THE UNIVERSITY OF ALBERTA

THE OBJECTIVE MEASUREMENT OF ALBERTA HAILFALL

by

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A THESIS

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DEDICATED TO

my patient and loving wife, Phyllis,

who has supported my efforts in every way possible,

my dear daughters Emma and Michelle,

and my constant, faithful companion Lass, a collie.

ABSTRACT

With the financial backing of Alberta Hail Studies, a study was undertaken to determine the feasibility of using a simple hail detector, called a hailpad, to measure Alberta hailfall and thereby help in evaluating hail suppression efforts. This hailpad consisted of a styrofoam pad covered with aluminum foil.

The study considers theories of hailstone dynamics, the choice of hailpad materials, calibration, error analysis, and wind effects. Because of the tediousness of detailed hand analysis, a reasonably accurate estimation procedure is described and the possibility of completely automated analyses using digital picture processing methods is discussed.

Known characteristics of Alberta hailstorms and results from previous U.S. studies using hailpads are carefully considered in designing the hailpad network. The final network consisted of 272 stations maintained by farmer volunteers, with an average station spacing of 2.6 miles. Results from 17 hailstorms during 1973 indicate that a maximum spacing of about 3 miles is necessary to adequately evaluate the pattern of damaging hailfalls. Several dense networks with hailpad spacing of .25 mile were established in order to test the areal representativeness of a single hailpad. These sampled two hailstorms and demonstrated the existence of small-scale spatial variations in hailfall, amounting to changes in impact energy of an

order of magnitude or more across distances of one mile or less.

A total of 761 hail-dented hailpads were collected from a two-month period. Hailpad measurements for three hailstorms are discussed in some detail, including the major damaging hailstorm of August 16th, 1973.

Relations between hailfall and per cent crop damage are suggested, including critical values of impact energy of about 50 J m^{-2} for negligible damage, and 450 J m^{-2} for total crop loss. When measuring the vertical partition of impact energy, the useful range of sensitivity of the hailpad is found to lie between 10^{-1} and 2×10^{3} J m^{-2}. Maps displaying smooth contours of impact energy for each storm date are presented.

Hail suppression is considered and a suggestion for its evaluation using hailpads is made. It is shown that such evaluation should include the measurement of rainfall. The importance of measuring minor as well as major hailfalls is emphasized. Finally, recommendations for future hailpad projects are outlined, including more detailed measurements of wind and rainfall, frequent calibration checks, hailpad spacings of three miles or less, more dense network studies, and careful consideration of hailpad analysis techniques.

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This work was completed after helpful co-operation from many people.

Special thanks are due to my departmental supervisor, Dr. E. P. Lozowski, whose scientific approach helped formulate my own ideas during the past two years. His tireless and thorough reviews of this dissertation, his many helpful suggestions, and his enthusiastic support throughout have been greatly appreciated.

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I also wish to express my appreciation to several fellow students who gave freely of their time: to Myron Oleskiw for his work on the photo-verification of hailpad calibrations, his re-analysis of several hailpads for consistency, and his help, along with Mike Morrow, with the end-of-summer hailpad retrievals; to Dennis Oracheski for his frequent aid with programming problems.

On the university staff, I thank Dr. R. B. Charlton of the Meteorology Division, and Dr. W. A. Davis of the Department of Computing Science, who served on the examining committee. Dr. Davis and his student, Norman Tsang, are also responsible for the initial work on automated hailpad analyses, a very important consideration for future hailpad projects. The technical staff of the Department of Geography provided help with drafting, and are responsible for the three photos in this manuscript. Special thanks go to Mrs. Laura Smith for her suggestions, patience, and excellent typing of the final draft.

My wife Phyllis, operated the Edmonton hailpad site and did most of the key-punching for programs. My daughter Emma, supplied the glass spheres of the calibration experiments from her marble collection, while my brother Bruce, did a number of final map drafts.

Last, but certainly not least, I wish to thank the many farmers of Central Alberta, and their wives, whose volunteer efforts during the field project made it all possible. To their truly co-operative efforts, I have dedicated a portion of this thesis by including some of their observant comments on hailstorms (from the hail cards) at the head of each chapter. I shall always remember the frequent refreshments and friendly chats on those many hot summer days.

This study was undertaken while the author was on educational leave from the Atmospheric Environment Service of Canada.

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CHAPTER I

INTRODUCTION

> *"Worst storm I have ever seen. First stones came from the south, larger stones first. Second burst came from northwest - smaller stones, then some big ones later on; 100 per cent (crop) damage, dents in car's roof, hailpad smashed. Wind after hail was very strong, from northwest. Also heavy rain for about an hour." .... C. Repas, August 16, 1973*[1].

1.1 Background

The southern half of Alberta is one of the most hail-prone regions in the world. An average of 67 hail days occur from May to September, including 56 of the 92 days of June through August (Summers and Paul, 1967). These hailfalls cause an annual average crop loss of more than $22 million (Summers and Wojtiw, 1971; Wojtiw and Summers, 1972).

Concern over such heavy agricultural losses and enthusiastic meteorological research interest in severe storms, led to the formation of the Alberta Hail Studies (ALHAS) Project in 1956. The task of the project was to investigate all aspects of Alberta hailstorms, and to test and design means to reduce crop damage by seeding potential hail-bearing clouds with Silver Iodide.

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[1]Dates after quotes of farmers refer to storm dates.

ALHAS chose a main project area in Central Alberta comprising roughly 22,000 square miles between Edmonton and Calgary. Typical damaging hailswaths[1] in Alberta are only 2-5 miles wide (Summers and Wojtiw, 1971). Therefore, in order to have an observing network of sufficient density to resolve hailfall patterns, ALHAS has had to rely on meteorologically untrained volunteer observers. Thus, an objective means of measuring hailfall, both for climatological studies and for evaluating hail suppression efforts, has so far been lacking.

A hail detector, consisting of a piece of styrofoam, one foot square, one inch thick, and covered with household aluminum foil, had been developed and used with moderate success by Schleusener and Jennings (1960), and by Decker and Calvin (1961). This 'hailpad' records dents made by impacting hailstones. Its low cost permitted a large network with the required density to adequately measure hailfall.

Early in 1973, J. H. Renick (personal communication) suggested that an investigation was necessary to determine the feasibility of using such hailpads in the ALHAS program, and that this project in return could make an ideal topic for the author's M.Sc. thesis. The hailpad's ability to discriminate 'hail or no hail' had been assured by the previous studies so that the main interest of ALHAS was in the hailpad's ability to measure hailfall intensity and to help find meaningful relationships between hailfall and crop damage. If such relations could be established, then one might have an indirect means of measuring the physical effects of hail suppression from measurements of crop damage alone.

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[1]A hailswath is defined (Thompson and Summers, 1970) as an elongated cluster of at least 10 hail reports which are temporally coherent.

This dissertation then, reports the results of the subsequent hailpad project and discusses the feasibility of using hailpads for measuring Alberta hailfall and assessing hail suppression.

1.2 Causes and Effects of Hail

There are five most favourable (though not essential) conditions for the occurrence of hail in Alberta. These are all interrelated but can be recognized individually as:

(1) unstable air from the ground to high levels (at least 500 mb);

(2) a moderate southwesterly flow at 500 mb, preferably with some cooling;

(3) a southeasterly flow at low levels, preferably with warm air advection;

(4) low-level moisture, though usually a dry environment at higher levels;

(5) some triggering mechanism, usually a synoptic-scale system such as a frontal wave, cold front, low, etc. Orographic lift, due to (3), might also provide the instigation.

Further discussion of the above conditions can be found elsewhere, such as in Longley and Thompson (1965), or Thompson and Summers (1970). These conditions combine sufficiently often in Alberta during summer to produce the intense multicell and supercell storms described by Renick (1971), Marwitz (1972), Chisholm and Renick (1972), Chisholm and English (1974), and others.

Crop damage resulting from hailstorms has been well-documented (Schleusener, 1968; Changnon and Barron, 1971; Changnon, 1971b; Summers and Wojtiw, 1971; Wojtiw and Summers, 1972; Wojtiw and Renick, 1973). Of the $22 million annual crop loss in Alberta (1961-70 average), about 50 per cent occurs during the 4 worst days, while 80 per cent is concentrated into the 12 worst days. Damage is also far from being uniformly distributed spatially, since these heaviest hailfalls are usually contained within relatively small areas of 50 to 500 square miles. Yearly crop damage amounts have varied from a low of $10.6 million in 1964, to a high of $57.9 million in 1966, reflecting the annual variability in hailfall.

Figure 1 (after Wojtiw and Summers, 1972) demonstrates the distribution of annual loss to risk (L/R) ratio[1] in Southern Alberta for the period 1938-71. This map is also the only indicator of long-term hailfall distribution, since hail insurance statistics are available for at least 20 years prior to adequate physical data on hailfall. Two major areas of crop damage due to hail are prominent; one just northwest of Red Deer, the other between Red Deer and Calgary. These are included in the ALHAS project area for cloud-seeding operations and were also considered in the hailpad network set-up. ALHAS operations are centered at CFB Penhold, an air base about seven miles southwest of Red Deer.

1.3 Previous Alberta Hail Data Sources

Since ALHAS came into being, the main source of hailfall data has been volunteer reports from farmers which are either mailed

[1]The L/R ratio, expressed as a percentage, is defined as the value of claims paid out (loss) divided by the amount of insurance written (risk).

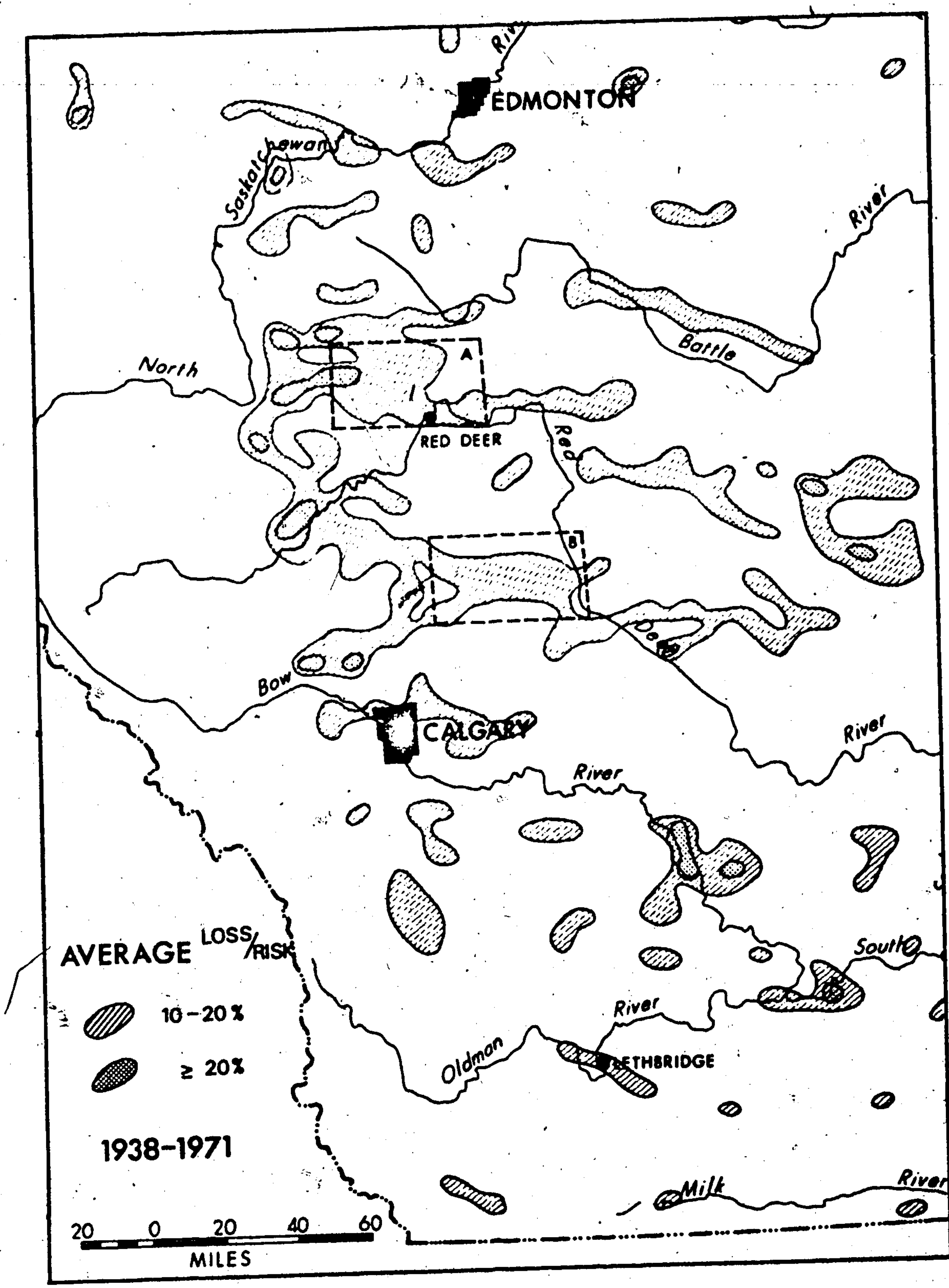

Figure 1. The regional distribution of the average L/R ratio for the period 1938-1971 (after Wojtiw and Summers, 1972).

in on hail report cards, or solicited by telephone surveys after each storm. More than 50,000 of these reports had been collected by the end of 1972. A copy of the 1973 hail report card, used in conjunction with the hailpads, is attached to the inside front cover of this thesis.

The format of questions on these reports is improved each year. Nevertheless, the data acquired can never be totally objective, since farmers and even meteorological observers will differ over what is meant by the various size categories[1]. Then too, many of the smallest (and usually most common size) hailstones melt quickly on impact and are not reported. Another difficulty is that observers tend to see mainly the largest stones and thereby over-estimate the most common size. These same failings have been discussed by Changnon (1971a).

Between 10 and 20 hail reports per 100 square miles are obtained for each hailswath (Renick, 1972), so that lack of quality is compensated somewhat by quantity. However, with wide variations in population density, even quantity is not a consistent factor, and one must be careful not to use the number of hail reports for a given storm as an indicator of storm size or intensity. In short, the hail report cards need to be supplemented by objective data based on physical measurements.

One such supplementary data source is weather radar, which is under continual improvement with ALHAS. It has been utilized not

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[1]Hail sizes are reported in terms of familiar objects; viz., shot, pea, grape, walnut, golfball, and greater than golfball. ALHAS (Wojtiw and Renick, 1973) have defined the mean diameters of these to be 0.2, 0.8, 1.6, 2.4, 4.0, and 6.0 cm respectively.

only to give advance indication of potential hail-producing clouds for seeding, but even to estimate hail sizes once they form (Barge, 1972). Some advances have been made in using the radar to detect effects of cloud-seeding (Summers and Renick, 1971). Other data sources include the collection of hail and rain samples by farmers and by mobile sampling vehicles from ALHAS for physical and chemical analyses. Aircraft reconnaissance and cloud photography have confirmed some of the theory concerning cumulus cloud dynamics (e.g., Warner et al., 1973).

In spite of all these data sources, accurate equipment for measuring hailfall intensity has been lacking. This, of course, is where the hailpad comes in.

1.4 The Hailpad Concept and Previous Studies

The aluminum foil and styrofoam combination, the hailpad, records hail dents, the diameters of which can be related directly to the hailstone diameters. Such hail-dented hailpads could be analyzed simply to answer the question whether hail occurred or not. But a more detailed analysis can yield information on (i) numbers, (ii) sizes, (iii) mass, (iv) impact momentum, (v) impact energy, and (vi) the per cent area of ground covered by hail.

Parameters (iii) to (vi) are dependent on hailstone diameter. Therefore, hail dents can be used directly to deduce hailfall intensity per unit area in terms of ice mass, momentum, and energy.

Schleusener and Jennings (1960) calibrated their hailpad in terms of dent area to measure impact energy as a measure of hail intensity. Using a rough estimation procedure, they suggested that even a 100 per cent error in total impact energy would be acceptable in view of the several orders of magnitude range of energies possible.

Decker and Calvin (1961) developed a hailpad independently of Schleusener and Jennings and published results on dent sizes and hardness for a storm on September 10th, 1959 in Oregon. Most of their hailpad dents were judged to have been made by soft hailstones in view of such dents having a splashed appearance. In contrast, Schleusener and Jennings estimated that less than 10 per cent of their hailstones were soft.

Hagen and Butchbaker (1967) used hailpad data to attempt an evaluation of hail suppression over North Dakota. They concluded that seeding 'probably' suppressed 'some' of the hail. A rough relation between impact energy and per cent crop damage was suggested. Butchbaker (1968) extended the previous hailpad study for another hail season but concluded that hail suppression did not show any significant success. Seeding had not been randomized, but rather was conducted by using one large target area compared with five smaller control areas.

Schleusener (1968) gave some hailpad results for the Shadehill and Rapid Projects in South Dakota. Ratios of hail impact energy to rain amounts on seed days over the target areas, were lower than on unseeded days over the control areas, suggesting suppression success. He pointed out, however, the need for randomized experiments to confirm these results.

Changnon (1969) showed hailpad results from several Illinois hailstorms and discovered 'hailstreaks', about 1 mile wide and 5 miles long, within larger 'hailswaths'. His group also tested hailstools, consisting of a circular hailpad attached to the top of a solid cylindrical upright hailpad, to record angles of impact. Curved surfaces have since been found difficult to calibrate properly. An automatic recording hailgauge based on the ballistic pendulum principle was also devised. Its cost is prohibitive for extensive use, however, while suffering from false starts due to wind, birds, etc. Work on this gauge is continuing.

Changnon and Towery (1972) presented more results for the hailpad, hailstool, and hailgauge. While establishing better limits of accuracy, their data suggests that one square foot is a minimum suitable size for hailpads. The data includes distributions of hail size, energy ranges, and hailstreak dimensions.

Newton and Wilke (1973) introduced another hail indicator employing a curved surface, but with the same inherent calibration problem mentioned above.

Miller and Cain (1973) examined four years of North Dakota hailpad data from randomized hail suppression programs. These showed no significant decrease in impact energy on seed days. Since each year's hailpad data had been analyzed by a different person, all of the hailpads were to be re-analyzed later by one person to check consistency. This problem will be discussed with regard to the Alberta hailpads later.

Morgan and Towery (1974) reported on results from an extremely dense hailpad network of one square mile, maintained in Nebraska in 1973. Some very interesting results were obtained, concurring with those of this 1973 Alberta project, and so will be discussed in more detail later.

1.5 Background on Hail Suppression

Since hailpad results on the evaluation of hail suppression have been mentioned, it would be helpful at this stage to briefly review some hail suppression theory.

The fundamental idea is to reduce crop damage by reducing the size of hailstones. To accomplish this, one must increase the number of hail embryos competing for the water supply available for hail production (Mason, 1956), the total mass of which is assumed to remain constant. The Silver Iodide crystal has a molecular structure similar to that of ice, so that it is used as a seeding agent to promote freezing of supercooled cloud water, resulting in many small hailstones in place of fewer large ones. Although this may increase total ice mass, the hailfall intensity or impact energy, can still be reduced in the following way.

The impact energy e, for a hailstone of mass m, diameter D, and terminal velocity W_T, falling straight down is

$$e = \frac{1}{2} m W_T^2 \tag{1}$$

For N such hailstones, the total energy E, is

$$E = \frac{1}{2} N m W_T^2 = \frac{1}{2} M W_T^2 \tag{2}$$

where $M = Nm$, the total ice mass, which is usually assumed to remain constant under seeding. Since $W_T \propto D^{1/2}$, and $m \propto D^3$, we see that $E \propto MD \propto ND^4$. This means that in order to decrease total impact energy by a factor of 5 say, while maintaining M constant, we must also decrease the hailstone diameters by the same factor. In doing this, N must be increased by a factor of 125. The goal for most suppression experiments is to achieve a factor increase in hailstone numbers of more than 100.

If hail damage is more closely related to impact momentum, then the same decrease in hailstone diameter to 1/5, reduces total momentum to about 1/2. In the case that damage may possibly be directly proportional to the total hail mass, then the same deductions lead to no net potential change in damage, so long as the total ice mass remains constant.

Such eventualities do not destroy the concept, however, as total ice mass, impact momentum, and impact energy would be reduced considerably by the melting of hailstones during fall below the $0^{o}C$ level. For if smaller hailstones are formed, then a greater total ice surface is exposed for heat exchange. For hailstones of diameters <2.5 cm, melting has been shown to be significant (Mason, 1956; Ludlam, 1958). More details of this process will be discussed with the results later.

1.6 The 1973 Alberta Hailpad Project

Two main hailpad networks were set up by the author as shown in Figure 2. These networks will henceforth be referred to as the Southern Network (south of Penhold), where most cloud-seeding was carried out, and the Northern Network (north of Penhold), where only occasional seeding was done (the single-storm experiments).

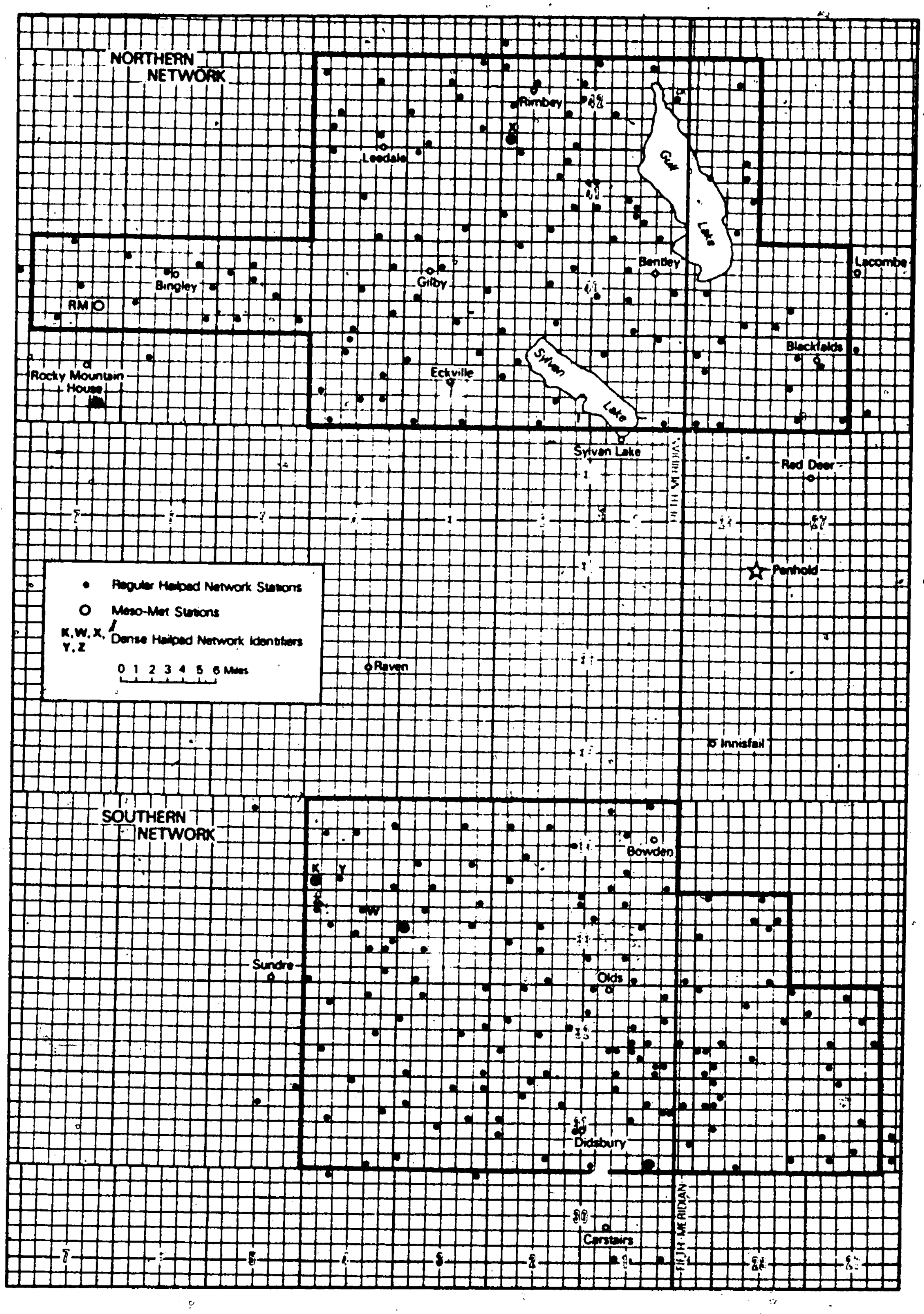

Figure 2. The 1973 Alberta hailpad networks.

Five dense networks (1 hailpad per .04 square miles)[1], indicated by the letters K, W, X, Y, Z on Figure 2, were operated during August for the purpose of testing how representative one hailpad could be. Five meso-meteorological stations provided additional data on winds, rainfall, temperature, and humidity.

Since there are many pitfalls and sources of error in the theory, calibration, network design, and analysis of hailpads, these four items will be discussed carefully at length, before the 1973 hailpad results are presented.

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[1] English units will be used when referring to the land survey system (see Appendix I).

CHAPTER II

THEORY

"Hailstones quite hard."
.... Lorne Chandler, July 5, 1973.

"Stones were very hard and centres were very clear. They bounced nearly 8 feet after hitting the ground."
.... Leslie Hake, August 16, 1973.

2.1 Assumptions

The hailpad was calibrated by dropping steel and glass spheres from heights which simulated the impact energy of hailstones of the same size. The justification for this procedure will become clear in this chapter. In order to perform any calibration, however, a number of simplifying assumptions first had to be made. The validity of each of these assumptions will now be examined.

(1) Sphericity

It is assumed that hailstones are approximately spherical, though not necessarily smooth, with diameter, D. Thus, an elongated dent on a hailpad was supposed due to a wind-blown spherical hailstone and the minor axis of the elliptic dent was taken to be the dent diameter. This supposition can lead to a slight underestimate of hailstone size and will be discussed further later.

Summers and Wojtiw (1971) estimated that 72 per cent of the hail of Central Alberta in 1969 was essentially spherical. Similarly, Schleusener and Jennings (1960) estimated that 75 per cent of the hailstone samples taken in Northeastern Colorado in 1959 approximated spheres. Furthermore, the dents on hailpads collected by them and also by this author suggested that the impacting hailstones were largely spheres, or at worst, slightly oblate spheroids, since when winds were light, most dents were roughly circular.

(2) <u>Constant drag coefficient</u>

The drag coefficient, C_D, for all hailstones in free-fall may be approximated by a mean value of 0.60.

The drag coefficient is not constant, being a function of the Reynolds number, Re, which is itself a function of the sphere's velocity, diameter, and the viscosity and density of the medium through which it is falling. Numerous measurements (e.g., Hoerner, 1965) have shown that for a smooth sphere, C_D is .45 ± .03 over the Reynolds number range 10^3 to 2×10^5. At this latter 'critical' value of Re, C_D decreases sharply to 0.1 because of the onset of turbulence within the sphere's boundary layer. Figure 3 shows the relation between drag coefficient and Reynolds numbers for smooth spheres and hailstones.

Because of surface roughness and lack of sphericity the drag coefficient for hailstones within the range of Reynolds numbers depicted is slightly higher than for smooth spheres, though the critical Reynolds number has about the same value (List, 1959; Macklin and Ludlam, 1961; Bailey and Macklin, 1968; Roos and Carte, 1973). Therefore, before fixing a single value for the drag coefficient of hailstones, it is important to know whether the critical Reynolds number will be exceeded in nature.

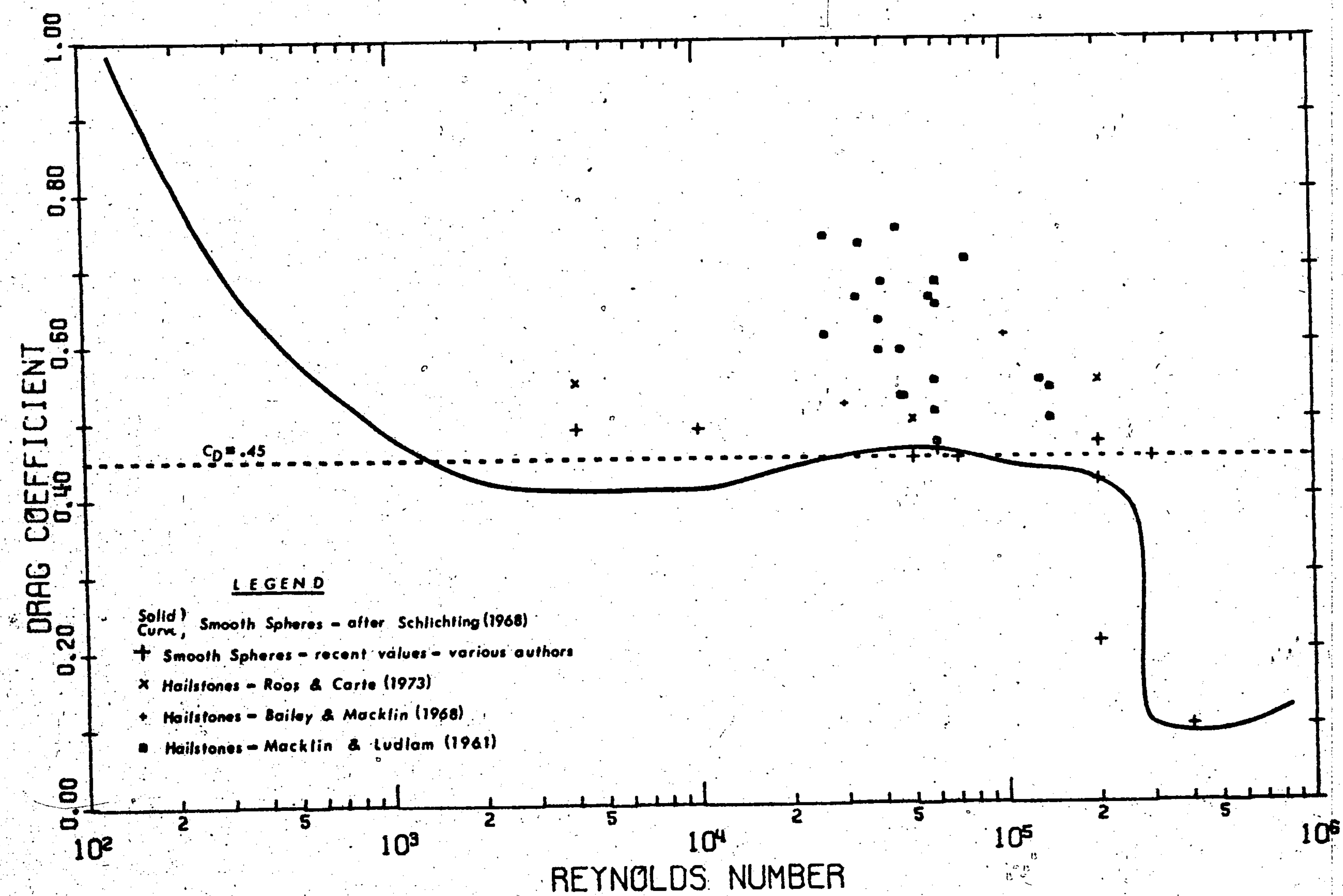

Figure 3. Reynolds number vs. drag coefficient for smooth spheres and hailstones.

The Reynolds number is defined as the ratio of inertia forces to viscous forces, or,

$$Re = \frac{UD}{\nu} = \frac{UD\rho_a}{\mu} \tag{3}$$

where U is the velocity relative to the medium, of a sphere of diameter D, falling through a medium of kinematic viscosity ν, or of density ρ_a and dynamic viscosity μ. Table 1 shows values of Reynolds numbers calculated from Equation 3 for hailstones of diameters .25, 1.0, and 3.0 inches for various combinations of pressure and temperature, as taken from a typical temperature sounding of a hail day in Central Alberta. Values of viscosity were extrapolated from CRC Tables (Weast, 1973), the densities were calculated from the equation of state for dry air, and the hailstone velocities are derived from a later equation (8) for terminal velocity.

One can assume from Table 1 that falling hailstones probably[1] do not achieve the critical Re (i.e., 20. by the table), though in rare events, large spherical hailstones (D > 3 in) may. It is interesting to note that in tests with models of the largest hailstone on record (circumference 44 cm, mass 766 gm; Ludlum, 1971), Roos (1972) found that the critical Reynolds number was not attained.

Even so, the drag coefficient for hailstones will still be quite variable, depending on shape, surface roughness, and orientation to the flow. Some recent measurements of drag coefficients of hail-

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[1]This assumption is not exactly valid since in calculating W_T, $C_D = .60$ was used, which in itself assumes that Re < critical Re.

Table 1. Typical values of Reynolds numbers for hailstones in free-fall. D = diameter; μ = dynamic viscosity; W_T = terminal velocity; Re = Reynolds number.

Pres. (mb)	Temp. (C)	Air Density ($g\ cm^{-3} \times 10^3$)	μ (poise $\times 10^4$)	D = .25 in* W_T ($m\ s^{-1}$)	D = .25 in* Re $\times 10^4$	D = 1.0 in* W_T ($m\ s^{-1}$)	D = 1.0 in* Re $\times 10^4$	D = 3.0 in* W_T ($m\ s^{-1}$)	D = 3.0 in* Re $\times 10^4$
500	-15	0.675	1.63	13.6	0.4	27.2	2.9	47.0	14.8
700	5	0.877	1.73	11.9	0.4	23.8	3.1	41.3	16.0
850	12	1.039	1.78	10.9	0.4	21.9	3.3	37.9	16.9
900	22	1.063	1.86	10.8	0.4	21.5	3.1	37.3	16.2

*Units used are metric, except for most units of length. For explanation see Appendix I.

stones and hailstone models, in what is thought to be their natural orientation to the flow, are also plotted on Figure 3. Below the critical Reynolds number, the values for hailstones have been measured to vary from .47 to .75, with C_D increasing with surface roughness and oblateness. The mean value of C_D for the hailstone values of Figure 3 is .59, while for the hailstone models of Roos and Carte (1973) the mean is .58. With this in mind, three different calibrations of the hailpads were performed assuming C_D = .50, .60 and .70. We shall see that only slight differences in calibration were evident. Final single values for the drag coefficient of smooth spheres and hailstones were chosen to be .45 and .60, respectively.

(3) Hailstone density

Hailstones in Alberta were assumed to have a density ρ, of 0.89 g cm^{-3}. This was verified by examination of density measurements on Alberta hail samples (ALHAS, 1970-71). Values varied from .86 to .92 g cm^{-3}, with both mean and median of .89 g cm^{-3}.

(4) Surface air density

The density of air, ρ_a, near the ground during Central Alberta hailstorms was assumed to be 1.05×10^{-3} g cm^{-3}, the density of dry air at 890 mb and 22°C. This figure was arrived at by inspecting station pressures and temperatures prior to hail during 1972. The hailstorms of 1973 in Central Alberta later yielded a mean air density of 1.07×10^{-3} g cm^{-3}.

(5) Constant density layers

The density of air may be considered constant over small height changes of the order of 50 meters or less. This assumption was for purposes of calibration of the hailpads and for subsequent verification. It is valid, since the maximum change in air density which could naturally occur in 50 meters is less than 0.2 per cent of 1.05×10^{-3} g cm^{-3}.

(6) Melting and accretion

Neither melting nor accretion of water droplets significantly affects the terminal velocity of a hailstone at the ground. Hailstone terminal velocity is approached within the first 50 meters of fall from rest (Figure 13, Chapter III). This velocity adjusts rapidly (decreases) during fall to compensate for any changes in air density, viscosity, or mass (due to melting or accretion). Melting can be significant for a 3-5 km fall (Mason, 1956; Ludlam, 1958; Macklin, 1963; List and Dussault, 1967), but not for 50 meters. McDonald and Orville (1962) estimated that by accretion of supercooled drops in cumulus with a very high liquid water content, momentum transfer will lower the terminal velocity of large hailstones by only a few per cent. At any rate, once leaving the cloud, a hailstone would quickly assume its natural terminal velocity.

(7) Hailstone hardness

It was assumed that hailstones were hard and would not shatter (or splatter) on impact. Summers (1966) showed that of all the volunteer hail reports from Central Alberta in 1965, only 31-40 per cent indicated 'some' soft hail occurring during July and August; the figure was slightly higher (45 per cent) for June. Schleusener and Jennings (1960) indicated that 90 per cent of the hailstones of northeastern Colorado in 1959 were hard. Inspection of the 1973 hailpads of this study suggests a figure at least as high, dents from soft hailstones having a characteristic splattered appearance.

(8) Hailstone bounce

Hailstones which impacted a second time after a bounce made negligible contribution to the total impact energy or momentum on the hailpad. Conversations with farmers during the 1973 hail season indicated that hard hailstones impacting on a 'hard' surface, will on occasion bounce six feet or more. During calibration-verification experiments in a 10-storey stairwell (Chapter III), some artificial hailstones, attaining 85-97 per cent of terminal velocity, were observed to bounce 3-6 feet off the hard floor. On striking a more flexible surface such as cardboard or the hailpad itself, bounces could usually be estimated in inches or fractions of an inch.

The percentage of hailstones which impact on the hailpad after bouncing on the ground, however, is likely to be small, and because their impact energy and momentum will normally be a small fraction of their original values, it is reasonable to neglect the effect. Nevertheless, because of the possibility of bounces, the 1973 hailpads were deliberately installed on either grass or soft ground (such as in a vegetable garden), so that bounces were minimized. But this introduced another source of error, since lack of time, man-power, and financial resources precluded the use of any form of hail-pad stand. Thus, a small amount of impact energy is absorbed by the soft underlying surface, giving slightly smaller dents. This effect will be discussed in Chapter III.

(9) Density differences

Density differences between ice and the steel and glass spheres used for calibrations, produced no apparent errors in the calibrations when drop heights were used which simulated the impact energy of hailstones of equivalent diameter. Initial tests using steel and ice spheres of the same diameter indicated no differences in hailpad dent size or shape.

(10) Rain dents

The field project analyses proved that very light dents on hailpads made by rain drops were easily distinguished from hail dents.

2.2 Derivation of Equations

Armed with the above assumptions, we will now proceed to derive the equations necessary for the calibration of the hailpads. In Figure 4 we consider a sphere of mass m, diameter D, and density ρ, falling with a velocity W, and acceleration a, through air of density ρ_a which exerts a drag force F_D, on the sphere in the opposite direction.

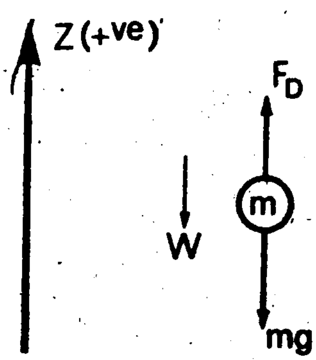

Figure 4. Forces acting on a sphere falling freely in air.

For this simple model, the equation of motion for the sphere, neglecting buoyancy, may be written as

$$-ma = -m\frac{dW}{dt} = mg - F_D \qquad (4)$$

NOTE: The negative sign appears on the L.H.S. of Equation 4 because W is considered to be negative when directed downwards.

The drag force is found empirically to be related to the air and hailstone parameters by

$$F_D = \frac{1}{2} A_x C_D \rho_a W^2 \tag{5}$$

where A_x is the cross-sectional area of the body projected normal to the air-stream, and C_D is the drag coefficient between the air and the body. The drag coefficient is generally a function of the Reynolds number (see Figure 3). Thus, for a sphere where

$$A_x = \frac{\pi D^2}{4}, \quad m = \frac{\pi \rho D^3}{6}, \tag{6}$$

we may write Equation 4 as

$$-a = \frac{dW}{dt} = g - \frac{3\rho_a C_D}{4\rho D} W^2. \tag{7}$$

For convenience, let

$$\frac{3\rho_a C_D}{4\rho D} = A \tag{7a}$$

Equation 7 immediately yields the terminal velocity $W = W_T$, which is achieved when the net forces acting on the sphere are zero. Hence,

$$-a = 0 = g - A W_T^2,$$

from which

$$W_T = \left(\frac{g}{A}\right)^{1/2} = \left(\frac{4\rho g}{3\rho_a C_D} D\right)^{1/2}. \tag{8}$$

We now have the terminal velocity expressed in terms of $D^{1/2}$, the other parameters of Equation 8 being held constant.

At any moment during fall, the kinetic energy E, of the sphere can be derived using Equations 2 and 6 as

$$E = \frac{\pi \rho D^3}{12} W^2 , \qquad (9)$$

while the momentum[1] Q, is

$$Q = \frac{\pi \rho D^3}{6} W . \qquad (9a)$$

On impact (subscript I) at terminal velocity, Equations 8, 9, and 9a yield

$$E_I = \left(\frac{\pi \rho^2 g}{9 \rho_a C_D} \right) D^4 , \qquad (10)$$

and

$$Q_I = \left(\frac{\pi^2 \rho^3 g}{27 \rho_a C_D} \right)^{1/2} D^{3.5} . \qquad (10a)$$

One should now be able to drop hailstones of known sizes onto a hailpad, and from the corresponding dent sizes, establish simple relations between dent diameter and the parameters of hailstone size, mass, impact energy, and impact momentum. But this presupposes that the dropped hailstones attain or nearly attain terminal velocity. Can such velocities be achieved to make calibration practical using hailstones or ice spheres? To answer this, we need to derive an equation for drop-heights. From Equations 7 and 8 we have

---

[1]The standard physics notation for momentum is P. Q is used here to avoid confusion with pressure and/or density.

$$-\frac{dW}{dt} = g - AW^2 = g\left(1 - \frac{W^2}{W_T^2}\right)$$

$$-\frac{dW}{dt} = -W\frac{dW}{dz} = -\frac{d}{dz}\left(\frac{1}{2}W^2\right)$$

$$\Longrightarrow -\int_h^0 dz = \frac{1}{2g}\int_0^{W^2} \frac{d(W^2)}{\left(1 - \frac{W^2}{W_T^2}\right)} \qquad (11)$$

Equation 11 is to be integrated from a small height h, (small enough to consider the air density constant over the range of integration) down to an arbitrary reference level, $z = 0$, not necessarily at ground level. Before doing this, we note that we are invoking several of the assumptions of section 2.1; in particular, sphericity, constant drag coefficient, constant hailstone density, and constant air density over small height changes. We are also neglecting the fact that for a short period following $t = 0$, $Re \ll 10^3$ such that C_D is not constant. All assumptions become valid, however, shortly after $t = 0$. With this in mind, we can carry out the integration of Equation 11 arriving at

$$h = -\frac{W_T^2}{2g}\ln\left(1 - \frac{W^2}{W_T^2}\right)$$

$$= -\frac{W_T^2}{2g}\ln\left(1 - f^2\right), \qquad (12)$$

where we have let

$$f = \frac{W}{W_T} , \tag{13}$$

which is the fraction of terminal velocity attained.

2.3 Calibration Design

The practicality of calibrating hailpads with real hailstones can now be determined. For example, suppose one wishes to drop a 2-cm hailstone from a height from which it will attain 95 per cent of terminal velocity (equivalent to 90 per cent of terminal impact energy by Equation 1),

Choosing $\rho_a = 1.05 \times 10^{-3}$ g cm^{-3},

$C_D = .60$,

and $\rho = .89$ g cm^{-3},

then by Equation 12, the required drop-height is $h = 43.3$ meters.

It should be clear that such drop-heights are out of the question since even a large hailpad would be difficult to hit, while one would have to be concerned also with drafts and cross-winds. A reasonable alternative which other authors (Schleusener and Jennings, 1960; Changnon, 1969) have also chosen, is to simulate a hailstone's impact energy with denser smooth spheres (glass and/or steel) of the same diameter. Drop-heights for such spheres are much lower because the fraction of terminal velocity, f, will be much lower.

Using the subscript 'S' to identify the parameters of the 'simulating sphere', then from Equation 9,

$$E_I = \frac{\pi}{12} \rho D^3 W_T^2 = \frac{\pi}{12} \rho_s D_s^3 W_s^2 .$$

Since we require that $D_S = D$, then

$$W_s = \left(\frac{\rho}{\rho_s}\right)^{1/2} W_T \quad . \tag{14}$$

If we wished to calibrate the hailpad by simulating a hailstone's impact momentum instead, then we get from Equation 9a,

$$W_s = \left(\frac{\rho}{\rho_s}\right) W_T \quad . \tag{14a}$$

Knowing the theoretical terminal velocity of the simulating sphere, W_{TS} from Equation 8, then by Equation 13, to simulate impact energy,

$$f_s = \frac{W_s}{W_{TS}} = \left(\frac{\rho}{\rho_s}\right)^{1/2} \frac{W_T}{W_{TS}} \quad , \tag{15}$$

or to simulate impact momentum,

$$f_s = \frac{\rho}{\rho_s} \frac{W_T}{W_{TS}} \quad . \tag{15a}$$

The drop-heights are then calculated by Equation 12; i.e.,

$$h_s = -\frac{W_{TS}^2}{2g} \ln\left(1 - f_s^2\right) \quad . \tag{16}$$

It was assumed that the drag coefficient for the simulating shpere, C_{DS}, was that of a smooth sphere as shown in Figure 3, i.e., $C_{DS} = .45 \pm .03$. This is valid only in the range of Reynolds numbers, 10^3 to 2×10^5. We shall examine this further in Chapter III to see if the criterion is violated in the case of the simulating spheres. For the present, let us assume that this drag coefficient is valid.

From the foregoing equations, tables of drop-heights were computed for combinations of different hailstone drag coefficients of

.45 to .75 in increments of .05 and different air densities of 1.02×10^{-3}, 1.05×10^{-3}, 1.085×10^{-3}, and 1.12×10^{-3} g cm^{-3}. The air densities are typical of Central Alberta on hail days. The drop heights varied little for changes in air density, so that a single value of 1.05×10^{-3} g cm^{-3} was eventually chosen. The resulting tables with drag coefficients of .50, .60, and .70 can be found in the Appendix II (Tables A1, A2, and A3, respectively).

2.4 The Hailstone-Hailpad Collision

The immediate goal of calibrating the hailpad is to establish a relation between the dent size and the size of the hailstone which made it. Before deriving an empirical relation, one should look at a simple model to see what form this relation will assume. Figure 5 then, is a simplification of a vertically-falling spherical hailstone, of radius R_H, which has just impacted without bouncing on a hailpad and caused a dent of radius R_D, and depth d.

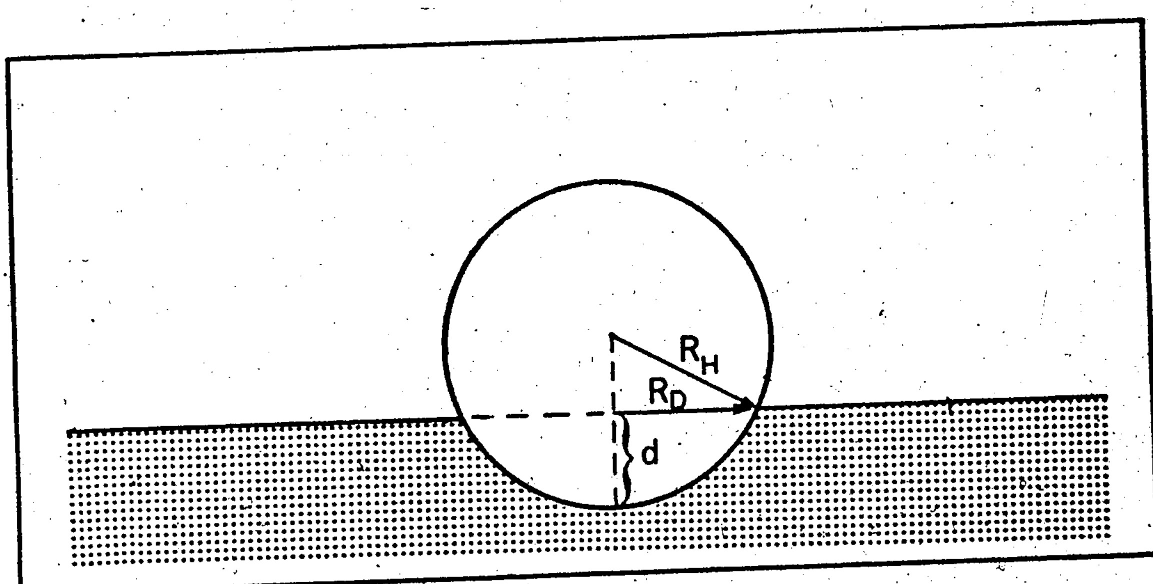

Figure 5. The Hailstone-Hailpad Collision

It is assumed that the elastic limit of the hailpad material is exceeded when any hailstone impacts; i.e., the dent is non-resilient and does not change shape or size later. Thus the dent parameters are solely determined by the hailstone size, shape, and impact velocity. We can therefore write the volume V of the dent in Figure 5 as the volume of the spherical cap, or from geometry,

$$V = \frac{1}{3}\pi d^2 (3R_H - d) = \frac{1}{6}\pi d (3R_D^2 + d^2)\,, \tag{17}$$

from which

$$4dD_H - 4d^2 = D_D^2 \tag{18}$$

where D_H and D_D are the hailstone and dent diameters.

It is reasonable to assume that the dent volume may be proportional to the kinetic energy absorbed by the styrofoam (confirmed by the calibration results presented later). Hence, for no bouncing,

$$E_I = \frac{1}{2}\rho \frac{4}{3}\pi \frac{D_H^3}{8} \frac{4\rho g}{3\rho_a C_D} D_H \propto V \text{ , or, } \quad D_H^4 \propto V$$

We may neglect d^2 in Equation 18 (to a first order approximation) such that

$$d = \frac{D_D^2}{4D_H}\,.$$

Substituting this into Equation 17,

$$V = \frac{1}{3}\pi \frac{D_D^4}{16 D_H^2}\left(\frac{3D_H}{2} - \frac{D_D^2}{4D_H}\right)$$

$$\Longrightarrow V \cong \pi \frac{D_D^4}{32\, D_H} \propto D_H^4$$

$$\Longrightarrow D_H = (\text{constant})\, D_D^{4/5} , \tag{19}$$

an almost linear relation, the same result obtained by Lozowski (1974).

This approximate linearity is most likely to break down as hailstone diameters approach the styrofoam thickness (one inch in this project), at which point these hailstones start breaking (rather than crushing) the styrofoam. An empirical relation will still be valid, however, up to the point where the hailstone passes through the hailpad, i.e., approximately where the hailstone radius equals the hailpad thickness (two-inch diameter hailstones).

CHAPTER III

HAILPAD CALIBRATION

"No wind with the larger stones which lasted five minutes." .... V. W. Repas, August 16, 1973.

"All the west windows are smashed. Hailpad is beaten to pieces." .... Mrs. Zoley Garnick, August 16, 1973.

3.1 The Choice of Hailpad Materials

The styrofoam padding and the aluminum foil covering of the hailpad both absorb a portion of the hail impact energy. The foil absorbs most of the energy of small shot-size hailstones, while the relative energy absorption by the styrofoam increases with hailstone size. For grape-size and larger hailstones, most absorption is by the styrofoam and one must even be concerned with energy absorption by the surface underlying the hailpad. This last effect is a field project problem which will be discussed later. These and factors such as water absorption and dent resilience of the styrofoam, and aluminum foil strength, meant that the combination had to be carefully chosen after many tests and calibrations, and that this combination could not be altered later without further calibration.

Utility and availability quickly narrowed the choice to two types of styrofoam used in building insulation, and three types of aluminum foil. Some particulars on these materials are given in Table 2.

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Utility and availability quickly narrowed the choice to two types of styrofoam used in building insulation, and three types of aluminum foil. Some particulars on these materials are given in Table 2.

Table 2. Available types of styrofoam and aluminum foil tested for hailpad construction.

Brand Name and Manu-facturer	Length & Width* (ft)	Thickness** (in)	Density* ($lb\ ft^{-3}$)	Average Compressive Modulus* ($lb \cdot in^{-2}$)	Maximum Water Absorption* (% by vol.)
Styrofoam *FR, DOW Chem.	8 x 2	1	1.9	1000	0.25
Styrofoam *SM, DOW Chem.	8 x 2	1	2.2	1000	0.25
Foilrapp, Foilrapp Ltd.	25 x 1.5	.0007	NA***	NA	NA
Reynolds Wrap, Reynolds Co. Can.	25 x 1.5	.0010	NA	NA	NA
ALCOA, Alum. Co. of America	25 x 1.5	.0010	NA	NA	NA

*Manufacturer's values, Dow (1972).
**Values measured by author.
***Not applicable.

Some material tests

Density checks on several samples of Styrofoam *FR gave mean values of .029 g cm^{-3} (1.83 lb ft^{-3}), close to the manufacturer's values. Buoyancy in the air was considered to be negligible.

The compressive modulus will determine the rate of styrofoam crushing as a sphere impacts on a hailpad. Although no attempt was made to measure the compressive modulus, the manufacturer's value for Styrofoam *SM may be an overestimate relative to the *FR type (depending on what SAE standard was used), since smaller dents were measured on the *SM type for equivalent sphere sizes and drop-heights, and the *SM type is a denser material.

The water absorption of styrofoam was checked for two reasons. First, in order to see whether dent sizes were affected by such absorption, two dented hailpads (*FR type) were submerged in water overnight. There were no detectable differences between dent sizes before and after. The second reason is that any significant water absorption will affect dent sizes on impact. Two more Styrofoam *FR pads were soaked in water. The increases in mass (and density) after soaking and wiping off excess surface water were 16 and 34 per cent. These represent water absorption increases by volume of 0.5 and 1 per cent respectively, about four times the given specification. Spheres dropped on these uncovered wet pads yielded dent diameters 3 to 10 per cent smaller than those on uncovered dry pads.

Styrofoam choice

A comparison of dent sizes on both styrofoam types is given in Table 3. The values were obtained by using steel balls to simulate the impact energy of hailstones for which the drop-heights are given in Table A2 (Appendix II). There were 12 trials for each dent diameter, and the standard deviation for dent diameters was between .005 and .020 in.

For spheres of diameters ≤ .5 in, the similarity of dent sizes between the two styrofoam types suggests to the author that the aluminum foil absorbs much of the impact energy. For spheres of .5 to 1.5 in, the dent diameters on the denser, smooth surface *SM type are noticeably smaller. Here, it would seem that the spheres have enough momentum to overcome the foil resistance, and most of the energy becomes absorbed

Table 3. Comparison of dent diameters on two different styrofoam types, covered with Reynolds Wrap aluminum foil. The drop heights (Table A2) assume a drag coefficient for hailstones of .60, for a smooth sphere of .45, and an air density of 1.05 x 10^{-3} g cm^{-3}.

Sphere Diameters (in)		0.25	.375	0.50	0.75	1.00	1.50	2.00
Styrofoam Type	Surface Structure	Average Dent Diameters (in)*						
*FR	cellular	.10	.21	.33	.55	.82	1.43	1.98
*SM	dense, smooth	.12	.22	.33	.49	.76	1.45	1.96

*With regard to the units and accuracy of dent measurements in this dissertation, see Appendix I.

by the styrofoam. Hence, dents are smaller for the denser *SM type. Spheres ≥1.5 in, have enough momentum to start breaking through the foam and significant differences in dent sizes between styrofoam types were not observed.

The surface of the Styrofoam *SM type, however, was found to be quite resilient; so much so, that having dropped a sphere of one-inch diameter or less, the styrofoam dent all but disappeared within hours. When this occurred, the foil dent was also distorted. For example, the average dent diameter for the .75-in sphere of Table 3 decreased from .49 to .40 in by the next day. The *FR type did not suffer from this drawback. For this reason, the Styrofoam *FR type was chosen for the 1973 hailpads. Hereafter, unless otherwise specified, the mention of styrofoam, foam, hailpad, or pad, will imply the *FR type.

Aluminum foil choice

One may ask why the styrofoam should be covered with aluminum foil at all, since one must then consider the hailstone impacts to be shared between both materials. There are three reasons for the aluminum covering: (i) Although the water absorption properties of the styrofoam are low, the cellular surface structure tends to collect water, so that when rain and hail occur together, the compressive modulus (and rate of crushing) of an uncovered hailpad will change somewhat near the surface, thereby invalidating the calibrations. With the aluminum foil covering, this problem is alleviated unless the hailpad becomes immersed in ground water. (ii) Tests showed that one-week exposure to sunlight of uncovered pads changed the chemical and physical properties of the styrofoam in such a way as to significantly reduce its density near the surface. This resulted in larger dent sizes. Extreme heat would probably cause some of this effect also. The bright aluminum foil acts as a reflector for both. (iii) The rough and cellular surface of the Styrofoam *FR made it impossible to detect all dents from sphere diameters of $\leq 3/8$ in (i.e., shot and pea size)[1]. This was borne out later while analyzing hailpads from which the foil had been torn by wind or birds. Measuring small dents was certainly not a problem when the hailpads were foil-covered, for even rain dents could then be distinguished.

During the actual field project, other reasons for the foil

[1]Preliminary tests for the 1974 hailpads indicate that sanding the surface of styrofoam *FR may alleviate this problem somewhat.

covering were realized: bird pecks, easily distinguished from hail dents on the foil, sometimes could not be differentiated with the foil off, though undoubtedly, the birds' attraction to the hailpads was due, in part, to the bright reflection from the foil. Finally, some small animals, particularly dogs, were prone to relieve themselves on the hailpads, and in cases where the foil had previously been torn, the effect was similar to that of sunlight.

Thus, some form of covering for the styrofoam appeared necessary. Painting the styrofoam might be an alternative, but this project stayed with aluminum foil as used by others.

The choice of aluminum foil was based on (a) resistance to tearing on hailstone impact, since minor tears would be magnified by winds, and (b) cost. Table 4 compares dent diameters for the three different aluminum foils. For this test, the drop-heights of Table A1, Appendix II, were used. The dent diameters are an average of 12 trials each, for which the standard deviations varied from .005 to .020 in.

Hailstones striking the two heavier grades of aluminum foil did not penetrate as deeply. This results in smaller dent sizes and greater resistance to tearing. For the light-weight Foilwrapp brand, a steel sphere of 9/16-inch diameter tore the foil. With a large number of impacts stretching the foil, even 1/2-inch spheres caused tears. The heavier brands absorbed many impacts before even spheres of one-inch diameter or larger started to make small tears, and then only at the bottom of the dent. The ALCOA brand, however, was available only from a scientific supply company, and was more than four

Table 4. Comparison of dent diameters using three different brands of aluminum foil on Styrofoam *FR. The drop-heights (Table A1) assume a drag coefficient for hailstones of .50, for a smooth sphere of .45, and an air density of 1.05×10^{-3} g cm^{-3}.

Sphere Diameters (in)		1/4	3/8	1/2	9/16	5/8	3/4
Aluminum Foil Brand	Measured Thickness (in)	Dent Diameters (in)					
Foilrapp	.0007	.15	.27	.38	.46	.52	.68
ALCOA	.0010	.11	.22	.34	.40	.46	.59
Reynolds Wrap	.0010	.12	.24	.34	.40	.46	.57

times the cost of the household Reynolds Wrap, with no significant differences in quality between the two. Therefore, the Reynolds Wrap, being readily available at wholesale or retail stores, was chosen for the hailpads.

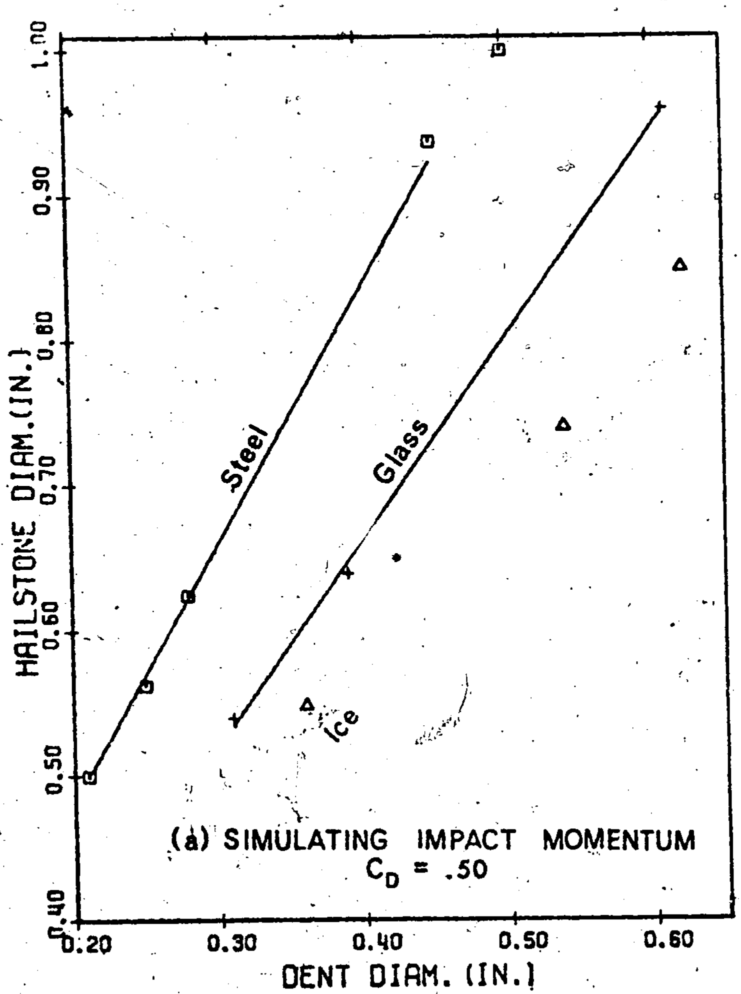
3.2 Calibration for Vertically-Falling Hailstones

The simulation problem

Two more problems had to be resolved before the final calibration could be performed: (i) What errors result from using spheres of different density (see assumption 9, Section 2.1) to simulate hailstone impacts, since it was shown (Section 2.3) that it is not possible to use hailstones alone for the calibration? (ii) Are real hailstone impacts best simulated by impact momentum or impact energy?

To answer these questions, preliminary calibrations were performed for both momentum similation and energy simulation of hailstones. To do this, the drop-heights of Table A1, Appendix II (assuming C_D = .50) were applied, using both steel and glass spheres. In addition, ice spheres of average diameters .55 in, .74 in, and .85 in, were dropped from a height of 34.5 meters (a 10-storey stairwell) onto a hailpad. From this height, these ice spheres should theoretically achieve 97, 94, and 92 per cent respectively of terminal velocity. Figure 6 shows the relations obtained between dent diameters and sphere diameters for these experiments. The straight lines are linear approximations obtained by a least squares method, which did not include any of the ice sphere data.

For momentum simulation, Figure 6(a), there are three relations, one each for steel, glass, and ice. For energy simulation, Figure 6(b), although some scatter appears, only one relation is evident and all points, ice included, lie approximately on the same line. The reason for the differences between (a) and (b) is plain if one accepts the reasoning of Lozowski (1974). He showed that the dent depth and diameter for the type of styrofoam used are functions of the kinetic energy and the diameter of the sphere alone, but not of the momentum and sphere diameter alone. In the latter case, another variable is required such as sphere density. Figure 6 is verification for this, since in 6(b), all spheres with the same diameter and the same energy made approximately the same dent size, whereas the spheres of Figure 6(a) had different energies (but the same momentum) and produced different dent sizes. Also, if the ice spheres had impacted with terminal velocity, then the spread between the relations for momentum



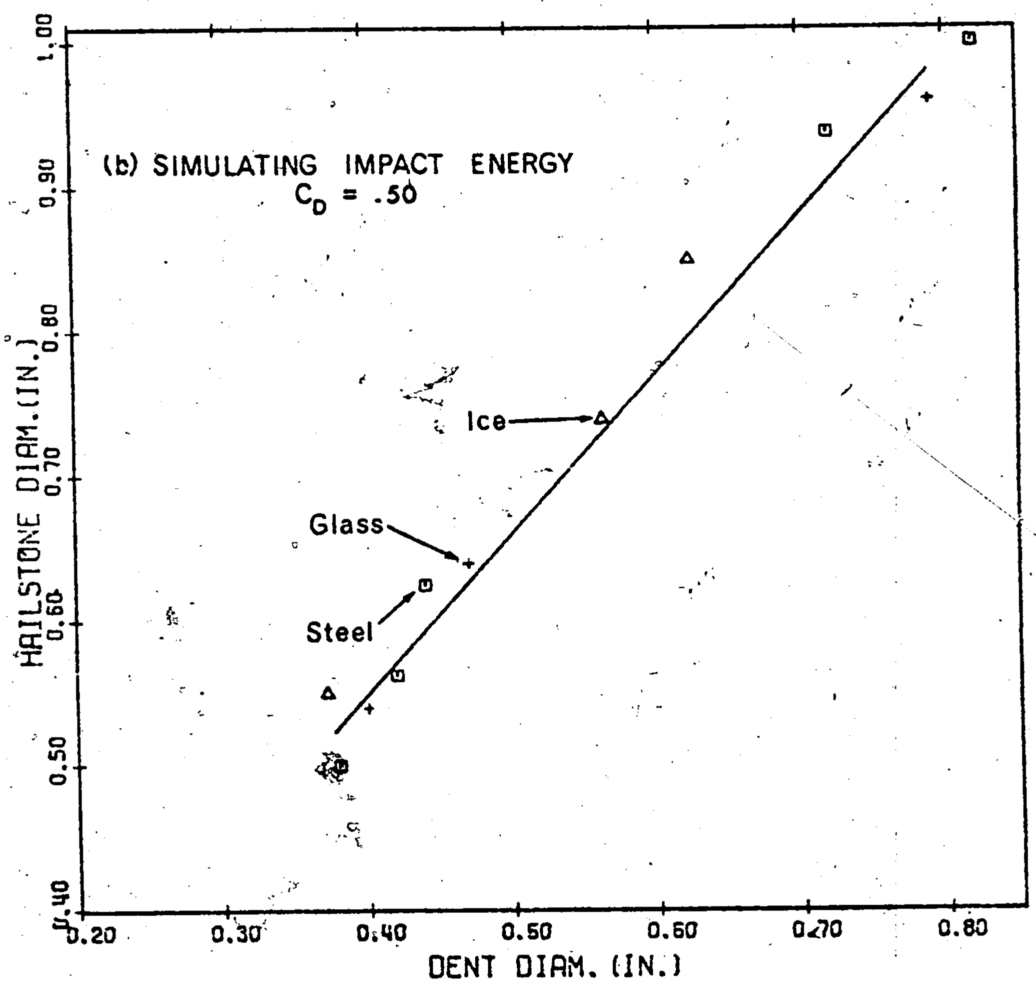


Figure 6. Dent diameters vs hailstone diameters for simulation of (a) impact momentum and (b) impact energy. ◘ = steel; + = glass; △ = ice.

simulation would be greater, while the scatter for energy simulation would be less.

As a check to see how the assumption of a constant drag coefficient for smooth spheres (.45) affect calibration, approximate Reynolds numbers for the impacting steel and glass spheres were computed (from Equations 3, 15, and 15a). These Reynolds numbers, along with the corresponding drag coefficients from Figure 3, are shown in Table 5.

Table 5. Reynolds numbers, Re (x 10^{-3}), on impact for the steel and glass hailstone simulation spheres of Figure 6, and the corresponding drag coefficients, C_{DS}, from Figure 3.

Simulation of Impact	Diameter (in) Sphere	.25 Re	.25 C_{DS}	.50 Re	.50 C_{DS}	.75 Re	.75 C_{DS}	1.00 Re	1.00 C_{DS}
Momentum	steel	0.52	.56	1.40	.43	2.70	.41	4.00	.41
Momentum	glass	1.56	.42	4.37	.41	8.10	.42	12.40	.42
Energy	steel	1.48	.43	4.22	.41	7.80	.42	12.00	.42
Energy	glass	2.63	.42	7.40	.41	13.50	.42	20.90	.44

Table 5 suggests that a slightly lower value of drag coefficient for smooth spheres (C_{DS} ~ .42)[1] would have been more accurate for diameters less than one inch. The values of drag co-

[1]The final calibration (using C_{DS} = .45) had already been performed when this aspect was inspected, and resultant errors were found to be negligible.

efficient in Table 5 may account for some of the scatter in Figure 6. Calibration uncertainties due to this effect will be discussed in Section 3.3.

Final calibrations

Although the range of drag coefficients for hailstones in free-fall is .47 to .73 under normal conditions, a final single value had to be chosen. Figure 7 shows how the terminal velocity of hailstones vary over this range of drag coefficient, while Figure 8 gives the variation of impact energy over the same range. The differences in terminal velocity and impact energy between hailstones with $C_D = .60$ and those with higher or lower drag coefficients (under normal conditions), are a maximum of about 5 per cent and 10 per cent respectively for hailstone diameters ≤ 1.5 cm. For such diameters, these differences are not considered to be serious. Furthermore, about 90 per cent of the hailstones of Central Alberta have diameters ≤ 1.5 cm (Paul, 1967). More important perhaps, is the fact that overall sampling errors should be virtually smoothed out by sheer numbers, since for a given hailstone, drag coefficients will be > .60 for some hailstones, and < .60 for others[1].

In order to check on other possible variations due to this range of drag coefficient, calibrations were performed for $C_D = .50$, .60, and .70, using Tables A1, A2 and A3 of Appendix II. Figure 9 displays the resulting relations between dent diameter (DD) and sphere (or hailstone) diameter (DH). The curves were smoothed by a least squares second order polynomial, using a method of Kuo (1972). A

[1] It is assumed that the measurements of hailstone drag coefficients are typical of hailstones in nature. Otherwise, most could have $C_D < .50$, or $C_D > .70$ for example.

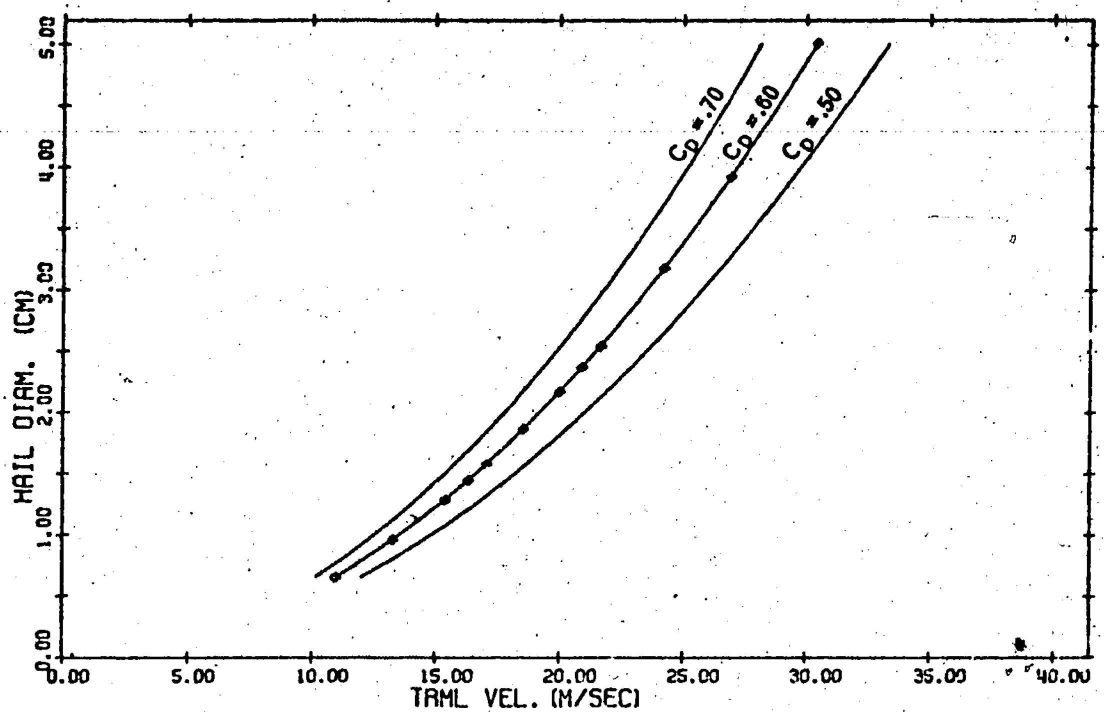


Figure 7. Variation of terminal velocity with hailstone diameter for drag coefficients of .50, .60, and .70.

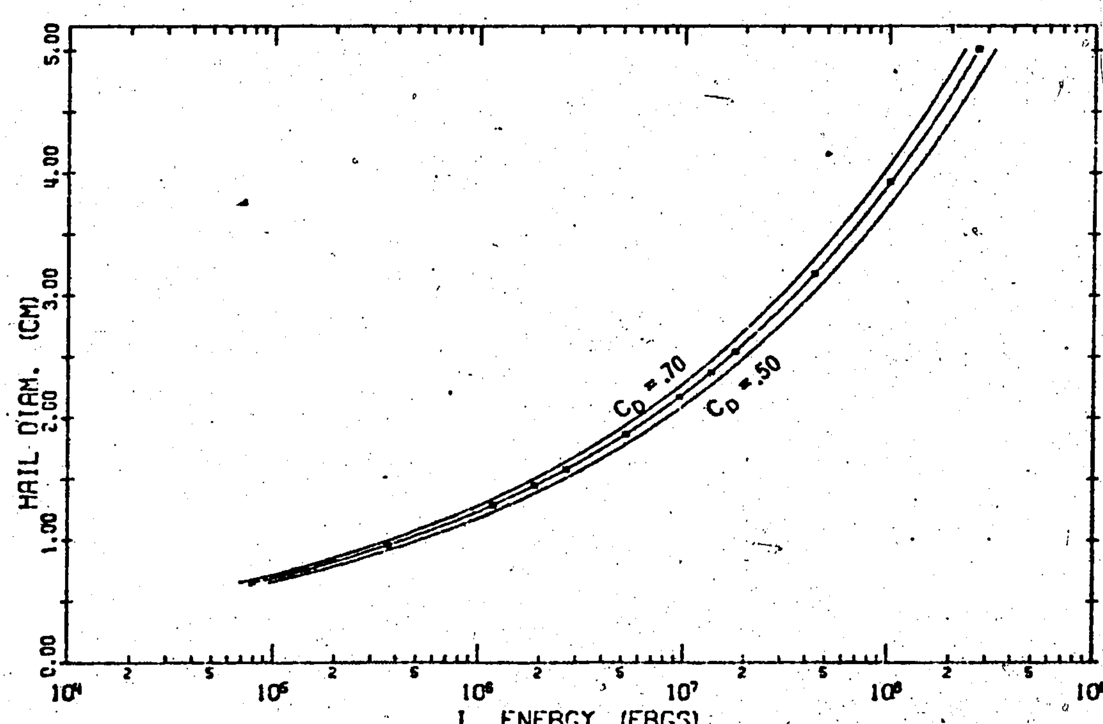


Figure 8. Variation of impact energy with hailstone diameter for drag coefficients of .50, .60, and .70.

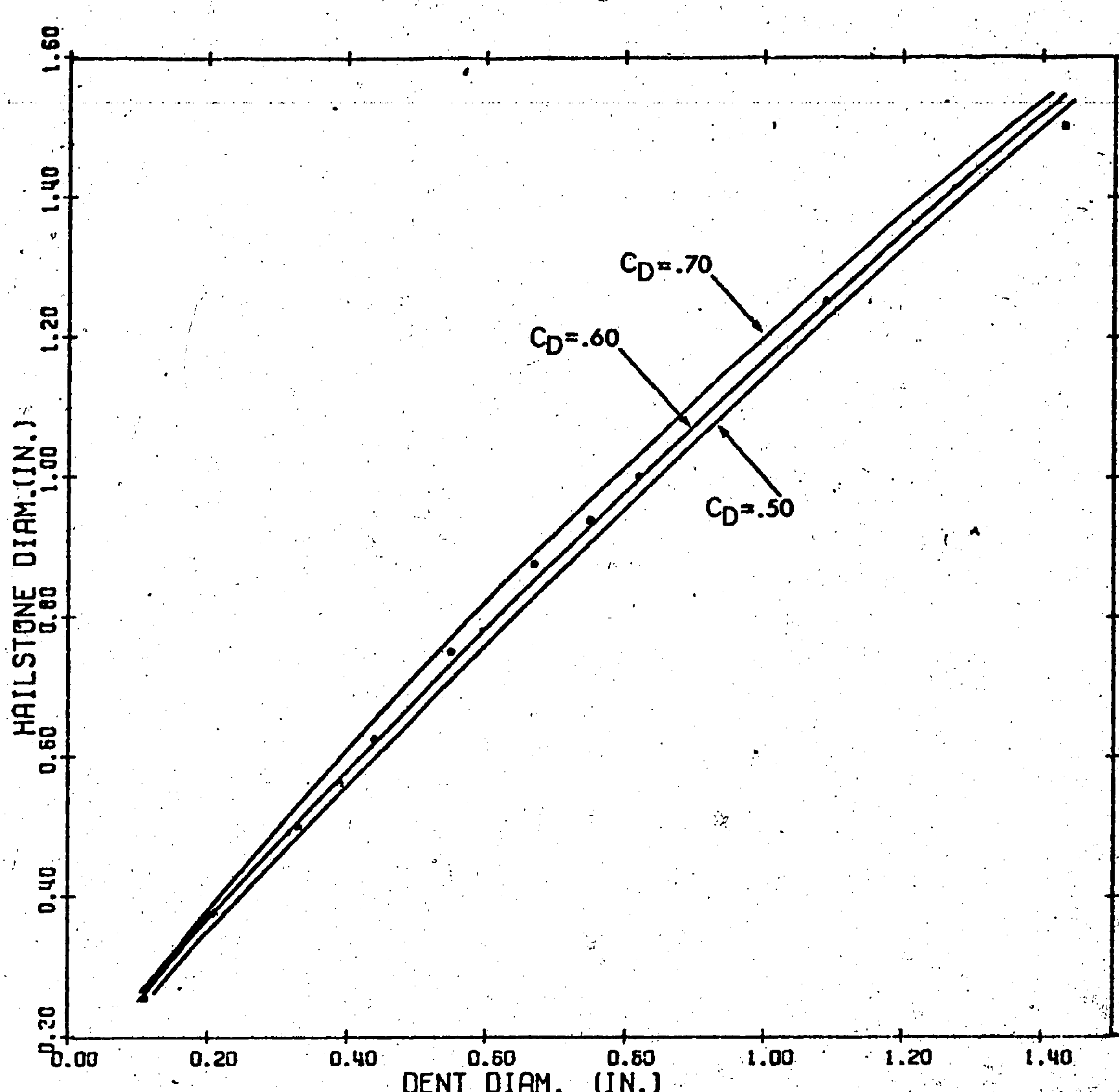


Figure 9. Dent diameter vs. hailstone diameter for drag coefficients of .5, .6, and .7. Plotted points are the original data for C_D = .60.

second order polynomial was used instead of a linear fit since this follows from the discussion of the collision process (Section 2.4), regarding sphere diameters ≥1 inch. The small curvature also agrees with the result of Lozowski (1974) that DH α $DD^{4/5}$. The calibration data points for C_D = .60 are also plotted onto the graph, while all of the data for the three curves appear in Table A4 of Appendix II.

The equations for the three curves of Figure 9 are:

$$DH = -.08\,DD_5^2 + 1.09\,DD_5 + .14 \quad (\text{for } C_D = .50) \qquad (20)$$

$$DH = -.09\,DD_6^2 + 1.11\,DD_6 + .15 \quad (\text{for } C_D = .60) \qquad (21)$$

$$DH = -.24\,DD_7^2 + 1.30\,DD_7 + .13 \quad (\text{for } C_D = .70) \qquad (22)$$

where DD is the dent diameter produced by a hailstone of diameter DH.

3.3 Calibration Errors

The assumptions made in order to calibrate the hailpads create uncertainties in the analysis of hailpad data from hailstorms. Although no drastic error sources have been noted so far, it seems logical at this point to summarize the uncertainties, which are of two types.

Errors due to choosing physical constants

First, we look at the relative uncertainties[1] in a hailstone's terminal velocity (W_T) and impact energy (E_I), due to the assumptions for hailstone density (ρ), air density (ρ_a), and drag coefficients (C_D and C_{DS}). By Equations 8, 10, and 16, we have for a given hailstone,

$$W_T \propto \left(\frac{\rho}{\rho_a C_D}\right)^{1/2}, \quad E_I \propto \frac{\rho^2}{\rho_a C_D}, \quad \text{and} \quad h_s \propto W_{TS}^2 \propto C_{DS}^{-1}.$$

[1]For treatment of error analysis and the calculation of relative uncertainties, see Baird (1962) for example.

Furthermore, $E_I \doteq$ (potential energy at h_s) = mgh_s, if we neglect any frictional loss of energy to the air. Therefore,

$$E_I \propto C_{DS}^{-1} \quad \text{and} \quad W_T \propto C_{DS}^{-1/2}$$

Table 6 now summarizes the uncertainties.

Table 6. Uncertainties in the calculated values of terminal velocity (or impact momentum) and impact energy, due to the calibration assumptions for ρ, ρ_a, C_D, and C_{DS}.

Parameter	Normal for Hail Conditions: Assumed Value	Expected Variation	Fractional Variation	Max. effect on calculations of: Terminal Vel. or Momentum	Impact Energy
ρ	0.89 g cm^{-3}	±.03	± 3%	±1.5%	± 6%
ρ_a	.00105 g cm^{-3}	±.00007	± 7%	∓3.5%	∓ 7%
C_D	.60	±.10	±17%	∓8.5%	∓17%
C_{DS}	.45	±.04	± 9%	∓4.5%	∓ 9%
Maximum combined effects of ρ, ρ_a, C_D, and C_{DS}				∓18 %	∓39%

It should be emphasized that the combined uncertainties represent the maximum error, due to these assumptions, for a single hailstone. When considering say, the total impact energy of several hundred to several thousand hailstones, then combined random errors in ρ, C_D, and C_{DS} tend to cancel out; i.e., the final error in the mean of N measurements of a quantity, each with error E, is $E_f = \frac{E}{\sqrt{N}}$

(Spiegel, 1961). For example, some of the hailstones may have a density of .86 g cm^{-3} due to trapped air bubbles, while others may be almost pure ice, say a density of .91 g cm^{-3}. A systematic error is possible of course, where all the hailstones from a given portion of a storm have density > .89 g cm^{-3}. But, the greatest source of actual error here in fact, may be the air density, depending on how close it is to the assumed value.

Errors from operational problems

Two operational problems may lead to additional errors when the calibration is employed. The first of these involves the absorption of impact energy by the surface underlying the hailpad. This surface may be considered to act in somewhat the same fashion as a spring. As previously mentioned, the hailpads of this project were nailed to the ground, mostly on bare earth, sometimes on softer, more energy-absorbent, low-cut grass.

For very small hailstones, energy is absorbed mainly by the aluminum foil and results are therefore not affected by the underlying surface, but the absorption can be significant for larger sizes. Table 7 gives calibration results for three sphere sizes with hailpads placed on various surfaces.

The importance of using one type of underlying surface is immediately obvious from Table 7. Differences between grass and soft earth, the conditions for this 1973 project, are negligible, although the calibrations used were those performed on the tile floor, since a hard surface such as that provided by a stand had been anticipated. Thus, hailstone sizes quoted in the results may be 5-10 per cent too low, meaning energy values (where $E_I \propto D^4$) could be 20-40 per cent too

Table 7. Hailpad dent variations caused by different underlying surfaces.

Sphere diameter (in)	.50	.625	.75
Mass ratio, hailstone/hailpad	1.3%	2.5%	4.3%
Terminal Velocity (m s^{-1})	15.3	17.1	18.8
TYPE OF UNDERLYING SURFACE	DENT DIAMETER (IN)		
Lying on:			
Tile floor (May, 1973)	.33	.44	.55
Tile floor (July, 1974)*	.35	.46	.58
Clipped onto 1-inch plywood, 1-ft^2, and nailed on post	.36	.45	.57
Lying on concrete	.35	.45	.57
Nailed onto:			
Damp, loose sand	.33	.43	.53
Soft earth (veg. garden)	.34	.42	.51
Low-cut grass	.33	.42	.50
Maximum standard deviation for 8 trials each	.015	.023	.021

*The second calibration on the tile floor employed hailpads from the previous year. Some aging process is suspected which may have slightly decreased the surface density of the styrofoam giving the larger dent sizes.

low. The use of a single type of hailpad stand may give slightly more uniform results, but most error here can be eliminated simply by using the proper calibration data.

The second operational error source cannot be handled as easily. This is the problem of wind-blown hailstones, to which we shall now give special consideration.

3.4 Calibration for Wind-Blown Hailstones

A major hailpad problem

Up to this point, the discussion has implied that hailstones in nature fall straight down, i.e., without any wind effects. Such an assumption would be totally unrealistic. While volunteer reports often indicate little or no wind during a hailfall, observations of winds in excess of 40 mph (> 18 m s^{-1}) during hail have frequently been reported.

Consider a simple model of a hailstone of mass m and diameter D, falling with terminal velocity W_T, in a horizontal wind, W_H. It is assumed that the horizontal velocity component of the hailstone equals the wind speed. Figure 10 describes the velocity components of this hailstone.

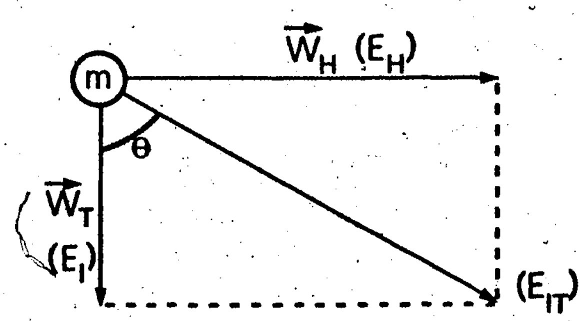


Figure 10. A hailstone falling in a wind.

The total impact energy[1] E_{IT}, is given by

$$E_{IT} = \frac{1}{2} m (W_H^2 + W_T^2) \qquad (23)$$

where

$$W_H = W_T \tan\theta . \qquad (24)$$

[1]Henceforth we shall call $E_I = \frac{1}{2} mW_T^2$ and $E_H = \frac{1}{2} mW_H^2$ the vertical and horizontal 'partitions' respectively of energy.

It is quite possible to have $E_{IT} = 5E_I$; e.g., if $W_H = 50$ mph $= 22.35$ m s^{-1}, and $D = .25$ in, for which $W_T = 10.83$ m s^{-1}, then $E_{IT} > 5E_I$. This means that the contribution of wind to the total impact energy can be quite significant.

Non-circular dents

The added horizontal velocity component results in a greater impact energy than for the same hailstone without any wind, and therefore tends to make an elliptical dent of larger area on a hailpad. The minor axis diameter of this elliptical dent, because of the larger impact energy, should be a close approximation to the diameter of a circular dent made by the same hailstone without any wind. In other words, it is hypothesized that the minor axis measurement yields a measure of the vertical component of impact energy, E_I only, and not of the total energy, E_{IT}.

To validate this approximation, hailpads were calibrated at various impact angles, so that the minor and major dent axes could be related to sphere diameters.

The method

If we were interested only in the total impact energy, E_{IT}, then hailpads would have to be calibrated by simulating the total impact energy corresponding to various size hailstones and various wind speeds. This would involve varying the angle of impact and the energy simultaneously, ~~a time~~-consuming process[1]. Then, hailpad

[1]Although time-consuming, this aspect of hailpad calibrations should be done in order to accurately measure hailfall occurring with high winds. The calibrations for wind-blown hailstones presented here should be considered only as preliminary work.

analysis would be complicated by having to measure both minor and major axes, and possibly impact angles as well.

Instead, the procedure followed was to calibrate hailpads for measuring the vertical partition of energy only; i.e., by changing the angle of impact for a given sphere diameter while holding the energy constant. In this case, the same tables of drop-heights could be used as for vertically-falling hailstones. Hailpads were inclined at angles of 15°, 30°, 45°, 60°, and 75°, and assuming a hailstone drag coefficient of .60, the drop-heights (of Table A2) were measured from the approximate point of impact on the pad, as in Figure 11.

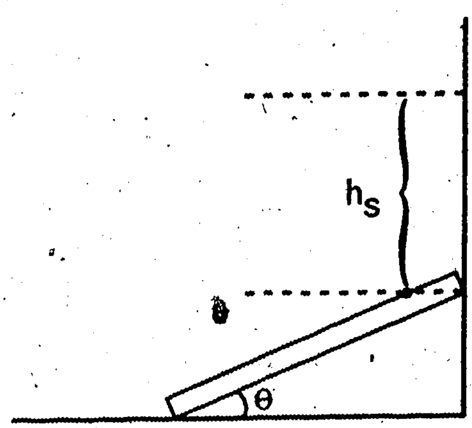


Figure 11. The drop-heights for calibrating hailpads for wind-blown hailstones.

The final relations between dent axes and hailstone diameters for given impact angles are shown in Figure 12. Once again, the data have been smoothed by the least squares second order polynomial approximation mentioned earlier. The 0° curve of course, is the curve for C_D = .60 in Figure 9. The curves to the left of this represent the minor axes and those to the right are the major axes. As only six trials were performed for each dent, the standard deviations of dent measurements varied from .005 up to .085 inch. Hence, at small hailstone diameters some of the smoothed curves of Figure 12 cross.

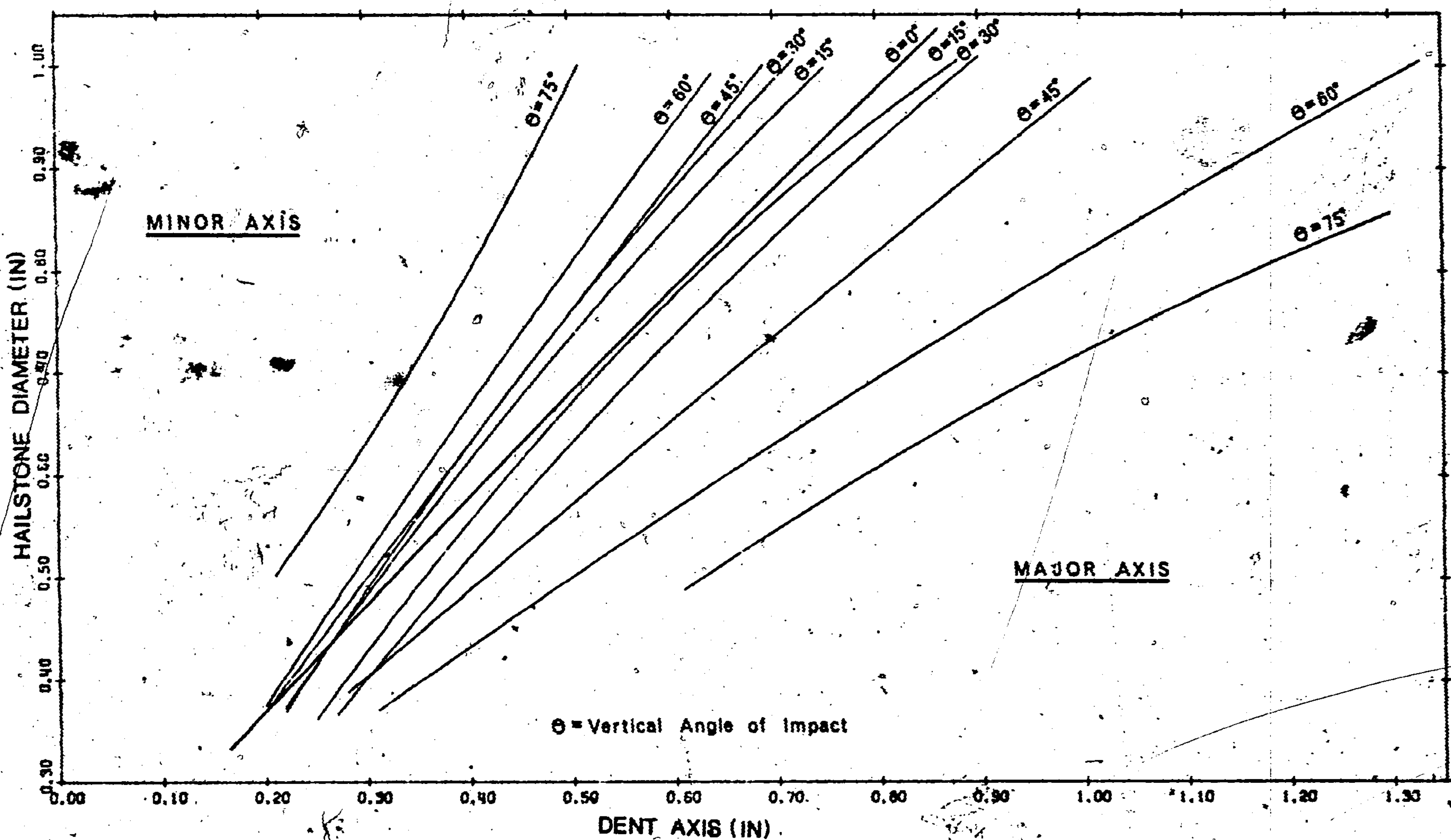


Figure 12. Dent axes vs. hailstone diameter for wind-blown hailstones.

Analysis errors due to winds

Since only the vertical partition of impact energy is simulated in Figure 12, the dent axes are therefore underestimates of the dents which would occur for such impact angles in a real event. For impact angles up to 45^{o} in Figure 12, the minor axis does not differ too drastically from the dent diameter of a vertically-falling hailstone with the same energy (the 0^{o} curve). In fact, if we were to add the horizontal component of wind, then the curves for the various minor axes would tend towards the 0^{o} curve.

Several trials were performed to simulate the appropriate total impact energy for a given hailstone size and wind speed. It was concluded that the maximum error in hailstone size resulting from the estimation procedure would occur for small hailstones in high winds (an uncertainty ~ + 15 per cent). The uncertainty is greatest for small hailstones because in a given wind the impact angle is greatest for these. Maximum errors of ±5 per cent in hailstone sizes were estimated for large hailstones (D ~ 1 inch). An error of 15 per cent in hailstone diameter would amount to an error of 60 per cent in the hailstone's impact energy.

When the minor dent axis from a wind-blown hailstone is assumed representative of the true hailstone diameter, errors will usually be overestimates according to the above trials. The estimated uncertainties imply a maximum error of ±.10 inch in hailstone diameter. Such an error is not serious in view of the fact that dents on hailpads from the field project could only be measured to ±.05 inch.

The advantage in using the foregoing estimation procedure for wind-blown hailstones, is that the total analysis time is at least cut in half, since only one axis of each dent must be measured. In other words, little lost, something gained.

3.5 Calibration Verification

Final calibrations for vertically-falling hailstones were verified in two ways.

(1) By dropping small ice spheres of known diameters down a 10-storey stairwell (34.5 m), achieving more than 90 per cent of their theoretical terminal velocity. Resultant hailpad dent sizes were compared with those made by the steel simulation spheres.

(2) By dropping larger ice spheres and real hailstones of known diameter in the same stairwell, and recording their velocity on photographic film just before impact. The derived impact velocities were then compared with those obtained by Equations 8, 12, and 13.

Samples of the ice spheres made for these two experiments both yielded mean densities of 0.89 g cm^{-3}, thus closely simulating the density of real hailstones (Section 2.1).

Equations 8, 12, and 13 give the terminal velocity, drop-height, and fraction of terminal velocity for a given hailstone diameter, density, drag coefficient, and air density. For assumed realistic conditions (ρ = .89 g cm^{-3}, C_D = .60, and ρ_a = .00105 g cm^{-3}), fractions of terminal velocity attained for various drop-heights and hailstone diameters were plotted. The results are shown in Figure 13.

Dent size verification

To recap the ice sphere results of Figure 6, ice spheres of diameters (with standard deviations of measurements in parentheses) .55(.02) in, .74(.02) in, and .85(.03) in, were dropped in the stair-

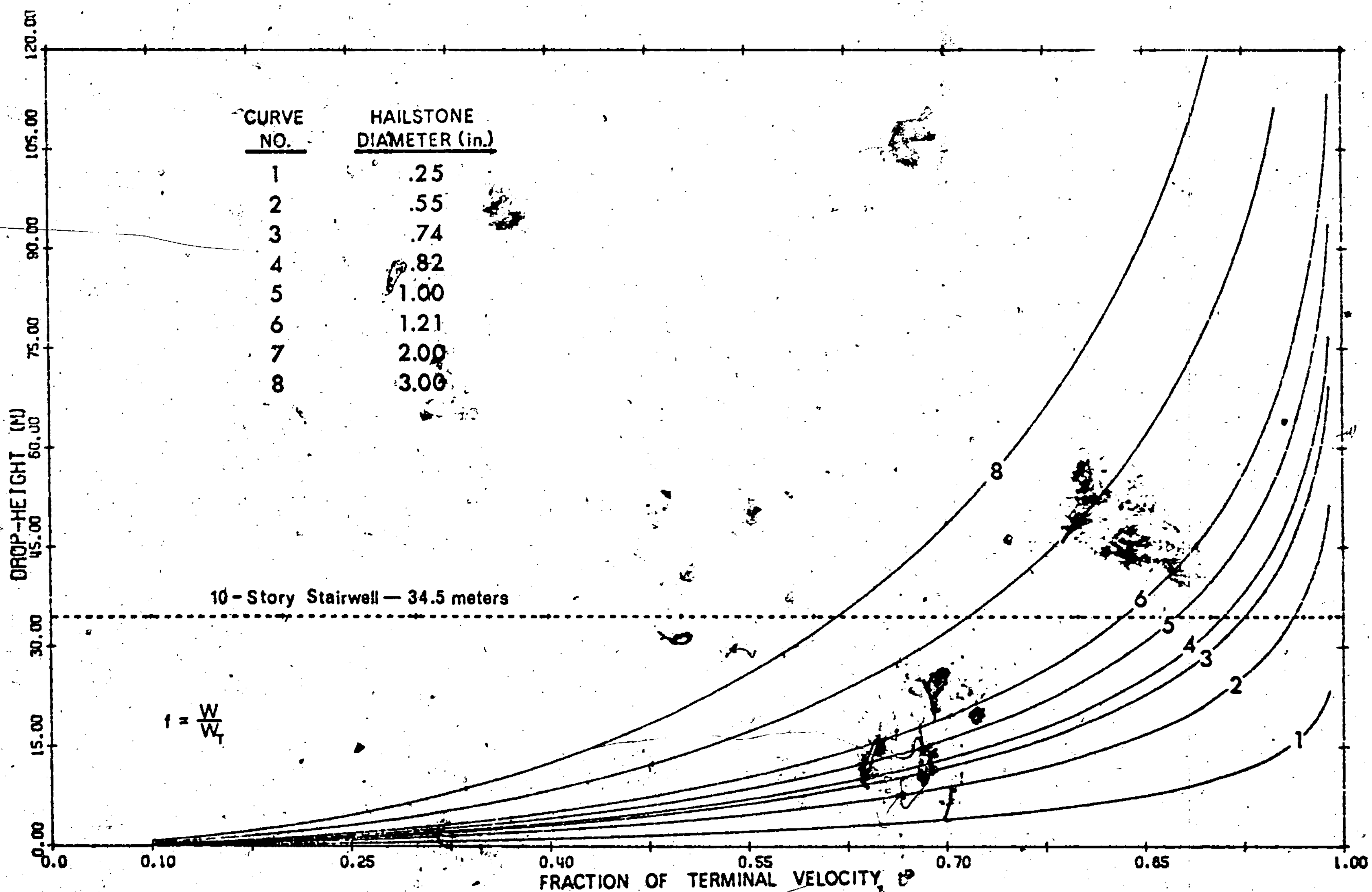


Figure 13. Fraction of terminal velocity vs. drop-height for various hailstone diameters.

well onto large hailpads, resulting in dent sizes (standard deviations in parentheses) of .36(.04) in, .54(.04) in, and .64(.04) in, respectively. A comparison of these dents with those of the steel spheres is shown in Figure 14. If one allows for a small dent size reduction (since impacts were 3-8 per cent short of terminal velocity), then the curve for C_D = .60 is a reasonable approximation.

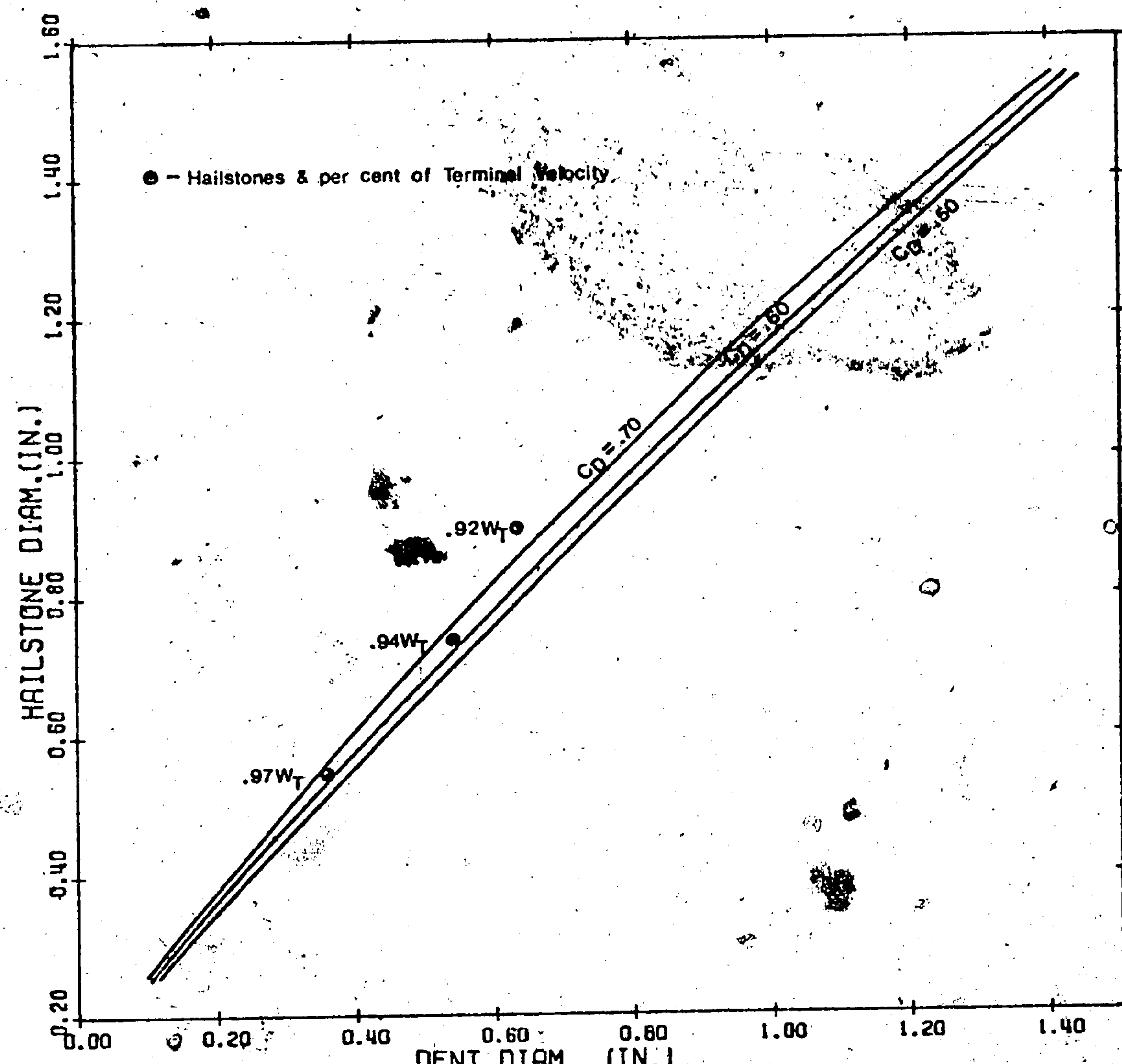


Figure 14. Calibration verification for vertically-falling hailstones.

Photo verification

In this experiment, ice spheres of diameters .82(.03) in and 1.21(.03) in were dropped in two trials, their impacts being recorded by high-speed photography with a 16mm cine camera operating at 500 frames s^{-1}. A gridded mirror system provided accurate three-dimensional positioning of the hailstones with ~~respect to the~~ camera. Details of this system are described by Lozowski et al. (1974). Impact velocities were calculated by fellow student, Myron Oleskiw, for those ice spheres which fell within the camera's field of view.

The physical conditions for this experiment were as follows:

drop-height, h = 34.5 meters;

pressure at impact level, P = 930 mb;

air temperature at impact level, T = 295°K;

air density at impact level (calculated for dry air),

$$\rho_a = 1.098 \times 10^{-3} \text{ g cm}^{-3};$$

acceleration due to gravity, valid at 53N (Weast, 1973),

$$g = 981.3 \text{ cm s}^{-2};$$

measured density of ice spheres, $\rho = 0.89 \text{ g cm}^{-3}$;

assumed drag coefficient for hailstones, $C_D = 0.60$.

Approximately two dozen ice spheres of each size were dropped with a total of 12 useable ones appearing on film after deleting those which obviously had been obstructed during fall (high impact angles and low impact velocities, combined with rapid spinning). Table 8 is a comparison between the theoretical and measured values of the impact velocities for statistical samples of the two ice sphere sizes.

Table 8. Photo-verification of the hailpad calibration - a comparison of theoretical and measured impact velocities of ice spheres dropped in a stairwell 34.5 meters high. Values in parentheses are standard deviations of measurements.

Mean Ice Sphere Diam. (cm)	Mean Velocities ($m\ s^{-1}$) THEORETICAL Terminal	Impact	PHOTOGRAPHIC Impact	Values derived from Mean Photog. Impact Velocities W_T ($m\ s^{-1}$)	C_D
2.08 (.05)	19.2*	17.6	17.8 (.3)	19.3	0.59
3.07 (.07)	23.3*	19.7	20.3 (.6)	23.9	0.57

*If the value of air density, 1.05×10^{-3} g cm^{-3}, had been assumed (as used elsewhere in this dissertation) instead of the measured value, then these values of terminal velocity would be 19.6 and 23.8 m s^{-1}, respectively.

For the few samples used in this experiment, the theoreticcl and measured values of impact velocity agreed within the standard deviation of measurement. Measured values were slightly higher, possibly because the artificial hailstones used had smoother surfaces than those found in nature.

Although these hailstones were dry during fall, having been kept at dry ice temperature prior to dropping, current literature on hailstone dynamics does not suggest any significant differences in drag coefficients between wet and dry hailstone surfaces, except near the critical Reynolds number which is not applicable here (see Section 2.1).

From the derived values of drag coefficient in Table 8, it appears that the assumed constant value of .60 for this elusive parameter was a reasonable assumption.

CHAPTER IV

HAILPAD NETWORK DESIGN AND INSTALLATIONS

"Unable to estimate all the damage done; bring more hailpads!" .... Howard Smith, July 23, 1973.

"The storm appeared to revolve over here and hailed about four times." .. Roy Johnson, July 23, 1973.

4.1 Network Design

Since this was the first attempt to objectively measure Alberta hailfall on a reasonably large scale, designing the network was one of the objectives of the project. This included consideration of the density and pattern of the hailpad stations. For the 1973 network, these questions were handled first in a qualitative fashion, then compared with the quantitative results by other researchers, primarily the studies outlined in Chapter I.

Practical considerations

For the 1973 hailpad project the following factors were considered:

(i) Manpower and vehicle: Full-time manpower consisted of the author and one summer student assistant using one vehicle. Many of the day-to-day station operations were undertaken by farming people who volunteered to look after the changing of hailpads after initial installations.

(ii) Cost: Costs were minimized by the simple design of the hailpad itself, and by installation with two six-inch spikes into the ground. The cost per hailpad for materials (styrofoam, aluminum foil, tape and spikes) was approximately 25 cents.

(iii) Area of coverage: Two networks were established, one in the area of operational cloud-seeding for hail suppression south of Penhold, the other in the area of single storm experiments north of Penhold. In addition, the networks were to be within the useful radar range of Penhold (about 100 miles), but outside the range of ground clutter (about 10 miles).

(iv) Accessibility of hailpad sites by road.

(v) Areas of known high hail frequency (as indicated by Figure 1).

(vi) Station density: Colorado data in 1959 (Schleusener and Jennings, 1960) showed that hailpads located two miles or more apart correlated with a coefficient of less than 0.5. Changnon (1969) suggested that at least one observation site per square mile was necessary to adequately measure the areal extent of damaging hail in Illinois. Supporting this requirement, Changnon (1970a) and Changnon and Towery (1972) determined the average dimensions of a 'hailstreak' within a 'hailswath' to be 1.1 miles wide and 4 to 5 miles long. It was suggested (P.W. Summers and J.H. Renick, personal communication) that Alberta hailswaths were better defined than in Illinois where freezing levels are generally higher; hence hailstones at ground-level are perhaps smaller and occur less frequently. In Alberta, a typical 'damaging' hailswath is two to five miles wide (Summers and Wojtiw, 1971); hence, hail detectors should be no more than five miles apart even if one only wishes to establish whether or not hail occurred. On the other hand, values of impact energy will range over several orders of magnitude. Therefore, if impact energies recorded on adjacent hailpads a couple of miles apart differ by, say 200 per cent, this may not be too critical.

Network plan

Given the above factors, it was decided to make each network six townships[1] long by four townships wide (or 36 miles x 24 miles = 864 mi^2 each). Both networks would be oriented west to east, the predominant direction of motion of Alberta hailstorms (Thompson, 1966; Paul, 1967). Hailpad station density was planned to be one per 10 square miles, giving a mean station spacing[2] of 3.4 miles and requiring a total of 173 hailpad stations for the two networks.

This plan included gridding of the stations in checkerboard fashion in order to make optimum use of the station spacing. The gridding was only partially successful, however, since volunteer operators were not always available at the desired locations.

Acquiring volunteers

Requests for volunteer hailpad operators were included in Alberta Hail Studies' pre-hail-season mailings to farmers in May. These mailings normally include business reply hail report cards, and appeals are made to save hail samples. The request for hailpad

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[1]For an explanation of Alberta's land survey system, see Appendix I.

[2]Mean spacing, S_p, of either hailpad sites or hailstones on the ground has been calculated in this dissertation by the formula, $S_p = \sqrt{\frac{2A}{\sqrt{3}N}}$ (Lozowski, personal communication), where N is the number in area A.

volunteers was directed specifically at farms where some form of hail insurance would likely be taken out. This was emphasized so that later comparisons could be made with insurance statistics on crop damage. Most farms have livestock to help offset losses in poor seasons, while large farms often consist of several scattered holdings, reducing the risk of complete bankruptcy in case of a major hail disaster. Thus many farmers play the odds with hail damage and do not take out any hail insurance for which premiums may be as high as 20 per cent of crop value (Summers and Wojtiw, 1971). Hence, of an anticipated 500 or more volunteers, only 65 had replied by June 7th, with many of these outside the planned network areas.

A follow-up two-week operation of telephone solicitations, however, produced several hundred volunteers, although this operation delayed the start of hailpad installations.

4.2 The Hailpad Field Project

Installations

Each farmer volunteer (or, as was usually the case, his wife) was initially given eight hailpads, four six-inch spikes, a number of ALHAS hail report cards with spaces for hailpad number, and an instruction card. Samples of the hail report card and the instruction card are attached to the inside front cover of this dissertation.

Operators were instructed to install the hailpad at a well-exposed location on bare ground or low-cut grass by inserting two spikes through opposite corners of the hailpad. One edge of the hailpad was labelled to face north, so that wind direction during hail could be inferred. The site was always chosen in consultation with the operator.

In most cases this was in the vegetable garden, which was convenient for the operator, was usually well-exposed, and was the least likely location for accidental damage. The directions for pad changes and recording information can be found on the instruction card.

Installations commenced on June 20th and were completed by July 13th. In the meantime, adequate (though incomplete) hailpad data were recorded for five storms, on June 25th, June 29th, July 5th, and July 6th in the Southern Network, and on July 4th in the Northern Network.

The resulting main networks

Because of unforeseen delays, three townships with relatively low hail frequency were deleted from the northeast corners of the planned networks. However, three more townships were added to the western end of the northern network to cover an apparent 'hail alley' near the town of Rocky Mountain House.

Thus the final network specifications were: in the Southern Network 152 stations in 783 mi^2, an average station density of one per 5 mi^2 and a linear spacing of 2.4 miles; the Northern Network, because of the two large lakes and a sparcity of farms in some areas, contained only 120 stations in 837 mi^2, or one in 7 mi^2 and a linear spacing of 2.8 miles. The detailed lay-out of the hailpad stations of both networks has already been displayed in Figure 2 (Chapter I).

Network servicing

During the summer, at least one extra trip was made to each station to replenish supplies and pick up used hailpads. Occasional contacts were also made by telephone. Final retrieval of all hailpads commenced August 28th and this was completed by September 5th. Records of 12 more storms were obtained during the 1 1/2-month period of complete operations (July 13th to August 27th) for a total of 17 storms. Several other minor storms were also recorded but at only one to three stations per storm.

Dense networks

The representativeness of one hailpad in six square miles (the average density) must at least be questioned. As soon as problems with the main networks were resolved, several dense hailpad networks were set up (August 1st to 4th). One of these in the Northern Network consisted of one land section (1 mi^2) with 25 hailpads spaced one-quarter mile apart. In the Southern Network, four quarter-sections were instrumented with 9 hailpads each, again spaced one quarter mile apart. The locations for these five dense networks were chosen on the basis of (a) climatologically-frequent hailfall, and (b) local hail knowledge acquired from the farmers during the early part of the summer. These locations are shown in Figure 2.

The dense networks were maintained by the author with checks at least weekly for four weeks. Regular hailpad stations were also located at each dense network so that frequent contact with these operators provided ample notice of any occurrence of hail or rain. The northern dense network, designated DNX, recorded a severe hailstorm on August 16th, and a less severe one on August 23rd. The southern dense networks, designated DNK, DNW, DNY, and DNZ, also recorded the August 23rd hailstorm. The data from these w · discussed in detail later.

Other hailpad operations

Five meso-meteorological stations consisting of recording tipping-bucket raingauges, wet and dry bulb thermometers, and wind anemometers were set up with extra help from ALHAS personnel at locations indicated in Figure 2. Unfortunately, it was necessary to use two-week recorders on these with the result that data resolution on the charts was difficult for certain crucial periods; i.e., during hail and heavy rainfall.

Several mobile hailpad operations were carried out. For these, radio communication with radar operations allowed hailpad installations just prior to hailfall. These data augmented regular network data, but more importantly, they provided sequential records of hailfall as well as variations in hailpad records over smaller distances than in the dense networks (e.g., hailpads placed on opposite sides of a road).

A 273rd regular hailpad station maintained in distant Edmonton (by the author's wife) also provided sequential and fine spatial resolution of hailfall.

Field problems

A number of potential problems arose during the summer. These will be mentioned here before discussing the analysis of and final results from the hailpads.

i) Since the hailpads were being 'nailed' onto the ground, proper exposure became a key question. Poor exposure in wind because of buildings, trees, fences, or even a high crop or tall grass, could have greatly distorted the final results. Usually there was no such exposure problem at any of the stations in the two regular networks. A few difficulties arose when setting up the dense networks, however, where 1/4-mile spacing was desired. In these instances, the hailpads were installed so that they were exposed best to the northwest quadrant, since most hail in Central Alberta is said to fall with a west to northwest wind, if any. The extent to which this became a source of error will be discussed later.

ii) Keeping hailpad sites away from the main tracks of farm vehicles, animals, and people was not usually a problem, and when damage did occur, operators had been asked to replace the hailpads. In the dense networks where it was occasionally necessary to place a hailpad in a pasture, it was, without exception, destroyed by the animals.

iii) Birds, particularly magpies, occasionally damaged hailpads by pecking them, undoubtedly attracted by the bright aluminum foil covering. Overall this was a minor problem because unless the foil was subsequently torn off by the wind or hail, the pecks were easily distinguished from dents. This problem appeared to be confined to certain areas, mainly in the Southern Network.

iv) One problem which could not be solved with the manpower and vehicle available was that of keeping a constant quality control check on operating sites. There were a few cases where hailpads were left unchanged for two to four weeks. In most of these cases no hail had occurred anyway, and the hailpads were found to weather well. Nevertheless, a small number of hailpads had to be discounted from final results because they were exposed to more than one hailfall, or else the operator had failed to note dates and times of hailpad installation and removal, and/or that of the hailfall. As this venture depended so heavily on volunteer efforts by the farmers, one cannot but be amazed that so few failings did result. In any event, hailpad changing at such stations improved noticeably after the mid-summer visits, suggesting that communication and public relations are important aspects of this type of operation.

v) This raises the problem of different hailfalls several hours or even minutes apart. The author has no illusions that hailpads are able to sequentially separate such hailfalls. Some hailpad operators dutifully changed hailpads 'immediately' following a hailfall. One lady produced three dented hailpads from one 60-minute period. It is more than likely that most did not do this, nor would one expect volunteers to do so. Therefore, it was decided to add together results from two hailpads or more if the time separation was three hours or less. These cases numbered fewer than half a dozen.

4.3 Hailpad Returns

The degree of cooperation received from the volunteer hailpad operators was gratifying, to say the least. Table 9 is a summary of hailpad returns by township, with no breakdown by range. Several details of this table are worthy of discussion.

Volunteer reliability

Of more than 2500 hailpads delivered to the volunteers, less than 7 per cent were unaccounted for by the summer's end, although a figure of 20 or 25 per cent had been anticipated. Much of the 7 per cent can be attributed to difficulties in finding people home during

Table 9. Summary of Hailpad returns by Township from the main networks.

Township	No. of Hailpad Stations	No. of Hailpads Delivered	No. of Hailpads Used	Breakdown of Used Hailpads* Hail Dents	% of No. Used	Rain Only	No Precip.	No. of Pads Unaccounted for
30	4	32	15	8	53.3	5	2	4
31	42	399	245	62	25.3	156	27	14
32	49	474	351	78	22.2	220	53	19
33	35	317	224	81	36.2	123	20	25
34	22	189	130	56	43.1	69	5	19
Southern Network	152	1411	965	285	29.5	573	107	81
39	31	282	219	83	37.9	116	20	24
40	38	343	244	122	50.0	107	15	30
41	26	224	138	73	52.9	61	4	21
42	24	243	191	96	50.3	75	20	13
43	1	10	9	3	33.3	5	1	0
Northern Network	120	1102	801	377	47.1	364	60	88
Volunteer Network Totals	272	2513	1766	662	37.5	937	167	169
PER CENT OF TOTALS			70.3	26.3	—	37.3	6.6	6.7
PER CENT OF NUMBER USED				37.5	—	53.1	9.5	-

*The number of hailpads collected unused is not included in these columns.

the brief final collection period.

Hail frequency

More than 70 per cent of the hailpads delivered were used; of these, 662 hail-dented pads were collected, about 38 per cent of the used hailpads. This latter figure is higher than had been expected, especially in view of the fact that the number of hail days during 1973 in Central Alberta was below normal (Meheriuk, 1974). This reflects the fact that a large proportion of these hailpads were dented by very small and/or very few hailstones normally not observed visually, especially when some of it occurs with heavy rain or during darkness. Other hailpad investigators concur in this observation (Changnon, 1971a; Morgan and Towery, 1974).

The percentage of hail-dented hailpads increases northward from 25 per cent in Township 31 to a maximum of 53 per cent in Township 41. Although it is tempting to do so, this cannot be taken by itself as evidence for hail suppression success, since not all storms in the Southern Network were seeded, while two in the Northern Network were. Also, some of this trend is due to having a relatively high density of hailpad stations in the southeastern portion of the Southern Network (Figure 2) where, ironically, very little hail occurred in 1973.

Rain dents

As stated earlier, rain dents are easily distinguished from hail dents. On the average, hailpads were exposed for eight days; some less because of hail or other damage, some longer because no weather occurred and the hailpad was undamaged or else the operator forgot to change it on time. Table 9 shows that there were very few 8-day periods at point locations in Central Alberta when precipitation of some form did not occur. Fifty-three per cent of these periods received rain only, 38 per cent had hail and rain, and only 9 per cent were dry.

Other hailpad returns

The dense networks yielded 83 hail-dented pads from two hail days in August. Eleven dented hailpads resulted from three mobile operation days, while the Edmonton site produced five hail-dented pads. Table 10 summarizes these returns and the 1973 season totals, including 761 hail-dented pads.

Table 10. Summary of hailpad returns for dense networks, mobile and Edmonton operations and the 1973 summer totals.

Operation	Hailpads Delivered/Used	Hailpads Collected: Hail Dents	Hailpads Collected: Rain Only	Hailpads Collected: Damaged or no Hail or Rain	Hailpads Unaccounted for*
DNK (Southern)	11 / 11	8	0	3	0
DNW (Southern)	11 / 11	8	0	2	1
DNY (Southern)	10 / 10	9	0	1	0
DNZ (Southern)	9 / 9	8	0	0	1
DNX (Northern)	52 / 52	50	0	2	0
TOTALS	93 / 93	83	0	8	2
Mobile	15 / 15	11	4	0	0
Edmonton	16 / 16	5	11	0	0
Totals from Main Networks	2513 / 1766	662	937	167	169
1973 Summer Hailpad Totals	2673 / 1890	761	952	[illegible]	171

*The number of hailpads collected unused is not included in these columns

CHAPTER V

HAILPAD ANALYSIS

> *"A few hailstones fell about the time rain started. Main hail was ten minutes later. There was a minute of two strong gusts of wind as hail started, but most of the time winds were light."*
> .... *John Hull, July 4, 1973.*

> *"Was unable to get a sample or notes on storm as it was an electrical storm and I wouldn't get up."*
> ... *C.H. Trautman, August 2, 1973.*

5.1 Procedure

Hailpad dent diameters are related [illegible]tion 21 to hailstone diameters, from which the other [illegible]ll parameters of ice mass, momentum, and energy are derived. The procedure used to obtain such information follows.

The largest dents are carefully measured and counted first. For the smaller dents which are less important in the overall impact energy, a subjective estimation procedure is applied. However, if this procedure is carried out in an organized fashion, then with practice, two analysts should be able to produce consistent hailpad results.

Random Analysis

Hailpads were chosen at random for analysis, the sorting by storm date and land location being done only after all analyses had been completed. This was beneficial in that deliberate or inadvertent bias, resulting from similarly-dented adjacent hailpads from the same storm, was then avoided. The randomizing also had some psychological benefit of reducing boredom.

Maximum dent sizes

Dent measurements were initiated by counting the largest sizes first, then working on down to the smallest. Most dents have ridges so that interpreting the edges of dents can be confusing at first. Since the hand analyses were performed by several people, the hailpads therefore were first maximized by the author; i.e., all (761) hailpads were scanned for the maximum dent diameter and this value was imprinted on the hailpad. The purpose in this was to place an accurate upper bound on the measurements, which would serve as a point of reference for the individual analyst's interpolation. The maximizing thus helped to reduce minor variations in measurement techniques and to create a trend towards uniformity of the dent size spectrum for each hailpad, especially since the bigger sizes often contribute a larger proportion of total mass, impact energy, and impact momentum even when their numbers are relatively small. Although this is a form of deliberate bias, (because of the dent ridges) the same weighting is applied to all hailpads.

Overlays

The analysis procedure involved the use of two transparent overlays for the hailpad. One had imprinted circles of diameters 0.1 to 1.0 inch at .1-inch intervals, and 1.0 to 2.0 inches at .25-inch intervals. Dents were estimated to the nearest .05 inch, interpolating between tenths on the overlay. Dents greater than one inch were usually measured by ruler also. The number of each size was recorded for each hailpad. A second 'squared' overlay, shown in reduced size in Figure 15, consisted of three squares of areas, 9, 36, and 100 square inches, representing 1/16, 1/4, and 100/144 of a hailpad, respectively.

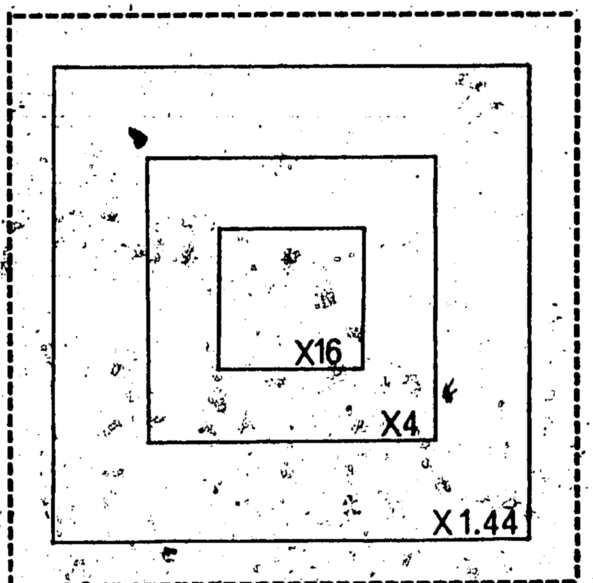


Figure 15. The hailpad overlay used in the counting and estimation procedure.

Number estimation

Hail dent numbers ranged from 1 to 8000 on the 197[illegible] hailpads. Counting several thousand dents on a hailpad would be a formidable task if each were measured and counted individually. Therefore, an approximate but reasonably accurate method of estimating numbers was devised.

With the 'squared' overlay fixed on the hailpad, systematic counting of one size at a time commenced on the inside (9-in^2) square, then proceeded to the remainder of the 36-in^2 square, then to the 100-in^2 square, and finished on the hailpad's outside one-inch edge. If, at the end of one of these counting stages, the accumulated count had exceeded 100 (although sometimes the figure 50 was used), then at this point the appropriate multiplication factor (16, 4, or 1.44) was applied to estimate the count per square foot. However, dent diameters ≥ .5 inch were always counted over the whole hailpad. Since hailpad edge effects could affect dents smaller than .5-inch diameter, such sizes were usually counted only within the 100-in^2 area (or a smaller area).

A concerted effort was made to measure occasional multiple dents; i.e., small dents within larger ones. All dents were marked on the overlay as they were counted, using different markings and pens with colored water-soluble ink for each size, in case of a pause during the analysis. The overlay could be wiped clean afterward and used on the next hailpad.

For hailpads having a large number of small dents from shot size hail (see Table 11 for dent sizes), these might be counted over the 9-in^2 area, but the overlay was first positioned so as to sample an area representative of the hailpad. This smallest area was usually used when numbers in excess of 1000 over the entire pad were involved. Such estimates were generally rounded off to the nearest 50, or 100 if exceeding 2000.

Quality control

Several checks on this method were carried out by labouriously counting all dents on a number of hailpads. On comparing with earlier estimates, differences for a given size were almost always less than 10 per cent, with much of this being explained by the choice between adjacent sizes; e.g., a dent diameter of .30 inch might be interpreted as .25 or .35 inch. To minimize error therefore, most hailpads with several hundred or more dents were analyzed at least twice, usually by different analysts, and the counts were averaged. Apart from using the same maximum size, all repeats were performed without knowledge of previous results. If the 9-inch^2 area only was used for a count, the hailpad was always re-analyzed. If differences in any numbers then exceeded 10 per cent, the count was repeated again. The average of all analyses of a hailpad was adopted.

Three part-time assistants were employed by [illegible] to assist in the analyses. Each one spent several days repeate[illegible]alyzing about 10 hailpads until their approach produced consistently uniform results. Nevertheless, more than 65 per cent of the hailpads were analyzed by the author, including 390 original analyses and 110 repeats.

The analysis commenced in mid-September and was completed in mid-January. Several months later, a few randomly chosen hailpads were analyzed yet again. Total values of impact energy differed from the previously measured values by less than 5 per cent for all cases.

5.2 Final Data

Total values of hail parameters were computed for each hailpad. At the same time, since little work had been done previously on accurate determination of the size spectrum of hailstones, it was considered useful to subdivide the data according to the conventional hailstone size categories; i.e., shot, pea, grape, walnut, golfball, and > golfball.

Size categories

In order to convert the quantitative size distributions obtained from the hailpad analyses into the above descriptive categories, appropriate size intervals for the categories were determined.

Since ALHAS had previously defined only mean diameters for these categories, upper and lower limits were based on volume medians of the mean diameters. The hail diameter intervals were also converted to hailpad dent diameter intervals (to the nearest .05 inch) via Equation 21. The intervals for both hailstone and dent diameter are shown in Table 11. These size intervals closely approximate those suggested by Paul (1967, 1968).

Table 11. Upper and lower boundaries for hail diameters and the corresponding dent diameters for the descriptive hail size categories reported by Alberta volunteer observers.

Observer Hail Size	ALHAS Mean Diameter (cm)	Hailstone and Dent Diameter Intervals: Hailstone (cm)	Dent (in)
Shot	0.2	< 0.6	≤ .05
Pea	0.8	0.6 - 1.2	.10 - .30
Grape	1.6	1.3 - 2.0	.35 - .60
Walnut	2.4	2.1 - 3.2	.65 - 1.10
Golfball	4.0	3.3 - 5.2	1.15 - 2.00
> Golfball	6.0	> 5.2	> 2.00

<u>Computations</u>

Computations of hail mass, impact energy, and impact momentum, as derived from the dents, were carried out on the University of Alberta IBM 360/67 computer. A sample of the type of output obtained appears in Appendix III. Later, hailpad analyses were sorted by storm date and location.

Errors of estimation

Errors result from (i) actual counting, (ii) the dent diameter measurements, and (iii) the estimation procedure.

Counting errors will usually result in underestimates of numbers partly because of unrecognized multiple dents where large numbers and large hailstones are involved, and partly because the analyst will miss a few (though this number is usually negligible), yet he will never, if the overlay is properly fixed and marked, count the same dent twice. Counts of shot-size dents may tend to be overestimated, not because he counts some twice, but because some of these dents are made by chips off larger hailstones on impact[1]. But where such large hailstones and numbers are involved, the overall contribution to impact energy of the shot-size stones is small, usually less than 5 per cent (see Appendix III for example).

It has already been mentioned that errors in the dent diameter measurements are a maximum of ±.05 inch. Errors from the estimation procedure are simply sampling errors, since counts are being made for areas smaller than 1 ft^2. Such sampling errors are similar to those estimated by Changnon (1969) and Changnon and Towery (1972), where various size sensing surfaces were used, except that in the current study, the smaller sensing surface applied only to the smaller and less important sizes.

A summary of uncertainties due to these measurement errors appears in Table 12. The uncertainties of this analysis technique are

[1]This effect has been observed during hailfalls.

Table 12. Summary of experimental errors due to the analysis technique.

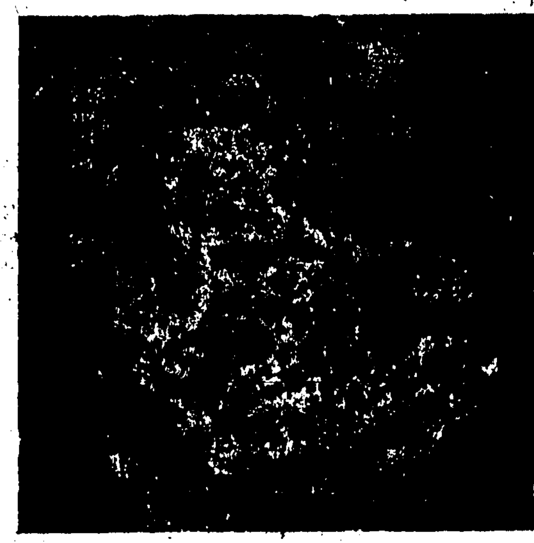
Error Source	Uncertainty for: Individual Hail Sizes (in)	Number of a Given Size	Total Impact Energy
Real counts	NA	- 5%	- 5%
Dent diameter*	±.05	NA	±10%
Estimated counts	NA	±10%	±10%
Combined uncertainty	.05	±15%	±25%

*This error is partially self-compensating for the total impact energy on a hailpad, since a dent not counted as one size is included in the number of the next smallest or largest size.

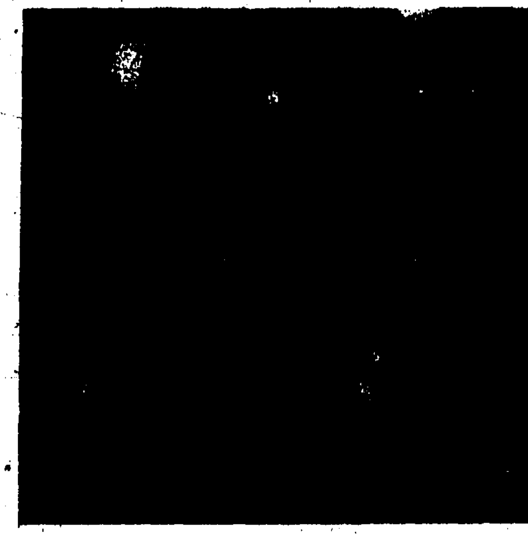
no greater than those brought about by the choice of physical constants (Table 6), or by the measurement of dent diameters of wind-blown hailstones (Table 8).

5.3 Complete Automation of Hailpad Analysis

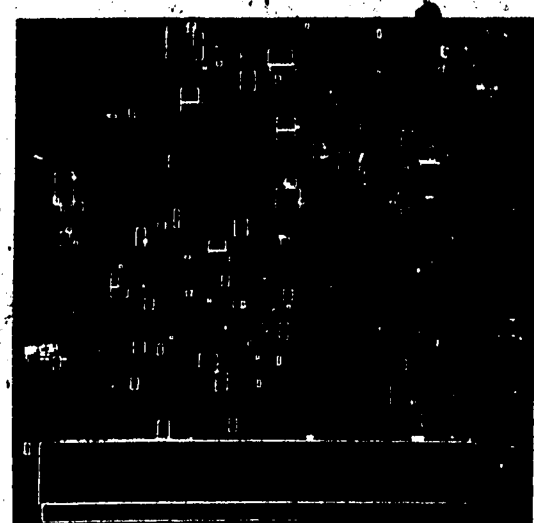
On the average, hailpads require 15 minutes to analyze, excluding time required for punching computer cards, etc., This time-consuming aspect of analysis was brought to the attention of Dr. W. A. Davis of the Computing Science Department at the University of Alberta. A graduate student, Tsang (1974) was assigned the task of developing a digital picture processing method for measuring and counting dent sizes on hailpads. Some results of his work are shown in Figure 16.



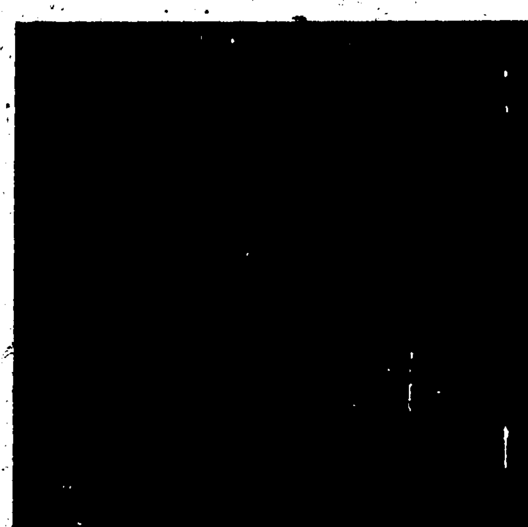
(a) Aluminum foil-covered hailpad (#1192). The long dark band is used later to calculate sizes.



(b) Picture of hailpad (dents by large steel spheres) with foil removed, styrofoam inked by roller to emphasize dents; black spots are accidental ink blotches.



(c) Digitized binary matrix picture output of (a) with boxes enclosing matrix dent regions; binary regions removed in this photo.



(d) Digitized version of (b) as in (c)

Figure 16. Some results of automatic hailpad analysis by digital picture processing. (after Tsang, 1974).

Equipment for this system includes a television camera mounted about three feet from the hailpad, which scans the hailpad and digitizes the information into a multi-grey-level picture matrix. A PDP-9 computer processes the digitized picture, transforming it into a binary picture matrix by the use of a specified threshold grey level. In Figure 16, (c) and (d) are the binary picture matrices of (a) and (b), but with the binary representations of the hail indentations replaced by rectangular boundaries tangent to the binary regions. These boundaries are only approximate, and, at this writing, do not accurately display elongated dents and pairs of touching dents for example. However, the computer is easily programmed to print out statistics on dent sizes, impact energy, etc.

The highly-reflective aluminum foil with many wrinkles and scratches, as on hailpad #1192 in Figure 16(a), created numerous shadow effects which confused the digital processing, making it necessary to try various combinations of illumination and grey-level threshold values. Using four such combinations on the same hailpad (#1192), values of impact energy[1] were 7.2, 18.9, 47.4, and 80.7 J m^{-2}, as compared with the hand-analyzed total of 204.6 J m^{-2}. Tsang's maximum value results from picture enhancement to improve the overall contrast before transformation into the binary form. The problem would probably be complicated by the wide variety of dented hailpad types.

In order to improve on these poor results, the aluminum foil was removed from a hailpad dented by large steel spheres and the styro-

[1] Impact energies were computed by the author from the values of dent diameters given by Tsang (1974).

foam inked with a roller (Figure 1 (b)). With less of an illumination problem two experiments on this pad using different grey-level threshold values, yielded impact energy values of 61.9 and 72.3 J m^{-2}, as compared with 187.5 J m^{-2} for the hand-analyzed version. These are relative errors of -67 per cent and -61 per cent. A problem when removing the aluminum foil, however, is that most dents of diameters ≤.30 inch (corresponding to shot and pea size hail) did not show up on the styrofoam, even when the pad was inked. Unless this problem can be surmounted[1], small dents will still have to be measured manually.

Most errors in this system were of two sources, both of which led to underestimates of impact energy. First, many small dents were missed, partly because of the above problem with uncovered pads, but also because there appeared to be some dent resolution problem in the system. Secondly, most dent sizes were underestimated, especially on the foil-covered hailpad. The reason for this is not obvious, but it appears to result from shadows across dents caused by the use of oblique lighting.

In spite of these difficulties, with further refinements this analysis system has the potential to make an extensive and more dense hailpad network a practical means for evaluation of hailfalls, since the whole process requires only three to five minutes per hailpad.

5.4 Hailpad Estimation of Winds

The problem of hailpad calibration for wind-blown hailstones has already been discussed in Chapter III. A major problem in the field

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[1]Preliminary 1974 tests by ALHAS indicate that sanding the styrofoam surface will alleviate some of this problem.

is how to effectively measure wind speed and direction during the few minutes that hail is falling, since the hail may not necessarily fall with the strongest surface winds. Paul (1968) gave a mean duration at a point for Alberta hailfalls of 10 minutes. It is difficult to accurately measure wind in the field with a recording anemometer and still keep the record in phase with hailfall durations of 10 minutes or less. Volunteer hail reports received by ALHAS indicate winds as light, moderate, strong or severe, but it is doubtful whether observers always estimate this wind just as hail is falling. Wind direction is not a request on the volunteer reports.

Previous hailpad wind estimates

Wind directions during hailfall were determined from hailpads by Schleusener and Jennings (1960) and by Changnon (1969). Changnon also used the hailstool (see Chapter I) to measure vertical angles of impact. More recently, Morgan and Towery (1974) used hailcubes (see Chapter I) on a one square mile network in Nebraska in 1973 and obtained estimates of wind speeds and directions during hailfall. Since hailpads had five exposed surfaces in the Alberta project (albeit, four of which were only 1 inch x 12 inches each), the author has made approximate determinations of wind speed during hailfall in addition to wind direction.

Wind direction

Visual inspection of a hailpad reveals wind direction during the hail, as long as winds had exceeded 3 m s^{-1} (> 7 mph), the hailpad was not badly damaged, and the orientation of the pad with respect to true north was known (usually fixed by reference to nearby fences and roads which run north-south and east-west). The orientation of the major axes of elliptical dents is the wind orientation but not direction (since there is an ambiguity of 180°). The true direction is then revealed by dents on one or two edges of the hailpad. If winds are less than 3 m s^{-1}, vertical impact angles are less than 10° and cannot be reliably read. Also, the two dent axes will be approximately the same.

Wind speed

Hailpad determination of wind speed during hailfall is more difficult. The vertical angle of impact of the hailstones must first be known. This can be derived from the angles of the streak-like dents made by hailstones impacting on the vertical edges of the pad. Winds must be strong enough (> 3 m s^{-1}) to cause these streaks, while hailpad edges must be undamaged and well-exposed. Also, one must be certain that the hailpad was installed reasonably level in order to obtain the horizontal component of the hailstone velocity.

Figure 17 schematically illustrates (a) a hailstone falling with terminal velocity $\vec{W}_T$, while moving horizontally with the wind speed $\vec{W}_H$, and (b) dent streaks which the hailstones make on the hailpad edges.

Assuming that the streaks corresponding to α_i and β_i were made by similar hailstones, then α_i and β_i can be considered to be components of the vertical impact angles θ_i and

$$\tan \theta_i = \frac{W_H}{W_{Ti}} \qquad (25)$$

There is no simple way (with just one hailpad) of determining what hailstone diameters make each of the angles α_i, β_i. If we suppose, however, that there is some average size hailstone which has an average

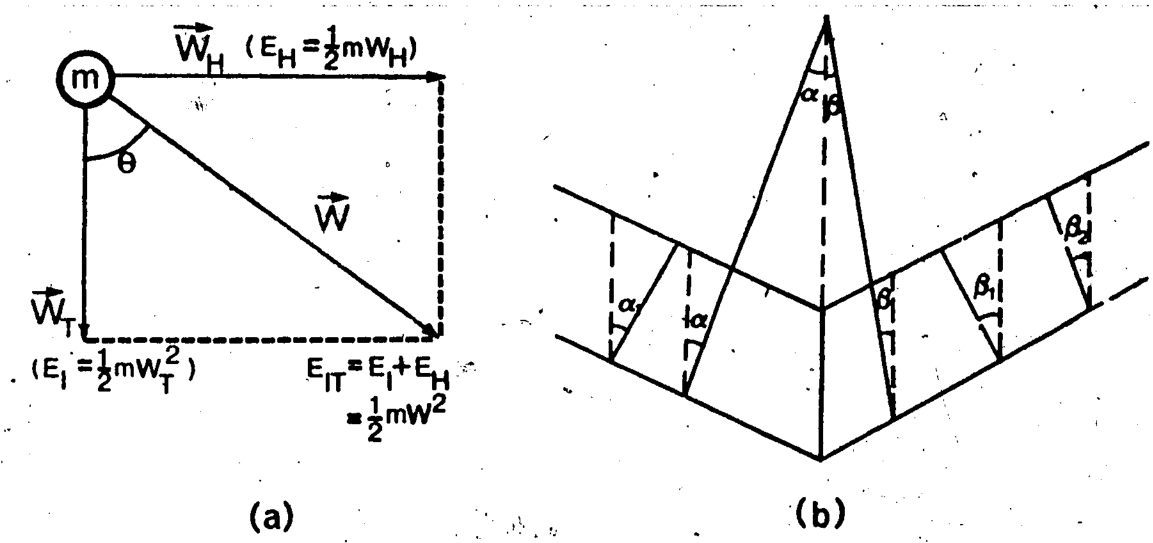


Figure 17. (a) A hailstone of mass m, terminal velocity $\vec{W}_T$, moving horizontally with a wind W_H, has total impact energy $E_{IT} = \frac{1}{2}m(W_T{}^2 + W_H{}^2)$.

(b) Two edges of a hailpad with dent streak angles $\alpha_1, \alpha_2, \ldots\ldots$ on one edge, $\beta_1, \beta_2, \ldots\ldots$ on the other. α and β represent means.

terminal velocity $\overline{W}_T$, then we can reasonably assume that two such hailstones make streak angles α and β on the two hailpad edges. Hence, the average of the α_i and β_i (usually 4-8 streaks per edge are clearly visible) will approximate α and β. These crude assumptions do not stray far from reality, since large hailstones (> .8 inch) mutilate the hailpad edge and cannot be used, while small ones (< .3 inch) rarely make visible streaks.

The remainder of the problem is one of geometry, and it can be shown (using spherical polar coordinates) that in Figure 17(b), the vertical angle of impact is given by:

$$\theta = \tan^{-1}\left[\left(\tan^2\alpha + \tan^2\beta\right)^{1/2}\right] \quad (26)$$

Substituting this into Equation 25 and re-arranging terms, the horizontal wind speed is given by:

$$W_H = \left[\frac{2E_I}{M_H}\left(\tan^2\alpha + \tan^2\beta\right)\right]^{1/2} \quad (27)$$

where we have also approximated $\overline{W}_T = (2E_I/M_H)^{1/2}$, where E_I and M_H are respectively the hailpad totals of vertical impact energy and ice mass over all sizes.

Accuracy

Taking the required precautions, the hailpad-inferred wind directions are believed accurate to 16 points of the compass. Since in almost all cases, impact angles will be measured from streaks made by hail diameters of about .3 to .8 inch, for which terminal velocities vary from 12 to 19 m s^{-1}, then Equation 27 should give wind speeds accurate to almost 5 m s^{-1} (about 10 mph)[1].

Of course, the hailcube as used by Morgan and Towery (1974) would give better results (at more cost and more effort), since one could theoretically measure the hailstone diameter D_i, which made each angle α_i or β_i. The method described, however, though a rough and ready one, accords far more confidence in the wind speed obtained than that estimated by a volunteer using ears and eyes as instruments.

Not all of the 761 hailpads were analyzed for winds because of the lack of time and manpower. But some results, where nearby wind

[1]In a few instances, $\overline{W}_T$ was as low as 10 and as high as 22 m s^{-1}.

anemometer data were available for comparison, verify the validity of the approach described. These will be discussed in Chapter VI.

CHAPTER VI

RESULTS

"A most terrifying storm. It kept going back and forth over the house for four hours. I was too frightened to get up and look."
.... Anna Jensen, July 23, 1973.

"A few as big as golfballs. Heavy wind at first; later nothing."
... Mrs. E. Gillund, August 16, 1973.

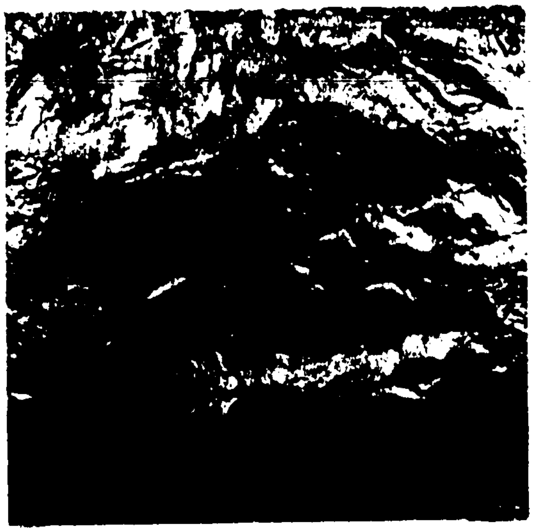
"Hail was too soft and light to cause any damage."
Mrs. M. Radford, August 23, 1973.

Four typical hail-dented hailpads from this 1973 study are shown in the photographs of Figure 18. A summary of data for all 761 hailpads appears in Appendix V.

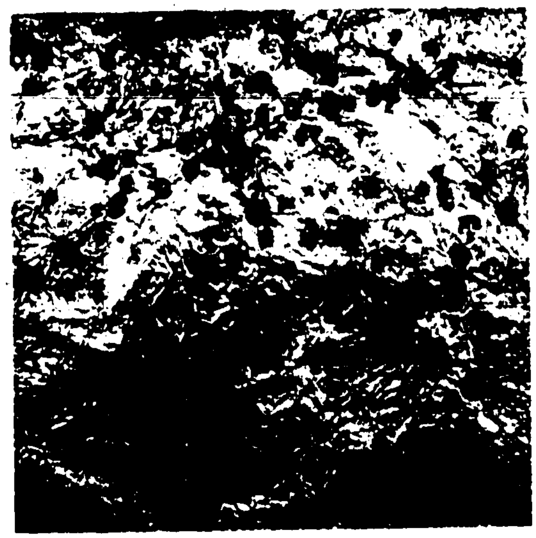
6.1 Comparative Summary of the Two Main Networks

The major hailswaths of 1973 in Central Alberta (as derived from hail card reports) are shown in Figure 19 (after Meheriuk, 1974). The two hailpad networks were favourably located for most of these storms, most of which tracked from west to east. Several hailswaths of only small hail were also well sampled.

A total of 17 hailstorms struck the two networks. These are summarized in Table 13, showing the maximum and mean values of several

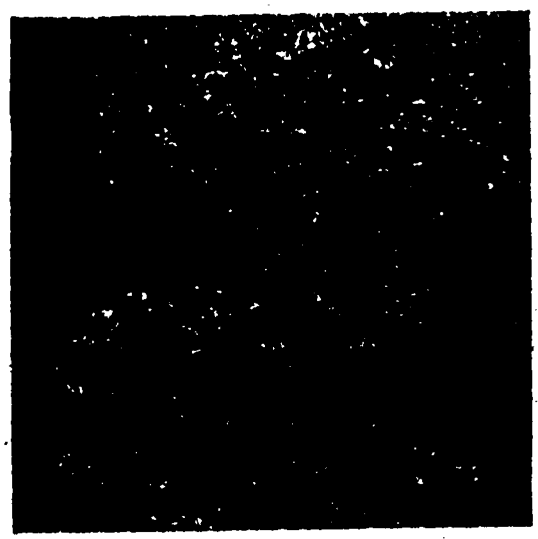


HAILPAD #2651, Site G76; 16/Aug/73.
$D_H(max) = 2.0$ cm; $M_H = 160$ g m^{-2};
$E_I = 21$ J m^{-2}; Wind SW/light.



HAILPAD #1656, Site G1; 16/Aug/73.
$D_H(max) = 2.0$ cm; $M_H = 1458$ g m^{-2};
$E_I = 164$ J m^{-2}; Wind Calm.

HAILPAD #2621, D.N. X10; 16/Aug/73.
$D_H(max) = 3.8$ cm; $M_H = 5256$ g m^{-2};
$E_I = 993$ J m^{-2}; Wind W/56 mph, $\theta = 52°$.



HAILPAD #2003, Site Q4; 24/Aug/73.
$D_H(max) = 1.3$ cm; $M_H = 2860$ g m^{-2};
$E_I = 182$ J m^{-2}; Wind NNE/light.

Figure 18. Four 1973 hail-dented hailpads with measured values of maximum hail size, hail mass, impact energy, and wind.

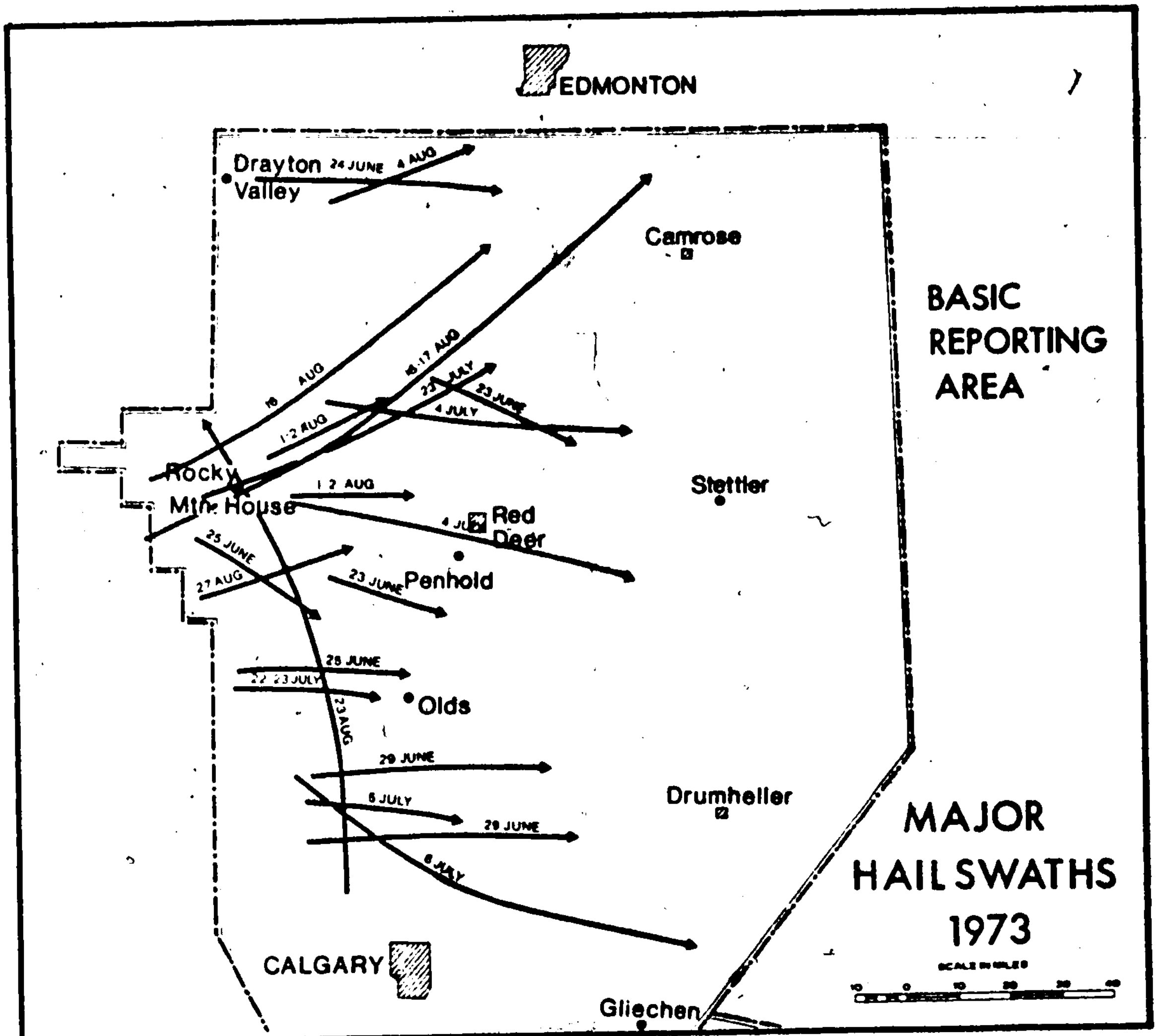


Figure 19. The major hailswaths (with walnut or larger hail) of 1973 in Central Alberta, (after Meheriuk, 1974).

parameters for each storm. It must be emphasized here that these values represent only the hail which fell on the networks, and that in several cases, much more damaging hail occurred outside (June 29 being a good example).

The mean values were based on the number of hail-dented hailpads only, rather than on all of the pads exposed throughout the network, while each pad had equal weight in the averaging. Also rain

Table 13. Summary of 17 Alberta hailswaths by date for the two main hailpad networks, dense network data not included; June 20 to August 28, 1973.

DATE	No. of hailpads	No. of hail-stones per pad		Max. Diam. (cm) per pad		Hail Mass ($g\ m^{-2}$)		Impact Energy ($J\ m^{-2}$)		Mass Ratio RAIN/HAIL
		Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	
SOUTHERN NETWORK:										
1 June 25	32	1350	201	1.8	.95	965	221	74	15.1	30.1
2 June 29	27	4608	1078	1.5	.73	2814	698	129	33.3	54.7
3 July 05	23	1713	590	1.3	.77	2033	549	140	31.7	3.9
4 July 06	26	3280	978	1.3	.73	2340	758	161	40.4	5.1
5 July 15	16	268	83	1.1	.75	302	82	19	4.9	21.7
6 July 22/23	55	7981	1794	2.5	1.11	17148	2045	1790	141.2	20.4
7 Aug. 23	54	1278	287	3.7	1.14	3799	401	826	38.8	34.6
8 Aug. 24	19	2606	961	1.3	.84	2860	787	182	42.7	14.7
9 Aug. 27	16	1655	558	1.6	.80	1630	448	93	24.4	11.7
Network maxima and means	268	7981	805	3.7	.94	17148	801	1790	53.2	26.6
NORTHERN NETWORK:										
1 July 04	41	1313	327	3.5	1.20	3008	540	439	46.7	19.7
2 July 15	32	1283	323	1.6	.91	1471	326	90	19.9	13.2
3 July 18	10	1331	437	1.2	.76	1414	361	95	20.0	33.2
4 July 23	75	1494	353	2.5	1.17	3595	517	450	41.9	18.4
5 Aug. 01/02	67	2352	521	3.3	1.20	3950	805	423	63.7	29.2
6 Aug. 0[illegible]	16	855	224	1.3	.88	529	188	28	10.6	58.4
7 Aug. 16	66	5535	738	5.2	1.98	10286	1741	1541	215.3	11.8
8 Aug. 23	32	4079	513	1.5	.87	3208	419	167	23.1	36.8
9 Aug. 27	14	1790	494	1.2	.81	1212	392	76	21.3	—
Network maxima and means	353	5535	467	5.2	1.24	10286	752	1541	72.4	20.0

amounts (which could have been measured or just estimated) were available at only 40 per cent of the hailpad sites, so that the mass ratios of rain to hail are based on values only at those sites. The following facts from Table 13 are worth pointing out:

(1) Rain mass outweighed hail mass in these hailstorms by a factor of 20-25. Much of this rain, however, may have resulted from the larger synoptic-scale system involved, since most volunteers do not check rain amounts until all precipitation has ended (personal communication with farmers).

(2) The Southern Network, where 'most' cloud seeding was carried out, received on the average, almost twice as many hailstones per unit area (about 800 ft^{-2}) as the Northern Network, but maximum sizes tended to be smaller.

(3) Average hail mass per unit area (where hail occurred) was about the same in both networks, but the Southern Network received a greater ratio of water mass to ice mass (27 to 20).

(4) The mean impact energy for the Northern Network was about 50 per cent higher than that for the Southern Network, a result of similar average hail masses, but relatively larger hailstones in the Northern Network.

It is tempting to use the data of Table 13 to consider the implications of hail suppression. One must be cautious, however, since not all of the Southern Network storms were seeded, nor were all the Northern Network storms left unseeded. In fact, the mere omission of data from the storm of August 16 from the Northern Network, drops the mean impact energy below that of the Southern Network. The evaluation of hail suppression will therefore be given limited treatment in a later discussion.

6.2 Hailfall and Crop Damage

Sensitivity of the hailpad

One of the major reasons for interest in the hailpad is to physically relate hailfall parameters to crop damage. Previous attempts by ALHAS to do this have relied on the calculation of impact energy from the information on hailstone size and spacing given on the volunteer hail report cards. The volunteer reports, however, tend to overestimate hail size and numbers in moderate to severe hailstorms, and underestimate the smaller storms. This conclusion rests on comparisons of hailpad data with a volunteer's hail card report at the same time and location. Another example of this is in the range of values of impact energy that Wojtiw and Renick (1973) obtained from hail cards; namely 10^{-2} to 10^5 J m^{-2}. On the other hand, the range of sensitivity of the hailpad in 1973 was 10^{-1} J m^{-2}, representing only 5 shot size hailstones on a hailpad, to 2×10^3 J m^{-2}, representing the whole spectrum of hail sizes up to golfball and larger. This maximum value resulted in shattered vehicle windows and holes in some barn roofs. Moreover, hail impacting with an energy of only 10^{-1} J m^{-2} would unlikely be seen on the ground after impact, even by the most trained observer, while 10^5 J m^{-2} would result in the ground being more than covered by golfball and larger hailstones only, a most unlikely situation. Thus the extremes of 10^{-2} and 10^5 J m^{-2} do not appear to be realistic.

Scatter graphs

Many hail-dented hailpads were accompanied by the volunteer's hail report card[1] which also usually included the farmer's estimate of crop damage. The various hail parameters were compared with these rough estimates[2] of per cent crop damage. Figure 20 shows the relation with impact energy, though considerable scatter is evident. Other graphs of crop damage vs. impact momentum, hail mass, and maximum hailstone size, showed as much or more variation.

There are several reasons for the scatter in these relations:

(1) Estimates of crop damage are made by farmers within hours of hail occurrences, often before they can properly assess damage, in order to prepare prompt hail reports.

In addition, because of lack of data, Figure 20 does not take into account

(2) different crop types[3],

(3) the time in the growing season,

(4) different soil types,

(5) local climatic differences,

(6) different farming methods,

and (7) differences in hailfall other than impact energy.

(8) It is quite possible that the farmer's damage estimate is not representative of damage at the hailpad site, but at another

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[1] Much of the light hailfall on hailpads goes unnoticed by the farmer, so that a hail report card was often missing.

[2] Crop insurance statistics by land location were not available in time for this dissertation.

[3] The major crop types in the hailpad network areas were barley, oats and rape.

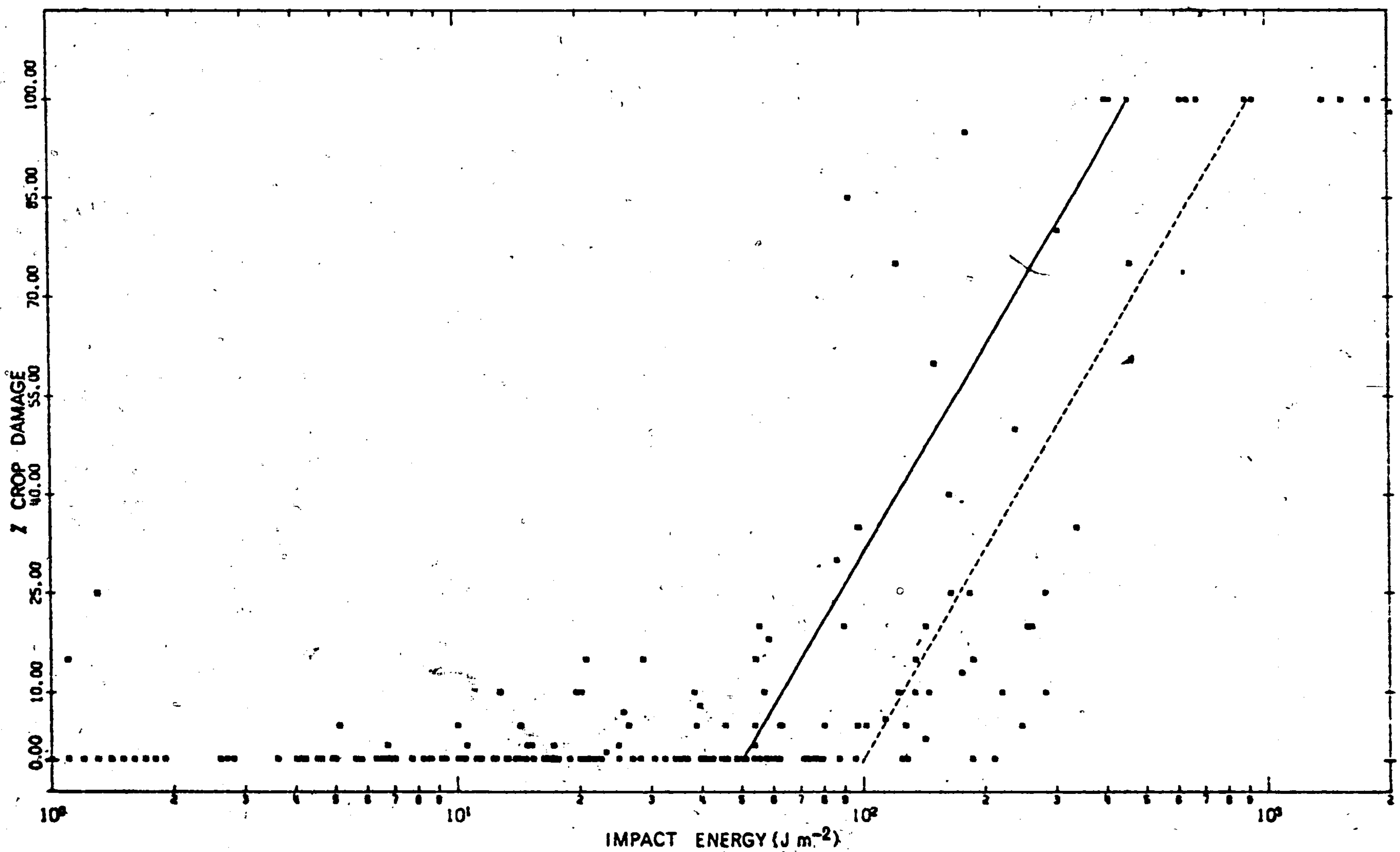

Figure 20. Impact energy vs. per cent crop damage.

location on his farm. It could also be an average estimate for all of his farm.

Critical value of impact energy

On this scatter graph there appears to be a critical value of impact energy above which crop damage is always 100 per cent. Thus, with better damage assessment, an exponential type curve could probably be drawn to approximate the energy-damage relation, stopping abruptly at the 100 per cent crop damage line. This critical value appears to lie around 450 J m^{-2}. There is also some basis for setting a minimum value, below which damage is negligible (i.e., not enough damage for one to be able to measure). This lies near 50 J m^{-2} so that in view of the large scatter, a straight-line relation is a reasonable compromise. Better relations must include more accurate estimates of crop damage.

It is interesting to note that 50 J m^{-2} could result from about 1800 shot size hailstones hitting a hailpad, covering a cross-sectional area on the ground of about 35 per cent of the pad area, or, by about 10 grape size hailstones which will cover an area of <5 per cent of the area of a hailpad. Hence, neither will do much damage if they fall with little or no wind, because the shot sizes are too small (D < .20 inch), while there are not enough of the grape size stones.

Damage and 'total' impact energy

The only extensive wind information available was the approximation given by volunteers on the hail report cards; i.e., light (0-10 mph), moderate (10-25 mph), strong (25-40 mph), and severe (>40 mph). Using values of 2.25, 7.85, 14.5, and 20.1 m s^{-1} respectively for the means of these estimates, 'total' values of impact energy were computed and plotted against crop damage estimates. Because of the uncertainties of the wind information, scatter was not significantly improved. Also, since wind estimates were available for only about 50 per cent of the hailpad data, total energy values are not included in the data summaries.

Table 14 gives suggested critical values for negligible damage and 100 per cent damage for several hail parameters, all based on the scatter graphs. It is interesting to note that a linear relation between total impact energy and per cent crop damage given by Hagen and Butchbaker (1967), also suggests a critical value for 100 per cent damage of about 800 J m^{-2}.

Table 14. Suggested critical values of hail parameters for negligible and 100 per cent crop damage.

Parameter	Critical Value for Negligible Damage (≤ 5%)	Critical Value for 100% Damage
Hail Mass (kg m^{-2})	0.5	4.5
Impact Momentum (kg m s^{-1} m^{-2})	10	60
Impact Energy (J m^{-2})	50 *	450
TOTAL Impact Energy (J m^{-2})	75	800

* Significant damage (≥ 10 per cent) probably starts around 100 J m^{-2}.

Although it has been shown that the hailpad is sensitive to values of impact energy[1] between 0.1 and 2000 J m^{-2}, the main range of

[1]At values near 2000 J m^{-2}, the hailpad begins to break up.

interest, insofar as most crop damage is concerned, is between 50 and 450 J m^{-2}. This is also the most accurate range for the hailpad, since it lies above values where very small and very few dents might be suspect, and below values where multiple dents might become plentiful and lead to underestimates.

Distributions of energy values in Illinois, North Dakota and Central Alberta

In Table 15 the distribution of impact energy for the 761 hailpads of the Alberta network is compared with those found in North Dakota in 1966 (Hagen and Butchbaker, 1967), and in Illinois in 1971-72

Table 15. Comparison of hail intensity distributions in Central Alberta, North Dakota (Hagen and Butchbaker, 1967), and Illinois (Changnon and Towery, 1972).

Range of Impact Energy (J m^{-2})	Number of Hailpads in Range	Per Cent of Total Number of Hailpads		
		Central Alta. (a) 1973	No. Dakota (b) 1966	Illinois (c) 1971-72
0.1 - 50	514	67.5	-	-
50.1 - 100	105	13.8	-	-
100.1 - 146	46	6.1	-	-
0.1 - 146	665	87.4	83.0	75.2
146.1 - 292	41	5.4	8.7	9.2
292.1 - 450	15	2.0	3.7	11.3 (292.1 - 1000)
450.1 - 1000	33	4.3	4.0	
> 1000	7	0.9	0.6	4.3

(Changnon and Towery, 1972)[1]. The unusual energy intervals result from the conversion of units from ft lb ft^{-2} as used in the comparative studies.

When Tables 14 and 15 are compared, it would appear that about 68 per cent of the hailfalls recorded in Central Alberta caused negligible damage in 1973. Eighty-one per cent were in the nil to light damage class (≤ 100 J m^{-2}), while 27 per cent were in the critical region of 50–450 J m^{-2} (a relatively small range of values where a small change either way in the hailfall pattern means the difference between nil or complete damage). More than 5 per cent of the hailfalls would appear to be 100 per cent wipe-outs (> 450 J m^{-2}).

On comparison with the other studies, Central Alberta received a greater percentage of light hailfalls with 87.4 per cent being ≤ 146 J m^{-2} (10 ft lb ft^{-2}) compared with 83.0 per cent for North Dakota, and 75.2 per cent in Illinois. The higher percentage in Alberta may be a real climatological difference, or it may mean that a more sensitive combination of styrofoam and aluminum foil was used. The minimum value in Hagen and Butchbaker's data was 5 J m^{-2} (.34 ft lb ft^{-2}), compared with 0.1 J m^{-2} for both Illinois (Changnon, 1969) and Alberta data.

Network dimensions for the three networks under comparison, along with hailpad returns are shown in Table 16. This table gives a rough idea of hail incidence in the three areas. Central Alberta yielded a return of 2.4 hailpads per site per season for the main networks, compared with 2.1 for North Dakota and 2.0 for Illinois.

[1] Changnon's (1969) and Changnon and Towery's (1972) published values of impact energy were a factor of 10^2 too low (personal communication), and hence have been corrected by this factor.

Table 16. Comparison of hailpad networks and hail-dented hailpad returns in Alberta (1973), North Dakota (1966), and Illinois (1971-72).

Network	Number of Hailpad Sites	Coverage Area (mi^2)	Number of Hail-dented Hailpads	Number per Site per Season	Remarks
Central Alberta**	272	1620	662	2.4	Main Networks only
North Dakota	155	2400	319	2.1	Area approx.
Illinois*	232	800	913	2.0	

* Includes two years of data including dense networks.
** Data for two months only, June 20 - August 27.

6.3 Impact Energy Analysis of Hailswaths

Armed with a general understanding of the relation between degree of crop damage and hailfall intensity, individual hailswaths can now be discussed in more detail.

Preparation of maps

Values of impact energy were plotted on network maps for each hail day, and isopleths were drawn for 0, 25, 50, 100, 200, 400, and 800 J m^{-2}. For energies > 800 J m^{-2}, gradients were found to be too high for resolution with the station spacing of 2.4 to 2.8 miles. Contour smoothing was minimal, and never at the expense of violating a station value of impact energy.

The zero ('hail or no hail') contour was always well-defined by the many hailpad returns having nothing more than rain dents. Two other important contours are 100 J m^{-2}, considered to usually delineate where 'significant' crop losses start, and the 400 J m^{-2} contour (close enough to the suggested critical value of 450), which should enclose areas of almost complete crop losses. Regions enclosed by this contour are shaded for emphasis on all main network maps.

The hailstorms of August 16 and August 23/24 will be discussed in some detail, as more data, including that of the dense networks, were available for these. Impact energy maps for the other 14 hail days of this study appear in chronological order with brief descriptive notes in Appendix IV.

<u>August 16</u>

The meteorological conditions for this storm were typical of severe Alberta hailstorms; i.e., an unstable temperature lapse rate, a southwesterly flow at 500 mb with slight cooling, a light southeasterly flow at low levels, strong surface heating, low-level moisture remaining from morning stratus, and to trigger the instability, a frontal wave and cold front which intensified over southeastern British Columbia during the morning. The wave and cold front are clearly evident in the cloud-cover satellite photo of Figure 21.

This system spawned two major groups of thunderstorm cells southwest of Rocky Mountain House, which subsequently tracked northeastward as depicted in the hailswath map of Figure 19. Two resulting hailswaths gave the pattern of impact energy shown in Figure 22. Hail began falling during the early evening of the 16th, and continued until after midnight, lasting more than 20 minutes at some locations.

Figure 21. Satellite cloud photo of 1927 GMT, August 16, 1973 showing a strong baroclinic zone with a wave in British Columbia, about 5-6 hours before the first reported hail occurred in Central Alberta. Photo, courtesy of University of Alberta Meteorology Division. Computer program for latitude and longitude gridding by Dennis Oracheski.

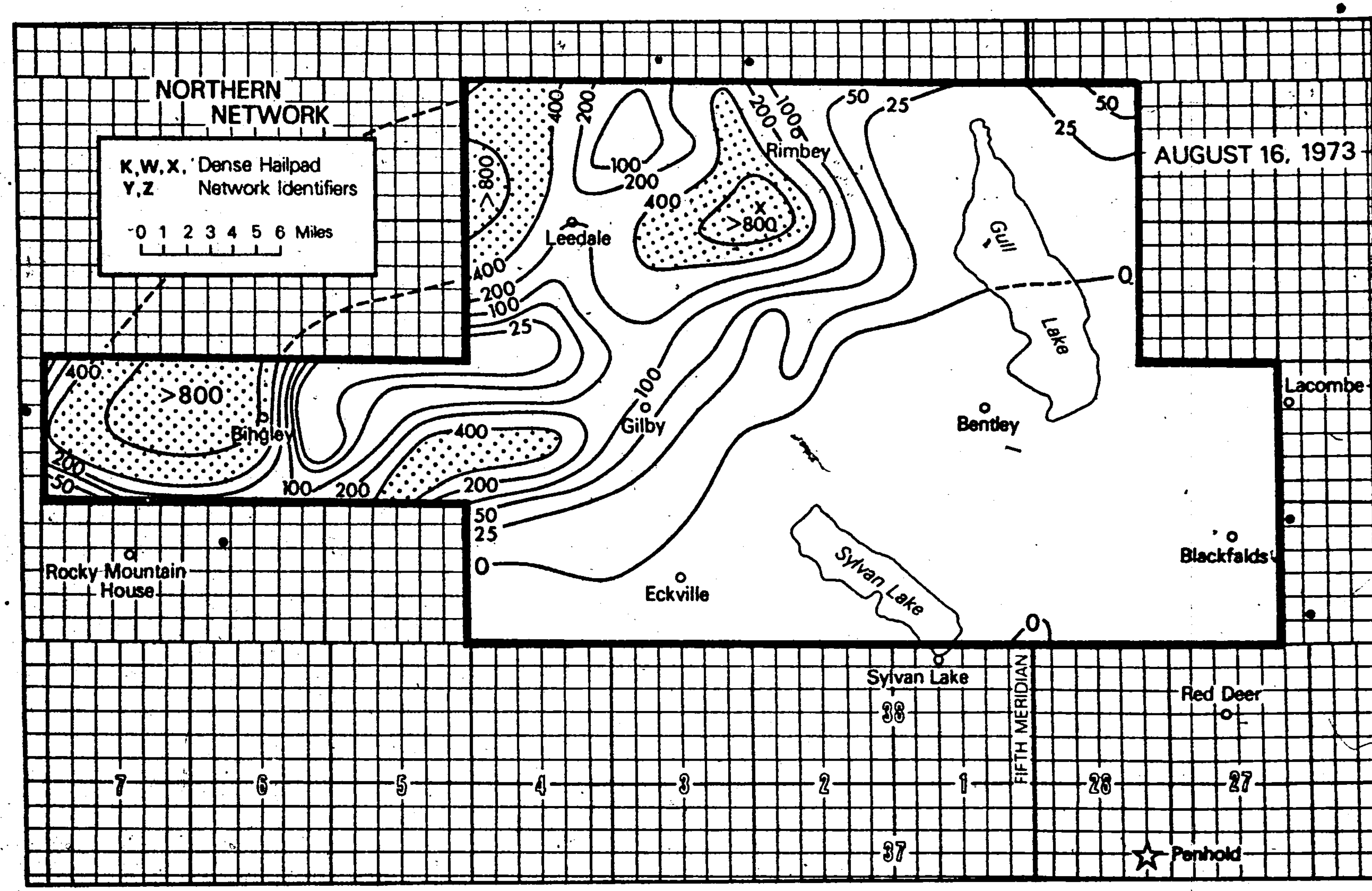

Figure 22. Pattern of impact energy (J m^{-2}) over the Northern Network on August 16, 1973.

The first of these hailstorms all but missed the Northern hailpad Network, but the second, following a path about 10 miles further southeast, was well-documented by hailpads, and the center of it passed directly over Dense Network 'X' DNX. From the relation of impact energy and crop damage, it would appear that the second storm alone, which was the smaller of the two, could have caused 100 per cent crop damage to at least 40 square miles in the main network. Because the 800 J m^{-2} contour encloses DNX, it appears as if all the energy values of this land section are > 800 J m^{-2}. The gradient of energy, however, is too great to put confidence in this inference.

Dense network 'X', August 16

The fine-scale features of DNX appear in Figure 23, portraying both values (upper right of site symbol) and contours of impact energy, and also the number of golfball and larger size hailstones per hailpad (in parentheses below the symbol). The most noticeable aspect of this map is the wide variation in impact energy, from 441 to 1956 J m^{-2}, with 12 of the values less than 800 J m^{-2}. The mean and standard deviation of all 27 values are 879 and 401 J m^{-2} respectively. A transparent overlay of the topographical features for Figure 23 is contained in a pocket on the inside back cover. This overlay also shows site numbers.

The energy value at Site X1 (hailpad #2525) on August 16 was the highest recorded value of all 1973 data, making it worthy of special mention, although information from it contains more uncertainty than other values as this hailpad had been shattered and the foil torn to shreds. It was pieced together like a jigsaw puzzle, and dents were measured on the styrofoam surface, a task requiring more than 8 hours

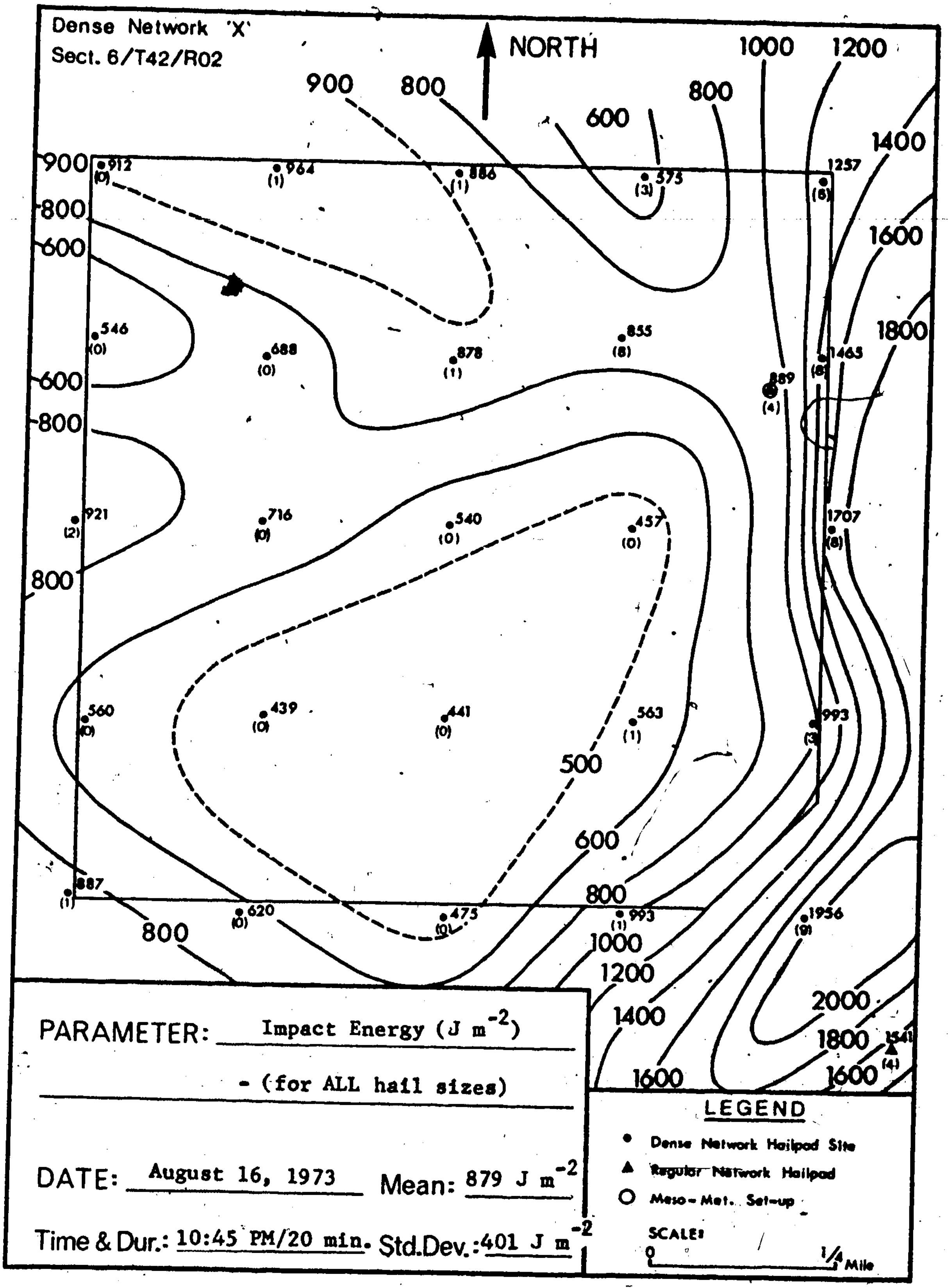

Figure 23. Pattern of impact energy for 'all hail sizes' over the northern dense network, DNX, on August 16, 1973.

of continuous work. Because dent diameters ≤ .30 inch (all shot and pea sizes) do not all show up on the styrofoam, these were averaged from the four surrounding hailpads, H77, X2, X9, and X10. This is not considered serious since the relative contribution of these was only 6.5 per cent of the total impact energy on X1. The effect of taking measurements from the styrofoam rather than the foil, probably is a slight underestimate of impact energy, and if this is done often enough, the hailpad should be calibrated accordingly.

Small pieces of several other hailpads were also broken off during this storm, but all were accounted for. Several others had holes completely through the styrofoam, but such occurrences were rare and only happened with hailstone diameters > 4 cm.

Because of some mutilated pads such as these, great care had to be taken in analyzing the August 16th hailpads. A further problem resulted because many hailstones impacted at 40 to 60 degrees from the vertical in winds > 40 mph (indicated at meso-meteorological Site G73, at several climatological stations, and by the hail report cards). Thus, all of the dense network pads were analyzed by the author, randomly and at different times to avoid bias. All of the main network hailpads of this storm were also analyzed by, or carefully checked by the author.

The original intention for the dense networks was to test the representativeness of a hailpad for a large area (1 ft^2 per 6 mi^2). In view of this, it is reasonable to ask whether the pattern of Figure 22 is due to large hailstones randomly hitting some hailpads but not others. This would put the representativeness and therefore usefulness of the hailpad in doubt. Indeed, the pattern of golfball and larger hailstones whose contribution to total impact energy ranges as high as

49 per cent (Sites X1 and H77) appears to suggest just this.

This problem was investigated further by examining the energy pattern of various ranges of the hailstone size spectrum. Figure 24 displays the energy pattern over DNX, but excludes golfball and larger sizes, while Figure 25 is the pattern without any walnut or larger size hailstones. Patterns of both impact energy and hail mass over DNX on August 16 were inspected for all size ranges, including shot and pea sizes alone, grape size, and so on. Throughout this size spectrum, the hailfall patterns were basically the same as in Figures 23-25, with a section centre minimum, and maxima near the southeast, southwest, and northwest corners of the section.

Having discounted one possible cause for the fine-scale pattern, the next step might be to suspect an exposure problem, especially since the hail fell at 40-60 degree angles from the vertical. A quick look at the topographical features of DNX (overlay, back cover pocket), quickly discourages this notion also, since the large region of minimum energy, for example, occurs in an open field. In fact, were exposure a problem at all, then some high values such as at Sites G73 and X20, might even be suspected of being slightly low because of lines of trees just to the west. It is reasonably certain then, that this pattern is a result of fine-scale features of the hailfall.

Concerning hailpad representativeness, we note that individual values of energy on this one square mile, varied by more than a factor of 2 from the mean. Thus, even with one mile spacing, errors of more than 200 per cent are possible.

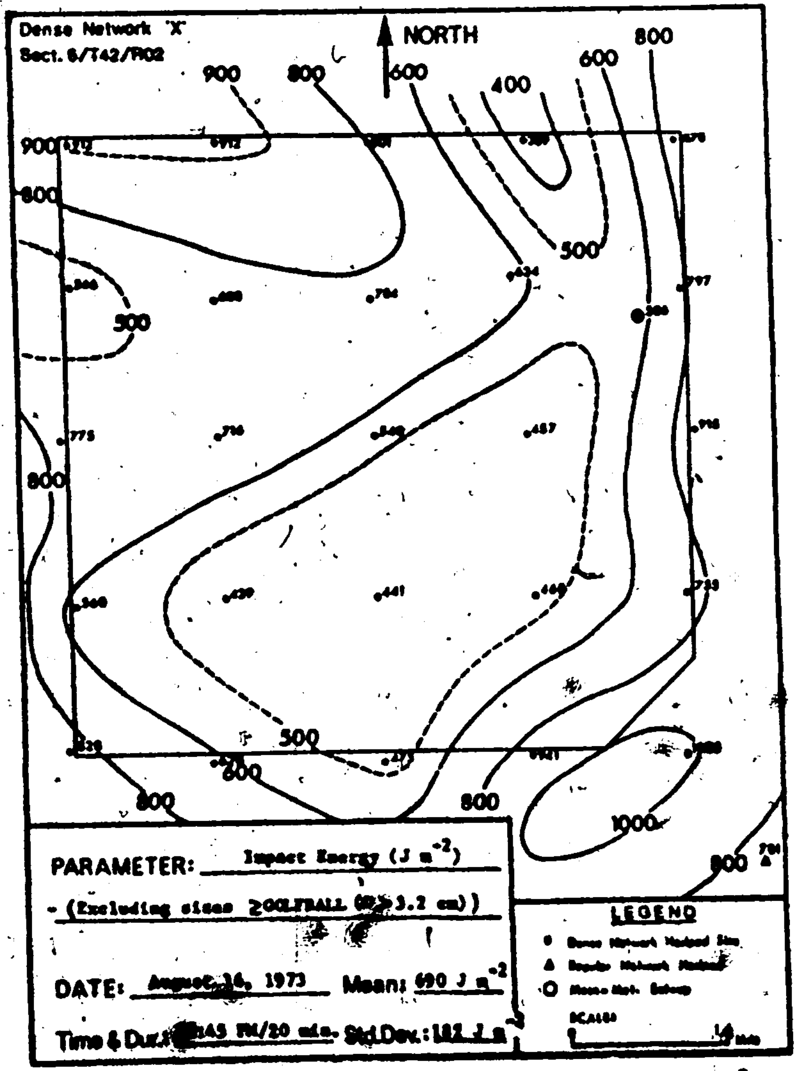

Figure 24. Pattern of impact energy (J m^{-2}) over DNX on August 16, 1973, EXCLUDING the contribution to energy by sizes ≥ GOLFBALL.

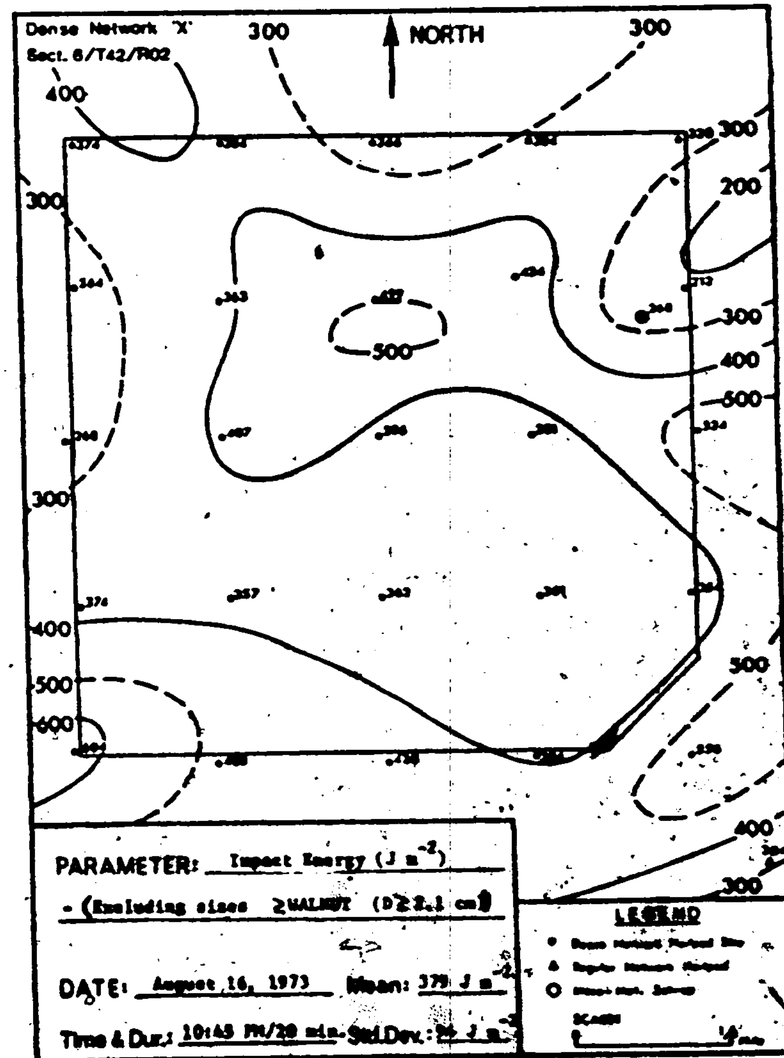

Figure 25. Pattern of impact energy (J m^{-2}) over DNX on August 16, 1973, EXCLUDING the contribution to energy by sizes ≥ WALNUT.

August 23 and 24, Southern Network

The August 23rd hailstorm was an exception for the summer in that it was the only one not following the usual west to east track of most Alberta hailstorms. Instead, developing northwest of Calgary during mid-afternoon (Figure 19), it moved north-northwest across parts of both hailpad networks.

Over the Southern Network (Figure 26), hail was confined mainly to the western edge, except for a minor swath in the eastern portion[1], while damaging hail occurred on the northwest corner of the network, and likely west of there, between 1700 and 1800 MDT.

Two smaller hailswaths resulted from basically the same synoptic system some 10-15 hours later on the 24th, as shown in Figure 27. The most southerly of these two storms occurred between 0400 and 0600 MDT, but ended halfway into the network. The second, occurring between 0700 and 0900 MDT, moved east-northeast, barely skirting DNZ and DNW by only 1/2 to 1 mile, these already having recorded hail on the previous evening. These hailpads, serviced by the author, were not removed until two days later. However, due to the timely changes of the main network hailpads between the two storms by the volunteer operators, an analysis problem was avoided since it was then known that the dense network hailpads had not recorded two storms. For the main networks, since volunteers had been told early in the summer that hailpad operations would cease on August 20th, half a dozen or so hailpads were left unchanged between the storms of August 23rd and 24th. Missing

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[1]The minor hailfall occurred at about the same time as that in the western part of the network, at about 1800 MDT.

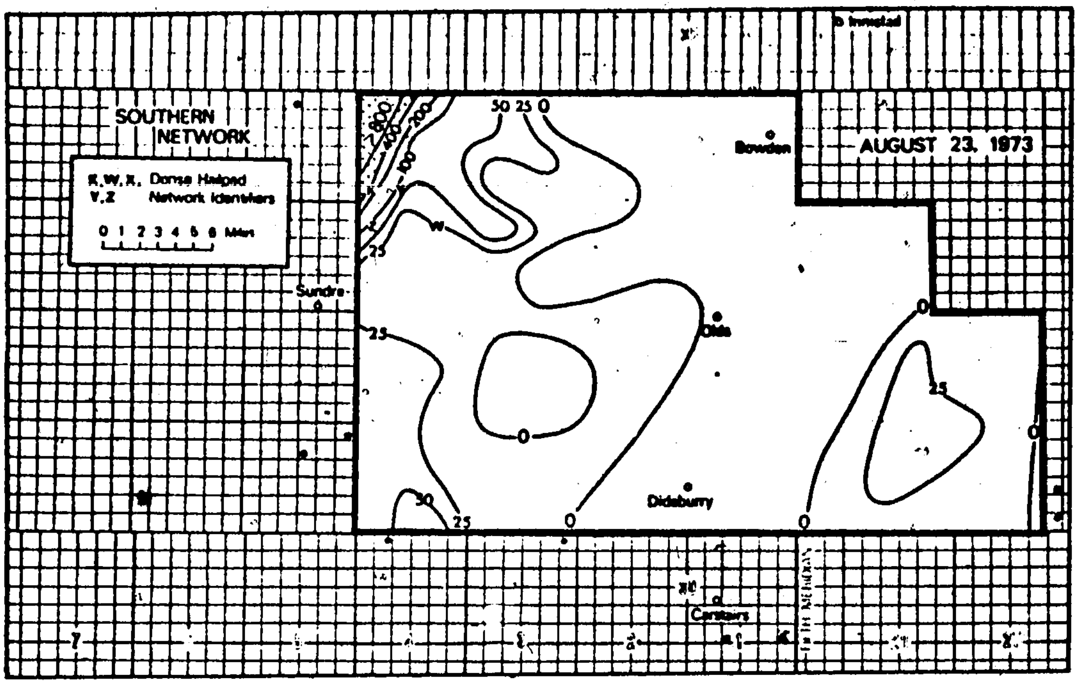

Figure 26. Pattern of impact energy (J m^{-2}) over the Southern Network, August 23, 1973.

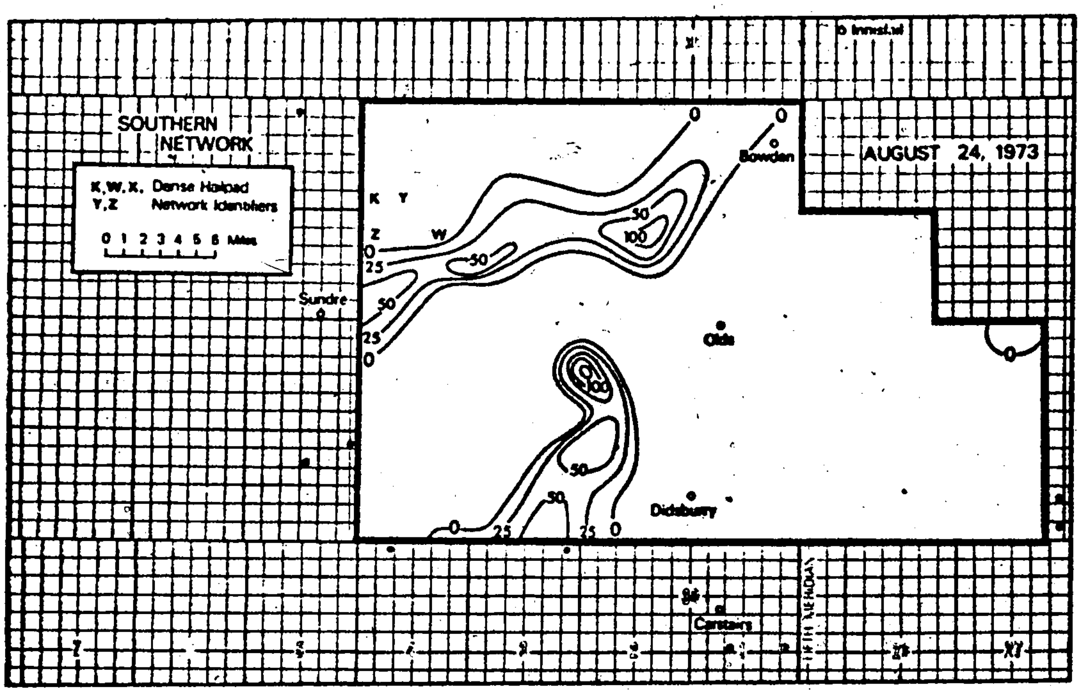

Figure 27. Pattern of impact energy (J m^{-2}) over the Southern Network, August 24, 1973.

and confused data did therefore create some problems for these two main network analyses.

Southern dense networks, August 23

The impact energy patterns across the dense networks DNK, DNY, DNZ, and DNW in Figure 28, do not appear to have the isolated regions of maximum and minimum energy that were observed over DNX on August 16th. In this case, the maximum of the large-scale map (Figure 26) is well northwest of the dense networks, and the dense networks exhibit instead a gradient of energy increasing from south-east to northwest. Some pads in these networks were destroyed by grazing animals. A minor exposure problem befell the three most southeasterly hailpads of DNY, which were sheltered by trees in a south-southeast wind of about 10 mph. Hence, the trough of relatively low values in the centre of Figure 28 is probably over-pronounced, though the trough does exist, even on the large-scale pattern.

August 23, Northern Network

As the August 23rd storm approached Rocky Mountain House (Figure 19) it may have split, as one cell or group of cells is known to have tracked northwest from there, while the pattern of impact energy, Figure 29, shows a ridging of contours towards the northeast, and suggests a second ridging out of this one towards the north or northwest. Note that an energy maximum is centered just southwest of DNX once more.

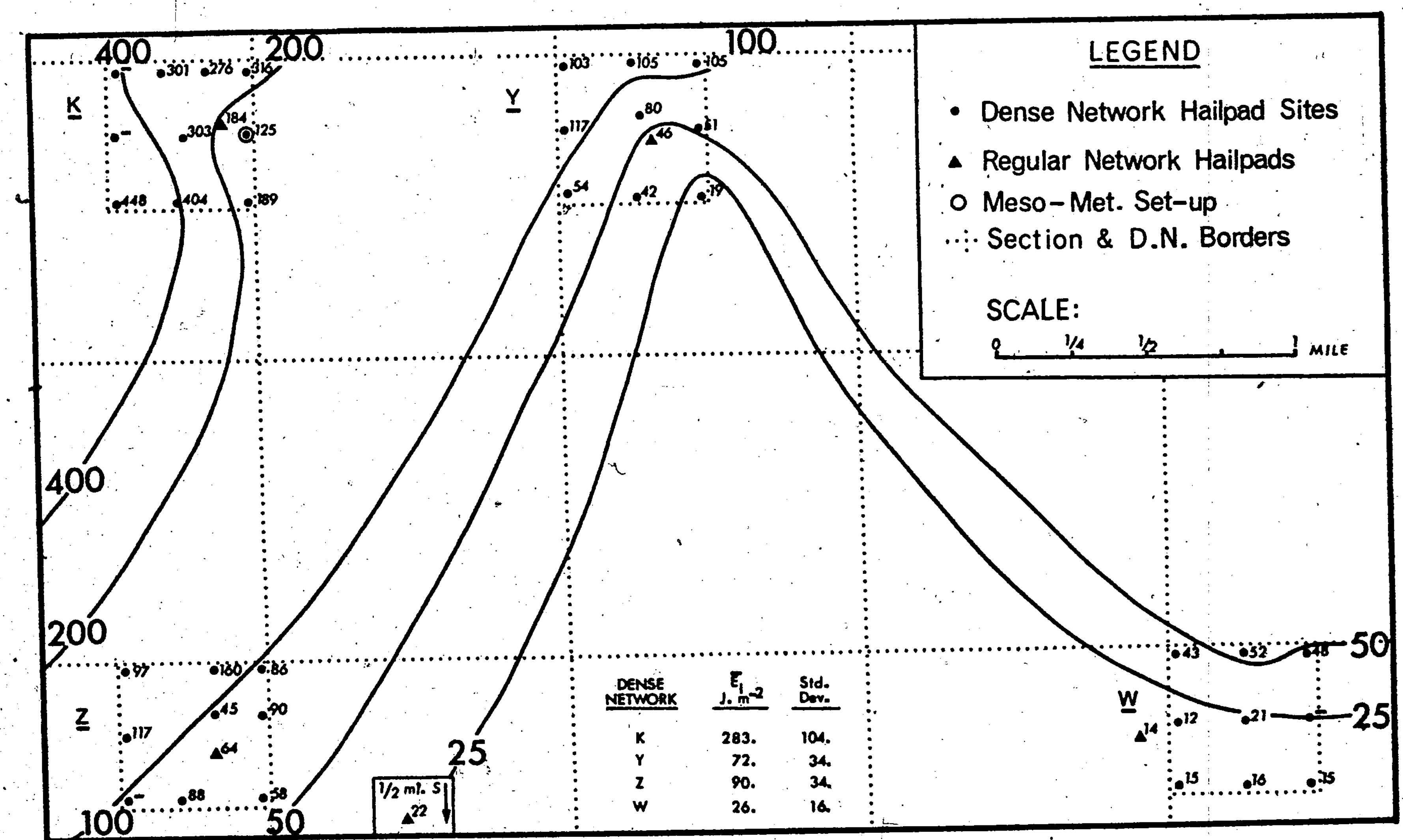

Figure 28. Pattern of impact energy (J m^{-2}) over the southern dense networks, August 23, 1973.

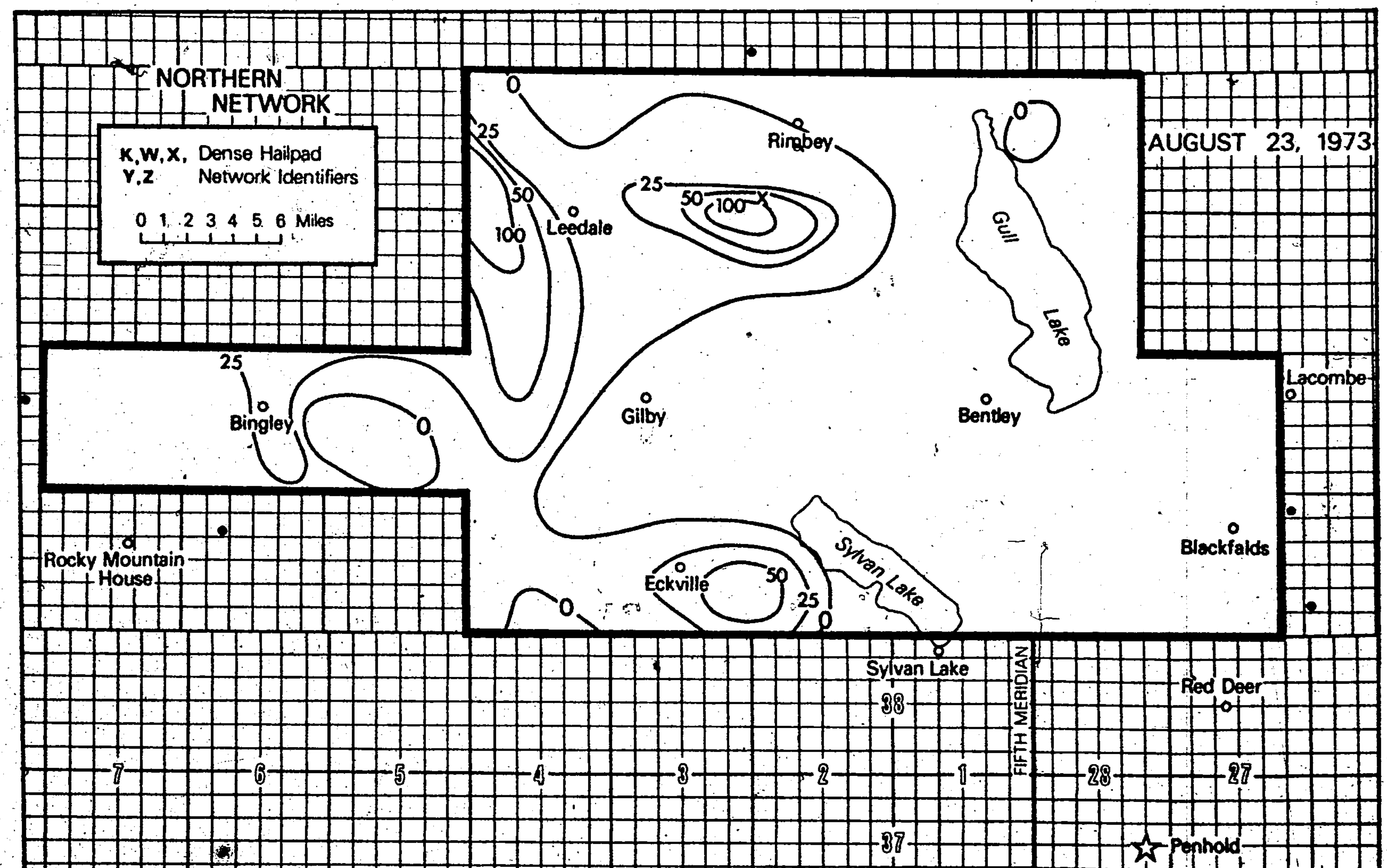

Figure 29. Pattern of impact energy ($J\ m^{-2}$) over the Northern Network, August 23, 1973.

Dense Network 'X', August 23

With this maximum of the main network pattern occurring near DNX much as it did a week earlier, the pattern of Figure 30 is similar to that of Figure 23. The August 23rd map suggests that the main energy peak (apparently more than 200 J m^{-2}) occurred southwest of the dense network. But in addition, a secondary peak (> 175 J m^{-2}) appears in the centre of the land section. Note that with the same (hailpad-inferred) wind directions (west to west-northwest, though not nearly so strong), the energy pattern is the reverse of the previous week; i.e., a maximum on the 23rd where there was a minimum on the 16th. This indicates once again that poor hailpad exposure is not a significant factor in these patterns. It is also noteworthy that on August 23rd, energy values differed by almost two orders of magnitude across about one mile, from 4 to 194 J m^{-2} (Sites X22 and X5).

6.4 Other Hailpad Results of this Study

Hailswath dimensions and network design

Dimensions of hailfall coverage were examined primarily to help solve problems of future network design. The 1973 networks were too small to yield any adequate data on hailswath length, but the width of many swaths could be measured. The distances between energy maxima were also measured, and mean distances were obtained for each map. Table 17 presents a summary of this study.

An average spacing between maxima of 12.4 miles implies that station spacing should be no more than half that distance, or 6 miles, in order to resolve the general hailfall pattern. This would detect the area of coverage of most Alberta hailswaths, which were from 5 to 20

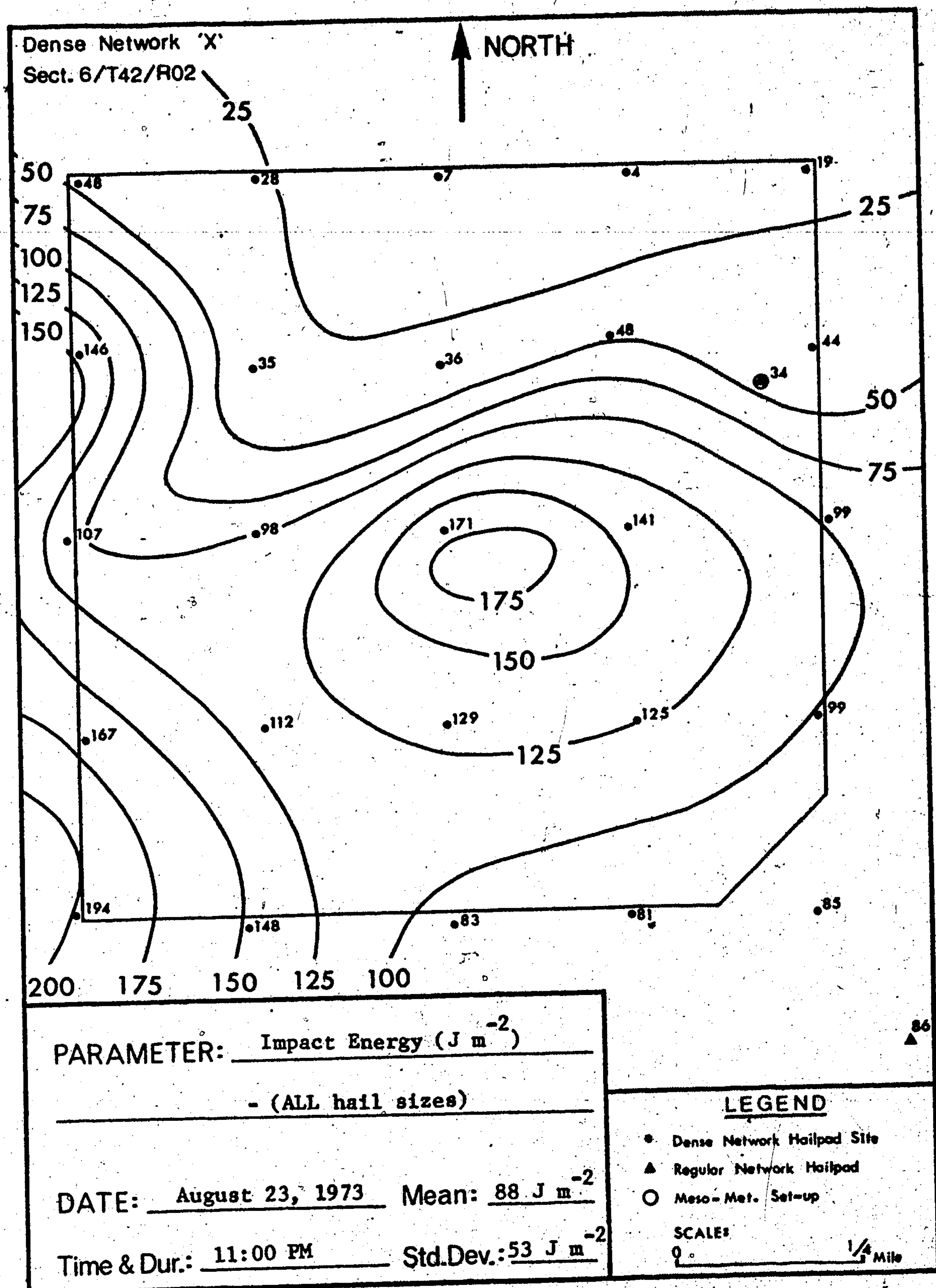

Figure 30. Pattern of impact energy ($J\ m^{-2}$) over the northern dense network, DNX, on August 23, 1973.

Table 17. Dimensions of 1973 hailpad network hailswaths. Average dimensions were taken for each map, then extremes and means for the season were calculated from these averages.

	Width (miles)	Maximum width inside 100 J m^{-2} Contour (mi)	Maximum width inside 400 J m^{-2} Contour (mi)	Average Distance Between Maxima (mi)
Minimum	5.0	0.0	0.0	10
Maximum	20 (Aug. 16)	9.0* (Aug. 16)	4.5 (Aug. 16)	15
Mean	10.0	3.3 (when 100 J m^{-2} occurs)	2.0 (when 400 J m^{-2} occurs)	12.4

* Width across two swaths which could not be easily separated.

miles wide in this study. But, since damaging hail usually occurs within a path about 3 miles wide (as suggested by Table 18), then spacings < 3 miles are required in order to sample damaging hail. Moreover, the dense network data shows that a spacing of about 1/4 mile is required to distinguish the fine-scale pattern.

The mean width for damaging hail (≥ 100 J m^{-2}) of 3 miles, incidentally, concurs with the 2-5 miles given by Summers and Wojtiw (1971). Finally, the fact that the average distance between hailfall maxima along a swath varied from only 10 to 15 miles for all hailswaths may be significant, for if such figures could be verified with more data, then it would suggest limits on the speed and lifetime of damaging hail cells.

The effect of increasing station spacing

In the Northern Network, 120 hailpad sites (excluding the dense network) gave a mean spacing of 2.8 miles. The effect of decreasing station density was tested on the August 16th storm. Deleting every second hailpad site, impact energy maps were drawn for 60 hailpads (a mean spacing of 4.0 miles), then for 30 hailpads (a mean spacing of 5.7 miles), and finally, with only 15 hailpads (a mean spacing of 8.0 miles), the latter of which is shown in Figure 31.

The main pattern was still evident with 4.0-mile spacing. With 5.7-mile spacing, a rough general pattern still survived, but with only the maxima southwest of Rimbey and north of Rocky Mountain House showing up (Figure 22). Other details were lost. With 8.0-mile spacing, the pattern was completely distorted, as Figure 31 shows.

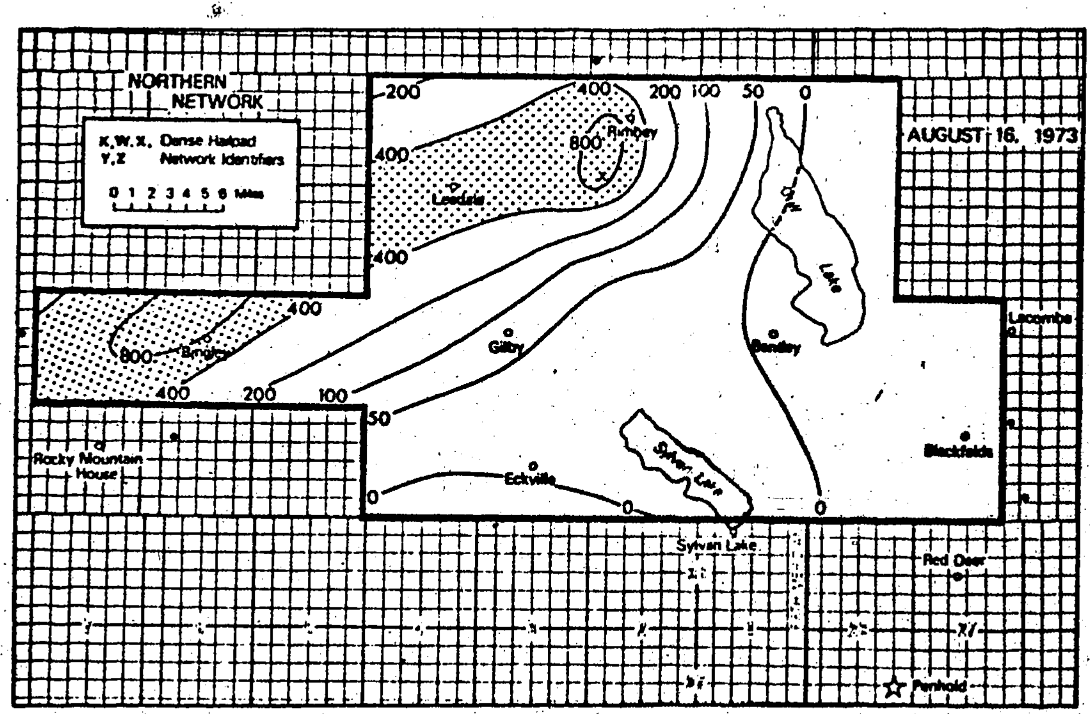

Figure 31. Distorted pattern of impact energy ($J\ m^{-2}$) over the Northern Network on August 16, 1973, analyzed using only 15 hailpads, giving an average station spacing of 8 miles.

There is another undesirable effect of changing the station density or of comparing data from networks of different densities. Table 18 illustrates the effect. Here, the mean of 79 values of impact energy from the August 23rd storm was taken. Means and standard deviations both decreased when the number of stations was reduced at random to 1/2 of the original number and again when reduced to 1/3 the original number.

Table 18. The effect on impact energy of changing station density; an example using data from the hailstorm of August 23, Southern Network.

Number of Hailpads	Mean Impact Energy ($J\ m^{-2}$)	Standard Deviation ($J\ m^{-2}$)
79	35.2	95.3
40	25.4	29.8
26	24.3	27.0

Causes of observed hailfall patterns

Two scales of impact energy variation have been noted in these results. On the large-scale pattern there is a distance of 10-15 miles between energy maxima along a swath; on the fine-scale pattern, this distance is 1/2-1 mile, though the latter is apparent (in this study) only in the vicinity of the large-scale maxima.

The now-familiar theory of the formation of new convective cells on the right flank of an existing thunderstorm[1], is a plausible

[1] Newton and Katz (1958), Browning (1964), Renick (1971), or Chisholm and English (1973).

explanation for the large-scale pattern. For, given an average lifetime for an average size thunderstorm cell of 30 minutes, and typical speeds for such systems of 20–30 mph, then one should expect an average distance between hailfall maxima of 10–15 miles as noted above. A good example of this is provided by Figure 22 for August 16th. One cell, indicated by the energy maximum east-northeast of Rocky Mountain House, appears to taper off to the east. Then a new cell probably builds up, continues northeastward, and results in the next maximum near Dense Network 'X'.

The fine-scale maxima are not as easily explained, but are probably the result of the very turbulent nature of such storms. Also, secondary maxima of radar reflectivity, called segments, have been observed within single cells (Barge, 1974, personal communication), and these may be related to the fine-scale maxima noted here; in other words, several concentrations of hail occur within a cell. Morgan and Towery (1974) observed the same type of maxima occurring within a similar dense hailpad network operated by the Illinois State Water Survey in Nebraska in 1973, and G.G. Goyer (personal communication, 1974) has referred to these as 'hail-cores'. Changnon and Barron (1971) noted semi-circular areas of crop loss ranging from 100–500 feet in diameter, which are undoubtedly due to this scale of hailfall. There would also appear to be a connection with the frequent reports, at least in Alberta, of more than one 'burst' of hail. These lead to the 'point hailfalls' described by Pell (1971).

The important observation is that there are at least two scales of hailfall, and one should be careful not to confuse them.

<u>Sampling errors and hailfall rate</u>

The dense networks have shown that the hailpad can record a hailfall sample which is representative enough to describe patterns across hundreds of feet, probably the finest scale of variation of importance. The problem of whether a hailpad records 4, 5, or 6 hailstones of one size on a hailpad, when, say, an average of 5 ft^{-2} are falling, is almost irrelevant when so many others, both smaller and larger, are also being recorded.

Nevertheless, during a mobile hailpad operation and also at the Edmonton hailpad site, several tests were performed using two or more hailpads ≤ 20 feet apart. Of course, a hailpad could have been halved or quartered and results on each section compared, but other studies (e.g., Changnon, 1969) suggest that 1 ft^2 is a minimum size for adequate sampling. A few measurements of hailfall rate were also taken during these tests.

During the August 23rd storm, pairs of hailpads were set out on opposite sides of a road (about 18 feet apart) at two locations 1/4 mile apart, prior to the hailfall. At a third location, 1/4 mile still further on, three other pads were set out next to each other, one prior to the hailfall, the second two minutes after the start, and the third four minutes after the start. The duration of the hailfall was 13.5 minutes. Table 19 shows some of the results.

The difference between hailpads in Set #1 (about 6 per cent in impact energy), and between hailpads in Set #2 (about 0.1 per cent in impact energy) are due to a combination of real hailfall differences, sampling error, and estimation error. Maximum gradients of impact energy measured over the dense networks, suggest that energy differences across

Table 19. Mobile experiment, August 23, at land location NE 13/T35/R4/W5. Hailpad Set #1 18 feet apart, Set #2 18 feet apart, and 1/4 mile south of Set #1. Set #3 side by side and 1/2 mile south of Set #1. Hailfall duration, 13.5 minutes.

Hailpad Set	No. Hailstones (ft^{-2}) SHOT	PEA	GRAPE	TOTALS	Maximum Diam. (cm)	Mass ($g\ m^{-2}$)	Impact Energy ($J\ m^{-2}$)
#1, T_o = 0 min.	385	230	6	621	1.6	927	72.2
	265	221	8	494	1.5	848	67.9
#2, T_o = 0 min.	255	253	6	514	1.5	822	62.9
	250	216	5	471	1.6	797	63.0*
#3, T_o = 0 min.	260	234	9	503	1.6	952	80.4
$T = T_o + 2$	260	258	6	524	1.5	936	74.2
$T = T_o + 4$	200	196	8	404	1.5	746	61.5

* On this hailpad, the average stone size within each category was somewhat bigger, so that it had a slightly larger energy than its neighbour.

18 feet should usually be less than 3 per cent. Hence, most of the 6 per cent difference can be attributed to sampling and estimation error.

The timed hailfall on Set #3 suggests that the hail commenced with mainly small stones, with most of the mass (about 80 per cent) after the first four minutes. Only about 2 per cent of the hail mass fell in the first two minutes.

Most other mobile operations were not so successful in finding hail, except on July 23rd when several timed hailpad exposures gave hail energy flux rates as high as 1000 J m^{-2} min^{-1}, but only for a minute or so.

Edmonton does not lie within the main hail belts of Alberta, and only two light hailfalls were recorded at the Edmonton site in 1973. Two hailpads, about 20 feet apart, recorded hail on August 4th. The first pad, to test its weathering durability, had been exposed for over two months, and recorded 16.0 J m^{-2} on this date, no other hail having occurred. The second, exposed only a few days, recorded the same hailfall as 16.7 J m^{-2}. No significant difference is evident to suggest major hailpad weathering effects, spatial differences across 20 feet, or errors due to sampling or measurement.

Three hailpads were used to measure hailfall rate again on September 11th at Edmonton. The hail lasted 10 minutes. Results are displayed in Table 20. Here we see that about 75 per cent of the total hail mass fell in the first 2 minutes, compared with only 2 per cent in the first 2 minutes of the August 23rd test (Table 19). Less than 1 per cent of the mass fell in the final half of the hail period. In the first 2 minutes the flux of impact energy was 32 J m^{-2} min^{-1}, compared to only 3 J m^{-2} min^{-1} during the first 2 minutes of the August 23rd test. Although duration and total impact energy were of the same magnitude in both tests, the order of hailfall events was completely different. It would seem that few generalizations can be made about hailfall rates.

Table 20. Hail from a 10 minute hailfall in Edmonton, September 11, 1973.

Hailpad Number	Time Out (T_o = 0 min.)	No. hailstones (ft^{-2}) SHOT	PEA	TOTAL	Hail Mass ($g\ m^{-2}$)	Impact Energy ($J\ m^{-2}$)
2596	T_o	865	512	1377	1401	83.6
2744	T_o + 2 min.	275	86	361	338	20.2
2745	T_o + 5 min.	16	0	16	10	0.4

Wind estimates

Wind speeds were extracted from hailpad data alone, according to the procedure described in Section 5.4. Table 21 shows the mean winds, as well as both vertical and horizontal partitions of impact energy for the 27 hailpad sites of DNX on August 16 and 23. Comparisons with the mean anemometer wind (at Site G73) and local estimates are shown. The comparisons indicate that the hailpad method of obtaining wind speeds and directions is at least worthwhile, in the absence of more reliable data.

Winds at the individual hailpad sites of DNX for August 16th are plotted on Figure 32. The isotachs have been analyzed and the maximum wind cores are shown as broad arrows. Adjacent to this is Figure 33, showing the total impact energy, $E_{IT} = E_I + E_H$, as derived from these hailpad-inferred winds. Two or three main bands of strongest winds are evident, perhaps tracing the path along which maximum downdrafts occurred. These wind cores and the 'total' energy pattern concur, while the latter pattern is also basically unchanged from that

Table 21. Mean winds and extremes extracted from hailpads, comparison with anemometer wind and farmer-volunteered estimates, and the partitions of mean impact energy, for Dense Network 'X' on August 16 and 23, 1973.

Date	Range of Impact Angle (°)	Mean Hailpad Wind & Range (mph)	Mean 1-hr Anemometer Wind (mph)	Farmer Estimates (mph)	Mean Partitions of Impact Energy ($J\ m^{-2}$) Vertical	Horizontal	Total
Aug. 16	40-61	W at 53 (33-77)	W at 40*	>40	879	1134	2013
Aug. 23	24-55	WNW at 22 (10-33)	(**) at 18	10-25	88	8	96

* The one-hour average was extracted from the anemograph by a technician and the actual record subsequently destroyed; hence, gusts during the hour are unknown. Hailpad values at the anemometer site and at nearby Site X20 were 37 and 47 mph, respectively.

** Wind direction recorder inoperative at this time.

of the vertical partition alone (Figure 23).

With finer detail on wind structure (perhaps by using the hailcubes of Morgan and Towery, 1974), the influence of large stands of trees and other obstacles would likely become more evident. Although the wind estimates have an uncertainty of about 10 mph, errors will be almost the same for all hailpads for a given hailfall over this small an area; i.e., there would be little error in the

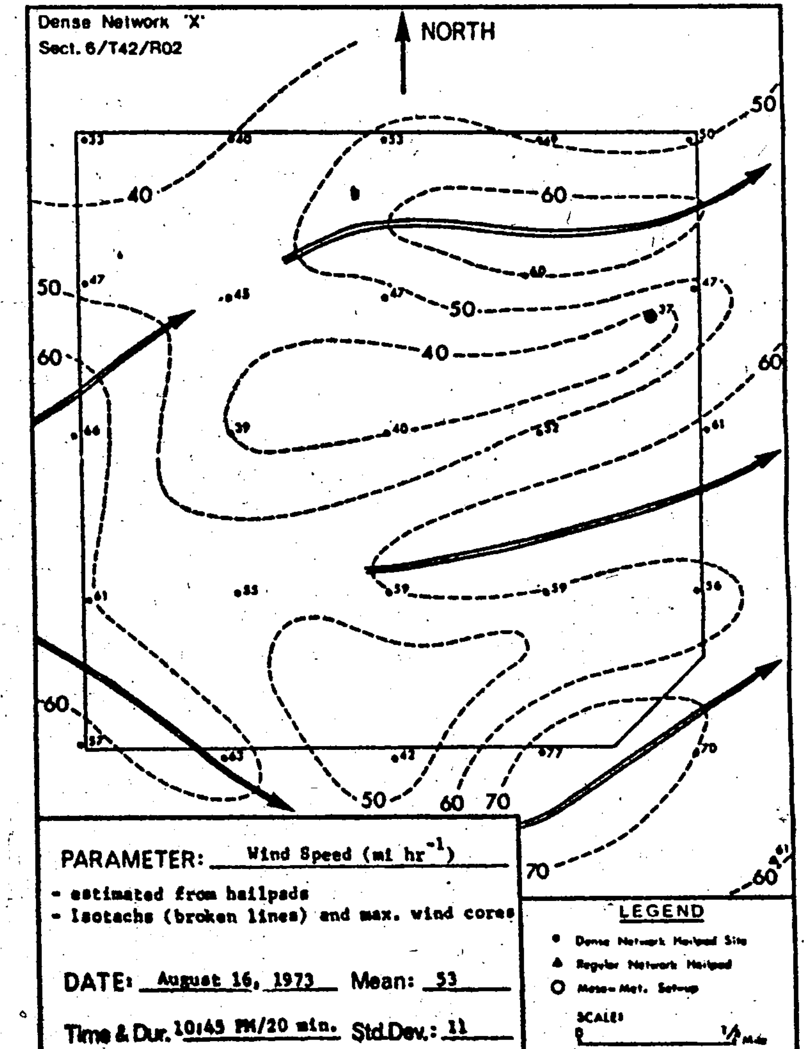

Figure 32. Isotachs (mph) and maximum wind cores over DNX, August 16, 1973, from hailpad-inferred wind speeds.

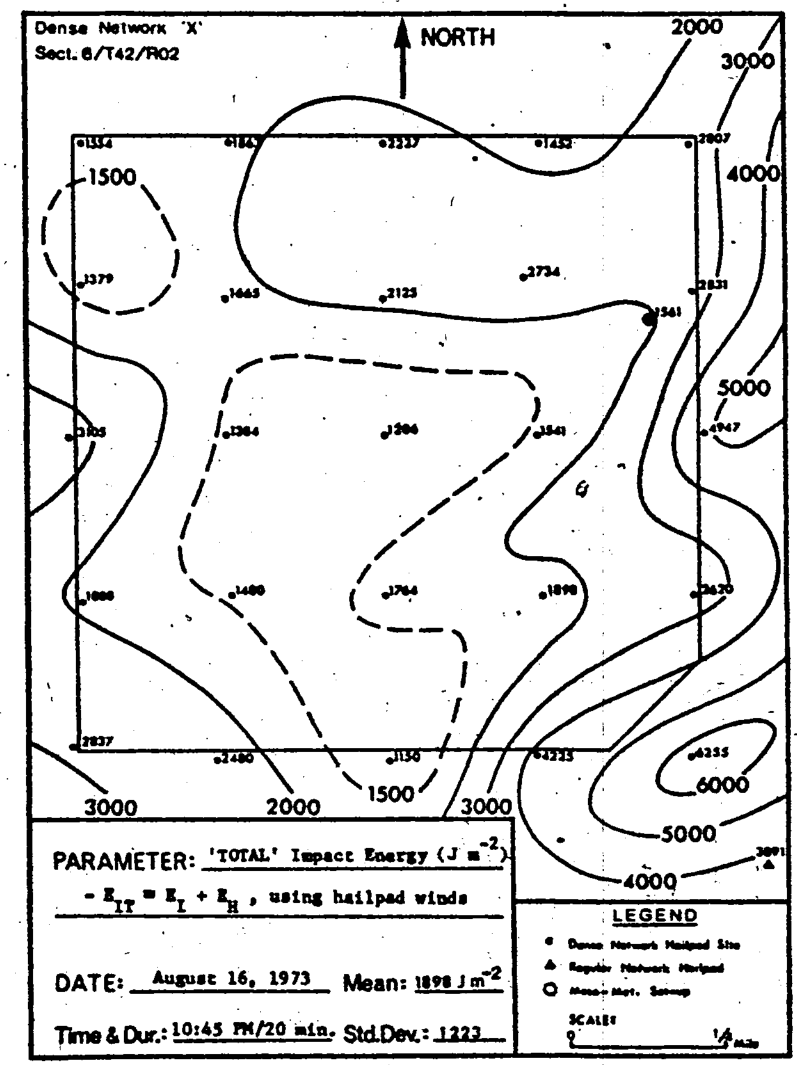

Figure 33. Pattern of TOTAL impact energy (J m^{-2}) over DNX, August 16, 1973, using the hailpad-inferred winds.

pattern of winds. It is interesting that the hailpad wind estimate at the anemometer site was 37 mph, while the next closest hailpad, at Site X20, gave 47 mph, both close to the 1-hour anemometer average value of 40 mph.

The case of August 16th demonstrates how important a role wind can play in crop damage, for total energies were three times the vertical partition of energy. Fortunately, the patterns of wind speed and total energy were quite similar, and this is believed to be the rule. This fact is perhaps not surprising if one assumes that the largest concentrations of hail probably are associated with the greatest downdrafts, and therefore the strongest horizontal outflow, or winds.

In attempting to form a relation between crop damage and hailfall parameters, one must now realize that allowances must also be made for angles of impact. Surely, a standing crop must be more susceptible to damage from hailstones impacting at 40 to 60 degrees (as on August 16th) than it is for vertically-falling hailstones. Thus, one more parameter is added to the growing list of crop damage variables[1].

Hailstone size distributions

Few objective measurements of hail size distributions have been made. Table 22 gives the total and average number of hailstones per pad for each of the six Alberta size categories, and their relative frequencies, for the 761 hailpads of 1973. The per cent contribution of each size category to impact energies is derived, using Equation 10

[1]Crop damage indirectly related to hail could also be caused by winds alone, rain-water run-off, or freezing due to hail on the ground; three additional variables.

Table 22. Hail size distributions and the mean per cent contribution to impact energy for all hailstones measured on 761 hailpads in 1973.

	SHOT	PEA	GRAPE	WALNUT	GOLF	>GOLF	TOTALS
Totals	324,146	155,204	4,888	654	73	1	484,966
Average per Hailpad	425	203	6	1	<1	<<1	634
% Frequency	66.8	32.0	1.0	0.1	.015	.0002	100
Average Energy per pad (J m^{-2})	11.9	38.7	19.5	13.2	11.4	0.5	95.2
% Contribution to Imp. Energy	12.4	40.7	20.5	13.9	12.0	0.5	100%

and assuming mean diameters of .495, .8, 1.6, 2.4, 4.0, and 5.2 cm for shot, pea, grape, walnut, golfball, and greater than golfball, respectively. The value of .495 is the only size within the shot size category detected by the hailpad (dents $\leq$ .05 inch), while only one hailstone greater than golfball size was recorded (5.2 cm). On the average, we see that almost 75 per cent of the impact energy is due to grape size or smaller hailstones.

A more easily obtainable distribution from volunteer reports in Alberta is that of 'maximum' hailstone sizes. Figure 34 shows the distribution of maximum hail sizes as recorded by the 761 hailpads. Table 23 summarizes this by size category, and compares the per cent frequencies with those obtained by Paul (1967) using the ALHAS hail report card data of 1957-66.

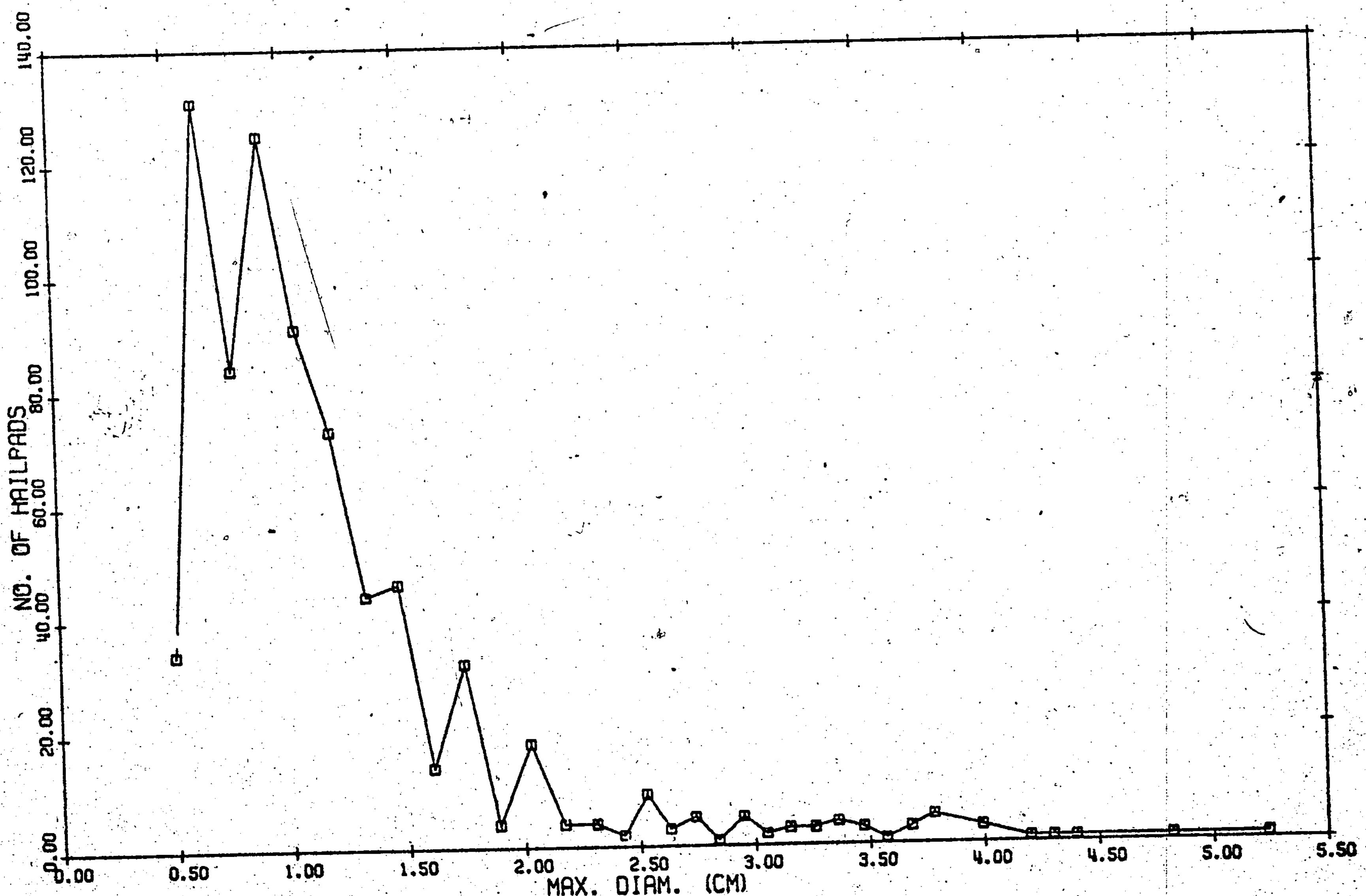

Figure 34. Distribution of maximum hailstone sizes from the 761 1973 hailpads.

Table 23. Maximum hail size distribution for the 761 hailpads of 1973, and comparison with information from volunteer hail report cards of 1957-66 (Paul, 1967).

	SHOT	PEA	GRAPE	WALNUT	GOLFBALL	>GOLF	TOTALS
No. hailpads	34	504	158	38	26	1	761
HAILPAD % Frequency	4.5	66.2	20.8	5.0	3.4	0.1	100%
HAIL CARD % Frequency	9.4	38.7	33.7	12.2	4.7	1.3	100%

Though the hailpad, in general, does not sample the actual maximum size, it will not usually be far off. Thus, the earlier statement that volunteer reports tend to overestimate maximum hail sizes from large storms, and underestimate maximum hail size from smaller storms, is suggested here, for the hail card data shows higher frequencies of maximum sizes for both the smallest (shot) and largest (> golfball) storms. It is suggested that since most of the (small) hail from small hailfalls melts almost immediately upon impact, it would be natural for an observer to often assume shot to be the largest size, although pea might have fallen also. On the other hand, when crop losses are suffered because of large hail, there is a natural tendency to subconsciously overestimate the maximum size, although not really by much, as Table 23 shows. Similar conclusions about volunteer estimates have been made by others (e.g., Changnon, 1971b).

6.5 A Means for Hail Suppression Evaluation

The discussion of this 1973 hailpad data would be incomplete without some particular reference to hail suppression evaluation. In 1973, operational cloud-seeding was carried out in the area south of Penhold, which encompasses the Southern Hailpad Network, while only single storm type seeding experiments were performed over the Northern Network. This latter type of seeding makes evaluation difficult, since the effects of cloud seeding are probably felt only over a small area. Because of this, many hail researchers (Goyer, 1971; Lovell, 1972) have expressed the view that hail suppression should be efficiently randomized, using the same area for both target and control.

It would be interesting to compare seeded and unseeded storms to see if any believable conclusions can be made. At this writing, the author had no way of deciding which areas were affected by seeding. Consequently, each storm date was simply labelled as 'seeded' if 50 or more Silver Iodide flares[1] had been dropped; otherwise, the storm was termed 'unseeded'. Schleusener (1968) suggested a seeding rate of ≥ 2000 g hr^{-1} for effective hail suppression. It is not known whether Alberta seeding rates conform to this.

Using the above criterion, of the 17 hailstorms recorded by the hailpads, seven were seeded. These occurred on June 25, June 29, July 5, July 6, and July 22/23 over the Southern Network, and July 23 and August 16 over the Northern Network. Mean values of several parameters, for both the seeded and unseeded storms, are displayed in Table 24.

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[1]For details on these flares and the method of seeding, see Summers (1972).

Table 24. Comparison of mean hail parameters for seeded and unseeded hailstorms.

	No. Hail-pads	No. Hail-stones (ft^{-2})	Average Maximum Size (cm)	Mean Hail Mass ($g\ m^{-2}$)	Impact Momentum ($kg\ m\ s^{-1}\ m^{-2}$)	Impact Energy ($J\ m^{-2}$)	MEAN WATER/ICE RATIO M_w/M_i
Seeded	304	817	1.20	1067	13.5	93.0	16.0
Unseeded	321	421	1.02	495	5.9	36.6	25.7

The unseeded storms would appear to have yielded smaller maximum hail sizes, and lower values of impact momentum and impact energy. Similarly, the mean mass ratio of water to ice (the sum of rain masses divided by the sum of ice masses) is higher for the unseeded storms. There are three suggested possible explanations for these undesirable trends:

i) that seeding was confined mainly to the most potentially dangerous storms, resulting in biased data in Table 24;

ii) that the seeding was working in reverse, producing more hail at the ground instead of water, hence more total ice mass;

iii) that the seeding was doing its job of producing smaller stones, most of which melted during fall, reaching the ground as rain and leaving no hailpad record of hail, therefore biased data in Table 24.

The first possibility may be partially valid, since the final decision to seed or not was based on radar reflectivity; i.e., if radar indicated potential hail, then seeding was undertaken.

For the second possibility, although no proof has yet been produced to show that seeding produces more ice mass, this may be the result if insufficient embryos are created to use up all of the available water. In this discussion, we shall disregard this possibility.

The validity of the third proposal appears to be of considerable practical importance. It has been shown (Mason, 1956; Ludlam, 1953) that hailstones of initial diameters less than 1.5 cm will melt completely when falling 5 km below the freezing level[1]. Yet, for a 4.4-cm hailstone, Ludlam calculated a diameter of 4.0 cm at the ground, with the fractional change in diameter due to melting decreasing still more with larger initial sizes. Since the larger stones do not melt relatively as fast, then one should not expect higher water/ice mass ratios from seeded storms, unless the areas where rain only occurs are also included in the data.

The author lacked the time necessary to delve further into rainfall data, but such data are available (using the hail card rain amounts) and should be investigated to resolve at least some of the mystery surrounding hail suppression evaluation. Without such data, the figures of Table 24 are, as suggested, biased and inconclusive, but may serve as an impetus to convince investigators of the importance of such evaluation.

[1]Values of 3 km and a melt diameter of 1 cm would be more typical of Alberta hailstorms.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

> *"Main storm was north of here, towards Rimbey. We got the tail end. One and one-half miles north it looks like a snow storm in winter, fields all white."*
> .... *Bruce Brown, July 4, 1973.*

> *"There was more damage from wind and run-off than from hail."* ... *Mrs. H. Beierbach, August 2, 1973.*

7.1 Findings

With proper controls on hailpad dent estimations, uniform and unbiased analyses can be performed manually and systematically with a minimum of tediousness. Tests with several hailpads in close proximity imply that combined errors due to the analysis procedure described herein, and to errors of sampling, are almost negligible (generally <5 per cent in measured values of ice mass and impact energy)[1]. Errors due to calibration assumptions were also shown to be negligible, if a constant drag coefficient for falling hailstones of .60 was assumed. This was later photo-verified, and it is expected that field calibration tests will show similar verification. Hailpad sensitivity is limited to hailfall with impact energy between 0.1 and 2000 J m^{-2}.

[1] A 5 per cent error can be termed negligible since the values of impact energy for a given storm can vary over four or five orders of magnitude.

This range covers most hailfalls, however, since the lower value assures no possible crop damage due to hail, while complete crop loss is a certainty with the higher value.

The 1973 hailswaths were found to be 5-20 miles wide, with a distance between hailfall[1] maxima (when more than one maximum occurred) of 10-15 miles. Such hailfalls were adequately described with an average hailpad spacing of 2.6 miles. The dense networks of this study, however, and that of Morgan and Towery (1974), have proven the existence of finer-scale variations in hailfall, across only hundreds of feet; such variations can be an order of magnitude or more in the impact energy and can only be resolved with spacings of 1/4 mile or less. These variations concur with earlier findings (Changnon and Barron, 1971) of small-scale differences in crop damage due to hail.

For the 1973 hailswaths, such fine-scale features in the dense networks were apparent only in the vicinity of the larger-scale maxima of hailfall, suggesting that the large-scale pattern was still reasonably well-defined with the hailpad spacings used in the two main networks (averages of 2.4 and 2.8 miles). Such an observation requires further data and study, since its validity is of prime importance in network design. One aspect of this problem which did become clear, was that with spacings $\geq$ 6 miles, resolution of the hailfall pattern becomes seriously distorted.

[1]Only maps of impact energy have been shown, but the same results hold for ice mass and impact momentum; the use of the word 'hailfall' covers all three.

7.2 The Hailpad as an Instrument for Hail Suppression Evaluation

The hailpad could be an important instrument in evaluating the success of hail suppression. But since hail suppression endeavours to create small hailstones, many of which will melt and occur as rain at the ground, a necessary counterpart for such evaluation is the rain-gauge. In other words, it makes sense to evaluate hail suppression through some joint rain and hail analysis such as the mass ratio of the two. There are three ways that one can use such ratios to compare seeded and unseeded storms, only one of which appears (in the author's opinion) to be the correct way. Using set theory notation, with the set of hail-dented hailpads denoted by 'H', the set of rainfall reports by 'R', and the hailpad/rain-gauge network by 'N' as in Figure 35, the three methods can be summarized as follows:

i) $H \cap N$: Consider rain and hail amounts at all stations where hailpads recorded hail, comparing the two ratios of total water mass to total ice mass, for 'seeded' and 'unseeded' storms.

ii) $H \cup N$: Compare the mass ratios throughout the whole hailpad network for seeded and unseeded storms, including 'zeros' where rain and/or hail do not occur.

iii) $(H \cup R) \cap N$: Compare mass ratios between seeded and unseeded storms within the network, but include data from stations only where rain and/or hail occur; this area will usually be defined by the 'zero' rainfall contour[1] within the network; e.g., the shaded area in Figure 35.

[1] In Alberta, hail almost always occurs with rain, although the reverse is not true.

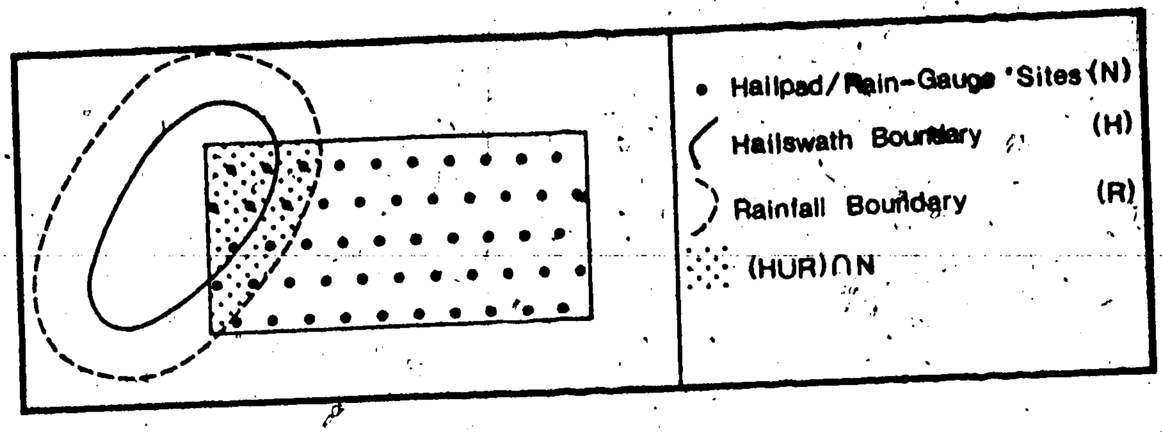

Figure 35. Schematic of hailfall evaluation methods.

The first method, which considers information only within the hailswath, is a poor one, for if small hailstones are successfully created by the seeding process, then many of these will melt during fall and consequently be excluded from the evaluation. The second method, where the total amounts of hail and rain are divided by the number of stations in the network, is equally undesirable, since a large hailstorm may miss all but a portion of the network, resulting in unrealistically low mean values, and thus throwing unnecessary variance into the evaluation. For the third method, which takes means over the whole region of precipitation within the network, a large hailstorm may still miss most of the sampling network, but at least a portion of the storm would be sampled.

This third method appears to be the best approach of the three for evaluating hail suppression efforts, and the same idea should be applied when inspecting mean hail impact energy; i.e., include those zero values where rain-only occurs. As implied, the mass ratio of water to ice would be best for direct evaluation of seeding effects, but if crop damage must be considered, then impact energies should be used.

7.3 Recommendations for Future Hailpad Projects

In addition to the suggestion for hail suppression evaluation, a few simple but desirable recommendations are in order.

(1) Laboratory calibrations must be performed carefully, with due consideration to the assumed physical constants[1], and on the same type of underlying surface as will be used in the field. Furthermore, calibrations should be repeated annually using new materials, since results here indicate that even styrofoam aging and exposure to the elements may eventually invalidate a calibration.

(2) Field calibration of hailpads would present final checks on accuracy. This is a difficult task consisting of collecting (or photographing) hailstones falling on a known area adjacent to a hailpad and comparing the two results. Unfortunately, most small hailstones melt almost immediately on impact. Field calibration trials are being carried out by E. P. Lozowski during 1974, with some help from the author, although results are not available in time for this dissertation.

(3) The underlying surface for hailpads should be consistent, and hailpads should be well-exposed. Clipping the pad onto 1/2-inch plywood and attaching the apparatus to a well-exposed post, would virtually eliminate both problems. In addition, accidental damage

[1] For example, it was shown that the values $C_{DS} = .42$ and $\rho_a = .00107$ g cm^{-3} might have been better choices than the ones assumed.

by livestock and people would be eliminated, while changing hailpads would also be easier and less messy (not having to contend with muddy ground).

(4) Hailpads should be spaced a maximum of three miles apart for resolution of the main hailfall patterns, while Changnon's (1969) suggestion of one-mile spacing is not unreasonable in view of the dense network results.

(5) Care must be taken in the construction and transportation of hailpads, since the aluminum foil becomes scratched and wrinkled rather easily. Wrapping pads with foil corners in towards styrofoam edges (as depicted in Figure 30) was found to be best.

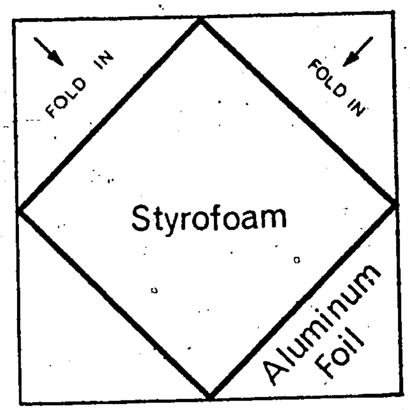

Figure 36. Best method to wrap hailpads with aluminum foil.

Transportation in cardboard boxes with paper sheets between hailpads is desirable.

(6) If volunteer help must be relied upon for maintaining hailpad sites, then extra emphasis must be placed on proper hailpad changes (daily checks, recording times, etc.); this is a public relations job, for which frequent contact is essential.

(7) Hailpads must be exposed at all times, for sequential pad exposures have shown that 2–80 per cent of the total hail mass

can fall in the first two minutes of hailfalls lasting ten minutes or more. In other words, having a volunteer install a hailpad as soon as he notices hail is inadequate.

(8) More study with dense networks, with a maximum spacing of 1/4 mile, should be a priority, in order to establish whether the fine-scale variations exist only, as noted here, in the vicinity of the large-scale maxima.

(9) Since the greatest single source of absolute error in this project was that due to the horizontal wind, attempts should be made to evaluate the wind field during a hailstorm, preferably using some variation of the hailcube of Morgan and Towery (1974). Current anemometers cannot accurately measure the times of wind and hailfall simultaneously, so that the method of wind extrapolations from hailpads is a rough, though reasonable substitute. Ideally, at least half of the hail detectors in a network should be hailcubes.

(10) A rain-gauge should be an integral part of every hailpad site, not just an occasional addition, if a thorough evaluation of hail suppression is to be carried out. Rain mass, in this respect, is a more important parameter than the wind speed, since the only other required parameter (for the suggested method of evaluation) is ice mass, which can be adequately measured from the hailpad without knowledge of winds.

(11) Analysis is one of the most difficult and time-consuming tasks facing any hailpad project, mainly because of the tedious work involved, but also because constant checks for uniformity and against bias should be made. Therefore, the search for better methods of analysis must be continued. An automated method such as the technique

described in Chapter V, though perhaps more objective, must first be thoroughly checked for accuracy and consistency.

7.4 Concluding Remarks

A simple, inexpensive hailpad has been shown to be a very useful instrument for measuring hailfall. It measures occurrences not only of damaging hail, but also of those minor hailfalls which otherwise go unnoticed by the casual observer, either because they occur at night, in heavy rainfall, or simply because the hail is so small that it melts on impact. Although they are generally of little significance for the farmer. It would be folly to consider such minor hailfalls insignificant, for the production of small hailstones and light hailfalls is the very objective of hail suppression experiments, not to mention their significance to hail climatology for describing the extent of hailswaths and overall hail size distributions.

Hailpad network dimensions and methods of hail suppression evaluation, both depend on the type of cloud seeding being carried out. Randomized seeding, using the same area for both target and control, appears to be best, since such practice would minimize spurious differences between seeded and unseeded storms resulting from topographic and climatic variations, and differences in crop damage due to varying crop types, soils, farming methods, and so on.

Finally, evaluating seeding effects on the basis of a few years of crop damage statistics, is questionable, not only because of the above variables, but also, and more importantly, because of unknown climatic cycles. But, with randomized seeding, the suggested rain/hail method of evaluation may show noticeable trends with even one year of hailpad data, _if_ significant hail suppression is being achieved. Any such trends, of course, would have to be subjected to statistical significance tests.

LIST OF SYMBOLS

(in order of appearance)

e	- kinetic energy of a hailstone
m	- mass of a hailstone
D	- diameter of a hailstone
W_T	- terminal velocity of a hailstone
N	- number of hailstones
E	- kinetic energy of N hailstones
M, M_H	- mass of N hailstones of mass m each
C_D	- drag coefficient of a hailstone in free-fall
Re	- Reynolds number
U	- velocity
ν	- kinematic viscosity
ρ_a	- air density (usually given the value 1.05 X 10^{-3} g cm^{-3})
μ	- dynamic viscosity
ρ	- hailstone density (assumes the value .89 g cm^{-3})
W	- fall velocity
a	- net acceleration
F_D	- drag force on a sphere
Z	- axis (positive) upward from the center of earth
g	- acceleration due to gravity (981.3 cm s^{-2} at 53N)
t	- time
A_x	- cross sectional area of a sphere
A	- arbitrary constant
Q	- momentum

E_I	- impact energy
Q_I	- impact momentum
h	- (drop-) height
f	- fraction of terminal velocity
S (as subscript)	- identifies parameters of 'simulating' spheres (W_S, W_{TS}, C_{DS}, etc.)
	- $C_{DS} \simeq .45 \pm .03$
R_H, D_H	- radius and diameter of a hailstone
d	- depth of dent
V	- volume
E_f	- final error
W_H	- horizontal wind velocity
E_{IT}	- total impact energy (sum of vertical and horizontal partitions of energy)
θ	- vertical angle of impact of a hailstone
P	- pressure
T	- temperature
S_p	- mean spacing
α, β	- angles of dent streaks on hailpad edges
$\overline{W_T}$	- average terminal velocity of all hail sizes

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APPENDIX I

EXPLANATION OF UNITS USED, THE LAND SURVEY SYSTEM AND ACCURACY OF DENT MEASUREMENTS

Units

Metric units were used throughout this dissertation, except for a few instances where it was convenient to use English units for length. To conform with the land survey system used in Alberta, distances are given in miles, areas in square miles.

Since farmers are familiar with inches rather than centimeters, and because the steel simulation spheres were readily available only in standard English sizes (i.e., diameters of ¼ in, ½ in, 1 in, etc.), dent sizes for both calibrations and hailpad analysis were measured in inches, but were converted to hailstone diameters in both inches and centimeters in final computations. Maximum hail sizes were output in centimeters only.

Derived hail parameters were converted to totals m^{-2}, except for numbers of hailstones which are shown as counted (ft^{-2}).

The Dominion Land Survey System

Land areas in Alberta are divided into six mile square townships, each square mile (or section) being identified by consecutive numbering from 1 to 36. Each section is further divided into quarters, and designated as southeast, southwest, northwest, and northeast quarter-sections. Townships are numbered northward from the 49th parallel, while the range of a township is numbered westward from a meridian, of which there are two in Alberta; the fourth meridian at 110W longitude, and the fifth meridian at 114W longitude. Convergence of the meridians necessitated certain 'correction' lines, such that not all townships are six miles square. Thus, a farm location is identified by quarter, section number, township number, range, and meridian; e.g., NE6/42/2/W5 is the northeast corner of section 6 in township 42, at range 2 west of the fifth meridian.

Accuracy of Dent Measurements

For the calibration measurements, dents were interpolated to the nearest .01 inch, and were believed accurate to ±.03 inch. For the hailpad analysis procedure, dents were interpolated only to the nearest .05 inch, and were believed accurate to ±.05 inch.

APPENDIX II

TABLES AND DATA FOR CALIBRATION EXPERIMENTS

Table A1. Drop-heights for calibration experiments.

...HAILSTONE DRAG COEFFICIENT = 0.50, SMOOTH SPHERE DRAG COEFFICIENT = 0.45, AIR DENSITY = 0.00105 G/CC.

	HAILSTONES (DENSITY=.89G/CC)			GLASS BALLS (DENSITY=2.51 G/CC)			STEEL BALLS (DENSITY=7.78 G/CC)		
DIAMETER IN INCHES	TERMINAL VELOCITY (M/SEC)	IMPACT ENERGY (ERGS)	IMPACT MOMENTUM (G-CM/SEC)	TERMINAL VELOCITY (M/SEC)	DROP-HEIGHT TO MATCH ENERGY (M)	DROP-HEIGHT TO MATCH MOMENTUM (M)	TERMINAL VELOCITY (M/SEC)	DROP-HEIGHT TO MATCH ENERGY (M)	DROP-HEIGHT TO MATCH MOMENTUM (M)
0.250	11.86	8.393E 04	1.415E 02	21.00	2.70	0.92	36.96	0.83	0.09
0.375	14.53	4.249E 05	5.850E 02	25.71	4.05	1.38	45.27	1.24	0.14
0.500	16.77	1.343E 06	1.601E 03	29.69	5.40	1.84	52.28	1.65	0.19
0.540	17.43	1.827E 06	2.096E 03	30.86	5.83	1.99	54.33	1.78	0.20
0.563	17.79	2.151E 06	2.418E 03	31.49	6.08	2.07	55.45	1.86	0.21
0.625	18.75	3.278E 06	3.496E 03	33.20	6.75	2.30	58.45	2.06	0.23
0.640	18.98	3.605E 06	3.799E 03	33.59	6.91	2.36	59.14	2.11	0.24
0.750	20.54	6.798E 06	6.618E 03	36.37	8.10	2.76	64.02	2.48	0.28
0.875	22.19	1.259E 07	1.135E 04	39.28	9.45	3.22	69.15	2.89	0.33
0.938	22.97	1.660E 07	1.445E 04	40.66	10.13	3.45	71.58	3.10	0.35
0.960	23.24	1.825E 07	1.570E 04	41.14	10.37	3.54	72.43	3.17	0.36
1.000	23.72	2.148E 07	1.811E 04	41.99	10.80	3.68	73.93	3.30	0.38
1.250	26.52	5.245E 07	3.956E 04	46.95	13.50	4.60	82.65	4.13	0.47
1.500	29.05	1.088E 08	7.488E 04	51.43	16.20	5.53	90.54	4.95	0.56
1.750	31.38	2.015E 08	1.284E 05	55.55	18.90	6.45	97.80	5.78	0.66
2.000	33.55	3.438E 08	2.049E 05	59.38	21.60	7.37	104.55	6.61	0.75

RATIOS OF IMPACT VELOCITIES TO TERMINAL VELOCITIES.......
RATIO(GLASS/ENERGY) = 0.336, RATIO(GLASS/MOMENTUM) = 0.200, RATIO(STEEL/ENERGY) = 0.109, RATIO(STEEL/MOMENTUM) = 0.037 .

Table A2. Drop-heights for calibration experiments.

...HAILSTONE DRAG COEFFICIENT = 0.60, SMOOTH SPHERE DRAG COEFFICIENT = 0.45, AIR DENSITY = 0.00105 G/CC.

DIAMETER IN INCHES	HAILSTONES (DENSITY=.89G/CC) TERMINAL VELOCITY (M/SEC)	IMPACT ENERGY (ERGS)	IMPACT MOMENTUM (G-CM/SEC)	GLASS BALLS (DENSITY=2.51 G/CC) TERMINAL VELOCITY (M/SEC)	DROP-HEIGHT TO MATCH ENERGY (M)	DROP-HEIGHT TO MATCH MOMENTUM (M)	STEEL BALLS (DENSITY=7.78 G/CC) TERMINAL VELOCITY (M/SEC)	DROP-HEIGHT TO MATCH ENERGY (M)	DROP-HEIGHT TO MATCH MOMENTUM (M)
0.250	10.83	6.994E 04	1.292E 02	21.00	2.23	0.76	36.96	0.69	0.08
0.375	13.26	3.541E 05	5.340E 02	25.71	3.34	1.15	45.27	1.03	0.12
0.500	15.31	1.119E 06	1.462E 03	29.69	4.45	1.53	52.28	1.38	0.16
0.540	15.91	1.522E 06	1.913E 03	30.86	4.81	1.65	54.33	1.48	0.17
0.563	16.24	1.792E 06	2.207E 03	31.49	5.01	1.72	[illegible]	1.55	0.18
0.625	17.12	2.732E 06	3.192E 03	33.20	5.57	1.91	[illegible]	1.72	0.20
0.640	17.32	3.004E 06	3.468E 03	33.59	5.70	1.96	59.14	1.76	0.20
0.750	18.75	5.665E 06	6.042E 03	36.37	6.68	2.29	64.02	2.06	0.23
0.875	20.26	1.050E 07	1.036E 04	39.28	7.80	2.68	69.15	2.41	0.27
0.938	20.97	1.383E 07	1.319E 04	40.66	8.35	2.87	71.58	2.58	0.29
0.960	21.22	1.521E 07	1.433E 04	41.14	8.55	2.94	72.43	2.64	0.30
1.000	21.65	1.790E 07	1.654E 04	41.99	8.9[illegible]	3.06	73.93	2.75	0.31
1.250	24.21	4.371E 07	3.611E 04	46.95	11.14	3.82	82.65	3.44	0.39
1.500	26.52	9.064E 07	6.835E 04	51.43	13.36	4.59	90.54	4.12	0.47
1.750	28.65	1.679E 08	1.172E 05	55.55	15.59	5.35	97.80	4.81	0.55
2.000	30.62	2.865E 08	1.871E 05	59.38	17.82	6.12	104.55	5.50	0.63

RATIOS OF IMPACT VELOCITIES TO TERMINAL VELOCITIES.......
RATIO(GLASS/ENERGY) = 0.307, RATIO(GLASS/MOMENTUM) = 0.183, RATIO(STEEL/ENERGY) = 0.099, RATIO(STEEL/MOMENTUM) = 0.034 .

Table A3. Drop-heights for calibration experiments.

...HAILSTONE DRAG COEFFICIENT = 0.70, SMOOTH SPHERE DRAG COEFFICIENT = 0.45, AIR DENSITY = 0.00105 G/CC.

	HAILSTONES (DENSITY=.89G/CC)			GLASS BALLS (DENSITY=2.51 G/CC)			STEEL BALLS (DENSITY=7.78 G/CC)		
DIAMETER IN INCHES	TERMINAL VELOCITY (M/SEC)	IMPACT ENERGY (ERGS)	IMPACT MOMENTUM (G-CM/SEC)	TERMINAL VELOCITY (M/SEC)	DROP-HEIGHT TO MATCH ENERGY (M)	DROP-HEIGHT TO MATCH MOMENTUM (M)	TERMINAL VELOCITY (M/SEC)	DROP-HEIGHT TO MATCH ENERGY (M)	DROP-HEIGHT TO MATCH MOMENTUM (M)
0.250	10.02	5.995E 04	1.196E 02	21.00	1.90	0.65	36.96	0.59	0.07
0.375	12.28	3.035E 05	4.944E 02	25.71	2.84	0.98	45.27	0.88	0.10
0.500	14.18	9.591E 05	1.353E 03	29.69	3.79	1.31	52.28	1.18	0.13
0.540	14.73	1.305E 06	1.771E 03	30.66	4.09	1.41	54.33	1.27	0.14
0.563	15.04	1.536E 06	2.044E 03	31.49	4.26	1.47	55.45	1.32	0.15
0.625	15.85	2.342E 06	2.955E 03	33.20	4.74	1.63	58.45	1.47	0.17
0.640	16.04	2.575E 06	3.211E 03	33.59	4.85	1.67	59.14	1.51	0.17
0.750	17.36	4.856E 06	5.593E 03	36.37	5.69	1.96	64.02	1.77	0.20
0.875	18.75	8.996E 06	9.594E 03	39.28	6.63	2.29	69.15	2.06	0.23
0.938	19.41	1.185E 07	1.221E 04	40.66	7.11	2.45	71.58	2.21	0.25
0.960	19.64	1.303E 07	1.327E 04	41.14	7.28	2.51	72.43	2.26	0.26
1.000	20.05	1.535E 07	1.531E 04	41.99	7.58	2.62	73.93	2.36	0.27
1.250	22.41	3.747E 07	3.343E 04	46.95	9.48	3.27	82.65	2.94	0.34
1.500	24.55	7.769E 07	6.328E 04	51.43	11.37	3.92	90.54	3.53	0.40
1.750	26.52	1.439E 08	1.085E 05	55.55	13.27	4.58	97.80	4.12	0.47
2.000	28.35	2.455E 08	1.732E 05	59.38	15.16	5.23	104.55	4.71	0.54

RATIOS OF IMPACT VELOCITIES TO TERMINAL VELOCITIES.......
RATIO(GLASS/ENERGY) = 0.284, RATIO(GLASS/MOMENTUM) = 0.169, RATIO(STEEL/ENERGY) = 0.092, RATIO(STEEL/MOMENTUM) = 0.031 .

Table A4. Hailpad calibration data assuming $\rho_a = 1.05 \times 10^{-3}$ g cm^{-3} and $C_{DS} = .45$. Dents were measured on one-inch thick Styrofoam *FR pads covered with .0001-inch Reynolds Wrap aluminum foil.

Sphere Diameter (in)	DENT DIAMETERS (in)			
	$C_D = .50$	$C_D = .60$	(Std. Dev.)	$C_D = .70$
1/4	.12	.10	(.007)	.09
3/8	.24	.21	(.009)	.20
1/2	.34	.33	(.007)	.31
9/16	.40	.39	(.009)	.36
5/8	.46	.44	(.009)	.41
3/4	.57	.55	(.011)	.53
7/8	.70	.67	(.019)	.64
15/16	-	.75	(.014)	.72
1	.83	.82	(.021)	.79
1 1/4	1.14	1.09	(.016)	-
1 1/2	1.44	1.43	(.023)	-
2	1.99	1.98	(-)	-

Table A5. Hailpad calibration data for wind-blown hailstones (hailpads inclined with only vertical partitions of impact energy simulated). Assumes $\rho_a = 1.05 \times 10^{-3}$ g cm^{-3}, $C_{DS} = .45$, and $C_D = .60$. Dents were measured on one-inch thick Styrofoam *FR pads covered with .0001-inch Reynolds Wrap aluminum foil.

Sphere Diameter (in)	Dent Axis	DENT AXIS MEASUREMENTS (in) Hailpad inclined at Angles of 15^o	30^o	45^o	60^o	75^o	Max. Std. Dev. (in)
3/8	Minor	.22	.22	.20	.20	-	.012
	Major	.25	.27	.28	.31	-	.011
1/2	Minor	.31	.31	.31	.29	.21	.018
	Major	.37	.39	.40	.50	.61	.057
5/8	Minor	.42	.40	.39	.36	.29	.020
	Major	.47	.50	.54	.72	.86	.048
3/4	Minor	.50	.50	.49	.46	.38	.016
	Major	.56	.63	.74	.86	1.07	.083
7/8	Minor	.63	.58	.58	.56	.44	.020
	Major	.70	.71	.88	1.09	1.30	.065
1	Minor	.75	.72	.69	.64	.51	.038
	Major	.88	.90	1.01	1.33	1.81	.149

APPENDIX III

SAMPLE OUTPUT OF HAILPAD DATA (2 PAGES)

(527)

H A I L P A D   A N A L Y S I S   S H E E T
****

HAILPAD NO.: 1683　　　　STORM DATE/TIME: AUG.2/0-2AM?/?

STATION NO.: J-51　　　　ANALYST: VS/SLO/AVG

LAND LOCATION: SE18/39/ 4　　　　DATE OF ANALYSIS: 07/JAN/74.

OPERATOR: LARRY DAVID　　　　CHECK IF/WHEN ANALYSIS REPEATED? ___

REMARKS: PAD OUT JUL.25-AUG.2.WIND N.

DENT DIAM. (IN)	HAILSTONE DIAMETER (IN)	HAILSTONE DIAMETER (CM)	IMPACT ENERGY (ERGS)	IMPACT MOMENTUM (G.CM/SEC)	NO. HAIL-STONES (/SQ.FT)	TOTAL IMPACT ENERGY (JOULES)	TOTAL IMPACT MOMENTUM (KG.M/SEC)
0.05	0.19	0.50	0.259E 05	0.541E 02	170	0.44	0.09
TOTALS FOR "SHOT"-SIZE HAILSTONES...........					170	0.44	0.0920
0.10	0.25	0.63	0.699E 05	0.129E 03	60	0.42	0.08
0.15	0.30	0.77	0.155E 06	0.259E 03	26	0.40	0.07
0.20	0.36	0.91	0.301E 06	0.463E 03	44	1.32	0.20
0.25	0.41	1.05	0.531E 06	0.761E 03	18	0.96	0.14
0.30	0.47	1.19	0.874E 06	0.118E 04	11	0.96	0.13
TOTALS FOR "PEA"-SIZE HAILSTONES............					159	4.06	0.6151
0.35	0.52	1.33	0.136E 07	0.173E 04	7	0.95	0.12
0.40	0.58	1.47	0.203E 07	0.246E 04	6	1.22	0.15
0.45	0.63	1.61	0.291E 07	0.337E 04	2	0.58	0.07
0.50	0.69	1.75	0.406E 07	0.451E 04	3	1.22	0.14
0.55	0.74	1.89	0.552E 07	0.590E 04	1	0.55	0.06
TOTALS FOR "GRAPE"-SIZE HAILSTONES..........					19	4.52	0.5307
0.65	0.85	2.17	0.957E 07	0.956E 04	1	0.96	0.10
TOTALS FOR "WALNUT"-SIZE HAILSTONES.........					1	0.96	0.0956
TOTALS EXCLUDING "SHOT"-SIZE (PER SQ.FT)....					179	9.54	1.2413
TOTALS "ALL" SIZES (PER SQ.FT)..............					349	9.98	1.3334
TOTALS "ALL" SIZES (PER SQ.METER)...........					3757	107.41	14.3522

SUMMARY OF HAILPAD/HAILCARD (#1683):

HAILPAD	SHOT	PEA	GRAPE	WALNUT	GOLF	>GOLF	TOTALS
NUMBER	170	159	19	1	0	0	349
% OF TOT.	48.7	45.6	5.4	0.3	0.0	0.0	100%
LOG(#)	2.23	2.20	1.28	0.0	****	****	2.54
HAIL AREA (SQ.IN.)	5.08	13.67	5.29	0.57	0.0	0.0	24.61
MASS(GM)	9.6	47.0	31.3	4.8	0.0	0.0	92.7
I.E.(J)	0.44	4.06	4.52	0.96	0.0	0.0	9.98
% OF TOT.	4.4	40.7	45.3	9.6	0.0	0.0	100%
I.MOM. (KG-M/SEC/FT2)	0.0920	0.6151	0.5307	0.0956	0.0	0.0	1.3334

	FROM HAILPAD	OPERATOR"S HAILCARD
1. APPARENT WIND DIRECTION AS INDICATED BY PAD		
2. NO. HAILSTONES(/SQ.FT) EXCLUDING "SHOT"-SIZE...	179	****
---NO. PER SQ.IN. (EXCLUDING "SHOT"-SIZE).....	1.24	****
---NO./SQ.IN.(EXCLUDING "SHOT"&"PEA").........	0.14	****
---LINEAR SPACING(INCHES) EXCLUDING "SHOT"....	1.01	)
---LINEAR SPACING EXCLUDING "SHOT"&"PEA"......	3.03	)
3. SIZE(RANGE) OF LARGEST HAIL......(=2.17CM)....		
4. SIZE(RANGE) MOST COMMON HAIL & % OF TOTAL.....		
5. EST.% DAMAGE AT OPERATOR"S FARM/& CROP TYPE...	****	
6. IMPACT ENERGY (JOULES PER SQ.METER)...........	107.41	****
---SIZE(RANGE) OF GREATEST CONTRIBUTOR TO I.E.	------	****
---% CONTRIBUTION TO TOTAL IMPACT ENERGY......		****
6A IMPACT MOMENTUM (KG-M/SEC PER SQ.METER)........	14.35	****
7. PER CENT AREA OF PAD DENTED BY HAIL(ALL)......	5.01	****
8. PER CENT AREA OF GROUND COVERED BY HAIL........	17.09	****

THE END

APPENDIX IV

PATTERNS OF IMPACT ENERGY

FOR 14 ADDITIONAL HAILSTORMS

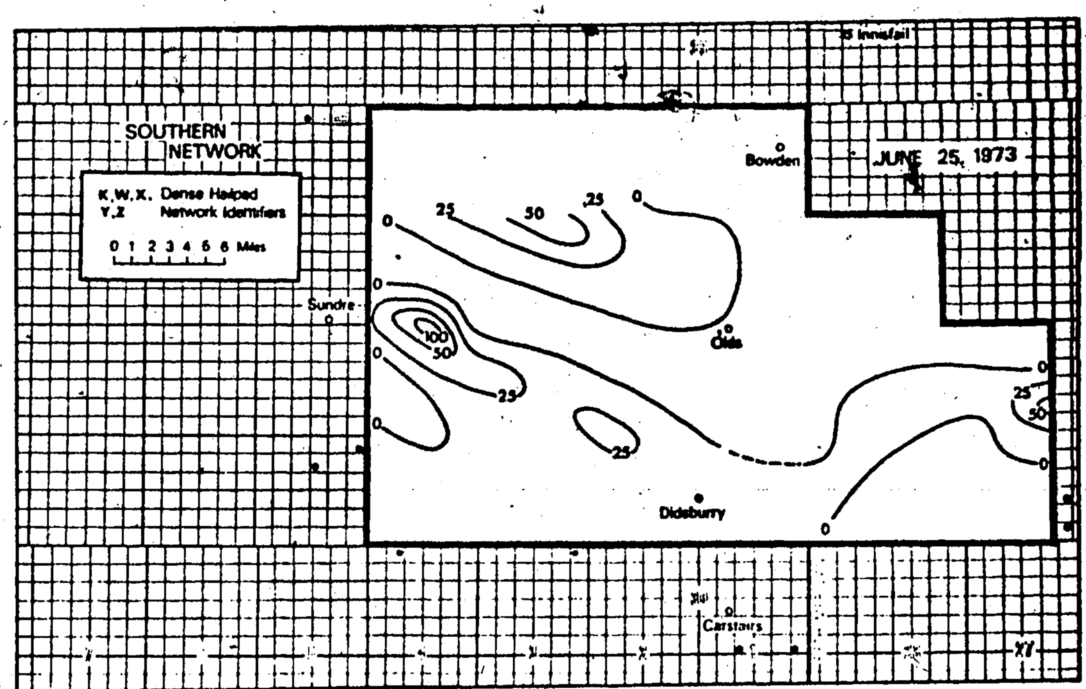

Figure A1. Pattern of impact energy (J m^{-2}) over the Southern Network on June 25th, 1973. (Hailpad installations were not complete at this time.)

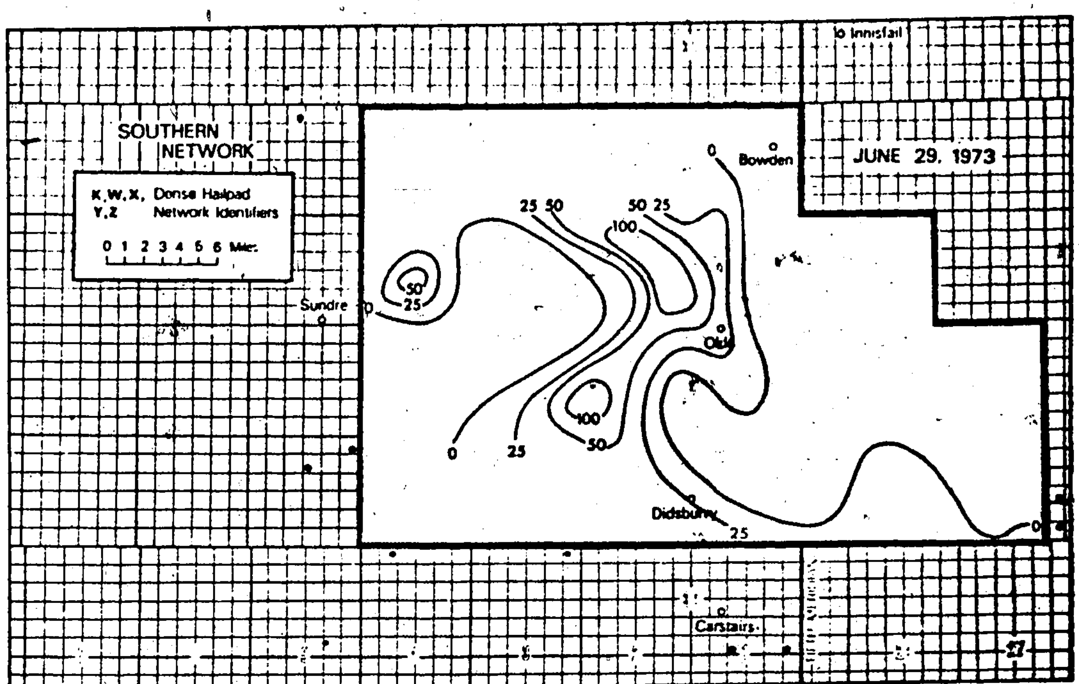

Figure A2. Pattern of impact energy (J m^{-2}) over the Southern Network on June 29th, 1973. (Hailpad installations were not complete at this time.)

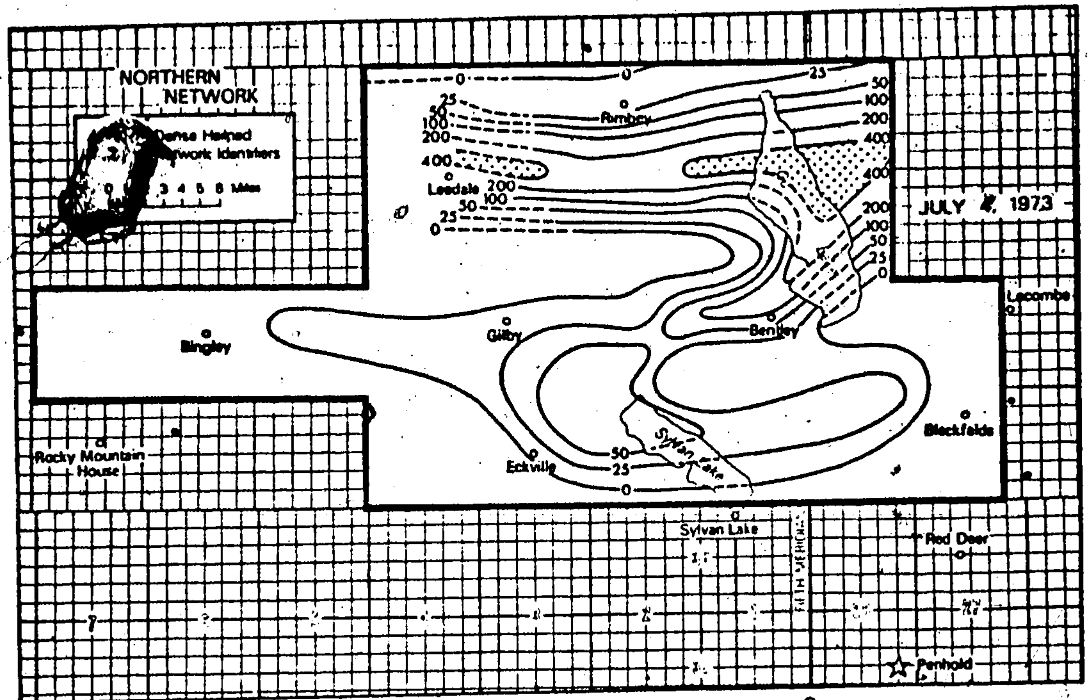

Figure A3. Pattern of impact energy ($J\ m^{-2}$) over the Northern Network on July 4th, 1973. (Hailpad installations were not complete at this time.)

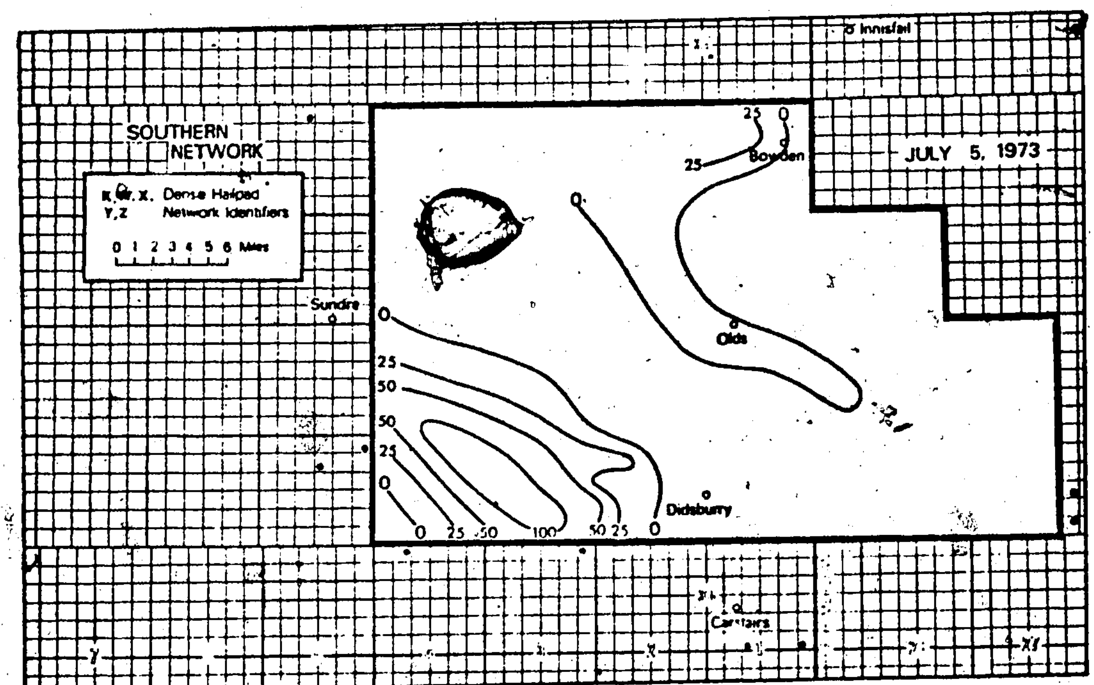

Figure A4. Pattern of impact energy ($J\ m^{-2}$) over the Southern Network on July 5th, 1973. (Hailpad installations were not complete at this time.)

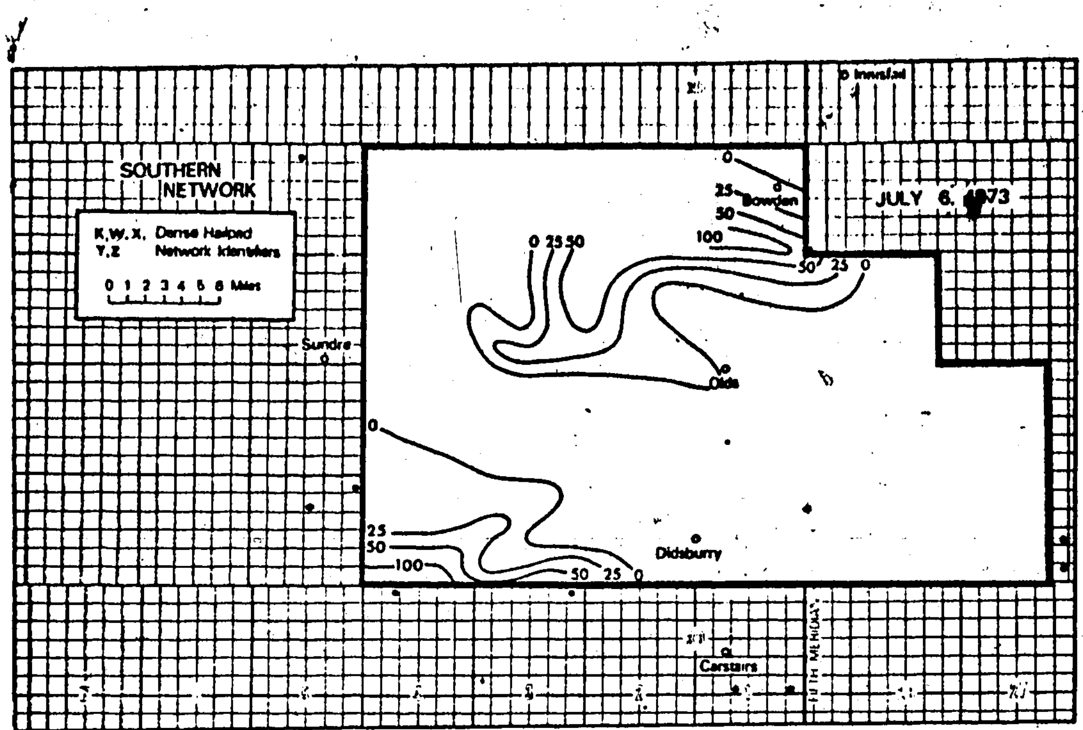

Figure A5. Pattern of impact energy (J m^{-2}) over the Southern Network on July 6th, 1973. (Hailpad installations were not complete at this time.)

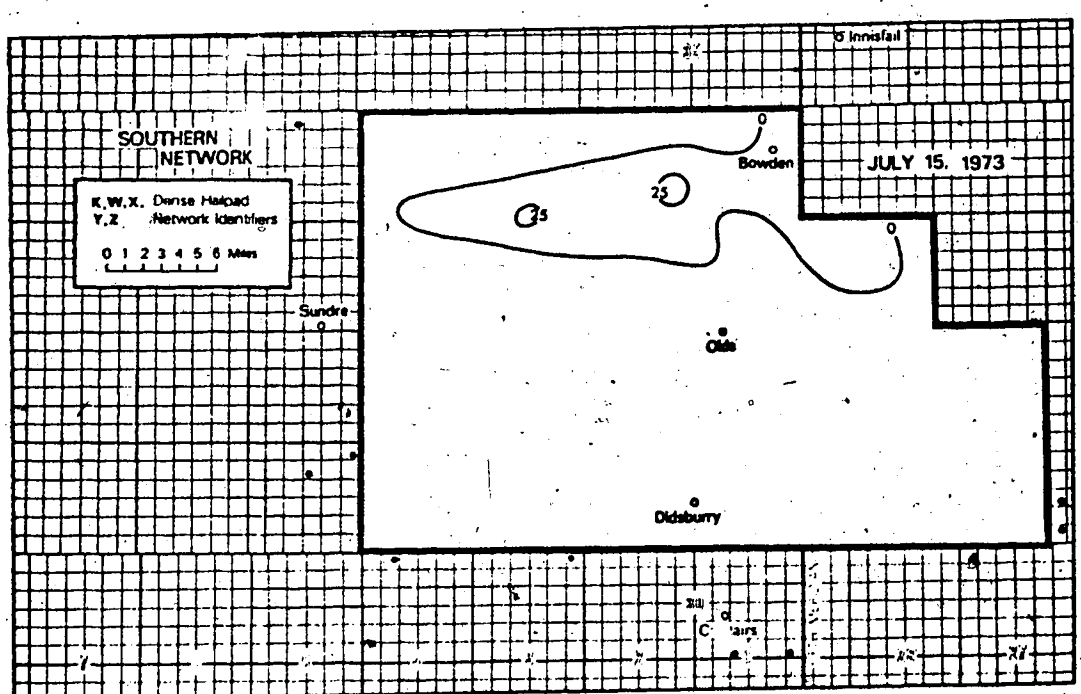

Figure A6. Pattern of impact energy (J m^{-2}) over the Southern Network on July 15th, 1973.

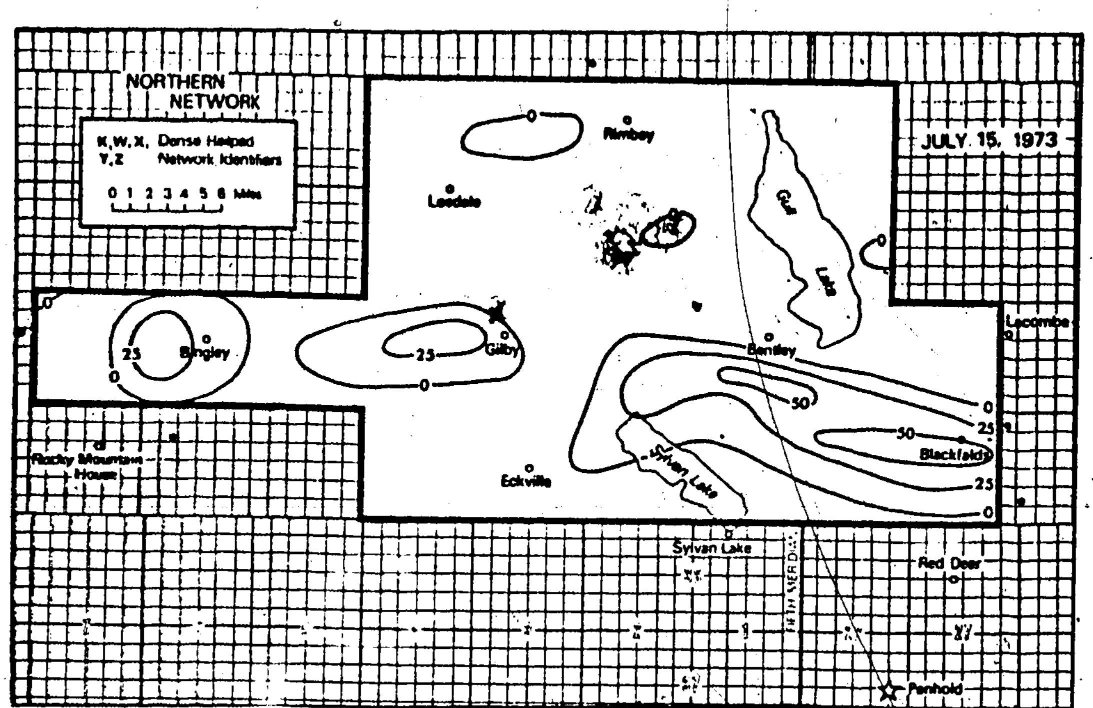

Figure A7. Pattern of impact energy (J m^{-2}) over the Northern Network on July 15th, 1973.

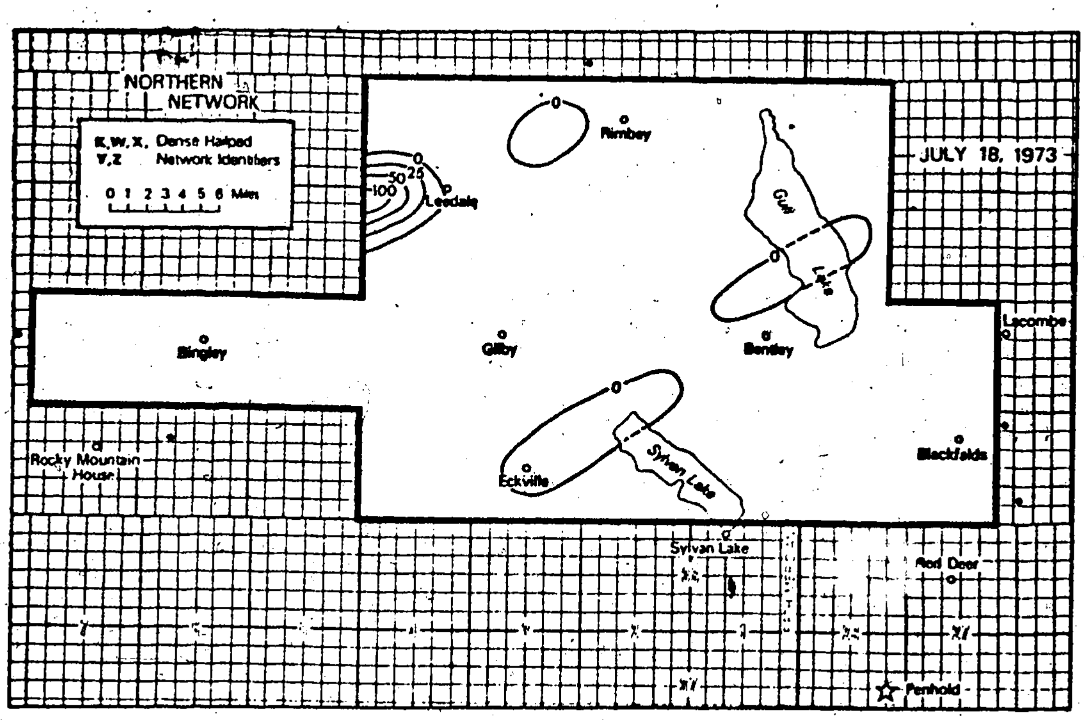

Figure A8. Pattern of impact energy (J m^{-2}) over the Northern Network on July 18th, 1973.

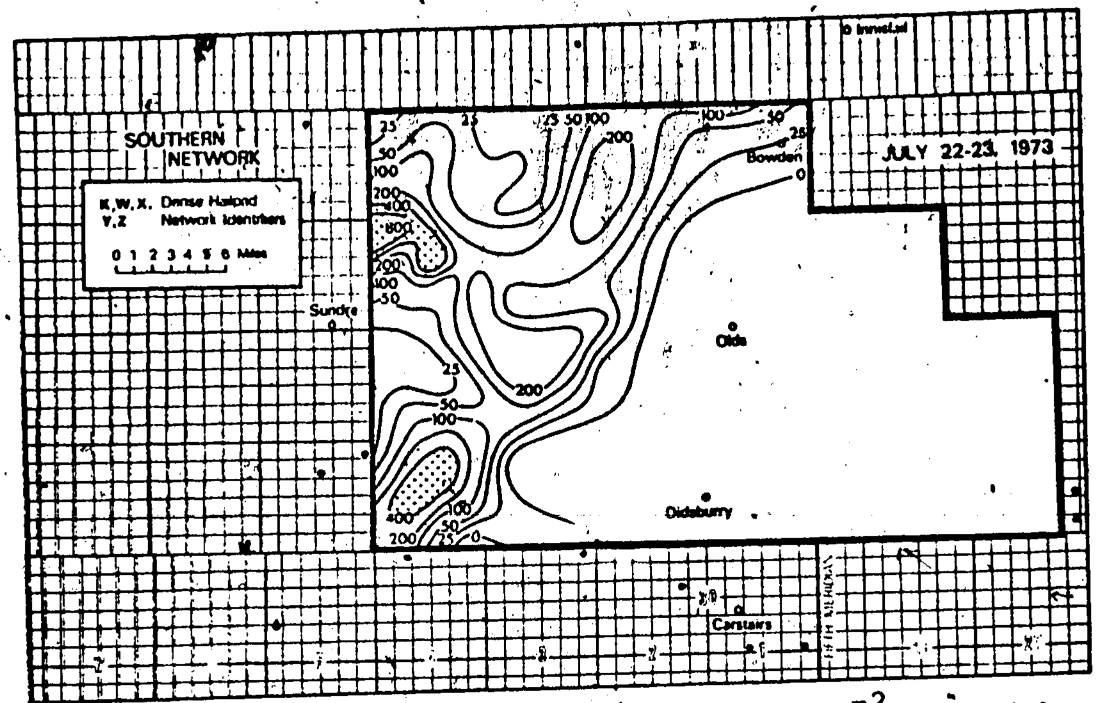

Figure A9. Pattern of impact energy ($J\ m^{-2}$) over the Southern Network on July 22-23rd, 1973.

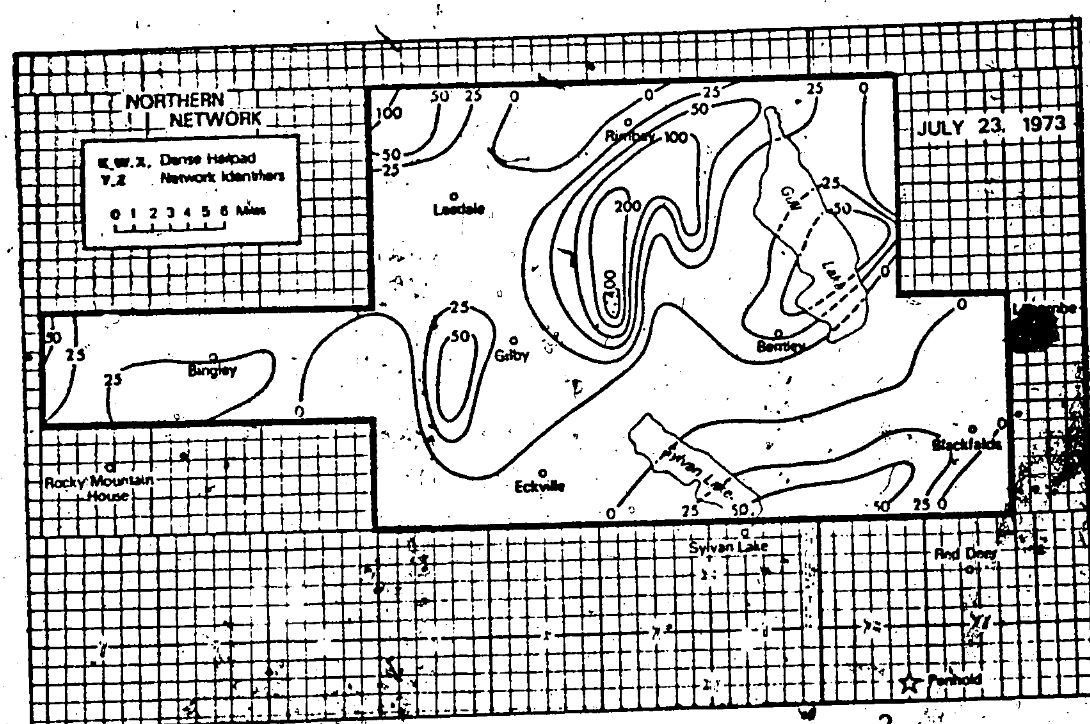

Figure A10. Pattern of impact energy ($J\ m^{-2}$) over the Northern Network on July 23rd, 1973.

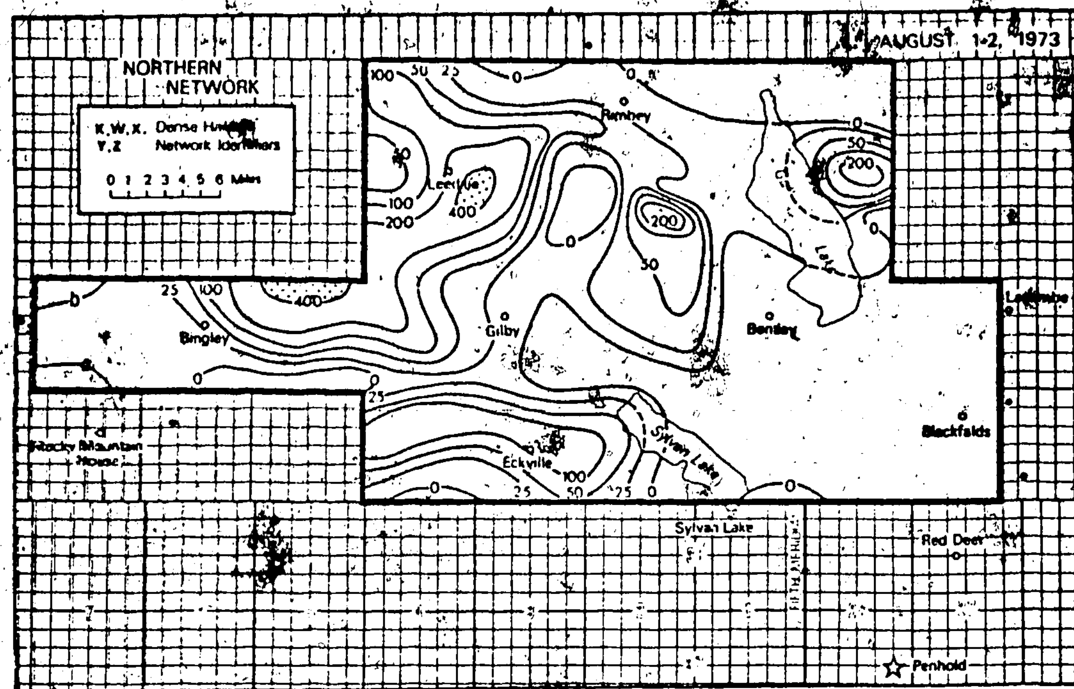

Figure A11. Pattern of impact energy (J m^{-2}) over the Northern Network on August 1-2nd, 1973.

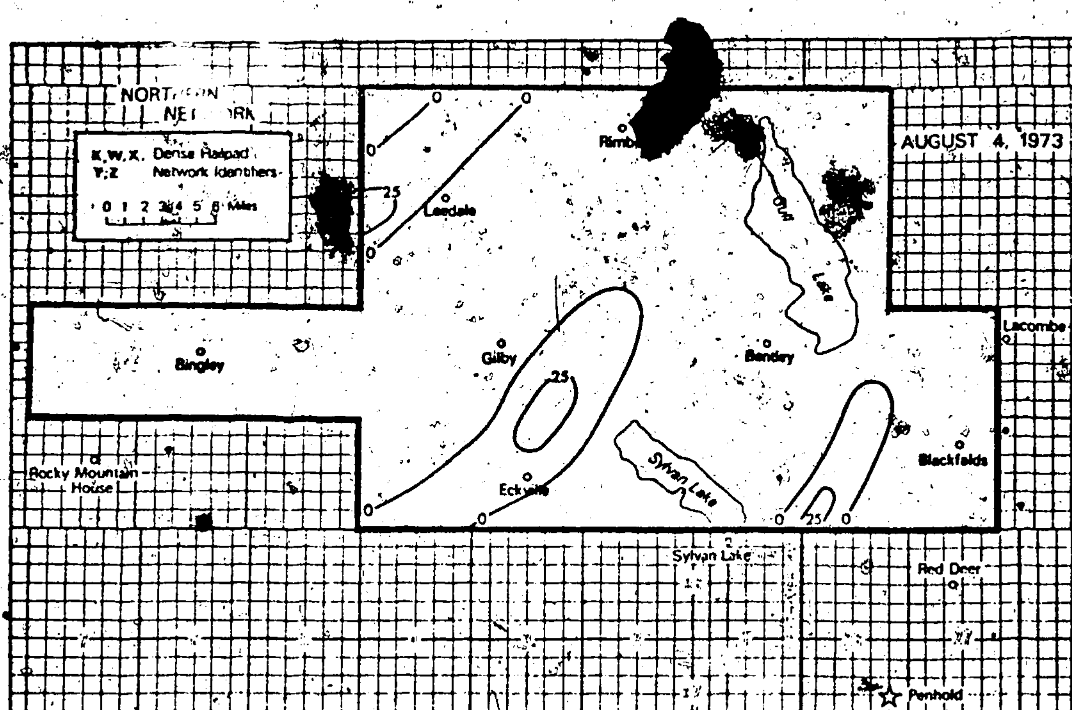

Figure A12. Pattern of impact energy (J m^{-2}) over the Northern Network on August 4th, 1973.

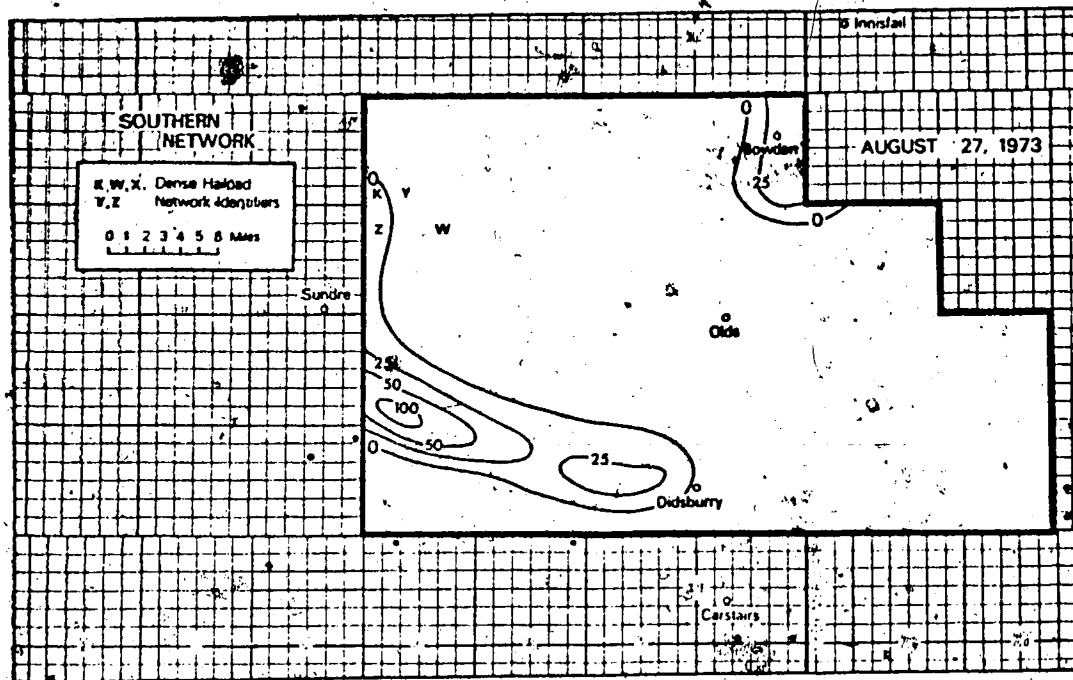

Figure A13. Pattern of impact energy (J m^{-2}) over the Southern Network on August 27th, 1973.

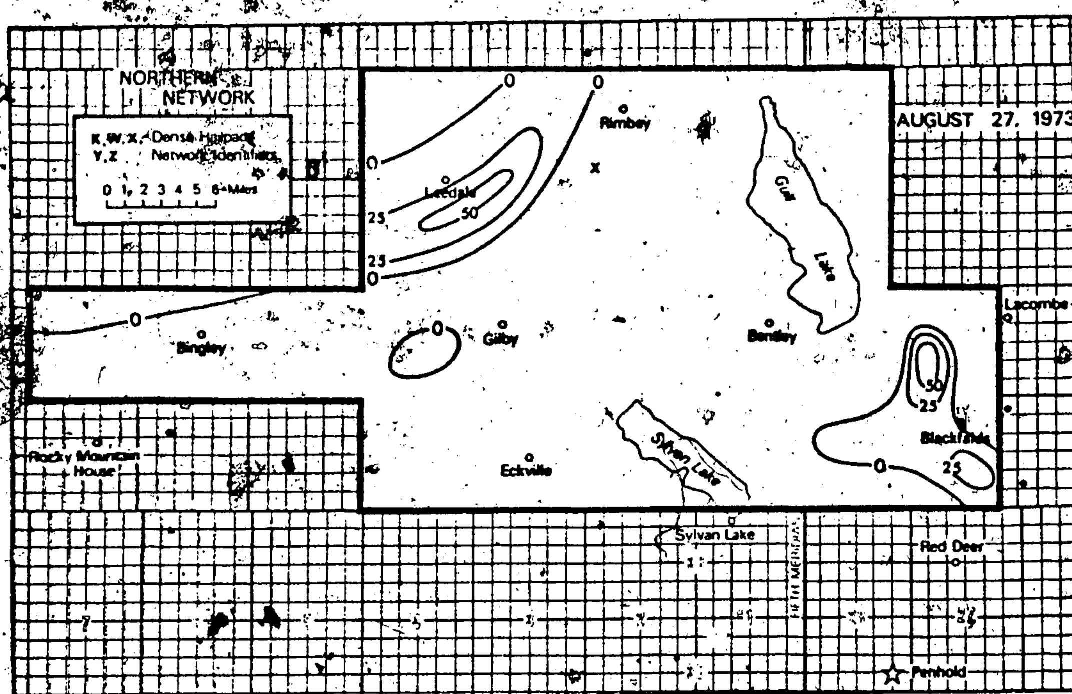

Figure A14. Pattern of impact energy (J m^{-2}) over the Northern Network on August 27th, 1973.

APPENDIX V

SUMMARY OF DATA FOR THE 761 HAILPADS OF THIS 1973 ALBERTA STUDY

Abbreviations used in the table heading are as follows:

Q - quarter-section (1-SE, 2-SW, 3-NW, 4-NE, 5-center of section)
SX - section number in the township (1,2,.....,36)
TS - township number
RG - range number (nos. 1-8 are west of 5th meridian while nos. >20 are east).

Values of ice mass, impact momentum, and impact energy, have units of g, kg m s^{-1}, and Joules respectively per m^2.

Numbers of hailstones are per hailpad (i.e., ft^{-2}).

PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	GRAPE	WALNUT	GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND CENTC	CVRG	MAX. DIAM.	MASS (CM)	IMPACT MOM.	ENERGY
JUNE 25TH. SOUTHERN NETWORK:																							
337	4	9	33	1	33	2	0	0	0	0	35	85.9	14.1	0.0	0.0	0.0	0.0	0.1	0.8	0.63	23.	0.22	[illegible]
887	3	22	33	2	95	106	1	0	0	0	202	11.4	62.2	6.3	0.0	0.0	0.0	1.4	7.2	1.33	311.	3.75	23.1
416	3	1	33	4	190	300	0	0	0	0	490	7.1	92.9	0.0	0.0	0.0	0.0	4.8	20.7	[illegible]	965.	11.90	74.4
879	2	6	33	4	20	4	0	0	0	0	24	[illegible]	35.1	0.0	0.0	0.0	0.0	0.0	0.6	0.63	17.	0.17	0.9
211	2	14	33	4	22	5	0	0	0	0	27	[illegible]	43.3	0.0	0.0	0.0	0.0	0.1	0.6	0.77	21.	0.21	1.1
225	4	29	33	3	[illegible]	46	0	0	0	0	346	57.6	42.4	0.0	0.0	0.0	0.0	0.8	2.2	1.05	269.	2.77	14.5
254	4	23	33	3	16	29	0	0	0	0	45	3.8	96.2	0.0	0.0	0.0	0.0	0.7	2.4	1.19	131.	1.75	[illegible]
830	3	17	33	2	35	41	1	0	0	0	77	7.5	75.8	16.7	0.0	0.0	0.0	0.8	3.1	1.47	153.	1.97	13.1
842	1	36	33	2	50	0	0	0	0	0	50	100.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.50	30.	0.29	1.4
339	3	7	33	1	100	69	0	0	0	0	169	33.9	66.1	0.0	0.0	[illegible]	0.0	0.5	4.5	0.91	152.	1.58	8.2
345	1	33	32	1	6	4	0	0	0	0	10	[illegible]	64.3	0.0	0.0	0.0	0.0	0.0	0.3	0.63	9.	0.09	0.5
178	3	8	32	4	12	1	0	0	0	0	13	[illegible]	18.4	0.0	0.0	0.0	0.0	0.0	0.3	0.63	9.	0.08	0.4
218	1	24	32	3	96	50	0	0	0	0	146	24.2	75.8	0.0	0.0	0.0	0.0	0.7	4.4	0.91	172.	1.94	11.1
382	1	3	32	2	180	22	0	0	0	0	202	75.2	[illegible]	0.0	0.0	0.0	0.0	0.4	4.5	0.63	138.	1.35	6.7
445	1	3	32	2	100	65	0	0	0	0	165	15.4	[illegible]	0.0	0.0	0.0	0.0	1.1	5.6	1.19	242.	2.92	18.1
65	1	13	32	27	1200	150	0	0	0	0	1350	74.6	[illegible]	0.0	0.0	0.0	0.0	2.5	30.0	0.63	924.	9.08	44.7
157	2	35	32	4	70	50	5	0	0	0	125	5.6	50.6	43.8	0.0	0.0	0.0	1.7	5.8	1.75	332.	4.72	34.9
535	1	1	32	3	60	23	2	0	0	0	85	20.5	43.6	35.9	0.0	0.0	0.0	0.3	2.6	1.33	108.	1.20	8.2
536	1	1	32	3	50	23	0	0	0	0	73	19.0	81.0	0.0	0.0	0.0	0.0	0.5	2.4	1.05	101.	[illegible]	7.3
367	1	6	32	3	0	13	0	0	0	0	13	0.0	100.0	0.0	0.0	0.0	0.0	0.2	0.6	0.91	30.	0.37	2.2
560	3	14	32	3	80	111	0	0	0	0	191	10.3	89.7	0.0	0.0	0.0	0.0	1.4	7.0	1.19	303.	3.59	21.6
177	1	32	32	3	115	17	0	0	0	0	132	64.3	35.7	0.0	0.0	0.0	0.0	0.3	3.0	0.91	97.	0.98	5.0
479	3	19	32	3	470	21	4	0	0	0	495	49.7	16.2	34.0	0.0	0.0	0.0	1.3	11.5	1.61	404.	4.48	26.3
542	4	7	32	2	150	139	0	0	0	0	289	16.7	83.3	0.0	0.0	0.0	0.0	1.6	9.3	1.05	376.	4.30	25.1
550	3	20	32	2	140	4	0	0	0	0	144	92.8	7.2	0.0	0.0	0.0	0.0	0.2	3.0	0.63	90.	0.87	4.2
292	3	5	32	28	320	157	0	0	0	0	477	26.7	73.3	0.0	0.0	0.0	0.0	2.1	13.7	1.05	520.	5.83	33.4
268	1	17	32	28	40	18	0	0	0	0	58	41.0	59.0	0.0	0.0	0.0	0.0	0.2	1.5	0.91	50.	0.52	2.7
122	1	16	32	27	500	5	0	0	0	0	505	97.4	2.6	0.0	0.0	0.0	0.0	0.7	10.5	0.63	311.	2.98	14.3
284	3	32	31	28	5	0	0	0	0	0	5	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.50	3.	0.03	0.1
553	3	15	32	2	5	1	0	0	0	0	6	64.9	35.1	0.0	0.0	0.0	0.0	0.0	0.1	0.63	4.	0.04	0.2
826	2	36	33	3	280	163	14	0	0	0	457	12.0	54.4	33.6	0.0	0.0	0.0	3.6	16.4	1.47	770.	9.84	65.2
33	3	34	31	27	11	0	0	0	0	0	11	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.50	7.	0.06	0.3

END OF FILE

	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= >GLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTO	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MCM.	ENERGY
	JUNE 29TH, SOUTHERN NETWORK:																						
1	343	4	30	33	2	480	92	0	0	0	0	572	65.9	34.1	0.0	0.0	0.0	0.0	1.2	13.1	0.63	411.	4.08	20.3
2	357	1	30	33	1	1350	8	0	0	0	0	1358	98.2	1.8	0.0	0.0	0.0	0.0	1.9	26.3	0.77	834.	7.99	38.3
3	867	2	30	32	1	465	6	0	0	0	0	471	98.6	1.4	0.0	0.0	0.0	0.0	0.7	9.8	0.63	291.	2.79	13.4
4	537	1	1	32	3	1600	0	0	0	0	0	1600	100.0	0.0	0.0	0.0	0.0	0.0	2.2	33.2	0.50	575.	9.33	44.6
5	847	2	2	31	1	180	78	1	0	0	0	259	19.9	71.4	8.7	0.0	0.0	0.0	1.5	5.2	1.47	344.	4.10	25.2
6	749	1	4	31	28	100	51	0	0	0	0	151	29.9	70.1	0.0	0.0	0.0	0.0	0.6	4.2	0.91	155.	1.69	9.3
7	438	4	27	33	4	84	67	0	0	0	0	151	22.4	77.6	0.0	0.0	0.0	0.0	0.7	4.5	0.91	171.	1.88	10.5
8	623	1	5	34	1	800	40	0	0	0	0	843	87.3	12.7	0.0	0.0	0.0	0.0	1.3	18.1	0.63	543.	5.26	25.9
9	868	3	22	33	2	3600	78	0	0	0	0	3678	94.5	5.5	0.0	0.0	0.0	0.0	5.3	77.3	0.63	2294.	22.07	106.2
10	839	4	20	33	4	385	143	0	0	0	0	528	48.3	51.7	0.0	0.0	0.0	0.0	1.4	13.0	0.77	427.	4.34	22.2
11	442	2	22	33	4	345	288	0	0	0	0	633	20.5	79.5	0.0	0.0	0.0	0.0	3.2	19.7	0.91	755.	8.38	47.0
12	831	3	17	33	2	550	7	0	0	0	0	557	96.7	3.3	0.0	0.0	0.0	0.0	0.8	11.6	0.63	344.	3.30	15.9
13	362	3	7	33	1	3900	1	0	0	0	0	3901	99.7	0.3	0.0	0.0	0.0	0.0	5.3	81.0	0.91	2381.	22.78	109.0
14	906	3	9	32	1	64	5	0	0	0	0	69	82.6	17.4	0.0	0.0	0.0	0.0	0.1	1.5	0.63	45.	0.44	2.2
15	388	1	6	32	3	450	4	0	0	0	0	454	97.7	2.3	0.0	0.0	0.0	0.0	0.6	9.5	0.63	279.	2.68	12.8
16	561	3	14	32	3	1600	6	0	0	0	0	1606	99.0	1.0	0.0	0.0	0.0	0.0	2.2	33.4	0.63	983.	9.41	45.0
17	563	4	7	32	2	4600	8	0	0	0	0	4608	99.5	0.5	0.0	0.0	0.0	0.0	6.3	95.7	0.63	2814.	26.92	128.8
18	531	3	15	32	2	1600	20	0	0	0	0	1620	96.7	3.3	0.0	0.0	0.0	0.0	2.3	33.9	0.63	1001.	9.60	46.1
19	551	3	20	32	2	3000	10	0	0	0	0	3010	99.1	0.9	0.0	0.0	0.0	0.0	4.1	62.6	0.63	1841.	17.62	84.3
20	766	2	22	32	1	640	4	0	0	0	0	644	98.3	1.7	0.0	0.0	0.0	0.0	0.9	13.4	0.63	395.	3.79	18.1
21	692	3	17	31	28	20	13	0	0	0	0	33	25.2	74.8	0.0	0.0	0.0	0.0	0.1	1.0	1.05	36.	0.39	2.2
22	782	4	29	31	28	32	24	0	0	0	[illegible]	56	33.0	67.0	0.0	0.0	0.0	0.0	0.2	1.5	0.63	50.	0.52	2.7
23	98	3	6	31	27	125	33	0	[illegible]	[illegible]	[illegible]	158	49.5	50.5	0.0	0.0	0.0	0.0	0.4	3.9	0.91	131.	1.35	7.0
24	57	2	11	31	27	0	6	0	[illegible]	[illegible]	[illegible]	6	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.2	0.63	8.	0.08	0.5
25	435	2	14	33	4	200	19	0	0	[illegible]	[illegible]	219	76.6	23.4	0.0	0.0	0.0	0.0	0.4	4.8	0.77	149.	1.47	7.3
26	824	2	36	33	3	1800	0	0	[illegible]	[illegible]	[illegible]	1800	100.0	0.0	0.0	0.0	0.0	0.0	2.5	37.3	0.50	1097.	10.49	50.2
27	900	2	15	32	1	100	22	0	0	0	[illegible]	122	62.7	37.3	0.0	0.0	0.0	0.0	0.3	2.8	[illegible]	69.	0.89	4.4

END OF FILE

	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= >GLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTO	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MCM.	ENERGY
	JULY 4TH, NORTHERN NETWORK:																						
1	324	2	19	39	2	64	161	5	0	0	0	230	3.2	82.3	14.5	0.0	0.0	0.0	3.4	12.1	1.47	637.	8.35	55.5
2	311	4	10	39	2	45	42	0	0	0	0	87	19.7	80.3	0.0	0.0	0.0	0.0	0.4	2.7	0.91	103.	1.14	6.4
3	330	4	30	39	1	130	117	4	0	0	0	251	13.5	64.8	21.8	0.0	0.0	0.0	1.7	8.6	1.33	366.	4.38	26.9
4	471	4	3	40	2	120	62	0	0	0	0	182	36.7	63.3	0.0	0.0	0.0	0.0	0.6	4.8	0.77	165.	1.72	9.1
5	472	4	3	40	2	40	62	0	0	0	0	102	6.8	93.2	0.0	0.0	0.0	0.0	1.0	4.4	1.19	207.	2.58	16.3
6	493	2	16	40	1	115	58	0	0	0	0	173	28.1	71.9	0.0	0.0	0.0	0.0	0.7	4.9	1.05	184.	2.03	11.4
7	1594	3	1	40	28	250	121	0	0	0	0	371	22.8	77.2	0.0	0.0	0.0	0.0	1.9	11.4	1.05	453.	5.20	30.5
8	1488	2	28	40	5	55	4	0	0	0	0	59	83.6	16.4	0.0	0.0	0.0	0.0	0.1	1.3	0.63	39.	0.38	1.8
9	683	2	21	40	5	17	9	0	0	0	0	26	33.8	66.2	0.0	0.0	0.0	0.0	0.1	0.7	0.91	24.	0.26	1.4
10	643	3	15	40	4	60	30	0	0	0	0	90	41.6	58.4	0.0	0.0	0.0	0.0	0.3	2.3	0.77	76.	0.78	4.0
11	1517	3	3	40	3	125	173	2	0	0	0	300	7.7	84.3	8.0	0.0	0.0	0.0	2.8	12.3	1.47	574.	7.15	45.4
12	1478	3	13	40	3	350	237	0	0	0	0	587	23.4	76.6	0.0	0.0	0.0	0.0	2.8	17.6	1.05	671.	7.43	41.7
13	1516	1	18	40	3	160	36	0	0	0	0	196	51.5	48.5	0.0	0.0	0.0	0.0	0.5	4.8	0.91	159.	1.65	8.7
14	1445	2	28	40	3	60	74	0	0	0	0	134	13.7	86.3	0.0	0.0	0.0	0.0	0.8	4.5	1.05	182.	2.09	12.2
15	463	2	22	40	2	100	111	0	0	0	0	211	11.2	88.8	0.0	0.0	0.0	0.0	1.6	7.8	1.19	340.	4.08	24.9
16	977	1	26	40	2	300	314	0	0	0	0	614	15.8	84.2	0.0	0.0	0.0	0.0	3.4	19.8	1.19	794.	9.08	52.8
17	993	1	26	40	2	310	380	0	0	0	0	690	12.9	87.1	0.0	0.0	0.0	0.0	4.5	23.8	1.05	585.	11.41	67.0
18	468	2	6	40	2	430	244	0	0	0	0	674	22.4	77.6	0.0	0.0	0.0	0.0	3.4	20.4	1.19	802.	9.17	53.5

	PAD NO.	Q	SX	TS	RG	SHOT	PEA	GRAPE	WALNUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% DENTD	GND CVRD	MAX. DIAM.	MASS (CM)	IMPACT MOM.	IMPACT ENERGY
19	246	1	4	40	1	36	33	0	C	0	0	67	17.8	82.2	0.0	0.0	0.0	0.0	0.4	2.2	1.05	67.	0.98	5.6
20	253	3	13	40	1	90	90	C	C	C	0	170	14.2	85.8	[illegible]	0.0	0.0	0.0	1.1	5.8	1.05	236.	2.70	15.6
21	515	2	18	40	1	49	27	0	[illegible]	[illegible]	0	76	20.9	79.1	0.0	0.0	0.0	0.0	C.4	2.4	1.05	97.	1.12	6.5
22	491	2	28	40	1	650	662	1	C	[illegible]	0	1313	16.8	81.8	1.4	0.0	0.0	0.0	7.0	41.8	1.33	1647.	18.69	107.8
23	1470	2	2	41	1	180	203	51	C	[illegible]	0	434	2.7	33.9	63.4	0.0	0.0	0.0	8.5	25.3	1.75	1633.	24.34	185.8
24	745	2	5	41	1	43	32	0	0	[illegible]	0	75	23.3	76.7	0.0	0.0	0.0	0.C	0.3	2.2	C.91	84.	0.92	5.1
25	1514	3	16	41	1	425	252	0	0	[illegible]	0	677	30.6	69.4	0.0	0.0	0.0	0.0	2.5	18.8	1.05	671.	7.17	38.7
26	1453	2	10	41	1	180	130	0	0	0	0	310	29.0	71.0	0.0	0.0	0.0	0.0	1.1	8.5	0.91	302.	3.22	17.3
27	1580	3	19	41	1	120	89	6	0	0	0	215	7.2	55.5	37.4	0.0	0.0	0.0	2.4	9.1	1.75	481.	6.58	46.7
28	850	4	24	41	2	175	207	11	0	0	0	393	5.4	65.4	29.2	0.0	0.0	0.0	4.8	18.0	1.75	557.	12.92	89.8
29	1318	2	14	42	2	170	239	2	0	0	0	411	6.0	88.4	5.6	0.0	0.0	0.0	4.8	18.7	[illegible].47	533.	12.00	78.5
30	1291	1	2	42	2	320	460	41	3	1	0	825	2.0	25.6	34.7	22.7	15.2	0.0	14.5	43.8	3.47	3008.	49.48	439.0
31	1255	4	6	42	2	320	294	20	0	0	0	634	5.4	50.2	44.5	0.0	0.0	0.0	7.9	28.6	2.03	1597.	22.58	166.1
32	1587	4	16	42	2	150	128	0	0	0	0	278	19.5	80.5	0.0	0.0	0.0	0.0	1.4	8.5	1.19	332.	3.74	21.4
33	1310	2	24	42	2	110	141	1	0	0	0	252	8.4	87.6	4.0	0.0	0.0	0.0	2.3	10.2	1.33	473.	5.64	36.7
34	1302	2	25	42	2	90	82	0	0	0	C	172	17.6	82.4	0.0	0.0	0.0	0.0	0.9	5.4	1.19	216.	2.46	14.3
35	1324	2	28	42	2	10	1	0	0	0	0	11	78.7	21.3	0.0	0.0	[illegible]	0.0	0.0	0.2	0.63	7.	0.07	0.4
36	1253	2	17	42	1	500	568	0	0	0	0	1068	12.9	87.1	0.0	0.0	0.0	0.0	7.1	37.0	1.19	1551.	18.18	108.3
37	462	2	29	39	2	450	338	6	0	0	0	794	16.0	68.2	15.8	0.0	0.0	0.0	4.7	25.9	1.75	1079.	12.82	78.5
38	1250	3	31	42	1	16	6	0	0	0	0	22	33.5	66.5	0.0	0.0	0.0	0.0	0.1	0.6	0.91	22.	0.24	1.3
39	1443	2	12	40	4	0	15	0	0	0	0	15	0.0	100.0	0.0	0.0	0.0	0.0	0.2	0.7	0.91	32.	0.39	2.4
40	642	3	15	40	4	180	144	0	0	0	0	324	30.9	69.1	0.0	0.0	0.0	0.0	1.1	8.7	0.77	299.	3.11	16.2
41	1479	3	13	40	3	168	15	0	0	0	0	183	73.2	26.8	0.0	0.0	0.0	0.0	0.3	4.1	1.05	127.	1.27	6.4

END OF FILE

	PAD NO.	Q	SX	TS	RG	SHOT	PEA	GRAPE	WALNUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% DENTD	GND CVRD	MAX. DIAM.	MASS (CM)	IMPACT MOM.	IMPACT ENERGY
	JULY 5TH. SOUTHERN NETWORK:																							
1	1233	4	16	31	3	960	752	1	0	0	0	1713	22.2	76.5	1.2	0.0	0.0	0.0	7.9	51.1	1.33	1934.	21.41	120.3
2	1365	3	36	30	3	650	202	0	0	0	0	852	51.3	48.7	0.0	0.0	0.0	0.0	2.1	20.7	0.77	679.	6.92	35.3
3	179	3	8	32	4	800	458	0	0	0	0	1258	37.9	62.1	0.0	0.0	0.0	0.0	2.7	32.5	0.91	1096.	11.32	58.8
4	478	4	14	32	4	800	15	0	0	0	0	815	95.2	4.8	0.0	0.0	0.0	[illegible]	1.2	17.1	0.63	507.	4.87	23.4
5	1238	1	19	31	2	45	37	0	0	0	0	82	26.3	73.7	0.0	0.0	0.0	0.0	0.3	2.3	0.77	83.	0.69	4.8
6	1747	3	24	31	4	1000	607	0	0	0	0	1607	29.[illegible]	70.9	0.0	[illegible]	0.0	0.0	6.1	44.7	1.19	1616.	17.47	95.8
7	1373	1	23	31	3	750	370	0	0	0	C	1120	33.[illegible]	66.4	0.0	0.0	[illegible]	0.0	4.0	[illegible]	0.91	1034.	11.55	62.2
8	153	1	30	31	3	600	775	0	0	0	0	1375	12.0	88.0	0.0	0.0	0.0	0.C	[illegible]	48.[illegible]	1.05	2033.	23.66	139.6
9	220	4	7	32	28	55	17	C	0	0	0	72	49.6	50.4	0.0	0.0	0.0	0.C	0.2	1.8	0.77	58.	0.60	3.1
10	947	3	24	32	1	80	48	0	0	0	0	128	38.2	61.8	0.0	0.0	0.0	0.C	0.4	3.3	0.63	110.	1.13	5.8
11	886	1	14	32	29	15	2	0	0	C	0	17	73.5	26.5	0.0	0.0	0.0	0.0	0.0	0.4	0.63	12.	0.12	0.6
12	596	4	21	34	1	1025	65	0	0	0	0	1090	84.9	15.1	C.0	0.0	0.0	0.0	1.8	23.5	0.77	710.	6.91	33.6
13	1730	1	20	31	4	7	5	0	0	0	0	12	34.1	65.9	0.0	C.0	0.0	0.0	0.0	0.3	0.63	11.	0.11	C.6
14	844	3	22	33	2	310	7	0	0	0	0	317	94.3	5.7	0.0	0.0	0.0	0.0	0.5	6.7	0.63	198.	1.90	[illegible]
15	267	2	6	33	4	60	2	0	0	C	0	62	91.7	8.3	0.0	0.0	C.0	0.0	0.1	1.3	[illegible]	39.	0.38	1.8
16	473	4	29	32	4	560	16	0	0	0	0	576	92.8	7.2	0.0	0.0	0.0	0.0	0.9	12.2	0.63	362.	3.49	16.8
17	538	1	1	32	3	22	0	0	0	0	0	22	100.0	0.0	C.0	0.0	0.0	0.0	0.0	0.5	0.50	13.	0.13	0.6
18	562	3	14	32	3	13	5	0	0	0	0	18	49.0	51.0	0.0	0.0	0.0	0.0	0.0	0.4	0.63	14.	0.15	0.7
19	480	3	19	32	3	330	6	0	0	0	0	336	95.3	4.7	0.0	0.0	0.0	0.0	0.5	7.0	0.63	269.	2.61	9.6
20	907	2	30	32	1	350	16	0	0	0	0	366	89.0	11.0	0.0	0.0	0.0	0.0	0.6	[illegible].8	0.63	234.	2.26	11.0
21	923	3	7	32	28	50	37	0	0	C	0	87	32.6	[illegible]	0.0	0.0	0.0	0.0	0.3	2.3	0.77	79.	0.62	4.3
22	1358	1	18	31	2	320	349	0	0	0	0	669	16.3	83.7	0.0	C.0	0.0	0.0	3.6	21.3	1.05	838.	9.49	[illegible]
23	1387	3	28	31	[illegible]	[illegible]	175	0	0	0	0	[illegible]	62.9	37.1	0.0	0.0	0.0	0.0	2.0	22.6	0.63	712.	7.10	35.5

END OF FILE

PAD NO.	Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTD	CVRD	MAX. DIAM.	MASS (CM)	IMPACT MOM.	ENERGY
JULY 6TH. SOUTHERN NETWORK:																							
629	1	9	34	1	1500	96	0	0	0	0	1596	82.8	17.2	0.0	0.0	0.0	0.0	2.7	34.6	0.77	1054.	10.30	50.5
351	2	1	34	1	2000	24	0	0	0	0	2024	96.9	3.1	0.0	0.0	0.0	0.0	2.9	42.3	0.63	1250.	11.99	57.5
622	1	5	34	1	2800	480	0	0	0	0	3280	68.3	31.7	0.0	0.0	0.0	0.0	6.4	74.4	0.63	2323.	22.59	114.2
1366	3	36	30	3	[illegible]	281	0	0	0	0	951	35.4	64.6	0.0	0.0	0.0	0.0	3.4	25.7	0.91	913.	9.76	52.8
594	4	21	34	1	50	0	0	0	0	0	50	100.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.50	30.	0.29	1.4
409	2	[illegible]	33	3	1050	0	0	0	0	0	1050	100.0	0.0	0.0	0.0	0.0	0.0	1.4	21.8	0.50	640.	6.12	29.3
308	4	23	33	3	2400	155	0	0	0	0	2555	84.7	15.3	0.0	0.0	0.0	0.0	4.2	55.1	0.77	1667.	16.21	79.0
1724	1	20	31	4	205	206	0	0	0	0	411	25.7	74.3	0.0	0.0	0.0	0.0	1.5	11.4	0.91	400.	4.21	22.2
1733	2	27	31	5	112	140	0	0	0	0	252	15.1	84.9	0.0	0.0	0.0	0.0	1.4	8.1	0.91	319.	3.61	20.6
1513	1	36	31	5	94	78	0	0	0	0	172	21.5	78.5	0.0	0.0	0.0	0.0	0.8	5.3	0.91	199.	2.19	12.2
1716	2	2	31	4	900	856	1	0	0	0	1757	15.5	83.5	0.9	0.0	0.0	0.0	10.3	57.3	1.33	2340.	27.19	161.3
1748	3	24	31	4	640	10	0	0	0	0	650	95.9	4.1	0.0	0.0	0.0	0.0	0.9	13.6	0.63	403.	3.87	18.6
1537	1	30	31	3	820	12	0	0	0	0	832	96.2	3.8	0.0	0.0	0.0	0.0	1.2	17.4	0.63	515.	4.95	23.8
610	4	31	32	1	90	0	0	0	0	0	90	100.0	0.0	0.0	0.0	0.0	0.0	0.1	1.9	0.50	55.	0.52	2.5
1746	4	32	30	4	400	791	0	0	0	0	1191	8.3	91.7	0.0	0.0	0.0	0.0	9.3	45.5	1.19	1945.	22.79	134.8
180	3	8	32	4	50	0	0	0	0	0	50	100.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.50	30.	0.29	1.4
1708	3	6	31	3	400	122	0	0	0	0	522	44.4	55.6	0.0	0.0	0.0	0.0	1.6	13.3	0.91	454.	4.75	25.1
422	1	34	31	3	33	5	0	0	0	0	38	71.0	29.0	0.0	0.0	0.0	0.0	0.1	0.9	0.63	27.	0.26	1.3
227	4	13	33	4	[illegible]	25	0	0	0	0	265	71.6	28.4	0.0	0.0	0.0	0.0	0.5	6.0	0.91	187.	1.86	9.3
829	2	36	33	3	2400	0	0	0	0	0	2400	100.0	0.0	0.0	0.0	0.0	0.0	3.3	49.8	0.50	1463.	13.99	66.9
832	3	17	33	2	900	10	0	0	0	0	910	97.1	2.9	0.0	0.0	0.0	0.0	1.3	19.0	0.63	561.	5.38	25.8
342	4	36	33	2	2440	176	0	0	0	0	2616	83.7	16.3	0.0	0.0	0.0	0.0	4.3	56.6	0.63	1713.	16.67	81.2
843	1	36	33	2	560	50	0	0	0	0	610	80.6	19.4	0.0	0.0	0.0	0.0	1.0	13.3	0.63	406.	3.96	19.4
344	1	33	33	1	850	25	0	0	0	0	875	92.6	7.4	0.0	0.0	0.0	0.0	1.3	18.5	0.63	550.	5.30	25.6
392	4	36	32	3	35	3	0	0	0	0	38	81.2	18.8	0.0	0.0	0.0	0.0	0.1	0.8	0.63	25.	0.25	1.2
1741	3	34	31	4	125	120	0	0	[illegible]	0	245	27.8	72.2	0.0	0.0	0.0	0.0	0.8	6.7	0.63	230.	2.40	12.5

END OF FILE

PAD NO.	Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTD	CVRD	MAX. DIAM.	MASS (CM)	IMPACT MOM.	ENERGY
JULY 15TH. SOUTHERN NETWORK:																							
915	2	1	34	1	65	23	0	0	0	0	88	47.4	52.6	0.0	0.0	0.0	0.0	0.2	2.2	0.77	72.	0.74	[illegible]
1820	1	1	34	4	10	12	0	0	0	0	22	10.4	89.6	0.0	0.0	0.0	0.0	0.2	0.8	0.91	37.	0.44	[illegible]
1675	2	16	34	2	90	37	0	0	0	0	127	45.8	54.2	0.0	0.0	0.0	0.0	0.3	3.2	0.77	104.	1.07	[illegible]
1804	4	11	34	3	20	36	0	0	0	0	56	13.6	86.4	0.0	0.0	0.0	0.0	0.3	1.8	0.77	68.	[illegible]	[illegible]
1002	3	4	34	[illegible]	22	6	0	0	0	0	28	57.6	42.4	0.0	0.0	0.0	0.0	0.1	0.7	0.63	21.	[illegible]	[illegible]
1808	2	4	34	3	120	106	0	0	0	0	226	17.8	82.2	0.0	0.0	0.0	0.0	1.2	7.1	1.05	284.	[illegible]	[illegible]
1810	3	8	34	3	20	4	0	0	0	0	24	58.7	41.3	0.0	0.0	0.0	0.0	0.1	0.6	0.77	[illegible]	[illegible]	[illegible]
1916	2	24	34	2	140	128	0	0	0	0	268	21.2	78.8	0.0	0.0	0.0	0.0	1.2	8.0	[illegible]	[illegible]	[illegible]	[illegible]
602	3	35	34	1	14	2	0	0	0	0	16	72.2	27.8	0.0	0.0	0.0	0.0	0.0	0.4	0.63	[illegible]	[illegible]	[illegible]
825	2	36	33	3	145	4	0	0	0	0	149	93.1	6.9	0.0	0.0	0.0	0.0	0.2	3.1	[illegible]	[illegible]	[illegible]	[illegible]
630	4	36	33	2	20	0	0	0	0	0	20	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.50	12.	[illegible]	[illegible]
841	1	36	33	2	21	10	0	0	0	0	31	43.7	56.3	0.0	0.0	0.0	0.0	0.1	0.8	0.63	26.	[illegible]	[illegible]
1059	1	27	33	28	5	1	0	0	0	0	6	45.5	54.5	0.0	0.0	0.0	0.0	0.0	0.2	0.77	5.	0.06	[illegible]
358	1	30	33	1	30	0	0	0	0	0	30	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.50	18.	0.17	[illegible]
1949	2	19	33	28	90	55	0	0	0	0	145	24.4	75.6	0.0	0.0	0.0	0.0	0.7	4.3	0.91	164.	1.82	[illegible]
1894	4	31	33	28	52	32	0	0	0	0	84	33.6	66.4	0.0	0.0	0.0	0.0	0.3	2.3	0.77	78.	0.82	[illegible]

END OF FILE

	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WALL	GLF	>GLF	% PAC/GND DENTO	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	ENERGY
	JULY 15TH. NORTHERN NETWORK:																						
1	331	4	30	39	1	12	1	0	0	0	0	13	81.6	18.4	0.0	0.0	0.0	0.0	0.0	0.3	0.63	9.	0.68	0.4
2	861	2	29	39	2	125	56	0	0	0	0	181	29.6	70.4	0.0	0.0	0.0	0.0	0.8	5.2	0.91	192.	2.11	11.8
3	1662	3	35	39	1	260	211	0	0	0	0	471	21.1	78.9	0.0	0.0	0.0	0.0	2.3	14.4	1.05	549.	6.10	34.3
4	1639	2	26	39	27	650	633	0	0	0	0	1283	20.1	79.9	0.0	0.0	0.0	0.0	[illegible]	39.0	1.05	1471.	16.20	190.2
5	1661	4	21	39	28	55	69	2	0	0	0	126	9.0	69.7	21.3	0.0	0.0	0.0	[illegible]	4.8	1.47	217.	2.68	17.1
6	1160	3	28	39	28	250	256	2	0	0	0	508	13.0	80.2	6.8	0.0	0.0	0.0	3.4	17.6	1.47	746.	8.54	53.6
7	1112	4	34	39	28	420	159	0	0	0	0	579	44.2	55.8	0.0	0.0	0.0	0.0	1.6	14.6	0.91	452.	5.05	26.5
8	1167	4	4	39	27	5	2	0	0	0	0	7	48.1	51.9	0.0	0.0	0.0	0.0	0.0	0.2	0.63	6.	0.06	0.2
9	1115	3	16	39	27	290	250	0	0	0	0	540	24.1	75.9	0.0	0.0	0.0	0.0	2.2	15.7	0.91	572.	6.17	33.5
10	403	4	28	39	27	410	419	0	0	0	0	829	18.9	81.1	0.0	0.0	0.0	0.0	4.0	25.4	1.05	568.	10.76	60.6
11	1672	4	7	40	6	560	200	0	0	0	0	760	50.9	49.1	0.0	0.0	0.0	0.0	1.9	18.4	0.63	598.	6.64	30.7
12	657	3	30	40	6	640	160	0	0	0	0	800	59.7	40.3	0.0	0.0	0.0	0.0	1.7	18.7	0.63	596.	5.95	29.9
13	494	2	16	40	1	145	227	2	0	0	0	374	6.4	89.0	4.6	0.0	0.0	0.0	4.0	16.2	1.33	783.	[illegible]	63.5
14	1274	3	1	40	28	870	157	0	0	0	0	1027	65.2	34.8	0.0	0.0	0.0	0.0	2.1	23.6	0.77	744.	7.42	37.2
15	708	1	26	40	6	15	4	0	0	0	0	19	34.4	65.6	0.0	0.0	0.0	0.0	0.1	0.5	0.91	[illegible]	0.21	1.2
16	714	4	21	40	6	100	16	0	0	0	0	116	69.8	30.2	0.0	0.0	0.0	0.0	0.2	2.6	0.63	81.	0.81	4.0
17	1504	1	15	40	5	150	6	0	0	0	0	156	85.7	14.3	0.0	0.0	0.0	0.0	0.3	3.4	0.91	102.	0.99	4.9
18	639	3	15	40	4	130	83	0	0	0	0	213	35.7	64.3	0.0	0.0	0.0	0.0	0.7	5.6	0.77	189.	1.95	10.1
19	1508	2	25	40	4	120	112	2	0	0	0	234	11.4	70.5	18.1	0.0	0.0	0.0	1.7	8.3	1.61	372.	4.60	29.4
20	728	1	18	40	3	50	4	0	0	0	0	54	82.2	17.8	0.0	0.0	0.0	0.0	0.1	1.2	0.63	36.	0.35	1.7
21	516	2	18	40	1	350	105	1	0	0	0	456	36.1	58.5	5.4	0.0	0.0	0.0	1.6	12.1	1.33	438.	4.60	27.0
22	1860	3	5	40	27	250	71	0	0	0	0	321	56.2	43.8	0.0	0.0	0.0	0.0	0.7	7.6	0.77	245.	2.49	13.4
23	1148	2	22	42	3	60	14	0	0	0	0	74	45.0	55.0	0.0	0.0	0.0	0.0	0.2	1.9	0.91	65.	0.64	3.7
24	1596	2	18	42	3	52	8	0	0	0	0	60	53.1	46.9	0.0	0.0	0.0	0.0	0.2	1.5	0.91	49.	0.51	2.3
25	851	4	24	41	2	160	3	0	0	0	0	163	90.4	9.6	0.0	0.0	0.0	0.0	0.3	3.5	0.91	134.	1.01	4.3
26	1612	4	13	41	28	15	10	0	0	0	0	25	35.7	64.3	0.0	0.0	0.0	0.0	0.1	0.7	0.63	22.	0.23	1.2
27	684	2	21	40	5	70	15	0	0	0	0	85	58.6	41.4	0.0	0.0	0.0	0.0	0.2	2.0	0.91	64.	0.65	3.3
28	466	2	22	40	2	480	99	0	0	0	0	579	62.3	37.7	0.0	0.0	0.0	0.0	1.2	13.4	0.77	427.	4.27	21.5
29	247	1	4	40	1	43	38	0	0	0	0	81	13.3	86.7	0.0	0.0	0.0	0.0	0.6	2.8	1.19	122.	1.47	9.0
30	326	2	19	39	2	12	0	0	0	0	0	12	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.50	7.	0.07	0.3
31	1863	2	8	39	26	48	36	0	0	0	0	84	27.0	73.0	0.0	0.0	0.0	0.0	0.3	2.4	0.77	85.	0.92	5.0
32	505	2	31	39	26	76	19	0	0	0	0	95	59.7	40.3	0.0	0.0	0.0	0.0	0.2	2.2	0.63	71.	0.71	3.5

END OF FILE

	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAC/GND DENTO	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	ENERGY
	JULY 18TH. NORTHERN NETWORK:																						
1	470	4	3	40	2	120	20	0	0	0	0	140	65.3	34.7	0.0	0.0	0.0	0.0	0.3	3.2	0.77	102.	1.02	5.1
2	1398	3	32	41	4	575	523	0	0	0	0	1098	16.9	83.1	0.0	0.0	0.0	0.0	6.1	35.2	1.19	1414.	16.22	94.7
3	1037	2	22	42	3	580	40	0	0	0	0	620	84.3	15.7	0.0	0.0	0.0	0.0	1.0	13.4	0.63	405.	3.94	19.2
4	1412	1	28	42	3	80	0	0	0	0	0	80	100.0	0.0	0.0	0.0	0.0	0.0	0.1	1.7	0.50	49.	0.47	2.2
5	981	2	5	41	1	60	21	0	0	0	0	81	45.1	54.9	0.0	0.0	0.0	0.0	0.2	2.0	0.77	69.	0.71	3.7
6	972	2	10	41	1	40	17	0	0	0	0	57	43.2	56.8	0.0	0.0	0.0	0.0	0.2	1.4	0.77	46.	0.50	2.6
7	489	2	6	40	2	190	86	0	0	0	0	276	44.3	55.7	0.0	0.0	0.0	0.0	0.7	6.9	0.77	228.	2.33	12.0
8	1838	1	28	41	28	60	22	0	0	0	0	82	46.4	53.6	0.0	0.0	0.0	0.0	0.2	2.0	0.77	68.	0.70	3.6
9	1080	4	26	39	3	600	7	0	0	0	0	607	96.9	3.1	0.0	0.0	0.0	0.0	0.9	12.7	0.63	375.	3.59	17.2
10	1428	2	8	42	4	1280	51	0	0	0	0	1331	89.7	10.3	0.0	0.0	0.0	0.0	2.0	28.3	0.77	849.	8.21	39.8

END OF FILE

	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DEN	TO CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	ENERGY
	JULY 22-23RD. SOUTHERN NETWORK:																							
1	1725	1	20	31	4	2000	1972	68	0	0	0	4040	10.7	48.5	40.9	0.0	0.0	0.0	27.0	136.6	2.03	6146.	78.00	522.1
2	386	1	6	32	3	1050	397	0	0	0	0	1447	47.3	52.7	0.0	0.0	0.0	0.0	3.8	35.7	0.91	1178.	12.04	61.9
3	408	2	5	33	3	735	581	0	0	0	0	1316	23.3	76.7	0.0	0.0	0.0	0.0	5.9	39.1	1.19	1455.	15.91	87.9
4	263	2	6	33	4	720	238	0	0	0	0	958	49.6	50.4	0.0	0.0	0.0	0.0	2.4	23.4	0.91	770.	7.87	40.5
5	1098	2	13	33	4	1600	1442	0	0	0	0	3042	18.1	81.9	0.0	0.0	0.0	0.0	16.4	97.0	1.79	3812.	43.02	246.1
6	437	2	14	33	4	1700	367	0	0	0	0	2067	59.3	40.7	0.0	0.0	0.0	0.0	4.7	48.6	1.05	1561.	15.74	79.9
7	224	1	17	33	3	1230	814	0	0	0	0	2094	27.9	72.1	0.0	0.0	0.0	0.0	8.3	59.3	1.19	2156.	23.32	127.7
8	429	1	24	32	3	91	58	0	0	0	0	149	23.4	76.6	0.0	0.0	0.0	0.0	0.7	4.5	1.05	171.	1.91	10.8
9	396	1	32	32	3	2500	897	6	0	0	0	3403	33.2	62.0	4.9	0.0	0.0	0.0	12.6	91.9	1.47	3369.	37.15	210.1
10	153	2	35	32	4	1000	627	0	0	0	0	1627	31.1	68.9	0.0	0.0	0.0	0.0	5.7	44.2	1.05	1564.	16.66	89.7
11	826	2	36	33	3	1725	1799	4	0	0	0	3528	18.9	78.3	2.9	0.0	0.0	0.0	17.0	100.4	1.47	4114.	45.30	254.8
12	1819	1	1	34	4	560	169	0	0	0	0	729	51.9	48.1	0.0	0.0	0.0	0.0	1.8	17.7	0.91	578.	5.87	30.0
13	964	2	4	34	3	90	60	0	0	0	0	150	25.1	74.9	0.0	0.0	0.0	0.0	0.6	4.4	0.91	163.	1.79	10.0
14	1907	2	16	34	2	1870	761	0	0	0	0	2631	43.2	56.8	0.0	0.0	0.0	0.0	7.5	66.6	0.91	2241.	23.17	120.7
15	1824	1	25	34	4	270	83	0	0	0	0	353	51.9	48.1	0.0	0.0	0.0	0.0	0.9	8.6	0.77	280.	2.84	14.5
16	1923	[illegible]	26	34	3	480	320	0	0	0	0	800	31.3	68.7	0.0	0.0	0.0	0.0	2.7	21.6	1.05	757.	8.00	42.7
17	[illegible]	[illegible]	24	34	2	400	205	0	0	0	0	605	36.4	63.6	0.0	0.0	0.0	0.0	2.0	16.0	0.91	552.	5.79	30.6
18	1677	1	27	34	2	440	357	0	0	0	0	797	26.3	73.7	0.0	0.0	0.0	0.0	3.0	22.4	1.19	604.	8.61	46.6
19	1103	2	29	34	2	1160	840	2	0	0	0	2002	19.1	79.2	1.7	0.0	0.0	0.0	10.8	62.9	1.33	2213.	28.87	169.2
20	606	1	32	34	1	1025	501	0	0	0	0	1526	32.9	67.1	0.0	0.0	0.0	0.0	5.6	41.8	1.05	1493.	16.01	86.8
21	1749	3	24	31	4	1200	1003	0	0	0	0	2203	20.7	79.3	0.0	0.0	0.0	0.0	10.5	66.7	1.19	2551.	28.46	161.2
22	1742	3	34	31	4	500	832	22	0	0	0	1354	4.9	69.0	26.1	0.0	0.0	0.0	15.4	60.0	2.03	3083.	40.99	261.9
23	1755	4	32	30	4	1400	493	1	0	0	0	1894	38.4	60.2	1.4	0.0	0.0	0.0	6.2	49.6	1.33	1745.	18.67	101.6
24	592	4	21	34	1	480	167	0	0	0	0	647	42.9	57.1	0.0	0.0	0.0	0.0	-1.9	16.5	1.19	562.	5.89	31.2
25	1780	3	33	32	2	9	7	0	0	0	0	16	32.2	67.8	0.0	0.0	0.0	0.0	0.1	0.4	0.63	14.	0.15	0.9
26	554	3	20	32	2	5	8	0	0	0	0	13	7.5	92.5	0.0	0.0	0.0	0.0	0.1	0.5	1.19	23.	0.29	1.9
27	544	4	7	32	2	27	31	0	0	0	0	58	20.7	79.3	0.0	0.0	0.0	0.0	0.2	1.7	0.77	63.	0.67	3.6
28	393	4	36	32	3	3502	294	0	0	0	0	3796	74.5	25.5	0.0	0.0	0.0	0.0	7.2	84.5	1.05	2636.	26.18	131.0
29	481	3	19	32	3	4400	1525	0	0	0	0	5925	47.6	52.4	0.0	0.0	0.0	0.0	15.7	146.7	0.91	4861.	49.85	257.3
30	557	3	14	32	3	735	776	0	0	0	0	1511	16.5	83.5	0.0	0.0	0.0	0.0	8.4	48.9	1.19	1929.	21.77	124.4
31	[illegible]	4	14	32	4	720	109	0	0	0	0	829	64.7	35.3	0.0	0.0	0.0	0.0	1.7	19.0	1.05	606.	6.10	31.0
32	181	3	8	32	4	560	355	0	0	0	0	915	33.9	66.1	0.0	0.0	0.0	[illegible]	[illegible]	24.3	0.91	836.	8.74	46.1
33	158	4	29	32	4	280	144	0	0	0	0	424	38.3	61.7	0.0	0.0	0.0	[illegible]	[illegible]	11.0	0.91	373.	3.89	20.4
34	367	3	19	33	3	1300	524	0	0	0	0	1824	39.9	60.1	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	1.19	1629.	17.11	90.8
35	256	4	23	33	3	1900	821	4	0	0	0	2725	29.1	67.7	3.2	0.0	0.0	[illegible]	[illegible]	[illegible]	1.33	2878.	32.02	182.2
36	834	3	17	33	2	730	275	0	0	0	0	1005	48.1	51.9	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	0.91	811.	8.26	42.3
37	373	4	29	33	3	1840	261	0	0	0	0	2101	70.7	29.3	0.0	0.0	0.0	0.0	[illegible]	47.3	0.77	1474.	14.59	72.5
38	214	4	27	33	4	2200	648	1	0	0	0	2849	45.8	53.1	1.1	0.0	0.0	0.0	8.1	71.2	1.33	2413.	25.23	133.8
39	1873	4	30	33	4	5000	2665	311	5	0	0	7981	7.8	36.2	51.7	4.3	0.0	0.0	81.1	317.[illegible]	2.53	17148.	241.41	1790.1
40	335	4	20	33	4	725	582	6	0	0	0	1313	13.9	78.1	8.0	0.0	0.0	0.0	8.9	45.4	1.47	1958.	23.55	145.2
41	230	2	22	33	4	1400	3671	6	0	0	0	5077	5.8	92.3	1.9	0.0	0.0	0.0	46.8	213.5	1.61	9423.	111.72	667.4
42	667	3	5	34	2	2300	1454	0	0	0	0	3754	31.7	68.3	0.0	0.0	0.0	0.0	13.1	102.0	0.91	3580.	37.86	201.9
43	439	4	13	33	4	1700	748	0	0	0	0	2448	38.5	61.5	0.0	0.0	0.0	0.0	7.8	64.1	1.19	2213.	23.22	123.0
44	846	3	22	33	2	30	8	0	0	0	0	38	58.1	41.9	0.0	0.0	0.0	0.0	0.1	0.9	0.63	29.	0.29	1.4
45	421	3	1	33	4	2560	1329	0	0	0	0	3889	34.6	65.4	0.0	0.0	0.0	0.0	13.3	104.6	0.91	3659.	38.66	206.0
46	1814	3	8	34	3	560	280	0	0	0	0	840	42.5	57.5	0.0	0.0	0.0	0.0	2.3	21.2	0.63	701.	7.16	36.7
47	1823	3	22	34	4	1300	500	0	0	0	0	1800	47.9	52.1	0.0	0.0	0.0	0.0	4.6	44.3	0.77	1455.	14.81	75.7
48	1879	3	4	34	4	510	295	25	0	0	0	830	12.6	43.9	43.5	0.0	0.0	0.0	6.0	28.6	1.61	1322.	16.92	113.2
49	1867	4	6	34	4	700	896	3	0	0	0	1599	10.2	86.4	3.4	0.0	0.0	0.0	12.1	58.7	1.47	2582.	31.17	192.1
50	1073	3	20	34	4	260	186	0	0	0	0	446	20.6	79.4	0.0	0.0	0.0	0.0	2.2	13.6	1.19	533.	6.06	35.1
51	1090	4	11	34	3	3300	640	0	0	0	0	3940	64.8	35.2	0.0	0.0	0.0	0.0	8.1	90.6	0.77	2854.	28.41	142.0

52	1368	2	36	30	3	200	3	0	0	0	0	203	96.1	3.9	0.0	0.0	0.0	0.0	0.3	4.3	0.63	126.	1.21	5.8
53	1714	3	6	31	3	500	0	0	0	0	0	500	100.0	0.0	0.0	0.0	0.0	0.0	0.7	10.4	0.50	305.	2.91	13.9
54	1258	1	36	31	5	520	11	0	0	0	0	531	91.1	8.9	0.0	0.0	0.0	0.0	0.8	11.2	1.05	337.	3.27	15.9
55	1734	2	21	31	5	130	0	0	0	0	0	130	100.0	0.0	0.0	0.0	0.0	0.0	0.2	2.7	0.50	79.	0.76	3.6

END OF FILE

	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	APE	GR- NUT	WAL NUT	GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAC/GND DENTO	CVRD	MAX DIA	MASS	IMPACT MOM.	ENERGY
	JULY 23RD. NORTHERN NETWORK:																							
1	414	1	3	39	28	545	328	0	0	0	0	873	26.9	73.1	0.0	0.0	0.0	0.0	3.7	25.2	1.05	934.	10.21	56.5
2	1161	3	28	39	28	250	43	0	0	0	0	293	68.3	31.7	0.0	0.0	0.0	0.0	0.6	6.7	0.63	208.	2.05	10.2
3	319	1	2	39	1	800	694	0	0	0	0	1494	24.2	75.8	0.0	0.0	0.0	0.0	6.1	43.1	1.05	1569.	16.92	92.1
4	1663	4	21	39	28	40	12	0	0	0	0	52	55.2	44.8	0.0	0.0	0.0	0.0	0.1	1.2	0.63	40.	0.40	2.0
5	402	4	28	39	27	30	30	1	0	0	0	61	9.2	74.6	16.1	0.0	0.0	0.0	0.5	2.4	1.33	112.	1.41	9.1
6	206	3	15	40	7	120	13	0	0	0	0	133	77.4	22.6	0.0	0.0	0.0	0.0	0.2	2.9	0.63	90.	0.88	4.3
7	1295	3	31	42	1	36	12	0	0	0	0	48	37.8	62.2	0.0	0.0	0.0	0.0	0.2	1.3	0.91	45.	0.48	2.7
8	173	1	29	39	6	40	7	0	0	0	0	47	59.0	41.0	0.0	0.0	0.0	0.0	0.1	1.1	0.91	36.	0.37	1.9
9	1157	1	23	39	4	21	13	0	0	0	0	34	19.0	81.0	0.0	0.0	0.0	0.0	0.2	1.1	1.05	44.	0.52	3.1
10	1063	3	28	39	4	16	6	0	0	0	0	22	31.4	68.6	0.0	0.0	0.0	0.0	0.1	0.6	0.91	23.	0.25	1.4
11	1133	5	33	39	4	33	61	7	0	0	0	101	2.5	37.0	60.5	0.0	0.0	0.0	1.7	5.5	1.89	332.	4.65	36.8
12	1075	2	30	39	3	5	5	0	0	0	0	10	16.3	83.7	0.0	0.0	0.0	0.0	0.1	0.3	0.91	13.	0.15	0.9
13	165	4	5	40	7	80	69	0	0	0	0	149	14.6	85.4	0.0	0.0	0.0	0.0	1.0	5.1	1.05	217.	2.56	15.3
14	1687	4	7	40	6	400	333	0	0	0	0	733	28.3	71.7	0.0	0.0	0.0	0.0	2.6	20.1	0.91	705.	7.43	39.4
15	636	4	13	40	6	100	73	3	1	0	0	177	7.5	31.8	17.6	43.1	0.0	0.0	1.5	6.5	2.43	338.	4.81	37.2
16	1518	1	4	40	4	100	60	7	1	0	0	168	5.2	28.6	47.1	19.1	0.0	0.0	2.1	7.4	2.17	448.	6.77	53.9
17	998	3	32	40	2	225	539	71	4	0	0	839	1.4	30.7	55.6	12.4	0.0	0.0	18.2	53.2	2.53	3595.	55.76	450.0
18	999	3	32	40	2	440	404	62	2	0	0	908	3.4	28.9	62.1	5.6	0.0	0.0	14.9	47.1	2.17	3018.	45.95	365.4
19	1648	3	24	40	8	250	354	1	0	0	0	605	9.8	87.1	3.1	0.0	0.0	0.0	4.5	22.2	1.47	966.	11.61	71.2
20	1548	4	33	40	7	100	45	0	0	0	0	145	36.4	63.6	0.0	0.0	0.0	0.0	0.5	3.8	1.05	134.	1.42	7.7
21	709	1	26	40	6	90	57	1	0	0	0	148	16.5	73.9	9.6	0.0	0.0	0.0	0.9	4.9	1.33	210.	2.50	15.2
22	1052	3	1	40	6	80	62	2	0	0	0	144	11.9	68.7	19.4	0.0	0.0	0.0	1.1	5.2	1.47	235.	2.92	18.8
23	716	4	24	40	6	50	51	0	0	0	0	101	20.7	79.3	0.0	0.0	0.0	0.0	0.4	3.0	0.91	111.	1.22	6.7
24	744	3	[illegible]	40	5	15	3	0	0	0	0	18	64.9	35.1	0.0	0.0	0.0	0.0	0.0	0.4	0.63	13.	0.13	0.6
25	1493	2	[illegible]	40	5	10	7	0	0	0	0	17	21.4	78.6	0.0	0.0	0.0	0.0	0.1	0.5	0.91	20.	0.23	1.3
26	1442	4	19	40	5	70	28	4	0	0	0	102	9.7	35.9	54.4	0.0	0.0	0.0	0.9	3.8	1.75	201.	2.77	20.0
27	1525	2	12	40	4	26	16	1	0	0	0	43	15.5	53.0	31.4	0.0	0.0	0.0	0.3	1.4	1.33	61.	0.74	4.7
28	638	3	15	40	4	220	248	11	0	0	0	479	7.6	55.4	37.0	0.0	0.0	0.0	4.2	18.3	1.89	895.	11.78	80.9
29	1491	2	25	40	4	200	167	0	0	0	0	367	20.3	79.7	0.0	0.0	0.0	0.0	1.8	11.2	1.19	430.	4.82	27.5
30	1498	3	3	40	3	0	7	0	0	0	0	7	0.0	100.0	0.0	0.0	0.0	0.0	0.1	0.3	0.91	12.	0.13	0.8
31	1484	3	13	40	3	65	34	0	0	0	0	99	28.7	71.3	0.0	0.0	0.0	0.0	0.4	2.8	0.91	105.	1.14	6.3
32	727	1	18	40	3	150	85	0	0	0	0	235	28.7	71.3	0.0	0.0	0.0	0.0	0.9	6.6	0.91	241.	2.63	14.6
33	1505	2	28	40	3	60	6	1	0	0	0	67	36.7	15.4	47.9	0.0	0.0	0.0	0.2	1.7	1.47	63.	0.73	4.6
34	1194	1	27	41	2	160	166	1	0	0	0	327	17.4	74.1	8.5	0.0	0.0	0.0	1.6	10.1	1.47	393.	4.44	25.6
35	1563	4	3	41	3	130	167	0	0	0	0	297	9.4	90.6	0.0	0.0	0.0	0.0	2.4	11.3	1.19	507.	6.18	38.4
36	703	1	6	41	3	220	91	0	0	0	0	311	41.6	58.4	0.0	0.0	0.0	0.0	0.9	7.9	0.91	269.	2.80	14.7
37	1180	4	31	41	3	160	82	0	0	0	0	242	40.1	59.9	0.0	0.0	0.0	0.0	0.7	6.2	0.91	208.	2.14	11.1
38	1021	3	3	41	2	65	39	0	0	0	0	104	22.0	78.0	0.0	0.0	0.0	0.0	0.5	3.1	1.05	124.	1.41	8.2
39	1554	3	7	41	2	365	454	11	0	0	0	830	7.1	79.7	13.2	0.0	0.0	0.0	8.5	34.8	1.47	1703.	21.87	143.8
40	1694	3	32	41	2	800	465	40	0	0	0	1305	10.1	51.5	38.4	0.0	0.0	0.0	11.5	46.2	1.75	2432.	32.11	220.3
41	1041	2	35	41	2	215	159	3	0	0	0	377	15.7	72.8	11.5	0.0	0.0	0.0	2.4	12.6	1.33	530.	6.28	38.2
42	982	2	5	41	1	320	65	0	0	0	0	385	59.2	40.8	0.0	0.0	0.0	0.0	0.9	9.0	0.91	291.	2.95	15.1
43	1590	3	19	41	1	190	165	1	0	0	0	356	13.9	82.2	3.8	0.0	0.0	0.0	2.4	12.2	1.33	523.	6.24	38.0
44	854	4	24	41	2	320	389	3	0	0	0	712	9.2	78.1	12.7	0.0	0.0	0.0	5.7	26.6	2.03	1213.	15.07	96.7
45	1187	3	2	42	4	50	90	0	0	0	0	140	13.6	86.4	0.0	0.0	0.0	0.0	0.7	4.4	0.91	168.	1.84	10.2
46	1429	2	8	42	4	280	117	0	0	0	0	397	36.4	63.6	0.0	0.0	0.0	0.0	1.3	10.5	1.19	369.	3.95	21.4

	PAD NO.	Q	SX	TS	RG	SHOT	PEA	GRAPE	WALNUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% PAD DENTC	% GND CVRD	MAX. DIAM.	MASS (GM)	MOM.	ENERGY
47	1202	1	17	42	4	365	393	0	0	0	0	758	15.6	84.4	0.0	0.0	0.0	0.0	4.3	24.8	1.05	550.	11.27	65.0
48	1175	2	26	42	4	800	64	0	0	0	0	864	79.3	20.7	0.0	0.0	0.0	0.0	1.5	18.9	0.91	580.	5.70	28.1
49	1420	4	30	42	4	440	504	0	0	0	0	944	13.0	87.0	0.0	0.0	0.0	0.0	6.3	32.9	1.19	1370.	15.95	[illegible]
50	1210	2	5	42	3	370	148	0	0	0	0	518	45.9	54.1	0.0	0.0	0.0	0.0	1.4	12.9	0.91	426.	4.36	[illegible]
51	1256	1	2	42	2	560	406	6	0	0	0	972	11.2	77.9	11.0	0.0	0.0	0.0	8.0	36.1	1.75	1690.	21.39	139.5
52	1800	4	6	42	2	850	515	9	0	0	0	1374	18.0	65.5	16.5	0.0	0.0	0.0	7.8	43.5	1.75	1608.	21.48	131.9
53	1586	4	18	42	2	140	50	0	0	0	0	190	49.3	50.7	0.0	0.0	0.0	0.0	0.5	4.6	0.91	152.	1.55	7.9
54	1013	2	24	42	2	285	425	2	0	0	0	712	8.2	87.3	4.5	0.0	0.0	0.0	6.1	27.8	1.47	1263.	15.50	97.0
55	1301	2	25	42	2	370	354	0	0	0	0	724	16.1	83.9	0.0	0.0	0.0	0.0	4.1	23.5	1.19	[illegible]	[illegible]	64.0
56	1305	2	28	42	2	130	69	0	0	0	0	199	40.0	60.0	0.0	0.0	0.0	0.0	0.6	5.1	0.91	170.	1.75	9.1
57	1545	1	[illegible]	42	3	18	4	0	[illegible]	0	0	28	56.1	43.9	0.0	0.0	0.0	0.0	0.1	0.5	0.77	17.	0.17	0.9
58	1630	2	24	42	1	200	153	[illegible]	[illegible]	[illegible]	0	[illegible]	22.5	77.5	0.0	0.0	0.0	0.0	1.6	10.5	1.05	296.	4.49	24.8
59	1254	2	17	42	1	80	135	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	85.2	9.8	0.0	0.0	0.0	2.7	10.1	1.47	516.	6.72	44.6
60	661	1	34	42	1	220	216	[illegible]	[illegible]	[illegible]	0	436	15.3	84.7	0.0	0.0	0.0	0.0	2.6	14.3	1.19	583.	6.76	40.9
61	1326	2	28	42	2	110	53	[illegible]	[illegible]	0	0	163	32.1	67.9	0.0	0.0	0.0	0.0	0.6	4.5	0.91	161.	1.74	9.5
62	1574	1	16	41	1	270	68	[illegible]	[illegible]	0	0	333	36.2	43.9	0.0	0.0	0.0	0.0	0.8	8.0	0.91	260.	2.63	13.4
63	741	3	16	[illegible]	1	300	85	[illegible]	[illegible]	0	0	395	53.1	46.9	0.0	0.0	0.0	0.0	0.9	9.3	0.91	303.	3.08	15.7
64	802	2	18	[illegible]	[illegible]	240	118	0	0	0	0	358	32.6	67.4	0.0	0.0	0.0	0.0	1.3	9.7	1.05	748.	3.75	20.5
65	1832	2	25	[illegible]	[illegible]	240	217	[illegible]	0	0	0	459	12.3	79.7	8.0	0.0	0.0	0.0	3.2	16.0	1.47	708.	8.66	54.5
66	816	4	13	40	[illegible]	90	40	[illegible]	0	0	0	130	45.4	54.6	0.0	0.0	0.0	0.0	0.3	3.2	0.63	106.	1.08	5.5
67	1854	3	9	40	27	160	120	[illegible]	[illegible]	0	0	280	22.0	78.0	0.0	0.0	0.0	0.0	1.4	8.6	0.91	327.	3.62	20.2
68	207	3	15	40	7	170	99	[illegible]	[illegible]	[illegible]	0	269	31.2	68.8	0.0	0.0	0.0	0.0	1.0	7.3	1.05	261.	2.75	15.2
69	880	2	28	40	1	160	80	[illegible]	[illegible]	[illegible]	0	240	19.9	80.1	0.0	0.0	0.0	0.0	1.4	7.7	1.19	315.	3.73	22.4
70	1856	3	5	40	27	50	21	0	0	0	0	71	38.5	61.5	0.0	0.0	0.0	0.0	0.2	1.9	0.77	65.	0.68	3.6
71	1641	2	26	39	27	80	13	0	0	0	0	93	67.6	32.4	0.0	0.0	0.0	0.0	0.2	2.1	0.77	67.	0.66	3.3
72	84	1	4	39	2	86	7	0	0	0	0	93	79.5	20.5	0.0	0.0	0.0	0.0	0.2	2.0	0.77	62.	0.61	3.0
73	332	4	30	39	1	10	1	0	0	0	0	11	78.7	21.3	0.0	0.0	0.0	0.0	0.0	0.2	0.63	7.	0.07	0.4
74	1467	4	34	39	28	25	7	0	0	0	0	32	46.5	53.5	0.0	0.0	0.0	0.0	0.1	0.8	0.77	27.	0.28	1.5
75	1116	3	16	39	27	600	185	0	0	0	0	785	46.7	53.3	0.0	0.0	0.0	0.0	2.2	19.6	1.05	659.	6.83	35.5

END OF FILE

	PAD NO.	LAND Q	LOCAT. SX	TS	RG	SHOT	PEA	GRAPE	WALNUT	= GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD DENTC	% GND CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	IMPACT ENERGY
	AUGUST 2ND; NORTHERN NETWORK:																							
1	1683	1	18	39	4	170	159	19	1	0	0	349	4.4	40.7	45.3	9.6	0.0	0.0	5.0	17.1	2.17	598.	14.35	197.4
2	1051	1	23	39	4	260	514	3	0	0	0	777	5.1	91.8	3.1	0.0	0.0	0.0	9.0	35.7	1.33	1749.	22.14	142.1
3	721	3	30	40	6	10	0	0	0	0	0	10	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.50	6.	0.06	0.3
4	1690	3	24	40	6	10	8	0	0	0	0	18	20.2	79.8	0.0	0.0	0.0	0.0	0.1	0.6	0.91	21.	0.24	1.4
5	268	3	15	40	7	10	7	0	0	0	0	17	34.6	65.4	0.0	0.0	0.0	0.0	0.1	0.4	0.63	15.	0.16	0.8
6	718	4	21	40	6	15	8	[illegible]	0	0	0	23	37.6	62.4	0.0	0.0	0.0	0.0	0.1	0.6	0.77	20.	0.21	1.1
7	1490	2	26	40	4	170	208	0	0	0	0	378	11.6	88.4	0.0	0.0	0.0	0.0	2.6	13.3	1.19	570.	6.76	40.9
8	729	1	18	40	3	280	173	0	0	0	0	453	35.4	64.6	0.0	0.0	0.0	0.0	1.4	11.9	0.91	406.	4.22	22.1
9	1422	2	36	41	28	416	440	6	0	0	0	862	7.1	87.2	5.8	0.0	0.0	0.0	9.7	37.9	1.47	1909.	24.78	164.2
10	1042	2	35	41	2	70	62	2	0	0	0	134	10.0	71.4	18.6	0.0	0.0	0.0	1.2	5.2	1.47	242.	3.04	19.6
11	1844	4	2	41	28	10	0	0	0	0	0	10	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.50	6.	0.06	0.3
12	1195	1	27	41	2	384	551	71	2	0	0	1008	[illegible]	[illegible]	44.7	7.6	0.0	0.0	19.5	59.5	2.53	3751.	55.45	423.2
13	1203	1	17	42	4	200	209	9	0	0	0	418	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	3.9	16.4	2.03	817.	19.67	75.5
14	1598	2	18	42	3	600	329	24	1	0	0	954	10.1	[illegible]	[illegible]	[illegible]	[illegible]	0.0	8.2	35.5	2.31	1763.	23.55	165.3
15	1474	1	28	42	3	44	20	0	0	0	0	64	32.7	67.3	0.0	0.0	0.0	0.0	0.2	1.8	0.91	63.	0.65	3.8
16	1798	4	6	42	2	25	25	0	0	0	0	50	16.1	83.9	0.0	0.0	0.0	0.0	0.3	1.6	0.91	65.	0.74	4.3
17	1463	4	11	39	4	156	114	[illegible]	0	0	0	270	24.7	75.3	0.0	0.0	0.0	0.0	1.1	7.8	1.05	290.	3.17	17.6
18	174	1	29	39	6	85	60	[illegible]	0	0	0	145	27.6	72.4	0.0	0.0	0.0	0.0	0.6	4.1	0.91	147.	1.58	8.6
19	1088	2	5	39	4	125	42	0	0	0	0	167	40.9	59.1	0.0	0.0	0.0	0.0	0.5	4.3	0.91	151.	1.59	8.5
20	1659	3	10	39	4	160	82	0	0	0	0	242	16.3	83.7	0.0	0.0	0.0	0.0	1.7	8.3	1.19	363.	4.40	27.3
21	1057	3	28	39	4	850	862	0	0	0	0	1712	17.2	82.8	0.0	0.0	0.0	0.0	9.2	54.7	1.19	2143.	24.12	137.5

22	1132	5	33	39	4	205	127	0	0	0	0	332	24.8	75.2	0.0	0.0	0.0	0.0	1.5	9.9	1.05	373.	4.12	23.0
23	1150	1	6	39	3	50	116	0	0	0	0	166	8.3	91.7	0.0	0.0	0.0	0.0	1.2	6.1	1.05	252.	2.89	16.7
24	1028	1	3	39	3	210	204	0	0	0	0	414	11.4	88.6	0.0	0.0	0.0	0.0	3.3	15.7	1.19	695.	8.28	51.2
25	1076	2	30	39	3	1100	892	0	0	0	0	1992	24.0	76.0	0.0	0.0	0.0	0.0	8.3	57.6	1.19	2119.	23.09	127.5
26	2171	2	19	39	2	1120	838	0	0	0	0	1958	29.6	70.4	0.0	0.0	0.0	0.0	6.9	53.8	0.91	1887.	19.90	105.6
27	486	2	29	39	2	1025	411	0	0	0	0	1436	40.7	59.3	0.0	0.0	0.0	0.0	4.4	37.1	1.05	1270.	13.28	70.1
28	2180	4	13	40	6	55	28	0	0	0	0	83	21.8	78.2	0.0	0.0	0.0	0.0	0.4	2.5	1.19	102.	1.19	7.0
29	1444	1	4	40	4	40	35	0	0	0	0	75	24.8	75.2	0.0	0.0	0.0	0.0	0.3	2.1	0.91	77.	0.83	4.5
30	710	1	26	40	6	200	299	15	0	0	0	514	5.1	73.0	22.0	0.0	0.0	0.0	6.4	24.1	1.47	1243.	16.35	109.8
31	1495	2	28	40	4	1300	1042	10	0	0	0	2352	13.8	76.1	10.0	0.0	0.0	0.0	15.9	80.8	1.75	3496.	42.18	261.6
32	1430	4	19	40	5	720	646	7	0	0	0	1373	12.2	78.6	9.3	0.0	0.0	0.0	10.0	48.7	1.47	2152.	26.28	164.8
33	2270	3	15	40	4	130	236	12	0	0	0	378	3.9	71.1	25.0	0.0	0.0	0.0	5.3	18.8	1.47	1013.	13.60	93.3
34	1614	4	13	41	28	60	32	0	0	0	0	92	25.0	75.0	0.0	0.0	0.0	0.0	0.4	2.7	1.19	103.	1.16	6.[illegible]
35	1181	4	31	41	3	800	1123	32	0	0	0	1955	6.6	68.7	24.7	0.0	0.0	0.0	19.4	81.2	1.75	3950.	50.86	337.[illegible]
36	855	4	24	41	2	640	683	0	0	0	0	1323	14.6	85.4	0.0	0.0	0.0	0.0	7.9	43.7	1.19	1784.	20.6[illegible]	12[illegible]
37	1527	2	8	42	4	178	195	1	0	0	0	374	10.0	85.7	4.4	0.0	-0.0	0.0	3.0	14.0	1.47	638.	7.85	[illegible]
38	1173	2	26	42	4	350	201	0	0	0	0	551	25.6	74.4	0.0	0.0	0.0	0.0	2.4	15.9	1.19	600.	6.69	[illegible]
39	1422	4	30	42	4	410	521	6	0	1	0	938	6.5	54.0	9.6	0.0	29.9	0.0	7.9	35.1	3.26	1719.	23.41	[illegible]
40	1211	2	5	42	3	640	633	28	0	0	0	1301	7.5	59.5	33.1	0.0	0.0	0.0	12.4	51.6	2.03	2594.	34.51	23[illegible]
41	1547	1	11	42	3	100	58	3	0	0	0	161	16.7	56.9	26.4	0.0	0.0	0.0	1.0	5.3	1.33	224.	2.69	16.7
42	1568	4	35	42	3	5	2	0	0	0	0	7	48.1	51.9	0.0	0.0	0.0	0.0	0.0	0.2	0.63	6.	0.06	0.3
43	1018	3	3	41	2	120	140	1	0	0	0	261	7.7	88.9	3.4	0.0	0.0	0.0	2.7	11.0	1.33	530.	6.71	43.3
44	1248	1	2	42	2	150	162	3	0	0	0	315	10.6	72.9	16.6	0.0	0.0	0.0	2.3	11.2	1.47	502.	6.20	39.5
45	1332	4	18	42	2	150	117	5	0	0	0	272	7.8	67.9	24.3	0.0	-0.0	0.0	2.9	11.3	1.75	582.	7.78	53.8
46	1327	2	28	42	2	25	10	0	0	0	0	35	31.7	68.3	0.0	0.0	0.0	0.0	0.1	1.0	1.05	35.	0.39	2.2
47	1399	3	32	41	4	350	263	0	0	0	0	613	23.3	76.7	0.0	0.0	0.0	0.0	2.7	18.0	1.19	676.	7.46	41.8
48	1192	3	2	42	4	310	565	17	0	0	0	892	4.2	70.2	25.6	0.0	0.0	0.0	11.4	42.4	1.75	2228.	29.76	204.6
49	1204	3	6	43	2	30	14	0	0	0	0	44	44.2	55.8	0.0	0.0	0.0	0.0	0.1	1.1	0.63	36.	0.37	1.9
50	1653	2	31	42	2	65	43	0	0	0	0	108	28.3	71.7	0.0	0.0	0.0	0.0	0.4	3.0	0.91	109.	1.18	[illegible]
51	1147	2	22	42	3	700	373	0	0	0	0	1073	25.5	74.5	0.0	0.0	0.0	0.0	4.7	31.0	1.19	1184.	13.31	[illegible]
52	1315	2	24	42	2	48	9	0	0	0	0	57	63.5	36.5	0.0	0.0	0.0	0.0	0.1	1.3	0.77	42.	[illegible]	2.1
53	1263	2	17	42	1	25	17	0	0	0	0	42	20.1	79.9	0.0	0.0	0.0	0.0	0.2	1.3	1.05	52.	0.59	3.5
54	1048	2	2	41	4	330	207	0	0	0	0	537	25.1	74.9	0.0	0.0	0.0	0.0	2.4	15.6	1.05	589.	6.52	36.7
55	1561	4	3	41	3	160	50	0	0	0	0	210	54.2	45.8	0.0	0.0	0.0	0.0	0.5	5.0	0.63	162.	1.63	8.2
56	704	1	6	41	3	120	125	0	0	0	0	245	24.0	76.0	0.0	0.0	0.0	0.0	0.9	7.0	0.77	247.	2.62	13.9
57	1217	1	14	41	2	355	397	0	0	0	0	752	12.6	87.4	0.0	[illegible]	[illegible]	0.0	5.1	26.3	1.19	1111.	13.07	78.2
58	158[illegible]	3	19	41	1	120	101	0	0	0	0	221	15.5	83.5	0.0	[illegible]	[illegible]	0.0	1.3	7.2	1.19	294.	3.[illegible]	20.3
59	2032	3	32	40	2	280	189	1	0	0	0	470	20.5	75.2	3.9	[illegible]	[illegible]	0.0	2.3	14.2	1.33	559.	6.39	37.4
60	1521	1	15	40	5	180	15	0	0	0	0	195	81.6	18.4	0.0	[illegible]	[illegible]	0.0	0.3	4.2	0.63	129.	1.26	6.1
61	581	2	21	40	5	595	718	0	0	0	0	1313	13.0	87.0	0.0	0.0	0.0	0.0	8.3	44.7	1.19	1849.	21.52	127.5
62	1503	2	26	40	3	190	84	0	0	0	0	274	34.0	66.0	0.0	0.0	0.0	0.0	1.0	7.4	1.05	264.	2.85	15.6
63	2037	1	26	40	2	735	198	0	0	0	0	933	44.0	56.0	0.0	0.0	0.0	0.0	2.8	23.8	0.91	821.	8.67	46.5
64	2043	2	18	40	1	56	22	0	0	0	0	78	43.6	56.4	0.0	0.0	0.0	0.0	0.2	2.0	0.77	67.	0.69	3.6
65	86	1	4	39	2	7	9	0	0	0	0	16	17.0	83.0	0.0	0.0	0.0	0.0	0.1	0.5	0.77	19.	0.21	1.1
66	309	1	2	39	1	60	20	0	0	0	0	80	52.6	47.4	0.0	0.0	0.0	0.0	0.2	1.9	0.63	62.	0.63	3.2
67	979	2	4	39	28	23	5	0	0	0	0	28	87.8	42.2	0.0	0.0	[illegible]	[illegible]	0.1	0.7	0.77	21.	0.22	1.1

END OF FILE

	PAD	LAND LOCAT. SX	TS	RG	SHOT	GR- PEA	WAL- APE	= NUT	> GOLF			TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTO		MAX. CVRD DIAM.	MASS (CM)	IMPACT MOM.	ENERGY
ATH. NORTHERN NETWORK																								
1	[illegible]	[illegible]	11	39	4	25	19	0	0	0	0	44	27.0	73.0	0.0	0.0	0.0	0.0	0.2	1.2	0.77	45.	0.48	2.6
2	[illegible]	[illegible]	5	39	4	25	28	0	0	0	0	53	12.0	88.0	0.0	0.0	0.0	0.0	0.4	1.9	0.91	82.	0.67	5.8
3	[illegible]	[illegible]	10	39	4	12	6	0	0	0	0	18	34.5	65.5	0.0	0.0	0.0	0.0	0.1	0.5	0.77	17.	0.18	1.0
4	[illegible]	[illegible]	26	39	3	400	45	0	0	0	0	445	72.1	27.9	0.0	0.0	0.0	0.0	0.9	10.0	0.77	312.	3.10	15.4

5	1078	2	30	39	3	25	7	0	0	0	0	32	56.9	43.1	0.0	0.0	0.0	0.0	0.1	0.8	0.63	24.	0.24	1.2
6	1400	3	32	41	4	100	103	0	0	0	0	203	9.9	90.1	0.0	0.0	0.0	0.0	1.8	7.9	1.19	364.	4.50	28.3
7	1395	2	8	42	4	50	35	0	0	0	0	85	13.1	86.9	0.0	0.0	0.0	0.0	0.7	3.1	1.19	138.	1.69	10.6
8	1204	1	17	42	4	90	51	0	0	0	0	141	23.2	76.8	0.0	0.0	0.0	0.0	0.7	4.2	1.05	165.	1.87	10.8
9	1174	2	26	42	4	45	30	0	0	0	0	75	35.7	64.3	0.0	0.0	0.0	0.0	0.2	2.0	0.63	96.	0.68	3.5
10	1277	3	1	40	28	180	20	0	0	0	0	200	72.8	27.2	0.0	0.0	0.0	0.0	0.4	4.5	0.77	140.	1.38	6.9
11	2381	3	3	40	3	575	104	0	0	0	0	679	58.9	41.1	0.0	0.0	0.0	0.0	1.6	16.0	1.05	521.	5.30	27.2
12	1480	3	13	40	3	50	52	1	0	0	0	103	16.0	67.3	16.8	0.0	0.0	0.0	0.5	3.2	1.33	129.	1.48	8.7
13	2236	2	6	40	2	40	6	0	0	0	0	46	71.2	28.8	0.0	0.0	0.0	0.0	0.1	1.0	0.63	32.	0.32	1.6
14	314	2	4	39	28	470	74	0	0	0	0	544	68.8	31.2	0.0	0.0	0.0	0.0	1.1	12.3	0.77	386.	3.62	19.0
15	2260	2	4	39	28	850	5	0	0	0	0	855	96.7	3.3	0.0	0.0	0.0	0.0	1.2	17.5	0.91	529.	5.09	24.5
16	2263	1	3	39	28	28	27	0	0	0	0	55	26.0	74.0	0.0	0.0	0.0	0.0	0.2	1.5	0.77	54.	0.57	3.0

END OF FILE

AUGUST 16TH. NORTHERN NETWORKS:

	PAD NO.	LAND LOCAT. O	SX	TS	RG	SHOT	REA	APE	NUT	GR- WAL- = G[illegible]	F	> TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTD	MAX. CVPD	DIAM.	MASS (GM)	IMPACT MOM.	ENERGY
1	1339	3	6	43	2	320	229	8	0	0	0	557	[illegible].2	64.7	26.1	0.0	0.0	0.0	5.1	21.5	2.03	1667.	14.10	96.9
2	1801	4	6	42	2	400	628	48	15	4	0	1095	1.3	15.3	13.5	35.7	34.2	0.0	23.1	63.3	3.78	4967.	90.06	889.3
3	2498	2	18	42	3	400	240	5	0	0	0	645	16.3	72.0	11.7	0.0	0.0	0.0	4.2	21.6	1.47	926.	11.12	68.5
4	2650	2	24	42	2	45	30	0	0	0	0	75	18.6	81.4	0.0	0.0	0.0	0.0	0.4	2.4	0.91	99.	1.15	6.7
5	2509	2	8	42	4	700	913	80	7	4	0	1704	2.1	20.4	31.6	14.9	31.1	0.0	28.5	87.5	3.99	6041.	101.33	928.3
6	2587	3	2	42	4	240	340	15	2	0	0	597	2.8	46.6	25.5	25.1	0.0	0.0	9.8	31.5	3.15	1942.	29.31	235.5
7	1205	1	17	42	4	2300	1211	38	14	0	0	3563	10.0	28.8	17.0	44.1	0.0	0.0	24.2	115.9	3.15	5757.	81.45	638.9
8	2591	2	26	42	4	1100	960	14	2	0	0	2076	10.9	58.9	20.8	9.4	0.0	0.0	14.8	72.3	2.31	3291.	41.91	281.7
9	2495	1	28	42	3	260	430	38	0	0	0	728	3.4	59.7	36.9	0.0	0.0	0.0	11.5	38.9	1.75	2198.	30.38	215.0
10	1570	4	35	42	3	500	586	58	4	0	0	1148	3.4	37.3	46.2	13.1	0.0	0.0	17.4	57.7	2.31	3512.	52.11	404.7
11	2489	1	11	42	3	600	605	65	7	0	0	1277	3.7	32.6	38.7	25.0	0.0	0.0	18.5	61.9	2.74	3798.	57.28	456.6
12	1213	2	5	42	3	700	1065	32	0	0	0	1797	4.7	76.2	19.0	0.0	0.0	0.0	23.6	86.6	1.75	4563.	60.96	412.6
13	1656	2	31	42	2	100	205	32	0	0	0	337	1.7	46.8	51.5	0.0	0.0	0.0	7.8	22.5	2.03	1458.	21.59	163.5
14	1323	2	14	42	2	50	60	4	1	0	0	115	3.2	24.4	20.3	52.0	0.0	0.0	1.5	5.2	2.63	320.	5.03	42.9
15	2640	2	26	42	2	400	431	2	0	0	0	833	11.6	83.8	4.6	0.0	0.0	0.0	5.8	29.3	1.47	1275.	15.42	95.8
16	2633	4	18	42	2	300	340	35	4	0	0	679	2.7	26.5	51.6	19.2	0.0	0.0	11.5	35.9	2.53	2367.	37.09	305.9
17	2651	2	25	42	2	26	33	2	0	0	0	61	3.5	20.4	76.1	0.0	0.0	0.0	0.7	2.6	2.03	160.	2.49	20.7
18	664	1	34	42	1	120	49	1	0	0	0	170	24.1	65.3	10.6	0.0	0.0	0.0	0.8	5.1	1.33	202.	2.33	13.9
19	1634	2	24	42	1	15	16	4	0	0	0	35	3.2	30.1	66.7	0.0	0.0	0.0	0.6	1.9	1.47	119.	1.74	13.1
20	1424	4	30	42	4	1000	1040	35	7	0	0	2082	5.1	39.7	25.0	30.2	0.0	0.0	22.3	86.2	2.95	4744.	68.95	541.3
21	1038	2	22	42	3	240	452	12	0	0	0	704	4.4	82.3	13.2	0.0	0.0	0.0	9.1	34.0	1.61	1745.	22.7[illegible]	150.8
22	1265	2	17	42	1	70	75	1	0	0	0	146	10.0	67.5	22.5	0.0	0.0	0.0	1.1	5.4	1.75	243.	3.01	19.4
23	2600	3	31	42	1	15	23	7	1	0	0	46	9.9	20.2	39.8	39.1	0.0	0.0	1.6	2.9	2.53	320.	5.46	48.5
24	1626	1	26	42	28	106	167	2	0	0	0	275	6.2	72.7	21.1	0.0	0.0	0.0	2.7	11.4	2.03	553.	7.14	47.8
25	1123	3	32	41	2	300	273	70	26	3	[illegible]	[illegible]73	0.5	5.3	13.8	31.0	26.7	22.6	27.9	57.9	5.24	6323.	134.35	1540.8
26	1557	3	7	41	2	53	47	2	0	0	[illegible]	102	11.3	53.6	35.1	0.0	[illegible]	0.0	0.7	3.6	1.61	161.	2.02	13.1
27	2457	2	35	41	2	102	63	19	0	0	0	184	4.5	17.8	77.6	0.0	0.0	0.0	2.7	8.9	1.75	547.	8.13	62.7
28	1183	4	31	41	3	700	1002	61	0	0	0	1763	4.9	60.5	34.6	0.0	0.0	0.0	21.7	81.3	2.03	4292.	57.73	400.4
29	2434	1	14	41	2	160	104	0	0	0	0	264	23.3	76.7	0.0	0.0	0.0	0.0	1.2	7.7	1.19	296.	3.33	19.1
30	2441	2	18	41	1	245	121	0	0	0	0	366	35.0	65.0	0.0	0.0	[illegible]	[illegible]	[illegible]	2.8	0.91	344.	3.65	19.5
31	2442	4	24	41	2	285	155	7	0	0	0	447	14.0	49.8	36.2	0.0	0.0	[illegible]	[illegible]	14.8	2.03	668.	8.45	56.7
32	1196	1	27	41	2	150	117	14	1	0	0	282	4.3	29.0	56.2	10.5	0.0	[illegible]	[illegible]	13.5	2.17	827.	12.42	58.0
33	2521	4	3	41	3	295	256	5	0	0	0	556	10.6	72.1	17.2	0.0	0.0	0.0	4.6	21.0	1.75	565.	12.04	77.3
34	2519	1	6	41	3	600	511	1	0	0	0	1112	13.2	85.7	1.2	0.0	0.0	0.0	8.1	39.9	1.33	1736.	20.79	126.8
35	1401	3	32	41	4	[illegible]	763	41	11	1	0	1816	4.1	17.6	23.0	31.8	23.4	0.0	19.7	72.4	4.30	4480.	73.61	677.2
36	1647	2	2	41	4	150	124	4	0	0	0	[illegible]	13.4	53.2	36.4	0.0	0.0	0.0	2.1	10.0	1.99	465.	5.97	40.3
37	2433	3	16	41	1	72	25	0	0	0	0	97	45.2	54.8	0.0	0.0	0.0	0.0	0.3	2.4	0.77	82.	0.65	4.4
38	2455	3	19	41	1	100	74	1	0	0	0	175	11.4	62.6	6.0	0.0	0.0	0.0	1.4	6.4	1.33	298.	3.76	24.4

39	210	3	15	40	7	600	594	75	5	1	0	1275	2.7	25.5	43.9	18.2	9.6	0.0	21.8	65.8	3.36	4501.	72.15	615.3
40	2178	3	30	40	6	375	479	8	0	0	0	862	7.3	77.4	15.3	0.0	0.0	0.0	8.3	35.5	1.75	1491.	21.64	142.7
41	2183	4	13	40	6	110	55	0	0	0	0	165	29.4	70.6	0.0	0.0	0.0	0.0	0.7	4.6	1.05	169.	1.85	10.4
42	2428	4	21	40	6	3500	1936	72	25	2	0	5535	7.1	18.8	20.8	44.7	8.5	0.0	43.0	197.6	[illegible]	10280.	159.57	1376.3
43	1060	3	1	40	6	296	316	10	0	[illegible]	0	622	9.3	63.6	27.1	0.0	0.0	0.0	4.9	22.6	1.75	1052.	13.40	85.7
44	712	1	26	40	6	240	154	0	0	0	0	394	25.4	74.6	0.0	0.0	0.0	0.0	1.7	11.3	1.19	422.	4.67	26.3
45	2580	3	5	40	5	525	623	37	0	0	0	1185	5.2	57.3	37.5	0.0	0.0	0.0	14.6	54.2	2.33	2509.	39.72	280.7
46	2584	1	15	40	5	1000	703	35	5	1	0	1744	6.1	28.2	28.0	23.1	14.5	0.0	16.6	66.2	3.47	3690.	55.56	459.9
47	568	3	[illegible]	40	5	370	359	3	2	1	0	735	5.5	30.5	3.5	14.1	40.3	0.0	6.6	27.6	3.57	1473.	22.05	186.9
48	1501	3	3	40	3	35	4	0	0	0	0	39	76.4	23.6	0.0	0.0	0.0	0.0	0.1	0.9	0.63	26.	0.28	1.3
49	2379	2	28	40	3	260	180	0	0	0	0	440	20.8	79.2	0.0	0.0	0.0	0.0	2.2	13.4	1.19	525.	5.99	34.8
50	2379	1	18	40	3	510	226	0	0	0	0	736	31.0	69.0	0.0	0.0	0.0	0.0	2.9	20.5	1.19	753.	8.24	45.9
51	1011	4	33	40	7	700	483	106	9	0	0	1298	3.4	20.4	55.4	20.7	0.3	0.0	21.5	67.1	2.53	4453.	69.75	572.6
52	858	2	21	40	5	137	197	2	0	0	0	336	7.0	87.5	5.4	0.0	0.0	0.0	3.3	13.8	1.33	652.	8.38	54.2
53	170	4	5	40	7	175	125	7	0	0	0	307	10.5	60.8	28.7	0.0	0.0	0.0	2.6	11.6	1.61	550.	7.04	46.5
54	1497	2	26	40	5	145	282	[illegible]	0	0	0	427	6.2	93.8	0.0	0.0	0.0	0.0	4.2	18.0	1.19	839.	10.34	64.7
55	2483	2	12	40	4	500	312	2	0	0	0	814	23.9	68.7	7.5	0.0	0.0	0.0	3.3	23.4	1.47	695.	10.01	56.4
56	895	3	15	40	4	151	247	33	8	2	0	441	0.8	13.0	20.6	29.3	36.2	0.0	12.7	31.1	3.09	2698.	50.44	506.1
57	1489	2	25	40	4	540	425	6	1	0	0	972	12.3	57.8	14.3	15.6	0.0	0.0	6.2	32.2	2.53	1427.	13.10	121.9
58	2034	3	32	40	2	120	90	3	0	0	0	213	12.0	72.3	15.7	0.0	0.0	0.0	1.7	7.8	1.33	354.	4.29	27.9
59	175	1	29	39	6	500	340	25	0	0	0	865	7.9	45.7	46.4	0.0	0.0	0.0	8.3	33.8	2.03	1765.	24.29	175.3
60	2565	3	28	39	4	75	34	0	0	0	0	100	41.7	58.3	0.0	0.0	0.0	0.0	0.3	2.8	0.77	94.	0.97	5.0
61	1136	5	33	39	4	5	3	0	0	0	0	8	38.2	61.8	0.0	0.0	0.0	0.0	0.0	0.2	5.63	7.	0.07	0.4
62	1433	4	19	40	5	160	130	2	0	0	0	292	10.8	73.3	15.9	0.0	0.0	0.0	2.3	19.7	1.75	436.	6.29	41.2
63	2569	1	23	39	4	16	0	0	0	0	0	16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.50	16.	0.09	0.4
64	136	5	33	39	4	10	2	0	0	0	0	12	64.9	35.1	0.0	0.0	0.0	0.0	0.0	0.3	0.63	9.	0.09	0.4
65	2253	1	2	39	1	5	5	0	0	0	0	10	13.8	86.2	0.0	0.0	0.0	0.0	0.1	0.3	0.91	16.	0.17	1.0
66	2686	2	25	41	28	5	6	0	0	0	0	11	18.0	82.0	0.0	0.0	0.0	0.0	0.1	0.3	0.77	13.	0.14	0.8

END OF FILE

	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	APE	GH- NUT	WAL- GOLF	'= >	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND MAX. DENTO	CVPD	DIAM.	MASS (CM)	IMPACT MOM.	ENERGY
	AUGUST 16TH. DENS[illegible] NETWORK, 'X'																							
1	2525	1	6	42	2	230	314	148	24	9	0	725	0.3	6.1	22.0	22.8	48.8	0.0	40.7	81.0	4.42	8796.	179.95	1955.6
2	2526	1	6	42	2	240	239	95	26	1	0	600	0.7	10.9	28.6	55.1	5.3	0.0	26.6	58.4	3.26	5526.	102.56	992.7
3	25[illegible]7	1	6	42	2	200	443	104	4	0	0	751	1.2	30.8	58.2	9.9	0.0	0.0	20.3	55.5	2.43	3412.	55.65	474.8
4	2528	2	6	42	2	250	500	96	8	0	0	854	1.1	33.0	43.2	22.6	0.0	0.0	24.6	65.2	2.95	4720.	75.69	620.1
5	2529	2	6	42	2	515	439	157	14	1	0	1125	1.6	15.0	51.5	25.3	6.7	0.0	29.7	77.6	3.36	6058.	103.95	897.3
6	2538	2	6	42	2	225	272	77	11	0	0	585	1.1	12.4	53.1	33.4	0.0	0.0	17.5	43.8	2.84	3669.	62.39	560.5
7	2505	2	6	42	2	240	437	80	5	0	0	762	1.5	31.8	48.2	18.4	0.0	0.0	18.0	51.0	2.63	3497.	54.35	438.6
8	2507	2	6	42	2	160	576	68	5	0	0	809	1.0	44.4	36.7	17.9	0.0	0.0	19.8	56.8	2.74	3746.	55.48	440.9
9	2506	1	6	42	2	180	405	51	8	1	0	655	0.9	27.2	34.2	20.9	16.8	0.0	19.0	49.5	3.78	3779.	63.40	563.6
10	2621	1	6	42	2	185	316	66	23	3	0	693	0.5	11.6	23.6	40.3	24.0	0.0	24.9	55.1	3.78	5256.	97.53	993.1
11	2632	4	6	42	2	550	823	91	23	8	0	1495	0.9	12.2	17.6	22.9	46.4	0.0	39.6	99.8	4.82	8577.	163.78	1707.0
12	2504	4	6	42	2	330	721	40	6	0	0	1097	2.0	49.7	31.6	16.7	0.0	0.0	20.5	64.3	2.53	3596.	59.17	457.1
13	2542	3	6	42	2	600	470	84	10	0	0	1164	3.1	25.5	44.8	26.6	0.0	0.0	20.6	62.9	2.63	4136.	65.76	540.4
14	2552	3	6	42	2	515	304	76	19	0	0	914	2.0	10.3	44.5	43.2	0.0	0.0	21.0	55.6	3.05	4481.	73.26	716.3
15	2553	3	6	42	2	560	374	53	31	2	0	1020	1.7	8.1	19.2	55.0	15.9	0.0	23.0	59.7	3.78	5379.	93.86	921.3
16	2544	3	6	42	2	750	429	47	15	0	0	1241	3.8	18.5	25.9	51.8	0.0	0.0	17.4	56.6	2.95	3723.	61.96	546.0
17	2533	3	6	42	2	320	593	66	20	0	0	999	1.3	22.4	28.9	47.3	0.0	0.0	23.2	64.6	2.74	4749.	78.74	666.3
18	2532	3	6	42	2	370	540	96	16	1	0	1023	1.2	16.7	39.0	32.3	10.8	0.0	26.9	70.2	3.78	5554.	96.03	878.3
19	2531	4	6	42	2	270	555	83	11	3	0	922	0.9	16.9	31.8	24.5	25.9	0.0	25.0	64.5	3.99	6145.	90.61	855.3
20	2523	4	6	42	2	550	292	37	22	8	0	909	1.0	5.8	7.6	40.0	45.6	0.0	27.2	59.3	4.20	6228.	133.68	1464.7
21	2537	4	6	42	2	700	288	63	26	[illegible]	0	1082	1.6	5.9	18.6	43.8	30.1	0.0	27.4	65.5	3.68	6153.	123.64	1257.3
22	2536	4	6	42	2	400	404	63	6	5	3	876	1.9	15.7	35.1	14.9	32.4	0.0	17.1	48.8	3.47	3614.	62.05	574.5

	PAD NO.	O	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% DENTD	% CVRD	MAX. DIAM.	MASS (CM)	IMPACT MCM.	IMPACT ENERGY
23	2535	4	6	42	2	240	356	47	27	1	0	671	0.8	11.4	17.8	60.5	9.5	0.0	22.3	52.4	3.68	4780.	89.57	885.8
24	2534	3	6	42	2	200	421	73	32	1	0	727	0.6	12.3	27.0	54.7	5.4	0.0	26.9	62.7	3.26	5605.	101.70	963.6
25	2551	3	6	42	2	850	666	58	28	0	0	1602	2.6	16.7	21.6	59.1	0.0	0.0	27.2	81.6	3.15	5880.	100.64	912.2

END OF FILE

AUGUST 23RD, BOTH NETWORKS.......
--SOUTHERN:

	PAD NO.	O	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% DENTD	% CVRD	MAX. DIAM.	MASS (CM)	IMPACT MCM.	IMPACT ENERGY
1	1005	1	25	34	4	600	272	6	0	0	0	878	19.4	66.9	13.8	0.0	0.0	0.0	5.1	27.[illegible]	1.61	1165.	12.96	86.3
2	1815	1	1	34	4	128	130	6	0	0	0	264	6.4	68.3	25.3	0.0	0.0	0.0	3.0	11.6	1.61	604.	5.07	55.5
3	2739	4	11	34	3	500	116	0	0	0	0	616	60.5	39.5	0.0	0.0	0.0	0.0	1.3	14.4	0.77	458.	4.58	23.0
4	1072	3	20	34	4	140	192	21	25	3	0	381	0.5	5.7	9.4	56.9	27.5	0.0	17.0	34.9	3.58	3799.	77.46	825.6
5	2411	3	4	34	4	480	163	1	0	0	0	644	29.3	61.1	9.6	0.0	0.0	0.0	2.6	17.7	1.75	676.	7.71	45.6
6	2477	4	6	34	4	530	305	32	0	0	0	867	8.0	40.5	51.4	0.0	0.0	0.0	8.6	34.3	2.03	1820.	25.25	183.5
7	2682	3	22	34	4	230	187	13	0	0	0	430	7.4	58.7	34.0	0.0	0.0	0.0	4.6	18.2	1.75	941.	12.59	87.1
8	1809	3	8	34	3	65	56	0	0	0	0	121	17.3	82.7	0.0	0.0	0.0	0.0	0.7	3.9	1.05	156.	1.80	10.5
9	419	3	1	33	4	110	96	0	0	0	0	206	27.5	72.5	0.0	0.0	0.0	0.0	0.7	5.7	0.91	200.	2.10	11.2
10	2089	2	6	33	4	172	88	0	0	0	0	260	28.7	71.3	0.0	0.0	0.0	0.0	1.1	7.4	1.05	273.	3.00	16.7
11	2051	2	14	33	4	300	60	0	0	0	0	360	56.3	43.7	0.0	0.0	0.0	0.0	0.9	8.6	0.91	282.	2.88	14.8
12	2080	4	20	33	4	285	66	1	0	0	0	352	35.8	57.6	6.6	0.0	0.0	0.0	1.3	9.4	1.33	346.	3.06	22.2
13	2054	4	27	33	4	57	57	1	0	0	0	115	11.2	78.5	10.3	0.0	0.0	0.0	0.9	4.3	1.33	190.	2.30	14.2
14	1876	4	30	33	4	360	320	1	0	0	0	681	15.7	80.9	3.4	0.0	0.0	0.0	4.0	22.3	1.47	917.	10.71	64.0
15	1988	2	5	33	3	190	6	0	0	0	0	196	92.1	7.9	0.0	0.0	0.0	0.0	0.3	4.1	0.63	124.	1.19	5.7
16	1973	1	17	33	3	40	13	0	0	0	0	53	41.2	58.8	0.0	0.0	0.0	0.0	0.2	1.4	0.51	48.	0.51	2.7
17	1892	3	8	32	4	300	254	0	0	0	0	554	23.1	76.9	0.0	0.0	0.0	0.0	2.4	16.1	1.05	598.	6.52	36.2
18	282	1	10	32	28	80	7	0	0	0	0	87	78.3	21.7	0.0	0.0	0.0	0.0	0.2	1.9	0.77	59.	0.58	2.8
19	71	[illegible]	13	32	27	55	15	0	0	0	0	70	57.6	42.4	0.0	0.0	0.0	0.0	0.2	1.7	0.63	53.	0.53	2.7
20	2330	4	23	32	27	95	59	0	0	0	0	154	23.1	76.9	0.0	0.0	0.0	0.0	0.7	4.6	1.05	178.	2.00	11.4
21	475	4	14	32	4	515	71	0	0	0	0	586	63.5	36.5	0.0	0.0	0.0	0.0	1.3	13.5	1.05	435.	4.41	22.6
22	161	2	35	32	4	160	40	0	0	0	0	200	59.7	40.3	0.0	0.0	0.0	0.0	0.4	[illegible]	0.53	149.	1.45	7.5
23	1996	1	1	32	3	16	4	0	0	0	0	20	44.8	55.2	0.0	0.0	0.0	0.0	0.1	0.5	0.91	17.	0.18	1.0
24	1992	3	19	32	3	20	7	0	0	0	0	27	31.6	68.4	0.0	0.0	0.0	0.0	0.1	0.8	0.91	28.	0.31	1.8
25	1979	4	36	32	3	150	45	0	0	0	0	195	51.1	48.9	0.0	0.0	0.0	0.0	0.5	4.7	0.91	156.	1.59	8.2
26	2326	4	24	32	28	400	139	0	0	0	0	539	42.2	57.8	0.0	0.0	0.0	0.0	1.7	13.9	0.91	476.	4.99	26.4
27	[illegible]	1	16	32	27	80	10	0	0	0	0	90	74.8	25.2	0.0	0.0	0.0	0.0	0.2	2.0	0.63	62.	0.61	3.0
28	2314	3	31	32	27	17	7	0	0	0	0	24	43.4	56.6	0.0	0.0	0.0	0.0	0.1	0.6	0.77	20.	0.21	1.1
29	2285	1	34	32	27	150	40	0	0	0	0	190	41.9	58.1	0.0	0.0	0.0	0.0	0.6	4.9	1.35	171.	1.63	10.0
30	1711	3	6	31	3	110	79	2	0	0	0	191	18.7	59.0	22.2	0.0	0.0	0.0	1.0	5.8	1.47	234.	2.72	16.4
31	39	3	34	31	27	290	130	1	0	0	0	421	28.1	64.3	7.6	0.0	0.0	0.0	1.7	11.8	1.47	446.	4.99	28.7
32	54	1	23	31	27	100	64	0	0	0	0	164	23.1	76.9	0.0	0.0	0.0	0.0	0.8	4.9	1.05	187.	2.10	12.1
33	1735	2	27	31	5	300	20	0	0	0	0	320	84.7	15.3	0.0	0.0	0.0	0.0	0.5	6.9	0.63	209.	2.03	9.9
34	1721	2	2	31	4	120	58	4	1	0	0	183	5.3	23.1	41.5	30.1	0.0	0.0	2.1	7.5	2.53	469.	7.41	62.9
35	1750	3	24	31	4	35	19	0	0	0	0	54	32.0	68.0	0.0	0.0	0.0	0.0	0.2	1.5	0.77	53.	0.57	3.0
36	1539	1	30	31	3	45	33	1	0	0	0	79	17.9	61.1	20.9	0.0	0.0	0.0	0.4	2.5	1.33	100.	1.17	7.0
37	754	1	4	31	28	150	118	1	0	0	0	269	20.6	68.7	10.7	0.0	0.0	0.0	1.3	8.0	1.47	310.	3.50	20.3
38	788	3	17	31	28	0	5	0	0	0	0	5	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.2	0.63	6.	0.07	0.4
39	2185	2	29	31	28	10	2	0	0	0	0	12	30.1	69.9	0.0	0.0	0.0	0.0	0.1	0.3	1.05	13.	0.15	0.9
40	691	4	29	31	28	20	13	0	0	0	0	33	36.3	63.7	0.0	0.0	0.0	0.0	0.1	0.9	0.63	29.	0.30	1.5
41	797	1	30	31	28	50	4	0	0	0	0	54	82.2	17.8	0.0	0.0	0.0	0.0	0.1	1.2	0.63	36.	0.35	1.7
42	2197	4	4	31	27	0	6	0	0	0	0	6.	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.2	0.63	8.	0.08	0.5
43	2364	3	6	31	27	170	71	0	0	0	0	241	35.6	64.4	0.0	0.0	0.0	0.0	0.8	6.4	1.05	227.	2.44	13.3
44	60	2	11	31	27	30	35	0	0	0	0	65	12.3	87.7	0.0	0.0	0.0	0.0	0.4	2.3	1.19	96.	1.13	6.8
45	1634	4	32	30	4	170	134	5	0	0	0	309	9.7	63.5	26.8	0.0	0.0	0.0	2.6	11.5	1.75	554.	7.21	48.8
46	1152	2	1	30	1	270	70	0	0	0	0	340	37.2	62.8	0.0	0.0	0.0	0.0	1.2	9.8	0.91	331.	3.62	20.2

47	2030	3	15	32	2	70	24	0	0	0	0	94	51.9	48.1	0.0	0.0	0.0	0.0	0.2	2.3	0.63	73.	0.74	3.8
48	2078	3	20	32	2	100	10	0	0	0	0	110	78.7	21.3	0.0	0.0	0.0	0.0	0.2	2.4	0.63	74.	0.72	3.5
49	1785	3	33	32	2	180	20	0	0	0	0	200	76.9	23.1	0.0	0.0	0.0	0.0	0.4	4.4	0.63	135.	1.33	6.5
50	2027	1	3	33	2	280	156	0	0	0	0	436	37.1	62.9	0.0	0.0	0.0	0.0	1.3	11.3	0.91	386.	4.02	21.0
51	1972	4	29	33	3	950	328	0	0	0	0	1278	42.9	57.1	0.0	0.0	0.0	0.0	3.8	32.6	1.05	1115.	11.67	61.8
52	1807	2	4	34	3	200	93	0	0	0	0	293	44.0	56.0	0.0	0.0	0.0	0.0	0.8	7.3	0.77	242.	2.47	12.7
53	2622	3	5	34	2	220	120	0	0	0	0	340	30.8	69.2	0.0	0.0	0.0	0.0	1.3	9.3	1.05	335.	3.62	19.9
54	2368	1	34	31	3	55	24	0	0	0	0	79	24.7	75.3	0.0	0.0	0.0	0.0	0.4	2.4	1.05	93.	1.06	6.2
	--NORTHERN:																							
55	1402	3	32	41	4	2700	432	0	0	0	0	3132	68.4	31.6	0.0	0.0	0.0	0.0	6.2	71.0	1.05	2222.	22.06	110.0
56	1184	4	31	41	3	100	47	2	0	0	0	149	22.3	54.2	23.5	0.0	0.0	0.0	0.7	4.4	1.33	174.	2.05	12.5
57	2500	3	32	41	2	1100	388	1	0	0	0	1489	35.7	62.6	1.7	0.0	0.0	0.0	5.2	39.6	1.33	1423.	15.46	85.8
58	2577	4	33	40	7	15	0	0	0	0	0	15	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.50	9.	0.09	0.4
59	2605	3	15	40	7	35	14	0	0	0	0	49	48.1	51.9	0.0	0.0	0.0	0.0	0.1	1.2	0.63	39.	0.40	2.0
60	713	1	26	40	6	600	192	0	0	0	0	792	51.6	48.4	0.0	0.0	0.0	0.0	1.9	19.2	0.91	625.	6.35	32.4
61	1061	3	1	40	6	1250	5	0	0	0	0	1255	98.9	1.1	0.0	0.0	0.0	0.0	1.7	26.1	0.63	766.	7.35	35.2
62	2619	4	21	40	6	390	6	0	0	0	0	396	96.0	4.0	0.0	0.0	0.0	0.0	0.6	8.3	0.63	245.	2.36	11.3
63	2581	2	28	40	5	16	0	0	0	0	0	16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.50	10.	0.09	0.4
64	2271	3	15	40	4	350	218	0	0	0	0	568	22.7	77.3	0.0	0.0	0.0	0.0	2.7	17.0	1.19	660.	7.46	42.9
65	1705	4	11	39	4	150	0	0	0	0	0	150	100.0	0.0	0.0	0.0	0.0	0.0	0.2	3.1	0.50	91.	0.87	4.2
66	176	1	29	39	6	17	14	0	0	0	0	31	26.3	73.7	0.0	0.0	0.0	0.0	0.1	0.9	0.77	31.	0.34	1.8
67	1697	2	5	39	4	100	41	0	0	0	0	141	44.7	55.3	0.0	0.0	0.0	0.0	0.4	3.5	0.77	118.	1.21	6.2
68	2480	1	23	39	4	185	2	0	0	0	0	187	97.2	2.8	0.0	0.0	0.0	0.0	0.3	3.9	0.63	115.	1.11	5.3
69	2397	1	6	39	3	12	0	0	0	0	0	12	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.50	7.	0.07	0.3
70	2466	4	26	39	3	17	9	0	0	0	0	26	35.5	64.5	0.0	0.0	0.0	0.0	0.1	0.7	0.77	24.	0.25	1.3
71	2392	1	3	39	3	500	71	0	0	0	0	571	67.1	32.9	0.0	0.0	0.0	0.0	1.2	13.0	0.91	412.	4.12	20.8
72	2173	2	19	39	2	75	169	1	0	0	0	245	4.2	91.5	4.3	0.0	0.0	0.0	3.1	11.8	1.47	596.	7.67	50.1
73	2589	4	30	42	4	360	106	0	0	0	0	466	51.4	48.6	0.0	0.0	0.0	0.0	1.2	11.3	0.91	371.	3.79	19.5
74	1214	2	5	42	3	104	90	3	0	0	0	197	9.0	77.4	13.6	0.0	0.0	0.0	1.9	7.9	1.33	382.	4.91	32.3
75	1551	1	11	42	3	26	13	0	0	0	0	39	24.4	75.6	0.0	0.0	0.0	0.0	0.2	1.2	1.05	45.	0.51	3.0
76	2496	1	28	42	3	55	12	0	0	0	0	67	45.6	54.4	0.0	0.0	0.0	0.0	0.2	1.7	1.05	58.	0.62	3.4
77	168	4	5	40	7	125	52	0	0	0	0	177	45.9	54.1	0.0	0.0	0.0	0.0	0.5	4.4	0.77	145.	1.48	7.6
78	1454	1	4	40	4	16	4	0	0	0	0	20	59.7	40.3	0.0	0.0	0.0	0.0	0.0	0.5	0.63	15.	0.15	0.7
79	569	3	1	40	5	17	8	0	0	0	0	25	35.8	64.2	0.0	0.0	0.0	0.0	0.1	0.7	0.91	23.	0.25	1.3
80	1695	2	35	41	2	260	44	0	0	0	0	304	63.4	36.6	0.0	0.0	0.0	0.0	0.7	7.0	0.91	224.	2.25	11.4
81	706	1	6	41	3	4	5	0	0	0	0	9	7.5	92.5	0.0	0.0	0.0	0.0	0.1	0.4	1.05	18.	0.23	1.5
82	2563	2	24	42	1	6	3	0	0	0	0	9	34.5	65.5	0.0	0.0	0.0	0.0	0.0	0.2	0.77	9.	0.09	0.5
83	1692	1	2	42	2	560	75	0	0	0	0	635	73.4	26.6	0.0	0.0	0.0	0.0	1.2	14.2	0.63	438.	4.31	21.3
84	2539	4	6	42	2	580	145	0	0	0	0	725	47.6	52.4	0.0	0.0	0.0	0.0	2.1	18.1	1.05	614.	6.42	34.0
85	1206	1	17	42	4	430	10	0	0	0	0	440	94.1	5.9	0.0	0.0	0.0	0.0	0.6	9.3	0.63	275.	2.65	12.7
86	2510	2	8	42	4	3200	879	0	0	0	0	4079	53.3	46.7	0.0	0.0	0.0	0.0	10.0	98.3	1.05	3206.	32.63	167.2

END OF FILE

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	PAD NO.	LAND LOCAT. Q	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	=. GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTO	CVRD	MAX. DIAM.	MASS (GM)	IMPACT VCM.	ENERGY
	AUGUST 23RD, "DENSE NETWORKS":																							
	--D.N. 'K', SOUTHERN....																							
1	2246	4	6	34	4	230	287	28	2	0	0	547	3.4	38.0	28.0	29.8	0.0	0.0	8.0	26.9	3.05	1601.	23.78	186.5
2	2188	4	6	34	4	510	504	40	6	0	0	1060	3.5	32.3	31.2	33.0	0.0	0.0	15.4	51.3	2.95	3190.	49.12	404.0
3	2152	4	6	34	4	1000	589	16	8	2	0	1615	6.2	26.4	8.2	34.3	24.9	0.0	14.7	59.6	3.36	3351.	51.82	447.9
4	2478	4	6	34	4	800	404	49	3	0	0	1256	7.4	38.9	33.7	20.1	0.0	0.0	13.5	51.3	2.74	2819.	40.16	303.0
5	2186	4	6	34	4	435	231	23	0	0	0	689	9.7	48.2	42.1	0.0	0.0	0.0	6.4	26.5	2.03	1337.	17.91	125.0
6	2479	4	6	34	4	480	406	47	4	0	0	937	4.2	35.8	32.7	27.3	0.0	0.0	13.2	44.9	2.95	2688.	40.02	316.2
7	2304	4	6	34	4	755	378	38	3	0	0	1174	7.6	39.8	40.3	12.3	0.0	0.0	12.5	47.8	2.31	2614.	37.00	275.5
8	2288	4	6	34	4	335	308	45	5	0	0	693	3.1	29.0	41.7	26.2	0.0	0.0	11.8	36.7	2.74	2387.	36.96	301.1

	--D.N. 'Y', SOUTHERN....																							
9	2548	3	4	34	4	220	90	1	0	0	0	311	32.9	59.2	7.9	0.0	0.0	0.0	1.1	8.4	1.33	305.	3.33	18.6
10	2415	3	4	34	4	385	166	3	0	0	0	554	25.3	49.9	24.8	0.0	0.0	0.0	2.4	15.6	1.89	605.	7.00	42.4
11	2416	3	4	34	4	350	142	3	0	0	0	495	18.0	64.2	17.8	0.0	0.0	0.0	3.1	16.0	1.75	696.	8.53	54.2
12	2417	3	4	34	4	480	446	9	0	0	0	935	11.4	73.0	15.6	0.0	0.0	0.0	7.0	33.7	1.75	1504.	18.50	117.2
13	2412	3	4	34	4	360	175	11	0	0	0	546	12.6	57.3	30.1	0.0	0.0	0.0	4.2	19.2	2.03	910.	11.79	79.7
14	2549	3	4	34	4	120	128	7	0	0	0	255	6.5	59.5	34.0	0.0	0.0	0.0	2.7	10.8	1.75	557.	7.44	51.4
15	2550	3	4	34	4	500	289	14	0	0	0	803	13.3	64.3	22.3	0.0	0.0	0.0	6.0	28.5	1.47	1299.	16.23	104.6
16	2414	3	4	34	4	230	178	21	0	0	0	429	6.1	53.8	40.2	0.0	0.0	0.0	5.5	19.8	1.75	1082.	14.87	105.2
17	2269	3	4	34	4	350	268	10	0	0	0	628	9.4	72.0	18.5	0.0	0.0	0.0	5.9	24.9	1.61	1211.	15.60	103.4
	--D.N. 'Z', SOUTHERN....																							
18	2421	4	30	33	4	575	247	0	0	0	0	822	27.8	72.2	0.0	0.0	0.0	0.0	3.6	23.7	1.19	991.	10.09	57.6
19	2422	4	30	33	4	730	497	1	0	0	0	1228	23.0	75.3	1.7	0.0	0.0	0.0	5.7	36.8	1.33	1403.	15.62	85.3
20	2424	4	30	33	4	800	485	0	0	0	0	1285	19.0	81.0	0.0	0.0	0.0	0.0	7.4	41.2	1.19	1689.	19.70	117.4
21	2419	4	30	33	4	352	202	0	0	0	0	554	21.6	78.4	0.0	0.0	0.0	0.0	2.9	17.1	1.19	681.	7.78	45.4
22	2420	4	30	33	4	545	423	0	0	0	0	968	16.9	83.1	0.0	0.0	0.0	0.0	5.8	31.9	1.19	1311.	15.23	90.1
23	2418	4	30	33	4	575	397	3	0	0	0	975	18.6	74.7	6.8	0.0	0.0	0.0	5.4	31.0	1.47	1255.	14.54	86.3
24	2427	4	30	33	4	880	730	6	0	0	0	1616	15.3	76.9	7.7	0.0	0.0	0.0	10.0	53.7	1.75	2243.	25.47	160.2
25	2425	4	30	33	4	850	446	0	0	0	0	1296	24.4	75.6	0.0	0.0	0.0	0.0	6.2	38.6	1.19	1494.	16.85	96.9
	--D.N. 'W', SOUTHERN....																							
26	2501	3	26	33	4	110	49	1	0	0	0	160	20.3	70.0	9.7	0.0	0.0	0.0	0.9	5.0	1.33	206.	2.46	15.1
27	2502	3	26	33	4	310	47	0	0	0	0	357	55.1	44.9	0.0	0.0	0.0	0.0	[illegible]	8.5	1.19	254.	2.95	15.7
28	2503	3	26	33	4	150	65	0	0	0	0	215	28.8	71.2	0.0	0.0	0.0	0.0	0.9	6.1	1.05	231.	2.57	14.5
29	2460	3	26	33	4	125	45	0	0	0	0	170	28.4	71.6	0.0	0.0	0.0	0.0	0.7	4.8	1.19	185.	2.10	12.2
30	2461	3	26	33	4	200	70	1	0	0	0	271	26.6	66.4	7.0	0.0	0.0	0.0	1.3	7.9	1.33	308.	3.54	20.9
31	2463	3	26	33	4	215	159	6	0	0	0	380	12.6	64.4	23.0	0.0	0.0'	0.0	2.8	13.5	1.47	605.	7.47	47.6
32	2464	3	26	33	4	65	106	8	0	0	0	179	3.5	59.9	36.6	0.0	0.0	0.0	2.8	9.4	1.75	529.	7.30	51.7
33	2518	3	26	33	4	98	123	4	0	0	0	225	6.4	78.2	15.4	0.0	0.0	0.0	2.5	9.9	1.47	498.	6.45	42.7
	--D.N. 'X', NORTHERN....																							
34	2724	1	6	42	2	1040	329	2	0	0	0	1371	34.0	62.6	3.4	0.0	0.0	0.0	5.2	37.3	1.33	1372.	15.12	85.2
35	2671	1	6	42	2	880	373	1	0	0	0	1254	30.3	67.0	2.7	0.0	0.0	0.0	5.0	34.9	1.47	1295.	14.31	80.8
36	2554	1	6	42	2	1200	354	0	0	0	0	1554	40.3	59.7	0.0	0.0	0.0	0.0	5.1	40.3	1.19	1419.	15.20	82.9
37	2555	2	6	42	2	1400	688	1	0	0	0	2089	26.4	72.6	1.0	0.0	0.0	0.0	9.4	61.0	1.33	2321.	25.94	[illegible]
38	2556	2	6	42	2	2650	1072	0	0	0	0	3722	38.1	61.9	0.0	0.0	0.0	0.0	12.2	98.0	1.19	3419.	36.19	193.7
39	9999	2	6	42	2	2960	859	0	0	0	0	3819	49.3	50.7	0.0	0.0	0.0	0.0	10.2	94.1	1.05	3129.	32.21	167.4
40	2612	2	6	42	2	1300	534	0	0	0	0	1834	32.3	67.7	0.0	0.0	0.0	0.0	7.0	59.5	1.19	1846.	20.15	112.0
41	2611	2	6	42	2	1370	645	0	0	0	0	2015	29.7	70.3	0.0	0.0	0.0	0.0	8.2	57.1	1.19	2109.	23.11	128.5
42	2681	1	6	42	2	900	646	0	0	0	0	1546	0.D	79.9	0.0	0.0	0.0	0.0	8.2	48.5	1.19	1510.	21.64	124.5
43	2610	1	6	42	2	930	526	0	0	0	0	1456	26.1	73.9	0.0	0.0	0.0	0.0	6.4	42.2	1.19	1589.	17.61	99.3
44	2736	4	6	42	2	530	687	0	0	0	0	1217	15.0	85.0	0.0	0.0	0.0	0.0	6.7	39.7	1.05	1553.	17.42	98.7
45	2683	4	6	42	2	1000	773	0	0	0	0	1773	19.8	80.2	0.0	0.0	0.0	0.0	9.3	55.6	1.19	2178.	24.58	140.8
46	2557	3	6	42	2	1800	983	0	0	0	0	2783	29.3	70.7	0.0	0.0	0.0	0.0	11.0	78.3	1.19	2801.	31.08	171.1
47	2558	3	6	42	2	1900	473	0	0	0	0	2373	54.2	45.8	0.0	0.0	0.0	0.0	5.8	57.0	1.05	1665.	19.01	97.7
48	2561	3	6	42	2	1800	528	0	0	0	0	2328	46.7	53.3	0.0	0.0	0.0	0.0	6.5	58.2	1.05	1966.	20.43	107.3
49	2560	3	6	42	2	2950	713	0	0	0	0	3663	56.4	43.6	0.0	0.0	0.0	0.0	8.6	87.2	0.91	2825.	28.01	145.8
50	2734	3	6	42	2	900	115	0	0	0	0	1015	72.4	27.6	0.0	0.0	0.0	0.0	1.9	22.8	0.77	707.	6.98	34.7
51	2733	3	6	42	2	850	128	0	0	0	0	978	66.4	33.6	0.0	0.0	0.0	0.0	2.0	22.4	0.91	709.	7.09	35.7
52	2732	4	6	42	2	1120	173	0	0	0	0	1293	65.4	34.6	0.0	0.0	0.0	0.0	2.7	29.7	0.91	944.	9.46	47.7
53	2735	4	6	42	2	485	258	0	0	0	0	743	30.4	69.6	0.0	0.0	0.0	0.0	2.9	20.8	0.91	753.	9.13	44.5
54	2725	4	6	42	2	370	92	0	0	0	0	462	55.3	44.7	0.0	0.0	0.0	0.0	1.1	11.0	0.91	359.	3.65	18.6
55	2726	4	6	42	2	80	17	0	0	0	0	97	61.9	38.1	0.0	0.0	0.0	0.0	0.2	2.3	0.77	72.	0.72	3.6
56	2727	4	6	42	2	205	18	0	0	0	0	223	76.8	23.2	0.0	0.0	0.0	0.0	0.4	4.9	0.77	152.	1.50	7.4
57	2728	3	6	42	2	700	91	0	0	0	0	791	70.5	29.5	0.0	0.0	0.0	0.0	1.5	17.8	0.91	558.	5.54	27.7
58	2559	3	6	42	2	970	237	0	0	0	0	1207	55.6	44.2	0.0	0.0	0.0	0.0	2.9	28.8	0.91	935.	9.48	48.4

END OF FILE

#	PAD NO.	O	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% PAD/GND DENTD	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	IMPACT ENERGY
	AUGUST 24TH. SOUTHERN NETWORK:																							
1	1969	4	13	33	4	1500	564	0	0	0	0	2064	43.8	56.2	0.0	0.0	0.0	0.0	5.9	52.0	1.05	1753.	18.20	95.4
2	2068	2	22	33	4	560	201	0	0	0	0	761	39.5	60.5	0.0	0.0	0.0	0.0	2.5	19.8	1.05	692.	7.34	39.5
3	1971	4	29	33	3	1500	0	0	0	0	0	1500	100.0	0.0	0.0	0.0	0.0	0.0	2.0	31.1	0.50	514.	8.74	41.8
4	2015	2	36	33	3	370	220	1	0	0	0	591	26.8	69.3	3.8	0.0	0.0	0.0	2.4	16.8	1.33	623.	6.85	38.4
5	2637	3	19	33	3	500	166	0	0	0	0	666	43.5	56.5	0.0	0.0	0.0	0.0	2.0	17.0	0.91	579.	6.06	32.0
6	1407	1	36	31	3	2600	6	0	0	0	0	2606	99.4	0.6	0.0	0.0	0.0	0.0	3.6	54.1	0.63	1592.	15.24	72.9
7	2355	3	36	30	3	890	191	0	0	0	0	1081	59.7	40.3	0.0	0.0	0.0	0.0	2.4	25.4	0.77	815.	9.21	41.6
8	2602	2	24	34	2	700	5	0	0	0	0	705	98.1	1.9	0.0	0.0	0.0	0.0	1.0	14.7	0.63	433.	4.15	19.9
9	599	3	35	34	1	15	18	0	0	0	0	33	15.3	84.7	0.0	0.0	0.0	0.0	0.2	1.1	0.91	43.	0.48	2.7
10	2114	4	36	33	2	0	10	0	0	0	0	10	0.0	100.0	0.0	0.0	0.0	0.0	0.1	0.4	0.91	15.	0.17	1.0
11	1932	1	34	32	27	50	30	0	0	0	0	80	33.2	66.8	0.0	0.0	0.0	0.0	0.3	2.2	0.77	75.	0.79	4.2
12	1722	2	2	31	4	50	0	0	0	0	0	50	100.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	0.50	30.	0.29	1.4
13	1361	1	18	31	2	225	38	0	0	0	0	263	64.8	35.2	0.0	0.0	0.0	0.0	0.6	6.1	0.77	192.	1.92	9.7
14	2670	3	8	34	3	12	4	0	0	0	0	16	52.6	47.4	0.0	0.0	0.0	0.0	0.0	0.4	0.63	12.	0.13	0.6
15	1375	1	23	31	3	1400	40	0	0	0	0	1440	92.8	7.2	0.0	0.0	0.0	0.0	2.1	30.4	0.63	905.	8.72	42.0
16	2349	1	19	31	2	385	317	0	0	0	0	702	24.3	75.7	0.0	0.0	0.0	0.0	2.9	20.5	0.91	749.	8.09	44.1
17	2003	1	24	32	3	1700	852	5	0	0	0	2557	26.0	70.0	4.0	0.0	0.0	0.0	11.6	75.0	1.33	2860.	31.99	182.3
18	2090	2	6	33	4	1040	406	0	0	0	0	1446	46.1	53.9	0.0	0.0	0.0	0.0	3.9	36.0	0.77	1193.	12.21	62.8
19	680	3	22	33	2	1070	620	0	0	0	0	1690	37.8	62.2	0.0	0.0	0.0	0.0	5.9	43.7	0.91	1475.	15.22	79.0

END OF FILE

#	PAD NO.	O	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% PAD/GND DENTD	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	IMPACT ENERGY
	AUGUST 27TH. SOUTHERN NETWORK:																							
1	2022	1	6	32	3	1100	5	0	0	0	0	1105	98.8	1.2	0.0	0.0	0.0	0.0	1.5	23.0	0.63	677.	6.48	31.0
2	966	1	34	31	3	750	0	0	0	0	0	750	100.0	0.0	0.0	0.0	0.0	0.0	1.0	15.6	0.50	457.	4.37	20.9
3	1198	1	36	31	3	620	0	0	0	0	0	620	100.0	0.0	0.0	0.0	0.0	0.0	0.8	12.9	0.50	378.	3.61	17.3
4	1745	3	34	31	4	375	275	1	0	0	0	651	14.1	81.6	4.2	0.0	0.0	0.0	4.6	22.9	1.61	998.	12.02	74.0
5	1893	3	8	32	4	1000	655	0	0	0	0	1655	29.8	70.2	0.0	0.0	0.0	0.0	6.1	45.8	0.91	1630.	17.37	93.4
6	2098	3	35	34	1	1000	0	0	0	0	0	1000	100.0	0.0	0.0	0.0	0.0	0.0	1.4	20.7	0.50	609.	5.83	27.9
7	2459	4	6	34	4	7	4	0	0	0	0	11	33.2	66.8	0.0	0.0	0.0	0.0	0.0	0.3	0.77	10.	0.11	0.6
8	2091	2	6	33	4	45	6	0	0	0	0	51	73.5	26.5	0.0	0.0	0.0	0.0	0.1	1.1	0.63	35.	0.35	1.7
9	1878	4	30	33	4	95	33	0	0	0	0	128	50.7	49.3	0.0	0.0	0.0	0.0	0.3	3.1	0.77	101.	1.03	5.2
10	1229	1	26	31	2	480	91	0	0	0	0	571	63.0	37.0	0.0	0.0	0.0	0.0	1.2	13.2	0.77	421.	4.22	21.2
11	1243	1	19	31	2	965	10	0	0	0	0	975	97.3	2.7	0.0	0.0	0.0	0.0	1.4	20.4	0.63	601.	5.76	27.6
12	1393	3	28	31	2	306	68	0	0	0	0	368	58.8	41.2	0.0	0.0	0.0	0.0	0.8	8.7	0.77	279.	2.81	14.2
13	2469	4	33	31	2	22	12	0	0	0	0	34	40.4	59.6	0.0	0.0	0.0	0.0	0.1	0.9	0.63	29.	0.30	1.5
14	2224	1	9	34	1	95	37	0	0	0	0	132	31.9	68.1	0.0	0.0	0.0	0.0	0.5	3.7	1.05	135.	1.48	8.3
15	625	1	9	34	1	75	53	0	0	0	0	128	22.5	77.5	0.0	0.0	0.0	0.0	0.6	3.9	1.05	148.	1.65	9.3
16	2223	2	1	34	1	500	252	0	0	0	0	752	38.0	62.0	0.0	0.0	0.0	0.0	2.3	19.5	1.05	665.	6.95	36.6

END OF FILE

#	PAD NO.	O	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% SHOT	% PEA	% GRP.	% WAL.	% GLF	% >GLF	% PAD/GND DENTD	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	IMPACT ENERGY
	AUGUST 27TH. NORTHERN NETWORK:																							
1	1193	3	2	42	4	96	30	0	0	0	0	126	47.2	52.8	0.0	0.0	0.0	0.0	0.3	3.1	0.77	105.	1.09	5.7
2	1417	1	28	42	3	300	0	0	0	0	0	300	100.0	0.0	0.0	0.0	0.0	0.0	0.4	6.2	0.50	183.	1.75	8.4
3	1403	3	32	41	4	600	0	0	0	0	0	600	100.0	0.0	0.0	0.0	0.0	0.0	0.8	12.4	0.50	366.	3.50	16.7
4	1039	2	22	42	3	100	90	0	0	0	0	190	12.5	87.5	0.0	0.0	0.0	0.0	1.4	6.9	1.05	301.	3.62	22.2
5	2267	4	1	39	27	800	27	0	0	0	0	827	91.6	8.4	0.0	0.0	0.0	0.0	1.2	17.5	0.63	522.	5.04	24.3

6	2190	4	28	39	27	800	2	0	0	0	0	802	98.2	1.8	0.0	0.0	0.0	0.0	1.1	16.7	0.91	493.	4.73	22.7
7	1569	4	35	42	3	63	76	0	0	0	0	139	17.8	82.2	0.0	0.0	0.0	0.0	0.7	4.3	0.91	162.	1.78	9.9
8	2497	2	18	42	3	85	21	0	0	0	0	106	47.7	52.3	0.0	0.0	0.0	0.0	0.3	2.6	1.05	89.	0.93	5.8
9	2508	2	5	42	3	520	459	0	0	0	0	979	19.2	80.8	0.0	0.0	0.0	0.0	5.0	30.7	1.19	1191.	13.32	75.5
10	1185	4	31	41	3	640	173	0	0	0	0	813	43.2	56.8	0.0	0.0	0.0	0.0	2.5	20.7	1.05	719.	7.64	41.3
11	1847	3	9	40	27	1650	140	0	0	0	0	1790	78.0	22.0	0.0	0.0	0.0	0.0	3.2	39.4	0.91	1212.	11.93	59.0
12	2654	4	33	40	7	175	2	0	0	0	0	177	97.0	3.0	0.0	0.0	0.0	0.0	0.2	3.7	0.63	109.	1.05	5.0
13	2272	3	15	40	4	20	3	0	0	0	0	23	71.2	28.8	0.0	0.0	0.0	0.0	0.0	0.5	0.63	16.	0.16	0.8
14	1666	4	21	39	28	35	2	0	0	0	0	37	86.6	13.4	0.0	0.0	0.0	0.0	0.1	0.8	0.63	29.	0.23	1.1

END OF FILE

	PAD NO.	LAND LOCAT. O	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTD	CVRD	MAX. DIAM.	MASS (GM)	I M P A C T MOM.	ENERGY
	MISCELLANEOUS HAIL DATES.......																							
	SOUTHERN NETWORK:																							
	--AUGUST 4TH....																							
1	418	3	1	33	4	15	6	0	0	0	0	21	48.1	51.9	0.0	0.0	0.0	0.0	0.1	0.5	0.63	17.	0.17	0.9
	--AUGUST 10TH....																							
2	2102	1	32	34	1	130	135	0	0	0	0	265	17.0	83.0	0.0	0.0	0.0	0.0	1.5	8.6	0.91	336.	3.76	21.3
	NORTHERN NETWORK:																							
	--JUNE 23RD....																							
3	404	4	28	39	27	45	7	0	0	0	0	52	55.1	44.9	0.0	0.0	0.0	0.0	0.1	1.2	1.05	41.	0.43	2.3
	--JUNE 25TH....																							
4	502	2	31	39	26	260	13	0	0	0	0	273	88.1	11.9	0.0	0.0	0.0	0.0	0.4	5.8	0.63	175.	1.70	8.2
5	508	4	1	39	27	162	10	0	0	0	0	172	75.1	24.9	0.0	0.0	0.0	0.0	0.3	3.8	1.05	119.	1.19	6.0
	--JULY 1ST....																							
6	1452	2	10	41	1	1850	33	0	0	0	0	1883	95.4	4.6	0.0	0.0	0.0	0.0	2.7	39.5	0.63	1170.	11.24	54.0
7	546	3	16	41	1	310	39	0	0	0	0	349	74.0	26.0	0.0	0.0	0.0	0.0	0.6	7.8	0.77	240.	2.36	11.7
8	1572	1	16	41	1	350	150	0	0	0	0	500	36.8	63.2	0.0	0.0	0.0	0.0	1.7	13.4	0.77	469.	4.96	26.5
	--JULY 7TH....																							
9	970	2	10	41	1	130	68	0	0	0	0	198	38.2	61.8	0.0	0.0	0.0	0.0	0.6	5.1	0.91	174.	1.81	9.5
	--JULY 8TH....																							
10	1397	2	8	42	4	40	24	0	0	0	0	64	28.5	71.5	0.0	0.0	0.0	0.0	0.3	1.8	0.91	65.	0.71	3.9
	--AUGUST 3RD....																							
11	1129	1	23	39	4	30	11	0	0	0	0	41	28.5	71.5	0.0	0.0	0.0	0.0	0.2	1.2	1.05	45.	0.51	2.9
	--AUGUST 9TH....																							
12	1556	3	7	41	2	360	170	0	0	0	0	530	39.9	60.1	0.0	0.0	0.0	0.0	1.6	13.7	0.91	463.	4.81	28.1

END OF FILE

	PAD NO.	LAND LOCAT. O	SX	TS	RG	SHOT	PEA	GR-APE	WAL-NUT	= GOLF	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND DENTD	CVRD	MAX. DIAM.	MASS (GM)	I M P A C T MOM.	ENERGY
	MOBILE OPERATIONS:																							
	--JULY 4TH (PENHOLD)....																							
1	1377	3	13	37	28	27	8	0	0	0	0	35	48.9	51.1	0.0	0.0	0.0	0.0	0.1	0.9	0.77	29.	0.30	1.5
	--JULY 23RD....																							
2	2161	2	25	41	8	75	215	42	0	0	0	332	1.3	40.8	57.9	0.0	0.0	0.0	8.0	23.0	1.75	1489.	21.93	165.0
3	2160	2	25	41	8	150	341	3	0	0	0	494	4.2	89.9	5.9	0.0	0.0	0.0	6.2	23.8	1.47	1191.	15.27	99.4
4	2159	2	25	41	8	160	154	0	0	0	0	314	14.5	85.5	0.0	0.0	0.0	0.0	2.0	10.8	1.19	448.	5.21	30.8
	--AUGUST 23RD....																							
5	2708	4	13	35	4	385	230	6	0	0	0	621	14.8	67.7	17.4	0.0	0.0	0.0	4.2	21.1	1.61	927.	11.38	72.2
6	2449	4	13	35	4	265	221	8	0	0	0	494	10.9	69.7	19.4	0.0	0.0	0.0	4.0	18.5	1.47	848.	10.58	67.9
7	2700	4	13	35	4	255	253	6	0	0	0	514	11.3	71.3	17.4	0.0	0.0	0.0	3.8	18.6	1.47	822.	10.03	62.9
8	2704	4	13	35	4	250	216	5	0	0	0	471	11.1	74.7	14.3	0.0	0.0	0.0	3.8	17.5	1.61	797.	9.88	63.0
9	2709	4	13	35	4	260	258	6	0	0	0	524	9.8	76.5	13.8	0.0	0.0	0.0	4.5	20.3	1.47	936.	11.64	74.2

10	2676	4	13	35	4	260	234	9	0	0	0	503	9.0	68.1	22.9	0.0	0.0	0.0	4.0	19.8	1.61	952.	12.19	80.4
11	2701	4	13	35	4	200	196	8	0	0	0	404	9.1	69.6	21.4	0.0	0.0	0.0	3.6	15.8	1.47	746.	9.45	61.5

END OF FILE

	PAD NO.	LAND LOCAT. O	SX	TS	RG	SHOT	GR- PEA	WAL- APE	= NUT	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND CENTC	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	ENERGY
	EDMONTON SITE:																						
	--AUGUST 4TH....																						
1	1607	3	11	53	25	210	116	0	0	0	0	326	35.0	65.0	0.0	0.0	0.0	0.0	1.1	8.7	0.91	300.	3.15	16.7
2	3000	3	11	53	25	240	98	0	0	0	0	338	41.7	58.3	0.0	0.0	0.0	0.0	1.0	8.7	0.91	294.	3.06	16.0
	--SEPTEMBER 11TH....																						
3	2596	3	11	53	25	865	512	0	0	0	0	1377	28.8	71.2	0.0	0.0	0.0	0.0	5.4	38.5	1.05	1401.	15.19	83.6
4	2744	3	11	53	25	275	86	0	0	0	0	361	38.0	62.0	0.0	0.0	0.0	0.0	1.2	9.5	1.05	338.	3.66	20.2
5	2745	3	11	53	25	16	0	0	0	0	0	16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.50	10.	0.05	0.4

END OF FILE

	PAD NO.	LAND LOCAT. O	SX	TS	RG	SHOT	GR- PEA	WAL- APE	= NUT	> GOLF	TOT. NO.	% CONTRIBUTION TO TOTAL ENERGY SHOT	PEA	GRP.	WAL.	GLF	>GLF	% PAD/GND CENTO	CVRD	MAX. DIAM.	MASS (GM)	IMPACT MOM.	ENERGY
	UNKNOWN DATES:																						
	SOUTHERN NETWORK....																						
1	1000	3	20	34	4	30	47	0	0	0	0	77	8.7	91.3	0.0	0.0	0.0	0.0	0.6	2.9	1.05	130.	1.57	9.6
2	1821	3	22	34	4	10	3	0	0	0	0	13	55.2	44.8	0.0	0.0	0.0	0.0	0.0	0.3	0.63	10.	0.10	0.5
3	1678	1	27	34	2	60	1	0	0	0	0	61	95.7	4.3	0.0	0.0	0.0	0.0	0.1	1.3	0.63	38.	0.36	1.7
4	1920	2	24	34	2	2	2	0	0	0	0	4	27.0	73.0	0.0	0.0	0.0	0.0	0.0	0.1	0.63	4.	0.04	0.2
5	2097	3	35	34	1	15	4	0	0	0	0	19	58.1	41.9	0.0	0.0	0.0	0.0	0.0	0.4	0.63	14.	0.14	0.7
6	1900	1	27	33	28	15	3	0	0	0	0	18	64.9	35.1	0.0	0.0	0.0	0.0	0.0	0.4	0.63	13.	0.13	0.6
7	265	2	6	33	4	24	12	0	0	0	0	36	33.0	67.0	0.0	0.0	0.0	0.0	0.1	1.0	0.77	35.	0.38	2.0
8	2065	2	22	33	4	12	4	0	0	0	0	16	40.9	59.1	0.0	0.0	0.0	0.0	0.1	0.4	0.77	15.	0.15	0.8
9	877	4	23	33	3	0	1	0	0	0	0	1	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.1	0.91	4.	0.05	0.3
10	48	4	23	32	27	10	0	0	0	0	0	10	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.50	6.	0.06	0.3
11	115	3	31	32	27	60	31	0	0	0	0	91	36.7	63.3	0.0	0.0	0.0	0.0	0.3	2.4	0.77	63.	0.86	4.6
12	189	2	22	31	1	20	10	0	0	0	0	30	42.5	57.5	0.0	0.0	0.0	0.0	0.1	0.8	0.63	25.	0.26	1.3
13	787	3	17	31	28	15	11	0	0	0	0	26	19.8	80.2	0.0	0.0	0.0	0.0	0.1	0.8	1.05	32.	0.36	2.1
14	36	3	34	31	27	60	0	0	0	0	0	60	100.0	0.0	0.0	0.0	0.0	0.0	0.1	1.2	0.50	37.	0.35	1.7
15	674	4	29	32	4	110	54	0	0	0	0	164	28.0	72.0	0.0	0.0	0.0	0.0	0.7	4.7	1.05	177.	1.96	10.9
	NORTHERN NETWORK....																						
16	1337	3	6	43	2	45	11	0	0	0	0	56	60.2	39.8	0.0	0.0	0.0	0.0	0.1	1.3	0.63	42.	0.42	2.1
17	1186	3	2	42	4	200	13	0	0	0	0	213	85.1	14.9	0.0	0.0	0.0	0.0	0.3	4.6	0.63	139.	1.35	6.6
18	1394	2	8	42	4	80	20	0	0	0	0	100	59.7	40.3	0.0	0.0	0.0	0.0	0.2	2.3	0.63	74.	0.74	3.7
19	1200	1	17	42	4	200	50	0	0	0	0	250	59.7	40.3	0.0	0.0	0.0	0.0	0.5	5.9	0.63	186.	1.86	9.3
20	1314	2	24	42	2	30	9	0	0	0	0	39	52.1	47.9	0.0	0.0	0.0	0.0	0.1	0.9	0.77	31.	0.31	1.6
21	1573	1	16	41	1	8	1	0	0	0	0	9	74.8	25.2	0.0	0.0	0.0	0.0	0.0	0.2	0.63	6.	0.06	0.3
22	1835	1	28	41	28	140	106	0	0	0	0	246	23.6	76.4	0.0	0.0	0.0	0.0	1.1	7.3	1.05	272.	2.98	16.6
23	1836	1	28	41	28	400	415	0	0	0	0	815	13.6	86.4	0.0	0.0	0.0	0.0	5.4	28.2	1.05	1182.	13.83	82.1
24	2665	1	28	41	28	5	3	0	0	0	0	8	30.5	69.5	0.0	0.0	0.0	0.0	0.0	0.2	0.77	8.	0.08	0.5
25	2573	1	29	39	6	107	1	0	0	0	0	108	97.5	2.5	0.0	0.0	0.0	0.0	0.2	2.3	0.63	66.	0.64	3.1
26	1134	5	33	39	4	25	10	0	0	0	0	35	37.0	63.0	0.0	0.0	0.0	0.0	0.1	0.9	0.91	33.	0.35	1.9
27	1135	5	33	39	4	235	214	2	0	0	0	451	13.3	77.8	8.9	0.0	0.0	0.0	3.0	15.4	1.47	664.	7.98	49.2
28	325	2	19	39	2	35	4	0	0	0	0	39	76.4	23.6	0.0	0.0	0.0	0.0	0.1	0.9	0.63	26.	0.26	1.3
29	1127	4	35	39	1	160	44	0	0	0	0	204	56.1	43.9	0.0	0.0	0.0	0.0	0.5	4.9	0.77	156.	1.57	8.0

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