B

TORNADO PROJECT SUMMARY SHEET

F=2 (see ONT)

1. DATE AND TIME Tue JUNE 27, 1978

2. LOCATION OR PATH (attach map)
VCNTY ST-BERNADIN To McALPINE 0697816

3. PATH LENGTH ☐ NOT KNOWN ☐ <1mi; ☐ 1-4mi; ☐ 5-10mi; ☐ 11-50mi; ☐ LENGTH IF>50m

4. PATH WIDTH ☐ 5. TORNADO PART OF SQUALL LINE? ☐ YES; ☐ NO; ☐ UNKNOWN:

6. ANY UNUSUAL COLORATION? ☐ YES; ☐ NO; ☐ UNKNOWN

7. ANY UNUSUAL SOUND? ☐ YES; ☐ NO; ☐ UNKNOWN

8. IF ANSWER TO 6 OR 7 YES, ELABORATE;

9. LIST ANY ASSOCIATED PHENOMENA (such as hail, vivid lightning heavy rain, no rain, etc.) Hail

10. TOTAL DAMAGE ESTIMATE $ 1,000,000 11. TOTAL DEATHS NONE

12. TOTAL INJURED NONE 13. TOTAL HOMELESS ~~NO~~ U.

14. LIST ALL REFERENCES

ALEXANDRIA GLENGARRY NEWS JULY 5, 1978
VANKLEEK HILL REVIEW, JULY 5, 1978, JULY 19, AUG 30 1978
Telephone Interviews May 3, 1980, by M.J Newark
Ontario Hydro Report. (unpublished)

15. SUMMARIZE REMARKS PERTAINING TO (a) FUNNEL; (b) INTERESTING OR CAPRICIOUS EVENTS.

(a) no remarks

(b) Barns and silos badly damaged. 5 hydro towers flattened.

WORKSHEET

IDTO 0697816

(1) ORIGIN x 18513400 (5) Standard Error S_x ∅1200

y 5030600

(2) LIFT-OFF x_1 18523050 (6) Standard Error S_y C30

y_1 5041000

(3) $(x_1 - x)$ = .9650

(4) $(y - y_1)$ = 10400

(7) DAMAGE LENGTH

$L = [(x_1 - x)^2 + (y - y_1)^2]^{1/2}$ (8) $\alpha = \tan^{-1} \frac{|y - y_1|}{|x - x_1|}$

(3)+(4) [→ r, θ] = .14187 m [x ↔ Y] = 47°

(9) Standard Error $S_L = (S_x^2 + S_y^2)^{1/2}$

(5)+(6) [→ r, θ] = 1200 ∅

(10) $\beta = \frac{\tan^{-1} S_L}{L}$

(7)+(9) [→ r, θ]

[x ↔ Y] = 5°

NE Quad $\phi = 90 - \alpha$

NW Quad $\phi = 270 + \alpha$

SW quad $\phi = 270 - \alpha$

SE quad $\phi = 90 + \alpha$

(11) ϕ = 223°



July 27, 1978

402.2-W-2.2

Tornado Damage
Vankleek Hill Area
June 27, 1978

On June 27, 1978 at 17:04 hours EST, an outage occurred on circuit D5A 230 kV (St. Isidore-Hawthrone) at St. Amour, Ontario. Five towers were destroyed and one badly damaged by a tornado. These towers were type X9S, rated to wind speeds of 160 km/h. Satellite photographs in the possession of AES show it travelling from the vicinity of Buckingham, Quebec to the Vankleek Hill area.

As well as the damage to hydro installations, a fair amount of damage was done to buildings and vegetation, as can be seen from the attached photographs.

At approximately the same time as the system outage, a line of severe thunderstorms struck the Vankleek Hill area. These storms were accompanied by very high winds (some estimates to 80 - 100 km/h) and hail. During the worst of these storms, visibility was reduced to nil because of heavy rain, hail and blowing debris. Some damage occurred along the Ridge Road because of these storms, but the major damage was sustained in the St. Amour area. There were no positibe sightings of either a funnel cloud or a funnel on the ground. I checked the Hydro Area Office and Mr. J.L. Venutti the Area Manager, had received no reports at that time, neither had the OPP detachment office for the area. There was one report from a woman in the St. Amour area who said she observed whole trees being uprooted and carried aloft but she did not see a funnel.

Several of the attached photographs indicate the typical whorl pattern of a tornado on standing vegetation. A tree line is shown across the road from one of the downed towers with all of the trees down in the same direction. This indicates that the tornado passed to the north of these trees in the area of the most heavily damaged tower. A damage track 300 - 400 m wide, was discovered to the west of the tower line extending approximately 4.5 km from the point of furthest damage east of the tower. From that point no damage could be seen to the west because the swampy nature of the terrain made investigation by foot or vehicle impractical. To the east of the tower line the terrain is open and contains no buildings or large stands of timber for 5 - 6 km and so no damage was observed in that direction. The areas of damage along the Ridge Road attributed to the line of thunderstorms are also indicated on the attached map.

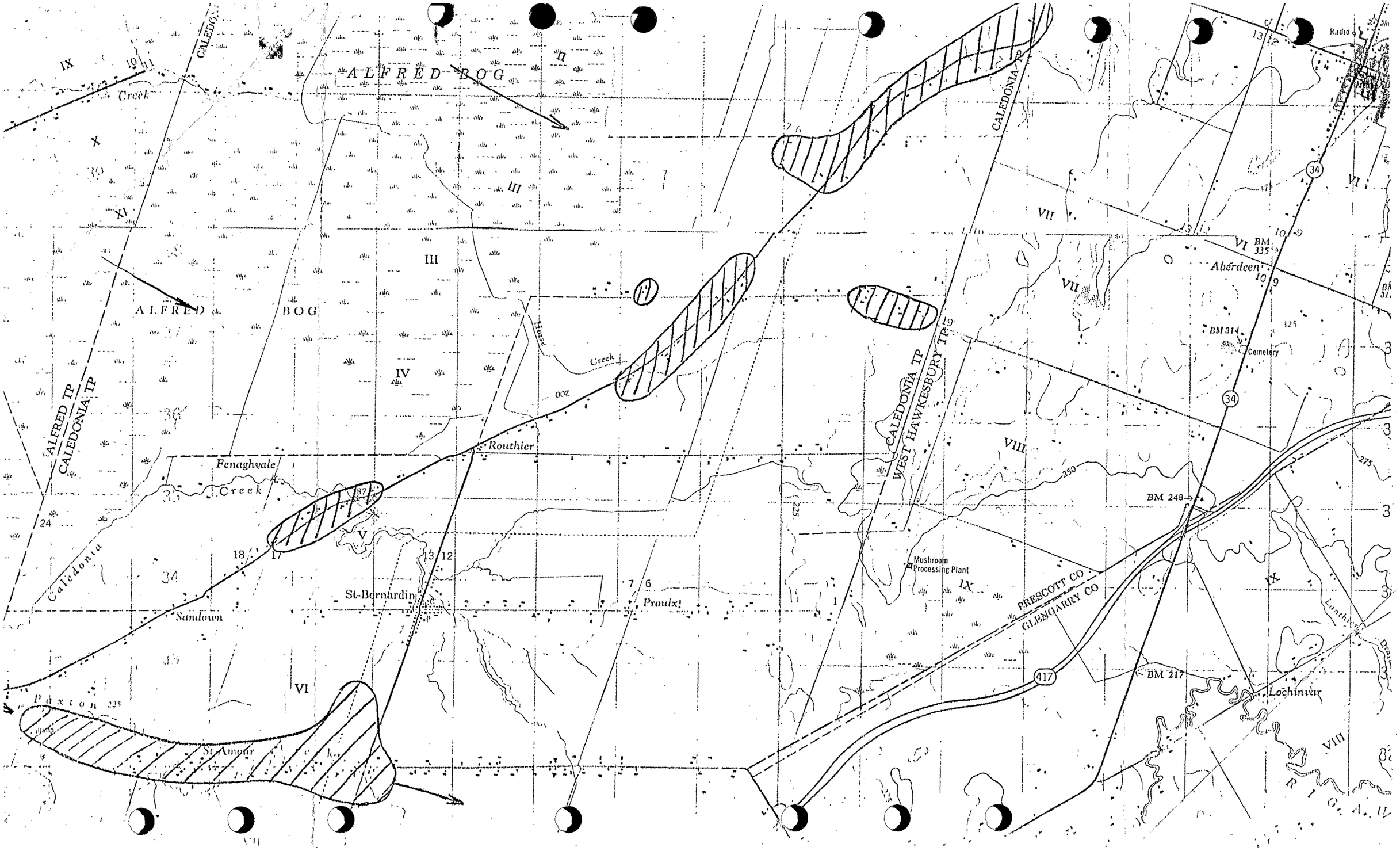
In summary, it would appear that the same tornado that damaged the Town of Buckingham, Quebec, also damaged the tower line at St. Amour. Because it was a tornado, I would estimate the winds at St. Amour to be in excess of 200 km/h.

The assistance of the Vankleek Area Officer and personnel, during my investigation of this event is greatly appreciated.

A. Fraser
Metrological Technician
Resource Utilization

Enc

cc: Mr. A.E. Boyer
Mr. J.L. Venutti
Mr. D.M. Sparrow
Mr. M. Newark


ALFRED BOG
ALFRED BOG
ALFRED TP
CALEDONIA TP
CALEDONIA TP
WEST HAWKESBURY TP
Creek
Creek
Creek
Fenaghvale
Routhier
St-Bernardin
Proulx
Sandown
Caledonia
Paxton
St-Amour
Aberdeen
BM 335
BM 314
Cemetery
BM 248
BM 217
Lochinvar
Mushroom Processing Plant
PRESCOTT CO
GLENGARRY CO
CALEDONIA RD
Radio
417
34
200
225
250
275
325

THE INTERACTION OF A TORNADO WITH ROUGH TERRAIN

By JAMES B. HARRINGTON and MICHAEL J. NEWARK

Petawawa National Forestry Institute
Canada

ON the 27 June 1978 the first of three tornadoes touched down near Thorne Lake, Quebec (45°41′N, 76°22′W) and proceeded eastward along a sinusoidal path over Lac-des-Loups. Another skirted north of Gatineau Park, through the village of Masson, crossing the Ottawa River into Ontario; the third occurred near St. Bernardin, Ontario. The tornadoes in Quebec exhibited considerable interaction with the rough terrain of the region. They tended to seek out valleys and avoid hills, they intensified on downslopes, and created their greatest destruction in the hollows between large ridges.

INTRODUCTION

Tornado damage to Canadian forests is more common than generally believed. Various estimates place the frequency of occurrence at approximately 0.4 to 0.8 per 10^4 km^2 annually in the forests of Ontario and Quebec (Newark 1983; East *et al.* 1974). The probability of tornado damage is about 0.02 per cent annually (Newark 1983), which, in Ontario, represents about one tenth of the area burned by forest fires each year (Harrington and Donnelly 1978).

The path taken by a tornado over rough topography, if known, could influence the design and location of structures and power lines. It could also influence the ecology of a region. This paper describes the damage patterns created by tornadoes which traversed the rough forested terrain of the Laurentian Highlands near Ottawa, Canada.

OBSERVATIONS

Satellite photographs on 27 June 1978 indicate that the Quebec–eastern Ontario tornadoes were produced by the same parent thunderstorm complex which originated near Huntsville, Ontario at about 1100 Eastern Standard Time. Small at first, this complex moved across Algonquin Park, then grew in size as it curved east-south-eastward across Calumet Island. It crossed the Ottawa River near Rockland and carried on across the western end of Montreal Island, finally moving into New Brunswick. At the time that the tornadoes were occurring, photographs show a multiple towered cumulonimbus complex with a huge anvil cloud streaming downwind. This complex in turn was one of several others aligned along a cold front oriented from the north-east to the south-west. Calculations show that the average motion of the particular complex was from 290° at 70 km h^{-1}.

The McGill weather radar in Montreal observed a large isolated storm-cell echo which came within range near Pembroke, Ontario at approximately 1415 EST. The cell motion was from 280° at an almost constant speed of 63 km h^{-1}. A hook echo appeared in the vicinity of St. Bernardin and persisted until about 1800 EST when the complex passed about 20 km south of Montreal with a hook still visible on the radar but no severe weather.

Eyewitness descriptions of the tornadoes

In the vicinity of Lac-des-Loups, the tornado so closely resembled a column of smoke that the volunteer fire chief dispatched a truck to put out the fire. To their dismay, the firemen could not catch up with the 'smoke'. To Roland Davis, 2.5 km south of Wilson's Corners, the funnel at first appeared to be about 15 m across and "looked like the Ajax tornado on television". It lifted, then came down again as a rope-like vortex. Oakley Carey, about 14 km to the east on the Perkins road, also saw something like the

Ajax advertisement tornado. He said that it was full of tin, leaves and debris and was narrow, about 6 m across, and white at the bottom but very wide and dark at the top. Raymond Trudel, located 0.5 km north of the tornado track and 1.5 km east of Oakley Carey, also had an excellent view. He reported that "the funnel was full of debris and pumping up and down" which was possibly a consequence of the stretching and shrinking of the vortex as it passed over the hills and valleys. No report of more than a single vortex has come to light, although (as described later) ground surveys revealed evidence of multiple damage paths.

Surveys and data collection

On 4 July 1978, after a preliminary survey by aircraft, two photographic missions were flown from the point where a tornado crossed the Gatineau River to Masson, Quebec. Black and white photographs were taken by personnel of the Forest Management Institute (FMI) of the Canadian Forestry Service at a scale of approximately 1:5 000 along the length of this track, and at a scale of 1:2 000 over the damage patches. On 25 July 1978, after the foliage on the felled trees had died, the damage area from Thorne Lake to Masson was photographed by the National Aeronautical Establishment of the National Research Council (NRC) from an altitude of approximately 1830 m at an average scale of 1:15 600. Maps made from the NRC photographs have since been published (Newark 1983). The FMI photographs were analysed stereoscopically at a resolution of 50 m and the orientation of downed trees and the fraction of the forest blown down was determined.

Details of the damage pattern were examined during fifteen expeditions on foot to various portions of the tornado track. These observations supplemented and checked the photographic analysis. Of particular interest were the effects of minor topographic features such as knolls and gullies which were unresolved in the photographs. Wind-thrown trees obscured by the foliage of undamaged trees, and trees whose tops has been severed were also more readily observed from the ground. In addition a ground survey was made in Masson by the National Research Council (Templin and Cooper 1978). No aerial photographs were made of the tracks through Ontario, but a telephone survey was conducted and damage report was plotted on a 1:15 000 topographic map. In the St. Bernadin area, a ground survey was made by Ontario Hydro (personal communication). Fig. 1 uses the data from all sources, and summarises the tornado tracks, the damage visible in aerial photographs, and the times reported by eye-witnesses.

TORNADO DAMAGE

Fig. 2 shows the location of the storm echoes at various times and the associated rainfall rates as observed by the McGill weather radar at Ste-Anne-de-Bellevue. The areas of tornado damage and times of tornado passage indicate that the tornadoes followed a path related to the south-western corner of the radar echo.

The damage visible from the air gave the appearance of frequent skipping, however, a close examination on the ground revealed a more or less continuous path varying in severity and marked by twisted, snapped or uprooted trees and damaged homes. Areas apparently undamaged when surveyed from the air actually contained fallen trees shielded from view by the foliage. In the open agricultural area of eastern Ontario traversed by the tornadoes, property damage and fallen hydro-electric transmission towers were the results.

In the community of Masson, estimates of property damage ran as high as $3 million, 36 were injured, and 50 or more families were left homeless. In Lac-des-Loups, one house was lifted into the air with its occupants (a mother and three children) and thrown a metre or two off its foundation. Well constructed homes even under the centre of the vortex suffered little damage.

Houses and trailers in dense woods appeared to have been protected from the wind even where the entire forest was flattened.

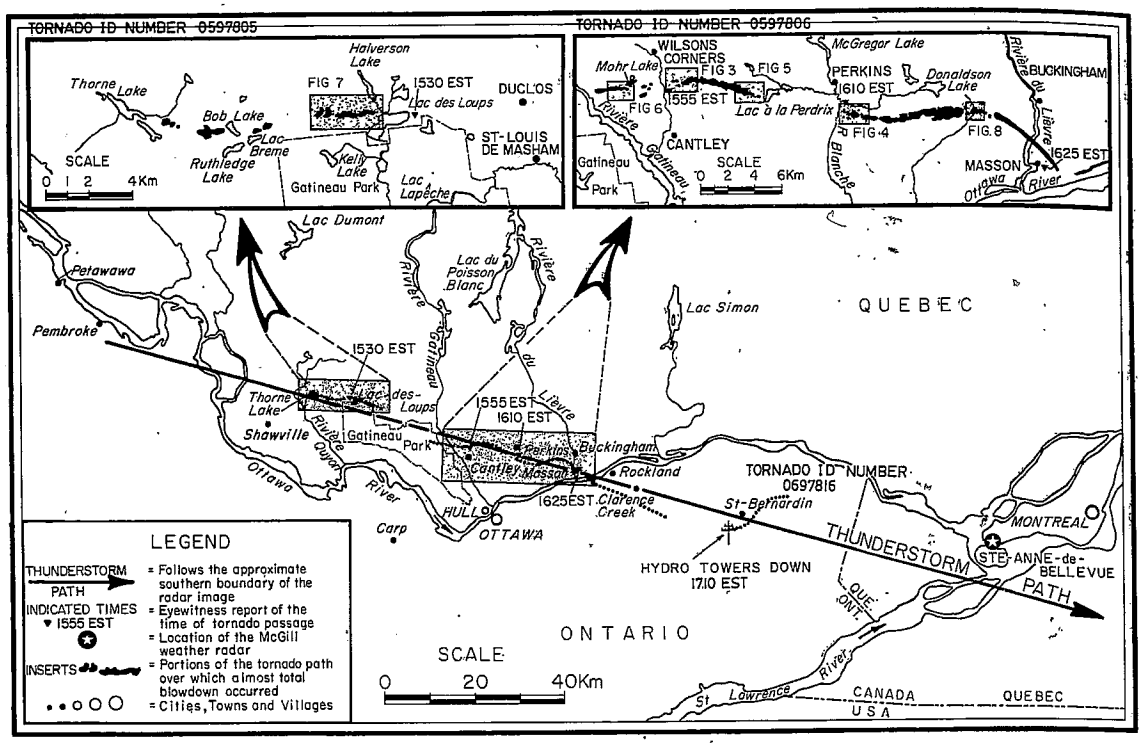


Fig. 1 The tornado damage tracks of 28 June 1978 superimposed on the general path followed by the parent thunderstorm. The inset maps show portions of tornado tracks in greater detail obtained from aerial photographs. Areas for which detail is available at a yet larger scale are indicated by their appropriate Fig. numbers

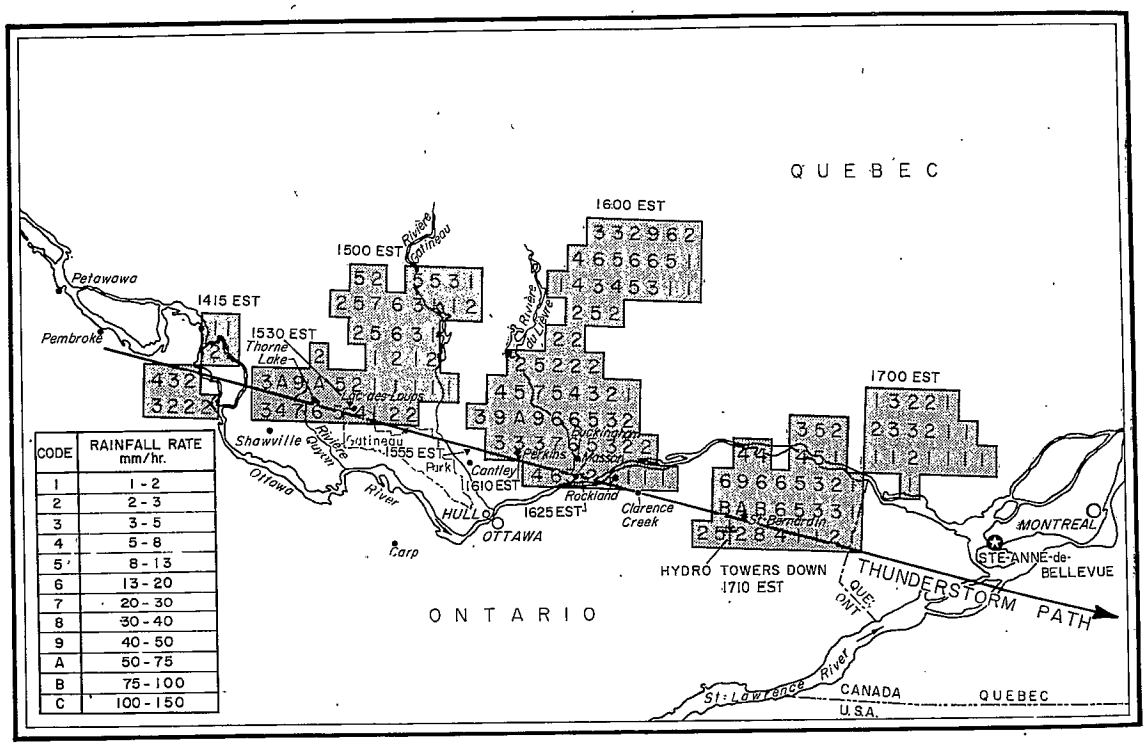


Fig. 2 The McGill weather radar (Ste-Anne-de-Bellevue) 2.5 km Constant Altitude Plan Position Indicator (CAPPI) rainfall rates for the period 1415 EST to 1700 EST, 28 June 1978. The times of tornado passage are indicated along the thunderstorm path. Scale as Fig. 1

Damage to the forest

The susceptibility of a tree to wind-throw is a function of its height relative to surrounding trees, drag coefficient, area exposed, and rooting (Grace 1977; Fraser and Gardiner 1967). In general, tall shallow-rooted trees with dense foliage and inflexible branches are most susceptible.

June 1978 was a wet month in the tornado area. The soil on the hills is shallow and the forest is generally mature, ranging in height from 15 to 22 m. Fraser and Gardiner estimate that, depending on rooting and soil moisture conditions, trees 15 m in height will suffer wind-throw with critical wind speeds of 60 to 80 km h^{-1}. For trees 22 m in height, the range is 50 to 72 km h^{-1}. Fraser and Gardiner's estimates concerned trees in sustained high winds where gusting could progressively weaken the grip of the roots. The speed requirements during a tornado may be higher because of the brevity of the strong winds. The trees along the tornado path were generally poorly rooted in shallow, nearly saturated soil. Wherever the larger trees were windthrown and smaller trees left standing, the minimum wind speed can be estimated as 50 to 60 km h^{-1}, based on Fraser and Gardiner's critical speeds. It should be noted that size and rooting are not the only significant factors. Species is also important, with balsam fir, because of its solid profile, and poplar, because of its concentration of branches near the top of the tree, being particularly vulnerable.

Damage tracks

The damage was resolved into three tornado tracks (Newark 1983) located as shown in Fig. 1 and whose physical characteristics are summarised in Table 1.

TOPOGRAPHY

The Laurentian Highlands, over which the tornadoes passed, are composed of rugged forested hills extending 90 to 120 m above the level of interspersed lakes and valleys. Along major rivers such as the Gatineau, the rise of the hills is greater by about 60 m. A gently sloping plain of variable width lies between the Ottawa River and the rough topography of the Laurentian Highlands. The proximity and length of the tornado damage paths afforded an unusual opportunity to study in detail the interaction between a tornado and rough terrain. Of particular interest are the effects of topographic features such as knolls and gullies.

Relationship of damage to topography

Figs 3 to 8 inclusive show maps of tree-fall on detailed topographical charts, and reveal several traits of the tornado's behaviour. First, the tornado appears to have systematically avoided passing over high terrain if a path through valleys or gullies was available (this can be seen in Figs 3, 5, and 6). Second, where the tornado did in fact pass over hills (south-east of Perkins in Fig. 4, and near Donaldson Lake in Fig. 8), it appeared

TABLE 1 Physical characteristics of the Ottawa Valley area tornadoes of 27 June 1978. The Universal Transverse Mercator (U.T.M.) grid is printed on National Topographic System maps. Number 0597805 refers to the Thorne Lake to Lac-des-Loups tornado; 0597806 refers to the Cascades, Quebec to Pendleton, Ontario, tornado; 0597816 refers to the St. Bernardin, Ontario tornado. All dimensions and times are approximations. For the meaning of F-number see Newark (1983), pages 82–83.

TORNADO IDENTITY NUMBER	TOUCHDOWN TIME (EST)	U.T.M. TOUCHDOWN COORDINATES	DAMAGE WIDTH AVERAGE (m)	DAMAGE WIDTH AVERAGE (m)	DAMAGE LENGTH (km)	DAMAGE AREA (km^2)	F-NUMBER
0597805	1520	395660,5059270	95	510	11	1	1
0577806	1545	428160,5050190	135	1000	60	8	3
06978126	1710	513400,5030600	Unknown	Unknown	14	Unknown	2

to undergo a cycle of weakening part way up the windward slope and strengthening part way down the lee slope. Generally it appears to have been weaker over ridge tops and strongest in the valleys (see Fig. 4a). This would be expected in theory because of the conservative nature of potential vorticity (the ratio of absolute vortex vorticity to the effective depth of the vortex) which implies that the absolute vorticity of the tornado increases as its vortex is stretched by moving downslope. Vorticity may be regarded as a measure of circulation; therefore, the orientation of tree-fall can be used as a rough indication of the degree of vorticity in the tornado.

Along the damage track most trees were felled either in a parallel direction (i.e. from west to east) or in the directions up to about 90° to the left of the track, with little evidence of circulation. However, on the windward side of the ridges there was a tendency for increased convergence with trees on the north side of the damage track falling in directions 180° opposite to those on the south side. This is particularly clear in Fig. 4. There is evidence of cyclonic rotation in the vicinity of the location labelled 'A' in Fig. 8. This pattern was typical of that occurring around small knolls. Trees atop the knoll were frequently undamaged as though a Taylor Column had settled over the knoll (Lamb and Janowitz 1985).

It was noticed during the ground survey that damage seemed to be accentuated in gullies, even those too small to be identified at a 7.6 m contour interval. The long fingers of damage shown in Fig. 4, which consitute multiple damage paths joining the main track at a large angle, are such a case. Each was associated with a sharp gully. The channelling, or funnelling, effect of gullies was observed as far as several hundred metres from the main damage path. Fig. 5 also shows fingers of damage, but in this case the orientation of tree-fall indicates counter-clockwise looping around the two prominent knolls. It is possible that the tornado was making an independent cycloidal damage track in this area, but the chance of the cycloidal loops being so neatly located around the knolls is a remarkable coincidence and it is more likely that the knolls and gullies themselves were responsible for this damage pattern. As a conjecture, these fingers of damage may have

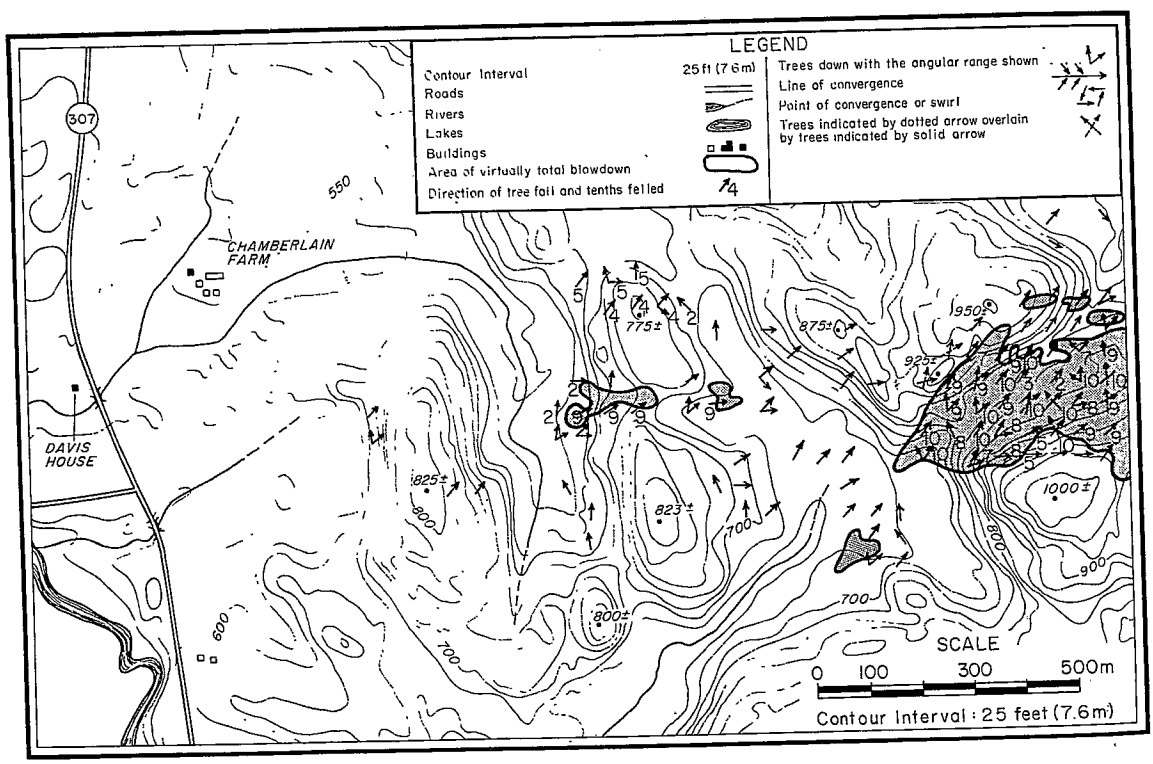


Fig. 3 Tornado damage patterns north-east of Cantley, Quebec

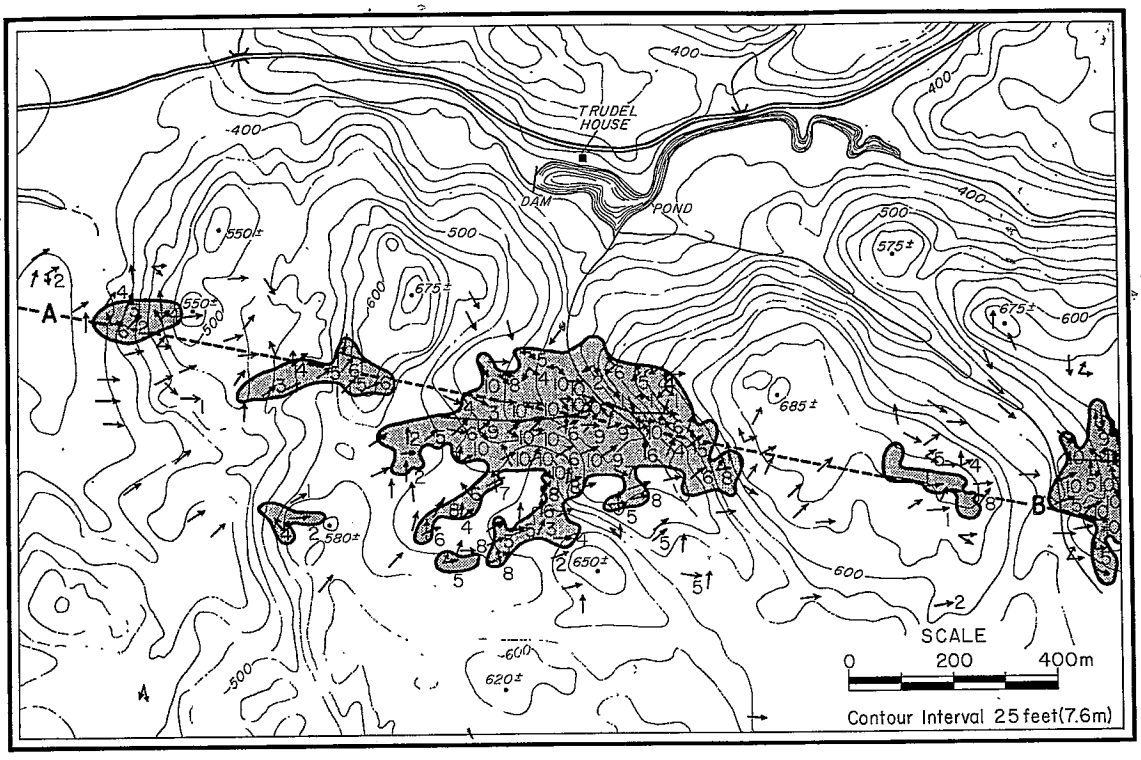


Fig. 4 Tornado damage south-east of Perkins, Quebec. (See Fig. 3 for the legend). A cross section of damage and elevation between A and B is shown in Fig. 4(a)

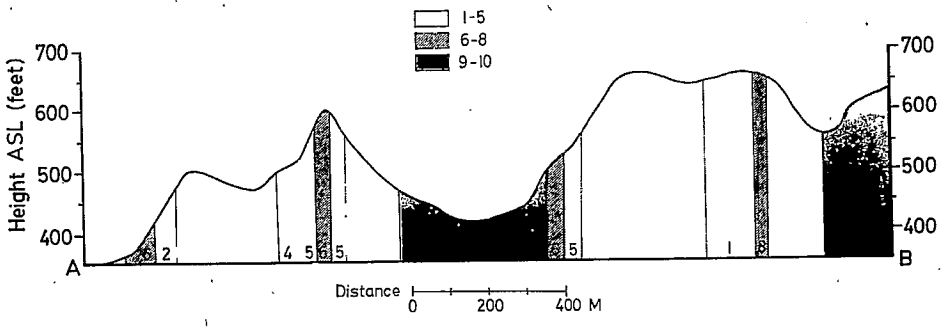


Fig. 4(a) A cross section showing the relationship between damage location, damage amount, and topographic elevation between points A and B in Fig. 4. Shaded areas show damage location with numbers showing tenths of felled trees

been caused by secondary vortices, induced by the increased absolute vorticity in the lee of the prominent knolls, and were then guided by the terrain.

The damage west of Lac-des-Loups (shown in Fig. 7) is a clear exception to the tendency of the tornado to avoid passing over high terrain if an easier alternative route was available (as has been noted in other parts of the track). In this case the damage trail led directly over some of the highest hills encountered, even though a parallel valley was conveniently located about 500 m to the north of the 320 m crest, and lower elevations were even closer alongside the 245 m hill to the east. The orientation of the two damage patches on the western side of the figure appear to indicate that the tornado was describing a cycloidal path independent of the terrain at that location, and with strength sufficient to

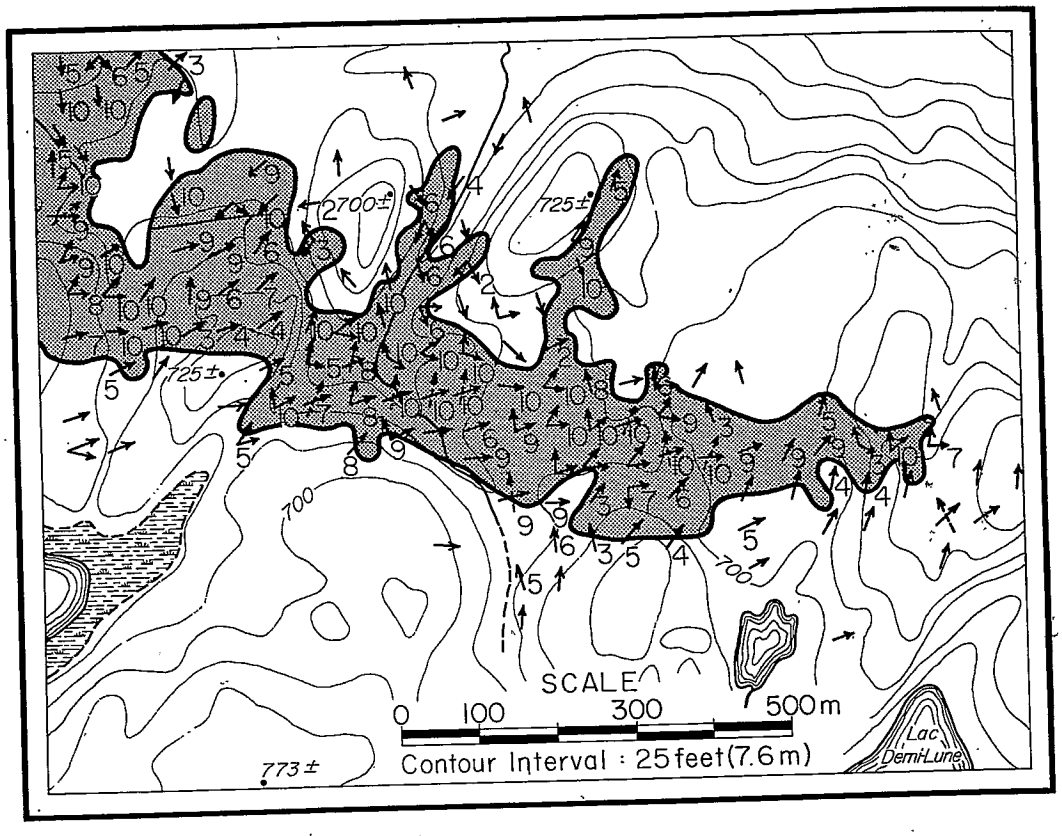


Fig. 5 Tornado damage path west of Lac-à-la-Perdrix, Quebec. (See Fig. 3 for the legend)

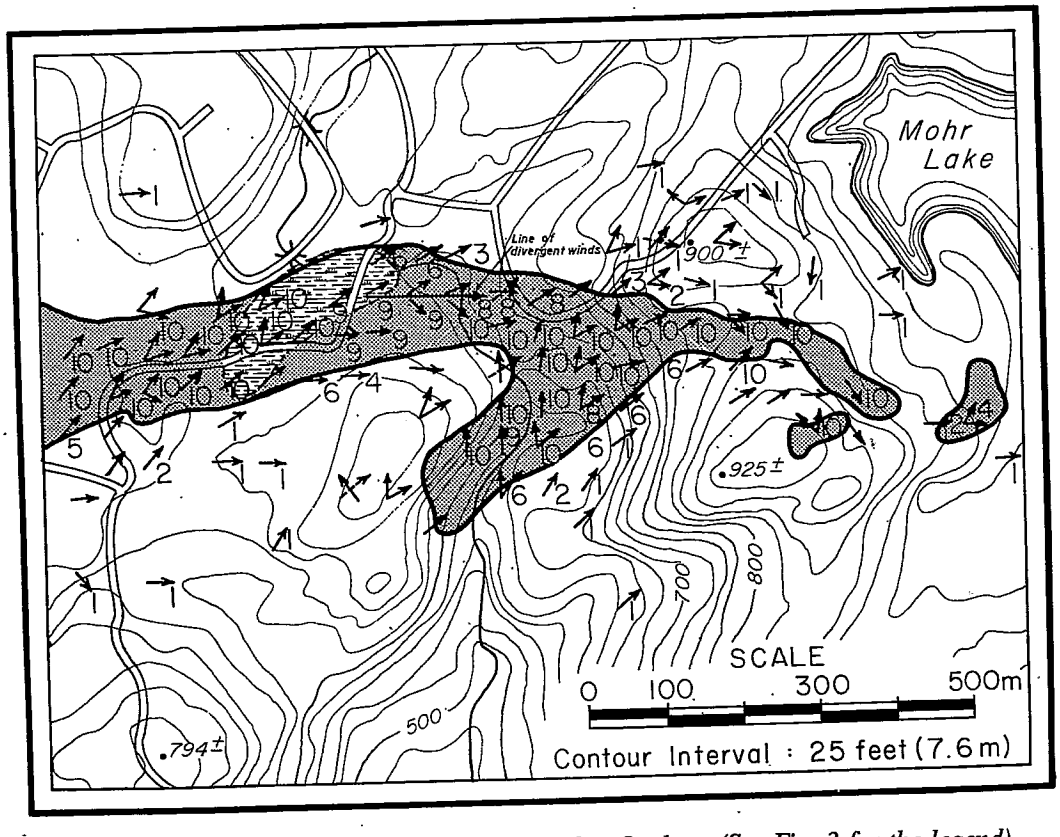


Fig. 6 Tornado damage path west of Mohr Lake, Quebec. (See Fig. 3 for the legend)

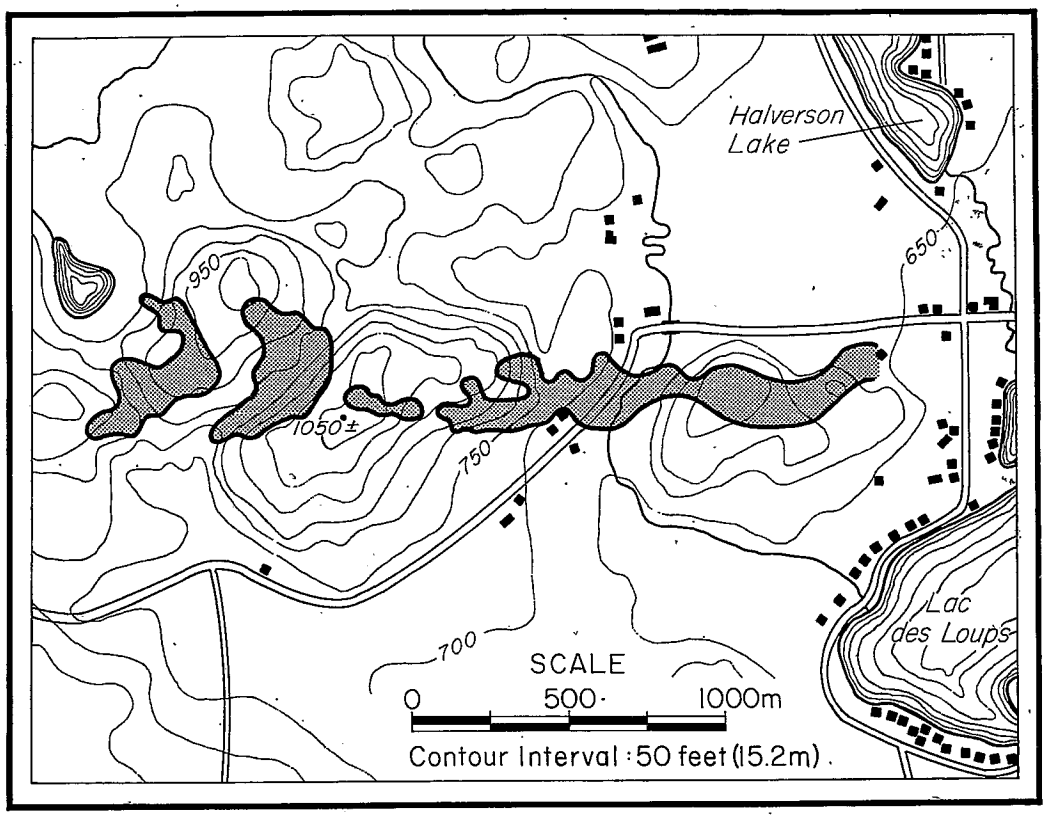


Fig. 7 Tornado damage path west of Lac-des-Loups, Quebec. (See Fig. 3 for the legend)

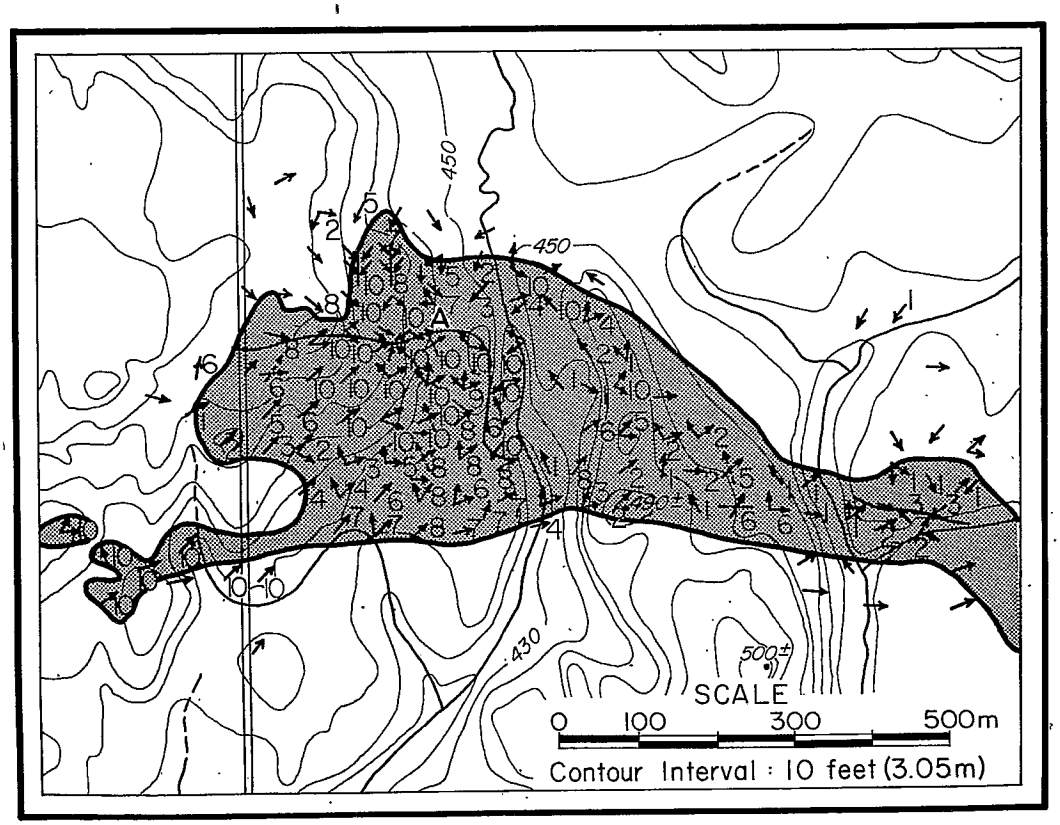


Fig. 8 Tornado damage path near Donaldson Lake, Quebec. (See Fig. 3 for the legend)

cause damage only during the south-to-north segments of the path. Subsequent to passing over the high hill it began following a straight line path. It may be that the considerable increase in surface roughness represented by this hill was responsible for the change in nature of the tornado's behaviour as has been noted by Blechman (1975) in the case of tornadoes moving over the Niagara Escarpment in Wisconsin.

SUMMARY

From a study of the tornadoes in Masson and area, which appear to be typical (with respect to their formation, lifetime, direction of travel, and type of damage etc.) of those which commonly occur in Ontario and Quebec, it can be inferred that there is a strong interaction between tornadoes and the terrain. The tornadoes of 27 June 1978 appeared to strengthen on downslopes, reaching their greatest intensity in valleys, and then weaken as they crossed hills or ridges. They exhibited a tendency to avoid high terrain if there were a convenient route across lower ground, although a significant exception to this was noted to the west of Lac-des-Loups. It is believed that valleys and gullies (some too small to appear at a contour interval of 7.6 m) funnelled damaging winds through distances of hundreds of metres, and channelled them into the primary path. Two forms of cycloidal motion are conjectured, one apparently independent of the terrain, and the other apparently caused by the particular topography of hills and valleys at a certain location.

ACKNOWLEDGMENTS

We wish to thank the personnel of the former Forest Management Institute and members of the National Research Council for their assistance. Particular thanks go to Derry Stroud who carried out the stereoscopic analysis, and to Kathleen Hefler and Peter J. Elms who assisted with the field work.

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ADDRESS WANTED

Attempts have been made to return a colour transparency to Mr Ian Somerton, who lived in Moseley, Birmingham, in 1980. It is returned by the Post Office marked 'Gone away'. Anyone able to provide his new address is asked to let the *Weather* office have details.