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P. Wittek
Institut für Meteorologie und Klimaforschung
Projekt Nukleare Sicherheit

Kernforschungszentrum Karlsruhe

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Summary

In the consequence assessment model, applied in the German Reactor Risk Study (GRRS), atmospheric dispersion of radioactive substances is beeing treated with a straight line Gaussian dispersion model. But some of the German nuclear power plants are located in complex terrain. In this report, the 19 sites which are considered in the GRRS, are described and classified by two different methods in respect to terrain complexity. The relevant effects of the terrain on the dispersion are commented. Two modifications of the GRRS consequence assessment code UFOMOD take into account in a simple way the terrain elevation and the enhanced turbulence effected eventually by the terrain structure. Sample calculations for two release categories of the GRRS demonstrate the effect of these modifications on the calculated number of early fatalities.

Topographie und ihr Einfluß auf die atmosphärische Ausbreitung in einer Risikostudie für nukleare Anlagen

Zusammenfassung

Im Unfallfolgenmodell der Deutschen Risikostudie Kernkraftwerke (DRS) wird die atmosphärische Ausbreitung radioaktiver Stoffe mit einem geradlinigen Gaußmodell berechnet. Einige Standorte deutscher Kernkraftwerke liegen allerdings in komplexem Terrain. Im vorliegenden Bericht werden die 19 Standorte der DRS beschrieben und mit zwei verschiedenen Methoden bezüglich der Komplexität ihrer Umgebung klassifiziert. Die relevanten Einflüsse des Terrains auf die Ausbreitung werden kommentiert. Zwei Modifikationen des Unfallfolgenmodell UFOMOD berücksichtigen in einfacher Weise Geländeerhebungen und die durch die Gebäudestruktur gegebenenfalls bewirkte erhöhte Turbulenz. Berechnungsbeispiele für zwei Freisetzungskategorien der DRS zeigen den Einfluß dieser Modifikationen auf die berechnete Zahl früher Todesfälle.

Contents

1. Introduction

The influence of topography on dispersion was neglected in the first generation of atmospheric dispersion models developed for nuclear accident consequence assessment. One of the reasons was the early stage of complex terrain model development being at research grade at the time when the first comprehensive assessment of risk and consequences, the Reactor Safety Study (Wash-1400) /WA75/, was published. The study appeared in 1975 and investigated the overall consequences from hypothetical accidents of nuclear power plants located at 68 sites in the United States. In a similar way like Wash-1400, the German Reactor Risk Study /DR79/, published in 1979, assessed the consequences associated with nuclear accidents of power plants at 19 sites. At that time the lack of appropriate meteorological and terrain data prevented the treatment of topographical effects. Furtheron modelling of plume dispersion and dilution over complex terrain has to take into account a combination of atmospheric stratification, topography, synoptic and local scale flow velocity and direction. The uncertainties involved in estimating the plume behaviour made it acceptable to ignore effects of complex terrain at the time the studies were commissioned.

In the meantime much effort is undertaken in this area combined with the tendency in risk assessment to conduct more site specific studies. This may allow to apply advanced models and detailed meteorological and topographical information. A first approach has been done in this field with the development of the CRACIT-Code, which emerged from the CRAC-Code of Wash-1400 /WO79, ZI81/. CRACIT is able to take into account topographic features and flow data in a defined area around a nuclear facility site.

In order to obtain a general view of topographic features around nuclear installations 24 German sites (Fig. 1.1) and additionally some sites in the United Kingdom have been analyzed in this report by objective methods considering the degree of dissection of the terrain. In a second step the effects of topography considered to be important to atmospheric dispersion of radioactive effluents are qualitatively discussed. This report finishes with illustrative calculations performed by the code of the German Reactor Risk Study, UFOMOD. The version used has been adjusted to complex terrain by a method of plume height correction. The effect of terrain induced turbulence is discussed as well.

2. Analysis of Types of Nuclear Power Plant Sites

2.1 Motivation and Definitions

In the German Reactor Risk Study, Phase A, the surroundings of nuclear power plants have been treated as being flat. One of the reasons was the lack of site specific topographical and meteorological data. In the meantime, the topographical data for more than 20 sites of German nuclear installations being in operation, being built or in the procedure of licensing have become available, so that a general view of the terrain structure around these sites and around some sites in the United Kingdom can be given. A classification of the sites will give some guidance, which types of sites to be selected for field studies. Furtheron the classification gives some justification for transferring atmospheric dispersion parameters evaluated in complex terrain to orographically similar sites of nuclear power plants.

The definition of topography comprises in general vegetation, water and urban built-up areas as well as terrain elevations. Topography is used here in the sense of orography, which indicates that only the effects of the surface form on atmospheric dispersion are regarded. The description of the terrain as flat, rolling, hilly or mountainous is subjective and rises difficulties of delimitation. Cooper /CO83/ assumes that topographic effects become significant if the elevational differences exceed 50 m over several km of horizontal distance. According to this, areas characterised by elevational differences of 20 m or 50 m over several km are classified as being flat (Prairie Grass) or rolling terrain respectively.* An elevational difference of 100 m or so over the same horizontal scale is defined as being hilly. Such terrain consists of shallow valleys, ridges and simple hills. Mountainous terrain is defined as comprising topographical features with horizontal dimensions of about 50 km and vertical dimensions of about 500 m. Such terrain is composed of mountain ranges and deep valleys.

2.2 Orographic Data Base

For utilization in the accident consequence model UFOMOD two data bases are available. The first one contains the height data of a 5 x 5 km rectangular grid, which covers the area of the Federal Republic of Germany. The reference point is the south-west corner of the plot in Fig. 2.1 with the coordinates 6-3-41 East/47-10-4 North. The grid consists of 116 x 173 points of intersection. Data of this kind can be used for α- and ß-mesoscale dispersion.

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*According to Gilbert /GI75/ the parallel stream lines of near ground flow are preserved if the angle of inclination of the elevated terrain does not exceed 5°. This agrees with Coopers definition.

The second data base includes the regions around the 24 sites of German nuclear facilities. The sites are located at the mid point of a square area of 60 km x 60 km. This square is subdivided into subsquares of the size 0.5 km x 0.5 km. The level of such a subsquare represents the average of the heights of the so-called basic squares (about 0.1 km x 0.1 km) /IA83/. The orographic information of one site consists of 14 400 average height values referred to sea-level (see plots in Appendix A.1-A.24).

The orographical data form part of the topographical data base of the "Deutsche Bundespost" /SC80/, which had restricted the evaluation of the data to the Federal territory. This explains the lack of data in the frontier area indicated in the plots as a plane depression.

2.3 Descriptive Method

As can be seen from Fig. 2.1 the Federal Republic of Germany is from the topographical aspect a non-homogenous country. The north is represented by the lowland region. When going southwards the chain of the German highlands follows; the elevated plain of South Germany and the Alps complete the orography. In the south west the Upper Rhine Valley takes an exceptional position. Sites of nuclear power plants are located in each of these regions.

In the following the orographic features of the German sites of nuclear facilities are described. This will be done by indicating the degree of dissection and continuity taking into account the definitions of chapter 2.1. Besides these definitions and typical descriptions like flat plain, hilly, rugged or mountainous terrain the terms convex and concave seemed to be useful and should be introduced. The attributive convex describes the phenomena of consecutive wide mountain ridges or domelike hills, which are intersected by more or less deep but very narrow depressions. The attributive concave stands for troughlike terrain with steep and sharp mountain crests or ridges rising above the level ground. The dominating impression in the second case is based on the flat and broad depressions between the hills. The aim of this description is to establish a common base of terrain definition because there are no generally accepted standard definitions.

The description of the following site regions is based on visual examination of the 3d-computer plots given in the appendix A. This method does not allow objective ranking or classification of the terrain irregularity but will identify main features.

Biblis

The area consists of 3 sections, which extend from the south to the north. The central part is occupied by the wide valley of the river Rhine. This flat region (with exception of an isolated ridge) is bounded to the west by relatively smooth mountains of convex character and to the east by mountainous terrain with some sharp, parallel ridges directed to the north-east. The elevational difference between site level and maximum height of 484 m indicates mountainous terrain.

Borken

The terrain is designated as mountainous with ridges and depressions in irregular directions. The area has predominant convex features. Towards the nuclear power plant the site terrain becomes more hilly and indicates a passage in southern to northern direction. The difference in elevation between site level and maximum height amounts to 473 m.

Brokdorf

The terrain is denoted as being flat with some slight elevations. The difference between site level and maximum height is 77 m.

Brunsbüttel

The terrain is flat with a smaller number of elevations as compared to Brokdorf.

Esenshamm

The terrain is flat.

Grafenrheinfeld

In the surroundings of the site rolling terrain predominates, becoming irregular and mountainous with convex character in further distances in all directions. The elevational difference between site level and maximum height is 451 m.

Grohnde

A diagonal line, connecting the north west corner with the south east corner of the area, separates mountainous terrain of convex character in the south west and terrain of concave character in the north-east direction. In the concave terrain the ridges are directed from NW to SE. The convex terrain is more irregular with dissections in different directions. The difference in height amounts to 451 m.

Gronau

Flat terrain dominates, some slight elevations especially in the south east part can be recognized. The smooth contours elevate up to a height of 138 m related to the site level.

Gundremmingen

A wide, flat valley divides the SE from the NW part of the area. The valley is not delimitated clearly but frayed out by foothills. In the SE a rolling and hilly terrain is prevailing while the NW-part becomes more dissected irregularly. The difference between site level and maximum height is 251 m.

Hamm

In the northern part of the site area the terrain is predominantly flat. A regular and continuous elevation can be stated in southern direction from the site. In this part the area is flat or rolling, some depressions exist. In the south the terrain terminates in a band of ridges parallel to WE-direction. The height difference of 435 m does not indicate the predominantly flat impression of the terrain.

Hanau

The western part of the terrain is relatively flat with some regular ridges going from SW to NE in the northern section. Towards the east the terrain becomes more dissected. The convex feature in this mountainous area is dominating. The difference in height between site level and maximum amounts to 417 m.

Isar-Ohu

With the exception of a well contoured valley going from SW to NE the terrain shows rolling features. The difference of the elevations above site level varies within a range of 133 m.

Kalkar

The flat environment of this site is only disturbed by some low ridges.

Krümmel

The terrain has a rolling surface intersected by the level ground of the river Elbe. The variation of height extends to 75 m related to the site level.

Lingen

The sites of Lingen-Emsland and -Exxon can be regarded as identical and therefore summarized to Lingen. The region around these nuclear facilities is flat. Some elevations can be recognized in the SE-corner of the area. The differences in elevation between the site levels and the maximum height are 137 m and 126 m respectively.

Mülheim-Kärlich

The surface contours are extremly irregular. In the center of the region the site itself is located in a kind of flat trough. Around this a lot of narrow valleys are arranged circularly. The terrain can be characterized being highly dissected and showing convex formations. The difference between maximum height and site level amounts to 578 m.

Neckarwestheim

The nuclear power plant is situated in the narrow valley of the river Neckar. The area is irregular with no preferred directions of the formations. Dissections and narrow valleys extending a lot of kilometers furrow the terrain. The shape can be denoted being convex mountainous with an elevational difference of 375 m.

Neupotz

The area of 60 km x 60 km is dominated by the wide, level valley of the river Rhine. The valley is bounded by hilly and mountainous chains elevating to a maximum height of 634 m. The north-eastern part is dissected and rugged. The terrain in the SE-corner has a more convex feature.

Philippsburg

This area, located some kilometers NE of Neupotz, has a very similar appearance in the NE and NW corner of the plot. The terrain is dissected. It is less rugged in the south-east compared to Neupotz. The region has a height difference of 530 m.

Stade

Although the height difference amounts to 143 m most of the terrain is flat.

Vahnum

A few elevational elements of rolling character extending from NW to SE do not disturb the impression of a level area.

Würgassen

The nuclear power plant Würgassen is situated in the Weser valley, which is a few kilometers wide and is directed to the north. The terrain around the valley site is dissected. No preferred directions can be identified. This mountainous area has a height difference of about 400 m.

Wyhl

Because of the lack of orographic data the terrain cannot be classified completely. The site is a part of the southern Upper Rhine Valley. This wide valley is directed from south to north and bounded by mountain chains. Near the site hills are embedded in the valley. Narrow valleys of tributaries of the river Rhine coming from eastern direction can be recognized. The mountains show a rugged formation. The height difference between site level and peak height exceeds 1000 m.

According to the description above 10 sites are regarded being more or less flat. Five sites show mountainous character all over the defined area of 60 x 60 km. Two sites are situated in narrow valleys. Four sites belong to the Upper Rhine Valley. They show a rather level area within the valley of several kilometers width but pass into mountainous terrain with extreme complexity in the case of Wyhl.

Two further sites can be identified being dominated by valleys but are less pronounced because of the more hilly or rolling structure of the terrain. The remainder of the districts show an inhomogeneous and irregular structure with partially flat or rolling sections but also hilly and mountainous parts.

The rotation angle between geostrophic and ground level wind direction frequency distribution will usually amount to about 20°, which is a consequence of the friction due to the surface roughness of flat terrain. The ground level wind rose at Bremen (comparable to the site of Stade) compared with the direction distribution of the geostrophic wind at the same station /MA79/ indicates that air flow regimes will be rarely influenced orographically at flat sites, see Fig. 2.2.

Airflow directed by orography can be observed in the Upper Rhine Valley near Freiburg. The frequency distribution in Fig. 2.2 shows a relative uniform distribution of the geostrophic wind directions compared to the ground level wind direction distribution. A peak between 200° and 240° indicates the prefered south western flow near Freiburg. The shearing angle of about 60° reveals a strong influence of orography /MA79/.

One of the merits of the descriptive method applied above is the possibility to predict the occurrence of directed air flow near the ground caused by dominating orographic features like major valleys and mountain ridges. An objective description of terrain irregularity cannot be achieved by this method.

2.4 Objective Methods

Methods which enable to compare sites of different orographical structures (in the sense of degree of dissection) in an objective and quantified way are a basic requirement for associating meteorological parameters. Therefore two methods, which fulfill this criteria will be presented.

2.4.1 Variance Coefficient Method (VCM)

The degree of terrain complexity is determined by the variation of the surface level ranging from mountain top to depression. The variance is a measure of the vertical deviation of the relief related to a reference point. The variance however does not reveal the sequence density of peaks and depressions within a defined area. So a further parameter should be taken into account, which enables to decide whether there are sections of flat terrain embedded into mountainous terrain as well as to indicate a spacious change from level ground to mountainous terrain within the considered area. To this end levels of intersections, which cut the lines of the relief have been defined (Fig. 2.3). At these levels the clear distance between the points of intersection can be determined. This is done along all lines of the horizontal grid. The length of clear distances may vary between 60 000 m and zero meter in units of 500 m. The maximum clear distance of 60 000 m is assigned if relief does not exceed the selected level, zero is assigned if the level undergoes the relief at each grid point. The average of the clear distances and the variance are combined into the terrain variance coefficient (TVC).

$$TVC = \sigma^2/\bar{x} \ [m]$$

with $\sigma^2 = \frac{1}{N-1} \sum_{n=1}^{N} (H_n - SL)^2$ and $\bar{x} = \frac{1}{L} \sum_{l=1}^{L} \frac{1}{M} \sum_{m=1}^{M} x_{m,L}$

SL: Site Level

H_n: Height of the grid point n

x: Clear distance along the grid lines between two relief points at a level l

M: Maximum number of clear distance cuts

L: number of levels

Similar variances may occur although landscape may be relatively different. For example Neckarwestheim and Neupotz are represented by roughly the same variance of about 16 000 m. The larger clear distances at the site of Neupotz give the difference between both sites in the TVC.

The TVC determination includes three levels at each site. 20 %, 30 % and 40 % of the difference between maximum height and site level have been added respectively to the site level in order to define the calculational levels.

In Fig. 2.4 a ranking of the sites according to their terrain variance coefficient is given. The ranking according to TVC is confirmed satisfyingly by the view of the plots. Ten of the 24 sites with a variance coefficient of zero show level ground. The consecutive sites from Gundremmingen up to Neckarwestheim show either a very moderate relief or the terrain is balanced between areas being essentially flat and hilly or mountainous regions. The remainder of 5 sites has clearly mountainous terrain. The site of Wyhl may keep a wrong position because about 50 % of height data (french part of the valley) are not available.

It has been demonstrated that this method is able to describe quantitatively the orographic structure of a site. This is a precondition in order to correlate terrain structure and meteorological parameters like wind direction fluctuations or dispersion parameters for example. A disadvantage of the method is that it doesn't consider directed or channeled flow.

2.4.2 Gradient Angle Method (GAM)

While the previous method considers only the site level related terrain complexity, the GAM rather follows the concept of a straight line plume diffusing in each of 36 sectors like in UFOMOD. The TVC-method has been applied to a relatively dense grid of height values (14 000 fieldpoints within a square of 3 600 km^2). The GAM works with a reduced number of height values. It benefits by the fact that a countryside has a certain kind of self-consistency, which means that changes in the surface relief are in general no singularities but each height value is correlated moderately to its environs. A well considered data reduction therefore should not result in a misleading description of the terrain.

For classification the terrain is divided into 36 x 10 degree sectors and into 7 circles with radii of 1, 3, 7, 10, 15, 20, 25 km from the origin of the plant site. The selection of the radii is confirmed by a characteristic massive length found between 2 and 6 km in mountainous terrain *). It is assumed that the behaviour of the plume is controlled rather by formations close to the site than further away. This explains why emphasis has been given to a dense succession of radii up to 10 km. The gradient angle related to the plant site level from which the height at the selected field points can be seen, is calculated. A cumulative relative frequency distribution (cfd) of gradient angles (7x36) shows the characteristics of the analysed terrain. As small angles appear with higher frequency than bigger ones emphasis has been given to a more detailed distribution of small angle classes as can be seen in the following table.

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*) Massive length : distance of the connection of two relief points which penetrates the massive geological formation (see Fig. 2.3).

Class Number	Angle interval (deg)
1	≤-0.1
2	-0.1-0.0
3	0.0-0.05
4	0.05-0.1
5	0.1-0.2
6	0.2-0.3
7	0.3-0.4
8	0.4-0.5
9	0.5-0.6
10	0.6-1.0
11	1.0-1.5
12	1.5-2.0
13	2.0-3.0
14	3.0-5.0
15	5.0-10.0

The procedure has been applied to the data being available of 24 German nuclear facility sites. The resulting cfd—functions associated to these sites show a homogenous spectrum of distributions (Fig. 2.5), which indicates a gradual increase of terrain complexity from the left to the right position of the curves. As a useful standard for classification the 75 percentile (3d quartile) has been chosen.

The sites represented by labelled curves in Fig. 2.5 are identified as being flat when compared to the corresponding 3d-plots. In this case at least 75% of the calculated gradient angles remain under a limiting angle of 0.05°. The nuclear facilities of Krümmel and Lingen/Exxon are located at elevations. That explains the increased part of negative gradient angles less than or equal to -0.1°. This fact by itself would not allow to classify them being flat. But the high percentage of gradient angles being less than or equal to zero indicates level terrain.

The terrain of 9 sites has been found to have little influence on dispersion of pollutants because of the level ground.

In the second group (Fig. 2.6 and 2.7) defined by a limiting gradient angle of 0.5° sites with valley formations of several kilometers width are prevailing. Exceptions are the sites of Hanau and Grafenrheinfeld, which form the transition to the mountainous sites successively with increased terrain complexity. The reason for belonging to this group is that essential parts of the terrain in the concerned area are still moderate.

The 3rd group with the 75 percentile beyond a gradient angle of 0.5° possesses mountainous formations being spread uniformly over the area and partially narrow, deep valleys of changing directions.

The sites of Gronau and Wyhl are not reflected correctly by the cfd-curves. This is due to the lack of orographic data of about 20% and 50% respectively.

The reduced number of orographic data (7x36 fieldpoints) of three British locations has been made available by NRPB in order to classify them within this scheme (Fig. 2.8). The curve of the Windscale site shows that there exists no comparable German site. More than 50% of the gradient angles is less than or equal to zero. This fact and the site being located close to the sea indicate that this coastal site consists of level surface to a considerable extent. On the other hand an increased number of big gradient angles indicates complex terrain comparable to the mountainous German sites, so the site of Windscale is determined by extreme orographic contrasts. Salisbury Plain has been chosen because this is roughly the place where Pasquill performed some of his early diffusion experiments. For these fundamental investigations it can be assumed that there was no emphasis given to look for very complex terrain structure. The corresponding curve may suggest this but it is nevertheless incorrect because more than 80% of the fieldpoints are below site level. One of the basic assumptions of the GAM scheme - a relatively low site compared to the environs - is not valid to the Salisbury Plain as well as to the site of Krümmel as already mentioned. The complexity can be derived from Fig. 2.9. For curve B the real site level has been replaced by the height of 98 m found in the 1 km vicinity of the origin. Curve C includes also the inverted negative angles. The example indicates the strong dependency of the scheme on the site level. The variations of the Salisbury Plain curves show that the area is not at all as flat as presumed but at the same time one should point out that these curves are not comparable with those of the original scheme.

The elevation of some tens of meters very close to the site shifts the curve of Sizewell towards the more complex one. However more than 50% of the area is of level surface represented by the sea (Fig. 2.9).

The influence of the number of radii on the analysis is demonstrated in Fig. 2.10 for the sites of Biblis and Borken. The uncertainty concerning the density of the radii amounts to about 10%.

2.4.3 Summary and Conclusions

The motivation for analyzing the complexity of the terrain around nuclear facility sites has several reasons. First it is useful to obtain objective knowledge about terrain structure in order to assess the problems in modelling atmospheric dispersion in nuclear risk studies. Secondly the knowledge of terrain types advices locations for future atmospheric field experiments. Thirdly the choice of meteorological parameters for orographically structured areas is alleviated by use of objective classification methods.

24 sites of German nuclear facilities and 3 British locations have been described and analyzed by three methods. The verbal description has its merits in determining preferred directions of geological formations. But it lacks a standard to classifiy terrain complexity and is not able to take into account the relation between the site itself and its surroundings. The variance and the gradient angle methods however illustrate the complexity of the terrain related to the site.

The variance coefficient examines uniformly and directly the relationship of mountain tops to depressions and the degree of dissection. With the gradient angle method terrain complexity is concluded from the frequency of occurrence of certain angles between the site and elevated fieldpoints. By definition and by consideration of an increased number of fieldpoints close to the origin it emphasises the nearer surroundings of the site which is assumed to influence predominantly the behaviour of the plume. A comparison of the two methods demonstrates that the gradient angle method works satisfyingly with a considerably smaller number of fieldpoints (Fig. 2.4).

According to the applied methods 4 or 5 sites can be classified having a high degree of dissection with no orographical preference direction. 9 or 10 sites show either a moderate relief or a terrain balanced between area parts being flat and others being complex. 6 sites out of these are characterized by valley formations with steady orientations. The remainder of 10 sites is regarded being flat with essentially no elevations in the neighbourhood of the site.

The assumption of flat terrain for all sites was standard in atmospheric dispersion modelling of the German Reactor Risk Study up to now. If the introduction of complex terrain in overall risk assessment is advocated about 60% of the examined sites are in consideration. In this case the use of an improved version of the existing atmospheric dispersion model or the use of more advanced models might be necessary for these sites.

3. Effects of Orography on Plume Dispersion

The behaviour of a plume is determined by flow patterns which are affected in the local scale by complex terrain features. The effects of different orographic components superpose and contribute to the flow regime of a mesoscale area like those analysed in the previous chapter. The following text is mainly referred to mechanically induced phenomena whereas thermally induced phenomena are only shortly considered.

3.1 Mechanically Induced Phenomena

3.1.1 Flow Acceleration

A familiar phenomenon is the acceleration of the flow when passing a ridge or mountain gaps. For Gaussian shaped isolated hills Pasquill /PA83/ gives a speed-up factor of the windflow at the crest, $\Delta u/u$ being approximately 2 h/L when h is the height of the hill and L is the half width at h/2. Considering groups of 2-dim. consecutive hills the windspeed increases over the first hill but decreases again passing the following ones if they are situated within the wake of the foregoing hill. Windtunnel measurements /CO74/ indicate (see Fig. 3.1) a speed up of 0.8 on the first hill and of 0.4 on the second and subsequent hill.

3.1.2 Channeling

Strong upper flow regimes may enforce a channelled flow in valleys if there exists a component parallel to the direction of the valley. The influence of channeling on the frequency of possible plume dispersion directions is illustrated in Fig. 3.2, where a collection of wind roses located on the mountains and at the bottom of the valleys shows the preferential wind flow in the neighbourhood of Oak Ridge National Laboratories. Channeling occurs in wide valleys (more than 10 km) (Fig. 3.3) as well as in valleys with no pronounced deepness (Fig. 3.4) like Gundremmingen.

Activity plumes are calculated to rise up to about 1000 m depending on the accidental scenario and the weather conditions. Valley formations must be examined under this aspect.

Channeling also includes the restricted lateral spread of a plume for example by the sidewalls of a canyon. Hanna /HA82/ states that diffusion in valleys is limited when the valley width W equals roughly $2\sigma_y$. At night elevated plumes could fill a horizontal layer. The highest concentration C at the valley walls in that case will amount to

$$C = \left(\frac{2}{\pi}\right)^{1/2} \frac{Q}{\sigma_z\ u\ W}$$

- Q source strength,
- σ_z vertical standard deviation,
- u wind speed.

In the morning the "break-up fumigation" process extends the layer of higt concentration to the valley floor. The concentration can be calculated being

$$C = \frac{Q}{u\ h\ W}$$

h: mixing height

3.1.3 Blocking and Deflection

Blocking or at least stagnation effects may occur for example in mountains, valleys or at ridges where the flow over the obstacles can be restrained by an inversion layer. In general blocking is avoided by deflection of the flow. The path of a plume flowing over or around a terrain obstacle depends on the orographic structure of the environment and on the thermal stratification of the atmosphere. During neutral or instable conditions the plume will flow over the orographic obstacle rather than around it, while during stable conditions a more detailed consideration is necessary. The behaviour of a plume can be predicted by the concept of the dividing streamline (see also /HA82/, /AP84/), which is based on the height of orographic formations and the Froude number Fr. Fr characterizes the dynamics of the flow.

$$Fr = \frac{u}{N\,h} = \frac{u}{h}\left(\frac{g}{T}\,\frac{\delta\theta}{\delta z}\right)^{-1/2}$$

Where u is the uniform velocity of the flow approaching a hill with the height h. N is the Brunt-Vaisala frequency, which is a measure of the stability of the atmosphere and gives the oscillation frequency of an airparcel displaced slightly by surface obstacles. It includes the potential temperature gradient $\delta\theta/\delta z$, the acceleration due to gravity g and the mean temperature T. The Froude number can be interpreted as the ratio of the kinetic energy of the air flow to the potential energy gained by air parcels displaced from the base to the top of the hill.

Froude numbers $Fr \leq 1$ can be associated to stable conditions, $Fr > 1$ to a neutrally stratified flow. Given the Froude number Fr, the critical dividing stream line height can be formulated as

$$H_c = h(1-Fr)$$

if mean windspeed and density gradient is assumed being constant.

An advanced formulation which takes into account arbitrary wind and density profiles and evaluates H_c by iteration can be found in /SN82/. A plume approaching a hill in a height above H_c will pass over it. The plume will be deflected if it approaches below H_c.

3.1.4 Shearing

The variation of windspeed and wind direction with height is called shearing. In flat terrain it is caused by surface friction and will consequently diminish with increasing height. Over land a deviation from the geostrophic wind direction of 20° - 40° can be found, over rough surfaces like urban areas the angle may amount to 35° - 50°. A similar effect can be observed due to orographic structures, which cause a deviation according to its directional formations. The flow in Fig. 3.5 can be regarded as an example for a wind direction shearing effect in complex terrain. Because of the wind direction shearing the plume or parts of it will disperse in different directions depending on the final rising height of the plume and on the time to reach it. The wind profile given in Fig. 3.6 is an example for velocity shearing. In this case shearing effects by acceleration or deceleration of the flow can be observed.

3.1.5 Turbulent Flow over Hills

In the lee of mountains a region can be observed where turbulent rotational flow with high mixing rates occurs. Wake effects caused by buildings in general don't have an extent of more than one kilometer, the region of turbulence in complex terrain however is associated to the mesoscale.

The turbulence intensity depends on the shape and the height to width ratio of the orographic obstacles, the velocity of the mean flow and the atmospheric stratification. Wind tunnel measurements carried out by Counihan /CO74/ indicate enhanced longitudinal turbulence intensities and different contours of constant turbulence intensity in an array of 2-dimensional hill groups with a pitch to height ratio of 3.0 and 6.0 respectively (see Fig. 3.7).

Separation effects are observed more frequently in the lee of sharp crests than at the downwind side of aerodynamically smooth shapes. Instable conditions or more neutral stratification promote separation and possible recirculation while stable conditions rather supress these effects but do not prevent them completely. In addition further effects like lee waves can be observed. Following the trajectories of air particles in Fig. 3.8 the oscillation of the curves mark a lee wave length of between 4 and 6 km with a tendency to shorter wave length in more stable cases.

In /HU82/ several cases of stratified flow over hills regarding the effect of lee waves or separation are discussed. The highest Froude number at which separation is first suppresse is designated as critical Froude number for separation (F_{crit}). The Froude number, see chapter 3.1.5, is here defined as

$$Fr = u/(NL_1).$$

L_1: semi-length at the half-height, see Fig. 3.9.

In a flow characterized by $F > F_{crit}$ no lee waves are possible, but separation occurs (Fig. 3.9a). In a subcritical flow with $F < F_{crit}$ and hills of low slope separation on lee slope is suppressed but downstream effects caused by lee wave rotors will appear (Fig. 3.9b). If the Froude number exceeds F_{crit} and the hills are of moderate slope boundary-layer separation occurs (Fig. 3.9c). In case of subcritical Froude number combined with moderate slope lee - wave - induced separation is produced (Fig. 3.9d).

A difference between flow over two and three dimensional hills can generally be seen in the wake structure and in case of stratified flow when $F \ll 1$, in the behaviour of air moving in horizontal planes around a hill rather than to pass the hills top as shetched in Fig. 3.10.

A series of effects were shown in order to demonstrate the manifold possible sources for increased diffusion in complex terrain, expecially in a stable stratified atmosphere. Under instable conditions convective processes dominate the effects of mechanical origin.

3.2 Thermally Induced Phenomena

Mountain-valley wind systems belong to this group and are therefore adressed shortly. Local wind systems in mountainous regions establish in periods of heigh solar radiation and low windspeed (weak gradient winds). The heating of the valley walls during the day generates lateral pressure gradients which drive a circular motion of the air like in Fig. 3.11. This system is superposed temporarily by a flow towards the mountains along the valley due to the pressure gradient caused by temperature differences between the valley and plains outside of the valley, see Fig. 3.11A-D. During the night the inverse processes can be observed (Fig. 3.11E-H). A description and interpretation of local wind systems can be found in /GE61/.

The circulations mentioned above may be disturbed by terrain irregularities within the valley, by flow coming from side valleys and by gradient wind flow near the mountain tops as is illustrated by Fig. 3.12.

4. Illustrative Calculations with a Modified UFOMOD Version

4.1 Scope of Calculations

The German Reactor Risk Study (GRRS) was designed to assess the collective risk associated with hypothetical accidents in nuclear power plants sited in the Federal Republic of Germany /DR79/. A series of nuclear facility sites of different orographic features was regarded combined with representative ensembles of weather sequences for these sites. The consideration of complex terrain requires site specific meteorological data, which exceed considerably the parameter set of a weather sequence (hourly values of atmospheric stability, wind speed and precipitation associated to the source location) used so far in the GRRS.

The consideration of orographical effects like those described in the previous chapter can be expected in principal only from complex numerical models. The application of such models in risk assessment is out of question due to computer capacity. Simpler numerical flow models like MATHEW inserted ADPIC /LE81/ and WAFT/TOMCAT/AP84/ consume much less computer time. They might be used together with a puff-trajectory model for site specific risk studies or for special investigations within a risk study. But one must be aware that the flow models don't consider some of the mentioned orographical phenomena.

Therefore it is doubtful whether the additional efforts for the acquisition and quality assurance of meteorological input data and for the control of numerical procedures involved /AP84/ are justified as compared to semi empirical approaches.

Common to all these semi empirical approaches is that they can introduce orographical effects only globally via effective plume height, dispersion parameters and windspeed.

But one should keep in mind a series of uncertainties arising from the original dispersion model and from other components of the consequence code like plume rise, source term, population distribution. Therefore here a modified Gaussian straight line model will be applied.

Two major aspects of structured terrain are considered in order to assess the potential of the consequences of hypothetical nuclear accidents: the approach of the plume to the ground and the enhanced turbulence. The terrain adjusted model is based on the dispersion model commonly used in the accident consequence code UFOMOD. Its principles are extensively discussed in the German Reactor Risk Study (GRRS) /FA81/, the version UFOMOD/B3 used for the calculations is described in /EH83/.

Four sites of different degree of terrain complexity and one dispersion direction in each have been selected under the aspect of surface relief and /or most frequent dispersion direction. Each region defined in the GRRS, is represented by one site. The scenarios comprise the release categories FK1 (core melt down followed by steam explosion) and FK2 (core melt down with a large containment leak) and the 115 standard weather sequences associated to the site regions defined in the German Reactor Risk Study.

4.2 Description of the Method

4.2.1 Plume Height Correction

The method used for correction of the plume height is similar to that proposed by Egan /EG75/ and Burt /BU77/. The modifications correspond to the following rules: In stable conditions it is assumed that the plume center line does not vary with the underlying topography. According to this the effective plume height is reduced by the terrain height. If the terrain height exceeds the plume height the plume would impinge the terrain. Then the plume is assumed to disperse along the surface in a height of 1 m. Fig. 4.1 illustrates the height corrections applied to the Gaussian equation during unstable and neutral conditions if terrain obstacles are smaller or larger than the effective plume height. If the terrain height h_t remains below the original effective plume height H_o then the formula $h_p = H_o - h_t/2$ should be applied to the actual plume height h_p. If the relative terrain height h_t exeeds h_p the semi-height of H_o replaces h_p.

In UFOMOD the activity concentration is being calculated at representative fieldpoints along a central line from the source, placed within ring segments. The segments are confined radially by inside and outside radii and laterally by 10° sector boundaries. Within a segment the population is assumed to be distributed uniformly. A respresentative terrain height (corresponding to h_t) being valid for the ring segments is associated to each of the fieldpoints up to a range of 30 km. The terrain heights h_t and the population distribution in the corresponding dispersion sectors are listed in Tab. 4.1.

4.2.2 Enhanced Turbulence

According to Cooper /CO83/ and others the horizontal and vertical dispersion parameters σ_y and σ_z evaluated in mesoscale areas with complex terrain are enhanced in case of ground level releases. For elevated releases σ_y is enhanced whereas σ_z might be not. An association to terrain complexity via the terrain variance coefficient or gradient angles frequency distributions was not undertaken because of the lack of adequate field experiments. Most of the field experiments are restricted to smaller areas and their results are not comparable. Consequently the following procedure was applied in order to consider enhanced turbulence: In the GRRS 3 σ-curves related to the Pasquill-Gifford stability categories A-B, C and D-E-F describe the lateral spread of the plume in dependency on the roughness length, see Fig. 4.2. The σ_y-curve related to the stability categories D,E,F has been replaced for stable and neutral weather sequences by the category C curve.

These diffusion parameters have been derived from dispersion experiments in the Upper Rhine Valley at a distance scale of about 10 km /TH76, TH76b, NE79/ and are assumed to be valid for similar structured sites. The two sites in the Upper Rhine Valley and the North German lowland belong to the group of sites with a gradient angle of $< 0.2°$ and are excluded from the procedure proposed above. For the sites of a higher degree of complexity (gradient angle $\alpha > 0.2$ the procedure of applying category C insted of D, E, F-curves may be justified.

4.3 Results

Fatalities due to acute radiation syndrome (early deaths) are regarded to be the indicative factor of these calculations. The dispersion sector selected for the Upper Rhine Valley site matches to the most frequent wind direction. Because the plume height correction is small up to a distance of 16 km from the site (see Tab. 4.1) the differences of the number of early fatalities between flat and real terrain calculations are small in case of FR2 (Tab. 4.2, Fig. 4.3). The decreasing terrain height results in a slightly reduced number of early fatalities. The number of early fatalities in case of FK1 is increased when the height corrected version of UFOMOD is used, because early deaths occur in farer distances from the source as compared to the level terrain version, while the plume height correction at a distance up to 16 km is negligible as compared to an average plume height of about 600 m.

The height relief is more pronounced at the site of the South German Plateau. This is expressed in the number of early deaths for FK1 but influences especially the results for FK2 (Fig. 4.4, Tab. 4.3). Both release categories yield in the height corrected version an increased number of early fatalities while the additional enhanced turbulence shifts the cumulative probability distribution below the level terrain curve. The tendency in the results of the sites discussed before is also confirmed by those received for the North German Lowland site.

The small absolute numbers of early fatalities at a site of the Valley Region are a consequence of the fact that in the selected dispersion sector no population is registered up to a distance of 8 km whereas an increased height of the terrain is given. This indicates that in complex terrain the population distribution should be taken into account, too, if a dispersion model is developed for complex terrain. Significantly increased relative numbers of early deaths however can be stated for both release categories (Tab. 4.5) if only the height correction is being applied.

It can be stated that for FK1 early fatalities are calculated up to a distance of 20 km if level ground is assumed. Terrain adjustment extends this range up to 30 km while enhanced turbulence reduces the distance to 20 km again. In case of FK2 the distance reached amounts to 14 km independently of the modifications.

In order to illustrate some details of the calculations cited before, several weather sequences have been selected and their results are discussed in the following (Tab. 4.6). According to Tab. 4.6 the stable weather sequences are identified to be the important ones. The number of early deaths calculated for the Upper Rhine Valley site is due to an activity concentration peak at a distance of 20 km from the source. At that distance the first elevated fieldpoint is located. For FK2 the number of early fatalities is reduced because terrain height along the dispersion sector is below the site level up to a distance of 5.4 km in combination with a small effective plume height. An example that enhanced turbulence does not generally mean a reduced number of early fatalities is given for the Valley Site Region under stable conditions.

4.4 Summary

A Gaussian straight line diffusion model has been modified to take into account complex terrain by correcting the plume height only. It has been applied in assessing the consequences of hypothetical nuclear accidents. A further modified version takes into account complex terrain and enhanced turbulence simultanously. If only the first modification is applied, the mean number of early fatalities is found to be increased up to a factor of 7 in case of FK1 and up to a factor of 2 in case of FK2. If enhanced turbulence is considered simultaneously, the number of early fatalities is reduced by factors up to 0.2 (FK1) as compared to the previous figures. According to this the choice of adequate dispersion parameters for complex terrain site is important.

Relative to the surrounding, higher concentration spots can be calculated within a distance of 30 km for release category FK1.

The resulting cumulative frequency distributions suggest that no essential changes might be expected if a straight line Gaussian standard model is modified to take into account complex terrain and the resulting enhanced turbulence.

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	1	2	3	4	5	6	7	8	9	10	11
Inside radius (KM)	0.	0.8	1.2	1.6	2.4	3.6	5.4	8.0	12.0	16.0	24.0
Outside radius (KM)	0.8	1.2	1.6	2.4	3.6	5.4	8.0	12.0	16.0	24.0	36.0
Field point (KM)	0.7	1.0	1.4	2.0	3.0	4.5	6.7	10.0	14.0	20.0	30.0
Upper Rhine Valley											
Population	0	0	0	0	408	466	3643	8957	501	44572	63608
Rel.Height	-1	-1	-1	-1	-1	-1	4	8	8	141	258
South German Plateau											
Population	0	0	0	43	1255	217	3590	2795	1925	2168	9547
Rel.Height	8	14	19	10	10	12	25	62	88	135	49
North German Lowlands											
Population	0	0	0	100	5	12	24	831	1429	4318	26099
Rel.Height	4	4	8	14	11	3	10	25	28	141	242
Valley site											
Population	0	0	0	0	0	0	0	640	154	1019	3600
Rel.Height	1	2	2	14	76	116	158	65	197	305	303

Tab. 4.1 Population and height data of the selected dispersion sectors

Release Category	Model Modification	Early Deaths Mean Value	Early Deaths Maximum Value
FK1	level terrain	$2.1 \cdot 10^{-2}$	83,0
	height correction	$2.3 \cdot 10^{-2}$	83,2
FK2	level terrain	$3.4 \cdot 10^{-1}$	191
	height correction	$3.2 \cdot 10^{-1}$	183

Tab. 4.2 Characteristic parameters of the early deaths distribution determined at a site of the Upper Rhine Valley region.

Release Category	Model Modification	Early Deaths Mean Value	Early Deaths Maximum Value
FK1	level terrain	$4.5 \cdot 10^{-3}$	13
	height correction	$5.2 \cdot 10^{-3}$	15
	height correction + enhanced turbulence	$1.8 \cdot 10^{-3}$	5
FK2	level terrain	1.0	580
	height correction	1.6	895
	height correction + enhanced turbulence	0.8	526

Tab. 4.3 Characteristic parameters of the early deaths distribution determined at a site of the South German Plateau region.

Release Category	Model Modification	Early Deaths Mean Value	Early Deaths Maximum Value
FK1	level terrain	$1.76 \cdot 10^{-2}$	39
	height correction	$1.84 \cdot 10^{-2}$	40
FK2	level terrain	$3.6 \cdot 10^{-1}$	105
	height correction	$4.7 \cdot 10^{-1}$	111

Tab. 4.4 Characteristic parameters of the early deaths distribution determined at a site of the North German Lowland region

Release Category	Model Modification	Early Deaths Mean Value	Early Deaths Maximum Value
FK1	level terrains	$0.4 \cdot 10^{-4}$	0.18
	height correction	$2.7 \cdot 10^{-4}$	0.46
	height correction + enhanced turbulence	$0.7 \cdot 10^{-4}$	0.13
FK2	level terrain	$3.5 \cdot 10^{-4}$	0.3
	height correction	$6.1 \cdot 10^{-4}$	0.74
	height correction + enhanced turbulence	$2.3 \cdot 10^{-4}$	0.3

Tab. 4.5 Characteristic parameters of early deaths distribution determined at a site of the Valley group.

Site	Modification	Weather	Early Deaths FK1	Early Deaths FK2
Upper Rhine Valley Region	flat	stable	0	256
	height correction		2.6	246
	flat	instable	0	0
	height correction		0	0
South German Plateau Region	flat	stable	0	687
	height correction		$4.4 \cdot 10^{-3}$	1110
	height correction + enhanced turbulence		0	721
	flat	instable	0	$2.26 \cdot 10^{-3}$
	terrains adjusted		0	$2.3 \cdot 10^{-3}$
North German Lowland Region	flat	stable	0	117
	hight correction		0.15	160
	flat	instable	0	$3.0 \cdot 10^{-3}$
	height correction		0	$3.1 \cdot 10^{-3}$
Valley Site Region	flat	stable	0	0.6
	height correction		0.48	2.1
	height correction + turbulence		0.14	3.6
	flat	instable	0	0
	terrain adjusted		0	0

Tab. 4.6 Early Deaths calculated for single weather sequences

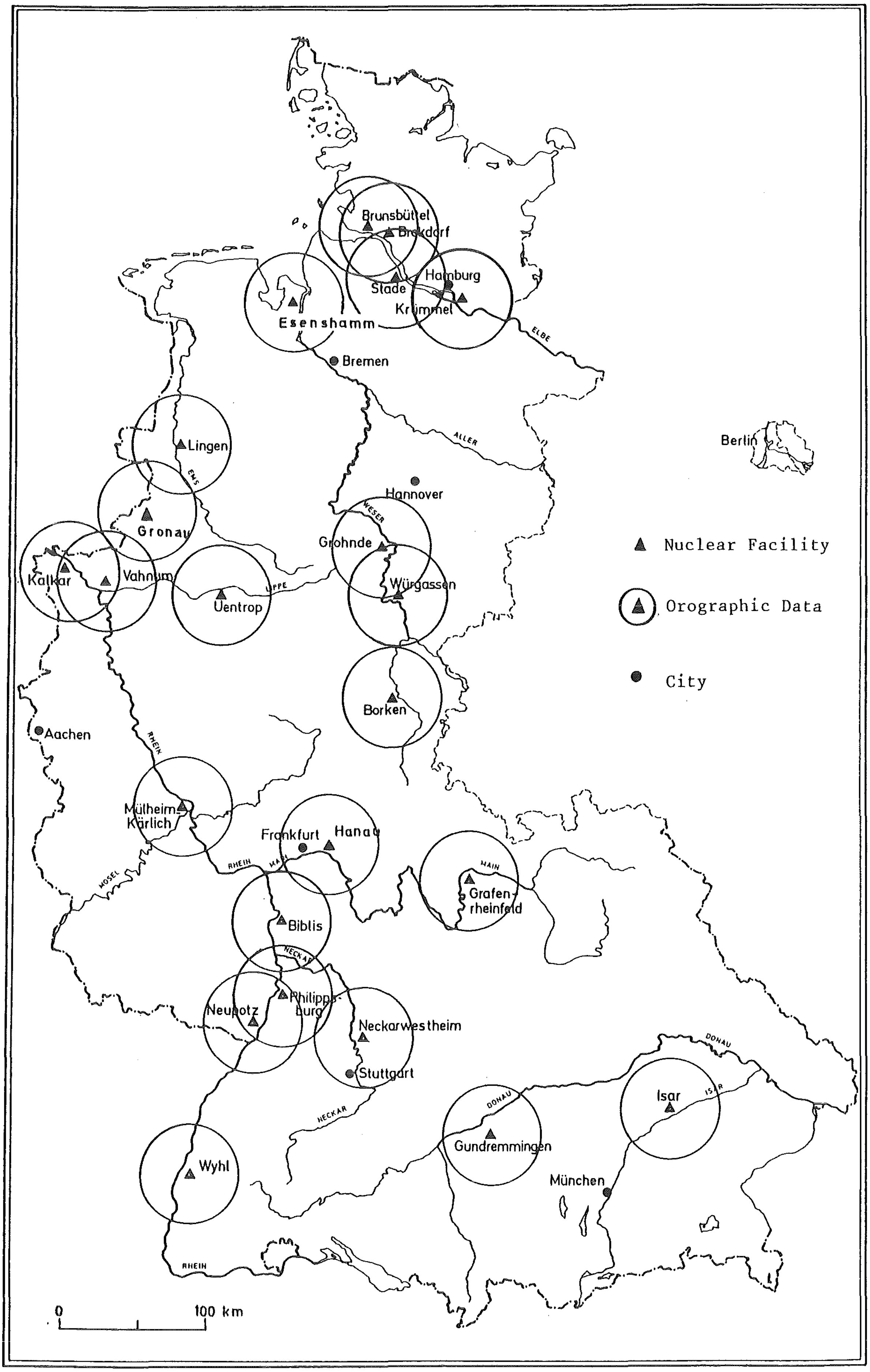


Fig. 1.1: Nuclear facility sites beeing subject of investigations

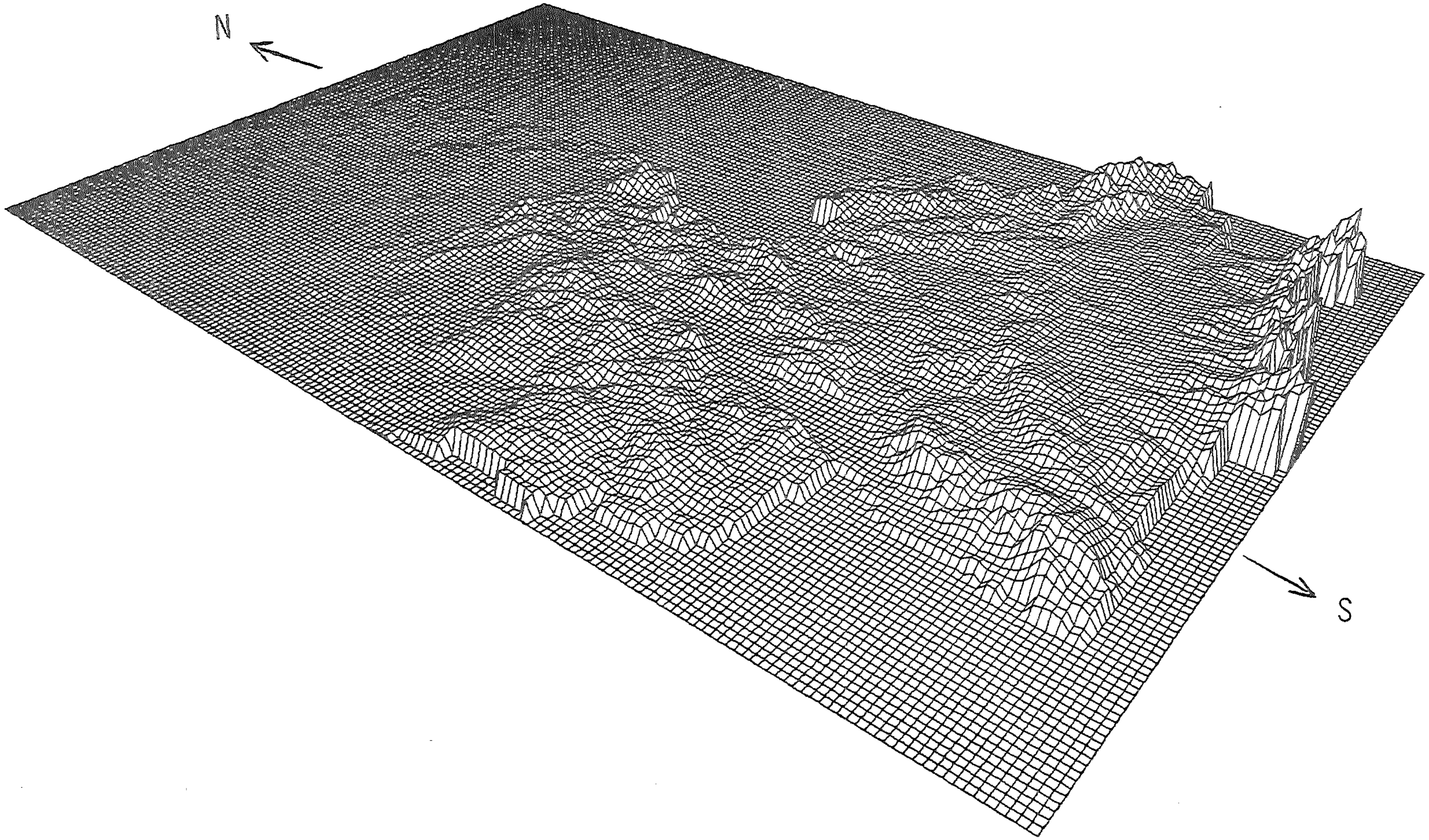
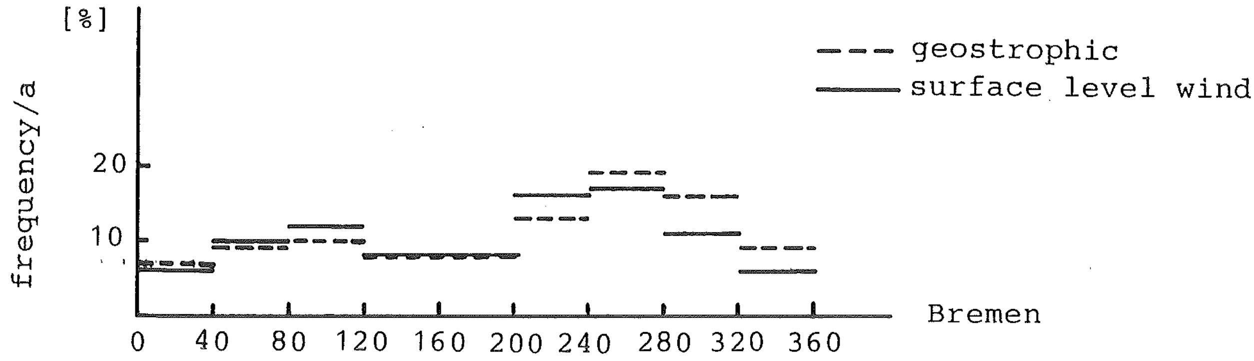


Fig. 2.1: Orography of the Federal Republik of Germany



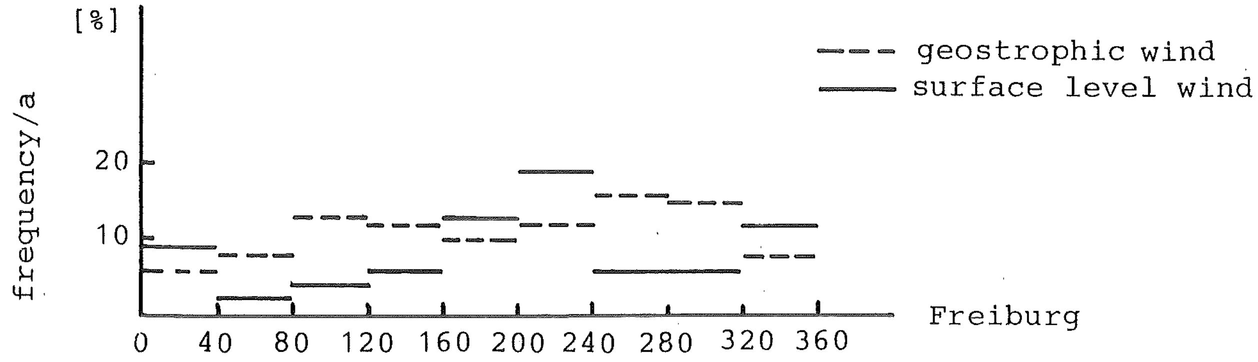


Fig. 2.2: Winddirection distribution at the sites of Bremen and Freiburg (flat and irregular terrain comparison)

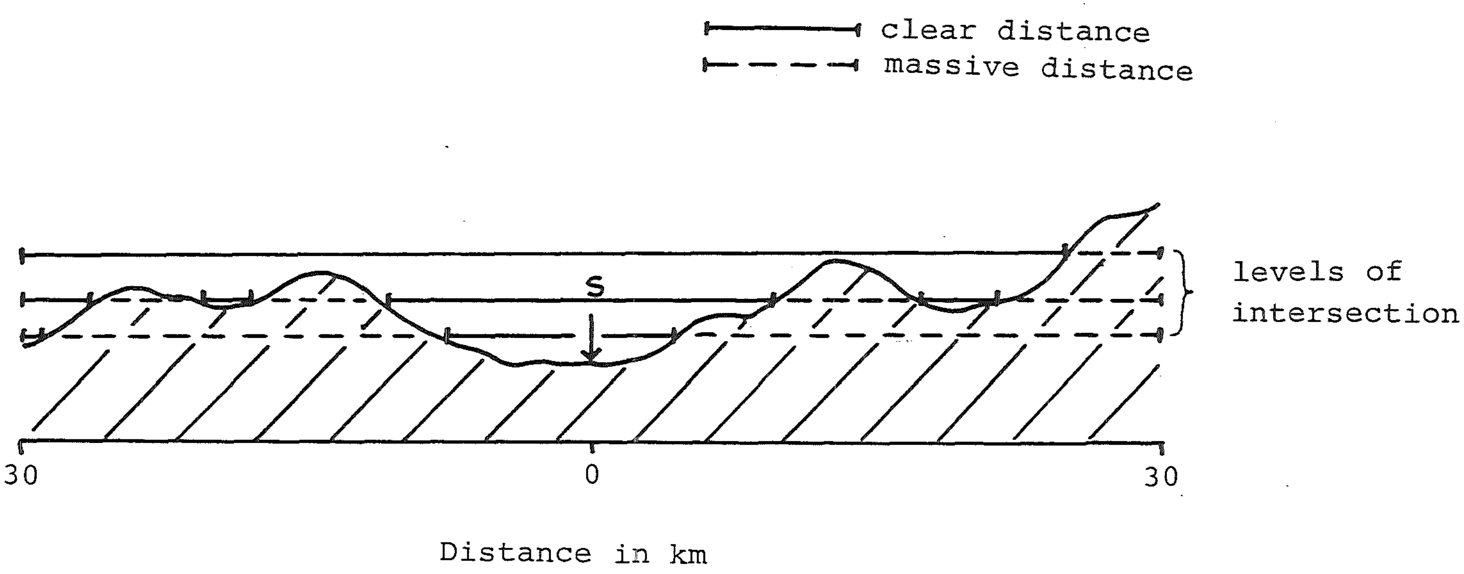


Fig 2.3: Definition of the clear distance and the massive lenghth
(S: site)

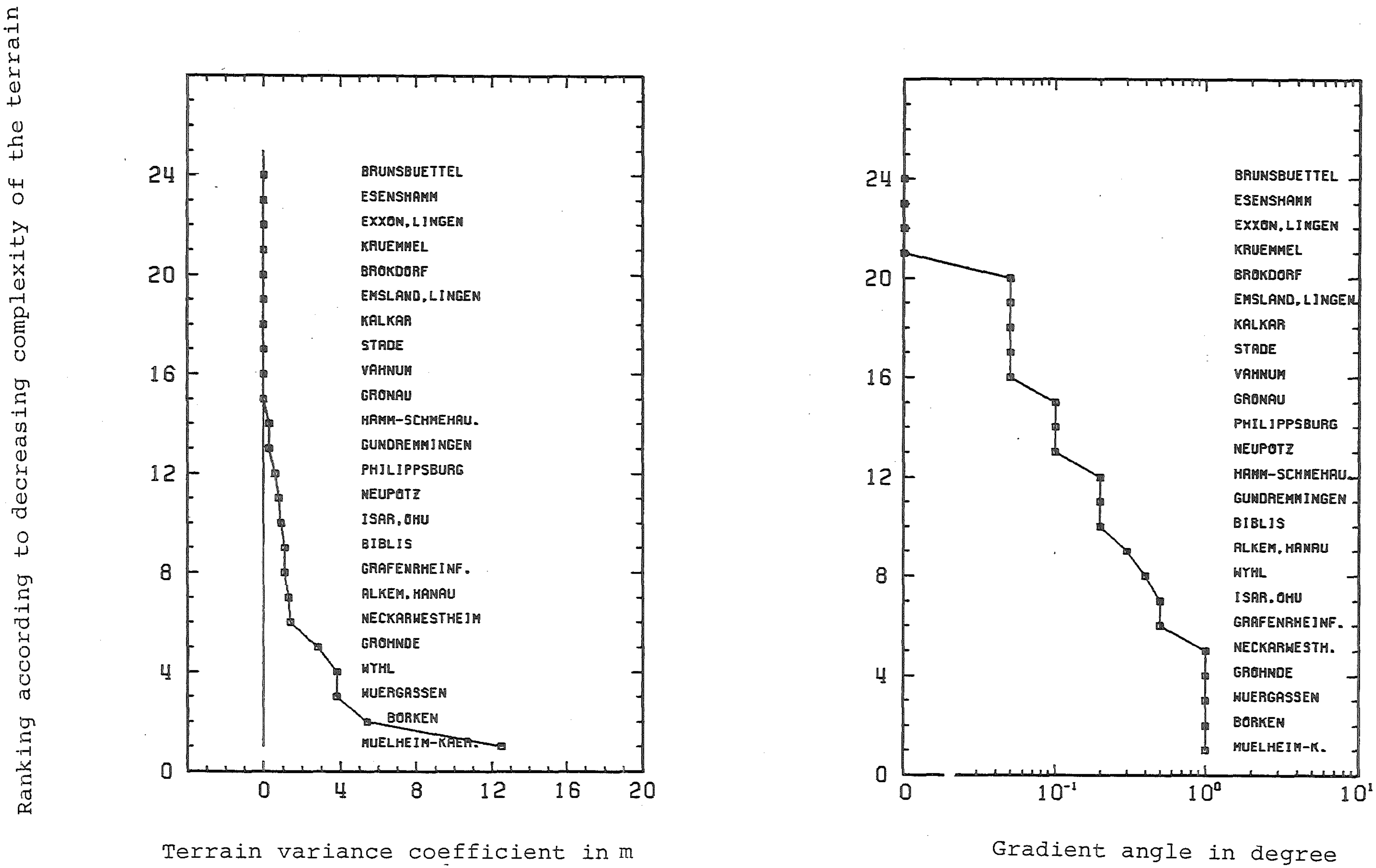


Fig 2.4: Classification of sites via terrain variance coefficient and gradient angle method

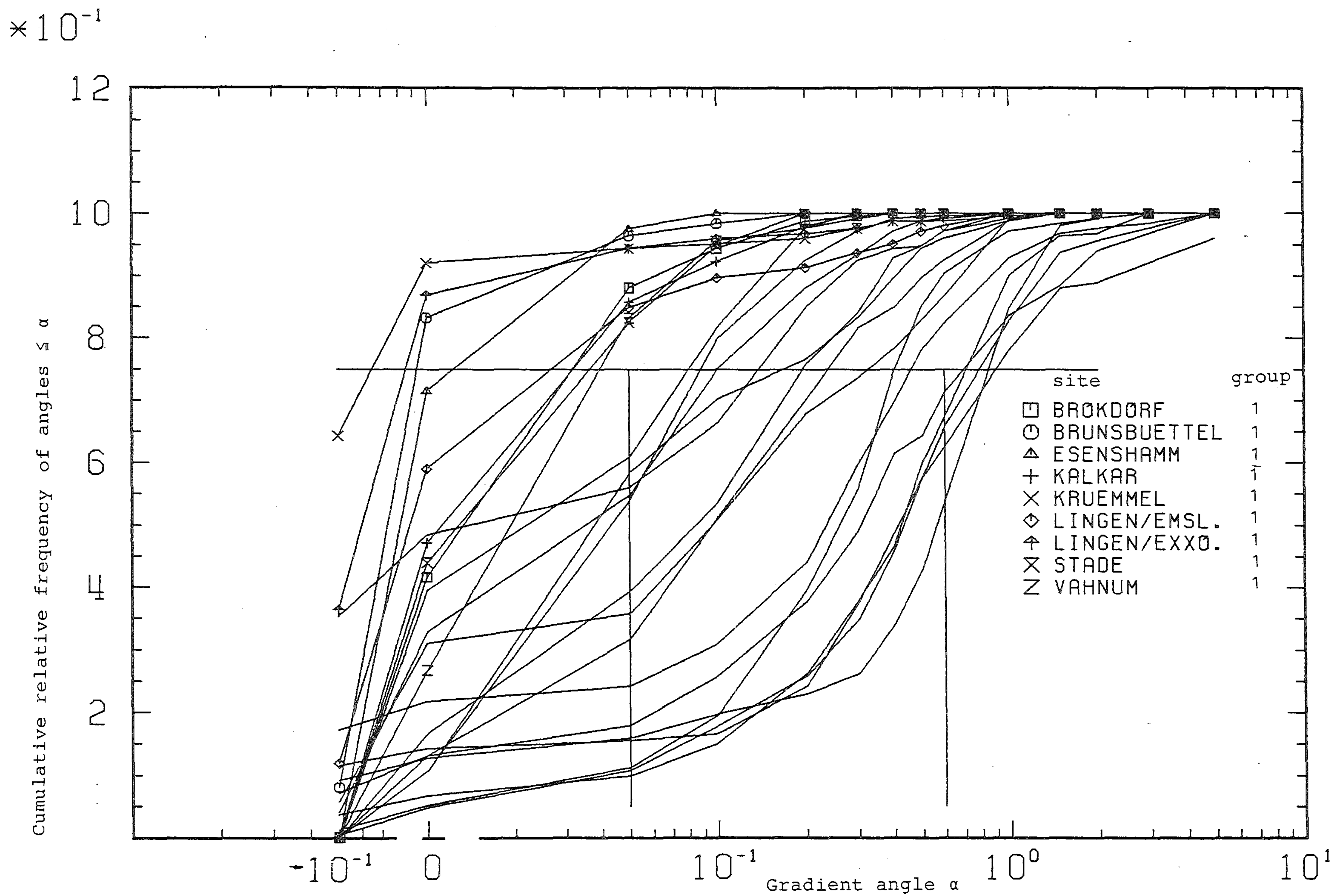


Fig 2.5: Frequency distribution of the gradient angles of 24 German nuclear facility sites

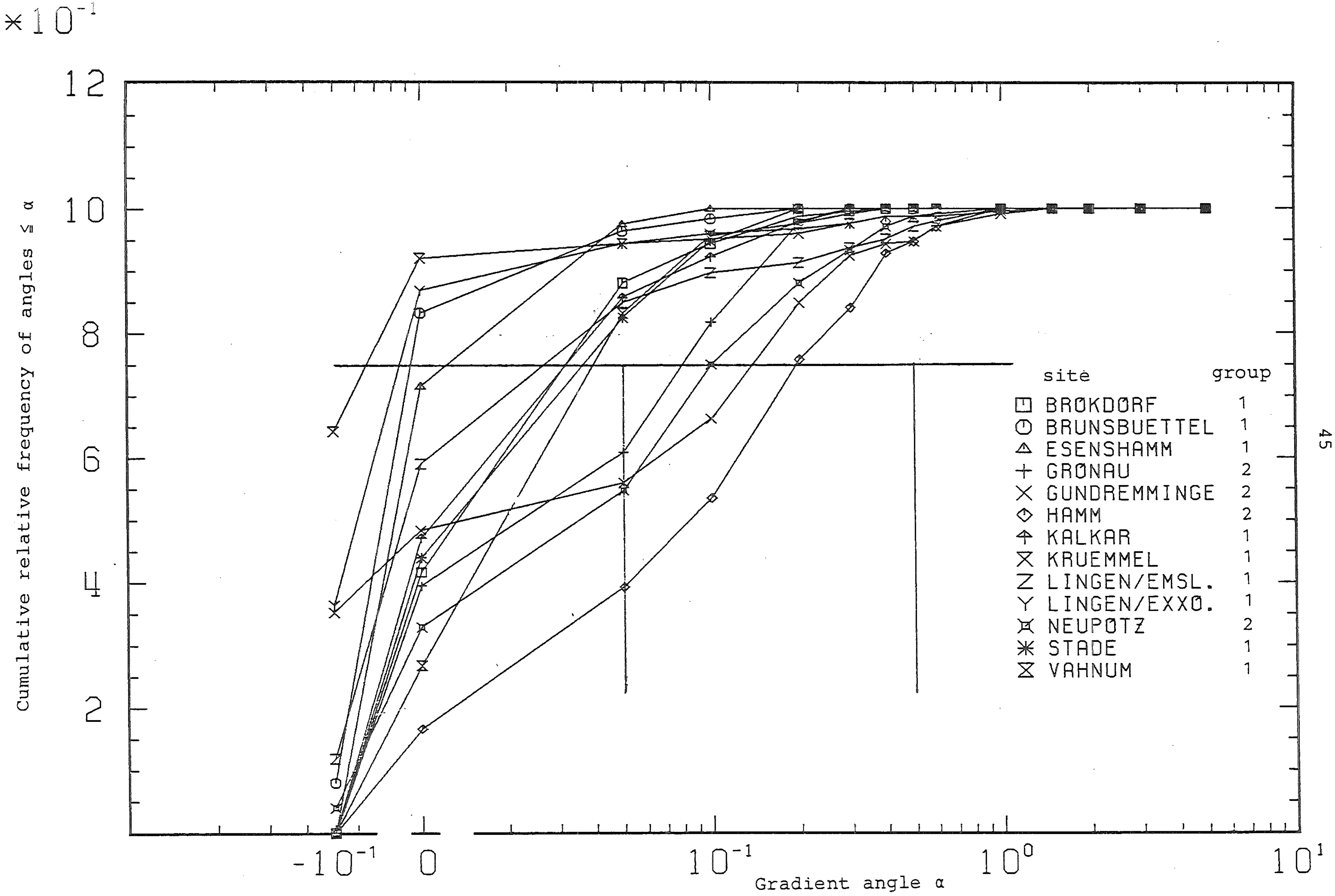


Fig 2.6: Frequency of gradient angles of flat to moderate sites.

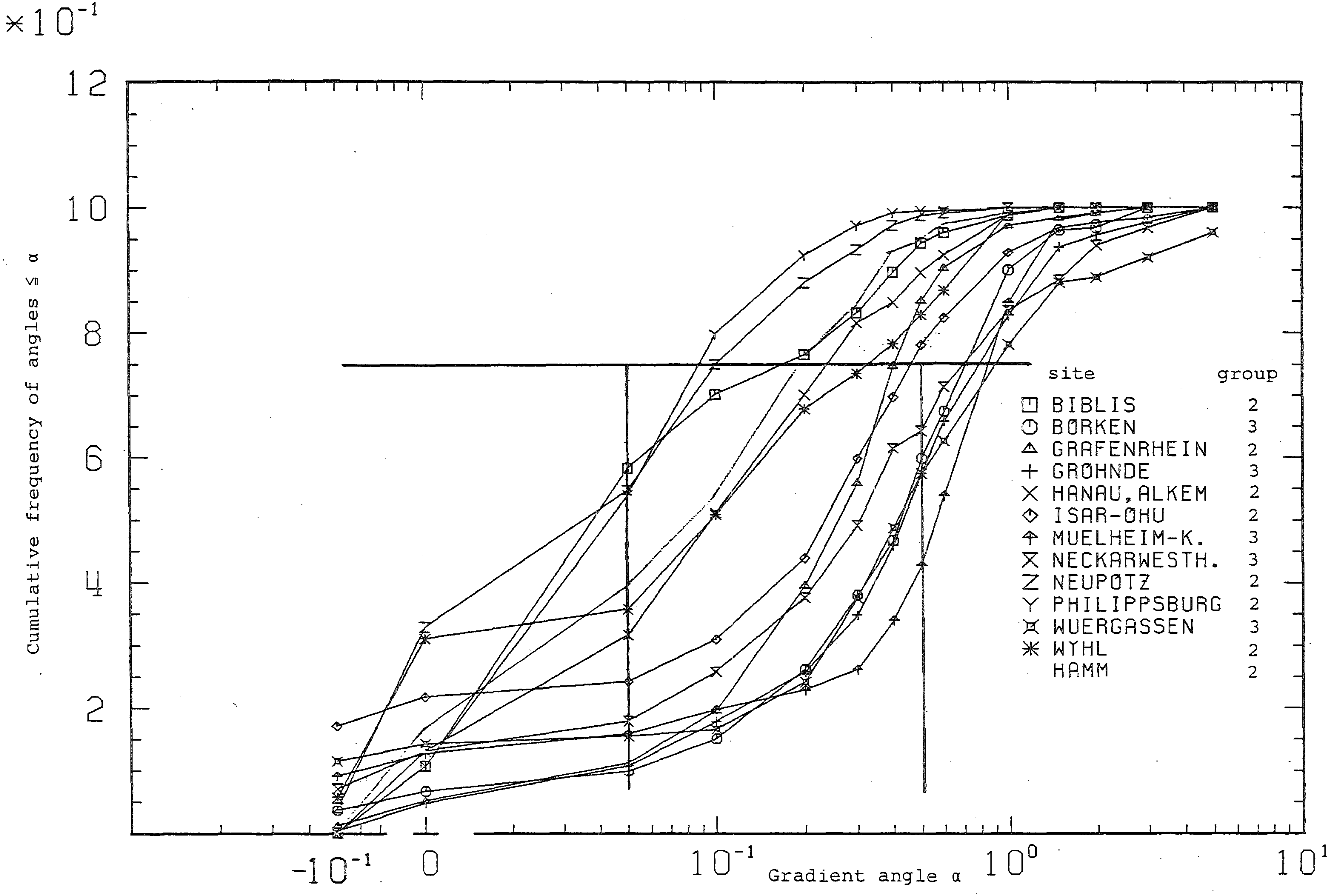


Fig 2.7: Frequency distribution of gradient angles of moderate to mountainous sites.

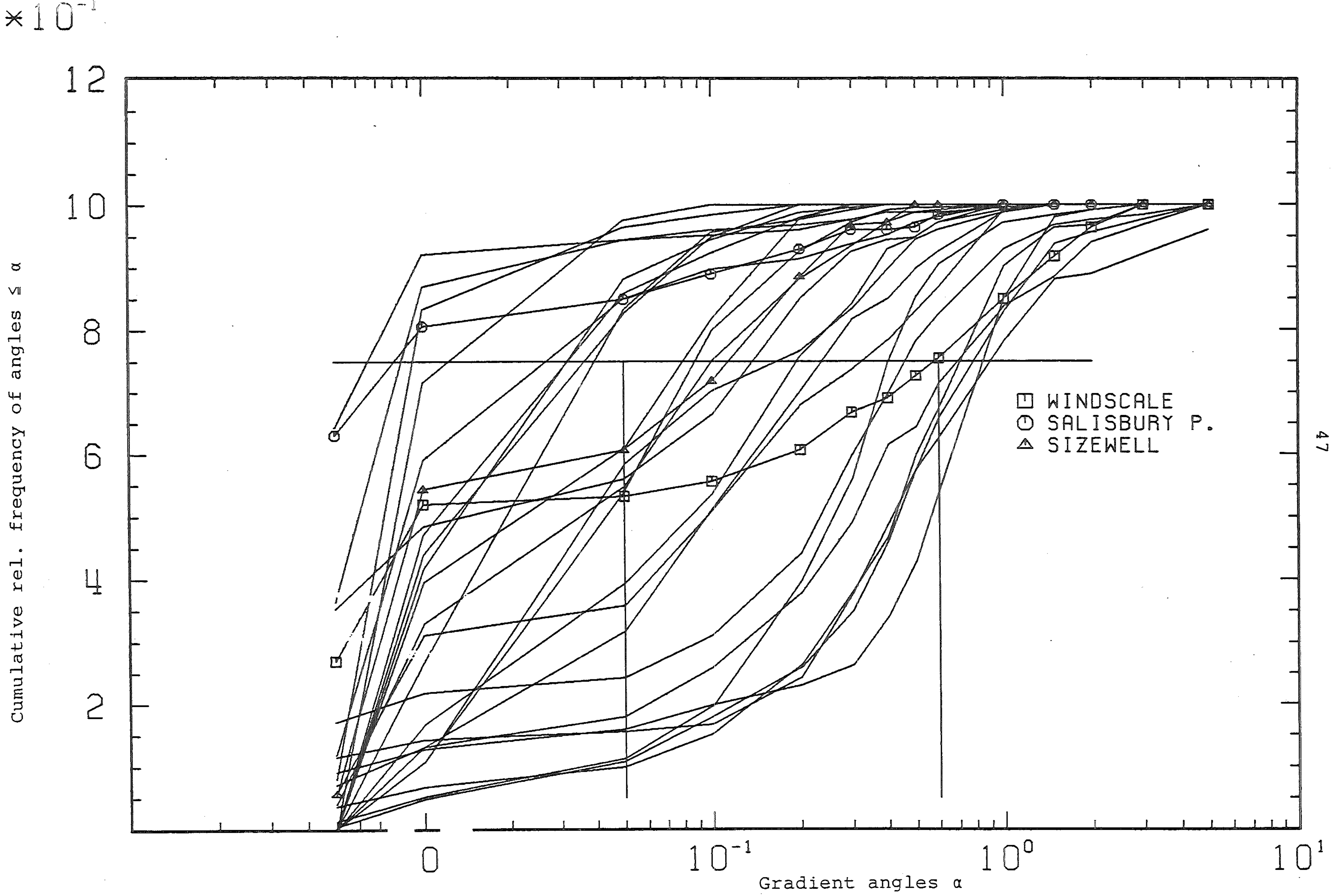


Fig 2.8: Frequency distributions of gradient angles of 3 British sites.

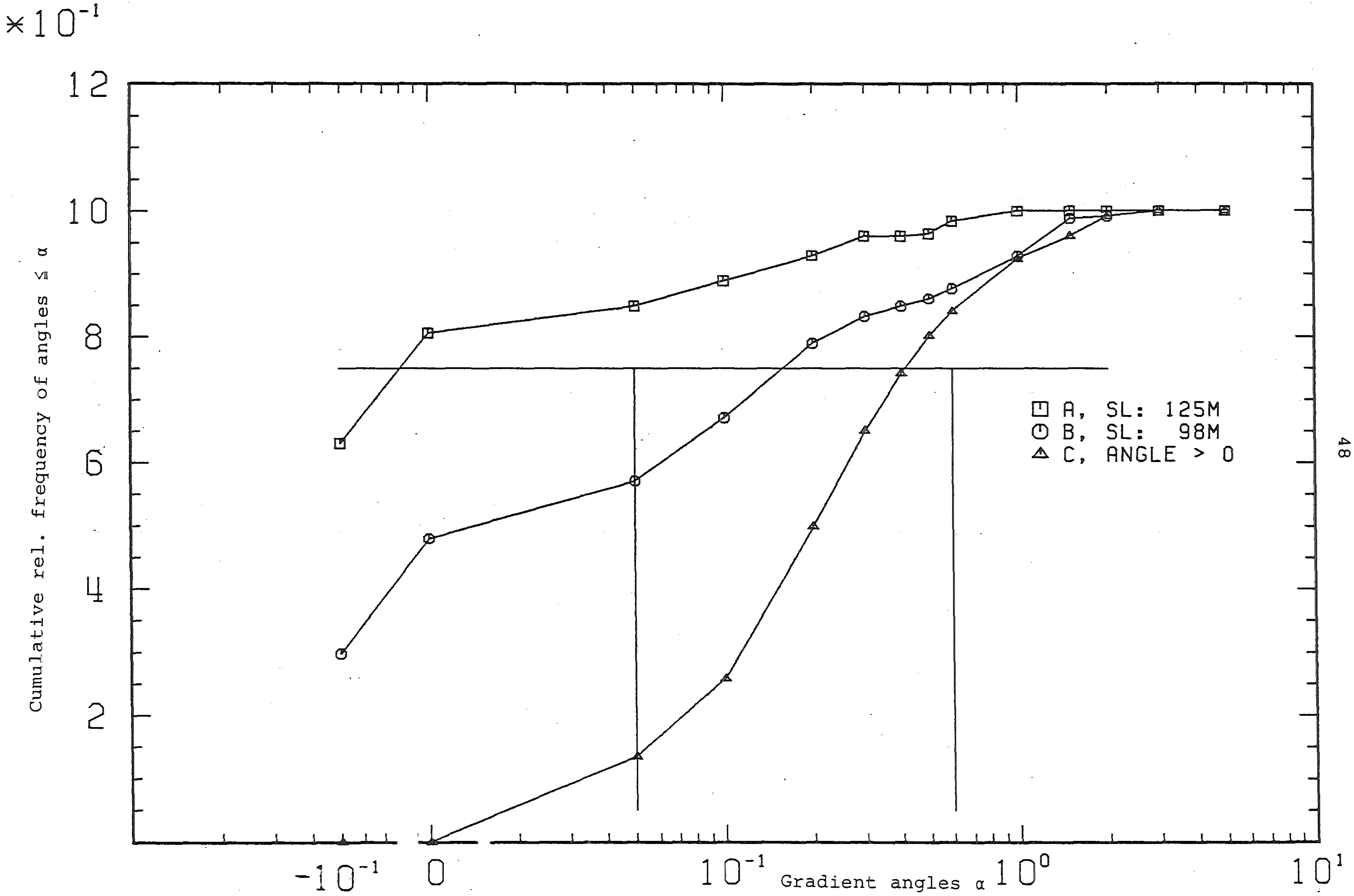


Fig 2.9: Variations of the site level for Salisbury Plain

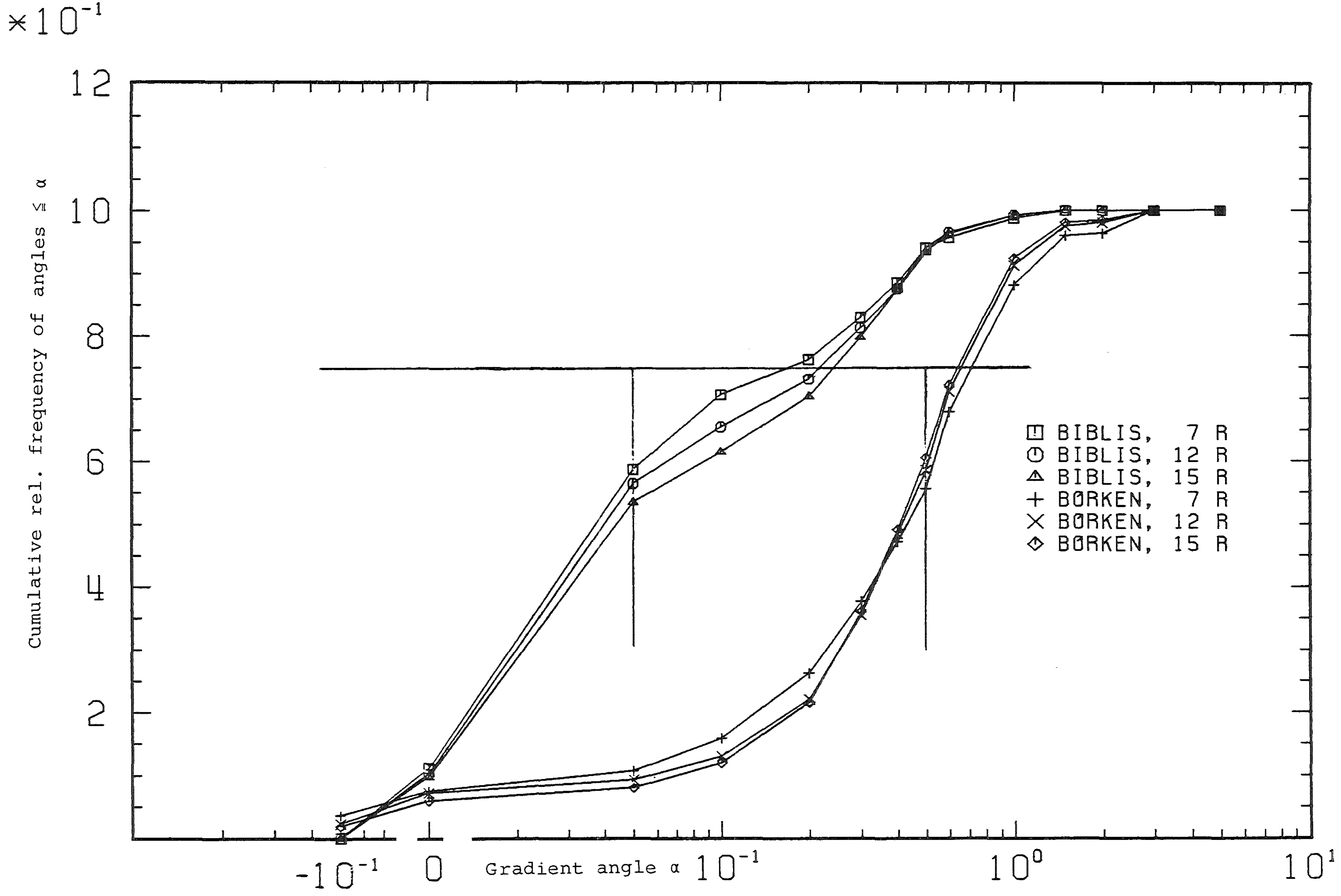
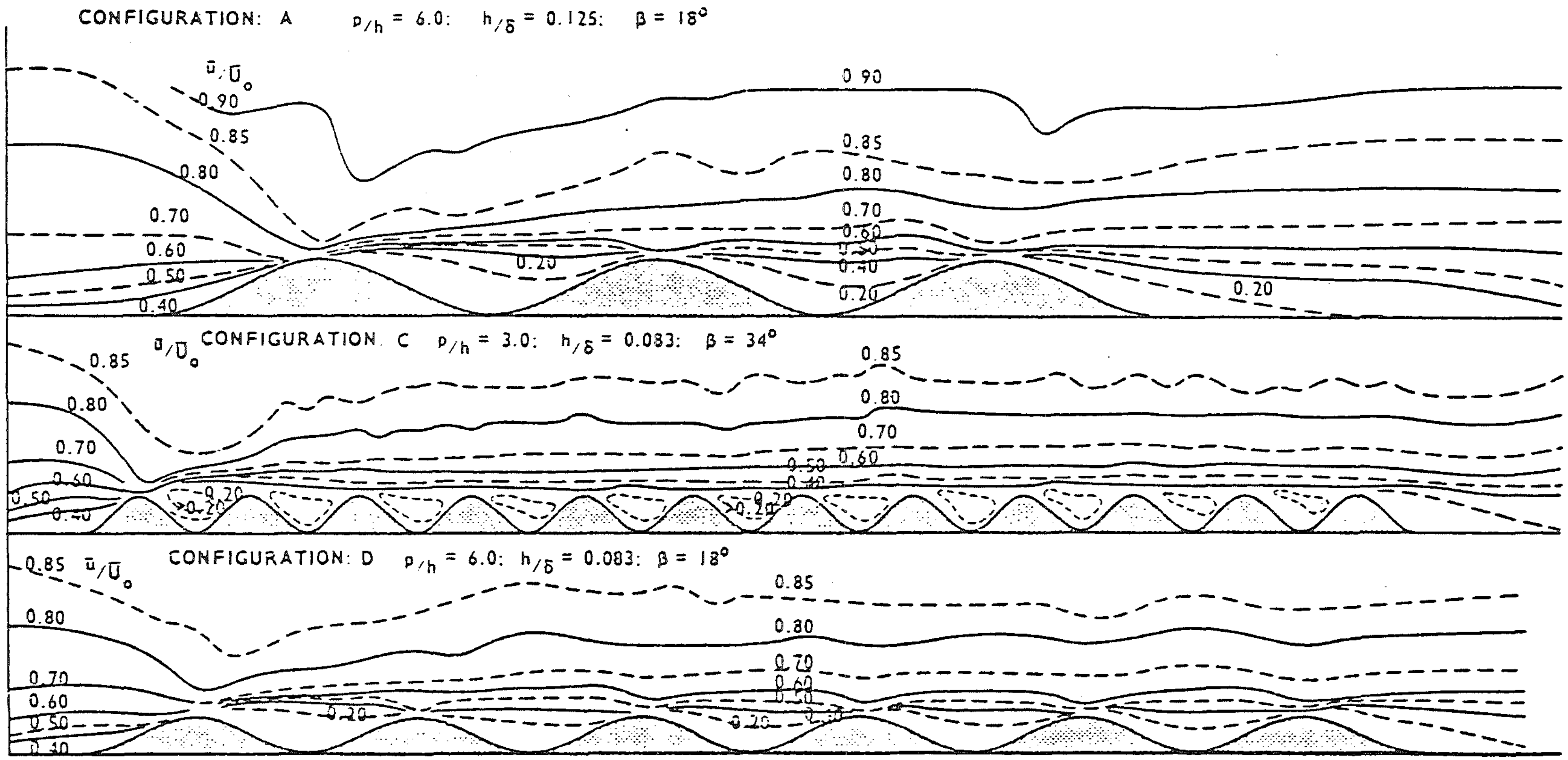


Fig 2.10: Frequency distribution of gradient angles for varying radii at two sites.



h: hill height
p: hill length
δ: boundary layer height

ß: $\tan^{-1}(\frac{2h}{p})$

Fig 3.1: Contours of constant mean velocity ratio: $u/\bar{U}_o$ in simulated boundary flow

Taken from /CO74/

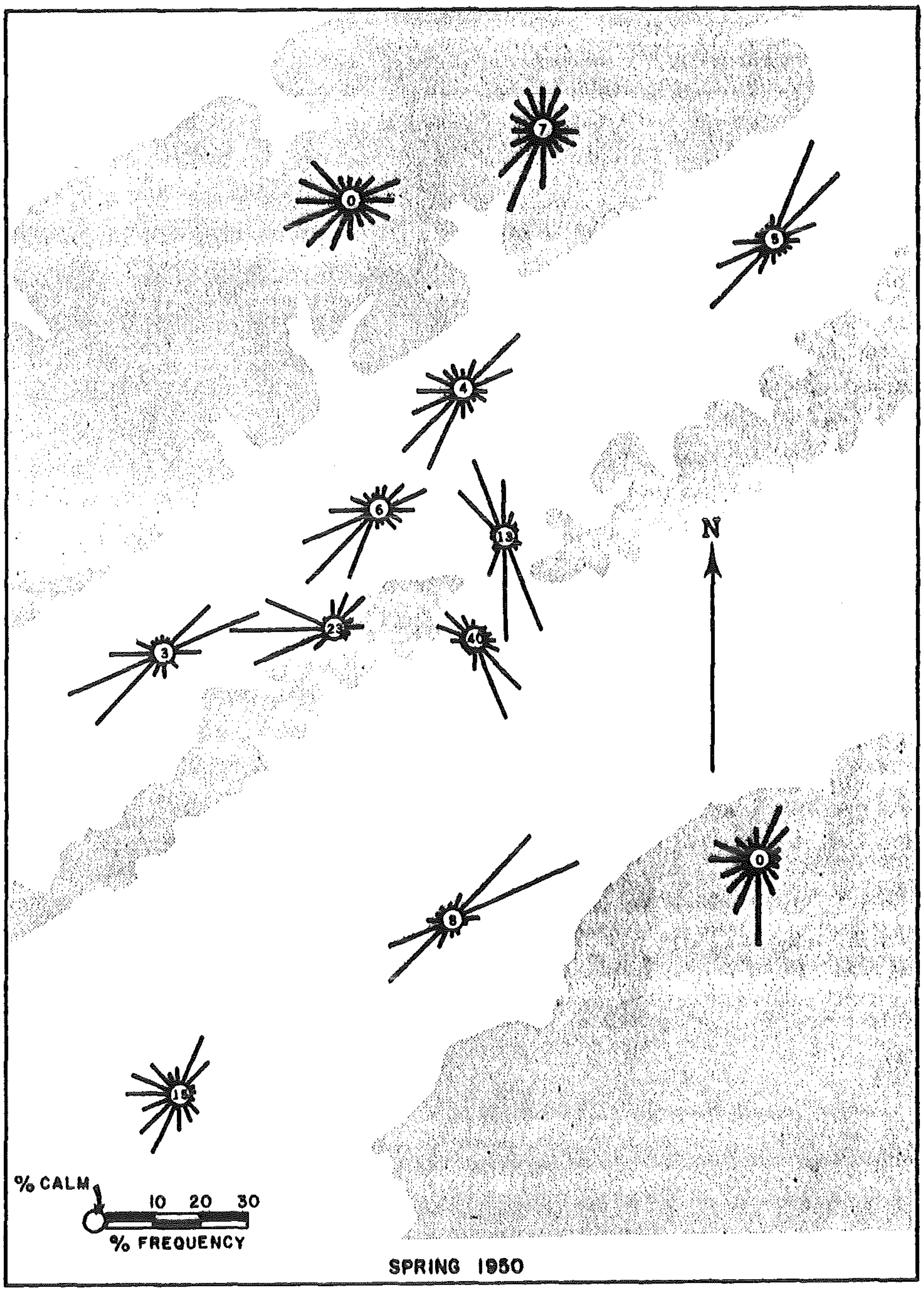


Fig 3.2: Wind flow in the neighbourhood of the Oak Ridge National Laboratory demonstrated by means of windroses. (Shaded area represents elevated terrain)

Taken from /SL68/

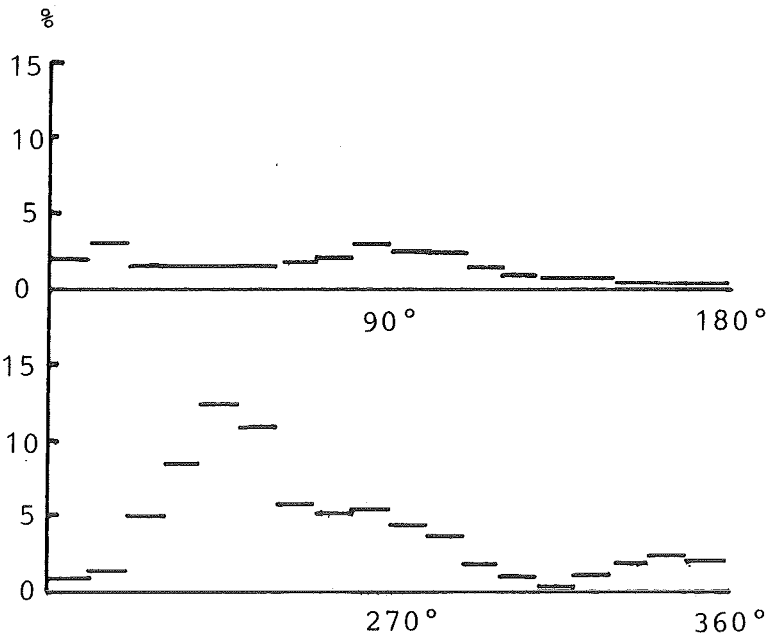


Fig 3.3: Wind direction frequency distribution at the Phillipsburg site.

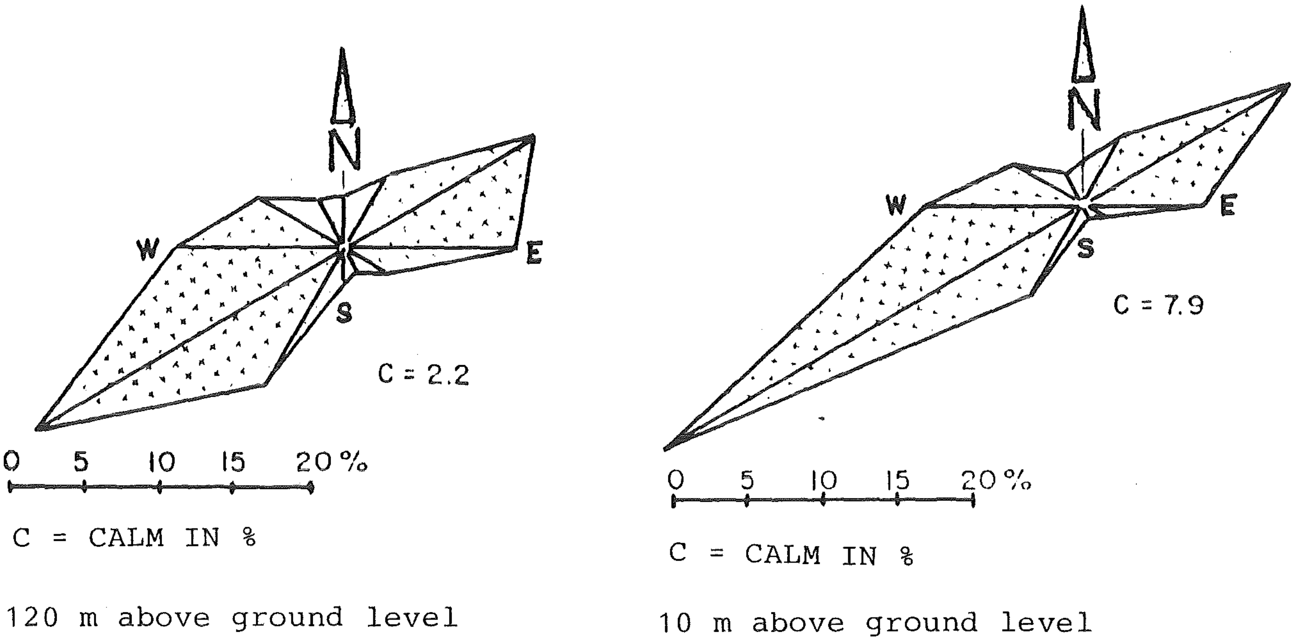
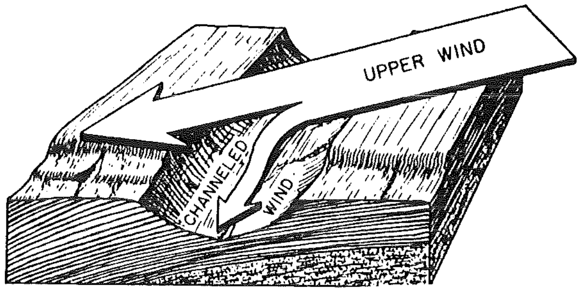


Fig 3.4: Annual wind direction rose at Gundremmingen



Taken from /SL68/

Fig 3.5: Example for wind direction shearing

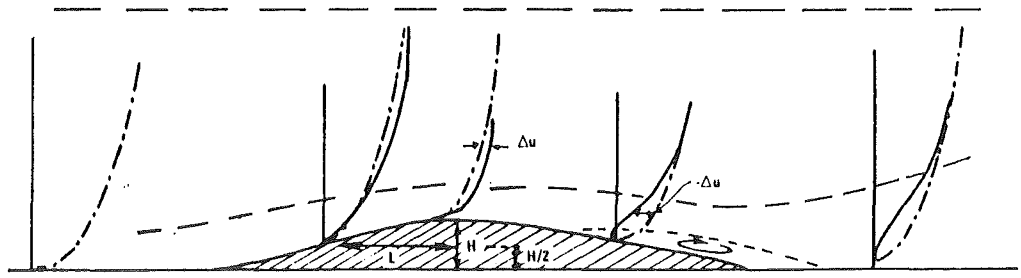
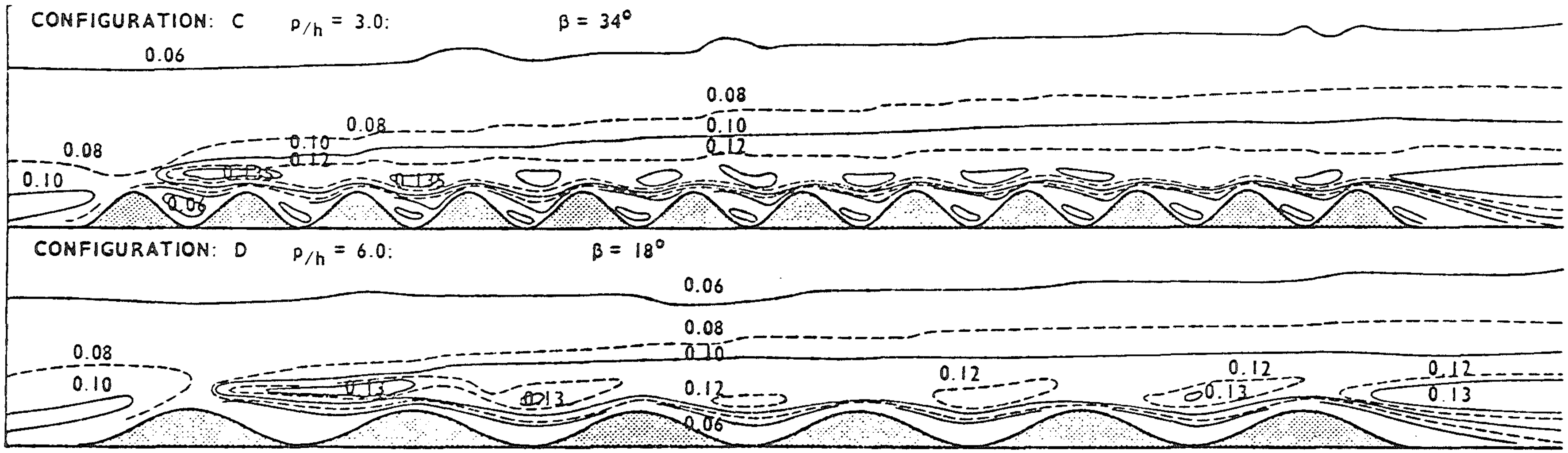


Fig 3.6: Example for velocity shearing
Taken from /PL82/



h: hill height
p: hill length
ß: $\tan^{-1}(\frac{2h}{p})$

Fig 3.7: Contours of constant turbulence intensities $\sqrt{\overline{u'^2}}/\bar{u}_o$ in a simulated boundary layer flow

(Taken from /CO74/)

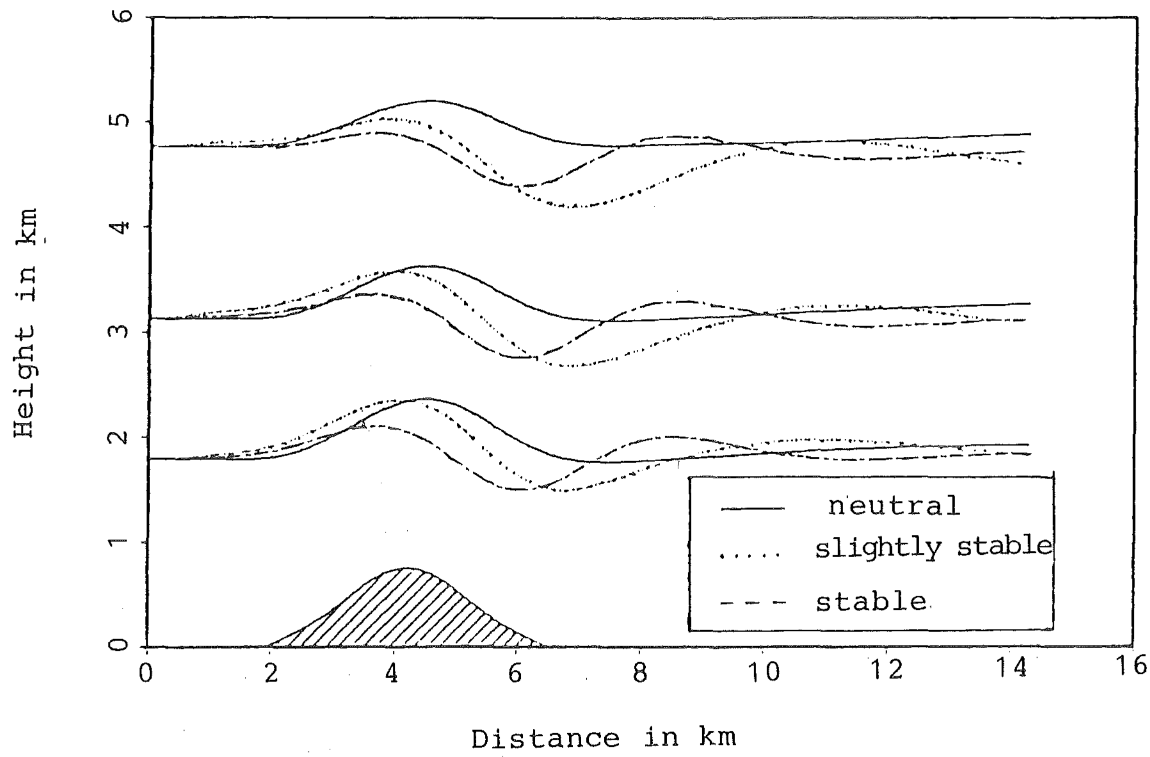
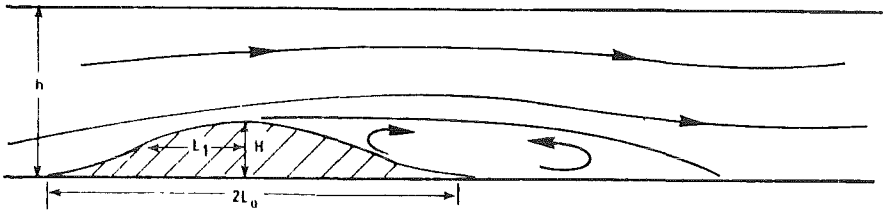
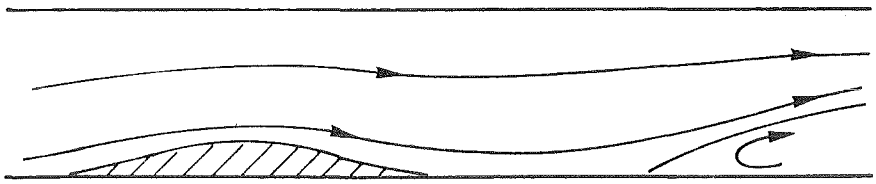


Fig 3.8: Generation of lee waves

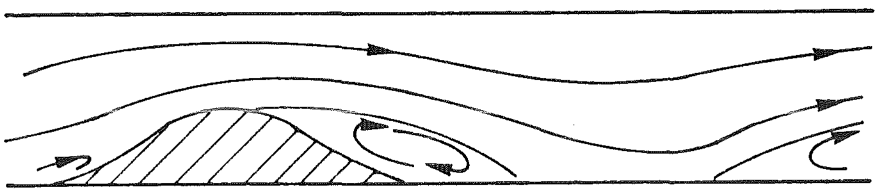
Taken from /ET81/



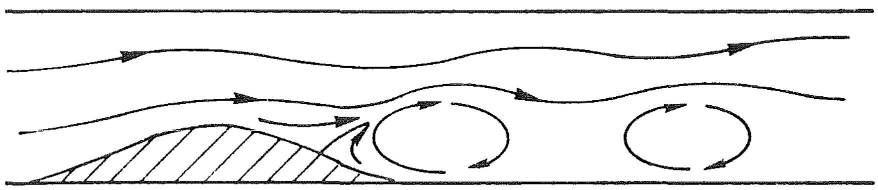
(a) Supercritical $F > F_{crit}$
controlled.



(b) Hill with low slope; subcritical Froude number $F < F_{crit}$



(c) Hill with moderate slope; supercritical Froude number $F > F_{crit}$



(d) Subcritical Froude number moderate slope

Fig 3.9: Stratified flow over 2-dim. hills under a strong inversion

Taken from /PL82/

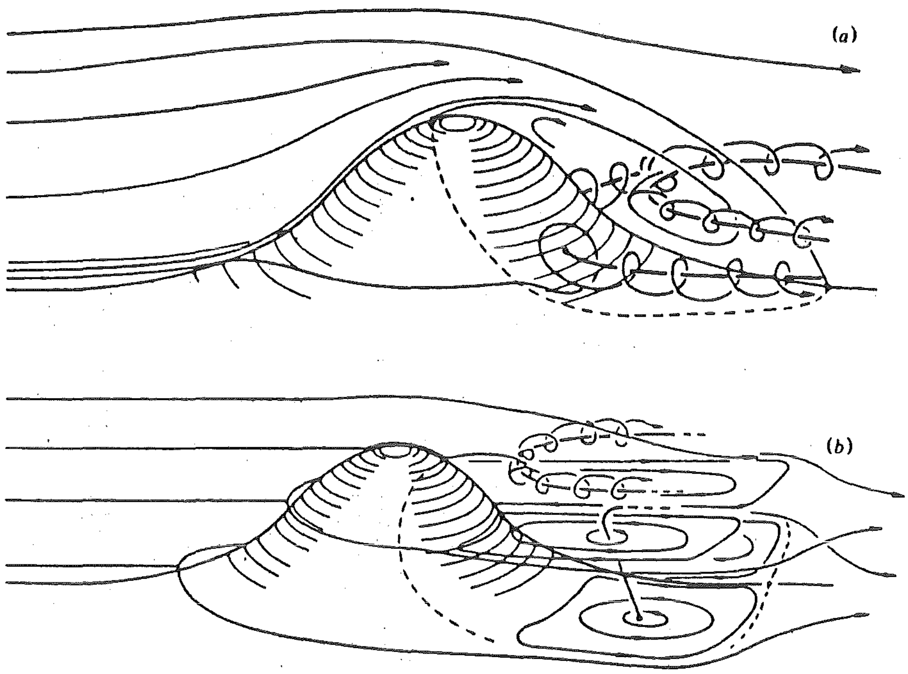
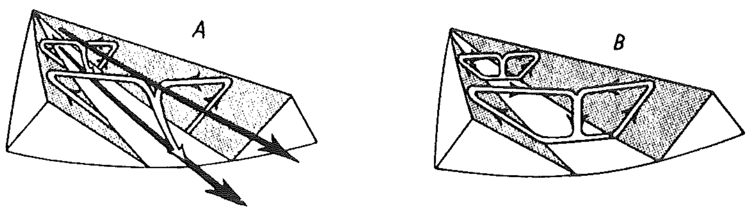
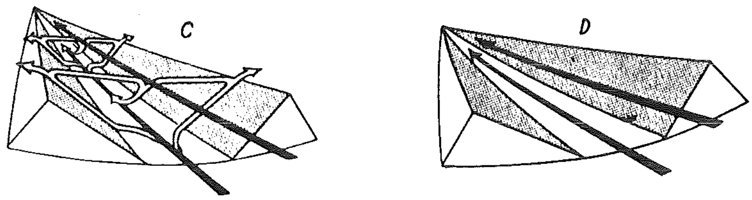


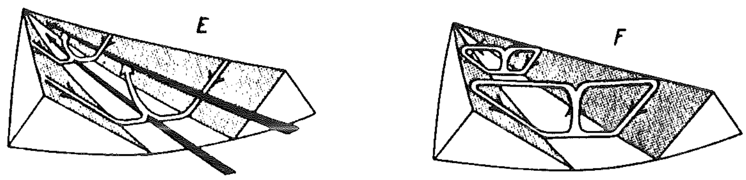
Fig. 3.10: Flow over a 3-dim hill in neutral (a) and very stable stratification (b).
Taken from /HU80/



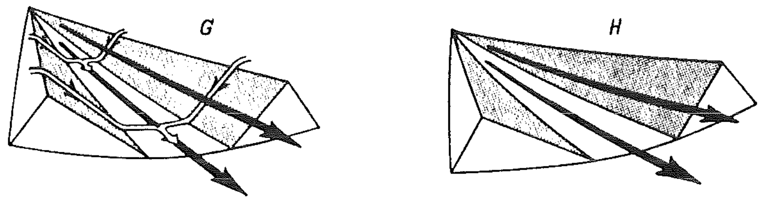
after sunrise



noon

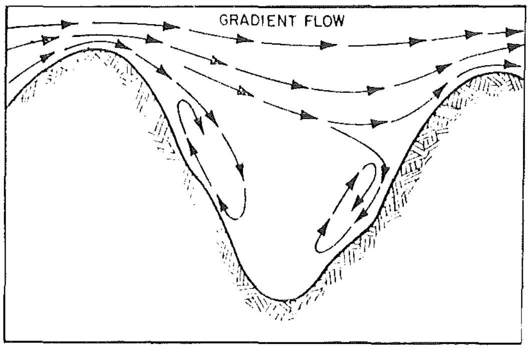


evening

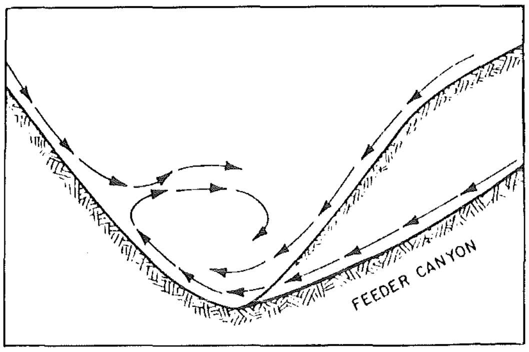


mid-night

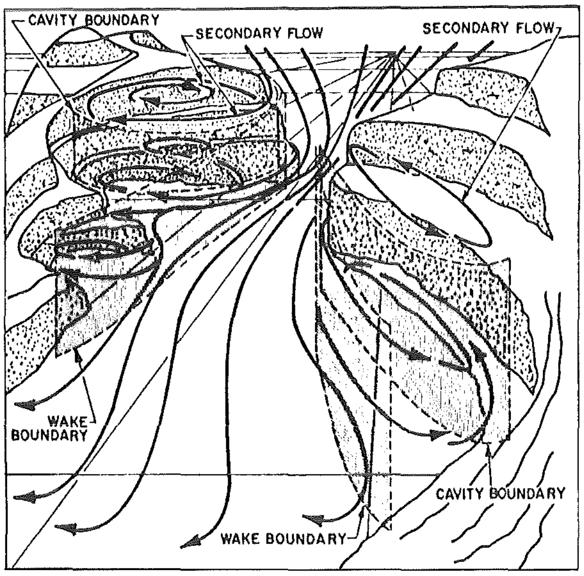
Fig 3.11: Slope and valley winds during a diurnal period. (Taken from /GE61/



Schematic illustration of mountain top influences upon the gradient-level flow component and the downward transporting of gradient flow momentum.



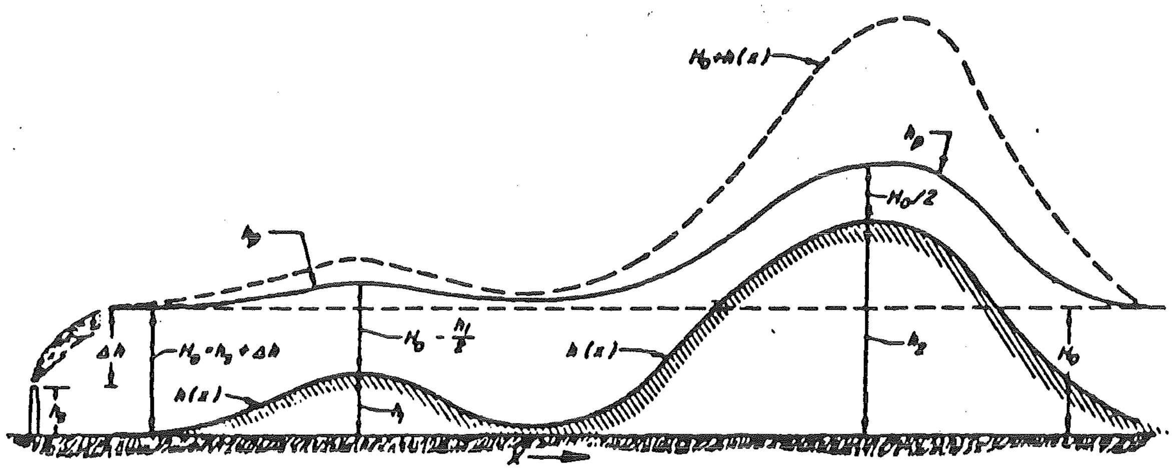
. Schematic illustration of circulations triggered by slope density flows and air drainage from a side feeder canyon.



Schematic illustration of turbulent wake effects caused by obstacles protruding into the primary flow pattern.

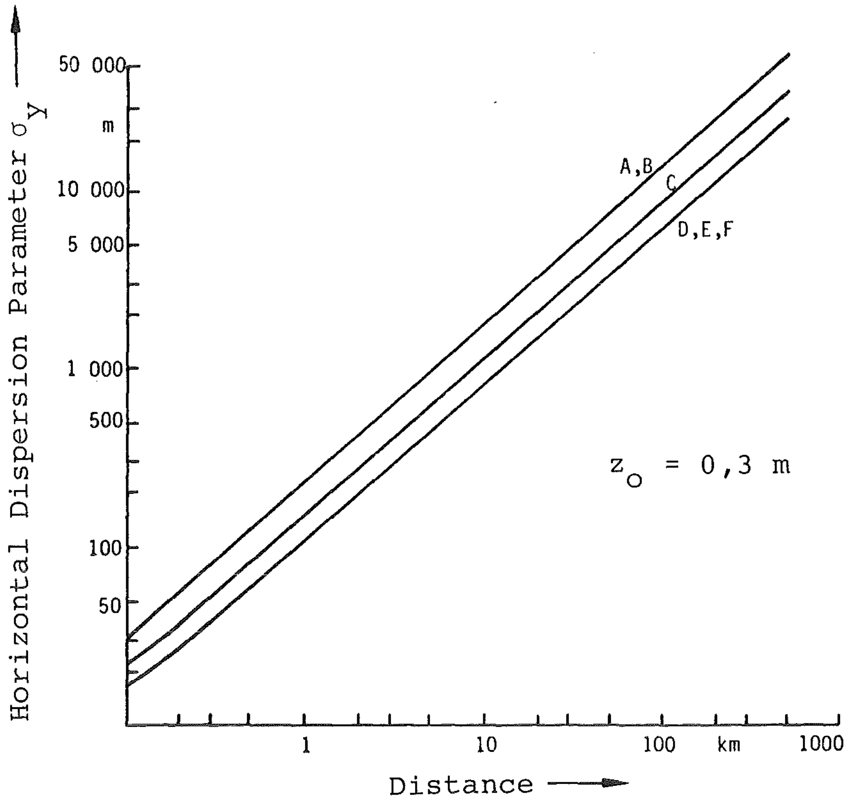
Taken from /ST75/

Fig 3.12: Sources of enhanced diffusion found in the Huntington Canyon



h_s	physical stack height
Δh	plume rise
H_o	effective stack height (physical stack height plus plume rise)
$h(x)$	terrain height above stack base elevation
h_p	plume centerline height above stack base elevation

Fig 4.1: Treatment of terrain influence upon plume height neutral and unstable conditions /EG75/



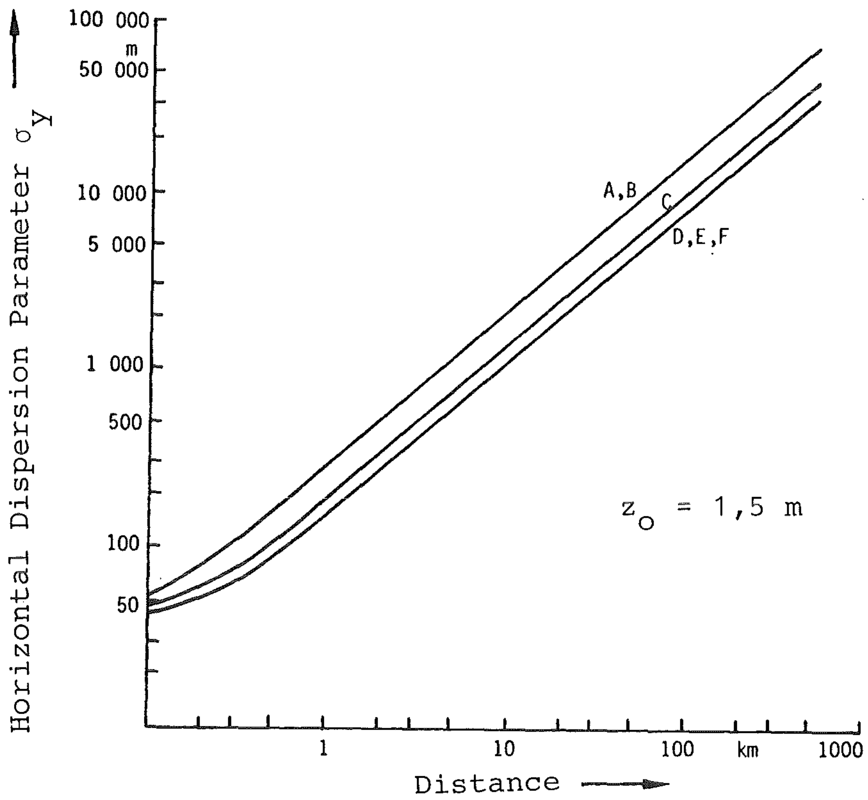


Fig 4.2: σ_y-Parameters applied in UFOMOD for different roughness length z_o.

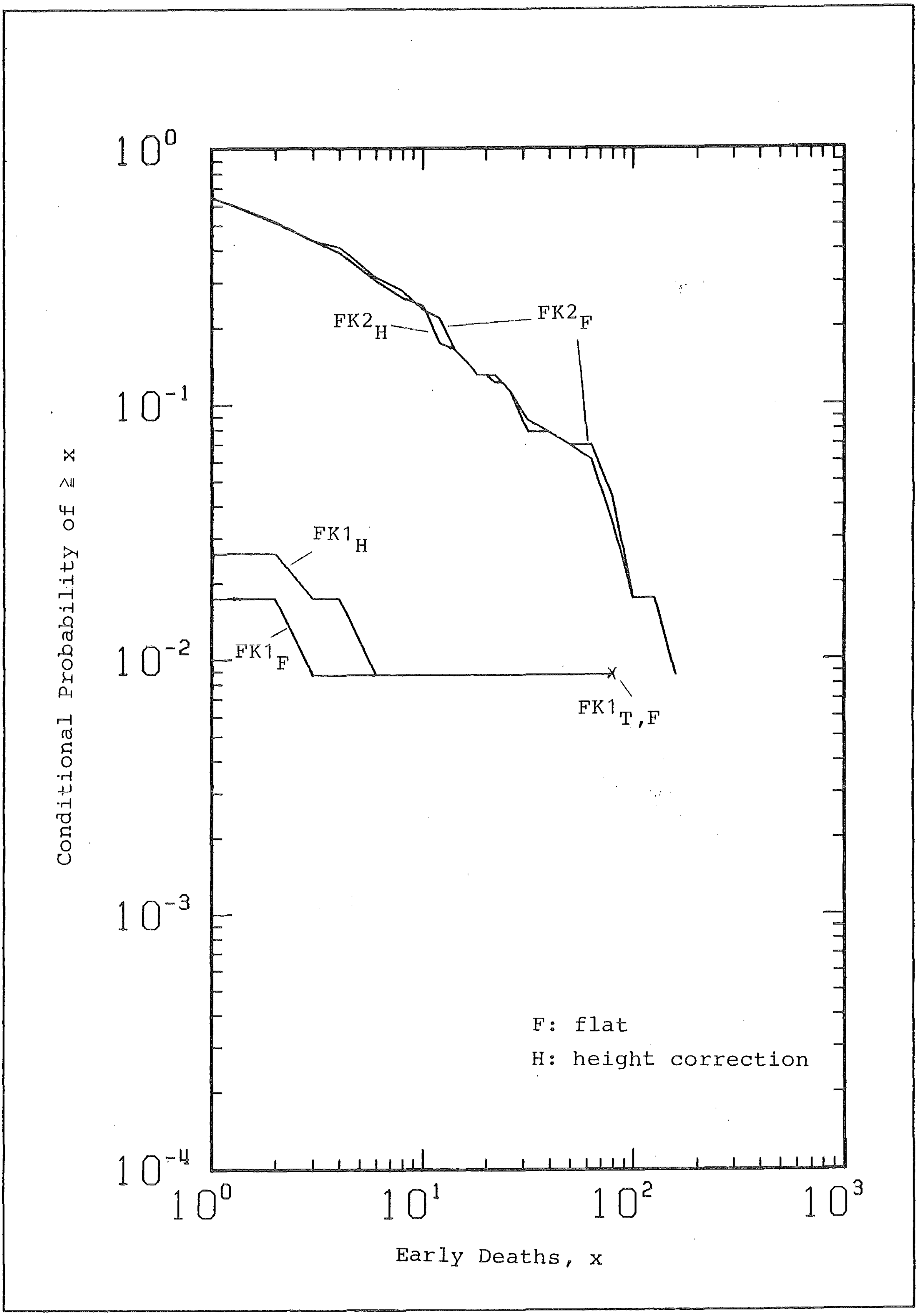


Fig 4.3: Sensitivity of the cfd's for early deaths to terrain adjustment modifications at the Upper Rhine Valley site

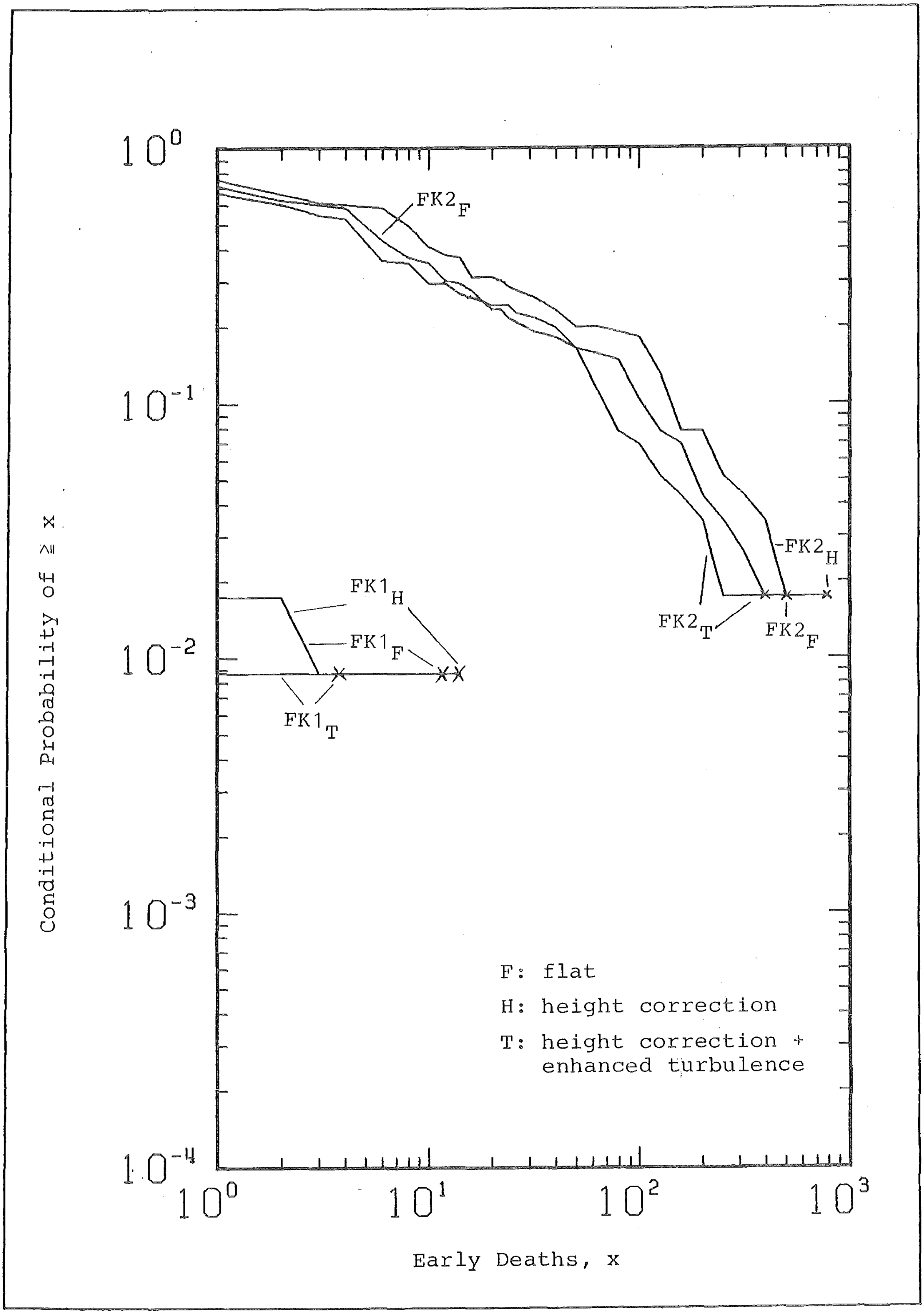


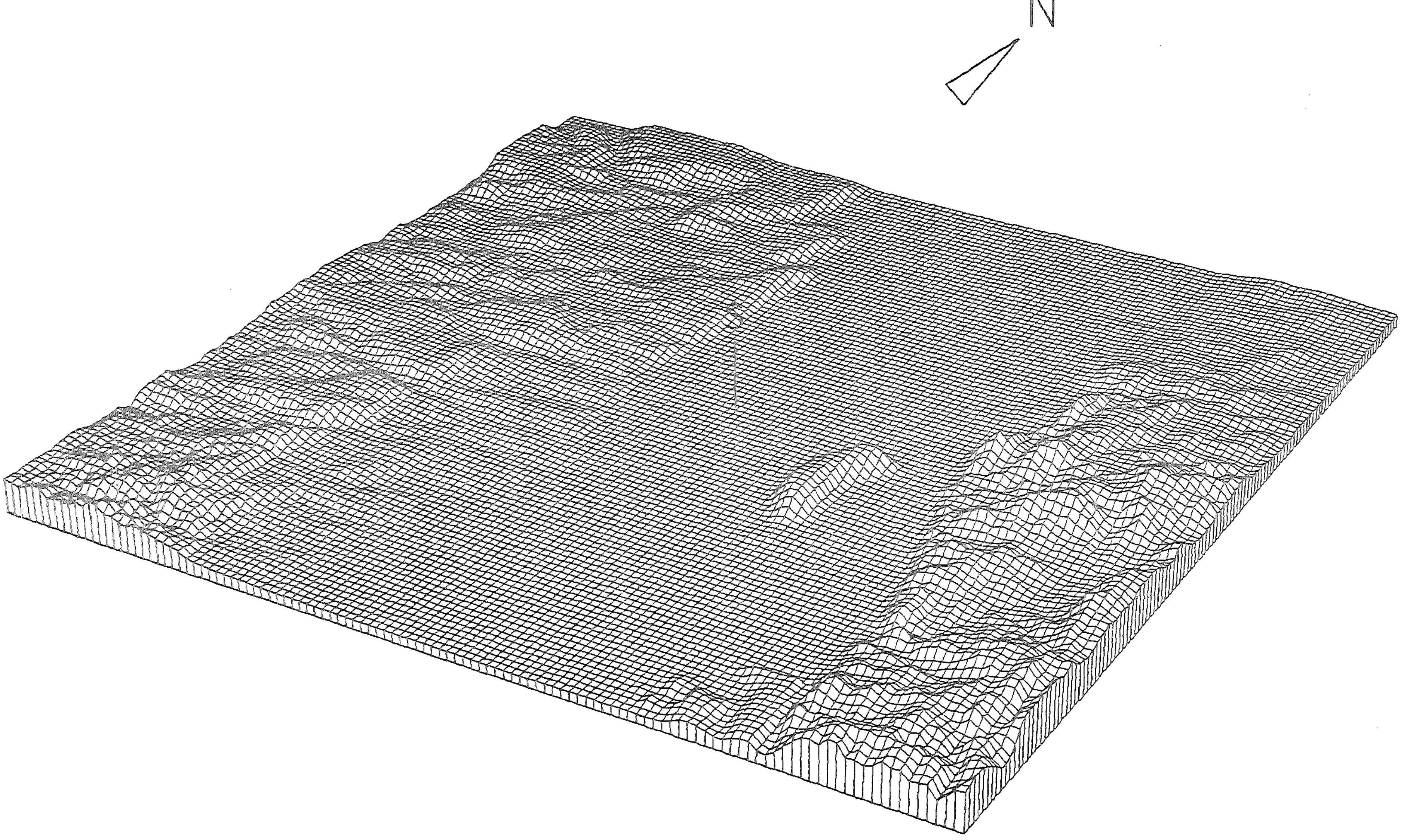
Fig 4.4: Sensitivity of the cfd's for early deaths to terrain adjustment modifications at the South German Plateau site.

Appendix A

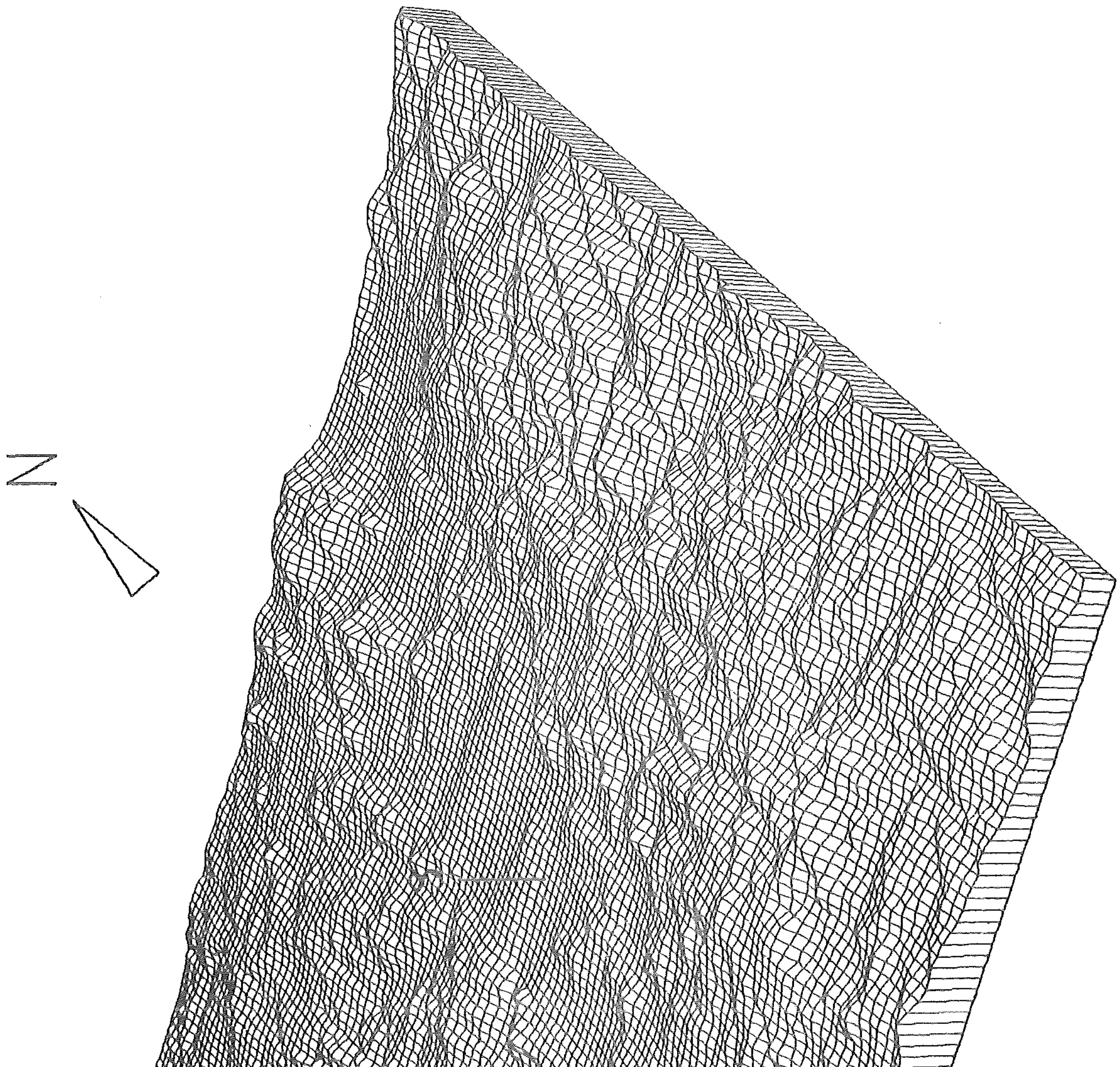
In the appendix the relief plots of the 24 sites of German nuclear facilities are represented, which have been examined under the aspect of orography.
The abbreviations used are:

SL: site level
MAXH: maximum height
MINH: minimum height
AVH: averaged height

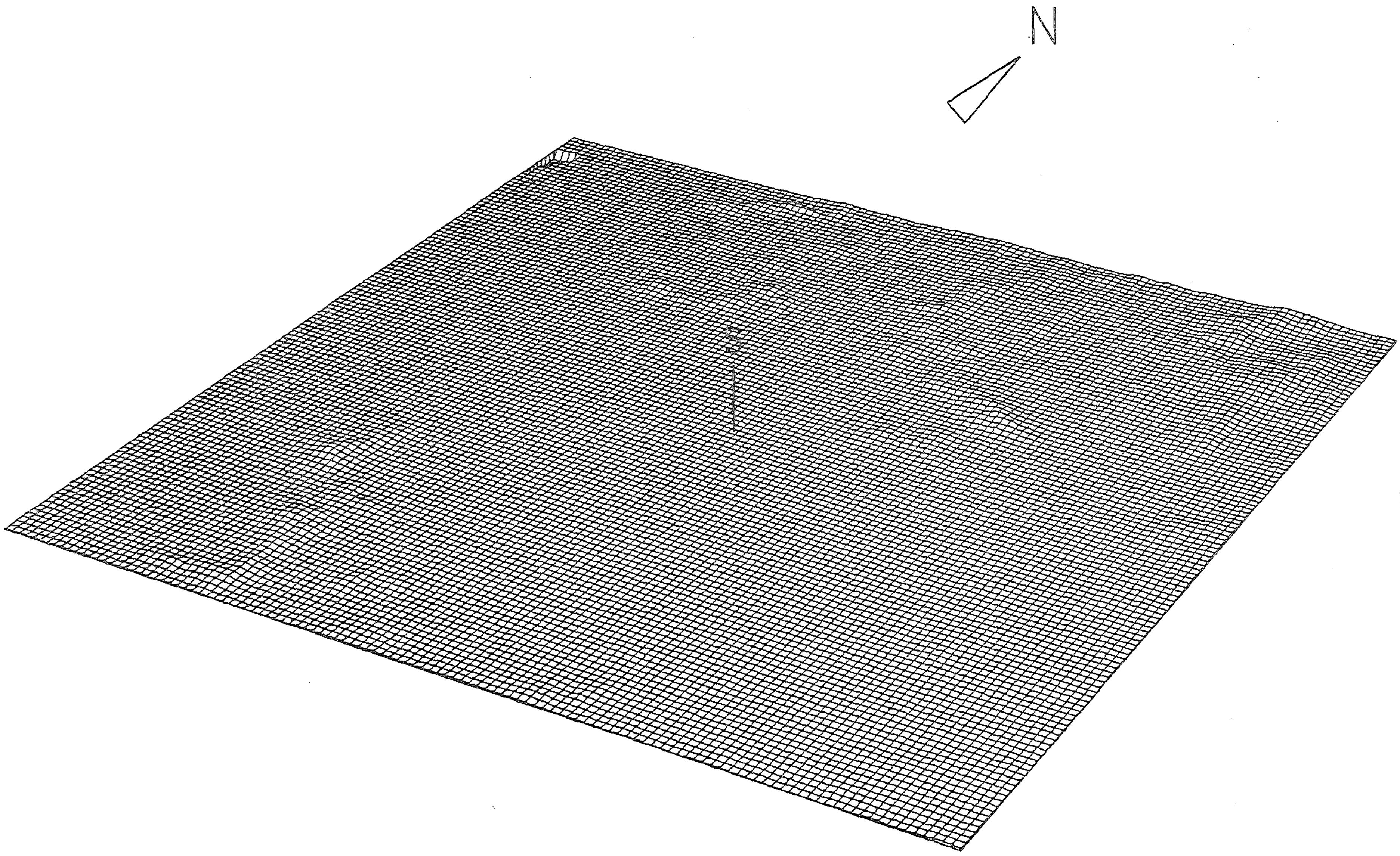
A general description of the data base applied can be found in chapter 2.2.



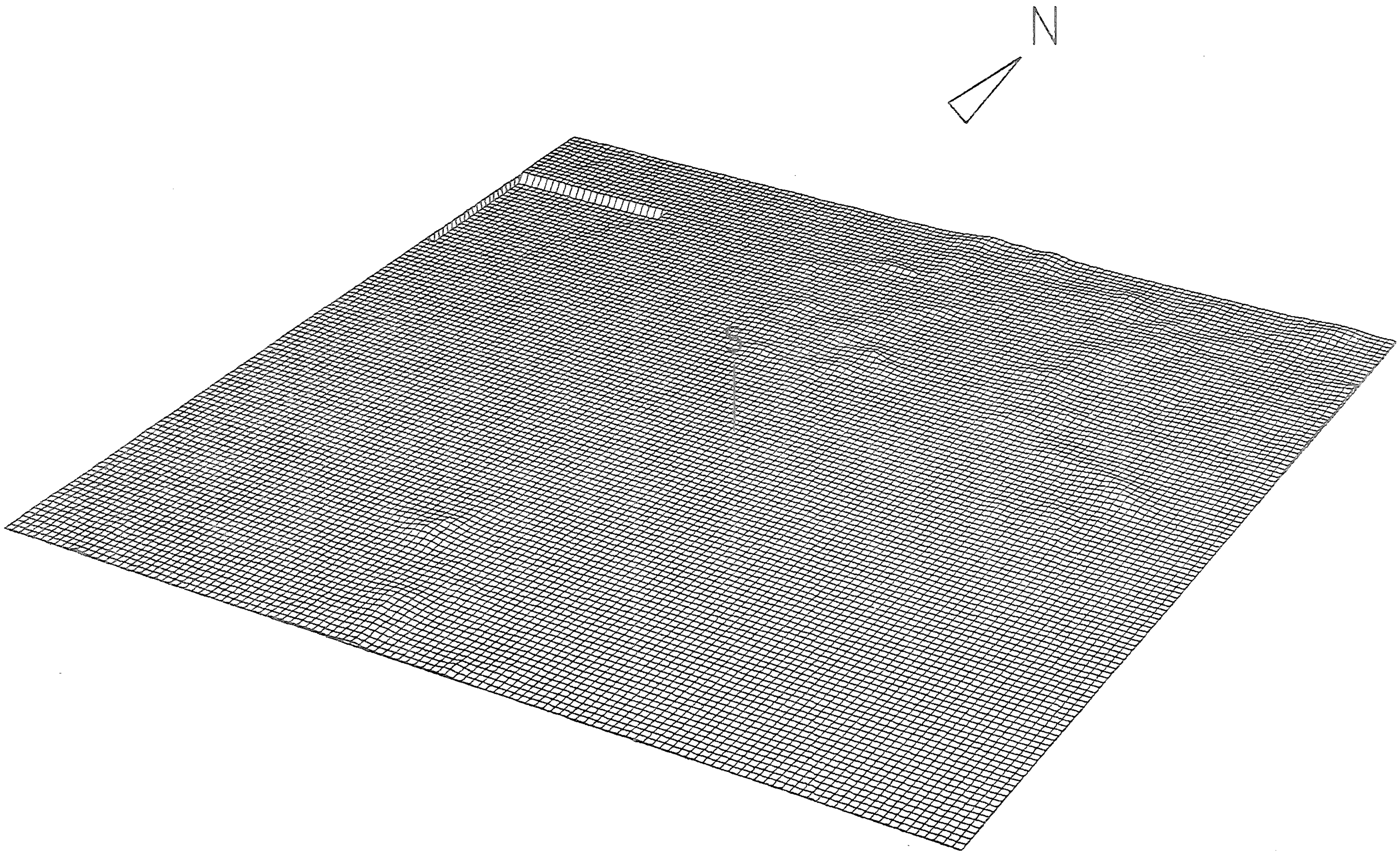
A.1 BIBLIS; SL:88M, MAXH:572M, MINH:81M, AVH:176M



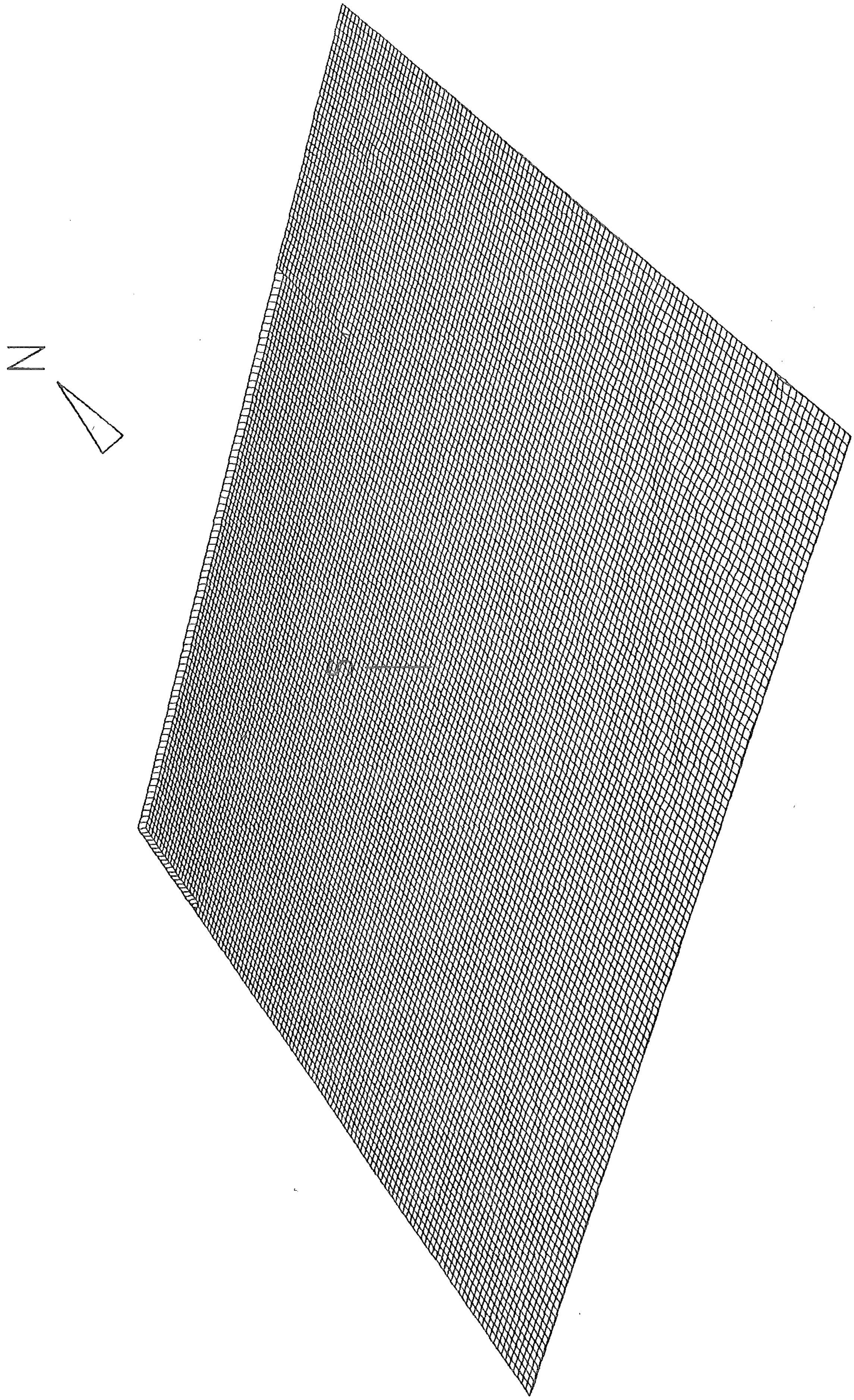
A.2 BORKEN; SL:173M, MAXH:646M, MINH:83M, AVH:320M



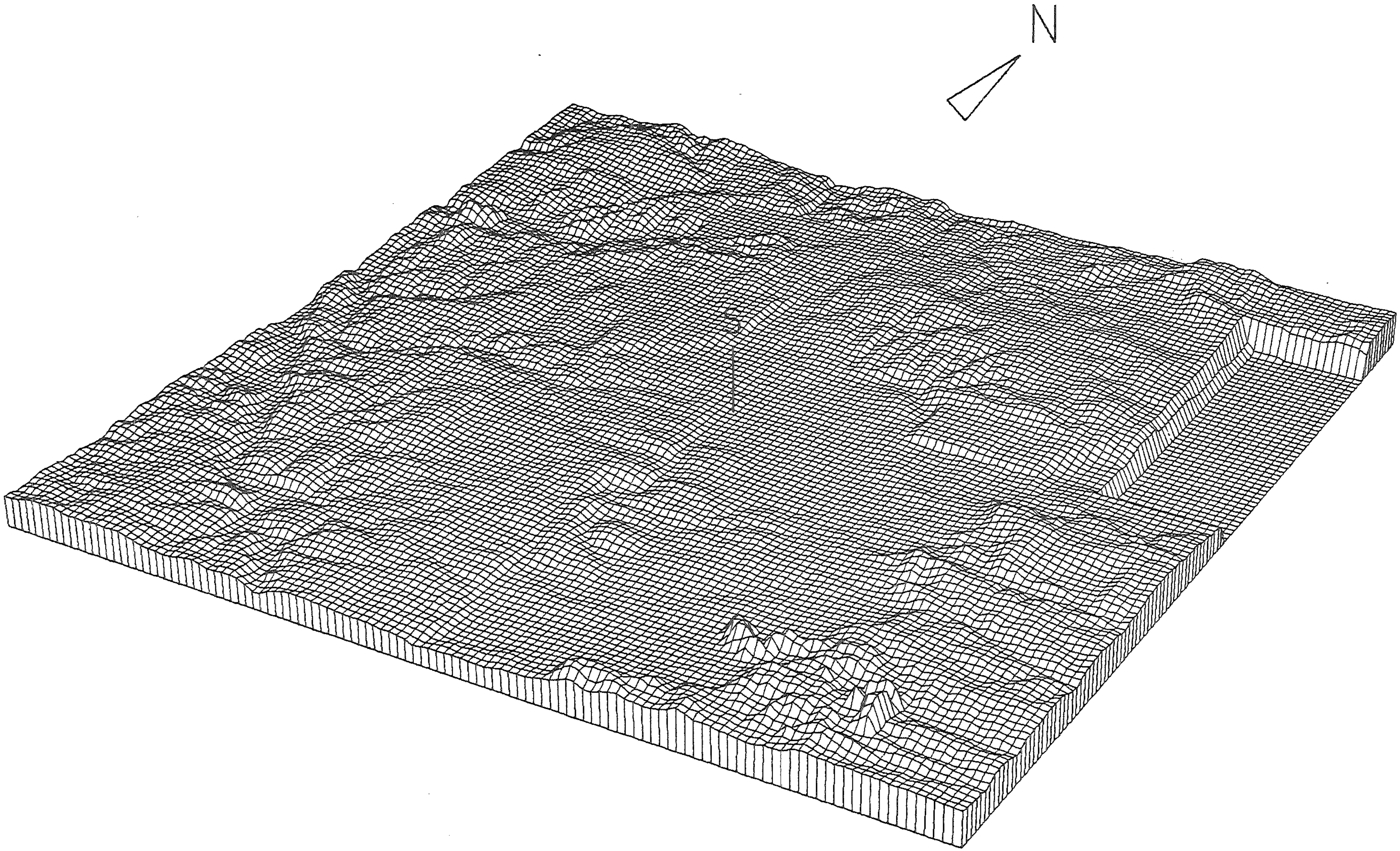
A.3 BRØKDØRF; SL:1M, MAXH:78M, MINH:1M, AVH:8M



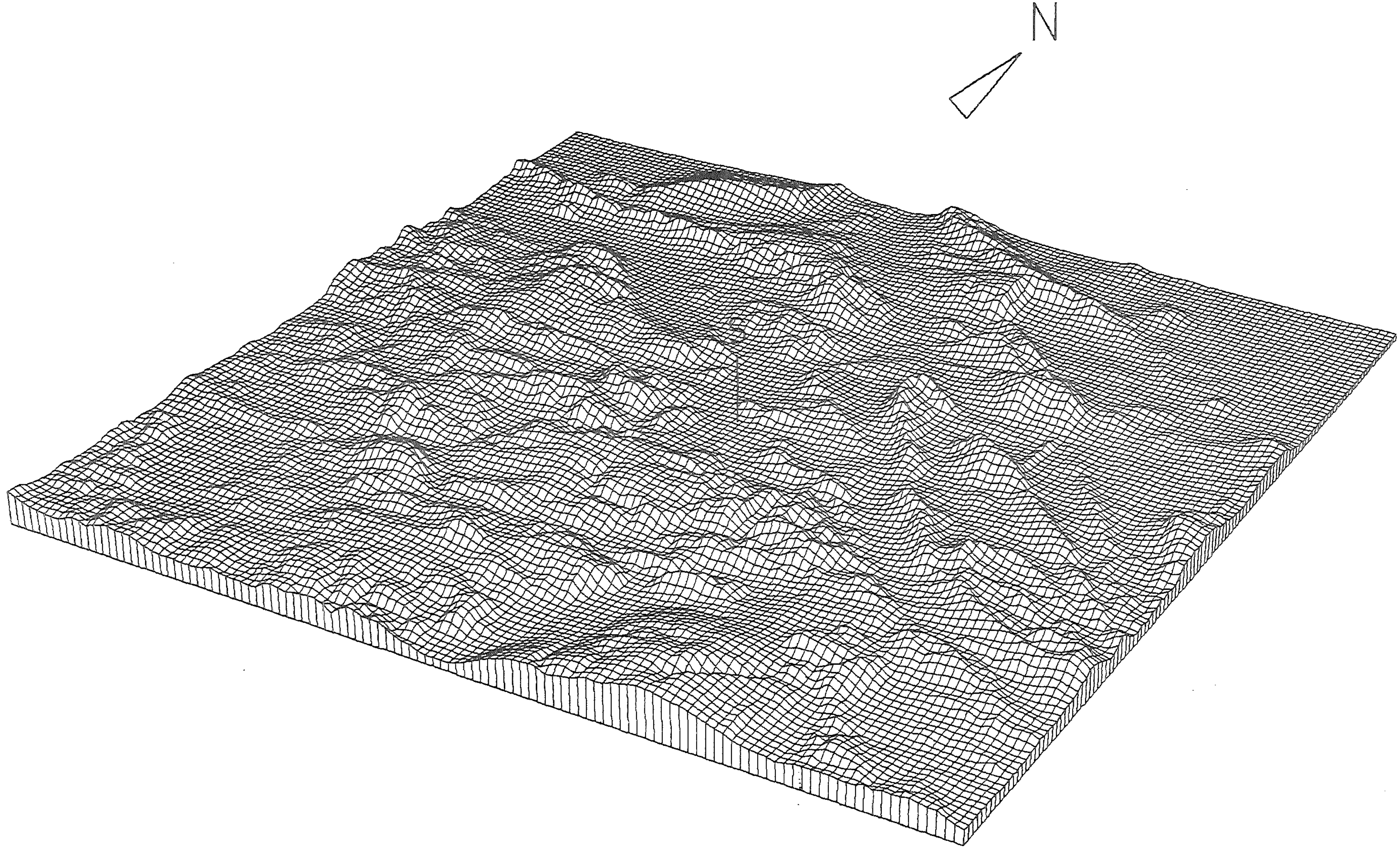
A.4 BRUNSBUETTEL; SL:6M, MAXH:64M, MINH:0M, AVH:4M



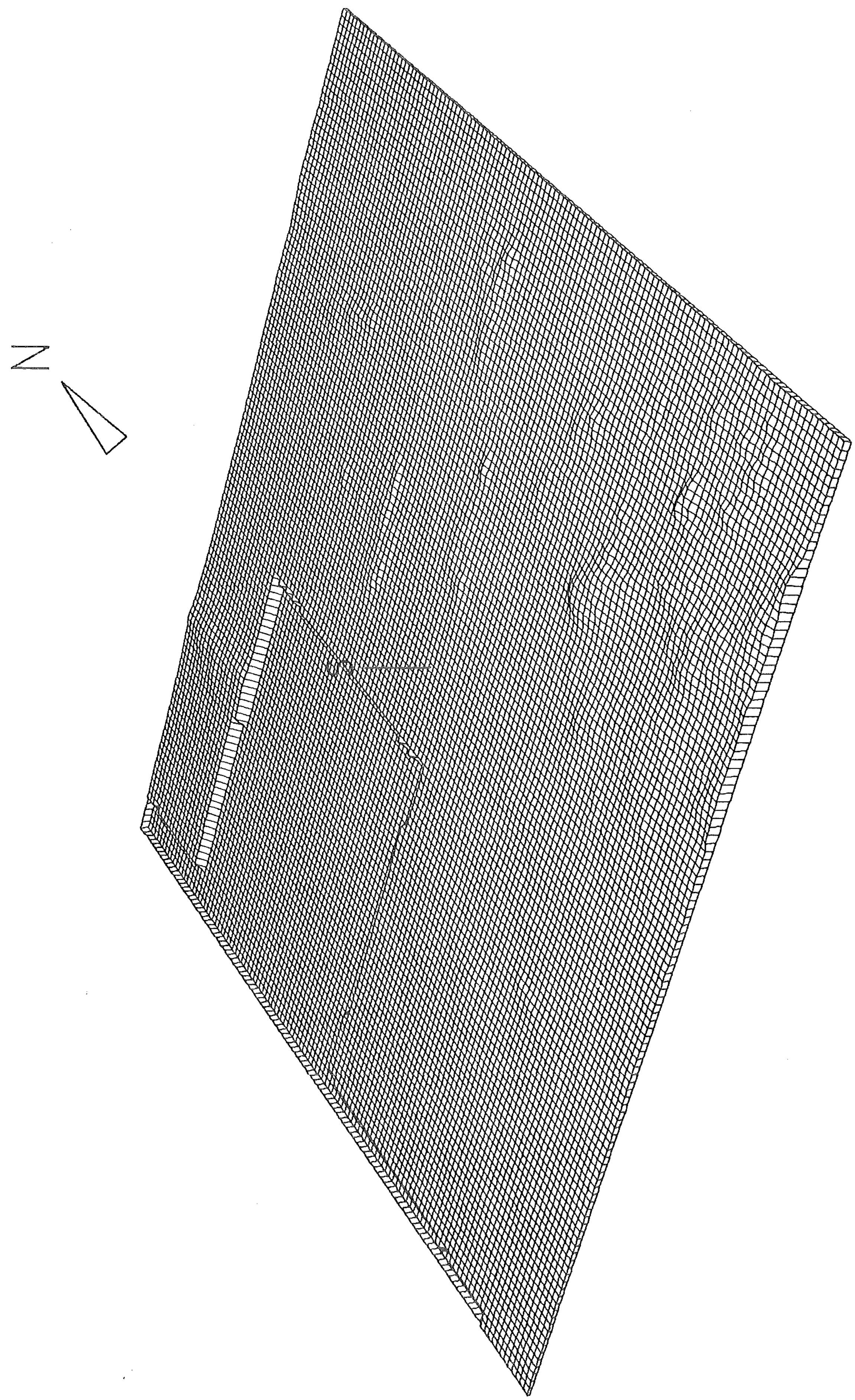
A.5 ESENSHAMM; SL:2M, MAXH:45M, MINH:1M, AVH:7M



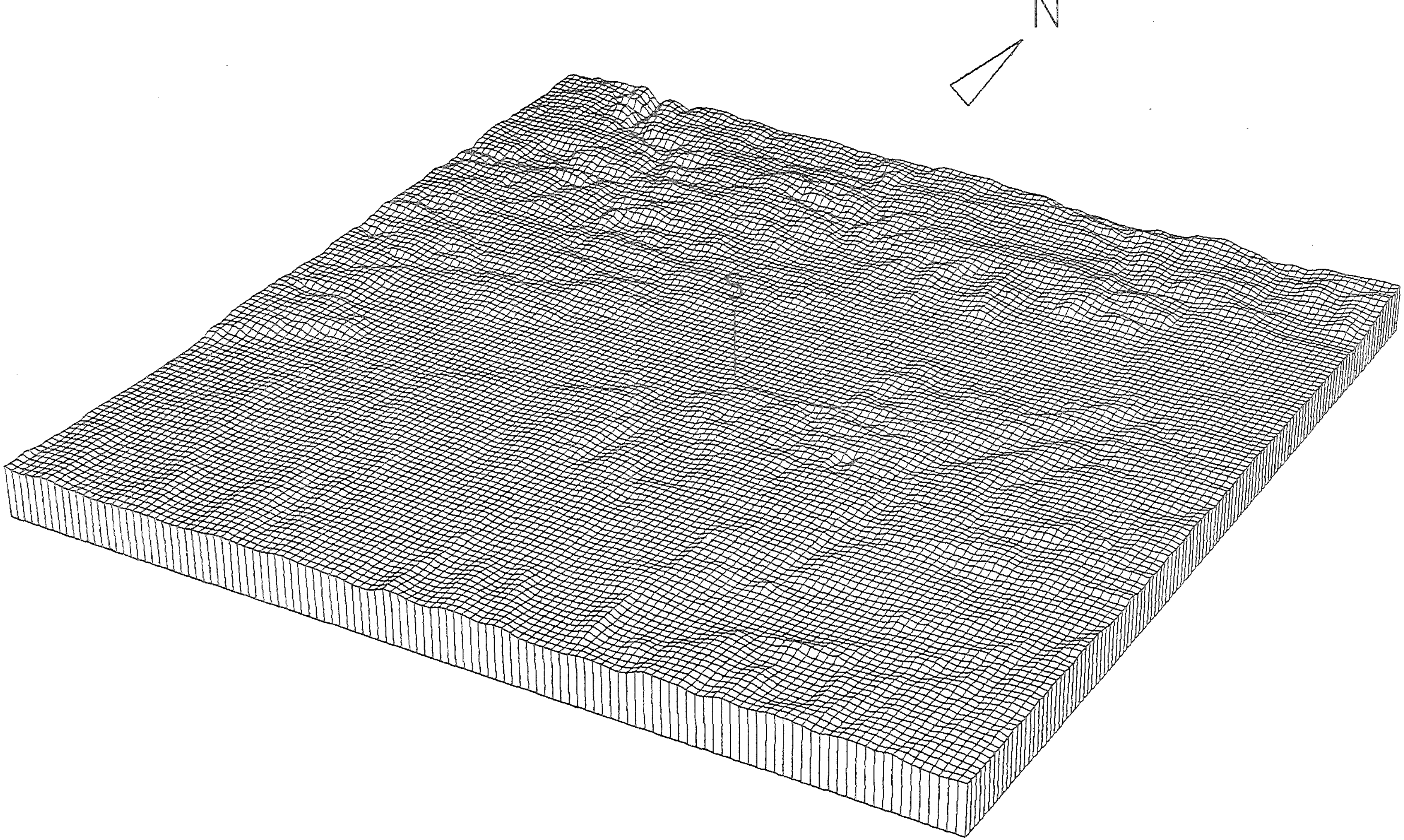
A.6 GRAFENRHEINFELD; SL:204M, MAXH:655M, MINH:0M, AVH:[illegible]



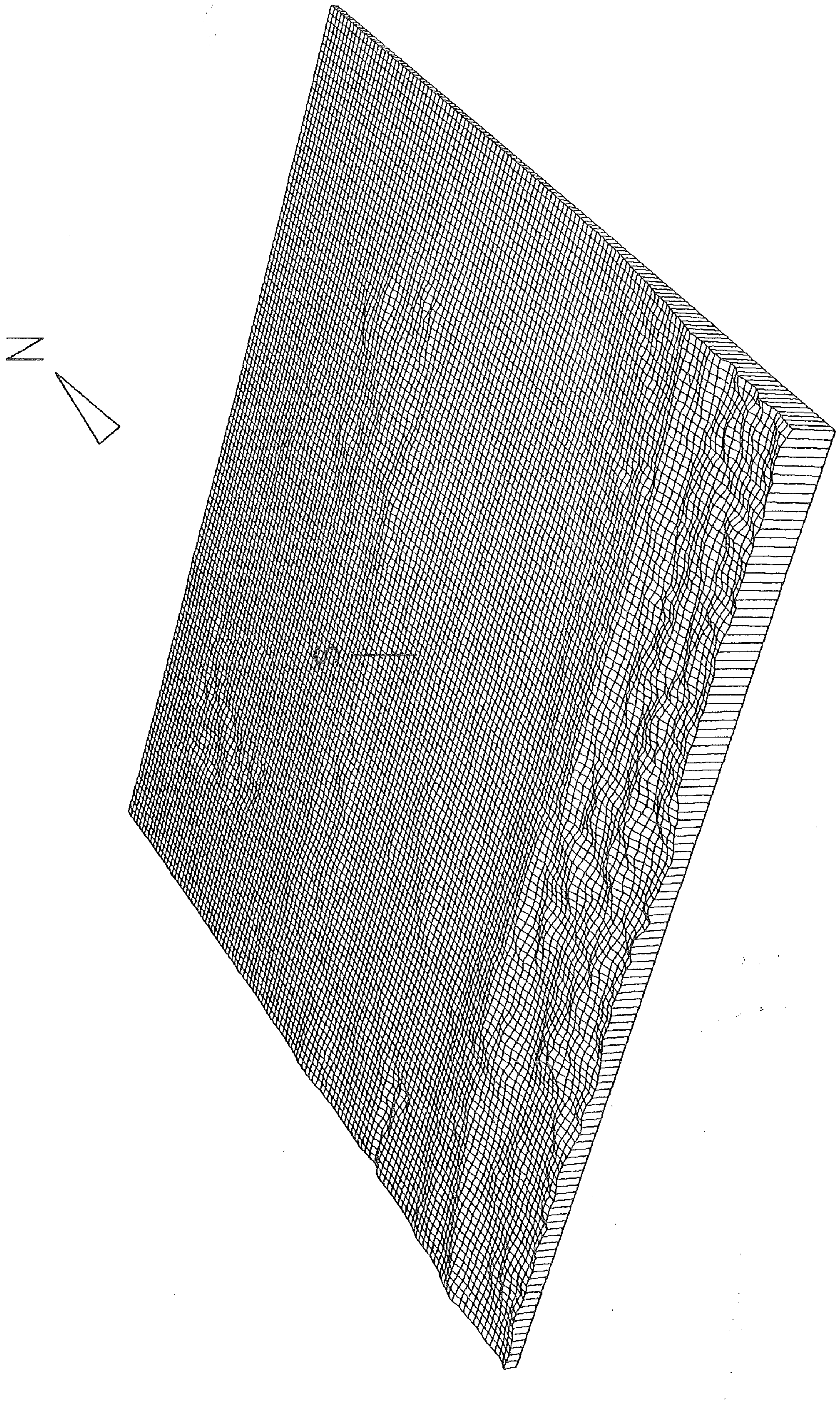
A.7 GRØHNDE; SL:72M, MAXH:523M, MINH:45M, AVH:184M



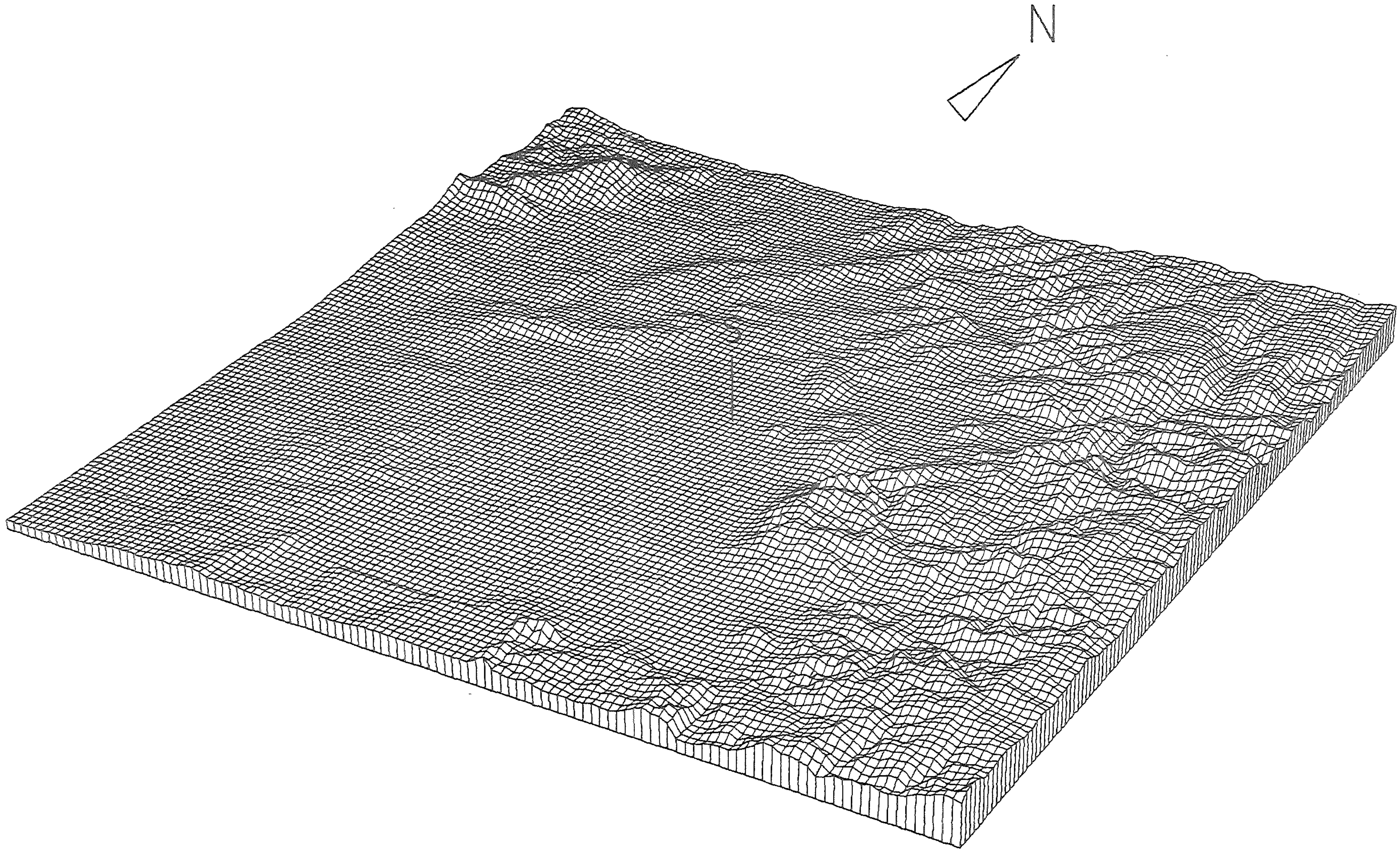
A.8 GRØNAU; SL:40M, MAXH:178M, MINH:10M, AVH:48M



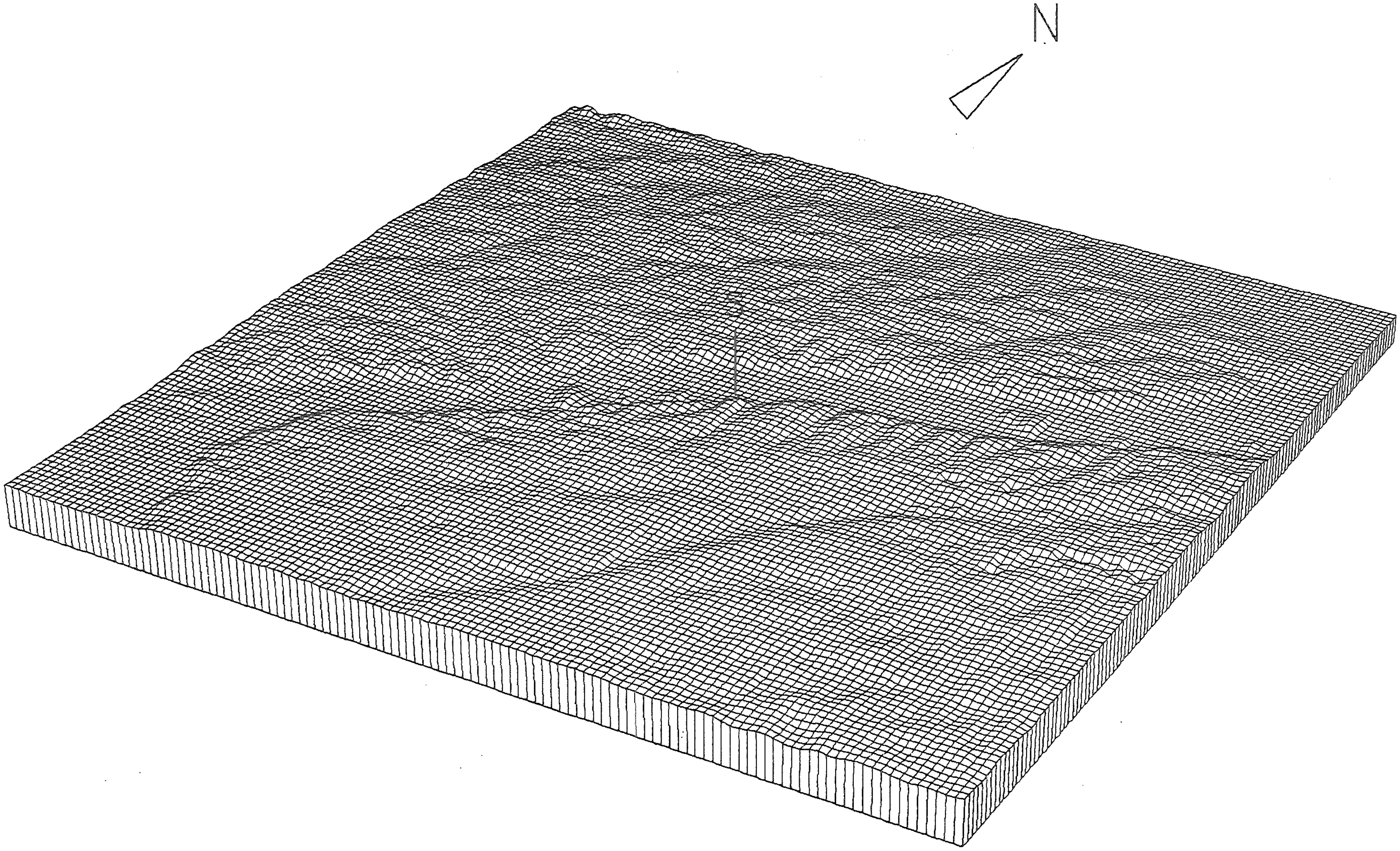
A. 9 GUNDREMMINGEN; SL:460M, MAXH:711M, MINH:399M, AVH : 501 m



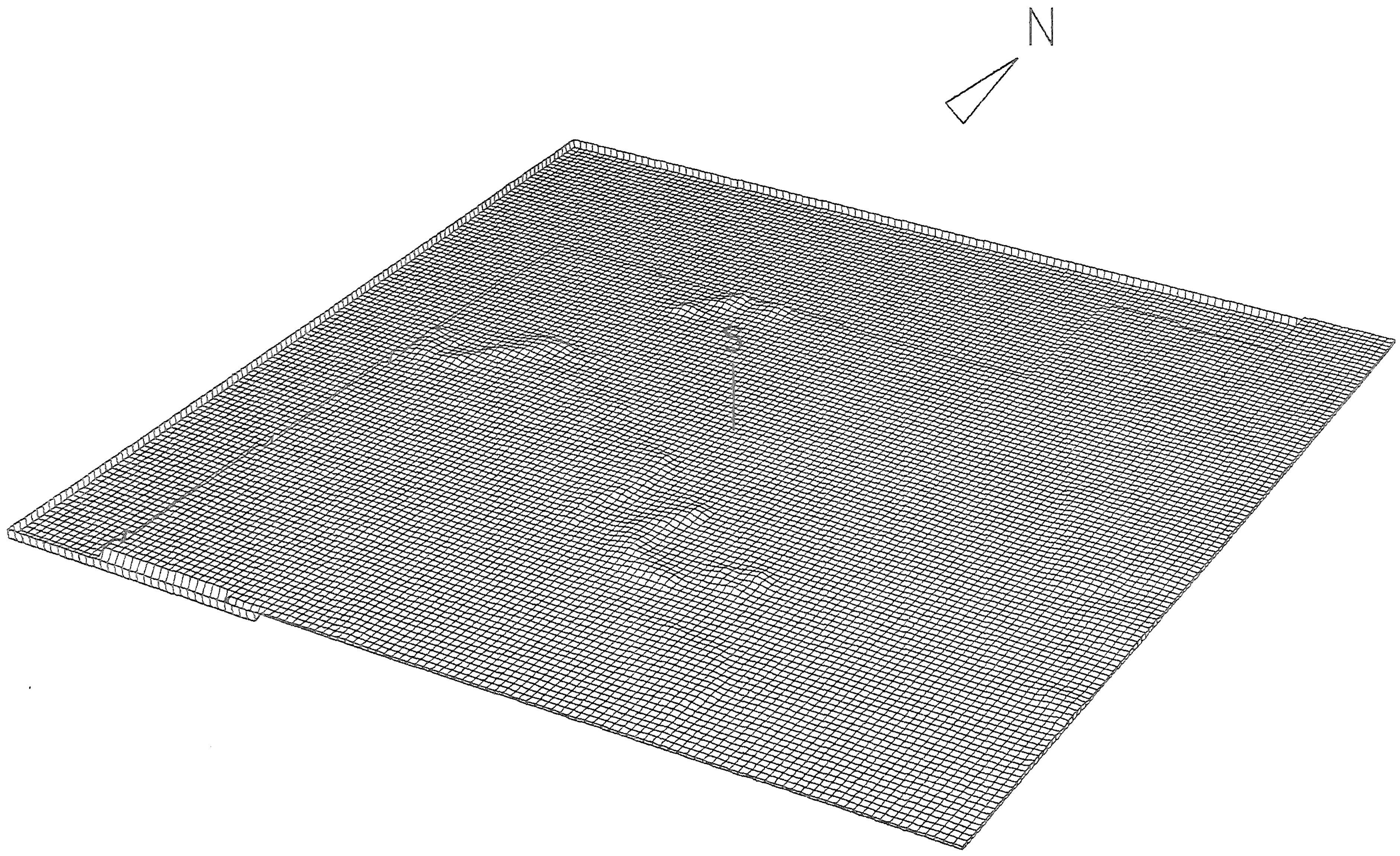
A.10 HAMM; SL:65M, MAXH:500M, MINH:7M, AVH:116M



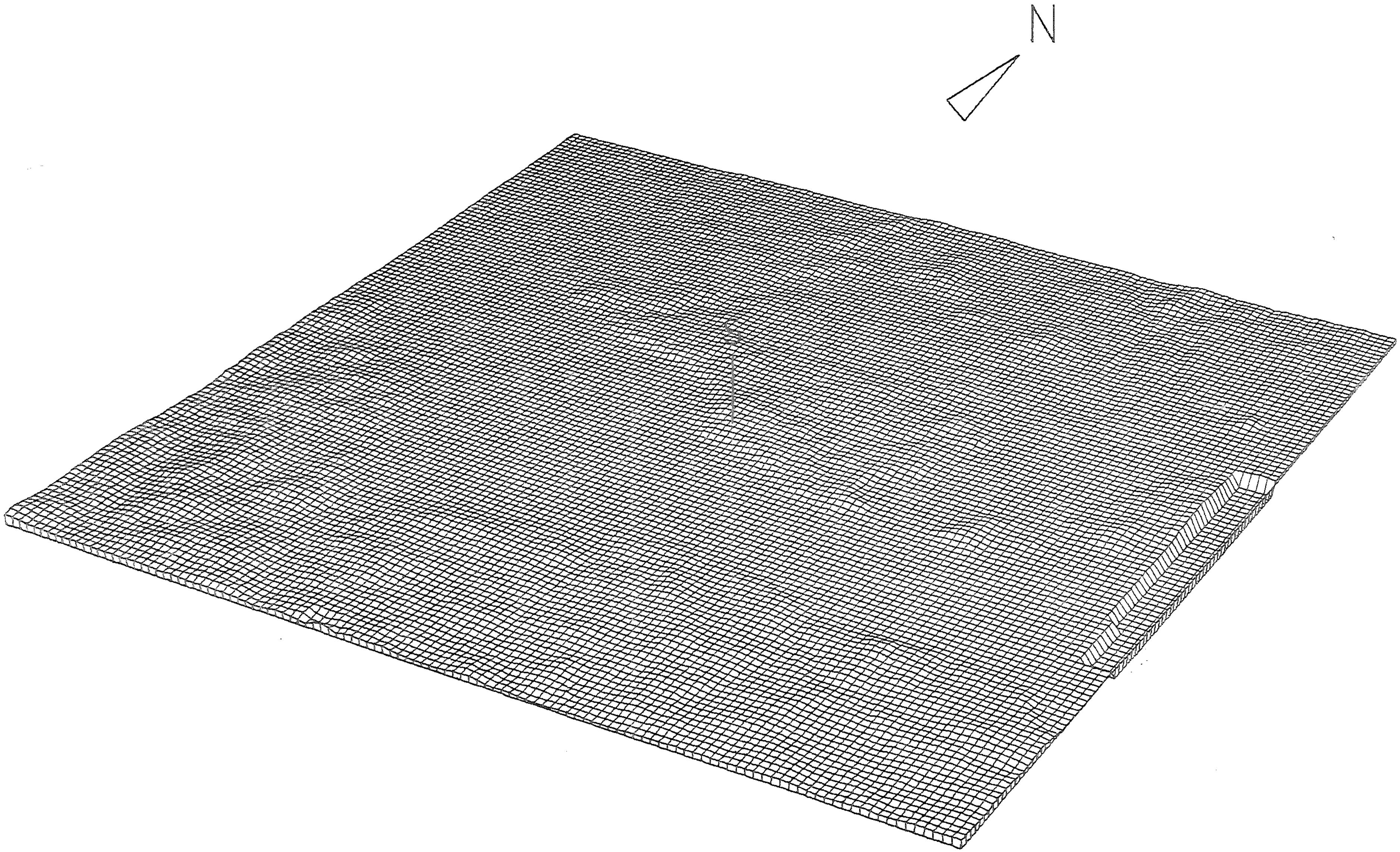
A.11 HANAU,ALKEM; SL:107M, MAXH:524M, MINH:92M, AVH:204M



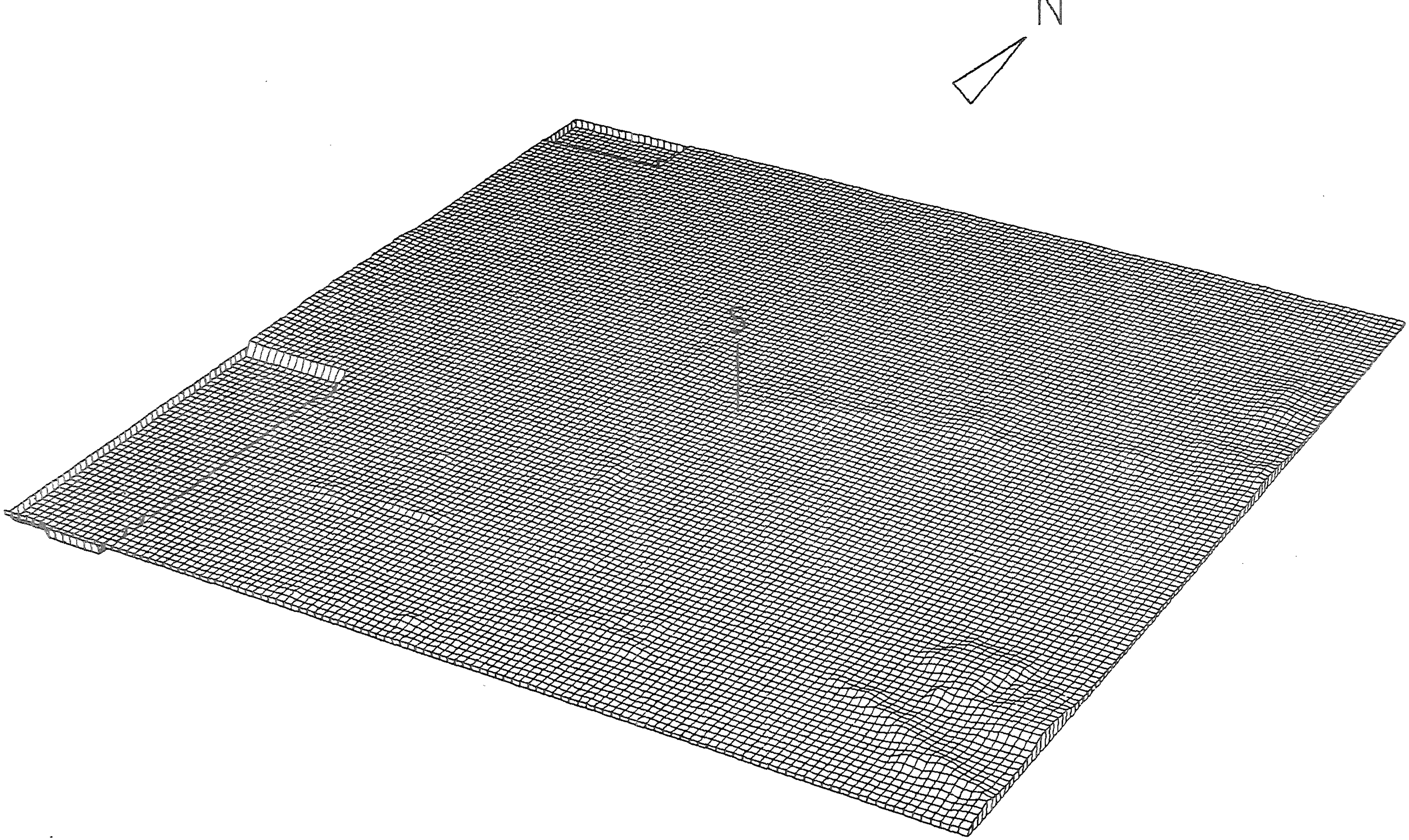
A.12 ISAR-OHU; SL:383M, MAXH:516M, MINH:316M, AVH:437M



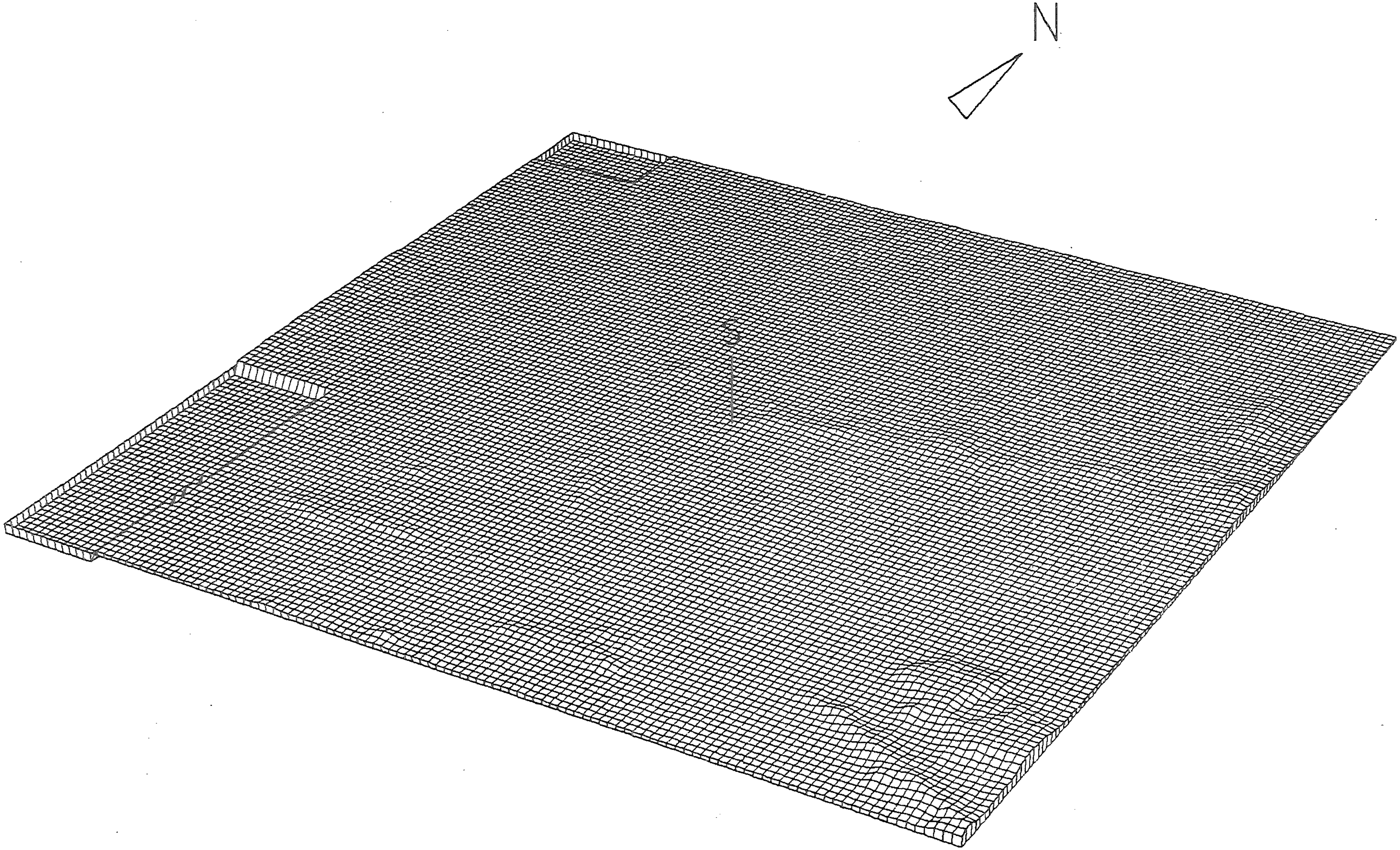
A.13 KALKAR; SL:17M, MAXH:82M, MINH:10M, AVH:25M



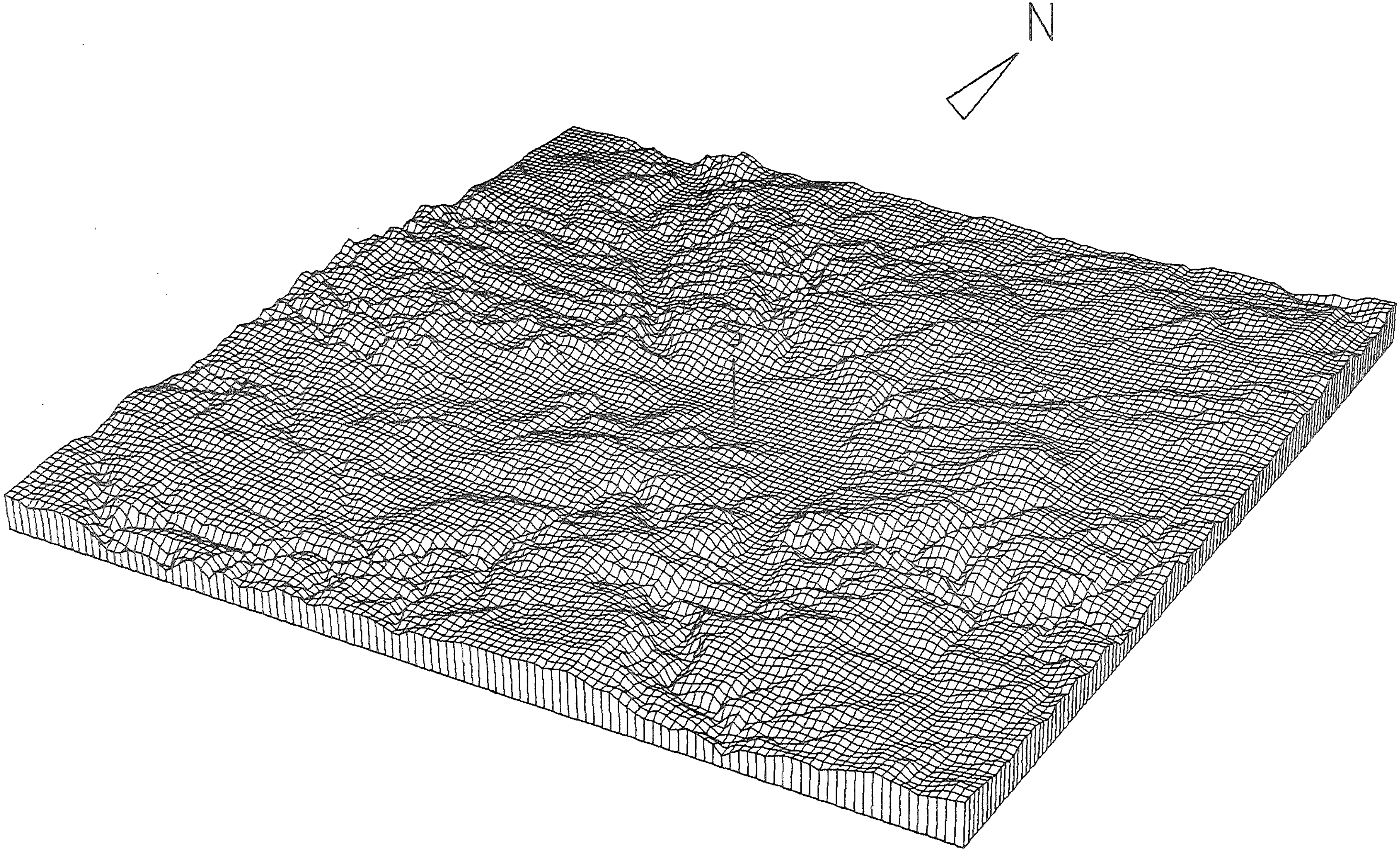
A.14 KRUEMMEL; SL:61M, MAXH:136M, MINH:1M, AVH:34M



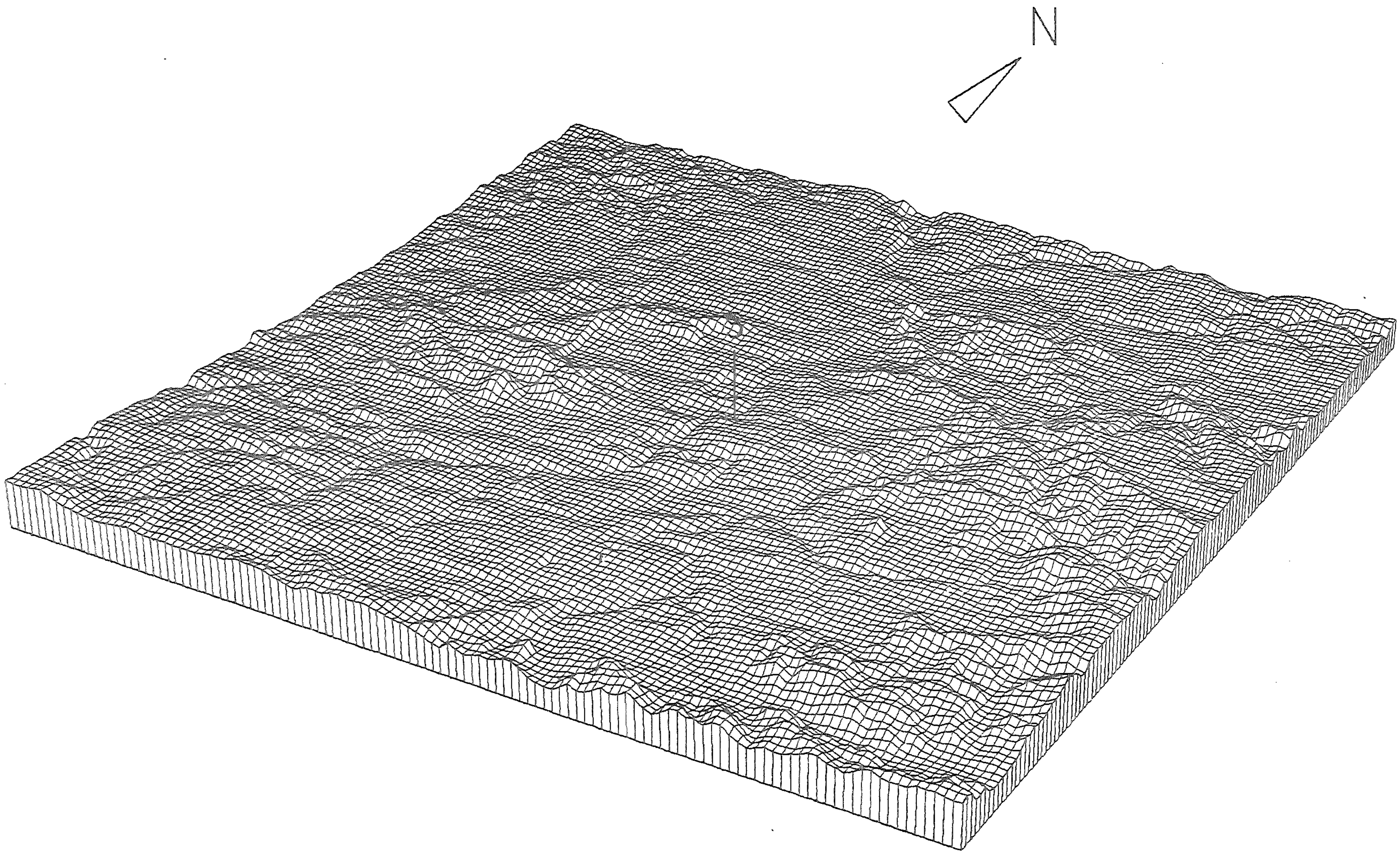
A.15 LINGEN,EMSL; SL:32M, MAXH:169M, MINH:7M, AVH:33M



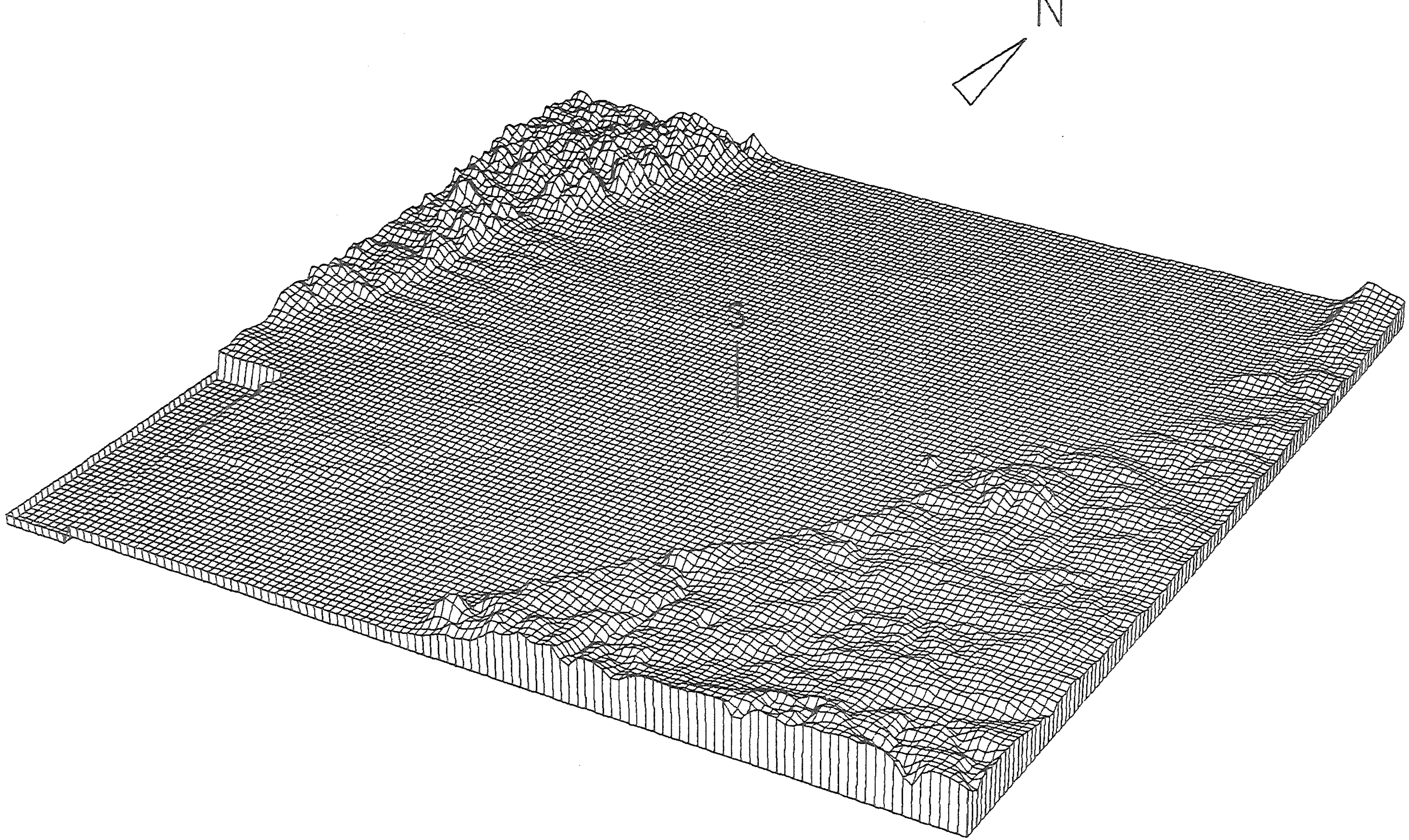
A.16 LINGEN,EXXO; SL:43M, MAXH:169M, MINH:6M, AVH:33M



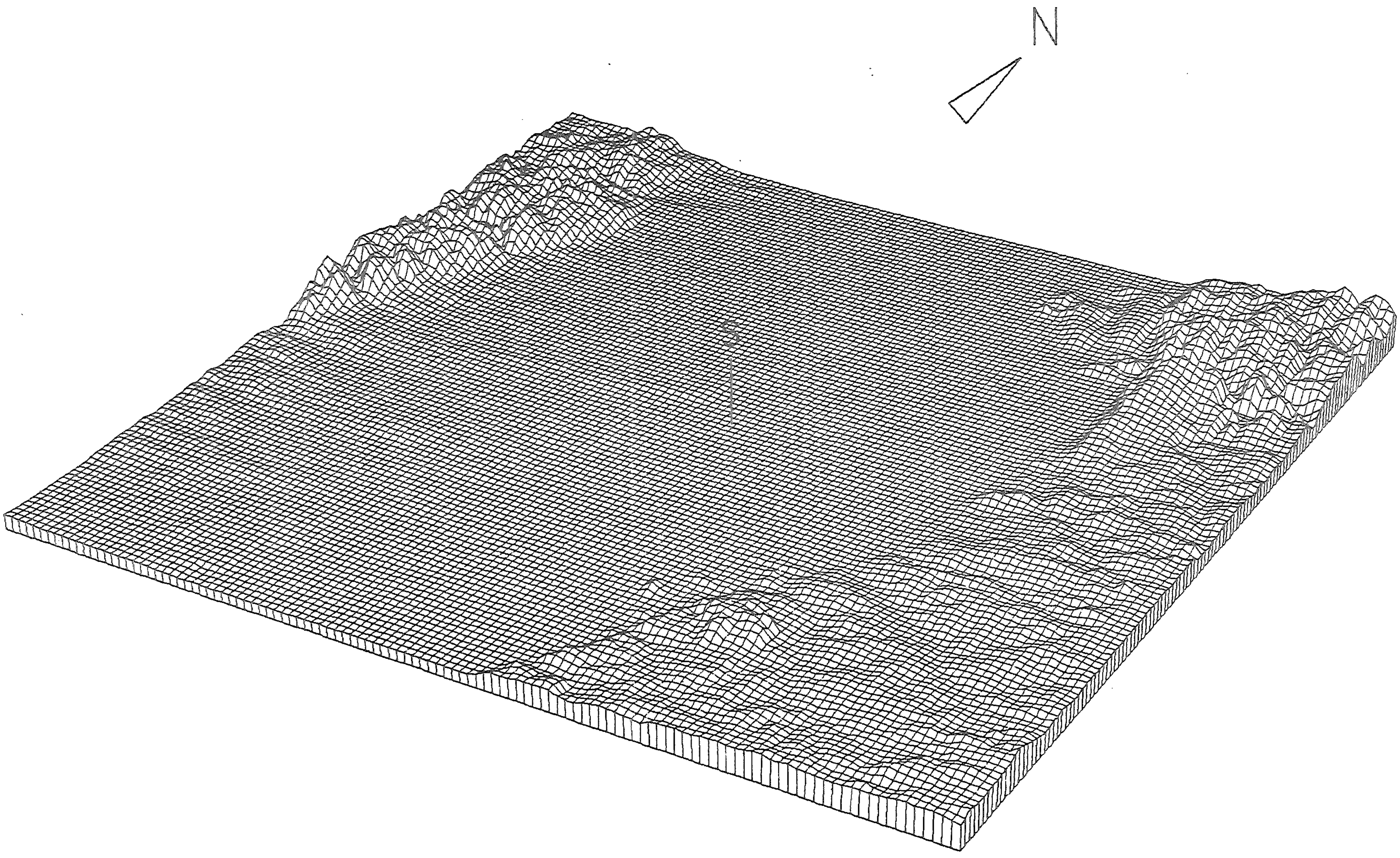
A.17 MUELHEIM-K.; SL:68M, MAXH:646M, MINH:51M, AVH:282 M



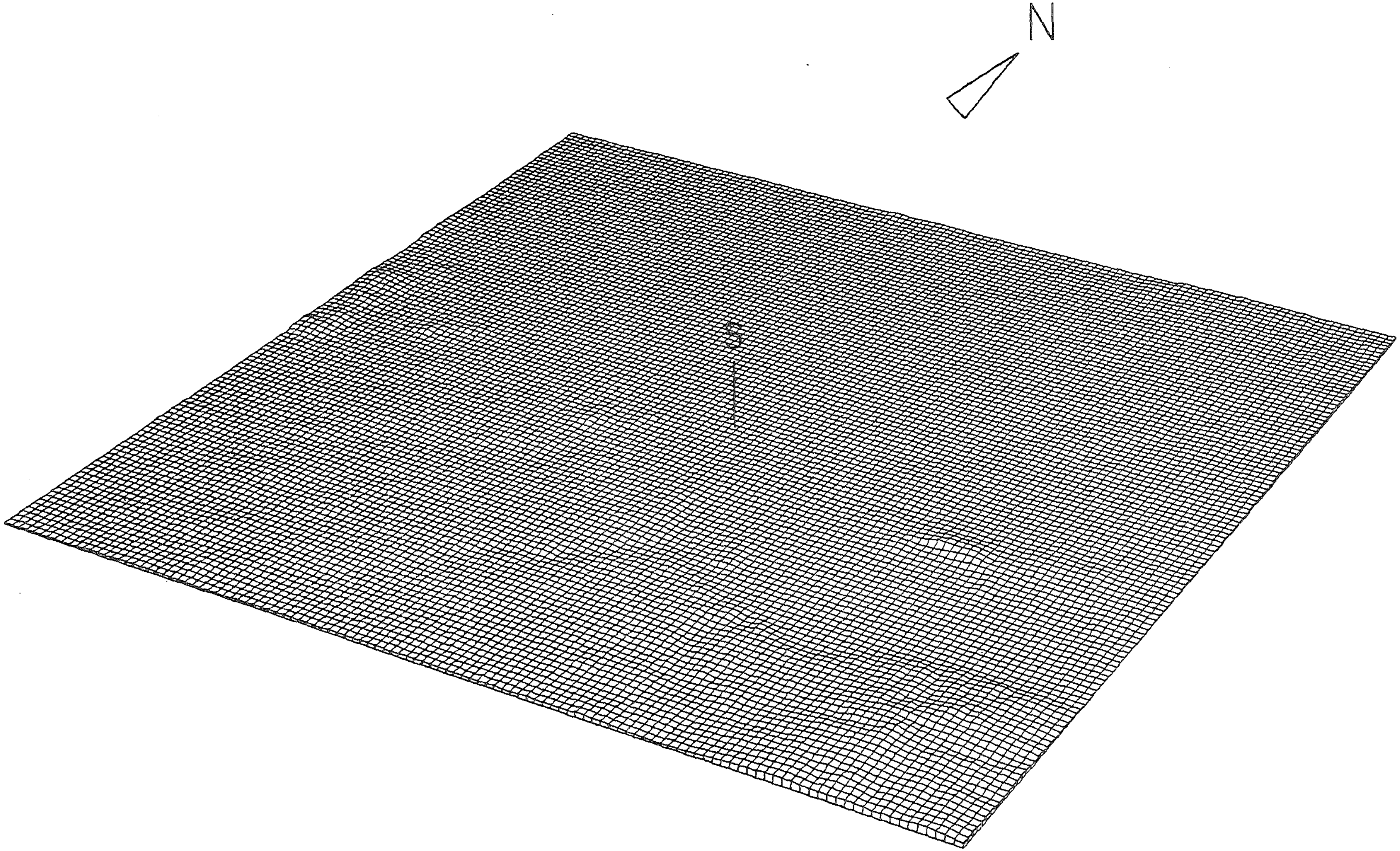
A.18 NECKARWESTH.; SL:195M, MAXH:570M, MINH:144M, AVH:291M



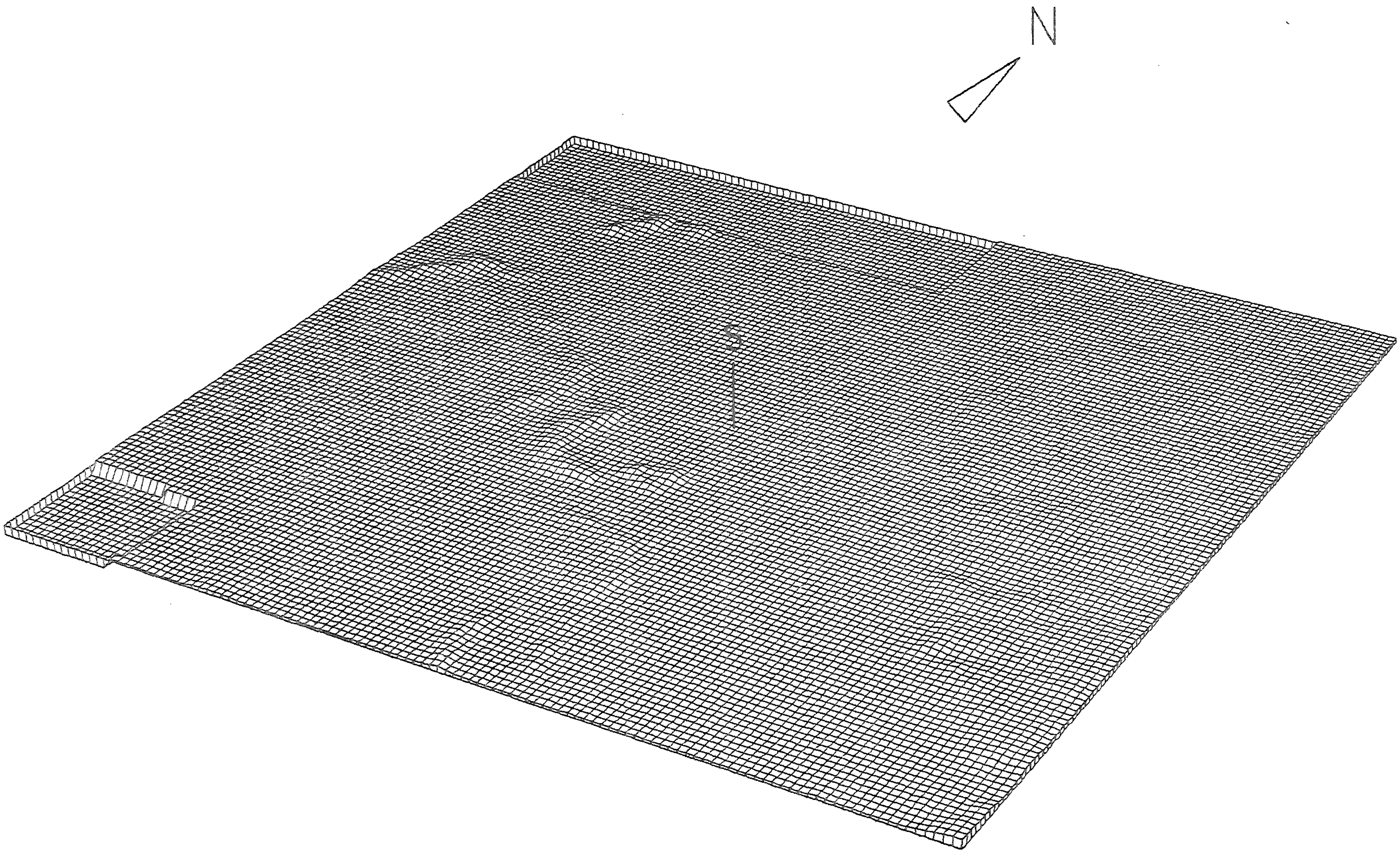
A. 19 NEUPOTZ; SL:103M, MAXH:634M, MINH:93M, AVH:181M



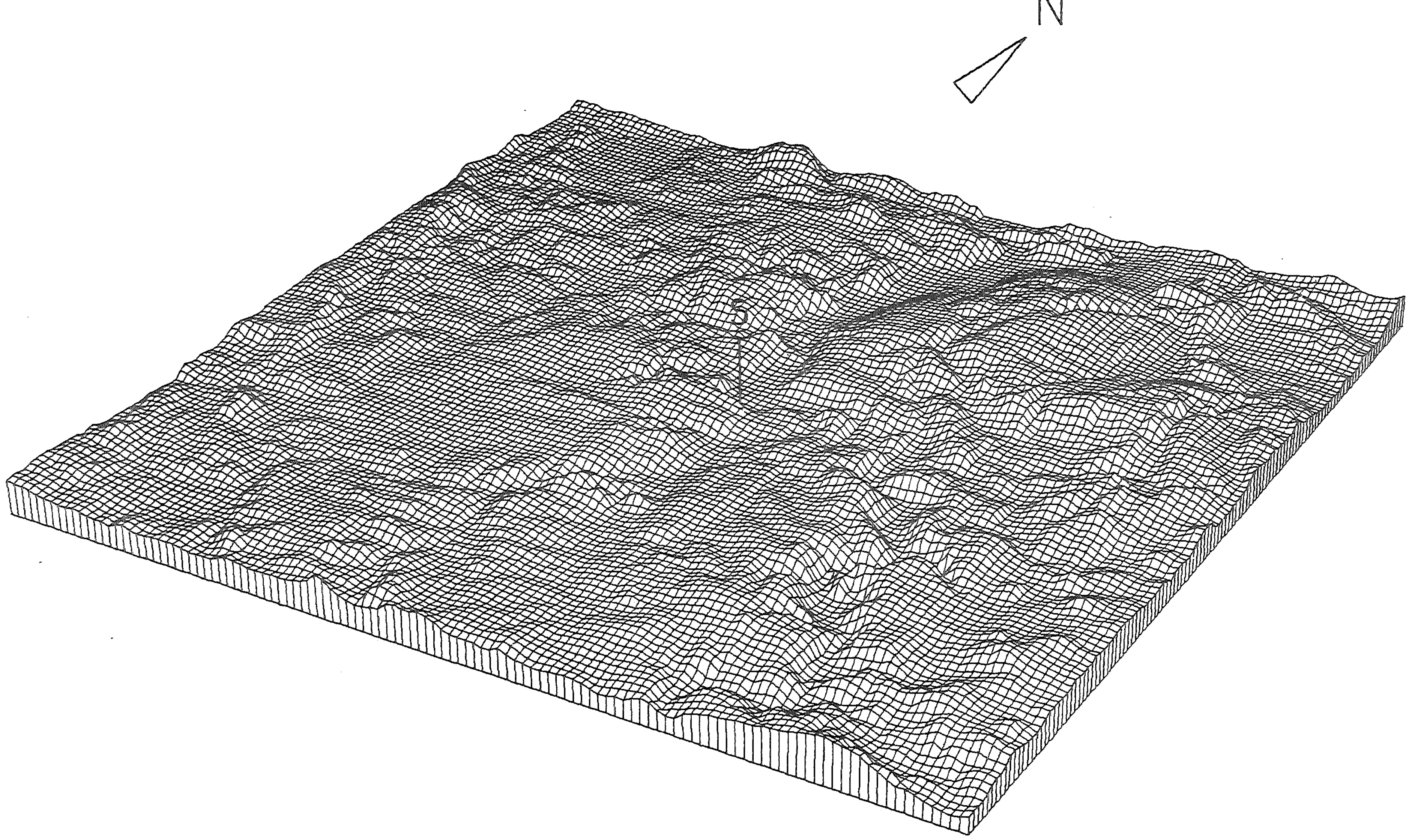
A.20 PHILIPPSBURG; SL:97M, MAXH:626M, MINH:90M, AVH:167M



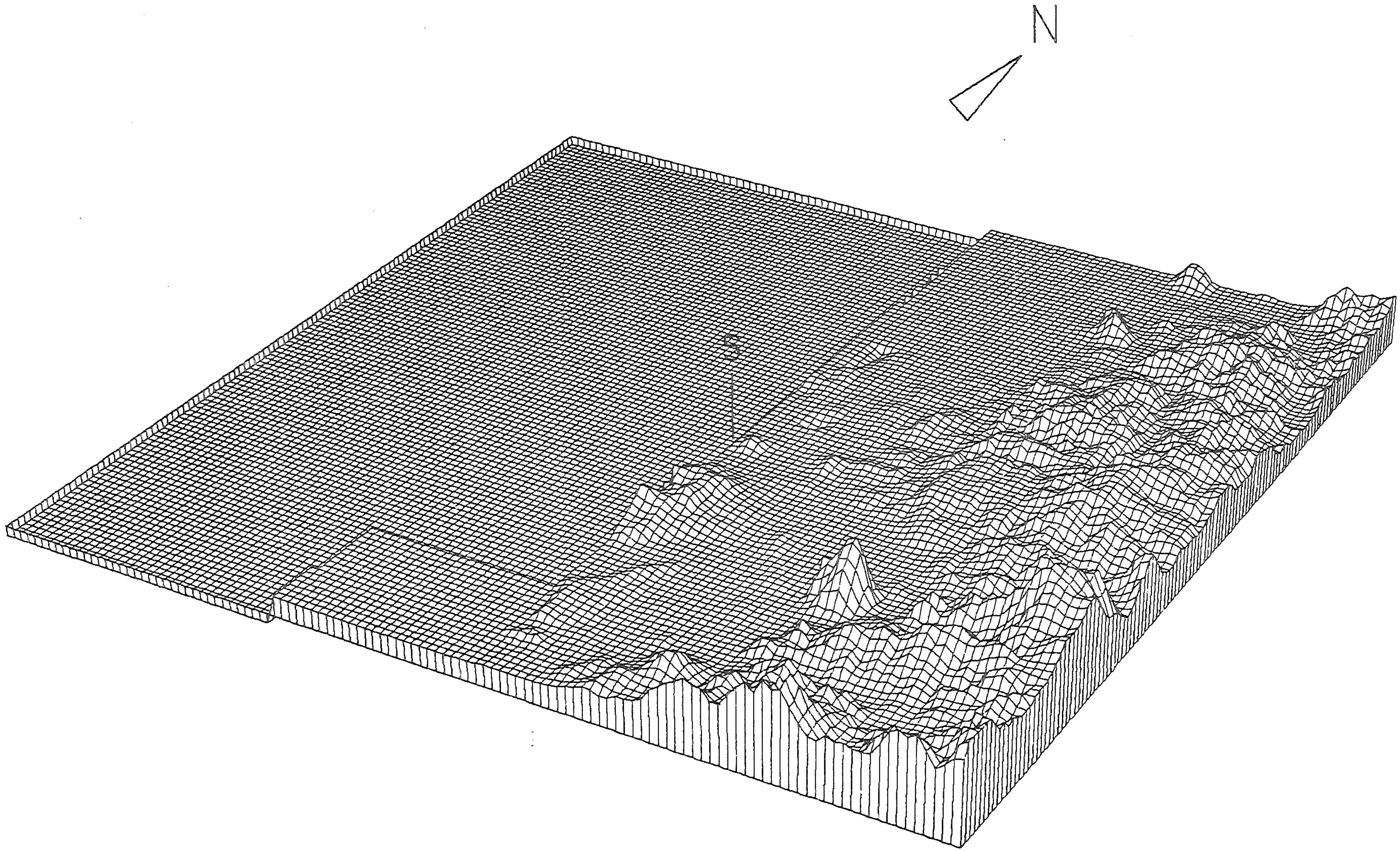
A.21 STADE; SL:2M, MAXH:145M, MINH:1M, AVH:16M



A.22 VAHNUM; SL:19M, MAXH:99M, MINH:10M, AVH:30M



A.23 WUERGASSEN; SL:136M, MAXH:523M, MINH:81M, AVH:255M



A.24 WYHL; SL:174M, MAXH:1184M, MINH:76M, AVH:313M