



Investigation of bird induced outages on Montana Power Company's 500kV transmission lines
by David Robert Maehl

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Electrical Engineering
Montana State University
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Abstract:

An unexpectedly high number of unexplained outages on Montana Power Company's 500kV transmission lines resulted in an investigation into the cause of the outages. Nearly all of the outages were of the single-phase-to-ground type, and they were self clearing with little or no evidence left behind as to the cause of the fault. It was hypothesized that birds were a source of the outages because of the large number of raptors seen perching and nesting on the transmission line towers. The most significant birds seen in the area include Golden Eagles, Red-Tailed Hawks, and Ravens.

Previous investigations into the cause of outages on Montana Power Company's 500kV lines as well as other utilities high voltage transmission lines were analyzed. Also, trends observed from the historical outage data on Montana Power's lines were examined and compared to the raptor activity along the transmission line corridor. Furthermore, 29 miles of transmission line towers were equipped with bird perches in an attempt to modify the behavior of the raptors and thus reduce the number of unexplained outages.

Although no outages have occurred on towers equipped with bird perches since their installation, not enough time has passed to classify the perches as statistically significant in reducing the outages. However, substantial data were gathered through this two-year study to suggest that birds are a likely source of faults on Montana Power Company's 500kV lines.

INVESTIGATION OF BIRD INDUCED OUTAGES ON
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A thesis submitted in partial fulfillment
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Bozeman, Montana

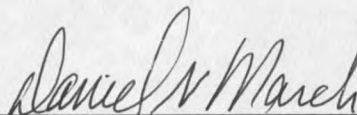
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David Robert Maehl

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.

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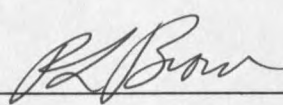
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ABSTRACT

An unexpectedly high number of unexplained outages on Montana Power Company's 500kV transmission lines resulted in an investigation into the cause of the outages. Nearly all of the outages were of the single-phase-to-ground type, and they were self clearing with little or no evidence left behind as to the cause of the fault. It was hypothesized that birds were a source of the outages because of the large number of raptors seen perching and nesting on the transmission line towers. The most significant birds seen in the area include Golden Eagles, Red-Tailed Hawks, and Ravens.

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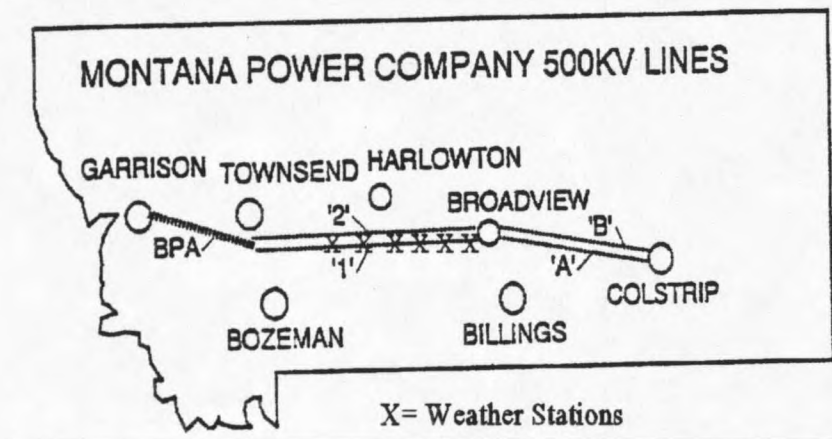
CHAPTER 1

INTRODUCTION

Montana Power Company 500kV Line History

Montana Power Company (MPC) maintains and operates two 500kV transmission lines between Colstrip, MT and Townsend, MT. The lines become Bonneville Power Administration's (BPA's) possession near Townsend and extend to the West coast. Figure 1 illustrates the location of the 500kV lines across Montana (Major 1993),[1].

Figure 1. MPC 500kV Line Route



Most of the electric power transmitted on the lines is generated at the Colstrip, coal-fired generating plant which consists of two, 350 MW generators and two, 750 MW generators. Each transmission line is capable of carrying approximately 2500 amps at a nominal voltage

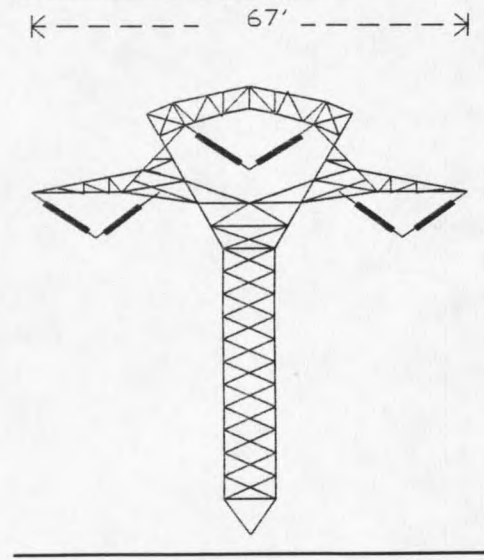
rating of 525kV. Two substations, Broadview and Garrison, are located along the line route in Montana.

MPC operates approximately 362 km (225) miles of parallel 500kV transmission lines, illustrated in Figure 1, which consist of separate, single-circuit, 500kV lines on steel towers. BPA uses double-circuit 500kV towers for transmission. As seen in Figure 1, the MPC lines between Colstrip and Broadview are labeled as 'A' and 'B' and the lines between Broadview and Townsend are labeled as '1' and '2'. The B-Line and Lines 1 and 2 are built exactly the same and the construction of these lines was completed in 1983. The A-Line is somewhat different in construction compared to the B-Line and Lines 1 and 2, however the lines are similar in voltage and phase configuration. The A-Line was converted from a double-circuit 230kV line to a single circuit 500kV line, also in 1983. Figures 2, 3, and 4 illustrate the different types of 500kV towers used by MPC and BPA. Similar type glass insulators (5-3/4" by 10") made by the Sedivar Company are used on both tower designs, although the A-Line towers have 25 insulators per string, compared to the B-Line and Lines 1 and 2, which have 22 insulators per string. Other differences exist in the tower constructions. The minimum air gap between a conductor and tower on the A-Line is 350.5 cm (138 inches), while the other lines have a minimum air gap of 294.6 cm (116 inches). Furthermore, the A-Line has no horizontal sections of angle iron above any of the phase wires, while the B-Line and Lines 1 and 2 do have a horizontal section above the top "window" phase. All of the tower heights vary between 30.5 m (100 ft) and 45.7 m (150 ft), depending on the change in elevation between the closest towers. Lines 1 and 2 are both 214 km (133 miles) long, compared to the B-Line and A-Line which are approximately 184 km (114 miles) in length.

**Figure 2. B-Line, Line #1, and
Line #2 Tower**



Figure 3. A-Line Tower



**Figure 4. BPA Double-Circuit
Tower**

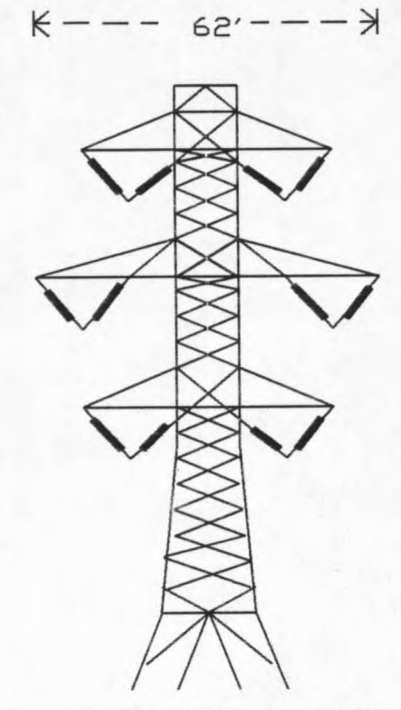
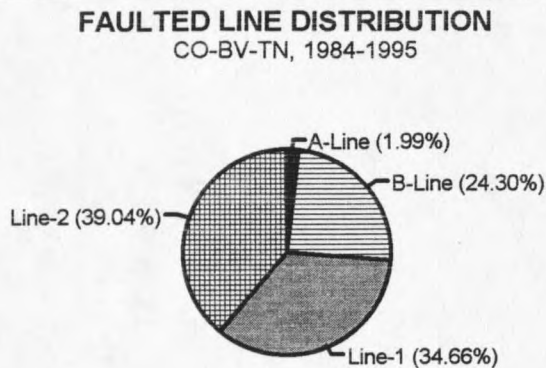


Figure 5 shows the fault activity on each MPC line and clearly, the A-Line is faulted less than all of the other lines. The BPA lines have experienced unexplained outage activity, although not as severe as MPC's B-Line and Lines 1 and 2.

Figure 5. MPC Line Fault Activity



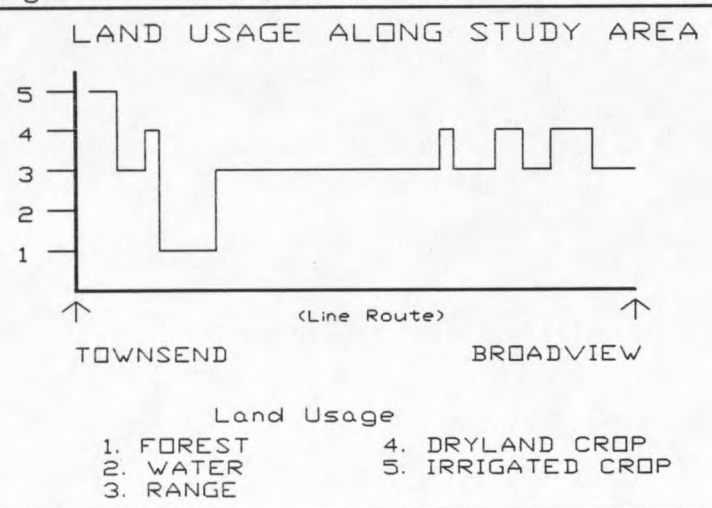
The towers illustrated in Figures 2 and 3 comprise approximately 88% of the towers used by MPC, while the other 12% of the towers are dead-end type structures that are used when the line changes direction and horizontal tension must be taken up on one or more of the phases, which consist of four conductors and are called conductor bundles. The dead-end structures are self supporting towers and a combination of horizontal and vertical insulator strings are used with this type of configuration to suspend the conductor bundles. The standard towers in Figures 2 and 3 use V-string insulators to suspend the conductor bundles and are supported by guy wires. Four strings of insulators (two on each side of the "V") are typically used to hold up each conductor bundle, although lighter mechanical loading of the

lines may call for only one string of insulators on each side of the "V".

The main study area considered in this research is between Broadview, MT and Townsend, MT. This 214 km (133 mile) section consists of 553 towers per line with the towers being separated by approximately a quarter of a mile. There are several reasons that the studies were focused in this area. First, it is near Bozeman, home of Montana State University (MSU) and furthermore, 75% of the unexplained outages have occurred in this area. The MSU Electrical Engineering Dept. also has six weather stations spread out along the transmission line in this area. The weather stations are discussed in detail in Chapter Four, Experimental Procedures.

The transmission lines in the study area pass through a variety of terrain including semi-arid rangeland, grassland, and a few areas where there is agricultural activity. Most of the line passes through rangeland with few or no trees. Figure 6 depicts the land usage along the transmission line route. The elevation along the line route ranges from approximately 1066 m to 2133 m (3500 ft to 7000 ft).

Figure 6. Transmission Line Land Use



Historical Fault Data (1984-1995)

Nearly all of the disturbances on MPC's 500kV lines are single-phase-to-ground faults. Any type of arc or conductive path between the grounded, metal tower and the hot phase wires could create this type of fault. Virtually all of the faults are self-clearing, within a few cycles of the disturbance, and little or no evidence is left behind as to the cause of the fault. The faults can become expensive to the utility because of excessive use of the equipment (i.e. circuit breakers and relays) and the stress put on the Colstrip generators created from the transients associated with the faults. Also, there is always the chance of loss of system stability whenever a fault occurs. Power system stability may be broadly defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance (Kundur 1993),[2]. In the event that the power system does not return to an acceptable state of equilibrium, the utility can experience loss of generation and/or severe damage to their equipment resulting in millions of dollars of losses. A fault on the MPC 500kV lines could initiate a transient into the western U.S. power grid. Additionally, it is becoming increasingly important for utilities to have a reliable transmission system because customers are demanding transient free, reliable power.

Design standards for typical high voltage transmission lines are for 1-2 unexplained outages/100 mi (161 km)/year (Sandhu et al. 1988),[3]. Table 1, on the following page, examines the outage rates (outages/100mi/yr) on MPC's different 500kV lines. The high

outage rates (6 times the expected rates) are what prompted an investigation into the cause of the outages. The first step in reducing the number of unexplained outages is determining the cause of the outages.

*Table 1. Unexplained Outage Rates for BV-TN 500kV Line		
YEAR	LINE #1	LINE #2
1984	5.26	3.01
1985	5.26	1.50
1986	3.01	6.02
1987	6.02	9.77
1988	3.76	4.50
1989	6.77	9.02
1990	9.77	6.77
1991	5.26	12.03
1992	6.77	7.52
1993	6.77	5.26
1994	4.51	3.01
1995	2.26	6.02
AVERAGE	5.45	6.20

* (outages/100 miles/year)

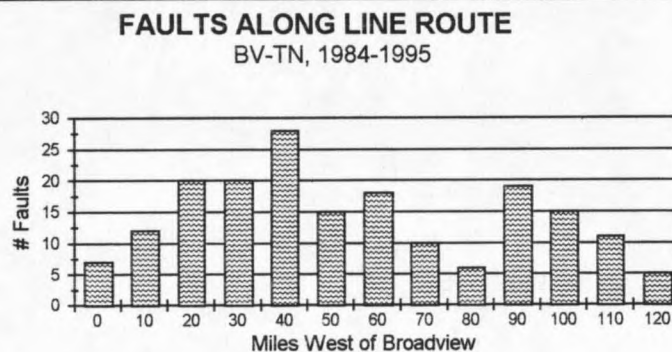
Whenever a fault occurs, Montana Power Company engineers supply Montana State University (MSU) researchers with the following data; date, time, line, phase, cause (if known), location, and the generators and series capacitors that were in service at the time of the fault. All of these data are entered into a spreadsheet for analysis to determine any trends in the data. Several histograms and descriptions pertaining to the historical fault data can be

seen in the following paragraphs. The fault data analyzed consists of Lines 1 and 2 between Broadview and Townsend, from 1984 through 1995. Appendix A provides a listing of all of the fault data used in the histograms.

Fault Location

Figure 7 discloses where the faults tend to occur along the line route. The estimated fault locations used in the plots were categorized into 10 mile intervals, with 0 representing 0 to 10 miles west of Broadview. The distances were calculated using a fault current ratio method up until 1991 and after that, the FLR (Fault Location Relay) was used to determine the general location of the faults. FLR data are based on the time of arrival, to different substations, of transient waves associated with the faults, and have been shown to be more accurate than the current ratio method. The areas of the highest fault activity along the line route (20-30, 30-40, 40-50, and 90-100 miles west of Broadview) were all areas of flat rangeland. The least fault activity occurred where the transmission line passed through forest-land with trees nearby (80-90 and 120-130 miles west of Broadview).

Figure 7. Fault Location Distribution



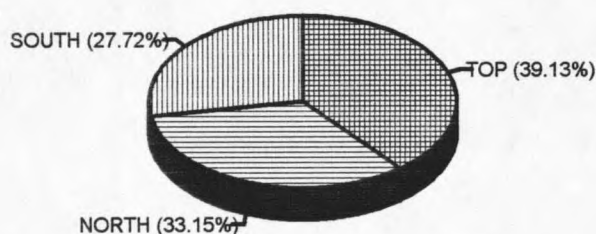
All of the other faults appear to be randomly distributed along the line route.

Phase Location

The top (window) phase was faulted slightly more than the two lower, north and south phases, although not by a significant amount. Other utilities with similar tower configurations have experienced significantly more outages on the window phase compared to the two lower phases (Sandhu et al. 1988),[3] however, Figure 8 shows that this was not the case with MPC's 500kV transmission lines.

Figure 8. Phase Location Distribution

FAULTED PHASE LOCATION
BV-TN, 1984-1995

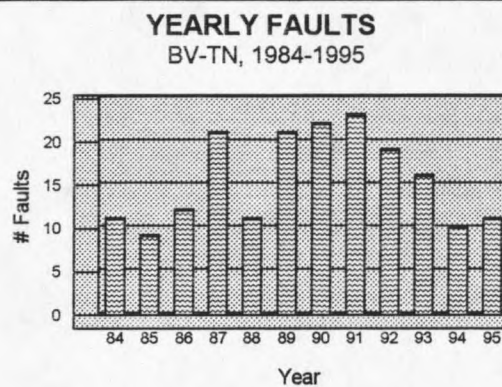


Yearly Faults

Figure 9 shows the number of faults that occurred each year, from 1984-1995,

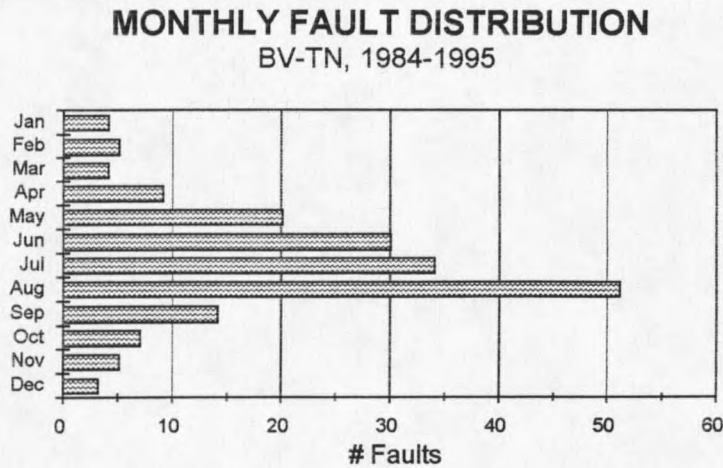
between Broadview and Townsend. The transmission lines experienced an exceptionally high number of outages between 1987 and 1993, excluding 1988 when the fault activity dropped significantly. Several fires occurred during the summer of 1988, most significantly the Yellowstone National Park fire which was approximately 100 miles south of the 500kV lines. The number of unexplained outages have been declining since the peak in 1991.

Figure 9. Yearly Fault Distribution



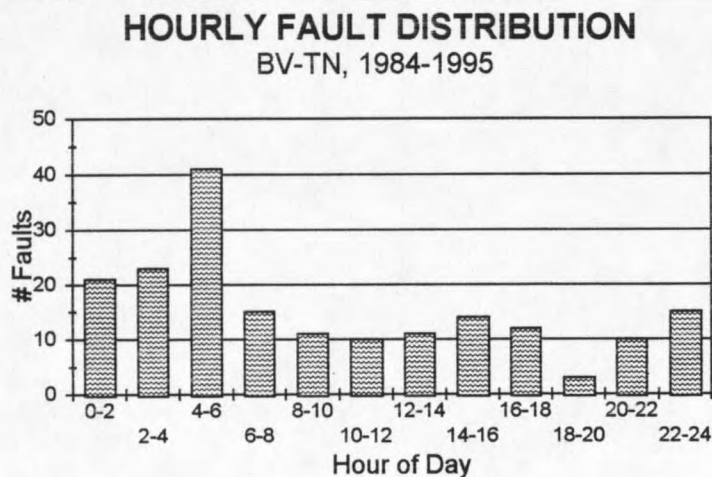
Monthly Faults

Figure 10, on the following page, depicts the Monthly Fault Distribution and illustrates the fact that more faults occurred during June, July, and August than the rest of the months combined. There was a steady increase in faults from March through August, then suddenly the fault activity dropped off in September. This was one of the most significant trends observed from the fault data.

Figure 10. Monthly Faults

Hourly Faults

From Figure 11, it can be seen that more faults occurred between 04:00 and 06:00 than any other time of the day. The fault times were fairly scattered throughout the rest of the day, with the exception of 18:00 through 20:00 where very few outages occurred.

Figure 11. Hourly Faults

CHAPTER 2

PREVIOUS INVESTIGATIONS

Other utilities, besides Montana Power have also reported a high rate of single-phase-to-ground, self clearing unexplained outages on their high voltage (345 to 500kV) transmission lines. Several common trends such as tower configuration, insulator configuration, time of day, and time of year exist between the utilities affected by the outages (Sandhu et al. 1988),[3]. Some of the suspected causes of the outages include equipment failures, switching surges, lightning, weather, insulator contamination, and birds. The following pages contain discussions of the findings of several utility investigations into the cause of faults.

Equipment Failures and Other Known Causes

Equipment failures such as circuit breaker and reclosure malfunctions have been known to cause outages on MPC's transmission lines. It is known when this type of phenomenon occurs, and therefore these outages are not classified as unexplained faults. Other known causes of outages that are not weather related include vandalism, (insulators damaged by gun shots) broken lines, and fires. Inspection of the line after a fault occurrence helps determine these causes. Only 13 of the last 123 faults (10.5 %) in the last four years have been attributed to these known causes.

Switching Surges

In the 1960's, switching surges were considered to be the leading cause of unexplained outages on high voltage transmission lines (Lloyd and Schneider 1982),[4]. A switching surge is an over-voltage occurring on a power system that occurs as a result of a perturbation caused by a switching operation (Zaffanella et al. 1982),[5]. Some examples of switching operations include the addition of capacitor banks, the energization or reclosing of a power line, and sudden load changes. The waveshape of switching over-voltages may vary over a wide range depending on the system configuration and the electrical parameters of the equipment. The waveforms are usually short in duration (a fraction of a millisecond to a few milliseconds) and they can be high in magnitude. Brown et al. (1982),[6] point out that this is important because the breakdown of the electrical insulation used to suspend the transmission lines from the towers depends to a great extent upon the over-voltage stress and the length of time during which the stress is applied. A single-phase-to-ground fault could occur when this overvoltage stress magnitude exceeds a critical value for a short duration of time. Breakdown across the insulators occurs when the voltage gradient exceeds about 500kV/meter. The insulators breakdown and a flashover (arc) occurs between the metal tower and the hot phase wires.

Several years ago, Montana Power Company engineers investigated switching surges as a possible cause of outages on their 500kV lines. They compared the times of the switching operations with the times of the faults and concluded that switching surges were not causing the outages on their lines, because the times did not match. In addition, digital

fault recorder data are now available for every fault that occurs on MPC's 500kV lines. The digital fault recorder data gives the waveforms of the currents and voltages of each phase before, during, and after the fault occurs. From the digital fault recorder data, it is apparent that before the fault occurs, there is not a transient switching overvoltage associated with any of the faulted phases. This further reinforces the conclusion that switching surges are not a cause of outages on MPC's 500kV lines.

Lightning and Weather

Lightning has long been a suspected cause of outages on high voltage transmission lines around the world. Sforzini (1971),[7] reported that over 70 % of the faults occurring on a particular 275kV line in England were caused by lightning and Florida Power and Light attributed 465 outages on their transmission lines between 1988 and 1992 to lightning (Burnham 1995),[8]. A subject committee on line outages was formed jointly in 1962-1963 by the Transmission and Distribution Committees of the Edison Electrical Institute and the Institute of Electrical and Electronics Engineers to obtain fundamental operating data on transmission line outages. Outage data were gathered from 42 different operating utilities across the country and a report was published (Rothfus et al. 1967),[9] which indicated that the number one cause of outages was lightning.

Lightning transients, similar to switching surges, have varying waveshapes that are usually short in duration and have a high magnitude. Lightning causes single-line-to-ground faults in two different ways (Brown et al. 1982),[6]:

- 1) Lightning directly striking a conductor and the resulting voltage wave

propagating along the conductor until a flashover develops at some weak point in the line insulation. This generally occurs across an insulator string at the first tower encountered by the lightning waveform.

- 2) Lightning striking a transmission line tower, which elevates the tower to a potential above that of the remote earth. The potential of the phase conductors remains the same and the net result is that a very high voltage develops between the phase conductors and towers. This type of flashover is commonly referred to as the "back-flashover" mechanism.

MPC's 500kV transmission lines have two shield wires suspended from the top of each tower. The shield wires are the highest conductors on the towers, and therefore provide some protection from lightning directly striking the phase conductors and causing a flashover. Any lightning caused faults on MPC's lines are most likely caused by the "back-flashover" mechanism. Whenever a fault occurs, the exact time and general location of the outage are recorded, and whenever a lightning stroke occurs, data are available to determine the exact time that the lightning stroke occurred and its location. If the fault data and lightning data match, the fault is classified as lightning caused. The lightning data have become of good quality and they are readily available now and from analysis of the historical fault and lightning data, it can be concluded that lightning is not a significant cause of outages on MPC's 500kV transmission lines (Maehl et al. 1995),[10]. Some utilities initially blame lightning as a cause of faults when in reality, the lightning data may not correlate with the fault data.

Other weather related faults such as high winds are also rare on MPC's lines because nearly all of the unexplained outages occur during moderate temperature periods and when the wind speeds are moderate. Figures 12 and 13 show the temperatures and wind speeds

during fault times for the last 41 faults. The weather data used in the plots were obtained from weather stations along the transmission line route that are spaced approximately 20 miles apart. Most of the faults occurred when the temperature was between 40 and 60 degrees Fahrenheit and when the wind speed was below 9 miles per hour.

Figure 12. Faults vs Temperature

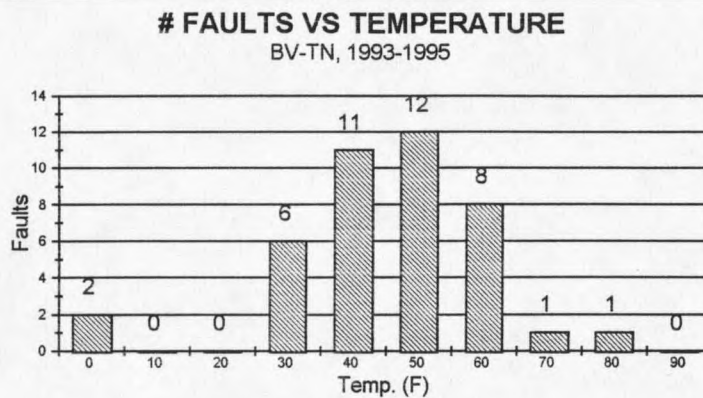
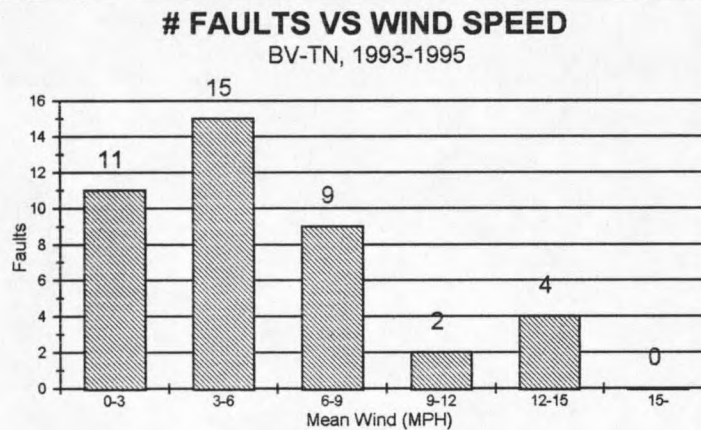


Figure 13. Faults vs Wind Speed



Insulator Contamination

Significant research has been conducted worldwide on insulator contamination as a source of faults on high voltage transmission lines. A joint utility investigation of unexplained transmission line outages, consisting of Sierra Pacific Power, Pacific Power & Light, Bonneville Power and Idaho Power, concluded that "A relationship between contamination and outages was identified as probable" (Sandhu et al. 1988),[3]. Kawai (1967),[11] from Japan and El-Arabaty et al. (1974),[12] from Egypt also reported significant outages caused by contamination flashover on their transmission lines.

Several different theories exist about insulator contamination, but when one considers all the research conducted, it is agreed upon that certain conditions must be present in order for insulator contamination to occur:

- wetting of the insulators (usually from dew, fog, or drizzle)
- contamination of the insulator surface most often caused by natural alkali dust from soils, sea salts, industrial pollution, or agricultural activity.

An insulator contaminated fault occurs when alkali or salt contaminated insulators become slightly wet, which causes leakage current to flow over the surface of the insulators and cause dry-bands to form, thus causing a breakdown of the insulator. The final result is a contamination flashover, or arcing across the insulators to the electrically grounded tower.

It was initially hypothesized that the excessive number of unexplained outages on the

MPC 500kV transmission lines were a result of contamination flashover. Extensive research was conducted by Major (1993),[1] to prove or disprove this theory. The meteorological conditions, gathered from the weather stations along the transmission line route, and corresponding in time to the 19 unexplained faults that occurred on MPC's lines, were carefully analyzed. An algorithm was designed to provide a general guideline for evaluating the weather data to see if it was consistent with contamination flashover conditions. Ideal contamination flashover weather conditions call for extended periods of dry weather to allow contamination to accumulate on the insulators, and the presence of light moisture on the insulators just before the fault occurrence. Of the 19 faults, only one was consistent with these contamination flashover conditions.

To determine the amount of contamination of the insulators, Major,[1] performed Equivalent Salt Deposit Density (ESDD) sampling on "dummy" insulators along the transmission line route and on insulators taken out of service, generally for repair. The ESDD is measured by removing the contaminants from the insulator with a cotton swab and dissolving it in distilled water, and then the conductivity of the water is determined. The equivalent density of NaCl to produce the same conductivity as that of the tested insulator surface area is then calculated and expressed in mg/cm^2 . An accepted standard in the electric utility industry (Lloyd and Schneider 1982),[4] for the site severity levels of ESDD contamination is shown in Table 2.

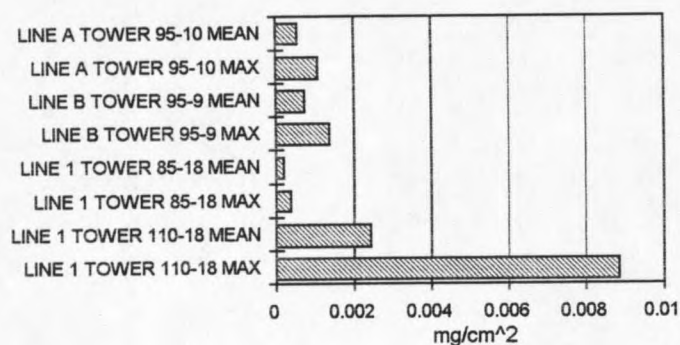
Table 2. ESDD Classification

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

The values obtained from ESDD measurements on MPC's 500kV line insulators are illustrated in Figure 14. Notice that the highest value measured was .009 mg/cm², which is three times less than a level considered to be light contamination.

Figure 14. ESDD Measurements**ESDD FOR STRINGS FROM 500KV LINE**

REMOVED FROM SERVICE SEPTEMBER, 1993



Due to the fact that the meteorological conditions were not consistent with contamination flashover and the very light levels of contamination of the insulators, it was

concluded that insulator contamination flashovers were not a significant cause of unknown faults on MPC's 500kV transmission lines.

Birds

Birds were considered as a source of faults on Southern California Edison's 220kV transmission lines as early as the 1920's (Stockbridge 1925),[13]. Since then, several other utilities have also reported bird related outages on their high voltage transmission lines. Some of the utilities with bird related problems include Pacific Power and Light (Young et al. 1988),[14] Bonneville Power Administration (West et al. 1971),[15] Florida Power and Light (Burnham 1995),[8] Minnkota Power Coop. (Gaines 1985),[16] and Sierra Pacific Power (Sandhu et al. 1988),[3]. However, as Burnham,[8] from Florida Power and Light points out, bird caused faults are generally not recognized as being a significant problem by the utility industry. It is not mentioned as a cause of outages in EPRI's Transmission Line Reference Book and is not considered in any of the design parameters of these reference books. There are several reasons for this general lack of acknowledgment; these faults are not witnessed because they often occur during the early morning hours in remote areas; there is little or no evidence left that a bird caused the fault; and it is easier to attribute faults to causes that have been extensively studied.

Montana Power's 500kV transmission lines go through some of the best eagle and raptor habitat in the country and the towers present an opportune place for raptors and ravens to nest and perch (Olendorff et al. 1981),[17]. The bird nests in the towers are somewhat

sheltered from the elements and the raptors have an excellent view of the open prairies from the towers. The exact tower where a fault occurred in September of 1993 was determined and it was located in the tower adjacent to an occupied Golden Eagle's nest. This is what initially triggered an investigation of birds as a possible cause of unexplained outages.

Statement of Hypothesis

After the occurrence of a fault, MSU researchers try to investigate the general location of the fault as quickly as possible. Upon arrival at the fault location, raptors are often seen perching and/or nesting on the towers. The most significant birds seen using the towers include Golden Eagles (*Aquila chrysaetos*), Red-Tailed Hawks (*Bufo jamaicensis*), and Common Ravens (*Corvus corax*). Based on the background developed in this thesis and the raptor observations, *it is hypothesized that bird caused flashovers are a major source of unexplained faults on Montana Power Company's 500kV transmission lines.*

CHAPTER 3

RESEARCH OBJECTIVE AND PROCEDURES

The objective was to determine if birds indeed do cause a majority of the unexplained faults on MPC's 500kV lines and, if so, how to prevent this from occurring. The following experimental procedures were designed to determine the objectives:

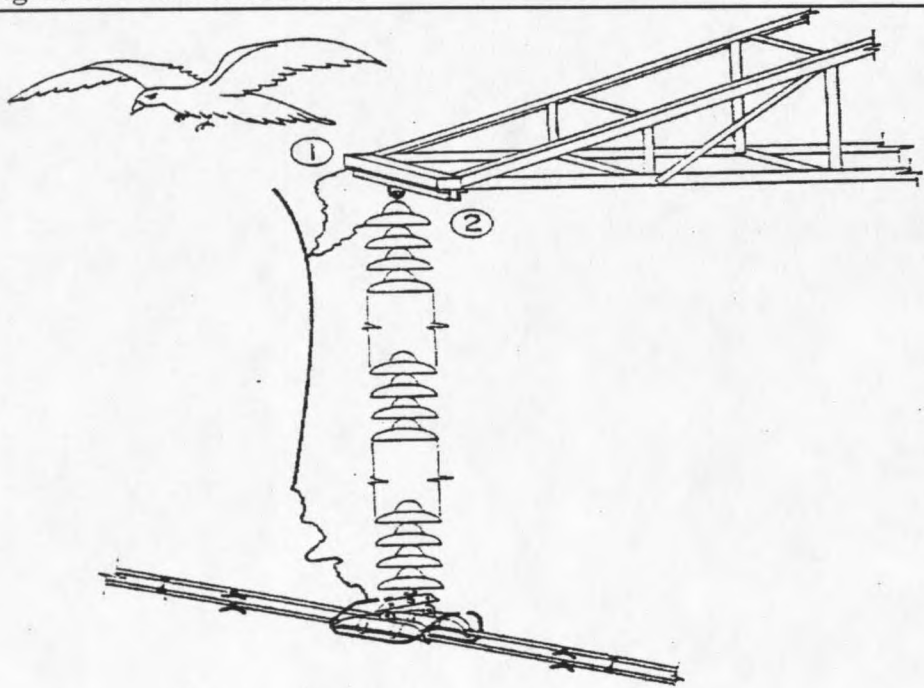
- Determine how birds cause faults
- Study large bird's habits
- Install bird perches on towers along transmission line route
- Locate exact tower where faults occurred with the use of magnetic flag fault indicators and relate fault locations to bird activity
- Perform an analysis of meteorological conditions surrounding faults and bird activity
- Analyze the digital fault recorder data from faults of both known and unknown cause.

Bird Caused Faults

It is hypothesized that the birds perch on the tower angle iron above the hot phase wires (actually an observed fact) and excrete a long stringy mucus material (mucous) while perching or when leaving the tower. The mucus string has sufficient conductivity and length to reduce the gap between the phase wires and the tower to a distance where the air will ionize across the remaining gap and a single-phase-to-ground fault will occur. Raptors and

other large birds will regurgitate all of the solid matter they eat such that their excretions are only the mucus liquid left over (West et al. 1971),[15]. Figure 15 illustrates a bird caused fault (West et al. 1971),[15]. It is believed that the bird is usually not harmed in the scenario because no signs of dead birds have been found along the transmission line route.

Figure 15. Bird Caused Fault



Engineers at Bonneville Power Administration (West et al. 1971),[15] performed laboratory simulation tests to demonstrate the possibility of bird excrement caused faults. Excrement samples from eagles and hawks were gathered from the Portland Zoological Gardens to determine the resistivities of the material (30 to 120 ohm-cm). Also, several bird

physiologists were consulted and the consensus was that large birds can store and release as much as 60 cm³ of excrement at any one time. At a BPA laboratory, a bird simulator with similar liquid, resistivity, and volume was set up and tests were performed on a 500kV line with insulation and air gap characteristics similar to MPC's lines. Test results indicated that it was definitely possible for bird mite to cause a flashover with very little evidence left behind. A 50 to 60 cm³ discharge can produce 2.43 to 2.74 m (8 to 9 ft) conductive strings and thus bridge the gap between the phase wires and tower and cause a flashover. The study also determined that the excrement stream can be as far away as 49 inches (1.24 m) from the insulator string and still cause an outage.

Bird excrement buildup on the insulators has also been suggested as a cause of faults on high voltage transmission lines (Young and Engel 1988),[14]. This is not considered a significant problem on MPC's lines because of the lack of evidence left behind after the faults. Also, materials that the birds bring into their nests located in the towers may be a source of faults. Barbed wire, animal entrails, and other conductive material are often found in nests, and if these materials fall out of the nest, they could potentially cause a flashover or short out the insulators. Furthermore, a raptor could cause a fault by taking the insides out of an animal while it was perched above a phase wire and thus short out the insulator string with the conductive animal parts.

Bird Habits

Several of the different large bird's habits were studied to determine if any of their routines correlate with the historical fault trends. Sources include personal observations,

literature, surveillance camera, and meetings with experts in the raptor field.

Golden Eagles are often spotted during the winter months along MPC's transmission line route and are, for the most part, resident birds in Southern Montana. Most Red-Tailed Hawks and Common Ravens, unlike Golden Eagles, migrate from Montana to southern destinations during the winter months. Very few of these birds are spotted along the transmission line routes during colder months. The historical Monthly Fault Distribution (Figure 10) shows that a majority of the faults occur during the summer months, which may suggest that the presence of Common Ravens and Red-Tailed Hawks increases the likelihood of faults on MPC's 500kV lines. August is the most faulted month of the year and also the month in which most of the different species of young birds begin to fledge (learn to fly), which signifies that fledging birds may also contribute to the fault activity.

Raptors often will mute upon take-off from their perching location. Time of day and quantity of food consumed are both factors that may affect the volume of the mute. It has been suggested (Burnham 1995),[8] that birds, after roosting on the transmission line towers all night, will mute a large quantity around sunrise prior to commencing their daily activity. This may be an explanation for the large number of faults that occur between 04:00 and 06:00 (see Figure 11).

All of the birds seen in the study area primarily eat the same foods; jackrabbits, ground squirrels, snakes, carrion, and some types of other birds. Most of these types of foods are found in the open prairies. Additionally, without the presence of trees, the transmission line towers present a commanding view of the open prairies. Referring back to Figure 7, Fault Location Distribution, it was noted that the areas of the highest fault activity along the line

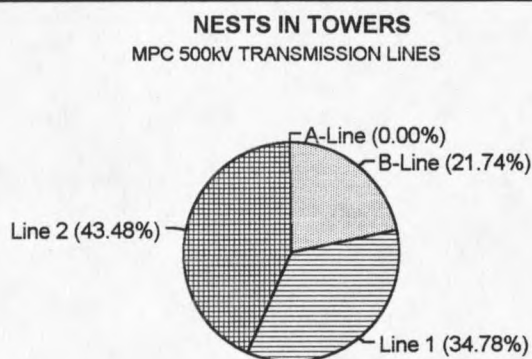
route are all located in expanses of flat rangeland and open prairies, which is also where most of the raptors have been spotted. There is a strong correlation between the bird activity and fault locations along MPC's lines.

Several studies have been performed to determine the impact of transmission lines on raptor behavior. One such study executed by Worley (1984),[18] determined that the presence of newly constructed transmission lines seemed not to adversely affect Golden Eagle nesting habits, but instead it provided a place for the birds to build more nests. The same study also concluded that within a year of the completion of the line, the birds became accustomed to the lines with ravens acting as pioneers (first users) for other large birds in the area. Unexplained outages started occurring on MPC's lines within one year of the energization of the lines. A different study (Gaines 1985),[16] found that "The number of occupied hawk nests located on power line towers has increased almost every year, while the local population has remained unchanged." This indicates that large birds become more accustomed with the tower structures as time progresses and therefore if birds are the cause of faults, it is important to address the problem now.

Dr. Al Harmata [20], eagle expert, has suggested that eagles and other large birds prefer to perch with their bellies resting on a flat surface. Also from several personal observations of birds perching on the towers, most of the birds seen on the towers were on a horizontal surface. The A-Line, which has experienced very few faults, has no horizontal surfaces on which the birds can perch. Additionally, no nests have been documented in the A-Line towers compared to several nests in the B-Line, Line 1, and Line 2 towers, which do have horizontal sections on which the birds can perch. Figure 16 shows the nesting sites

relative to the different 500kV lines. Nests were documented from land observations as well as helicopter surveys. A complete listing of the towers with nests located in them can be seen in Appendix B. Notice the striking similarities that exist between Figure 16 and Figure 5, Faulted Line Distribution. The percentage of nests in towers on each line is almost exactly the same as the percentage of faults on each line.

Figure 16. Nests in Tower

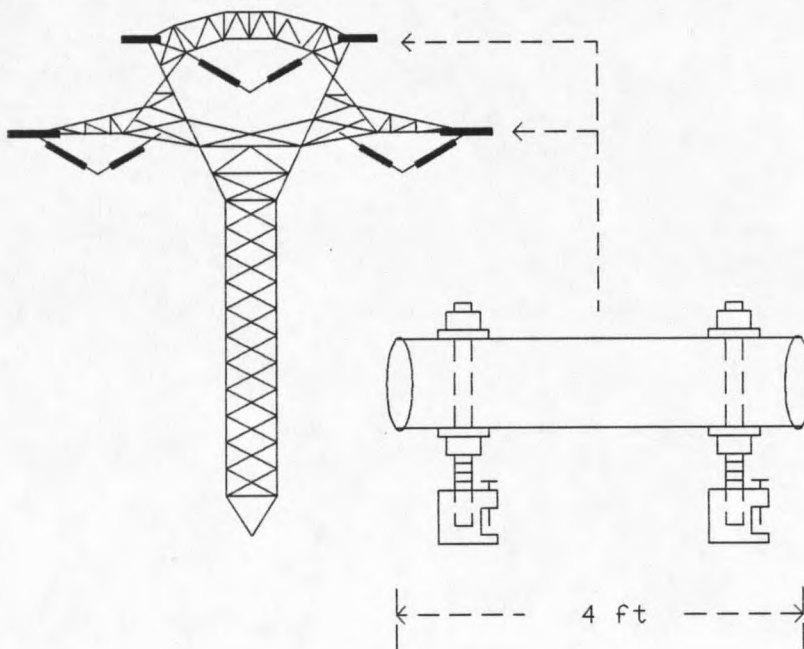


Bird Perches

To prove or disprove that birds are the cause of most faults listed as "no-known cause" is difficult. One way to give an indication if birds are causing the faults is to install bird diverters on one of the lines and determine any new trends in the fault data. Other utilities such as Sierra Pacific Power, Florida Power and Light, and Bonneville Power Administration tried bird diverters on their lines several years ago. Bird diverters were also considered for use on MPC's 500kV lines. However, due to the large areas on each tower

to cover with bird diverters, the ability of raptors to perch anywhere they desire, the high costs per tower of the diverters, and the importance of not harming the raptors, it was decided to not use bird diverters on MPC's lines. Instead, "friendly" bird perches were installed on several of MPC's towers to make a more desirable place for the birds to perch so that they were not directly above the phase wires. The idea behind the perches was to get the large birds to perch in such a location as to not cause a mute induced outage. The perches also needed to be inexpensive, easy to build, and easy to install on the towers. With this in mind, wooden perches were first built from landscape timbers that were 1.22 m (4 ft) in length and 7.62 cm (3 inches) in diameter. As illustrated in Figure 17, the perches were installed on the outer fringes of the upper and lower parts of the towers. MPC linemen attached the perches by tightening the screw clamps to the tower angle iron.

Figure 17. Phase I Bird Perches



These perches were labeled as Phase I perches and were installed in three separate "significant bird activity" areas; namely where the lines pass through Ringling, the Breeding Ranch, and the Welborn Ranch.

Ringling

Phase I perches were installed on Line 1 on 25 towers (6 miles) near Ringling on 7/20/94. This area, 94 to 100 miles west of Broadview (MWOB), consists of flat rangeland and some agricultural activity. It is known as "The Valley of the Eagles" and rightly so because of the significant Golden Eagle population. This is also one of the areas where the most faults occur along the line route. JT McCurry, a resident of Ringling, has been checking the line twice daily for a year and a half to determine the birds' response to the perches. On 10/26/95 five more miles of Phase I perches were installed on alternate towers just west of this area on Line 2. The perches were introduced here because during the previous summer, 3 outages occurred on this stretch of line (100 to 110 MWOB). The perch use has not been documented in this area, therefore the effectiveness of the perches will be determined by the future outage rate in this area or new arrangements for observations will have to be made.

Breeding Ranch

Phase I perches were also installed on 25 towers on Line 1 near the Breeding Ranch. The Breeding Ranch is located approximately 15 miles south of Harlowton and 37 to 43 miles west of Broadview. It is also an area of flat rangeland with some agricultural activity and

significant bird and fault activity. A large Golden Eagle's nest is located here in a tower where a bird caused fault was suspected to have occurred. Seth Breeding occasionally checks the bird activity relative to the perches and a surveillance camera was also installed here to observe the nest activity and perch usage.

Welborn Ranch

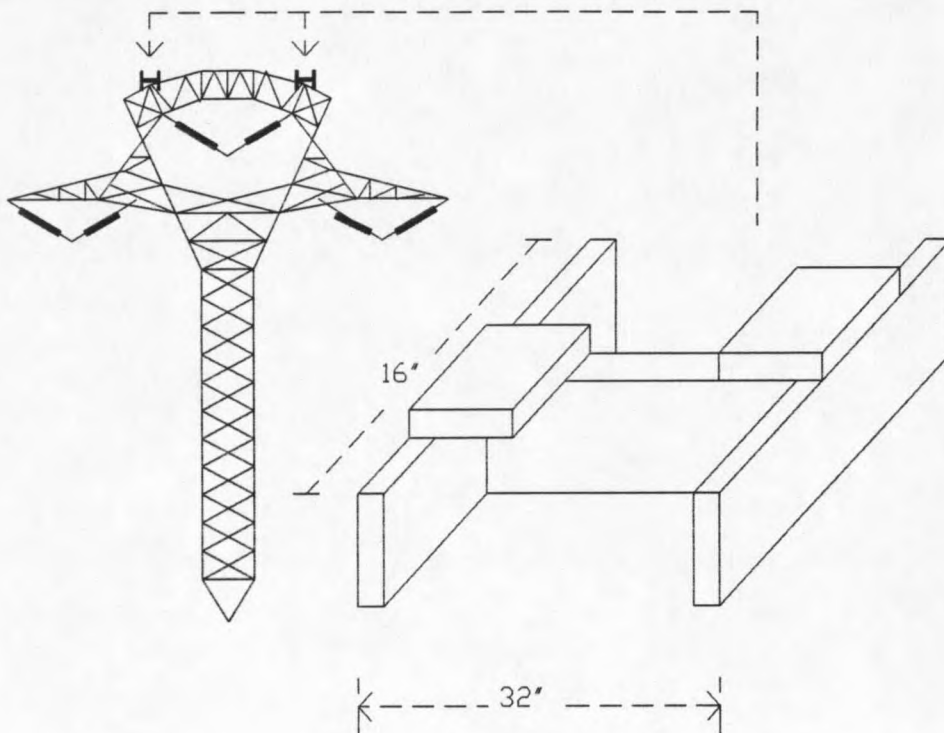
The Welborn Ranch is located east of Broadview near Worden, MT approximately 65 miles west of Colstrip. Located in the area are trees, some rangeland, and a prairie dog town which is within a bird's eye view of the towers. Several Golden Eagles have been spotted on towers in the area, although no faults had been documented prior to the installation of perches on the one mile stretch of towers with perches. Different types of perches such as tree branches, landscape timbers, and distribution cross arms were used here as a "test" to determine if the birds prefer a particular type of perch. The perches were installed on 8/4/94 and Brian Welborn checked the line twice daily for one year to determine the effectiveness of the perches.

Phase II

Phase II perches were installed during the fall of 1995. After further consideration it was decided that with a bird perching on the outer edges of the top Phase I perches, a mute caused lower phase fault could possibly still occur. Therefore, perches illustrated in Figure 18 were installed on the tops on 42 different towers (10 ½ miles) on Line 2 between 94 and

110 miles west of Broadview. The towers between 100 and 110 MWOB alternate between Phase I and Phase II type perches and are not checked daily. Instead, the success of these perches will be determined by the future fault activity. The Phase II perches were moved more towards the center of the towers so the likelihood of a bird caused lower phase outage was zero if the bird was on the perch. Also, the perches were only installed on the tops of the towers because very few birds had been seen on the lower arm Phase I perches.

Figure 18. Phase II Bird Perches



The Phase II perches were built in such a manner that the birds could rest their bellies on a flat surface, take off and land into the wind, and let their tail hang out over the edge while perching, all characteristics observed from Dr. Al Harmata's captive Golden Eagles. The platforms on the perches varied between 8 by 8 inches and 10 by 10 inches and artificial grass was used on some of the platforms. Other Phase II perches consisted of a simple piece of 2 by 6 ft lumber.

A total of 29 miles of transmission lines were equipped with bird perches and the locations along the line route can be seen in Appendix C. A complete discussion of the results and conclusions are presented in the following chapter.

Magnetic Flag Fault Indicators

MPC presently uses four different distance relays to determine the general location of a fault. Often, the relays will estimate the fault to be in a ten mile radius which prompts the inspection of many towers after a fault occurrence. Obviously it is beneficial to determine the actual tower where the fault occurred if the cause is to be identified. For this reason, manually reset magnetic flag fault indicators (mag flags) were installed along 91 miles of the transmission line route. The mag flags, attached to the ground wire or metal tower, operate as simple magnetic balance circuits. A fault current in excess of the trip rating demagnetizes the yoke, thus causing the flag to change state (turn red). The mag flags used on MPC's lines are rated for 100 amps, therefore the thousands of amps of fault current easily trip the mag flags. The mag flags are checked and reset approximately three times a year. Because of

cows interfering with the mag flags on the ground wire at the base of the towers, the mag flags have recently been elevated on the towers to prevent this from occurring. The mag flags trip when they are installed directly on the metal towers so a small piece of PVC was used as a medium between the tower and the flags. Tests and calculations were performed to determine if a "normal" fault current would still trip the mag flags that were attached to the tower and it was concluded that the flags would trip in the presence of a single-phase-to-ground fault. Therefore, mag flags were installed approximately six feet above the ground on all towers equipped with bird perches, all towers with nests, and in areas of recent fault activity. A complete listing of the mag flag locations and status can be seen in Appendix D. Since the installation of the mag flags, four actual towers have been located where outages have occurred and all four faults were thought to have been bird related.

Weather Stations

Six weather stations were initially installed approximately 20 miles from each other along the transmission line study area to evaluate insulator contamination flashover as a cause of outages. The weather stations provide average temperature, wind speed, wind direction, precipitation, relative humidity, barometric pressure, solar, and dew sensor outputs every 15 minutes. Each weather station data logger is equipped with enough memory to store the data for a month. Therefore, once a month the weather data is downloaded via a lap-top computer and a standard RS232 communications interface. The meteorological data are then entered into a spreadsheet allowing the generation of plots and statistical calculations. The data from the nearest weather station are now analyzed after every fault to determine if the weather

conditions give any insight as to the cause of the fault. The weather stations also provide meteorological conditions surrounding the bird activity on the wooden perches.

Digital Fault Recorder

For all of the faults since 1995, both of known and unknown cause, digital fault recorder data have been available. Digital fault recorder data consists of voltage and current waveforms of all phases before, during, and after a fault occurrence. The data are gathered at the Colstrip, Broadview, and Garrison substations. The current and voltage waveforms on the faulted phase are dependant upon the amount of generation at Colstrip, the location of the fault along the line, and the fault resistance, among other factors. It is possible that some type of "signature" waveform is associated with particular causes of faults. The digital fault recorder data have been analyzed in detail to determine if there is such a "signature" for bird caused outages. These data will be presented in the following chapter, Results and Discussion.

CHAPTER 4

RESULTS AND DISCUSSION

To help determine if birds were a source of faults on Montana Power Company's 500kV lines, wooden bird perches were installed on 29 miles of transmission line towers. This chapter deals with a statistical analysis of the bird perches in terms of changing the behavior of the raptors and in terms of fault reduction since the installation of the perches. Only Phase I type perches are considered in the analysis because of the relatively short data collection time since equipping the towers with Phase II type perches. Also included in this chapter is a discussion of the digital fault recorder data.

Behavioral Changes Due to Bird Perches

A total of 412 trips to the line to observe the bird perch activity and use had been documented north of Ringling in an 18 month time span. Sixty percent of the time, at least one bird was observed during a trip to the line and 34% of the birds were seen on a wooden bird perch. A study of the bird activity in the area was not performed before the perches were installed. However, only one line (#1-line) was equipped with bird perches for nearly two years, so the #2-line was used as an indicator of the raptor activity on "non-perch" towers. From the "non-perch" towers it was determined that 28% of the time a bird would perch on the tower in a location where an installed perch was located on the adjacent line. In other

words, 28% of the birds would perch in non-harmful (or non-fault causing) locations on the tower before the perches were installed and 34% of the birds were in non-harmful locations (on the perches) after the installation of the perches. Confidence interval estimates, that is, intervals for which it can be asserted with a reasonable degree of certainty that they will contain the parameter under consideration, were used to illustrate the difference between the two values. In this case the level of significance of the confidence interval was selected to be 0.05 ($\alpha=0.05$). A test concerning the differences between two proportions was used for the analysis and following is a description (Johnson 1994),[19].

Problem -

The study revealed that before the perches were installed, 21 out of 74 birds (28%) would land on a tower in a non harmful location. After the perches were installed, 96 out of 283 birds (34%) landed in non harmful locations. Use $p_1=34\%$ and $p_2=28\%$ and determine if they are statistically different at the 0.05 level of significance.

Null hypothesis-

$p_1=p_2$ Where:

$$p_1 = X_1 / n_1 = 96 / 283$$

$$p_2 = X_2 / n_2 = 21 / 74$$

Alternate hypothesis-

$p_1 > p_2$

Level of significance-

$\alpha=0.05$

Criterion-

Reject the null hypothesis if $Z > 1.645$, where Z is given by the following formula:

$$Z = \frac{\frac{X_1}{n_1} - \frac{X_2}{n_2}}{\sqrt{p'(1-p')\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}; \quad p' = \frac{X_1 + X_2}{n_1 + n_2}$$

Calculations-

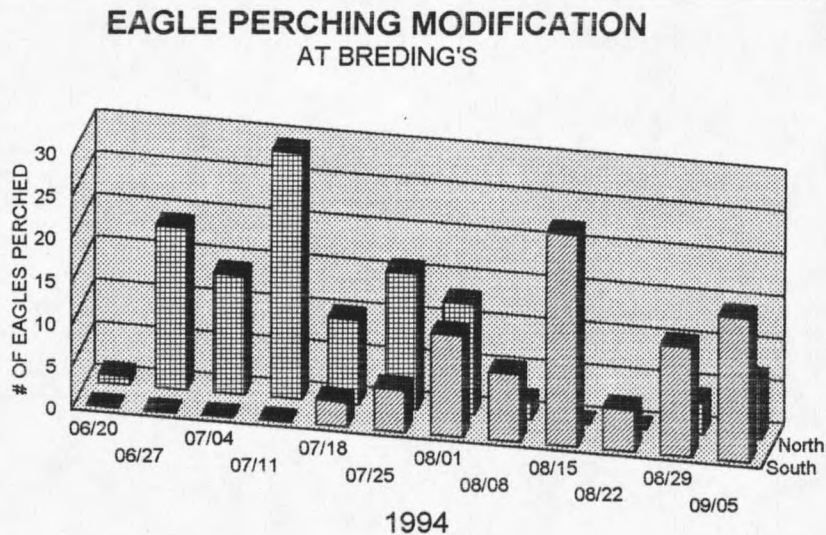
$$Z = 0.9044$$

Decision-

Since $Z = 0.9044$, which does not exceed 1.645, the null hypothesis must be accepted and the two proportions are not considered to be statistically different at the $\alpha = 0.05$ significance level.

Although the perches changed the behavior of the raptors somewhat, the statistics indicate that it was not a significant change (p_1 and p_2 are not significantly different).

Sufficient data were not available from observations of the Breeding Ranch perches to perform a statistical analysis. A surveillance camera installed in the area did provide some insight on the impact of the perches in changing the bird's behavior. Becky Charles,[21] analyzed the VCR tapes obtained from the surveillance camera site and noted some interesting observations. Figure 19 illustrates the use of the towers by the eagles in the area before and after the perch installation on July 21, 1994. The y-axis in the figure represents the number of birds landing on a tower corresponding to the particular date labeled on the x-axis. Note that the eagles used the north line to perch or hunt from before the installation of the perches on the south line, and then utilized the south line after the installation of the perches. Once again, it can be said that the raptors' behaviors were changed somewhat, due to the presence of perches, but it cannot be said that the changes were statistically significant because of the lack of data.

Figure 19. Eagle Behavior at Breeding's

A total of 402 trips to the line near the Welborn Ranch were documented over a one year time span. In this one-mile section of transmission line, not one bird was spotted on a perch. There were two main differences between this area and other areas with perches. First, the other areas were in locations with no trees nearby to perch on and second, the other perches were installed perpendicular to the conductors as opposed to the Welborn Ranch where they were installed parallel to the conductors. From the Welborn Ranch data, it was concluded that bird perches were not useful in locations with trees nearby and also, the perches were most effective when installed perpendicular to the conductors. Nearly 75% of the birds spotted on towers in this area were located on B-line towers, which are the types of towers where virtually all of the faults occur.

In conclusion, the Phase I type bird perches were only somewhat effective in changing the behavioral perching habits of the raptors. Also, the perches were not at all effective in areas where trees are located nearby. It is important to note that one of the purposes of the bird perches was to change the bird's perching behavior, not their hunting behavior, and from the observations, it is impossible to tell if the birds were perching or hunting from the towers. Therefore, the perches may be very effective in changing the bird's perching habits and not their hunting habits.

Fault Reduction Due to Bird Perches

Hypothesis tests were not performed with the fault data to determine the statistical significance of the bird perches in terms of reducing the number of unexplained outages; instead a Poisson Process was used to analyze the data. Unexplained outage data, prior to the installation of the perches, were analyzed at both the Ringling area and the Breeding Ranch. No faults have ever occurred at the Welborn Ranch, and therefore a statistical analysis was not performed for that area.

For ten years prior to the installation of the perches north of Ringling, an average of 0.9 unexplained outages per year occurred on the #1-line located in this 10-mile segment of line. No faults have occurred on a tower with perches in this area since they were installed nearly two years ago. A Poisson Process was used to analyze the success of the perches in terms of fault reduction because the faults are considered a random queuing process, namely, they do not take place at regular intervals of time and the Poisson Distribution is a very good

approximation to this type of data (Johnson 1994),[19]. A problem statement and results from the Poisson Distribution analysis of the fault data at Ringling are presented below.

Problem-

Given the historical fault data of 0.9 faults per year in this area, find the probability of getting zero faults for two years in a row.

Calculations-

$$f(x;\lambda) = \frac{\lambda^x e^{-\lambda}}{x!}$$

$$x = 0$$

$$\lambda = (0.9) 2 = 1.8$$

$$*F(0;1.8) = 0.165 \text{ or } 16.5\%$$

*Value obtained from Poisson Distribution table shown in Appendix E.

Conclusions-

Based on the above calculations, there is a 16.5% probability of no faults occurring in the Ringling area for two years in a row.

This probability is too high to draw any direct conclusions, however if one more year passes with no faults, the probability becomes 6.5%. Consequently, more time is needed to determine the effect of the perches in this area, although it is approaching statistical significance.

Similar to Ringling, no faults have occurred on "perch" towers at the Breeding Ranch. An average of 1.4 faults per year had occurred in this area over the past ten years prior to the installation of the perches. Once again, a Poisson Distribution, shown below, was used to model the data.

Problem-

Given the historical fault data of 1.4 faults per year at the Breeding Ranch, find the probability of getting zero faults for two consecutive years.

Calculations-

$$\lambda = (1.4) 2 = 2.8$$

$$*F(0;2.8) = 0.061 \text{ or } 6.1\%$$

*Value obtained from Poisson Distribution table shown in Appendix E.

Conclusions-

Based on the above calculations, there is a 6.1% probability of no faults occurring at the Breeding Ranch for two years in a row.

These data infer that perches are effective in reducing the number of unexplained outages at the Breeding Ranch only two years after their installation. The important parameter to note is that no faults have ever occurred on towers with perches, and although it is too early to classify this as statistically significant, it is encouraging preliminary evidence that the perches are effective in reducing the outage rate.

Other Bird Perch Observations

Several other patterns were determined from the bird perch observations. This section describes some of the other observed trends.

A weather station was installed north of Ringling at the base of a transmission line tower to help determine if any meteorological patterns correlated with the bird activity. Figures 20 and 21 show the Probability of a Bird on a Perch vs. Temperature and Wind Speed, respectively. The raptors tend to perch during moderate temperatures and wind

speeds, which matches the meteorological fault data shown in Figures 12 and 13 on page 16.

Figure 20. Perch vs Temperature

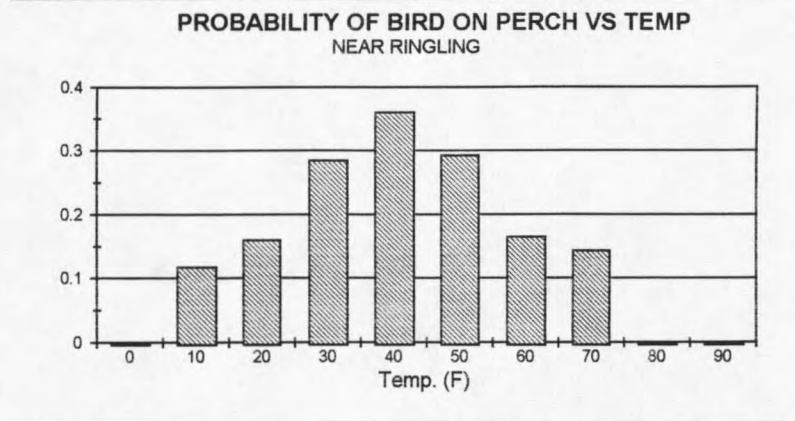
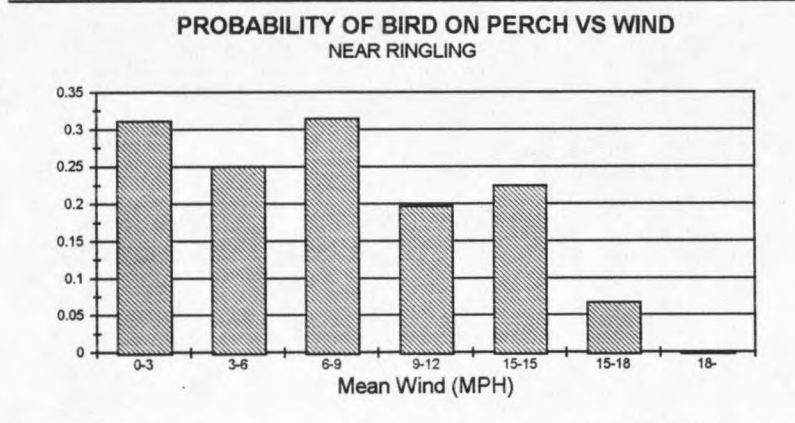


Figure 21. Perch vs Wind Speed

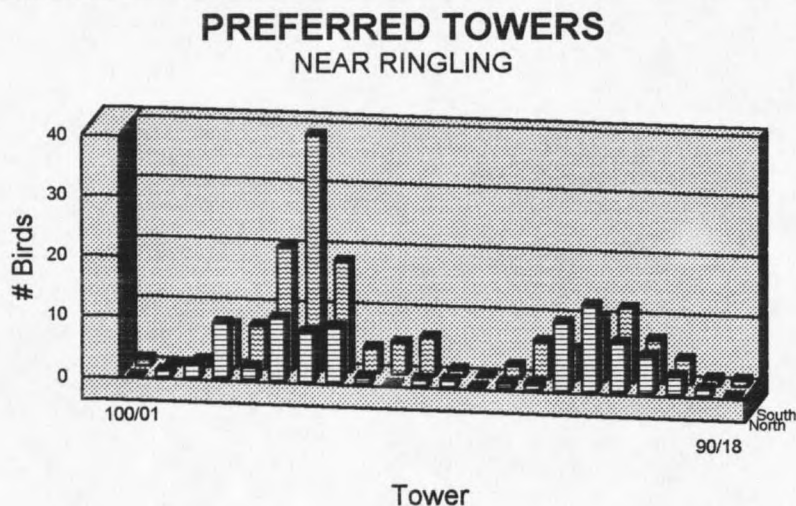


The probabilities used in the histograms were determined by dividing the number of birds seen on a perch in certain weather conditions by the number of trips taken in the same weather

conditions (# on perch at temp. / # of trips at temp.).

It was also observed that the birds tend to prefer certain towers to perch on or hunt from, most likely due to the food habitat nearby. Figure 22 illustrates the preferred towers near Ringling, and it appears likely that 90% of the raptors perch on 10% of the towers. The North and South legends used in the plot represent the #2 and #1 lines, respectively.

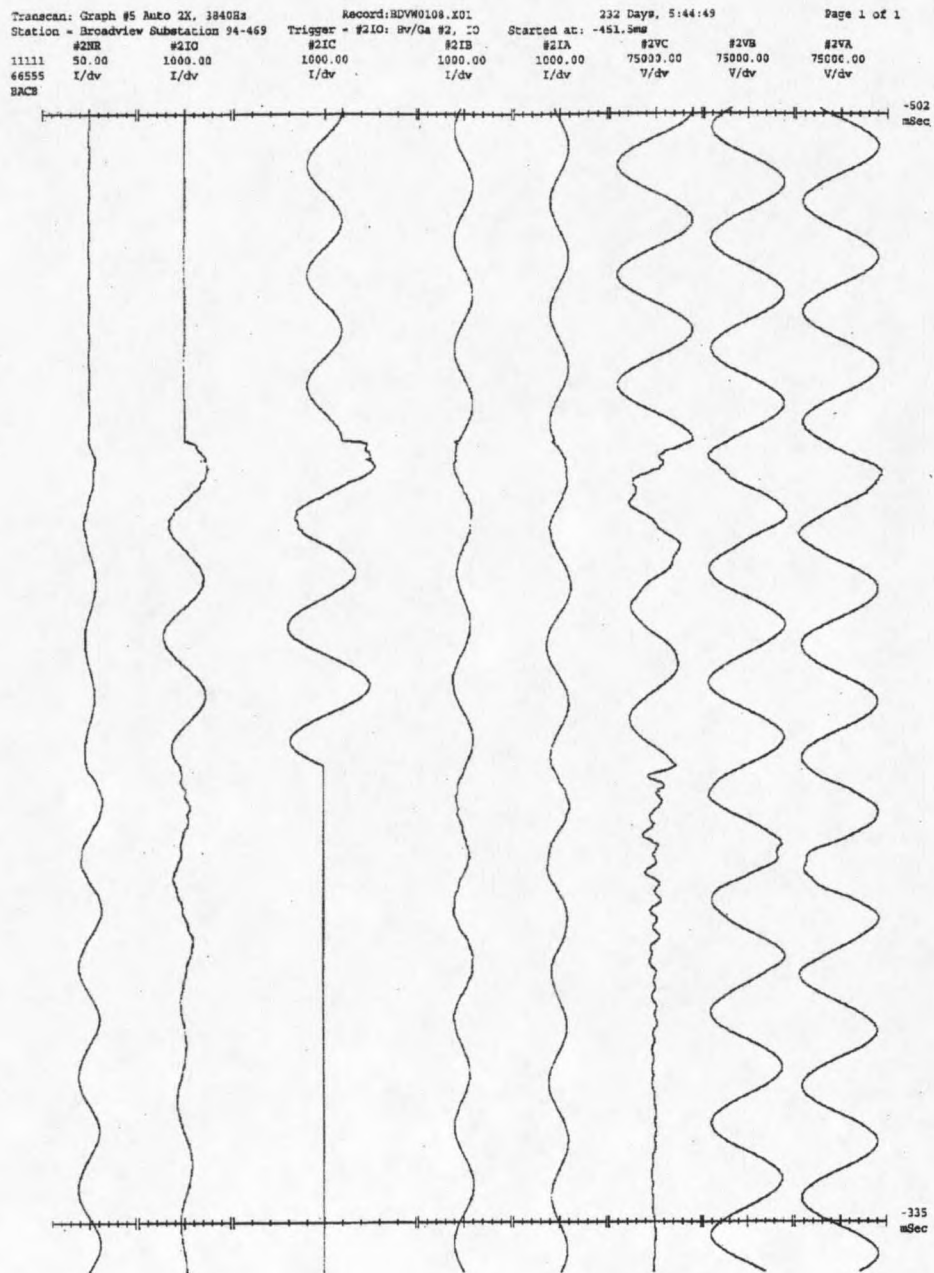
Figure 22. Preferred Towers



Digital Fault Recorder

As mentioned earlier, digital fault recorder (DFR) data have been available for faults occurring since 1995. The digital fault recorder allows for the generation of plots of the waveforms of each phase before, during, and after a fault. For illustration purposes, a DFR plot is shown on the following page in Figure 23 and the rest of the DFR plots discussed are shown in Appendix F.

Figure 23. Digital Fault Recorder Data



Faults Attributed to Birds, Foreign Object Caused

Two faults that occurred on 5/20/95 and 5/27/95 were attributed to birds by MPC engineers because of an active nest with barbed wire hanging out of it located in a tower where the faults were suspected to have occurred. The fault on 5/20/95 occurred at 01:44 and the fault on 5/27/95 occurred at 12:29. Their DFR plots are very similar and can be seen in Appendix F, Figures 24 and 25. The faulted phase voltage occurs at a peak (+, -) and quickly goes to zero and stays at zero, even before the breaker is operated. The fault currents are high in magnitude, which may be due to the fact that both faults occurred close to the Broadview Substation. It appears as though the fault resistance was minimal and solid (constant). In other words, it may have been that there was a solid, conductive, connection between the phase wire and tower, such as barbed wire.

Faults Attributed to Bird Mute

Faults occurring on 5/16/95, 6/25/95, and 8/20/95 were also suspected to be bird caused because of nests that were located in neighboring towers. All of these faults occurred on the outside phases during the early morning hours (between 4:45 and 6:45) approximately 95 to 110 miles west of Broadview. The DFR plots are very similar to each other, although they are different from the DFR plots discussed in the preceding paragraph. The faulted phase voltage, as seen in Appendix F, Figures 26, 27, and 28 does not immediately go to zero after the fault, unlike the DFR plots for the "Faults Attributed to Birds, Foreign Object Caused". It is speculated that these faults may have been caused by mute. West (1971),[15]

determined from the bird mute simulation tests that, "stream breakup occurred such that the mute would not drop in a continuous column", and thus a discontinuity was created in the arc flashover between the tower and conductor. This suggests that the fault resistance was not solid, which appears to be the case with these DFR plots. Furthermore, all of the faults occurred early in the morning which is the most likely time for a mute induced outage to occur because it is common for birds to mute a large quantity prior to commencing daily activity (Burnham 1995),[8].

Other DFR Plots

Seven faults in 1995 were attributed to the transmission lines sagging into trees. The DFR plots for these faults are very similar to the plot shown in Appendix F, Figure 29. The faulted phase voltage waveform does not immediately go to zero after the fault, similar to the waveforms just discussed. However, the fault current gradually becomes larger with time, unlike the DFR plots discussed earlier. All of these faults occurred at the same location along the line (approximately 105 miles east of Broadview) and the same time of day (14:00), although not all of the same capacitor banks were in service.

It is apparent that similarities in the DFR plots exist between some of the faults, however, it is important to reiterate that other parameters, besides the cause of the fault, influence the shape of the DFR plots. The similarities may be more of a function of the location of the fault, than a function of the cause of the fault. Not enough DFR data are available to develop any direct conclusions from the plots and the previous discussions of the DFR data are only speculative.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Due to the randomness and relatively little fault data available since the installation of the bird perches, it is difficult to attribute the fault problem entirely on birds. However, the results of this two-year study strongly suggest that birds are a source of faults, and most likely, the major source of faults on Montana Power Company's 500kV lines. There was strong evidence to support the hypothesis that bird caused flashovers are a source of unexplained faults and little or no evidence contradicting the hypothesis. A summary of the evidence supporting the hypothesis is listed below.

1. Strong correlation between fault locations and bird locations (nests, sightings) along the line route.
2. Annual summer peaks in outages relate to the raptor's migratory habits.
3. Similarities between the fault and bird perch meteorological conditions.
4. Morning bird (mute) activity correlates with the large number of early morning faults.
5. Possibilities of several other sources of faults have been eliminated through previous investigations.
6. Tests performed on similar transmission line configurations by engineers at BPA determined that bird mute induced outages can very likely occur.
7. And no outages occurring on towers equipped with bird perches.

No faults occurring on towers equipped with bird perches are the most significant data gathered to date. The recent installations of the Phase II perches allow for a larger sample area, and thus the conclusions may be stated with more confidence as time progresses. Preferred towers, or the 10% of the towers that birds perch on most, should be targeted for the future installation of perches or other "bird" modifications. A night study of the bird activity along the transmission line is also suggested because the study discussed in this thesis is mainly limited to daytime bird observations. Night vision binoculars were tried, although they did not work because one had to get too close to the tower to see a bird. It is possible that owls or other nocturnal birds may contribute to the fault activity along MPC's 500kV lines.

The foremost evidence to determine if birds are responsible for the faults is to catch them in the act, and therefore it is recommended that the surveillance camera continue to operate at the Breeding Ranch, in the event that a fault may occur in the area. Modifications to the surveillance camera site, such as motion detectors and transmittable data via phone line are additionally recommended to reduce the time involved in analyzing the data and to increase the reliability of the data. It is also recommended that each fault continue to be carefully analyzed for its cause in the future. This includes an analysis of the digital fault recorder data, as well as an investigation of the fault location after such an occurrence. The digital fault recorder database of both known and unknown causes is small at the present time, and will be of more value as the database becomes larger.

Before any direct conclusions are developed, an investigation of insulation and air gap levels of the A-Line compared to the B-Line and Lines 1 and 2 is suggested. The A-Line is

undisputedly superior in performance, which may be directly related to the tower and insulation design of this type of structure and indirectly related to the bird activity. Although bird perches may be an economically viable alternative to tower modifications such as increased air gaps and insulation, more data are needed before any corrective action is taken.

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LITERATURE CITED

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APPENDICES

APPENDIX A

MPC Unexplained Outage Data: Broadview - Townsend, 1984-1995

Table 3. Unexplained Outage Data

Broadview-Townsend 500kV Operating Events

NUMBER	DAY	DATE	TIME	LINE	PHASE	LOC.	MWOB	YEAR
1	139	18-May-84	04:55	1	C	TOP	89	84
2	150	29-May-84	07:52	1	C	TOP	94	84
3	165	13-Jun-84	04:43	1	B	SOUTH	76	84
4	176	24-Jun-84	09:51	1	C	TOP	21	84
5	196	14-Jul-84	08:34	2	A	TOP	55	84
6	197	15-Jul-84	10:45	1	C	TOP	40	84
7	199	17-Jul-84	04:17	2	B	NORTH	23	84
8	210	28-Jul-84	04:38	1	A	NORTH	37	84
9	230	17-Aug-84	17:28	1	C	TOP	34	84
10	240	27-Aug-84	13:37	2	A-C	SOUTH	120	84
11	270	26-Sep-84	06:27	2	C	SOUTH	28	84
12	73	14-Mar-85	14:23	1	B	TOP	10	85
13	160	09-Jun-85	04:54	1	C	TOP	27	85
14	219	07-Aug-85	03:47	1	C	TOP	94	85
15	227	15-Aug-85	03:13	1	B	SOUTH	31	85
16	229	17-Aug-85	00:23	2	B	NORTH	38	85
17	236	24-Aug-85	01:26	2	C	SOUTH	90	85
18	239	27-Aug-85	02:57	1	B	SOUTH	28	85
19	239	27-Aug-85	22:55	1	C	TOP	46	85
20	240	28-Aug-85	05:33	1	C	TOP	48	85
21	77	18-Mar-86	22:30	1	B	SOUTH	50	86
22	137	17-May-86	08:44	2	B	NORTH	40	86
23	152	01-Jun-86	17:40	2	B	NORTH	74	86
24	155	04-Jun-86	11:15	2	A	TOP	113	86
25	162	11-Jun-86	01:15	1	C	TOP	45	86
26	212	31-Jul-86	07:39	1	C	TOP	38	86
27	213	01-Aug-86	03:12	2	A	TOP	45	86
28	219	07-Aug-86	00:09	2	C	SOUTH	43	86
29	223	11-Aug-86	06:48	1	B	SOUTH	95.5	86
30	230	18-Aug-86	23:58	2	B	NORTH	94	86
31	231	19-Aug-86	00:43	2	A	TOP	39	86
32	298	25-Oct-86	21:11	2	A	TOP	44.5	86
33	132	12-May-87	06:33	1	C	TOP	19	87
34	193	12-Jul-87	12:05	2	A	TOP	78	87
35	194	13-Jul-87	20:18	1	C	TOP	35	87
36	208	27-Jul-87	23:45	2	B	NORTH	49	87
37	209	28-Jul-87	02:57	1	B	SOUTH	25	87
38	209	28-Jul-87	00:30	1	B	SOUTH	25	87
39	212	31-Jul-87	01:34	2	C	SOUTH	49	87
40	212	31-Jul-87	03:08	2	C	SOUTH	49	87
41	212	31-Jul-87	00:03	2	C	SOUTH	45	87
42	213	01-Aug-87	04:58	1	B	SOUTH	49	87
43	214	02-Aug-87	05:08	2	B	NORTH	56	87
44	215	03-Aug-87	22:37	2	A	TOP	21.5	87
45	218	06-Aug-87	02:26	1	B	SOUTH	72.5	87
46	219	07-Aug-87	02:08	2	B	NORTH	62	87
47	220	08-Aug-87	15:27	1	C	TOP	70	87
48	221	09-Aug-87	00:42	1	B	SOUTH	61	87
49	225	13-Aug-87	04:18	2	B	NORTH	60	87
50	264	21-Sep-87	03:12	2	A	TOP	66	87
51	265	22-Sep-87	15:31	2	B	NORTH	6.5	87

Table 3 Continued

Broadview-Townsend 500kV Operating Events

NUMBER	DAY	DATE	TIME	LINE	PHASE	LOC.	MWOB	YEAR
52	306	02-Nov-87	00:27	2	B	NORTH	47	87
53	309	05-Nov-87	20:08	2	B	NORTH	126	87
54	52	21-Feb-88	15:33	1	C	TOP	35	88
55	142	21-May-88	11:11	1	C	TOP	17.3	88
56	155	03-Jun-88	09:07	2	A	TOP	73	88
57	211	29-Jul-88	14:28	1	B	SOUTH	80.5	88
58	222	09-Aug-88	23:25	1	C	SOUTH	3	88
59	223	10-Aug-88	04:28	2	A	TOP	113	88
60	224	11-Aug-88	22:10	2	A	TOP	32	88
61	227	14-Aug-88	21:27	2	C	SOUTH	63	88
62	236	23-Aug-88	17:24	2	A	TOP	61	88
63	243	30-Aug-88	02:17	1	C	TOP	98	88
64	256	12-Sep-88	01:05	2	B	NORTH	99	88
65	140	20-May-89	05:17	2	A	TOP	39	89
66	141	21-May-89	05:01	1	A	NORTH	38	89
67	141	21-May-89	05:01	1	A	NORTH	40	89
68	178	27-Jun-89	15:12	2	B	NORTH	57	89
69	178	27-Jun-89	01:45	2	B	NORTH	57	89
70	181	30-Jun-89	03:41	1	A	NORTH	14	89
71	196	15-Jul-89	04:28	2	B	NORTH	80	89
72	210	29-Jul-89	04:34	2	C	SOUTH	68	89
73	212	31-Jul-89	04:46	1	C	TOP	54	89
74	224	12-Aug-89	05:11	1	B	SOUTH	89	89
75	225	13-Aug-89	04:29	2	B	NORTH	68	89
76	226	14-Aug-89	20:45	1	A	NORTH	110	89
77	234	22-Aug-89	06:45	1	C	TOP	16	89
78	236	24-Aug-89	05:37	2	A	TOP	119	89
79	240	28-Aug-89	10:08	2	B	NORTH	71	89
80	241	29-Aug-89	13:37	2	A	TOP	50	89
81	245	02-Sep-89	00:26	2	B	NORTH	60	89
82	250	07-Sep-89	05:33	2	A	TOP	68	89
83	312	08-Nov-89	15:59	2	A	TOP	67	89
84	312	08-Nov-89	15:59	1	C	TOP	100	89
85	352	18-Dec-89	23:20	1	B	SOUTH	128	89
86	20	20-Jan-90	05:37	2	C	SOUTH	117.3	90
87	70	11-Mar-90	08:15	2	B	NORTH	62.4	90
88	115	25-Apr-90	05:18	2	B	NORTH	93.3	90
89	123	03-May-90	06:09	1	B	SOUTH	95.3	90
90	140	20-May-90	05:26	2	B	NORTH	92.5	90
91	167	16-Jun-90	08:11	1	C	TOP	94.5	90
92	174	23-Jun-90	17:08	1	B	SOUTH	65.0	90
93	174	23-Jun-90	20:56	1	B	TOP	23.5	90
94	178	27-Jun-90	02:15	1	B	SOUTH	104.4	90
95	197	16-Jul-90	03:07	1	A	NORTH	71.0	90
96	199	18-Jul-90	05:01	1	A	NORTH	70.0	90
97	211	30-Jul-90	00:19	1	B	SOUTH	38.0	90
98	222	10-Aug-90	23:58	1	C	TOP	22.2	90
99	222	10-Aug-90	05:28	1	C	TOP	58.9	90
100	227	15-Aug-90	05:45	2	B	NORTH	98.2	90
101	229	17-Aug-90	23:46	2	A	TOP	100.5	90
102	230	18-Aug-90	05:41	2	B	NORTH	93.3	90

Table 3 Continued

Broadview-Townsend 500kV Operating Events

NUMBER	DAY	DATE	TIME	LINE	PHASE	LOC.	MWOB	YEAR
103	237	25-Aug-90	21:55	2	B	NORTH	58.6	90
104	245	02-Sep-90	15:31	2	A	TOP	93.3	90
105	250	07-Sep-90	12:26	1	C	TOP	22.1	90
106	328	24-Nov-90	02:45	1	C	TOP	88.7	90
107	343	09-Dec-90	10:31	1	A	NORTH	102.8	90
108	16	16-Jan-91	16:18	1	A	NORTH	0	91
109	107	17-Apr-91	07:42	2	C	SOUTH	44	91
110	107	17-Apr-91	02:00	2	B	NORTH	105	91
111	109	19-Apr-91	12:34	2	C	SOUTH	36.4	91
112	114	24-Apr-91	01:03	2	A	TOP	25.4	91
113	140	20-May-91	05:01	2	A	TOP	48.2	91
114	157	06-Jun-91	03:03	2	B	NORTH	105.9	91
115	163	12-Jun-91	11:28	1	C	TOP	113	91
116	164	13-Jun-91	23:15	2	B	NORTH	42.2	91
117	172	21-Jun-91	04:08	2	A	TOP	64.2	91
118	173	22-Jun-91	13:38	2	B	NORTH	56.4	91
119	185	04-Jul-91	02:44	2	B	NORTH	64.4	91
120	193	12-Jul-91	16:56	1	B	SOUTH	46.3	91
121	194	13-Jul-91	10:22	1	A	NORTH	44	91
122	207	26-Jul-91	19:51	1	B	SOUTH	114.6	91
123	210	29-Jul-91	08:03	2	B	NORTH	65.6	91
124	224	12-Aug-91	05:07	1	C	TOP	56.5	91
125	242	30-Aug-91	19:45	2	C	SOUTH	119.2	91
126	242	30-Aug-91	23:17	2	B	NORTH	21.8	91
127	246	03-Sep-91	23:49	2	A	TOP	59.3	91
128	256	13-Sep-91	00:27	2	C	SOUTH	45	91
129	275	02-Oct-91	19:00	1	B	SOUTH	46.8	91
130	361	27-Dec-91	07:10	2	B	NORTH	109.6	91
131	52	21-Feb-92	09:27	2	B	NORTH	38.7	92
132	66	06-Mar-92	08:02	1	B	NORTH	3.3	92
133	118	27-Apr-92	06:44	2	B	NORTH	102.5	92
134	120	29-Apr-92	20:14	1	B	TOP	15.7	92
135	143	22-May-92	04:25	1	B	SOUTH	54.8	92
136	143	22-May-92	07:54	1	B	SOUTH	115	92
137	148	27-May-92	05:14	2	B	NORTH	93.2	92
138	152	31-May-92	20:13	2	C	SOUTH	25.1	92
139	161	09-Jun-92	15:55	1	A	NORTH	14.5	92
140	172	20-Jun-92	00:41	1	A	NORTH	57.1	92
141	176	24-Jun-92	06:34	1	C	TOP	35.4	92
142	200	18-Jul-92	03:05	1	B	SOUTH	1.1	92
143	208	26-Jul-92	02:32	2	B	NORTH	45.1	92
144	210	28-Jul-92	04:17	2	B	NORTH	25.9	92
145	211	29-Jul-92	02:48	2	A	TOP	15.6	92
146	229	16-Aug-92	02:43	2	C	SOUTH	102.5	92
147	275	01-Oct-92	14:52	1	A	NORTH	42.5	92
148	292	18-Oct-92	12:36	2	A	TOP	100	92
149	297	23-Oct-92	16:17	2	C	SOUTH	119.4	92
150	38	07-Feb-93	12:08	1	C	TOP	99.2	93
151	54	23-Feb-93	17:09	2	A	TOP	35.7	93
152	56	25-Feb-93	09:46	2	A	TOP	64.4	93
153	119	29-Apr-93	12:19	2	C	SOUTH	36.1	93

Table 3 Continued

Broadview-Townsend 500kV Operating Events

NUMBER	DAY	DATE	TIME	LINE	PHASE	LOC.	MWOB	YEAR
154	156	05-Jun-93	16:16	1	C	TOP	48.3	93
155	161	10-Jun-93	05:04	1	A	NORTH	82.3	93
156	162	11-Jun-93	10:16	1	C	TOP	48.3	93
157	182	01-Jul-93	05:12	2	C	NORTH	45	93
158	188	07-Jul-93	04:21	2	B	NORTH	54.8	93
159	196	15-Jul-93	05:17	1	B	SOUTH	96.8	93
160	201	20-Jul-93	05:02	1	C	TOP	16.5	93
161	202	21-Jul-93	01:45	2	C	SOUTH	102.5	93
162	236	24-Aug-93	01:46	1	B	SOUTH	22.3	93
163	250	07-Sep-93	16:46	1	A	NORTH	41.8	93
164	279	06-Oct-93	01:23	1	A	NORTH	35.5	93
165	304	31-Oct-93	14:11	2	B	TOP	100.1	93
166	20	20-Jan-94	15:42	1	A	NORTH	35.8	94
167	122	02-May-94	11:52	2	B	TOP	6.6	94
168	136	16-May-94	23:12	2	B	NORTH	31.5	94
169	166	15-Jun-94	09:47	2	A	TOP	25.7	94
170	174	23-Jun-94	10:09	2	A	TOP	99.2	94
171	214	02-Aug-94	06:41	1	C	TOP	111.4	94
172	225	13-Aug-94	05:01	1	B	TOP	14.9	94
173	247	04-Sep-94	23:59	1	B	SOUTH	23.4	94
174	248	05-Sep-94	03:37	1	B	SOUTH	23.4	94
175	254	11-Sep-94	02:24	1	B	SOUTH	23.6	94
176	24	24-Jan-95	17:05	1	C	TOP	125.3	95
177	97	07-Apr-95	06:36	2	B	NORTH	131.7	95
178	133	13-May-95	16:25	1	C	TOP	79.7	95
179	136	16-May-95	06:42	2	B	NORTH	95.9	95
180	140	20-May-95	01:44	2	C	SOUTH	11.2	95
181	147	27-May-95	12:29	2	B	TOP	11.4	95
182	160	09-Jun-95	21:17	2	A	TOP	106.7	95
183	176	25-Jun-95	04:48	1	B	SOUTH	100.6	95
184	219	07-Aug-95	14:15	2	B	NORTH	67.7	95
185	223	11-Aug-95	13:07	2	B	TOP	0.9	95
186	232	20-Aug-95	05:44	2	C	SOUTH	108.5	95

APPENDIX B

Listing of Nests Located in Towers

Nest Locations Documented From Helicopter Surveys and Ground Surveys:

Line-1, Tower #:

00-00	90-16
05-12	95-08
20-21	95-19
40-07	105-04
45-01	100-09
45-12	120-19
60-09	125-12
60-16	125-17

Line-2, Tower #:

00-09	80-09
00-19	90-06
05-12	90-16
10-03	95-08
20-17	95-19
30-03	100-01
35-03	100-07
40-02	105-03
45-05	125-08
45-11	125-13

B-Line, Tower #:

40-08	65-18
40-09	105-12
40-10	110-03
65-02	110-06
65-03	110-11

A-Line, Tower #:

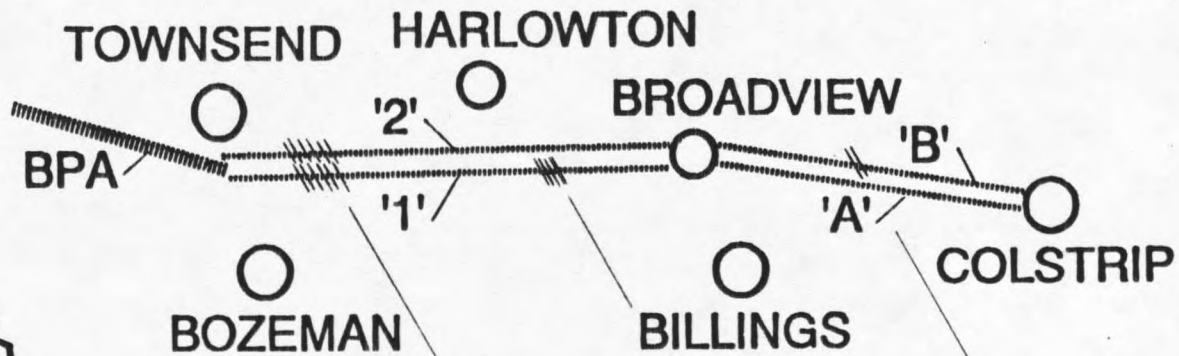
0 nests observed

APPENDIX C

Bird Perch Locations Along Line Route

Bird Perches

MONTANA POWER COMPANY 500KV LINES



Ringling

Breeding's

Welborn's

APPENDIX D

Magnetic Flag Fault Indicator Status

Magnetic Flag Locations and Status (3/21/96)

#1, #2 Lines: Townsend - Broadview

135-13 to 120-16: All Flags Elevated

110-02 to 90-15: All Flags Elevated

65-00 to 60-09: All Flags Elevated

45-13 to 30-12: Most Flags Elevated

20-12 to 20-09: All Flags Elevated

10-04 to 10-02: All Flags Elevated

B-Line: Broadview - Colstrip

80-05 to 80-18: No Flags Elevated

60-15 to 60-20: No Flags Elevated

40-06 to 40-11: All Flags Elevated

91 miles of transmission lines are currently equipped with magnetic flag fault indicators.

APPENDIX E**Poisson Distribution Table**

Table 4. Poisson Distribution Function

$$F(x; \lambda) = \sum_{k=0}^x e^{-\lambda} \frac{\lambda^k}{k!}$$

$\lambda \backslash x$	0	1	2	3	4	5	6	7	8	9
0.02	0.980	1.000								
0.04	0.961	0.999	1.000							
0.06	0.942	0.998	1.000							
0.08	0.923	0.997	1.000							
0.10	0.905	0.995	1.000							
0.15	0.861	0.990	0.999	1.000						
0.20	0.819	0.982	0.999	1.000						
0.25	0.779	0.974	0.998	1.000						
0.30	0.741	0.963	0.996	1.000						
0.35	0.705	0.951	0.994	1.000						
0.40	0.670	0.938	0.992	0.999	1.000					
0.45	0.638	0.925	0.989	0.999	1.000					
0.50	0.607	0.910	0.986	0.998	1.000					
0.55	0.577	0.894	0.982	0.998	1.000					
0.60	0.549	0.878	0.977	0.997	1.000					
0.65	0.522	0.861	0.972	0.996	0.999	1.000				
0.70	0.497	0.844	0.966	0.994	0.999	1.000				
0.75	0.472	0.827	0.959	0.993	0.999	1.000				
0.80	0.449	0.809	0.953	0.991	0.999	1.000				
0.85	0.427	0.791	0.945	0.989	0.998	1.000				
0.90	0.407	0.772	0.937	0.987	0.998	1.000				
0.95	0.387	0.754	0.929	0.984	0.997	1.000				
1.00	0.368	0.736	0.920	0.981	0.996	0.999	1.000			
1.1	0.333	0.699	0.900	0.974	0.995	0.999	1.000			
1.2	0.301	0.663	0.879	0.966	0.992	0.998	1.000			
1.3	0.273	0.627	0.857	0.957	0.989	0.998	1.000			
1.4	0.247	0.592	0.833	0.946	0.986	0.997	0.999	1.000		
1.5	0.223	0.558	0.809	0.934	0.981	0.996	0.999	1.000		
1.6	0.202	0.525	0.783	0.921	0.976	0.994	0.999	1.000		
1.7	0.183	0.493	0.757	0.907	0.970	0.992	0.998	1.000		
1.8	0.165	0.463	0.731	0.891	0.964	0.990	0.997	0.999	1.000	
1.9	0.150	0.434	0.704	0.875	0.956	0.987	0.997	0.999	1.000	
2.0	0.135	0.406	0.677	0.857	0.947	0.983	0.995	0.999	1.000	

Reprinted from Johnson (1994), [19].

Table 4 Continued

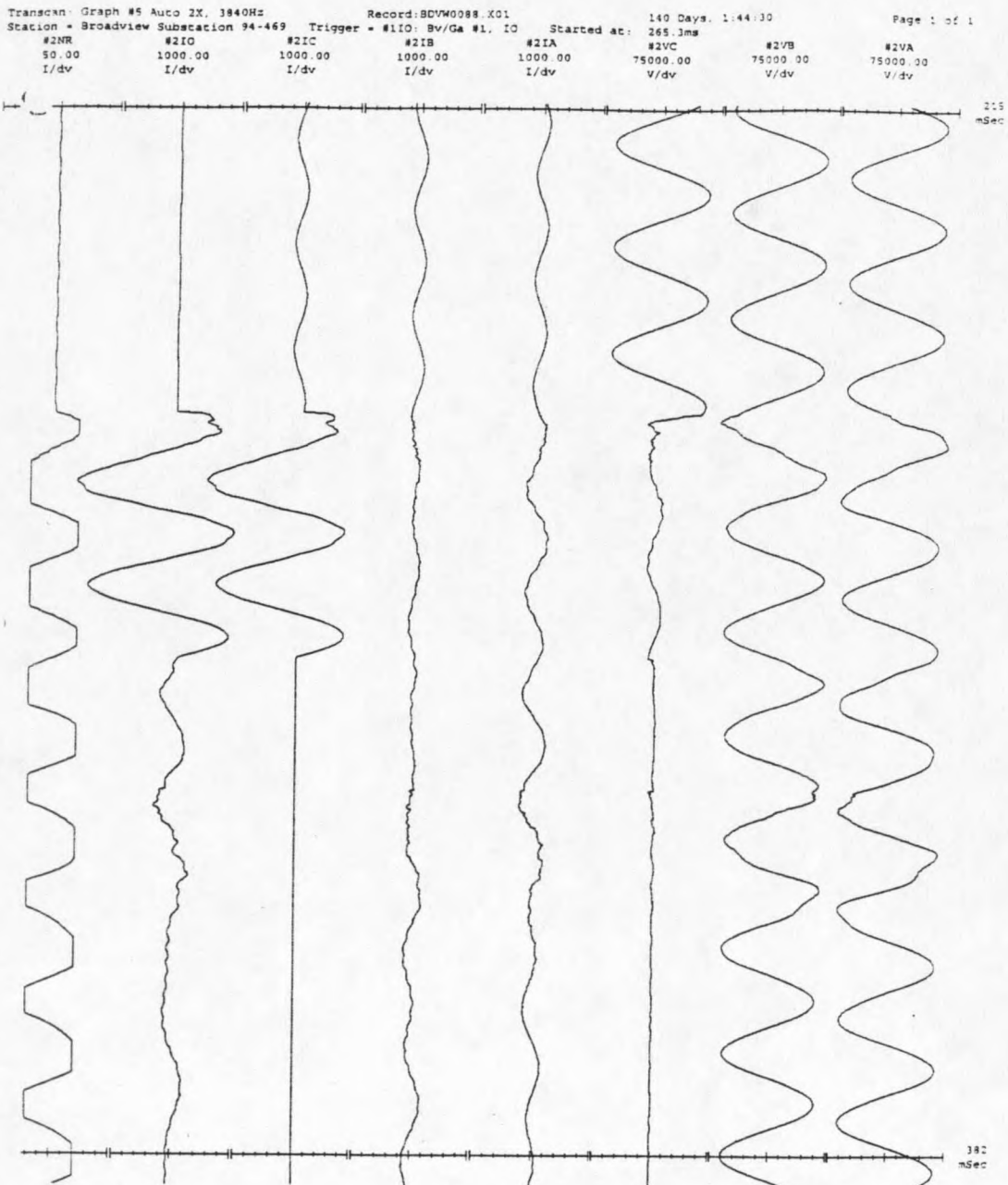
$\lambda \backslash x$	0	1	2	3	4	5	6	7	8	9
2.2	0.111	0.355	0.623	0.819	0.928	0.975	0.993	0.998	1.000	
2.4	0.091	0.308	0.570	0.779	0.904	0.964	0.988	0.997	0.999	1.000
2.6	0.074	0.267	0.518	0.736	0.877	0.951	0.983	0.995	0.999	1.000
2.8	0.061	0.231	0.469	0.692	0.848	0.935	0.976	0.992	0.998	0.999
3.0	0.050	0.199	0.423	0.647	0.815	0.916	0.966	0.988	0.996	0.999
3.2	0.041	0.171	0.380	0.603	0.781	0.895	0.955	0.983	0.994	0.998
3.4	0.033	0.147	0.340	0.558	0.744	0.871	0.942	0.977	0.992	0.997
3.6	0.027	0.126	0.303	0.515	0.706	0.844	0.927	0.969	0.988	0.996
3.8	0.022	0.107	0.269	0.473	0.668	0.816	0.909	0.960	0.984	0.994
4.0	0.018	0.092	0.238	0.433	0.629	0.785	0.889	0.949	0.979	0.992
4.2	0.015	0.078	0.210	0.395	0.590	0.753	0.867	0.936	0.972	0.989
4.4	0.012	0.066	0.185	0.359	0.551	0.720	0.844	0.921	0.964	0.985
4.6	0.010	0.056	0.163	0.326	0.513	0.686	0.818	0.905	0.955	0.980
4.8	0.008	0.048	0.143	0.294	0.476	0.651	0.791	0.887	0.944	0.975
5.0	0.007	0.040	0.125	0.265	0.440	0.616	0.762	0.867	0.932	0.968
5.2	0.006	0.034	0.109	0.238	0.406	0.581	0.732	0.845	0.918	0.960
5.4	0.005	0.029	0.095	0.213	0.373	0.546	0.702	0.822	0.903	0.951
5.6	0.004	0.024	0.082	0.191	0.342	0.512	0.670	0.797	0.886	0.941
5.8	0.003	0.021	0.072	0.170	0.313	0.478	0.638	0.771	0.867	0.929
6.0	0.002	0.017	0.062	0.151	0.285	0.446	0.606	0.744	0.847	0.916
	10	11	12	13	14	15	16			
2.8	1.000									
3.0	1.000									
3.2	1.000									
3.4	0.999	1.000								
3.6	0.999	1.000								
3.8	0.998	0.999	1.000							
4.0	0.997	0.999	1.000							
4.2	0.996	0.999	1.000							
4.4	0.994	0.998	0.999	1.000						
4.6	0.992	0.997	0.999	1.000						
4.8	0.990	0.996	0.999	1.000						
5.0	0.986	0.995	0.998	0.999	1.000					
5.2	0.982	0.993	0.997	0.999	1.000					
5.4	0.977	0.990	0.996	0.999	1.000					
5.6	0.972	0.988	0.995	0.998	0.999	1.000				
5.8	0.965	0.984	0.993	0.997	0.999	1.000				
6.0	0.957	0.980	0.991	0.996	0.999	0.999	1.000			

Reprinted from Johnson (1994), [19].

APPENDIX F

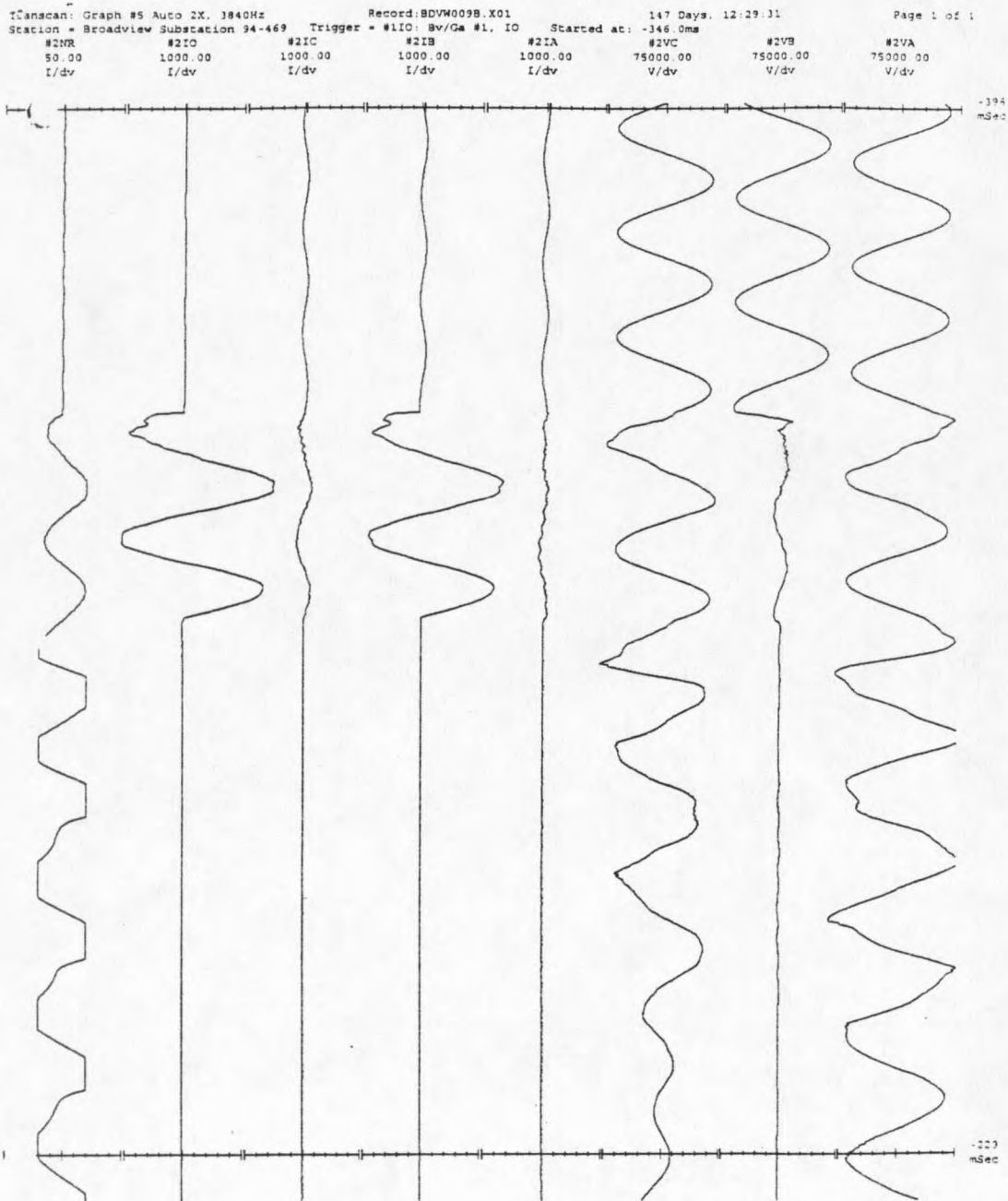
Digital Fault Recorder Data

Figure 24. DFR Data for Fault on 5/20/95



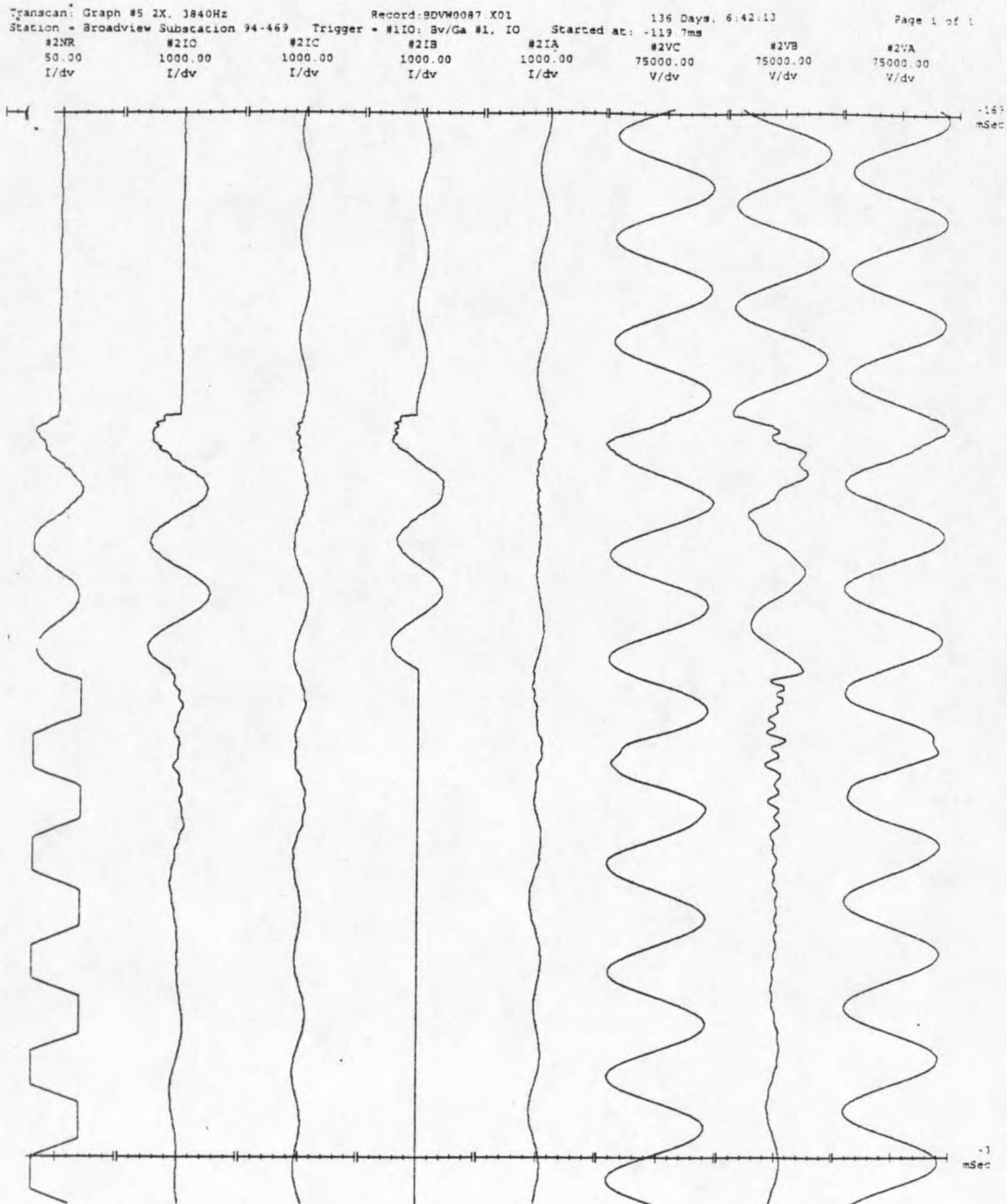
Suspected Cause; Birds, Foreign Object

Figure 25. DFR Data for Fault on 5/27/95



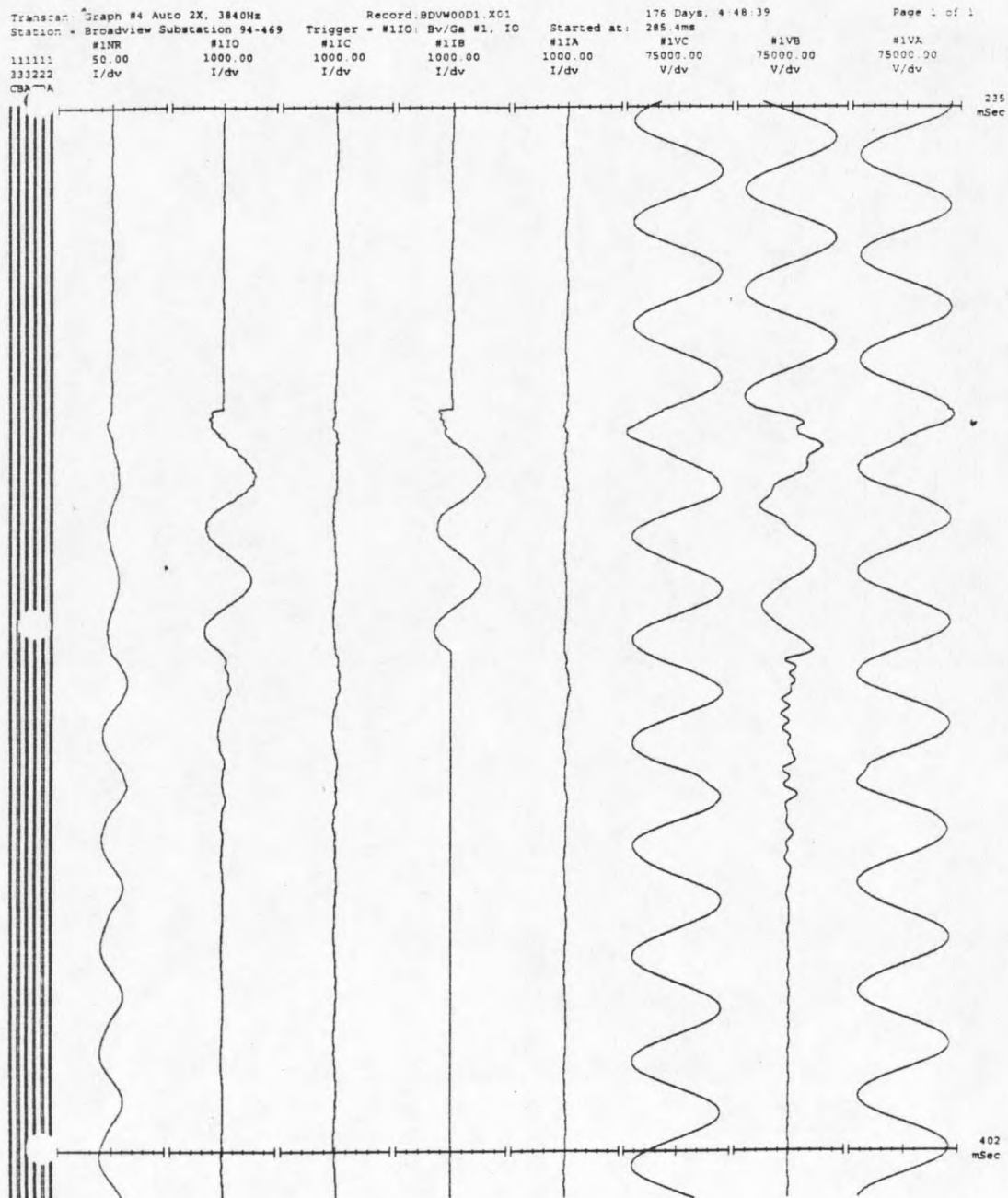
Suspected Cause; Birds, Foreign Object

Figure 26. DFR Data for Fault on 5/16/95

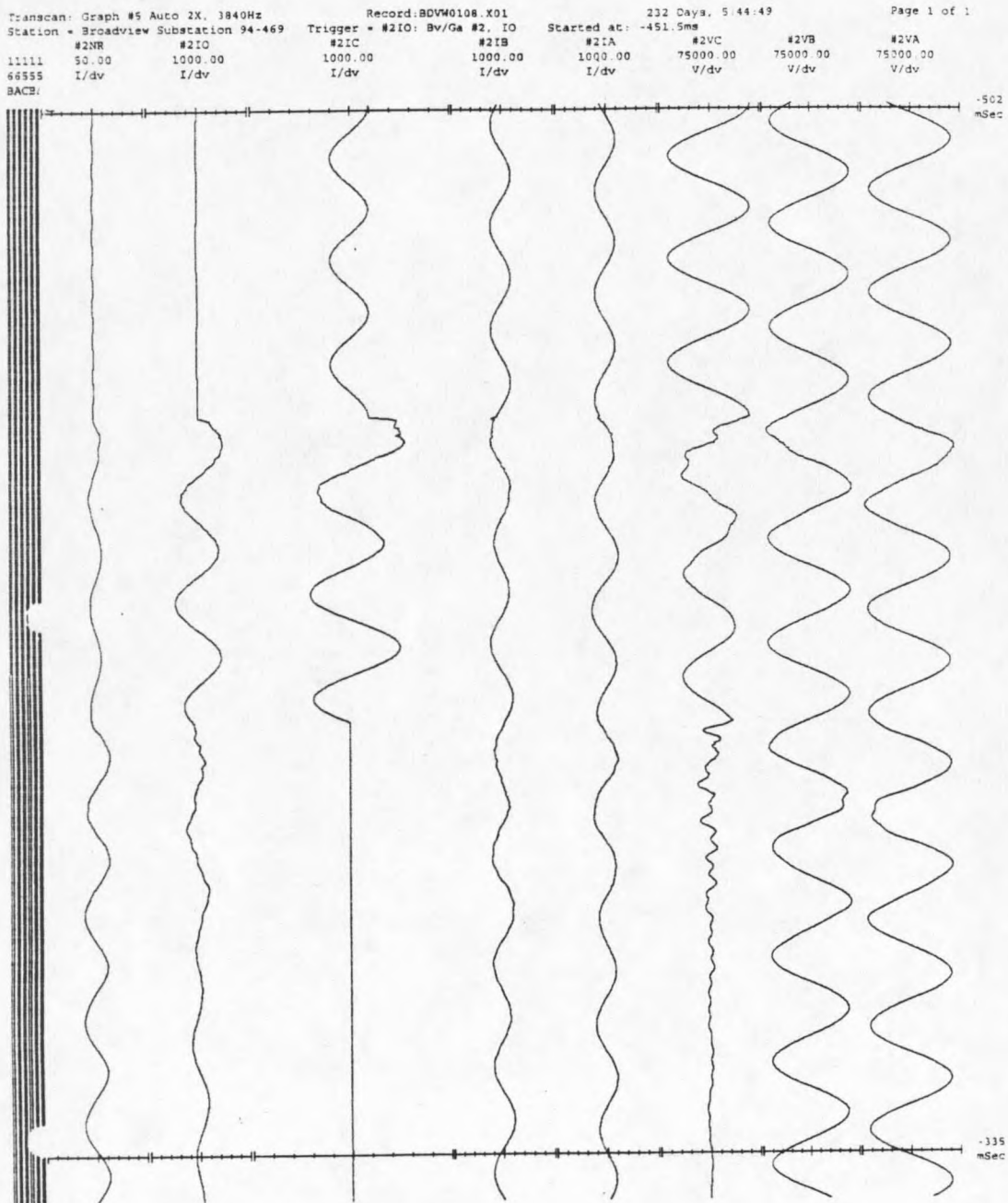


Suspected Cause; Birds, Mute

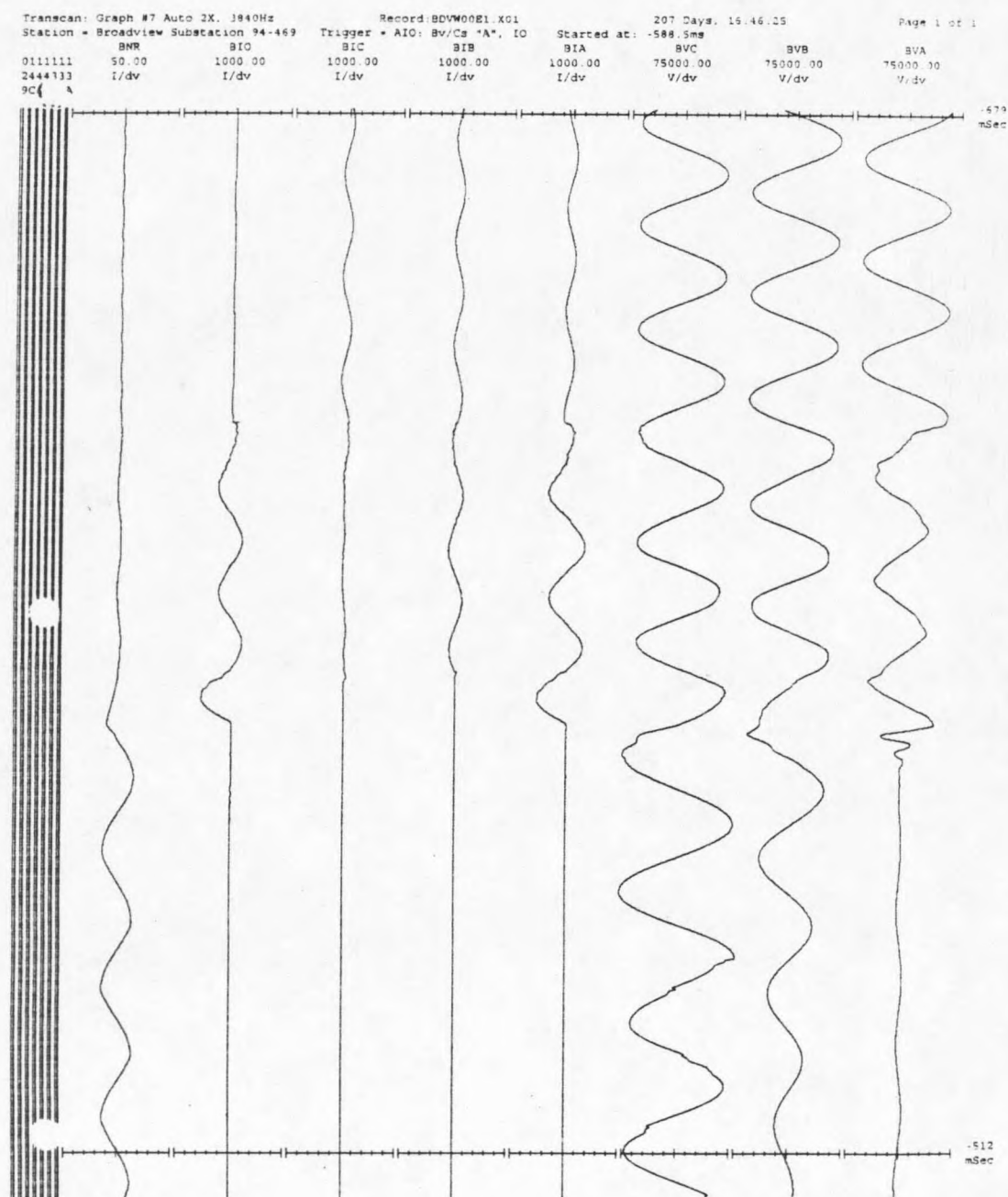
Figure 27. DFR Data for Fault on 6/25/95



Suspected Cause; Birds, Mute

Figure 28. DFR Data for Fault on 8/20/95

Suspected Cause; Birds, Mute

Figure 29. DFR Data for Fault on 7/26/95**Known Cause; Line Sagging Into Tree**

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