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AIRBORNE DISPERSAL OF BIOLOGICAL AGENTS: SOME ELEMENTARY PRINCIPLES OF ATMOSPHERIC DIFFUSION THEORY

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Knowledge of the spatial and temporal distribution of people and animals affected by an outbreak of infectious disease can, in some situations, identify the mode of transmission and the source of the infectious agent. Thus, Thucydides, noting that people in the port city of Piraeus were afflicted before those in the upper city, surmised that the Plague of Athens in 430 B.C. had come from overseas.

In a more recent example, a California medical student, Clyde Wellock, found that the residences of people who contracted Q fever during a 1953 outbreak in the San Francisco Bay area were clustered in a narrow swath 7 miles long parallel to the direction of the prevailing wind (Figure 1). This led him to conclude that the infection was airborne and to identify the probable source of the infectious aerosol as a rendering plant that processed sheep and goats, located at the upwind apex of the swath (Wellock 1960; Wellock and Parker 1959).

Similarly, it was the mapping of the residential and workplace locations of human cases in the city and the locations of livestock cases in the countryside, combined with meteorological records, that enabled us to conclude that the 1979 anthrax outbreak in Sverdlovsk, USSR resulted not from the consumption of contaminated animal products, the explanation put forward by Soviet officials, but rather from the escape and downwind travel of an infectious aerosol that originated at a military microbiological facility within the city during the day on Monday, April 2 (Meselson *et al.* 1994; Meselson 1995).

Aerosol dissemination has received far more attention than any other mode of biological weapons delivery in each of the offensive BW programs of which we have specific knowledge, including those of Imperial Japan, Britain, the United States, Canada, the Soviet Union, and Iraq. An understanding of the principles of atmospheric diffusion is therefore important to the problem of distinguishing disease outbreaks that are natural from those that are not and which may or may not be the result of activities prohibited by the

As the distribution moves downwind from the release point, the standard deviations of the Gaussians increase--the probability distribution spreads out in each direction. Because the eddy structure of the atmosphere is generally not isotropic, the standard deviations of the distribution along different axes will generally increase at different rates.

If individual aerosol particles are assumed not to interact, the probability distribution of a single particle is obviously equivalent to the concentration distribution of many such particles released at a point source to form a cloud. Consideration of the behavior of a single particle has simply made it easier to visualize the diffusion process and to delineate the approximations made in the model.

In practice, the along-wind concentration distribution of the cloud need not be known, since one integrates over the entire cloud passage time to obtain the quantity of interest, the total dosage at any given downwind location. This is fortunate, as variations of wind speed with altitude and other factors make the Gaussian Plume Model ill-suited for predicting along-wind concentration distributions and the model is not used for that purpose. Integration over the entire cloud passage time also allows us to ignore the duration of the initial release, so long as the assumptions we have made remain valid throughout, so that the probability distribution for each single particle integrated along the *x*-axis remains independent of when it was released.

A further simplification results if we confine our attention to situations in which the vertical distance between the release point and the population at risk is small compared to the downwind distance of the population from the source, so that source height can be ignored. The cross-wind distribution of dosage at any downwind distance *x* is then simply a Gaussian distribution in *y*, the standard deviation of which increases and the area under which decreases as the cloud moves downwind. If the number of particles released at $x=0$, $y=0$ is Q, the total dosage $T(x,y)$ at the downwind position (x,y) will be:

$$(1)\quad \mathbf{T}(x,y) = \mathbf{Q}[\pi u \sigma_y \sigma_z]^{-1}\exp[-(1/2)(y/\sigma_y)^2]$$

where

u = wind speed in meters per second

σ_y = cross-wind standard deviation, in meters, at x

σ_z = vertical standard deviation, in meters, at x

The quantity $[\pi u \sigma_y \sigma_z]^{-1}$ in the coefficient of the exponential is determined by the normalization condition that no particles are lost from the cloud. Losses from surface impaction, fallout, rainout, or any other process are assumed to be negligible.

For a line source, the total dosage T' at a location downwind, obtained by integrating equation (1) with respect to *y* is:

presentation is the set of polynomials in x given by Briggs (1973) for open-country conditions.

Table 2
Formulae for Standard Deviations as a Function of Downwind Distance x

Pasquill Stability	σy (m)	σz (m)
A	$0.22x(1+0.0001x)^{-1/2}$	$0.20x$
B	$0.16x(1+0.0001x)^{-1/2}$	$0.12x$
C	$0.11x(1+0.0001x)^{-1/2}$	$0.08x(1+0.0002x)^{-1/2}$
D	$0.08x(1+0.0001x)^{-1/2}$	$0.06x(1+0.0015x)^{-1/2}$
E	$0.06x(1+0.0001x)^{-1/2}$	$0.03x(1+0.0003x)^{-1}$
F	$0.04x(1+0.0001x)^{-1/2}$	$0.016x(1+0.0003x)^{-1}$

Some examples from the field. There is an immense body of experimental data from field studies of atmospheric diffusion. Such studies have been performed for a variety of purposes, including the development and calibration of atmospheric diffusion models, the assessment of hazards from industrial pollution and chemical spills and the estimation of CW and BW target effects and munitions requirements. An extensive study of aerosol cloud travel in cities was undertaken for the later purpose during 1953 in Minneapolis, Minnesota, Saint Louis, Missouri, and Winnipeg, Canada, altogether comprising some 173 releases of aerosol tracer materials from single point sources, multiple point sources, and line sources (Calder *et al.* 1954). A typical pattern measured over a grid of sampling stations for a point source located in a parked automobile in Saint Louis at night with a clear sky and a light wind is shown in Figure 2, along with the distribution calculated from

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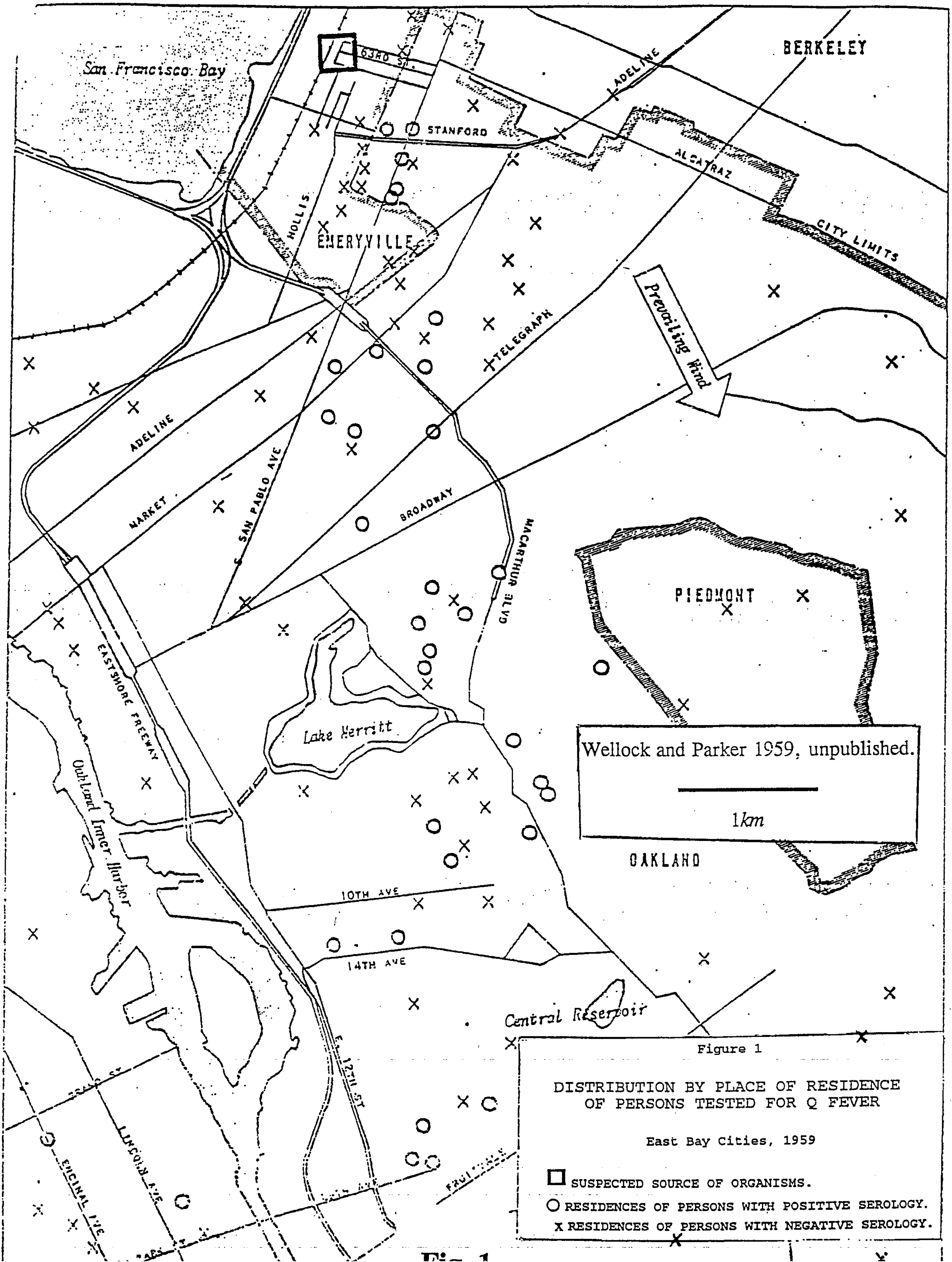


Wellock and Parker 1959, unpublished.

Figure 1

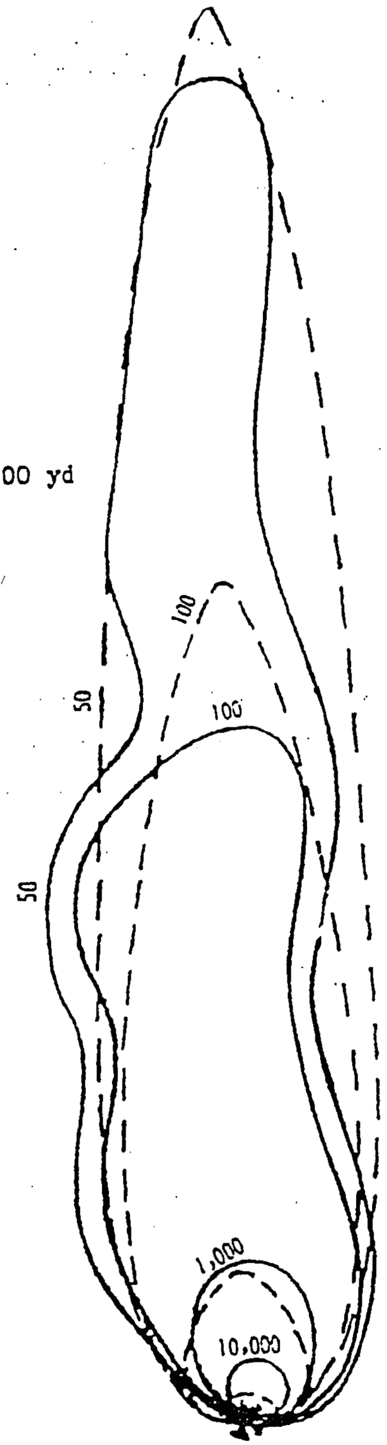
DISTRIBUTION BY PLACE OF RESIDENCE OF PERSONS TESTED FOR Q FEVER

East Bay Cities, 1959

□ SUSPECTED SOURCE OF ORGANISMS.
○ RESIDENCES OF PERSONS WITH POSITIVE SEROLOGY.
x RESIDENCES OF PERSONS WITH NEGATIVE SEROLOGY.

Fig. 2

COMPARISON OF EXPERIMENTAL AND CALCULATED DOSAGE IN AN URBAN ENVIRONMENT



- Saint Louis, Missouri
- 25 May 1953
- 10:35 PM CST
- Built-up area one mile west of principal business district.
- Wind SSW at 2-3 m/sec
- Neutral atmosphere stability, clear sky
- Aerosol release for 5 min. from parked automobile.

Fig 3

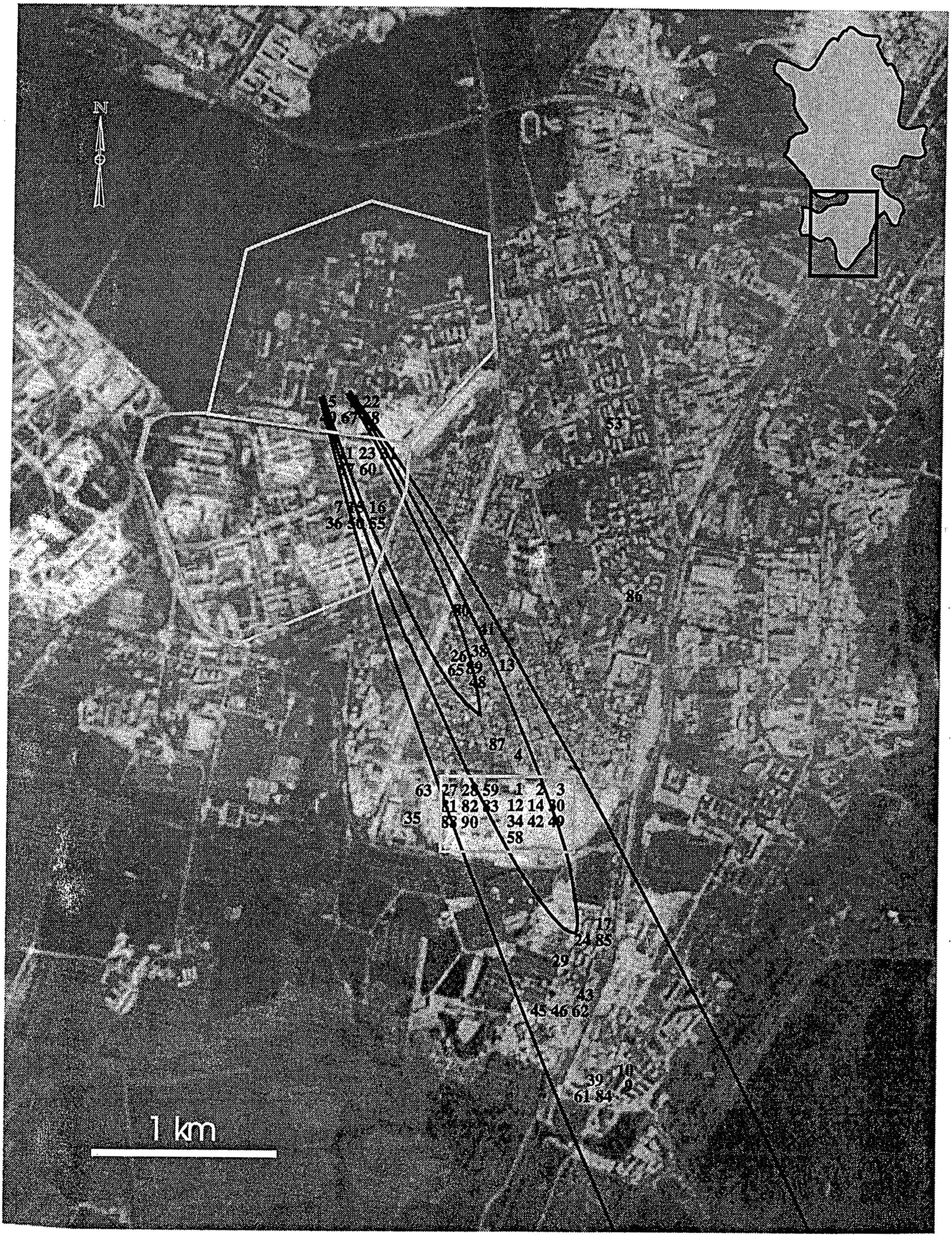

N
15 22
19 67 18
11 23 81
17 60
7 16
36 55 65
53
86
80
41
26 38
65 89 13
48
87
4
63 27 28 59 1 2 3
81 82 83 12 14 30
35 88 90 34 42 40
58
17
24 85
29
43
45 46 62
39 10
61 84 9
1 km

Fig. 4