

CHOICE IN FIELD SURVEYING



Roger R Kirby



ISSN 03066142

ISBN 0 86094 174 4

© Roger P. Kirby 1985

Published by Geo Books, Norwich

Printed by W.H. Hutchins Sr Sons, Norwich

CATMOG - Concepts and Techniques in Modern Geography

CATMOG has been created to fill in a teaching need in the field of quantitative methods in undergraduate geography courses. These texts are admirable guides for teachers, yet cheap enough for student purchase as the basis of classwork. Each book is written by an author currently working with the technique or concept he describes.

1. Introduction to Markov chain analysis - L. Collins
2. Distance decay in spatial interactions - P.J. Taylor
3. Understanding canonical correlation analysis - D. Clark
4. Some theoretical and applied aspects of spatial interaction shopping models - S. Openshaw
5. An introduction to trend surface analysis - D. Unwin
6. Classification in geography - R.J. Johnston
7. An introduction to factor analysis - J.B. Goddard & A. Kirby
8. Principal components analysis - S. Daultrey
9. Causal inferences from dichotomous variables - N. Davidson
10. Introduction to the use of logit models in geography - N. Wrigley
11. Linear programming: elementary geographical applications of the transportation problem - A. Hay
12. An introduction to quadrat analysis (2nd edition) - R.W. Thomas
13. An introduction to time-geography - N.J. Thrift
14. An introduction to graph theoretical methods in geography - K.J. Tinkler
15. Linear regression in geography - R. Ferguson
16. Probability surface mapping. An introduction with examples and FORTRAN programs - N. Wrigley
17. Sampling methods for geographical research - C.J. Dixon & B. Leach
18. Questionnaires and interviews in geographical research - C.J. Dixon. & B. Leach
19. Analysis of frequency distributions - V. Gardiner & G. Gardiner
20. Analysis of covariance and comparison of regression lines - J. Silk
21. An introduction to the use of simultaneous-equation regression analysis in geography - D. Todd
22. Transfer function modelling: relationship between time series variables - Pong-wai Lai
23. Stochastic processes in one dimensional series: an introduction - K.S. Richards
24. Linear programming: the Simplex method with geographical applications - James E. Killen
25. Directional statistics - G.L. Gaile & J.E. Burt
26. Potential models in human geography - D.C. Rich
27. Causal modelling: the Simon-Blalock approach - D.G. Pringle
28. Statistical forecasting - R.J. Bennett
29. The British Census - J.C. Dewdney
30. The analysis of variance - J. Silk
31. Information statistics in geography - R.W. Thomas
32. Centographic measures in geography - A. Kellerman
33. An introduction to dimensional analysis for geographers - R. Haynes
34. An introduction to Q-analysis - J. Beaumont & A. Gatrell
35. The agricultural census - United Kingdom and United States - G. Clark
36. Order-neighbour analysis - G. Aplin
37. Classification using information statistics - R.J. Johnston & R.K. Semple
38. The modifiable areal unit problem - S. Openshaw
39. Survey research in underdeveloped countries - C.J. Dixon & B.E. Leach
40. Innovation diffusion: contemporary geographical approaches - G. Clark

This series is produced by the Study Group in Quantitative methods, of the Institute of British Geographers.

For details of membership of the Study Group, write to the Institute of British Geographers, 1 Kensington Gore, London SW7 2AR, England.

The series is published by:

Geo Books, Regency House, 34 Duke Street, Norwich NR3 3AP, England, to whom all other enquiries should be addressed.

CHOICE IN FIELD SURVEYING

by

Roger P. Kirby
(University of Edinburgh)

CONTENTS

	Page
I <u>NATURE OF FIELD SURVEYING</u>	3
II <u>WHETHER TO SURVEY</u>	9
(1) Logistics of the field operation	9
(ii) Range of suitable map scales	9
(iii) Pre-existing documents available	11
(iv) Revision mapping	12
III <u>CLARIFYING THE MAP SPECIFICATION</u>	13
(i) Area of ground	13
(ii) Map content	13
(iii) Types of measurement and their precision	14
(iv) Presentation of information	15
(v) Precision of presentation	15
IV <u>STRATEGY FOR DATA COLLECTION</u>	17
(i) Point-by-point collection	17
(ii) Sampling designs	18
V <u>SELECTING FROM TERRAIN POINTS AND TERRAIN LINES</u>	19
(i) Points and straight lines	19
(ii) Generalisation of curved lines	19
(iii) Locations along a straight line	21
(iv) Imprecise vegetation boundaries	23

VI <u>SELECTING FROM TERRAIN AREAS</u>	24
(i) Surveying implications	24
(ii) Representative single points and strings of points	27
(iii) Representative networks of points	29
(iv) Representative topographical networks: digital terrain models	30
(v) Representative bathymetrical networks	32
(vi) Representative areas: quadrats	34
VII <u>GEOMETRICAL POSSIBILITIES IN SURVEYING</u>	35
VIII <u>CHOICE OF EQUIPMENT</u>	41
<u>APPENDIX A</u> Conversion factors for length and area	44
<u>BIBLIOGRAPHY</u>	45

Acknowledgements

Thanks are due to Mr. Ray Harris for cartographic drafting and to the Faculty of Social Sciences, University of Edinburgh, for grants towards field work and secretarial services.

1 NATURE OF FIELD SURVEYING

Field or ground surveying is a form of primary data collection in which the surveyor has to establish personal rules of collection depending on the particular mapping requirements and the nature of the ground. Physical measurements are preceded by decisions on what is to be surveyed and what methods of survey measurement are to be employed. These decisions involve a sequence of choices related principally to the nature of the investigation, that is, to the customer specification. This monograph attempts to guide the field scientist who has little or no formal training in surveying through this sequence of choices.

Surveying is a venerable method of collecting information about the landscape, historically used by geographical explorers to make maps where none previously existed, and more recently used by professional surveyors to systematically map or remap national territories and smaller districts. The major use of surveying today is still in routine national mapping surveys, where it plays a supplementary role to photogrammetric surveys. But it is also employed by civil engineers, geographers and other field scientists in schemes to produce original maps containing information not available on maps in standard series. It has been argued that surveying should be employed more for one-off maps, especially at larger scales, as there is an over-dependence on secondary sources of topographical data in scientific analysis (Rhind and Adams, 1980).

To produce these specialist maps of smaller areas required by field scientists, the alternative standard methods are ground surveying and photogrammetry, for which some ground surveying is also essential to establish fixed control. Photogrammetric methods are generally preferred for speed of production and convenience but, especially in small schemes and where precise data are required, there is frequently no alternative to original ground surveying for the complete operation. Also the advent of electronic reduction tacheometers has meant that data can be measured on the ground and reduced far more rapidly than by previous manual methods, to the point where ground surveying becomes more competitive with photogrammetric surveying again (Tempfli *et al.*, 1980). On this basis the utility of ground surveying systems seems assured.

Field surveying is usually regarded as an equipment-orientated subject, distinguished by surveyors at work with red-and-white ranging poles and theodolites and other instruments on tripods. By the dextrous use of this equipment, data emerge in the form of lengths, angles and height differences related to coded landscape features. But it must be recognised that the field handling of equipment is only a midway stage in a sequence of operations, all of which require thought.

This monograph deals with the string of decisions required before, during and subsequent to the specific field surveying. It does not deal with surveying instrumental techniques, which are mostly clear-cut simple mechanical methods that can be mastered by anyone with some mechanical aptitude and common sense. Instrumental techniques and equipment design are well covered by existing surveying textbooks.

Discussion on choice of equipment is limited to a broad classification only (section VIII). Families of equipment exist in many manufacturers' varieties to suit all problems and purses, with the traditional designs, based on manual reading of graduated staves and graduated circles, manual booking and manual reduction, being superseded at the professional end of the market by designs incorporating digital data readout, storage and automatic processing.

Field surveying for the geographer, geologist, forester or other field scientist aims at producing either data or a graphical document in the form of a profile, transect, map or block diagram. Three distinct uses for field surveying must be appreciated:

- SURVEY TYPE 1 - to produce a document for graphical description
- SURVEY TYPE 2 - to produce a document for numerical analysis
- SURVEY TYPE 3 - to select and set out points for subsequent analysis according to a preordained plan

If a document is required for descriptive purposes only (SURVEY TYPE 1), it is uncommon for a researcher to go to the trouble of original field surveying, particularly as the difficult decisions on procedure still have to be made. For such general illustrative purposes most workers would be content to modify existing topographical or thematic maps by revision mapping.

As analytical procedures, aided by recent advances in techniques for data reading, computation and presentation, have largely replaced descriptive surveys in the field sciences, the more common product of surveying will be an accurate document based on precise measurements (SURVEY TYPE 2), allowing analysis from values taken off the document itself. Stringent geographical analyses may also be made from the survey data directly. Most commonly a redrawn map is published to illustrate the results of any analysis, but at a smaller scale with more generalisation that no longer permits distances to be scaled off directly.

Surveying also frequently involves setting out points at theoretically-decided positions (SURVEY TYPE 3), most readily by systematic grid spacing, but by random distributions if required. Frequently these ordered points are then surveyed in their field context. Pre-ordered points may also be surveyed without having to be set out previously.

Typical landscape examples for which field surveying followed by data analysis and descriptive mapping are used are:

- valley long profile (analysis of data; descriptive profile)
- valley river terraces (analysis of profile and/or map for dimensions, slopes and field associations)
- areal subsidence (analysis of data; descriptive map)
- cryoturbation features (repetitive measurements; descriptive map)
- vegetation communities (analysis of map for dimensions and field associations)
- abandoned cultivation terraces (analysis of map for dimensions, slopes and field associations)

A specific case study for an ecological survey (Example 1) is now presented to introduce the arguments and practical considerations involved.

Example 1 (SURVEY TYPE 1)

Location: South Black Hill, Lothian; Nat. Grid ref. NT 19 59.
Extent and altitudinal range: 4 ha, 290-322 m, 0.D.

General objective: to map areal infestation of bracken (*Pteridium aquilinum*) and rush (*Juncus effusus*) within hill area of improved pasture.

Map specification: map scale 1:1 000 with 2 m contour interval; six vegetation classes; vegetation class boundaries defined; reference locational detail determined.

Surveying objectives: absolute heights; north orientation; vegetation boundaries by purposive sampling with staff placement to 1 m; locational detail with staff placement to 5 cm.

Surveying methods: control by traverse loop, detail by tacheometry, both using wild RDS self-reducing tacheometer with 4 m staff; orientation by prismatic compass; reference height by levelling using Hilger and Watts Autoset level.

Control points 2; station points 8; detail points 209.

Surveying time: 24 man-hours (3 persons for 8 hrs).

Cartographic time: 16 man-hours (2 persons for 8 hrs).

Field completion: 2 man-hours (1 person)

Map achievement: general-purpose map relating vegetation communities to altitude and slope at specific date; map suggests sites for detailed transects or quadrat surveys. See Figure 1.

Routine schemes involving ground surveying such as that described in Example 1 follow the sequence of planning and implementation stages described in Figure 2. This begins with an essential appreciation of the terrain to be surveyed, either in the field or from pre-existing maps or aerial photographs, and continues through to the fine drawing and publication. Within this framework the stages requiring major decisions are defined by rectangular boxes; these stages are discussed in subsequent sections of this text as indicated.

Determining the overall objectives of the total scheme often constitutes the most difficult and crucial part of the planning. This has been stressed by numerous authors, including Yates (1960) in the context of sampling surveys, and Lakhani (1983). But only when these overall objectives have been defined clearly can the surveying requirements be resolved.

It is important to register the fundamental dimensional labels associated with terrain description. Ground surveying deals with the relative and absolute positioning of features in physical space, described simply as X, Y, Z. X & Y represent the planimetric location, being spatial co-ordinates that can be designated with increasing levels of universality as required: as a local point relative to another local point; as a point within a local grid reference system; as eastings and northings in a national grid reference system; or as latitude and longitude related to the spheroid Earth. On a map, XY co-ordinates

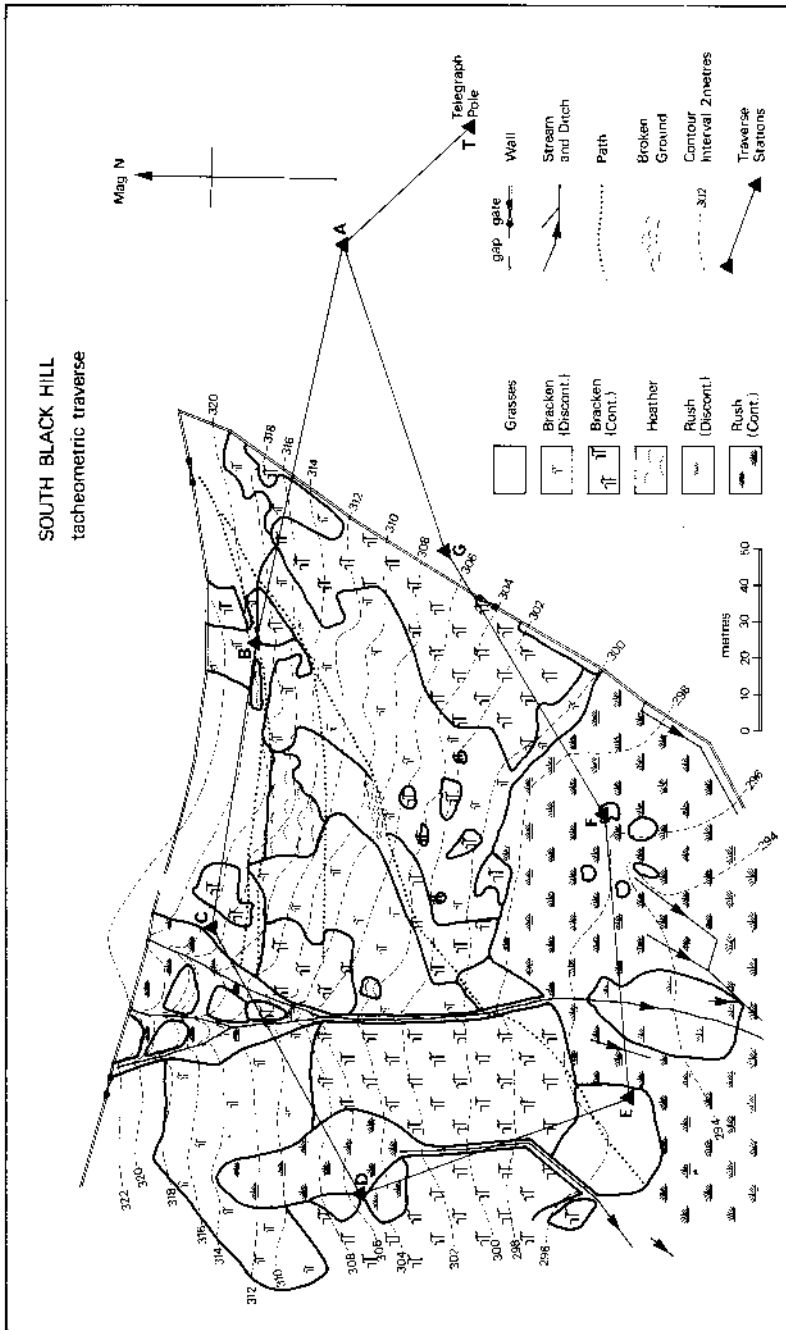


Figure 1. South Black Hill, Lothian: map of vegetation classes

define the locations of topographical and non-topographical (that is, thematic) distributions equally, by a variety of conventional symbols.

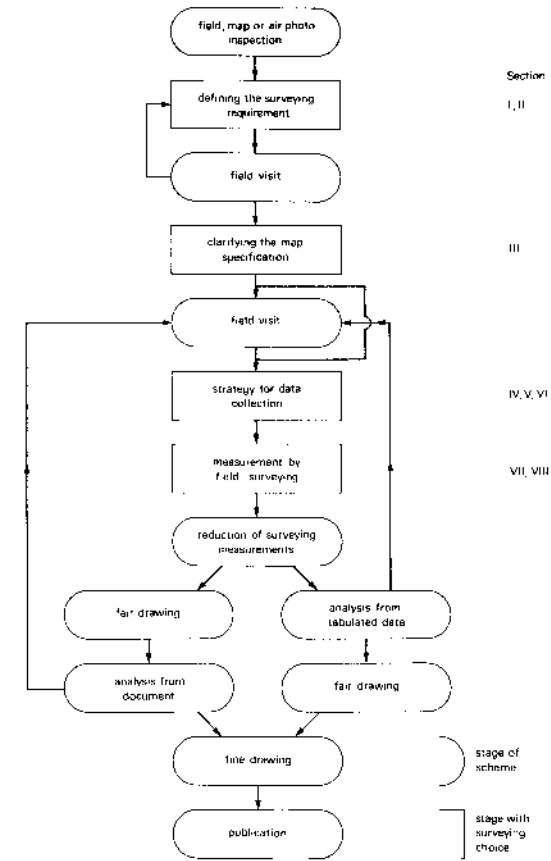


Figure 2. Stages of a ground surveying scheme

On a map, Z defines a value at the the point XY , and has no meaning independently of the location XY . Z can be further defined as a topographical value Z_t , that is, a height, or a thematic value Z_i , that is, any other continuously distributed quantifiable element, for example depth to bedrock or soil texture. At any location XY there may be defined only one Z_t value but in addition numerous Z_i values for different elements.

For a topographical map, X, Y and Z_t are generated in one process by the sole use of surveying techniques but, for a thematic map, these X, Y, Z_t values are not sufficient, and data Z_1 for the particular subject of the map have to be found by other, non-surveying, methods. For example, soil texture data are found by subjecting samples to laboratory analysis. For field sampling involving Z_1 at numerous sites, surveying copes only with the positional siting X, Y, Z_t of the samples.

It is also important to register whether what is to be surveyed is base (background) material in a map or is the subject (foreground) material (Table 1). For a topographical map, Z_t values are the objective so that the resulting map will be dominated by spot heights, contours and breaks of slope. But for a thematic map, topographical information will commonly be part of the base material on which the subject material is positioned.

Table 1. Types of information for topographical and thematic maps

	base material XY	subject material XYZ _t
Subject: topographical distribution	field boundaries rock outcrops roads and paths buildings (+ labels; grids)	spot heights contours stream courses breaks of slope
	base material XYZ _t	subject material
Subject: thematic distribution (bracken)	field boundaries rock outcrops roads and paths buildings spot hts, contours stream courses breaks of slope (+ labels; grids)	boundaries of bracken growth (XY) density of bracken growth (Z_1)

Because topographical surveying is such a well-developed and precise science, X, Y, Z_t data can have very small standard errors so that, as a supportive base for thematic distributions, topographical XY or XYZ_t maps are easily of adequate geometrical standard. In general, field surveying will be found to be rapid, accurate and even over-precise for XYZ_t in comparison with subsequent measurements for Z_1 .

II WHETHER TO SURVEY

Preliminary consideration of the overall objective produces the first choice for the field scientist, which is whether or not it is sensible to start surveying at all. Independently of the quality of the surveying, any map needs a significant effort and an unsatisfactory map is often avoided by forethought.

(i) Logistics of the field operation

There is no point in attempting a scheme for which there is not adequate logistical provision. The size and nature of the ground will determine whether the amount of time available, the number of personnel, and the equipment obtainable are all sufficient to produce a surveyed map adequate to meet the objectives. For most simple surveying techniques, the most efficient surveying party is of two or three persons. Four persons in one party leads to enforced idleness; if there are more than four persons available, it is better to operate two teams.

One-person surveying is for the specialist only. Although some surveying operations are described as suitable for one-person operation, such as heighting by barometric and by clinometric methods and plane-table surveying, these operations are all more efficient with two persons. Basic plane-tableing with one person allows a limited number of inefficient routines; to use a modern self-reducing alidade on the plane table requires two persons.

There is no rule of thumb that determines what area can be surveyed by a typical party in one day; variables include the experience of the surveyors, equipment effectiveness, and the density of individual measurements to be taken. A relatively inexperienced team in an eight-hour working day could be expected to record measurements manually for, say, 200 points over an area of 5 ha but such notional figures would have to be qualified in the light of the sampling style used in measuring any particular distribution. An automatic measuring and recording system could produce, say, 400 points under the same circumstances.

(ii) Range of suitable map scales

No piece of ground is too large or too small to be surveyed; but if precise geodetic and engineering surveying are excluded, the residual plane surveying is best suited to producing documents at scales in the range 1:500 to 1:10 000. If the required mapping scale is outside of this range, alternative methods of measuring and recording data are probably better. For scales smaller than 1:10 000, analysis from existing maps may be sufficient, or air photo interpretation and a photogrammetric plot may be considered. For scales larger than 1:500, the implication is of a relatively small piece of terrain on which distributions must be precisely located; intensive survey probably using a specialist technique will be the answer. For example, for an archaeological record over a small site, it is common to produce a plot at 1:100 scale by laying out a grid of 5-metre squares and making a complete census of the stones or artifacts within each square and for each distinct horizon, the information being transferred to a plot graphically by the method of squares (Hogg, 1980). To give another example, over a site one metre square, frost heave can be measured by arranging a

bedstead-type of constructional framework within which long needles are set vertically on a 10 cm square grid basis. The needles can be lowered to the ground surface and their heights measured by optical levelling at timed intervals. Surveying equipment is here utilized solely for the optical precision it can ensure to the measurement of frost heave.

It must be restated that ground surveying methods do not monopolize the mapping process in the scale range 1:500 to 1:10 000. Standard photogrammetric mapping from aerial photographs can be used over a similar range of scales, as well as at smaller scales. The obviously different requirements for a photogrammetrically-derived map are the availability of aerial photographs and ground control, a suitable plotter and rather more technical expertise to operate it than is necessary with field surveying.

Table 2. Commonly used map and aerial photographic scales

<u>Representative</u> Fraction	<u>Imperial</u>	<u>Metric</u>
1: 500	-	2 mm to metre
1: 1 000	-	1 mm to metre
1: 1 250	about 50 inch to mile	-
1: 2 500	about 25 inch to mile	40 cm to kilometre
1: 5 000	about 12.5 inch to mile	20 cm to kilometre
1: 10 000	about 6 inch to mile	10 cm to kilometre
1: 20 000	-	5 cm to kilometre
1: 25 000	about 2.5 inch to mile	4 cm to kilometre
1: 50 000	-	2 cm to kilometre
1: 63 360	1 inch to mile	-
1:100 000	-	1 cm to kilometre
1:125 000	about 0.5 inch to mile	8 mm to kilometre
1:250 000	about 0.25 inch to mile	4 mm to kilometre
1:500 000	-	2 mm to kilometre
1:625 000	about 1 inch to 10 miles	-
1:m	-	1 mm to kilometre

As listed in Table 2, maps at scales smaller than 1:10 000 are normally either produced photogrammetrically or derived by cartographic generalisation from existing maps at larger scales. For instance, the Ordnance Survey topographical sheets at 1:25 000 scale are derived from 1:10 000 (or earlier from 1:10 560) scale originals.

If the final product is to be a profile or transect, a similar range of scales as for maps is appropriate for the horizontal scale, but an element of vertical exaggeration is normally necessary to represent slopes so that they appear natural to the eye. Fluvial or marine deposits adopt slopes so slight that only a gross vertical exaggeration will give any impression of slope at all.

(iii) Pre-existing documents available

A key issue in the initial decisions as to whether or not to survey afresh is the quality of existing map material. An essential preliminary to any proposed fresh surveying should be a keen search through standard sources, looking for maps providing complete solutions, partial solutions and also original ideas on presentation. Existing maps or aerial photographs are more likely to be sufficient at smaller scales and for lower levels of analysis, such as when dealing with the regional boundaries of land cover types and, conversely, new field surveying is more likely to be necessary at larger scales and where higher topographical precision and ephemeral landscape features are sought.

Obvious sources of existing maps are departmental and college map libraries, society and institute collections, public record offices and, ultimately, national map libraries. These organisations house national and local map series at different scales and of different editions, in the forms both of topographical maps and plans and of thematic maps printed on a topographical base. Until 1981 the Ordnance Survey published a free 64 page map catalogue describing the range of official British maps, selling outlets and indices of sheets at scales up to 1:25 000. Since 1981 a more limited brochure without sheet index information has been available. The most up-to-date information on the basic scale maps of the Ordnance Survey is provided on master survey drawings, as yet unpublished but accessible through Ordnance Survey offices by the SUSI service (Supply of Unpublished Survey Information). Microfilm copies of published large scale plans and unpublished master survey drawings are available. General descriptions and large plate examples of Ordnance Survey maps and plans are to be found in the official publication by Harley (1975).

For physical site investigations in Britain, many of the preliminary sources of information are listed by Dumbleton and West (1971), and include sources held on geological, soil and land-use thematic maps. Archival sources are described by Sheail (1983). A very comprehensive guide to sources of geological information is produced by the Institution of Geologists (Brassington, 1982). Commercial surveying firms, civil engineering firms, public utilities such as the National Coal Board, and regional and district authorities, especially their highways departments, are all possible sources of appropriate material.

Aerial photographs are a potential source of information of great value, often existing in stereoscopic coverage at different scales and for different dates. However, the regional coverage in Britain is patchy, particularly at larger photographic scales. For the situation in Scotland, which is typical, see Kirby (1980). Numerous different commercial, governmental and national agencies take their own aerial photographs and hold library copies of prints. There is no central clearing house for the United Kingdom but national registers of prints are held by the Ordnance Survey (for England and Wales), by the Scottish Development Department and by the Ordnance Survey of Northern Ireland. These and other organisations are listed by Dowman (1982).

The accuracy of content and of representation of existing maps is usually hard to determine, particularly as the question of accuracy always be posed in the light of each map user's personal requirements.

Most maps carry dates of production and latest revision; few maps specify their quantitative standards. In the descriptive manual by Harley (1975), the accuracy of the detail survey of Ordnance Survey maps is described mostly in terms of errors in planimetric positions and heights. For example, concerning heighting precision, it is current Ordnance Survey policy that contour standard errors should not exceed one quarter of the contour interval for heights derived from air machine survey (sic). Consistency of content is regulated by specification manuals used by field surveyors and photogrammetric machine operators (for example, Ordnance Survey, 1976), which are modified periodically, partly by customer panels meeting at map users conferences (Mumford, 1981).

An example of the accuracy of content on selected editions of Ordnance Survey maps is given by Ovenden (1981) in the context of the drainage network in the New Forest. The accuracy of early topographical maps must be regarded with suspicion in respect of both content and geometrical errors, as numerous historical cartographers have indicated (for example, Harley, 1968; Hooke and Perry, 1976).

The specification for accuracies of maps of other countries should not be assumed to be the same as for the United Kingdom. As an instance, for maps of the United States the national map accuracy standards, for which the 1947 revision was still recently in effect (Thompson, 1979), related to permitted errors in horizontal and vertical accuracy; for example, for contours at all published scales, not more than 10 per cent of elevations tested shall be in error by more than half the contour interval. Regarding consistency of content, the national standards are less specific, and there are no recommendations as to the checking of how conscientiously map specifications are adhered to by map compilers.

(iv) Revision mapping

If discovered maps are wholly satisfactory then, after paying regard to copyright regulations, the search is at an end. If discovered maps are partially satisfactory they may be revised, and this is almost always worthwhile for speed and quality of result compared to resurveying.

The normal case for revision is where existing Ordnance Survey topographical maps or plans at 1:1 250, 1:2 500 or 1:10 000 scale can be used as a base onto which the surveyor's own subject material can be added, either by direct drawing in the field or by subsequent plotting in the laboratory of the field measurements. The result is a new map containing the surveyor's data plus as much base material from the original map as is necessary to support and frame the theme. The map can be redrawn to any new scale, again subject to copyright regulations.

Surveying in order to revise a map is more simple than surveying *ab initio* as existing map detail aids location. In addition, a co-ordinated framework and possibly also height and positional control points may be present, in the forms of bench marks and triangulation stations respectively. After finding one's own position on the map, thereafter the inclusion of new subject material requires the same set of decisions as when surveying without the benefit of an existing base map.

III CLARIFYING THE MAP SPECIFICATION

Consideration has to be given to numerous simple issues that together will decide the content and final appearance of the surveyor's map. It is obvious enough that what to collect has to be thought out very fully before field measurements start. It is less obvious but highly desirable that decisions should also be made before surveying measurements start as to how the collected data are to be handled as the basis for subsequent analysis. The surveyor must think back from the required graphical or digital product to the necessary means of achieving it, or otherwise risk limitations in the analysis.

The three main criteria for a successful map are adequate content, locational precision and legibility. Each of these contributes to the map specification in a subjective manner, insofar as almost any design for a one-off map is possible. There is no obligation to include standard information or to conform to convention over cartographic methods and symbols as used by governmental or other mapping agencies, as long as the map succeeds.

(i) Area of ground

If the subject has specific limits in the landscape, as in the three cases of a small river valley bounded by local watersheds, a farm unit, and the site of a Roman manor-house, the area of ground to be incorporated is self-evident. But if the subject requires to be placed in a locational context a boundary limit has to be imposed. An example occurs with a topographical survey of an isolated hill with detrital fans spreading onto the surrounding lower ground; the limits of plain included have to be judged on the basis of the physical relationships being investigated.

(ii) Map content

The map content must be planned so as to provide material for descriptive or analytical objectives, or for both. Yet not only is the map a scaled model of reality, it contains a deliberate generalisation and selection of this reality in order to be a workable document. While the principal aim must be to represent sites so that the subject can be investigated in an unbiased way, the nature of the subject will determine which of two strategies for including spatial information XY will be adopted:

- where for specific themes, some of the available information will be included, chosen either by a rigorous sampling routine or, much more likely, by some other less rigorous selection;
- whether for specific themes, all of the sites will be surveyed, that is, a census. This would be possible for a small number of discrete sites

The strategy for locating sites from within the target population is discussed in sections IV, V and VI. On this strategy depends the degree of faithfulness to reality of the result. From this viewpoint, surveying can be seen to be a major exercise in field selection, which may also become field sampling for certain objectives.

The map content has already been defined in terms of subject and base distributions and this distinction should be used as the basis of a checklist drawn up to represent the particular requirements of each map.

A secondary aim will be to minimize effort. In such special purpose investigative documents, the standardisation of approach necessary in national series of sheet maps or plans can again be relaxed in respect of base distributions. Base material can be surveyed selectively with an eye to the eventual graphical effect which should be adequate but without visual clutter (Phillips and Noyes, 1982).

Initial uncertainty over the map content can only be overcome by experience, and in general it is safer while in the field to collect more locational data than seems essential, particularly relating to the foreground subject as opposed to the background base. However, there are two guiding principles for the over-enthusiastic surveyor. Firstly, for non-topographic subjects involving field analysis of some element Z_i , the field collection of Z_i will almost certainly be more time consuming and laborious than fixing XYZ_t , and the number of sample sites should be based on what is required to obtain good estimates of true values for Z_i rather than on surveying considerations for fewer or more points. Secondly, for topographical base detail, over-elaboration beyond the needs of the situation is a costly luxury. In particular the real requirements in respect of accurate topographical heighting Z_t as opposed to planimetric detail should be carefully considered because of the effort involved. Although individual spot-heights may easily be determined, it requires very many spot-heights to produce accurate contours by interpolation. A less accurate but perhaps adequate model of the topography can be produced very economically by presenting fewer exact heights in a combination of spot-heights, form-lines and hachures. If accurate contouring with small vertical interval is essential for the analysis, direct contouring is precise but only possible with certain surveying techniques; alternatively the superior structuring of digital terrain models (section VI, iv) can be considered.

(iii) Types of measurement and their precision

The measurement of data may be considered in terms of four levels of measurement of increasing power, namely nominal, ordinal, interval, and ratio. These terms, first proposed by Stevens (1946), have subsequently been described for geographers by Chorley (1966) in a statistical context and by Robinson, Sale and Morrison (1978) and by Unwin (1981) in a cartographical context. Surveying for locations XY and for heights Z_t involves only interval and ratio scale measurements, the levels of measurement for Z_t including

- interval scale: heights over mean sea level; bearings from a reference object (R.O.);
- ratio scale: including fundamental units such as length and relief and derived units such as area and slope.

By comparison, for thematic maps the (non-surveying) methods of data collection for Z_t use all levels of measurement (Robinson, Sale and Morrison, 1978, figure 5.6; Unwin, 1981, table 2.3), although those methods with more dimensional characteristics involve ratio scales.

The standard units of measurements in the United Kingdom are now SI units which encompass the metric system for length and the sexagesimal system for angles. Conversions for length and area from the Imperial system are sometimes necessary (see Appendix A, Tables 9 and 10).

The accuracy of a network of surveyed points is expressed in terms of its reliability and precision. The reliability of the network is expressed as the potential for detecting error in terms of an independent survey of higher reliability, which may not be available. Precision can be either absolute or relative, that is it denotes either the precision of the surveying measurements of XYZ_t for individual points in a co-ordinate system or their location relative to one another in terms of lengths, angles and height differences. In general, precision can be easily achieved at as high a level as is required, and over-precision must be guarded against. But precision is still a natural function of the type of equipment used, the cheapest and fastest to employ usually being the least precise.

Whatever equipment is employed, scaling has the effect of reducing the errors in linear measurement by the scale factor. A map scale factor of 2500 therefore reduces an error in the horizontal measurement of 50 cm to 0.2 mm, which is too small to plot. Such calculations guide the surveyor to the correct levels of precision in field measurements of detail. The scale factor does not cushion errors in angular measurement, or errors incurred in connection with cumulative measurements especially for control, or gross errors.

(iv) Presentation of information

A check list of symbols should be prepared and used experimentally. Natural symbols are used wherever possible. Detail too small to be drawn to scale in its correct position is represented conventionally. For topographical maps, cartographic symbolisation has become standardised through usage and official conventions are hard to improve on. Conventional signs for Ordnance Survey maps are given by Harley (1975) and include symbols and signs, boundaries, heights, rock features and word abbreviations.

For several types of specialist thematic map, separate sets of symbols and colours have evolved and are widely used. Geological, soil survey and land-use maps all use commonly agreed colour tints for their chorochromatic distributions. The sets of symbols for geomorphological and geological mapping are provided in convenient form by Dackombe and Gardiner (1983), and the symbols and colours for orienteering maps are illustrated by Petrie (1977). Orienteering maps require an internationally agreed set of symbols and colours if they are to be used for competitive purposes. A study of the symbols, covering land forms, rocks and boulders, water and marsh, vegetation, and man-made features in a wide variety of types, is recommended for any field scientist involved in spatial mapping as it is likely to stimulate new ideas on style of presentation.

(v) Precision of presentations

The surveyor must retain a clear mental distinction between the accuracy of content of the map and the precision of presentation of this content, for which comments relating to existing published maps have been made above. The golden rule of good surveying is embodied in the aim to locate the contents of the map to the limit of plottable precision, this being a standard that cannot be excelled. Plottable precision means that all lines and natural symbols occur positioned relative to each other as correctly as it is possible to measure. There is a choice of two methods: by direct

drawing up of the field measurements at the final scale, or by drawing up at a larger scale and reducing the fair drawing to the final scale graphically. The extra step in the second method assures finer linework and hence greater precision. There is no appreciable difference in the amount of fieldwork necessary.

Manual plotting of measurement of a line (with a finely graduated ruler and a sharp 3H pencil) should be readily possible to a precision of 0.30 mm or *0.15 mm. This precision is independent of the field length of the line or of the scale of the map. Such a standard of plottable precision will then give rise to different errors in real distance according to the plotting scale (Table 3).

Table 3. Relationship between map scale and plotting precision

<u>Map scale</u>	<u>Error in real distance</u>	<u>Approximately suitable precision of measurement of detail point</u>
(LARGE SCALE)		
1: 50	1.5 cm	5 mm
1: 100	3.0 cm	1 cm
Constant		
1: 200	6.0 cm	2 cm
plottable		
1: 500	15.0 cm	5 cm
precision		
1: 1 250	37.5 cm	10 cm
of		
1: 2 500	75.0 cm	25 cm
0.30 mm		
1:10 000	3.0 m	1 m
1:25 000	7.5 m	1 m
(SMALL SCALE)		

The plotting scale is therefore the ultimate constraint on the limits of measurement possible from the map. A final choice of one scale can occasionally be avoided by using two scales, one for the main map and a larger scale of representation for an inset map.

Precision of presentation is also affected by errors in the drawing up. Other sources of error that can produce minor inaccuracies in the fair drawing are: faulty drafting technique; use of poorly graduated drafting tools; and use of a dimensionally unstable drawing medium.

Automatic plotting of a line with a computer-controlled flatbed plotter is possible to stated precisions commonly of the order of 0.05 mm. This permits the use of much more precise field measurements, particularly the sorts of measurements obtainable from electronic distance measuring (EDM) equipment, where distances are measured to 1 mm. With an integrated system of survey data collection and presentation, the errors encountered with a manual system are largely avoided, but such high precisions are unnecessary for the typical surveying problems currently investigated by field scientists..

IV STRATEGY FOR DATA COLLECTION

(i) Point by point collection

The standard observational methods of ground surveying, which are intersection, traversing, radiation and offsetting (see section VII), require that field observations and measurements are made to points of detail, point by point. The points are located by the temporary positioning of a pole, staff or optical prism. Therefore, in order to accommodate surveying methods, all the features of the landscape have to be considered as discrete points or combinations of points, whether these features be naturally terrain points, terrain lines or terrain areas (for example: a stream, a spring, or a lake).

Also, for surveying purposes, the landscape to be mapped has to be straddled by a framework of surveying control and station points that have no natural presence but are temporarily pegged out and fulfil one of the basic principles of surveying, to work from an overall framework of high accuracy to local measurements of the terrain of less accuracy. This is described as working from the whole to the part. Control points are established initially, and many of them will also be instrumental station points. Whereas the instrumental stations are positioned according to the survey method and the terrain to provide sufficient viewing points, the detail points are located according to what the map must contain. Cumulatively the detail points form the final map. In Example 1 (section 1) the numbers of control, station and detail points were seen to be 2, 8 and 209 respectively, which are of typical frequency.

As well as the points of topographical and thematic detail, which may form the map base or the map subject, and the survey control and instrumental points, there may be further points in the landscape identified for the purposes of some thematic investigation (SURVEY TYPE 3). These points will have to be set out relative to one another, pegged and surveyed in position. For all of these different sorts of points, natural or artificially created, the principal scientific task is not their spatial measurement but their selection initially.

Points of detail required for the map base are relatively easy to select. The surveyor records as many points as is conveniently possible, spread out evenly and representing the most obvious landmark and positional features. In Example 1 the map base in Figure 1 was reconstituted from 74 points, located at boundary walls, gateways drainage ditches, paths and breaks of slope. Other possible features depending on scale are buildings, quarries, power transmission pylons and other upstanding features, as published maps illustrate.

Points of detail for the map subject require the most comprehensive consideration, as they must reflect the research objective. Firstly, the population of the subject, disaggregated into spatial point locations, must be considered. To use the language of statistical theory, once the objectives of the study have been defined, the population has been defined (Krumbein, 1960). More specifically, consideration has to be given to a target population, that is, the available population of points for the particular subject being studied. In practical terms of subjects in which surveying plays a part, the target population can range from thousands of

points making up a general landscape map (SURVEY TYPE 1) to a handful of points to be set out as sites for thematic investigation (SURVEY TYPE 3). To make a map where the subject occurs at a finite number of discrete locations (SURVEY TYPE 2), for example the locations of stream junctions in a small drainage basin, or every tree in a mature shelter belt, the sampled population can equal the target population and a complete census takes place. For continuous linear or areal distributions, the idea of the infinite population can be applied, so that the target population becomes what is the realistic number of possible measuring points. It then becomes a matter of general judgment whether the sampled and target populations are near enough identical for results of analysis from the sampled population to be applied without qualification to the target population (Krumbein, 1960). In Example 1, the subject of vegetation extent and vegetation boundaries was dealt with by 150 boundary points (Figure 1).

If statistical analysis is to be attempted, the size of the sampled population of sites should be decided on the basis of statistical arguments related to the confidence required in the results of analysis. If the sample size is limited to the order of 30 sites for any spatial variable, any statistical analysis based on normal distribution functions is suspect. Note should be made of the substantial literature available on sample size, including Chorley (1966), Gregory (1968), Cochran (1977), and Dixon and Leach (1978).

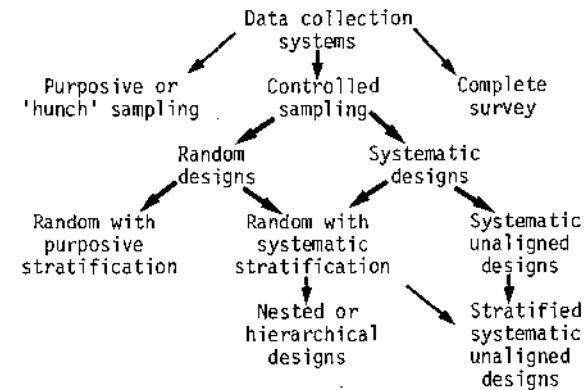
(ii) Sampling designs

Alternative sampling designs (Table 4) may be applied according to the nature of the subject and the target population. Spatial sampling designs should properly be used only in the context of field phenomena which are continuous, such as slope angle and soil pH, not discrete, such as erratic boulders and fungal rings, as bias results. Furthermore a principal distinction is made between sampling of topography and surface vegetation, which are visible and therefore can be assessed purposively, and sampling of bathymetry, soil pH and other thematic subjects which are not visible and therefore must be investigated by controlled sampling, of random or systematic design. An exception is the digital terrain model for a large number of data, considered later.

For thematic subjects distributed continuously with assumed isotropic variation (that is, variation is much the same in all directions), the rigour of random sampling to establish site locations has classically recommended itself on statistical grounds because, when the data from these surveyed sites are analysed, the resulting sample estimates will be unbiased, and the calculated standard errors will not be misleading (for example, Kershaw, 1973). But it must be recognized, firstly, that many field investigations involving surveying are extremely loose in design and, secondly, that ground conditions are often ill-suited to choice of site by rigorous random selection. For the field surveyor, the practical difficulties of setting out sample points at random over an area, along a line or along transect lines may outweigh any theoretical advantage. But, more importantly, systematic sampling has been favoured even on statistical grounds in some quarters in both theoretical and empirical studies (Petersen and Calvin, 1965; Burgess, Webster and McBratney, 1981). A statistical weakness of systematic sampling occurs if the sampling

periodicity corresponds exactly with any natural periodicity in which case the sample estimates may be grossly incorrect, with a misleadingly small standard error. Petersen and Calvin (1965) declared that such periodicities seldom occur in nature. The problem may be bypassed by using a stratified systematic unaligned design.

Table 4. A model of sampling designs



Source: Haggett (1965)

Purposive sampling (also variously called judgment, hunch, and choice-based sampling) is made on the basis of convenience, experience and/or intuition. Such sampling is perfectly valid as long as the temptation of inferential statistical analysis is resisted and conclusions are properly limited. Literature dealing with sampling design and data analysis, in addition to that already cited on sample size, includes Jeffers (1983) and Lakhani (1983). Illustrations of some of the alternative designs of Table 4 are developed in sections V and VI.

V SELECTING FROM TERRAIN POINTS AND TERRAIN LINES

The terrain has already been described as being composed of a combination of point, linear and areal features, of which a selection can be used as base material and as subject material to form a map. We look in the next two sections at the ways in which the surveyor can choose representative material, working point by point. The first cases are trivial.

(i) Points and straight lines

A point location in the landscape (terrain point) is surveyed as a single point of detail and represented accordingly. The scale of presentation will determine whether a very small feature (for example, a stone polygon; bole of a tree) is plotted as a point or as a finite area.

As a straight line is defined by its two end points, a terrain line is surveyed as two single points of detail which are then joined in the fair drawing. An area bounded by straight lines is treated by surveying the apices.

Lines are one-dimensional by definition. Nevertheless, 'thick' terrain lines commonly occur (for example, stone walls, earth banks, pathways) and are treated as two parallel lines or as one line represented with a calculated width.

(ii) Generalisation of curved lines

Traditional point-by-point surveying methods for curved terrain lines such as natural water courses encounter difficulty because of the uncertainty over the number of points necessary to provide a map representation that is not over-generalised. Field surveying and mapping of curved lines (SURVEY TYPES 1 and 2) require two types of simplification:

- systematic point sampling with variable interval depending on curvature;
- feature enhancement or exclusion

These two types are analogous to point elimination and feature elimination in cartographic generalisation (Robinson, Sale and Morrison, 1978).

Figure 3 is a theoretical example, illustrating various types of curved terrain lines. In surveying, all corner points (abrupt angular changes of direction) are included. Thereafter, sampling intervals decrease as the curvature increases (points 2-12) and are constant on curves of constant radius (points 15-21). Other points included are points

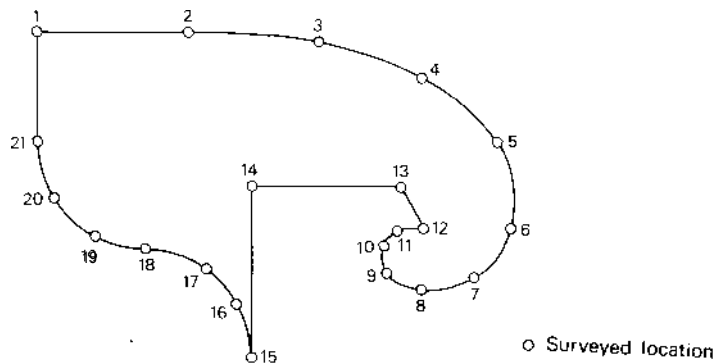


Figure 3. Pattern of curved lines

of inflexion (18) and at the ends of curves (2, 12, 15, 21). The general interval between surveyed locations depends on the required level of generalisation or analysis but is absolutely limited by map scale. A rough rule of thumb is to aim for an interval of 0.5 cm multiplied by the map representative fraction; for example, for map scale of 1: 2 500, a survey interval of 12.5 m.

Features on a line include abrupt changes of direction and junctions, and the simple suggestions above may not be adequate for complicated sinuosities or for many-ordered networks. The decisions whether to enhance or exclude features and what linear interval to take are normally made on the basis of field judgment, experience and a 'feel' for generalisation. As a result the map will almost certainly show some inconsistency of standard. This may be avoided by observing many more locations on curved lines than can be mapped, and selecting objectively from these by a machine processing route in which decisions on inclusion or exclusion are reached in a less overtly subjective manner, by some pre-determined rules. To collect and discard locational data in such an apparently extravagant manner requires an automatic measuring and recording tacheometric system linked to a computer-assisted cartographic plotter. It is not practical with a conventional surveying system such as manual tacheometry.

Coping with curved terrain lines is one of the greatest advantages that fast computer-based surveying systems have to offer over manual systems, but currently seem relevant only for topographical objectives (see also section VI, iv). There are not case studies available yet to support any inference that superior analysis obtains from topographical data so elaborately derived.

(iii) Locations along a straight line

Dealing with thematic subjects distributed continuously, selection along a line to set out ordered points (SURVEY TYPE 3) commonly encounters two circumstances:

- Case 1: for subjects distributed with assumed isotropic variation, where topography is influencing thematic measurements equally and expected values at the selected sites will be normally distributed;
- Case 2: for subjects distributed where topography varies, and expected values at the selected sites will be a function of the land surface.

It is convenient to use two aspects of ground surface slope as an example to illustrate the two cases. In Figure 4a, points selected along the horizontal line HH would be expected to yield similar values for slope angle (Case 1); points selected along the vertical transect VV would yield values depending on the landform evolution. In the second case, the methods of analysis likely to be employed are graphical and mathematical (by curve fitting) rather than statistical, although serial analysis and angle frequency may possibly be employed (Young, 1974).

In Case 1, locations at n points are to be selected to measure angles of slope in the direction of maximum slope. HH is located horizontally midway between top and bottom of the uniform slope. The origin for sampling along HH is judged with respect to the dimensions of the feature. The sample size n and sampling design will relate to the defined

morphological objectives. Systematic sampling with 5-25 m intervals would be a realistic procedure, but might produce wrong sample estimates if the periodicity of the interval corresponded, for example, with an unsuspected regular buried gully (Figure 4a, ggg). A design of random sampling within systematic stratification (Table 4) would allow short irregular sampling intervals for example, three random locations within every 25 m block length (Figure 4b, HH)

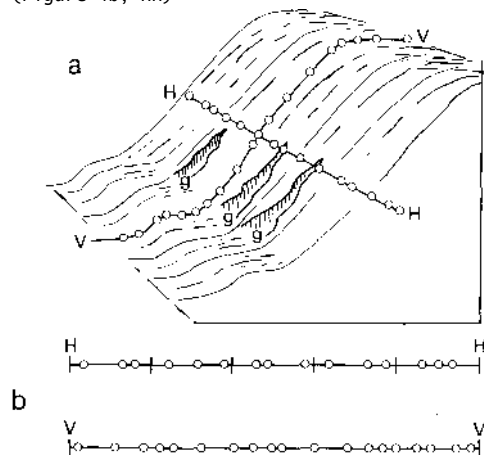


Figure 4. (a) Linear measurements on a slope: (b) Linear sampling intervals

In Case 2, locations are to be selected to measure angles of a hillside profile of markedly varied slope angles. In Figures 4a and 4b, VV is the profile line from a scarp crest down through various slope facets to a river course. The apparently simple decisions over sampling interval along VV (and also over instrumental surveying techniques) have been discussed very fully in published literature, reflecting both the importance of slope analysis in landscape morphological studies and the increasing refinement of measurement within research objectives.

Downslope profiles may be expected to exhibit breaks of slope as well as continuously changing slope angles. Random interval sampling being discounted, the choice lies between overall systematic interval sampling, stratified systematic interval sampling (within slope facets) and purposive selection (at identifiable breaks of slope). Pitty (1967), Gerrard and Robinson (1971), Young (1974) and other workers have concluded empirically that slope-angle observations based on constant sampling interval are always to be preferred, especially if the standard length adopted is very short in relation to the total length of the profile. Identification of breaks of slope is left to subsequent analysis. Young (1974) favoured a constant interval of 5 m for all schemes, to facilitate comparability of results, but 2 m, 10 m, or 20 m are regarded as suitable otherwise. Alternatively, it has been considered that the interval should depend on

the characteristics of the slope (Gerrard and Robinson, 1971) or that a variable unit should be employed, using greater intervals for portions of the profile with slight change and lesser intervals for portions with rapid change. The writer has found that over flights of river terraces one systematic sampling interval with additional intermediate points, located subjectively where the slope angle was judged to change abruptly, provided a good visual summary suited to the research objectives. A similar compromise has been suggested by Doornkamp and King (1971).

(iv) Imprecise vegetation boundaries

The boundaries of natural vegetation communities, commonly presented on maps as precisely located lines, are in reality diffuse zones of transition. The mapping scale is the principal factor determining how much generalisation has been involved in reducing a curvilinear zone to a curved or even straight line.

The amount of generalisation from zone to line that can be tolerated must be specified within the research objectives; the surveyor's problem is to decide how such a level of generalisation can be satisfied by a minimum number of surveyed locations. Ultimately the surveyor has to use general field judgment and accept inconsistency of standard. Even by using automatic measuring and plotting systems, it is not economic to survey every plant in order to find exact community boundaries except possibly in the case of trees surveyed at a large scale (Lindsay, 1981). With small plant species, as also with the faint markings of archaeological features, the surveyor may have to peg out ground positions by careful inspection.

Figure 5 shows the edge of a theoretical vegetation community with outliers. Four versions of the community boundary are given, which in sequence register the 'correct' boundary with increasing levels of accuracy. But this sequence is associated with increasing surveying effort.

- Boundary 1 : cape to cape enclosed limit with no external acute angles on boundary line;
- Boundary 2 : nearest communities on outer limit linked;
- Boundary 3 : outliers and voids amalgamated; define minimum sized outliers and voids for consideration;
- Boundary 4 : outliers and voids surveyed singly; define minimum sizes based on mapping scale.

Because of the foreshortened viewpoint in ground observations, none of these solutions may be as satisfactory as an air photo interpretation and photogrammetric plot of the boundaries.

Although the essence of biogeographical investigation is areal sampling or selection within each community rather than on the boundary of communities (Harrison, 1971), community boundaries can also be discovered as a by-product of this broader spatial selection. For example, by taking a systematic grid sample over the boundary zone, consideration of the percentage presence of a dominant species within quadrats at each grid intersection provides a distribution of percentage values. If, say, 25 per cent species cover is taken as a boundary value for that species, the surveyor has only to cope with the relatively easy task of establishing the systematic areal grid. The boundary line has emerged as the result of numerous quadrat counts.

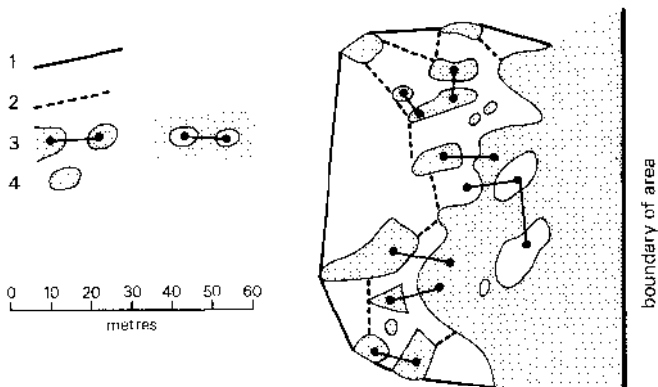


Figure 5. Alternative vegetation boundaries

VI SELECTING FROM TERRAIN AREAS

A terrain area is defined as a unit of landscape with a common topographical expression. Distributions within areas of terrain may be represented by data located according to any of the following sampling designs: at one or more points, at strings of points, at network intersections, along lines and by smaller areas. The simplest case of representation, at a single point, is again trivial (Figure 6, type 1). A string of points seriatim across an area provides more data representing one dimension of the area, which may be chosen to be the longest axis (Figure 6, type 2). Networks have the most general application for continuously distributed phenomena, only a selection of the more common networks being shown in Figure 6 (types 3-8). Continuous line transects in random or systematic directions (Figure 6, types 9-10) and areal sampling (Figure 6, type 11) are most commonly employed in land use and biogeographical studies.

(i) Surveying implications

The surveying implications of these alternative designs in terms of setting out vary considerably but common to all setting out are the requirements in terms of the research objective, firstly, that the areal boundaries are defined, which ensures that the target population will include all locations of the specified type and exclude all locations of other types. And, secondly, that the sample size is sufficient. Thereafter the surveying practice depends on the sampling design. Random sampling methods (Figure 6, types 1, 3, 4, 9) involve a few simple steps of surveying and statistical selection:

1. An origin point (Figure 7, 0,0) is positioned outside the area such that the whole area lies within a quadrant from it.
2. From the origin point, a base-line direction is observed, corresponding to the major axis of the area. The base line is set out on the ground by tape with permanent markers, and serves as one of the co-ordinate axes.

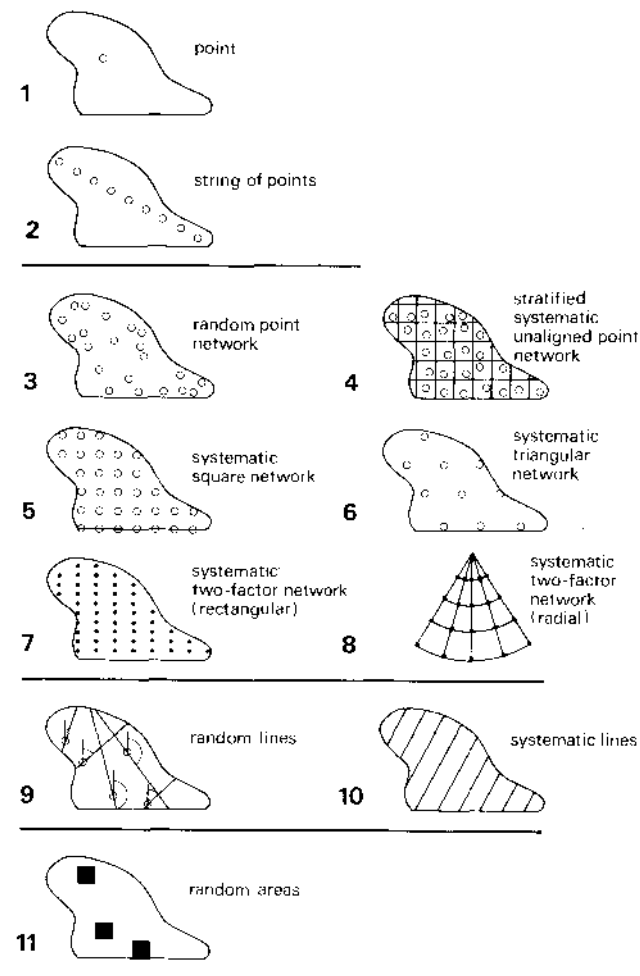


Figure 6. Alternative selections from terrain areas

3. Pairs of random co-ordinates are generated by table or by hand calculator, to a precision depending upon the scale of operation but commonly to one metre.
4. Along the base line, one co-ordinate of each pair is set off. In Figure 7 the base line is the x-direction and the first co-ordinate (abscissa) is used.
5. At the distance set off, a right angle is sighted by cross-staff or, if the distance is greater, by the horizontal

circle of a compass, level, theodolite or tacheometer. This sighting creates the y-direction (ordinate) in an arbitrary co-ordinate field.

6. The second co-ordinate of each pair is set out along the ordinate by tape or by tacheometer as distance demands.
7. Random points have now been established. For random lines (Figure 6, type 9), there is a further step. At each point, a random bearing is taken clockwise with respect to a distant reference object, and the lines set out.

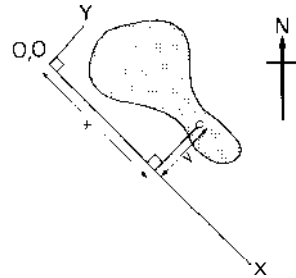


Figure 7. Surveying for random locations

Systematic sampling methods (Figure 6, types 2, 4-8, 10, 11) require more field effort. Surveying practice for the many alternative methods cannot be described individually, but the two general steps are:

1. An origin point is chosen at random outside the area and a random bearing taken at this point with reference to a distant object. This provides an initial line which should be set out permanently on the ground. An exception to this routine occurs where a two-factor network is specifically aligned to a visible feature as is likely, for example, with the radial network in Figure 6, type 8.
2. Further lines are set out with reference to the initial line, using the same equipment for angles and distances as listed above. The line density and pattern depends on the network design adopted. It is good field practice to set out an accurate skeletal network initially, say every 250 m and fill in at, say, every 25 m subsequently.

The number of intersections for even a modest network can total hundreds, so that considerable quantities of flagged canes, stakes or ranging poles are needed as markers. Equipment requirements can be reduced if the systematic network can be set out and then lifted, a part at a time, but it is best to retain the low density skeletal network for the duration of the survey, in case of surveying or sampling errors. For the randomised location of subareas (quadrats; Figure 6, type 11) set in a systematic network, the entire network may be needed at the one time in order to determine the target population number of quadrats and then to carry out measurements at a number of them.

The last words in this introductory section on terrain areas must go to Kershaw (1973, p. 37) describing areal sampling: "... the sampling procedure most suitable for a given problem is usually chosen or designed

for that individual problem. The choice of measure ... can be decided more by common sense than by resorting to complex statistical theory".

(ii) Representative single points and strings of points

If the value at a single point is to represent values over a designated area of landscape, the surveyor would be hard put to improve on a purposive selection of some central site, but the probability that any data produced from this site are typical of the designated area remains unknown. In such circumstances, personal convenience features strongly. An exceptional case concerns the surface altitude of an enclosed water body, as the correct height will result no matter which point the surveyor selects to measure.

A linear string of points as a sample of an area would produce data biased in favour of the linear zone, but there are some circumstances in which such a selection is considered adequate or even the only possibility. This is particularly true for topographical objectives Zt and is directly related to the subsequent methods of analysis. Two common topographical cases are considered.

The first case concerns river terraces and valley benches, which are recognised as individual flat-topped fragments, characterized by gentle surface slopes down-valley and cross-valley. The slopes are often too slight for even the maximum slope direction to be detectable by eye. Each fragment may be associated with other fragments at similar altitudes on the other side of the valley, and at higher altitudes upstream and lower altitudes downstream, the sets of fragments indicating stages of geomorphological evolution. In a typical survey of down-valley slopes (Figure 8), for each fragment a straight string of sample points is selected by visual judgment on the basis of what is going to be most useful in the subsequent analysis. Alignment could be the long axis of the fragment, equidistant between the front edge nearer the river and the back edge, both edges being liable to post-depositional modification (Figure 8a). The origin and terminus of the string need not be located critically as anomalous data from end points can be rejected for analysis. Linear sampling design can be either systematic or random within systematic stratification (Table 4). The strength of the heighted points is cumulative, depending on the form of the string of points as a whole (Figure 8b) and the orientation and height relationship of the string with adjacent strings on other terrace fragments.

Example 2 (SURVEY TYPES 2 AND 3)

Location: River Esk, Lothian; Nat. Grid ref NT 26 and 36.

Extent and altitudinal range: 17 km, 25-225 m O.D.

General objective: to produce height-distance diagram and plan of terrace fragments.

Map specification: horizontal scale 1:10 560; vertical exaggeration on height-distance diagram of x18.

Surveying objective: revision plotting of 142 terrace fragments onto O.S. sheets at 1:10 560 scale; absolute heights of strings of points systematically spaced at 50 m interval; heighting precision 0.01 m.

Surveying method: control provided by 49 bench marks; heighting by closed levelling traverses using Autoset level and 4 m staff; detail points 1224.

Comments: maps at 1:10 000 metric scale not available at time of survey. Using standard levelling procedure, standard error for Z_t of ± 0.02 m; by contrast the surveyed eccentricities of field values of Z_t for individual points of ± 0.15 m are due to undulations of the natural soil and vegetation surface. For further details relating to this example including published maps, see Kirby (1969).

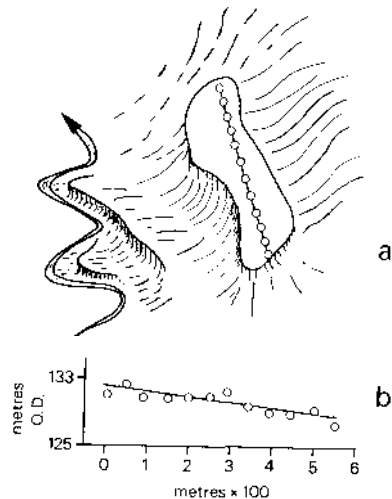


Figure 8. (a) Sampling along river terrace; (b) Height-distance diagram

The second common topographical case concerns raised shoreline features, which pose a similar type of sampling problem but with greater practical difficulty. Raised shorelines are flat-topped features, straight or curvilinear in plan and often of considerable length but negligible width. Surveying is typically required to elucidate absolute altitude and the very slight regional slope. Sampling follows a similar procedure to that described for Example 2, except that visual alignment is along the back edge of the feature. Most commonly a systematic sample is taken at an interval of 50-100 m, although the interval can be varied to avoid ground irregularities (Gray, 1975).

Example 3 (SURVEY TYPES 2 AND 3)

Location: Firth of Lorn, western Scotland Nat. Grid ref. NM 54 to 93. Extent and altitudinal range: considerable shoreline, 12.04 to 4.66 m O.D. Newlyn.

General objective: to produce height-distance diagrams and XYZt data for analysis.

Surveying objective: revision plotting of 106 platform fragments; absolute heights of strings of points spaced at 30-60 m intervals; heighting precision 0.01 m.

Surveying method: control provided by O.D. Newlyn bench marks and by calm sea conditions; heighting by Autoset level and staff; detail points 304.

Comment: For further details relating to this example, including published maps, see Gray (1974).

For river terraces, raised shorelines and similar dispersed fragments, both graphical and numerical methods of analysis are commonly applied. In the past, coarse measurements of the heights of such features by surveyor's aneroid barometer have provided height-range diagrams (e.g. Brown, 1952) from which limited visual judgments can be made. In more recent work, greater confidence in the judgment is afforded by three developments: more precisely heighted measurements at more points; use of all surveyed points to extrapolate between fragments; and, in the case of river terraces, the reorientation of the sample strings to fit a subjectively determined base line common to all fragments, that is the general direction of the movement of water contemporary with the formation of the terraces. In the example described by Kirby (1969), it is concluded that the errors introduced in presenting the data are potentially more serious for graphical analysis than the errors of measurement.

Numerical analysis of either river terraces or raised shorelines requires many data that ideally should be widely spaced over the original features but in practice occur in clusters over the separate residual fragments. Autocorrelation between the spatially adjacent data on each fragment means that regression techniques have to be regarded with caution. A preferred solution is to represent the altitude of each whole fragment by a single mean Z_t value at a calculated mean location of the sample points which, in the case of a curved fragment, might occur off the fragment completely (Gray, 1975). Following this, linear regression or trend surface analysis can be used to calculate regional trends, for example Gray (1974).

(iii) Representative network of points

Networks provide the most flexible sampling alternatives for continuous areal distributions, even though the network designs for topographical subjects generally differ in type from those for non-topographical subjects. The topographical networks used for land and water are dealt with more specifically in the two sections following this one, where the emphasis is on thematic objectives.

The attractive features of networks are, firstly, that the density of the network may be adjusted according to the survey scale or to the level of analysis proposed, the number of network intersections being made to equal the required sample size. Secondly, there is a wide choice of sampling designs, including systematic, random, stratified and sampling combinations thereof (Table 4). Systematic sampling (Figure 6, types 5-8) has the comforting advantage of persuading the investigator that all the ground is being covered and, in the form of a stratified systematic unaligned network (Figure 6, type 4), also has the theoretical advantage of randomisation.

A third advantage of systematic networks is that variation of pattern allows further sampling refinement. A square or a triangular network is used with uniform ground conditions that are assumed not to be responsible for any variation in the samples (that is, isotropic variation; one-factor control). Of these two patterns, the square network is marginally easier to set out but interpolation between data located in square patterns in order to form isopleths occasionally produces ambiguity. To overcome this a

solution due to MacKay (1953) based on averaging the interpolated central values is still frequently quoted. A triangular network allows more logical manual interpolation between sample points but has less priority in machine interpolation, particularly in interpolation procedures involving an intermediate grid, which are by far the most common machine interpolation procedures used (Rhind, 1975).

If ground conditions are varying in different directions such that the samples are assumed to be affected (that is, anisotropic variation; two-factor control), a rectangular, log-linear, radial-linear or other network may be used. In all one-factor networks, the initial point and grid orientation should be chosen at random but in a two-factor network, the topography will control the grid orientation and, for a fan network, will determine the radial point of origin also. The less common networks such as radial-logarithmic and multi-stage designs, described originally by A. N. Strahler and by W. C. Krumbein, have been more recently collated by Chorley (1966). Areal sampling frames for general geographical use are described by Petersen and Calvin (1965) and by Dixon and Leach (1978).

On uniformly sloping terrain, the angle of slope will determine whether a one-factor or a two-factor style of network is appropriate for a particular research objective. On steeper slopes a two-factor network will commonly be more satisfactory. On gentle slopes or on small isolated steep slopes within the design area, one-factor networks established for thematic sampling seldom need to be adjusted for any bias in spacing. This is because, for example, a ground slope as great as 15° still gives a corrected horizontal distance with a discrepancy of less than 5 per cent of the measured slope distance.

If a research objective is to produce a general statistical surface from the thematic sample data, and if many sample points are involved, the calculating power of the numerous available computer contouring routines (Rhind, 1975) reduces the labour. Some of the routines specify or permit non-linear interpolation and care must be taken to avoid criteria that will produce a smoothed isopleth distribution inconsistent with the original objectives. Arguments on spatial interpolation are conveniently presented by Unwin (1981).

(iv) Representative topographical networks: digital terrain models

In the common case of a thorough topographical survey for a limited area, many XYZt data are collected. Where the locations are systematically located, the set of data forms an ordered array of numbers representing the spatial distribution of terrain characteristics, and is called a digital terrain model (DTM). This term is much better established in scientific literature than terrain line or terrain area, being apparently first employed in connection with work at Massachusetts Institute of Technology on highway design by digital computation of terrain data acquired by photogrammetric means (Miller and Laflamme, 1958).

Essentially a DTM consists of numbers in XYZt form representing a series of points of known height, which bear a predetermined spatial relationship with one another. It is commonly agreed that the term DTM should be reserved for a surveyed, not a computed, model (Doyle, 1978; Yoeli, 1983). Such comments as "a DTM is derived by digital computation"

(Ackermann, 1978, p. 1537) are misleading and refer to the mathematical model of the ground developed from the DTM which inevitably has different characteristics.

The DTM has little direct value in itself to describe the landscape but as a data base it can be processed by programs with specific applications for topographical description. Typical direct applications for the data are contour drawing, generation of profiles and perspective view, determining intervisibility of points, terrain simulation, and the production of real three-dimensional relief models (Doyle, 1978). The derivation of a topographical surface, which is the special case of a statistical surface devoted to altitude, is a standard application, and is easier to derive than other thematic surfaces of equivalent size such as surfaces for soil type or for depth of superficial deposit because the DTM is relatively easier to assemble.

If the DTM is to be an accurate representation of the continuous surface of the ground, a large number of closely spaced sample points are required. The obvious sources of DTM data for field scientists are: ground surveying, photogrammetric surveying, and existing contour maps. In addition, Doyle (1978) mentions the likely potential of radar and laser altimeters carried in aircraft and spacecraft, relevant only for larger areas of ground. Ground surveying will suffice as an economic source of data for small areas and at large mapping scales, where the possibilities of precision in surveying for XYZt are most appreciated. To survey the topography accurately, the points must be selected by a purposive scheme following geomorphological guide-lines with respect to slope facets, breaks of slope, irregular ground, and special features. A systematic one-factor network of points will result in a smoothed surface that might be unacceptable. The surveying principles to represent the surface accurately are:

- between any two adjacent points the ground slope must be accepted as linear;
- points must be located in strings along breaks of slopes and on each side of breaks of slopes;
- unnatural levels must be ignored or specially noted;
- point density should reflect the evenness of the ground, with a stipulated minimal density of points for uniform ground;
- where special features require a density of heightened points considerably greater than for the general ground surface, a separate small DTM will be required.

These principles are best satisfied for small areas by tacheometric traversing, which provides complete flexibility in positioning points. As an example of the efficiency in compiling a DTM by tacheometric surveying under test conditions, Ackermann (1978) quotes an average of 42 terrain points surveyed per hour or 450 points per day, by Reg Elta electronic tacheometer. A total of 6000 points with an average spacing of 15 m were surveyed in 13 working days. Most DTMs collected by ground surveying contain fewer points than this.

Of ground methods other than tacheometry, area levelling as a source of DTMs is suitable only for dealing with minor height variations over limited areas, as used for example in braided stream channels on a river flood plain. Engineering surveys for highway design and landscape architectural studies remain the primary source of theoretical material.

The problem of collecting large data sets for XYZt has hitherto restricted the use of ground surveying methods. Electronic tacheometers with automatic data storage facilities, the so-called total station systems, offer great promise but are currently still under development and are expensive. In the meanwhile the most efficient practical method is likely to be by use of a photogrammetric plotter fitted with digitizers, especially for larger schemes. This is scarcely less expensive but has been an implemented system for some years. From a photo stereo-model, the DTM can be formatted either as contour lines, as sectional profiles or as morphological terrain lines. Alternatively, a contoured map can be produced photogrammetrically (or may be available independently) and a network of heighted points can be taken from the map by use of a translucent grid overlay.

Heighted points can be derived far more rapidly from a stereo-model than by any form of ground survey. For the same test area, Ackermann (1978) quotes collection on a Planimat D photogrammetric plotter of 8400 profile points in 51 hours, and direct photogrammetric plotting of the contour lines in 11 hours, all to a similar accuracy as with ground surveying.

Because so many data can be collected with relative ease by photogrammetric methods, a high density of points is normal, and the principles underlying ground surveying for a DTM may be relaxed. This is particularly true with the dense DTM, developed on the Gestalt GPM II photogrammetric plotter which can systematically scan each stereo-model to produce a DTM of 700 000 points. Computer algorithms intended for operation with DTMs of 10^7 to 10^8 points or more are under development to provide completely new quantitative and qualitative descriptions of the terrain (Collins and Moon, 1981).

DTM data, however acquired, are rarely in a form suitable for immediate application, and extensive computer preprocessing may be required to rearrange them in appropriate format, perhaps a strictly systematic altitude matrix, including data editing and compression, co-ordinate transformation and interpolations (Evans, 1972). Computer interpolation techniques may be as simple as bilinear interpolation or as complicated as multiparameter surface-fitting by polynomials or Fourier series. For terrain analysis, numerous commercial packages relating especially to highway engineering are available.

(v) Representative bathymetrical networks

The objective of a bathymetrical survey is descriptive, to measure the relief of the continuous bottom surface including all natural and man-made features, and to depict as for a topographical map of land areas. Submarine contours are derived from a network of spot-depths, which raises problems of surveying, sampling design, and data presentation.

Because bottom surfaces are not visible except where water is very shallow, bathymetrical surveying proceeds as though for a thematic rather than a topographical subject; preliminary rough sample soundings are necessary to find approximate depths and the types of features likely to occur. Thereafter a suitable full sampling design has to bear in mind the following constraints:

- submarine depths can be assumed to increase with distance

- from the shoreline and be constant along lines parallel to the shoreline;
- boats move best in straight lines, ideally along the line of points in transit;
- the angular coverage of an echo-sounder is in the form of a cone directed vertically downwards. When allied with the forward movement of the boat, this gives a swath coverage whose width depends on water depth. To obtain full coverage, the combination of cone angle and water depth controls the spacing of transect lines.

This leads naturally to two-factor systematic grid sampling of either rectangular or radial-linear type (Figure 6, types 7 and 8). Exceptionally, sampling may degenerate to systematic linear sampling. The density of points must vary according to the assumed complexity of the underwater topography (Figure 9), and must be sufficient to allow total reliance on the echo-sounder. The echo-sounder provides data continuously by systematic lines (Figure 6, type 10) in graphical form. From this graph systematic spot-depths follows. Ingham (1974) provides further theoretical details of the sounding plan. There is no equivalent to the visually sketched form-lines on topographical maps of dry land.

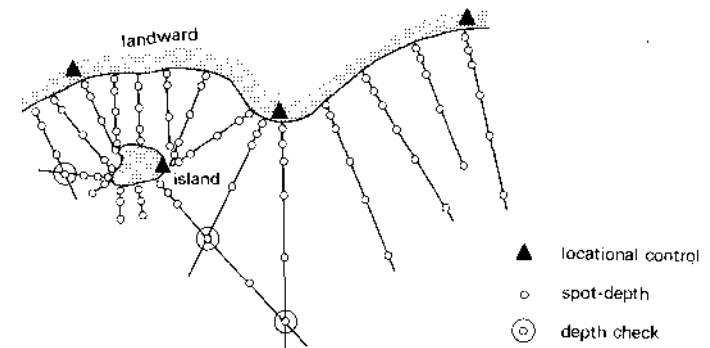


Figure 9. Sampling scheme for shoreline zone

The process of interpolating from the spot-depths assumes that the distribution being mapped is continuous, but otherwise only vague assumptions based on the topography are justified as to the kinds of gradients that exist between the Zt values. In the absence of any other information, the surveyor is forced to agree to the general solution, which is to assume the validity of the average value (Robinson, Sale and Morrison, 1978, p. 227).

Example 4 (SURVEY TYPES 2 AND 3)

Location: Loch Leven, Kinross; Nat. Grid ref. NO 13 02.

General objective: bathymetrical survey to produce maps for hydrologists and biologists.

Map specification: map scale 1: 2 500 with precise contouring especially in the peripheral zone of shallow water according to Table 5.

Table 5. Depth and contour interval

<u>Depth (metres)</u>	<u>Contour interval</u>
0 - 1	25 cm
1 - 4	50 cm
4 - 5	1 m
5 -25	2 m

Surveying objective: revision mapping onto existing Ordnance Survey plans containing no bathymetrical data; local datum.

Surveying methods: control heighting to water-level gauge by Autoset level; position fixing by double-sextant observations or by 350 m taut line; depth of deeper water by Ferrograph Offshore 500 echo-sounder, of shallow water by hand line and rods.

Control points c.60; detail points over 25 000.

Comments: in water deeper than 4 m, echo-sounder gave depths with less than 10 per cent error so that, with sufficient density of points and depth controls, subsequent contour lines were accurate to this percentage error. Direct depth measurements in shallow water are more precise. For further comments on surveying results and accuracy, and a published map, see Kirby (1971).

(vi) Representative areas: quadrats

The final possibility for obtaining representative samples lies in selecting sub-areas (quadrats) of the original terrain area. The normal point-by-point surveying practices lead immediately to the point locations involved in string and network sampling but cannot cope immediately with addressing all locations within an area, and so, for quadrats, the setting out stage by surveying is followed by a second stage, sampling over the quadrat itself.

In the general case, quadrat methods describe and analyse frequency distributions of a point pattern (Thomas, 1979). Complete investigation of all quadrats provides quadrat censuring, for which there is no natural equivalent in the point, network, or line methods of investigating areas. In the simplified common usage by ecologists and biogeographers, quadrat methods are used to select random sub-areas which are then studied intensively; this is quadrat sampling (Figure 6, type 11)

The survey component consists of setting out a systematic grid of squares of any chosen size, for example 10 m, 1 m or 10 cm. Individual quadrats are selected at random and, within each quadrat, distributions may be sampled, perhaps by presence/absence at the intersections of a finer internal systematic grid. Alternatively, distributions may be described comprehensively. In the case of plants this may be in terms of the shoot frequency (areal coverage of foliage) or the rooted frequency (stem count), as described by Kershaw (1973).

Example 5 (SURVEY TYPE 3).

Location: Winterton, Norfolk; Nat.Grid ref. TG 49 19.

General objective: to sample areal spread of *Rhododendron ponticum* L. on coastal sand dunes.

Surveying methods: systematic two-factor rectangular network was established, with transect lines 50 m apart at right angles to the shoreline. Along each transect line, 5 m x 5 m quadrats were placed at 20 m intervals, using level and staff and tapes.

Comments: the areal coverage of the quadrats was therefore 2.5 per cent of the target area. Percentage cover values within each quadrat were then calculated. Comparative figures for areal coverage were also available from maps derived from sequential aerial photographs. For details of results see Fuller and Boorman (1977).

VII GEOMETRICAL POSSIBILITIES IN SURVEYING

In the point selection that has been described, the points have been related either to the map subject, topographical or thematic, or to the map base material. All of these points have to be addressed and measured within the mechanical constraints imposed by field surveying methods which are outlined in these final two sections. No further details are given for bathymetrical surveying, already discussed in Section VI, v.

Ground surveying measurement to establish the position XY of any point relative to another point can be of five basic varieties. These are:

- by two distances (intersection of arcs);
- by two angles (intersection of bearings);
- by distance and angle combined (traversing; radiation);
- by two distances at right angles (offsetting);
- by three angles (resection).

If a line AB is of known horizontal length and position, a new point P can be located with respect to AB by knowing a pair of values in one of the first four combinations listed above (Figure 10, 1-4). When angle ABP is 180°, measurement is along the straight line. When angle ABP is 90°, main line distance AC and offset distance CP are required. Figure 10, 5 illustrates the fifth case, the principle of resection for finding one's own position P in respect of three known stations A, B and C by measuring the three angles at P; this provides a unique solution for P as long as the four points ABCP are not concyclic.

Areal coverage to locate many points is achieved by using the five basic varieties repetitively (Figure 10, 6-11) and in combination (Figure 11, 1-4). Repetition of distance measurements and of angle measurements are the basis of trilateration and triangulation respectively. Repetition of angle and distance is the basis of traversing (when alternated) and of radiation (when used in pairs from one fixed point).

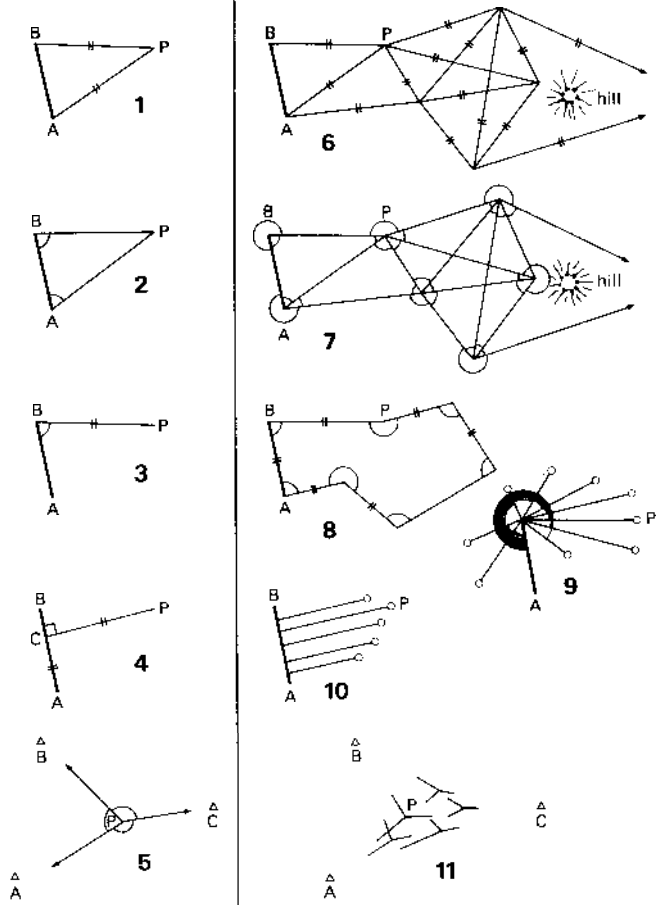


Figure 10. Alternative methods for surveying new points

The primary surveying principle that work should proceed from the whole to the part, in order to minimize regional XYZ errors, requires that the surveyor accurately establishes a few fixed control points throughout the area. To these control points are linked more numerous station points which in turn provide control for the very numerous points of detail. If the map is to be related to the national co-ordinate system as is generally desirable, rather than left in an arbitrary co-ordinate field, then at the control points observations for orientation should be taken by magnetic bearing or by sun azimuth; observations for co-ordinate position related

to national triangulation stations should be taken by trilateration or triangulation; and observations for heighting related to national Ordnance Survey bench marks should be taken by levelling.

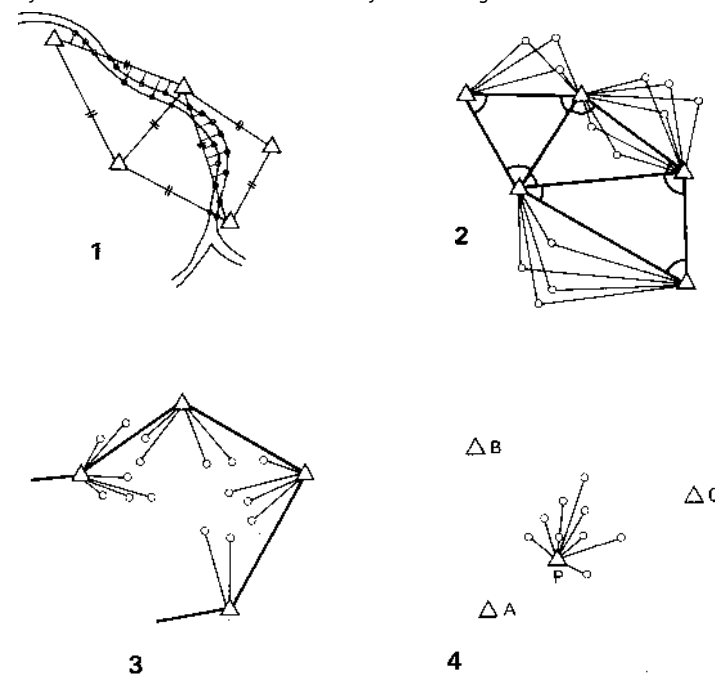


Figure 11. Surveying methods in combination

In most surveying schemes, the control points will almost certainly double as instrument stations. Table 6 shows which methods are suitable for locating instrument station points and points of detail.

Table 6. Surveying methods for establishing types of points

Method	Station point	Detail point
intersection by distance	✓	✓
intersection by angles	✓	✓
traversing	✓	-
radiation	-	✓
offsetting	-	✓
resection	✓	✓

The basic surveying methods are used in combination much more frequently than they are used separately; in small schemes, combinations of methods are normally chosen to cope with station points and detail points simultaneously. In Figure 11, 1-4, common combinations are illustrated: respectively, trilateration with offsetting, as used crudely in chain surveying; triangulation with intersection by two angles; traversing with radiation; and resection with radiation.

Current practice, reflecting recent technical developments, favours the regular use of a few survey methods, particularly traversing and radiation, and the relative neglect in small schemes of triangulation and chain surveying. Traversing involves locating successive station points by alternate measurements of distances and bearings, the series of legs compounding the overall longer distance. A traverse can be properly adjusted if it lies between terminal control points or is arranged in the form of a loop. Traverse surveying has always been widely used as a utility method at all scales of mapping and in many different field circumstances (Berrange, 1975). Except in reconnaissance surveys, the laborious process of measuring the terrain distances either directly, by pacing, by wheel or by tape, or optically by subtense means has been largely superseded by electromagnetic distance measurement (EDM) methods. These methods allow precise horizontal-equivalent distances to be obtained with great simplicity and speed. In the same way, triangulation has been superseded by trilateration as the principal scheme for establishing a strong control framework, and radiation using EDM methods is used rather than intersection wherever detail is accessible. For the surveying of detail, tacheometric measurement of distance by optical means is less precise than by using infrared EDM but is equally rapid and still admirably suited to mapping by radiation.

Ground surveying methods to establish the height Z_t of any point relative to another height can be of three basic varieties. These are:

- by horizontal collimation (step by step; as with level);
- by vertical angle of inclination (slope angle; as with theodolite, tacheometer);
- by barometric pressure (atmospheric measurement; as with aneroid barometer).

Differences of height between two points A and B may be determined directly by levelling or by barometric readings without requiring the positions $X_A Y_A$ and $X_B Y_B$ (Figure 12, 1 and 3). The use of the slope angle method requires that slope distance AB or the horizontal equivalent is known (Figure 12, 2).

Heighting may be carried out independently of or integrally with planimetric surveying. It is necessary that the planimetric surveying should precede or be concurrent with the heighting using the angular method, and angular heighting as incorporated into tacheometers and theodolites is the norm for detail points. The horizontal collimation method is most precise, being used to establish national controls, but is laborious. It is evident that to include the Z_t of any point on a map requires that XY for the point are previously known.

Textbooks on ground surveying provide full information on these methods and their instrumental implementation, but are generally lacking in comparative assessment of techniques and in examples of field applications.

However, as J. C. Pugh has pointed out, any surveying can usually be done accurately by several different methods, and the equipment available and the surveyor's experience will affect the choice (Pugh, 1975, p. xix and introductory table).

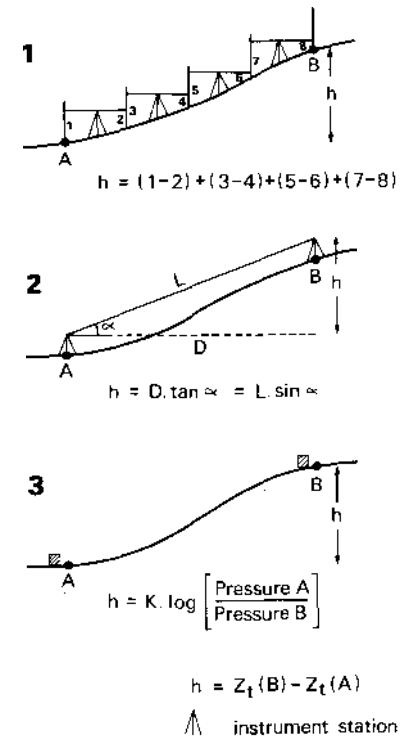


Figure 12. Alternative methods for surveying height differences

Given the flexibility of surveying frameworks, particularly those involving traversing, there is little difficulty in arranging a framework to fit any form or density of spatial selection of detail. For a systematic point sampling network, the sample points are surveyed as detail in regular array. Instrument stations should be sited so that detail is within a radius of 50-200 m, depending on line of sight conditions, telescope power (normally x25 to x32) or prism reflecting power, and the precision required.

In setting out systematic sampling schemes, the first instrument station should correspond with the point of origin of the string or network, so that points can be sighted and set out readily at a constant bearing, which bearing may be at a random angle from the reference object (Figure 13, 1). To set out all the necessary bearings at right angles in a square network, a line of instrument stations is required. In Figure 13, 2, instrument

station A is at an arbitrary location adjacent to the research area and AI represents the line of instrument stations at random bearing α to a reference object. Instrument stations can be on corners of adjacent squares (rook's move) or on the diagonal of squares (bishop's move) as in Figure 13, 2. The instrument at A sets out along Aa_1 and Aa_2 ; instrument at B sets out along Bb_1 and Bb_2 ; and so on, the diagonal distances AB, BC, being $2^{0.5}$ times the side length of the required grid square. This method may require fewer stations to achieve areal coverage, depending on the shape of the area.

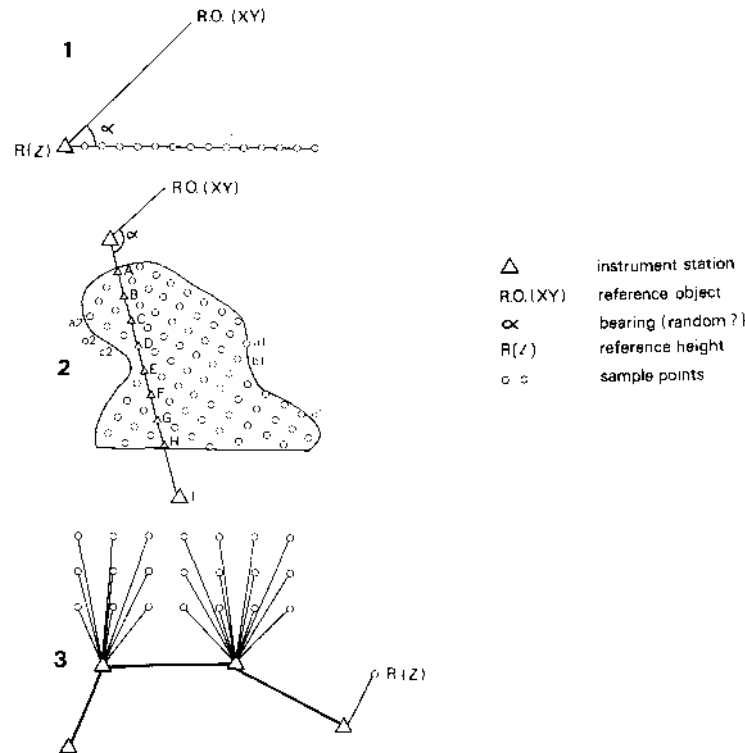


Figure 13. Setting out sampling schemes

As opposed to setting out points, when measuring points in systematic array and in most measurement of detail, it is convenient to keep the instrument stations to one side so that the instrument does not get in the way of the target staff, pole or prism. In Figure 13, 3, a small network is being heighted by radiation from levelling traverse stations so positioned that all of the network points can be seen without interference in one direction.

All comments in this section have so far related to surveying observations point by point. For completeness, mention is now made of those

surveying methods which dispense with single point mode in favour of continuous line mode of measurement. These are all graphical methods, and are not suited to setting out networks directly. The methods are:

- graphical sketching to complete a plan, within a close network of instrumentally fixed points. Best described by Allan, Hollway and Maynes (1968), based on Ordnance Survey practices;
- plane table surveying for field sketching and direct contouring;
- analogue photogrammetric plotting, which registers points, lines and areas directly in their natural mode. From the stereoscopic model, it is easy to judge ground conditions, measure areas and set out a network as a photogrammetric plot. Following this, ground surveying is required to transfer the network from plot to field.

In the final section of this text, emphasis will be placed on the relative precision of particular classes of equipment. The surveyor has genuine choice about equipment and about the geometrical types of framework and the methods just considered. But over the scientific principles that control the use of equipment and methods, there is no scope for choice or deviation at all. In surveying by whatever equipment or method, the same principles apply as in all scientific measurement:

- use calibrated equipment, and check and adjust before starting work;
- make independent checks on all readings, linear or angular, whenever possible;
- be rigorously honest to yourself about the justification of all measurements taken.

A common pitfall in field surveying is general lack of confidence, leading to casual working or abandonment. The correct guard is to plan from the whole to the part, follow scientific principles, and work in orderly fashion. Whyte (1976) gives further details of these aspects of the conduct of a survey.

VIII CHOICE OF EQUIPMENT

The wide and potentially confusing range of surveying equipment can be classified for the purposes of the non-specialist surveyor into five categories of approved items:

- for measuring distance directly: legs, rangefinder, linen and steel tapes, vertical and horizontal staff tacheometers, EDM equipment;
- for measuring horizontal angle directly: compass, level (H circle), tacheometer, theodolite, some EDM equipment;
- for measuring slope or height difference: clinometer, level, tacheometer, theodolite, EDM equipment;
- general field accessories: ranging poles, targets, pegs, cross-staff, pocket tape, wax crayons;
- calculating and drafting aids: booking forms, scientific hand calculator, scales and ruler, large protractor.

For each category above, the surveying items are listed in approximate order of increasing accuracy, which corresponds to their suitability for schemes of increasing size or complexity. Where alternatives are available

the equipment used should be chosen to perform the function fastest to the necessary precision.

In the usual surveying schemes where both linear and angular measurements are involved such as traversing and radiation, distances and angles must be of consistent quality. In Table 7, items by rows represent reasonable pairings of equipment, while items reading downwards are of increasing accuracy. The values quoted are typical of the equipment of that class; specifications for particular instruments vary.

Table 7. Equipment accuracy

LINEAR	best accuracy	worst accuracy	ANGULAR	direct reading to:
legs (pacing)	1:100	1:25	prismatic compass	30'
linen tape	1:500	1:100	vernier or scale-reading theodolite	1'
vertical staff tacheometer	1:2000	1:500	tacheometer	1'
steel tape	1:5000	1:500	microptic theodolite	20"
horizontal staff tacheometer	1:10000	1:2000	precision tacheometer	10"
EDM equipment	1:300000	1:10000	EDM equipment	1"

An alternative way to consider pairings of distance and angle is to assess the greatest individual distances likely to be involved. In brief, the longer the lines and the more precise their necessary measurement, the more finely must the angles be measured (Table 8).

Table 8. Distance and angle pairings

Number of significant figures in line length	Angle measured to nearest:
3	5' or 0 ⁰ .1
4	1' or 0 ⁰ .02
5	10" or 0 ⁰ .003
6	1" or 0 ⁰ .0003
7	0.1" or 0 ⁰ .00003

Source: after Whyte (1976)

For the smallest schemes, a great deal can be achieved with a surveyor's prismatic compass on a lightweight tripod and a 30 m tape and, together with some general accessories, these are recommended as 'best buys'. The Autoset level and staff are justifiably popular with geomorphologists for heighting and setting out on terrain with little vertical amplitude. For detail on more rugged terrain, there is no substitute for the self-reducing tacheometer with vertical staff, which has the multiple functions of providing horizontal distances, horizontal bearings and differences of

height directly. Next higher in succession, the tacheometer for use with horizontal staff has the same functions for taking in detail and in addition is precise enough for establishing traverse stations, and local control.

The self-reducing tacheometers have for several decades provided an excellent way of mapping detail and contours at large scales over limited areas. Horizontal staff tacheometry is a standard method used by the Ordnance Survey to provide control and distant detail for large scale plans in resurvey areas. If a tacheometer is not available, results of similar accuracy for XYZ co-ordinates can be achieved with a scale-reading theodolite and a programmable hand calculator (Sneddon, 1982).

The price paid for the efficiency of tacheometers is in slightly heavier equipment and in the quality of bookings, which may necessitate a team of three persons rather than two. EDM equipment is also bulky, as well as being difficult to acquire cheaply, but it may be justified for its speed and convenience in measuring distances over the range 100-1000 m. For short range radiation, the higher precision of EDM equipment is not likely to be fully utilized, giving it no advantage over a self-reducing optical tacheometer for the part-time surveyor. High technology in surveying is not at its most efficient when used only occasionally.

Current commercial practice in ground surveying is moving towards the use of EDM equipment in tacheometric mode because of its field efficiency, as described for example by Johnston (1979) and Morrison (1981). The Wild T2000 theodolite with O14 distance meter and GRE3 data terminal, and the Kern E2 electronic theodolite with DM503 distance meter are both recent introductions that, by virtue of their attachments for recording and addressing data and the available interfacing to computer processing and drawing facilities, can justifiably be described as being parts of completely integrated systems. Numerous commercial systems that can start with the field survey are currently on offer. These include the Wild GEOMAP interactive graphics and surveying system, the Kern SICORD system, the Kongsberg SYSSCAN system, and the Survey and General Instruments DIGICAL survey system for data acquisition and analysis.

Returning to consider the simple traditional surveying equipment, no special recommendation can be made in respect of the plane table, although it must be stated that its devotees find virtue enough in its simplicity, cheapness and the immediate graphical product. Its disadvantages include: limited range of effective mapping scales; difficulty of precise drawing under field conditions; cumbrousness with many accessories; and lack of data if scale requires to be changed. Steeply inclined lines of sight are impossible to observe except by the use of a plane table tacheometric alidade; this makes sighting less tiring, and gives auto-reduction of horizontal distances and differences of height.

The plane table with tacheometric alidade may be described as useful for reconnaissance mapping at topographical scales in conditions of reliable weather, and for learning the principles of traversing, intersection, radiation and resection. Numerous other tacheometric attachments, for other instruments, described by Hodges and Greenwood (1971), have generally met with limited success. The Ewing stadi-altimeter attachment to a theodolite (accuracy 1:1000 to 1:150) is of this type and is not recommended.

Sources of surveying equipment include colleges and universities, especially teaching departments of civil engineering, geography or geology; civil engineering companies; land or aerial survey companies, and statutory agencies. Equipment may be purchased new or second-hand, and some commercial agents operate a complete hire service. It is well worth considering the hire of surveying equipment for a week or month, as the rates over these periods for, say, an automatic level or a self-reducing tachometer, are very attractive in terms of the data that can be collected. All such sources are listed in a directory of land surveying activities, edited by Dowman (1982).

The final choice for the field surveyor, and perhaps the next step for the non-specialist who has read to this point, is in selection of a text-book. Whyte (1976) provides elementary guidance that is neither too formal nor too rigorous. More elementary still, but directed to the field scientist are Myers and Shelton (1980), Hogg (1980), and Ritchie *et al.* (1977). More advanced general textbooks include Bannister and Raymond (1984), and Allan, Hollwey and Maynes (1968), the latter (although more dated and not in metric units) dealing comprehensively with detail survey. Finally, other published sources to the whole field of land surveying are listed by Dowman (1982).

APPENDIX A

Table 9. Conversion factors for length

1 metre	39.370 inches
	3.280 feet
1 km	1000 metres
-	0.621 miles
1 inch	2.540 centimetres
1 foot	30.480 centimetres
•	0.3048 metres
1 yard	0.914 metres
1 mile	1.609 kilometres

Table 10. Conversion factors for area

1 chain	100 links = 22 yards
1 acre	10 sq. chains
	70 yards square (nearly)
1 sq mile	640 acres
	259.0 hectares
	2.590 kilometres
1 acre	0.405 hectares
1 sq. km	0.386 sq. miles
1 hectare	10 000 sq. metres = 100 metres square
	2.471 acres
100 hectares =	1 sq. kilometre

BIBLIOGRAPHY

- Ackermann, F. (1978). Experimental investigation into the accuracy of contouring from DTM. *Photogrammetric Engineering and Remote Sensing*, 44, pp. 1537-1548.
- Allan, A.L., Hollwey, J.R. and Maynes, J.H.B. (1968). *Practical field surveying and computations*. (London: Heinemann).
- Bannister, A. and Raymond, S. (1984). *Surveying*, 5th ed. (London: Pitman).
- Berrange J.P. (1975). Advice for small expeditions to forested regions. *Geographical Journal*, 141, pp. 421-429.
- Brassington, R. (ed.) (1982). *The Geologists' Directory*, 2nd ed. (London: The Institution of Geologists).
- Brown, E.H. (1952). The river Ystwyth, Cardiganshire: a geomorphological analysis. *Proceedings of the Geological Association*, 63, pp. 244-269.
- Burgess, T.M., Webster, R. and McBratney, A.B. (1981). Optimal interpolation and isarithmic mapping of soil properties. IV. Sampling strategy. *Journal of Soil Science*, 32, pp. 643-659.
- Chorley, R.J. (1966). The application of statistical methods to geomorphology, in: *Essays in geomorphology*, ed. G.H. Dury, (London: Heinemann) pp. 275-387.
- Cochran, W.G. (1977). *Sampling techniques*, 3rd ed. (New York: Wiley).
- Collins, S.H. and Moon, G.C. (1981). Algorithms for dense digital terrain models. *Photogrammetric Engineering and Remote Sensing*, 47, pp. 71-76.
- Dackombe, R.V. and Gardiner, V. (1983). *Geomorphological field manual*. (London: George Allen & Unwin).
- Dixon, C. and Leach, B. (1978). Sampling methods for geographical research. *Concepts and techniques in modern Geography No. 17*. (Norwich: Geo Books).
- Doornkamp, J.C. and King, C.A.M. (1971). *Numerical analysis in geomorphology*. (London: Edward Arnold).
- Dowman, I.J. (ed.) (1982) *Directory of research and development activities in the United Kingdom in land survey and related fields*, 3rd ed. (London: RICS).
- Doyle, F.J. (1978). Digital terrain models: an overview. *Photogrammetric Engineering and Remote Sensing*, 44, pp. 1481-1485.
- Dumbleton, M.J. and West, G. (1971). *Preliminary sources of information for site investigations in Britain*. Road Research Laboratory Report LR 403, Crowthorne.
- Evans, I.S. (1972). General geomorphometry, derivatives of altitude, and descriptive statistics, in: *Spatial analysis in geomorphology* ed. R.J. Chorley (London: Methuen), pp. 17-90.

- Fuller, R.M. and Boorman, L.A. (1977). The spread and development of *Rhododendron Ponticum* L. on dunes at Winterton, Norfolk, in comparison with invasion by *Hippophae Rhamnoides* L. at Saltfleetby, Lincolnshire. *Biological Conservation*, 12, pp. 83-94.
- Gerrard, A.J.W. and Robinson, D.A. (1971). Variability in slope measurements: a discussion of the effects of different recording intervals and micro-relief in slope studies. *Transactions of the Institute of British Geographers*, 54, pp. 45-54.
- Gray, J.M. (1974). The main rock platform of the Firth of Lorn, western Scotland. *Transactions of the Institute of British Geographers*, 61, pp. 81-99.
- Gray, J.M. (1975). *Measurement and analysis of Scottish raised shoreline altitudes*. Occasional Papers No. 2, Dept. of Geography, Queen Mary College, University of London.
- Gregory, S. (1968). *Statistical methods and the geographer*, 2nd ed. (London: Longmans).
- Haggett, P. (1965). *Locational analysis in human geography*. (London: Edward Arnold).
- Harley, J.B. (1968). Error and revision in early Ordnance Survey maps. *Cartographic Journal*, 5, pp. 115-124.
- Harley, J.B. (1975). *Ordnance Survey maps: a descriptive manual*. (Southampton: Ordnance Survey).
- Harrison, C.M. (1971). Recent approaches to the description and analysis of vegetation. *Transactions of the Institute of British Geographers*, 52, pp. 113-127.
- Hodges, D.J. and Greenwood J.B. (1971). *Optical distance measurement*. (London: Butterworths).
- Hogg, A.H.A. (1980). *Surveying for archaeologists and other field-workers*. (London: Croom Helm).
- Hooke, J. and Perry, R.A. (1976). The planimetric accuracy of tithe maps. *Cartographic Journal*, 13, pp. 177-183.
- Ingham, A.E. (1974). *Hydrography for the surveyor and engineer*. (London: Crosby Lockwood Staples).
- Jeffers, J.N.R. (1983). Analysis of spatial data, in: *Ecological mapping from ground, air and space*, ed. R.M. Fuller, ITE Symposium No. 10, (Cambridge: ITE), pp. 16-21.
- Johnston, W.F. (1979). Some considerations for a fully automated survey system - from field to finished plan. *Survey Review*, 25, (192), pp. 51-55.
- Kershaw, K.A. (1973). *Quantitative and dynamic plant ecology*, 2nd ed. (London: Edward Arnold).
- Kirby, R.P. (1969). Morphometric analysis of glaciofluvial terraces in the Esk basin, Midlothian. *Transactions of the Institute of British Geographers*, 48, pp. 1-18.
- Kirby, R.P. (1971). The bathymetrical resurvey of Loch Leven, Kinross. *Geographical Journal*, 137, pp. 372-378.
- Kirby, R.P. (1980). The role of remote sensing in land assessment, in: *Land assessment in Scotland*, ed. M.F. Thomas and J.T. Coppock, (Aberdeen: University Press), pp. 9-23.
- Krumbein, W.C. (1960). The "geological population" as a framework for analysing numerical data in geology. *Liverpool and Manchester Geological Journal*, 2, pp. 341-368.
- Lakhani, K.H. (1983). Strategy for successful survey, in: *Ecological mapping from ground, air and space*, ed. R.M. Fuller, ITE Symposium No. 10, (Cambridge: ITE), pp. 8-15.
- Lindsay, J.M. (1981). Mapping techniques in recording trees and analysing woodland, in: *The study and use of British woodlands. Proceedings IBG Rural Geography Study Group, Nottingham. 1981*, ed. C. Watkins and P.T. Wheeler, pp. 76-81.
- Mackay, J.R. (1953). The alternative choice in isopleth interpolation. *The Professional Geographer*, 5(4), pp. 2-4.
- Miller, C.L. and Laflamme, R.A. (1958). The digital terrain model - theory and application. *Photogrammetric Engineering*, 24, pp. 433-442.
- Morrison, A. (1981). From field to map - untouched by human hands. *Civil Engineering - ASCE*, 51(2), pp. 48-50.
- Mumford, I. (1981). Ordnance Survey Map Users Conference 5 November 1980. *Cartographic Journal*, 18, pp. 56-57.
- Myers, W.L. and Shelton, R.L. (1980). *Survey methods for ecosystem management*. (New York: Wiley).
- Ordnance Survey (1976). *Ordnance Survey surveyors' instructions, Module 3 (Specifications)*.
- Ovenden, J.C. (1981). Hydrological data on large scale maps of the Ordnance Survey. *Cartographic Journal*, 18, pp. 19-24.
- Petersen, R.G. and Calvin, L.D. (1965). Sampling, in: *Methods of Soil Analysis, Part 1, Physical and Mineralogical properties including statistics of measurement and sampling*, ed. C.A. Black, (Madison, Wisconsin: American Society of Agronomy), pp. 54-72.
- Petrie, G. (1977). Orienteering maps. *Cartographic Journal*, 14, pp. 14-22.
- Phillips, R.J. and Noyes, L. (1982). An investigation of visual clutter in the topographic base of a geological- map. *cartographic Journal*, 19, pp. 122-131.
- Pitty, A.F. (1967). Some problems in selecting a ground-surface length for slope-angle measurements. *Revue Geomorphologie dynamique*, 17, pp. 66-71.
- Pugh, J.C. (1975). *Surveying for field scientists*. (London: Methuen)
- Rhind, D.W. (1975). A skeletal overview of spatial interpolation techniques *Computer Applications*, 2(3-4), pp. 293-309.

- Rhind, D.W. and Adams, T.A. (1980). Recent developments in survey and mapping, in: *Geography Yesterday and Tomorrow*, ed. E.H. Brown, (Oxford: University Press).
- Ritchie, W. et al. (1977) *Mapping for field scientists*. (Newton Abbott: David and Charles).
- Robinson, A.H., Sale, R.D. and Morrison, J.L. (1978) *Elements of cartography*, 4th ed. (New York: Wiley).
- Sheail, J. (1983). The availability and use of archival sources of information, in: *Ecological mapping from ground, air and space*, ed. R.M. Fuller, ITE Symposium No. 10, (Cambridge: ITE), pp. 22-27.
- Sneddon, J. (1982). A note on the status of self-reducing tacheometers. *Survey Review*, 26(205), pp. 321-326.
- Stevens, S.S. (1946). On the theory of scales of measurement. *Science*, 103, pp. 677-680.
- Tempfli, K. et al. (1980). Large scale surveys: aerial versus ground survey methods. *ITC Journal*, 1980-84, pp. 696-717.
- Thomas, R.W. (1979). An introduction to quadrat analysis, 2nd ed. *Concepts and techniques in modern Geography No. 12*. (Norwich: Geo Books).
- Thompson, M.M. (1979). *Maps for America. Cartographic products of the U.S. Geological Survey and others*. (Washington: U.S. Dept. of Interior, Geol. Survey).
- Unwin, D. (1981). *Introductory spatial analysis*. (London: Methuen).
- Whyte, W.S. (1976). *Basic metric surveying*, 2nd ed. (London: Newnes-Butterworths).
- Yates, F. (1960). *Sampling methods for censuses and surveys*, 3rd ed. (London: Charles Griffin).
- Yoeli, P. (1983). Digital terrain models and their cartographic and cartometric utilisation. *Cartographic Journal*, 20, pp. 17-22.
- Young, A. (1974). *Slope profile survey*. Technical Bulletin No. 11, British Geomorphological Research Group. (Norwich: Geo Books).