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An air pollution model of Zeeland

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CONTENTS

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by

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1. Introduction

An air pollution model is the only useful tool if one wants to calculate the influence of different kinds of sources at specific sites or the consequences of changing source pattern. In this report the consequences of changing source pattern in Zeeland are studied with the aid of an air pollution model. The model is described in section 2. A similar approach formed the basis for the calculations by Meade and Pasquill (1958) of annual SO_2 concentrations in the vicinity of the Staythorpe Power Station (using the Sutton formula). Furthermore, the same approach has been applied by Martin (1971) to estimate the average concentrations over seasonal periods for St. Louis, Mo.

In the present study the seasonal averages of concentrations are calculated by using the diffusion climatology from the meteorological station Vlissingen. Pollutant concentration patterns for three different cases are given only for winter. The physical chimney heights of the planned sources are varied in order to assess the changes in the ground-level concentrations and which may assist the planners in deciding the chimney heights for the planned sources. The ground-level concentrations were also calculated for spring, summer and autumn but the results are not included in this report because of the occurrence of much lower concentrations during these three seasons as compared to the winter season.

2. Basic equation

If the wind directions are taken to n compass points and it is assumed that wind directions within each sector are distributed randomly over a period of a month or a season, it can be further assumed that the effluent is uniformly distributed in the horizontal within the sector (Holland, 1953). The appropriate equation for average concentration is

$$\bar{\chi} = \frac{2Q}{\sqrt{2\pi}\,\sigma_{zs}\,\bar{U}(\frac{2\pi x}{n})} \cdot \exp\left[-\tfrac{1}{2}\left(\frac{H}{\sigma_{zs}}\right)^2\right], \qquad (1)$$

where

$\bar{\chi}$ = concentration (units/m^3),

Q = the source strength or emission rate (units/sec),

σ_{zs} = the standard deviation of vertical concentration evaluated at the distance x for the stability s (m),

$\bar{U}$ = the mean horizontal wind speed (m/sec),

$\frac{2\pi x}{n}$ = the sector width for each of n sectors at the distance x (m),

H = the effective chimney height (m).

For the derivation of equation (1) one is referred to Slade (1968).

One needs the diffusion climatology in order to estimate the seasonal averages of concentrations in an area. Here the wind speed is divided in five classes (for details see section 4).

The estimation of $\bar{\chi}$ for a particular direction and downwind distance can be accomplished by choosing a representative wind speed for each class solving the above equation for all wind speed classes and stabilities. One obtains the average concentration for a given direction and distance by summing all the concentrations and weighting one according to the frequency of the particular stability and wind speed class. The average concentration (in case n = 12) can then be expressed by

$$\bar{\chi}\,(x,\theta) = \sum_S \sum_N \left\{ \frac{2Q\, f(\theta,S,N)}{\sqrt{2\pi}\,\sigma_{zs}\,\bar{U}_N\,(\frac{2\pi x}{12})} \cdot \exp\left[-\tfrac{1}{2}\left(\frac{H}{\sigma_{zs}}\right)^2\right]\right\}, \qquad (2)$$

where $f(\theta,S,N)$ = the relative frequency of winds blowing into the given 30^o wind direction sector (θ) for a given wind speed class (N) and atmospheric stability (S),

$\bar{U}_N$ = the representative wind speed for class N (see section 4),

$\frac{2\pi x}{12}$ = the sector width for each of 12 sectors at the distance x,

and the symbols Q, σ_{zs} and H have the same meaning as defined above.

3. Emission parameters

The location of the sources is marked with solid circles on the concentration maps. The numbers attached to the solid circles correspond to the numbers shown in Table I and therefore represent the sources together with their

related data. For example number 1 attached to the solid circle in the concentration map refers to the location of PZEM-Vlissingen, its emission rate and the chimney height as given in Table I.
Emission data of all the sources are given in Table I.

Table I: Emission data

Number	Name of the source	Type of the source	Chimney height (m)	Emission rate (SO_2 kg/hr)
1	PZEM, Vlissingen	point	125	1500
2	PZEM, Borssele	"	125	500
3	Hoechst	"	55	210
4	Péchiney	"	20	90
5	Union Kraftwerk	"	70 (48,5)	432
6	Total (raffenaderij)	"	100 (70)	1133

4. Meteorological data

Diffusion climatology of Vlissingen for the period 1949-1970 is computed with the help of the computer. The wind speeds are grouped in 5 classes i.e. ≤ 5 knots, 6-12 knots, 13-17 knots, 18-25 knots and greater than 25 knots and the wind directions are taken to 12 compass points. The seasonal and annual joint frequency distribution of Pasquill stability categories and wind directions are determined for each wind speed class. Incidentally, air pollution climatology of the Netherlands for use in long-range planning of the air resources management programme has been developed by K.N.M.I. (Royal Netherlands Meteorological Institute) and will be published soon (1972).
It is to be noted, however, that the mid-interval value of a wind speed class adjusted to the height of the chimney with the aid of the well-known power law wind profile is used as an input for $\bar{U}_N$.
The power law wind profile is given by $U = U_{10} \times (\frac{Z}{10})^P$ where U_{10} and U are the wind speeds at anemometer level and at height Z respectively. The values of P are indicated in Table II.

Tabel II: Values of P according to various stabilities

Stability	P
A, B	0,1
C, D	0,2
E, F	0,5

The vertical dispersion parameter (σ_{zs}) is a function of atmospheric stability and the distance from the source. Pasquill-Grifford curves of σ_{zs} (Turner, 1970) were put in tabular forms which could be readily used by the computer in the calculation of concentrations.

5. Effective chimney height

Effective chimney height is equal to the sum of the physical chimney height and the plume rise due to buoyancy and initial momentum of the effluent discharged in the atmosphere. In this study plume rise is taken to be zero in all the calculations of ground-level concentrations because data concerning the stack parameters (the stack effluent velocity, stack diameter and heat emission rate) were not available. Once the stack parameters are known, the plume rise can be determined and its inclusion would not give any undue difficulty in the calculations. One is referred to Briggs (1969a) for a state-of-the-art report on plume rise. Some of the results on plume rise are also summarized in Briggs (1969b).

6. Results

Ground level concentrations of SO_2 are calculated for four seasons with the help of equation (2). Emission data and meteorological data as described in sections 3 and 4 respectively form the basic input data for the equation (2). Computer-plotted pollutant "winter" concentration patterns are shown in Figures 1, 2 and 3. The value of the isolines in the Figures 1, 2 and 3 multiplied by 0.01 gives the concentration of SO_2 in microgram/cu m. Figure 1 shows the concentration isolines due to the sources 1, 2, 3 and 4. Here the numbers 1, 2, 3, 4, 5 and 6 correspond to the numbers as shown in Table I. Figure 2 shows the concentrations isolines due to the sources 1, 2, 3, 4, 5 and 6. The chimney heights used in the calculations for the sources 5 and 6 are 70 m and 100 m respectivily. On the other hand Figure 3 showns the concentration isolines due to the sources 1, 2, 3, 4, 5 and 6 but the chimney heights used here for the sources 5 and 6 are 48,5 m and 70 m respectivily. Note that the emission data of sources 1, 2, 3 and 4 are kept invariable in all the calculations of concentrations and only the chimney heights of the sources 5 and 6 are changed. The consequences of changing the source heights are clearly evident in the Figures 2 and 3. Also the effect of additional sources (5 and 6) on the existing level of SO_2 concentrations due to the sources 1, 2, 3 and 4 (Figure 1) is vividly brought out in Figure 2.

7. Concluding remarks

One must be careful in interpreting the results of the model and every due consideration should be given to the limitations and assumptions of the model (Pasquill, 1962) as well as to the accuracy of the raw data namely the meteorological data and emission data needed for the model. One is referred to Pasquill (1971) for an up-to-date review of the problems in atmospheric dispersion.

The model fails in case of calm and variable winds and therfore these cases are left out while making dispersion estimates. No provision was made to incorporate the land-sea effect in the model.

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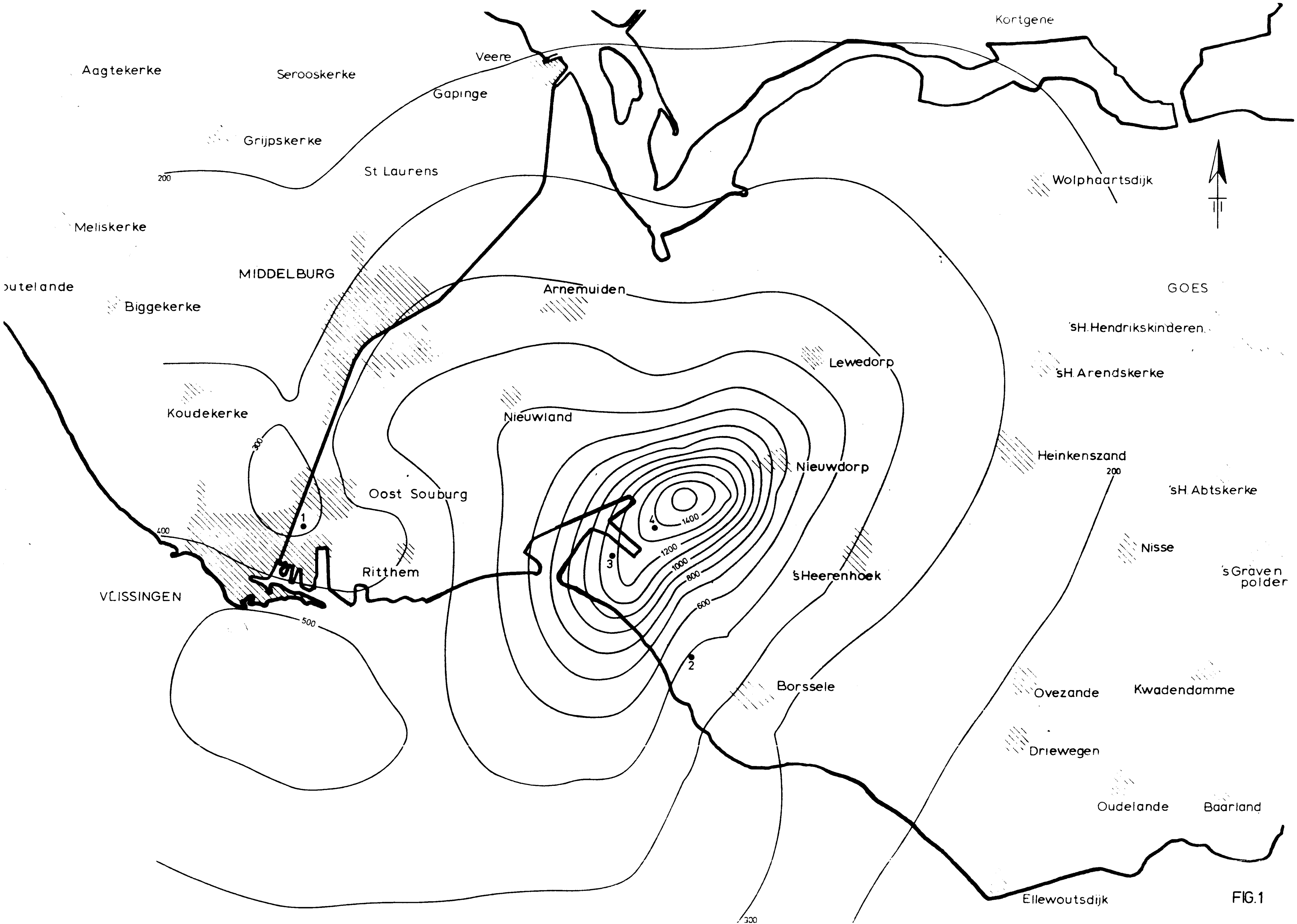
Note: The value of the isolines in the Figures 1, 2 and 3 multiplied by 0.01 gives the concentration of SO_2 in microgram/cu m.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Biggekerke
'sH.Hendrikskinderen
Lewedorp
'sH.Arendskerke
Koudekerke
Nieuwland
300
Heinkenszand
Nieuwdorp
Oost Souburg
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'sH.Abtskerke
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1200
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Ritthem
1000
'sHeerenhoek
'sGraven polder
800
VLISSINGEN
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Baarland
Ellewoutsdijk
300

FIG.1

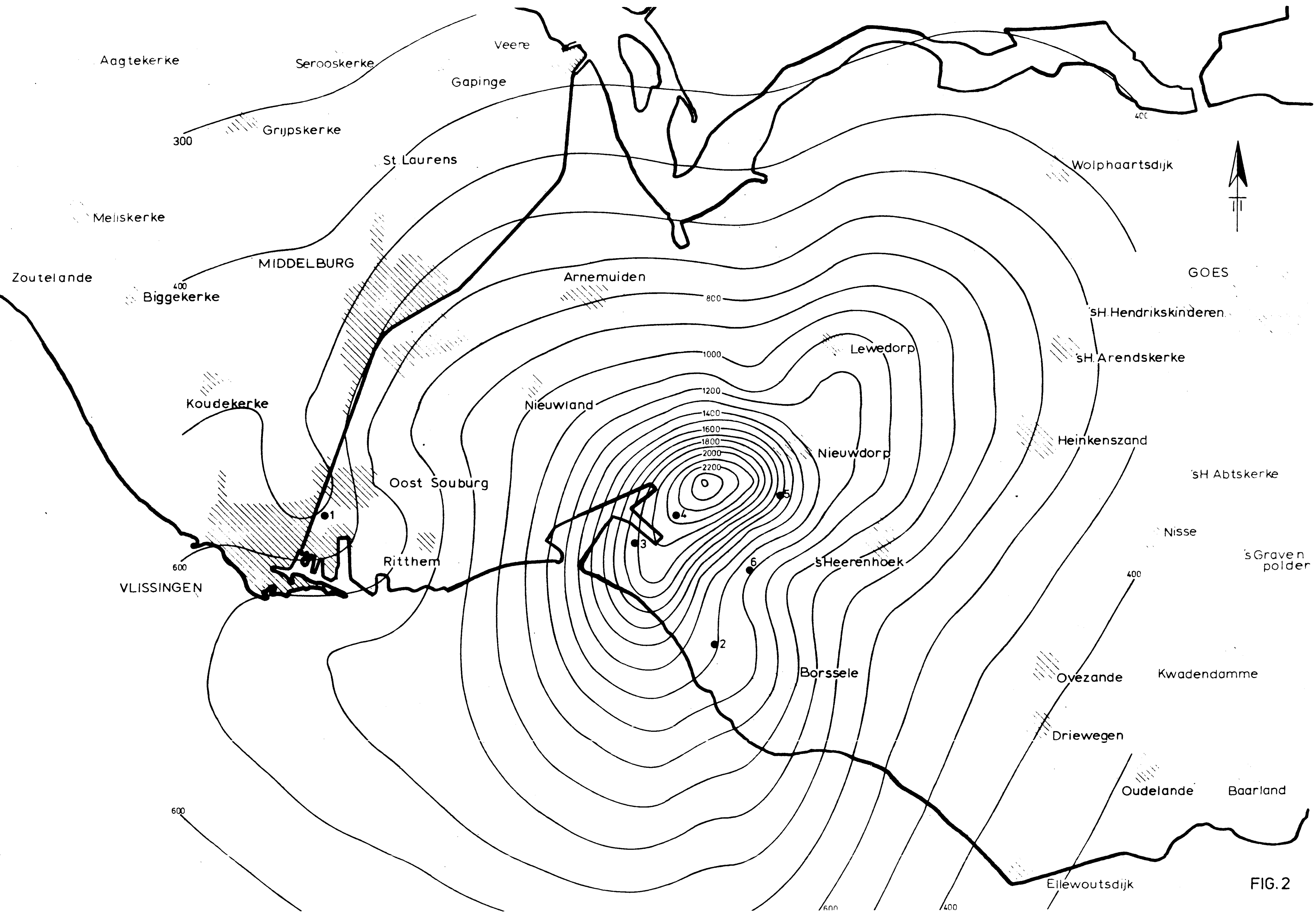
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FIG. 2

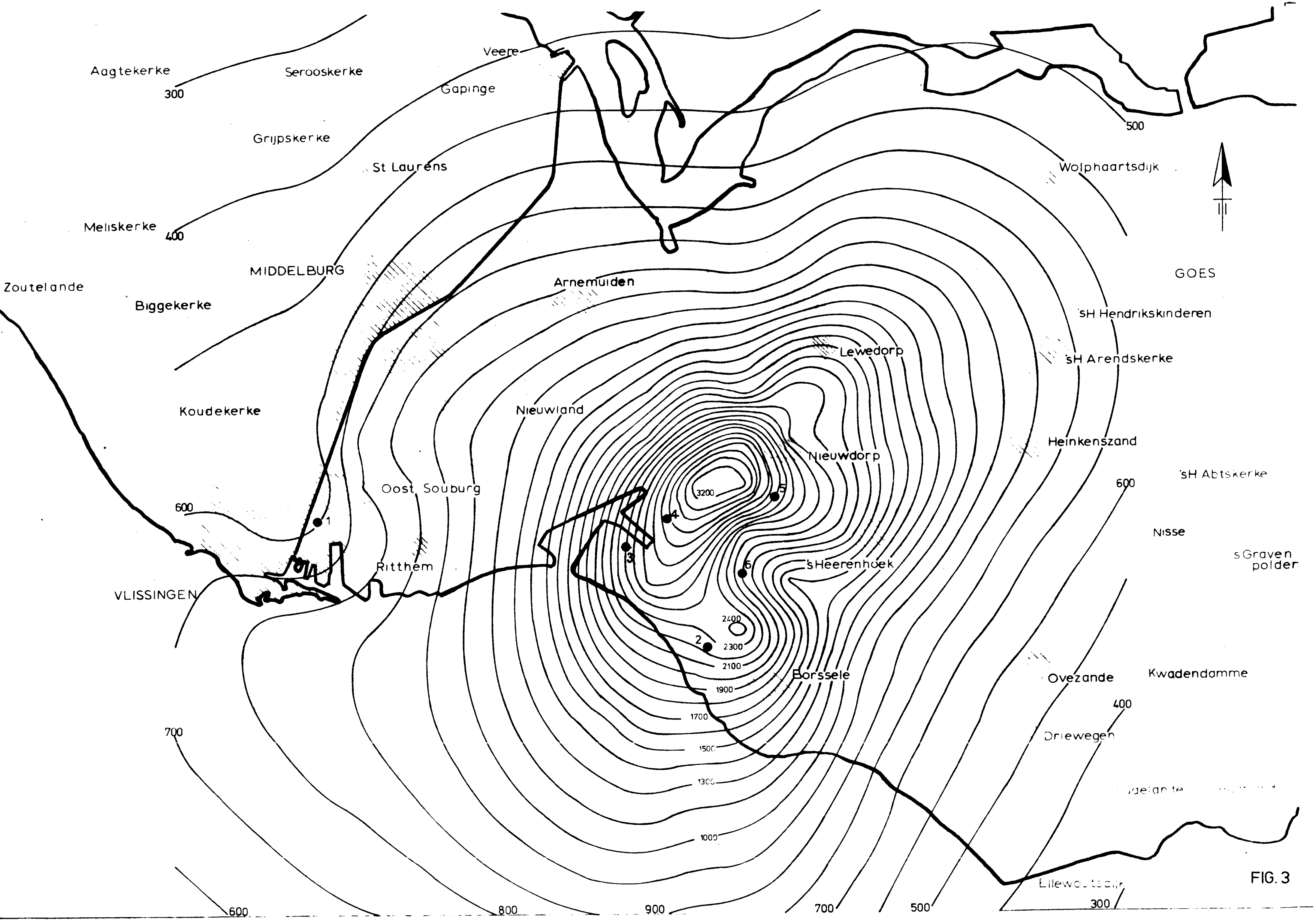

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FIG. 3