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Meteorological Support Systems for the Control of Foot-and-Mouth Disease of Animals

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Summary

For the management and control of foot-and-mouth disease (FMD) of animals, cognisance must be taken in a systematic way of veterinary, meteorological and terrain factors to indicate the areas where susceptible livestock are at risk from secondary infection. The physical parameters influencing the dispersion of FMD particles in the atmosphere have been related to the aerobiological properties of the FMD virus. Rates of virus emission and survival have been simulated. While the UK Gaussian plume model and the Danish LINCOM and RIMPUFF dispersion and flow models are mostly reported on here, dispersion models developed in other national research institutes may equally be considered. Increased use of information technology and GIS systems has prompted interest by state veterinary services in the use of total information systems such as the EpiMAN system. The recently completed three year EU project on the management of epidemiological data and prediction of risk factor during outbreaks of FMD has provided a timely evaluation and prototype of EpiMAN (EU). The importance of weather reports from meteorological stations, and outputs from numerical weather prediction (NWP) models, as input to the dispersion and flow models to predict FMD virus plume concentrations has been demonstrated. Links between National Meteorological Services and State Veterinary Services are important to facilitate the extension of the EpiMAN management to other states.

Meteorological Support Systems for the Control of Foot-and-Mouth Disease of Animals

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Introduction

Foot-and-Mouth disease (FMD) is a long established (probably first recorded in Italy in the sixteenth century) highly contagious disease of cloven hoofed animals, e.g. cattle, sheep, goats. Movement of infected animals is the single most important means of transmission of FMD. Infection is also spread by contact with vehicles or people from infected areas, feeding to animals of infected meat or milk, or spreading of infected slurry. Other causes of FMD virus dispersion are related to low level winds during the period when infected animals have been emitting the virus (Hugh-Jones and Wright, 1970). Airborne spread represents an essentially uncontrollable means of transmission which is important only where the meteorological and epidemiological factors are favourable (i.e. temperate, but not tropical or sub-tropical climates). While the spread of FMD by the wind stream is frequently restricted to short ranges, i.e. less than 10 Km, under certain conditions FMD can be transmitted over long distances - spread is possible for a distance of 60 Km over land and 250 Km over sea (Gloster *et al*, 1982; Donaldson *et al*, 1982; Sorensen and Jensen, 1996).

FMD has been endemic in low latitudes, particularly in African, South American and Asian countries, and incidences of the disease have been common to some European countries. The EU has been free from FMD since 1990 with the exception of sporadic incursions. For the Turkish Thrace and countries around the Black Sea the disease has been endemic. The most recent outbreaks to have been reported in Europe include those in Italy in 1993, the Balkans in 1996, Greece in 1994 and 1996, and Bulgaria in 1991 and 1993 (mainly in sheep). The outbreak in Albania in 1996 was attributed to the importation of infected buffalo meat from India. The number of recorded outbreaks of FMD in Europe rose to an annual peak in the late 1960's. Subsequently following compulsory vaccination there was a sharp fall off and currently the rate is 100 outbreaks annually (Mackay, *personal communication*).

The more widespread serotypes of the virus in Europe have been identified as types O and A. With the reduced level of incidences, the practice of vaccinating is being replaced in the EU by the so called 'stamping out policy' (as already employed in the UK and Ireland). With the latter system infected animals, or animals at risk, are slaughtered and the carcasses disposed of by burning and burial. The slaughter method is a costly procedure and meteorological assistance to identify herds at risk is most helpful to the veterinary authorities. Knowledge of atmospheric dispersion becomes important when all other sources of infection (animal movement, milk, slurry, etc.) have been controlled. Vaccination within the EU would be used to limit spread of disease if 'stamping out' proved inadequate.

FMD Dispersion Modelling

During an animal health emergency, time and resources need to be conserved as much as possible. Mistakes can also occur when making numerous unfamiliar computations under pressure. Modelling aerosol transmission of FMD was pioneered in the United Kingdom in the 1970's and 1980's by the development of a computer program for simulating FMD virus dispersion. The FMD model stemmed from a co-operative venture between the UK Meteorological Office and the UK Animal Virus Research Institute at Pirbright (Gloster *et al*, 1981; Donaldson, 1986). In the model cognisance was taken in a systematic way of veterinary, meteorological and topographical factors to indicate the areas most likely at risk from secondary infection. The physical parameters influencing the dispersion of particles in the atmosphere were related to data of the aerobiological properties of the FMD virus.

The main factors to be considered in FMD modelling

Studies have found that the main factors which influenced the spread of FMD disease over distance are: (a) virus emission; (b) virus survival; (c) virus dispersion; (d) virus deposition; and (e) susceptible livestock (Blackall and Gloster, 1981(i, ii)).

(a) Virus Emission: The quantities of airborne infectivity which may be released at source have been determined experimentally and are dependent on the species of the animal, the strain of the virus, the stage of disease and the number of animals affected. At the time of peak excretion a pig can liberate 277,000 $TCID_{50}$ (bovine thyroid tissue culture infectious units) of airborne virus per minute. By contrast the emission by an infected steer or sheep is about 170 $TCID_{50}$ per minute (Donaldson, Lee and Gibson, 1987). Emission from infected pigs thus amounts to 8.6×10^6 virus daily, while the corresponding figure for cattle and sheep is 5.2×10^6. The incubation period is usually 2 to 14 days. It can occasionally be longer, but this is unusual and usually occurs because disease is not traced until 2 incubation periods have passed, the first resulting in only subclinical or mild disease.

(b) Virus Survival: The emitted virus is encapsuled in a small respiratory moisture droplet exhaled by the infected animal and this droplet must remain intact to sustain the virus in the atmosphere sometimes over a period of a number of days. A high atmospheric relative humidity (RH) is required to ensure viability. A threshold RH of 55-60% (to avoid excessive evaporation of the small droplets) has been found to permit the virus to survive for many hours (Barlow, 1972; Donaldson 1972). At lower RH values the virus becomes inactivated. The effects of temperature and sunlight are thought to be of secondary importance only.

(c) Virus Dispersion: For the probability of downwind infection of other animals to be high, the aerosol plume should remain concentrated. An aerosol containing the virus will be carried away from source and dispersed by a combination of two processes, one by direct transport away by the wind and the other by diffusion or spreading sideways and vertically through the wind stream by turbulence. The vertical and lateral spread of the virus plume depends on wind speed and direction, distance travelled and diffusion pattern of the aerosol, the latter being a function of both the horizontal and vertical currents of the low-level atmosphere as well as its vertical temperature structure (lapse rate). The calculation of further dilution downstream due to turbulent diffusion and other processes while a complicated problem is nevertheless amenable to computation (Pasquill, 1974).

Winds create turbulence which mixes air from different levels. Light winds favour greater concentrations, especially near the plume source. In strong wind the plume can be diffused higher into the atmosphere and the virus concentration become smaller although there may be little lateral spread. While a function of wind speed, the vertical dispersion of the virus plume is also a function of the type of underlying surface. The rougher the surface the greater the turbulence and the deeper the mixed layer becomes. For example, for a given wind speed and stability, the virus plume is more likely to remain trapped near the surface for long periods over the sea than over land. Therefore, infection at great distances is more likely to occur if the virus has passed over a sea track rather than a comparable land passage. Also wind speed is often lighter at night-time so that the virus is likely to remain near the surface during this time. Because of the likelihood of much variability of direction, however, light winds will cause very large lateral diffusion.

The Effect of Topography

The effect of topography is to deflect and modify the characteristics of the virus plume. Hills and valleys have considerable influence on the path of the virus plume. This effect is greatest in stable conditions or in light winds as the topographical features channel the wind, sometimes deflecting it to flow at right angles to the prevailing wind direction. This channelling of wind can lead to animals in low-lying areas being at greatest risk. Because stable and slack wind conditions are more likely at night-time, the effect of topography can be most marked during the night.

(d) Virus Deposition: The most frequent cause of natural infection of FMD is by direct contact through inhalation rather than by ingestion and accounts for 95% of outbreaks (Gloster *et al*, 1981). Therefore virus viability and concentration in an aerosol are important factors. Deposited virus on the herbage by natural deposition or by precipitation effectively decreases the amount of airborne virus challenge to animals. Deposition is affected by the aerosol characteristics or by precipitation.

The role of precipitation

There has been no clear agreement as to the role of precipitation. According to Hugh-Jones and Wright (1970) precipitation serves to remove virus from the atmosphere through capture by falling raindrops. Any virus removed by precipitation will not be available for inhalation. In general, the percentage of virus removed from the air will be greater when the rainfall rate is high, raindrop size is small, wind speed is low, precipitation continues for a long time and the capture efficiency is high. However, precipitation is also associated with favourable atmospheric conditions (stable low level conditions with little vertical dispersion of the plume) to maintain increased concentrations of the virus aerosol. Blackall and Gloster (1981) postulated that the main significance of precipitation as indicated by the literature was that rainfall is likely to restrict the distance downwind to which virus are likely to be carried.

(e) Susceptible Livestock: A number of factors are associated with the susceptibility of animals to infection. As previously stated, natural infection is more likely to occur through direct inhalation by the animal than through ingestion (Gloster *et al*, 1981). If the disease is spread by airborne means, then having the larger air intake cattle are more likely to become infected in secondary outbreaks than sheep or pigs. The estimated virus dose is 25 $TCID_{50}$ per day to infect cattle (Donaldson, Lee and Gibson, 1987); 15 $TCID_{50}$ to infect a calf, sheep or goats; and 400 $TCID_{50}$ for pigs. In some experimental studies using an O_1 strain of FMD virus it has been found, however, that a dose of 10 $TCID_{50}$ is sufficient to infect a sheep and 25 $TCID_{50}$ can infect a calf or a pig. High risk situations occur when cattle are present in large numbers and inhale infected air for a long time. Low wind speeds suit high virus concentrations in the plume; low winds can be very variable, however, thereby reducing exposure time of animals to virus.

Aerosol Dispersion in the Atmosphere - Gaussian Plume

An insight into the processes of diffusion may be gained from observing the everyday example of a smoke plume from a chimney stack. In moderate winds and with a cloudy sky, the downwind plume of smoke forms a fairly straight well defined trail which increases steadily in width and height as distance from source increases. With light winds and if the underlying surface is heated by the sun, a much greater degree of irregularity appears in the form of the plume. In quite atmospheric conditions such as often occurs at evening or night time, by the cooling of underlying surface, bodily rise and vertical spread are greatly reduced and the smoke trails off downwind in a compact visible form for a considerable distance. The following three classes are an exemplification of diffusive conditions. Each class is associated with characteristic vertical gradients or changes of temperature and the associated stability's in the lower atmosphere.

Class	**Vertical temperature gradient**	**Associated stability conditions**	**Lateral/vertical diffusion produced**
Neutral	small decrease	steady air flow	lateral spread restricted
Unstable	large decrease with height	mixing of the air	vertical spread occurs
Stable	near zero or increase with height	mixing of air restricted	restriction on vertical spread

Dispersion in the atmosphere is therefore governed by the vertical temperature structure of the lower atmosphere, the low level wind and the surface over which the air is passing.

The dispersion from a point source under real conditions can vary considerably from the above simplified patterns (*see* Pasquill, 1974). The rate of change of temperature with height (and by implication, atmospheric stability) can take a variety of forms. In order to maintain high concentrations of virus near the surface, vertical dispersion must be limited. Virus in higher concentrations will be trapped near the surface by a stable layer of air, e.g. when warm air moves over a cool surface or in anticyclonic conditions with a temperature inversion occurring at low levels. Donaldson (1988) concluded that a stable atmosphere, i.e. when convectional activity is minimal, a low wind speed, a high relative humidity and wind in the 'right' direction are the main meteorological factors of importance.

UK Operational Model

The UK numerical model on FMD is based on the general principles used for calculating the dispersion of aerosols or pollutants from a release point. This simple model solves a form of the well known Gaussian diffusion equation (Pasquill, 1974).

Assuming source and sink are at ground level the form of the Gaussian dispersion equation simplifies as follows:

$$C_{xy} = \frac{Q}{\pi U_{10} \sigma_y \sigma_z} e^{\frac{-y^2}{2\sigma_z^2}}$$

where Q is source strength, U_{10} is 10 m wind speed, σ_y, σ_z are dispersion coefficients in the y and z direction, and C_{xy} is the concentration at co-ordinates x,y.

The Gaussian plume is widely used for calculating the dispersion of aerosols from a continuous point source. The plume diffuses across wind (Y-direction) and in the vertical (Z-direction). As the plume spreads downwind pollutant concentrations within it decrease, becoming diluted in an increasing volume of air. The distribution of concentration in the Y-and Z-directions has standard deviations of σ_y and σ_z. Within these limits, the plume retains some 67 per cent of the concentration with maximum value at the central line. The values of the dispersion coefficients, σ_y and σ_z, increase downwind at rates which depend on both the turbulence in the air and on the wind speed.

Meteorological parameters used in the model

To operate the FMD program the following information is required: an estimation of the duration and total quantity each day of airborne FMD virus dispersed from the infected premises or herd; hourly or 3 hourly observations of wind speed and direction, relative humidity, cloud cover and precipitation in the vicinity of the outbreak; and latitude and topographical features of the area. However in the absence of such information at the early stages of an outbreak, default values are used. The meteorological data for the dispersion model are taken from a representative weather station near to the outbreak or from a weather station sited for the occasion within the affected zone.

Shortcomings of a Gaussian plume model are poor treatment of non-stationary and non-homogeneous flow and turbulence. The model represents a statistical time-averaged concentration pattern, which may be a gross simplification of reality (Sorensen and Jensen, 1996). Stability parameters are derived from cloud type and amount as well as surface flux parameterisations leading to limitations of the model.

The data is processed at grid points radially extending out to 10 Km from the initial source spaced at intervals of 1 Km and at 10 degree intervals from 0° through to 360° (polar co-ordinates). It is thought that the 10 Km distance from source is sufficient limit for over 90% of the virus to have been deposited. Topographic features are also included to provide greater realism to the outputs. A gradient of 1:50 is allowed to deflect the wind. The model incorporates the effects of precipitation apparently by assuming none of the emission is available for advection away from the source for those hours for which precipitation is reported in the meteorological data.

All output quantities in the UK FMD model are given in terms of dose per day required to infect animals. Daily accumulated dose outputs at each 1 km grid point are given in tabular form, while graphical outputs delineate areas at risk by contours of designated threshold doses. These thresholds have been modified and the areas at risk considerably reduced over the last decade as further studies indicate that greater doses are required to infect animals (Donaldson, Lee and Gibson, 1987).

Figure 1 shows a typical example of a plume where 10 infected pigs have been emitting for four days. The local terrain features cause the plume to be deflected from the original wind direction. In the eighties the model was run on a centralised mainframe computer from a remote terminal. Recent advances have enabled the model to be run on a local PC or laptop computer with access by modem to NMS weather observations and the terrain data bank. Because of its size the latter may be held in a central server and the relevant section downloaded for the model simulation.

Danish Models

The simple Gaussian plume models are too simplistic to apply in cases with time- and space-changing dispersion scenarios[1]. Sorensen and Jensen, 1996 reported (*after* Mikkelsen) that for practical and operational use, Lagrangian-type models are the most appropriate for real-time local- and meso-scale atmospheric diffusion problems, and among the various models, Gaussian puff models were fastest in terms of PC processing time.

The RIMPUFF mesoscale dispersion model and the LINCOM diagnostic flow model have been developed in the Riso National Laboratory, Denmark. In the case of flat terrain or moderate topography, the RIMPUFF local- and meso-scale atmospheric dispersion model may be run without the use of a flow model and only weather station reports or numerical weather prediction model outputs are required as the meteorological input. In the case of complex terrain, the LINCOM local- and meso-scale atmospheric model, which can handle difficult terrain, may be used with input from the terrain data bank. In complex terrain the location of the weather-recording station increases in importance. Enquires on the model may be made at DMI (*see* Appendix).

Virus dose

To estimate the spread of FMD, knowledge is required of the minimum infectious doses for cloven-hoofed animal species, the inhalation rates and the virus concentration in the inhaled air. The amount of virus inhaled can be expressed by the integral:

$$N = \int_0^T c(\mathbf{r},t) I dt$$

where N is the amount of virus, c(**r**,t) is the concentration in units of TCID$_{50}$/m^3, I is the inhalation rate of the animal in units of m^3/24 hr and T is the period of time of integration (e.g. 24 hr).

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[1] The COST Technical Committee (TC) on Meteorology initiated a project in 1994 to review and compare the various methods used to provide input data for atmospheric dispersion models (report of COST 710, 1997). The COST 710 project set up four working groups, namely, WG1: surface energy balance (chair: U.Pechinger, Austria); WG2-boundary layer depth (Petra Seibert, Austria); WG3-profiles (J. Erbrink, Netherlands); and WG4-complex terrain (D. Szepesi, Hungary and P Jeannet, Switzerland). The project was completed in 1997 and received a positive evaluation by the TC, as competent, complete and up to date. There has also been a concerted effort within Europe on the development of methods for predicting atmospheric dispersion, for example within ERCOFTAC (European Research Community for Flow, Turbulence and Combustion). Also see reference to Olesen and Mikkelsen (1992).

The viability of the virus is maintained at RH > 55% and this is modelled in an "on/off" switch. Virus decay rate is given by the following equation where λ is an exponential decay constant (sec^{-1}) and the decay rate s (hour^{-1}) depends on the virus strain:

$$\lambda = \frac{\ln 2}{\log_{10} 2} \times \frac{s}{60^2} = 0.64 \times 10^{-3} \times s$$

where a typical value for s is said to be 0.5 hour^{-1}.

Meteorological considerations

The LINCOM/RIMPUFF flow and dispersion model system can be run on weather observations. The necessary data are wind (at 10 metres), precipitation, relative humidity and cloud cover. The meteorological station used should be representative of the area of concern. This may be achieved by an existing station or by the setting up of a special weather station for the purpose.

The output of a limited area NWP models may also be used to generate weather reports. The resolutions of NWP models, e.g. HIRLAM (in operational use in Scandinavian and Nordic countries, the Netherlands, Ireland and Spain), the Unified Model (UK), Aladin model (France and eastern European countries), EM/DM (models) (Germany and Switzerland are typically 20-50 km and 20-30 layers in the vertical and a short time step in some instances of 5 minutes.). ECMWF (European Centre for Medium range Weather Forecasting) forecast model has a horizontal resolution of 90 km and extend up to 10 days. Parameters such as wind (speed and direction) at different heights, precipitation intensities, cloud cover and relative humidity can be obtained from the NWP models. Also atmospheric stability, the height of the boundary (mixing) layer, wind shear and temperature gradients from NWP may be used as additional parameters to the LINCOM/RIMPUFF model complex. The value of NWP is that forecast parameters can be input to provide a prediction of future dispersion thus avoiding the assumption of persistence for extrapolating future plume spread over the following few days. Historical data sets may also be obtained from NWP databases (e.g. ECMWF).

For maximum plume range, the optimum meteorological conditions for maintaining virus plume concentration are persistent wind direction and speed approximately 5 ms^{-1}, high degree of atmospheric stability (class F, *see* Pasquill, 1974), an absence of precipitation, and relative humidity above 55% to ensure virus survival. Sensitivity studies did not show any significant difference with respect to the effective transport height when transmission took place in the lower part of the boundary layer, i.e. less than 250 metres irrespective of the degree of stability. With respect to stability, the effect of increasing the Pasquill-Turner stability category was to intensify the plume in a narrow band provided that the wind direction remains constant (Sorensen and Jensen, 1996).

LINCOM/RIMPUFF Model Evaluations

Tests with reconstructed data have been carried out in the Netherlands. A program to construct appropriate weather reports from the NWP output has been developed in the Danish Meteorological Institute (DMI). Case studies (without taking exponential decay of the virus into account) have been undertaken in DMI on a number of previous European outbreaks in the eighties such as Brittany/UK (1981), (Denmark (1982) and East Germany (1982).

Simulating the Brittany/UK March 1981 event, where an FMD outbreak first occurred among a large amount of pigs near the coast of Brittany, Sorensen and Jensen (1996) showed a narrow intense plume to have reached Jersey and the Isle of Wight (Figure 2). Internal spread from premise to premise is also illustrated in the simulations (Figure 3). For possible long-range transmission across the English Channel, the simulation gave a 24-hour average concentration about a factor 500 times too small in comparison with the threshold value of 0.06 $TCIF_{50}/m^3$ needed for to infect cattle. As expert opinion concluded that windborne spread was the cause of the outbreak, and as the simulated plume flow was realistic, the underestimated dose available to susceptible animals seems to be due to the grossly underestimated number of infected pigs which emitted virus (Mackay, *personal communication*).

In the Danish outbreaks in 1982, due to small plumes, none of the simulations could support the thesis of airborne transport from the south-eastern region to the northern region, except if the excretions had started one day earlier.

Implementation of LINCOM/RIMPUFF

The LINCOM/RIMPUFF atmospheric flow and dispersion model complex, and the Rimpuff2ArcInfo interface between the RIMPUFF output and the Arc/Info GIS, have been compiled and implemented on the Sun Sparc10 workstation at the Pirbright Laboratory and on a DECstation at Wageningen Agricultural University (Sorensen and Jensen, 1996). The source code and PC executables of the models have been passed to Massey University, New Zealand, so that their version of EpiMAN (NZ) will use the same versions of the codes as is being used in EpiMAN (EU). Software enabling simulation of meteorological stations at any point in time and any geographical location based on the output of the operational DMI-HIRLAM model has been developed at DMI.

Improved FMD computerised support system - EpiMAN

Massey University in association with MAFQUAL, New Zealand, developed a computerised decision support system (DSS) 'EpiMAN' to assist in control of outbreaks of Foot-and-Mouth disease (FMD) (Sanson, Liberona and Morris, 1991; Sanson, 1994). In 1993 the EU funded a 3 year project to test the feasibility of adapting EpiMAN to produce a version capable of operating within the European Union (EpiMAN (EU)). The requirements for the proposed system were that its operation should comply with EU contingency plans for dealing with outbreaks of FMD, that it should be adaptable for use within any Member state, and that the system could function usefully despite constraints on data availability (Mackay *et al.*, 1997).

The EpiMAN system consists of a number of PC 'clients' linked to a central database server. Client PC's run the EpiMAN software under the Microsoft Windows operating system. The server is hardware-independent and can run the EpiMAN database using any standard ODBC, SQL compliant high-end databases. The system is inherently flexible and whilst it is envisaged that the server would be situated at the emergency Headquarters (EHQ) and linked to the clients by local area network (LAN), it is also possible to operate the system over a wide are network (WAN) or even using dial-up access *via* a modem. The predictive modelling part of EpiMAN relate to airborne spread (Windspread module); epidemic pattern (Interspread module); economic costs (Economic module).

The EpiMAN software comprises a central database, a geographical information system (GIS) and a knowledge base. The knowledge base consists of a number of mathematical models, predictive models and expert systems which contain information on the epidemiology of FMD. Epidemiological data from a central database is processed by the knowledge base to predict the risk of spread of disease associated with events or items (e.g. farms, vehicles, people, animals, virus plumes). A graphical display system for the plume display, which is not part of the EpiMAN (EU) system, has been developed though not operational in DMI (Sorensen, *personal communication*).

In order for EpiMAN to function optimally the following data should be stored in advance (Mackay, 1997):

Geographic: digital maps of the area of interest; the co-ordinates of holdings containing susceptible species; the co-ordinates of livestock-related premises, e.g. markets; slaughter houses, AI centres, milk processing plants, etc.; topography. Demographic: details of holdings, owner, address, etc.; the number and species of susceptible livestock; land ownership; milk tanker routes, AI rounds, etc. and Economic: factors influencing cost/benefit analyses.

The data collected during an outbreak should include: confirmation of demographic data in database; locations of infected premises (IPs); details of infected animals on IPs; movement onto and off IPs of animals; animal products; non-animal products; personnel and equipment. The meteorological data required are the meteorological conditions during periods of potential spread obtained from regional weather stations; on-farm recording; and numerical weather prediction (NWP) model.

Structure of EpiMAN Operating System

EpiMAN (NZ) is a multi-user operating system such as Microsoft Windows NT or Unix, to which personal computers (PCs) are networked for data entry (report of the EpiCentre, Massey University, 1997). Figure 4 shows the structure of EpiMAN. The core of the system is a complete information system which handles all of the information flows associated with the operational responsibilities at the emergency headquarters (EHQ). The EpiMAN database consists of spatial data managed by a geographical information system (GIS), textual data managed by a database management system (DBMS) and epidemiological knowledge of FMD contained within a series of models and expert systems. In relation to input to the FMD model, an on farm infection model quantifies virus release to the atmosphere together with the most recent weather conditions from an existing meteorological station or from a specially erected on-farm weather station, and these are stored in the database.

There are four models of FMD contained within the EpiMAN NZ system. Two of these are the FMD virus production model and the meteorological model. The third model is an inter-farm spread model (InterSpread) that can simulate an entire epidemic or can pick up the state of an epidemic at any given time and simulate forwards a user-definable time period. Various control strategies can then be investigated prior to implementation. The fourth model is a simple deterministic model that estimates the dissemination rate throughout the epidemic and then extrapolates forwards to new IPs and to the conclusion of the epidemic.

Constraint

The availability and quality of the data required for EpiMAN in the EU (and other European countries) varies considerably between States. EpiMAN will function without the data listed but the quality of the analysis performed will be adversely affected if the data is poor or absent. The module incorporates an updated windborne dispersal module (e.g. LINCOM/ RIMPUFF) to predict the airborne spread of FMD. Also to address the question of poor data availability, a module entitled AIROPLOT was developed within the EU project (Mackay *et al.*, 1997). AIROPLOT also incorporates a number of plotting, querying and visualisation routines which maximise the use of the GIS. An EpiMAN (EU) system comprising a combination of EpiMAN and the AIROPLOT module offers a prototype solution to the problem of implementing EpiMAN of poor data availability. A considerable commitment is required in terms of acquiring or creating the databases necessary for EpiMAN to function effectively and to adapting EpiMAN to provide input and output routines suited to local requirements. The EU project demonstrated that it is possible to adapt EpiMAN to work in languages other than English.

Validation of the system

The underlying data structure and the integration of the various software tools provides a very powerful analysis platform to service the diverse needs of data processing and decision making during an epidemic that could stretch across vast geographical areas. EpiMAN[1] also provides a model for animal disease control that could easily be adapted to other veterinary problems. Conceived, designed and constructed under theoretical conditions, EpiMAN (EU) has yet to be validated. The EpiMAN (NZ) has been extensively validated in simulation exercises in New Zealand. The EU project has shown that the system operated extremely well, and according to Mackay (*personal communication*) is now the system of most use in an emergency.

Conclusion

During an animal health emergency, time and resources need to be conserved as much as possible. Mistakes can occur when making numerous decisions under pressure. The continuing reduction of manpower in state veterinary services and the increased use of information technology (IT) has prompted interest in the use of information systems such as the EpiMAN system. For FMD control, where the airborne virus challenge to animals at risk can be estimated and predicted using appropriate airstream and diffusion models, the incorporation of modules with FMD models into a management information system holds much promise. The results from the recent EU funded three year project to develop a prototype of a computer-based management system for use in the prediction of risk factors for the control of FMD were promising. Institutes from Denmark, Italy, the Netherlands and UK participated in the EpiMAN EU project. The system is likely be brought into use in some of the participating countries. A list of some who participated in the EU project is attached as an Appendix.

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[1] Other variations of the EpiMAN decision-support system are EpiMAN-SF for swine fever; EpiMAN-TB for tuberculosis; and EpiMAN-Food Safety.

The Danish LINCOM/RIMPUFF flow and dispersion models have been considered in the context of the EpiMAN EU project. The UK Gaussian plume may also be considered - a small study is planned in the Netherlands to evaluate both (Dijkhuizen, *personal communication*). Other appropriate dispersion models have been developed within various national research institutes but these have still to be tested with the EpiMAN system. The importance of weather reports from meteorological stations and outputs from numerical weather prediction models to predict FMD virus plume concentrations has been demonstrated in the project. Co-operation between NMSs and the veterinary authorities in the development of such a computerised system is to be welcomed.

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FOOT AND MOUTH DISEASE VIRUS DISPERSION MODEL (UK)

SOURCE

DATE	COWS	PIGS	SHEEP
21 1 1998	0	10	0
22 1 1998	0	10	0
23 1 1998	0	10	0
24 1 1998	0	10	0

LATITUDE OF FARM IS 54.00

ACCUMULATED DOSAGE FOR THE WHOLE PERIOD (ALL OCCASIONS)

Contours: (1,5,10,25,50,75)
Daily dosage. $TCiD_{50}$ Units

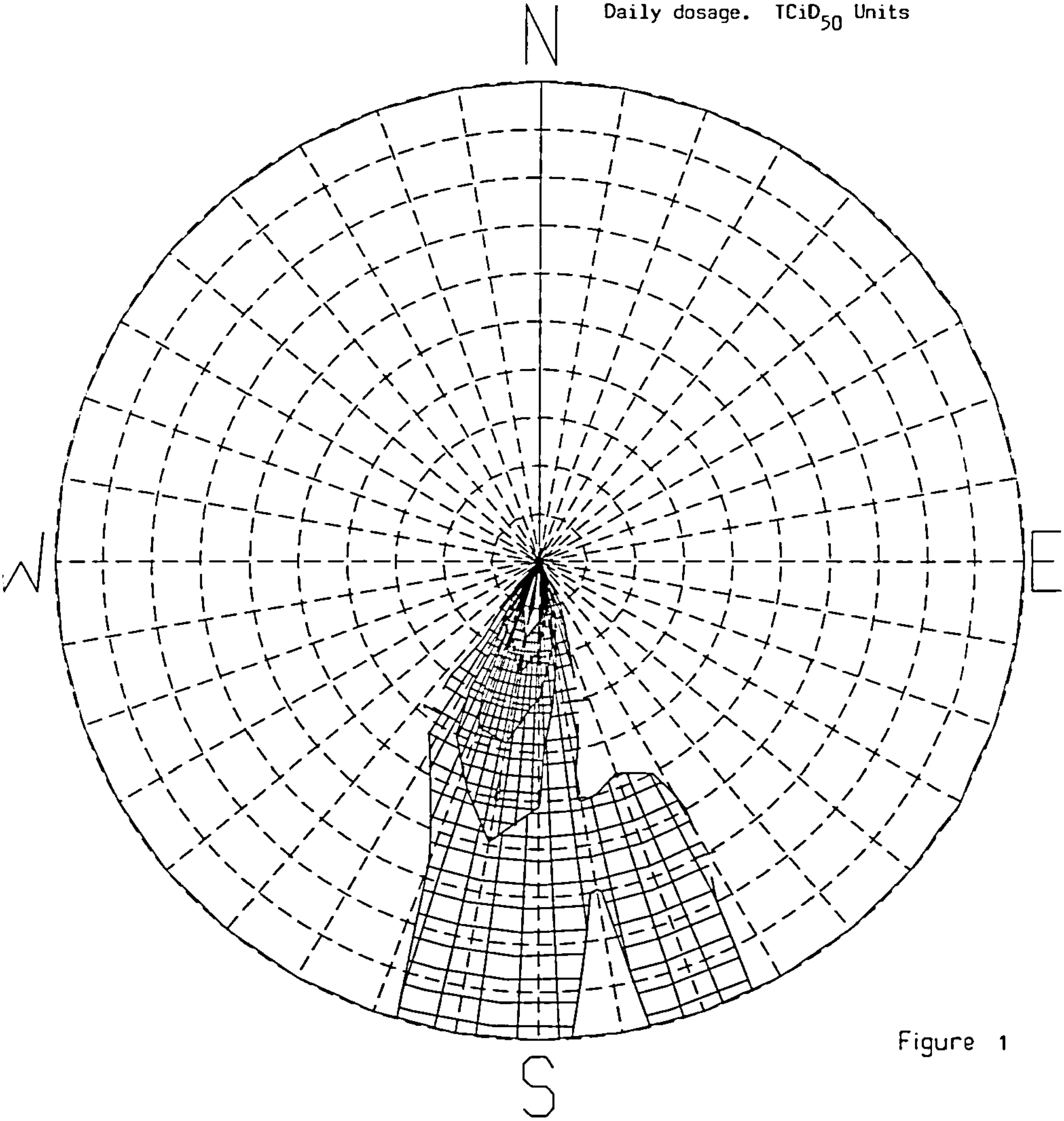
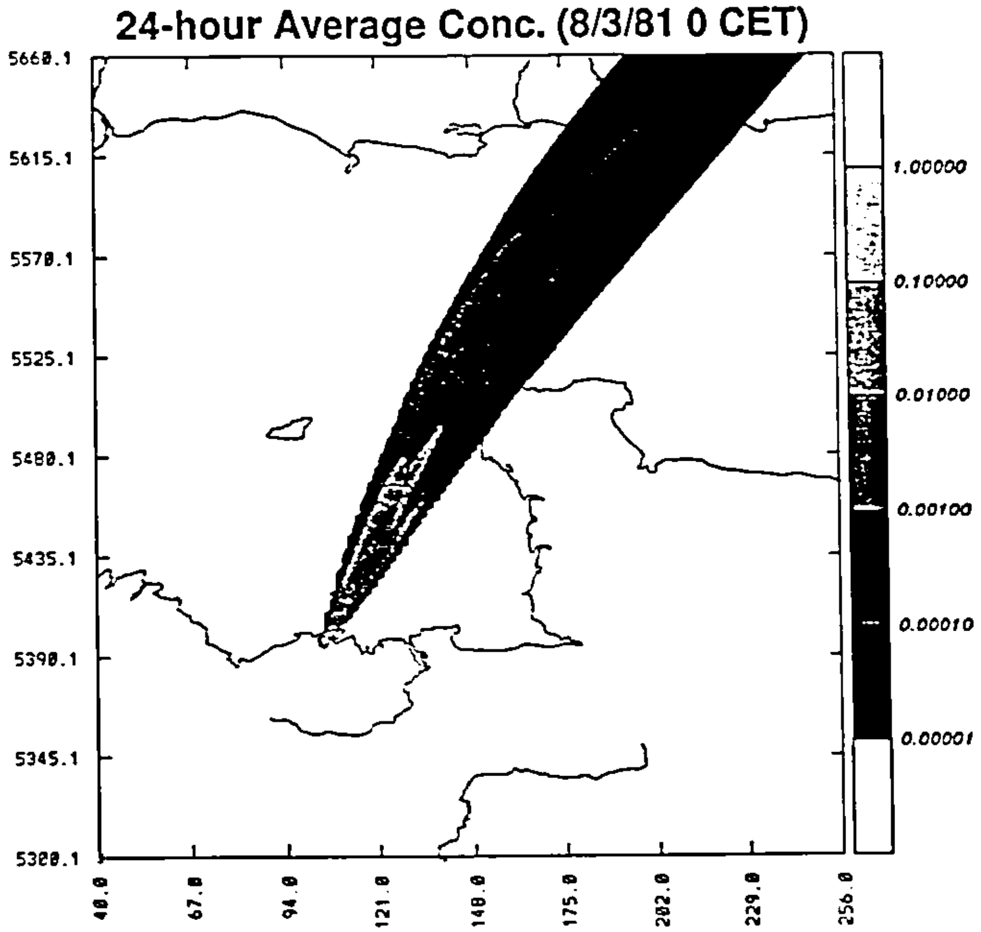


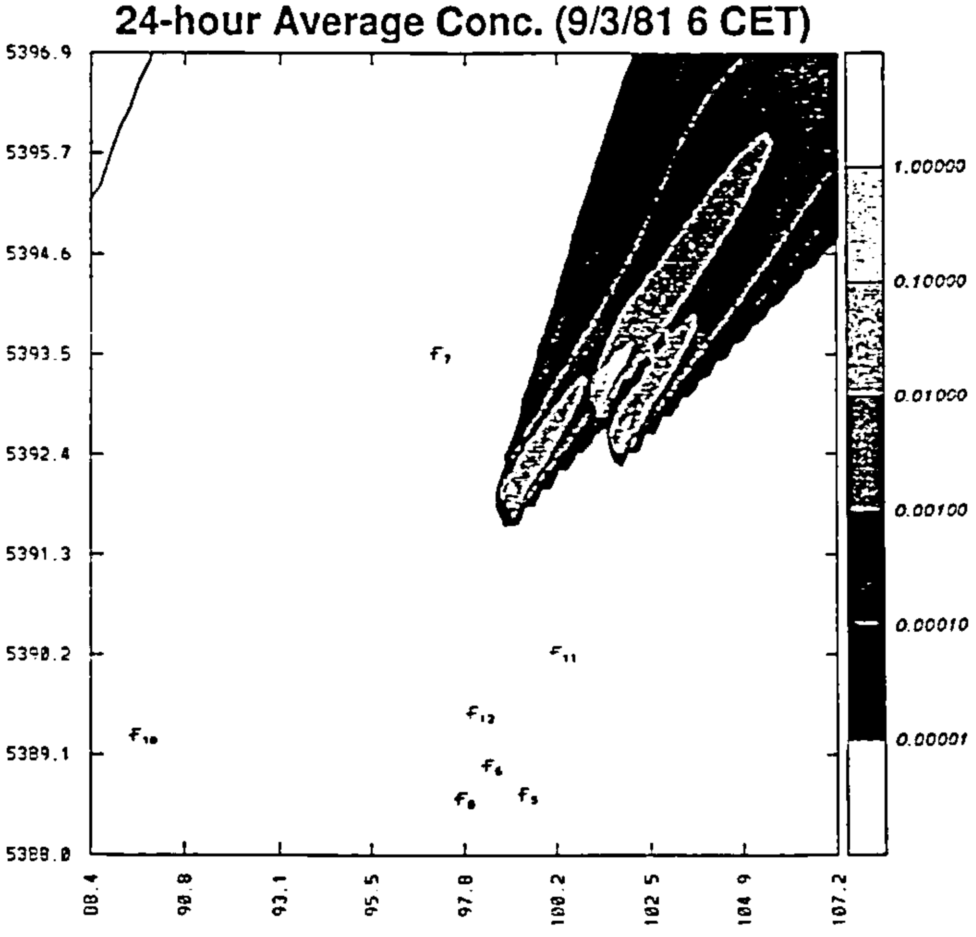
Figure 1



24-hour Average Conc. (8/3/81 0 CET)

FIG. 2 Virus plume from an outbreak on a pig-holding farm in Brittany reaching Jersey and the Isle of Wight. The contours indicate 24-hour average FMD virus concentrations on March 8, 1981, at 0 CET, in units of $TCID_{50}/m^3$. The axis units are UTM coordinates, zone 31.

(From Sorensen and Jensen, 1997)



24-hour Average Conc. (9/3/81 6 CET)

FIG. 3 Virus plume from infected premises no. 2, 3 and 4 reaching no. 9, cf. Table 3.2. The contours indicate 24-hour average FMD virus concentrations on March 9, 1981, at 6 CET, in units of $TCID_{50}/m^3$. The axis units are UTM coordinates, zone 31. (From Sorensen and Jensen, 1997).

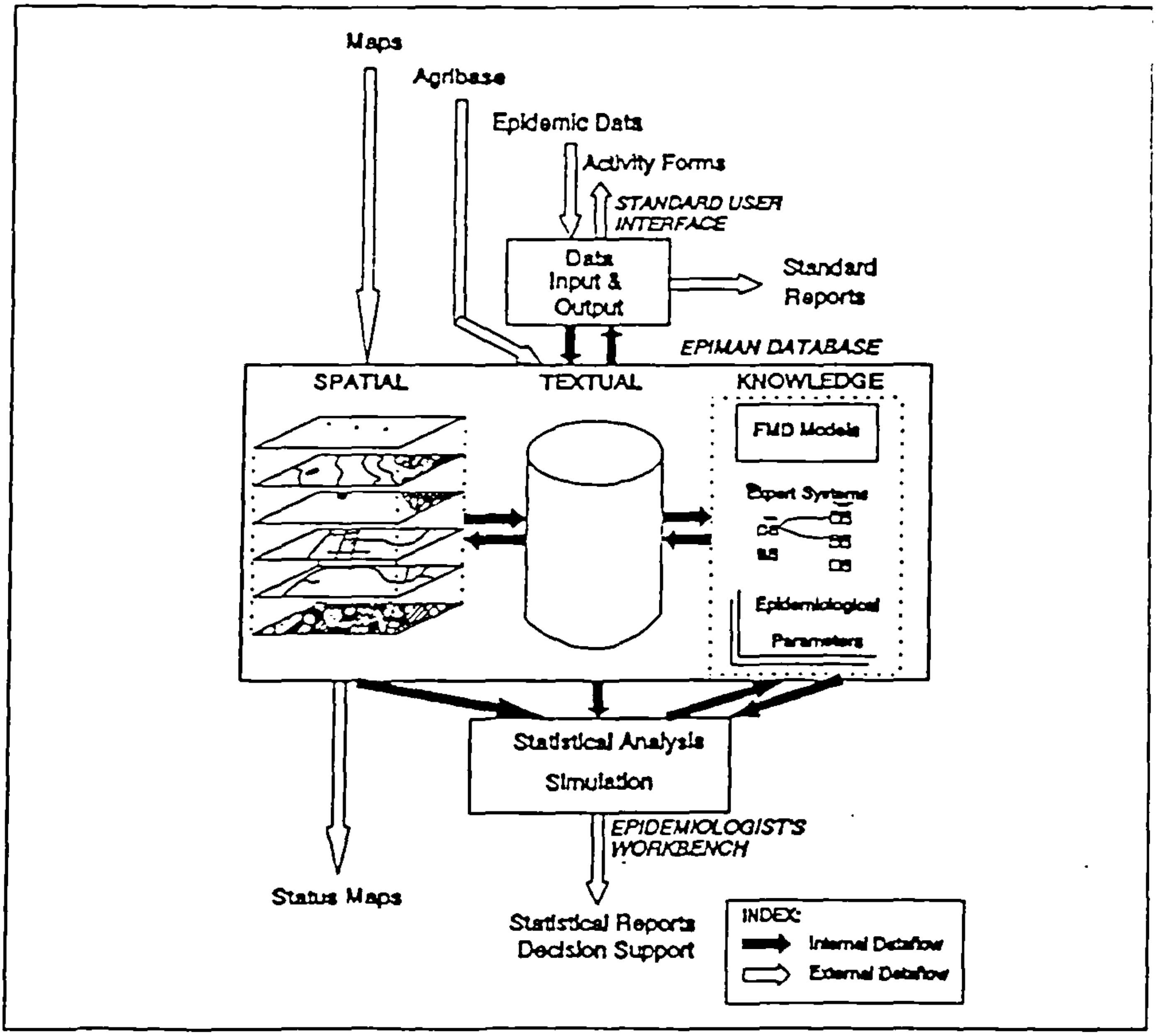


Figure 4: The structure of EpiMAN.