DEPARTMENT OF SCIENCE
AND THE ENVIRONMENT

BUREAU OF METEOROLOGY

CYCLONE JOAN

DECEMBER 1975

JULY 1979

FOREWARD

Tropical cyclone Joan was the most destructive cyclone to affect the Port Hedland area in more than 30 years. Although the eye crossed the coast some 50 km west of Port Hedland, the city was subjected to sustained winds exceeding 90 km/h for about 10 hours with wind gusts of 208 km/h on 8 December 1975is the fourth highest on record in Australia. Severe property damage occurred at Port Hedland and at other settlements Close to the cyclone's path. Subsequent flooding damaged roads and sections of the iron ore railways, particularly that of Hamersley Iron Pty Ltd. Sheep losses were heavy but, remarkably, no loss of human life or serious injury was reported. The estimated damage to private property and public facilities is believed to have exceeded $25 million.

This report documents the meteorological features of cyclone Joan and outlines the operation of the Bureau's tropical warning system at that time. The report was compiled, after careful port-analysis, by the staff of the Perth Tropical Cyclone Warning Centre. The principal investigator was Mr A.N. Scott.

(J.W. ZILLMAN)
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CYCLONE JOAN

A report by Staff of the Regional Office,
Bureau of Meteorology, Perth, Western Australia

INTRODUCTION

This report has been prepared to provide data acquired during cyclone Joan and to present the results of assessments made of some of its characteristics.

All times referred to are Western Standard Time (WST) which is Greenwich Mean Time plus 8 hours. The location of towns, observing sites, geographical features, etc. can be found in Figs 1 and 2.

Damaging cyclones on the Queensland coast – Ada (Great Barrier Reef 1970) and Althea (Townsville 1971) – were responsible for generating a renewed critical study of cyclone preparedness and building design criteria appropriate to cyclone-prone areas of the Australian tropics. The impact of tropical cyclone Tracy on Darwin on 25 December 1974, Trixie on Onslow on 19 February 1975, and now Joan on Port Hedland, all within twelve months, has further heightened public, industrial, engineering, and scientific interest in tropical cyclones.

Joan was an intense, moderate-sized tropical cyclone with the region of maximum winds located at a radius of 20 to 40 km from the centre. It generated a recorded surface wind gust of 208 km/h at Port Hedland. The only higher gusts actually recorded in Australia are 217 km/h at Darwin during the passage of Tracy on 25 December 1974, 232 km/h at Onslow in 1963 and 246 km/h at Onslow during Trixie on 19 February 1975. Gusts of 260 km/h were measured by a Synchrotac anemometer at Mardie on 19 February 1975 during Trixie.

At about 0600 8 December 1975 the eye of the tropical cyclone Joan crossed the coast about 50 km west of Port Hedland. The cyclone was travelling in a southerly direction at that time. Severe property damage occurred at Port Hedland and at other settlements adjacent to its track, particularly in the first 12 hours of its path over land. Subsequent flooding caused damage to roads and to sections of some of the iron ore railways, particularly that of Hamersley Iron Pty Ltd. Sheep losses were heavy on pastoral properties that lay along and slightly east of the track between the coast and the Hamersley Range. No loss of human life or serious injury was reported but damage to private property and public facilities exceeded $25 million.

The track of cyclone Joan provided an opportunity to test the effectiveness of the recent introduction by the Bureau of Tropical Cyclone Alerts*, in addition to Cyclone Warnings, to accommodate the actual threat posed by a cyclone to coastal communities.

The first Tropical Cyclone Alert indicating the possible formation of a tropical cyclone was issued by the Darwin Tropical Cyclone Warning Centre at 1530 30 November 1975. The Alert was upgraded to a Tropical Cyclone warning at 0915 1 December 1975, by which time the cyclone had crossed the coast, moved well inland and weakened.

Data from satellites, weather watch radar, automatic weather stations, shipping, and the synoptic network all played an essential role in detecting the cyclone and monitoring its movement. In the 20 hours before landfall the weather watch radar, operated by the Bureau at Port Hedland Airport, continuously monitored the cyclone.

- The term Tropical Cyclone Alert was renamed Tropical Cyclone Watch at the beginning of the 1977-78 cyclone season.

HISTORY OF CYCLONE JOAN

On the morning of 30 November 1975 photographs transmitted by the United States meteorological satellite NOAA 4, and received in the Bureau of Meteorology's Tropical Cyclone Warning Centres in Darwin and Perth, showed a large cloud mass in the Timor Sea centred about 310 km west-northwest of Darwin. At 1530 the Darwin Tropical Cyclone Warning Centre issued the first Tropical Cyclone Alert indicating the presence of a tropical low and the possibility of a tropical cyclone developing.

The satellite photograph received on the morning of 1 December showed that significant organisation had occurred in the cloud mass during the previous 24 hours. The spiral cloud-banding characteristic of tropical cyclones was quite evident. On this basis Darwin Tropical Cyclone warning Centre issued the first Tropical Cyclone warnings at 0915 and named the developing cyclone Joan. It was then still located about 310 km west-northwest of Darwin. Joan's movement in the following 48 hours was towards the southwest at an average 5 km/h. The cyclone's generally west-south-westerly track after 2 December took it away from the coast until 0900 6 December when it was about 420 km north of Port Hedland.

The smoothed complete track of cyclone Joan is shown in Fig. 1 while the developing track in the Port Hedland area (determined from radar facilities) is given in Fig. 2.

The first evidence of the increasing strength of Joan, apart from that indicated on satellite photographs, came as the cyclone moved west-southwest past the northernmost areas of Western Australia on 3 December. Kalumburu Mission reported a mean wind of 74 km/h and the vessel *Bluff Creek* sheltering in a bay just to the northeast of the Admiralty Gulf experienced mean winds of 93 km/h.

During 4 December Joan passed the south of Browse Island and Scott reef automatic weather stations and north of the automatic station on Adele Island. These stations confirmed the increasing intensity of the cyclone and its west-southwesterly movement away from the coast. Joan's average speed during the 24-hour periods following 0900 on 3, 4 and 5 December was 13, 15 and 12 km/h, respectively.

At 0900 6 December cyclone Joan was about 120 km north-northwest of Rowley Shoals automatic weather station. In the following 24 hours it moved through an arc of about 90 degrees around this station so that the 0900 7 December it was a similar distance west of this station and moving southwards. During this change of direction the cyclone's speed decreased to a mean 6 km/h between 0900 and 2100 6 December and then increased to average 10 km/h between 2100 6 December and 0900 7 December.

After 0930 7 December the eye of tropical cyclone Joan was within the range of the weather watch radar at Port Hedland Airport and its position was monitored continuously by radar until 2000 8 December (Fig. 2). From 0900 7 December to 0600 8 December the cyclone's track was almost due south and its average speed 14 km/h. By 1100 7 December the recording anemometer at Port Hedland Airport Meteorological Office was measuring mean winds of 46 km/h with occasional gusts above 63 km/h (Fig. 3). By 2000 7 December wind speeds were averaging 86 km/h and gusting to 126 km/h, until at 0600 8 December, when the cyclone crossed the coast some 50 km west of Port Hedland and just west of the mouth of the Yule River, winds were averaging 141 km/h. The maximum gust of 208 km/h at Port Hedland Airport was recorded at 0620. After Joan crossed the coast winds at Port Hedland Airport began to moderate and by 1100 8 December were averaging 83 km/h with gusts to 132 km/h (Fig. 4). It was not until 1745 8 December that the mean wind speed at Port Hedland Airport fell below gale force (63 km/h).

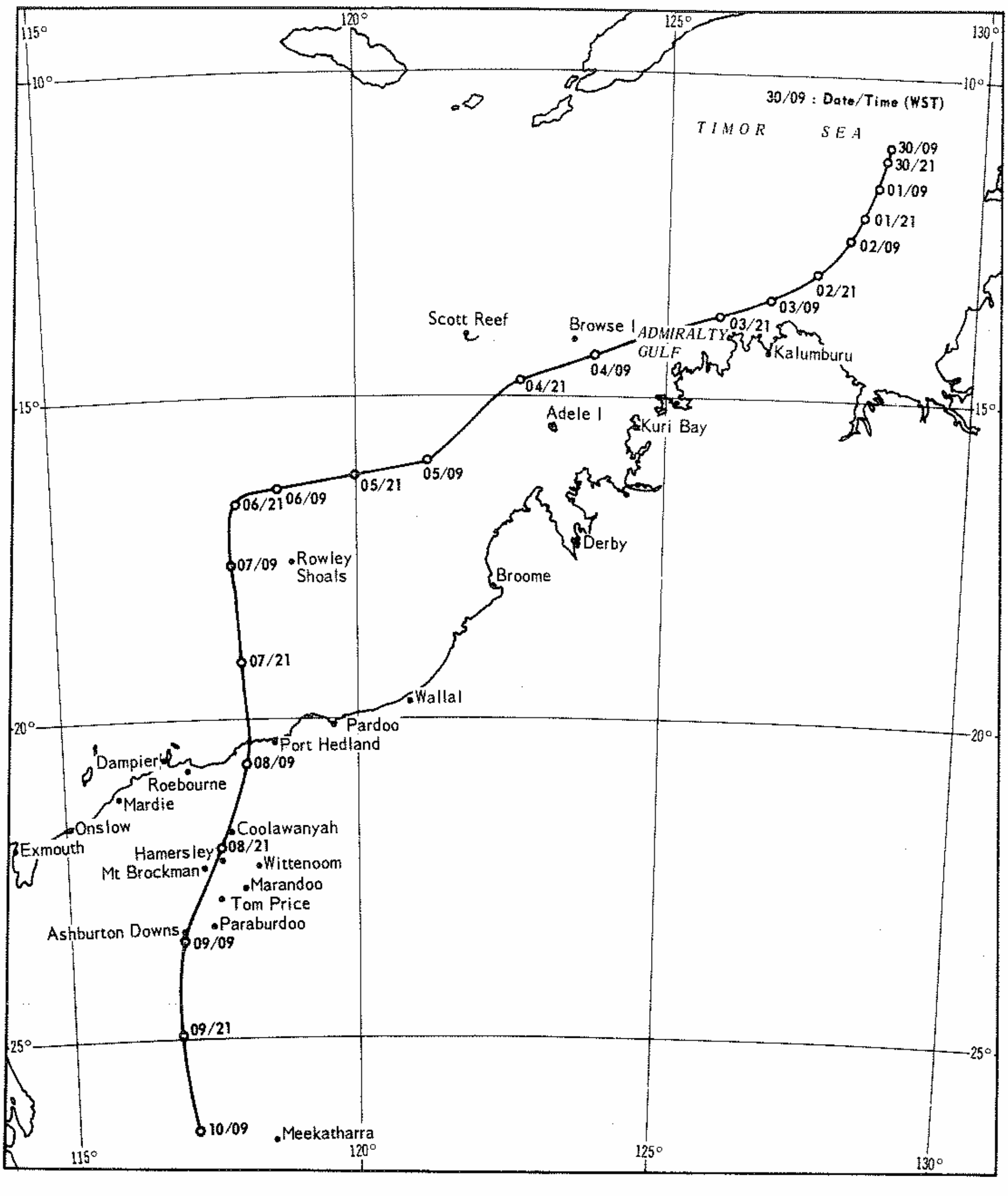


Fig. 1 Track of tropical cyclone Joan, 30 November to 10 December 1975.

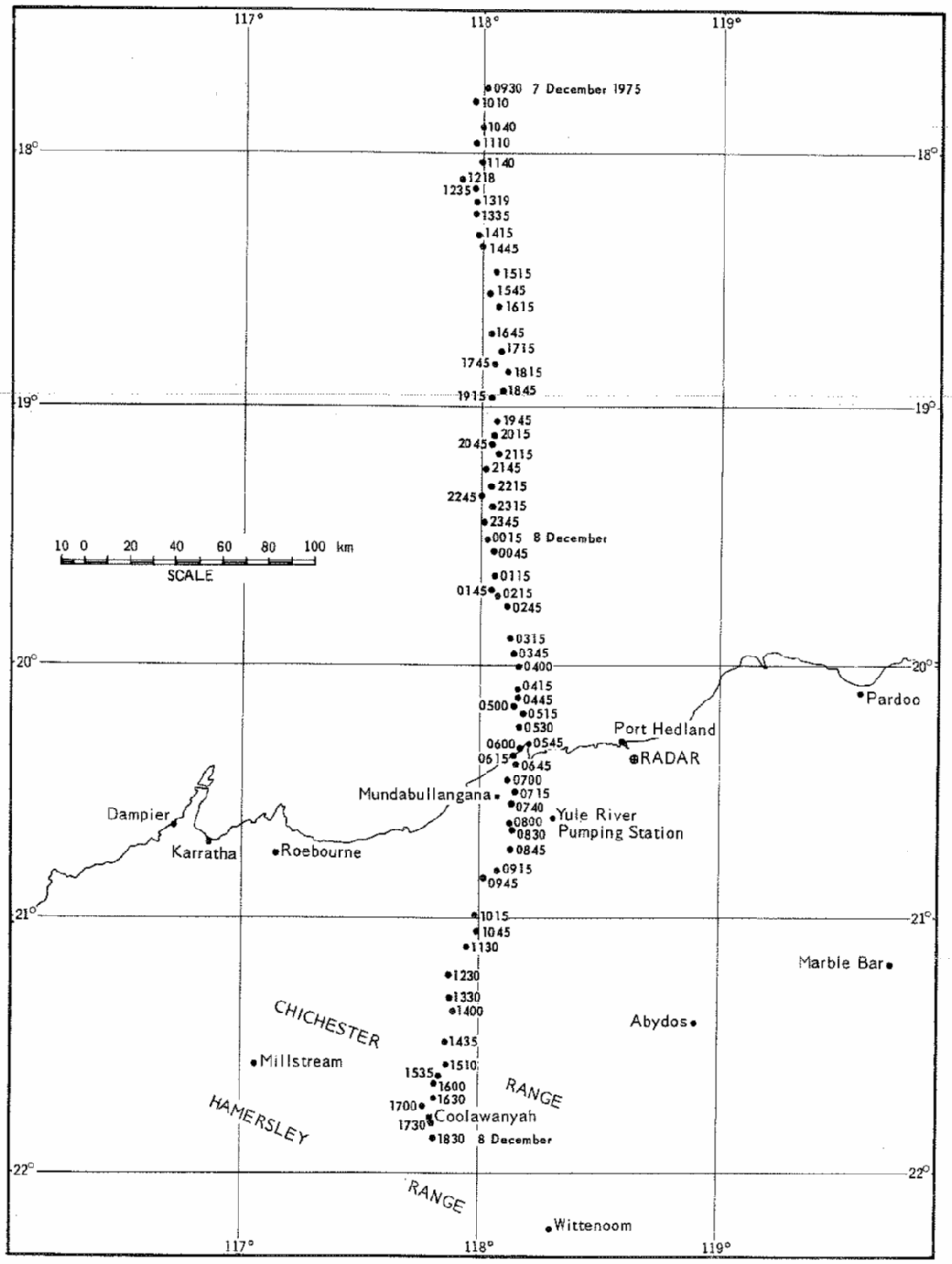


Fig. 2 Track of tropical cyclone Joan from radar positions. (Times in WST)

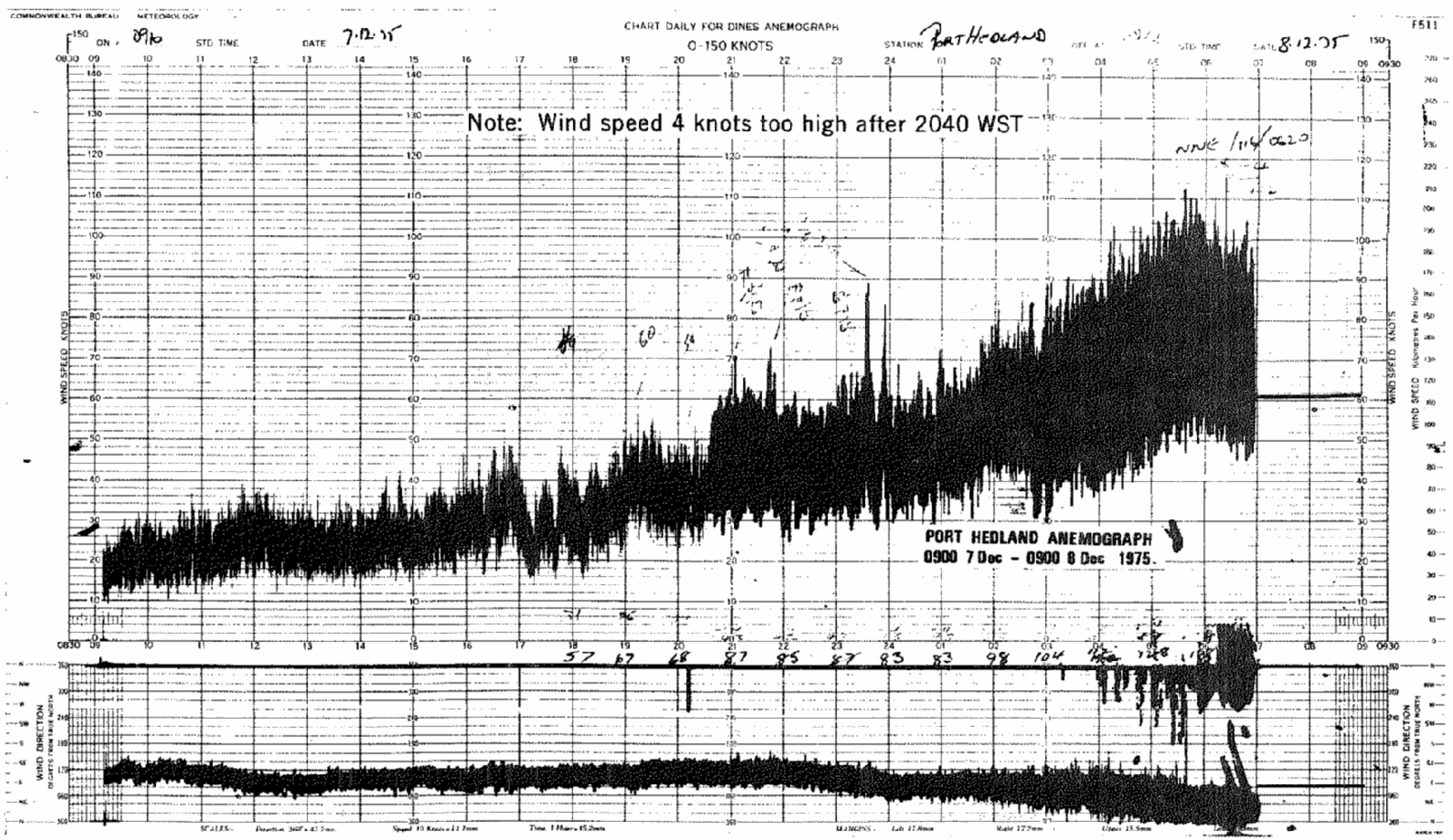


Fig. 3 Dines anemograph trace 7—8 December 1975 at Port Hedland Meteorological Office.

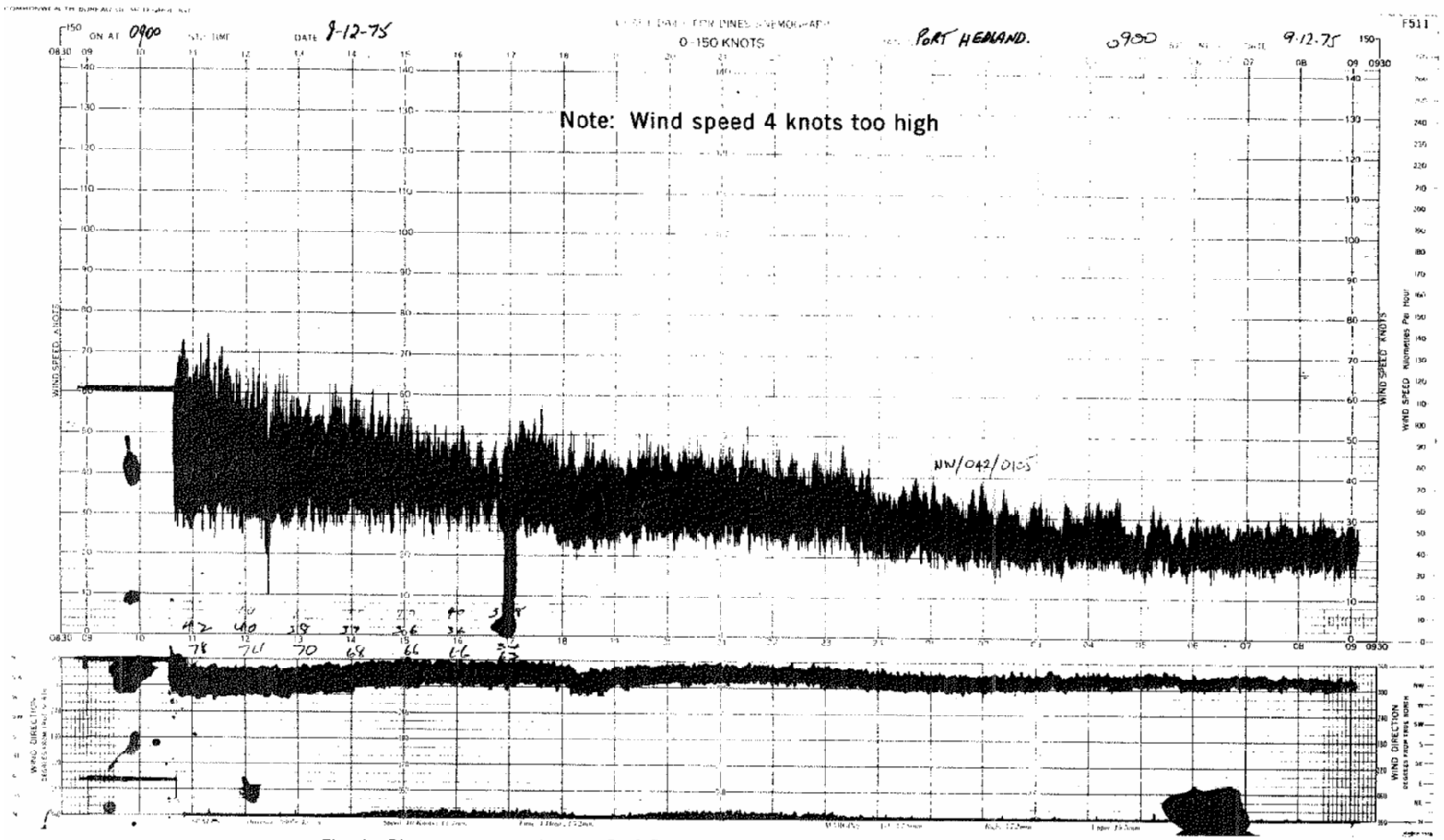


Fig. 4 Dines anemograph trace 8–9 December 1975 at Port Hedland Meteorological Office.

After crossing the coast tropical cyclone Joan moved towards the south-south-west at about 14 km/h and crossed over or adjacent to the homesteads on the pastoral properties Mundabullangana, Mallina, Coolawanyah, Hamersley, and Mount Brockman. Its path took some 40 km west of Tom Price and Paraburdoo Aerodrome and placed it just to the south of Ashburton Downs at 0800 9 December.

As cyclone Joan crossed the coastal plain and the Chichester Range only a slow moderation of its intensity seems to have occurred, but as the cyclone crossed the Hamersly Range the available evidence suggests that a rapid weakening took place. Recording anemometers at the proposed Marandoo town and mine sites about 65 km from the cyclone track recorded maximum mean winds of about 65 km/h when Joan was 150 km to the north, but when the cyclone reached its closest points to these sites at 0000 to 0200 9 December the mean wind speed had dropped to 30 to 40 km/h/.

DETECTION AND TRACKING

Weather satellites

Photographs from the two United States meteorological satellites ESSA 8 and NOAA 4 were received daily by the Bureau's readout stations at Darwin and Perth. These photographs were available for interpretation by meteorologists as soon as they had been processed. Meteorologists were able to detect the genesis of Joan to the northwest of Darwin and monitor its development and movement from 30 November until it lost its identity on 9-10 December 1975.

ESSA 8 provided cloud photographs at visible wavelengths at approximately 24-hourly intervals about 0900 each day while NOAA 4 gave photographs at infrared wavelengths at approximately 12-hourly intervals about 0900 and 2100, with visible wavelength imagery also about 0900 each day.

Satellite photographs provided the primary location data from the time of the cyclone's genesis until about 0930 7 December, when the eye of the cyclone came within the range of the weather watch radar at Port Hedland. Fig. 5 shows cyclone Joan as photographed by NOAA 4 at 0826 7 December when the cyclone was about 310 km north of Port Hedland.

Radar

Joan was under surveillance by the Plessey WF44 radar at Port Hedland Airport Meteorological Office intermittently on 5 and 6 December and continuously from 0750 7 December until 20008 December. Fig. 2 depicts the locations of the centre of the eye of the cyclone as detected by the radar at various times.

Photographs of the radar screen were taken at intervals throughout the tracking period. Those taken on 5 and 6 December showed the rain bands in the southern quadrants of the cyclone. The eye of the cyclone became apparent on the radar when it was about 300 km from Port Hedland Airport on a bearing of 347 degrees true. The appearance of the radar echoes shortly after the eye was identified is reproduced in Fig. 6. As Joan approached the coast the radar showed a more complete picture of the rain echoes within the storm circulation. Fig. 7 illustrates the circular banded nature of these echoes: note that the inner ring of echoes, which defines the eye, is not complete but has a horseshoe type of appearance.

As the radar was able to position the eye of the cyclone accurately, reliable statements of its speed and direction of movement could be passed to those communities threatened by its approach.

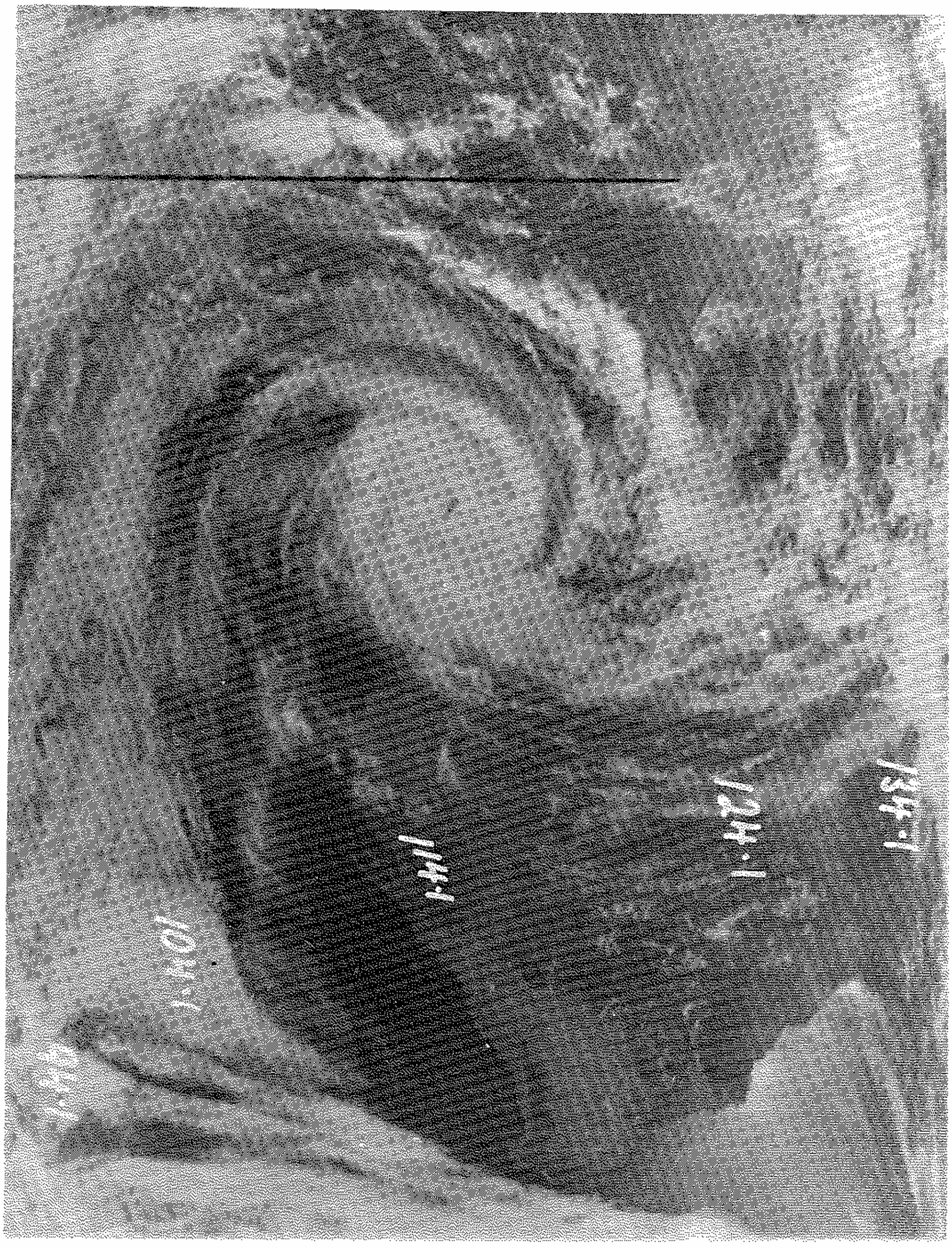


Fig. 5 Satellite photograph of Joan 0826 7 December 1975.

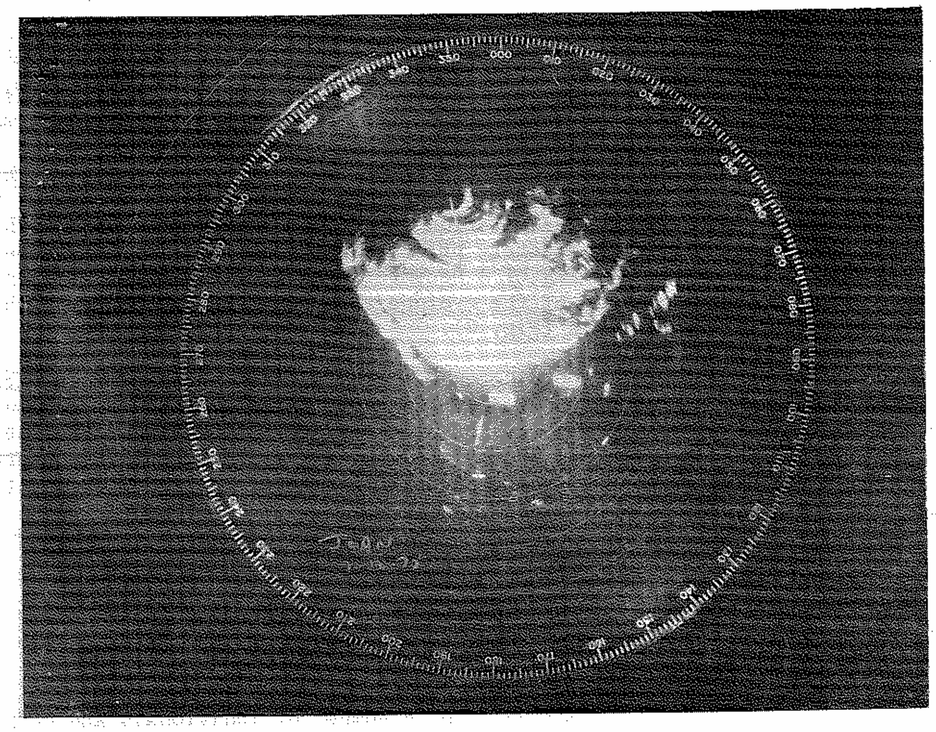


Fig. 6 Radar photograph of Joan 1218 7 December 1975.

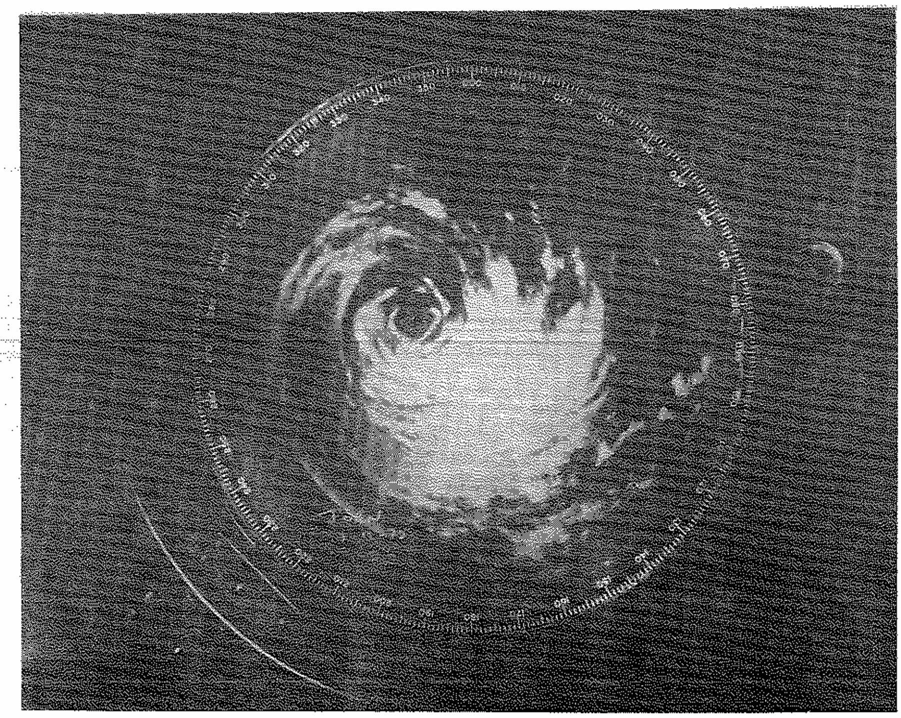


Fig. 7 Radar photograph of Joan 0442 8 December 1975.

Automatic Weather Stations

On 4 December cyclone Joan passed south of the automatic weather stations on Browse Island and Scott Reef and north of the automatic station on Adele Island. The observations from these stations are plotted in Fig. 8. Although the stations monitor the weather continuously, they have no recording facility and only transmit information on prevailing conditions every three hours. Browse Island, which was closest to the track, gave a good indication of the increasing intensity of the cyclone and confirmed the position and movement that had been derived earlier that day from the satellite photographs. This station reported a mean wind of 154 km/h averaged over a ten-minute period immediately prior to a three-hourly transmission at 1200 4 December. During the evening of 4 December data from the three stations provided a more accurate location of the cyclone than could be deducted from the corresponding satellite photograph (Fig. 8).

In the 24 hours following 0900 6 December location data, derived from satellite photographs and at the end of the period, from radar, revealed that the cyclone slowed and then moved in an arc from the north to west of the automatic weather station on Rowley Shoals. The observations transmitted by this station could be interpreted as indicating conclusively a significant intensification of the storm during this period.

Routine and emergency surface observations

The synoptic network over the northern half of Western Australia functioned normally during this period and was supplemented by a number of reports from ships on the periphery of cyclone Joan.

Supplementary reports were received from a number of individuals and companies in the weeks following cyclone Joan's passage through the Pilbara region.

BEHAVIOUR AND CHARACTERISTICS

Track

Cyclone Joan's track (Fig 1 and 2) was quite typical if it is compared with the tracks of all other cyclones that have affected this region. Nevertheless it is unusual for an early season cyclone generated in the eastern part of the Timor Sea to move so far westward before tuning to cross the coast.

Intensity

Until the development of meteorological satellites, the intensity of a tropical cyclone was impossible to assess without surface or aircraft reconnaissance reports close to the centre of the storm. Research by meteorologists in the United States of America in the last decade has led to the development of interpretative techniques that can be applied to satellite photographs of tropical cyclones to assess their intensity. The most recent methods presented by Dvorak (1973, 1975) were applied to cyclone Joan, and a minimum central pressure and mean maximum ten-minute wind speed have been deduced from each morning's satellite photograph during its path over the ocean. These data are shown in Table 1.

As Dvorak's technique does not produce a unique assessment for each photograph because of the limitations imposed by picture quality, subjective judgement, storm environment, etc., these values should be accepted as indicating only the order of magnitude of the storm parameters. The intensity of cyclone Joan in the Port Hedland Area is discussed separately later.

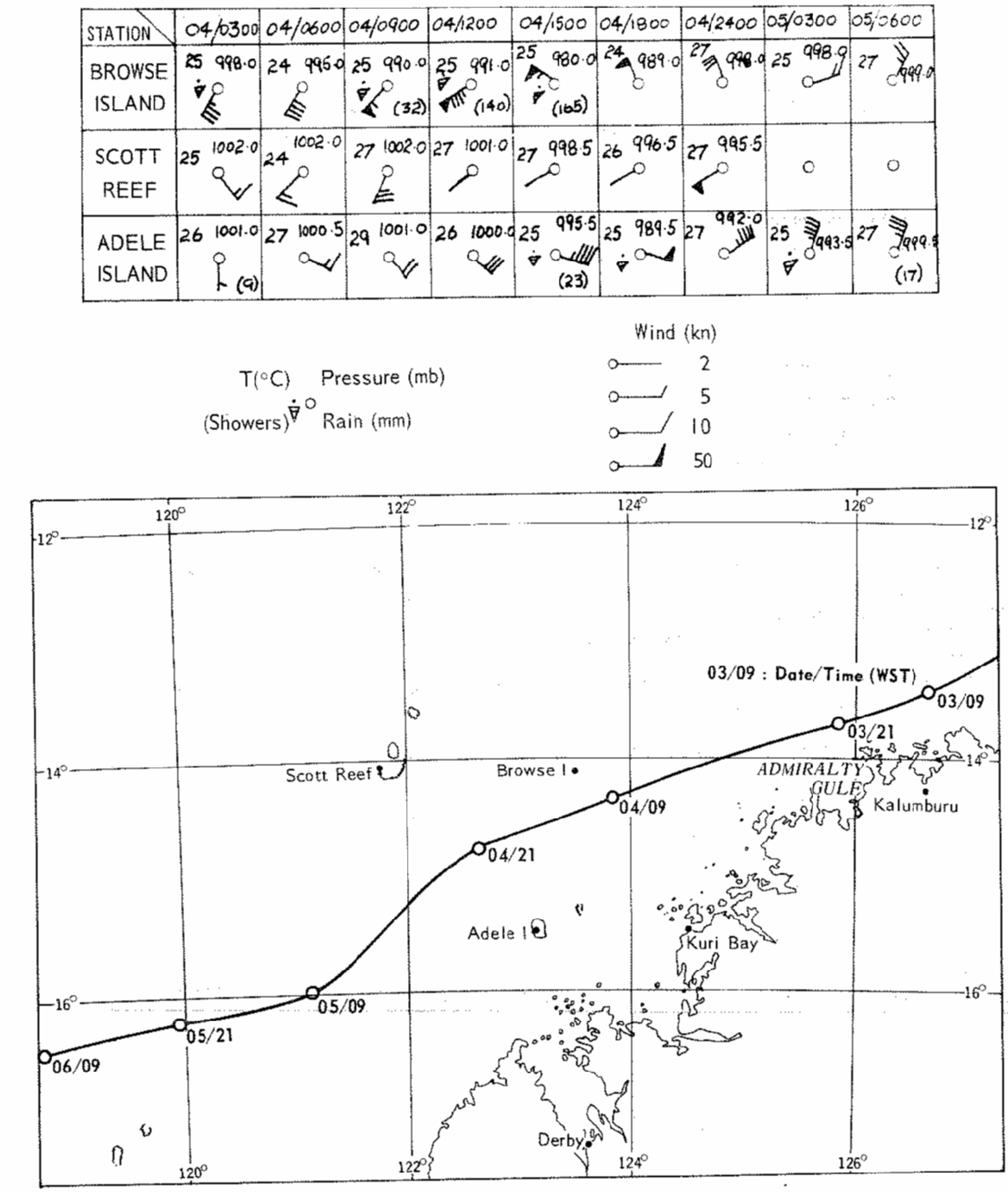


Fig. 8 Sequence of observations from the automatic weather stations at Browse Island, Scott Reef, and Adele Island and their positions relative to the track of cyclone Joan.

Table 1 daily minimum central pressure and maximum 10-minute mean wind Derived from Dvorak's technique

Satellite Picture Date/Time	Minimum central pressure	Maximum 10-minute mean wind (km/h)
30 Nov 75/0746	-	41
1 Dec 75/0840	994	73
2 Dec 75/0741	988	90
3 Dec 75/0836	973	126
4 Dec 75/0736	954	166
5 Dec 75/0831	942	187
6 Dec 75/0923	929	207
7 Dec 75/0826	915	228

Rainfall

The rainfall isohyets for the four-day period 0900 7 December to 0900 11 December are shown in Fig 9. The rainfall associated with Joan's passage over land showed a markedly asymmetrical distribution about the cyclone track, the area of maximum precipitation being the average some 70 km to the east of the track on 8 December. The dense private rainfall recording network along the Hamersley Iron railway indicated an isohyetal gradient in excess of 500 mm gradient in excess of 500 mm in 60 km along the western edge of the four-day isohyetal pattern (Fig.9).

Although the centre of the cyclonic circulation continued to move southwards, the rainfall maximum remained centred over the Hamersley Range during 9 December and most of 10 December. It is estimated that falls in excess of 600 mm occurred in an area northeast of Tom Price during this period. The highest rainfall reported was 591 mm registered on a Lambrecht pluviometer installed by Texasgulf Marandoo Ltd at a proposed site for Marandoo township. This fall was recorded in the 60-hour period between 0000 7 December and 1200 10 December.

Flooding occurred along a number of streams flowing into the Fortescue River. In particular, the Weelumurra and Weeli Wolli creeks overflowed, causing washways along the respective railway lines of Hamersley Iron Pty Ltd and Mount Newman Mining Co. Pty. Ltd. Further to the north serious flooding occurred along the Yule River.

Rainfall intensity

The Public Works Department of the Western Australian Government maintains a number of long-term Leopold-Stevens pluviometers in the Pilbara. Rainfall intensity data from only three of these pluviometer stations (Yule River-Jelliabidina Well, Marillana Creek-Flat Rock and Marillana Creek-Munjina) have been considered in this report.

As previously mentioned the Lambrecht pluviometer located at Marandoo provided valuable rainfall information even though it was not possible to obtain accurate short-term rainfall intensities from the seven-day chart used by this instrument.

The siphoning mechanism of the pluviometer at the Port Hedland Airport Meteorological Office developed a malfunction at the height of the cyclone, and both timing and rainfall totals are in doubt. Nevertheless, an attempt has been made

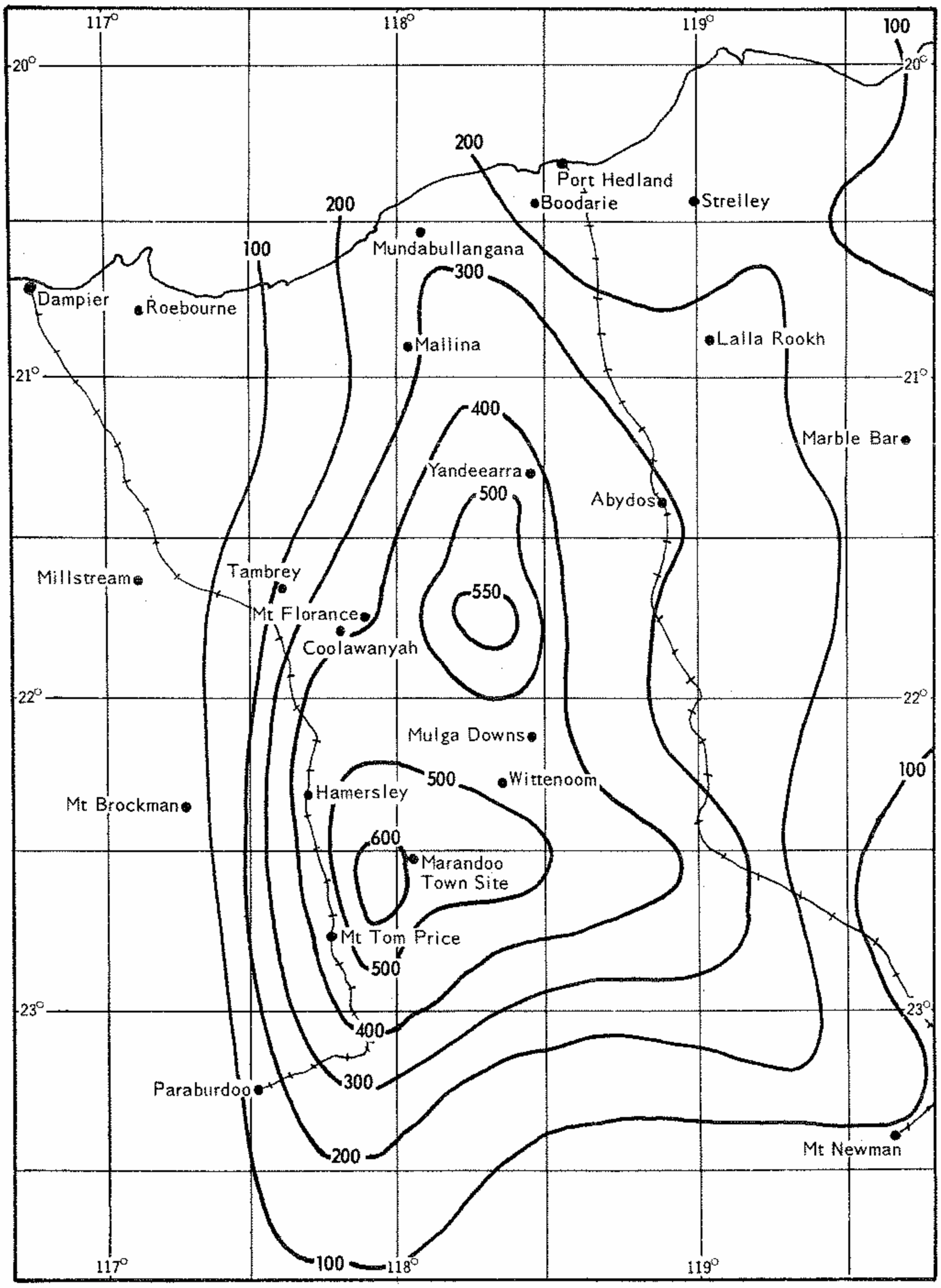


Fig. 9 Rainfall isohyets (mm) for the 4–day period 0900 7 December to 0900 11 December 1975.

to reconstruct the pluviograph and rainfall intensities have been deduced from this graph.

Rainfall intensities were estimated by eye from the pluviographs mentioned above and additional intensities were provided by the frequent observations taken at the Hamersley Iron Pty Ltd plant site at Tom Price. Maximum rainfall intensities for a number of time periods are shown in Table 2.

Table 2 Maximum rainfall intensities (mm/h) to the nearest millimetre

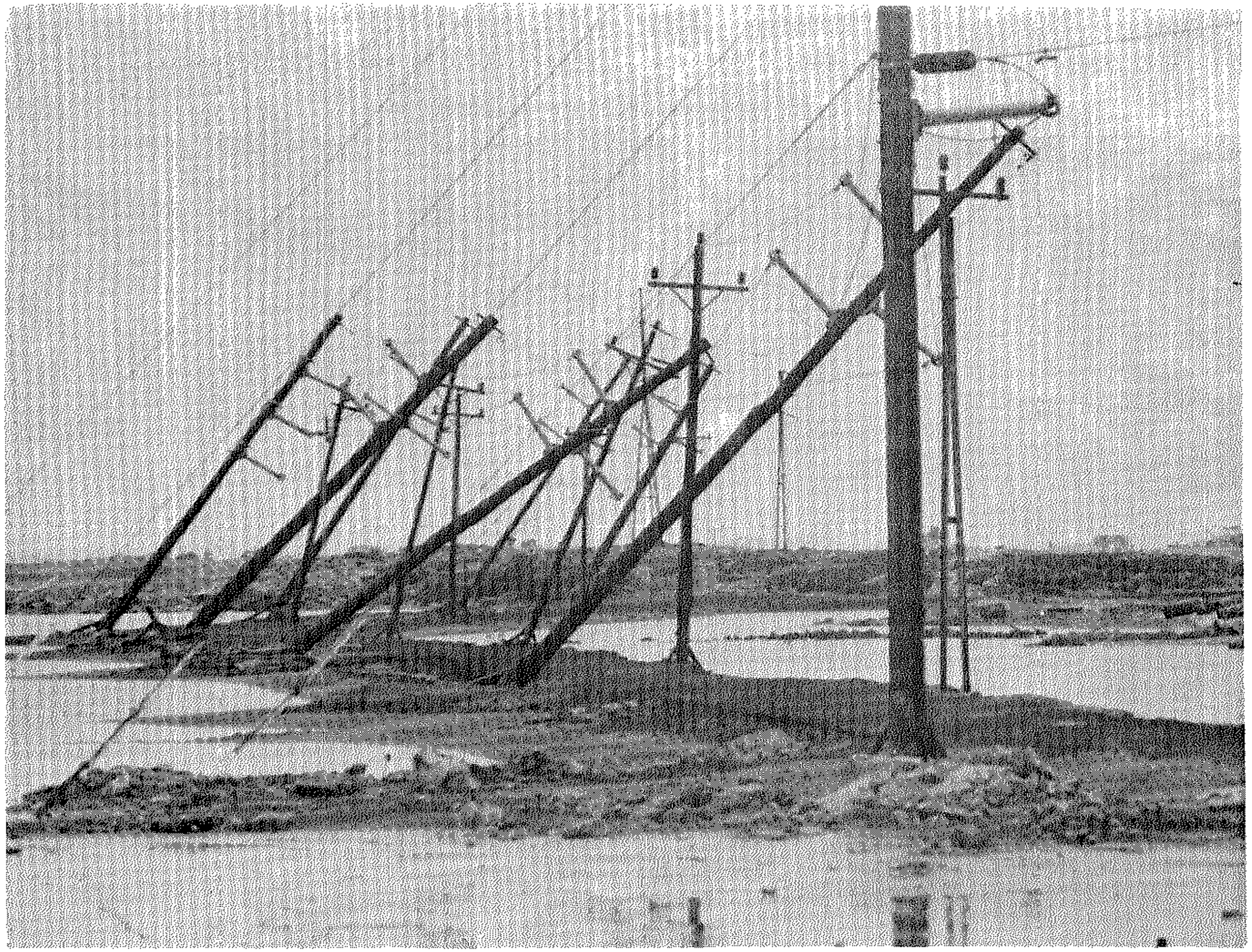
	Period (hours)					
	1	4	12	24	48	72
Port Hedland Airport Meteorological Office	26	17	11	6	4	2
Yule River-Jelliabidina Well (20°42'S 118°28'E)	53	41	21	12	7	5
Tom Price	n.a	22	12	12	9	6
Marandoo (20°32'S 118°04'E)	n.a	20	15	15	12	8
Marillana Creek-Flat Rock (22°43'S 118°58'E)	20	19	15	12	7	6
Marillana Creek-Munjina (22°41'S 118°43'E)	31	22	20	15	10	8

Record rainfalls and return periods

Collawayah, Mulga Downs, and Hamersley Station all recorded their highest ever three-day rainfall totals. The 24-hour totals (0900-0900) were also records at Coolawanyah and Mulga Downs, while Hamersley Station received its second highest one-day fall. Further to the north Mundabullangana, Tabba Tabba, Indee and Boodarie all received near record 24-hour rainfalls.

Bureau of Meteorology workers (Pierrehumbert 1975 – unpublished) have developed an empirical relationship between 24-hour rainfall totals registered at long-term recording stations and 12-hour rainfall intensities have been produced and, when used in conjunction with a series of nomograms, rainfall intensities for periods less than 12 hours and for return periods up to 50 years can be duduced. Return periods for rainfall intensities from 12 to 96 hours have also been derived for a number of stations throughout Western Australia.

According to this work the maximum four-hour intensities recorded in the Hamersley Range area during cyclone Joan represent slightly less than a once in a ten-year occurrence. Over a 12-hour period the estimated return period increases to greater than once in 50 years in the area near Marillana Creek-Munjina and approximately once in 40 years elsewhere. The three-day totals registered over the Hamersley Range represent in excess of a once in a 50 year event. In the Yule River-Jelliabidina Well area the four and 12-hour intensities are estimated to represent a return period of 40 years.



High tension power poles near Port Hedland Airport bent by the combined effects of the wind and rain during cyclone Joan.

Part of the damage to the Port Hedland District Hospital.

A house at Port Hedland damaged by cyclone Joan.

A fortnight after Joan much of the debris had been cleared but many houses were awaiting repair.

Electrical activity

During the lifetime of cyclone Joan lightning reported by observers or detected by sferics equipment* was without exception located in the outer regions of the cyclone or remote from its influence.

A lightning counter installed at the Port Hedland Airport Meteorological Office recorded 14 counts in the 24 hours to 0830 3 December, 26 counts in the 24 hours to 0830 4 December, 36 counts in the 37.5 hours to 2200 5 December, but no counts on 6 and 7 December. The instrument failed on 8 December because of water entry. The range of its apparatus is not known but it is significant that no lightning was detected as the cyclone approached Port Hedland.

OBSERVED FEATURES OF CYCLONE JOAN NEAR PORT HEDLAND

Wind

The anemograms at Port Hedland Airport on 7, 8 and 9 December 1975 are shown in Figs 3 and 4. Although a power failure resulted in the loss of about 3.6 hours of record shortly after the cyclone crossed the coast, observations by the staff on duty seem to confirm that the anemometer record covered the period when the mean wind speed was at its highest and that this occurred when the cyclone was at its closest point to the west at about 0545 8 December (Fig. 3).

In the southeastern quadrant of the cyclone, as it approached the coast, destructive winds (i.e. mean winds of 90 km/h or more) extended some 125 km from the centre and commenced at about 2330 7 December at the Port Hedland Airport. In the northeast quadrant mean winds dropped below 90 km/h about 1020 8 December at a distance of approximately 100 km from the centre.

Very destructive winds (i.e. mean winds of 120 km/h or more) extended as far as 60 km from the centre in the southeast quadrant and probably a similar distance from the centre in the northeast quadrant. At the Meteorological Office they commenced at about 0430 and probably ceased about 0740 8 December.

Thus mean winds in excess of 90 km/h were experienced at Port Hedland for about 10 hours and mean winds exceeding 120 km/h for about three hours.

Considering Shea and Gray’s (1973) statistical relationship between radar observed precipitation patterns and the maximum wind field in tropical cyclones, it could be inferred from radar photographs of cyclone Joan that the most destructive winds were in a band lying between 25 and 40 km from the centre of the eye. This implies that Port Hedland experienced winds somewhat less than the maximum generated by Joan. The anemometer at the Port Hedland Airport meteorological Office, which recorded a maximum gust of 208 km/h and a maximum mean (10 minute) wind of 141 km/h, was located 51 km from the centre of Joan at or shortly after landfall.

Wind data recorded at the Nelson Point port site at Port Hedland by an anemometer owned by Mount Newman Mining Co. Pty Ltd, suggest that a mean wind in excess of 160 km/h probably occurred between 0500 and 0515 87 December. (Unfortunately the anemometer was not capable of actually recording speeds greater than about 155 km/h, but this observation is consistent with the wind recording at the Port Hedland Airport Meteorological Office.)

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*By using a network of two or more stations with radio direction finding equipment it is possible to locate lightning flashes since they are a source of electromagnetic radiation in the atmosphere (sferics).

Pressure

The minimum pressure recorded at the Port Hedland Airport Meteorological Office and corrected to mean sea level was 966 mb. A barograph at the Mount Newman Mining Co. Pty Ltd office at Nelson Point measured a minimum pressure of 960 mb. The record from this instrument prior to the approach of Joan was generally within one millibar of that from the Meteorological Office and suggests a minimum sea level pressure of about 961 mb.

The lowest reading from an aneroid barometer at the Yule River Pumping Station operated by the Public Works Department of Western Australia, some 43 km southwest of Port Hedland and about 20 km east of cyclone Joan's track, was 953 mb. A check of this barometer against that of the Port Hedland Airport Meteorological Office and reduction of the reading to mean sea level produced a corrected value of approximately 941 mb.

A barograph owned by Texasgulf Marandoo Pty Ltd and located at Mundabullangana homestead, about 60 km west-southwest of Port Hedland and six or seven kilometres west of Joan's track, recorded a minimum sea level pressure, after correction, of about 935 mb. This was the lowest pressure recorded during cyclone Joan. It occurred about 1.5 hours after the eye of the cyclone had crossed the coast and when it was approximately 20 km inland from the point of landfall. A reconstruction of this barograph trace is presented in Fig.10.

Storm surge

When a tropical cyclone approaches a coastline there is a rise in the water level along a certain section of that coastline caused by the combined effects of wind stress on the water surface and the reduction in atmospheric pressure in the eye of the storm. The surge is thus a single abnormality of the water level directly associated with the storm and it is superimposed on the normal tide pattern.

A tide gauge is operated by the Port Hedland Port Authority within the main port area. An hourly log of the water level was maintained in the control tower until 1800 7 December when the threat of a power failure forced operations to cease. Almost 24 hours of crucial data were lost before the log was resumed. Unfortunately a malfunction in the timing mechanism in the actual gauge recorder allowed only the height of high and low water to be deducted. All available tidal information as well as the predicted tidal pattern is shown in Fig. 11. The tide gauge recorded a rise of 1.45 m above the predicted level of 6.5 m at the high tide at 0136 8 December and, at the subsequent low tide, the actual water level was 2.58 m above the predicted value. Thus at Port Hedland it is probable that a storm surge in excess of 2.6 m occurred prior to the predicted low at 0752 8 December.

DEDUCED CHARACTERISTICS OF CYCLONE JOAN NEAR PORT HEDLAND

Radius to the maximum wind speed band

Mundabullangana Station homestead is located about 20 km south-southwest of the landfall point of Cyclone Joan and about 7 km west of its track. As the cyclone passed at a speed of about 16 km/h this station experienced the eye for 2.25 hours. This implies that the inner edge of the maximum wind speed band was at least 18 km from the centre of the eye.

The mean radius from the centre of the eye to the inner edge of the inner-most band of rain echoes, as measured by radar during the five hours before landfall, was 16.4. km. During this period measurements were made every 15 minutes. The reported radii ranged from 14 to 18.5 km.

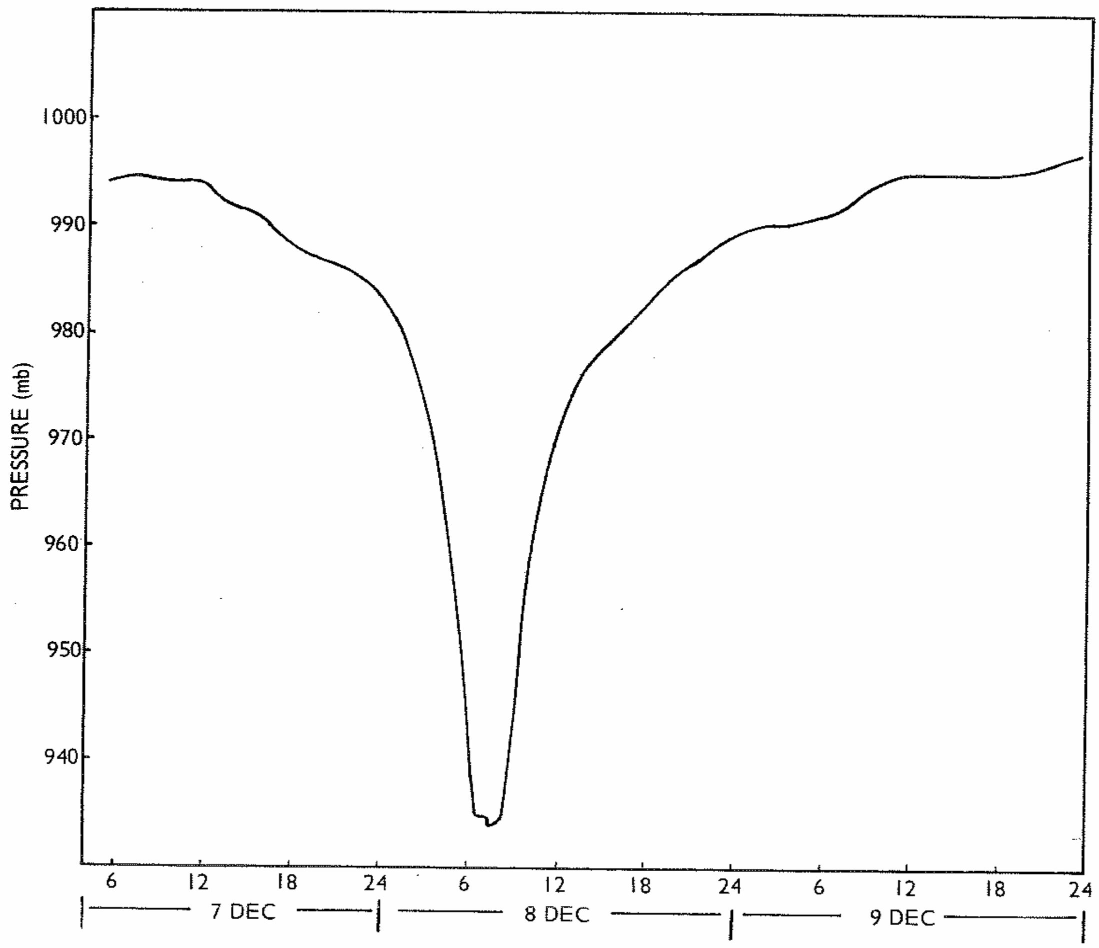

Fig. 10 Reconstructed barograph trace derived from that recorded at Mundabullangana during cyclone Joan.

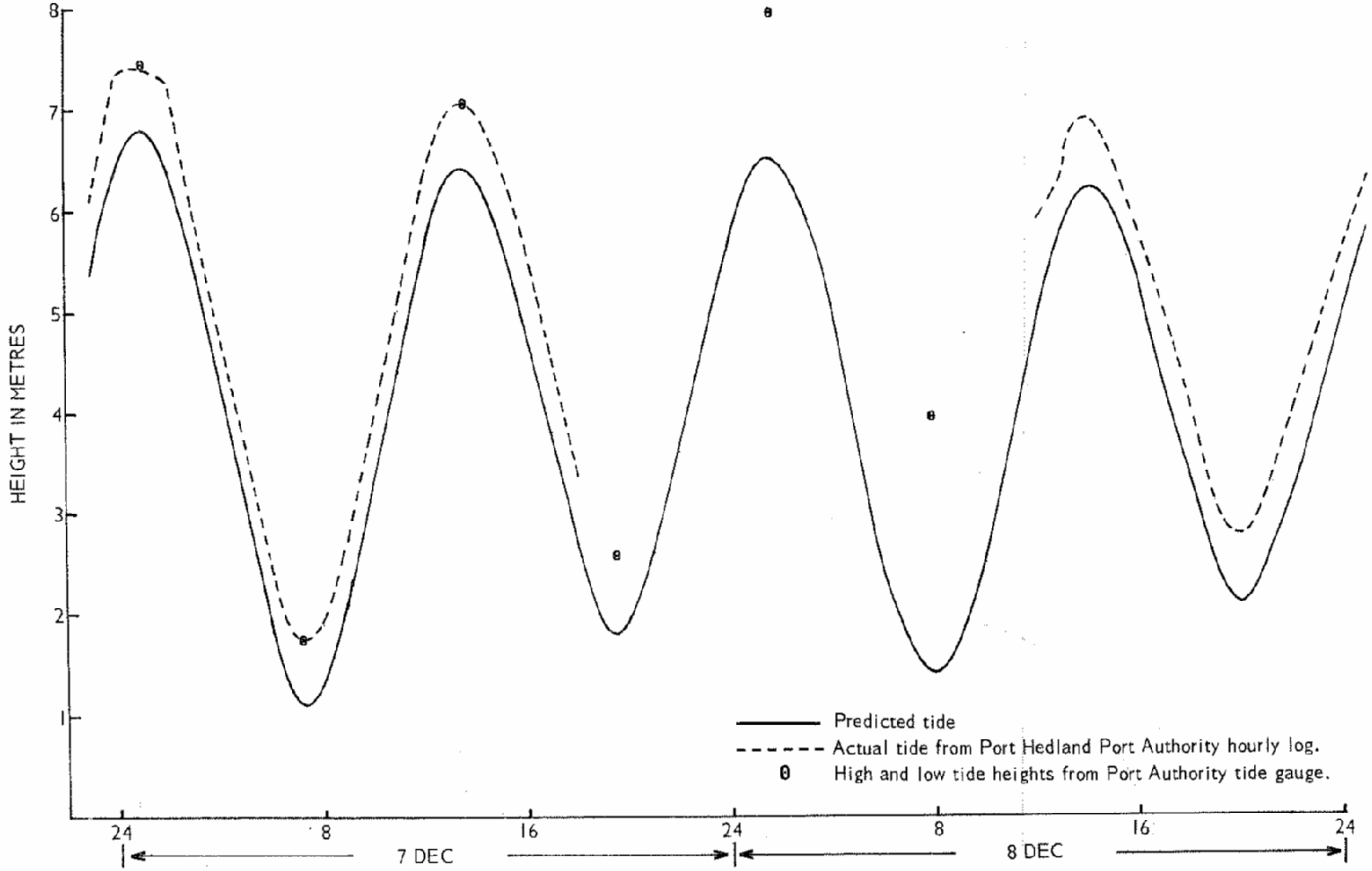

Fig. 11 Tidal data for Port Hedland during cyclone Joan.

Shea and gray (1973) show that in the mean tropical cyclone the radius of maximum wind lies within the inner precipitation band at a mean distance of about 9 km outward from the inner edge of the band. Naturally individual storms exhibit rather wide variations from this mean situation. The double eye wall structure apparent at times in the radar photographs of cyclone Joan has added to the difficulty of confidently locating the radius of maximum wind speed within a narrow band.

When considered overall, the available data seem to imply that in the Port Hedland area the radius of maximum wind lay in the range of 20 to 40 km and was probably about 30 km.

Minimum central pressure

The lowest mean sea level pressure recorded at Mundabullangana was 935 mb. This occurred about 1.5 hours after landfall. Allowing for land effects, and considering evidence from satellite and radar photographs, the lowest mean sea level pressure in cyclone Joan, at the point of landfall, is estimated to have been in the range of 925 to 930 mb.

Pressure profile

By using the radar measured positions of the times of these reports, the corresponding pressure recordings from Port Hedland Airport Meteorological Office and Mundabullangana have been converted to partial cross-sections of the cyclone. These are shown in Fig. 12.

A pressure profile of the form:

$$P_r = P_o + (P_n - P_o) \exp\left(\frac{-a}{r^b}\right) \quad \text{(after Schloemer 1954)}$$

has been fitted to these profiles where:

P_r = pressure (mb) at radius r;

P_o = central pressure;

P_n = pressure at the periphery of the storm - usually taken as the first anticyclonically curved isobar;

exp = base of natural logarithms; and

a, b = two constants, a having the dimension of length, and b being dimensionless.

In the fitted profile P_o = 930 mb, P_n = 1004 mb, a = 44.54 and b = 1.0357. This curve is not unique but is dependent on the values of the two pairs (P_r, r) substituted in the equation to solve for a and b. It can be seen in Fig. 12 to be a very satisfactory fit of the available data.

Wind profile

The gradient wind profile corresponding to the modelled pressure profile can be deduced from the equation:

$$V_g = 36\left(\frac{ab}{\rho r^b}(P_n - P_o)\exp\left(\frac{-a}{r^b}\right)\right)^{\frac{1}{2}} - \frac{rf}{2}$$

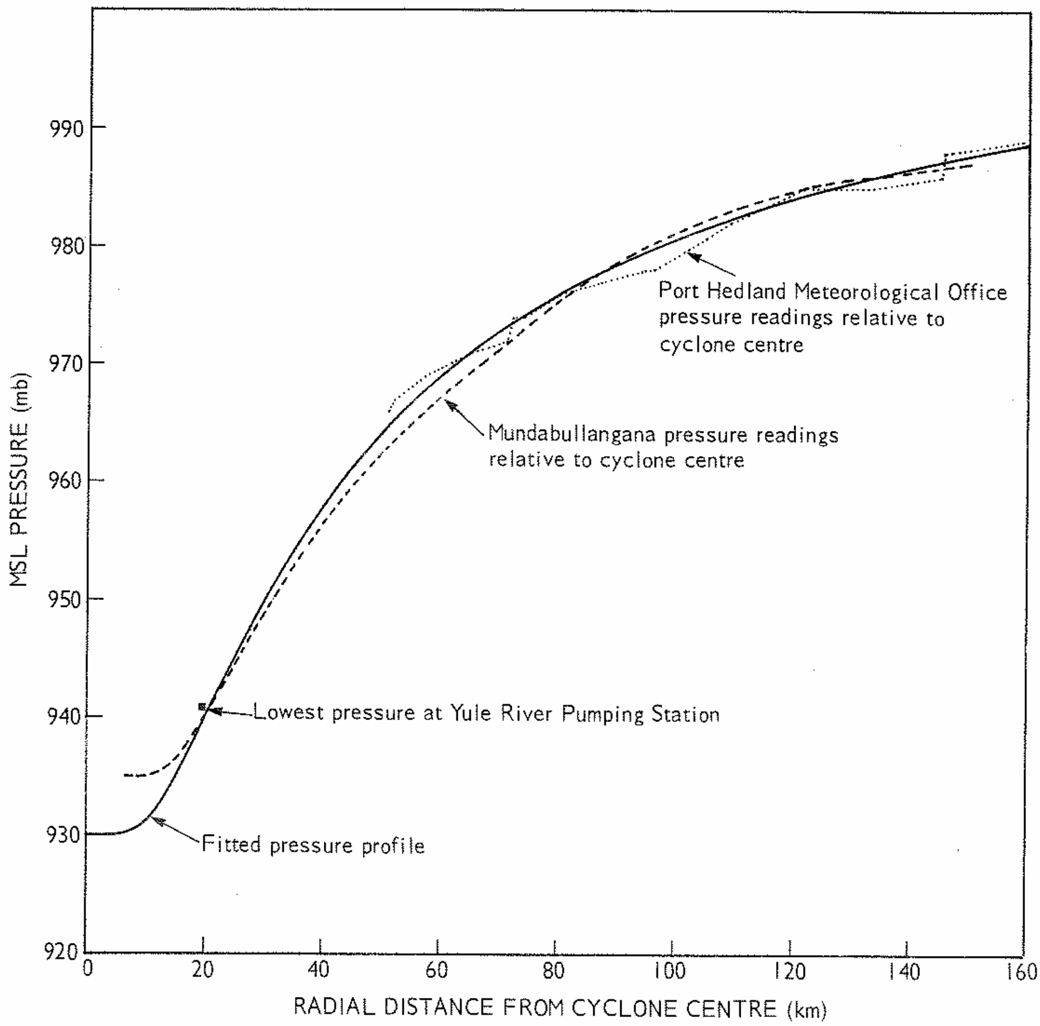

Fig. 12 Partial pressure profiles of cyclone Joan deduced from data acquired at Port Hedland Meteorological Office and Mundabullangana and a fitted pressure profile.

Where V is the gradient wind in km/h, the density of air (p) is assumed constant at 1.15gkg m $^{-3}$, the coriolid parameter (f) is 0.1796 h $^{-1}$ at latitude 20°, pressures are in mb, and the radius (r) in km. This profile is shown in Fig.13.

Graham and Hudson (1960) provide empirical ratios to reduce the gradient wind, V, to a 10-minute mean over-water wind, V, related to a height of 10 m. This mean over-water profile (Fig. 13) shos a maximum wind speed of 152 km/h at a distance of 39 km (a 1/b) from the eye.

In a manner similar to that described above for the pressure recordings, the anemograph trace from Port Hedland Airport Meteorological Office has been converted to a partial cross-section of the wind field in the cyclone as it approached the coast. From Fig. 13 it is obvious that the derived over-water profile would be regarded as a good fit of this partial profile. However, the over-water profile would normally be expected to lie above the partial profile because increased friction over a land surface compared with that over the ocean causes a reduction in the mean wind speed.

Nevertheless, despite its apparent underestimation of the mean over-water wind speeds, this profile does in this case produce realistic values.

Maximum wind speeds

If the radius to the maximum wind speed band in cyclone Joan was in the range 25 to 40 km and the partial wind profile from Port Headland Airport meteorological Office is representative, then from extrapolation of this profile in Fig. 13 a maximum 10-minute mean wind over land of 150 to 160 km/h may be inferred near the time of landfall. The corresponding maximum gusts would have been in the range 215 to 230 km/h if a gust factor of 1.43 for open glassland is assumed (Atkinson 1974; Deacon 1955, 1965; Shellard 1963).

A number of empirical relations have been derived to estimate the maximum sustained wind speed (one minute average) over water from the minimum central pressure, however the wide range of results and the normal absence of reliable values of central pressure have minimised their usefulness in the Australian region. Recently Atkinson and Holliday (1975) derived a similar relation for the western north Pacific using only selected quantitative data. Their relation is:

$V_m = 12.4 (1010 – P_o) 0.644$

Where V_m is the maximum sustained wind speed (km/h) and P_o is the central pressure (mb). A general accuracy of +20 km/h is ascribed to its use.

Applying this relation to cyclone Joan near landfall gives a value of V_m of 208 km/h. The maximum gust, derived by applying a factor of 1.20 – 1.25 (Atkinson 1974), lies in the range 250 to 260 km/h. The 10-minute mean over-water wind, obtained by applying a factor of 0.88 (Atkinson 1974), is 183 km/h.

The anemograph record from the Nelson Point Port site at Port Hedland of the Mount Newman Mining Co. Pty Ltd, that indicated a maximum wind speed slightly in excess of 160 km/h, tends to support the estimated values of the mean maximum wind speeds both over the land and water. Although these results cannot be accepted without some reservation they do imply that over the land a maximum mean 10-minute wind speed of at least 215 to 230 km/h. The maximum over-water 10-minute mean winds in the cyclone near landfall are estimated to have been in the range 175 to 185 km/h with maximum wind gusts of the order of 245 to 260 km/h. There must of courses be a transition zone between the over-water and over-land values and the length of this zone is primarily influenced by the nature of the terrain and its cover.

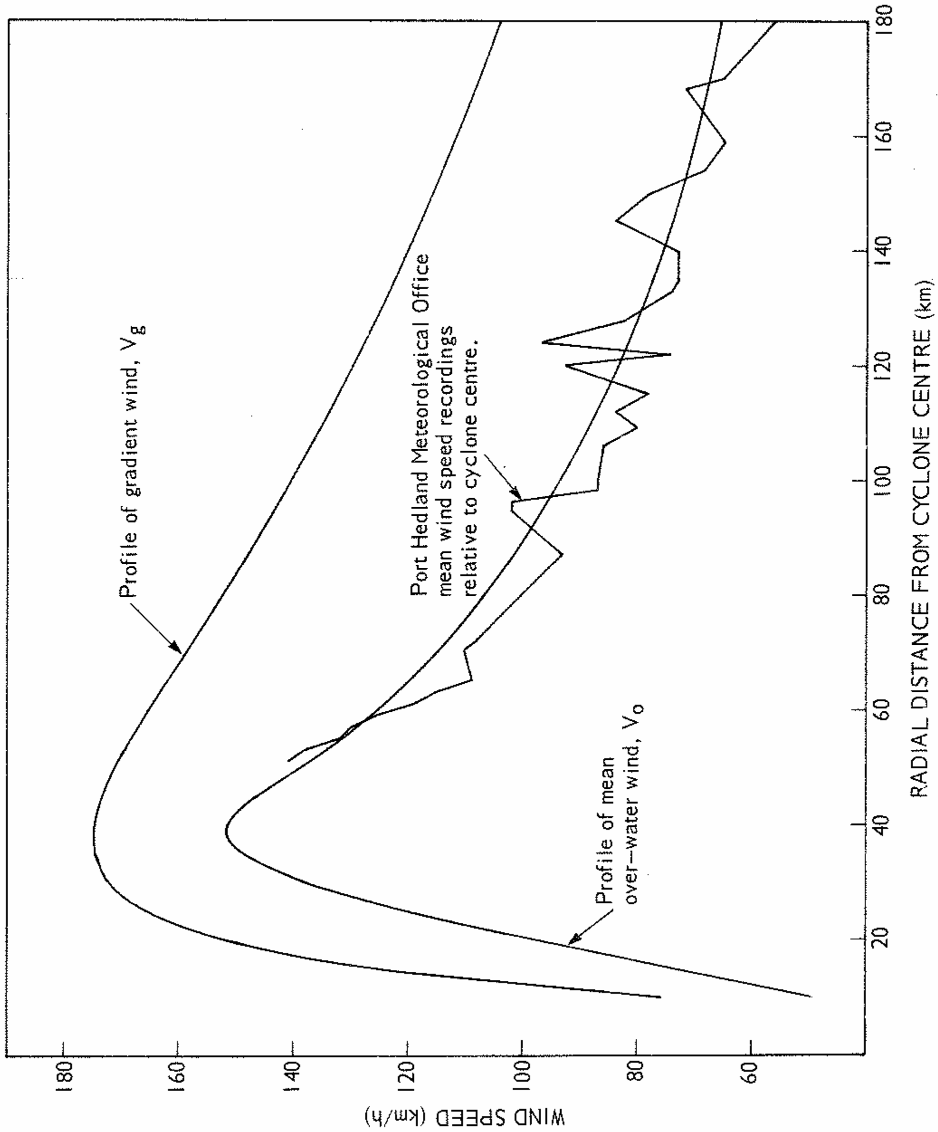

Fig. 13 Calculated gradient wind and mean over-water wind profiles for cyclone Joan and a partial cross-section of the surface wind field deduced from data recorded at the Port Hedland Meteorological Office.

Intensity variation

The satellite photographs available on the morning of landfall (8 December) show that a significant modification of the cloud structure of the cyclone had taken place by two or three hours after landfall due mainly to the restriction of the inflow of moisture. Dvorak's (1975) method of intensity analysis cannot be applied under these circumstances so no indication of any change could be deduced in this manner.

Nevertheless, at 0930 7 December when cyclone Joan was first accurately positioned by radar, it was approximately 105 km west-southwest of the automatic weather station at Rowley Shoals, which reported a pressure of 983 mb at 0900 and 1200. When cyclone Joan was a similar distance to the northwest of Port Hedland Meteorological Office at about 0100 8 December the mean sea level pressure at this office was also 983 mb. This provides some evidence that cyclone Joan was in an almost steady state condition during the 18 to 24 hours prior to landfall. It is unusual, However, for cyclones to remain in a steady state for such a long period. Thus in the absence of central pressure measurements, and considering that the comparative observations were along way from the centre, this result should be regarded as in-conclusive.

Storm surge prediction

Research workers in the United States of America and elsewhere have in recent years attempted to model tropical cyclones and their associated storm surges for prediction purposes. A technique developed by Jelesnianski (1966, 1967) and refined further by Nickerson (1971) uses a series of pre-computed nomograms to deduce the storm surge height profile for some distance left and right of the cyclone landfall point. The basic input data include storm speed, direction of storm movement relative to the coast, the radius of maximum winds, the pressure differential between the centre of the cyclone and the periphery, and the bathymetry of the coastal waters near the point of landfall.

The technique is based upon first computing the storm surge profile for a standard storm over a standard basin and then correcting for the actual storm conditions. The nomographs are based on data accumulated from hurricanes that have been observed over the continental shelf of the Gulf of Mexico and the east coast of the Unite States of America.

In applying the method to cyclone Joan the basic input parameters are:

Pressure at the periphery of the storm, P_n = 1004 mb;
central pressure, P = 930 mb;
assumed radius of maximum wind, r = 30 km;
speed of movement = 14 km/h;
coastal crossing angle = 75 °;
landfall time = 0600 8 December.

The derived storm surge profile shown in Fig. 14. The peak surge of 3.6 m is predicted to occur 34 km east of landfall and at Port Hedland, 46 km east of landfall, a maximum surge of 3.25 m is forecast at 0550 8 December.

If the time of arrival of the storm surge peak and the high tide had been coincident at Port Hedland the resulting water level of 9.75 m would have been about 1.9 m above the highest astronomical tide.

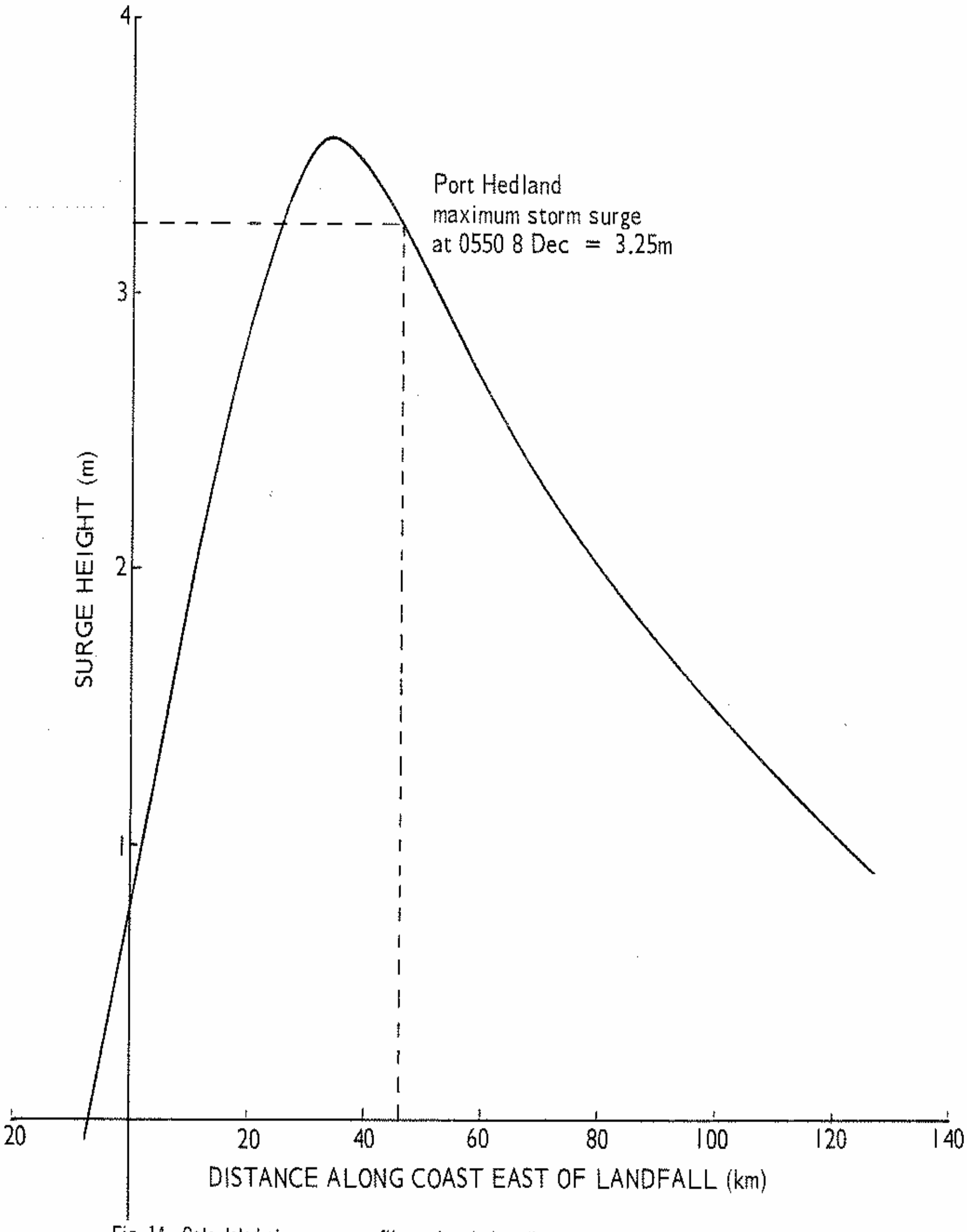

Fig. 14 Calculated storm surge profile produced along the coast east of landfall by cyclone Joan.

CYCLONES IN THE PORT HEDLAND AREA

In the past fifty years severe tropical cyclones have seriously affected or threatened Port Hedland on 16 occasions. Table 3 summarises the principal characteristics of these cyclones. Many other cyclones have posed a potentially severe threat to Port Hedland before making landfall at more distance localities on the northwest coast or continuing seaward.

Historical surveys published by the Bureau (Visher and Hodge 1925; Australian Bureau of Meteorology 1929) have documented the story of damage, coastal erosion, and inundation by the sea, flooding, and exceptional loss of life at sea during cyclones that affected the northwest between the early days of settlement and 1925.

Cyclone Joan ranks with the severe cyclones of January 1939, March 1942, and March 1943 in terms of the damage caused to Port Hedland. On the latter two occasions evidence points to the eve of the cyclone passing over the town, and in the former, the eye apparently passed a short distance to the west.

Descriptive accounts of damage during the 1939 cyclone have been documented in the *West Australian* of 16 January 1939. Thirty per cent of the population was assessed as homeless and property damage of up to $200,000 was incurred. Most damage was due to inundation by the sea with the rising tide causing flooding of low-lying homes and the lower floors of commercial premises. The storm surge was probably of the order of 3 m. The avoidance of loss of life was attributed to the gathering of townspeople into the more substantial buildings during the daylight and was probably aided by the occurrence of the high tide storm surge during the afternoon.

RETURN PERIOD OF CYCLONE JOAN

The frequencies of all cyclones passing within 167, 111, and 56 km (i.e.) 90, 60, and 30 nautical miles) of Port Hedland during the period 1940 to April 1977 have been assessed as 21, 14, and six respectively (updated from Coleman 1972). From 1956 onwards Coleman considered only those tropical cyclones with surface winds exceeding 62 km/h, but prior to this year all cyclones were included as no wind speed data was available.

An analysis of the 23 annual maximum gusts covering the complete period of record at Port Hedland Airport Meteorological Office to the end o1975, using the method of Gumbel (1954), reveals that the gust of 208 km/h measured during cyclone Joan has a return period of 60 years. The care with which such estimates must be treated when the record is short is illustrated by the fact that a similar analysis of the 22 annual maximum gusts recorded to the end of 1974 predicts a return period of about 250 years for this gust. When the record is extended to include the maximum gusts from 1976 and 1977 the return period for a gust of 208 km/h is reduced to about 34 years.

In spite of the deficiencies and pitfalls that accompany analyses of extremes and their statistical interpolation, it seems unlikely on the basis of the historical and enemograph data available that a return period much shorter than 30 years could be assigned to cyclone Joan.

COMPARISON OF CYCLONES JOAN, TRIXIE AND TRACY

Joan, Trixie and Tracy all produced a significant community impact within a 12 month period. Comparative meteorological data for these three cyclones are given in Table 4. Although all three cyclones produced approximately the same peak wind gust, the respective eye sizes, wind distributions, and extent of the gales were quite different.

Table 3 Severe tropical cyclones that have closely threatened Port Hedland since 1925

Closest approach to Port Hedland					Port Hedland		
Date	Distance (km)	Movement	Landfall (nearest town)	Estimated minimum central pressure (mb)	minimum pressure (mb)	maximum wind speed (kn)	Impact near Port Hedland
21 Jan 1925	150 (NW)	SW	Roebourne	950	987	NE-120*	Severe pastoral damage
27 Feb 1925	95 (E)	S	Pardoo	950	986	W- 85*	Severe pastoral damage
29 Mar 1931	80 (W)	S	Whim Creek	960	990	NE-120*	Nine drowned from luggers
11 Jan 1939	20 (W)	S	Port Hedland	940	954	NE-145*	Storm surge, widespread damage
2 Mar 1941	70 (E)	SE	De Grey Station	940	990	W-120*	Wind damage
25 Mar 1942	0	SE	Port Hedland	935	937	W-200*	Widespread heavy damage
6 Mar 1943	0	SW	Port Hedland	960	974	NE-190*	Widespread damage
29 Dec 1947	70 (E)	S	De Grey Station	960	978	SE-140*	Wind damage
1 Mar 1961	50 (N)	SW	Dampier	950	972	SE-170	Moderate damage
2 Apr 1966 (Shirley)	200 (W)	S	Dampier	965	999	NE-138	Small craft damage
3 Feb 1971 (Sheila)	120 (W)	S	Roebourne	970	984	NE-125	Washaways, wind damage
22 Jan 1973 (Kerry)	90 (W)	S	Whim Creek	970	988	NE-125	Minor damage, oil rig damage
18 Feb 1975 (Trixie)	65 (N)	W	Onslow	930	981	SE-124	Minor damage
8 Dec 1975 (Joan)	50 (W)	S	Port Hedland	915	966	NE-208	Widespread damage
6 Mar 1977 (Karen)	85 (N)	WSW	Exmouth	970	996	SE-115	Nil
27 Mar 1977 (Leo)	50 (ENE)	SE	De Grey Station	960	983	S-200	Moderate damage

* Estimated wind velocities. Dines anemograph records commenced in 1954 at Port Hedland.

Table 4 Comparative data for cyclones Tracy (Darwin, 1974), Trixie (Onslow, 1975), and Joan (Port Hedland, 1975)

		Joan	Trixie	Tracy
1.	Latitude of initial development	$10^{o}S$	$16.5^{o}S$	$8^{o}S$
2.	Type of development (Dvorak)	Slow	Rapid	Rapid
3.	Lifetime as a tropical cyclone	8 days	5.5 days	Less than 4 days
4.	Mean speed of movement	11 km/h (12.5 km/h for last six days)	12.7 km/h	6 km/h (approx.)
5.	Latitude of recurvature		$25^{o}S$	$11.5^{o}S$
6.	Central pressure on landfall (MSL)	925-930 mb	Probably less than 930 mb*	950 mb
7.	Eye diameter on landfall	33 km (mean)	46 km (mean)	12 km (mean)
8.	Radius of maximum wind on landfall	In the range 20-40 km	Not determined	7 km
9.	Maximum winds on landfall	Mean 175-185 km/h Gust 245-260 km/h	Mean 185 km/h Gust 260 km/h	Mean 140-150 km/h Gust 217-240 km/h
10.	Radial extent of gale force winds	170 km (approx.)	100 km	50 km (approx.)
11.	Rate of decay after landfall	Winds below gale force within 24 hours	Winds below gale force 56 hours after landfall	Winds below gale force within 24 hours

* Open to question.

ACKNOWLEDGMENTS

The Bureau gratefully acknowledges the assistance provided by those people and companies who answered the questionnaire distributed to them after the cyclone. It also acknowledges the assistance provided by the Port Hedland and Perth offices of the Public Works Department of Western Australia.

The Bureau also wishes to thank the following for supplying their private meteorological data and allowing its incorporation in this report: Hamersley Iron Pty Ltd, Mount Newman Mining Co. Pty ltd, Port Hedland Port Authority, and Texasgulf Marandoo Ltd.

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ORGANISATION OF TROPICAL CYCLONE SURVEILLANCE

Throughout the cyclone season, 1 November to 30 April, the Tropical Cyclone Warning Centres (TCWC) at Darwin, Brisbane, and Perth maintain a routine surveillance for cyclonic developments. This oversighted by the Regional Director of the Supervising Meteorologist.

In the maintaining the surveillance, information from all sources is used. Conventional observations of surface and sky conditions, automatic weather station reports, observations of upper level winds and temperatures, ship and aircraft reports, satellites cloud pictures, and radar observations are all considered in the analysis of meteorological conditions.

Immediately indications of the development of a tropical cyclone are confirmed or wind speeds in excess of 63 km/h are expected, the following advices are issued as necessary:

(a) Tropical Cyclone Watch message or Cyclone Warning to the Public;

(b) Gale or Storm Warning to shipping and special users interests, e.g. oil rigs;

(c) Tropical Storm Advice to aviation;

(d) short statement to the Australian Broadcasting Commission (ABC) to update information in (a).

Tropical Cyclone Watch

A tropical Cyclone Watch message (known as tropical Cyclone Alert prior to the 1977-78 cyclone season) is issued whenever a cyclone or potential cyclone is located within 800 km of coastal communities and there is no strong indication of gales affecting these communities within 24 hours but they are possible after that time. The message is distributed to relevant broadcasting media, meteorological offices, selected authorities and special user interests. It prepares recipients to take appropriate action if a Cyclone Waning is subsequently issued. The Watch message is reviewed every three hours until it is replaced by a Cyclone warning or the watch is finalised. The message is re-issued every six hours or more frequently when necessary. During the Watch phase the ABC may be given short statements that are intended to updated to the watch. These statements are issued hourly.

Cyclone Warning

If the cyclone is centred more than 800 km from the coast, warnings are not issued to the public thus avoiding needless alarm. Nevertheless, the needs of island communities and off-shore installations are recognised. If the centre is within 800 km of the coast and gales are expected to effect the coastal communities in the following 24 hours, Cyclone Warnings are issued every three hours to all recipients in the threatened area. If the centre is close to the coast and poses a severe threat, Warnings are issued hourly (or more frequently if practicable) to severely threatened areas. Such frequent Warnings are usually possible only when the cyclone is under radar surveillance. During the Warning phase short statements are issued to the ABC at hours between the issue times of Warnings.

TROPICAL CYCLONE SURVEILLANCE DURING JOAN

Tropical Cyclone Alerts and Cyclone Warnings to the public

The relatively long track of cyclone Joan, the variation in its threat to coastal communities, and final approach to a major town provided a test of the effectiveness of the Bureau's cyclone warning system. Advices for Joan moved progressively through cyclone Alert (as it was then known) and Cyclone Warning phases in accord with the threat to the coastal towns.

In all, six Tropical Cyclone Alerts and 63 Cyclone Warnings were issued for Joan as follows:

Initial Tropical Cyclone Alert Phase: The initial four Tropical Cyclone Alerts covering Joan's formation in the Timor Sea were issued at six-hourly intervals by Darwin TCWC commencing 1530 30 November 1975.

Initial Cyclone warning phase: Darwin TCWC upgraded the Tropical Cyclone Alert to a Cyclone Warning at 1430 1 December 1975, naming the cyclone Joan. A further 21 warnings were issued at three-hourly intervals as the cyclone moved westward off the North Kimberley coast.

In accord with the standard transfer arrangements at longitude 125°E Perth TCWC assumed responsibility for issue of warnings commencing 1000 3 December 1975 and a further 18 warnings were issued, at three-hourly intervals, as cyclone Joan proceeded west-southwest off the West Kimberley coast.

Second Tropical Cyclone Alert phase: At 2300 6 December 1975, when it became apparent from successive satellite photographs that Joan's continuing westward path would take it further seaward from coastal towns such as Broome and Port Hedland, Perth TCWC returned from the Warning to the Alert phase. Two further Tropical Cyclone Alerts were issued. However, this situation was short-lived.

Second Cyclone Warning phase: A satellite photograph, and observational evidence from Rowley Shoals automatic weather station, confirmed a quite rapid turn of cyclone Joan towards the south late on 6 December. Cyclone warnings recommenced at 2200 6 December 1975 and a further 23 warnings, at three-hourly intervals, were issued until the cyclone was well inland. The last warning was issued at 1500 9 December 1975.

During the period 1100 4 December to 1400 9 December a total of 74 brief hourly statements, providing the latest estimate of Joan's position and movements, were issued and broadcast by the ABC.

The progressive alerting and warning coastal communities as cyclone Joan approached Port Hedland is depicted in Fig. 15.

Gale or Storm warnings to shipping

The initial Gale warning to shipping was issued by Darwin TCWC at 0845 1 December and this was upgraded to a Storm Warning at 1530 1 December. The Darwin TCWC subsequently issued 10 Storm Warnings at six-hourly intervals, the last being issued at 0315 4 December.

The Perth TCWC assumed responsibly for the issuing of Storm Warnings from 1000 WST 4 December and issued a further 19 Storm Warnings at six-hourly intervals, the final Storm Warning being issued at 100 8 December. One Gale warning was issued at 1900 8 December after which no further warnings were issued to shipping.

Tropical Storm Advice to aviation

During the period 0900 1 December to 1400 4 December the Darwin TCWC issued 14 Advices.

During the period 2000 2 December to 0400 9 December the Perth TCWC issued 26 Advices to aviation.

All advices were issued at six-hourly intervals.

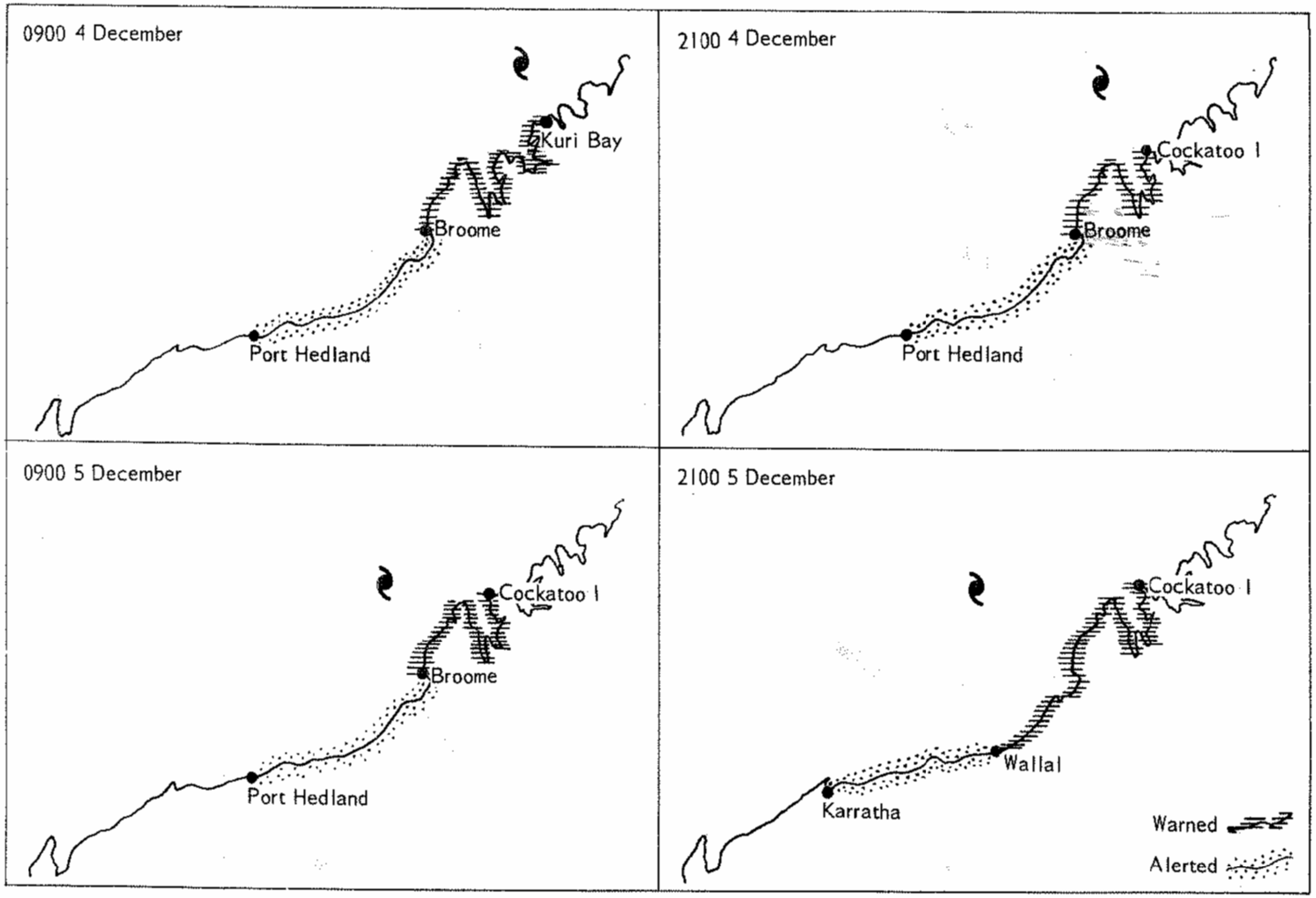

Fig. 15(a) Cyclone positions and times and the corresponding sections of coastline warned and alerted.

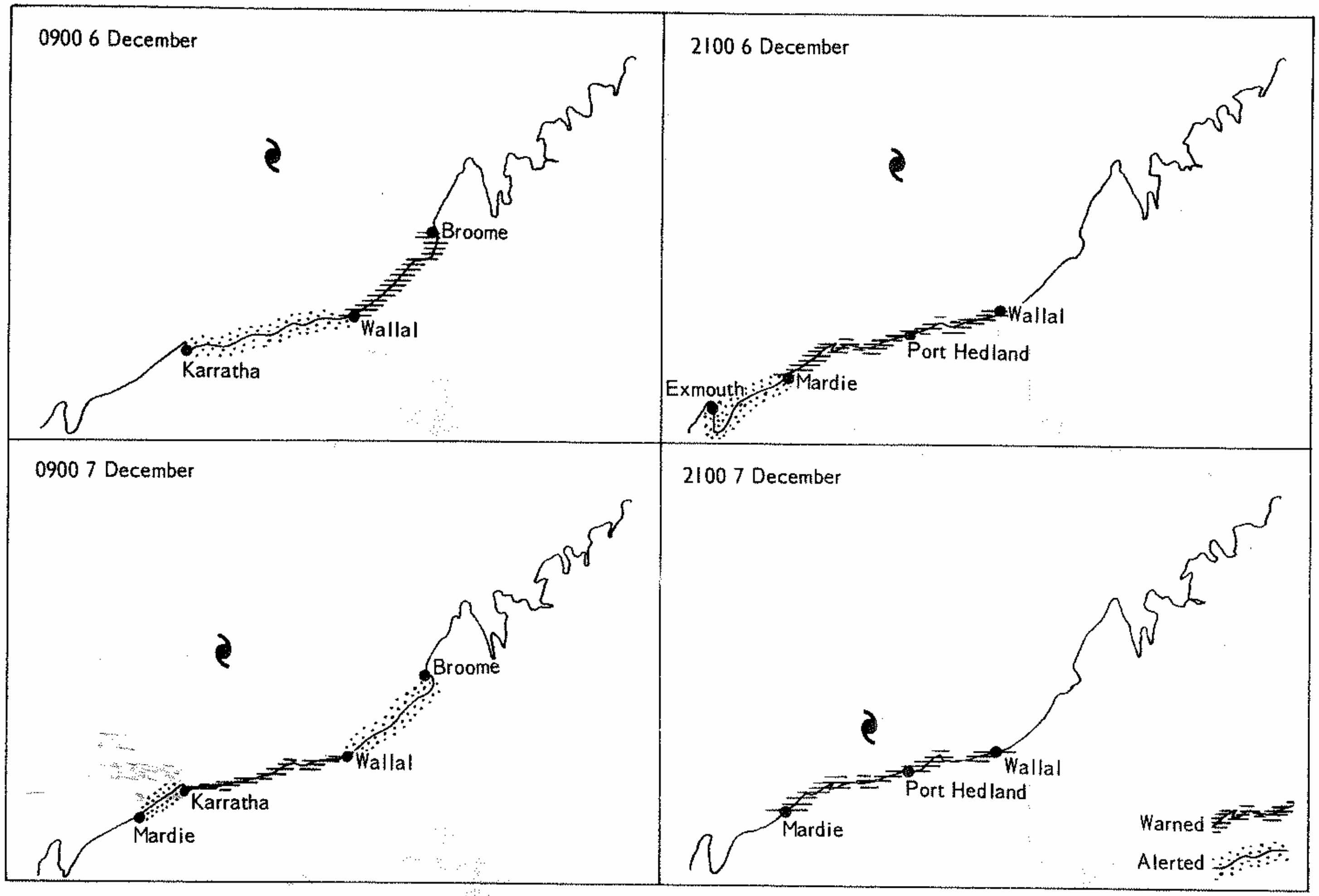

Fig. 15(b) Cyclone positions and times and the corresponding sections of coastline warned and alerted.