Airborne Spread of Foot-and-Mouth Disease in Saskatchewan, Canada, 1951-1952

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ABSTRACT

Farms affected with foot-and-mouth disease during the epidemic in Saskatchewan, in 1951-1952, for which the origin of virus was not known or uncertain, were studied to determine if infection could have been introduced by the airborne route. A short-range Gaussian plume dispersion model was used to estimate the concentration of virus downwind and the dose available for individual animals. The investigation suggested that a large virus source due to infected pigs in a feedlot in January 1952 could have been responsible for airborne dispersion northwestwards downwind to farms up to 20 km distant. Subsequent spread from these farms was to neighboring farms and was influenced by the local topography of a creek. The dispersion model could be used for predicting airborne spread if foot-and-mouth disease should occur.

RÉSUMÉ

Les fermes de la Saskatchewan touchées par l'épidémie de fièvre aphteuse de 1951-1952, épidémie dont l'origine est toujours demeurée incertaine, ont fait l'objet d'une étude afin de vérifier si le virus aurait pu être introduit par voie aérienne. Un modèl de Gausse a courte étendue de dispersion a été utilisé afin d'évaluer les concentrations de virus emportés par le vent ainsi que les quantités de virus pouvant infecter chaque animal. Les résultats de l'étude démontrent qu'un parquet d'engraissement de porcs aurait été la source de contamination pour des fermes situées à plus de 20 km. Une dispersion subséquente du virus dans les fermes avoisinantes aurait été favorisée par la topographie du terrain. Ce modèl de dispersion pourrait étre avantageusement utilisé si une autre épidémie du méme genre survenait. ***(Traduit par Dr Pascal Dubreuil).***

INTRODUCTION

During the epidemic of foot-and-mouth disease (FMD) in Saskatchewan, in 1951-1952, there were a number of infected farms where the source and method of infection were unknown or uncertain (1). It was decided to see if spread to these farms could have been by the airborne route using the type of analysis used in previous investigations (2,3).

MATERIALS AND METHODS

VIRUS OUTPUT

Numbers of animals on each farm and numbers affected by FMD were obtained from the records and are given in the previous paper (1). However, it was not possible in every instance to find out how many animals were infected and for how long. The assumption was therefore made that all animals on the farm could have been infected at some time and could have been a source of airborne virus. Pigs were assumed to be excreting at a rate of 3.23×10^3 infectious units (IU) s^{-1} and cattle and sheep at 1.98 IU s^{-1} (4,5) (1 IU is regarded as equivalent to 1.4 ID_{50} assuming a Poisson distribution).

VIRUS INTAKE

Cattle were considered to be inhaling 0.1 m^3 min^{-1} or 6 m^3h^{-1} (6). Donaldson *et al* (7) found experimentally that the minimal dose of FMD virus for calves by the natural route was 25 ID_{50}, i.e. 17.5 IU and Burrows *et al* (8) infected a steer with six plaque-forming units by intranasal spray. However, as virus output could be underestimated by a factor of fivefold to a hundredfold (9) one IU was taken to be the infectious dose for cattle.

METEOROLOGICAL DATA

Temperature, relative humidity, wind direction and speed, and cloud amount and ceiling were obtained from the Canadian Climate Centre.

CALCULATION OF DOWNWIND CONCENTRATION OF VIRUS

A short-range Gaussian plume dispersion model was used to estimate the virus concentration downwind from the virus source. This computer program was originally developed by the senior author for the Atmospheric Environment Service to assist meteorologists at regional Weather Centres across Canada in response to accidental release of toxic chemicals into the atmosphere (10). The model can be used for gases or for aerosols consisting of particles less than about 20 μm

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TABLE I. Concentration and dose of virus at farm 7 on 7 January 1952 with feedlot 4 as source

Concentration (IU m^{-3})	Duration of wind (h)	Dose (IU/beast)
4.9 x 10^{-2}	3	0.882
2.1 x 10^{-1}	4	5.040
1.2 x 10^{-1}	1	0.720
Total dose for the day		6.642

TABLE III. Numbers of animals on source farms and estimated period of excretion of virus

Farm	Number of animals	Period of excretion
4	207C, 56P, 145S[a]	Middle of Dec - end of Feb
20	180C	Middle of Dec - middle of Feb
6	10C	9-31 Jan
7	40C	17 Jan-3 Feb
8	19C, 2P	20 Jan-11 Feb
10	12C, 1P	23 Jan-10 Feb
16	34C	21 Jan-12 Feb

[a]C = cattle, P = pigs, S = sheep

in diameter released from a continuous point source. Thus it was appropriate for determining the concentration downwind of FMD virus particles, diameter 3-10 μm (6).

CALCULATION OF DOSE

The dose per cattle beast was calculated from the concentration downwind at the farm multiplied by the volume of air breathed by one cattle beast during the hours that the wind was blowing from the source to the farm. The dose was expressed on a daily basis (Table I).

RESULTS

RELATIVE HUMIDITY AND TEMPERATURE

Foot-and-mouth disease virus retains its infectivity in an aerosol at relative humidities (RH) of 60% or higher (11, 12). From December 1951 to February 1952 the RH did not fall below 77%. Temperatures during the period were between -43°C and 2.8°C. Extremely low temperatures do not affect survival of viruses as an aerosol; for example Ehrlich and Miller (13) found that aerosols produced from Venezuelan equine encephalitis virus had similar survivals between temperatures of -40°C and 24°C. Therefore inactivation of virus during dispersion as an aerosol is unlikely to have occurred.

AIRBORNE DISPERSAL

The farms that could have been infected by the airborne route are those described in the previous paper for which no source was given or for which a method of infection was rated as possible or improbable (1). The dates of first appearance of lesions, the possible sources together with distance and bearings were derived from the information available and are shown in Table II. The numbers of animals on the premises that could be sources together with the likely period of virus excretion are given in Table III. The location of the farms is shown in Fig. 1.

The outbreaks from 28 January 1952 onwards (farms 9, 11, 13, 19, 14, 17 and 18) were clustered around previous outbreaks on Wascana Creek. Farms 11 and 14 were within 2 km of farm 7 and farm 13 was contiguous. At this point along the Creek the valley is 5 m deep and 0.5 km wide. Farm 17 was contiguous to farm 10 and here the valley is 10 m deep and 0.5-0.8 km wide. Farm 19 was contiguous to farms 8 and 16 and lay in a valley 10-15 m deep and 0.5 km wide. Farm 9 was downstream of farm 8; the depth of the valley varies from 30 m at farm 8 to 45 m at farm 9 with a width of 0.1-0.5 km. Thus the topography of Wascana Creek would have influenced wind direction and the downwind concentration of virus in the plume could have been greater than if the dispersion was over open country. Farm 18 was contiguous to farm 20. The records of wind direction made at Regina Airport during January and February showed that there were suitable winds on days during the incubation periods for carriage of virus to infect these farms (Table IV).

The airborne spread to premises 6, 7, 8, 16 and 10 would have involved carriage of virus over distances from 3 to 20 km and would have been mainly over level ground. Virus concentration, downwind at farms 7, 8, 16 and 10 was calculated using the plume dispersion model (10). The calculations showed that there was insufficient output from farm 6 to give a dose sufficient to infect downwind. Suitable winds to carry infection from farm 20 to farm 7 were few and there was insufficient output for carriage to the other farms. The feedlot 4 could have given rise to infection of farms 7, 8, 16 and 10 by the airborne route. The days on which a dose of > 1 IU could have been inhaled by a cattle beast on the various farms are shown in Table V. Winds were also available to carry infection from feedlot 4 to farm 6 (Table IV).

The results of the investigations on airborne dispersal are summarized in Table VI, which lists the likely airborne source for each recipient farm as well as other possible routes of infection. The analysis suggests that infected pigs at feedlot 4 could have been the source of FMD virus, which

TABLE II. Possible sources, distances and bearings for farms infected by the airborne route

Farm	Date of disease	Source farms	Distance (km)	Bearing (o)
6	10 Jan	4, 20	3, 3	90, 340
7	18 Jan	4, 6, 20	9, 5.65, 3.75	110, 120, 85
8	21 Jan	4, 6, 20	20, 18 15	115, 120, 115
16	22 Jan	4, 6, 20	19, 16.25, 13.4	110, 110, 110
10	24 Jan	4, 6, 20, 7	14.3, 10.9, 9.4, 5	105, 105, 90, 90
9	28 Jan	8	5	185
11	29 Jan	6, 7	3, 1.5	100, 320
13	29 Jan	6, 7	3.5, 1	100, 350
19	29 Jan	8, 16	1, 1	360, 95
14	30 Jan	7	2	85
17	10 Feb	10	0.8	180
18	12 Feb	20, 7	0.8, 2	130, 250

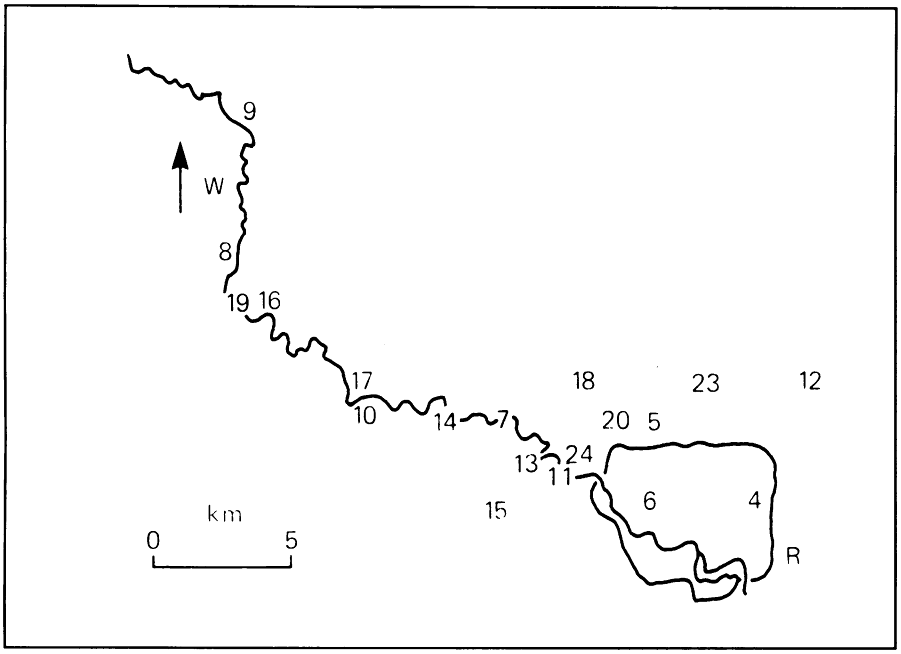

Fig. 1. Location map of FMD outbreaks in Saskatchewan, 1951-1952, in Regina and surroundings. 4-24 = farms 4-24; R = Regina showing city boundary; W = Wascana Creek; → = direction of flow of water in creek.

was carried by the airborne route to farms 7, 8, 16 and 10 during the middle two weeks of January. These farms in turn could have been the source of airborne infection to neighboring farms in Wascana Creek.

DISCUSSION

The short range Gaussian plume dispersion model (10) was used to estimate the concentration of FMD virus downwind and hence the dose likely to be inhaled by an animal. It should therefore have applications in any future outbreaks of FMD or in outbreaks caused by pathogens capable of being spread by the airborne route. This model is available at the Weather Centres of the Atmospheric Environment Service throughout Canada and uses weather data observed within the previous 24 h and earlier. However allowance would have to be made for the topography of the area involved as has been made in other models (3, 14). In the cases examined in the paper the spread of FMD virus was over reasonably level terrain.

TABLE IV. Dates on which farms were downwind to sources

Source farm	Recipient farm	Dates	Interval (days)
7	11	21-23 Jan	6-8
7	13	21-23 Jan	6-8
7	14	20-21 Jan	9-10
8	9	20-21 Jan	6-7
8	19	21-22 Jan	7-8
16	19	21 Jan	8
10	17	30 Jan	11
		2-4 Feb	6-8
20	18	30 Jan	13
		1-2 Feb	10-11
		4 Feb	8
		6 Feb	6
4	6	1-4 Jan	6-9

The infection of farms 6, 7, 8, 16 and 10 by the airborne route depended on there being a large source of virus. The only possible large source among the farms reported as having disease at that time was feedlot 4, where there were 56 pigs. None of the reports makes reference to there being disease in the pigs at feedlot 4 (1). However the following points should be considered in coming to a conclusion about infection:

(a) Vesicular stomatitis was the diagnosis until 18 February 1952. Up to 1951 vesicular stomatitis had been reported in swine on only four occasions, in Venezuela 1941, Colombia 1943, Missouri 1943 and Colorado 1944 (15). During the outbreak of vesicular stomatitis in Manitoba in 1949, in the control of which some of the veterinarians in Saskatchewan took part, vesicular stomatitis affected only cattle and horses (15).
(b) Little attention was paid to pigs during the epidemic until after 11 February 1952, when, on farm 18 pigs were seen to have separation of the hoof (1).
(c) The pigs were in the feedlot, where more than 100 cattle were affected with vesicular lesions.
(d) Foot-and-mouth disease in pigs is often difficult for the inexperienced to detect, e. g. outbreaks in the UK in 1966 and 1967, one of which was in an abattoir (2).
(e) The impression is given in the reports that more attention was paid to the continuing operation of the packing plant than to the feedlot; for example quarantine for vesicular stomatitis was not imposed until 28 December 1951 — nine days after disease was reported.

In this connection Donaldson *et al* (16) suggested that wild boars suffering from FMD in Jordan could have been the source of airborne infection in sheep and gazelles in Israel.

There were reports of pigs being affected with FMD on farms 1 and 2; however, this information was not

TABLE V. Virus dose for days on which farms 7, 8, 16 and 10 were downwind to feedlot 4

Source farm	Recipient farm	Dates	Interval (days)	Dose (IU)
4	7	3 Jan	15	42.9
		4 Jan	14	18.1
		5 Jan	13	5.5
		7 Jan	11	6.6
		12 Jan	6	1.7
		14 Jan	4	6.0
4	8	5 Jan	16	2.0
		7 Jan	14	2.6
		10 Jan	11	2.0
		14 Jan	7	2.6
		15 Jan	6	1.2
4	16	7 Jan	15	2.6
		10 Jan	12	2.3
		14 Jan	8	2.6
		15 Jan	7	1.2
		18 Jan	4	5.5
4	10	10 Jan	14	2.9
		14 Jan	10	5.2
		15 Jan	9	5.2
		17 Jan	7	2.9
		18 Jan	6	7.2
		20 Jan	4	4.6
		21 Jan	3	4.3

TABLE VI. Summary of sources for airborne infection

Farm	Source farm of airborne infection	Other routes of infection
6	4	Person
7	4	
8	4	
16	4	
10	4	
9	8	
11	7	Person
13	7	Person
19	8, 16	Person
14	7	
17	10	Animal
18	20	Person

given to the authorities until March 1952 (Table VI, reference 1). Winds blew from the northwest and southeast during the likely period of FMD virus emission from these farms. There were woods to the north, southeast and south of farm 1 and to the west, northeast and south of farm 2. The woods would have shielded the farms emitting virus and the farms at risk downwind. Therefore despite the possible high output of virus from the pigs infection would not have occurred by the airborne route.

The virus output from cattle where they could have been the source was insufficient to ensure a high enough concentration downwind. In some instances dilution of the plume could have been less due to the topography of Wascana Creek. In addition there may have been a katabatic (downslope) effect, whereby the virus aerosol could have been transported along and down the valley (17).

The first animal to show disease on farm 8 was the bull. This was to be expected if infection was by inhalation owing to the larger volume of air sampled compared with the cows (6).

The information from weather stations in North America is of high quality and a short-range dispersion model can be used to eliminate possible sources of airborne virus as with farms 6 and 20 and indicate areas which are not at risk from airborne spread (3, 18). This information can be made available rapidly and enable the areas at risk to be monitored and the resources for control to be deployed to the best effect. However, the successful use depends on knowledge of the number of animals on the farm affected with FMD and the extent of lesions to give an estimate of virus output based on previous work (4, 5). Complete information was not available for the outbreaks in Saskatchewan in 1951-1952, but, if it is accepted that the pigs on feedlot 4 could have been infected, airborne spread would have been feasible.

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