OIL SPILLS: SOME ASPECTS OF CONTINGENCY PLANNING

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Environmental impact assessments for offshore oil projects require an oil spill contingency plan containing predictions of where spilled material will go, and how quickly it will get there. In practice spill movement is largely determined by the local wind. Regional currents influence longterm transport and tidal flows have local modifying effects. Impacts can thus be predicted from reviews of winds, currents and tides. For winds, statistics of wind speed and direction, collected from coastal meteorological stations or offshore ship reports, define the average frequency of wind in different directions with associated wind speeds. The likelihood of impact in a particular area and a range of impact times can then be stated. The persistence time of wind with a given direction and speed is more applicable than long term averages, but good persistence data is difficult to derive particularly for the offshore. An alternative prediction method involves a vector sum prediction of movement using wind speed and direction at say hourly intervals. This can be done for historical wind data to derive hindcasts. Thousands of different predicted historical paths can be calculated, starting for example, every few hours, for years of data. The statistics of impact can then be determined.

The differnt approaches are illustrated with examples from hypothetical situations at several locations around New Zealand. Potential impacts from a shipping spill provide interesting comparisons with a drilling spill.

Offshore oil and gas exploration or development programmes require many planning approvals and environmental impact assessments. One requirement is an oil spill contingency plan. Part of such a plan will be predictions of where spilled material will go, and how long it will take to reach various places. The coastline is usually considered the most important area for impact, although an offshore area such as a fish spawning ground, may also be important. In this paper we discuss the factors important to predicting where spilled material may go, and, with examples, illustrate the capabilities and limitations of available information for making predictions.

The discharge material of concern will be less dense than seawater so it is the movement of surface material that is of concern. Movement of such material is determined by advection (mass transport as a whole), and by dispersion, which is spreading without any external advection forces. Dispersion is complex, both in theory and in practice, and there are many factors which control it, for example: density differences, surface tension, chemical properties, evaporation, turbulent mixing, temperatures and seastate. Dispersion will be quite different if a discharge stays in the form of a thin slick, or whether it forms a *chocolate mousse* emulsion, or whether high winds and waves mix material over depths of several metres. The factors involved in dispersion are so numerous and complex, that it is often considered that in a typical spill situation effective modelling of dispersion will only be possible after a significant amount of field data from the actual discharge has been obtained. Dispersion is important if discharge is semi-continuous over long periods of time, but in most situations the advective mass transport is more significant than dispersion. Therefore for predictive purposes dispersion is often ignored. We will do that, and consider only advection.

Advection is transport by any process in which the discharged material moves as a whole mass. The nature of the material itself normally has little effect on the transport processes, and therefore the material can be treated as passively moving with the water mass. The primary factors for advection are the effects of wind, waves, tides, and currents. There are many publications reporting theoretical and practical studies of these factors, for example: Ridgway (1972), Smith (1968), Conomos (1974), Wardley-Smith (1979), Baker (1981) and Jenkins (1987). They indicate a significant range of theoretical and observational uncertainties, however complexities and uncertainties in the knowledge of local conditions will usually be greater than uncertainties in understanding of the transport mechanisms.

Wind is usually the single most important transport mechanism. Theory can be used to predict the rate of surface movement, and the most recent theories give movements at a rate of between 2.5 and 3.5% of the wind speed, in a direction, in the southern hemisphere, of 20-30° to the left of the wind direction. Observations of many accidental and experimental oil spills indicate that although there can be deviations up to 70° either side, with up to 20° being more typical, on average surface material moves with the direction of the wind. The typical speed of movement is between 2.5 and 5% of the wind speed. A figure of 3.5%, and with the wind direction, is commonly taken for predictive purposes.

Waves produce nett transport, but this effect is included in the 3.5% wind factor typically assumed. However wave conditions are important for containment or clean up operations, and a contingency plan will normally contain estimates of likely sea conditions. At any locality the waves may be due to swell which propogates into the area from a distance, and waves generated by the local wind. For containment or clean-up operations, wave breaking (whitecapping) is often an important limiting factor. Whitecapping can begin at a wind speed of about 11 kts, and is quite significant at 17 kts. Waves take time to build up, but after several hours reach a steady state. The longer period swell is independent of the local wind and builds up and decays more slowly than the local wind-sea. In most conditions swell whitecapping would not occur but swell can severely restrict operations of small vessels in the nearshore area. Persistent swell is a feature of many New Zealand coastal areas.

Currents can be produced by the local wind stress, but also by regional effects including: regional winds, seawater density differences, atmospheric pressure differences, upwelling, and globally induced flows. They can vary over intervals ranging from days to years. In predicting the movement of discharge material, regional currents are usually of secondary importance to wind effects, for impact over periods of days. However for longer term impacts, say weeks, the regional currents become important.

Flows induced by tides are often the fastest flows in any area. However there is usually little nett flow over a whole tidal cycle, so long term impacts are not significantly altered by tidal effects. Short term impact times will be affected though, and tidal flows introduce important local variations in coastal regions.

In practice prediction of trajectories and impact times requires simplifications and generalisations of the theoretical and practical factors, and of local and regional conditions. Wind is the dominant factor, with regional currents a secondary factor. To illustrate the practical derivation of predictions we will discuss New Zealand data for several areas.

The pattern of regional currents and wind directions in the Taranaki area is shown in Fig. 1. The wind data are for annual statistics, and are from statistical summaries purchased from the New Zealand Meteorological Service. The currents are compiled from a variety of publications; Kibblewhite (1982) and Heath (1985) provide good summaries. The currents shown are the predominant regional flows, but at any given time they may be different, primarily due to wind effects. Under normal conditions the currents seldom exceed 0.5 kts. A wind induced surface flow with a 20 kts wind and a 3.5% factor would be 0.7 kts. Given that some of the regional current flow is driven by the wind anyway, it is justifiable to initially concentrate on just the wind.

Data from the coastal stations, and the offshore Maui A platform, are from Meteorological Service instruments. Data of interest for oil spills are wind speed and wind direction. At some stations, particularly the airports and Maui, hourly data are available, manually read from strip chart records. At other locations only three hourly data are available, read by observers at the location. All these data will be fairly good quality, consistent data.

Since the proposed exploration or development site will be somewhere offshore we need to have estimates of wind conditions relevant to the site. There is not likely to be much site specific data available for predictions, so we must turn to reports from shipping and exploration rigs. To get a sufficient number of observations we have to combine data from an area. In Fig. 1 we show wind roses for ship reports in an area of the South Taranaki Bight, and for observations made on the Cook Strait ferries going between Wellington and Picton. The ship reports are irregular in space, time, and to a certain extent, quality. Wind data quality is adequate for our purposes, but the observations of sea conditions, which we also use, are only visual, and not so reliable (Laing, 1985). The amount of data in a ship file is typically very much less than in a land file. For example in the South Taranaki Ship File there are 2399 observations from a 22 year period, whereas Maui has 25 times as many readings from only eight years, and New Plymouth has 144 000 readings from 16 years. If we wish to examine a time series of data (which we will do later) the ship reports are quite restrictive, as the only time series would be from oil exploration rigs, which would at most provide rather short series. Only the coastal stations and Maui can provide adequate time series data. The situation is the same elsewhere around the New Zealand coast.

The wind roses in Fig. 1 illustrate the general wind flows in the area, hence the general directions in which spill material would move. In Cook Strait flows are predominantly either north or south due to the funnelling action of the Strait. When there is a regional southerly airflow over the country the southerlies flowing through Cook Strait swing more to the southeast in the South Taranaki Bight, and this is seen in both the offshore and coastal directions. In the western part of the region the predominant winds are from the westerly quadrant, and as these flow into Cook Strait they are diverted into northerlies. It is these predominant westerlies, and other regional effects, which give rise to the normal current flows in the area. If southerly-southeasterly winds persist for some time they can however counteract the normal current flows, and lead to flows northwestwards out of the South Taranaki Bight.

The wind roses in Fig. 1 are for all wind speeds. However for oil spill studies the higher wind speeds, leading to fast drift rates and rough seas, are of most concern. Fig. 2 shows the distribution of wind speeds for Cape Egmont and Maui compared to that from the South Taranaki Ship File. At Cape Egmont 26% of the winds are ≥ 17 kts, but in the Ship File it is 57% and at Maui 61%. This is partially because winds on land are normally less than over the sea, due to terrain and drag effects. For oil spill planning this means that wind speeds from coastal stations may under-estimate the speeds, therefore drift rates, well offshore. Data from off the South Island west coast indicates that the width of the transition zone between onland conditions and undisturbed offshore conditions is tens of kilometres wide. (Neale and Thompson, 1978; Bradford, 1983.) The drift rates in the coastal areas will probably be less than further offshore.

There is however a complicating factor in the data, as the Maui measurements are made at an elevation of 94 m above sea level, whereas Cape Egmont measurements are from 10 m above ground level. The height of 10 m is the standard for meteorological observations and modelling. Strictly speaking a 3.5% speed factor would apply for 10 m wind only. Maui wind speed would have to be reduced by 25-30% to make it equivalent to values at 10 m elevation.

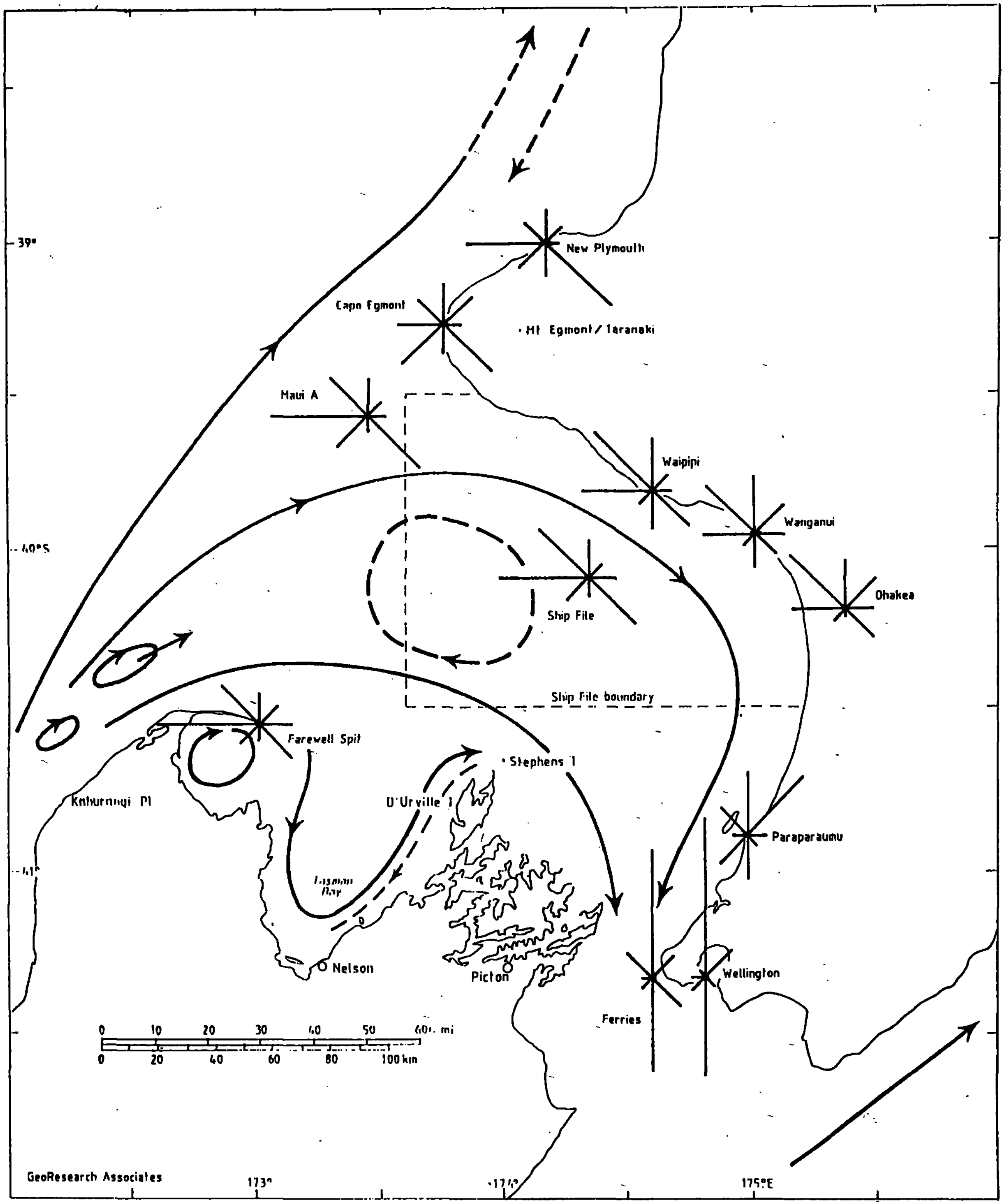

Fig. 1: Regional currents and wind direction statistics.

The Ship File data may also be biased high, as some, but not all, of its observations would come from drilling rigs with high anemometers. A breakdown of the Ship File data to indicate the location and source of all the observations would be helpful, but is not a standard Meteorological Service product. It would require access to the original data, which would be expensive in today's climate of cost recovery. In the case illustrated the Ship File data ties well with the Maui and coastal data, and one would probably quite confidently use it for predictive purposes, or would use Maui if a time series was needed. Since Ship File data is often the only source of information on conditions offshore around New Zealand a careful evaluation of it against other data is a part of any oil spill study.

Since the higher wind speeds are of concern it is appropriate to look at the statistics of wind direction for different speeds. Fig. 3 shows a comparison of Maui wind roses for winds

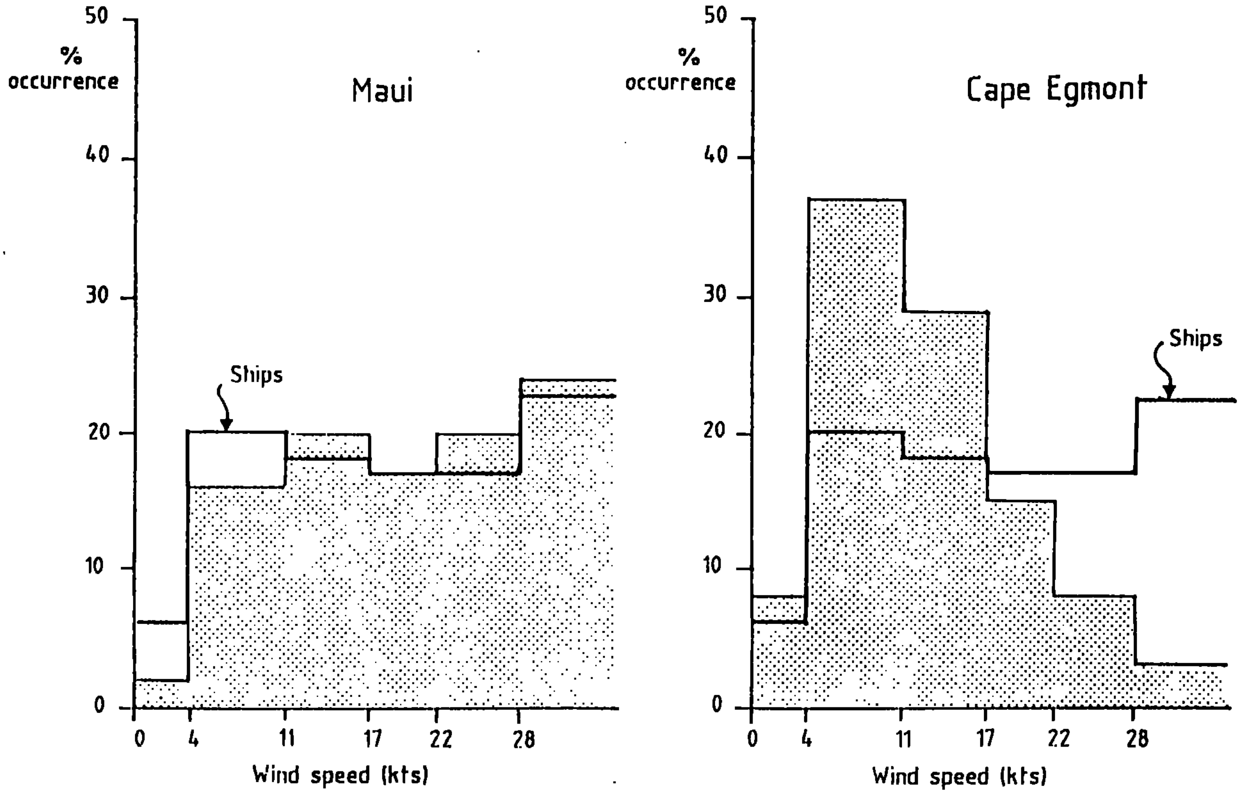

Fig. 2: Wind speed distributions, annual statistics. Ships data is for South Taranaki Ship File area shown in Fig. 1.

≥ 28 kts and for all speeds. A speed of 28 kts would be equivalent to about 20 kts at 10 m elevation, and occurs 24% of the time. The wind roses, which are also presented for the four standard seasons, show that for high winds it is the southeasterly quadrant that is dominant, whereas for all speeds the westerly quadrant is dominant. Near the coast the situation may be different. For example New Plymouth has a broadly similar distribution to Maui for all speeds, with westerlies predominant, but at speeds ≥ 17 kts westerlies (35%) dominate southeasterlies (18%), for the annual statistics.

An exploration programme would probably be for only a short period of the year, so annual statistics may not be so relevant. For longer term programmes consideration of how conditions vary during the year would also be important. Analyses therefore should be carried out for different seasons. The amount of data in a ship file then becomes a problem. For example in the South Taranaki File there are only 500 readings in winter which is rather small for good statistics. If a fair percentage of the readings happen to come from one or two drilling programmes the data may not represent a good long term or regional average. The long term coastal data then becomes more important. In many coastal areas of New Zealand seasonal effects are not extreme, and differences from one year to the next may be bigger than seasonal differences.

The statistics presented so far are average occurrences. For example at New Plymouth 13% of the winds are ≥ 17 kts. That is 13% of all the hourly observations. But in fact the wind is ≥ 17 kts on 53% of the days. Of course on many days the wind may be ≥ 17 kts for only one hour. For example in a sample of 60 days at New Plymouth in 1987, winds ≥ 17 kts made up 11% of the observations, but 53% i.e., 32 of the days. There were 51 separate periods with winds ≥ 17 kts; 50% lasted only one hour and 70% lasted three hours or less. For predicting movement of spilled material over periods of time, we need the speed and direction statistics for something longer than individual hours on individual days, but on the other hand, a straight percentage of total time has limitations also. One then seeks persistence statistics.

Persistence provides a measure of how common it is for wind to exceed certain thresholds for certain periods of time. Furthermore one would normally be interested in the persistence of winds from particular directions. For example at New Plymouth winds blowing from the sea towards the land at ≥ 17 kts, would persist for 48 hours or more less than 1% of the time, and would persist for 24 hours or more for about 2% of the time. For speeds ≥ 11 kts the percentages would increase to 3% and 7% respectively. You cannot meaningfully make the persistence direction sectors very small, say west ± 20°, because even steady wind may fluctuate 25° and that would break the run, leading to underestimates of practical duration. For persistence studies you need time series data without gaps in it, which rules out most ship file data, and all but the best coastal stations. For most areas of New Zealand weather systems cross the country at intervals of about three to seven days. This usually means a marked change in wind direction and/or speed every few days. Winds do not normally persist from any one direction for a long time in New Zealand, and even less so at steady high speeds.

The above discussions and illustrative statistics may present a picture of confusion; no data in key areas, insufficient numbers of observations, differences between wind speeds offshore and onshore, measurement elevation problems, variations with direction, seasonal effects, inter-annual dif-

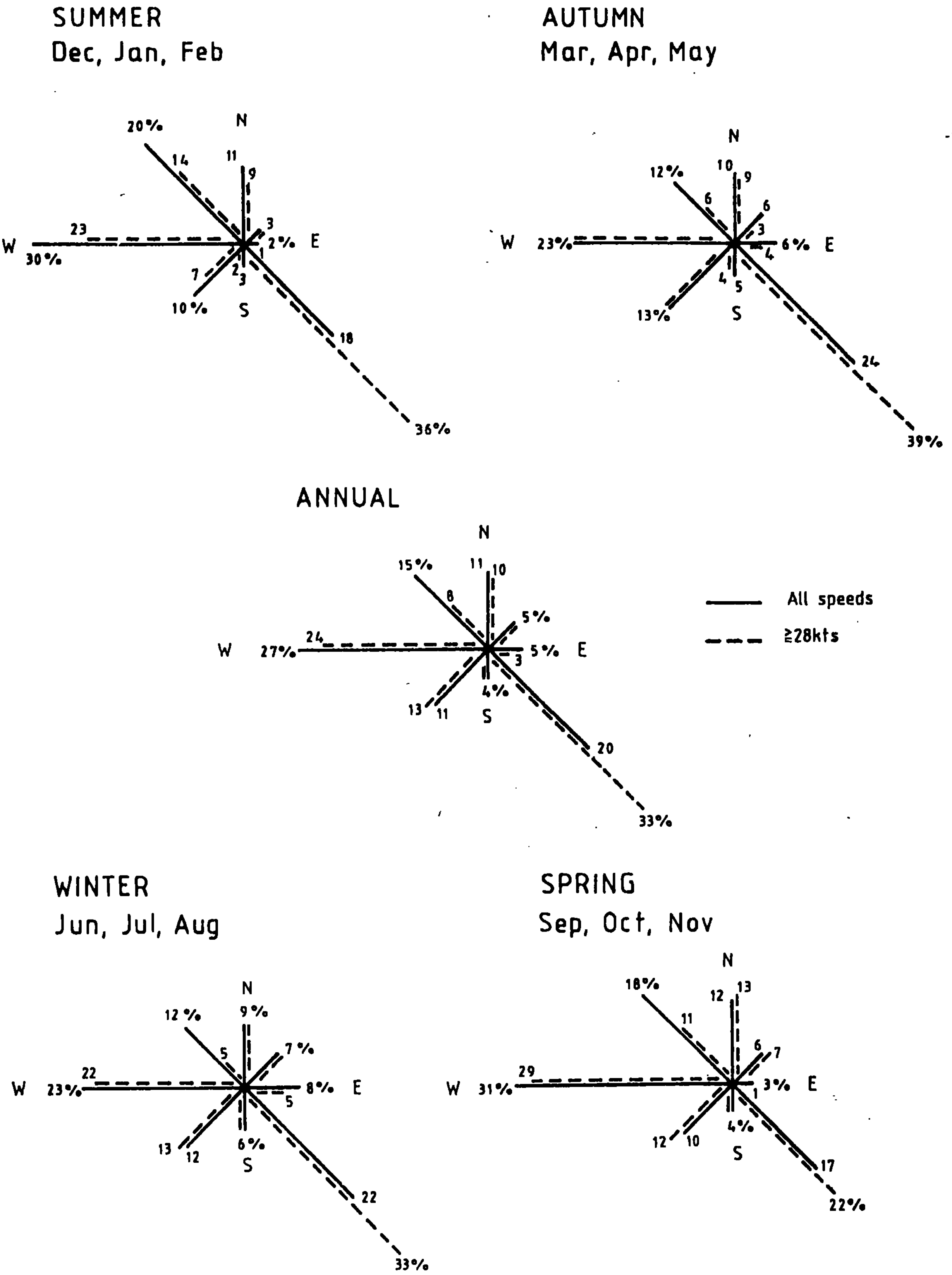

Fig. 3: Wind direction statistics for Maui A Platform, ten years data.

ferences, differences in speed with direction, uncertainties in persistence, average frequencies versus daily frequencies, the influence of currents, not to mention tidal effects and nearshore local variations. The fact is that weather and sea conditions are complex and variable. In practice for oil spill predictions simplifications have to be made, and predictions made for a few illustrative cases. Simplification doesn't negate the need to consider the detailed variations. One has to examine them to assess the likely range either side of the illustrative cases.

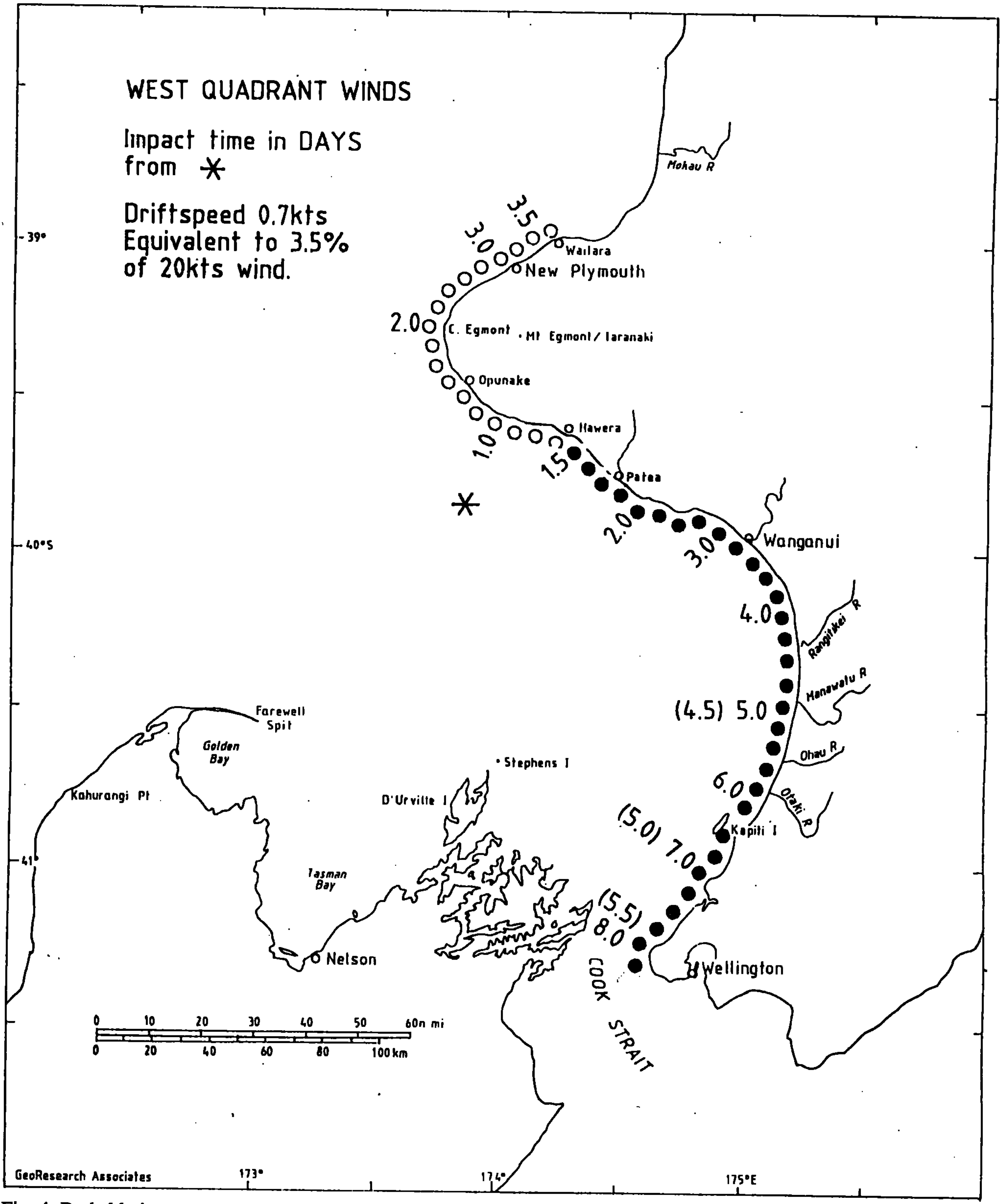

Fig. 4: Probable impact areas and times. Open circles for southwest winds, closed circles for southwest-west-northwest winds. Times in brackets for direct path.

Fig. 4 is an example of the type of long distance impact prediction which could be made. It is for a spill location not in anybody's licence block! The illustration is for westerly quadrant winds i.e. winds between southwest and northwest. These are the predominant winds in that area and the current patterns would be as in Fig. 1. The majority of impact would take place along the North Island coast east of the location, but with southwesterlies some material could go straight towards the coast and then be transported around the coast to the north. The impact times are given in days assuming a wind speed of 20 kts and a speed factor of 3.5%. Of course one doesn't expect that wind speed to persist for a long time, certainly not eight days. But the diagram does give an indication of the minimum times under those conditions. If the wind doesn't last for say four days it doesn't mean that there would never be impact at a four day location. If the wind shifts, for example to the south and southeast for two days, it merely means that material is moved back to the north or held up in the bight, and then when the wind shifts back to the west material originates from a point not at the initial spill location, but somewhere else. In the South Taranaki Bight there is sometimes a gyre in the middle of the Bight, and this may trap material well offshore. In a study such as this one would also provide diagrams of the coastal area close to the site at a higher resolution. Typically one would provide indications of the impact at four or six hourly intervals for the area affected out to about 48 hours.

By way of illustration for an area beyond the Taranaki oil patch, Fig. 5 illustrates a Northland example. The response to the recent Government block offer of Northland doesn't suggest that the origin for this incident is likely to be an exploration well! Tanker traffic into the Marsden Point Refinery would however be a not improbable source for an oil spill. Transport of oil, and other hazardous materials, has probably been a source of more spill incidents worldwide than exploration and production. The illustrated example could originate from a grounding at the Mokohinau Islands. For this area the most adverse conditions are strong northeasterly and these are not uncommon. Just recently Auckland Airport recorded northeasterlies that never went below 14 kts for 3.5 days and averaged 19 kts over that period. The winds offshore in the Hauraki Gulf probably would have averaged about 25 kts or more. In these conditions almost all oil spill containment or clean-up operations would be severely hampered. The extent of possible impact is fairly sobering, particularly when one considers the extent of coastline in the Hauraki Gulf, and the fishing and recreational usage of the area.

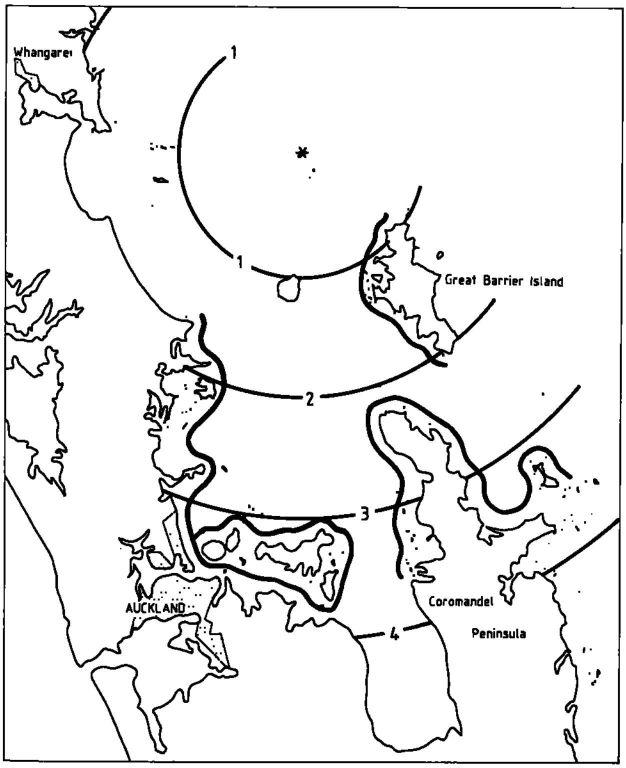

Fig. 5: Impact times, in days, from *, for a drift speed of 0.7 kts, corresponding to 3.5% of 20 kt wind. Heavy line shows possible impact within 3.5 days for northerly winds

The impact illustrations presented so far use single values of drift speed, one wind sector, and some consideration of the regional currents. Over periods of several days, however, the wind speed and direction obviously does not stay the same. To overcome this a vector average prediction method can be used. Fig. 6 illustrates the principle. A vector calculation is carried out using the wind speed and direction over a short interval, with a chosen drift speed factor, to predict the amount of movement over each time interval. This is then summed to predict the total movement over a chosen time. This is the approach that would probably be taken during the course of an actual spill. To predict the probability of impacts one can apply the calculation to historical data. You could do many runs, starting the calculation at chosen intervals. Each run is allowed to progress for a chosen length of time, say five or ten days. The result would be a collection of vectors, as illustrated in Fig. 6b. A statistical analysis of coastal impact can be carried out by examining the number of impacts, as a percentage of the total number of runs, for any chosen section of coast. That would give the probability of impact in that area. You could also examine the statistics of impact times by examining the travel times for those vectors that impact the selected section of coast. The effect of steady currents, or tidal currents could be applied as additional component vectors to the wind driven movement.

Useful application of the vector method requires a time series of wind data, and the data must be relevant to the area being studied. Data from coastal meteorological stations could be used, but if it was to be applied for far offshore then

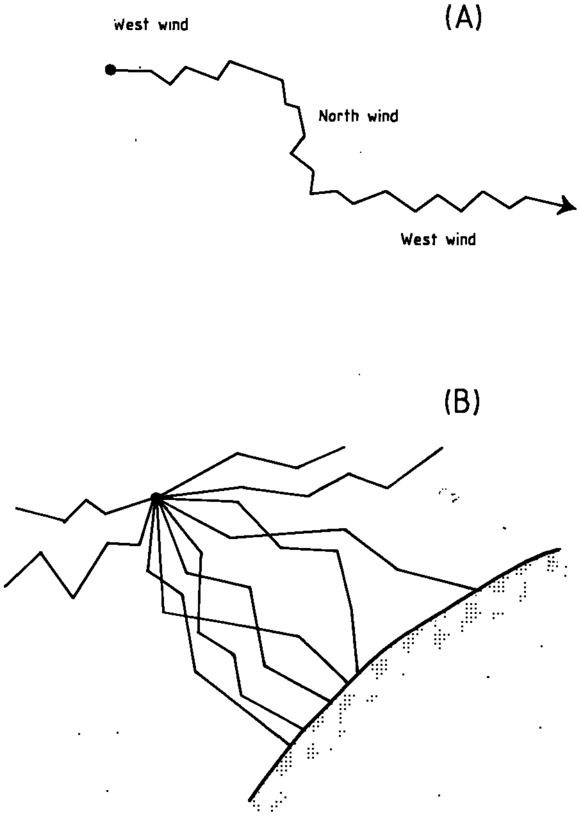

Fig. 6 (A): Schematic drift vectors determined from wind speed and direction at uniform intervals. (B): Schematic illustration of vectors from several data samples.

some transformation of speeds and or directions would probably have to be applied. Alternatively there are statistical methods for generating synthetic time series from average statistics of the wind. The basic calculation uses wind at a point. That is not likely to be valid if one was trying to predict over large distances, say from Cape Egmont to Cook Strait. To do that rigorously you would have to change the wind field progressively along the path. Then the client, or regulatory authority, will probably also ask to see the calculations for more than just a 3.5% factor, and how many years of data are they going to want to be run? The complexity of the vector model and the possible number of runs can quickly escalate. Nevertheless it is the most rigorous approach for prediction, and would be particularly helpful for predicting probability of impact and range of impact times for the close range impacts from any given location.

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