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COMPUTER MODEL TO SIMULATE MOVEMENT OF OIL AT SEA

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INTRODUCTION

The exploration for oil in the North Sea directs attention of both marine and terrestrial ecologists to the effects of oil spillage and oil contamination on organisms of their respective disciplines. Sea-birds and coastal birds n general, seem especially vulnerable and this study sought to examine the likely patterns of dispersion of oil so that some measure of the risks and possible dangers could be assessed. Although this study was geared for use in recording oil movement at sea the basic principles used in the model could well be used for the study of movement and dispersion generally.

All programming work has been carried out on a PDP 8/I computer in the time-sharing mode which was found to be ideal for development purposes.

GENERAL INTRODUCTION ON OIL MOVEMENT AT SEA

a) Movement

Knowledge of the way in which an oil slick moves on the surface of the sea is of value for predictive purposes. Prediction of the possible shore-line pollution, following an oil accident and of the probable "life" of the slick in the light of the current meteorological conditions and the magnitude of the spillage, are necessary.

Apart from spreading, an oil spill will move as a whole under the influence of tides, currents and wind and the efficiency of prediction depends on the amount and reliability of the data available.

A thin layer of oil on the open sea is affected very largely by the wind. The exact dependence is not known with high accuracy, but a movement of between 3-4 per cent of wind speed in the direction of the wind is a good working figure.

The oil which escaped from the 'Torrey Canyon' was driven primarily by the wind. Although, in some examples of the present work, tidal movements, apart from giving an appreciable to-and-fro movement of the oil, sometimes show a residual net movement remaining at the end of a tidal cycle. The net effect of the tidal stream on the movement of a slick which is not close inshore will be of little importance if measured over the period of a tidal cycle, but the tidal stream vector may be very important if the slick is within a few miles of land.

Some inaccuracies in the predicted movement can undoubtedly be attributed to the fact that wind data are normally taken at periodic observations by neighbouring meteorological stations, although this usually agrees well with wind speeds calculated from isobaric plots.

The movement of the Torrey Canyon oil was related fairly closely to the wind direction and speeds (subsequently predicted with reasonable success). Progress of other spillages round the coast have been accounted for with varying degrees of success, depending on the number of observations and variability of the wind.

b) Wind direction and speed

Studies of the Torrey Canyon spill off Land's End, yielded an empirical rule that the oil drifted in the direction of the surface wind (the wind at a height of 10 m above the sea surface) and at a calculated rate of 3.4 per cent of its velocity. This agrees well with the measurements made by Hughes (1956) on the determination of the relation between wind and sea-surface drift. He found that the drift was parallel to the surface winds, and that the velocity of drift was about 3.3 per cent of the velocity. Tomczak (1964) reported on a study made by the German Hydrographic Institute on the movement of oil released from the tanker Gerd Maersk in the North Sea. They found that slick drift was 4.3 per cent of the surface wind velocity. Many other studies have been made on this subject and they all revealed similar results. Varying from 2.5 to 4.3 per cent of the surface velocity.

c) Spreading of oil at sea

The basic mechanisms affecting the spreading of an oil slick over calm water are gravity, surface tension, viscosity, and inertia. Gravity constitutes the principal driving force during the early stages (roughly the first week for a 10,000 ton spill) and the surface tension spreads the slick thereafter.

The spreading of an oil slick can be considerably enhanced by turbulence of the underlying water.

d) Tidal and residual movement

Movement is not solely dependent on wind, tidal currents will also move the water surface and so move the oil, but in many cases these tidal movements are cyclic with only a small residual movement in any one direction. The first models considered only used wind data as sources of movement for the oil. Later models were developed for use inshore and these used tidal data for calculating movement.

It is hoped that some link will be able to be made between the first models (wind dependent) and the inshore models (wind and tide dependent). One method considered was to construct zones around particular areas. These zones would separate the wind dependent models from the tidal and wind models. It is planned that these zones will be constructed in a way in which probabilities can be attached. Hence one would be able to predict at what point the tidal currents will have an appreciable affect on the movement of oil near land given calm conditions.

e) Mechanisms by which oil is removed from surface

Oil that is spilled on the sea surface will form a relatively thin film on the surface. Part of the oil evaporates into the atmosphere, and part dissolves into the water. Oil can also be emulsified in the form of a suspension in the water column. The oil that is in solution or suspension can be expected to mix in the water column down to the thermocline. In addition some of the oil may precipitate from the water column and sink to the bottom. The oil on the surface, in the water column both in suspension and solution, and on the sea floor, is subject to biological degradation. Thus the five major mechanisms by which oil is removed from the surface of the sea are evaporation, solution emulsification, precipitation and decay. The rate at which oil changes phases is highly dependent on the type of oil; the weather conditions in particular the wind, temperature and the turbulence of the sea.

Evaporation of oil from a slick on the surface of the sea is most important in the early life of the slick. The rate at which the oil is evaporated from the slick is dependent on the temperature the type of oil, and the exposed area. The higher the temperature the higher is the evaporation rate. The important role of evaporation in removing oil from the sea was demonstrated in a study conducted during the 'Torrey Canyon' spill. The study indicated that 25 per cent of the oil by volume, was lost in the first few days after the spill (Smith, 1968).

COMPUTING TECHNIQUES USED

a) System used

All programs used in the models are written in the computer language BASIC. With the exception of later programs, the programs were run on the time-sharing system available on the DEC PDP/8/I computer. Later programs were run on the stand-alone system OS/8 BASIC which gave greater capacity and speed.

The time-sharing system (TSS/8) provides programs with the facilities for editing, assembling, compiling, debugging, loading, saving, calling and executing programs ON-LINE. This vastly improved the development of the programs in their initial stages. All programs use the facilities provided for two-dimensional array storage of data on magnetic disc and DEC-tape. It was found that capacity within the TSS/8 systems was limited and hence later programs were written for use on the OS/8 system. The OS/8 system provides storage of data within core and does not need to use other sources of storage as used with the TSS/8 programs. Its use is of course restricted.

b) Basic model

The basic principle of the model is to represent the movement of oil within a matrix structure. The movement of oil is recorded within the matrix by moving from block to block. The block being represented in the matrix by a single element. The basic model takes the approximate centre of the spill and represents this by a single matrix element.

Over a set period of time, vectors, giving wind distance (velocity of wind x time) and direction, are added geometrically to give resultant wind distances and direction. At this stage the dependence of the oil movement is brought into the model. Movement of between 3-4 per cent of the wind speed in the direction of the wind was found to be a good working figure.

c) Wind data structures

Four different sources of wind data have been used

1) Actual data for period for which spill is at sea (with a set time interval between movements). Hence using this data will give a time plotting of movement.

2) Data in the form of a probability distribution for particular periods in the year. Meteorological data in this form has made it possible to see if there is any set trend for particular areas for a given season or month. These distributions have been coupled with a random number generator so as to provide a means of sampling.

3) The third source of data is similar to the second but makes provision for forecasting particular trends in direction and wind speed. A set of distributions have been set up to record the day by day "chain of events", i.e. if the direction is north one day, what is the probability of it being north the next day? There are nine distributions in this system. Each giving the probability of the next event for that particular distribution: Suppose the starting direction was taken to be east; then the model would predict the next direction by sampling from the Distribution of Probabilities from east; supposing this was found to be north, then for the next direction it would sample from the north distribution.

4) The final source of data used is mentioned later and is concerned with building up a Probability matrix in which directions are related to speeds.

A study was also carried out on meteorological data used in the "chain of events" system. The meteorological data used was from the meteorological station at Dyce, near Aberdeen. Five different years were chosen at random and the distributions were constructed for a particular month in each of the years data. These distributions were first compiled with the use of a program which set up the data in the form of a file on magnetic disc. The results showed that within each year there were particular trends for each month. When a comparison of the five different years was made it could be seen that there was little agreement between the total year trends. It was concluded that for this type of system unless the data is very accurate then to go to such a level of accuracy does not produce a feasible system. Hence it was decided for the trial simulations it would be more feasible to use a single distribution for the direction sampling and not to break this down into lower level distributions, i.e. the "chain of events" system.

d) <u>Computer techniques used for sampling</u>

The initial models use a single Probability Distribution for sampling direction and speed of wind vectors. These basic sampling mechanisms are carried out within each program as a subroutine. A subroutine showing this basic sampling mechanism is shown in Table 1. (The sampling is taken from meteorological readings at four different times in the day; 0, 6, 12 18 respectively).

e) <u>Computation of the resultant vectors</u>

The segment of the program used for computing the resultant is given in Table 2. A and B are the components of direction, S1 is the wind speed, T is the time interval and X and Y are the components of its original position.

The new position is then found by taking the components of the new X and Y values. Later models which use wind and tidal current to estimate the next position have a much more complicated system. A brief summary of the computing techniques are shown in the program segment in Table 3, A and B are components of direction for wind, and C and D are the components for the tidal stream, all other variables are the same as the previous segment (Table 2).

SINGLE TRACE WIND DEPENDENT MODEL

The single trace model deals with the single path from a spill. The movement of the spill is recorded in the matrix in the manner shown in Fig. 1.

There are three main structures of this model:

a) Single path plot

This model just traces one path of movement through the matrix. When the plot is completed the results are printed. Fig. 2 shows a computer printout using this model.

b) Single path simulation

This model has also been adapted to carry out simulation runs. Hence obtain probabilities of oil hitting particular coastal sites.

Taking an example, for a particular spill, the model simulates the effect of the movement of oil close to shore using the wind direction and speed distributions for that particular region. After, say, 100 simulations of this supposed spill the matrix will be printed out in the form shown in Fig. 3, recording the numbers of hits (H), misses (M) and the spillage point as (*).

c) Single plot (complete trace)

From the complete trace of a particular slick. This model deals with the problem of the slick moving off the scale of the matrix. In the earlier model the movement was restricted to the scale of the matrix. Fig. 4 shows a diagram which demonstrates its use.

CONTINUOUS SPILL

This model deals with the problem of a continuous flow of oil from a ruptured pipeline or tanker. For a set interval of time a fixed rate of oil escapes. In the model this is represented similar to that of a patch of oil. The model works on the principle of a fixed quantity of oil in the form of a slick being released at set intervals of time. Fig. 5 shows how the oil is recorded, moving within the matrix. During the first time interval a slick moves west to B. Then in the next time interval the paths of two slicks are to be considered. First the slick at B and second the new slick formed at A. The model continues simulating the paths until the source of the oil is stopped or runs out. The matrix is then printed out in a similar form to the other models.

There are two main programs used in this system:

a) Simulation program - sampling from wind distributions

For a continuous flow of oil from a tanker or pipeline this program simulates the possible long term effects of the oil. Movement is calculated from wind speed and wind direction distributions for the region in the proximity of the spill.

b) Simulation program - using actual data for region

This program is similar to the above program, but instead of using probabilities for calculating directions and speed, uses actual data for calculating the movement of the slicks. This program was used initially for testing the workings of the model.

In later developments of the above mentioned programs, the capacity of storage had to be increased. Hence it was necessary to chain several programs together for reasons of capacity within the time-share system.

TRIAL SIMULATIONS USING SINGLE TRACE AND CONTINUOUS TRACE MODELS

Introduction

Having built up models for single spills and continuous seepage a test of the accuracy of the models by using recorded data from past oil disasters was made. a) First using the substantial data of the "Arrow" oil spill in Nova Scotia - good results were obtained with substantial agreement between the model and the actual events. The second area of trial work b) was to test the accuracy of the models using data from the North Sea region.

a) The Arrow spill in Nova Scotia

On 4 February 1970, amidst heavy rain and winds from the south-east, reportedly gusting up to 60 knots, the Liberian tanker "Arrow" ran aground on Cerbirus Rock in Chedabucto Bay Nova Scotia. She was under charter to Imperial Oil Limited and had been enroute to Nova Scotia Pulp Limited. It is apparent that the eight days immediately following the grounding were critical in determining the magnitude of the disaster.

Wind-driven surface currents played a major role in the distribution of oil about the Bay. On the 4 February winds were 30 knots from the SSE, and oil was transported onto the shores of Isle Madane and Janurin Island. Over the next several days the wind shifted to NW and then to north, causing contamination of the south shore in the vicinity of Canso. During this period it was observed that some oil was also carried out to sea, no doubt, under the influence of favourable tides and water circulation patterns. Trial simulations on the "Arrow" spill have been approached in three ways:

1) Using actual data for first eight days
2) Using Probability distributions obtained from monthly meteorological returns.
3) Plot of the path of oil which escaped from Chedabucto Bay.

Using actual data for Chedabucto Bay

At the time of the "Arrow" grounding, the only source of relevant wind data was the automatic station at Canso. An alternative source of wind information is the surface pressure charts over the ocean, from which the winds over Chedabucto Bay can be estimated through the use of the geostrophic approximation. An analysis of six-hourly and daily mean winds (Neu, 1970) showed that the Canso wind is generally about one half of the gradient wind over the ocean. Southerly winds over the open ocean become more westerly near shore.

Fig. 6 shows the reduced geostrophic wind calculated from the surface pressure charts for the period 3 February to 12 February, and Fig. 7 shows the recordings taken at the Canso Meteorological Station for the same period. It can be seen from Figs. 6 and 7 that the prevailing direction and mean speed agree favourably.

It was found from the results of the simulation that the simulated effect of the oil agreed well with the true distribution of oil.

Using probability distance from monthly meteorological data

The second method used for the Arrow disaster was to use the monthly wind (data) records from the Canso meteorological station. These were obtained from the monthly summaries published by the Meteorological Branch of the Department of Transport, Toronto. The data from these were used in the model in the form of a probability distribution used in the normal way.

The model was first run using a time interval of 12 hours and the results showed a very general distribution of oil which only vaguely resembled the true picture. It was decided that the time interval should be reduced to six hours. The results from this simulation showed a greatly improved picture of the distribution of oil which agreed fairly well with the first simulation.

From the two simulation runs it was concluded that there was quite reasonable agreement between model and observed results provided the wind direction and speed interval were short. From Fig. 8 it can be seen that there are certain danger areas where there was a high deposit of oil.

Plotting of path for oil that escaped from Bay

The "Arrow" went aground on 4 February, and immediately started to leak oil, some of this (Slick A) moved out to a. This was also suggested in the earlier simulations.

Using the complete path model with the data obtained from the Canso Meteorological station it was found that the path was in good agreement in the vicinity of Canso. But as the slick moved out into the ocean the weather conditions taken at Canso did not give a true picture of the actual movement. To obtain a more accurate prediction of the movement more meteorological data is needed from a larger range.

b) Trial runs in Scotland

A series of trial runs were also carried out on the North East Region of Scotland.

A ten year record of wind speeds and direction was obtained from a meteorological station near the coast at Fettercairn. With this data the wind speed and direction probability distribution were created. The trials were set up in two main ways:

1) Taking possible spills at random in the area to be considered (Fettercairn area).
2) Model set up for the area round Cruden Bay (site at which pipeline comes ashore).

Fettercairn area

The area to be considered was first mapped into the matrix structure. Three simulations were then run, each at different starting positions. From the results it was possible to make a rough prediction of which areas have a high probability of oil damage in the case of a disaster.

Cruden Bay area

Using the data from the meteorological station used in the Fettercain area. The matrix was increased in size to facilitate the area around Aberdeen - the approximate route was mapped into the matrix.

The simulation was then carried out along set intervals of the proposed pipeline.

Each result of a simulation was then plotted on a "master" plan of the area with the use of transparencies. The idea was to give a rough picture of the likelihood of oil hitting particular sites from a particular break in the pipeline. These models were not considered very helpful because of the great difficulty of deciding on the likely spillage points (Sir P. Kent (pers. comm.) was of the opinion that the most likely point of spillage is at the well head.) This is a long way out to sea in the case of the Forties field and the danger of shore pollution in Scotland correspondingly low.

INSHORE COMPUTER MODEL

a) Introduction

1) Wind and tidal simulation model

As found earlier in the project, the net effect of the tidal stream on the movement of an oil slick which is not close inshore will be of little importance if measured over the period of a tidal cycle. In an estuary, oil slick motion predictions depend on the relationships relating the drifting motion to tidal currents and wind effects and the spreading motion to oil properties.

It was thus decided that a model should be developed to trace movements of oil close inshore, e.g. an estuary. Hence for this type of model a number of new variables were introduced. The movement would now have to be calculated by taking the resultant of the tidal stream vector and the wind component vector. The basic model works on the same principle as earlier models, that is of recording movement within a matrix structure. It was found that with the tidal streams being reasonably fixed throughout the tidal cycle, that the variability of movement is very dependent on the starting position of the spill and its starting time in the tidal cycle.

2) Tidal data

It is commonly assumed that oil drift will occur at the same rate as the drift of water at the surface of the sea. In shallow waters, surface flow due to tides, can be reasonably high in velocity; much greater than that produced on the open ocean. Tidal amplitude tables and tidal current tables are usually available for most coasts.

The data used within the model for predicting tidal stream direction and speed was extracted from Admiralty charts for the respective area being studied. The table below shows a typical set of data used.

Tidal streams referred to H.W. at Leith for position 56°18'.5N 2°32'.0W

Hours	Direction	Sp rate (Kn)	Np rate (Kn)
6 before HW	347°	.5	.3
5 before HW	325°	.2	.1
4 before HW	188°	.3	.1
3 before HW	173°	.6	.2
2 before HW	167°	.8	.4
1 before HW	157°	.9	.5
HW	148°	.8	.5
1 after HW	134°	.6	.4
2 after HW	062°	.3	.2
3 after HW	016°	.7	.3
4 after HW	003°	1.2	.5
5 after HW	359°	1.1	.5
6 after HW	353°	.7	.4

For simplification purposes the tidal speed was estimated from the mean of the spring and neap tides. It will also be appreciated that due to the limited number of tidal readings available for an area that the number within the matrix is limited. Hence boundaries have been built into the matrix to separate different tidal readings for particular areas.

3) Wind data

As for the tidal data, the wind data were compiled in a form which was relative to daily time intervals. With the help of data from the Meteorological Office, monthly returns readings, a system was devised for sampling wind readings. Initially to keep within the capacity of the computer and hence greater speed for sampling, the swindd sampling system was reduced to six hour intervals. Table 4 shows a sample set of meteorological data.

Knowing the time of spill the program was constructed in a way in which the respective wind speed and direction were sampled from a distribution of within this time interval. As the project progressed a more accurate system was devised. A system in which the direction distributions were directly linked to particular speeds. Table 5 shows a typical set of data used.

b) Brief description of models

1) Model 1 - Basic model for use on TSS/8 system

The model was set up in a similar way to that of the previous "Land Hit recording models". Movement was calculated by taking the resultant of the tide and wind effect and recording within the usual matrix structure. The main computer program was designed so as to be used for any estuary or close inshore region.

As mentioned earlier there is an increased number of variables used in this program. Hence the program has been so designed so that the operator inputs the values of the variables at the beginning of the program. These values consist of the following information:

1. The area to be studied (i.e. land bearings)
2. Spillage position of the oil spill
3. Tidal data to be used (i.e. files containing this data)
4. Time of spill in tidal cycle
5. Wind data to be used (i.e. files containing this data)
6. Time interval between movements
7. Number of simulation runs required
8. Printout of results spacing intervals
9. Storage of results

This information then forms the basis for the key variables used in the program. The program then carries out the set number of simulation runs and stores the results within the matrix. These results are recorded in the form of the number of hits to certain land sites relative to starting time and starting position of the spill. With these results "Danger Risk Areas" can be calculated relative to the time in the tidal cycle.

Flow chart of the "OIL TID" system (Figs. 9a, b).

2) <u>Model 2 - for use on larger system (OS/8 Basic)</u>

After development of the first estuary model it was decided that greater detail regarding movement within the estuary should be included. With the previous model the final results only record where the oil ended up. Hence the second model was devised to record actual movement within the estuary, giving information regarding each area (i.e. each square mile). This information would then help to locate where high risk areas are within the estuary. This sort of information could then be coupled with information about the area (i.e. birds present, marine features, other species present, etc.). A project concerned with this type of work is considered later, in respect of Eider ducks in the Tay Estuary.

With this increased capacity required for storage of information the simulation time of each run was greatly increased. Hence programs were altered for use on a larger system (OS/8 BASIC system). This meant that without too much extra work in converting the programs from the time-sharing system (TSS/8) to the stand-alone system (OS/8) the speed was greatly increased and also the storage capacity was enlarged.

The basic principle of this model is similar to that of the first model. Each element of the matrix represents a unit square of one mile. Within each element of the matrix is recorded the time at which the oil arrived relative to the starting time of the spill. Fig. 10 shows a diagram of this system.

3) Model 3 - Bird hit model (TSS/8 version)

The third model of the "Bird Hit Program" was developed for estimating the number of birds hit in an estuary for a possible oil spillage. This model works on the principle mentioned earlier, that of coupling bird distributions within the estuary with oil spill movement. In the earlier models it was found that the actual movement of oil within an estuary is very dependent on the start time of the spill in the tidal cycle. Hence it was decided that the bird data used should be in the form of distributions of birds relative to different times in the tidal cycle.

The program was written similar to the previous programs. For each simulation run whenever oil made contact with a flock of birds, the time and place of contact is recorded within a separate file. This file is then processed later by an additional program which produces the results. The results are in the form of the mean number of hits for the number of simulation runs completed and also details of where high hits have occurred relative to the time in the tidal cycle. A similar program was also written for this system for use with decreasing numbers of birds. In this system a more realistic picture of the total number affected is found. The first program does not take into account that some birds will be moving from one area to another, hence affecting the final total. In the "Decreasing Numbers" program, if the oil hits a raft of birds, then it is taken that all these birds are affected and hence will not move on. The next raft affected by the oil will have its total population cut by a proportion of the birds hit in the first hit.

TAY ESTUARY STUDY

a) Introduction

1) The Tay Estuary

After completion of the initial programming work for the Estuary model, a test area was sought for trial simulation purposes. The area chosen was the Tay Estuary, having a compact area and good source of wind and tidal data.

Oil pollution in the Tay has occurred for many years and cannot be eliminated for the future. There are several records of oil pollution incidents in the Tay about which advice concerning oil problems has been given by the Tay River Purification Board. In June 1963, oil pollution occurred as a result of a pipeline fracture between a tanker and the refinery. In April 1967 widespread oil pollution occurred following a mishap in a refinery. On Thursday, 29 February 1968 a crack developed in the hull of the tanker "Tank Duchess" as she lay in the Tay Estuary preparatory to discharging her cargo. As a result, at least 87 tons of oil were lost in the Estuary. Consequently at least 1300 birds were killed. The oil remained in the Estuary for some time, moving about the Estuary with the tide.

In the winter of 1970 some 12,856 birds, mostly oiled, were recorded dead or dying on beaches north-east Britain as a result of a possible discharge of oil off the east coast, probably late in December. A later discharge in the mouth of the Tay on 20 January affected a large number of birds in the region.

Fig. 11 shows the area studied.

2) Wind data

The Tayside region has a relatively high frequency of gales and strong winds when compared with other parts of the British Isles. Two locations in the region, Leuchars meteorological station and the Bell Rock lighthouse have detailed wind records available for a reasonably long period of years. The valley of the River Eden, which runs parallel with the Firth of Tay, exerts a chanelling effect on westerly winds. Twenty eight per cent of all winds at Leuchars blow seawards down the Eden valley from directions between 230° and 250°, south-west and west-south-west respectively. For initial trial simulations using the first model wind data was taken from several monthly return summaries at random. Later more accurate data was compiled with the help of data from a Meteorological Office publication (Climatological Memo 65, The Climate of the Tayside Region of Scotland).

3) Tidal data

Data used in the form described earlier. Within the Tay several tidal streams readings are available for different positions about the Estuary. These were obtained from the Admiralty charts of the Tay Estuary region.

b) Results

1) Results of using Model 1

The first set of simulations performed simulated the effect of a possible spill entering the estuary in the main shipping entry channel. Initially, the time interval used for this system was three hours and the number of simulations chosen was 100. Hence the starting times in the tidal cycle were 3, 6, 9, 12 respectively, from the entry position (6 being High Water).

As might be expected, the results showed a cyclic pattern of distribution of oil about the estuary. From the simulations started before high tide, it could be seen that the main distributions of oil were in the west of the area considered. The main areas affected being between Tayport and Broughty Ferry and also the approaches to Dundee. Simulations started at high tide revealed distributions of oil north of the region in the areas between Broughty Ferry and Monifieth and also high deposits around Barry Sands and Buddon Ness. Simulations started after the turn of the tide showed that most oil was carried out to sea with the exception of some quantities being carried around Buddon Ness.

For a more detailed distribution of possible hits to land, the time interval was reduced to one hour intervals. This showed a much more detailed distribution of oil with more information on key areas at risk. As for the simulations mentioned earlier, these simulations showed high risk areas around Tayport and Broughty Ferry and again the entrance channel to Dundee. Agreement was also good for the region around Barry Sands and Buddon Ness.

Although more accurate data is required for this region, the results of the possible distributions of oil agree well with the distribution of oil released during the Tank Duchess spillage. It was reported after the spillage that oil was carried into the estuary by the incoming tide. Heavy pollution was reported from the area between Newport and Tayport and moderately heavy pollution was reported around Broughty Ferry. On the northern shores the deposits were not as heavy, being mainly concentrated at Douglas Terrace with traces at high tide mark at Monifieth and Carnoustie.

It will be appreciated that a true comparison of the results of the simulations with the true results at the Tank Duchess spill cannot be made with any accuracy due to the difference in points of origin of spilled oil.

2) <u>Results of using Model 2</u>

As mentioned earlier, this system uses a larger system (OS/8 BASIC). With this increased capacity the system was able to produce a more detailed picture of movement within the estuary. The simulations were carried out in a manner similar to the previous simulations, using Model 1. For greater accuracy the number of simulations was increased to 1000 while the time interval remained at one hour intervals.

From the final results it was noted that the distribution of oil around the land sites was similar to the results of Model 1. Using Model 2 results it was possible to break down each square mile unit into distributions showing arrival times of a possible oil slick relative to a starting position and a starting time in the tidal cycle. These arrival times distributions were then mapped onto a large map of the area and high risk areas were colour coded for easy viewing.

From this map it was then possible to locate for the given spillage the probability of oil reaching different areas in the estuary and at what time they were likely to arrive relative to the time of release. Fig. 10 shows an abbreviated form of the map showing low, medium, high and very high risk areas likely to be polluted. As was expected the main areas for pollution for a spill released before high tide were in the main entry channel to the estuary, that is the areas west of the starting positions.

3) <u>Results of using Model 3</u>

For experimental purposes the Eider duck was chosen for work on the Tay. With the kind help of Dr. H. Milne of Aberdeen University, maps were drawn showing the main distribution of Eider ducks. The Tay Estuary is famous for holding the largest winter concentrations of Eiders in Great Britain. This is probably between 10,000 and 20,000 birds, the population varies from time to time. The Eider flocks that winter in the Tay Estuary are shown to carry out a tide-dependent daily movement cycle and it is due to this fact that the data was so compiled. For each two hour interval in the tidal cycle a distribution of Eiders in the Estuary was calculated. From these distributions a picture was obtained of the total movement of Eiders about the estuary, see Fig. 12, showing these distributions.

The simulations were carried out from three different positions in the main tidal entry channel. For each set of simulations for a given starting position the results gave information on the mean number hit for that particular starting position and at what time in the tidal cycle the Eiders were most vulnerable. Details were also compiled on which areas were most vulnerable to oil pollution. As previously mentioned these results were stored on separate files. These files were then later processed with the help of a program which was written to summarise the results, see Fig. 13. Results.

It can be seen from Fig. 13 that the printout gives results for each area for the three possible positions of the spills. Equating the total number of Eiders present in the area with the number of times oil has entered the area give an approximation to the high risk areas. From the printout it can be seen that Eiders are especially vulnerable in the following areas:

Area 23 - Area east of Broughty Ferry
Area 24 - Area east of Broughty Ferry
Area 25 - Area east of Broughty Ferry
Area 28 - Area south of Barry Sands
Area 29 - Area west of Buddon Ness

Fig. 11 shows positions of these areas

CONCLUSIONS

From the results obtained from the models so far, a number of interesting facts have arisen. An attempt has been made to apply the transport laws to various oil spills, with the aim of seeing whether a reasonable prediction of oil slick movement could be made after the fact. I have found that the primary limitation on the success of such an attempt generally is the lack of complete sets of oil movement and of environmental data. More complete data, together with additional interpretation of available data, are needed for a definite conclusion to be reached on the accuracy of a particular model for oil slick prediction. It should also be noted that at this stage the aim was more to check the workings of the models than to investigate any given area of a spill.

The results of the inshore model showed that the distribution of oil about an inshore area is very dependent on the time of the spillage in the tidal cycle. It is also suggested that a more accurate prediction is possible if the spillage point is fixed. The unloading area for tankers is an ideal example of such an area. From this position simulations could be run at different times in the tidal cycle and hence giving different distributions of oil. Weight could also be given to the different weather conditions and state of the sea. Thus a picture could be obtained of which areas could be affected by oil pollution.

An extensive study was made of the various methods of predicting wind direction and speed. It was concluded from these studies that a wind data system is best constructed in a form which is not too complex. From the tests carried out on the structure of data for Dyce it was found that to break distributions of particular directions into further distributions makes the system no more efficient for prediction purposes. A system which involves sampling from a single distribution for speed and likewise for direction gives good accuracy for the purposes of this study. Improvements on this could be made if the speed and direction distributions were related (i.e. Table 5).

The Tay Estuary study demonstrated how the model can be adapted to finding the possible dangers to particular species in an estuary. This study revealed that the extent of damage in the Tay Estuary is determined more by the time at which a spill enters the estuary than the position it enters. Also that the distribution of oil about the estuary was more accurate when the time step size between movements was reduced.

The object of this project was to use computer techniques to simulate the movement of oil at sea. This has been achieved using wind (direction and speed) and tidal data. In the initial stages of the project certain variables concerned with movement were eliminated for simplicity. The models at their present stages could easily be adapted to facilitate extra variables. One such variable is spreading. It is hoped that the combination of oil slick spreading theory with current and wind surface movement will help to predict the location and size of a slick as a function of time.

A further study which is expected to be made in the course of future studies is using the models to build up "zones" for particular areas. These "zones" would be constructed so that they could be used in two ways. First a tidal dependent zone. As mentioned earlier oil slick prediction for slicks that are not close to shore is determined by wind alone with the tidal cycle. Inshore prediction is determined by calculating the resultant of the wind and tidal effects. Hence the object of this "zone" system is to determine at what point the slick approaching a coastline is likely to be substantially affected by the tidal effect and consequently hit the coastline. The second use of these "zones" would be for the fixed point source of possible oil pollution (i.e. an unloading area for tankers). These zones would be constructed so as to provide a picture of the probable extent of damage to surrounding areas. With these zone systems it is hoped that an interactive system can be developed so as to link oil movements with possible species movement (i.e. bird movement and flight paths) and hence provide a means of evaluating the threat to particular species in a given area.

ACKNOWLEDGEMENTS

I am particularly grateful to Mr. A. J. P. Gore who supervised the project, Dr. W. R. P. Bourne for his useful help in the initial stages of developing the models and also to Dr. H. Milne for providing the information on Eider's in the Tay.

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Table 1.

```
10   DIM   W(12, 3), P1(4)
20   REM   T1 = TIME, T3 = KEY TO SAMPLING DISTRIBUTION
 .     .      .
 .     .      .
 .     .      .
120  IF T1  =6 GOTO 160       " DETERMINE TIME IN TIDAL CYCLE
130  IF T1  =12 GOTO 161
140  IF T1  =18 GOTO 162
150  IF T1  =24 GOTO 163
160  T3 = 0 GOTO 170          " FIX VARIABLE (T3) TO APPROPRIATE ARRAY ELEMENT
161  T3 = 1 GOTO 170
162  T3 = 2 GOTO 170
163  T3 = 3
170  For I = 0 TO 7           " LOOP Ø TO 7
180  W2 = W2 + W(I, T3)       " SUMMING PROBABILITIES
190  NEXT I                   " RETURN TO LOOP
200  Z1 = RND(1)              " GENERATE RANDOM NUMBER
210  FOR J = 0 TO 7           " LOOP Ø TO 7
220  W3 = W3 + W(J, T3)/W2    " CALCULATE CUMULATIVE FREQUENCIES
230  IF Z1 W3 GOTO 250        " IF CUMULATIVE FREQUENCIES GREATER THAN RANDOM NUMBER GOTO LINE 250
240  NEXT J                   " RETURN TO LOOP
250  M = W3                   " M = DIRECTION CODE
255  FOR I1 = 8 TO 12         " LOOP 8 TO 12
260  S2 = S2 + W(I1, T3)      " SUM PROBABILITIES
270  NEXT I1                  " RETURN LOOP
280  ZZ = RND(1)              " GENERATE RANDOM NUMBER
290  FOR J1 = 8 TO 12         " LOOP 8 TO 12
300  S3 = S3 + W(J1,T3)/S2    " CALCULATE CUMULATIVE FREQUENCIES
310  S1 = P1 (J1-8)           " S1 = SPEED (OBTAINED FROM P1 ARRAY)
320  IF Z2  S3 GOTO 340       " IF CUMULATIVE FREQUENCIES GREATER THAN RANDOM NUMBER GOTO 340
330  NEXT J1                  " RETURN TO LOOP
340
 .     .
 .     .
 .     .
 .     .
```

Table 2.

```
.      .
.      .
.      .
200    D1 =  SQR ((A**2) + (B**2))                           " RESULTANT VECTOR SUM OF SQUARES
220    X1 =  INT (((S1*T*ABS(A))/D1) + (ABS(A)*.5))          " CALCULATION OF NEW
240    Y1 =  INT (((S1*T*ABS(B))/D1) + (ABS(B)*.5))            VERTICAL AND HORIZONTAL
250    X  =  X +(A*X1)                                         COMPONENTS
260    Y  =  Y + (B*Y1)
.      .
.      .
.      .
.      .
.      .
```

Table 3.

```
 .     .
 .     .
 .     .
300   D1 = SQR ((A**2) + (B**2))                              "  CALCULATION
310   X1 = INT (((S1*T*ABS(A))/D1) + (ABS(A)*.5))                 OF WIND
320   Y1 = INT (((S1*T*ABS(B))/D1) + (ABS(B)*.5))                 COMPONENTS
330   D2 = SQR ((C**2) + (D**2))                              "  CALCULATION
340   W1 = INT (((S2*T*ABS(C))/D2) + (ABS(C)*.5))                 OF TIDAL
350   Z1 = INT (((S2*T*ABS(D))/D2) + (ABS(D)*.5))                 COMPONENTS
360   U1 = (A*X1) + (C*W1)                                    "  COMBINE WIND AND
370   V1 = (B*Y1) + (D*Z1)                                        TIDAL VECTORS
380   IF (ABS(U1) + ABS(V1)) = 0 GOTO 100                     "  RETURN IF NO MOVEMENT
390   X  =  X + U1  Y = Y + V1                                "  UNDATE X AND Y
400   R1 =  ABS(X-C1)  R = ABS(Y-C2)                          "  R1 = VERTICAL COMPONENT TRAVELLED R2 = HORIZONTAL COMPONENT
                                                                      TRAVELLED
410   IF R1  R2  GOTO 430                                     "  DETERMINE IF R1  R2
420   A2 = R2  Z = 1  GOTO 440                                "  SET A2 = R2 Z = 1
430   A2 = R1  Z = 0                                          "  SET A2 = R1 Z = 0
440   FOR G3 = 0 TO INT (A2)                                  " LOOP FROM 0 TO INT (A2)
450   IF Z = 0 GOTO 530                                       " LINES 450 TO 570
460   B2 = INT (C2 +((G 3)*((V1)/ABS(V1))))                      TRACE THE SINGLE
470   IF R1 = 0 GOTO 510                                         PATH, MOVING BLOCK
480   B1 = INT (C1 + ((R1/R2)*G3*(U1/ABS(U1))))                  BY BLOCK
490   GOTO 580                                                   B1 and B2
510   B1 = INT (C1)                                              ARE THE INTERMEDIATE
520   GOTO 580                                                   POSITIONS TRACED
530   B1 = INT (C1 + (G3*(U1/ABS(U1))))                          BETWEEN THE OLD
540   IF R2 = 0 GOTO 570                                         AND NEW POSITION
550   B2 = INT (C2 + ((R2/R1)*G3*(V1/ABS(V1))))                  OF THE SPILL
560   GOTO 580
570   B2 = INT (C2)
580
 .     .
 .     .
 .     .
 .     .
 .     .
```

Table 4.

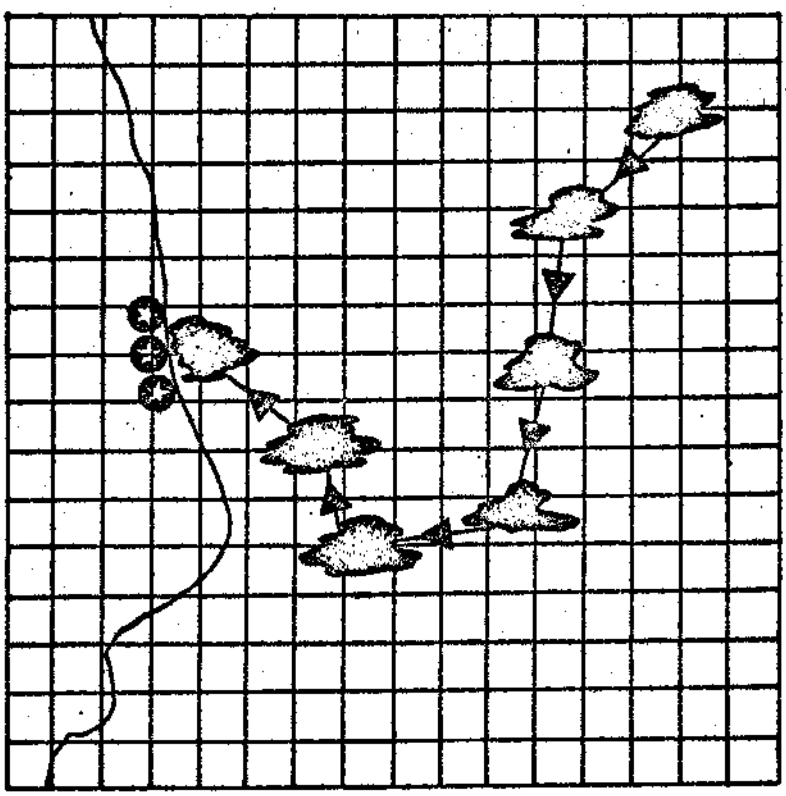
Time	Directions									Speeds			
	N	NE	E	SE	S	SW	W	NW	Calm	1-10	11-21	25-33	34
6 hours	13	36	38	15	6	98	99	14	46	173	128	18	0
12 hours	17	27	65	17	14	83	90	21	31	149	164	21	0
18 hours	17	22	102	29	18	59	86	25	7	115	203	39	1
24 hours	24	41	49	22	13	75	88	14	39	171	134	20	1

Table 5.

	Directions								
	N	NE	E	SE	S	SW	W	NW	All dir.
● mph	.35	.35	.35	.35	.35	.35	.35	.35	2.8%
1- 3 mph	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	8.5%
4- 7 mph	1.4	1.5	1.85	1.15	.9	3.9	2.8	1.1	14.6%
8-12 mph	2.1	2.8	4	1.9	1.7	10.3	3.85	.65	28.3%
13-18 mph	1.7	3.3	3.75	1.85	2.05	10.65	4.3	1.7	29.3%
19-24 mph	.35	1.05	1.2	.6	.7	4.1	1.65	.55	10.2%
25-31 mph	.1	.4	.65	.35	.4	2.1	.8	.2	5.0%
32-38 mph	0	0	.15	.05	.1	.5	.25	.05	1.1%
39-46 mph	0	0	0	0	0	.1	.1	0	2%
Totals	7.07	10.45	13.02	7.32	8.27	33.07	15.17	6.67	100%

FIG 1.

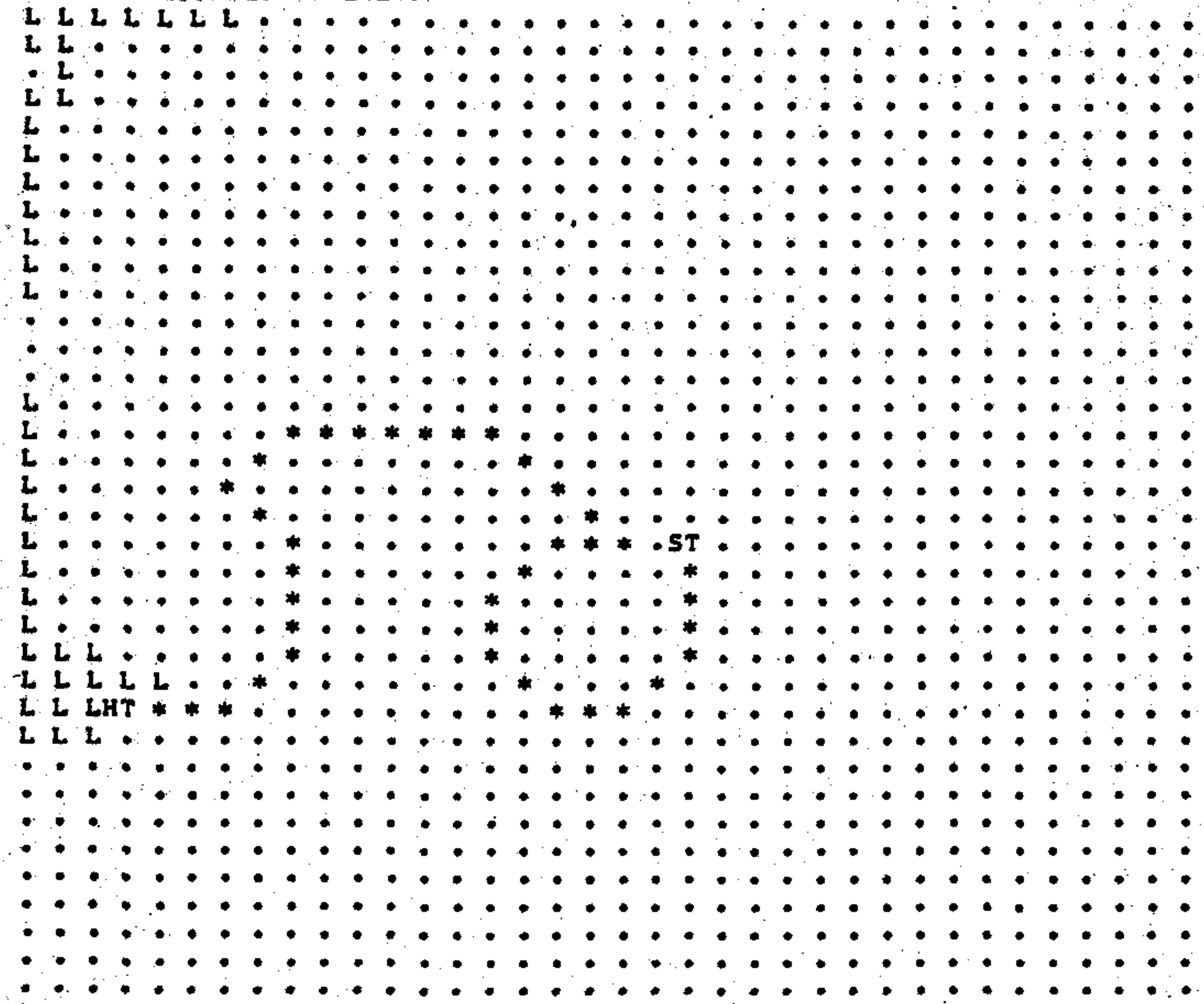
RECORDING MOVEMENT WITHIN MATRIX



L	L	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
L	L	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
L	L	L	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	1	∅	∅
L	L	L	∅	∅	∅	∅	∅	∅	∅	∅	∅	1	∅	∅	∅
L	L	L	∅	∅	∅	∅	∅	∅	∅	∅	2	∅	∅	∅	∅
L	L	L	∅	∅	∅	∅	∅	∅	∅	∅	2	∅	∅	∅	∅
L	L	L	7	∅	∅	∅	∅	∅	∅	∅	2	∅	∅	∅	∅
L	L	L	∅	6	∅	∅	∅	∅	∅	∅	3	∅	∅	∅	∅
L	L	L	L	∅	6	∅	∅	∅	∅	3	∅	∅	∅	∅	∅
L	L	L	L	∅	∅	5	∅	∅	∅	3	∅	∅	∅	∅	∅
L	L	L	L	L	∅	5	5	4	4	4	∅	∅	∅	∅	∅
L	L	L	L	∅	∅	∅	5	∅	∅	∅	∅	∅	∅	∅	∅
L	L	L	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
L	L	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
L	L	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
L	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅

FIG 2.

```
OIL HITTING AT 'HT'
 '*' IS RECORDED MOVEMENT
```




```
READY
```

FIG 3.

```
NEW OR OLD--OL
OLD PROGRAM NAME--DISPLA

READY
```

RUN

```
MODEL AFTER      100 RUNS
```

L	L	L	H 16	0	M 13	M 10	M 4	0	0
L	L	L	H 3	0	0	0	0	0	M 1
L	L	H 12	0	0	*	0	0	0	M 12
L	L	0	0	0	0	0	0	0	0
L	L	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	M 3
H 7	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	M 1	0	0	M 2	M 12	M 3	0	M 1	0

FIG 4.

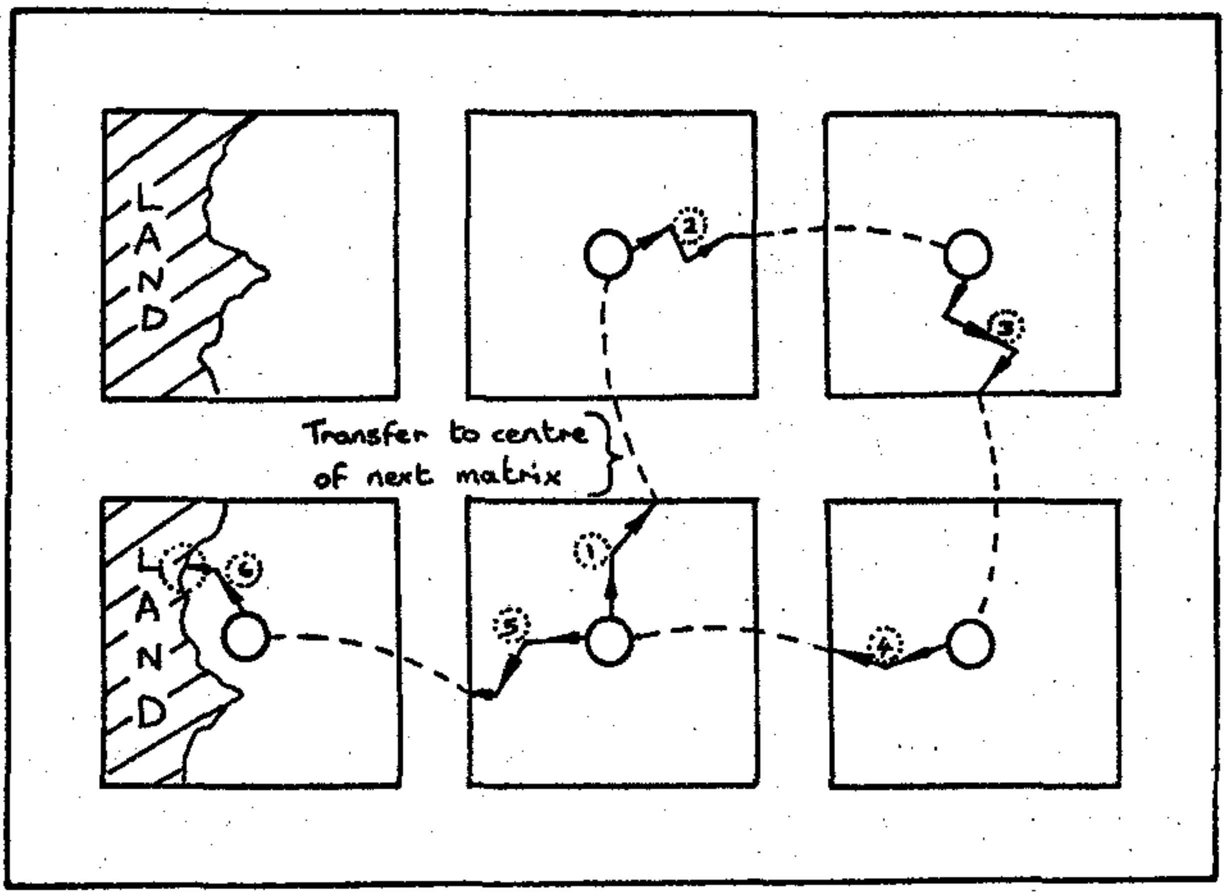

LAND
Transfer to centre of next matrix
LAND

FIG 5.

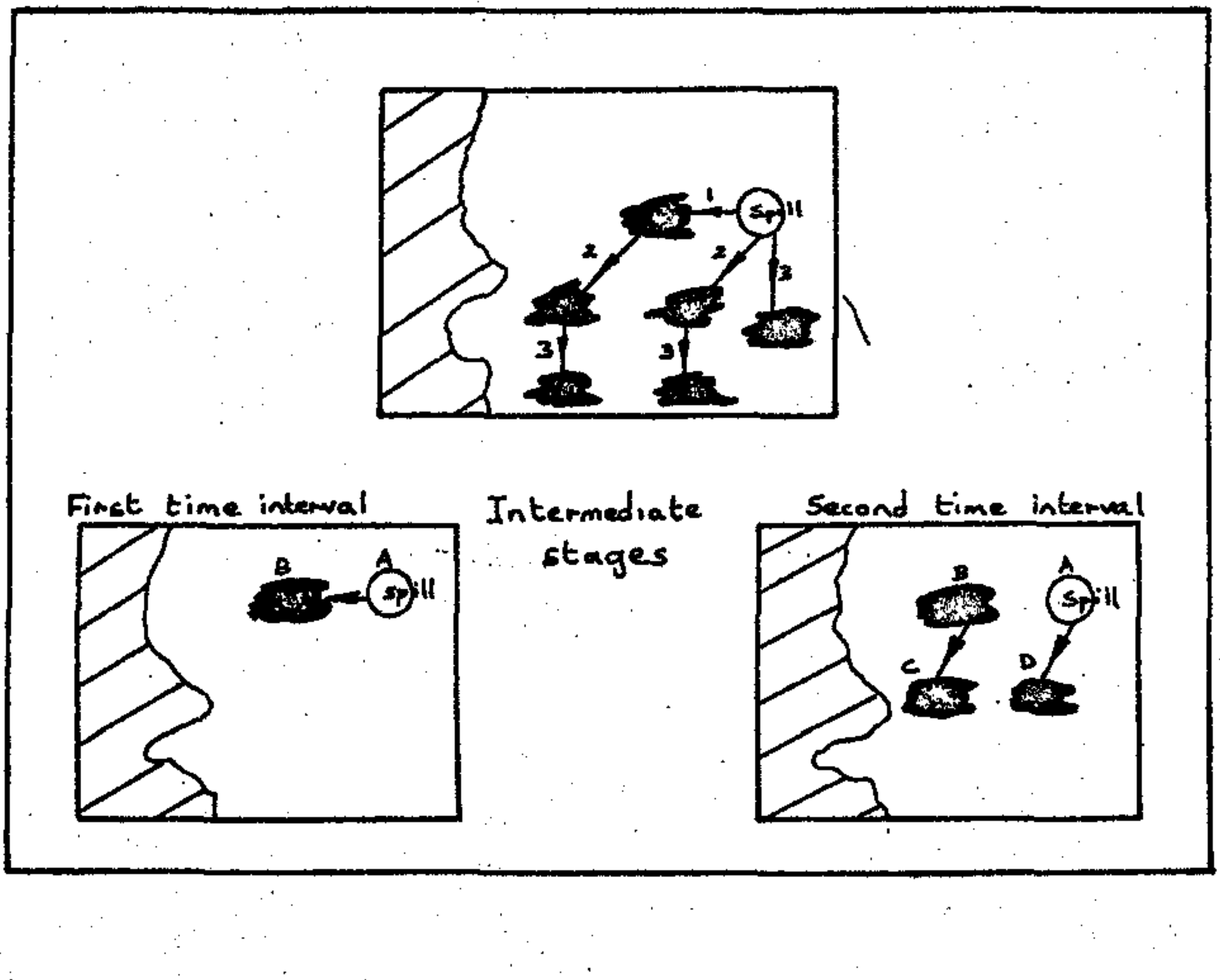

Spill
First time interval
A
B
Spill
Intermediate stages
Second time interval
A
B
Spill
C
D

FIG 6.

Speed of wind-driven Surface Current 0 1 2 3 ft/sec

Wind Speed 0 30 60 Knots

REDUCED GEOSTROPHIC WIND

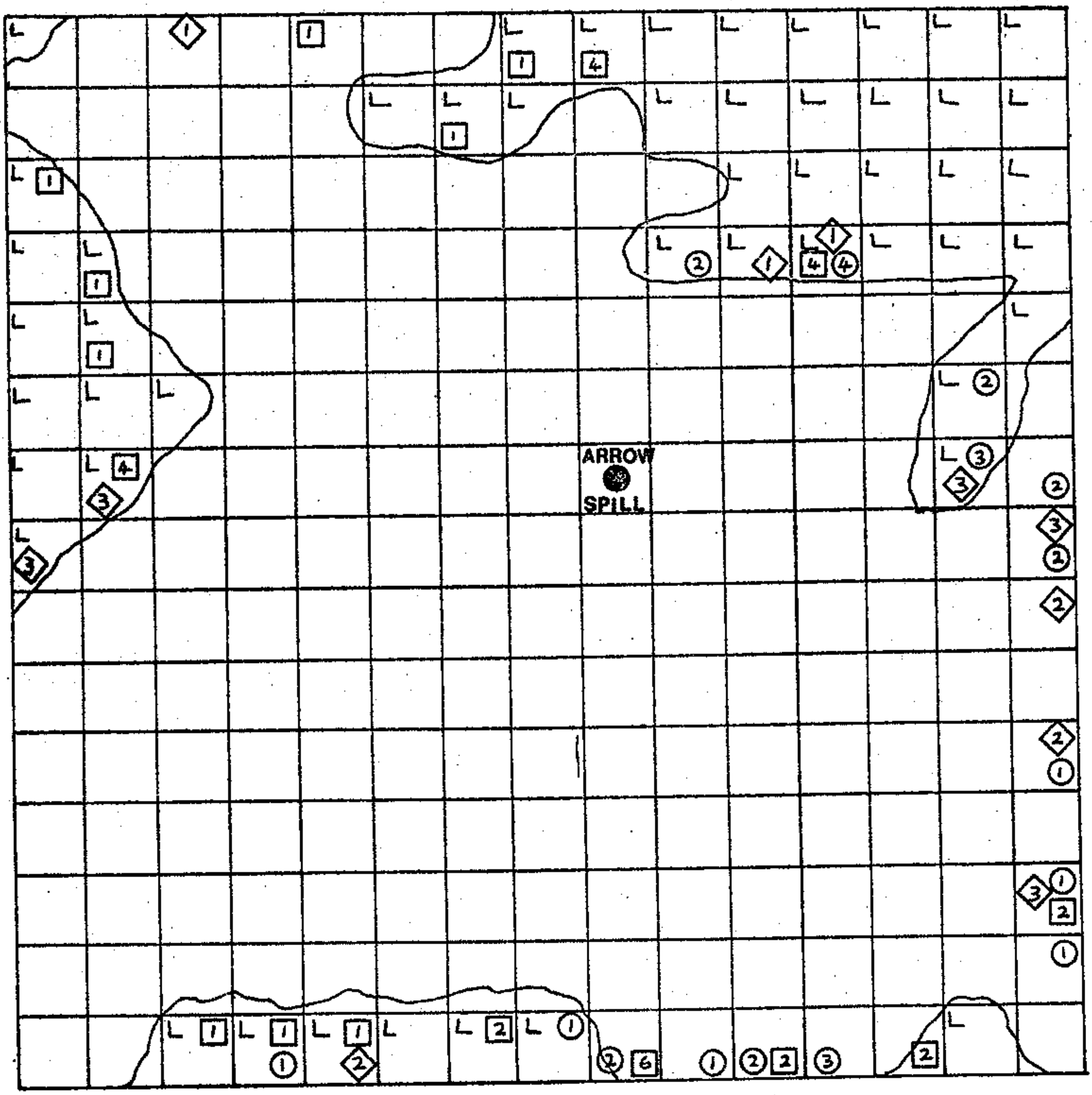
day \ hour	0 – 6	6 – 12	12 – 18	18 – 24	0 – 24	PREV DIRECT^{N}	MEAN SPEED
3 Feb						SSW	22·5
4 Feb						SSE	33·75
5 Feb						NNW	13·75
6 Feb						NE	11·05
7 Feb						N	12·5
8 Feb						N	8·75
9 Feb						NW	8·8
10 Feb						SE	7·9
11 Feb						ESE	25·75
12 Feb						SW	24·75

Canso Wind Summary Hour ending [Feb 1970]

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PREV DIR	MEAN SPEED	MAX VEL
3	SE	SE	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	S	S	S	S	S	S	S	S	SE	SE	SE	SE	SSW		
	7	6	13	16	17	16	16	16	18	20	20	13	12	17	22	21	19	22	23	24	23	20	18	20		17.7	24
4	S	S	SE	SE	SE	SE	SE	SE	SE	SE	SE	S	S	SE	SE	SE	SE	SE	SE	SE	SE	S	SW	SW	SSE		
	25	27	26	24	20	17	21	25	23	30	26	29	29	28	27	28	26	27	24	29	27	22	18	16		25.0	30
5	SW	SW	SW	SW	SW	SW	W	NW	NW	NW	NW	N	NW	NW	NW	NW	NW	NW	N	NE	NE	N	NE	NE	NW		
	23	29	23	22	22	17	15	15	12	15	11	14	11	12	11	11	11	12	9	8	7	6	8	9		13.7	25
6	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	N	NW	M	M	M	M	M	NE		
	9	11	12	11	15	12	12	12	12	7	11	13	10	9	10	11	9	8	6	M	M	M	M	M		10.5	15
7	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M		
	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M		M	M
8	M	M	M	M	M	M	M	M	M	M	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW		
	M	M	M	M	M	M	M	M	M	M	8	9	11	11	10	10	10	11	9	7	7	7	6	8		8.9	11
9	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	N	N	N	NW	NW	N	W	NW		
	7	7	6	5	5	4	5	5	7	7	7	6	6	5	5	5	7	7	7	7	4	4	2	1		5.6	8
10	W	NW	W	W	SW	SW	SW	SW	SW	S	SW	SW	SW	SW	SW	SW	S	SE	SE	SE	SE	SE	SE	SE	SSW		
	3	2	2	2	1	2	1	4	4	5	5	5	5	6	6	7	6	6	7	6	7	7	6	8		4.7	8
11	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	S	S	SE		
	9	10	15	15	24	21	22	20	21	24	24	24	23	23	25	25	27	30	22	18	18	16	11	8		19.8	30
12	S	SE	SE	SE	S	SW	S	S	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SSW		
	9	9	12	17	21	19	20	20	21	20	23	24	27	25	23	28	29	28	26	30	27	24	27	26		22.3	30

FIG 7

FIG 8.



ACTUAL DATA ○ FEB DIST^N [6 HOURLY] ◇ FEB DIST^N [12 HOURLY]

FIG 9a

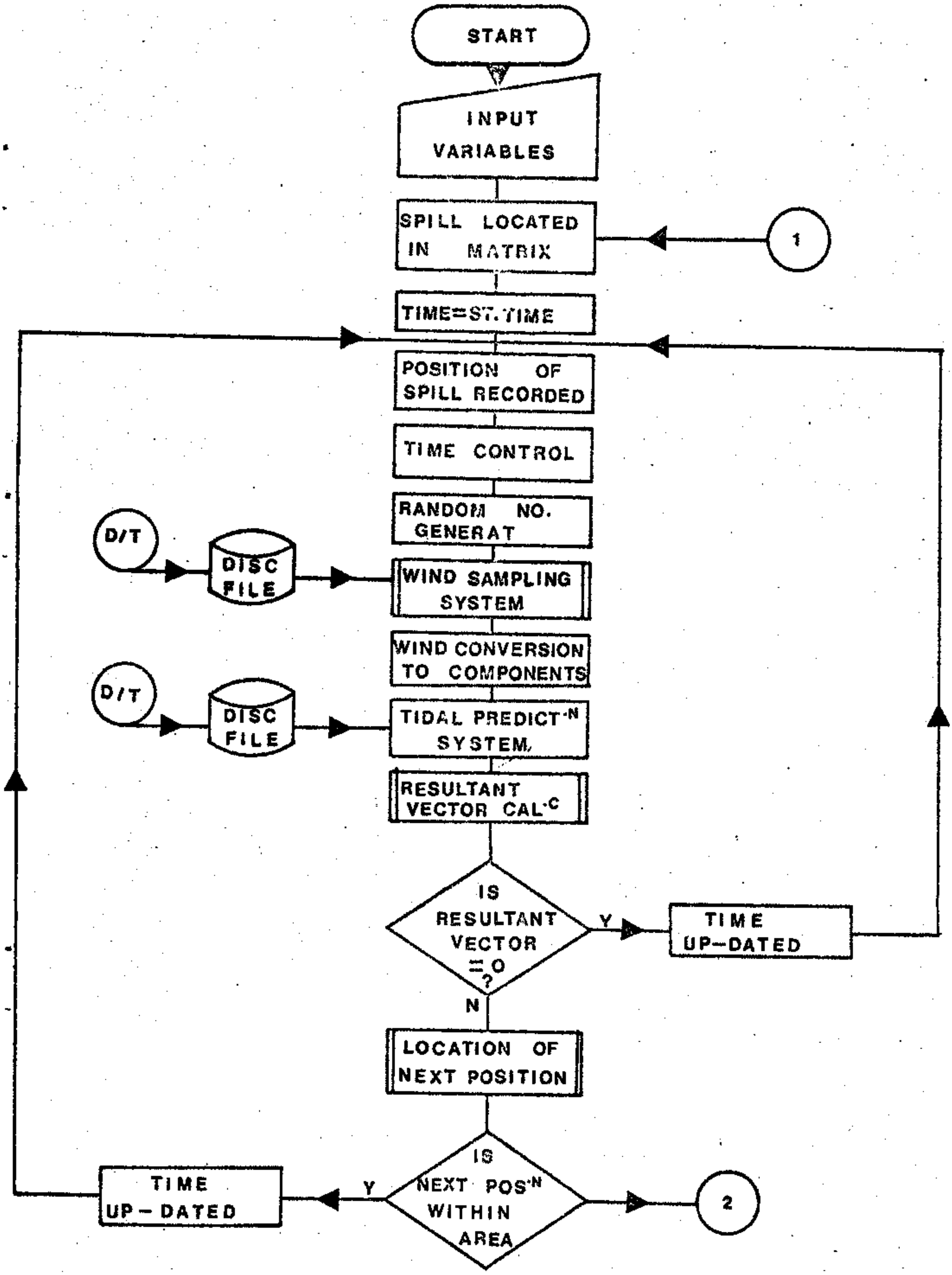

START
INPUT VARIABLES
SPILL LOCATED IN MATRIX
1
TIME=ST.TIME
POSITION OF SPILL RECORDED
TIME CONTROL
RANDOM NO. GENERAT
D/T
DISC FILE
WIND SAMPLING SYSTEM
WIND CONVERSION TO COMPONENTS
D/T
DISC FILE
TIDAL PREDICT·N SYSTEM
RESULTANT VECTOR CAL·C
IS RESULTANT VECTOR =0 ?
Y
N
TIME UP-DATED
LOCATION OF NEXT POSITION
IS NEXT POS·N WITHIN AREA
Y
TIME UP-DATED
2

FIG 9b

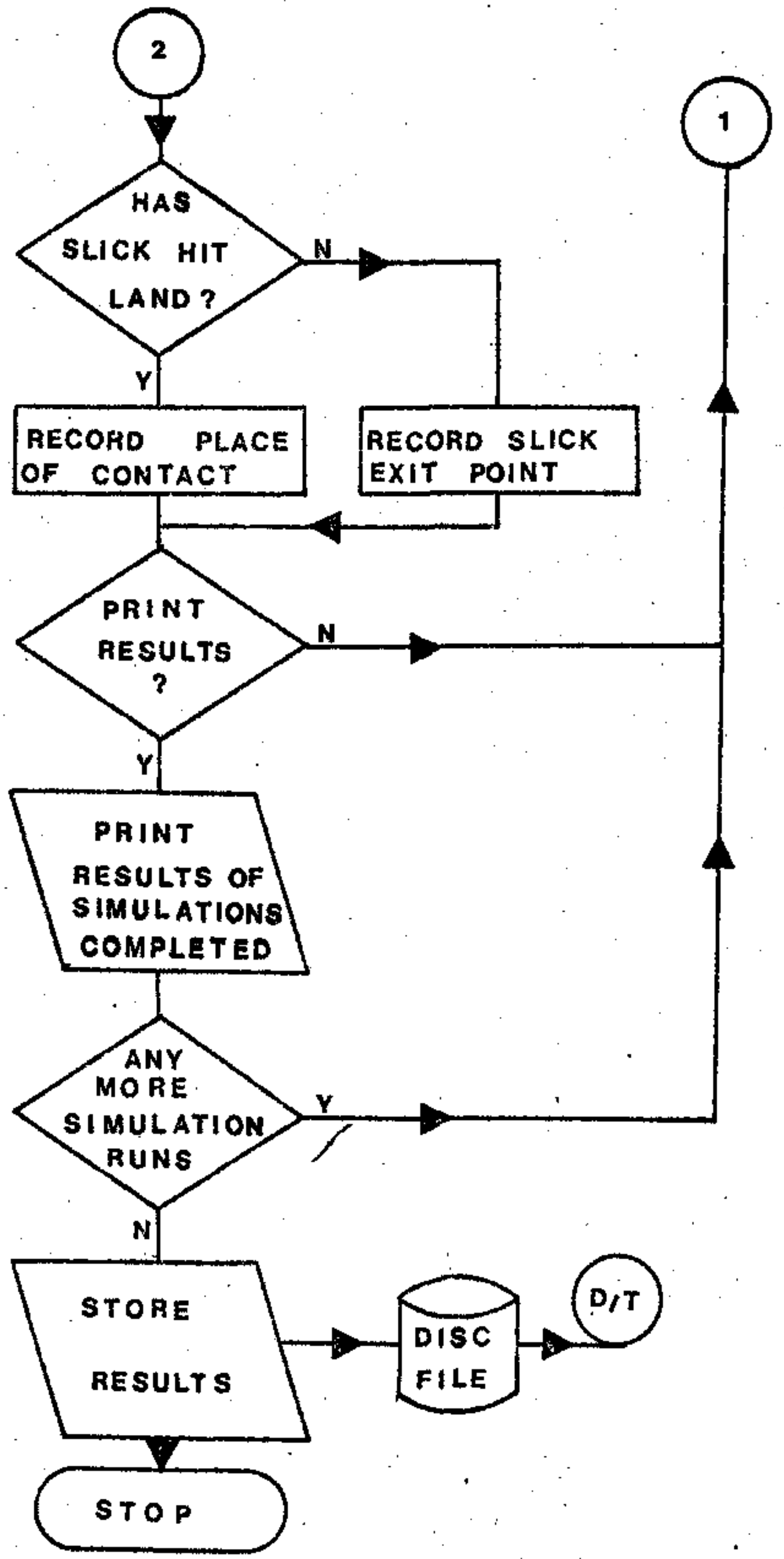

2
1
HAS
SLICK HIT
LAND ?
N
Y
RECORD PLACE
OF CONTACT
RECORD SLICK
EXIT POINT
PRINT
RESULTS
?
N
Y
PRINT
RESULTS OF
SIMULATIONS
COMPLETED
ANY
MORE
SIMULATION
RUNS
Y
N
STORE
RESULTS
DISC
FILE
D/T
STOP

FIG 10.

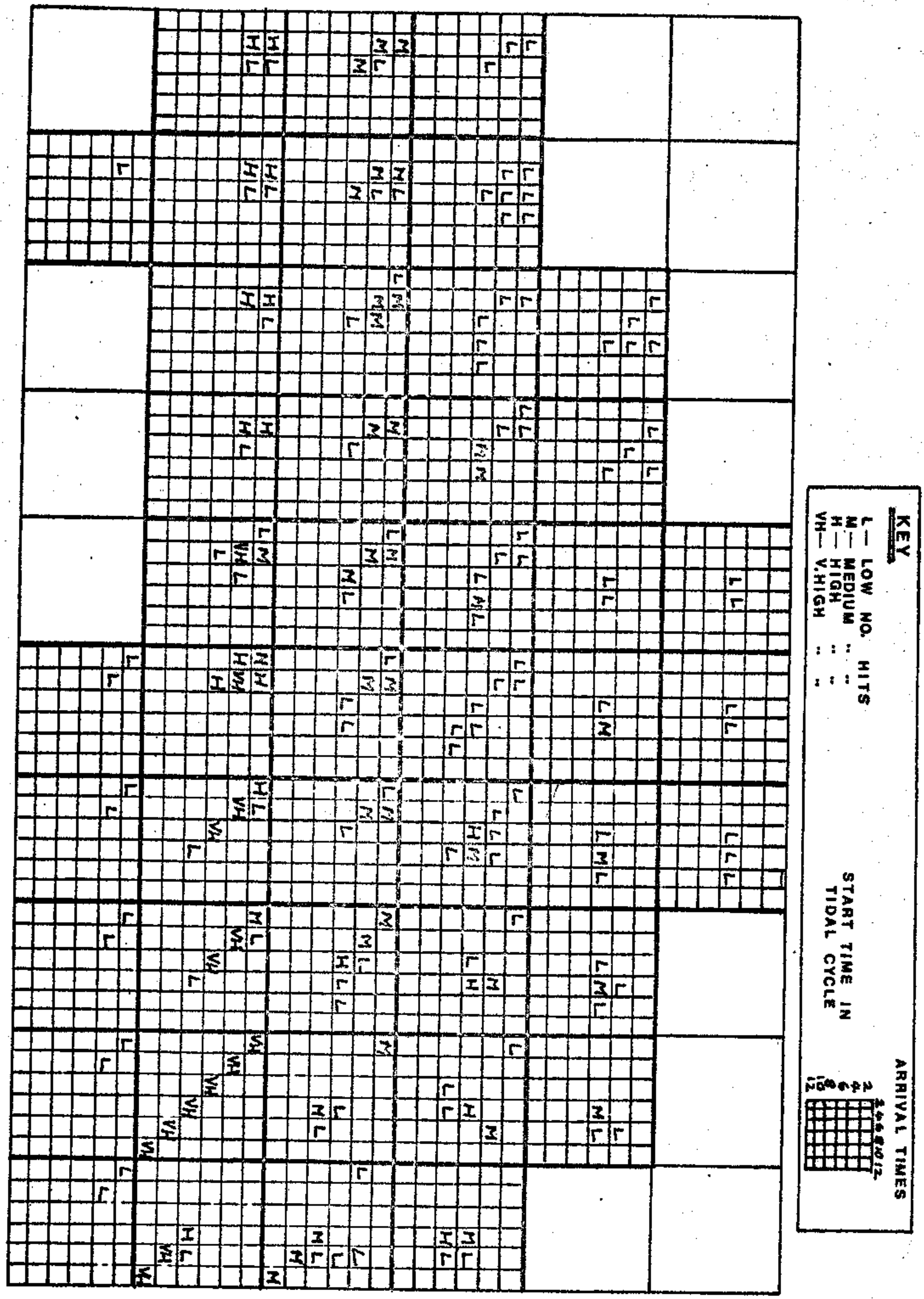
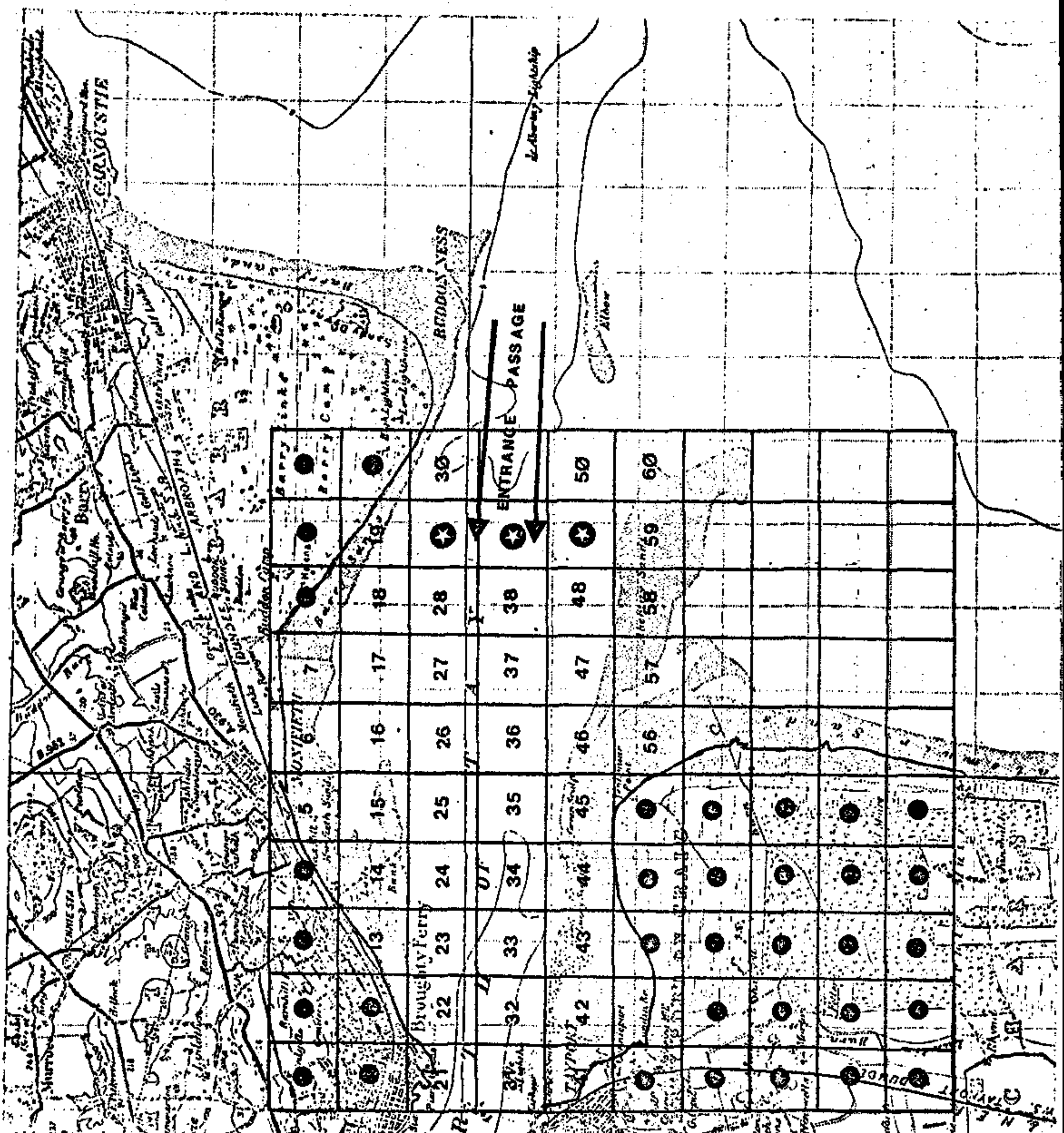

KEY
L— LOW NO. HITS
M— MEDIUM " "
H— HIGH " "
VH— V.HIGH " "
START TIME IN TIDAL CYCLE
ARRIVAL TIMES

FIG 11.


CARNOUSTIE
BUDDON NESS
ENTRANCE
PASSAGE
Broughty Ferry
TAYPORT
5
6
7
13
14
15
16
17
18
22
23
24
25
26
27
28
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32
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47
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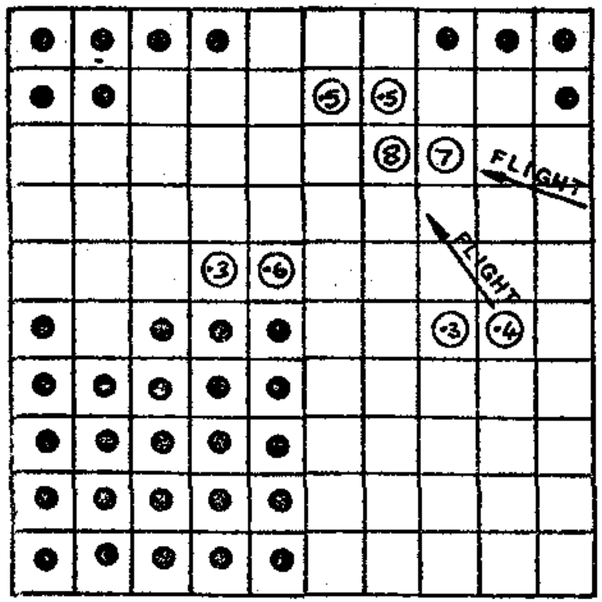
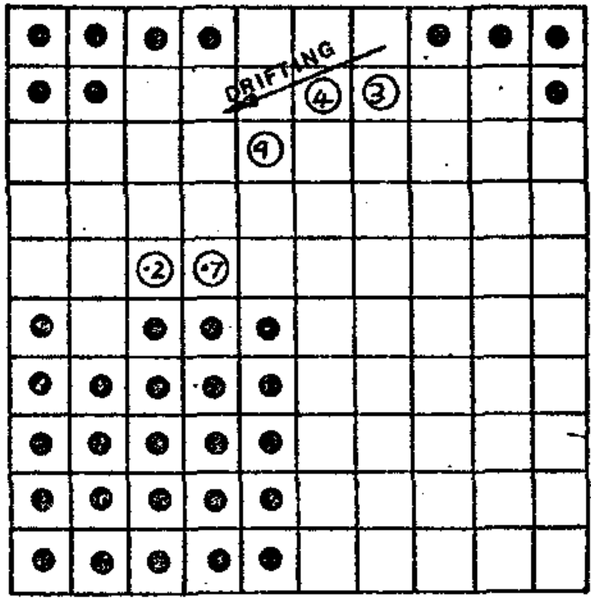
50
56
57
58
59
60

DISTRIBUTION OF EIDERS IN THE TAY ESTUARY (NO. IN 1000'S)

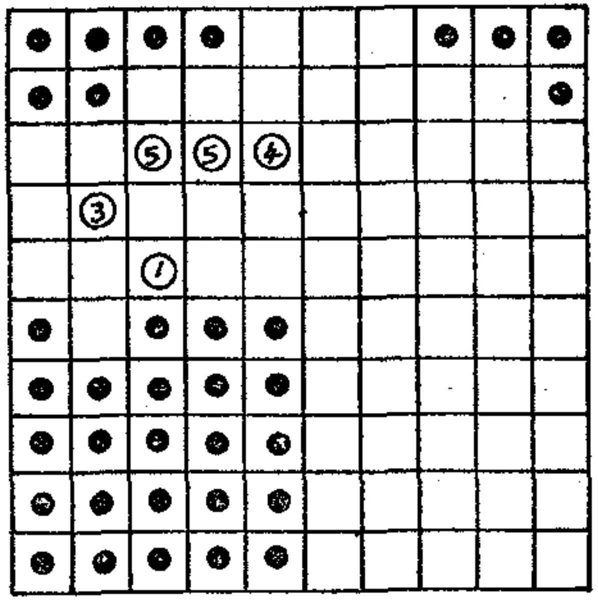
LOW TIDE



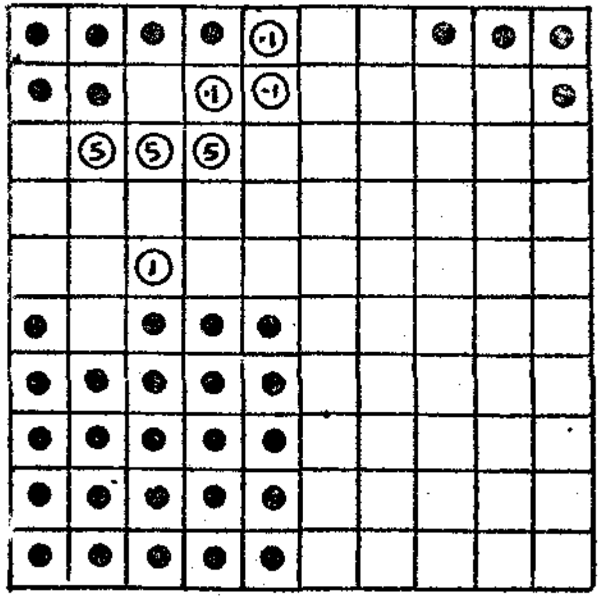
2 HOURS AFTER LOW TIDE



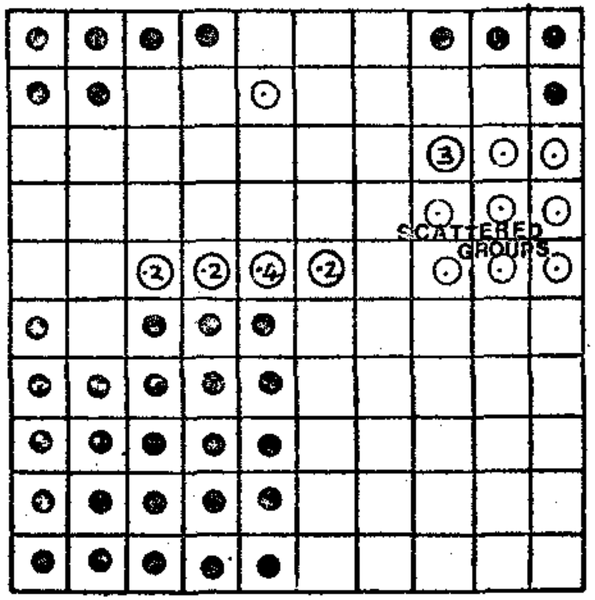
4 HOURS AFTER LOW TIDE



HIGH TIDE



2 HOURS AFTER HIGH TIDE



4 HOURS AFTER HIGH TIDE

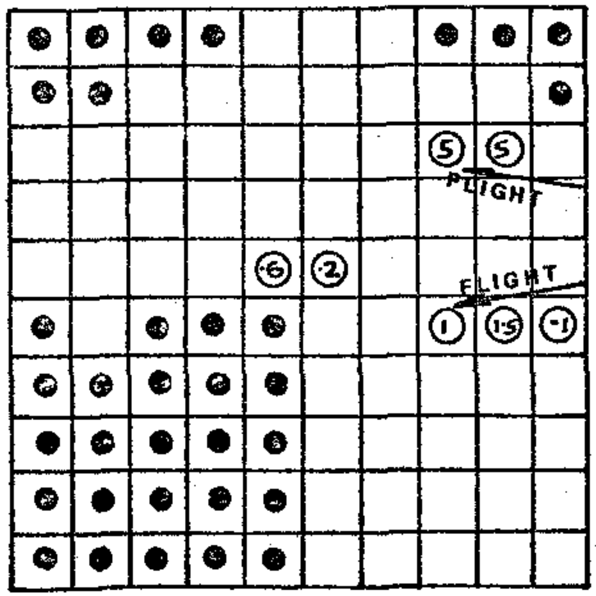


FIG 13.

OLD PROGRAM NAME--EIDTAY

READY

RUN

ENTER FILES
? HIT40
? HIT30
? HIT20

****AREAS****

.05	.14	.15	.16	.17	.22	.23	.24	.25	.28	.29	.30	.32	.43	.44	.45	.46	.48	.50	.58	.59	.60
0	0	0	2	0	0	2	2	0	0	0	0	11	25	20	0	0	0	0	2	2	0
0	0	0	0	0	0	1	2	0	0	0	0	8	42	39	0	0	0	0	0	0	0
1	7	15	20	0	0	12	57	14	24	1	15	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
0	0	0	2	0	0	0	0	11	0	3	0	13	4	4	0	0	0	0	0	0	0
0	0	0	1	1	0	7	0	13	0	0	0	29	0	3	0	0	0	0	0	0	0
4	54	33	25	0	0	0	0	37	2	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	20	18	0	3	0	20	3	82	0	1	0	0	0	0	0	0	0	0	0
0	0	0	12	16	0	9	3	36	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	42	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	3	3	0	0	0	0

TOTAL NO. OF EIDERS PRESENT IN TIDAL CYCLE (MULT/100)

1 1 1 41 30 50 1001001301301001 30 22 11 16 6 1 1 20 30 2