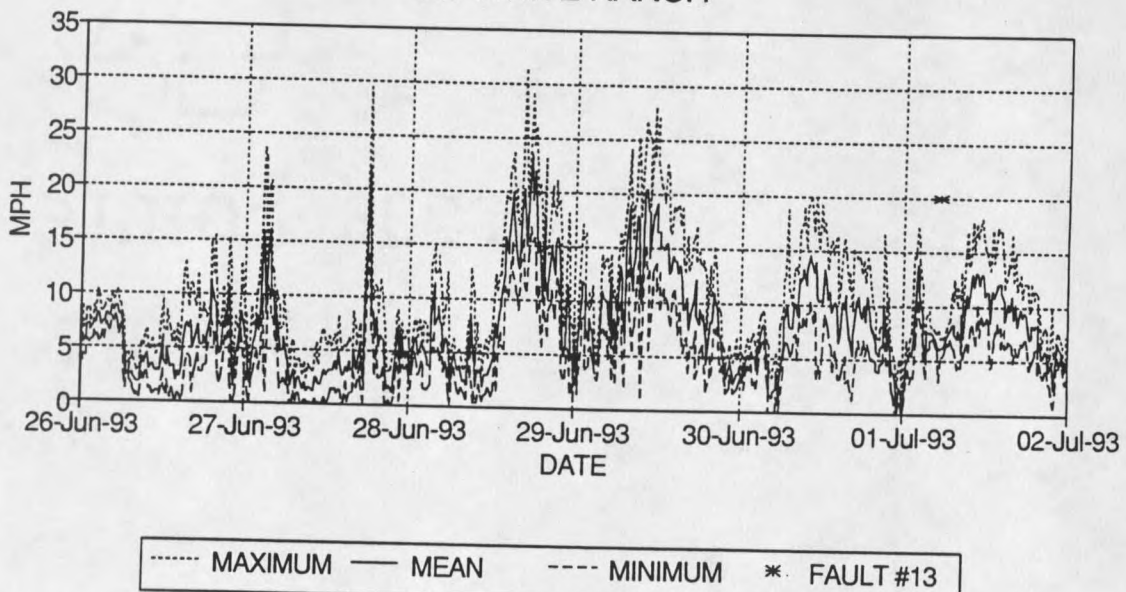
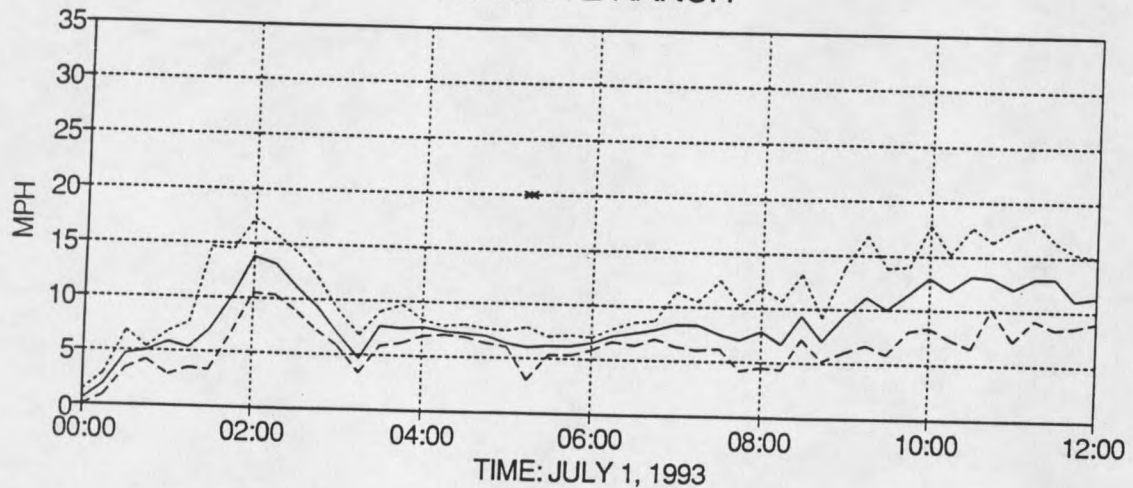
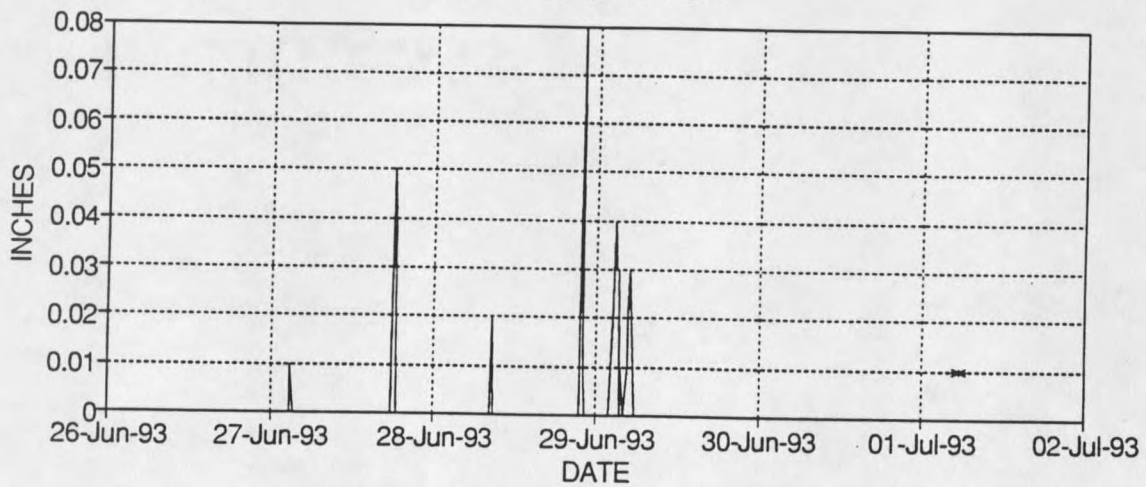


Figure 116
WIND SPEED
AT WHITE RANCH



----- MAXIMUM — MEAN ---- MINIMUM * FAULT #13

Figure 117
PRECIPITATION
AT WHITE RANCH



— PRECIPITATION * FAULT #13

Figure 118
INSULATOR AND AIR TEMPERATURES
AT WHITE RANCH

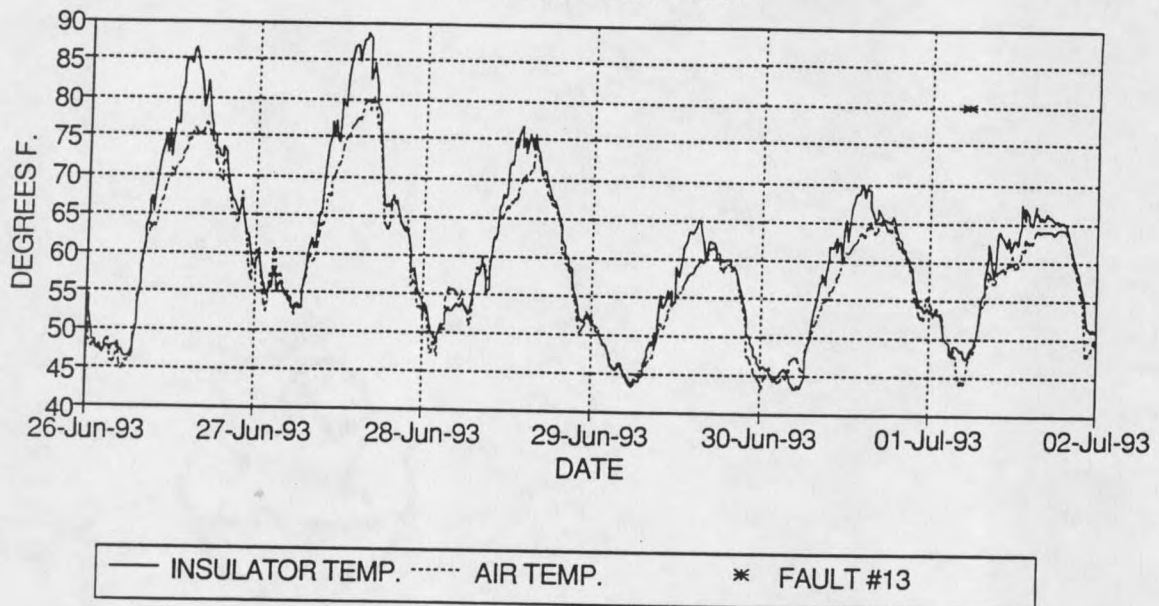


Figure 119
INSULATOR, AIR & DEW POINT TEMPERATURES
AT WHITE RANCH

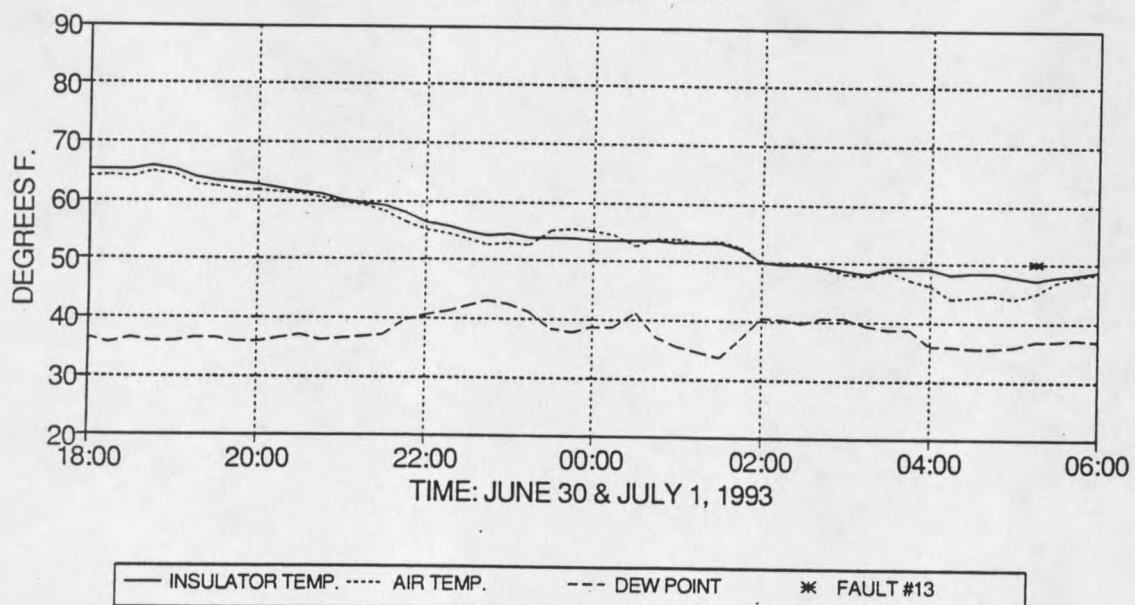


Figure 120
BAROMETRIC PRESSURE
AT WHITE RANCH

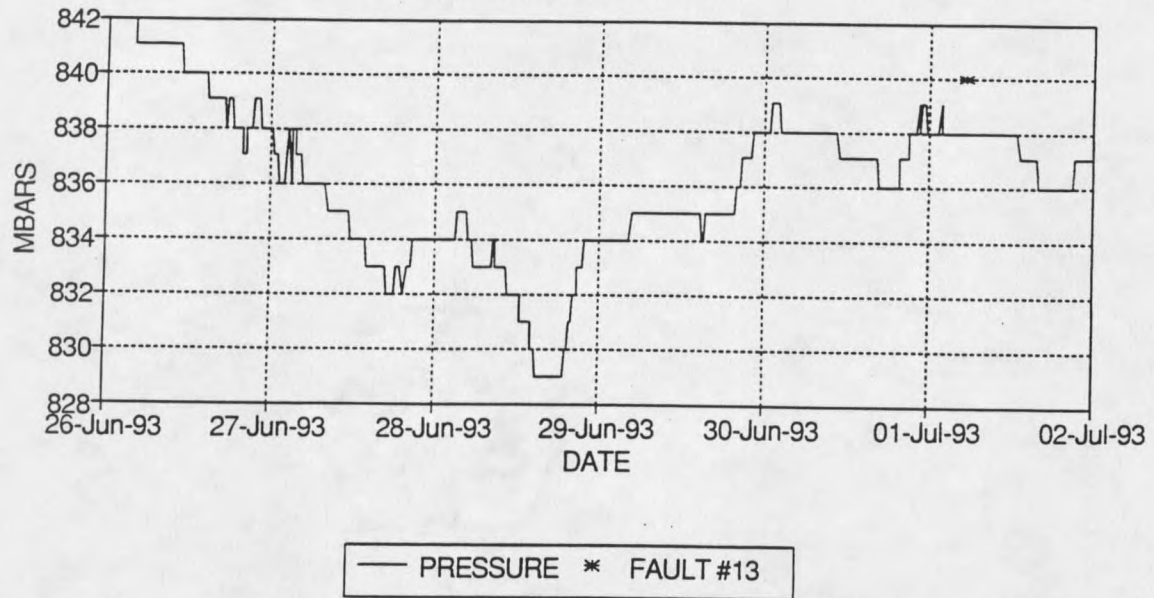


Figure 121
DEW SENSOR RESISTANCES
AT WHITE RANCH

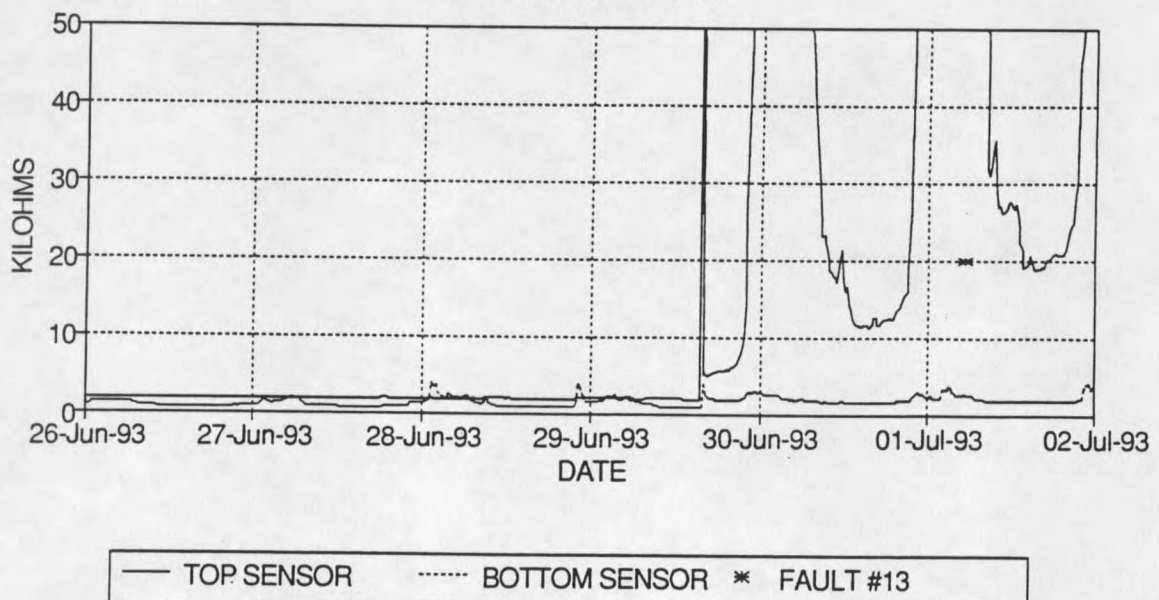


Figure 122

AIR TEMPERATURE AND RELATIVE HUMIDITY AT WHITE RANCH

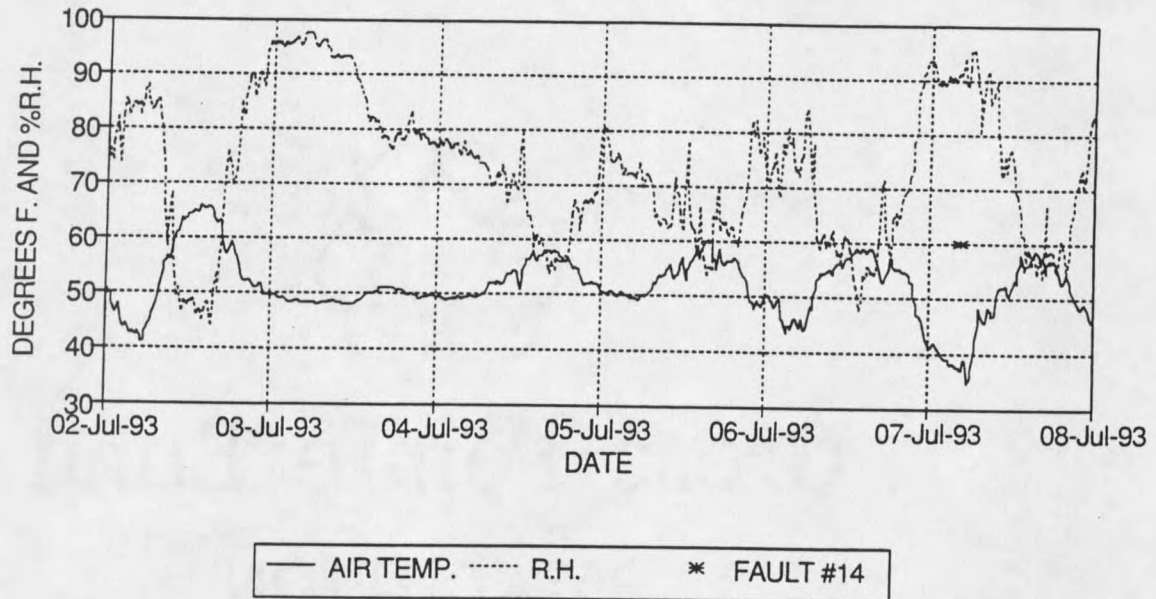


Figure 123

PRECIPITATION AT WHITE RANCH

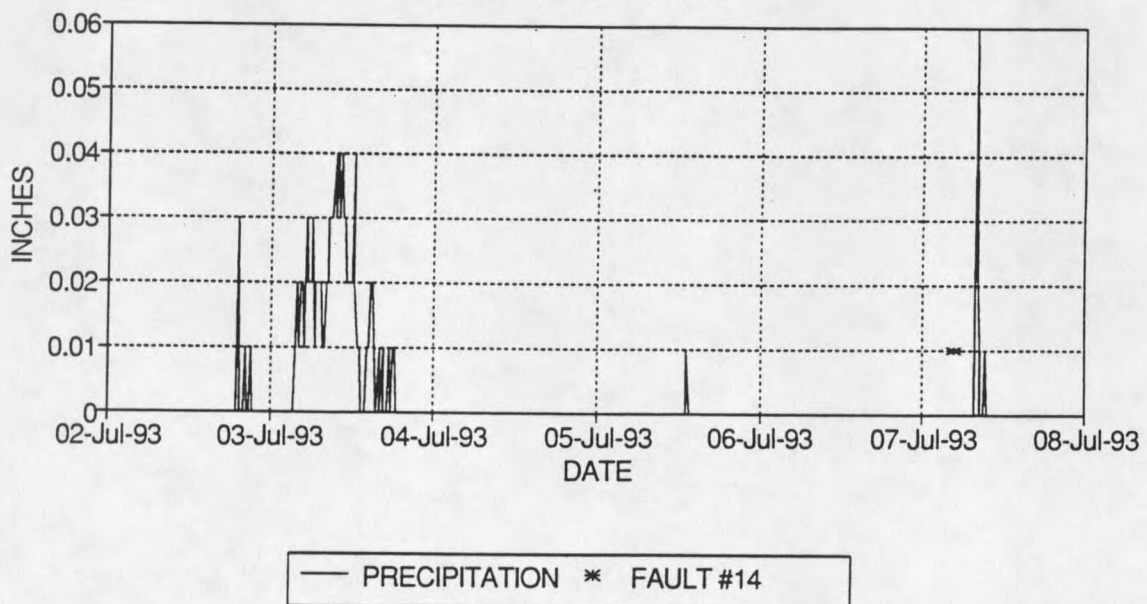


Figure 124
WIND SPEED
AT WHITE RANCH

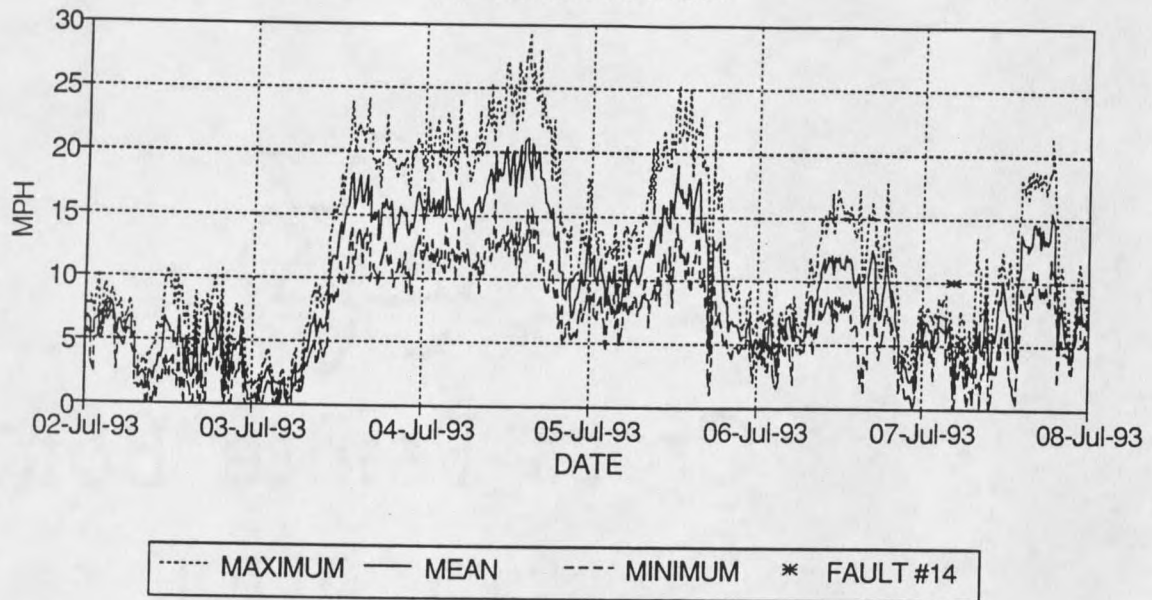


Figure 125
WIND SPEED
AT WHITE RANCH

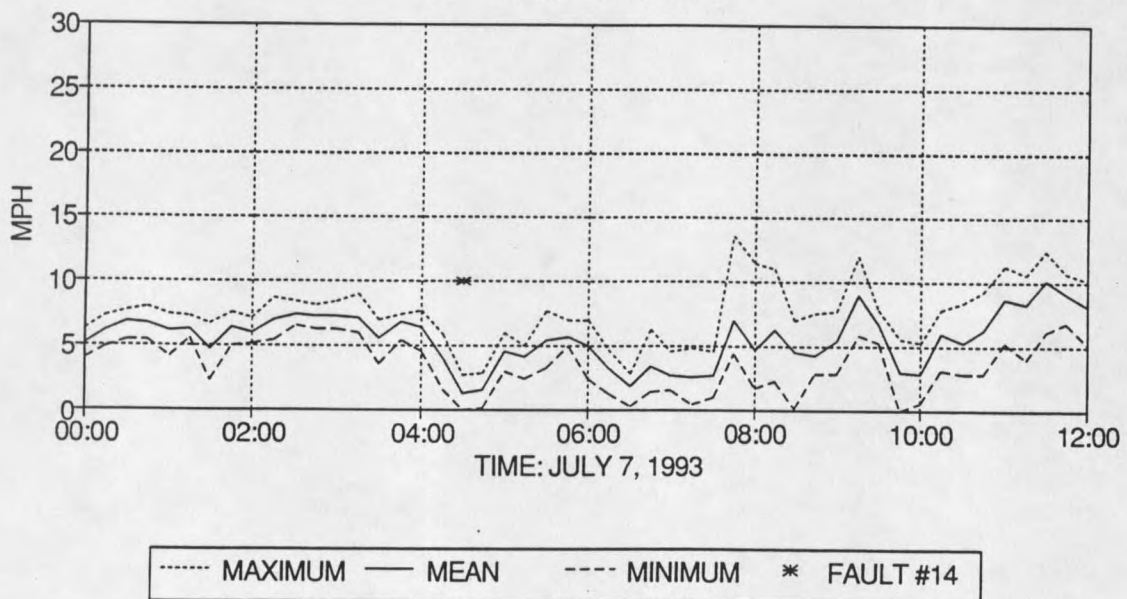


Figure 126

DEW SENSOR RESISTANCES AT WHITE RANCH

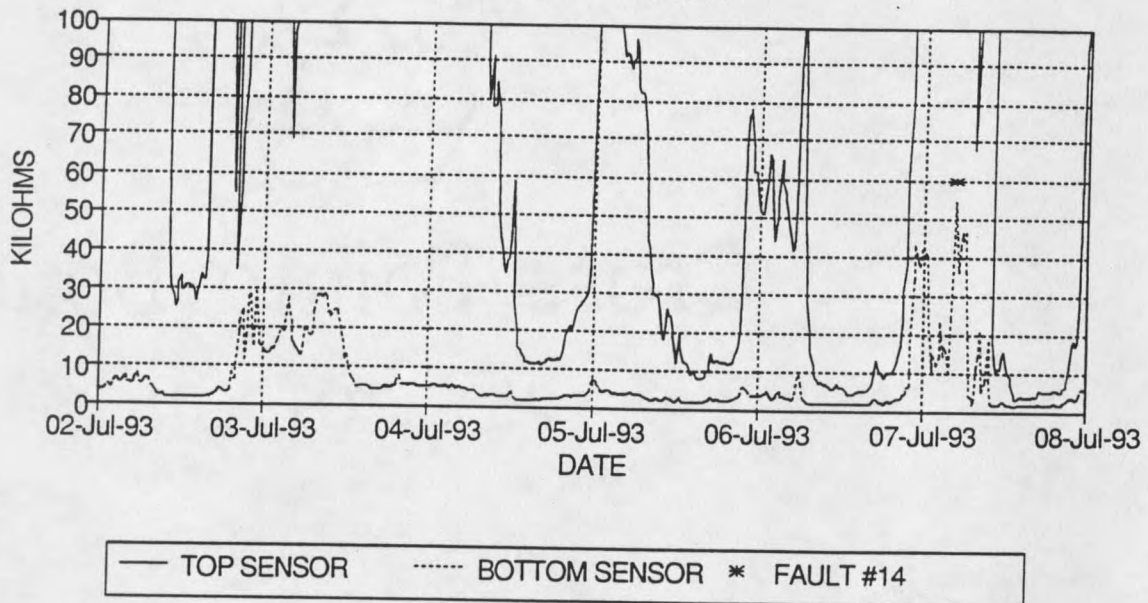


Figure 127

INSULATOR AND AIR TEMPERATURES AT WHITE RANCH

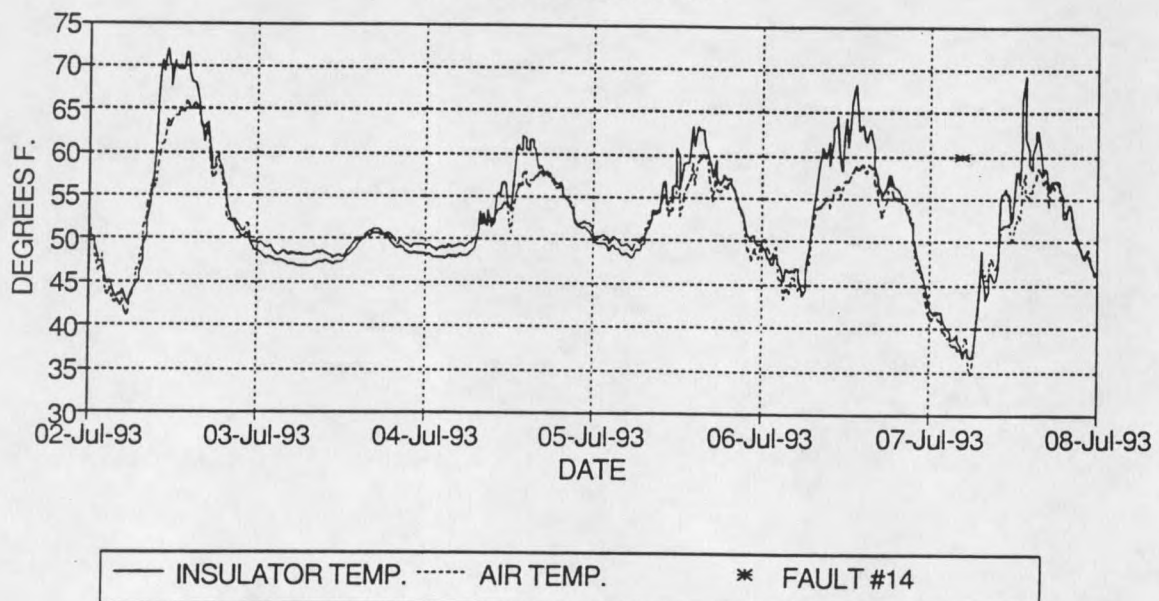


Figure 128
INSULATOR, AIR & DEW POINT TEMPERATURES
AT WHITE RANCH

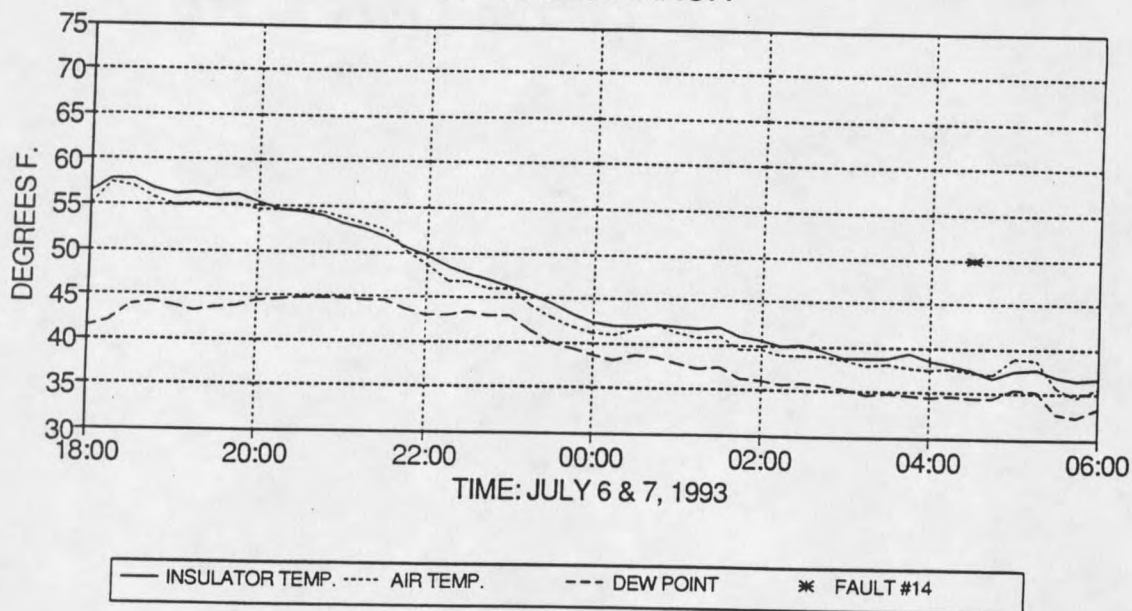


Figure 129
BAROMETRIC PRESSURE
AT WHITE RANCH

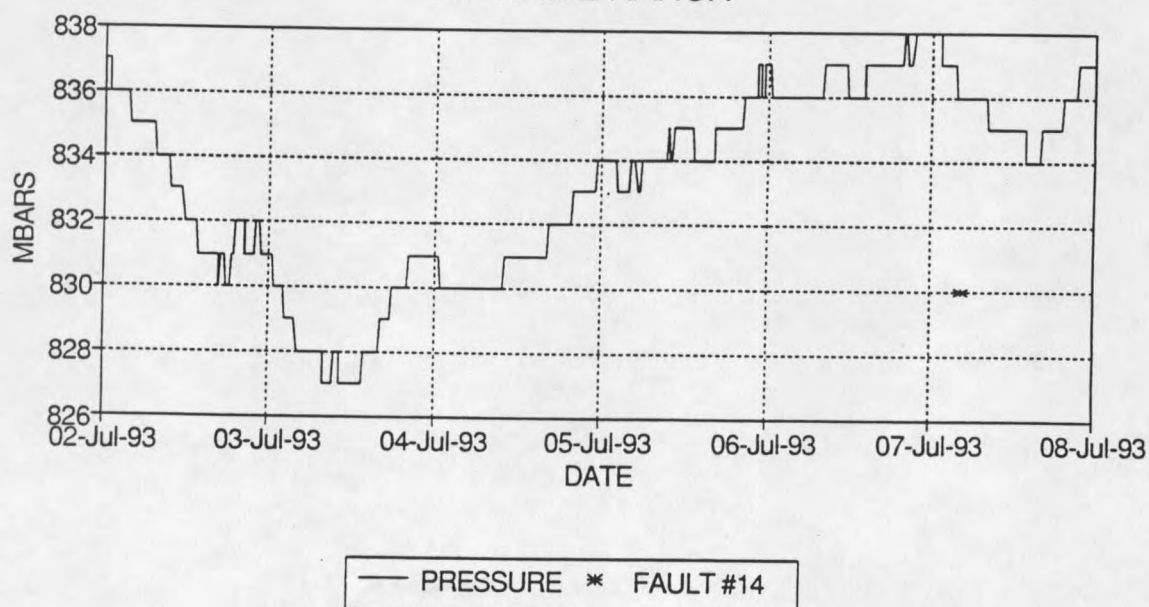


Figure 130

AIR TEMPERATURE AND RELATIVE HUMIDITY AT GALT RANCH

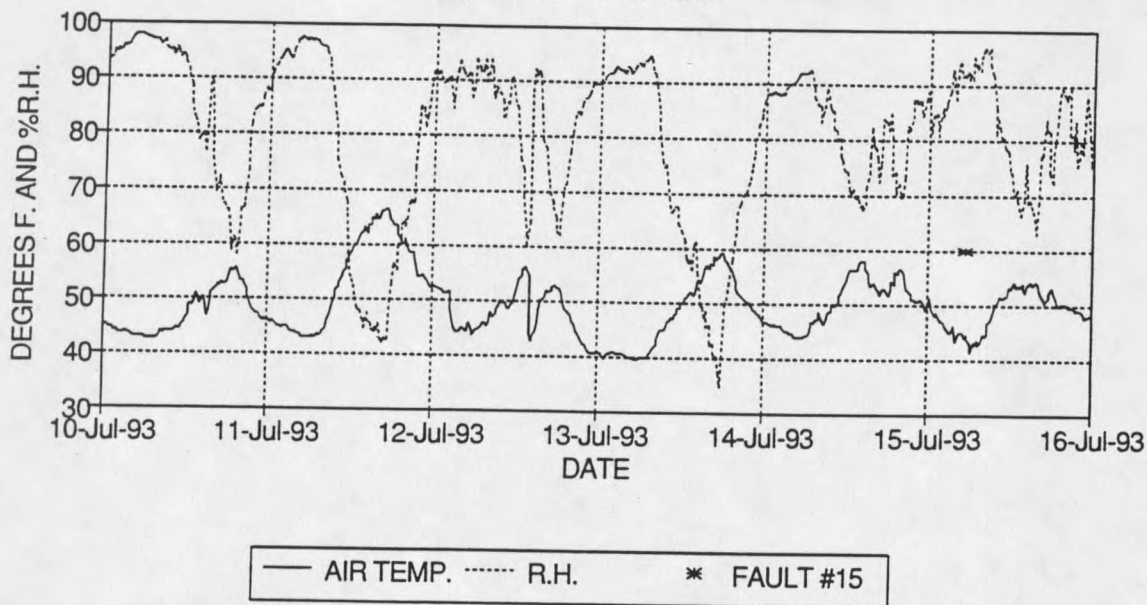


Figure 131

AIR TEMPERATURE AND RELATIVE HUMIDITY AT ROSTAD RANCH

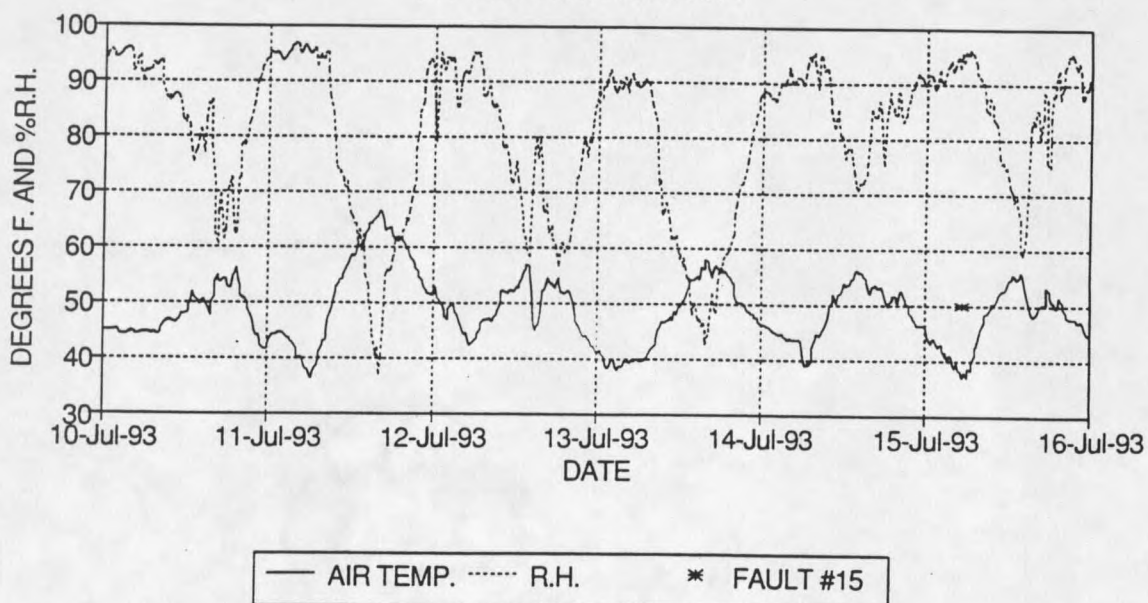
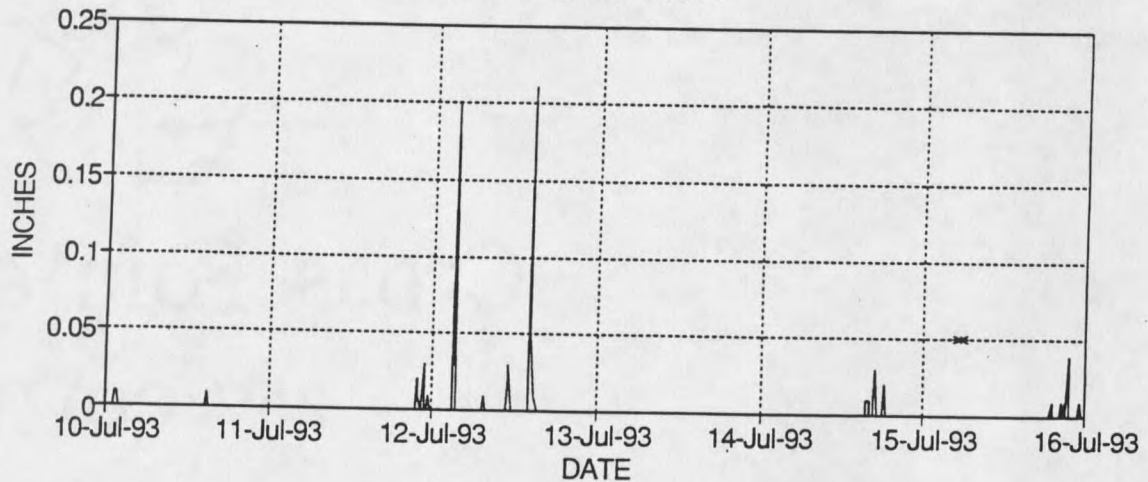


Figure 132

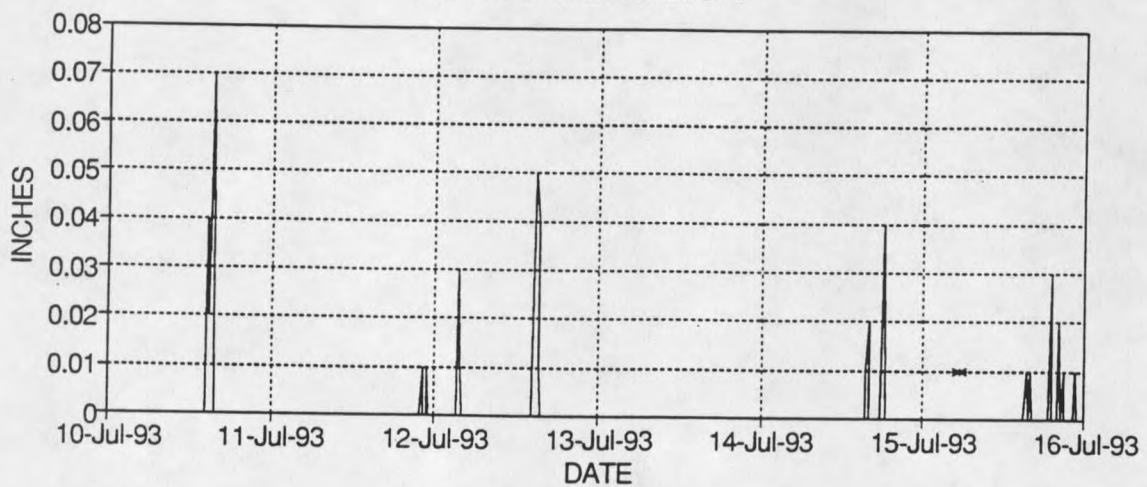
PRECIPITATION AT GALT RANCH



— PRECIPITATION * FAULT #15

Figure 133

PRECIPITATION AT ROSTAD RANCH



— PRECIPITATION * FAULT #15

Figure 134
WIND SPEED
AT GALT RANCH

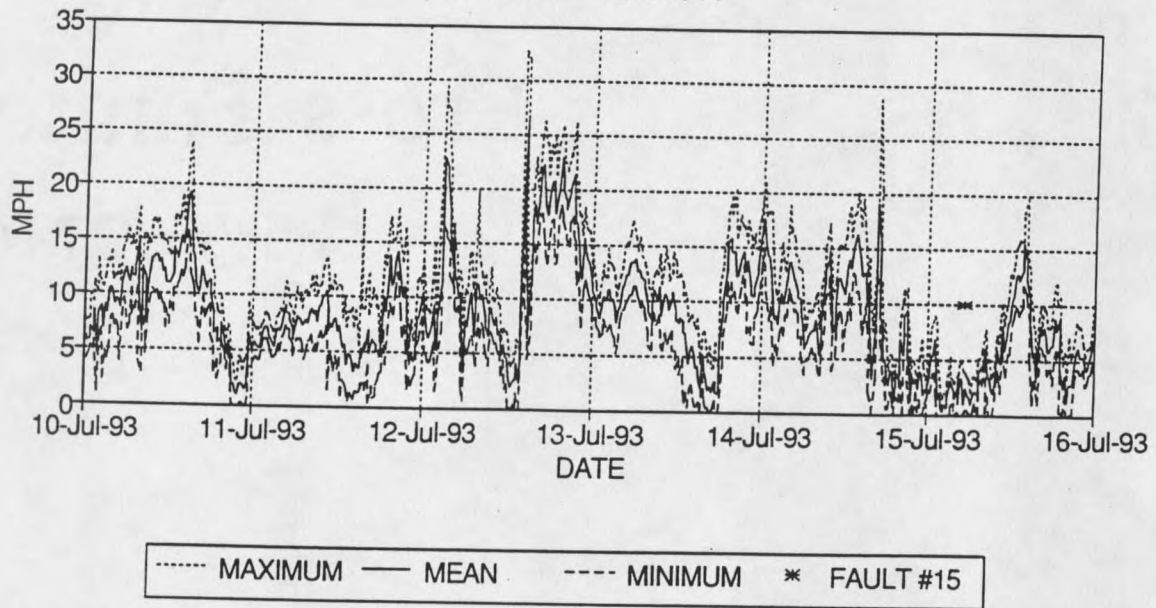


Figure 135
WIND SPEED
AT GALT RANCH

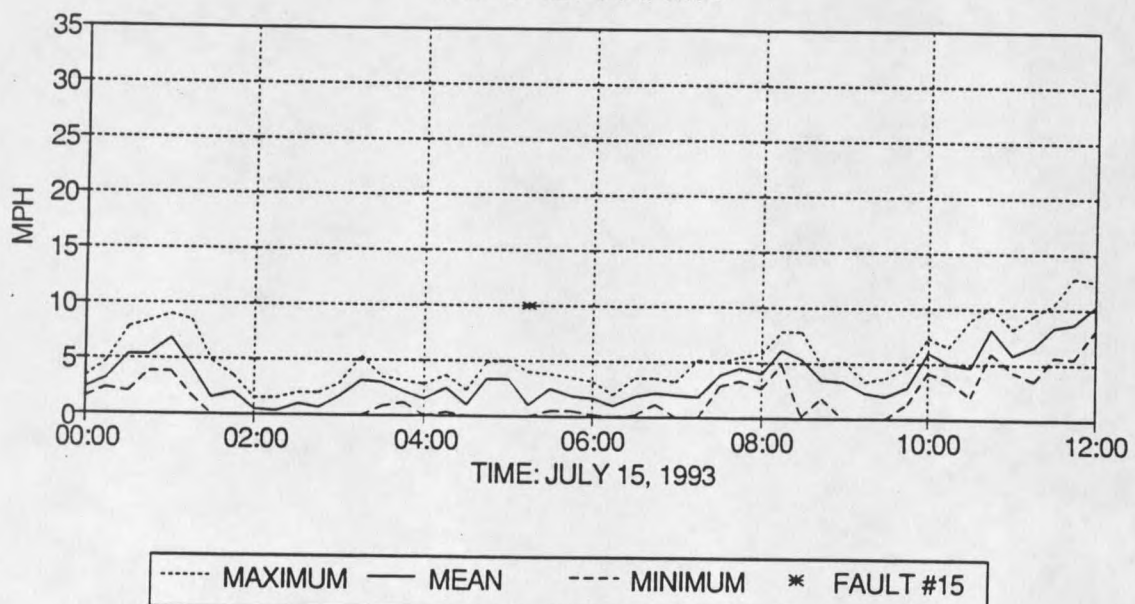


Figure 136

WIND SPEED AT ROSTAD RANCH

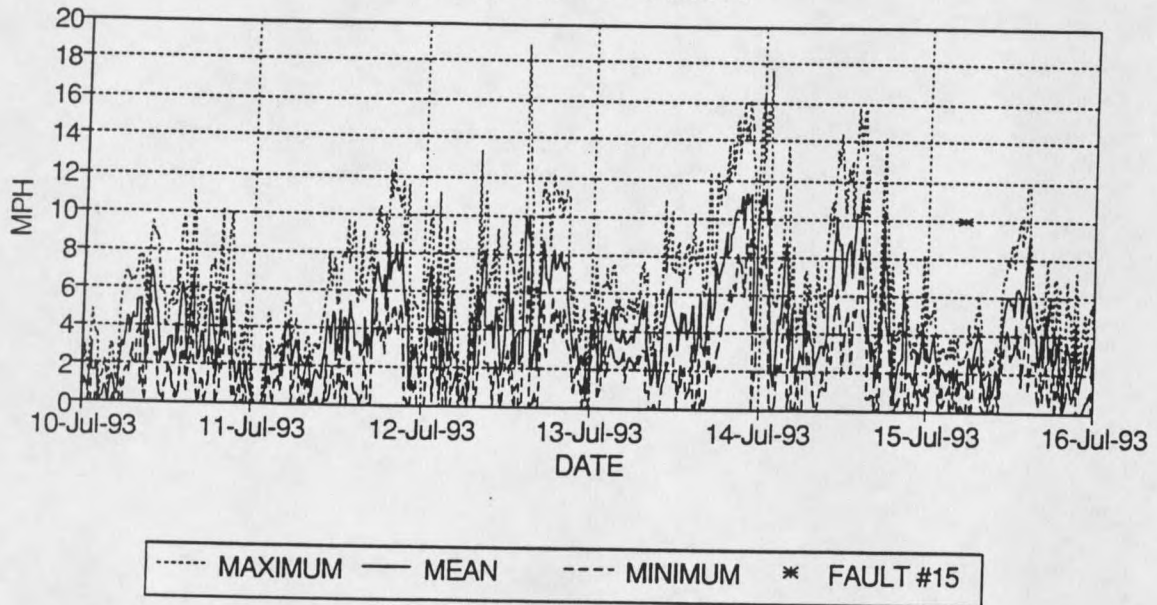


Figure 137

WIND SPEED AT ROSTAD RANCH

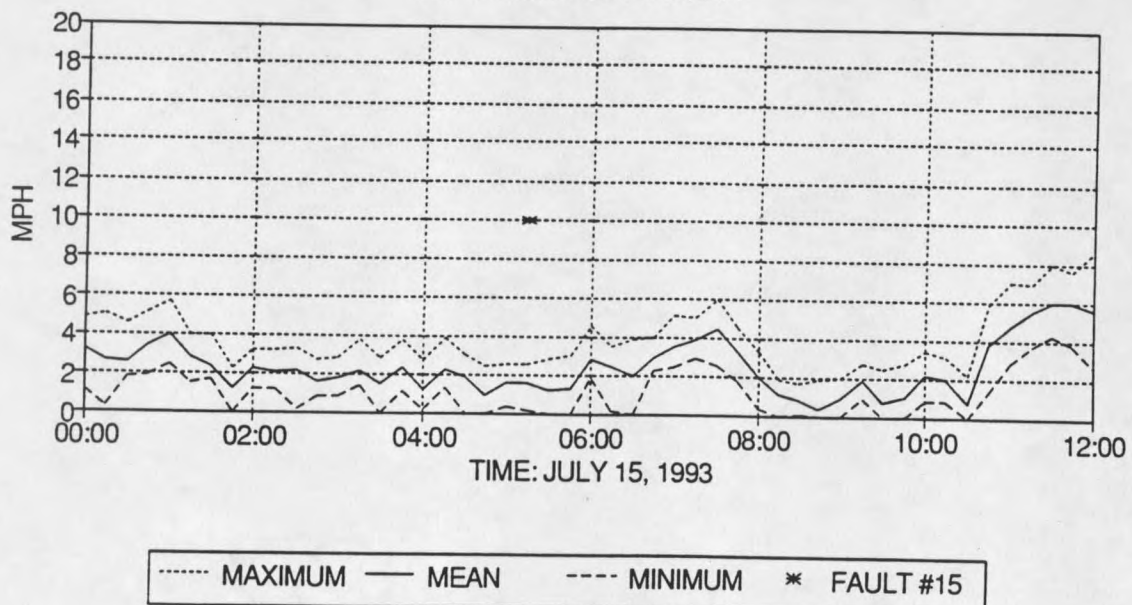


Figure 138

DEW SENSOR RESISTANCES AT GALT RANCH

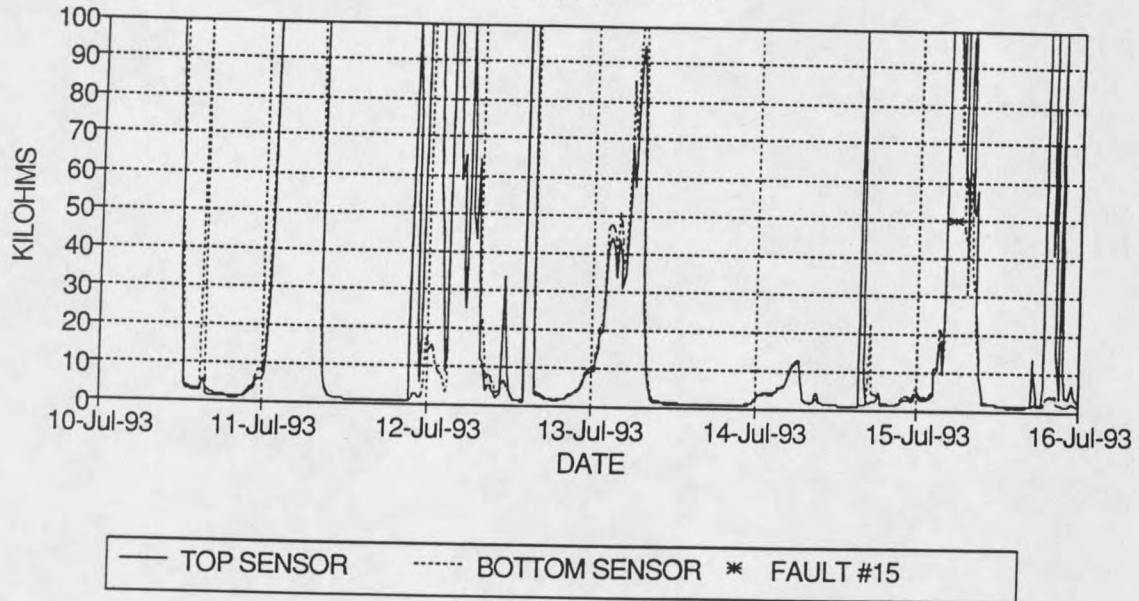


Figure 139

DEW SENSOR RESISTANCES AT ROSTAD RANCH

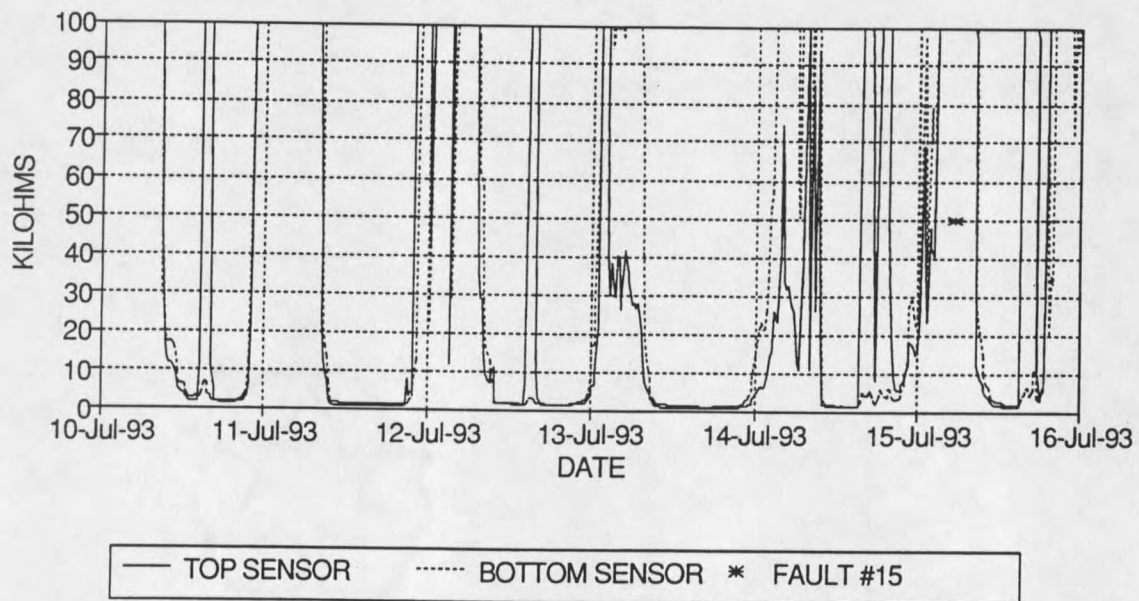


Figure 140

INSULATOR AND AIR TEMPERATURES AT GALT RANCH

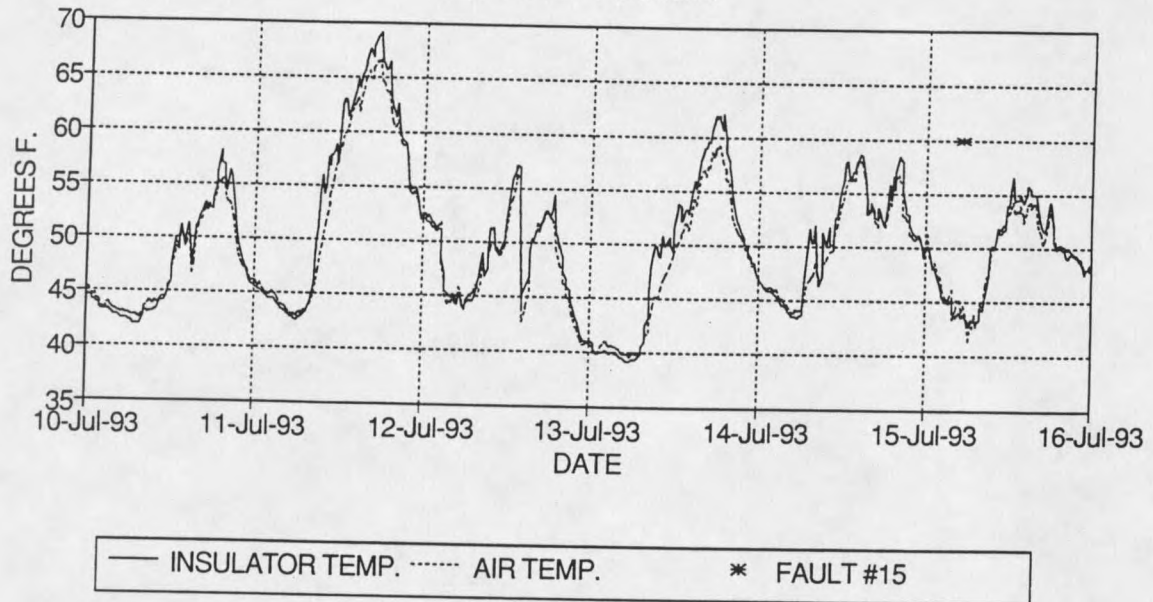


Figure 141

INSULATOR, AIR & DEW POINT TEMPERATURES AT GALT RANCH

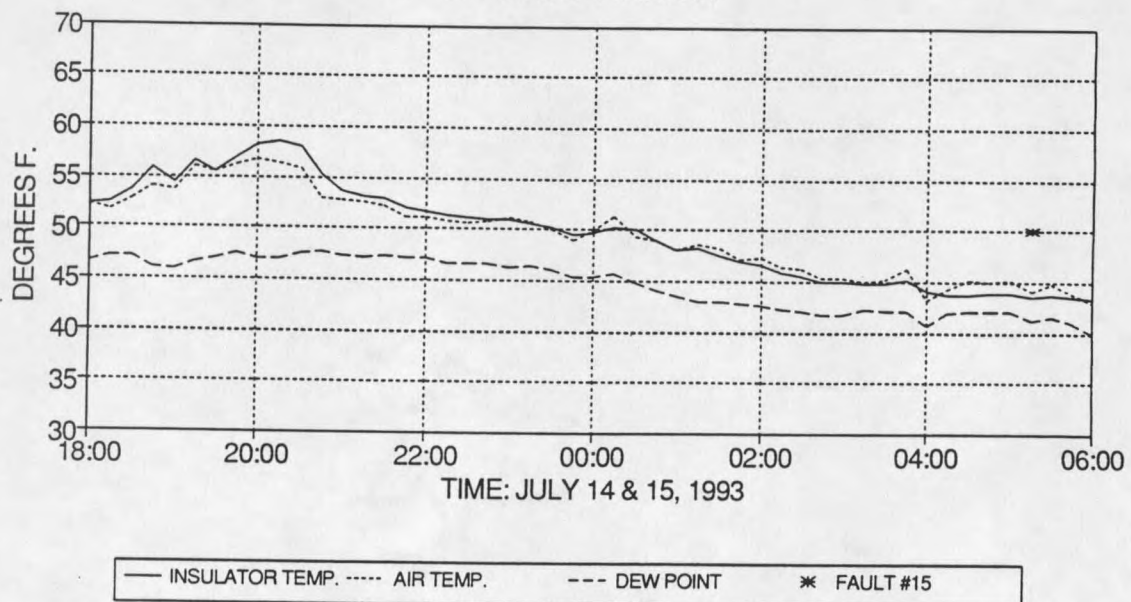


Figure 142

INSULATOR AND AIR TEMPERATURES AT ROSTAD RANCH

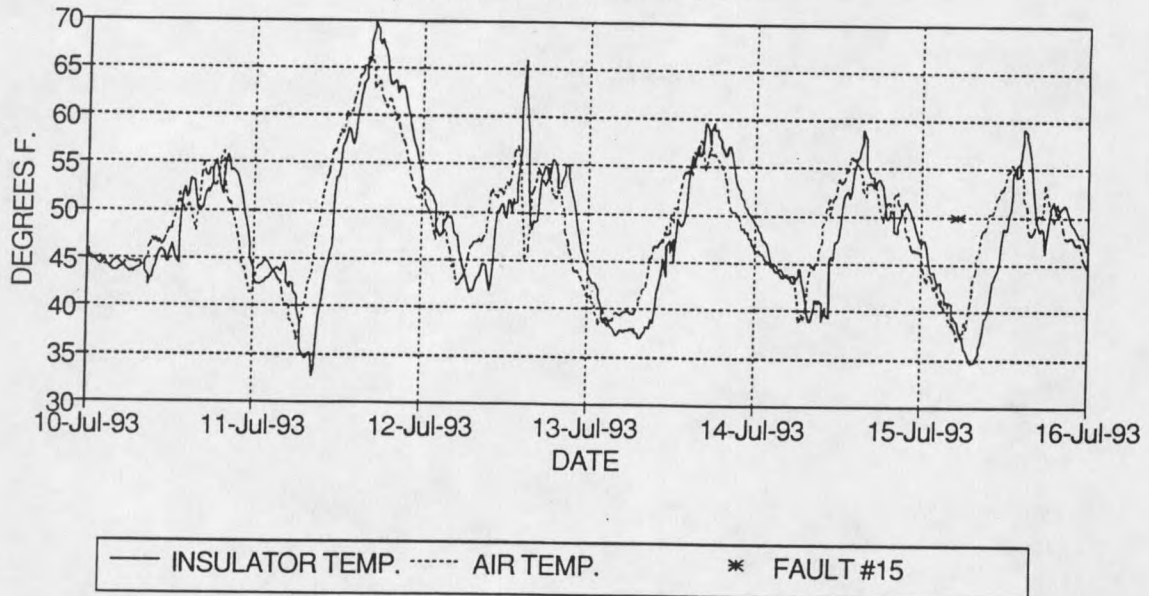


Figure 143

INSULATOR, AIR & DEW POINT TEMPERATURES AT ROSTAD RANCH

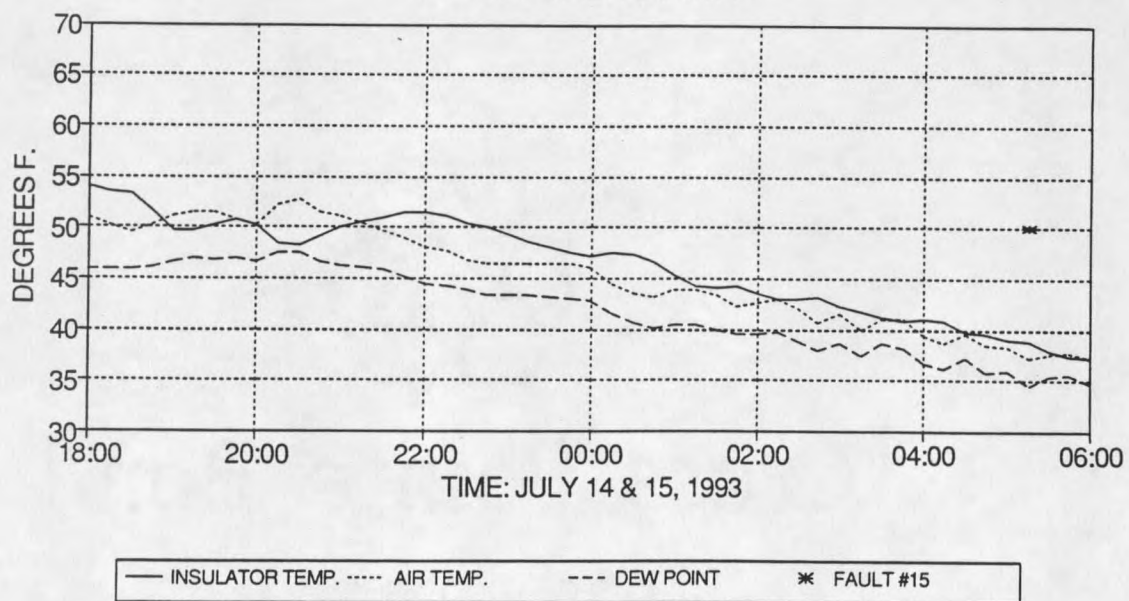
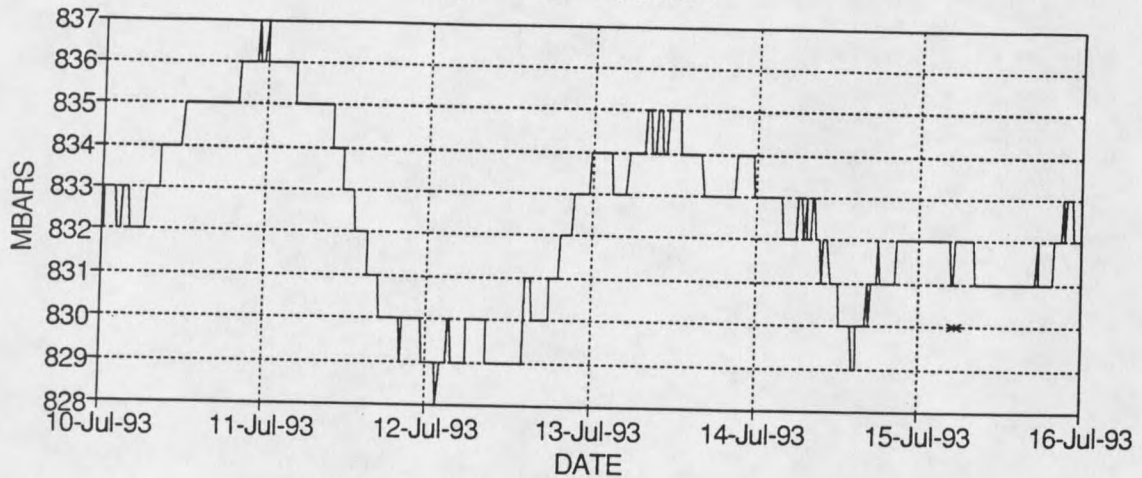


Figure 144

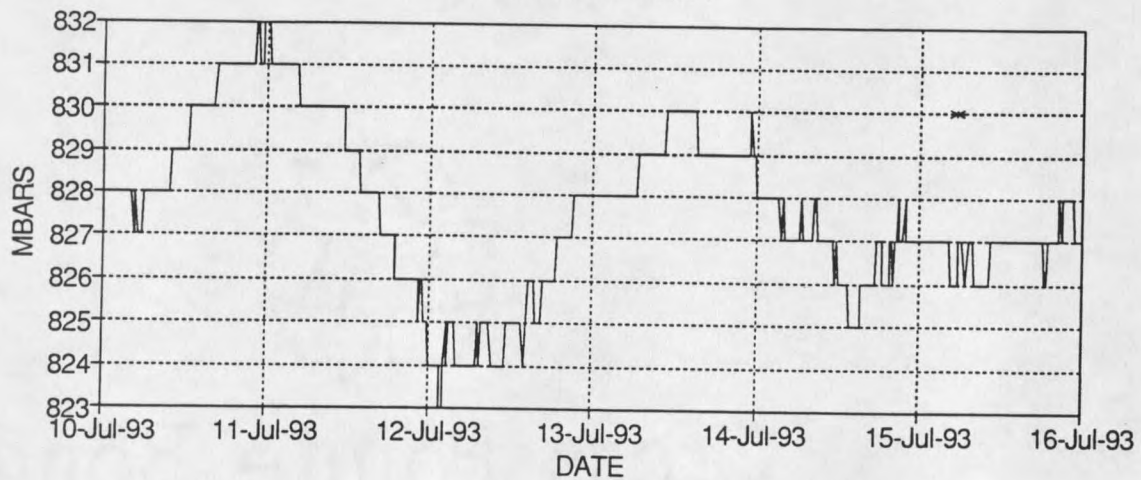
BAROMETRIC PRESSURE AT GALT RANCH



— PRESSURE * FAULT #15

Figure 145

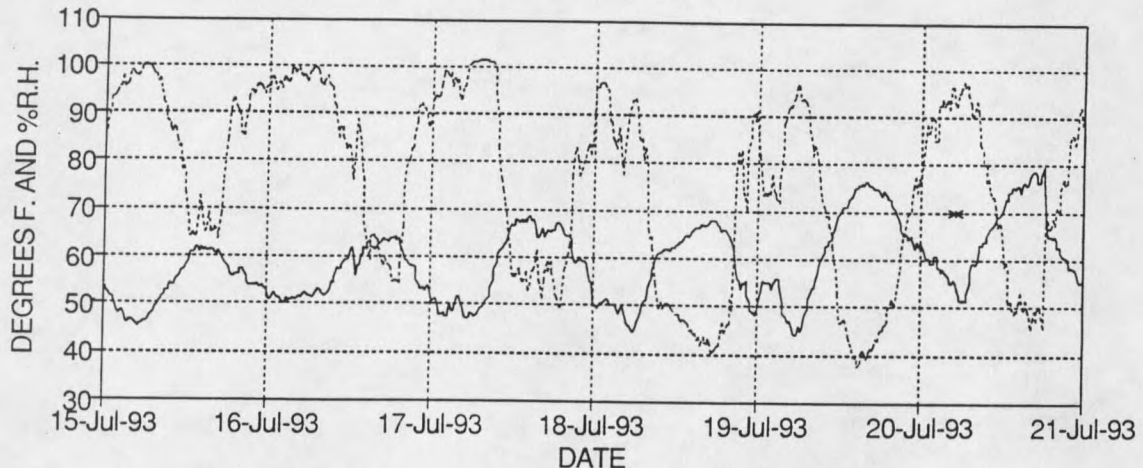
BAROMETRIC PRESSURE AT GALT RANCH



— PRESSURE * FAULT #15

Figure 146

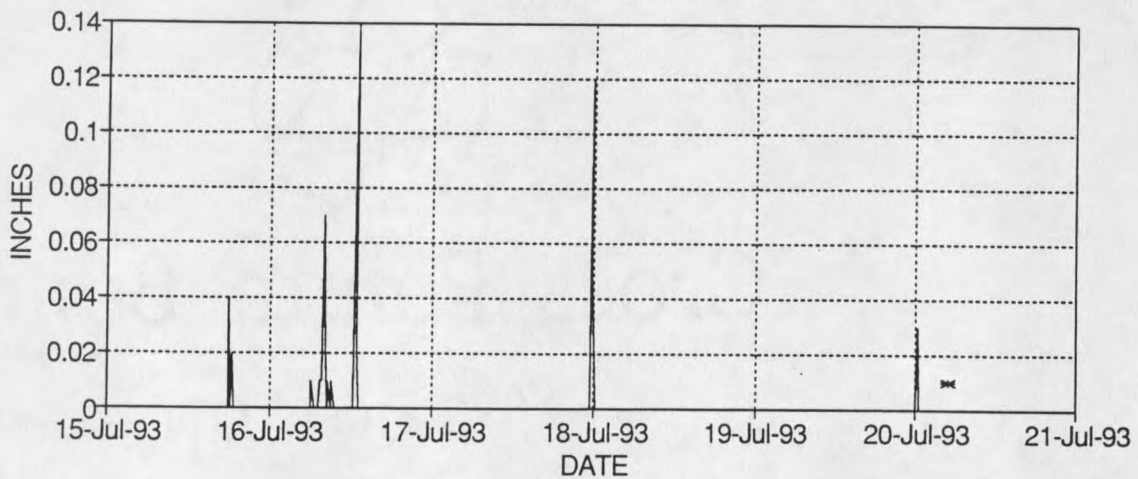
AIR TEMPERATURE AND RELATIVE HUMIDITY AT GOLDEN VALLEY



— AIR TEMP - - - - R.H. * FAULT #16

Figure 147

PRECIPITATION AT GOLDEN VALLEY



— PRECIPITATION * FAULT #16

Figure 148

WIND SPEED AT GOLDEN VALLEY

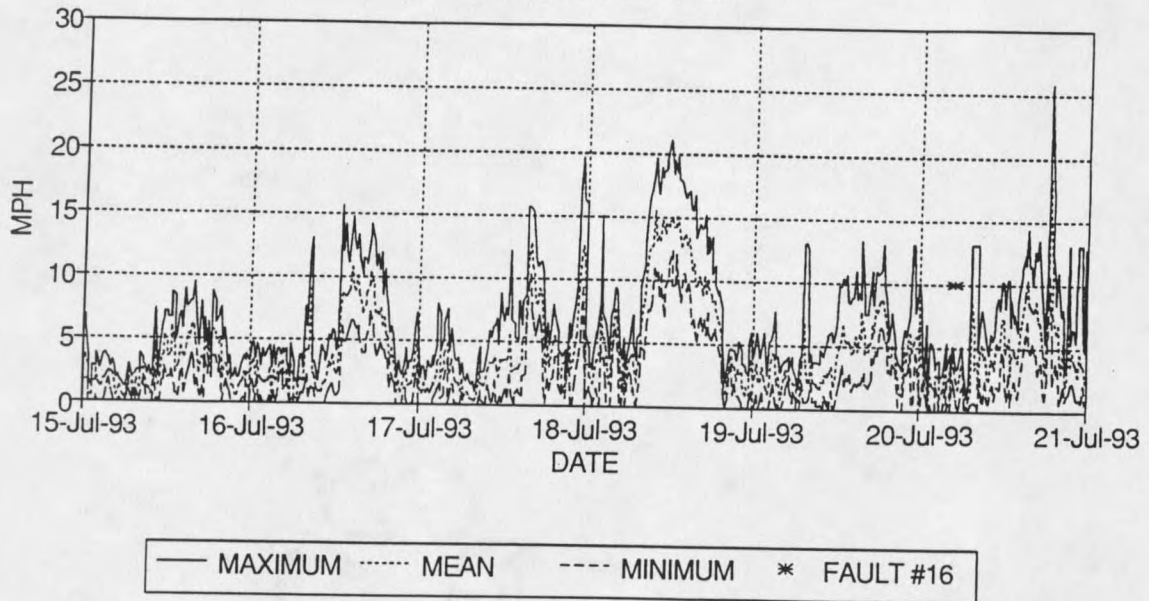


Figure 149

WIND SPEED AT GOLDEN VALLEY

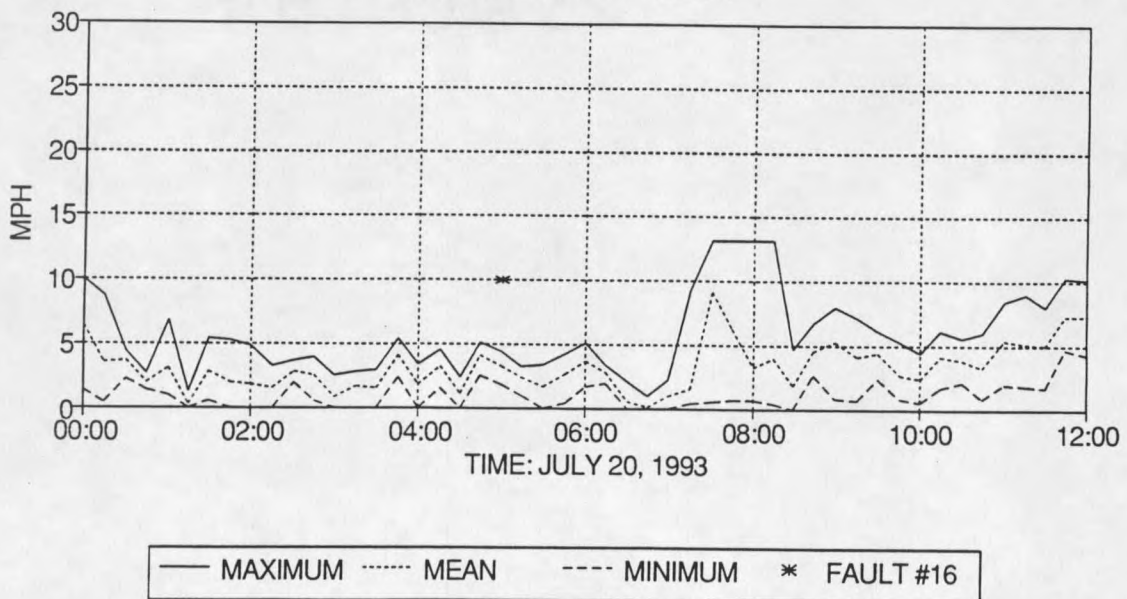


Figure 150

DEW SENSOR RESISTANCES AT GOLDEN VALLEY

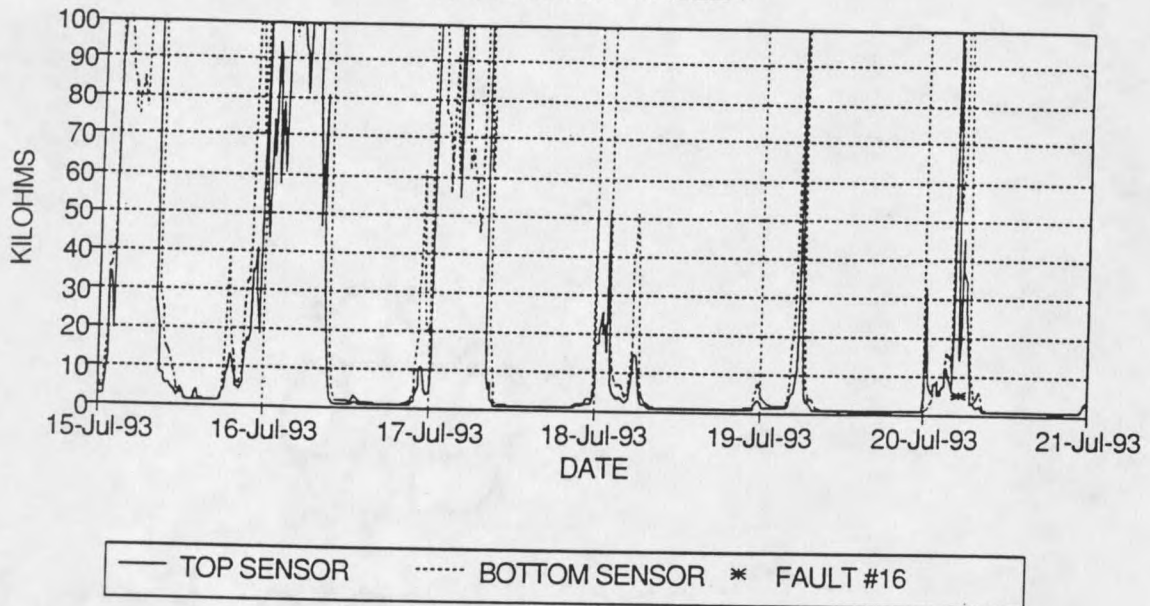


Figure 151

INSULATOR AND AIR TEMPERATURES AT GOLDEN VALLEY

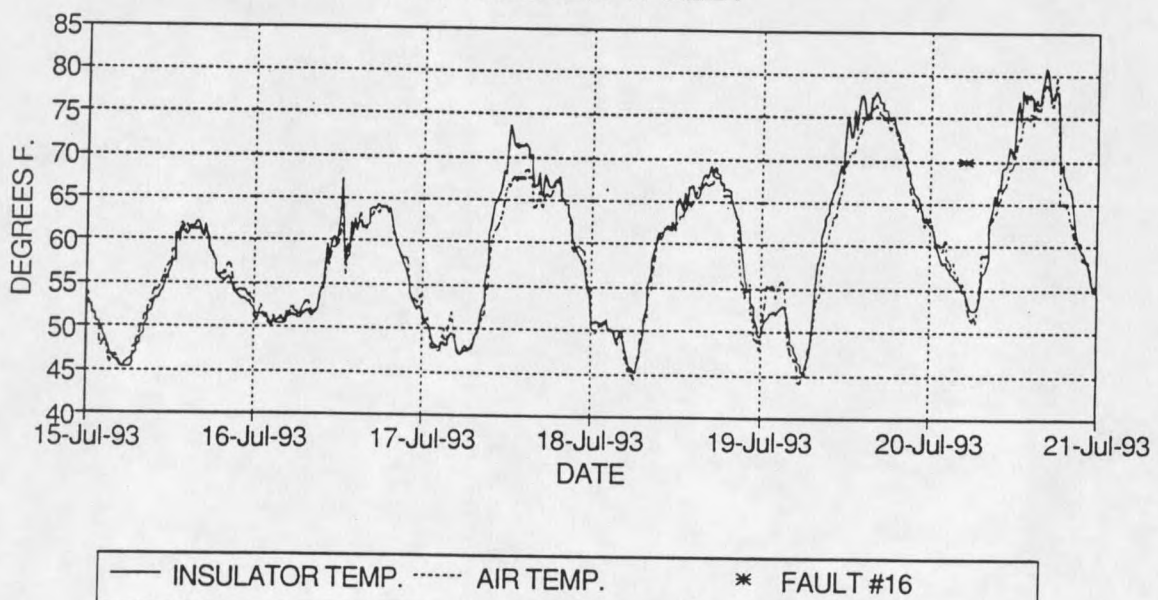


Figure 152

INSULATOR, AIR & DEW POINT TEMPERATURES AT GOLDEN VALLEY

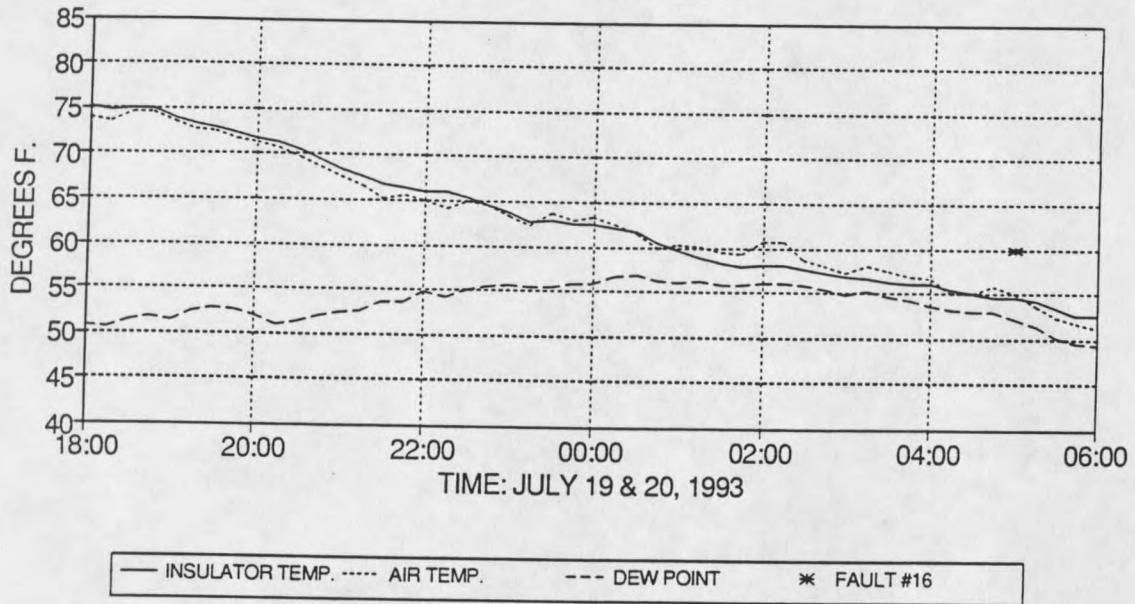


Figure 153

BAROMETRIC PRESSURE AT GOLDEN VALLEY

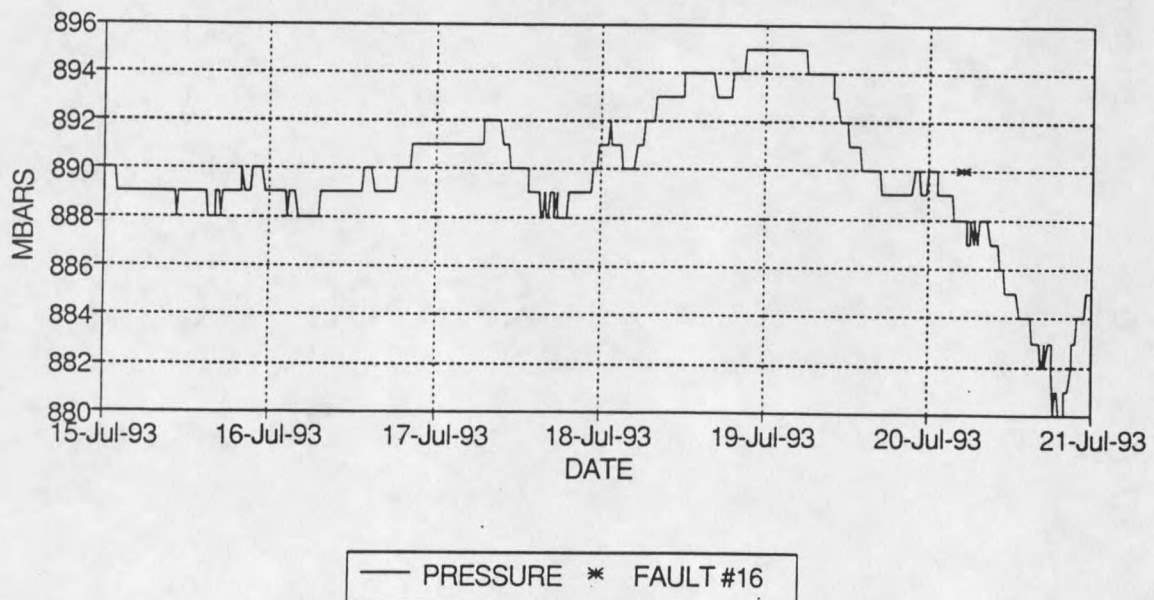


Figure 154
PRECIPITATION
AT GALT RANCH

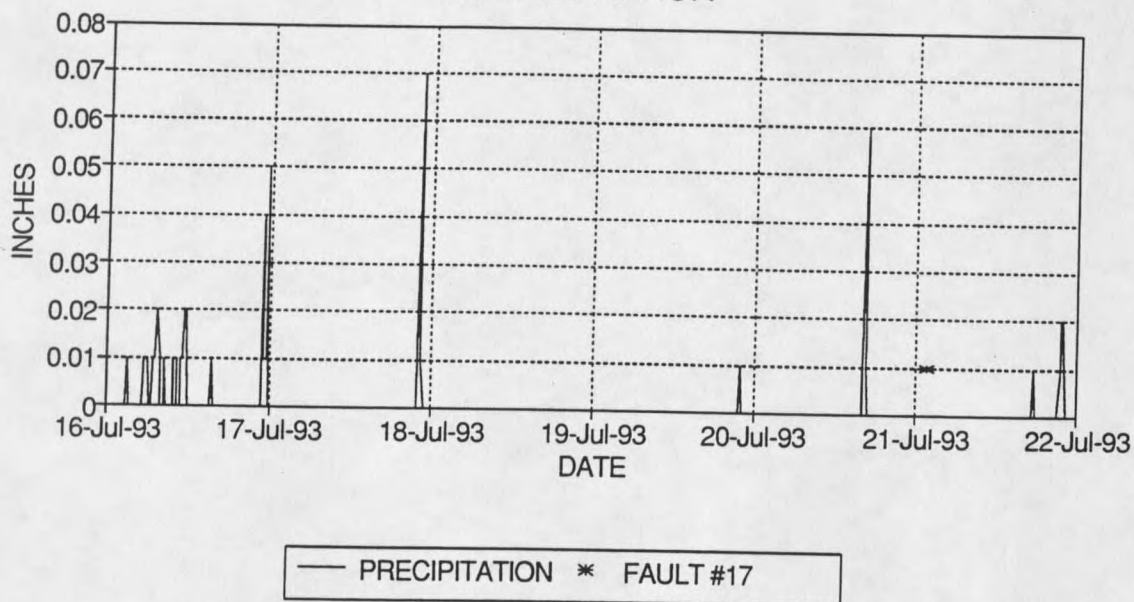


Figure 155
AIR TEMPERATURE AND RELATIVE HUMIDITY
AT GALT RANCH

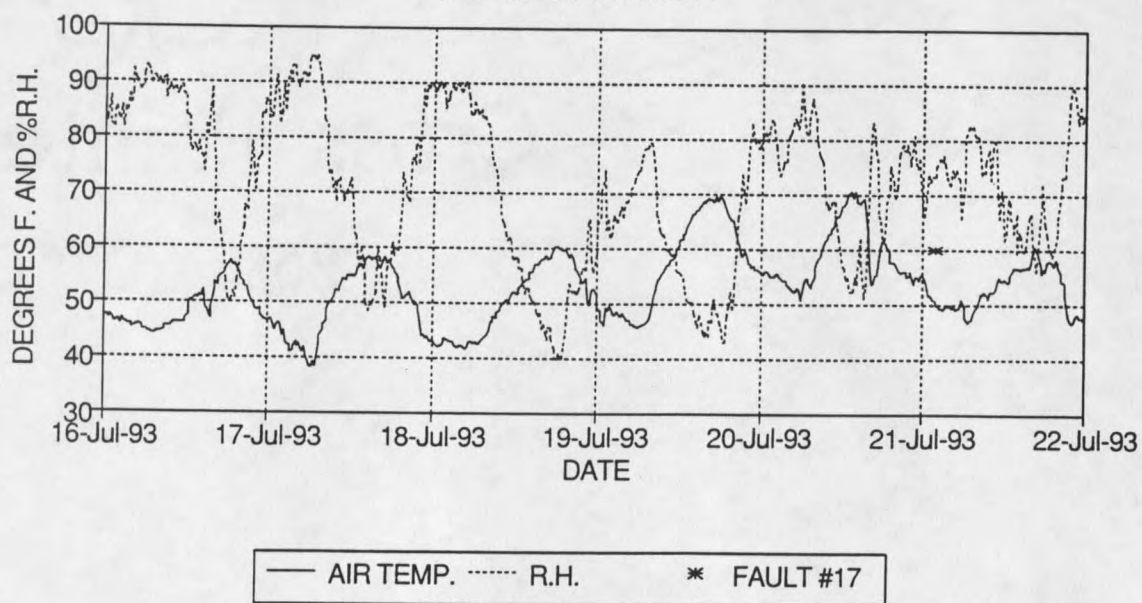


Figure 156

WIND SPEED AT GALT RANCH

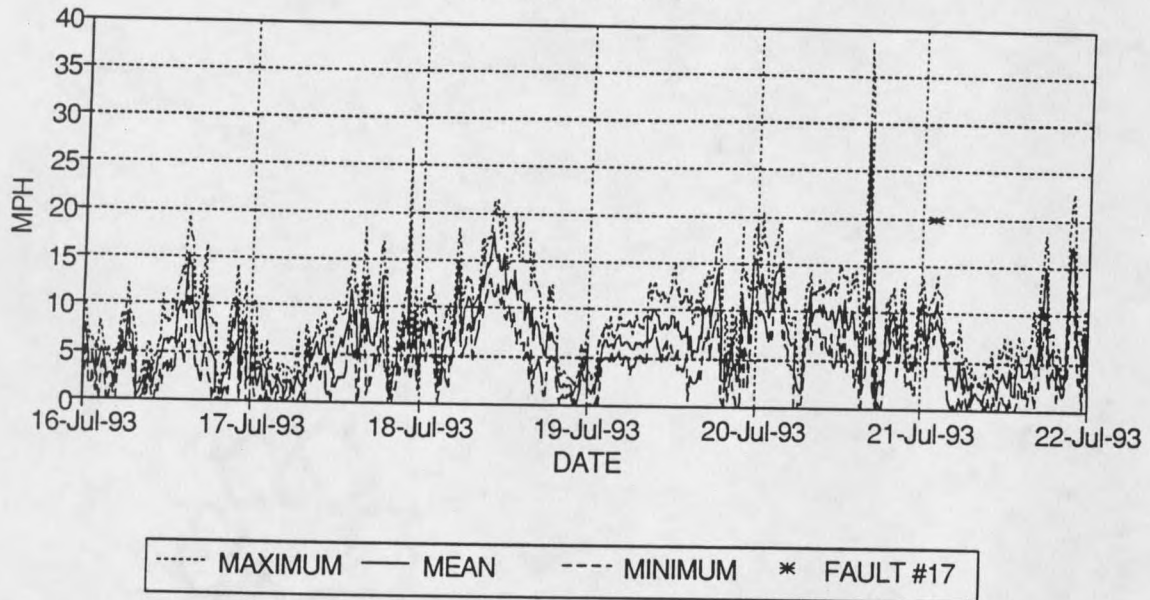


Figure 157

WIND SPEED AT GALT RANCH

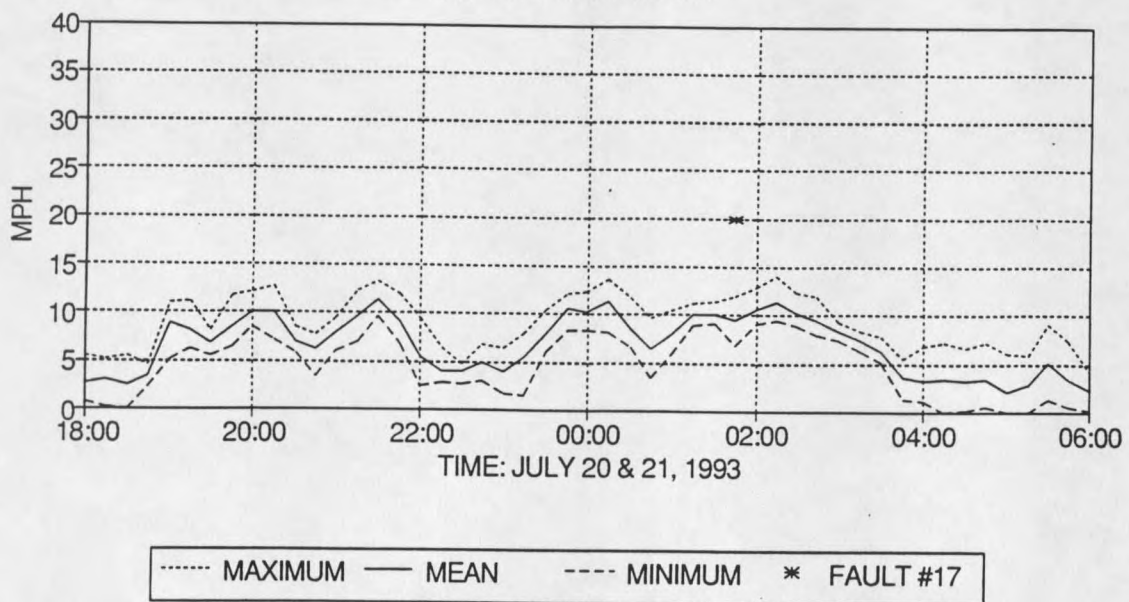


Figure 158

DEW SENSOR RESISTANCES AT GALT RANCH

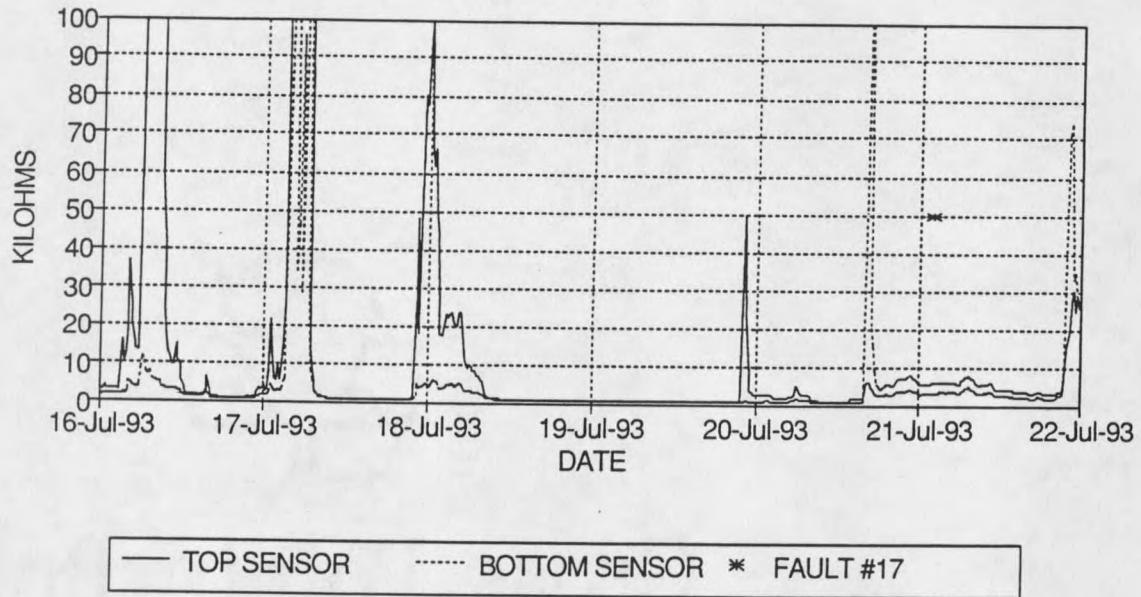


Figure 159

INSULATOR AND AIR TEMPERATURES AT GALT RANCH

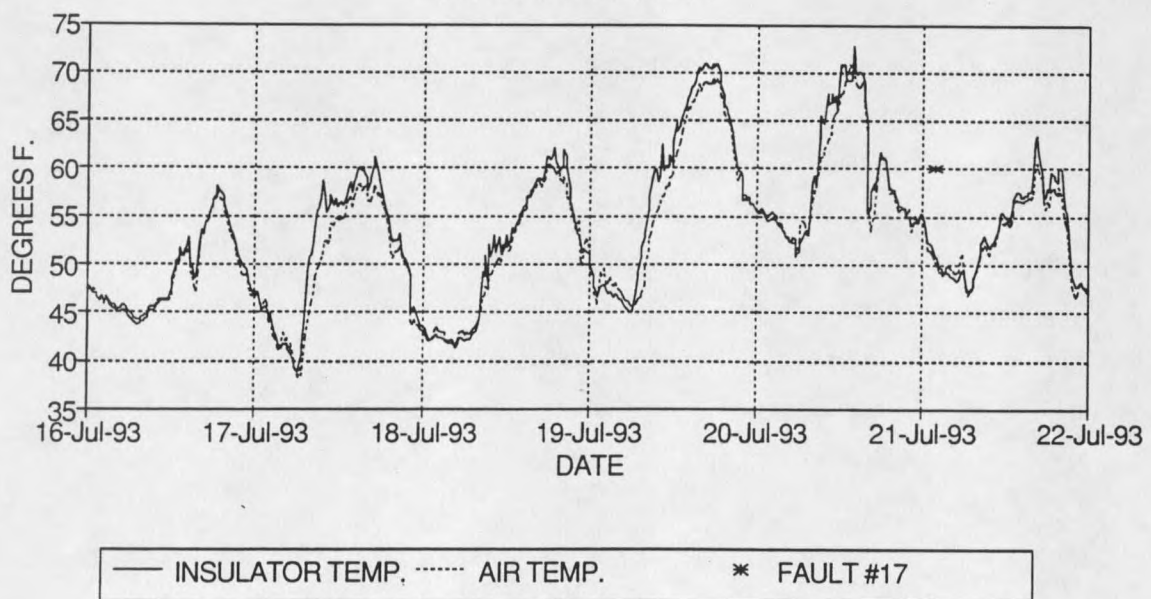


Figure 160

INSULATOR, AIR & DEW POINT TEMPERATURES AT GALT RANCH

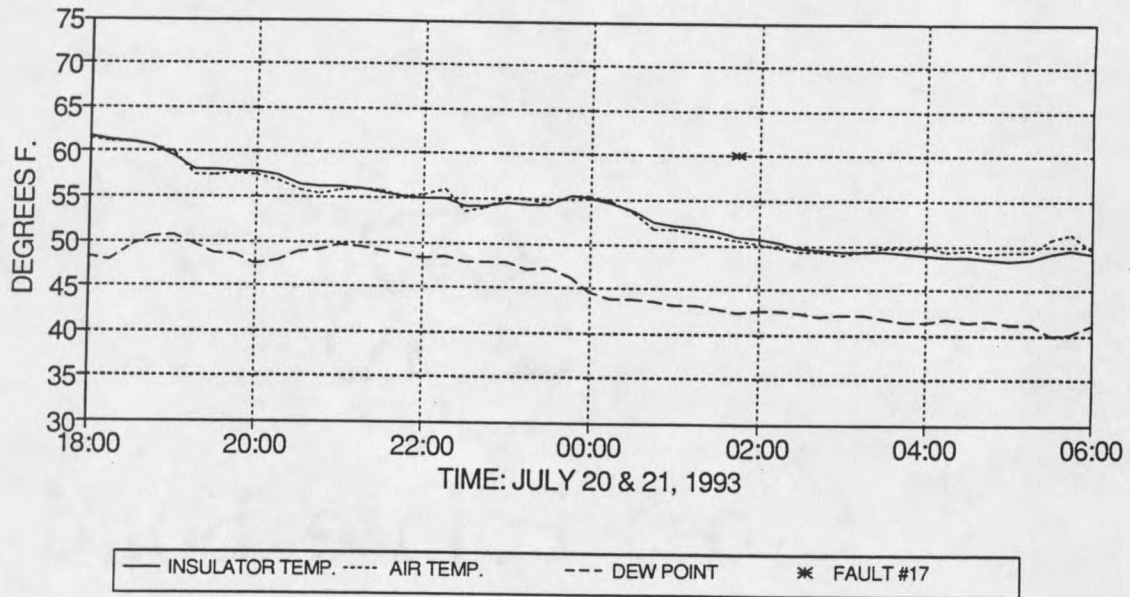


Figure 161

BAROMETRIC PRESSURE AT GALT RANCH

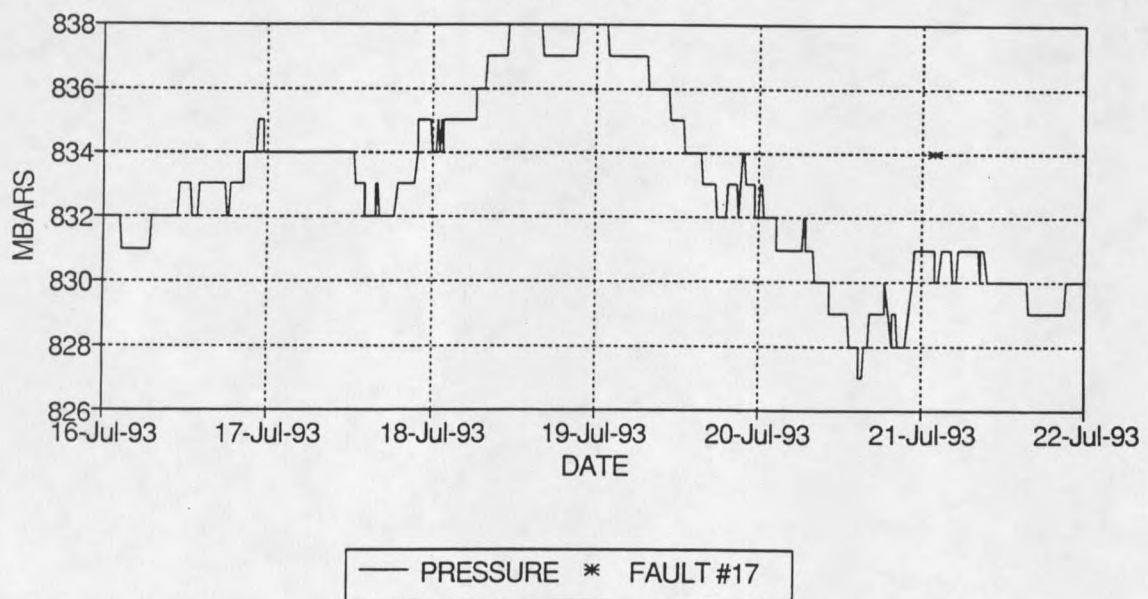


Figure 162

AIR TEMPERATURE AND RELATIVE HUMIDITY AT BROADVIEW SUBSTATION

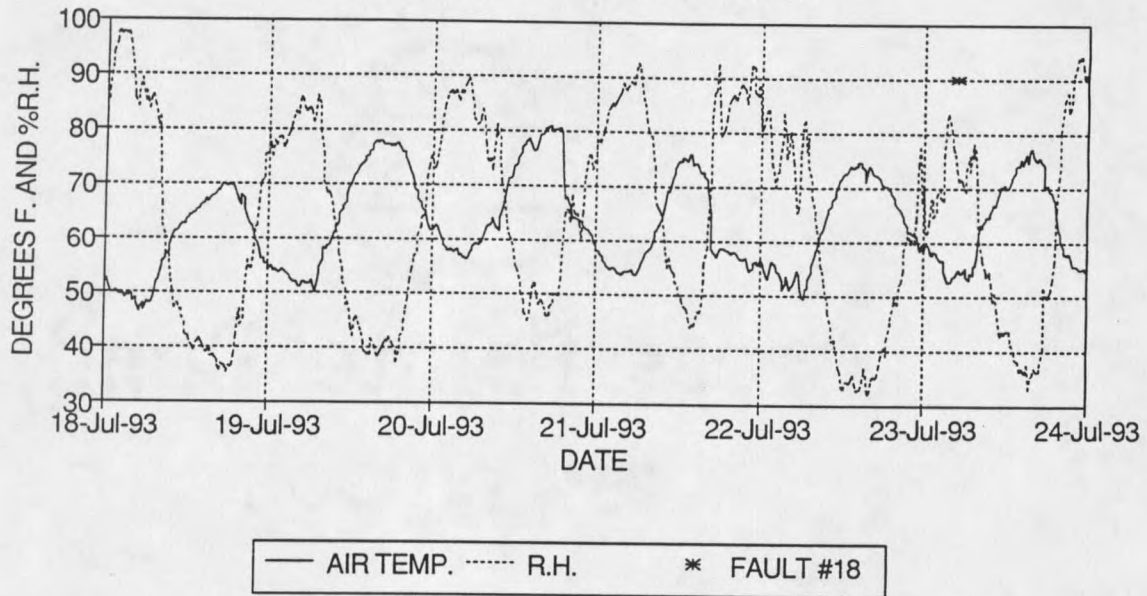


Figure 163

PRECIPITATION AT BROADVIEW SUBSTATION

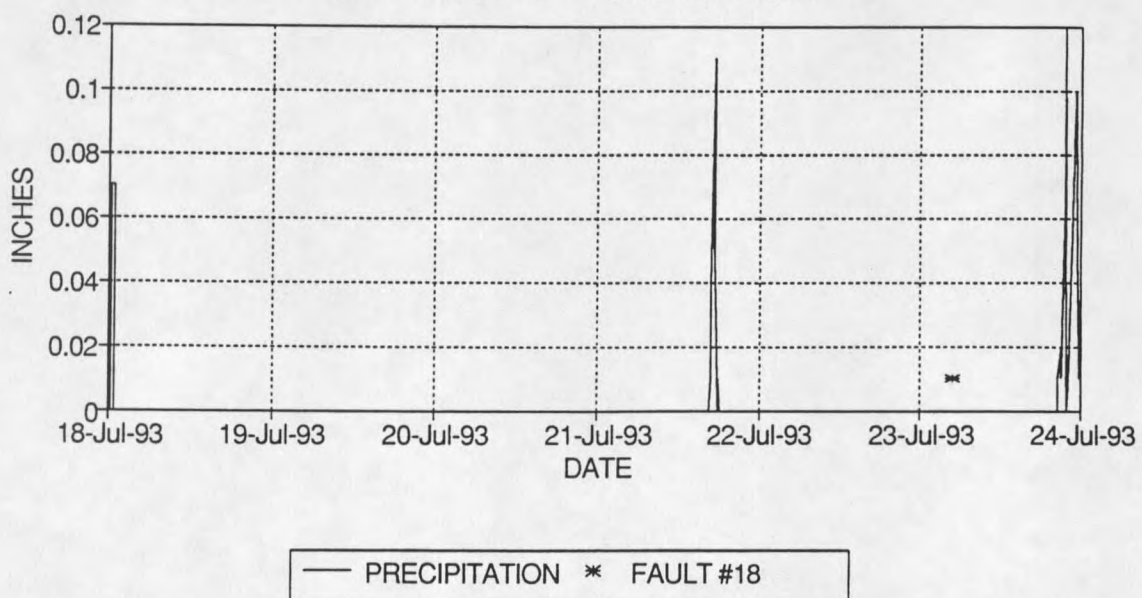
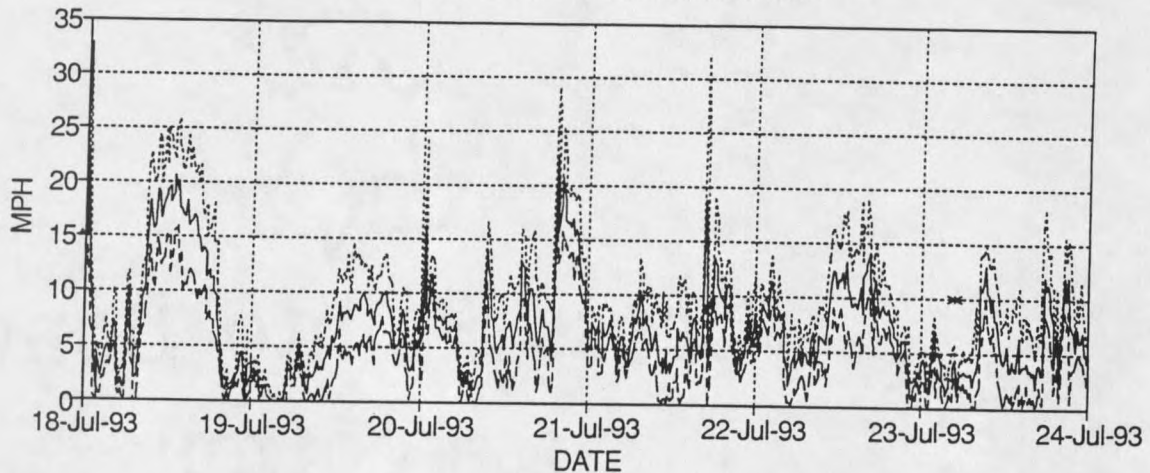


Figure 164

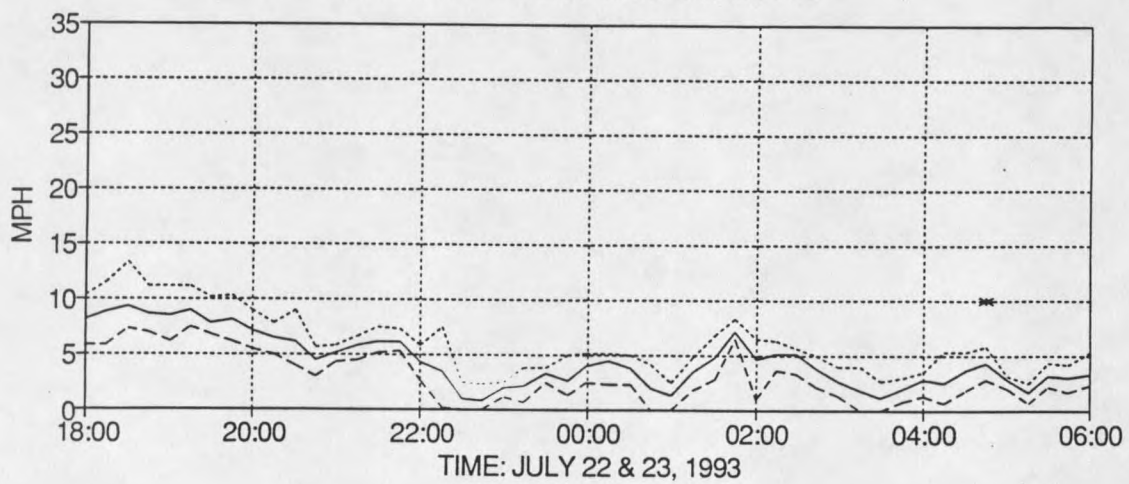
WIND SPEED AT BROADVIEW SUBSTATION



----- MAXIMUM — MEAN ---- MINIMUM * FAULT #18

Figure 165

WIND SPEED AT BROADVIEW SUBSTATION



----- MAXIMUM — MEAN ---- MINIMUM * FAULT #18

Figure 166

DEW SENSOR RESISTANCES AT BROADVIEW SUBSTATION

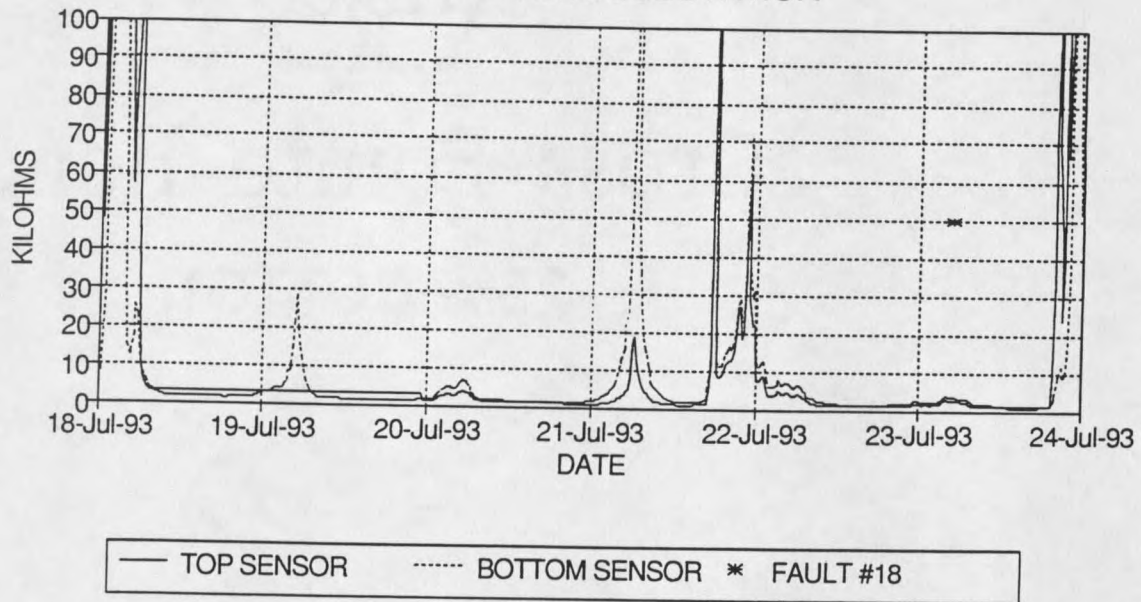


Figure 167

INSULATOR AND AIR TEMPERATURES AT BROADVIEW SUBSTATION

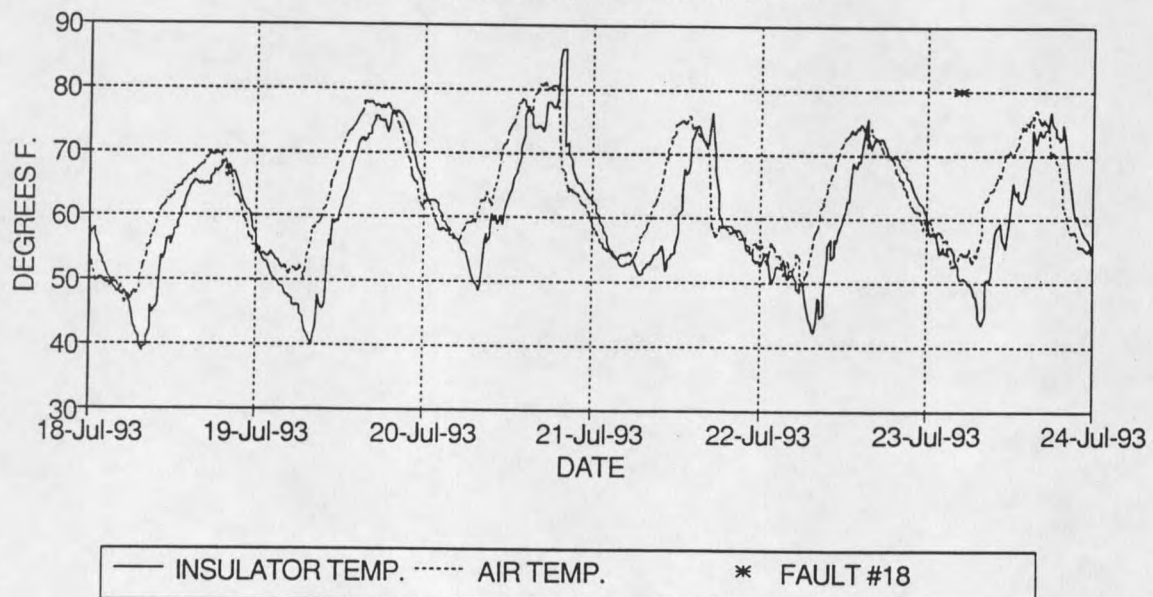


Figure 168

INSULATOR, AIR & DEW POINT TEMPERATURES AT BROADVIEW SUBSTATION

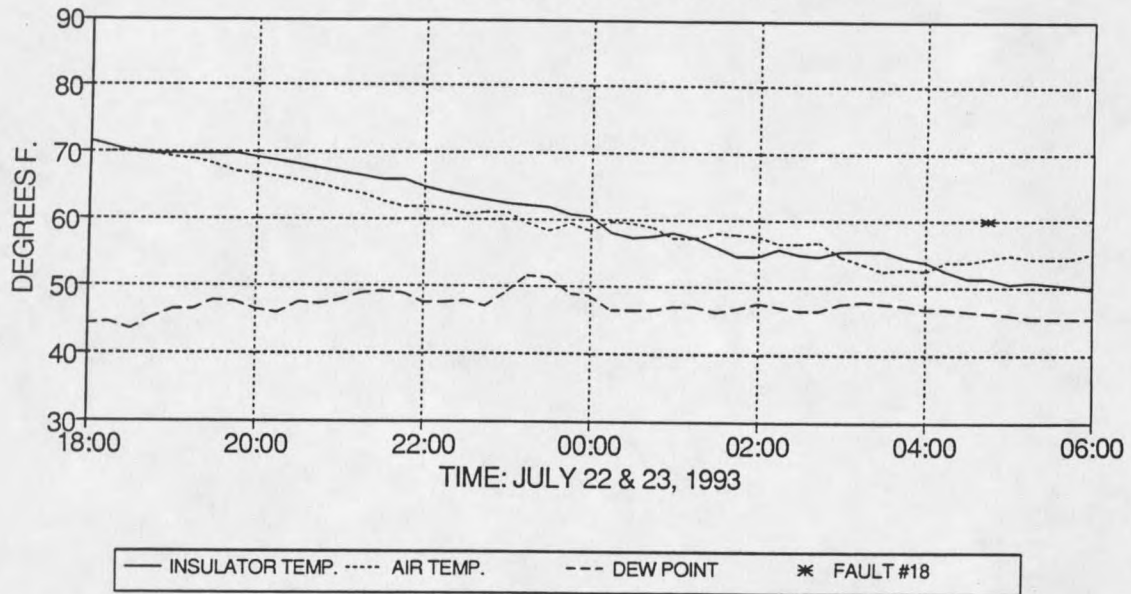


Figure 169

AIR TEMPERATURE AND RELATIVE HUMIDITY AT COONEY RANCH

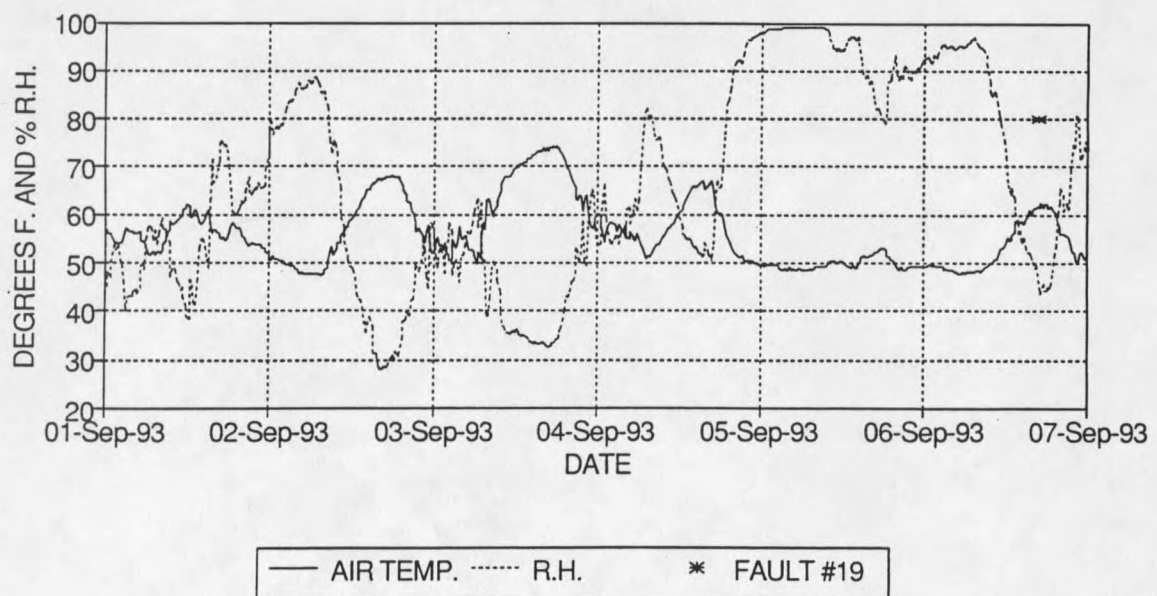


Figure 170

PRECIPITATION AT COONEY RANCH

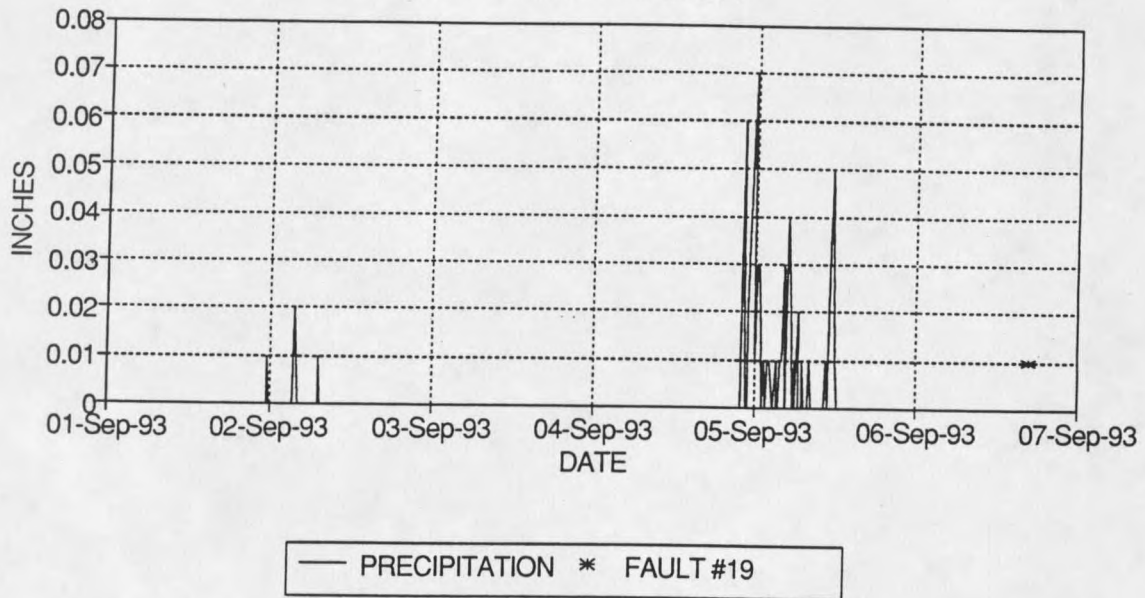


Figure 171

WIND SPEED AT COONEY RANCH

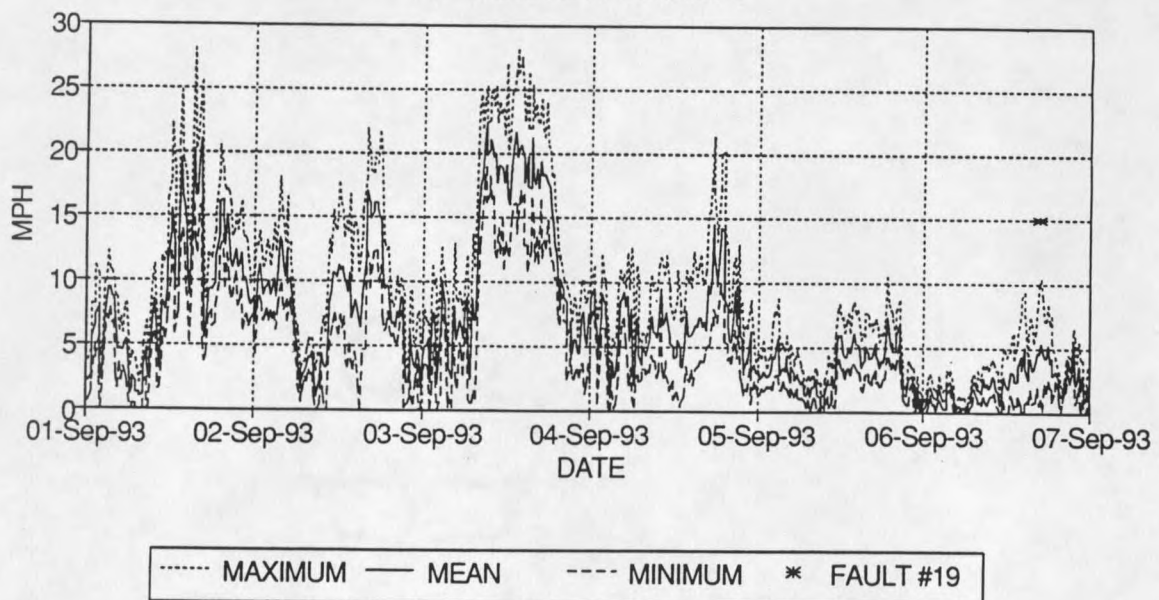


Figure 172

WIND SPEED AT COONEY RANCH

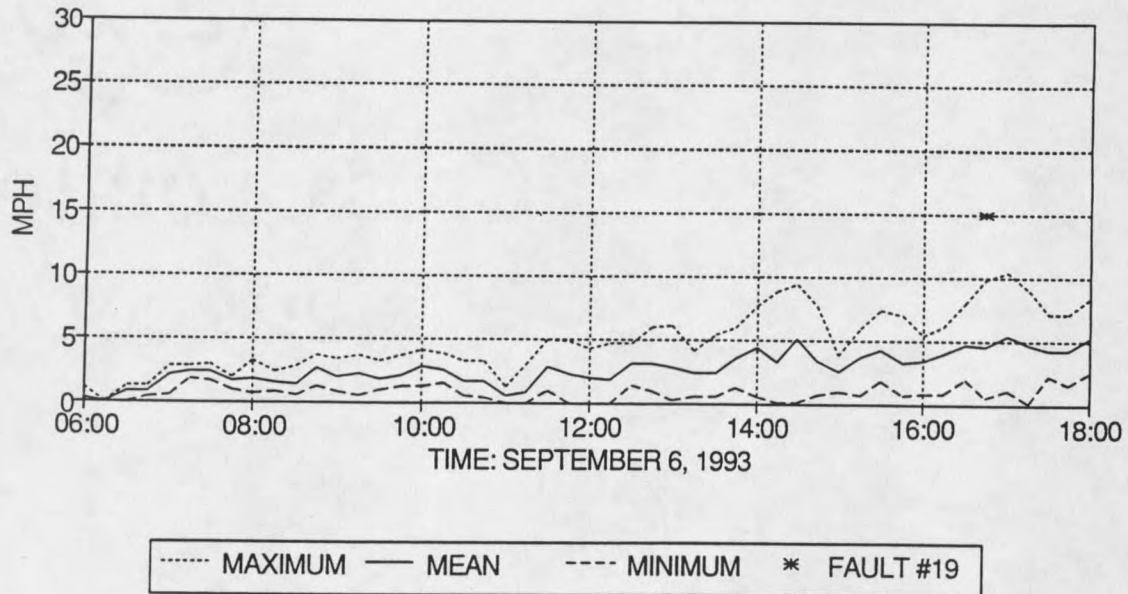


Figure 173

DEW SENSOR RESISTANCES AT COONEY RANCH

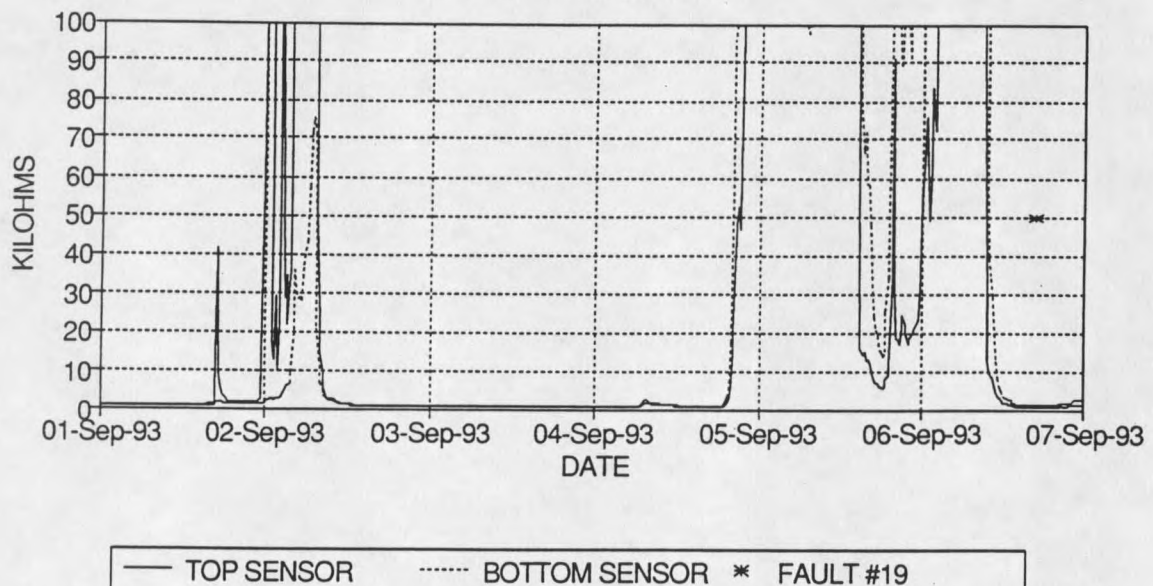


Figure 174

INSULATOR AND AIR TEMPERATURES AT COONEY RANCH

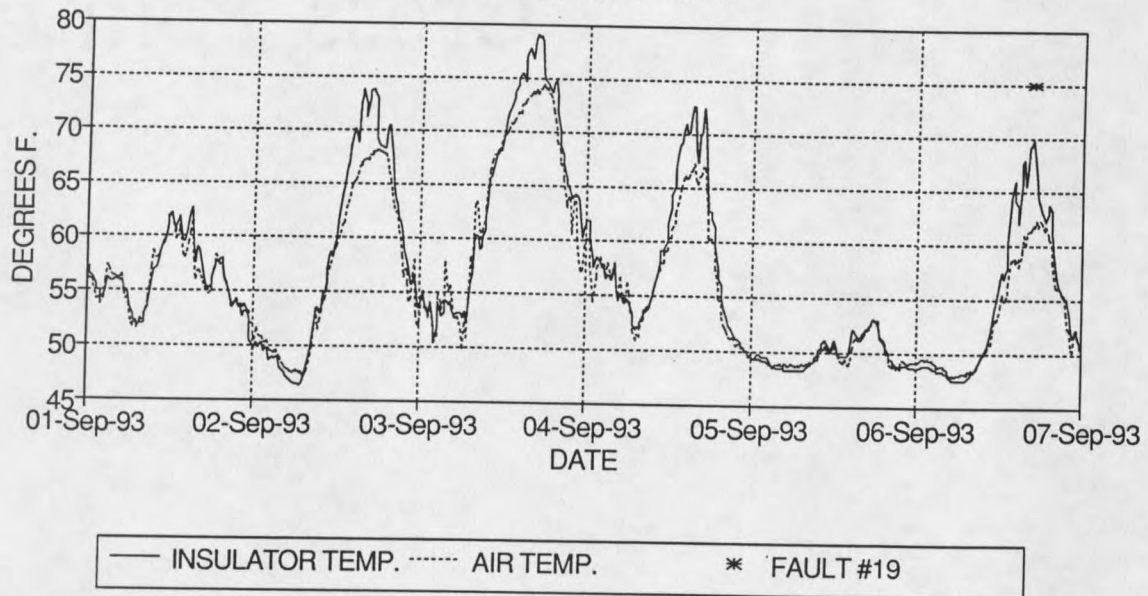
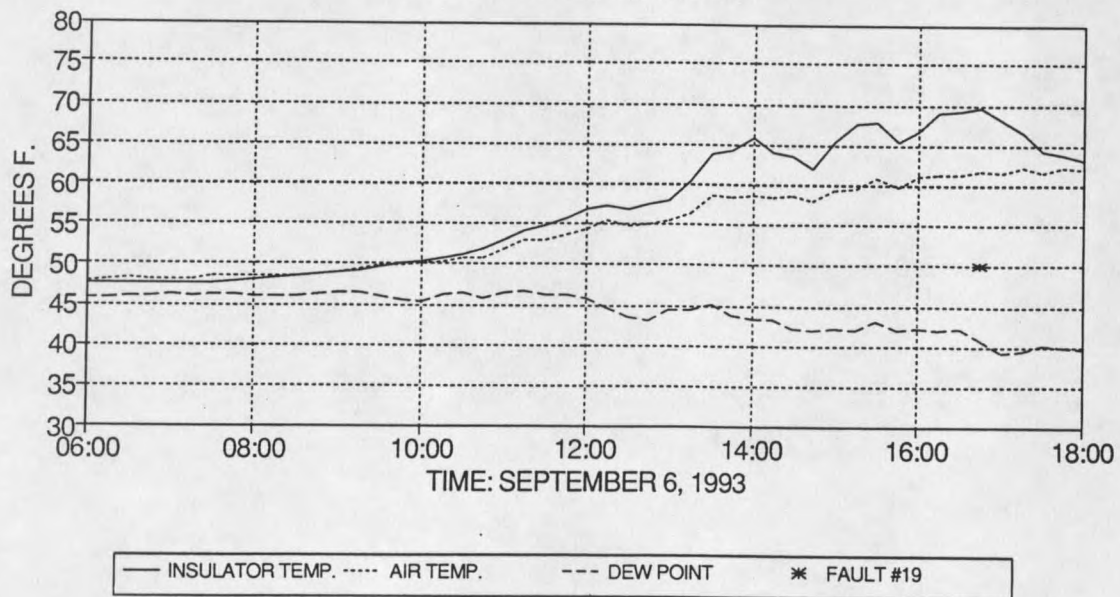


Figure 175

INSULATOR, AIR, & DEW POINT TEMPERATURE AT COONEY RANCH



— PRESSURE * FAULT #19

APPENDIX C

**LOCATION AND METEOROLOGICAL DATA FOR
FAULTS WITHIN WEATHER STATION COVERAGE**

Table 9: Location and Meteorological Data for Faults Within Weather Station Coverage

FAULT #	1	2	3	4	5	6						
DATE	16-Aug-92	01-Oct-92	18-Oct-92	23-Oct-92	02-Nov-92	07-Feb-93						
TIME	02:43	14:52	12:36	16:17	23:36	12:08						
LINE	2	1	2	2	B	1						
PHASE	C	A	A	C	B	C						
PHASE POSITION	SOUTH	NORTH	TOP	SOUTH	NORTH	TOP						
MILES WEST OF BROADVIEW (MPC)	102.7	42.5	99.6	117	17.2 E	93.7						
FLARE	102.5	N/A	100	119.4	17 E	99.2						
SEL	110.3	55.2	114.4	126.8	N/A	115.1						
BPA	105.8	48.6	115.6	134.8	N/A	107.5						
MEAN DISTANCE	105.325	36.575	107.4	124.5	17.1 E	103.875						
LONGITUDE (MPC ESTIMATE)	110.88	109.7	110.82	111.17	105.53	110.7						
LATITUDE	46.3	46.22	46.32	46.28	46.07	46.35						
WEATHER STATION SITE	GALT	ROSTAD	WHITE	COONEY	GOLDEN	GALT	ROSTAD	GALT	BROADVIEW	GALT	ROSTAD	WHITE
WEATHER STATION SITE ORIENTATION	CENTRAL	EAST	WEST	CENTRAL	EAST	CENTRAL	EAST	EAST	WEST	WEST	CENTRAL	EAST
MILES FROM SITE TO FAULT (MEAN)	5.8	15.8	26.7	11.2	13.6	7.9	17.9	25	17.1	4.3	14.4	40.6
MILES FROM SITE TO FAULT (MPC)	3.2	13.2	20.8	5.3	19.5	0.1	10.1	17.5	17.2	4.2	4.2	30.5
AIR TEMPERATURE (F)	57.3	55.1	84.4	85.8	90.5	53.8	54.7	63.8	33.2	39.3	38	44.9
INSULATOR TEMPERATURE (F)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	63.8	N/A	47.5	39.4	45.9
R.H. (%)	82	88	10	9	8	37	41	24	73	51	54	43
TOP DEW SENSOR (KILOHMS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.269	N/A	0.923	1.156	0.475
BOTTOM DEW SENSOR (KILOHMS)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.879	N/A	0.954	1.194	1.191
MEAN WIND SPEED (MPH)	0.6	2	4.6	10.1	4	2.9	14.2	4.2	20	3.1	10	11.9
MAX WIND SPEED (MPH)	2.8	3.9	9	14	8.3	5.4	17.9	6.4	25.4	4.2	11.6	14
MIN WIND SPEED (MPH)	0	0.3	0.6	5.7	1.2	1.4	9.8	1.9	15	1.3	8	7.2
WIND DIRECTION (DEGREES)	33	198	285	202	247	209	243	275	342	112	213	341
STANDARD DEV. (DEGREES)	62	37	52	14	44	42	17	19	7	13	7	11
BAROMETRIC PRESSURE (MBARS)	837	833	841	865	889	831	827	842	887	831	825	838
PRECIPITATION DURING FAULT (")	0	0	0	0	0	0	0	0	0	0	0	0
HOURS SINCE LAST PRECIPITATION	6	2	439	456	723	32	72	144	17	372	289	333
MOST RECENT PRECIPITATION (")	0.04	0.07	0.01	0.01	0.01	0.01	0.02	0.01	0.13	0.01	0.11	0.1
PLOTS GENERATED?	YES	NO	NO	YES	NO	YES	NO	YES	YES	YES	YES	NO
CRITERIA FOR EVALUATING WEATHER DATA:												
DUST ACCUMULATION CRITERIA SATISFIED?	YES			YES		YES		YES	YES		YES	
CONDENSATION CRITERIA SATISFIED?	N/A			N/A		N/A		NO	N/A		NO	
FOG OR DRIZZLE CRITERIA SATISFIED	N/A			N/A		N/A		NO	N/A		NO	
ICE CRITERIA SATISFIED?	N/A			N/A		N/A		NO	N/A		NO	
CONSISTENT WITH CONTAMINATION FLASHOVER?	YES			NO		NO		NO	INCONCLUSIVE		NO	

Table 9 Continued

FAULT #	7			8			9			10			11		
DATE	23-Feb-93			25-Feb-93			29-Apr-93			05-Jun-93			10-Jun-93		
TIME	17:09			09:46			12:19			16:16			05:04		
LINE	2			2			2			1			1		
PHASE	A			A			C			C			A		
PHASE POSITION	NORTH			NORTH			SOUTH			TOP			NORTH		
MILES WEST OF BROADVIEW (MPC)	44.9			69.6			42.1			41.8			72.2		
FLARE	35.7			64.4			36.1			48.3			82.3		
SEL	49.4			83.1			46.8			69.3			96.8		
BPA	56.5			82			38.5			40.5			N/A		
MEAN DISTANCE	46.625			74.775			40.875			49.975			62.825		
LONGITUDE (MPC ESTIMATE)	110.32			110.25			109.68			109.68			110.28		
LATITUDE	46.22			46.33			46.2			46.2			46.35		
WEATHER STATION SITE	WHITE	COONEY	GOLDEN	ROSTAD	WHITE	COONEY	WHITE	COONEY	GOLDEN	WHITE	COONEY	GOLDEN	ROSTAD	WHITE	COONEY
WEATHER STATION SITE ORIENTATION	WEST	CENTRAL	EAST	WEST	CENTRAL	EAST	WEST	CENTRAL	EAST	WEST	CENTRAL	EAST	WEST	CENTRAL	EAST
MILES FROM SITE TO FAULT (MEAN)	16.6	1.1	23.6	14.7	11.5	27.1	22.4	6.9	17.9	13.3	2.2	27	26.7	0.4	15.1
MILES FROM SITE TO FAULT (MPC)	18.4	2.9	21.9	19.9	6.4	21.9	21.2	5.7	19.1	21.5	6	18.8	17.3	9	24.5
AIR TEMPERATURE (F)	0.2	3.2	3	10.3	8	12.2	47.5	51.8	56.2	52.6	53.9	59.1	44.7	48.2	53.2
INSULATOR TEMPERATURE (F)	4.3	7.3	11.4	-5	11.2	19.6	52.2	54.1	58.7	53.5	54.5	59.9	45.1	48.9	55.1
R.H. (%)	80	71	73	61	67	54	31.4	46	44.8	57	66	58.5	78.5	74	65.2
TOP DEW SENSOR (KILOHMS)	0.626	3.647	1.68	1.799	0.502	1.78	0.946	1.259	1.148	2.063	2.504	1.088	1.436	1.986	0.973
BOTTOM DEW SENSOR (KILOHMS)	2.165	1.244	1.31	1.552	3.619	1.08	1.342	1.016	1.012	1.931	1.1	1.194	2.316	1.402	0.758
MEAN WIND SPEED (MPH)	4.7	1.6	5.8	3.9	5.6	0.5	13.25	12.9	5.5	3.1	1	7.1	6.1	4.6	6.6
MAX WIND SPEED (MPH)	5.8	2.9	13	4.6	6.6	1.8	19.8	16.2	10.8	5.4	2.2	9.9	7.4	8	7.7
MIN WIND SPEED (MPH)	3.4	0.4	0.7	3.2	4	0	9.1	11	0.5	0.8	0	3.8	4.9	2.4	5.2
WIND DIRECTION (DEGREES)	148	125	139	182	239	228	293.2	348	220.7	90.7	245	0.8	174.1	249	273
STANDARD DEV. (DEGREES)	15	37	28	8	5	31	16.7	15	24.2	12	28	10	8.4	24	3.9
BAROMETRIC PRESSURE (MBARS)	836	859	890	820	836	859	843	862	889	836	859	885	826	839	862
PRECIPITATION DURING FAULT (*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HOURS SINCE LAST PRECIPITATION	54	52	50	358	96	94	73	72	72	4	11	9	48	41	31
MOST RECENT PRECIPITATION (*)	0.01	0.01	0.1	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.01	0.34	0.32	0.16
PLOTS GENERATED?	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO
CRITERIA FOR EVALUATING WEATHER DATA:															
DUST ACCUMULATION CRITERIA SATISFIED?	YES			YES			YES			YES			NO		
CONDENSATION CRITERIA SATISFIED?	NO			NO			NO			NO			NO		
FOG OR DRIZZLE CRITERIA SATISFIED	NO			NO			NO			NO			NO		
ICE CRITERIA SATISFIED?	NO			NO			NO			NO			NO		
CONSISTENT WITH CONTAMINATION FLASHOVER?	NO			NO			NO			NO			NO		

Table 9 Continued

FAULT #	12	13	14	15	16										
DATE	11-Jun-93	01-Jul-93	07-Jul-93	15-Jul-93	20-Jul-93										
TIME	10:16	05:12	04:21	05:17	05:02										
LINE	1	2	2	1	1										
PHASE	C	C	B	B	C										
PHASE POSITION	TOP	SOUTH	NORTH	SOUTH	TOP										
MILES WEST OF BROADVIEW (MPC)	44.2	69.1	62.6	94.1	18.4										
FLARE	48.3	45	54.8	96.8	16.5										
SEL	65.4	61.4	72.8	106.1	24.1										
BPA	43.5	64	73.9	107	20										
MEAN DISTANCE	50.35	59.875	66.025	101	19.75										
LONGITUDE (MPC ESTIMATE)	110.3	110.3	110.12	110.7	109.27										
LATITUDE	46.22	46.35	46.3	46.35	46.17										
WEATHER STATION SITE	WHITE	COONEY	GOLDEN	ROSTAD	WHITE	COONEY	ROSTAD	WHITE	COONEY	GALT	ROSTAD	COONEY	GOLDEN	BROADVIEW	
WEATHER STATION SITE ORIENTATION	WEST	CENTRAL	EAST	WEST	CENTRAL	EAST	WEST	CENTRAL	EAST	CENTRAL	EAST	WEST	CENTRAL	EAST	
MILES FROM SITE TO FAULT (MEAN)	12.9	2.6	27.4	29.6	3.4	12.1	23.5	2.8	18.3	1.5	11.5	28	3.25	19.8	
MILES FROM SITE TO FAULT (MPC)	19.1	3.6	21.2	20.4	5.85	21.35	26.9	0.65	14.855	5.4	4.6	29.4	4.6	18.4	
AIR TEMPERATURE (F)	60.5	61.4	64.4	46	44.9	50.3	37.6	37.4	45.4	44	37	53.2	55	56.2	
INSULATOR TEMPERATURE (F)	68.1	70.3	68.8	44.2	47.3	51.6	35.7	37.5	44.1	43.5	38.9	54.9	54.7	56.3	
R.H. (%)	48.7	47	53.6	67	72	62	88	92	86	93	94	83.9	92	90	
TOP DEW SENSOR (KILOHMS)	2.094	0.869	0.81	1.39	409.1	2.03	85.9	6999	40.75	286.8	1769	4.701	14.14	4.087	
BOTTOM DEW SENSOR (KILOHMS)	0.983	0.743	0.949	1.227	2.8	0.84	277	54.8	13.92	252.1	119.9	1.763	52.64	6.973	
MEAN WIND SPEED (MPH)	5.7	3.7	1.565	3.9	5.9	8.6	1.1	1.3	1.3	0.9	1.1	4.8	3	7.1	
MAX WIND SPEED (MPH)	10.7	7.3	3.8	5.9	7.8	10.3	3	2.8	3.2	4	2.6	7.8	4.4	8.1	
MIN WIND SPEED (MPH)	1.4	1	0	1.3	3	6.1	0	0	0	0	0.2	1.6	1.8	6.2	
WIND DIRECTION (DEGREES)	278	334	262	173	259	274	166	260	25	246	175	277	229	0	
STANDARD DEV. (DEGREES)	75	30	48	16	8	8	24	42	3	74	42	14	23	6	
BAROMETRIC PRESSURE (MBARS)	835	858	884	852	838	860	822	836	859	832	826	862	888	874	
PRECIPITATION DURING FAULT (*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
HOURS SINCE LAST PRECIPITATION	70	13	25	55	48	46	40	82	81	11	11	5	5	53	
MOST RECENT PRECIPITATION (*)	0.31	0.01	0.08	0.06	0.23	0.32	0.07	0.98	2.36	0.08	0.09	0.02	0.03	0.68	
PLOTS GENERATED?	NO	YES	NO	NO	YES	NO	NO	YES	NO	YES	YES	NO	YES	NO	
CRITERIA FOR EVALUATING WEATHER DATA:															
DUST ACCUMULATION CRITERIA SATISFIED?		NO			NO			NO		NO			NO		
CONDENSATION CRITERIA SATISFIED?		NO			NO			NO		NO			NO		
FOG OR DRIZZLE CRITERIA SATISFIED		NO			NO			YES		YES			YES		
ICE CRITERIA SATISFIED?		NO			NO			NO		NO			NO		
CONSISTENT WITH CONTAMINATION FLASHOVER?	NO				NO		INCONCLUSIVE		INCONCLUSIVE				INCONCLUSIVE		

Table 9 Continued

FAULT #	17	18	19	
DATE	21-Jul-93	23-Jul-93	06-Sep-93	
TIME	01:45	04:46	16:46	
LINE	2	B	1	
PHASE	C	B	A	
PHASE POSITION	SOUTH	NORTH	NORTH	
MILES WEST OF BROADVIEW (MPC)	104.6	18.1 E	43.3	
FLARE	102.5	N/A	41.8	
SEL	118.3	N/A	72	
BPA	105.3	N/A	52	
MEAN DISTANCE	107.675	18.1 E	40.5*	
			*ACTUAL LOCATION	
LONGITUDE (MPC ESTIMATE)	110.9	105.3	109.7	
LATITUDE	46.3	46.4	46.2	
WEATHER STATION SITE	GALT	ROSTAD	BROADVIEW	COONEY
WEATHER STATION SITE ORIENTATION	CENTRAL	EAST	WEST	CENTRAL
MILES FROM SITE TO FAULT (MEAN)	8.2	18.2	18.1	7.25*
MILES FROM SITE TO FAULT (MPC)	5.1	15.1	18.1	7.25*
AIR TEMPERATURE (F)	50.5	46.1	54.5	61.7
INSULATOR TEMPERATURE (F)	51	46.3	50.7	69.7
R.H. (%)	73	89	73	46.5
TOP DEW SENSOR (KILOHMS)	3.379	10.64	2.812	1.144
BOTTOM DEW SENSOR (KILOHMS)	5.893	15.61	3.796	1.573
MEAN WIND SPEED (MPH)	9.5	3.9	4.4	4.6
MAX WIND SPEED (MPH)	12.1	5.7	5.7	9.8
MIN WIND SPEED (MPH)	6.9	1.8	2.9	0.7
WIND DIRECTION (DEGREES)	314	187	290	73
STANDARD DEV. (DEGREES)	14	8	8	31
BAROMETRIC PRESSURE (MBARS)	831	826	862	867
PRECIPITATION DURING FAULT (")	0	0	0	0
HOURS SINCE LAST PRECIPITATION	9	9	35	29
MOST RECENT PRECIPITATION (")	0.08	0.23	0.22	0.74
PLOTS GENERATED?	YES	NO	YES	YES
CRITERIA FOR EVALUATING WEATHER DATA:				
DUST ACCUMULATION CRITERIA SATISFIED?	NO		NO	YES
CONDENSATION CRITERIA SATISFIED?	NO		NO	NO
FOG OR DRIZZLE CRITERIA SATISFIED	NO		NO	NO
ICE CRITERIA SATISFIED?	NO		NO	NO
CONSISTENT WITH CONTAMINATION FLASHOVER?	NO		NO	NO

APPENDIX D

**MEAN AND STANDARD DEVIATION FOR TEN DAY PERIODS
OF METEOROLOGICAL PARAMTERS RECORDED BY WEATHER STATIONS**

Table 10: Galt Ranch Mean and Standard Deviation
For Ten Day Periods of Meteorological Parameters
(Sum is given for precipitation)

DATES		MEAN AIR TEMP. (DEG. F)	MEAN WIND SPEED (MPH)	MEAN WIND DIRECT. (DEG.)	DIR. STND. DEVIAT. (DEG.)	MAX. WIND SPEED (MPH)	MIN. WIND SPEED (MPH)	MEAN RELATIVE HUMIDITY (%)	TOTAL PRECIP. (INCHES)	MEAN BARO. PRESSURE (MBAR)	MEAN TOP RESIST. (KOHMS)	MEAN BOTTOM RESIST. (KOHMS)	MEAN INSUL. TEMP. (DEG. F)
AUG 1-10, 92	MEAN	67.48	7.94	170.55	44.63	11.30	4.82	30.25	0.00	832.80			
	STD. DEV.	8.48	4.64	114.68	19.65	5.97	3.84	12.67		4.51			
AUG 11-20, 92	MEAN	65.47	6.67	142.90	35.23	9.77	3.83	45.16	0.20	837.11			
	STD. DEV.	10.24	4.87	108.78	18.47	6.04	4.06	22.54		2.19			
AUG 21-31, 92	MEAN	39.43	11.75	276.35	16.02	15.65	7.84	76.37	0.15	833.05			
	STD. DEV.	11.70	7.91	93.83	13.06	9.31	6.43	18.74		4.37			
SEP 1-10, 92	MEAN	52.76	9.94	263.25	17.62	13.44	6.69	46.17	0.42	831.01			
	STD. DEV.	10.77	5.91	59.65	13.94	7.12	5.01	21.71		3.28			
SEP 11-20, 92	MEAN	50.44	9.69	252.52	19.06	13.09	6.59	45.68	0.55	828.64			
	STD. DEV.	10.66	7.25	70.74	15.21	8.46	6.19	19.77		3.08			
SEP 21-30, 92	MEAN	54.78	7.92	249.43	21.08	11.17	5.00	42.88	0.32	832.34			
	STD. DEV.	11.74	5.99	60.83	16.32	7.38	4.96	20.81		5.60			
OCT 1-10, 92	MEAN	47.46	8.83	174.66	30.17	11.75	6.17	53.00	4.27	833.14			
	STD. DEV.	13.83	6.55	116.54	19.86	7.49	5.80	27.56		5.23			
OCT 11-20, 92	MEAN	41.51	8.51	245.95	17.73	11.26	5.97	58.49	0.01	831.31			
	STD. DEV.	13.57	6.47	79.59	15.05	7.41	5.61	24.17		3.62			
OCT 21-30, 92	MEAN	43.55	7.42	209.53	18.29	10.08	4.97	56.70	0.35	830.18	171.16	103.35	43.48
	STD. DEV.	10.65	4.68	76.21	14.08	5.45	4.09	21.03		7.60	837.75	444.83	11.09
NOV 1-10, 92	MEAN	30.02	10.29	271.44	13.92	13.25	7.55	75.44	0.27	829.48	503.10	161.27	29.51
	STD. DEV.	5.32	6.93	55.49	11.17	7.95	6.07	13.36		5.54	1557.57	392.73	5.58
NOV 11-20, 92	MEAN	35.41	8.08	249.78	17.91	10.66	5.72	64.79	0.00	832.05	96.57	44.77	34.88
	STD. DEV.	6.46	6.21	58.30	15.43	7.17	5.36	12.42		3.27	550.70	189.65	6.79
NOV 21-30, 92	MEAN	22.92	7.93	248.75	19.54	10.72	5.45	61.78	0.01	832.17	46.58	15.27	22.09
	STD. DEV.	7.28	7.76	67.19	14.95	9.10	6.66	17.95		6.62	250.96	41.51	7.86
DEC 1-10, 92	MEAN	19.95	6.91	234.94	21.33	9.70	4.52	59.35	0.01	827.25	27.69	13.60	19.26
	STD. DEV.	9.31	6.48	72.40	17.21	7.70	5.43	16.36		5.83	153.24	55.44	9.84
DEC 11-20, 92	MEAN	18.41	9.32	243.81	14.70	12.15	6.66	66.04	0.03	825.15	62.40	47.47	18.09
	STD. DEV.	8.35	5.43	64.29	12.22	6.23	4.84	13.05		5.11	208.74	158.27	8.36
DEC 21-31, 92	MEAN	10.85	11.31	236.11	16.73	14.94	8.03	64.06	0.04	826.64	9.64	11.09	10.35
	STD. DEV.	19.20	7.83	83.17	15.48	8.69	6.96	13.26		5.20	18.62	18.82	19.10
JAN 1-10, 93	MEAN	8.30	8.02	213.08	18.62	11.09	5.67	68.75	0.04	824.42	38.41	15.89	7.80
	STD. DEV.	6.02	6.10	86.25	16.56	7.10	5.04	10.65		3.34	128.75	52.52	11.76
JAN 11-20, 93	MEAN	5.95	5.63	223.32	22.01	8.35	3.76	65.75	0.00	826.22	14.38	5.96	18.31
	STD. DEV.	4.77	4.86	68.82	17.34	5.65	4.02	10.47		2.69	69.10	24.47	12.20
JAN 21-31, 93	MEAN	28.03	9.53	235.10	16.07	12.23	7.01	65.54	0.03	832.61	104.38	116.73	27.96
	STD. DEV.	7.97	6.89	71.77	14.93	7.66	6.31	18.19		5.16	228.67	252.38	8.58
FEB 1-10, 93	MEAN	28.23	5.26	228.08	24.03	7.37	3.29	59.51	0.00	832.62	168.64		
	STD. DEV.	6.94	5.25	81.75	18.45	6.09	4.34	18.33		4.60	504.80		
FEB 11-20, 93	MEAN	9.04	10.34	251.19	13.92	12.97	7.87	73.34	0.04	827.50	114.13	140.81	9.33
	STD. DEV.	14.17	7.01	95.53	14.36	7.77	6.21	10.27		6.15	390.74	448.15	14.70
FEB 21-28, 93	MEAN	11.84	5.41	221.13	24.08	7.66	3.49	63.20	0.02	827.00	14.49	16.50	12.91
	STD. DEV.	10.34	5.25	77.67	18.89	5.94	4.65	15.81		4.68	45.63	31.33	12.10
MAR 1-10, 93	MEAN	32.77	10.13	237.93	16.99	12.91	7.65	59.22	0.01	833.75	6.05	10.03	33.63
	STD. DEV.	8.25	8.26	79.38	15.77	9.16	7.46	13.05		3.12	34.57	48.71	9.41
MAR 11-20, 93	MEAN	25.97	10.37	244.64	14.66	13.29	7.69	68.03	0.25	830.00	41.08	139.99	26.34
	STD. DEV.	11.74	6.84	74.93	13.27	7.84	6.07	17.61		7.54	279.07	665.70	11.73
MAR 21-31, 93	MEAN	40.06	7.16	235.69	16.71	9.85	4.63	68.44	0.09	828.30	370.17	181.82	40.17
	STD. DEV.	8.46	4.09	84.83	12.34	4.78	3.61	23.32		3.42	956.01	551.54	9.15
APR 1-10, 93	MEAN	38.34	8.24	241.25	16.59	11.33	5.39	59.78	0.20	825.55	42.62	25.23	38.54
	STD. DEV.	7.02	4.58	62.00	11.59	5.55	3.92	17.47		3.35	265.49	127.34	7.53
APR 11-20, 93	MEAN	35.03	8.08	249.00	15.81	10.60	5.75	73.90	0.38	827.25	235.46	1009.45	35.75
	STD. DEV.	5.94	5.92	90.49	13.51	6.66	5.29	18.12		4.33	581.69	2344.16	7.02
APR 21-30, 93	MEAN	40.35	8.76	262.44	15.94	11.72	6.00	63.34	0.67	829.55	180.30	60.71	40.50
	STD. DEV.	6.12	4.91	65.62	12.31	5.97	4.21	19.78		3.76	654.14	383.82	6.56
MAY 1-10, 93	MEAN	44.83	10.39	255.20	15.25	13.92	7.00	63.07	1.97	826.89	120.64	173.52	45.25
	STD. DEV.	8.23	5.55	81.16	11.10	6.54	4.79	23.59		6.18	343.03	713.17	8.89
MAY 11-20, 93	MEAN	57.25	7.63	182.11	18.79	10.75	4.78	57.35	1.18	831.83	22.69	32.02	58.41
	STD. DEV.	8.91	4.42	89.13	14.17	5.40	3.77	21.38		2.34	84.73	226.52	9.39
MAY 21-31, 93	MEAN	51.99	9.22	217.31	16.34	12.35	6.24	65.45	1.16	830.84	13.30	16.06	52.85
	STD. DEV.	7.97	5.22	95.88	12.61	6.05	4.60	17.99		3.31	58.07	103.63	8.38
JUN 1-10, 93	MEAN	47.72	9.40	205.61	14.51	12.37	6.58	75.17	1.33	827.19	67.14	21.79	48.10
	STD. DEV.	5.52	5.91	94.72	11.26	6.94	5.02	15.05		2.97	250.79	67.01	6.04
JUN 11-20, 93	MEAN	53.45	8.19	216.86	17.54	11.39	5.21	64.23	1.60	832.48	44.12	32.49	54.25
	STD. DEV.	10.73	5.22	83.95	12.95	6.37	4.32	20.03		3.70	164.80	203.79	11.46
JUN 21-30, 93	MEAN	54.40	11.68	255.67	15.27	15.38	8.18	55.89	0.55	828.95	2.19	3.01	55.21
	STD. DEV.	10.15	6.90	67.96	11.37	8.08	5.95	16.16		3.73	8.55	17.47	10.72
JUL 1-10, 93	MEAN	49.90	9.09	274.40	17.22	12.06	6.31	75.64	2.33	827.90	110.81	218.62	50.18
	STD. DEV.	5.58	6.10	75.51	14.12	7.19	5.26	16.53		3.56	282.96	845.31	6.27
JUL 11-20, 93	MEAN	51.31	7.89	214.20	17.33	10.84	5.12	75.01	1.27	832.76	77.52	97.66	29.97
	STD. DEV.	6.94	4.44	96.17	13.40	5.28	3.95	15.12		2.43	437.75	580.52	393.62
JUL 21-31, 93	MEAN	57.34	8.10	253.88	16.85	10.92	5.39	65.02	1.83	832.63	29.85	155.88	58.09
	STD. DEV.	8.52	4.28	75.86	13.16	5.09	3.75	19.79		3.15	73.81	557.24	9.31
AUG 1-10, 92	MEAN	59.66	6.23	213.15	23.69	9.11	3.56	60.83	0.71	835.38	129.96	142.26	60.94
	STD. DEV.	8.78	4.48	89.61	16.08	5.47	3.75	20.39		4.26	740.24	604.99	9.75
AUG 11-20, 93	MEAN	57.59	7.39	196.38	18.87	10.42	4.58	70.88	0.60	833.05	152.85	69.98	58.42
	STD. DEV.	7.38	4.34	88.96	13.37	5.27	3.68	16.02		2.67	699.55	269.52	8.36
AUG 21-31, 93	MEAN	51.51	7.20	255.78	19.28	9.92	4.68	67.07	2.66	833.13	150.54	73.55	52.06
	STD. DEV.	8.93	4.80	79.39	15.22	5.62	4.19	19.75		3.65	719.57	356.81	9.67
SEP 1-10, 93	MEAN	54.94	7.63	218.40	18.11	10.42	5.02	61.85	0.29	835.57	86.71	126.91	55.83
	STD. DEV.	8.11	4.85	98.08	14.21	5.66	4.24	20.22		2.85	316.30	405.78	8.94
SEP 11-20, 93	MEAN	44.58	8.50	238.09	16.13	11.22	5.92	69.13	0.60	829.97	768.72	812.99	44.91
	STD. DEV.	10.52	6.30	90.71	14.10	7.37	5.40	22.05		3.81	2012.83	2044.75	11.23

NOTE: EMPTY CELLS INDICATE MISSING OR DEFECTIVE SENSORS

Table 11: Rostad Ranch Mean and Standard Deviation
For Ten Day Periods of Meteorological Parameters
(Sum is given for precipitation)

DATES		MEAN AIR TEMP. (DEG. F)	MEAN WIND SPEED (MPH)	MEAN WIND DIRECT. (DEG.)	DIR. STND. DEVIAT. (DEG.)	MAX. WIND SPEED (MPH)	MIN. WIND SPEED (MPH)	MEAN RELATIVE HUMIDITY (%)	TOTAL PRECIP. (INCHES)	MEAN BARO PRESSURE (MBAR)	MEAN TOP RESIST. (KOHMS)	MEAN BOTTOM RESIST. (KOHMS)	MEAN INSUL. TEMP. (DEG. F)
AUG 1-10, 92	MEAN	64.20	5.63	204.49	20.83	8.68	2.97	40.23	0.00	829.05			
	STD. DEV.	10.89	3.91	66.00	11.57	5.13	2.97	19.71		4.11			
AUG 11-20, 92	MEAN	62.80	4.20	166.64	24.44	6.94	1.86	50.85	0.30	833.44			
	STD. DEV.	11.51	2.82	83.24	13.55	4.05	1.97	22.63		2.07			
AUG 21-31, 92	MEAN	46.43	5.68	188.97	19.27	8.50	3.14	61.20	0.60	829.20			
	STD. DEV.	12.74	3.65	75.71	10.76	4.77	2.77	22.78		3.59			
SEP 1-10, 92	MEAN	51.45	8.91	222.02	15.08	12.31	5.90	47.67	0.27	826.41			
	STD. DEV.	10.37	4.57	39.74	7.88	5.89	3.59	20.41		3.01			
SEP 11-20, 92	MEAN	49.31	8.28	202.68	16.63	11.42	5.48	48.10	0.48	823.79			
	STD. DEV.	11.18	4.85	57.45	10.41	6.04	3.89	21.13		2.85			
SEP 21-30, 92	MEAN	53.84	9.23	211.62	15.29	12.55	6.29	43.18	0.24	827.76			
	STD. DEV.	11.50	5.10	36.44	9.81	6.41	4.08	19.95		5.71			
OCT 1-10, 92	MEAN	46.41	7.14	198.47	17.48	10.05	4.58	52.67	1.64	828.18			
	STD. DEV.	13.20	3.94	58.24	11.82	4.84	3.32	24.92		4.76			
OCT 11-20, 92	MEAN	40.96	7.15	206.59	16.08	9.89	4.76	56.87	0.03	825.80			
	STD. DEV.	12.91	4.82	61.11	10.89	5.91	3.89	22.21		3.56			
OCT 21-30, 92	MEAN	42.47	6.90	186.46	15.95	9.49	4.80	56.91	0.38	824.68	284.03	389.42	41.12
	STD. DEV.	11.68	4.52	56.75	11.40	5.53	3.61	21.96		7.75	1149.21	1083.40	12.74
NOV 1-10, 92	MEAN	29.31	9.10	219.68	11.95	11.94	6.51	73.49	0.69	822.85	816.77	99.85	28.41
	STD. DEV.	5.18	4.18	39.92	6.33	4.86	3.67	13.03		5.37	1934.42	297.57	5.52
NOV 11-20, 92	MEAN	34.33	8.47	206.23	11.43	11.04	6.14	65.43	0.00	825.85	5.11	4.65	32.98
	STD. DEV.	6.37	4.31	26.52	6.07	5.27	3.54	11.24		3.39	5.03	3.15	7.18
NOV 21-30, 92	MEAN	23.70	10.04	208.98	11.56	13.06	7.33	57.82	0.02	824.93	4.59	3.82	22.29
	STD. DEV.	7.10	4.88	36.55	5.29	6.02	3.95	17.37		6.67	4.07	2.42	8.36
DEC 1-10, 92	MEAN	8.56	8.36	195.24	12.98	11.51	5.93	55.56	0.00	819.93	7.89	3.49	18.85
	STD. DEV.	4.31	4.30	54.36	7.70	5.23	3.65	15.83		5.70	29.75	5.52	9.66
DEC 11-20, 92	MEAN	10.15	9.97	203.65	12.43	13.15	7.49	65.78	0.01	817.53	78.10	29.24	17.27
	STD. DEV.	6.13	6.11	52.06	8.82	7.13	5.26	13.03		5.22	299.45	121.16	8.22
DEC 21-31, 92	MEAN	10.44	10.15	204.05	16.08	14.12	7.33	64.16	0.00	818.92	16.73	5.10	11.18
	STD. DEV.	7.58	7.61	75.96	12.39	8.65	6.58	12.61		5.28	52.50	7.40	17.94
JAN 1-10, 93	MEAN	8.05	7.78	172.20	15.67	11.02	5.56	65.44	0.03	816.79	12.98	4.78	8.03
	STD. DEV.	4.83	4.90	65.55	12.90	5.52	4.33	10.75		3.23	42.82	8.78	11.99
JAN 11-20, 93	MEAN	8.70	8.53	196.72	14.51	11.16	6.52	67.00	0.02	818.72	13.07	3.48	17.11
	STD. DEV.	6.53	6.53	52.97	12.95	7.32	5.67	9.68		2.69	43.40	7.97	11.94
JAN 21-31, 93	MEAN	28.40	10.91	201.51	11.01	13.79	8.29	63.18	0.21	825.51	244.95	37.09	27.07
	STD. DEV.	7.96	5.49	47.31	7.99	6.20	4.90	18.52		5.26	801.90	123.84	8.27
FEB 1-10, 93	MEAN	28.57	5.92	179.36	14.46	8.03	4.08	55.61	0.02	825.88	18.82	4.27	26.77
	STD. DEV.	7.43	3.55	62.69	11.74	4.10	3.14	17.38		4.61	52.22	8.26	9.28
FEB 11-20, 93	MEAN	10.08	7.08	172.03	12.85	9.51	4.93	69.70	0.00	820.02	9.72	3.38	9.15
	STD. DEV.	14.53	3.49	70.30	9.90	3.99	3.11	9.48		6.01	34.49	3.41	15.61
FEB 21-28, 93	MEAN	13.52	8.57	184.92	11.40	10.84	6.48	61.05	0.00	819.57	2.80	1.96	12.15
	STD. DEV.	9.88	4.86	57.49	9.29	5.37	4.38	14.99		4.77	2.23	1.01	10.91
MAR 1-10, 93	MEAN	31.97	10.62	201.05	10.59	13.43	8.01	58.94	0.01	827.18	27.96	5.15	30.69
	STD. DEV.	8.16	4.46	34.04	6.72	5.22	3.91	12.66		3.13	126.64	20.64	9.28
MAR 11-20, 93	MEAN	25.59	8.51	197.80	14.18	11.31	6.01	65.24	0.24	823.16	347.95	35.94	24.65
	STD. DEV.	11.73	5.55	69.47	9.94	6.82	4.75	16.22		7.43	1051.43	139.87	12.36
MAR 21-31, 93	MEAN	39.17	6.44	176.50	16.86	9.05	4.17	68.04	0.14	822.74	1272.33	267.84	38.41
	STD. DEV.	7.90	4.30	74.83	11.60	5.12	3.61	21.05		2.74	2502.48	510.84	8.37
APR 1-10, 93	MEAN	36.88	8.03	209.07	15.67	11.01	5.31	62.09	0.18	819.40	443.27	38.96	35.77
	STD. DEV.	7.61	4.40	43.05	9.75	5.55	3.47	18.72		3.27	1485.66	199.27	9.41
APR 11-20, 93	MEAN	33.71	5.47	173.13	16.84	7.95	3.32	75.52	0.87	821.70	1516.71	75.78	32.88
	STD. DEV.	6.10	3.81	75.55	10.24	4.85	3.04	16.88		4.40	2665.31	197.20	7.72
APR 21-30, 93	MEAN	39.31	7.51	217.32	15.93	10.41	4.81	63.51	0.19	823.63	248.50	43.08	38.53
	STD. DEV.	6.62	3.92	51.19	9.48	5.07	3.07	19.11		3.83	1017.09	158.70	8.37
MAY 1-10, 93	MEAN	44.14	7.74	183.23	16.92	10.97	4.88	63.85	2.21	821.29	294.96	64.10	43.13
	STD. DEV.	8.30	4.76	79.82	10.18	5.86	3.94	22.49		6.36	623.47	191.03	9.52
MAY 11-20, 93	MEAN	54.60	4.96	162.28	23.05	7.79	2.48	61.96	0.69	827.42	230.50	58.40	53.23
	STD. DEV.	10.64	3.22	82.04	12.41	4.50	2.36	21.38		2.24	671.88	179.78	12.78
MAY 21-31, 93	MEAN	50.50	5.82	169.06	20.69	8.78	3.19	68.10	0.59	826.10	184.52	31.35	49.53
	STD. DEV.	8.58	3.32	82.18	12.44	4.46	2.54	16.92		3.23	978.77	108.02	10.27
JUN 1-10, 93	MEAN	46.64	6.37	166.85	18.45	9.44	3.74	75.92	1.27	822.22	310.61	82.33	45.91
	STD. DEV.	5.88	3.59	86.82	10.64	4.70	2.87	14.56		2.99	616.65	191.07	6.88
JUN 11-20, 93	MEAN	51.98	7.23	179.81	17.71	10.44	4.42	66.27	1.00	827.75	250.65	27.38	50.56
	STD. DEV.	10.80	4.87	74.92	10.05	6.24	3.92	18.41		3.87	588.48	76.60	11.83
JUN 21-30, 93	MEAN	53.00	8.68	219.77	18.85	12.39	5.42	58.93	0.24	824.31	19.02	2.31	51.84
	STD. DEV.	10.36	4.77	55.70	10.86	6.19	3.78	16.15		3.66	118.09	3.34	11.30
JUL 1-10, 93	MEAN	49.31	5.46	200.22	18.60	8.11	3.16	75.44	1.66	823.09	184.73	57.41	48.46
	STD. DEV.	5.90	3.08	73.91	10.65	4.15	2.33	15.08		3.65	665.22	135.41	7.28
JUL 11-20, 93	MEAN	50.00	4.81	164.28	22.14	7.48	2.50	77.18	1.09	828.13	354.04	62.55	49.17
	STD. DEV.	7.43	3.11	86.43	12.79	4.17	2.38	14.28		2.30	1081.24	125.81	8.81
JUL 21-31, 93	MEAN	55.63	5.70	197.37	18.12	8.28	3.38	69.32	1.00	828.05	54.65	79.58	54.27
	STD. DEV.	8.88	3.36	62.16	9.67	4.33	2.66	19.35		3.19	262.29	325.17	10.03
AUG 1-10, 93	MEAN	57.76	4.90	178.18	21.91	7.46	2.69	64.01	0.60	830.77	40.80	51.01	56.15
	STD. DEV.	9.34	3.30	72.60	13.77	4.33	2.61	18.87		4.25	183.44	193.98	11.24
AUG 11-20, 93	MEAN	55.98	5.92	166.87	21.00	8.76	3.39	74.25	1.32	828.25	55.51	77.51	55.02
	STD. DEV.	7.85	3.72	81.87	12.86	4.73	2.98	15.19		2.62	223.46	228.30	9.57
AUG 21-31, 93	MEAN	50.20	6.12	189.35	18.07	8.74	3.79	70.84	1.81	827.88	58.97	71.57	49.06
	STD. DEV.	8.65	3.75	70.20	10.48	4.71	3.07	18.15		3.33	151.54	199.11	10.00
SEP 1-10, 93	MEAN	53.11	6.14	174.94	18.30	8.92	3.68	64.10	0.35	830.74	143.32	65.57	52.07
	STD. DEV.	8.76	3.66	74.95	9.62	4.83	2.94	19.86		2.78	486.87	184.63	10.67
SEP 11-20, 93	MEAN	43.55	5.49	183.06	20.29	8.07	3.19	69.16	0.44	824.91	169.40	87.48	43.01
	STD. DEV.	10.52	4.01	77.13	12.25	5.07	3.08	20.35		3.49	638.64	267.93	11.86

NOTE: EMPTY CELLS INDICATE MISSING OR DEFECTIVE SENSORS

Table 12: White Ranch Mean and Standard Deviation
For Ten Day Periods of Meteorological Parameters
(Sum is given for precipitation)

DATES		MEAN AIR TEMP. (DEG. F)	MEAN WIND SPEED (MPH)	MEAN WIND DIRECT. (DEG.)	DIR. STND. DEVIAT. (DEG.)	MAX. WIND SPEED (MPH)	MIN. WIND SPEED (MPH)	MEAN RELATIVE HUMIDITY (%)	TOTAL PRECIP. (INCHES)	MEAN BARO PRESSURE (MBAR)	MEAN TOP RESIST. (KOHMS)	MEAN BOTTOM RESIST. (KOHMS)	MEAN INSUL. TEMP. (DEG. F)
AUG 1-10, 92	MEAN	63.25	6.30	212.52	15.13	8.87	3.91	49.55	0.15	841.82			
	STD. DEV.	10.84	2.86	83.81	11.92	3.80	2.58	21.91		5.31			
AUG 11-20, 92	MEAN	63.66	6.35	212.61	14.00	8.74	4.17	54.44	0.20	845.17			
	STD. DEV.	11.82	2.58	79.55	10.42	3.29	2.52	22.46		2.47			
AUG 21-31, 92	MEAN	48.73	6.39	211.76	16.12	9.03	3.96	62.11	0.37	842.03			
	STD. DEV.	12.32	3.51	92.05	12.20	4.58	2.87	23.87		3.80			
SEP 1-10, 92	MEAN	53.98	9.42	261.11	15.09	13.08	6.16	44.05	0.32	838.36			
	STD. DEV.	10.73	4.97	66.49	9.79	6.47	3.81	19.14		3.60			
SEP 11-20, 92	MEAN	52.33	9.09	242.18	16.73	12.73	5.90	45.65	0.34	836.00			
	STD. DEV.	11.80	5.49	78.45	11.36	6.93	4.47	19.46		3.38			
SEP 21-30, 92	MEAN	56.38	10.09	243.10	15.99	13.93	6.66	39.19	0.00	839.41			
	STD. DEV.	12.69	6.26	67.80	12.19	7.96	5.07	18.10		6.14			
OCT 1-10, 92	MEAN	49.13	8.56	239.76	14.89	11.71	5.75	48.09	0.53	840.39			
	STD. DEV.	12.98	4.50	76.96	10.56	5.78	3.67	22.12		5.38			
OCT 11-20, 92	MEAN	41.69	7.26	217.63	17.26	10.29	4.56	59.81	0.06	838.93			
	STD. DEV.	15.17	5.72	91.17	12.99	7.40	4.46	26.28		4.07			
OCT 21-30, 92	MEAN	44.76	6.66	211.23	17.08	9.39	4.25	54.48	0.04	837.72			
	STD. DEV.	12.31	3.93	80.57	13.29	4.96	3.35	21.17		7.35	24.59	334.71	12.46
NOV 1-10, 92	MEAN	34.23	9.50	262.67	16.62	13.37	6.11	57.53	0.00	836.22	0.58	71.16	33.38
	STD. DEV.	6.67	4.76	78.17	13.08	5.93	4.02	14.25		5.67	0.19	332.36	6.71
NOV 11-20, 92	MEAN	38.27	8.86	256.55	16.20	12.14	5.90	55.20	0.00	838.90	0.53	3.26	37.59
	STD. DEV.	8.54	5.98	74.52	12.92	7.50	4.85	13.71		3.00	0.36	8.87	8.33
NOV 21-30, 92	MEAN	27.12	9.79	259.16	15.55	13.43	6.49	47.35	0.13	838.47	0.49	1.65	26.89
	STD. DEV.	10.39	6.52	62.02	11.76	8.53	5.12	17.88		6.60	0.02	0.66	10.26
DEC 1-10, 92	MEAN	21.25	8.08	233.64	15.09	10.99	5.50	55.52	0.00	834.31	0.49	11.00	21.85
	STD. DEV.	10.15	5.22	78.97	13.14	6.51	4.41	15.58		6.05	0.04	37.39	9.28
DEC 11-20, 92	MEAN	21.66	9.35	227.92	16.19	12.99	6.17	60.00	0.00	831.91	0.54	88.63	21.35
	STD. DEV.	9.83	6.86	82.55	13.04	8.65	5.80	17.68		5.13	0.14	340.33	9.47
DEC 21-31, 92	MEAN	12.70	11.07	215.16	13.71	15.02	7.58	62.04	2.53	834.08	0.52	9.64	12.19
	STD. DEV.	22.03	9.89	87.34	9.91	12.47	7.73	19.41		5.12	0.08	20.66	21.98
JAN 1-10, 93	MEAN	6.20	5.89	214.26	15.87	8.57	4.01	67.76	0.01	832.50	0.51	4.29	8.93
	STD. DEV.	3.77	3.80	78.93	14.49	4.84	3.23	14.59		3.71	0.05	9.60	11.56
JAN 11-20, 93	MEAN	6.85	6.30	214.50	16.82	9.33	4.21	67.35	0.11	833.45	0.49	2.80	19.25
	STD. DEV.	4.91	4.92	77.46	14.86	6.28	4.13	15.07		3.10	0.05	3.56	14.37
JAN 21-31, 93	MEAN	11.82	11.54	248.96	12.95	15.59	8.49	59.60	0.09	839.19	0.66	129.08	31.65
	STD. DEV.	8.56	8.53	79.39	10.75	10.68	6.98	20.30		5.03	0.44	373.90	11.00
FEB 1-10, 93	MEAN	31.00	7.04	211.77	11.25	9.05	5.14	57.49	0.04	839.70	0.59	121.66	31.47
	STD. DEV.	11.12	4.02	85.33	9.75	4.78	3.50	22.54		4.34	0.27	360.88	11.13
FEB 11-20, 93	MEAN	9.56	6.61	206.62	10.84	8.64	4.74	71.91	0.08	835.71	0.54	10.54	10.61
	STD. DEV.	16.07	3.66	78.67	8.71	4.53	3.08	12.77		5.66	0.07	18.15	16.16
FEB 21-28, 93	MEAN	13.26	5.86	208.36	16.97	8.23	3.68	63.91	0.07	834.29	0.54	7.77	15.50
	STD. DEV.	14.21	3.93	76.28	15.20	4.93	3.49	19.37		3.64	0.10	14.96	15.28
MAR 1-10, 93	MEAN	36.64	11.36	251.39	12.82	15.06	8.01	53.15	0.00	840.54	0.54	8.38	37.17
	STD. DEV.	10.25	6.62	77.21	9.02	8.28	5.32	18.09		3.24	0.20	44.69	10.32
MAR 11-20, 93	MEAN	27.68	7.82	217.30	16.79	10.99	5.03	63.51	0.15	837.61	0.73	74.40	28.54
	STD. DEV.	13.71	6.19	87.39	12.22	7.85	4.91	19.12		8.31	0.59	246.76	13.43
MAR 21-31, 93	MEAN	42.09	6.42	179.63	16.85	9.19	4.00	65.87	0.39	836.41	2.96	151.73	42.43
	STD. DEV.	10.31	4.51	91.72	13.21	5.74	3.70	28.04		2.95	6.85	296.28	11.10
APR 1-10, 93	MEAN	40.80	8.99	241.71	16.23	12.34	5.89	52.49	0.07	832.86	0.50	2.64	41.53
	STD. DEV.	7.95	4.97	78.99	11.56	6.21	4.16	18.40		3.53	0.02	7.08	9.01
APR 11-20, 93	MEAN	35.16	6.91	214.36	11.66	9.11	4.85	75.14	1.56	835.95	2.28	106.58	37.49
	STD. DEV.	6.90	4.38	91.08	9.67	5.36	3.63	17.31		4.67	7.80	289.60	9.26
APR 21-30, 93	MEAN	42.46	9.09	254.08	15.27	12.25	6.15	57.98	0.26	837.07	1.08	24.83	43.05
	STD. DEV.	7.08	4.82	82.49	10.68	5.95	3.90	17.93		4.00	0.68	130.22	8.33
MAY 1-10, 93	MEAN	46.94	8.97	231.94	15.07	12.35	5.98	59.67	0.72	834.53	1.12	18.10	47.63
	STD. DEV.	7.60	5.74	89.51	10.34	7.31	4.63	20.99		6.37	0.67	57.40	9.12
MAY 11-20, 93	MEAN	55.14	6.27	180.07	15.44	8.85	3.91	63.03	0.68	840.18	0.98	17.86	56.90
	STD. DEV.	10.02	3.19	80.23	11.24	4.15	2.75	19.59		2.46	0.35	81.32	11.51
MAY 21-31, 93	MEAN	52.51	7.51	207.39	15.04	10.29	4.98	64.17	0.55	839.03	1.47	2.86	53.78
	STD. DEV.	8.60	4.10	90.80	10.75	5.18	3.38	17.60		3.50	0.56	4.94	9.76
JUN 1-10, 93	MEAN	48.64	6.85	204.20	15.42	9.51	4.36	74.29	2.41	835.31	2.25	47.42	48.89
	STD. DEV.	6.59	4.05	100.48	10.35	5.02	3.27	15.84		2.98	0.52	118.84	7.45
JUN 11-20, 93	MEAN	54.05	8.44	214.90	15.74	11.75	5.49	64.21	0.58	840.37	2.13	23.09	55.45
	STD. DEV.	10.31	5.35	84.15	11.00	6.97	4.19	18.70		4.18	0.41	92.73	11.90
JUN 21-30, 93	MEAN	56.15	10.50	249.28	16.52	14.62	6.86	54.83	0.45	836.55	16.22	1.32	57.53
	STD. DEV.	9.63	6.03	76.42	10.84	7.77	4.67	14.47		3.75	227.36	0.51	11.26
JUL 1-10, 93	MEAN	52.06	8.22	246.54	14.14	11.13	5.56	71.63	1.57	835.62	477.26	6.91	53.07
	STD. DEV.	6.07	4.88	91.49	9.13	6.18	3.79	15.58		3.99	1341.49	8.51	7.59
JUL 11-20, 93	MEAN	52.28	5.66	186.08	18.27	8.31	3.30	75.26	1.17	841.11	332.98	8.16	53.89
	STD. DEV.	6.97	3.37	98.33	11.27	4.35	2.72	13.89		2.38	1169.90	10.94	8.67
JUL 21-31, 93	MEAN	58.43	6.38	233.96	17.49	9.12	3.92	66.02	1.93	840.02	45.59	79.80	39.47
	STD. DEV.	8.57	3.56	91.64	12.11	4.61	2.83	18.96		3.01	379.54	491.17	9.84
AUG 1-10, 93	MEAN	60.03	5.77	205.19	18.07	8.37	3.39	62.85	0.54	842.76	13.82	4.94	61.48
	STD. DEV.	9.43	3.14	86.64	12.86	4.19	2.58	19.30		4.56	90.50	20.18	9.99
AUG 11-20, 93	MEAN	57.87	6.58	205.03	16.86	9.34	4.13	71.64	0.75	840.44	116.24	23.99	58.97
	STD. DEV.	7.68	3.80	91.33	11.12	4.92	3.06	16.84		2.87	708.89	91.94	8.27
AUG 21-31, 93	MEAN	53.21	6.52	233.67	17.39	9.34	3.98	66.63	1.19	840.16	40.23	37.74	54.05
	STD. DEV.	8.52	3.80	88.45	11.45	4.92	3.06	18.42		3.94	129.41	155.06	9.79
SEP 1-10, 93	MEAN	55.52	6.72	222.57	15.01	9.44	4.31	62.23	0.79	842.89	119.45	56.48	56.26
	STD. DEV.	9.35	3.77	89.02	10.60	5.01	2.98	22.95		3.13	567.80	158.30	9.46
SEP 11-20, 93	MEAN	45.53	6.90	219.71	15.30	9.62	4.51	69.80	0.75	837.73	239.55	45.53	46.00
	STD. DEV.	11.66	4.18	88.87	10.49	5.42	3.38	22.80		4.23	850.41	125.96	11.96

NOTE: EMPTY CELLS INDICATE MISSING OR DEFECTIVE SENSORS

Table 13: Cooney Ranch Mean and Standard Deviation
For Ten Day Periods of Meteorological Parameters
(Sum is given for precipitation)

DATES		MEAN AIR TEMP. (DEG. F)	MEAN WIND SPEED (MPH)	MEAN WIND DIRECT. (DEG.)	DIR. STND. DEVIAT. (DEG.)	MAX. WIND SPEED (MPH)	MIN. WIND SPEED (MPH)	MEAN RELATIVE HUMIDITY (%)	TOTAL PRECIP. (INCHES)	MEAN BARO PRESSURE (MBAR)	MEAN TOP RESIST. (KOHMS)	MEAN BOTTOM RESIST. (KOHMS)	MEAN INSUL. TEMP. (DEG. F)
AUG 1-10, 92	MEAN	69.45	7.51	212.40	23.36	10.84	4.45	37.24	0.26	864.00			
	STD. DEV.	9.09	6.12	121.83	15.69	7.16	5.30	18.38		5.26			
AUG 11-20, 92	MEAN	68.90	6.59	212.52	20.42	9.66	3.76	42.48	0.31	868.04			
	STD. DEV.	10.21	4.73	106.75	14.22	5.91	3.95	20.17		2.57			
AUG 21-31, 92	MEAN	51.80	9.36	187.54	16.78	12.60	6.22	56.07	0.16	864.80			
	STD. DEV.	12.15	7.52	123.66	11.75	8.86	6.28	23.16		3.92			
SEP 1-10, 92	MEAN	57.10	10.45	265.22	16.65	14.11	7.14	40.23	0.32	861.19			
	STD. DEV.	10.96	6.18	96.10	11.94	7.56	5.21	19.15		3.64			
SEP 11-20, 92	MEAN	55.51	10.94	234.93	17.48	14.59	7.58	39.27	0.20	858.72			
	STD. DEV.	11.19	7.64	106.12	13.28	8.94	6.49	16.58		3.45			
SEP 21-30, 92	MEAN	60.18	9.88	255.60	17.94	13.47	6.60	33.60	0.00	862.33			
	STD. DEV.	12.21	7.16	81.08	13.00	8.61	5.90	15.86		6.18			
OCT 1-10, 92	MEAN	52.14	8.41	230.87	16.70	11.49	5.64	44.16	0.39	863.24			
	STD. DEV.	13.52	6.01	105.92	12.64	7.17	5.14	22.30		5.48			
OCT 11-20, 92	MEAN	43.24	8.76	215.08	17.05	11.74	6.02	56.96	0.04	861.75			
	STD. DEV.	14.76	7.82	114.56	12.32	9.29	6.60	23.71		4.12			
OCT 21-30, 92	MEAN	47.97	7.68	234.68	18.16	10.58	5.04	49.10	0.08	860.60			
	STD. DEV.	12.33	5.99	97.47	13.16	7.03	5.15	19.71		7.49			
NOV 1-10, 92	MEAN	35.54	10.18	254.96	15.65	13.41	7.19	59.11	0.04	859.02	109.02	65.82	35.37
	STD. DEV.	6.10	6.28	110.22	12.56	7.48	5.27	15.69		5.68	425.31	255.76	6.19
NOV 11-20, 92	MEAN	39.38	8.89	257.74	17.28	11.67	6.22	55.15	0.00	861.82	82.73	49.71	39.30
	STD. DEV.	8.25	6.37	106.13	14.03	7.41	5.47	14.98		3.22	466.82	300.28	8.44
NOV 21-30, 92	MEAN	29.38	10.33	258.65	15.51	13.59	7.30	45.27	0.00	861.33	26.83	1.86	29.25
	STD. DEV.	9.55	7.16	102.38	11.40	8.75	5.96	16.94		6.74	227.17	2.99	9.79
DEC 1-10, 92	MEAN	8.52	8.21	254.24	17.79	11.36	5.77	52.01	0.00	856.84	7.39	2.03	23.67
	STD. DEV.	6.12	6.20	92.42	14.12	7.00	5.36	13.34		6.10	19.29	2.67	9.53
DEC 11-20, 92	MEAN	9.41	9.12	255.17	15.98	12.54	6.54	60.04	0.01	854.64	228.83	51.44	22.27
	STD. DEV.	7.04	7.09	95.85	13.27	8.32	6.13	16.15		5.13	991.41	192.74	9.52
DEC 21-31, 92	MEAN	10.74	10.49	208.83	14.36	14.08	7.74	60.67	0.01	857.87	3.46	1.94	12.56
	STD. DEV.	8.77	8.73	110.36	11.90	10.56	7.35	15.19		5.22	2.10	0.92	21.63
JAN 1-10, 93	MEAN	7.59	7.30	209.68	18.43	10.31	5.09	65.77	0.02	855.48	2.23	1.62	9.56
	STD. DEV.	6.46	6.51	121.49	15.17	7.41	5.65	10.73		4.15	0.78	0.51	10.29
JAN 11-20, 93	MEAN	6.55	6.22	251.00	21.14	9.09	4.19	64.76	0.16	856.46	4.51	2.09	19.46
	STD. DEV.	7.02	7.03	91.72	15.22	8.17	6.09	11.13		3.39	8.72	1.86	14.12
JAN 21-31, 93	MEAN	32.68	9.92	254.27	15.02	13.09	7.00	59.30	0.05	862.13	280.39	38.27	32.93
	STD. DEV.	10.02	6.62	96.47	12.71	7.82	5.74	17.71		5.11	820.46	143.29	10.39
FEB 1-10, 93	MEAN	33.47	8.06	224.24	16.60	10.65	5.53	55.51	0.00	862.50	332.74	59.31	33.82
	STD. DEV.	9.19	6.87	114.96	13.13	7.83	6.02	19.25		4.55	903.92	164.70	9.65
FEB 11-20, 93	MEAN	12.51	9.13	192.19	14.37	11.69	6.73	66.76	0.01	858.92	41.40	7.29	13.14
	STD. DEV.	14.21	6.96	130.23	12.66	7.93	6.07	12.43		6.08	140.64	13.87	14.53
FEB 21-28, 93	MEAN	13.75	5.34	237.57	18.83	7.36	3.45	62.63	0.03	857.39	61.19	6.17	15.91
	STD. DEV.	12.17	4.45	95.25	15.24	5.07	3.95	15.08		3.67	182.20	13.32	13.62
MAR 1-10, 93	MEAN	38.68	10.99	271.29	13.87	13.99	8.17	51.90	0.00	863.47	43.01	6.76	39.29
	STD. DEV.	9.25	7.09	85.43	10.81	8.32	6.07	16.30		3.35	191.66	36.36	9.52
MAR 11-20, 93	MEAN	28.74	9.69	204.18	15.48	12.78	6.78	61.74	0.05	860.69	73.58	5.15	29.53
	STD. DEV.	12.90	7.67	113.99	11.80	9.23	6.40	16.12		8.44	371.72	19.74	12.79
MAR 21-31, 93	MEAN	43.93	8.36	172.89	16.68	11.33	5.63	63.64	0.14	859.32	831.24	129.41	44.26
	STD. DEV.	10.21	6.23	117.22	13.07	7.27	5.30	25.98		3.10	1981.13	245.96	10.75
APR 1-10, 93	MEAN	43.81	9.45	258.27	16.62	12.65	6.41	48.97	0.10	855.60	6.49	7.43	44.73
	STD. DEV.	7.57	5.69	96.32	11.94	6.97	4.78	18.29		3.66	37.28	46.68	8.13
APR 11-20, 93	MEAN	39.00	8.11	221.25	15.94	10.83	5.47	68.33	1.37	858.79	538.29	45.78	39.86
	STD. DEV.	6.99	5.31	112.38	11.42	6.33	4.49	19.37		4.95	1641.74	119.37	7.57
APR 21-30, 93	MEAN	45.50	10.80	270.10	14.40	14.12	7.60	53.90	0.28	859.72	36.81	8.82	46.34
	STD. DEV.	7.08	5.64	88.91	9.89	6.73	4.83	18.38		4.16	263.16	52.70	7.68
MAY 1-10, 93	MEAN	50.09	11.40	213.87	15.47	14.96	8.01	54.08	0.32	857.03	37.08	12.73	50.97
	STD. DEV.	7.71	6.50	120.48	11.38	7.48	5.68	20.73		6.66	136.33	46.47	8.38
MAY 11-20, 93	MEAN	58.40	6.56	186.49	18.89	9.64	3.74	55.86	0.78	863.04	32.76	2.75	60.24
	STD. DEV.	9.24	5.30	98.06	12.22	6.82	4.27	18.97		2.54	231.69	10.48	9.96
MAY 21-31, 93	MEAN	55.95	9.12	195.47	17.44	12.47	6.02	55.96	0.29	861.71	3.73	0.89	57.26
	STD. DEV.	8.32	5.83	120.58	12.54	6.97	5.01	16.14		3.64	19.93	0.38	8.98
JUN 1-10, 93	MEAN	51.85	8.15	202.23	16.37	11.15	5.39	69.33	1.23	857.93	205.77	7.52	52.55
	STD. DEV.	6.56	5.47	118.70	11.50	6.50	4.64	16.66		3.16	789.36	31.24	7.22
JUN 11-20, 93	MEAN	57.96	9.14	219.86	17.61	12.60	5.92	57.78	0.61	863.20	100.18	6.35	59.46
	STD. DEV.	10.47	6.46	100.73	12.68	7.92	5.34	19.68		4.31	595.46	23.90	11.50
JUN 21-30, 93	MEAN	60.46	12.72	267.68	16.98	16.98	8.78	46.23	0.37	858.92	1.98	0.77	61.81
	STD. DEV.	9.70	7.18	86.09	12.27	8.55	6.07	14.60		3.78	8.97	0.28	10.70
JUL 1-10, 93	MEAN	55.57	10.92	233.32	14.59	14.31	7.71	64.74	2.96	857.92	61.47	8.62	56.33
	STD. DEV.	5.93	6.08	129.57	10.13	7.13	5.22	16.91		4.25	239.57	26.01	6.94
JUL 11-20, 93	MEAN	54.77	6.94	179.81	17.48	10.02	4.21	72.34	1.23	863.93	83.43	20.16	40.62
	STD. DEV.	6.42	4.56	114.97	11.28	5.73	3.81	14.43		2.35	465.44	324.92	327.42
JUL 21-31, 93	MEAN	62.20	8.71	226.42	16.32	11.75	5.81	60.06	1.66	862.78	37.84	13.66	63.04
	STD. DEV.	8.26	5.54	119.86	11.80	6.57	4.67	18.93		3.16	167.74	59.25	9.31
AUG 1-10, 93	MEAN	64.15	7.43	200.78	18.86	10.67	4.58	55.18	1.63	865.76	5.50	2.25	65.40
	STD. DEV.	8.46	5.11	107.63	12.92	6.59	4.30	18.01		4.68	27.08	4.50	9.85
AUG 11-20, 93	MEAN	61.71	8.23	197.33	17.74	11.40	5.27	64.82	0.26	863.33	135.14	27.37	62.62
	STD. DEV.	7.09	5.82	114.45	13.06	6.87	5.03	16.76		3.02	737.45	110.89	8.36
AUG 21-31, 93	MEAN	56.72	8.95	218.17	16.57	12.13	6.05	59.30	1.05	862.89	41.57	25.75	57.70
	STD. DEV.	9.30	5.88	122.28	11.29	6.88	5.11	17.31		4.08	153.77	119.65	10.40
SEP 1-10, 93	MEAN	57.90	7.35	216.47	16.15	10.15	4.79	59.78	0.79	865.68	80.18	60.53	58.90
	STD. DEV.	8.51	5.22	114.26	11.64	6.39	4.37	21.69		3.22	293.87	182.93	9.52
SEP 11-20, 93	MEAN	49.06	8.95	206.51	17.47	12.04	6.11	64.52	0.99	860.42	139.19	10.80	49.51
	STD. DEV.	10.65	7.29	122.15	13.27	8.66	6.12	20.23		4.45	629.01	34.70	11.21

NOTE: EMPTY CELLS INDICATE MISSING OR DEFECTIVE SENSORS

Table 14: Golden Valley Mean and Standard Deviation
For Ten Day Periods of Meteorological Parameters
(Sum is given for precipitation)

DATES		MEAN AIR TEMP. (DEG. F)	MEAN WIND SPEED (MPH)	MEAN WIND DIRECT. (DEG.)	DIR. STND. DEVIAT. (DEG.)	MAX. WIND SPEED (MPH)	MIN. WIND SPEED (MPH)	MEAN RELATIVE HUMIDITY (%)	TOTAL PRECIP. (INCHES)	MEAN BARO. PRESSURE (MBAR)	MEAN TOP RESIST. (KOHMS)	MEAN BOTTOM RESIST. (KOHMS)	MEAN INSUL. TEMP. (DEG. F)
AUG 1-10, 92	MEAN	71.01	5.72	196.65	26.97	10.14	2.68	37.77	0.01	889.57			
	STD. DEV.	12.51	2.93	107.69	16.82	3.83	2.40	20.42		5.60			
AUG 11-20, 92	MEAN	70.16	5.70	192.79	24.62	10.10	2.62	43.12	0.56	893.53			
	STD. DEV.	12.64	3.23	95.55	16.71	4.26	2.60	22.66		2.97			
AUG 21-31, 92	MEAN	53.58	6.38	199.38	22.47	10.71	3.29	58.72	0.19	889.96			
	STD. DEV.	13.00	4.04	105.47	15.94	4.79	3.42	23.89		4.25			
SEP 1-10, 92	MEAN	58.94	8.72	229.11	19.44	13.20	5.39	43.61	0.29	887.34			
	STD. DEV.	12.25	5.23	88.46	14.68	5.90	4.52	21.67		4.14			
SEP 11-20, 92	MEAN	55.45	7.44	206.45	23.27	12.04	4.32	44.03	0.37	885.05			
	STD. DEV.	13.18	5.95	94.55	16.91	6.69	5.06	19.53		3.99			
SEP 21-30, 92	MEAN	60.80	8.65	212.13	20.81	13.04	5.39	35.02	0.00	888.44			
	STD. DEV.	13.80	6.51	90.04	15.97	7.46	5.55	16.27		6.36			
OCT 1-10, 92	MEAN	51.59	7.32	217.18	19.87	11.31	4.51	48.68	0.20	889.72			
	STD. DEV.	15.08	5.94	89.76	15.82	6.75	5.15	23.70		5.92			
OCT 11-20, 92	MEAN	42.53	5.95	189.15	22.34	10.07	3.05	63.57	0.13	889.03			
	STD. DEV.	14.52	4.45	97.88	17.72	5.28	3.77	22.48		4.61			
OCT 21-30, 92	MEAN	47.98	6.09	193.77	22.70	10.13	3.28	52.26	0.03	887.68			
	STD. DEV.	13.91	3.78	87.50	17.34	4.46	3.33	20.94		7.27			
NOV 1-10, 92	MEAN	35.86	9.54	247.64	16.01	13.66	6.38	68.69	0.19	884.56			
	STD. DEV.	6.84	6.79	94.90	14.89	7.44	6.06	17.48		5.72			
NOV 11-20, 92	MEAN	38.81	6.50	218.97	21.00	10.76	3.70	60.64	0.00	889.64	217.96	133.57	39.13
	STD. DEV.	9.53	4.53	91.12	17.22	5.12	4.01	17.54		3.25	938.06	579.89	9.91
NOV 21-30, 92	MEAN	9.37	8.89	223.41	19.69	14.05	6.14	50.22	0.00	889.69	3.20	1.46	29.41
	STD. DEV.	7.46	7.62	86.79	16.26	8.07	6.35	18.27		7.00	6.68	1.35	10.87
DEC 1-10, 92	MEAN	8.21	7.72	209.08	19.70	12.51	5.13	54.52	0.03	885.64	93.68	22.46	24.89
	STD. DEV.	6.26	6.42	80.86	16.73	7.00	5.54	15.50		6.58	428.57	109.07	10.28
DEC 11-20, 92	MEAN	8.42	8.07	217.38	16.49	12.33	5.53	66.42	0.04	883.61	143.20	132.91	22.84
	STD. DEV.	6.66	6.79	92.49	15.46	7.55	5.87	17.05		5.26	460.98	496.44	10.67
DEC 21-31, 92	MEAN	9.40	9.08	175.73	14.13	13.37	6.32	63.92	0.03	887.51	4.63	3.36	13.14
	STD. DEV.	7.34	7.39	104.30	13.05	8.62	6.18	15.77		6.13	6.36	3.18	21.57
JAN 1-10, 93	MEAN	5.02	4.59	178.30	19.86	9.16	2.39	74.80	0.01	885.49	6.13	2.33	6.72
	STD. DEV.	2.90	2.99	95.00	16.48	3.97	2.49	9.02		4.53	13.32	0.91	10.59
JAN 11-20, 93	MEAN	6.44	5.98	204.37	19.31	10.71	3.46	72.68	0.20	885.68	46.69	4.83	15.83
	STD. DEV.	5.42	5.49	77.98	16.26	6.25	4.78	12.51		3.93	155.31	12.65	16.49
JAN 21-31, 93	MEAN	31.77	7.04	200.54	20.69	11.36	4.15	68.21	0.07	890.52	116.56	17.98	32.65
	STD. DEV.	10.17	5.61	94.59	17.87	6.47	4.92	15.36		5.45	326.74	67.96	10.52
FEB 1-10, 93	MEAN	32.89	5.41	186.09	19.81	9.30	2.98	65.65	0.04	890.68	36.61	2.36	33.72
	STD. DEV.	9.56	3.15	94.35	16.48	4.02	2.87	18.27		4.53	149.37	2.50	10.70
FEB 11-20, 93	MEAN	13.54	5.55	177.73	15.28	8.81	3.15	72.54	0.01	888.45	27.70	3.85	14.66
	STD. DEV.	14.03	3.03	108.88	14.03	3.94	2.69	12.94		6.25	79.14	5.24	14.56
FEB 21-28, 93	MEAN	10.55	4.98	180.34	19.35	9.05	2.19	69.96	0.21	886.78	25.28	4.20	14.21
	STD. DEV.	13.99	3.58	88.56	16.52	4.81	2.88	15.32		3.32	43.70	4.53	17.05
MAR 1-10, 93	MEAN	38.76	7.84	218.67	18.98	11.74	5.12	60.91	0.02	891.16	33.02	19.40	39.91
	STD. DEV.	9.95	5.56	99.12	16.10	6.27	4.91	16.88		3.47	128.73	93.80	10.89
MAR 11-20, 93	MEAN	29.94	7.08	215.66	17.39	10.42	4.41	67.25	0.06	889.15	27.97	15.49	31.45
	STD. DEV.	12.96	5.73	95.27	14.55	6.98	4.73	16.69		9.12	118.55	83.70	13.22
MAR 21-31, 93	MEAN	46.40	6.74	184.90	15.57	9.32	4.44	63.93	0.37	886.66	496.97	79.03	46.99
	STD. DEV.	11.20	5.45	98.64	12.51	6.45	4.65	26.86		3.47	1396.71	188.36	12.10
APR 1-10, 93	MEAN	45.64	7.50	230.25	17.48	10.64	4.68	50.35	0.00	881.04	57.66	13.48	46.63
	STD. DEV.	10.08	5.65	81.63	12.95	6.89	4.77	20.82		40.48	478.36	97.35	10.87
APR 11-20, 93	MEAN	41.30	6.32	199.67	16.69	8.98	3.94	69.78	0.92	886.21	546.99	107.07	42.13
	STD. DEV.	8.54	5.00	100.42	12.86	6.02	4.21	23.37		5.18	1440.99	280.55	9.26
APR 21-30, 93	MEAN	48.24	8.58	235.05	17.03	11.83	5.67	56.32	0.37	886.80	41.23	20.31	48.70
	STD. DEV.	8.44	5.42	80.17	12.81	6.45	4.64	21.18		4.34	179.85	95.02	9.03
MAY 1-10, 93	MEAN	52.93	8.37	217.59	16.51	11.66	5.33	55.43	0.26	883.93	52.68	18.79	53.32
	STD. DEV.	8.76	5.48	97.51	11.91	6.60	4.59	22.09		6.70	439.38	88.82	9.44
MAY 11-20, 93	MEAN	60.44	5.60	168.90	21.48	8.60	2.96	53.76	0.23	889.15	29.41	14.00	61.63
	STD. DEV.	11.80	4.40	92.54	14.30	5.87	3.41	21.33		2.74	179.59	82.13	12.49
MAY 21-31, 93	MEAN	58.74	6.54	204.82	20.16	9.63	3.75	57.00	0.63	887.98	4.53	3.31	59.61
	STD. DEV.	9.06	4.78	108.88	13.67	5.90	3.97	19.04		3.89	24.79	20.19	9.88
JUN 1-10, 93	MEAN	54.51	6.46	185.37	17.36	9.16	4.02	73.52	2.88	884.43	231.70	45.02	54.65
	STD. DEV.	7.17	4.57	113.92	12.98	5.67	3.66	17.90		3.24	853.03	123.13	7.80
JUN 11-20, 93	MEAN	60.13	6.73	203.33	19.98	9.76	4.13	60.06	0.07	889.37	11.43	7.47	60.91
	STD. DEV.	10.89	5.92	93.94	14.21	7.28	4.82	21.01		4.51	77.19	28.08	11.96
JUN 21-30, 93	MEAN	63.16	8.06	235.27	21.05	11.83	4.91	48.43	0.16	885.03	1.12	1.02	63.90
	STD. DEV.	10.15	5.63	87.24	14.53	6.91	4.59	16.68		3.92	1.67	0.78	11.16
JUL 1-10, 93	MEAN	57.63	6.66	237.56	19.44	9.87	4.09	71.24	3.68	884.06	69.88	22.30	57.85
	STD. DEV.	7.07	4.78	101.80	13.36	5.86	3.90	18.85		4.40	290.78	56.01	7.87
JUL 11-20, 93	MEAN	57.81	4.46	173.44	22.08	7.04	2.31	76.31	0.86	889.71	94.31	46.43	43.59
	STD. DEV.	7.86	3.03	112.47	13.84	4.05	2.35	17.43		2.82	477.51	327.92	321.90
JUL 21-31, 93	MEAN	63.63	5.45	211.86	23.04	9.13	2.92	68.35	2.58	884.73	92.96	62.58	63.87
	STD. DEV.	9.30	3.27	101.03	16.43	4.31	2.71	21.89		3.25	312.19	215.38	10.36
AUG 1-10, 93	MEAN	65.97	5.13	178.26	28.35	9.29	2.49	60.48	0.50	889.30	42.97	18.12	66.64
	STD. DEV.	9.67	3.43	102.35	17.49	4.80	2.76	21.45		5.13	309.30	107.56	10.85
AUG 11-20, 93	MEAN	63.84	5.59	178.01	23.17	9.80	2.88	67.20	0.39	888.01	14.92	7.66	64.08
	STD. DEV.	9.09	3.81	97.51	15.52	4.96	3.02	20.00		3.67	65.55	32.62	9.88
AUG 21-31, 93	MEAN	58.81	6.47	207.48	22.85	10.50	3.64	62.36	0.78	888.45	78.08	32.30	59.20
	STD. DEV.	10.93	4.19	100.47	15.53	5.04	3.53	21.33		4.90	454.57	144.25	11.61
SEP 1-10, 93	MEAN	59.11	5.59	198.98	22.70	9.03	3.10	63.45	0.81	891.43	76.63	45.48	59.59
	STD. DEV.	10.47	3.72	109.44	15.43	4.65	3.07	22.55		3.61	415.56	160.88	11.24
SEP 11-20, 93	MEAN	50.93	5.69	208.19	21.45	9.48	3.00	68.34	0.38	886.86	131.32	31.01	51.03
	STD. DEV.	11.56	4.09	101.63	15.74	5.25	3.31	22.36		4.97	529.83	138.34	11.79

NOTE: EMPTY CELLS INDICATE MISSING OR DEFECTIVE SENSORS

Table 15: Broadview Substation Mean and Standard Deviation
For Ten Day Periods of Meteorological Parameters
(Sum is given for precipitation)

DATES		MEAN AIR TEMP. (DEG. F)	MEAN WIND SPEED (MPH)	MEAN WIND DIRECT. (DEG.)	DIR. STND. DEVIAT. (DEG.)	MAX. WIND SPEED (MPH)	MIN. WIND SPEED (MPH)	MEAN RELATIVE HUMIDITY (%)	TOTAL PRECIP. (INCHES)	MEAN BARO. PRESSURE (MBAR)	MEAN TOP RESIST. (KOHMS)	MEAN BOTTOM RESIST. (KOHMS)	MEAN INSUL. TEMP. (DEG. F)
AUG 1-10, 92	MEAN	73.89	6.40	155.41	26.79	9.44	3.67	31.72	0.01	885.28			
	STD. DEV.	10.21	3.27	135.35	17.04	4.38	2.83	16.97		5.69			
AUG 11-20, 92	MEAN	72.39	6.27	160.89	28.96	9.03	3.75	38.99	0.46	889.27			
	STD. DEV.	11.14	4.14	122.84	17.41	5.34	3.48	20.99		2.97			
AUG 21-31, 92	MEAN	55.24	6.54	177.77	17.32	9.29	4.02	54.72	0.19	887.31			
	STD. DEV.	12.76	4.77	121.20	12.67	5.85	3.94	23.88		4.37			
SEP 1-10, 92	MEAN	59.63	9.39	244.36	14.23	12.54	6.44	41.15	0.21	883.34			
	STD. DEV.	12.03	5.56	96.83	10.17	7.02	4.48	21.12		4.20			
SEP 11-20, 92	MEAN	56.81	8.17	214.38	17.25	11.03	5.44	40.80	0.27	880.88			
	STD. DEV.	12.35	5.78	110.84	13.57	6.92	4.89	17.87		4.01			
SEP 21-30, 92	MEAN	62.64	9.02	234.62	15.87	11.92	6.27	32.06	0.00	884.33			
	STD. DEV.	13.26	6.53	84.63	10.47	7.69	5.56	14.86		6.43			
OCT 1-10, 92	MEAN	53.59	8.81	218.39	23.69	11.49	6.31	44.97	0.52	885.51			
	STD. DEV.	14.56	6.28	100.01	14.70	7.33	5.42	24.17		6.00			
OCT 11-20, 92	MEAN	43.66	6.12	182.41	13.95	8.26	4.16	60.30	0.00	884.97			
	STD. DEV.	13.79	4.57	108.77	11.07	5.48	3.90	21.88		4.52			
OCT 21-30, 92	MEAN	47.70	7.91	216.29	15.22	10.35	5.66	50.21	0.14	882.94			
	STD. DEV.	12.99	5.92	107.02	12.44	6.81	5.15	20.50		7.00			
NOV 1-10, 92	MEAN	36.63	10.42	261.88	11.54	13.08	7.85	65.02	0.20	882.75			
	STD. DEV.	6.80	7.57	91.51	9.76	8.83	6.27	18.40		5.85			
NOV 11-20, 92	MEAN	39.67	6.43	222.83	15.11	8.65	4.39	59.93	0.00	885.23	251.90	398.78	37.64
	STD. DEV.	9.15	4.93	108.50	12.22	5.77	4.26	18.54		3.33	1028.46	1389.68	10.01
NOV 21-30, 92	MEAN	29.47	10.61	246.34	12.10	13.34	8.08	50.14	0.00	885.09	214.45	19.98	27.15
	STD. DEV.	9.52	7.18	82.06	10.42	8.53	6.00	17.32		6.97	1100.12	226.19	10.62
DEC 1-10, 92	MEAN	8.23	8.01	216.51	14.89	10.67	5.94	53.63	0.00	880.91	35.27	14.73	22.35
	STD. DEV.	6.16	6.21	96.25	12.39	7.21	5.32	15.34		6.49	138.78	52.19	10.16
DEC 11-20, 92	MEAN	8.01	7.86	213.20	12.12	10.30	5.90	69.36	0.01	878.85	537.65	301.03	21.01
	STD. DEV.	4.99	5.01	100.59	10.14	5.72	4.42	16.63		5.20	1393.93	781.70	10.31
DEC 21-31, 92	MEAN	8.59	8.46	173.32	10.14	10.99	6.38	64.35	0.13	882.63	34.75	18.80	11.54
	STD. DEV.	6.58	6.55	104.16	7.66	7.73	5.64	13.12		5.85	143.58	65.13	20.41
JAN 1-10, 93	MEAN	5.41	5.26	165.50	15.46	7.15	3.80	71.60	0.04	880.27	8.69	8.08	5.48
	STD. DEV.	4.46	4.50	114.03	14.09	4.96	4.02	10.41		4.50	29.05	19.22	10.55
JAN 11-20, 93	MEAN	4.61	4.43	177.19	16.82	6.33	3.05	72.09	0.18	880.58	19.87	19.95	11.20
	STD. DEV.	4.90	4.92	103.74	15.85	5.64	4.31	11.90		3.81	55.06	55.65	15.34
JAN 21-31, 93	MEAN	31.90	9.04	236.90	11.89	11.12	7.10	66.00	0.04	885.62	203.78	172.89	30.41
	STD. DEV.	8.86	6.29	90.94	11.73	6.81	5.88	14.95		5.38	564.54	493.61	9.24
FEB 1-10, 93	MEAN	33.51	6.07	190.39	13.73	8.00	4.25	59.31	0.01	885.98	55.97	69.51	31.65
	STD. DEV.	9.21	4.11	97.43	11.14	4.72	3.64	17.96		4.61	173.88	208.81	9.99
FEB 11-20, 93	MEAN	13.33	5.47	169.80	12.61	7.27	3.77	72.62	0.01	883.57	72.29	84.91	12.73
	STD. DEV.	14.33	3.76	112.79	10.39	4.36	3.27	12.57		6.35	240.62	223.27	14.96
FEB 21-28, 93	MEAN	11.98	4.58	172.99	15.59	6.20	3.06	68.73	0.03	882.01	533.10	22.81	10.69
	STD. DEV.	13.62	4.31	107.52	12.68	4.80	3.86	14.93		3.36	1830.85	30.98	13.96
MAR 1-10, 93	MEAN	39.94	9.30	230.62	13.25	11.83	6.90	56.74	0.02	886.61	390.48	46.33	38.41
	STD. DEV.	8.96	6.50	107.54	11.49	7.42	5.62	15.88		3.53	1556.23	319.86	9.52
MAR 11-20, 93	MEAN	29.83	7.59	214.23	12.59	9.96	5.40	66.18	0.19	884.52	346.68	198.14	28.64
	STD. DEV.	12.93	5.65	102.38	8.40	6.82	4.66	20.97		9.08	1035.62	609.00	12.96
MAR 21-31, 93	MEAN	45.70	7.09	167.04	13.40	9.45	4.94	63.94	0.19	882.16	949.22	293.95	44.02
	STD. DEV.	11.77	4.82	106.36	9.89	5.75	4.15	27.58		3.51	1916.79	624.41	11.55
APR 1-10, 93	MEAN	46.37	7.86	236.70	15.75	10.86	5.12	47.21	0.00	878.23	1702.01	12.10	44.35
	STD. DEV.	8.64	5.00	104.71	11.12	6.36	4.07	18.38		3.88	2991.96	118.48	9.99
APR 11-20, 93	MEAN	41.53	7.25	184.29	15.14	9.76	4.95	68.28	0.29	881.46	191.14	40.10	
	STD. DEV.	8.17	5.49	121.42	12.66	6.53	4.73	22.98		5.28	458.79	8.79	
APR 21-30, 93	MEAN	47.83	9.29	247.18	13.53	12.30	6.54	56.83	0.34	882.20	35.79	46.15	
	STD. DEV.	8.23	5.24	100.14	10.44	6.47	4.37	21.75		4.39	206.82	9.53	
MAY 1-10, 93	MEAN	53.11	10.10	201.20	13.27	13.18	7.15	54.42	0.07	879.24	33.48	51.12	
	STD. DEV.	8.45	5.03	116.44	10.11	6.14	4.28	22.18		6.86	140.70	8.57	
MAY 11-20, 93	MEAN	61.49	6.20	155.81	18.63	9.05	3.66	50.33	0.48	862.46	4083.59	5.91	59.08
	STD. DEV.	10.36	4.26	103.82	11.97	5.51	3.65	19.17		18.37	3435.65	38.98	10.69
MAY 21-31, 93	MEAN	59.56	7.82	184.20	16.17	10.90	4.95	54.63	0.46	868.39	2619.83	5.18	57.77
	STD. DEV.	9.20	4.59	125.80	11.62	5.72	3.92	19.03		15.18	3374.80	36.70	9.22
JUN 1-10, 93	MEAN	55.51	9.15	171.23	12.58	12.19	6.35	69.00	1.12	869.49	546.39	63.41	54.82
	STD. DEV.	7.63	4.75	130.38	8.40	5.72	4.03	20.19		12.57	1647.98	131.51	7.65
JUN 11-20, 93	MEAN	60.99	8.23	197.27	16.91	11.27	5.42	56.66	0.40	879.74	2322.77	16.24	58.60
	STD. DEV.	11.28	6.26	103.28	12.86	7.64	5.14	22.05		17.68	3277.69	38.71	11.74
JUN 21-30, 93	MEAN	64.57	10.49	241.09	16.36	14.28	7.02	43.56	0.09	875.59	4152.48	2.73	62.48
	STD. DEV.	10.99	6.09	104.30	11.98	7.44	5.17	16.89		17.64	3434.10	2.60	11.43
JUL 1-10, 93	MEAN	58.71	9.53	221.72	13.81	12.57	6.59	74.15	3.01	869.60	4171.88	18.85	57.07
	STD. DEV.	7.53	6.50	125.82	10.74	7.73	5.40	29.16		11.95	3339.34	59.69	8.14
JUL 11-20, 93	MEAN	58.63	6.42	135.90	16.09	9.09	3.96	72.98	1.02	877.74	6341.84	41.87	41.89
	STD. DEV.	8.25	4.40	114.27	11.08	5.48	3.59	17.73		14.14	2020.91	333.13	321.83
JUL 21-31, 93	MEAN	64.94	7.12	189.03	16.04	9.73	4.71	65.52	3.29	880.22	92.52	128.02	61.56
	STD. DEV.	9.67	4.53	126.56	12.62	5.51	3.83	21.19		13.47	463.52	487.78	9.79
AUG 1-10, 93	MEAN	66.86	5.79	181.14	18.48	8.31	3.47	57.26	0.60	883.60	8.30	4.16	62.81
	STD. DEV.	9.19	3.84	114.35	12.69	4.83	3.31	18.73		13.37	87.52	25.16	10.11
AUG 11-20, 93	MEAN	65.33	7.70	187.34	15.20	10.34	5.20	63.47	0.30	879.96	136.26	63.99	54.68
	STD. DEV.	8.68	4.76	119.84	10.78	5.63	4.10	18.45		11.84	786.58	277.95	227.97
AUG 21-31, 93	MEAN	59.93	8.10	199.89	15.86	10.79	5.57	59.38	0.42	884.89	24.45	17.23	57.15
	STD. DEV.	10.67	5.28	123.50	12.31	6.27	4.51	20.10		4.62	189.32	96.55	11.46
SEP 1-10, 93	MEAN	60.86	6.72	193.97	16.34	9.24	4.39	56.62	0.48	887.83	30.31	39.64	58.01
	STD. DEV.	9.35	4.61	123.80	12.33	5.53	3.95	19.56		3.53	315.53	173.43	10.13
SEP 11-20, 93	MEAN	52.04	6.68	176.78	14.93	9.00	4.55	65.27	0.95	882.92	137.09	37.93	50.29
	STD. DEV.	11.10	5.82	120.29	11.98	7.04	4.83	21.85		5.01	620.68	131.12	11.34

NOTE: EMPTY CELLS INDICATE MISSING OR DEFECTIVE SENSORS

APPENDIX E

LOCATIONS AND ESDD LEVELS FOR INSULATOR STRINGS SAMPLED

Table 16: Locations of Strings Sampled May 1992

TOWER NUMBER	LINE NUMBER	PHASE	SUSPENSION TYPE	INSULATOR TYPE	DATE REMOVED
0-7	2 (North)	North	Double "V"	N-16 (Fog Type with Petticoats)	May 12, 1992
40-17	2 (North)	South	Double "V"	N-14 (Bell Type without Petticoats)	May 14, 1992
95-12	2 (North)	Window	Double "V"	N-16 (Fog Type with Petticoats)	May 13, 1992

Table 17: ESDD Levels For Strings Sampled May 1992

INSULATOR	TOWER 0-7		TOWER 40-17		TOWER 95-12	
	TOP	BOTTOM	TOP	BOTTOM	TOP	BOTTOM
1	9.308E-05	2.369E-04	9.864E-04	1.114E-03	7.160E-04	4.633E-03
2	5.504E-05	1.918E-04	1.066E-03	7.923E-04	1.430E-04	3.003E-03
3	2.012E-04	1.826E-04	2.713E-04	8.634E-04	9.053E-05	2.377E-03
4	1.869E-04	1.572E-04	2.085E-04	1.441E-03	6.135E-05	2.410E-03
5	6.894E-05	1.359E-04	N/A	N/A	6.642E-05	6.190E-04
6	4.874E-05	1.481E-04	2.461E-04	1.678E-03	8.417E-05	2.068E-03
7	6.515E-05	1.867E-04	N/A	N/A	1.071E-04	2.072E-03
8	6.136E-05	1.208E-04	6.184E-03	N/A	1.071E-04	1.825E-03
9	5.504E-05	1.329E-04	4.113E-04	8.814E-04	5.378E-05	1.792E-03
10	5.757E-05	1.369E-04	2.336E-04	5.278E-04	9.435E-05	1.725E-03
11	3.994E-05	2.596E-04	1.091E-04	4.929E-04	6.136E-05	1.758E-03
12	3.366E-05	1.238E-04	1.958E-03	N/A	1.572E-04	2.184E-03
13	3.115E-05	1.460E-04	8.672E-04	1.061E-03	3.706E-04	2.331E-03
14	6.894E-05	2.246E-04	6.441E-04	8.992E-04	6.895E-05	2.763E-03
15	N/A	N/A	3.093E-04	6.508E-04	3.617E-05	2.388E-03
16	1.084E-04	1.087E-04	3.093E-04	9.529E-04	5.504E-05	2.229E-03
17	7.782E-05	1.582E-04	1.710E-04	7.214E-04	4.622E-05	2.717E-03
18	5.000E-05	2.092E-04	1.264E-04	9.100E-04	6.515E-05	2.888E-03
19	8.545E-05	1.908E-04	1.710E-04	2.460E-04	N/A	N/A
20	4.622E-05	1.663E-04	2.751E-04	1.689E-03	9.181E-05	2.343E-03
21	7.782E-05	1.959E-04	2.260E-04	1.455E-03	1.289E-04	1.547E-03
22	1.148E-04	2.293E-03	2.010E-04	3.870E-03	1.417E-04	5.160E-03

Table 18: Locations of Strings Sampled April 1993

STRING NUMBER	TOWER NUMBER	LINE NUMBER	PHASE	SUSPENSION TYPE	STRING POSITION	INSULATOR TYPE	DATE REMOVED
1	130-7	2 (North)	North	Double "V"	North (Outside) West String	N-14 (Bell Shaped)	April 20, 1993
2			North	Double "V"	South (Inside) West String	N-14 (Bell Shaped)	April 20, 1993
3			South	Double "V"	South (Outside) East String	N-14 (Bell Shaped)	April 20, 1993
4			South	Double "V"	North (Inside) East String	N-14 (Bell Shaped)	April 20, 1993
5	100-4	1 (South)	South	Single "V"	South (Outside)	N-16 (Flat & Petticoats)	April 21, 1993

Table 19: ESDD Levels For Strings Sampled April 1993

STRING #1			STRING #2		
INSULATOR	TOP	BOTTOM	INSULATOR	TOP	BOTTOM
2	2.49E-04	3.34E-03	1	3.24E-05	5.36E-05
3	2.91E-04	2.44E-03	2	3.27E-04	3.52E-04
10	2.07E-04	2.53E-03	11	3.56E-04	3.14E-04
12	3.91E-04	2.05E-03	12	3.98E-04	2.38E-04
21	1.79E-04	4.97E-03	21	3.98E-04	5.84E-04
22	4.20E-04	4.12E-02	22	3.98E-04	5.84E-04
STRING #3			STRING #4		
INSULATOR	TOP	BOTTOM	INSULATOR	TOP	BOTTOM
1	1.74E-03	4.38E-04	1	2.49E-04	2.95E-03
2	4.49E-04	5.35E-04	5	2.78E-04	2.76E-03
10	5.64E-04	1.11E-03	10	3.77E-04	2.87E-03
11	7.84E-04	0.000	11	2.35E-04	3.10E-03
20	8.57E-04	1.11E-03	21	3.92E-04	8.90E-03
21	1.05E-03	1.43E-03	22	7.40E-04	6.93E-02
STRING #5					
INSULATOR	TOP	BOTTOM			
1	1.92E-03	2.72E-04			
2	1.43E-04	8.89E-05			
10	1.72E-04	1.23E-04			
11	2.89E-04	8.89E-05			
21	5.66E-05	1.12E-04			
22	1.14E-04	2.26E-04			

Table 20: Locations of Strings Sampled August and September 1993

STRING NUMBER	TOWER NUMBER	LINE NUMBER	PHASE	SUSPENSION TYPE	STRING POSITION	INSULATOR TYPE	DATE REMOVED
1	95-10	B	South	Double "V"	South (Outside) West String	N-14 (Bell Shaped)	August 27, 1993
2	95-9	A	North	Double "V"	North (Outside) East String	N-14 (Bell Shaped)	August 28, 1993
3	85-18	1	South	Double "V"	South (Outside) West String	N-14 (Bell Shaped)	September 1, 1993
4	110-18	1	North	Double "V"	South (Inside) East String	N-16 (Flat & Petticoats)	August 31, 1993
5	110-18	1	South	Double "V"	North (Inside) West String	N-16 (Flat & Petticoats)	August 31, 1993

Table 21: ESDD Levels For Strings Sampled August and September 1993

STRING #1			STRING #2		
INSULATOR	TOP	BOTTOM	INSULATOR	TOP	BOTTOM
2	4.41E-04	4.50E-04	2	5.17E-04	1.06E-03
3	5.76E-04	7.11E-04	3	5.36E-04	9.02E-04
10	2.81E-04	9.96E-04	12	7.72E-04	7.33E-04
11	3.93E-04	1.08E-03	13	6.34E-04	1.28E-03
20	2.76E-04	9.32E-04	23	7.17E-04	7.29E-04
21	4.36E-04	9.09E-04	24	4.93E-04	1.16E-03
STRING #3			STRING #4		
INSULATOR	TOP	BOTTOM	INSULATOR	TOP	BOTTOM
3	3.53E-04	4.13E-04	2	2.92E-04	2.11E-04
4	3.52E-04	3.19E-04	3	2.21E-04	1.62E-04
10	1.21E-04	3.77E-04	10	2.23E-04	1.38E-04
11	1.94E-04	1.77E-04	11	1.40E-04	6.81E-05
19	1.81E-04	2.41E-04	19	1.32E-04	1.68E-04
20	2.36E-04	2.44E-04	21	1.94E-04	1.51E-04
STRING #5					
INSULATOR	TOP	BOTTOM			
2	1.11E-04	3.73E-04			
3	2.70E-04	5.73E-04			
10	1.77E-04	5.04E-04			
11	2.81E-04	2.95E-04			
19	4.08E-04	8.26E-04			
20	4.58E-04	8.91E-03			

Table 22: ESDD Levels For #2 Test Insulator at Each Weather Station Site

SAMPLE	ESDD (mg/cm2)
GALT RANCH - BOTTOM	0.00135
GALT RANCH - TOP	0.000864
ROSTAD RANCH - BOTTOM	0.000512
ROSTAD RANCH - TOP	0.000319
WHITIE RANCH - BOTTOM	0.00119
WHITE RANCH - TOP	0.0000939
COONEY RANCH - BOTTOM	0.000846
COONEY RANCH - TOP	0.000269
GOLDEN VALLEY - BOTTOM	0.000606
GOLDEN VALLEY - TOP	0.00019
BROADVIEW SUB - BOTTOM	0.000487
BROADVIEW SUB - TOP	0.000214

