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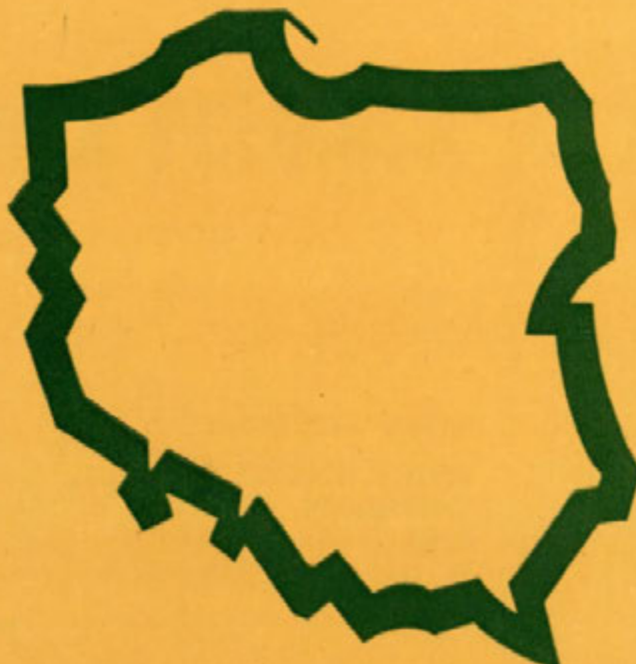

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APPROACHES TO THE STUDY OF MAN-ENVIRONMENT INTERACTIONS

PROCEEDINGS
OF THE ANGLO-POLISH GEOGRAPHICAL SEMINAR
TORUŃ, SEPTEMBER 1974

Edited by
ERIC H. BROWN AND RAJMUND GALON

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REPORT OF THE MEETING

The Fifth Anglo-Polish Seminar organized by the Institute of Geography of the Polish Academy of Sciences in co-operation with the Institute of British Geographers, was held from 24th to 29th September 1974. The sessions held in Toruń at the Institute of Geography of the University of Nicolaus Copernicus, were followed by scientific excursions. In this meeting ten geographers from Great Britain and fifteen from Poland took part. The chairman of the British group was Professor Eric H. Brown (London) and the Polish group was led by Professor R. Galon (Toruń). Organizers of the Seminar were Professor R. Galon, Professor J. Szupryczyński and Dr. E. Wiśniewski. During the Seminar 23 papers were delivered in 6 sessions, each chaired by a different participant.

The Seminar was inaugurated by Professor K. Dziewoński (Warsaw) who also read a letter to the participants of the Seminar from Professor S. Leszczycki, Director of the Institute of Geography, Polish Academy of Sciences, Warsaw, who unfortunately was unable to be in Toruń for the opening. Introductory speeches were then made by Professor R. Galon in the name of the organizers, and by Professor E. H. Brown as Chairman of the British group.

Papers were followed by questions and discussions. A general discussion on the subjects touched upon during the seminar, and the possibility of further bilateral work by Anglo-Polish Seminars led on 26th September to the adoption of the following resolution:

The participats in the Fifth Anglo-Polish Seminar 1974 wish to make the following recommendations to the Institute of Geography of the Polish Academy of Sciences and the Institute of British Geographers:

1. That the papers presented to the Seminar be published in a special issue of "Geographia Polonica",

2. The Anglo-Polish geographical Seminars, having been and continuing to be of great mutual benefit to the geographers of both countries, should be followed by a further seminar held in the United Kingdom,

3. That it be held either before or after the INQUA Congress to be held in Birmingham in August 1977,

4. That the theme of the next seminar should again cover the field of physical geography, with special reference to the relation of contemporary environments to those of Quaternary times.

On 27th September the participants led by Professor J. Szupryczyński took part in an excursion to the reservoir of Włocławek to familiarise themselves with studies concerning slope processes induced in the Dobrzyń region on the valley flanks by ponding of the Vistula river. The studies are being carried out by the Department of Physiography of the Institute of Geography of the Polish Academy of Sciences in Toruń. The principal guide was Mr. M. Banach.

On the next day (28th September) there began an excursion to the coast *via* the Pomeranian Lake District. On the way Professor W. Niewiarowski (Toruń) demonstrated in Chełmno an evaluation of the physiography of the area of this town for planning purposes. In Grudziądz, on one of the moraine hills in the bottom of the Grudziądz basin, Dr. Z. Churska (University of Toruń) demonstrated the studies made by an investigation team dealing with a physiographical evaluation of the valley basin with special reference to the prevention of soil erosion. Dr. E. Drozdowski (Institute of Geography of the Polish Academy of Sciences) outlined the geological structure of the Grudziądz basin and the possibilities of utilizing the local mineral resources.

The next stop was at the Limnological Station of Gdańsk University in Borucino in the Kashubian Lake District, where Dr. J. Szukalski (Institute of Geography of Gdańsk University) reported on his geomorphological and hydrographical work for the Kashubian National Park and outlined the work of the Hydrographical Station in Borucino.

On the last day (29th September), in the course of the trip along the Gdańsk coast, Dr. J. Szukalski characterized the physiography of the area of Gdańsk agglomeration from the point of view of urban planning in this area. On the cliff coast at Redłowo Mrs. I. Semrau gave some information about coastal processes, and during a short visit in the Maritime Institute in Gdańsk she also spoke about problems of coast protection.

Lastly in the Regional Planning Office in Gdańsk Mr. J. Szczepkowski presented problems of town planning in the urban-industrial agglomeration along Gdańsk Bay.

INTRODUCTORY REMARKS OF PROFESSORS R. GALON AND E. H. BROWN

The Fifth Anglo-Polish Geographical Seminar is devoted to one of the most vital contemporary problems in geography, namely the interrelations between the geographical environment and man's life and work. Never before has so much been written and spoken about the geographical environment as an element indispensable to life. But, at the same time, never before has the geographical environment been more endangered and damaged as it is at present.

This dramatic discrepancy between theory and practice constitutes one of the essential difficulties in the development of the world community. It is why the importance of science as a social force should continue to grow, so that those holding responsibility for communities, societies and countries can better understand the menace of decline faced by humanity.

We should admit that this new function of science, and particularly that of geography, has found us unprepared — at least to some degree — especially in regard to research methods and an appropriate approach to the object of research. At the same time, other sciences are tending to penetrate the field of geographical research and introduce new terms and definitions. Physical Geography is undergoing a stage of reorganization as regards its goals and methods and it has — too readily, if not unnecessarily — given up some fields of its activity in favour of a new central research objective, namely the study of the influence of human activity upon the geographical environment.

The problem of interaction between man and environment is reflected in the papers prepared for this Seminar, which have been grouped in the following manner: first, papers will be presented dealing with the geographical environment itself, its structure and dynamics and methods of mapping it. The papers that follow deal with the impact of man's activities upon the geographical environment and, conversely, the impact of the geographical environment upon man's activity. The last group of papers concern the evaluation of the geographical environment as made for definite purposes — economic, settlement development, recreational etc. In this group of papers, planning problems are discussed, as well as the role of geography with respect to the tasks involved in the protection of nature.

Closing these opening remarks — let me express the conviction that the fifth meeting of British and Polish geographers will contribute to a better understanding of the role and tasks of geography in solving the actual social and economic problems of the World.

R. Galon

Professor E. H. Brown, on behalf of the Institute of British Geographers, thanked the Polish Academy of Sciences for the arrangements which had been made for the 5th Anglo-Polish Seminar; in particular he asked Professor Dziewoński to convey to Professor Leszczycki, Director of the Institute of Geography, the thanks of the British party for the welcome they had received. That welcome had already been expressed in a most efficient manner by the Organising Committee, Professors Galon and Szupryczyński and Dr. Wiśniewski.

It was particularly good of the Polish delegation to give their papers and be prepared to conduct discussions in the English language. In the British team there was a mixture of older and younger participants — those of us who had been to Poland before were pleased to see old friends and expressed the hope that the younger members of the British team would establish through this seminar as pleasant and fruitful contacts with Poland and Polish geographers as the older members had in the past. The composition of the British team and the papers they were to present reflected a feeling in British physical geography that there is a need for physical geographers to pay particular attention to the impact of human activity upon their chosen field of investigation, and thereby to tie studies in physical geography more closely to those of human geography than had always been evident in the immediate past.

E. H. Brown

GEOGRAPHIA POLONICA 34, 1976

LAND EVALUATION AND THE NUMERICAL DELIMITATION OF NATURAL REGIONS

V. Gardiner

The mapping and measurement of land ... is traditionally part of the geographer's stock-in-trade.

TAYLOR 1974

The characteristics of the land surface, and its suitability for supporting mankind, vary in an infinite number of ways, and the need for some kind of subdivision and categorisation to enable problems of land use planning and economic assessment to be approached systematically is evident enough not to require emphasis.

CHRISTIAN 1958

Evaluation of land must necessarily be based upon an initial classification of terrain, and one of the major contributions of the physical geographer to the solution of applied problems is the differentiation of the earth's surface. The adoption of numerical methods and systems concepts has adequately equipped geography to deal with many complex demands of modern society. Furthermore, the availability of funds for applied research and developments in remote sensing and data processing have encouraged the development of land evaluation as an increasingly important geographical research field. Despite the traditional concern of the geographer with the environment many problems remain to be solved, thus presenting the geographer with both challenge and opportunity. Land has been defined (Thomas 1969; Christian 1958) by "The term land refers to all those physical and biological characteristics of the land surface which affect the possibility of land use.", and by the techniques of physical geography all of the basic resources implicit in the term "land" may be studied.

LAND FORM AND SYNTHETIC CLASSIFICATIONS OF LAND

Land classification demonstrates a profusion of methods, purposes and scales, but approaches to land classification may be divided into two groups. The first, "synthetic" classification, is techniques which have classified land from examination of only one of its physical attributes. These attributes have been classified and evaluated in a multiplicity of ways, but when methods are examined two common themes emerge. The first is that studies usually include consideration of land form. For example, the close association between soil type or geology, and topography, is often used in the mapping or aerial photograph interpretation of the former factors, and concepts such as the soil catena (Milne 1935), the terrain unit (Cruickshank 1971) and the topo-soil association (Wall 1964) emphasize the close conceptual links between soil and topography. Relationships between vegetation and topography have also been stressed (Haffner 1968), and links between topography and climate exist at all scales (Geiger 1965; Pedgley 1967). The study of land form is therefore not only useful in itself but is also of use for classification of other land attributes. The second theme recurring in synthetic land classification is that methods are becoming increasingly quantitative. Techniques such as the use of principal components analysis (Morgan 1971) and discriminant analysis (Casetti 1964) in climatic classification, taxonomic methods in soil classification (Rayner 1966), and association analysis in vegetation classification (Williams and Lambert 1960), have encouraged acceptance of the results of geographical research by workers in other fields, but have also given rise to significant problems for physical geographers not fully acquainted with statistical, mathematical and computer techniques. Techniques of land form analysis would however appear to be of greatest value if similarly based on numerical procedures.

LAND FORM AND INTEGRATED CLASSIFICATIONS OF LAND

Synthetic classification is appropriate to evaluation for specific purposes, but general-purpose or reconnaissance surveys require that the total environment be considered. Such compilation of information (Christian and Stewart 1968) can be achieved by synthesis of single element classifications, but this is seldom entirely satisfactory as classifications of individual elements are developed for a wide range of scales and purposes. Each element has a different spatial distribution and some such as climate also have a temporal distribution. More often classifications are derived by integrated survey (Christian and Stewart 1968). No firm distinction exists between these two approaches, as "integrated" surveys often stress the elements most relevant to their particular purpose. For example, Kiefer (1967) synthesised maps of topographic and soil characteristics to evaluate suitability of land for building, Galon (1962) gave a hydrographical regionalisation based largely upon the hydrological characteristics of geology, soil and topography; evaluations of scenery are also often based on land form and land use (Fines 1968; Linton 1968).

A second approach to integrated survey is limited combined studies, in which related independent surveys are performed and the results combined to yield units as a basis for further study. This is particularly appropriate to single purpose surveys but represents only a step towards fully integrated survey.

The use of soil mapping units is a third approach to integrated survey. Soil is so important in the environment that considerable overlap and confusion exists between integrated land survey and soil surveys, concepts such as the "natural land type" (Wright 1958) and "soil landscape" (Woodyer and Van Dijk 1961) being closely related to concepts of overall land character.

The fourth, and most widely used, method of integrated survey is that of landscape units. This was developed independently for different areas and purposes, and rests upon the principle that units of land, however defined, recur in the landscape in recognisable patterns. Following early physiographic work (Fenneman 1928) concepts were crystallised by Bourne (1931) who defined the "site", Wooldridge (1932) who defined morphological aspects of land, and Unstead (1933) and Linton (1951) who recognised the hierarchical nature of physical regions.

The ready availability of aerial photography after the Second World War stimulated applications of this approach, the most important being the initiation of surveys in Australasia by the Commonwealth Scientific and Industrial Research Organisation (C.S.I.R.O.). These surveys are based upon the concept of land units and land systems, the land system being (Christian and Stewart 1947, 1953): "an area or group of areas, throughout which there is a recurring pattern of topography, soils and vegetation." Surveys based on those of the C.S.I.R.O. have since been made in many other areas (Christian and Stewart 1968; Brink *et al.* 1966).

Independently Beckett and Webster (1965; Beckett *et al.* 1972) developed a terrain classification method for the Military Engineering Experimental Establishment (M.E.X.E.) in Britain, and in South Africa the National Institute for Road Research (N.I.R.R.) used physiographic subdivisions for engineering purposes. The common ground and terminological relationships of these three groups and later workers have been reviewed by Brink *et al.* (1966) and Thomas (1969). The landscape unit approach has also been developed in Russia (Kalesnik 1962; Solntsev 1962; Vinegradov 1962; Prokayev 1962; Isachenko 1965) and in East European countries as physico-geographical regionalization (Pecsi and Samogyi 1969; Bartkowski 1968; Czarnecki 1969). It is clear that there is a uniformity of approach to integrated terrain classification despite the different areas, disciplines, times and scales involved. All methods are concerned with the simplest land unit having low variability of the basic elements in the physical environment, and combine these together according to their pattern of occurrence to form a hierarchy of increasingly more complex regions, usually derived from aerial photograph interpretation. The same underlying themes are apparent in integrated survey as in synthetic classification, namely the importance of land form and the increasing use of numerical methods. For example, specific-purpose assessments of land suitability for residential development (Różycka 1962), for airfield construction (Barrie 1968), of scenery (Linton 1968), and of trafficability (Van Lopik and Kolb 1959) all stress the importance of aspects of land form, and the dependence of the fully integrated survey upon a land form basis is evidenced by Christian (1958), Mabbutt (1969), and Young (1969). The form of the land must necessarily control, and be controlled by, all other factors in the physical environment. In this sense land form affords an "integrated index" of the total physical environment. Similar claims can be made for soil (Ganssen 1970) and vegetation (Gaussen 1958), but for many purposes land form is the most useful index. A practical advantage of the classification of land form over that of other attributes of the physical environment is that land form information is more readily available from field work, published maps or remote sensing imagery than is other information.

The desirability of numerical description of land form has been emphasised (Mabbutt 1969; Thomas 1969), and suggestions have been made for numerical land system description (Thomas 1969; King 1972; Scott and Austin 1971). The basis of these attempts is work such as that of Woodruff (1963, 1964) who described geomorphic provinces by drainage basin attributes, and Woodyer and Brookfield (1966) who reasoned that as the land system has a distinctive assemblage of those environmental factors controlling steam runoff and geometry it should be characterised by a distinctive basin morphometry. Another important contribution was that of Speight (1969), who found agreement between maps of "land systems" produced from measured land form parameters and existing maps of land systems produced by conventional means.

It is apparent however that although the multivariate nature of land as a resource has stimulated a variety of approaches, and although the importance of land form and numerical techniques have been acknowledged, the description of land form by objective numerical methods has not been a highly favoured avenue of research. Methods developed by geomorphologists for numerical land form description are accordingly examined below, and the use of some of these methods for practical purposes is illustrated.

NUMERICAL LAND FORM DESCRIPTION

Numerical land form description and analysis, or morphometry, was attempted during the nineteenth century (Chorley *et al.* 1964) but the effect of these early works on modern morphometry was minimal. Geomorphologists traditionally classified landforms in terms of their genesis (Howard and Spock 1940), and methods of analysis of form have usually been used only as a key to the elucidation of geomorphological evolution. There has however grown a disenchantment with genetic classifications of land form for land evaluation (Kesseli 1946, 1954; Mabbutt 1969), because the internally complex regions produced are usually large with indefinably defined boundaries. The roots of modern morphometry lie in a number of early studies of slope and area-altitude relationships (Finsterwalder 1890; Penck 1894), and their subsequent development for regional slope mapping (Smith 1935; Raisz and Henry 1937; Hanson-Lowe 1935). Efforts to remove by quantification the subjective elements from more traditional methods of land form description have also given considerable impetus. At the largest scale attempts have been made to recognise small uniform slope facets, by computer, from digital records of contours, and to delimit these facets by breaks or inflexions of slope, as in conventional morphological mapping (Linton 1951; Waters 1958; Savigear 1965). At the smallest scale there have been attempts to describe in numerical terms land form regions on a physiographic scale (Hammond 1964), akin to that of early workers such as Powell (1895).

Lustig (1969) has divided quantitative analyses of topography into parametric landform description describing individual landforms, and parametric terrain analysis giving overall descriptions of areas without regard to individual landforms. This is to some extent an artificial division because measurements of individual landforms can be compounded to give terrain descriptions, but it does afford a useful conceptual framework.

A variety of landforms ranging from micro-relief features (Stone and Dugundji 1966) to whole beaches (Yasso 1965) have been numerically described, including of course the drainage basin. In 1945 Horton provided a remarkable catalyst to the development of modern morphometry, by linking form and process within one quantitative framework, using the drainage basin as the fundamental unit. Hortonian methods have since been widely applied (for example, Ore and White 1958; Strahler 1964; Williams 1971; Ghose *et al.* 1969), concepts of stream ordering have been further developed, and many indices of basin character have been suggested (Gregory and Walling 1973; Gardiner 1975). Although the river basin has been most widely adopted as the fundamental unit of land form (Chorley 1969) other units have also been employed. Slopes, especially slope angles, have received much attention (Young 1969) and numerous attempts have been made to describe the plan shape of landforms. These have frequently involved the fitting of mathematical functions to the plan outline or even, threedimensional outline of the feature, as illustrated for drumlins (Reed *et al.* 1962), river basins (Anderson 1973), lakes (Koshinsky 1970) and pediments and alluvial fans (Troeh 1965). River plan geometry has been much investigated (Gregory and Walling 1973). Descriptions of individual landforms have also been based upon simpler descriptive indices, and examples of simple descriptors of landforms are given by Crozier (1973) for landslips, Gardiner (1975) for drainage basins and Barnett and Finke (1971) for drumlins.

Terrain analysis has evolved from attempts to measure slope over large areas and from methods used for individual landforms. Simple measures have been suggested (Williams 1967; Nir 1957) for land form mapping (Swan 1967; 1970), whilst other methods have been based upon statistical procedures applied to a sample from the infinite population of altitudes in an area (Evans 1972). Global mathematical surfaces have been fitted to terrain (Bassett and Chorley 1971; Rayner 1972), and mathematical parameters descriptive of aspects of land form, such as roughness, have been derived (Turner and Miles 1968; Hobson 1972; Horton *et al.* 1962).

Despite this abundance of methods for numerical land form portrayal their application to practical land form description is, as noted above, limited, apart from a few specific applications. The regional scale has been particularly neglected, excepting for a few studies employing drainage basins (for example Eyles, 1970). Even fewer attempts have been made to employ morphometric techniques in a classificatory rather than descriptive mode, to arrive at objective subdivisions of the earth's surface on the basis of land form. Lewis (1969) produced a regionalisation of Indiana based on drainage basin morphometry, Mather (1972) attempted a regionalisation of grid square data using a simple cluster analysis method, and Greysukh (1966) presented an intuitively attractive but computationally formidable searchbased computer method for the spatial partitioning of an altitude matrix by recognition of simple landforms. Despite these examples and recent developments (Speight 1974) the fullest exploitation of numerical land form analysis for practical purposes has yet to be performed, and some of the possibilities inherent in the use of simple morphometric techniques are now illustrated.

ILLUSTRATION OF THE USE OF THE DRAINAGE BASIN FOR LAND EVALUATION

The use of the drainage basin as a basic unit for land evaluation may be demonstrated by an example in which morphometric measurements are used to derive a map depicting scenic value (Gardiner 1974). Scenic evaluation is of considerable importance for delimitation of Areas of Outstanding Natural Beauty, routing of motorways and electricity pylons, and planning for tourism. Although many factors must be taken into account in the solution of these problems, land form is important in the initial assessment of scenery as a resource, and the geomorphologist can contribute to such studies by presenting accurate descriptions or inventories of land form. Elements of land form which it is suggested are of relevance to subjective impressions of scenery include relative relief, slope and the presence or absence of water. The techniques of fluvial geomorphology can be used to estimate these land form elements. For example drainage density affords an estimate of the amount of water present, basin relief gives an estimate of average relief, and relief ratio of average slope. Combinations of these can also be meaningful, for example the product of drainage density and relief ratio is an estimate of ruggedness (Table 1). Distance from the sea may also be included, as a surrogate for the presence or absence of sea views.

TABLE 1. Morphometric estimates of scenic elements

Element of scenery	Morphometric measurement
Presence of water	Drainage density (Horton 1945)
Average slope	Relief ratio (Schumm 1956)
Ruggedness	Ruggedness No. (Strahler 1958)
Average relief	Basin relief (Strahler 1952)

For an area of North-west Devon measurements of drainage density, relief ratio and basin relief were made for 379 Strahler second order basins from Ordnance Survey 1 : 10,560 Regular Edition maps. These data were then mapped by means of an automated contouring procedure which generated values for regular figure-fields (Fig. 1). The individual elements were then combined by the point scores in Table 2 for each 1 km cell of the map to produce the final

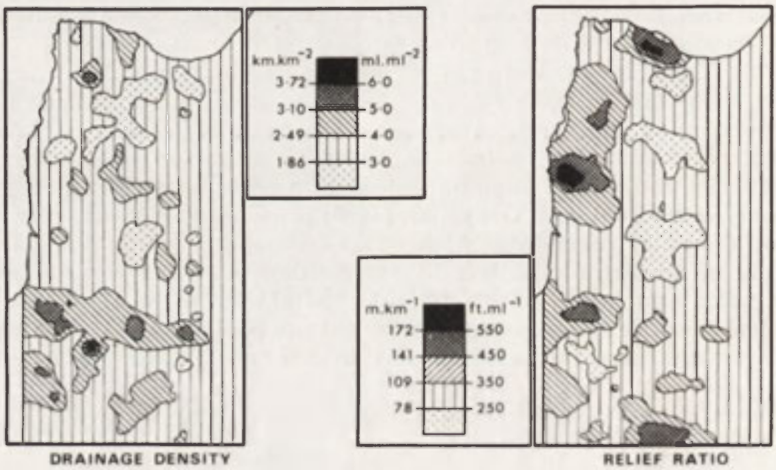

Fig. 1

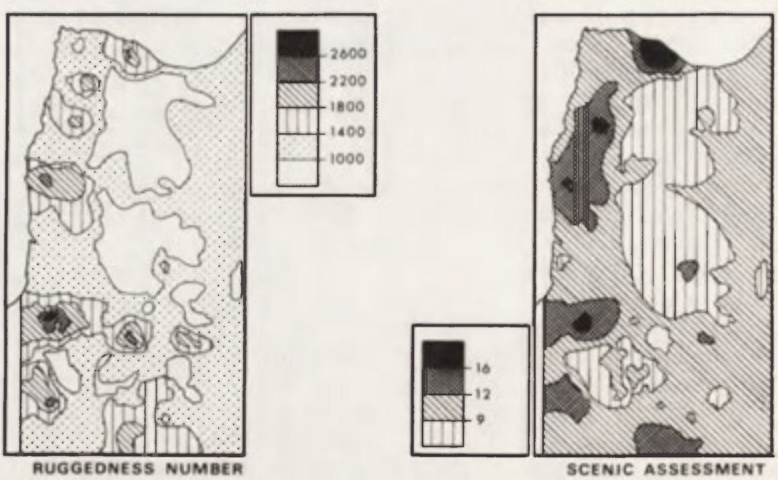

Fig. 1 and 2

assessment of scenery mapped in Fig. 2. This point scale is of course only illustrative; other variables could be included, other weightings could be explored, or numerical optimisation could be employed to achieve an optimal weighting in accord with *a priori* expectations of relative scenic value. The scale used is, furthermore, relevant only to this area.

TABLE 2. Point scores used in the preparation of Figure 2

Measurement	Point score
Ruggedness number	1 per 200
Relative relief	1 per 50 ft.

By such means numerical descriptions of land form may be used as a basis on which considerations of accessibility and land use can be superimposed to give a solution to practical problems. The use of the drainage basin in this way is, however, attended by operational and conceptual problems. The first is choice of the method of the subdivision of the stream net in that at least eight ordering methods have been suggested (Gardiner 1975), none of which are wholly satisfactory for the selection of basins for land classification. Secondly, delimitation of basin watersheds is not only time consuming but is also subject to error, and the execution of accurate area and length determination is both time consuming and attended by operational difficulties (Gardiner 1975). The third problem is that although the use of the electronic computer is necessary (for example, maps in Fig. 1 required a minimum of 60,000 arithmetic operations per map), the basin itself does not afford a machine-orientated data structure in the same way as do for example grid squares, whose National Grid or map co-ordinates can be easily related to machine storage locations. The structural properties of networks can be exploited to give a machine identification procedure (Smart 1970; Loudon 1970), but such methods often have prohibitive machine time requirements.

A fourth, and perhaps the most significant problem associated with the use of basin based morphometry for land evaluation is that concerning the non space-filling nature of drainage basins. In this study the total population of Strahler second order basins from the chosen map source occupy less than 60% of the total land surface. The 379 basins are furthermore unevenly distributed. The applicability of the scenic evaluations to the whole area may therefore be questioned. An associated problem concerns the validity of cartographic techniques for these data (Gardiner 1975). Basins may be individuals in choropleth maps, or the centre of the basin may be used as a point to which values are related for spatial interpolation as above. The former is a theoretically more valid representation of the data, but the latter is cartographically pleasing and yields results more suitable for further analysis. The example above could have been performed for individual basins, but as scenery is normally considered a quality of continuous areas and not isolated portions, this would have been self-defeating.

THE USE OF THE GRID SQUARE IN LAND FORM ANALYSIS

Despite the theoretical elegance of the river basin as a system whose morphological characteristics can be used for land evaluation, its use is attended by considerable operational difficulties, and alternatives should be considered. A network of regular polygons provides an attractive alternative operational unit for which data may be gathered, and the most convenient regular lattice is that composed of squares. Both geomorphologists (Hammond 1954; Kaitanen 1969) and hydrologists (Soloman *et al.* 1968; Foyster 1972) have used grid-based methods for the measurement of land form parameters. Several studies of land form suggest that, for land classification land form can be operationally regarded as consisting of a small number of independent attributes. For the drainage basin the attributes measured by the most commonly used morphometric indices are the size, mean slope and shape of the basin, and the density, frequency and topological characteristics of the stream net. Of these it has been suggested (Gardiner 1972; King 1972) that the most important for land classification are relief/slope characteristics and stream density. Many methods have been suggested for the measurement of the average slope of areas bounded by grid squares (Zakrewska 1967), and by using the edges and diagonals of the grid square as sampling transects a ready measurement of the average slope of the cell may be achieved (Wentworth 1930; Hamilton 1930). Drainage density of grid cells may be measured by simple measurement of the length of stream within the cell, or it can be estimated from more readily obtainable topological characteristics of the drainage net, such as number of river junctions or stream links (Gardiner 1971). Practical advantages of the grid square are that the tedium and uncertainty of watershed insertion and stream ordering are avoided, and if drainage density is estimated only counting operations are necessary. Measurement problems are obviated, operator error is reduced and time is saved. The total area is considered by the grid method, not only that part lying within basins of a given order, and the grid square affords a machine--orientated data structure. Grid square data are also eminently suitable for choropleth mapping and for the application of numerical generalisation.

AN ILLUSTRATION OF THE USE GRID SQUARE IN LAND EVALUATION

Although maps of single elements of land form have uses (for example, Gregory and Gardiner 1975), most practical applications of such techniques demand a multivariate consideration of land form. A grid square multivariate study is illustrated by an examination of part of Southwest Uganda (Gardiner 1972), for which data were gathered from Directorate of Overseas Survey 1 : 50,000 maps prepared by photogrammetric means, with some ground control. Four land systems representing a wide range of environmental conditions were chosen from the Atlas of Uganda (Ollier *et al.* 1969). Within each of these a 10 km×10 km representative area was chosen (Fig. 3A, B, C, D) and each was divided into twenty-five squares, of four square kilometers, for which the following characteristics were determined:

(1) Number of river junctions.
(2) Number of intersections between contours and grid square diagonals.
(3) Number of independent river networks.
(4) Number of stream links.
(5) Number of stream sources.
(6) Number of intersections between the river network and the grid square edges.
(7) Number of closed summit contours.

The aims of this exercise were to portray the land form of the regions by readily available information, to examine the redundancy amongst the variables used, to relate the results to *a priori* considerations of the basic attributes of land form, and finally to examine the delimitation of land form regions by such measures.

A factor analysis was performed to examine the intercorrelation present amongst the variables, and three components were rotated (Table 3). Factor 1 is heavily loaded by the number of river junctions, number of stream links

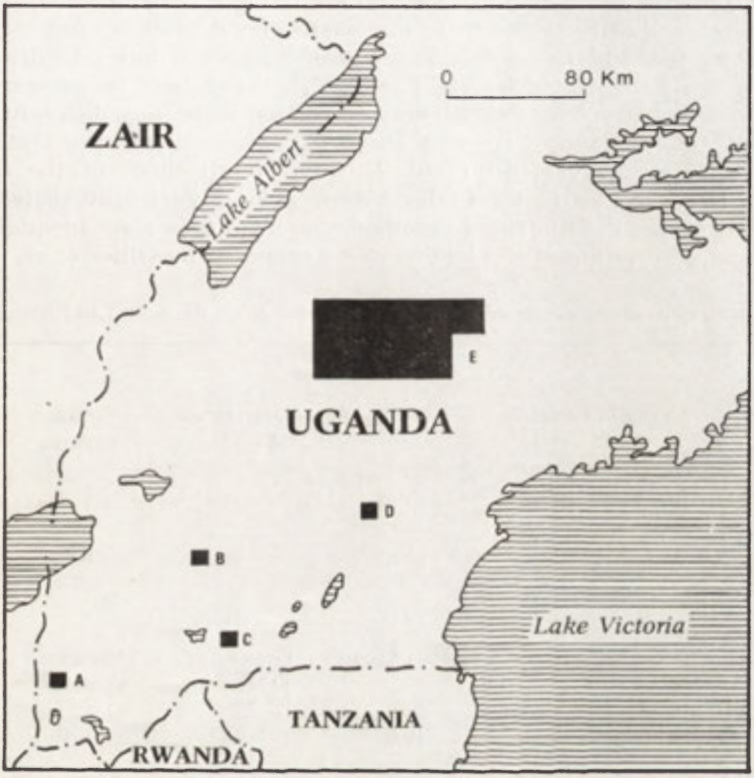

Fig. 3

TABLE 3. Factor Analysis of grid-square derived variables

Principal Components Analysis					
Eigenroots	3.200	1.700	0.912	0.493	0.468
% of total variance	45.719	24.285	13.033	7.050	6.686

Varimax Rotation Analysis	Loadings		
	Factor 1	Factor 2	Factor 3
% of total variance	31.544	27.714	23.770
Number of junctions	0.877	0.244	−0.037
Number of contour intersections	0.130	−0.179	−0.842
Number of individual networks	0.068	−0.909	−0.303
Number of stream links	0.911	−0.248	−0.151
Number of stream sources	0.058	−0.926	−0.094
Number of intersections with grid square edges	0.744	−0.275	−0.363
Number of closed summit contours	0.175	−0.166	−0.836

and number of stream/grid square edge intersections, and may be interpreted as indicating the amount of stream length present in the grid square. Factor 2 has high negative loadings of number of river networks and number of sources; this may be tentatively identified as an inverse index of the size of basic land unit or landform scale. Factor 3 has high negative loadings by the relief variables, and is a relief/slope factor. Thus three basic attributes of land form, bearing close similarity to the more important of the drainage basin attributes can be identified and measured. The use of these attributes to discriminate between areas is illustrated by Fig. 6, which shows plots of factor scores of the three factors in pairs. The four land systems tend to occupy different parts of these plots, and this subjective impression is confirmed for each factor separately by analysis of variance (Table 4) in which all three of the indices of land form produced by factor analysis show greater variability between than within land systems. This simple method therefore offers an adequate means of numerical description of the land systems proposed by Ollier *et al.*

TABLE 4. Analysis of variance for Factor Scores from the four Land Systems

MEANS		Source of variance	Sums of Squares	Degrees of Freedom	Variance Estimate	
FACTOR 1						
Kabale	0.48	Between samples	17.33	3	5.78	F = 6.7
Koki	0.37					
Nsika	−0.22	Within samples	82.62	96	0.86	
Lwengo	−0.53					
FACTOR 2						
Kabale	0.57	Between samples	19.06	3	6.35	F = 7.53
Koki	−0.26					
Nsika	0.32	Within samples	80.94	96	0.84	
Lwengo	0.51					
FACTOR 3						
Kabale	−0.25	Between samples	71.74	3	23.91	F = 81.37
Koki	0.52					
Nsika	−0.26	Within samples	28.22	96	0.29	
Lwengo	0.99					

Factor scores of the total sample have a mean of zero.

A great deal of redundancy is however apparent amongst the variables, seven variables reducing to only three factors with a loss of only 17 per cent of the total variance, and a considerable saving of time spent in data capture can be realised by the use of one diagnostic variable to represent each factor. The number of river junctions, number of stream sources and number of contour intersections each load highly onto separate factors and are readily derived with only low intercorrelation (Table 5). Pair-wise plots of these variables against one another may be prepared, and an alternative illustration of their use to demonstrate differences between land systems is given by Fig. 5; the suggestion that the land systems are distinct is again supported by an analysis of variance (Table 6).

TABLE 5. Correlations between morphometric variables

	No. of junctions	No. of sources	No. of contour intersections
No. of junctions	1.00	0.12	−0.07
No. of sources		1.00	0.29
No. of contour intersections			1.00

TABLE 6. Analysis of variance of diagnostic variables from the four Land Systems

NUMBER OF JUNCTIONS

MEANS		Source of variance	Sums of Squares	Degrees of Freedom	Variance Estimate	
Kabale	2.16	Between samples	31.71	3	10.57	F = 3.83
Koki	1.84					
Nsika	0.84	Within sample	265.04	96	2.76	
Lwengo	0.96					

NUMBER OF CONTOUR INTERSECTIONS

MEANS		Source of variance	Sums of Squares	Degrees of Freedom	Variance Estimate	
Kabale	33.16	Between samples	10 111.7	3	3 370.57	F = 117.65
Koki	20.76					
Nsika	25.72	Within sample	2 750.4	96	28.65	
Lwengo	5.68					

NUMBER OF STREAM SOURCES

MEANS		Source of variance	Sums of Squares	Degrees of Freedom	Variance Estimate	
Kabale	2.60	Between samples	65.16	3	21.72	F = 11.48
Koki	1.84					
Nsika	0.76	Within sample	181.68	96	1.89	
Lwengo	0.64					

This demonstrates that even simple indices can be effective in the description of land systems, but of greater significance in an applied sense is the derivation of land form regions, which may possibly approximate to land systems, or which may be of use in other ways. Data on the three variables used above were gathered for an area of 4400 sq km (E in Fig. 3), and are used below to derive land form regions by a numerical classification technique. This area was chosen because of its distinctive land systems without small or fragmented areas, and due to map availability. Details of the six land systems occurring in the area are given in Table 7, and their spatial distribution is shown in Fig. 4.

TABLE 7. Character of land systems in area E (after Ollier *et al.* 1969)

	ROCK	LANDSCAPE	ALTITUDE	RELIEF	SOIL AND VEGETATION
KAWANDA	Metamorphics — schists, gneisses, quartzites	Much dissected, no surface remnants, wide aggraded valleys	1100–1250 m	30–120 m	Deep clay loams, forest/ /savanna mosaic.
BUWEKULA	Grantie and gneiss	Rolling to rugged tor landscape	1300 m	120 m	Clay loams, much bare rock, heavily weathered. Alluvial soils in aggraded valleys. Moist forest savanna.
NSALA	Quartzite	Quartzite ridges, steep slopes	up to 1600 m	200 m	Stony, skeletal. Few areas of loam on lower slopes. Forest/savanna mosaic.
BUTA	Fine-grained sandstones	Flat-topped hills	1500 m	200 m	Skeletal soils. Dry savanna.
LUKAYA	Quartz-mica schist	Gentle ridges and hills, some flat-topped	1300 m (peaks to 1500 m)	30 m	Gravelly loams, mixed grass savanna.
NGOMA	Granite, gneiss, and other metamorphics	Dissected plain, wide interfluves, flat, broad valley bottoms	1150 m	less than 30 m	Clay loams or sandy clays; laterite. Dry savanna.

Simple scaling-up of existing hierarchical cluster analysis programs is unsatisfactory for data sets as large as this because of their excessive computer time requirements but the application of a contiguity restraint before grouping greatly speeds up the process (Openshaw 1971). At each grouping stage dissimilarities are only calculated for those individuals which are contiguous; this acknowledges the geographical nature of the data, in that the technique becomes one not only of grouping but of spatial grouping or regionalisation. So-called contiguity errors may however occur at the late stages of the process as illustrated below:

A	A			C	C
A	A			C	C
B	B	B	B	B	B
B	B	B	B	B	B

This represents twenty original cells which have been clustered to give three regions, A, B, and C. Dis-similarities are then re-calculated between both contiguous combinations of these three regions, and then either A or C join to B, dependent upon which is most similar to B. One of these possibilities, must occur, even if A and C are identical in all respects, as A and C cannot be allowed to join until they have a boundary common. In the earlier stages of classification contiguity errors are negligible because spatial autocorrelation ensures that small similar units are usually close to one another. To avoid this

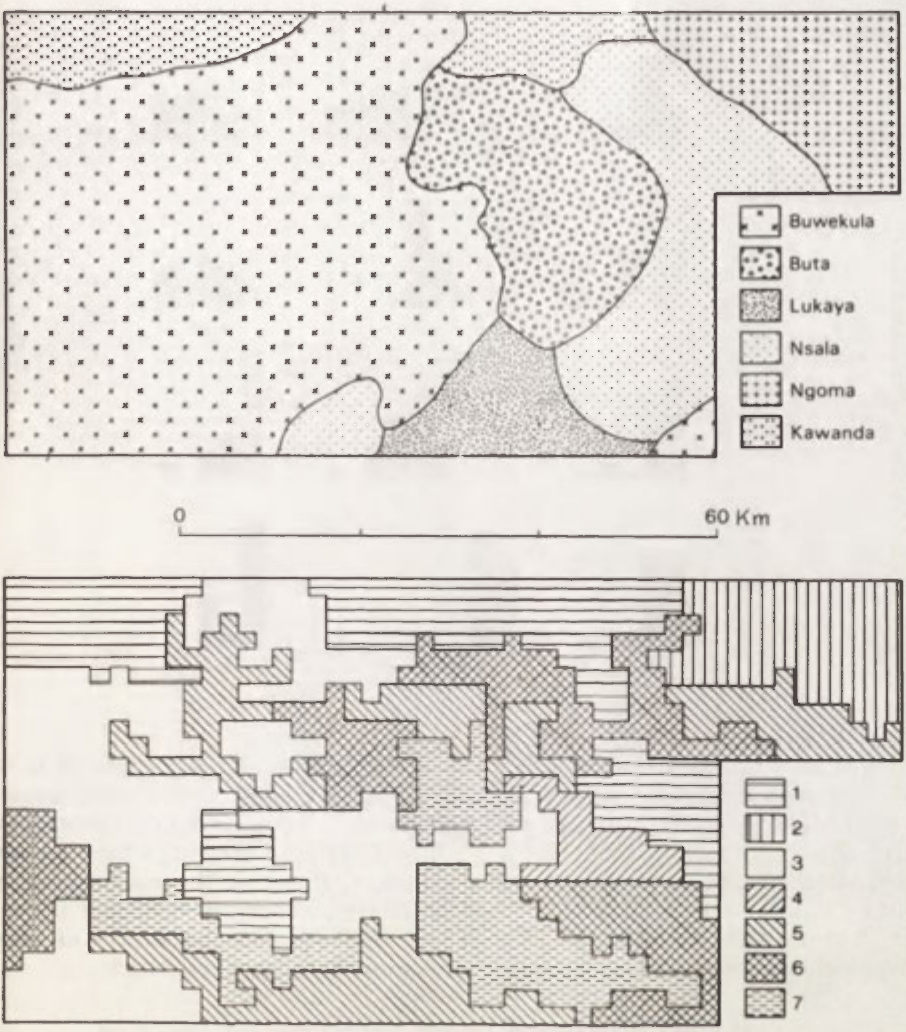

Fig. 4

problem contiguity restrained clustering is employed until contiguity errors occur. Clustering of the fairly small number of regional types identified is continued without a contiguity restraint, so that a few not necessarily non-fragmented regional classes are produced. This accords with real-world situations where two separate areas may belong to the same land system (for example Kawanda in Fig. 4). In this study the objective function used for grouping was the error sums of squares (ESS) (Ward 1963) which tends to create groups of approximately similar size. A plot of ESS against number of grouping cycles showed steps indicative of the introduction of contiguity errors when thirty groups remained; at this point the contiguity restraint was removed. The spatial distribution of the seven land form regions or land types finally arrived at is shown in Fig. 4.

Land type 1 occurs in four areas. At the northern boundary of the region two patches occupy the area of the Kawanda land system, although these

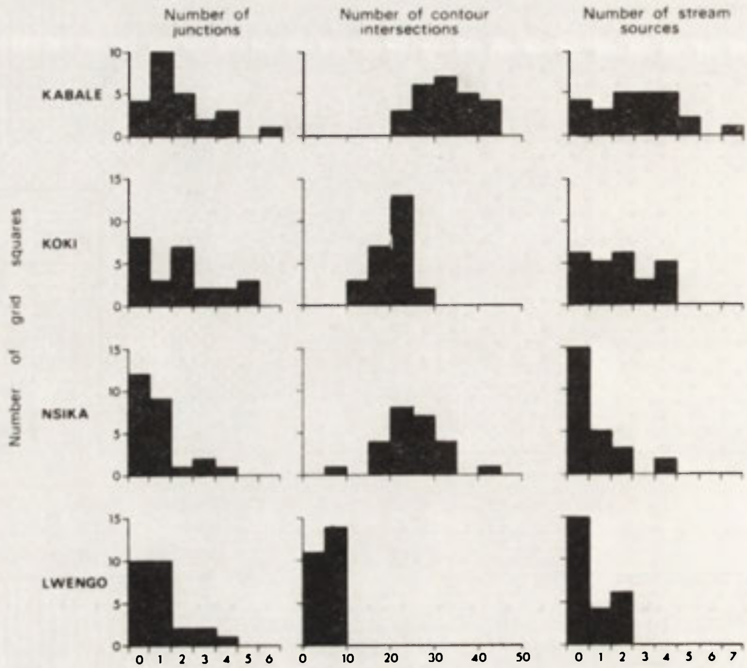

Fig. 5

patches also extend onto other land systems. Type 2 land is restricted to only one occurrence, almost entirely within the Ngoma land system. The centre of the Buta land system coincides with the only occurrence of land type 4. A very different situation is presented by the Buwekula land system, which has some part of five of the seven land types within it. However the major land type within this land system is type 3, which is almost entirely confined in occurrence to the Buwekula land system. There is therefore some degree of one-to-one correspondence between land systems and land types (Table 8).

TABLE 8. Correspondence between land systems and form types

Land system		Land types
Kawanda		1
Ngoma		2
Buwekula	predominantly	3
Buta		4

The distribution of the remaining three land types is more complex. They do not correlate directly with land systems and tend to form transition zones between the core areas of the land systems as characterised by the land types 1 to 4. This incomplete correspondence arises for a number of practical and methodological reasons. The clustering technique produces groups of approximately equal sizes small areas of systems such as the Lukaya system and the small patches of Nsala and Buwekula in the south of the area are more likely to amalgamate with surrounding areas than to remain discrete individuals. Similarly large land systems such as that of Buwekula become differentiated. Results also depend upon subjective decisions taken as to the number of groups to derive and the point at which the contiguity restraint is removed. Only a relatively small area is covered because of limitations imposed by available computing resources. If larger areas were to be processed the problem of disparity of size of land types would be reduced and the proportion of the total area being classified as transitional in nature may well also be reduced. Furthermore, of course, no exact correspondence between land form types and land systems is expected, or sought, as the land system is recognised and delimited by many environmental factors other than land form. However it is indicated that land form analysis based upon easily derived data may be used as a basis for land system description and derivation, although there remain considerable problems to be solved in the methodology and technology of the necessary computer processing of large data sets.

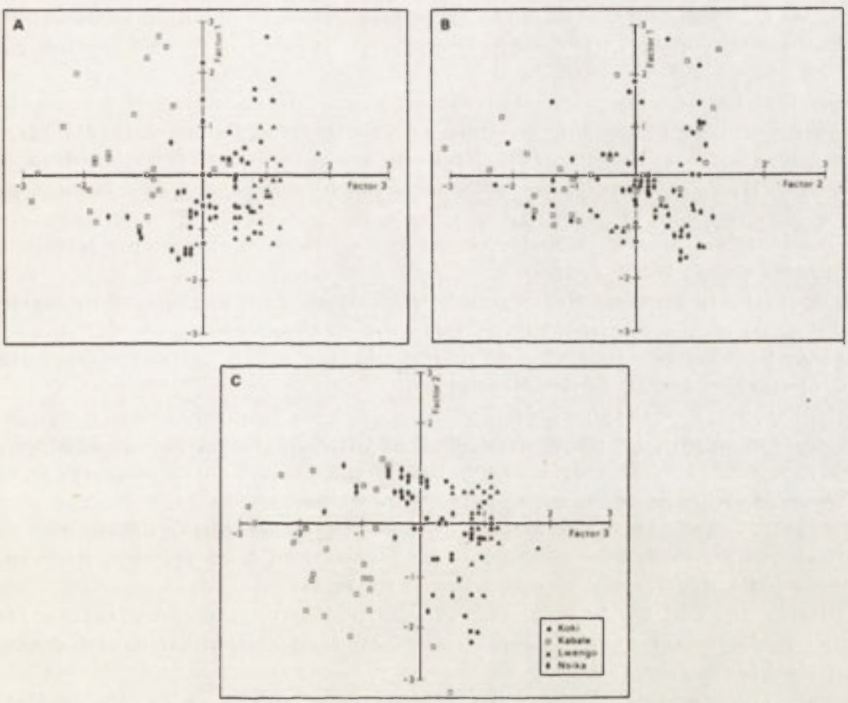

Fig. 6

This skeletal review of the application of numerical land form description to land classification has attempted to indicate only some of the many possibilities unfolding to the geomorphologist. For example, little reference has been made to hydrological land evaluation. There are many opportunities to be taken and many challenges to be faced in land evaluation. Opportunities arise from the increasing availability and applicability of automated measurement, processing and sensing techniques, and from the expansion of human activity into spatial and systematic areas for which no land classifications exist. Challenges arise from the need to apply methods to scales and purposes of which the geomorphologist may have little experience, and from the need to produce worthwhile results within a short time. If geomorphology is to meet these challenges successfully and to reap the full reward applied geomorphologists may have to reconcile themselves to some changes of philosophical viewpoint — landform description may become more important than landform genesis, land form may become more important than landforms.

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TERRAIN TYPES CONSIDERED AS WORKING INFORMATION SURFACE UNITS

TADEUSZ BARTKOWSKI

I

Complex landscape research enables us to identify terrain types. These latter units, while internally resembling each other in terms of lithology and relief (cf the definition given by F. N. Milkov 1970), consist each of a number of smaller units called urotshistshes (or urotshistshe complexes), tat are non-homogeneous. In the hierarchy of natural surface units the terrain type represents an intermediate form between urotshistche and landscape.

A number of methods are in use for identifying terrain types. For example, in the Opatówka basin of the Sandomierz loess plateau, R. Czarnecki (1969) identified by his detailed mapping of the components of the geocomplex a number of terrain types: a flat loess plateau, dry valleys and slopes of a main valley, areas above flood level in river valleys, flat bottoms of river valleys, and others. The main criterion applied in this identifying is morphogenesis, but the application of this criterion, though sometimes objective, is usually subjective and differs among authors. This is particularly the case in areas of glacial accumulation where terms like kames dead ice moraines, end moraines, frontal moraines, outwash terraces and river terraces can be misleading and should be avoided in identifying terrain types.

II

In the Poznań Geographical Centre, terrains are classified on the basis of morphology (or, more precisely, of "morphometry") and of land use. Morphometry is the decisive criterion, and it is used to delimit terrain forms (T. Bartkowski 1971). Separate classes were identified as follows: flat, undulating, hummocky, hilly with long or short slopes, and each was assigned its morphometric value (Fig. 1). These units, demarcated from topographic maps compiled in 1 : 25 000 scale, were in turn subdivided depending upon land use: arable land, forest, meadow, open water (lake), urban areas, etc. This subdivision was carried out by means of morphometric and land use profiles (Fig. 2), spaced at approximately 1 km intervals.

The terrain type designation made by R. Czarnecki (1969) is based on morphogenetic subdivisions, while the Poznań method uses objective information derived from topographic maps and is therefore less controversial. Admittedly morphometric surface units are somewhat artificial; nevertheless, they are natural units reflecting natural surface processes of accumulation and degradation.

By comparison, the land use criterion is more artificial, because it depends on the pattern of land ownership and plot division. However, this is only a

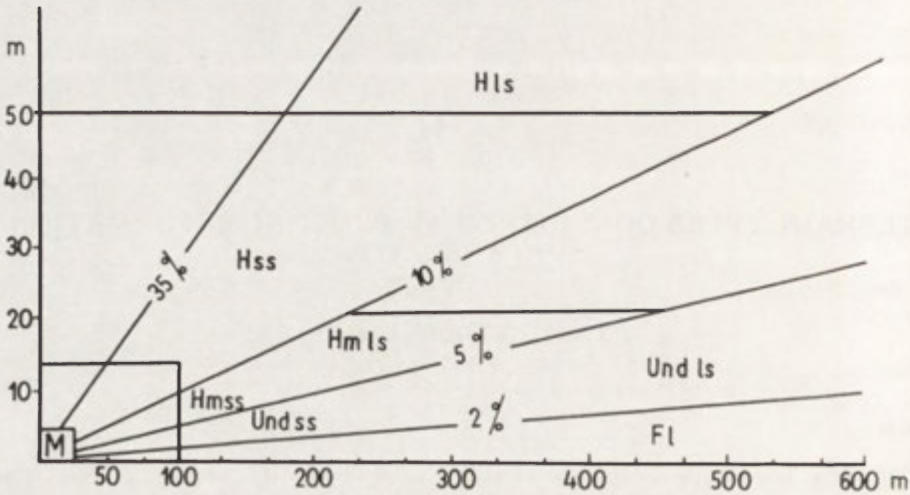

Fig. 1. Diagramme of morphometric criterion for delimiting relief types: vertical — relative height; horizontal — length of base of hypsometric profile; slope gradient — in%; Abbreviations: Fl — flat, Undss — undulating with short slopes; Undls — undulating with long slopes; Hmss — hummocky with short slopes; Hmls — hummocky with long slopes; Hss — hilly with short slopes; Hls — hilly with long slopes; rectangle — area of individual form types; M — inner limit for delimiting landforms on large-scale maps.

secondary criterion and merely assists in subdividing natural surfaces. The non-morphometric elements of a natural complex have natural limits, mostly conformable to morphometric limits; hence the units defined by morphometric terms may be used as basis for assigning geographical information. For example, the areal limit between a flat and a hummocky surface may also be, at least superficially, the limit between two soil types, because the soil limit reflects in turn elements like limits of subsurface water levels, underground water regimes, soils, microclimate, and vegetation cover. The same limit can also be observed in other elements of the natural complex, such as topoclimate and certain land use features resulting from the effect of morphometry upon agricultural techniques. Hence it may be claimed, that morphometrically defined surfaces are an appropriate basis for an unequivocal information about the remaining elements of the natural complex. The land use criterion, although subject to changeable features, can be very easily recognized from detailed maps or more rapidly from aerial photographs. Land use represents the human factor in the natural complex.

One should add that the morphometric criterion can be used for discerning, among basic surface units of balancing, the first underground water table level. Terrains that are flat or hummocky, with numerous undrained depressions, constitute what are called autochthonous surfaces (due to obstructed runoff — see "illuvial" landscapes of A. I. Perelman 1966), while terrains that are inclined (with long slopes), as well as undulant, hilly, mountainous terrains constitute allochthonous surfaces (for this term see T. Bartkowski 1960). Between these two extreme types of water regime balance surfaces lie a variable number of transitory type surfaces. In the first type of surfaces the "input-output balance" (in an application of Leontieff's model — see T. Bartkowski 1974b) as applied to surfaces of primary production, can be in a certain equilibrium, while in the second extreme type this balance can assume a state of disequilibrium, i.e. it can be positive or negative, depending on the relations

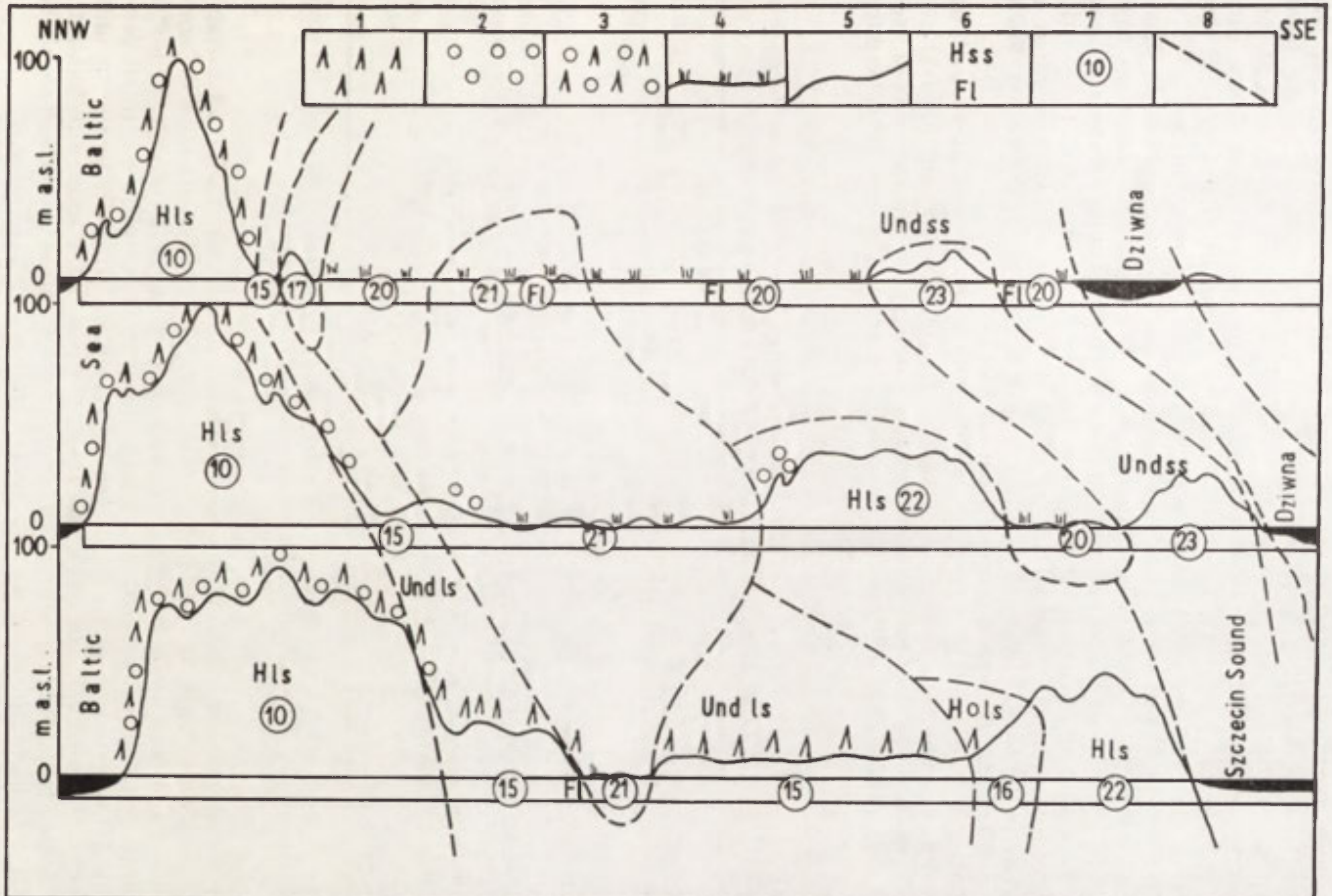

Fig. 2. Method for delimiting terrain types applying two criteria.

A — land use criterion: features of land use: 1 — coniferous forest; 2 — deciduous forest; 3 — mixed (coniferous-deciduous) forest; 4 — permanent meadow. B — morphometric criterion: 5 — hypsometric profile, 6 — morphometric relief type designations. C — Delimitation: 7 — number of surface units, 8 — limit between surface units.

between lateral groundwater inflow or water "influence", the "affluence" in the upper part of the valley bottom, and runoff in the lower part of the valley bottom. Equally significant are these balance surfaces in the local topoclimatic balance of air masses, i.e. stagnation of cold air masses in depressions and flow of air masses on more strongly inclined slopes. These surface units are also of greatest importance in the migration balance of pollution and represent the immediate share of nature in the migration balance.

The second criterion, the land use criterion, portrays the immediate share of man's activities in the input-output balance. It indicates the functions that are imposed by man's land use upon the balance surface units. Obviously these functions change when man changes his land use. A change most frequently observed occurs, when arable land is changed into building sites or when a meadow is inundated by water storage or when a terrain is deforested. Such changes bear directly upon the input-output balance.

Amalgamation of the two criteria enables one to discuss categories such as a flat morainic plateau used agriculturally (a flat terrain with agricultural use over more than 90% of its surface), or a flat morainic plateau with mixed use: agriculture and forestry where, for instance, corn growing covers 35%, verdure production 25%, and forestry 40%.

TABLE 1. Characterization of surface units shown on profiles in Fig. 2 (based on the division of the Wolin Island made by M. Stolzmann-Pietkiewicz, 1970)

Number of unit	Morphometry			Land use		
	predominant	proportion		predominant	proportion	
		large	small		large	small
10	Hls	—	Hss	For	—	—
15	Undls	—	Fl	For	—	Agr
16	Hmls	—	—	Agr	—	—
17	Hss	—	—	Agr	—	—
20	Fl	—	Undls	Agr	Mead	—
21	Fl	Undls	—	Agr	Mead	—
22	Hls	—	Fl	Agr	—	For
23	Undss	—	Fl	Agr	—	—

Abbreviations: Fl—flat, Und—undulatory, Hm—hummocky, H—hilly, ls—long slopes, ss—short slopes, For—forest, Agr—agriculture, Mead—meadows.

A precise record of the two criteria applied in the delimitation of surface units is given in Table I and is illustrated in Fig. 3. The classification of morphometry and land use is based on the proportion of each type of unit: 50–100% is considered dominant, 25–50% — a large proportion, 15–25% — a small proportion. For instance, in unit "10" Hss occupy 85%, Hls 15%, while in unit "21" Fl occupy 65%, Undls 30%, and Hmss 5% (the latter omitted in Table I). In this way both dominance and subdominance of features within surface units can be determined in the most objective — *ceteris paribus* — manner.

The complex and comprehensive terrain types singled out by R. Czarnecki's method may also serve well as information on surface units, although here some bias might bear upon the morphogenetic criterion. However, the practical usefulness of this method is handicapped by its being more time consuming.

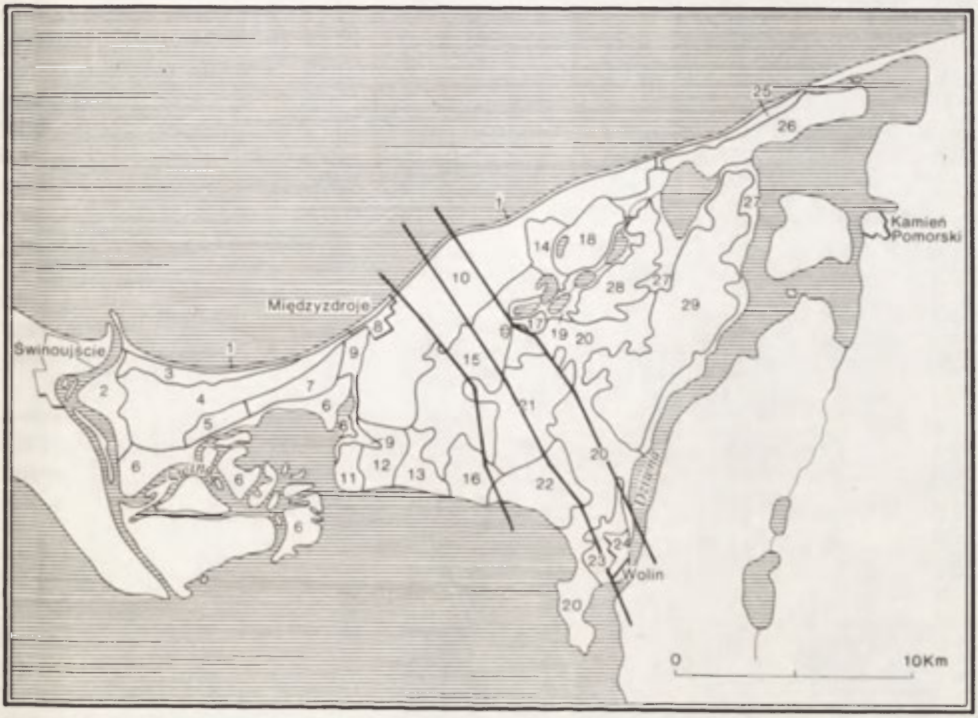

Fig. 3. Division of Wolin Island into "type of terrain" units (after M. Stolzmann--Pietkiewicz 1970). Note lines of profiles shown in Fig. 2.

For example, delimiting 150–200 units over an area of 1000 sq km by Czarnecki's method takes 2–3 scientific workers doing field work for 2 to 3 summer seasons, whereas by the morphometric method the same results can be obtained by one worker spending only about two weeks in the field and two weeks in the laboratory. Worth mentioning is also, that the use of aerial photographing as was used in Soviet landscape surveys (A. A. Vidina 1962; B. V. Vinogradov 1959) significantly reduces the time required. This shows that the morphometric method has advantages: it is more rapid, consumes less materials, and is applicable for large areas provided large-scale topographic maps are on hand. Because in our case the criteria for delimiting surface units are reduced to two, and because topographic surveys are the only ones covering vast areas of Europe and of other continents while other surveys, like geological or pedological surveys, do not exist yet for most of these areas, the surface units as discerned by the morphometric method must be looked upon as "practically the most useful units". They should be treated as temporary tools for spatial planning until the time, when all land area of the World shall be covered by surveys and portrayed on topographical maps and maps of land use; some day this may be accomplished by the use of "sputnik" — made surveys of the whole Earth.

III

This chapter deals with the kind of "geographic information" that can be ascribed to available information about surface units. Two different methods yet resembling each other, are in use at the Poznań Geographic Centre for recording information. The first method makes use of available cartographic and statistical data like soil maps, forest maps, topoclimatic data, wells registry, etc.; it has been applied in numerous surveys of terrain units performed for particular *poviats* of Greater Poland (Fig. 4). In addition, topoclimatological and hydrogeological data were obtained from interpreting morphometric and land use criteria. The sum of all this material was coded and recorded in the

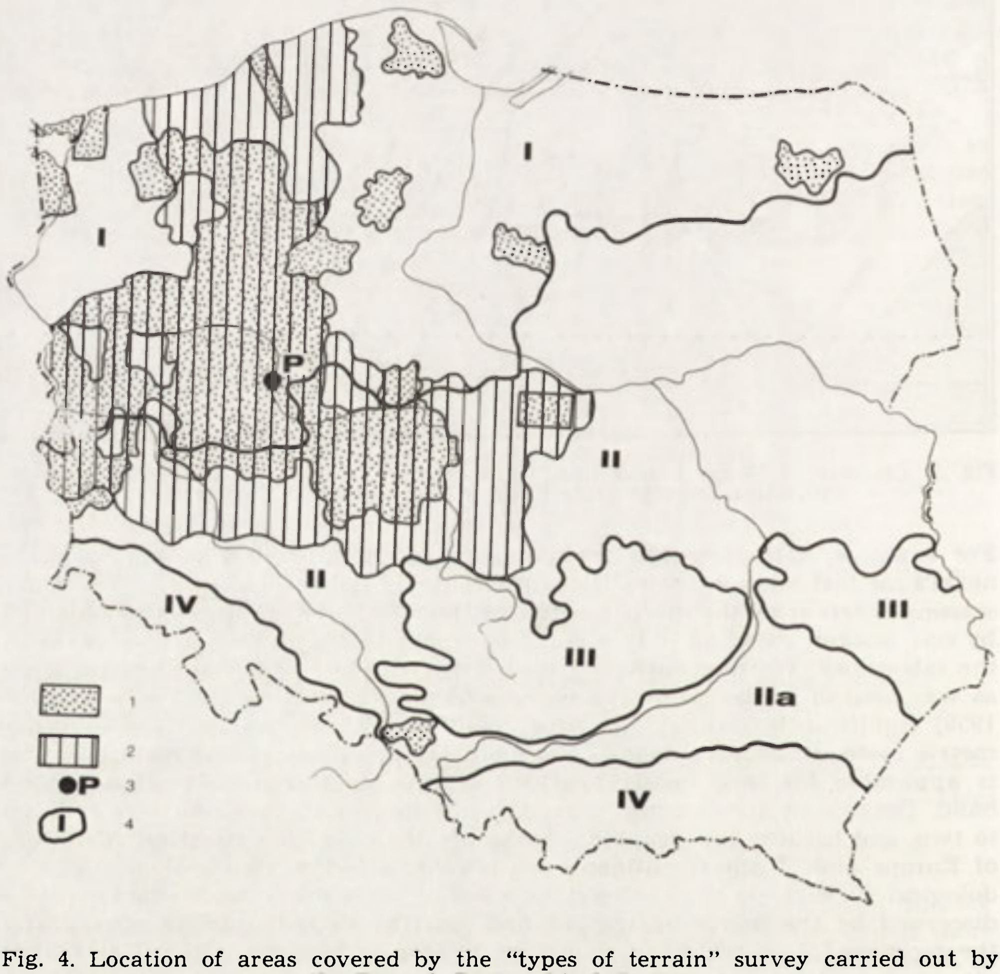

Fig. 4. Location of areas covered by the "types of terrain" survey carried out by the Poznań Geographical Centre

1 — areas covered by "types of terrain" survey, mainly of poviats.
2 — areas covered by the "complexes of types of terrain units" survey.
3 — The Poznań Geographical Centre.
4 — main landscape zones:
I — Young-glacial landscape within the limit of occurrence of glacial lakes
II — Old-glacial accumulation landscape with strong periglacial relief deformation
IIa — Variety in the Subcarpathian Depression
III — Landscape of old (pre-Quaternary) plateaus, middle-scale mountains, scarplands, etc.
IV — Landscape of young mountains: folded structures (Carpathians) or horst-like structure (Sudetes).

form of a "Table of Geographic Information". As an example, data for former Złotów *poviat* are shown in Table 2.

In the second method of recording, all information is coded on perforated recording cards. In this an abundance of data have been obtained compared with the first-mentioned method. Each card bears 74 columns recording 45 features of 9 elements: location, surface area, geological structure, land relief, soils, climate, water conditions, vegetation, land use. A detailed description of this method is given in "*Studies on the Method of Gathering Information on the Geographic Environment of Poland*", published in 1973 by the Institute of Geography of the Polish Academy of Sciences. However it must be stressed, that collecting data on this extensive scale is an extremely wearisome venture, and this is why this method has been applied in Poland only for a few mountain landscape and a few lowland zone sample sheets.

A modification of this coding, in the form of an "Information Card", has been applied in studies of an area of former Wejherowo *poviat* by M. Marsz (1975). On a surface of 943 sq km this author discerned 213 surface units covering an average of 5 sq km each. In this particular identification she made use of criteria of morphometry and land use, supplementing them by criteria of soil types and forest stands.

IV

Many practical applications of the first method are known (see T. Bartkowski 1974a). We shall discuss, as an example, a study for regional land planning as has been performed in former Złotów *poviat* (South Pomeranian Lake District). Here each surface unit was evaluated as to its suitability for the two main land uses: Activity I "on surfaces" (primary production) and II, "at points, in places and along lines" (industry, manufacturing, communications). To each one of these two variances the respective values and limitations were identified as indicated in Appendix 1. Appendix 2 gives evaluations for the three most common types of terrain: hummocky morainic plateaus, glacial channel valleys with lakes, and outwash plains with forest stands. By setting values against limitations a decisive evaluation is obtained, indicating generally the form of land use (Activities I or II) best suited for the given surface unit. In addition, readily determined can also be particular types of land use among those covered by Activity I like, for instance, extensive agrotechnics (la), intensive agrotechnics (lb), forest exploitation (Id).

The estimate described above can be expanded into what might be called a numerical "balance of factors". Values and limitations listed for both Activity I and Activity II can each be added up; the final difference between these two sums can be considerable or very slight. A large difference may indicate, for instance, that a terrain marked as being well suited for "use in places" (towns, settlements) i.e. IIa, or for "use at points" (factories, mines), i.e., lIb, is of little or no value for agricultural use. In contrast, flat peaty bottoms of valleys (especially of the pradolina type) are best suited for two types of agricultural production (Activity I): animal breeding (Ic) and forest exploitation (Id), and least for Activity II. Another example: where between Activities I and II the differences might be slight or not exist at all, a flat or slightly undulant plateau with fertile soils is preeminently suited for intensive and/or extensive agriculture (Activities la and b), but in most cases it would also be well suitable for Ic, Id, or for Ila, lIb, lIc.

This shows, that planning authorities may face difficulties in deciding about proper land use; in controversial cases they must be governed in their decision by what is of best advantage from an all-Poland point of view.

TABLE 2. Geographic information for the "terrain type" surface units delimited in the Złotów poviat (South Pomeranian Lakeland) by K. Mieszkowska, 1973. A selection of typical units is shown. The locations are given in Fig. 5A

Number of Unit	Delimiting criteria						Additional geographic information								
	Morphometry			Land use			Morphogenesis and Substratum	Water: surface or underground	Soils type/class			Topoclimate class	Vegetation		
	Pre	La	Sm	Pre	La	Sm			Pre	La	Sm		Pre	La	Sm
5	Fl	—	—	For	—	—	outwash pl.	—	A	—	B	41	P.r.	—	P. dry M.P. M.P. wet
							sand	v. deep, all.	V	—	—				
18	Undss	Fl	—	Agr	—	For	valley	—	B	—	A	11/13	peat bog	—	—
							sand	mddl. deep, all.	V	—	IVb				
24	Undls	—	—	Agr	—	—	mor. plateau	—	A	—	B	22	—	—	—
							bould. clay	shall. aut.	III	—	—				
39	Fl	—	Undss	Mead	—	Agr	gl. channel -valley	brook	A	B	T	31	—	—	peat bog
							bould. clay	shall. all.	III	—	3				
41	Fl	—	—	Agr	For	—	mor. plateau	—	B	A	—	22, 41	—	P.r.	—
							sand up. bould. clay	variable, aut.	V	—	—				

43	Hmss	—	—	Mead	Agr	—	mor. hummocks sand. grav. boulder clay	— variable, aut.	— —	A+B IV+V	T 3	23/14 14	—	—	peat bogs
76	—	—	Fl	Water	—	Mead	gl. channel lake sand + b.clay	lake v. shall, all. + aut.	— —	— —	T 3	61/31	—	—	peat bogs
26	Undls	—	—	Agr	—	For	mor. plateau sand. grav. b. clay	— variable, aut.	B III	— —	A V	23	—	—	P.dry

Abbreviations:

I) in the heading: Pre — predominant, La — large, Sm — small proportions:

II) in the code: Morphometry and Land use as in Figs. 1 and 2; Morphogenesis and Substratum: outwash pl. — outwash plain; mor. plateau — morainic plateau; gl — glacial; grav. — gravel; sand up. b. clay — sand upon boulder clay; Water — Underground: v. deep — very deep; shall. — shallow; mddl. deep. — middle deep; surface water: all. — water regime allochtonous; aut. — water regime autochtonous; all + aut. — water regime mixed; Soils: type A — podsols and pseudopodsols: B — brown soils; T — peaty soil; soil classes; III, IV, V — classes of soil fertility; Topoclimates (after M. Kluge and J. Paszyński, 1973) "Key" to determining types of topoclimate; Vegetation: P. dry — pine forest dry; P.r. — pine forest with rich low vegetation; M.P. — pine forest mixed (deciduous and coniferous); M.P. wet — mixed pine forest wet.

The estimate is liable to develop into what might be called a numerical "balance of factors". The map fragments presented in Fig. 5 are illustrations of conflicting factors of possible land use, met with in one section of a poviat. Fig. 5a shows the distribution of surface units (some of them characterized in Table 2), while Fig. 5b gives an evaluation of these units as far as they are suited for Activity I. This evaluation is arrived at by first counting the totals

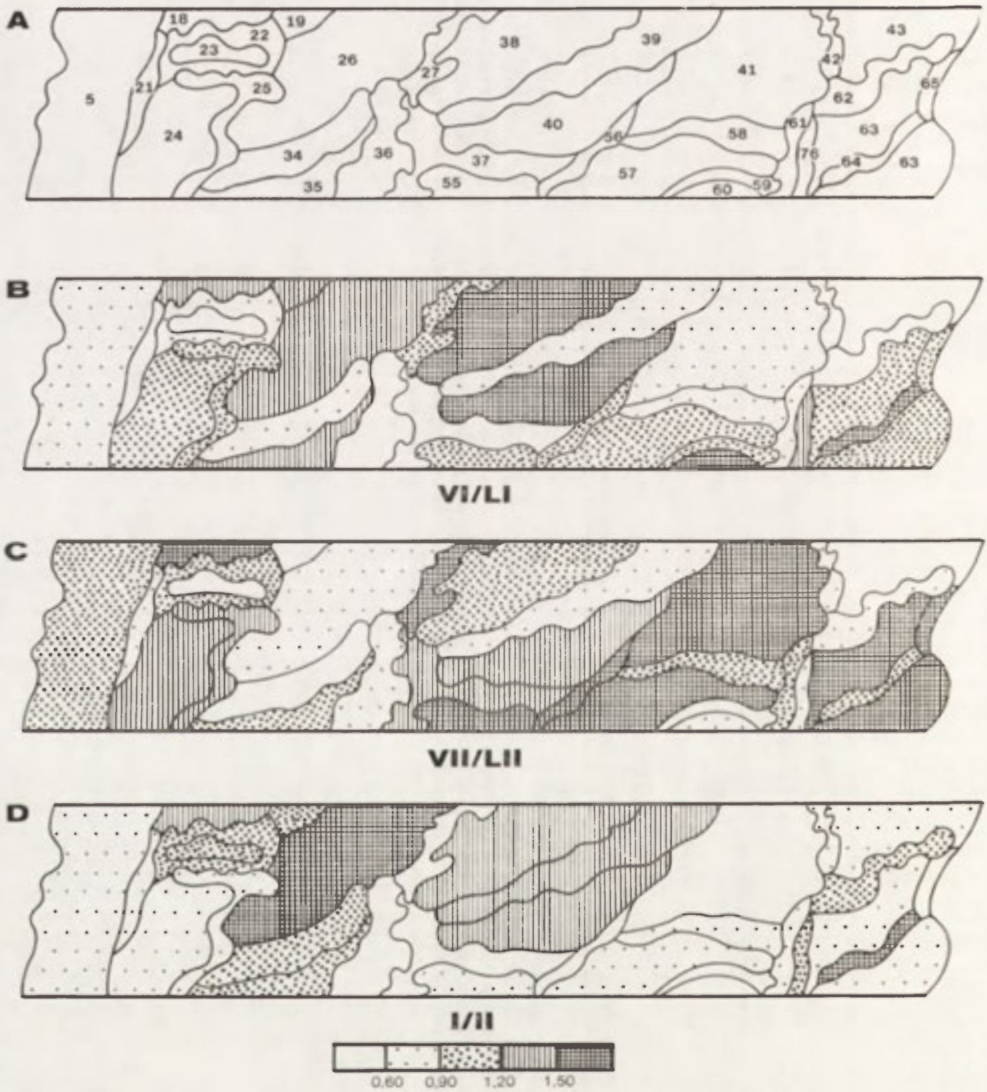

Fig. 5. The use of "type of terrain surface units" for practical purposes

A — Section of former Złotów *poviat* (South Pomeranian Lake District). Division into "type of terrain surface units" after K. Mieszkowska 1973. (Some of these units are described in table 2); B — Estimate of suitability for Activity "I" (V I : L I); C — Estimate of suitability for Activity "II" (V/II: L II); D — Contradistinction of suitability for Activity "I" to suitability for Activity "II" (I : II)

NOTE: In B, C and D the scale of index values is: 1 — below 0.70; 2 — 0.61–0.90; 3 — 0.91–1.20; 4 — 1.21–1.50; 5 — above 1.50

of "Values" and of "Limitations" for Activities I and II, and then dividing ΣV by ΣL. In the case of unit 24 we note:
Values: V 1, V 2, V 3, V 4, V 6, V 7, V 8, V 13 — totalling 8 items.
Limitations (here for items of medium "weight" only halves are counted and marked by parentheses):
(L 3, (L 5), (L 6), L 7, L 8, (L 11), L 12, L 13, L 14, (L 16) — totalling 7.5 items.

Hence here the ratio of ΣV to ΣL is 8 : 7.5 = 1.06, and this figure is called the "Index" of evaluation of a surface unit.

Obviously, each unit has its own index, and for convenience these indices can be grouped into five classes (Fig. 5 — Legend). Lowest (below 0.6) are the indices for units with marked slope gradients (unit numbers 21, 28, 36, 42, 43) associated with morainic hillocks, deeply incised valleys, or peaty channel valley depressions of the type of channel valleys (units 37,62). The next higher index class (0.61 to 0.90) comprises units marked either by an abundance of minor peaty depressions (units 22,34) or by a predominance of non-agricultural use like forests (units 5,41) or other less dominant purposes like meadows (unit 39). Definitely higher are the indices in the successive class, around 1.0, hence from 0.91 to 1.20; these indices cover various types of morainic plateaus, and valleys with lakes, well suited for all sort of agricultural use (units 24, 55, 59, 63 and 25, 37, 56, 59, 65). The two highest index classes (1.21 to 1.50 and above 1.50) refer to the most fertile areas, like morainic plateaus with high-grade soils (units 26, 35, 40, 60) and well-drained valleys (units 19, 64, 76).

The division into index classes can be interpreted as follows. Where indices are low, "limitations" prevail over "values", because the land surface shows poor or very natural qualities and is, at best, suited for greenland and forests, or for other uses foreseen under Activity II. With rising index figures "values" and "limitations" tend to be equal or "values" start predominating, so that the land surface is more and more suitable for a variety of types listed under Activity Ia, b and c. However, where indices show intermediate values (units 18, 34, 35, 62, 76) it will often be difficult to decide which of Alternatives I or II is preferable, and it is up to the planners to decide in conflicting cases like these. For example, an index of 0.68 applies to forested areas; whether a town or settlement can be planned for such areas may depend, among other factors, upon whether deforestation is permitted or not. Similar is the case where industrial plants are planned to be put up, because they may constitute a danger to the surrounding areas (air and water pollution), prohibited by the "Law of Protection of Productive Surfaces" enacted in 1961.

V

The appraisal of surface units as has been described above is an effective means for recommending the most appropriate type of land use and for disregarding, as less advisable, suggestions probably submitted regarding other ways of using the land. Complex physical geographical research is certain to indicate the most appropriate way of "landscape exploration", preventing encroachment upon urotshistshes and physiotopes (ecotopes) (R. Czarnecki 1969), or of applying "urban physiography", i.e., an evaluation of locations by the complex research method for siting towns and settlements (T. Bartkowski 1974a).

Forms of evaluating units of terrain surfaces are of high practical importance, because involved are various decising-making levels. Decisions made at the local level must be co-ordinated with opinions held at the regional level; and vice versa, the regional level must to a certain extent be guided by what the local level decides. This leads to an interaction between local planning and regional planning, expressed by a chain of procedures: general loose information — approval or disqualification of proposed surfaces — collection of more explicit information — local examination of proposed sites and — finally, definite approval of given surface units.

It seems worth mentioning, that the two methods discussed above for identifying terrain units can also be used one after the other in the study of units of land surface: first the cartometric method, for delimiting the practical information basis, followed by the complex investigation method as the more comprehensive research method. This shows that the two methods are detailed and of equal usefulness.

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APPENDIX 1. ESTIMATE SCALE OF VALUES AND LIMITATIONS

A. VALUES

I. Activity on Surfaces

(a) *Extensive (traditional) Agrotechnics*:
V 1 — on fertile soils; V 2 — on soils with good humidity conditions; V 3 — on flat surfaces

(b) *Intensive Agrotechnics*:
V 4 — on fertile soils; V 5 — on soils fertile after improvement; V 6 — on flat surfaces; V 7 — on soils with good humidity conditions; V 8 — with a favourable topoclimate; V 8a — for growing vegetables; V 8b — for keeping orchards and vineyards

(c) *Animal Breeding Factors*:
V 9 — meadows, permanent pastures, V 10 — abundance of pools, lakes and running water; V 11 — forest with rich low vegetation

(d) *Forest Exploitation Factors*:
V 12 — Forest with homogeneous tree species; V 13 — flatness of land surface

(e) *Attractiveness for Recreation*:
V 14 — relief much diversified; V 15 — predominance of forests; V 16 — occurrence of open water

II. Activity in Places, at Points, and along Lines

(a) *Activity in Places (human settlements, towns, industrial workers quarters)*:
V 17 — bearing strength of ground; V 17a — on sandy ground; V 17b — on clayey ground; V 18 — slight undulation of surface; V 19 — abundance of open water (as running water); V 20 — favourable topoclimate (good airing conditions); V 21 — rich resources of renewable underground water; V 22 — rich resources of mineral building materials; V 22a — of brick clay; V 22b — of sand, gravel, stone

(b) *Activity at points (Factories)*
V 23 — bearing strength of ground: V 23a — sandy, V 23b — clayey; V 24 — flatness of surface; V 25 — rich resources of surface water: V 25a — running water; V 25B — stagnant water; V 26 — rich resources of renewable underground water; V 27 — topoclimate favourable (good airing conditions); V 28 — rich natural resources of fuel and water power; V 29 — rich resources of mineral building materials, V 30 — other mineral resources (raw materials for industry)

(c) *Activity along lines*:
V 31 — rivers navigable; V 32 — flatness of surface

B. LIMITATIONS

I. Activity on Surfaces

(a) *Extensive (traditional) agrotechnics*:
L 1 — poor soils; L 2 — humidity of soil unfavourable: L 2 — dryness of soil, L 2b — extensive wetness of soil; L 3 — marked surface inclination (danger of soil erosion);

(b) *Intensive agrotechnics*:
L 4 — extremely poor soils; L 5 — marked surface inclination (danger of soil erosion); L 6 — topoclimate unfavourable to plants sensitive to frost action during their vegetation period

(c) *Animal breeding factors*:
L 7 — lack of permanent meadows or pastures; L 8 — lack of lakes, pools, running water; L 9 — forests with poor-grade vegetation;

(d) *Lumbering factors*:
L 10 — forests comprising different tree species; L 11 — marked surface inclination (impediment to transport of felled trunks)

(e) *Attractiveness for recreation*:
L 12 — lack of a differentiated relief; L 13 — lack of forests; L 14 — lack of open water reservoirs

II. Activity in Places, at Points and along Lines

(a) *Activity in Places (human settlements, towns, industrial workers' quarters)*:
L 15 — low strength ground (organogenic); L 16 — marked surface inclination: L 16a — very dense dissection by ravines or little valleys, L 16b — mosaic of hummocks and small undrained depressions; L 17 — lack of running water (of brooks, rivulets, rivers); L 18 — occurrence of stagnant water basins in river catchment basin; L 19 — lack of renewable underground water resources; L 20 — unfavourable topoclimate; L 21 — lack of building materials

(b) *Activity at Points (Industrial Plants)*:
L 22 — low strength ground (organogenic); L 23 — marked surface inclination: (L 23a and L 23b as in L 16); L 24 lack of running water; L 25 — lack of renewable underground water; L 26 — unfavourable topoclimate (danger of valley smog); L 27 — lack of building materials; L 28 — lack of fuel

(c) *Activity along Lines*:
L 29 — marked surface inclination; L 30 — lack of navigable rivers.

NOTE: The estimate symbols refer to the whole area of a given unit. Where the estimated features are at random dispersed, and where they fail to occupy the whole area, they are noted by parentheses ( ).

APPENDIX 2. SAMPLES OF ESTIMATION (FOR TYPICAL SURFACE FORMS)

HUMMOCKY MORAINE

(V 5), V 9, (V 11), (V 12), V 14, V 15, V 16, V 17, (V 21), V 22, (V 23), (V 25b), V 28, V 29

(L 1), (L 2), L 3, (L 4), L 5, L 6, (L 10), L 11, (L 15), L 16, L 17, L 18, L 20, (L 22), L 23, L 24, L 26, L 29, L 30

STATEMENT:

THIS AREA IS NOT SUITED FOR "ACTIVITY II" (BECAUSE OF THE HUMMOCKY RELIEF) AND IS LITTLE SUITED FOR "ACTIVITY IA". AS A RESULT A COMPLEX USE OF PRODUCTIONAL SURFACES CAN BE PROPOSED FOR ACTIVITIES "IB", "IC", "ID", "IE).

GLACIAL CHANNEL; VALLEY WITH LAKES

(V 3), (V 5), (V 6), (V 7), (V 8a), V 9, V 10, V 11, (V 13), V 14, V 16, V 19, V 21, V 22, (V 24), (V 25a), (V 25b), V 26, V 28, (V 29)

(L 1), L 2, (L 3), (L 4), (L 5), L 6, L 10, (L 11), (L 15), (L 16), L 18, L 20, (L 22), (L 23), L 26, L 29, (L 30)

STATEMENT:

THE DEEP INCISION OF THE CHANNEL VALLEY IN THE SURROUNDING MORAINIC SURFACES MAY CAUSE VALLEY SMOG FORMATION AND THIS IS WHY THIS UNIT IS UNFIT IN RESPECT TO ITS SUITABILITY FOR "ACTIVITY II" (ESPECIALLY AS TO "IIA" AND "IIB"); THIS SURFACE UNIT IS WELL SUITED FOR ACTIVITIES "IC" AND "IE"

OUTWASH PLAIN WITH FOREST

V 3, (V 5), V 6, V 8, (V 11), V 12, V 13, (V 14), V 15, V 17a, (V 18), V 20, (V 21), V 22, V 23a, V 24, (V 26), V 27, V 28b

L 1, L 2a, L 4, (L 5), (L 7), L 8, (L 12), L 14, (L 16), L 17, (L 23), L 24, L 28, (L 29), L 30

STATEMENT:

THE FLATNESS OF THE SURFACE AND THE EXCELLENT, BEARABLE GROUND OF THIS SURFACE MAKE THIS TERRAIN BEST SUITED FOR "ACTIVITY II" AND EQUALLY GOOD FOR "ACTIVITY ID" AND "IC".

GEOGRAPHIA POLONICA 34, 1976

COMPLEX PHYSICO-GEOGRAPHICAL INVESTIGATIONS AND THEIR IMPORTANCE FOR ECONOMIC DEVELOPMENT OF THE FLYSH CARPATHIAN AREA

Eugeniusz Gil and Leszek Starkel

INTRODUCTION

The Department of Physical Geography of the Institute of Geography, Cracow, in close cooperation with the Research Station at Szymbark near Gorlice, has been carrying out investigations into the geographical environment of the Carpathians. The work covers general and detailed studies and stationary investigations of processes. For the detailed studies, the starting point was the detailed geomorphological and hydrographical map (Kimaszewski 1956) while for the general ones it was the outline geomorphological map of the Carpathians (Starkel 1967). Research into the dynamics of the processes on a detailed scale for a wide range of environmental elements has been meticulously undertaken by the Institute of Land Reclamation and Green Crops at Jaworki near Szczawnica (cf. Gerlach 1966), and by the Committee for the Protection of Nature, PAN (Medwecka-Kornaś *et al.* 1968), as well as by our Department which systematically since 1968 has developed the scope of its work in the vicinity of the research station at Szymbark. This station is situated in a region lying between 300–740 m a.s.l. at the border between the Beskid Niski Mts. (Low Beskid) and the Carpathian Foothills and has a complex geological structure and relief. Detailed stationary investigations of various physico-geographical processes are simultaneously recorded there. The aim of the einvestigations is to elucidate the mutual relations among the elements of the environment; to distinguish typological units, and to understand the mechanisms of energy and matter circulation within them (especially concerning water circulation and the denudation balance). The investigations are also designed to study the disturbance of natural equilibria by various patterns of land utilization and to forecast changes in the environment on the basis of both present tendencies and their evolution in the past.

Themes linking the different scales of enquiry of the Department and its station are: the understanding of the evolution of the geographic environment of the Carpathians; the estimation of environmental resources from the viewpoint of rational land utilization, and the elaboration of a method enabling extrapolation from detailed site and profile (stationary) investigations, through detailed spatial studies, to those of general regional character.

In order to understand the results presented below, the authors are providing in summary the scope of work realized in the region of Szymbark. The basic records at the scale of 1 : 10,000 covered geomorphological (Kotarba 1970), hydrographic (Niemirowska 1970; Soja — manuscript), pedological (Adamczyk *et al.* 1973), land utilization and landscape type (Gil, manuscript) surveys, in

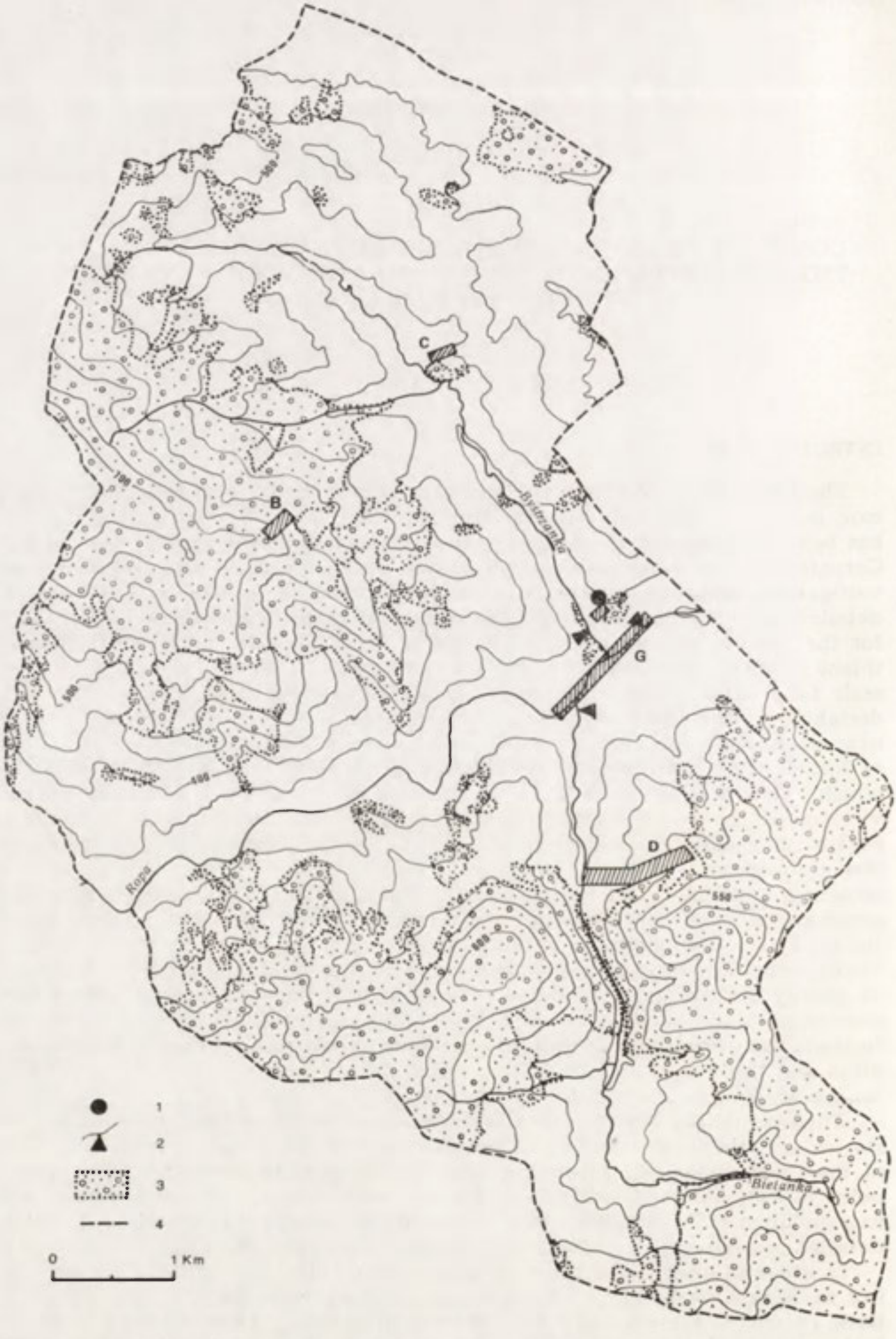

Fig. 1. Situation and scope of research of stationary type carried out in basic types of the geographical environment ("types of terrain") in the region of Szymbark

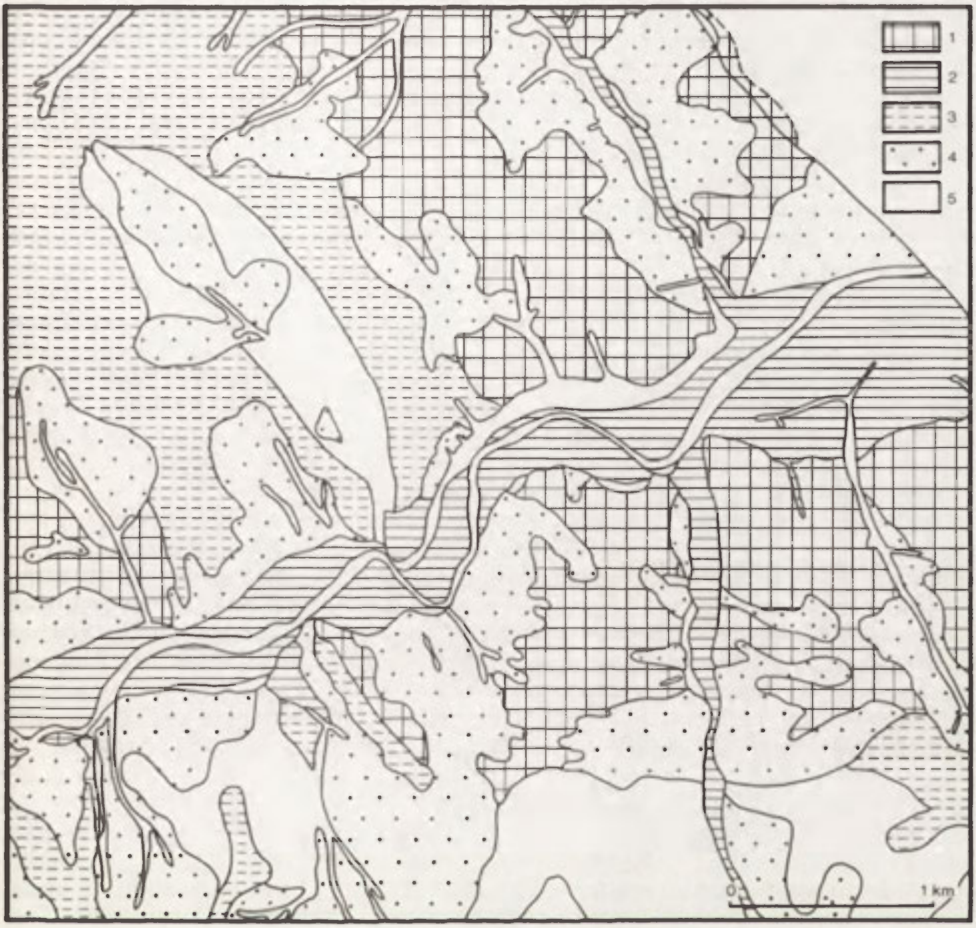

Fig. 2. Bonitation map of the types of terrain for land utilization

1 — arable land without major limitations (C_1, C_2, C_5, A_3, A_4); 2 — admissible arable land: limitations to climate-dependent crops (G_1, G_2, G_4, G_5 C_4); 3 — forests, meadows and pastures with admissible arable land (A_1, A_2, B_2, B_3, B_4, F_2, F_3); 4 — forests with admissible meadows and pastures (D_1, D_2, D_3, C_3); 5 — forests (B_1, E, F_1).

Type B of terrain: Extreme temperatures of the air, precipitation, depth of snow cover, ground humidity, surface and sub-surface run-off, slopewash, chemical denudation.

Type C of terrain: Temperature and humidity of the air, precipitation, depth of snow cover, ground humidity, ground water level, surface and sub-surface run-off, slopewash, chemical denudation, deflation.

Type D of terrain: Precipitation, ground humidity, ground water level, physical and mechanical properties of the ground, movement of landslide masses (geodetic, seismic and electric resistance measurements).

Type G of terrain: Reach of bed covered by investigations of fluvial processes (erosion, transport, sedimentation) with the aid of geodetic methods. It covers hydrometric sites closing the catchment basins of the Ropa, Bystrzanka and Bielanka.

1 — basic meteorological station; 2 — limnographs; 3 — forests border of forests; 4 — border of the research area.

addition to work on macro-, meso-, and microclimate (Obrębska-Starkel 1974; Soja, 1972), forest communities (Staszkiewicz 1973) and meadow and arable land communities (Wójcik 1975).

Stationary studies concentrate on selected slopes and valley-bottoms (Fig. 1) within chosen catchment basins (Dauksza *et al.* 1970; Starkel, 1973). They include the following:

1. observation of meteorological elements;
2. measurements of elements or indices of water circulation on hillsides of various land utilisation, including precipitation, surface runoff, level of ground water (Słupik 1973);
3. measurements of water circulation elements for small catchment basins, including precipitation, snow cover, stages and water discharge in rivers (Dauksza *et al.* 1970; Soja 1972, 1973);
4. measurements of denudation processes on slopes, including downwash, (Gil 1974, Gil, Słupik 1972a and b), chemical denudation (Welc), sliding movements — using geodetic (Dauksza, Kotarba 1973), electrical resistivity and seismic methods (Chrzanowska);
5. observations of deflation by mobile patrol (Welc).

At the same time, in the region of Szymbark, studies have been carried out concerning the evolution of relief, vegetation and alterations of water conditions. The estimation of the environmental values from the standpoint of farming are determined in close cooperation with the Agricultural Commission of the Committee for Space Economy and Regional Planning. This work included among other things working out maps of the elements unfavourable to farming and those of environmental improvement (Gil, Fig. 2, 5), as well as studies of the relationships between land structure and farming effectiveness as applied to environmental features (Pohl).

PRINCIPLES OF ENVIRONMENT TYPOLOGY

Investigations of the natural environmental complex lead to the understanding of mutual relationships among its elements and to the separation of units of various taxonomic levels, having similar kinds of internal relationships. The most stable and, at the same time, differentiating elements are the relief and lithology which are linked with each other throughout the evolution of the environment. A feature of the mountainous area is the gravitation-controlled course of slope and fluvial processes, as reflected in particular components of the environment and also in vertical zonality of physico-geographic phenomena. In such conditions the relief together with lithology is the element determining the type of processes and is therefore of basic importance in distinguishing and classifying typological units. Each one of the basic landforms (slope, valley-bottom) is described not only by morphometric features, but is also characterized by a specific type of structure and of Quaternary cover, lithosol (regolith) pattern and depth of soil, type of water circulation, microclimatic conditions and morphogenetic processes.

These factors were the basis for typological mapping and of the recognition, in terms of similarity, of spatial units of the ranks of facies and ranges (Gil 1975). With reference to relief features and lithology, the individual spatial units distinguished during mapping were included in 25 types of ranges. The basis for grouping the 25 types of ranges into major units, or types of terrain, was the identification of ranges revealing common origins and forming a single unit with regard to the trend of present-day physical and chemical processes. Seven types of terrain were distinguished:

A. Plateaus, including the watershed zones of mountain ridges and of uplands and foothills, built of various lithologic complexes with lithosol covers and brown soils, exhibiting the prevalance of subsurface run-off and affected by the advection of fresh air-masses.

B. Steep slopes of the Beskid, on sandstone complexes, with skeletal brown soils and sub-surface run-off; in most part afforested, and covered by communities of *Fagetum carpaticum* (a response to higher altitude).

C. Gentle slopes of foothill hummocks, on shaly-sandstone complexes with varying kinds of brown soils, mainly deforested (within assemblage of *Tilio-carpinetum*) and experiencing some degree of surface run-off.

D. Landslide slopes, on predominantly claystone complexes, with irregular relief and brown-type gley soils and plastosols, with impeded sub-surface water circulation and with various land utilization.

E. Erosional undercut slopes, shaped by lateral erosion of running waters aided by mass wasting, developed on shaly-sandstone complexes with various types of poorly developed soils, within the mesoclimate of valley-bottoms, under pastures and forests.

F. Small valley forms, dissecting slopes under forests or meadows.

G. Valley-floors, flat on almost alluvial deposits, shaped under the influence of the fluvial regime, with a thin cover of muds, within the mesoclimate of valley-bottoms, experiencing contrasting thermal conditions; generally deforested.

The arrangement of terrain types of a defined internal differentiation coincides with the differentiation of the climate and of vegetation. It accounts not only for the pattern of typological units of the lower order (various slope exposures and plant communities), but, in spite of the small height differences in the vicinity of Szymbark, it also reflects the features of vertical differentiation (Gerlach, Hess, Starkel 1966). The expressions of the vertical zonality modified by the relief of valleys are the three types of mesoclimates (Obrębska-Starkel 1974), of, 1) the valley-floors and lower parts of valley-sides, which experience the greatest contrasts in thermal conditions and humidity; 2) the warm and dry slopes revealing optimal values (40–200 m above valley-floors); 3) the ridges under the influence of advection of fresh air-masses. These types of mesoclimates coincide in part with the forest communities: (Staszkiewicz 1973) *Alnetum incanae* in valley-floors; *Tilio-carpinetum* on slopes up to some 150 m of relative altitude and *Fagetum carpaticum* above 450 m a.s.l. on north-facing slopes and above 600 m a.s.l. on hillsides with a southern exposure.

The types of terrain in question (structural units) have been disturbed in the mechanisms and intensities of processes modelling them by various land utilizations. For example, in the catchment basin of the Bystrzanka (13.6 sq km) the forests cover as much as 39.8% of the area, meadows and pastures 22.5%, and cereals 28.7%, while root plants cover 9%. Detailed stationary and semi-stationary investigations (Fig. 3) on chosen surfaces, belonging to types B, C, D make it possible to determine the role of changes in land utilization in altering the intensity of processes (Table 1). For instance, surface run-off appears to be some 400 times greater over areas planted with root crops than it is in a forest, and soil downwash under cereals is 500 times and under potatoes 350 000 times greater than in a forest. The deforested plateaus (type A) are modelled in winter by deflation (on leeside slopes accumulation exceeds at times 3000 grams per sq m, according to A. Welc). Repeated levelling on landslides aimed at determining the denudation balance reveals an annual displacement of the order of 2 m (Dauksza, Kotarba 1973). In valley-floors the river channels undergo deepening, due in part to the exploitation of gravels, which decreases the

TABLE 1. Physico-geographical typology of the Szymbark area

CRITERIA	TAXONOMIC DEGREE	TYPOLOGICAL UNITS DISTINGUISHED						
Climatic-vegetal belts	Landscape species	OF THE BESKIDY MTS. B +(A, D, G, F)			OF THE CARPATHIAN FOOTHILLS C + (A, D, G, F)			
Landform types, their relation to lithology, guiding types of hydrologic and geomorphologic processes	Type of terrain	A Ridge plateaus (interfluves)	B Slopes of mountain ridges developed on sandstones	C Slopes of foothill hummocks on shaly-sandstone series	D LANDSLIDE SLOPES mainly on shales	E Erosional undercuts	F Small valleys dissecting slopes	G Valley-floors with alluvial covers
Inclination and shape of slopes, lithology, mechanical composition of soils, intensity of physical-geographic processes	Type of range	A_1 A_2 A_3 A_4	B_1 B_2 B_3 B_4	C_1 C_2 C_3 C_4 C_5	D_1 D_2 D_3	E	F_1 F_2 F_3	G_1 G_2 G_3 G_4 G_5
homegeneity of elements and connections	Facies	Individual homogeneous surfaces						
Basic types of landforms of varying circulation of energy and matter		SLOPES						VALLEY-FLOORS

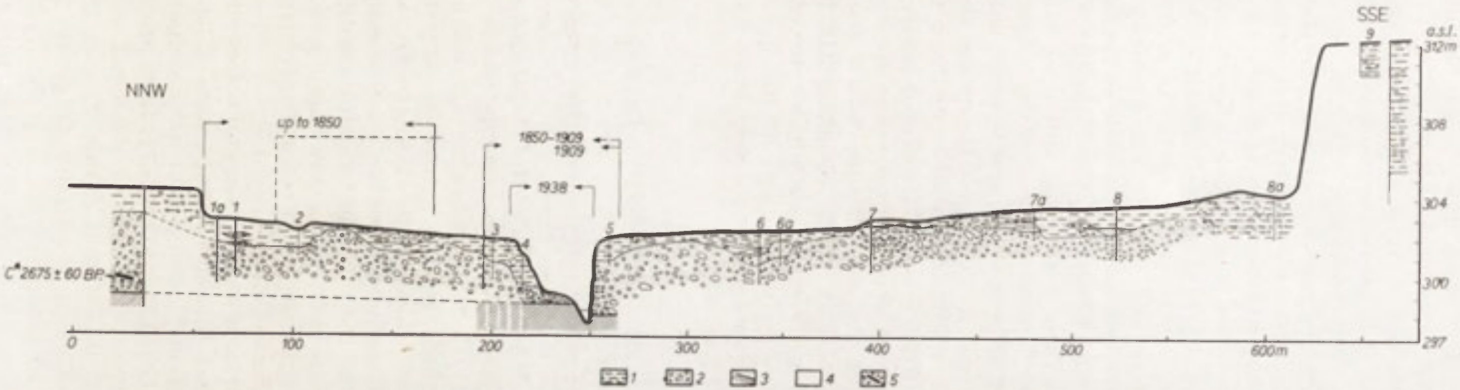

Fig. 4. Section across the floor of the Ropa valley at Szymbark and changes of river channel in the years 1850–1970 (Excursion Guide-Book, Symposium of the INQUA Commission on Studies of the Holocene, Poland 1972).

1 — clayey muds; 2 — gravels and boulders; 3 — rock pedestal; 4 — situation of the Ropa channel according to old maps (year of survey); 5 — organic horizon dated by C^{14}.

danger of inundation but, at the same time, brings about the lowering of ground-water level.

The investigations also involved study of the changes and evolution of the environment in time, assuming that the recognition of the origins of the different types of the environment and, especially, of the causes of their modelling in natural and in man-changed circumstances, not only favours better comprehension of the present-day mechanisms, but also enables us to forecast changes. An example of that may be studies of landslides. Landslide movements are very characteristic of the series of variagated Eocene shales and of sandstone-shaly Inoceramus beds in the region of Szymbark (landslides constitute some 30% of the slopes). Apart from some constantly active landslides, there are also large landslides active only during exceptionally wet years, as for example in 1913 (Sawicki 1917) and in 1974, as well as landslides now inactive that were formed during humid periods of the Holocene. For instance, on a landslide near Kamionka the base of deposits filling in a hollow dates from 8,210 ± 150 BP (Gil *et al.* 1974). The comparison of the magnitude of downflow and rainwash in a forest, and on a piece of arable land, with the structure of the vegetation covers throws light on the role of slopewash and deflation during the period of human occupation (compare studies in the neighbouring region: Gerlach 1966; Gerlach *et al.* 1972). Investigations of deposits and fluvial forms in the Ropa valley near Szymbark (Fig. 4) prove that the deepening of its bed is very recent and the river in the past century was shifting its shallow bed flowing down the plain of the 4–5 m terrace (Dauksza, Gil 1972), and the prevailing bulk of gravels building the whole bottom terrace can be attributed to the period of human activity. At the bottom of the gravels, far from the present-day bed were found organic remains dating from 2,675 ± 60 BP (due to kindness of Dr. Geyh from Hannover).

TYPES OF TERRAIN AND MODES OF LAND UTILIZATION

The widespread scope of these investigations of the geographic environment makes it possible to distinguish the areas favourable or unfavourable to agriculture. Such attempts have been performed at the Department for other regions of the Carpathians, although based on considerably poorer materials (Starkel 1954; Bąk *et al.* 1969). Figure 5 shows the factors restricting farming in the region of Szymbark. These include, areas unfavourable in terms of the technical possibilities of ploughing (steep slopes with skeletal soils, active and inactive landslides with uneven relief and unfavourable water conditions); areas unfavourable because of extremes of thermal and humidity conditions (areas of cold, inversion and extremely dry; areas of excessively humid soils, water-logged and heavily gleyed), and areas of intensive soil erosion (active land-slides, steep deforested hillsides, plateaus affected by deflation).

The comparison of the harmful elements present (described by the magnitude and intensity of processes) with the present state of land utilization in an area leads to practical conclusions. Examples of such comparisons may be seen in the works by Słupik and Gil (1972, 1973, 1974) from which it emerges that the kind of utilization determines the height of abnormal water-stages in small catchment basins, the rate of denudation (Table 1) and, indirectly, provides information about the yield of crops. Especially dangerous is the continuation of potato growing as well as of other root crops in the flysh Carpathians. The widespread introduction of these crops into the mountains at the beginning of the 19th century was probably the cause of the formation of wandering river

Fig. 5. Map indicating elements restricting agriculture in mountain areas
1 — Slopes with gradients in excess of 30% (apart from landslide areas); 2 — Slopes with gradients from 10% to 30% (apart from landside areas); 3 — Slopes with gradients of less than 10% (apart from landslide areas and with vertical hatching omitted); 4 — Places of active landslides; 5 — Other areas disposed to sliding; 6 — Areas above warm zone; 7 — Areas with frequent thermic inversions and night-frosts; 8 — Slopes threatened by excessive drying-out (S and SW exposure) and to deflation; 9 — Areas excessively humid; 10 — Waterlogged and swampy surfaces.

channels (Klimek, Trafas 1972). On these statements was based the map estimating the types of terrain for agriculture as shown in Figure 2 which also embodies recommendations concerning land use. A comparison with the present-day state of land utilization points to necessary alterations. However, it still does not take into consideration recommendations regarding changes of crop structure within arable land.

SPECIES OF LANDSCAPE AND THE OUTLINE GEOMORPHOLOGICAL MAP

The dominance of particular types of terrain within major surfaces makes it possible to distinguish in the region of Szymbark two typological units of higher order, to be called "species" of landscape; one characteristic of the Beskidy Mountains; the other of the Carpathian Foothills. They differ, not only in the prevailing types of terrain and slope but also in altitude above sea level and relative heights, all of which reflect the vertical zonality of climate and vegetation (Gil 1975). This is illustrated in Figure 3 and 6. For the Beskid landscape species B types of terrain are characteristic (with a proportion of A and also C, D, E and F types); steep slopes on sandstone series, and the presence of all the types of mesoclimates and plant communities in vertical arrangement. Within the landscape species of the Carpathian Foothills terrain types C and A prevail (with a share of C, D and also E, F and locally B types), and gentler slopes are typical on the sandstone-shaly series, along with types mesoclimates I and II; the *Tilio-carpinetum* assemblage and a considerable disturbance of the equilibrium of processes as a result of deforestation.

The outline geomorphological map of the Carpathians, worked out in manuscript, on a scale of 1 : 300,000 (Starkel 1967) represents the types of relief, according to vertical zones, and also according to origin and age. The types reflect, at the same time, the connections with the lithology. The higher the level of mountains or mountain foothills, the older are their foundations and they have survived on harder rocks. Within the flysch Carpathians three basic types of relief were distinguished (Starkel 1972): 1) low and middle mountains; 2) mountain foothills, and 3) valley-floors and basins. The relief type of low and middle mountains is characterized by steep slopes (more than 20°) related, on the whole, to the resistant and medium-resistant sandstones and it shows sharp contrasts with the surrounding foothill hummocks. Within them there occur ridges of low mountains (300–350 m of relative height) and those of middle mountains (relative heights 400–800 m). The Carpathian Foothills relief type is more differentiated. Here there are three distinct vertical zones (high, middle and low) equivalent to three planation levels of relative altitude 250–300 m, 120–200 m and 40–100 m. According to the resistance of their rocky substratum (low mountain foothills on less resistant rocks); the distance from the main valley, and the situation relative to active tectonic structures, they possess steeper or gentler slopes, are more or less deeply dissected, and have hillsides covered with a varying proportion of permeable regolith. Therefore, in the elaboration of the relief of the Carpathians (Starkel 1972) there were distinguished within each of the vertical zones of mountain foothills variants of steeper and deeper-cut foothills, and also those less dissected, and with more gentle slopes. Cumulative curves of slope inclination worked out for chosen terrains, representing the various kinds of relief (Starkel *et al.* 1973) and, at the same time, based on slope maps at a scale of 1 : 25,000, show that the higher the level of mountain foothills and the more resistant the substratum, the steeper are the slopes (Fig. 6).

The comparison of the results obtained from the detailed investigations of the species of Beskid and Carpathian Foothill landscapes with the types of relief distinguished on the outline map shows that we are dealing with elements of similar order of magnitude. The types of relief, reflecting the relation with the lithology of the substratum, accord in principle with the species of landscape. Hence it was possible to attempt to present approximately the probable share of terrain types distinguishable in the region of Szymbark by using the types of relief shown on the outline geomorphological map (Fig. 3, 6). It appears

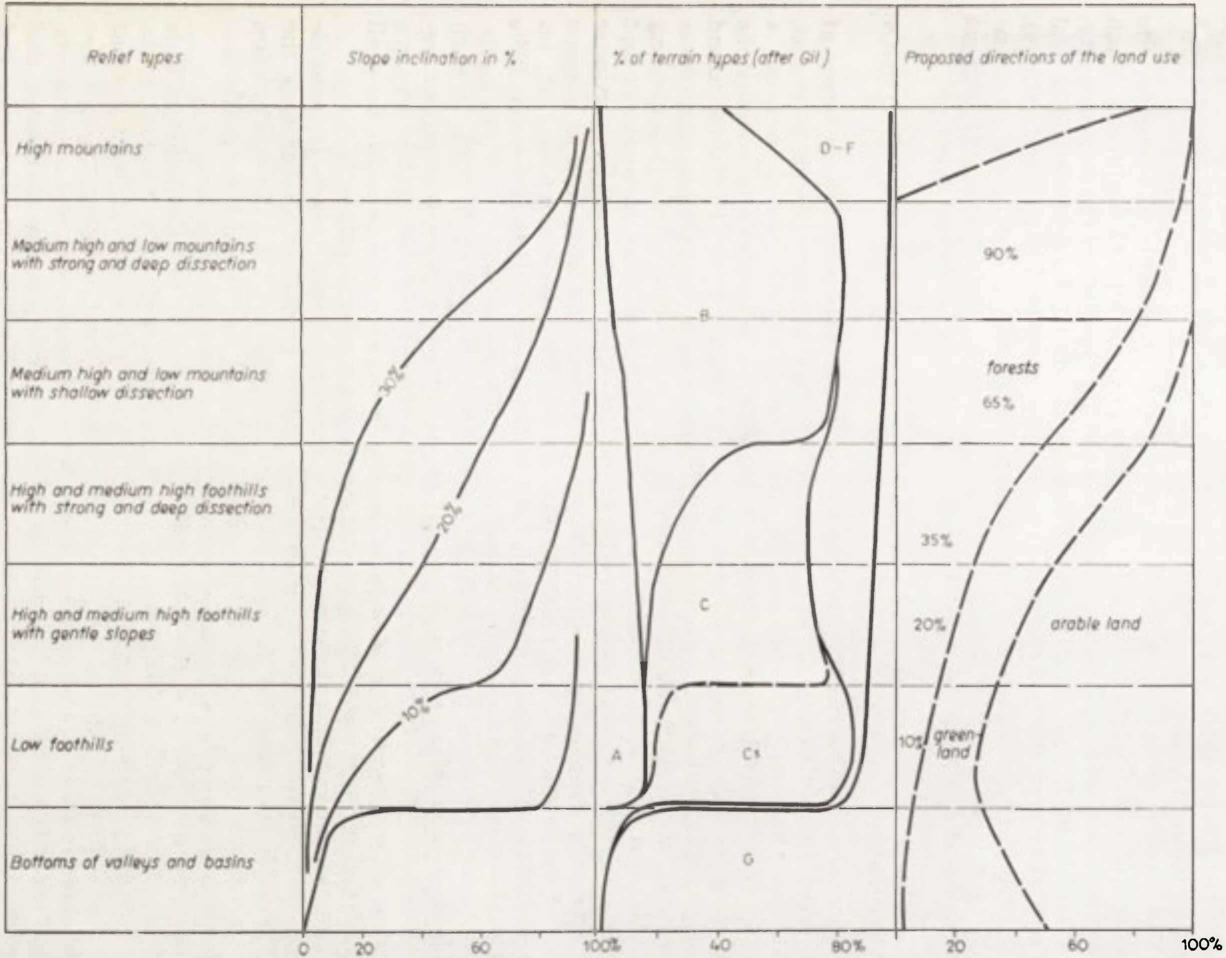

Fig. 6. Types of relief based on the general geomorphological map and their relation to terrain types and directions of land use.

on comparison, that, although the Beskid species prevails within the low and middle mountains and that the Carpathian Foothills species is dominant within the majority of foothill varieties, it is necessary to introduce for the areas of low foothills of very gentle slopes (0–10°) and long footslopes, a new type of terrain, which by analogy to one of the distinctions within type C was given a working name "C_5".

The outline geomorphological map also makes it possible to recognise the typology of relief within the major units (i.e., micro- and mesoregions). Such an attempt is shown in Figure 7. The basis for the typology is the homogeneity, or a variety of the types of relief distinguished within the regional units and the spatial arrangement of elements, e.g., parallel courses of ridges and valleys). If we accept the criterion of morphologic-lithological features of the environment as a base for its typology, then the types of geomorphological regions distinguished could, at the same time, be regarded as landscape types.

AN ATTEMPT TO EVALUATE ECONOMIC USEFULNESS OF THE CARPATHIAN ENVIRONMENT

An analysis of connections among the environmental elements, in terms of the type and intensity of the present-day physico-geographical processes, and of directions of changes in the environment, carried out on a sample area from Szymbark, makes it possible to draw definite conclusions regarding land utilization in the mountains. The mutual interelationships found between relief, lithology, soil and the hydrologic and geomorphologic processes within the major units enable the formulation of recommendations regarding rational land utilization. From the cumulative curves of slope inclinations and of percentage of terrain types in various kinds of relief, it is possible to propose the necessary share of forests and the possible share of arable land in various types of mountains and its foothills (Fig. 6). We have assumed here that, on account of flood and erosion control, forests should cover all slopes above 30% and parts of the water divides, as well as zones adjacent to the river channels. Arable land is generally advisable only on hillsides sloping up to 15%. In such a scheme, essential corrections must be made for climatically determined vegetation belts (Hess 1965; Gerlach *et al.* 1966). Upper limit of arable land (ca 800 m a.s.l.) should be put at varying height due to thermal inversions as well as to the occurrence of the flat glacis at the feet of mountain ridges.

The typological classification of the Carpathian relief makes it possible therefore to distinguish the types of relief and of landscape conditioning the four possible solutions: (a) the predominance of arable land; (b) the equilibrium between arable land and green crops with a share of forests; (c) the equilibrium of forests, meadows and pastures; (d) nearly complete afforestation.

In a broader view of the whole of the economy in the Carpathians it is possible to ascribe, to the types of relief distinguished on a regional scale, the following leading kinds of land utilization and modes of management (Fig. 7) in order of importance: types 1–3 — arable land, housing; types 4–6 — arable land, meadows and pastures; types 7–9 — meadows and pastures, forests, arable land; types 10 and 12 — forests, meadows and pastures, recreation and tourism; types 11 and 13–15 — forests, recreation and tourism, meadows and pastures.

FINAL REMARKS

This article presents an attempt, not yet terminated, to view the features of the Carpathian geographical environment from the standpoint of their importance for the mountain economy. The systematic approach to the problem requires detailed studies of the elements of the environment within all the terrain types recognised, as well as the understanding of the mechanism of processes modelling them. Without the knowledge of the entire water circulation, or of soil denudation under the various types of land utilization, it is difficult to speak of practical recommendations, or of the elaboration of ways leading to the creation of equilibrium in the natural environment.

The results of physico-geographical investigations should be presented in the form of predictions of environmental changes, taking into consideration the present pattern of land utilization (including increase in production), and of forecasts taking into account the changes in utilization that would re-establish the equilibrium of processes in the environment. In order to formulate the forecasts it is necessary to carry out parallel investigations of present-day physico-geographic processes and of the history and trends of changes in the environment before and throughout the economic activity of man, that is to say, covering at least the entire period of the Holocene.

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GEOGRAPHIA POLONICA 34, 1976

ON THE ELABORATION OF DETAILED PHYSICO-GEOGRAPHICAL MAPS: THE CASE OF THE POLISH LOWLAND

Rajmund Galon

New trends in Polish geography which are obviously connected with the increasing social concern for the natural or geographical environment indicate the necessity for complex investigation of this environment. Besides the analysis of particular elements or components of the environment, such as relief, climate, water conditions, soil and vegetation, a second research direction exists which analyses the complex structure and dynamics of the geographical environment and distinguishes different spatial complex units or landscape units.

While the first kind of analysis runs in a sense parallel to the earth's surface, the second is vertically disposed. It should be stressed, however, that the dividing line between the two types of analysis is indistinct and may only be formal. The geographical studies of each landscape component are carried out against the background of all the other components and in functional and genetic connection with them, and they regard the environment as a whole, taking into account one selected element. On the other hand, complex studies the geographical environment are not possible without detailed knowledge of landscape elements occurring in a given area. There is also a method of investigation which combines the two above mentioned directions. It is based on the construction of landscape profiles, which usually include a few complex units and which show in their stratum scheme the more important features of the geographical environment such as relief, surface and underground water, vegetation, soil and so on.

Therefore detailed maps of each geographical element of the environment are advisable not only because they are necessary for such branches as geomorphology, hydrography, soil science or biogeography, which concern the environmental components, but also for examination of the structure of the environment. However, a cartographical picture is required which would combine all more important components of the geographical environment and it should show the spatially differentiated landscapes of a given area. Thus, as well as geomorphological, hydrographical and other detailed maps of landscape elements, physico-geographical or physiographical maps should be made which should be easily legible. These maps must give a spatial presentation of the more important or characteristic elements and features of the geographical environment, and an immediate analysis of spatial landscape structures.

The idea of preparing physico-geographical or environmental maps is not new. There are many survey maps containing orographical and hydrographical data on which deciduous and coniferous forests are differentiated. Good topographical maps contain landforms, river pattern and lakes, springs and marshy areas. Also detailed maps dealing with only one element of the geographical environment include information about other elements. Thus, for example, geomorphological maps also include the whole hydrographical net, and some maps show the lithology of surface sediments. Hydrographical maps also include some details of hydrogeological relations and the degree of infiltration by giving lithological features of the area. Prof. Jean Tricart of Strasbourg, during a hydrological meeting in Paris, demonstrated a detailed project concerning a morpho-hydrological map (in the presence of the author). Similarly the author has prepared and demonstrated a detailed map of the Torun region, with geomorphological, hydrographical and lithological features, at the meeting of the Sub-Committee of Geomorphological Mapping of the IGU in 1964 at Brno. This map was collectively prepared in the Department of Geomorphology and Hydrography of Lowland in the Institute of Geography of the Polish Academy of Sciences, in Torun (Galon 1967).

With regard to possible controversial comments which would point to the existence of synthetic complex maps reflecting the full differentiation of the geographical environment as a result of different spatial arrangements of environmental elements, and which therefore play the role of physico-geographical maps, I suggest the following: Synthetic, complex maps include spatial units based on regionalization of given areas. Although those units based on one of many methods of delimitation of the terrain are complex in type and can be estimated as useful for a given practical task, that sort of complexity is not exposed cartographically and thus it is not testable. On such a map only the boundaries of delimited units are marked and the conceivable figures, signs or colours used for the cartographical differentiation express the author's typological or taxonomic classification. A similar problem is the delimitation of regional units with the range of particular elements of the geographical environment, for example: the landforms or water occurrence. A detailed cartographical picture of those elements, based on delimitation is replaced by a net of boundaries between regional units which were distinguished on the basis of a typology of relief or water phenomena.

Undoubtedly regionalization, as one of the subjects of geographical studies, with regard to both particular components of landscape and as a concept of the complex geographical environment, has not achieved the required perfection and precision in spite of many interesting conceptions. Until now it has not provided a sufficient base for planning and has lacked the expected scientific value.

The main condition for obtaining an objective and detailed picture of the geographical environment — no matter what method used — is the existence of detailed maps of the most important components of the given environment, based on systematic mapping. Immediate mapping of complex units is only possible for small areas or as a survey picture prepared by use of aerial photography.

The next step is to construct a physico-geographical map of the investigated area, which includes all environmental components occurring there. That kind of map may theoretically be made by superimposing the full substance of each component map whilst retaining all marks, symbols and signs. However, such a cartographical picture of the geographical environment, if joined mechanically, would be extremely illegible and thus it is out of the question. To make such a map — compounded from several component maps — legible, different colours for each element of the landscape and appropriate simplified patterns, which do not interfere with each other, should be used.

Studies concerning the preparation of physicogeographical maps are being carried out in the Institute of Geography at the Nicolaus Copernicus University in Toruń. The Institute of Geography of Polish Academy of Sciences in Toruń published a vast set of sheets of detailed geomorphological and hydrographical maps at the scale of 1 : 50,000 for the area of the Polish Lowland. The next step in this cartographical work is the preparation of a detailed physico-geographical map at the same scale by the utilization of the geomorphological and hydrographical maps and also other cartographical data concerning soil, plants and other environmental components (Fig. 1). In this scheme of studies, supervised by the author, a few model sheets were made, among others a map of Golub-Dobrzyń district. This map was made (in manuscript) by W. Morawiec (1973) for her M. Sc. Diploma.

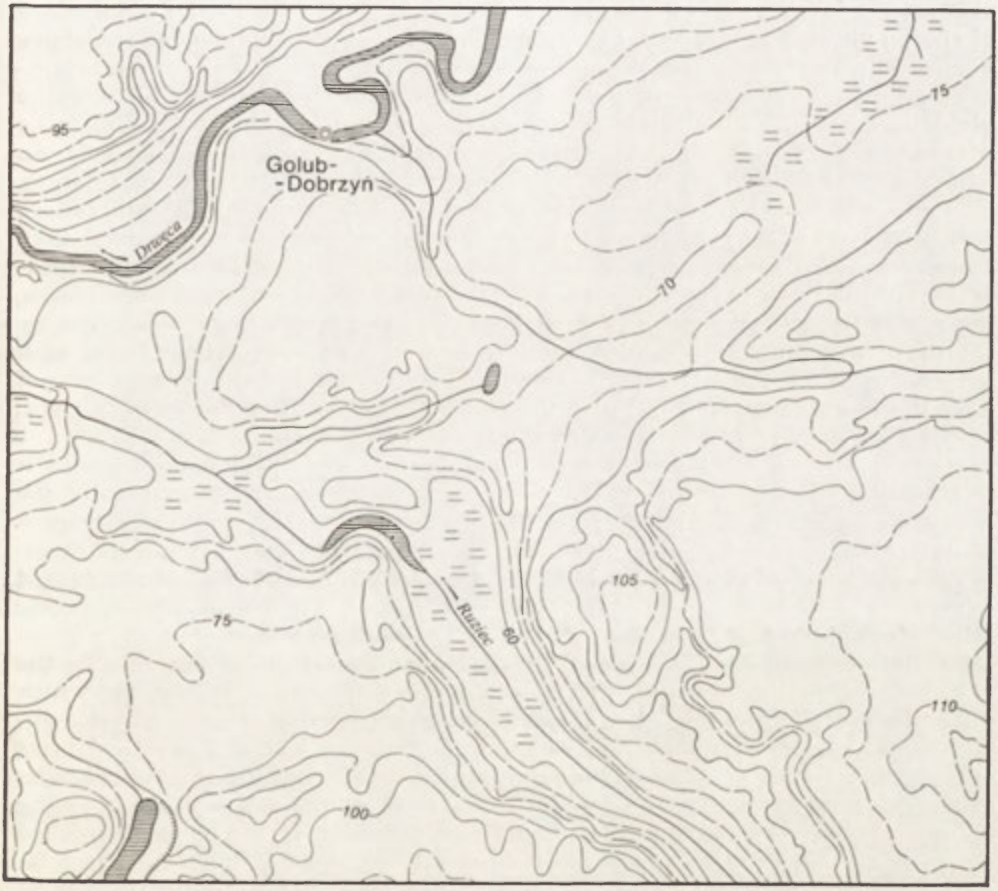


Fig. 1. Fragment of the hypsometrical map 1 : 50,000 of the Golub-Dobrzyń district

The physico-geographical map of Golub-Dobrzyń district, prepared at the scale of 1 : 50,000, shows a typical young glacial landscape connected genetically with the last glaciation of the Polish Lowland and transformed later under periglacial and Holocene climatic conditions. The above mentioned map contains the following elements of the geographical landscape: landforms, lithological properties of surface sediments, hydrographical pattern with lakes and marshes and also the forest cover. The landforms marked by several shades of brown, yellow and light green were used as a coloured background. The map distinguishes flat and undulating moraine plateau, end moraines, kames and other ice-marginal landforms, outwash plains, subglacial channels and kettle holes, valleys, valley terraces and valley bottoms, scarps and dunes. These are the more important landforms of the Polish Lowland, besides their origin their morphographic features were also taken into account. Lithological features such as glacial, glaciofluvial, fluvial, eolian and slope sediments have been marked by hachures and other signs in red. Hydrographical occurrences, which are marked in blue, were comparatively rare in the investigated area as were forests, for which green signs have been used.

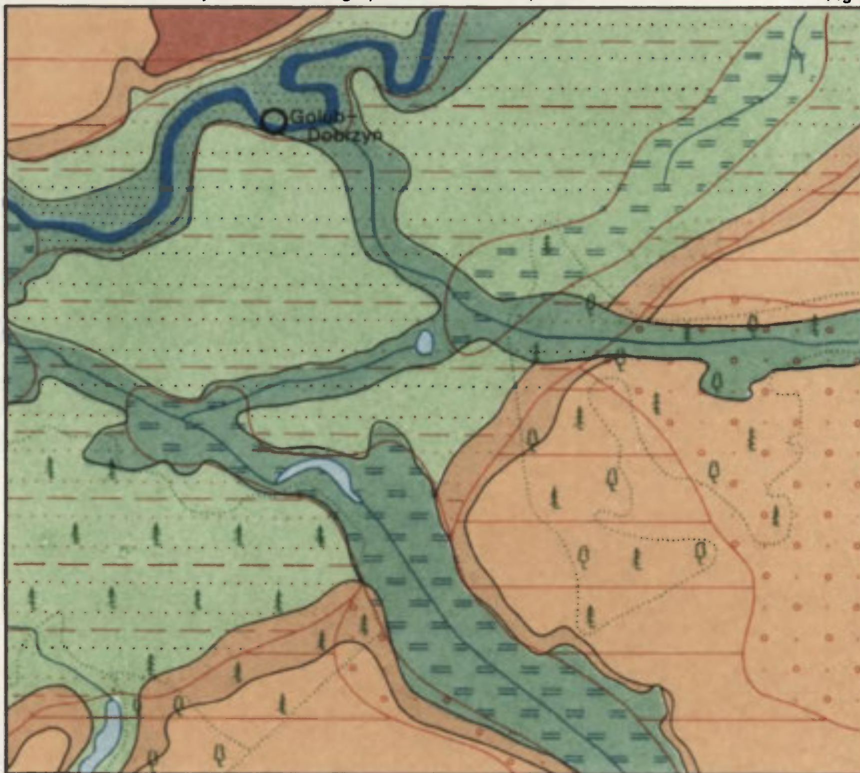
It is evident from a fragment of this map (Fig. 2) that the combined cartographical picture of the given geographical environment is not only legible but also impressive. At any rate it gives a good insight into the spatial connections of chosen physico-geographical components. The enclosed fragment of the above described map shows a portion of the valley of the Drwęca river which originated as a *pradolina* (ice-marginal streamway) with the surrounding moraine plateau cut by subglacial channels. (Niewiarowski 1968). The moraine plateau, built mostly by boulder clay and locally by sands and gravels, on which multispecies deciduous and coniferous forests occur, is flat or undulating. It is an agricultural area. The boundaries between the moraine plateau, valleys and subglacial channels appear as distinct scarps of relative height more than 20 metres. The slopes are cut in many places by side valleys. In the valley (*pradolina*) of the Drwęca river there are sandy terraces onto which, at some places, the forest from the moraine plateau descends. The lower terraces are cut by the narrow channel of the winding river bed of the Drwęca river, filled with silty deposits. The subglacial channels filled with peat and small lakes cut not only the moraine plateau but also the flat valley bottom of the Drwęca river, causing a notable differentiation of the landscape.

It is necessary to elaborate detailed physico-geographical maps because it is an important task of geography to carry out complex investigations of the geographical environment. There is the problem of choice of the most representative environmental elements for a given area and of a competent cartographical complex picture of the geographical environment. The demonstrated example of such a map whilst far from being perfect, is intended to stimulate other attempts in this field — an undoubtedly desirable aim.

A detailed physico-geographical map may play an important role in the work of regionalization and, therefore, in the delimitation of regions which differ in the composition of environmental elements or features. Physico-geographical regionalization belongs to the main theoretical and practical tasks of geography. There is a wide range of papers concerning the theoretical basis of the problem (lately amongst others — Marsz 1974) and the problem of fixing boundaries between terrain units. Landscape mapping on the basis of detailed complex field investigations worked out by Russian geographers is very laborious, it concerns only small areas and can be speeded up by the use of aerial photography. The traditional method of distinguishing different physico-geographical units consists of superimposing the lines of previously established

Fig. 2. Fragment of the physico-geographical map 1 : 50,000 of the Golub-Dobrzyń district (elaborated by W. Morawiec, 1973)

1 — flat moraine plateau, 2 — undulating moraine plateau, 3 — dissected or denudated scarps of river valleys or subglacial channels with colluvial cover, 4 — lower terraces of Drwęca valley, 5 — subglacial channels and bottom of Drwęca valley, 6 — boulder clay, 7 — morainic sands and gravels, 8 — sands of lower valley terraces, 9 — recent fluvial silt, 10 — rivers and rivulets, 11 — lakes, 12 — swampy areas and peat bogs, 13 — pine wood, 14 — multispecies mixed forest.



Fragment of the physicogeographical map 1:50 000 of the Golub-Dobrzyń District
(elaborated by W. Morawiec, 1973)

- flat moraine plateau
- undulating moraine plateau
- dissected or denudated scarps of river valleys or subglacial channels with colluvial cover
- lower terraces of Drwęca valley
- subglacial channels and bottom of Drwęca valley
- boulder clay
- morainic sands and gravels
- sands of lower valley terraces
- recent fluvial silt
- rivers and rivulets
- lakes
- swampy areas and peat bogs
- pine wood
- multispecies mixed forest

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limits of geomorphological, hydrographical, soil and plant units. It is performed in order to derive the boundaries of terrain units which differ in various geographical contents. According to the Finnish school of Granö (Ruotsalo 1967), because of considerable discrepancy of extent of chosen environmental components, in such a cartographical picture border zones and even vast transitional areas may dominate.

The problem of the content and limits of geographical complex units enters into a new phase of investigation when there is a full picture of the environment for a given area, in the form of a detailed physico-geographical map. In the light of their real distribution and variable setting the representative landscape features, shown on the map, are an unbiased basis for the delimitation of distinctive physico-geographical complex units for a given area. Such delimitation differs fundamentally from the above described method of superimposition of boundaries of each component on one map. There is here at our disposal a cartographic picture of the most characteristic features of the geographical environment, which allows a detailed analysis of reciprocal influence to be performed, and also the borders of different spatial environments to be outlined.

Fig. 3. Fragment of the physico-geographical complex units 1 : 50,000 of the area of Golub-Dobrzyń district (elaborated by W. Morawiec, 1973). Explanation at the end of the paper.

By way of illustration such a physico-geographical regionalization was made on the enclosed fragment of the physico-geographical map of the Golub-Dobrzyń district (Fig. 2). The distinctive complex units (Fig. 3) belong in type to two landscapes: to the moraine plateau and to the valley area, and regionally to Chełmno moraine plateau, Drwęca valley and Dobrzyń moraine plateau. On the whole physico-geographical map of Golub-Dobrzyń district in the light of different morphological, lithological, hydrographical and plant geographical features 10 repetitive typological complex units were distinguished on the moraine plateau and 13 typological complex units in the valley area.

On the discussed fragment of the physico-geographical map of the Golub-Dobrzyń district the following typological complex units are distingushed (see Fig. 3):

(A) Typological units on the Chełmno moraine plateau

A_1 flat moraine plateau with clayey surface without forest

A_2 undulating moraine plateau with clayey surface without forests

(B) Typological units on the Dobrzyń moraine plateau

B_1 flat moraine plateau with clayey surface, without forest cover

B_2 flat moraine plateau with clayey surface partially covered by multispecies mixed forest

B_3 flat moraine plateau with sands and gravels on the surface

B_4 flat moraine plateau with sands and gravels on the surface, prevailing forest overgrowth

(C) Typological units in the valley (pradolina) of Drwęca river

C_1 lower valley terraces with prevailing sand cover without forests

C_2 lower valley terraces covered by sands, with prevailing coniferous overgrowth

C_3 lower valley terraces covered by sands, with polyspecies mixed forests

C_4 older river channels mostly marshy

C_5 valley bottom

(D) Typological units on the whole area

D_1 bottom of subglacial channels mostly with peat bogs and locally marshy

D_2 bottom of subglacial channels mostly with polyspecies mixed forest.

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MAPPING OF THE GEOGRAPHICAL ENVIRONMENT IN THE WEST CARPATHIANS

Zdzisław Czeppe

The demands of the law for the protection of man's natural environment together with a growing understanding of the need for such protection as a result of the rapid economic development of southern Poland have brought about an increasing interest in the results of studies of the geographical environment and of the interrelation between man and his environment, not only in planning offices, various branches of administration and services, but also in the larger industrial establishments. Geographical monographs and other publications that contain analytical data characterizing particular elements of the natural environment of any part of Poland are soon sold out. Many offices and institutions prepare their own reports concerning the natural environment of the areas interesting to them. Such reports are necessarily narrowly limited both in space and information according to the immediate needs of the department concerned.

There is a great need for maps and texts providing a synthetic picture of the geographical environments of large regions, prepared in a unified way, similar to geological and soil survey maps. Maps of this sort should satisfy the needs of various users. Therefore at first they should be made at the scale of 1 : 100,000 and should show types of geocomplexes. Knowing the definition of each type, one can easily work out the characteristics of any given area, and evaluate it for any particular purpose. The map should cover at least one voivodship in aset of sheets, for in practice only maps of administrative divisions are useful to potential users.

The Physical Geography Department in the Institute of Geography of the Jagellonian University in Cracow has for some years been engaged in working out the right method of mapping for the plateau and mountainous types of environment in southern Poland. The work began with mapping of geocomplexes of *urochysko* order (equivalent to *Ekotopgefüge*) at the scale of 1 : 25,000, within the catchment basins of the southern part of the Jurassic Plateau, where the components of the natural environment are comparatively well known and the differences in natural conditions caused by relief and surface geology are sharp. Uniform geocomplexes on the surface of the Plateau are often very extensive, while those in the valleys and gorges are small, but both frequently have definite limits, clearly visible in the field. Mapping the geocomplexes is therefore comparatively easy. The same method of mapping was used in the Carpathian Foothills and at the more detailed scale of 1 : 10,000 in the High Beskid, within the National Park of Babia Góra (1725 m a.s.l.). This proved to be a much more difficult task. The diversified relief and geology of the Flysh Carpathians, and especially the irregular changes in mantle rocks and soils, as well as a frequent lack of maps for the components of the natural environment, made the mapping of geocomplexes difficult and time consuming. Beyond the settlements it is often very difficult to get any detailed information about, for instance, the ground water level or thickness of the regolith, although it may be fairly easy to determine the general character of the geocomplex. Boundaries between geocomplexes are rarely sharp, unless marked by scarps or scars, such as those produced by landslides. Air-photo interpretation helps a great deal wherever it can be used.

Most of the actual mapping has been done by senior students as part of the research programmes for the master's degree. One student can map during his 6 weeks diploma practice about 30 km² of mainly agricultural country. Mapping of the former voivodship of Cracow which covered an area of over 15,000 km² would therefore occupy 500 students but we get only a few of them every year. Therefore an experiment has been undertaken to make a map at the scale of 1 : 100,000 by a mixed method of cameral interpretation of maps and air photographs, with the mapping of some chosen fragments of the area in the field. For practical reasons, we started doing it by administrative units called *poviat*, comparable with the former English county. The voivodship of Cracow consisted of 16 such units, excluding the county towns. Their areas varied from about 400 to over 1800 km². In the new administrative division operating since June 1975 voivodships are smaller and *poviat* disappeared. Nevertheless area to be mapped remained the same.

The whole work was done in 3 phases. First, an analysis of the components of the geographical environment is made for the whole area in question at the scale of 1 : 100,000. This is based on published and unpublished sources of various kinds. Spatial differentiation of the components and their relationships to each other are stressed. In this respect some features of a geocomplex are more important than others; for instance, fractional composition of the regolith may be much more important than lithology of the base rock, and the morphometric characteristics of relief are more important than the age of forms. Therefore the geomorphological map, if there is one, is supplemented by maps of slope declivity and exposure, and sometimes by maps of density of dissection and of relative height. In hydrography the first water-table, the extent of floods, and data concerning the potential water supply are looked for. For the climate, areal and vertical differentiation of such features as the length of frostfree period or the frequency of temperature inversions are needed.

On the basis of such an introductory, analytical studies a map of the smallest regional units — microregions — is prepared. With its help, 2 or 3 areas are chosen for field mapping. These should either be representative of some larger areas or they may be contiguous, to allow the boundary between two microregions to be checked in the field.

The second phase of work consists of mapping the basic geocomplexes in the previously delimited areas at the scale of 1 : 25,000. In the mountainous regions relief, geological structure and hydrographic conditions are the leading factors. The crest lines and stream net are usually axes of symmetry for the mosaic pattern of geocomplexes. Each geocomplex marked on the map is allocated a number, and is described on a separate form. The form contains the following 14 categories of information and most of them require only the entry of the right word or value: (1) administrative unit and identity number of the map; (2) height a.s.l. and relative relief; (3) declivity of slope in 11 classes; (4) exposure in 8 sectors; (5) lithology; (6) mantle rock type and thickness in 6 variants; (7) soil thicknes, texture class, permeability and acidity; (8) relief form, microforms, and observable processes in 10 variants, and their intensity (strong, moderate, weak); (9) ground water, including depth to the water-table in 13 classes, and surface water including 4 types of springs, and 3 types of streams; flooding, and mineralization of water; (10) microclimate; (11) land-use in 8 classes; (12) forest, composition and eco-type; (13) human activity; and (14) other information. An instruction leaflet helps the researcher to fill up the form.

The third phase of the work consists of the analysis of the information collected. First, geocomplexes are grouped into types, then according to the pattern on the map and the functional interrelations between them, bigger areal units are delimited. These are called "terrains". A unit of this order is characterized by one prevailing type of geocomplex with one or two other types recurring in a more or less regular manner. For example, a fairly uniform cultivated slope, dissected by narrow, v-shaped, wooded valleys, running more or less parallel to each other, would be classed as a "terrain". This type of terrain may appear frequently but individual stretches are separated by other types of terrain. Finally, microregions may be delimited or limits previously drawn may be checked.

The results of this work are presented in the form of maps of the units discerned, together with tables containing their characteristics, number and size; percentage of the area occupied by a given type, and the numbers of the individual units belonging to a given type. The written text also contains observations on the general harmony or disagreement of the present land-use with the natural conditions, as shown by the stability or acceleration of geomorphological processes.

Forested areas belonging to the state are not mapped in the field. There is detailed information available for these areas, and maps of the ecological types of forest and their actual composition already exist. Ecological typology of forests is based on the physiographic conditions, therefore we can accept areas occupied by the types of forest as equivalent to our basic geocomplexes.

So at the end we get a map of microregions at the scale of 1 : 100,000 and two maps at the scale of 1 : 25,000, showing the basic geocomplexes mapped in field for the chosen areas. Sometimes results of field mapping can be extrapolated, but as a rule numerous sample areas should be mapped in each microregion.

We are fully aware of the deficiencies of the present work. There are many theoretical, practical and technical problems. However, it seems that this method with all its shortcomings, many of which can and will be eliminated, brings us nearer to the recognition of the variety of types of environment of the West Carpathians, while it also provides much needed maps. The sections of the map already completed are much sought after, and this method of field mapping of geocomplexes has been successfully used in making maps for practical use in planning and in economic land evaluation.

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MAN'S IMPACT ON THE COASTAL ENVIRONMENT

IVAN P. JOLLIFFE

INTRODUCTION

When Henry David Thoreau (1817–1862) wrote: "Thank God men cannot as yet fly, and lay waste the sky, as well as the earth", he had presumably witnessed something of man's intrusion into the marine environment; an intrusion that has continued at an ever-increasing rate. However, many have been slow to realise, or at least to take seriously, the full implications of man-modification of a fragile environment; one that is vulnerable to rapid, and sometimes irrevocable, deterioration.

It has been suggested that at least three significant happenings in the present century have served to galvanise attention, in Britain, on the vulnerability of the marine environment (Coastal Ecology...), First, shortly after the turn of the century, the Royal Commission on Coast Erosion and Afforestation briefed

Fig. 1. Porthleven Harbour, Cornwall, England: use of detergent following the "Torrey Canyon" incident

the Parliament of the day on the numerous instances of existing (or potential) coast erosion, many of them in populated or otherwise exploited areas. Second, early in 1953, 300 people lost their lives and about 160,000 acres of land were flooded in south-east England, and heavy loss of life and property occurred around other parts of the southern North Sea, as a result of a major tidal surge. Third, 1967 withnessed the grounding of a super-tanker "Torrey Canyon", off Cornwall, with the release of some 100,000 tons of crude oil that ultimately affected extensive tracts of the coasts of Cornwall (Fig. 1) and Brittany (Coastal Ecology ...).

There have been other catastrophes since, as with the heavy oil pollution that occurred in Bantry Bay in late 1974. The paper reviews a broad spectrum of human activity in the marine environment and some of the problems related to such activities; though it does not attempt to be, nor could it reasonably be, a comprehensive discussion. It aims to illustrate the multiplicity and diversity of marine developments, on the premise that such an awareness is fundamental to sound coastal-zone planning and management.

THE COAST IN ITS NATURAL STATE

It is barely necessary to emphasise the dynamic nature of the marine environment. The existence of numerous variables, the complexity of the processes, the problems of observation and measurement, and the wide array of coastal types render systematisation and accurate prediction of future events in coastal studies extremely difficult. Coastal regime is easily modified by man intervention, sometimes intentionally, but often unintentionally. There has always existed a conflict of requirements: for many hundreds of years, man has endeavoured to rid river-mouths, harbour entrances, and harbour approaches of sediment, in the interests of navigation, while at the same time clinging desperately to sediments resident between harbours and river-mouths in order to secure adequate protection against coastal erosion and flooding. Modern technology makes the struggle less desperate.

Coastal systems often operate in dynamic equilibrium fashion. For example, the Ribble Estuary, England, experiences two quite separate yet superimposed systems of erosion and accretion. The first of these is the influx and efflux of sediment at the mouth of the estuary under the influence of wave and tidal action. The other is a shifting pattern of erosion and accretion further upstream in response to river flow: the higher river discharges in winter cause erosion upstream and siltation downstream, while the situation is reversed during the lower discharges of summer. Both systems have been influenced by channel dredging and by the construction of training-walls (Fig. 2).

Natural coastal systems may exist in the sense that there is often an approximate balance between sediment supplied to the coast via rivers, the sediment transported along the coast as part of the littoral drift, and the sediment ultimately lost offshore, possibly down steep submarine gradients like those of canyons cut into certain shelves. Indeed, such cells of sediment circulation have been identified along parts of the Californian coast. Moreover, the construction of harbour breakwaters has tended to divert beach sediments seawards towards certain of the canyons.

Coasts vary greatly in the amount of wave, tidal and wind energy they experience. Energy levels are fundamental to man's use of coastal and shelf regions. Tidal range helps to determine the strength of tidal currents, currents that figure prominently in problems of resource use. In general terms, high

Fig. 2. The Ribble Estuary, north-west England: artificially straightened and dredged (after Aerofilms)

energy waves occur mainly in storm wave environments, high to medium in west coast swell environments, low to medium-high in east coast swell environments, and low in enclosed seas and along Arctic and Antarctic coasts (Davies 1972). It is obvious, however, that most coastlines display marked spatial and temporal variations in energy levels that tend to blur such generalisations; and that the construction of breakwaters perpendicular or parallel to the coast may induce quite different hydraulic conditions affecting resource use. Offshore dredging may increase energy levels at the coast.

Sediment transport systems, which show subtle variations from place to place, generally fall into two main categories: free transport and impeded transport systems (Davies 1972). Where the movement of sediment along coasts is uninhibited, it may show marked fluctuations in direction: and there are many instances in which net littoral drift is but a small difference between big movements in opposite directions. For this reason, it is almost as serious to dredge downdrift of a particular beach as it is to dredge immediately updrift of it (Jolliffe 1961). Highly crenellate coasts usually experience impeded transport.

In the same context, the offshore zone displays both open and closed cells of water and sediment circulation. In the former case, sediments may travel considerable distances up-coast or down-coast, shorewards or seawards, even in relatively short periods of time; and largely, in respect of finer-grade sediments, under the influence of tidal streams (Jolliffe 1963a). In contrast, sediments may circulate within relatively well-defined areas, in a closed-cell fashion (Cloet 1954). Such contrasting patterns of circulation are clearly fundamental to fishing, navigation, and especially pollution control.

The coast of Britain displays a great diversity of coastal types: this is reflected in the lithology and structure of its rocks; the morphological forms that have evolved; and the enormous variety of coastal habitats and the diverse communities of plant and animal life that these support. Rapid variations in character may be manifest over short distances. This complex of physical environments and natural habitats collectively constitute unique natural resources that are highly susceptible to damage, sometimes irreversibly. This is particularly true of the delicately-balanced freshwater and marine ecosystems.

The character of the coast is all-important to coastal resource use, in numerous respects. The overall character of any coast, including the hinterland region, forms the backcloth or tapestry against which people live, work, play and relax in the marine environment. Clayey or crumbling cliff-faces, with outflowings of groundwater, make beach access difficult and beach use generally undesirable. Bouldery beaches may be virtually impassable, shingle beaches too steep for bathing and muddy beaches too soft for more than very limited use. The optimum beach for holiday use is obviously a flattish, though not too flat, beach formed in moderate to fine sand. Otherwise conducive surroundings may be marred by persistent winds. It is argued, therefore, that man's use of the marine environment should ideally be based on a sound understanding of natural coastal systems, and of his own perception of the marine environment. Regrettably, our knowledge of such systems is, as yet, incomplete, while perception studies in coastal situations are still little more than an interesting possibility.

THE NATURE AND EXTENT OF MAN'S USE OF THE COASTAL ENVIRONMENT

The coastal zone is difficult to define in strict spatial terms, and many different definitions have been applied. The National Parks Commission in Britain have taken the "coastal belt" to mean that part of the coast that lies between high water mark as indicated on the O. S. One Inch to the Mile maps and a line drawn 1 mi inland, i.e. a belt of uniform width. Collectively, this land strip represents only 4% of the total surface area of England and Wales (Countryside Commission ...). The high water mark is taken to refer to that part of the coast with a direct frontage to the sea together with all inlets that can be regarded as 'arms of the sea'. The term beach zone is taken by the author to mean the zone between extreme tide-marks; the breaker zone as the zone between the waters edge and the outer edge of the breaker (or surf) zone; and the offshore zone as the zone seaward of the breaker zone extending out to the line where wave action virtually ceases to influence the seabed, i.e., probably the shelf-edge line.

The coastline of mainland Britain is some 6000 mi long, that of England and Wales, 2742 mi. Of the latter, 2054 mi (or 75%) is substantially un-developed, many portions lying between towns and other settlements. Some 687 mi (or 25%) are already substantially developed or are, under present legislation, scheduled for development of one kind or another (Countryside Commission ...).

The pressures on the coast are diverse, and ever-increasing. This would present less problems if people, and their uses of the coast, were spread more evenly, both spatially and temporally. This is not so: for various reasons, people tend to concentrate in particular areas, so that some stretches of the coast are under immense pressure, other parts of the coast are hardly used at all. It is obvious that concentration in some areas is deliberate, forming part of coastal planning policies. On the other hand, concentration may be a direct consequence of the physical environment; since large tracts of coast are quite inaccessible, or are otherwise unsuitable for development, and are destined to remain virtually if not completely undeveloped; for example, along precipitous coasts, in excessively high-energy environments, and where the character of beaches is such as to virtually preclude their use for normal purposes. In the supply-and-demand equation, therefore, it is rarely sufficient to think merely in terms of numbers of people as against miles of coastline.

What are the pressures? Until the nineteenth century, only a few stretches of the British coast were developed — for fishing, commercial seaports, naval bases, and spas serving the leisured classes. The Industrial Revolution introduced more industry to the coast, concentrating especially around the larger estuaries. During the so-called Railway Age which continued up to 1914, seaside resorts constituted the major developments; the general trend towards amenity and recreation continuing after 1918. More recently, in response to growing recreational and leisure demands, beaches have assumed enormous importance, being regarded now as valuable resource assets. In Britain, the dominant function of the coast continues to be recreation and leisure. Investment in beaches and related facilities, together with real-estate developments, has been considerable. Pressure upon the more accessible beaches have increased, and man is actively engaged in retaining, improving, and even creating new beaches. There is a need for coastal footpaths, like that in Pembrokeshire, Wales. Marina developments have proliferated; marinas that range greatly in size and type, from those sited within sheltered waters like Chichester Harbour, Sussex, to others like Brighton Marina, Sussex, that involve the construction of substantial breakwaters, and the reclamation of land (Fig. 3). Extensive tracts of tidal marshland, like those within Boca Ciega Bay, Florida, are being developed for

Fig. 3. Brighton Marina, southern England: a stage in coastal reclamation and the construction of breakwaters

Fig. 4. Miami Beach, Florida: an amenity-recreational complex requiring defences against coast erosion and flooding

the same purpose; invariably involving filling and dredging operations, and reducing cubature of the areas in question. Caravans, chalets, huts and holiday-camps occupy many stretches of coast. Major tourist centres like Miami, Florida (Fig. 4), or Bournemouth-Poole in southern England, have expanded coastwise and inland; and entirely new coastal towns have rapidly evolved in countries like Spain and France. There has been a marked increase in water-based activities, perhaps occupying several miles width of coastal waters.

Urban and residential development in the wider sense is increasingly concentrating along the coastal strip. One estimate suggests that by the year 2000, roughly half of the estimated (412M) population of North America will live on only 5% of the land mass, land flanking the east and west coasts and the Great Lakes (Wenk 1969).

Industry and commerce impose heavy and diverse demands. By 1966, industrial and commercial development occupied roughly 157 mi (or 5.7%) of the coastal frontage of England and Wales (Countryside Commission). More recent (and proposed) waterfront development consists of the extension and development of docks and harbours — for example, super-ports that combine modern port facilities and industrial complexes. There are other industries whose special requirements demand coastal sites, often along the undeveloped coast: oil refineries (Fig. 5) and certain other industries require the import of bulk car-

Fig. 5. Shellhaven refinery, Thames Estuary: an industrial-port complex served by deep-draught tankers

goes; electricity generating plants need cooling water; coal mining and other extractive industries exploit coastal minerals; and natural gas from shelf areas requires shore-based facilities and undersea pipelines. There are increasing demans on raw materials of all kinds, many of which can be recovered economically from the marine environment.

The mineral deposits exploited in coastal areas include consolidated subsurface deposits (coal, iron ore and other metals), semi-consolidated or unconsolidated surface deposits (sand and shingle, diamonds, tin and other heavy minerals, oyster shell and so on), and fluids and soluble minerals (including oil, natural gas, sulphur and potash) (Wenk 1969). The sub-surface minerals like coal are mostly mined from tunnels or adits reaching out from beneath the coast; fluids and soluble minerals are extracted via boreholes from floating rigs and other structures. In environmental terms, the problems are less (except in the case of severe oil spillages, such as occurred at Santa Barbara, California) than those emanating from the extraction of the surface deposits. These are mostly dredged, largely from well out to sea; but in certain areas, they involve the mining of beaches, cliffs and dunes. In Queensland, Australia, for instance, iron ore and certain of the heavy minerals are derived in this way, so that considerable disruption of the coastal morphology and the littoral and backbeach ecosystem is really unavoidable.

Military use of the coast, by the various departments of the Ministry of Defence, is a significant category; again, its claims are widespread and diverse. It affects the land strip, for firing-ranges and equipment testing, and beaches for assault exercises and cliff-climbs; it affects also, the coastal waters for sea to surface firing ranges, underwater firing ranges, and air to sea ranges. Specialist weapon training and de-gaussing zones add to this. Much coastal land has

Fig. 6. Lulworth Cove, Dorset, England: a unique resource serving recreational, leisure, educational and military needs

deteriorated because of military use, but even more important is the loss of public access to considerable lengths of coastline and prohibited sea areas. The Dorset coast well illustrates this aspect (Fig. 6).

Science, Education and Wildlife conservation account for many coastal sites. They offer opportunities for geological ecological, historical and other studies. They include such areas as Scolt Head Island nature reserve in Norfolk and Dover Castle in Kent. All such sites need careful conservation, especially when they lie in close juxtaposition to populated areas. In fact, this use category conflicts with almost all other uses, especially in the case of nature reserves.

The need in all of the resource use categories is to cater for all legitimate interests, i.e. to maximise coastal resource use. But as with all other forms of resource development, there are many problems to be faced. There is the difficult problem of measuring the capacity of the coast to support various uses. There are the inevitable problems of conflicting uses, either between different uses or within a given use category. At Lulworth Cove in Dorset, recreation-leisure pursuits abut directly against military uses; at Pagham Harbour in Sussex, a large caravan and chalet development partly circumscribes a newly-created nature reserve of great ecological interest; while on almost every holiday resort beach, beach, inshore and offshore leisure-recreational pursuits are juxtaposed and may conflict, as where water-skiing and bathing coincide. Apart from their impact on wildlife, such activities call for careful zoning and disciplined management.

There are problems of beach quality, often arising out of toolittle sand, or perhaps the presence of pollutants, or both. Influxes of seaweed tend to downgrade the beach at Worthing, Sussex. Many public beaches are marred by adjoining privately-owned beaches in which the sea defences have fallen into disrepair. Coasts may become down-graded in the visual sense; at Galveston, Texas, advertising boards have been erected along the esplanade road, and even on the foreshore itself (Fig. 7). The need is to preserve, and enhance, coastal quality. Bournemouth, England, potentially suffers from too-little sand, for erosion has tended to reduce beach dimensions. A continuing programme of beach nourishment, using sand dredged from Bournemouth Bay, is now proving a viable method of sustaining the very considerable tourist industry which is largely orientated towards the local beaches. There are reports that hotels have been built in Hawaii, Spain, and elsewhere, with the beach being added afterwards. Unfortunately, there have been instances in which natural conditions have not been conducive to beach development, and the dumped material has been rapidly lost. The Principality of Monaco had, until quite recently, only privately-owned beaches. Its public beaches have been created by man, using sea-dredged materials; one example being Larvotto Beach.

Fig. 7. Galveston Eeach, Texas: an example of the down-grading of a sandy coastline throught advertising.

MAN-MODIFICATION OF COASTAL REGIME CONDITIONS

Coastal regime conditions are being modified by man, to a greater or lesser extent, in numerous ways. Some of the changes so wrought are essentially irreversible.

Coastal regime conditions may be significantly altered by up-river, up-estuary, and even inland structures and practices. At Port Swettenham, which lies at the mouth of the Klang River in Malaysia, up-river wharfage construction led to siltation problems. Because of foundation problems encountered in the mangrove swamp areas, close-spaced piling was essential, yet it obstructed tidal flow and resulted in siltation. The construction of the Kaptai Dam, 64 km upstream from the port of Chittagong on the River Karnafuli, led to marked morphological changes in the lower reaches of the river, though not all of these were detrimental. The Aswan Dam solved certain of Egypt's economic problems, but it also virtually halted the discharge of nutrient-rich water into the eastern Mediterranean which hitherto had supported commercial fisheries; also, it reduced freshwater discharge and thereby altered salinity levels for several hundred kilometres north of the delta. A further example is southern California, where flood-control structures, dams, and other works, many of which were built several decades ago, have tended to trap sediment loads that would otherwise have reached the coast to become part of the littoral drift system. There is evidence to suggest that many beaches have diminished in size (though not necessarily in importance) because of this.

Coastal resource use often involves reclamation works. These may be on a very large scale, as in parts of the Netherlands, or on a comparatively small scale, as in the minor filling operations that are effected along the lower courses of rivers and along estuarine shores. Not all reclamations are man-engineered: the water area of San Francisco Bay was 1751 km² in 1850, and only 1036 km² in 1968, but this was partly due to sediment discharge from the Sacramento and San Joaquin Rivers. Additionally, however, much silt resulted from placer-gold operations in adjacent catchment basins.

A small reclamation project proposed for Portsmouth Harbour, England, involving some 180 hectares of tidal mudflats, would have reduced the tidal capacity by roughly 16% thereby leading to some siltation in the main channels. Proposals to reclaim some 800 hectares in the Tees Estuary, England, could increase siltation rates by up to 40%, though the effect of widening and deepening the river would be to decrease siltation by some 25% (Hydraulics Research...).

Reclamations on a large scale are involved in the Dutch Delta Project. The environmental issues are numerous and involved, and make the point that because the scheme as a whole is in the interest of the entire community. the interests of various minor factions have usually to be overridden. For instance, the scheme involves the closure of a number of fishing harbours, and the culmination of the oyster-breeding industry in a number of areas. The hydrological issues are illustrated by the way in which closure of the Haringvliet will divert the freshwater flow of the Rivers Waal and Merwede, which should help to control groundwater salinity levels and incursions of saline water from seaward. Large expanses of seawater, "trapped" behind the coast, will ultimately be placed under recreational use. Changes in coastal configuration and patterns of freshwater discharge at the coast will gradually alter the coastal currents, together with their salinity, suspended mud and pollutant distributions. Whilst every attempt is being made, using scale hydraulic models and mathematical techniques, to minimise deleterious effects, the forecasting of such changes remains somewhat imprecise. Unfortunately, many previous projects have been inadequately documented.

Estuaries are particularly susceptible to man-modification; for example, as a result of the construction of docks, revetments, canal locks, and so on. The Mersey Estuary, England, was more or less in a regime condition during the nineteenth century, i.e. a state of dynamic equilibrium, in which there occurred fluctuations in capacity of a much as 40,500,000 m³ over five years, but these were fluctuations about a mean value. During the 45 years from 1861 to 1906, there was practically no net change in the tidal capacity of the estuary. During the ensuing 45 years, however, a marked decline occurred; the loss in capacity amounting to 72,900,000 m³. This decline coincided with, and was probably caused by, an increase in civil engineering work in Liverpool Bay and inside the estuary (Hydraulics Research...).

Coastal dredging generally falls into the following categories: (1) beach dredging for industrial purposes; (2) beach-offshore dredging for beach nourishment; (3) nearshore-offshore dredging for navigational purposes; and (4) offshore dredging for industrial purposes. All such practices, if carried out without due regard for ecological and hydraulic consequences, may have serious environmental repercussions (Jolliffe 1974).

There are numerous British examples of the removal of sand, shingle and rock from the littoral zone for such purposes as building construction, ball-milling, and pottery manufacture. Many licences were revoked earlier this century after Royal Commission and other reports had made careful appraisals of the sea defence implications; nowadays, stringent restrictions have been applied. Yet there are a number of instances of present-day beach mining that still give rise to fears. Beach mining in Shetland has destroyed populations of

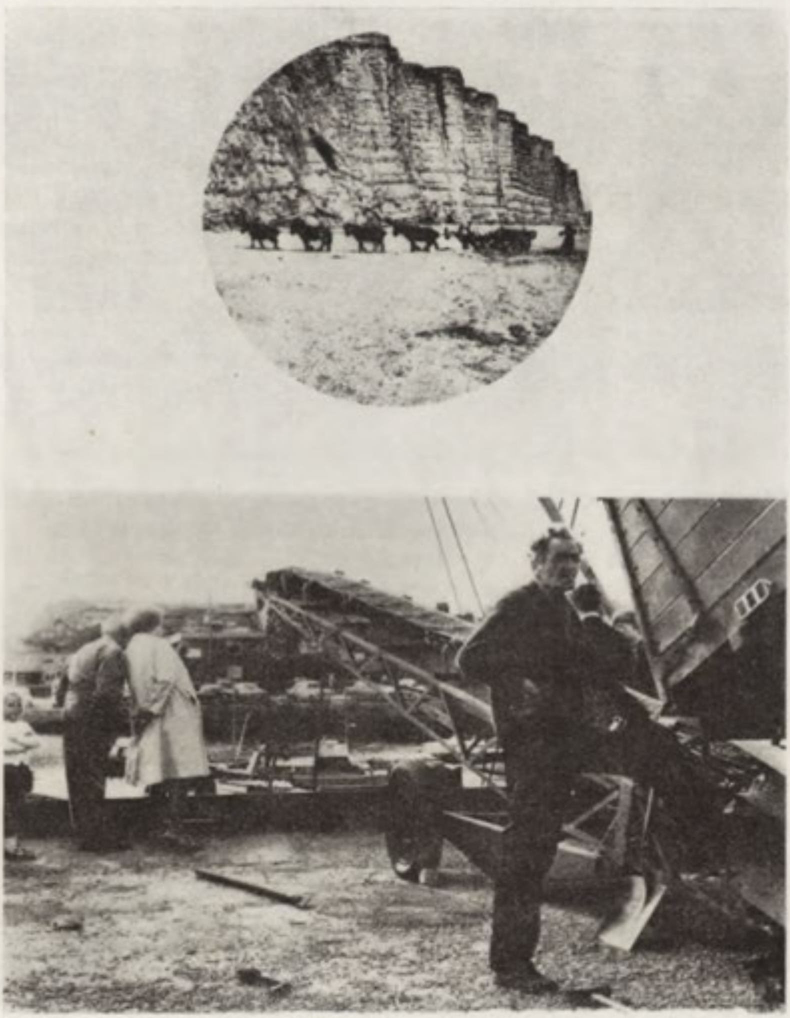

Fig. 8. East Beach, West Bay, Dorset: an example of continuing beach removal since 1828

the rare Oyster Plant (*Mertensia maritima*) (Coastal Ecology...). A number of sites along the world-famous Chesil Bank are dredged, ranging from peagrit (Fig. 8) and small shingle, up to large cobbles that are used in the cosmetic industry. The total rate of removal along Chesil Bank, though regarded by some as small, may prove critical to the future stability of the bank if it is no longer being replenished naturally.

Harbour-approach dredging is essential to the viability of many ports and harbours, particularly because of the increasing draught of ships using them. Giant bulk-carriers, including supertankers, make very heavy demands in this connection. Problems have arisen, however, not so much from a technological standpoint but rather from the effects such dredging has. In the Mersey Estuary, England, poorly-sited spoil grounds have led to the rapid return of silt to the estuary, thereby increasing the proportion of silt in dredgings and hindering the effectiveness of suction-dredgers. Ill-conceived dredging in Botany Bay,

Fig. 9. Marine aggregate plant, Port of London, England: one of many such plants handling offshore dredgings

Australia, in connection with the extension of the principal runway at Kingsford Smith Airport, led to erosion of Lady Robinson Beach and Brighton-le-Sands Beach, both of which are important amenity beaches serving the Sydney region. Such problems arose out of changed wave patterns inshore of the dredged areas (Jolliffe 1974).

At Thyboroen in Denmark, an inlet was opened up in 1825 for navigational purposes. It was cut through an originally straight offshore barrier. There ensued a continuing phase of erosion, on both sides of the inlet; during the period 1921–1950 the southern flank eroded at rates up to c.2.75 m/yr and the northern flank up to c.4.74 m/yr. In spite of sea defences, the beaches have steepened.

Similar problems may emanate from offshore dredging for minerals (Fig. 9). During 1970, more than 12M tons of sand and gravel were dredged from sites around Britain, sites that are limited for economic reasons, and because of navigational hazards, fishing interests, and considerations of coastal erosion. The industry is a rapidly expanding one. There are, in fact, several ways in which such dredging could affect coastal regime. First, dredging might intercept a natural feed to the coast, thereby reducing the quantity of littoral sediment and the natural protection it affords the coast behind. Second, increased depths in the dredged area could lead to increased waveheights in-shore of the dredged site, increased wave-energy at the shoreline, and accelerated erosion of the shoreline. Third, increased depths in the dredged area can alter the angle of incidence of waves onto the beaches and also the tidal circulation patterns inshore of the dredged site, thereby altering the rates (and even directions) of littoral drift, and the incidence of erosion and accretion. Dredged areas have, on occasions, been shown to be focal points where fish gather in response to the presence of abundant food or shelter, to be spawing-grounds, or productive trawling grounds. The turbidity levels caused by dredging may be very detrimental to the marine ecosystem (Jolliffe 1974).

In the absence of human intervention, coasts would change, sometimes rapidly, sometimes slowly, but in harmony with prevailing, natural conditions. Erosion and accretion would fluctuate within natural dynamic coastal systems. The presence of man in coastal areas demands protection of one sort or another against erosion, siltation and flooding: but this interferes with natural systems. Sea defence structures have proliferated, and large tracts of Britain's coastline display numerous defensive structures. They take many forms, both large and small; seawalls, jetties, moles, harbour breakwaters, permeable and impermeable groynes, wave dissipators, wave screens and so on. While many such structures have proved successful in terms of their primary function, they have given rise to many secondary problems.

Seawalls may be so steep that they lead to wave overtopping and the loss of beach material to areas behind them. The same waves may scour the ground behind the wall. Breakwaters may trap sediments on one side, thereby reducing harbour situation but may also intensify erosion on their downdrift flank. A large breakwater constructed at Santa Barbara, California, led to erosion that spread 16 km downdrift after only a few years. Likewise, systems of groynes usually lead to the development, at their downdrift end, of a scour area (Fig. 10). In counter-drift situations, the scour may occur at both ends. Such terminal scour problems exist at Seaford and Eastbourne in Sussex, Deal in Kent, Aldeburgh in Suffolk, and at numerous other coastal sites. Coastas are becoming increasingly "compartmentalined", as sea defence systems that effectively inhibit littoral drift proliferate. This has obvious legal and administrative implications.

Fortunately, modern technology may provide solutions to many of these problems, utilising such techniques as sand by-passing (eg. South Lake Worth inlet in Florida), nearshore nourishment using suction-dredgers (e.g. Bournemouth, England) controlled dredging and nourishment programmes (e.g. as practised in parts of Kent, England); and the use of synthetic seaweed to trap sediments on the inshore submarine slope. Again, secondary problems have arisen, as when plastic seaweed has fouled boats' propellors and even swimmers.

Some of the most vulnerable parts of the coast are dune areas, being subject not only to wave and wind erosion but also to the trampling caused by pedestrian traffic. But even dune stabilisation can lead to problems: on the Outer Banks near Cape Hattears, North Carolina, dunes were bulldozed to prevent wavee washover, but this had the effect of concentrating hurricane wave energy on the foreshore with consequent loss of beach. The lower dunes, by allowing washover, enabled sand from the seaward flank to be supplied to the backbeach zone.

The exploration and exploitation of oil and natural gas has had a far-reaching impact on the marine environment. Numerous structures, including floating platforms and pontoons, have been sited in the offshore zone. Trans-shipment and transportation of crude oil often requires single- or multi-point mooring systems, pipelines on the sea surface and along or under the seabed, and float-

Fig. 10. Lowestoft Harbour, England: an example of terminal scour due to the construction of walls and groynes (after Aerofilms)

ing storage tanks or tanks placed on a moveable seabed. Off California, man-made islands have been built as oil-drilling platforms; and in order to satisfy the aesthetic demands of Long Beach residents they have had to be camouflaged. In time, they may be converted into offshore recreational sites. Supertankers, like all bulk-carriers, raise many problems: they are difficult to manoeuvre, they require minimum depths of 20 m or more, and there are few ports in the world that can accommodate them or their cargoes unless they remain well offshore. Pollution of the open coast, because of crude oil or fuel oil from ships at sea, occurs all round the British coastline. Navigation presents many problems to bulk-carrier ships, and there have already been collisions and groundings. Some of the world's critical shipping-lanes include the Dover Straits, the outher Thames Estuary, the Gulf of Maracaibo and the Malacca Straits. The problems multiply where dangerous cargoes are being carried.

A multiplicity of pipes and cables lie upon, or beneath the seafloor. Some are jetted into the seafloor sediments, others are left to articulate and partially bury themselves. But like oil rigs, outfall pipes, and other structures, they are prone to damage, from dredging, or from shifting sediments, and may lead to serious pollution. Submerged tunnels, like that connecting Hong Kong Island with the Kowloon Peninsula, are similarly vulnerable. Floating and semi-submersible rigs, and other offshore structures, are navigational hazards.

Perhaps the most widespread modification of the marine environment stems from pollution. The situation of a century or more ago might well have been described by words from *Pilgrims Progress*: "In this land they heard nothing, saw nothing, smelt nothing, tasted nothing that was offensive". Indeed, up to comparatively recently, it was assumed that the natural processes of dispersion, dilution and breakdown would soon reduce all pollutants to a harmless state (Wenk 1969). However, the sheer bulk of waste products placed in the sea, including a number of "non-perishable" wastes, creates very many problems, and fears for the future.

Marine pollution takes many forms. The more important classes of pollutants discharged into estuaries or the open sea are: sewage, heavy metals, organochlorine compounds, industrial effluents, cooling water, oil, radioactive discharges, spoil from mining and drilling at sea, and inert wastes that include colliery and china clay waste, and dredgings. Generally, discharges of pollutants into coastal waters do not present such acute problems as discharges into estuaries because the potential diluting factor is so much greater (Royal Commission...). Estuaries are, amongst other things, natural productivity traps, and obvious areas for the practice of mariculture. Hence, this industry is very susceptible to the generally high pollution levels encountered in estuaries, and awaits legal safeguards.

A Royal Commission Report (1972) points out that the discharge of sewage can affect: human health, on account of pathogenic bacteria in untreated sewage; fish, because the oxygen content of the water is increased; plant growth, because of the presence of excessive amounts of nutrients; fish nursery grounds and spawning grounds, because of sludge dumping at sea; and bird life and mammals, if the discharges contain certain industrial effluents. The build-up of heavy metals in the sea, partly because of the concentration effected by certain species, can have lethal effects — witness the case in which inhabitants around Minimata Bay, Japan, suffered an epidemic of neurological disorders which was eventually traced to mercury poisoning from eating fish and shellfish. Organochlorine compounds used as pesticides have raised anxieties, for they are very toxic to crustacea, and pesticides may slowly accumulate in the bodies of certain species of fauna that include sea birds, seals, and large fish (Royal Commission...).

Other effects outlined in the Report include thermal discharges into the relatively cool waters around Britain, which have had both detrimental and beneficial repurcussions: they have caused certain kinds of bottom-dwelling species to spawn much earlier than usual, as when small molluscs off the power-station outfall at Hunterston in Ayrshire spawned, though not very successfully, three months early. Set against this, thermal discharges from the Marchwood power-station in Southampton Water have produced a fast-growing, viable colony of the American hard-shell clam. Oil spills, perhaps not so serious well out to sea, can be very serious in more confined coastal and estuarine waters. There are very many documented cases of the deaths of sea-birds, often in large numbers, and these include between 150,000 and 450,000 birds lost annually because of oil pollution in the North Atlantic-North Sea. Fish and shell-fish may develop a persistent oily taste which renders them unfit for human consumption. Oil influxes onto beaches constitute a serious amenity problem, while the use of certain detergents (Fig. 1) may be even more harmful and toxic to marine organisms (Royal Commission...).

The dumping of inert wastes, like pulverized fuel ash or the residues from china-clay production, may blanket parts of the seafloor and increase turbidity levels above the seafloor, making these areas unsuitable for organisms like lobsters and crabs. The same wastes, like sewage sludge, may damage spawning and nursery grounds, unless the dumping grounds are carefully selected (Royal Commission...). Such effects have already been discerned in certain Cornish bays and off the North-East Coast of England. Industrial wastes discharged off the Durham coast have down-graded littoral and sub-littoral kelp forests, with obvious implications for the marine ecosystem as a whole. The effect of littoral drift and the on-shore drift of water may be to carry wastes on to amenity beaches, even considerable distances from the dumping sites. Discharge of coal wastes along the Durham coast has downgraded sandy beaches, and is thought to have reduced light penetration in important areas of kelp-forest, even some distance offshore. Quarrying at the coast has disturbed seabird populations. Even off-shore dumpings in comparively deep water may create problems, as when drums of waste cyanide arrived back on the Cornish coast. Poorly-sited spoil grounds, and almost any dumpings at sea, may, if they occur within an open-cell circulation system, affect places some distance away, even some time after, dumping has occurred. The use of plastic drifter cards qualifies this fear.

Man's impact on the biological resources of the sea is by no means limited to the effects of pollution. Over-fishing has, and still is, a critical problem. Several decades ago, the salmon industry of North America's west coast suffered dramatically from over-exploitation, the Sacramento River of California being virtually cleared. The polar and sub-polar regions suffered a similar setback to the whale industry. In spite of improved policies and techniques, it was concluded less than a decade ago that fully-fished or over-fished stocks included: some tunas, in most ocean areas; herring, cod and ocean perch in the north Atlantic; and anchovy in the south-east Pacific.

One Coastal Ecology Report (Coastal Ecology...) suggests ways in which fauna and flora at or behind the coast may be threatened. Such changes are manifest in numerous ways. Water-tables close to built-up areas may become lowered because of domestic and industrial extraction. Lowered water tables in dune areas are thought to have impoverished flora in dune slacks at Ainsdale, Lancashire, and in Holland. Increased freshwater discharge into estuaries occurs as a result of improved drainage of agricultural land bordering on the coast: this may alter salinity gradients and ultimately the zonations of estuarine fauna and flora. More intensive crop cultivation near the coast may alter both the rate of accretion on salt marshes and the turbidity levels in estuarine waters because of the increased sediment loads arriving at the coast (Coastal Ecology...). The Report goes on to state that far-reaching changes in trophic (food) relationships may be wrought in estuaries and other coastal waters because of influxes of nutrients and toxins (which result from the use of fertilisers, chemical sprays and fertilisers, domestic and industrial effluents, and oil pollution). Apparently, this has most affected certain of the estuaries in southern England, including Poole Harbour, Dorset. The seasonal trampling of holiday-makers may quickly destroy dune vegetation, and enhance the damage to cliff-top turf already suffer from drought and salt-spray (Coastal Ecology...). Dunes at East Head, and at Camber, Sussex, soon called for fencing off and careful restorative measures; while grass-covered coastal slopes at Lulworth Cove, Dorset, have suffered a similar fate. Plants like Sea Lavenders are rapidly downgraded because of grazing; while Eel grass (*Zostera*), on which the famous Brent Geese depend, is very susceptible to disease (Coastal Ecology...).

LEGISLATION, ADMINISTRATION AND RESEARCH

Management of the coastal zone is made more difficult because of its fragmentation into numerous zones of jurisdiction. Private ownership is superimposed on public ownership. The United States, for instance, has 24 states, more than 240 counties, something like 600 coastal cities, townships, towns and villages, and numerous regional authorities and special districts (Wenk 1969). They all have their own regulatory powers and special terms of reference. The problem in Britain and elsewhere is basically similar. A further problem in Britain stems from the fact that the responsibility for waterfront land falls within numerous jurisdictions, both public and private, while the seabed and overlying waters directly adjacent to this land are owned by the Crown.

The need for improved monitoring, legislation and administration can be illustrated by three simple, yet typical problems: (1) In the cases of beach groyning in which the terminal scour areas develop, such eroding areas often lie within the area of jurisdiction of a neighbouring authority. For instance, groyning carried out for the Deal Corporation in Kent led to erosion of a shingle bank maintained by the Kent River Authority. (2) Offshore dredging may result in the removal of material that forms part of an open-cell circulation system, in which event the dredging may affect conditions some distance away, even some time after, dredging has been carried out. (3) Pollutant discharges into the sea may be carried, in significant amounts, into other territorial waters, or into fishing-grounds used by several countries. Norway strongly objected to one British proposal to dump industrial effluents and sewage in the outer Thames Estuary, claiming that metal salts might ultimately affect their fisheries.

Among the general improvements being sought in Britain are that with regard to pollution control the central Government should integrate "regional" coastal management policies within a national policy; that steps should be taken to unify or co-ordinate the activities of all authorities exercising jurisdiction over coastal areas (Royal Commission...).

It should be clear, from the foregoing discussion, that coasts constitute valuable, yet vulnerable, resources; their exploitation calls for careful scientific study and monitoring, improved legislation, sound planning, and disciplined management — an important contribution towards which can be made by geographers.

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THE CHANGES IN THE LANDSCAPE CAUSED BY MAN'S ACTIVITY IN THE SANDOMIERZ DISTRICT

RYSZARD CZARNECKI AND IRENA MARIA GRZYBOWSKA

While investigations of anthropogenic changes in the landscape usually refer to industrial regions, the present study deals with the Sandomierz district which is predominantly rural. Our study was worked up almost exclusively from analytical examination of landscape map; this is the reason why it is limited in scope and principally concerned with defining the problems involved.

The Sandomierz district lies in the central part of the Lesser Poland Plateau, with the Vistula river as its eastern and south-eastern boundary. It covers 766 km^2.

For evaluating the anthropogenic changes it is imperative to sketch, even in the briefest manner possible, the initial landscape as it must have looked before the first agricultural and pastoral tribes arrived. This period was the early Neolithic (or the mid-Atlantic), some 6000 years BP. To the warmer climate ruling at that time W. Szafer (1972) ascribed an extensive spread of compact mixed and deciduous forests. However, ecological conditions in the Sandomierz district were by no means uniform: its larger central part, some 60% of the total, is formed by a loess upland dissected by deep valleys. W. Szafer (1972) believed that in this part a *Querco-Carpinetum* assemblage has been growing which up to this day is the most important forest stand. According to the consensus of many authors, A. Musierowicz, K. Konecka-Betley and F. Kuźnicki (1963) among them, brown soils would have been found underneath the forest cover. In today's loess mantle an important part is also played by chernozems which are believed to have originated beneath grass or a wooded steppe.

In the northern and southern parts of the district the loess mantle is discontinuous, and often the ground surface consists of sands and loams of glacial accumulation. Here the upland is incised by shallow valleys of much smaller depth than those in the loesses; moreover, occasional dunes may be observed.

By investigating contemporary profiles of the forest soils on the slopes, it seems probable that during the Atlantic period the soils had well developed profiles both in the loess area and in the parts covered by sands.

Along part of the boundary of the district the narrow flood plain of the Vistula extends. During the Atlantic this was worked over by the meandering river and covered by silt, probably also carrying a swamp forest. Only the dunes situated on an older sandy part of this plain carried a coniferous forest. It is likely that a forest of swamp trees and alders grew in the valley bottoms of the smaller upland streams.

The differences between the Neolithic landscape and the landscape observed today are not only the result of man's activity but of climatic changes as well, although it is very difficult to separate the effect of these two agencies. Here

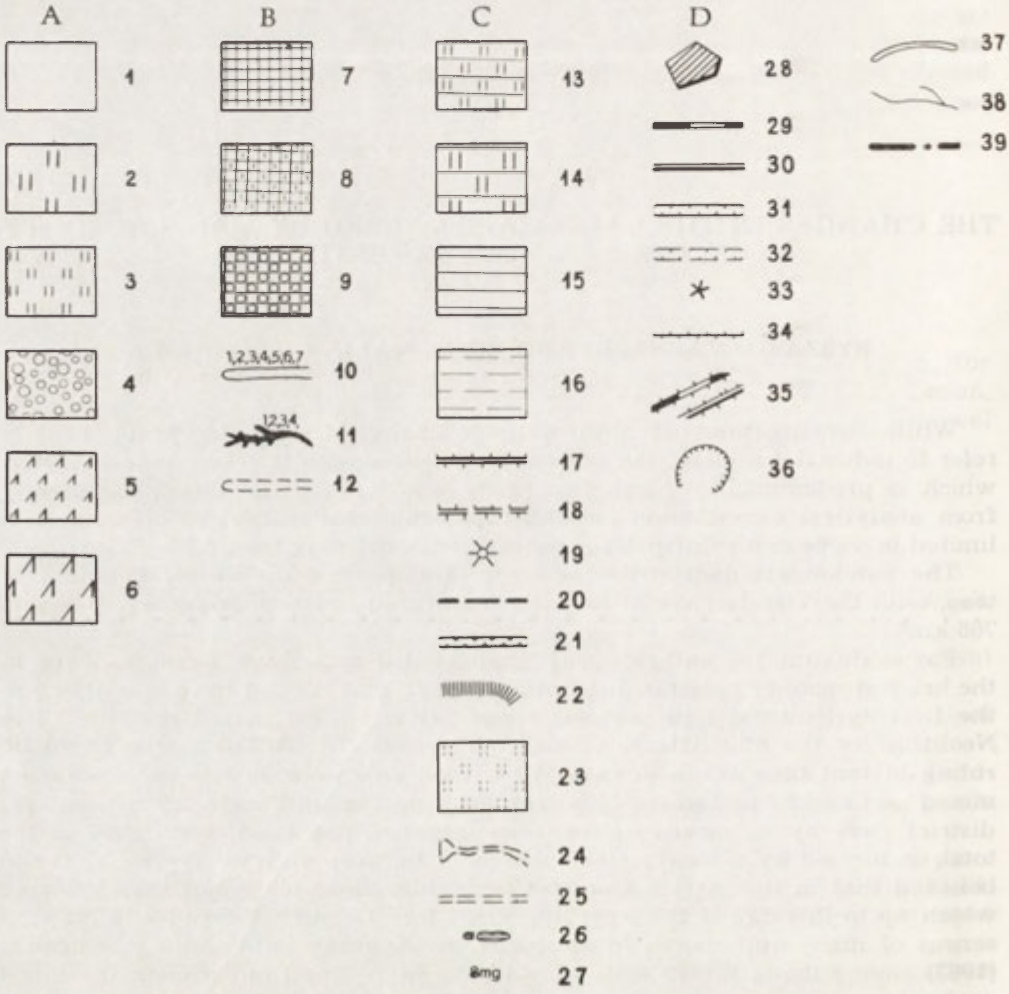

Fig. 1. Changes in the landscape caused by man's activities in the Sandomierz district (Legend)

A. Changes developed due to man's direct activities upon vegetation on not denuded or slightly denuded areas:

1 — cultivated fields; 2 — meadows, cultivated; 3 — meadows; 4 — river-bank brushwood; 5 — young forest planted on habitat which has passed the agrocenoses stage; 6 — forest on old forest habitat;

B. Important changes developed due to man's indirect activities in consequence of denudation (strongly denuded areas):

7 — ploughed land areas with secondarily non-developed soil profiles; 8 — areas strongly eroded underneath turf cover; 9 — steep scarps covered by forest or by planted tree stands; 10 — flat-bottom ravines: 1 — occupied by agrocenoses; 2 — occupied by agrocenoses on slopes and meadows on floors; 3 — with turf growth on slopes and meadows on floors; 4 — with turf growth on slopes and shrubs on floors; 5 — with trees and shrubs planted on scarps and meadows on floors; 6 — with forest growth on slopes and meadows on floors; 7 — overgrown by forest; 11 — V-shaped ravines: 1 — lacking soil and vegetation; 2 — with turf growth; 3 — with planted trees and shrubs; 4 — overgrown by forest; 12 — bowl shaped ravines.

C. Changes developed due to man's direct activities upon hydrographical conditions:

13 — meadow melioration; 14 — meadow melioration and cultivation; 15 — ploughland melioration; 16 — ploughland draining; 17 — flood control embankment; 18 — flood control embankment,

we shall discuss matters of undisputed anthropogenic origin which led to changes in the landscape.

First of all, man's activity was turned upon the most readily changeable elements of the landscape: the vegetation cover and the animal world. A large part of the forest was cut down very early, and the remaining forest stands have been modified many times and now cover barely some 4% of the district. These forest patches occur for the most part in the sandy regions. Also shown on the map is the brushwood vegetation growing on some parts of the flood plain. By far the greatest part of the district, some 86%, is now cultivated land. Industrial plants are rare, and, as mentioned above, the economy is strongly agricultural in character.

Cultivation initiated and gradually intensified processes of denudation. We shall discuss in greater detail the manifold results of these processes. Denudation and related accumulation of eroded sediments developed in particular intensity on the loess areas; in modern times they are the principal landscape-forming processes. Denudation has flattened the original irregularities of the ground surface of the upland; in older valley forms, benches and steps were obliterated, slopes were lengthened and become more gentle, on valley floors an accumulation of colluvium occurred, alongside the undercutting boundary strips on steep arable land. On the slopes, mature and well developed soils were transformed into varieties of eroded brown soils, and into new soils lacking secondarily developed profiles. In valley bottoms and other depressions colluvial brown soils and redeposited chernozems were formed. In this way differences in soil quality were developed, especially in the loess areas. Generally speaking, these processes lowered the fertility of the soils. Even today denudation continues unimpeded, for so far no preventive measures against soil erosion have been undertaken in the Sandomierz district.

Up to now no detailed studies have been made of the extent of surface denudation. However, adopting the commonly applied criterion that on loess soil erosion occurs on slopes of 3% and above, R. Czarnecki (1970) estimates from his field measurements that about 33% of the area of the Sandomierz district suffers erosion. Earlier, calculations of slope gradients from the map made by other authors yielded higher figures 40% to 50%. Areas not eroded at all, or only to a limited extent, and part of the areas of accumulation now transformed into tilled land or into orchards, have not been marked separately on the map (Fig. 1a and 1b) and appear blank.

Areas strongly subject to erosion are usually identified from slope gradients measured on maps. However, since slope alone might not be the only control on the rate of erosion, in our study all areas subject to considerable denudation have been identified on the basis of soils lacking secondarily developed profiles. Z. Mazur (1963) holds that through erosion these soils can lose 75% to 100% of their profiles. On the map (Fig. 1a and 1b) these truncated soils are shown

abandoned; 19 — watermills; 20 — millraces, artificial water courses, improved streamlet channels; 21 — "V-shaped gullies" of antropogenic streams; 22 — boundary of depression cone of open-cast mine, 23 — dried-out meadow within boundaries of depression cone; 24 — dried-out lake within boundaries of depression cone; 25 — artificial stream bed, dried-out within depression cone; 26 — artificial water basin; 27 — river water pollution: BZT_5 in mg/l O_2.

D. Sundry changes developed due to man's activities:
28 — compact town and village building areas; 29 — railway line; 30 — highway; 31 — road incision; 32 — road incision, abandoned: 1 — with natural or semi-natural vegetation, 2 —ploughed over; 33 — mounds, barrows, mine dumps; 34 — dykes; 35 — road and railway embankments; 36 — exploitation pit.

Others: 37 — lakes; 38 — rivers; 39 — district boundaries.

Fig. 1a. Fragment of the map "Changes in the landscape caused by man's activities in the Sandomierz district"

Fig. 1b. Fragment of the map "Changes in the landscape caused by man's activities in the Sandomierz district"

by lines following the contours and are emphasised by cross-hatching. Tilled soils and mature soils underneath turf covers are shown separately. The latter occupy fairly large areas: 11% in loess areas, some 7% in the whole district. Also marked on the map are steep scarps covered by forests or plantations.

It is commonly believed, that it was man's activities that caused erosion — a natural process initiated by deforestation — and that really man is responsible for starting and furthering the formation of gullies. However, preliminary studies made by R. Czarnecki (1969) of the soils found in gullies suggest that these, or their initial forms may have already existed in the ancient forests; ravines of the same type are seen even in present-day forested areas. Later deforestation led to the growth of such features and to the development of an extensive system of gullies. The subject has received considerable attention in literature, so that further comment here would be out of place. On the map, different symbols have been introduced: a thin continuous line for gullies with flat floors, a heavier black line for sharp-edged gully forms, dashed lines for bowl-shaped forms. The density of gully forms is up to 8200 m/km^2 and they cover some 2% of the district; 95% of all ravines occur in the loess area. In modern times man's activities considerably affect these gullies, especially the bowl-shaped forms; while even the flat-bottom and V-shaped gullies are but to use by ploughing across them, modifying them towards natural forms of a more mature phase. This is one of the instances where man operates to speed up the natural relief evolution.

Many authors have studied and written about flood plains in the valleys of the Polish Lowland rivers, such as E. Falkowski (1970). He suggests that it has been the increased rate of deforestation which since the 17th century has been the principal of changes in river regimes. It is during the last few centuries that a new fragment of the Vistula flood-plain has been developing.

As well as these problems connected with erosion it seems worth paying attention to some aspects of the ways in which human activities are reflected by changes in hydrographical conditions. The action which probably led to the farthest reaching consequences was the building of flood control embankments along the Vistula river and within the confines of the Vistula flood plain, the construction of new channels and high banks for the tributairies of the river. In consequence, the accumulation of alluvial material came to an end over most of the Vistula flood plain; in a morphological sense the flood plain became stabilized; the soils are affected by percolating rainfall and ground water oscillations, and they are now less waterlogged. As a further result of this river regulation work, the Vistula channel was reduced in width and during the 20th century a narrow belt of a new flood plain was formed at a lower level.

In the valleys of smaller streams the minor flood control measures carried out are of but local significance, channel regulation is rare. On the other hand, here many watermills and millraces were built, as on Koprzywianka creek where they line almost its entire course. The map (Fig. 1a and 1b) also shows areas where land improvement works, mostly of meadow areas, have been performed; this sort of reclamation is of considerable extent, covering some 4000 ha; the aim has always been to drain the land. One impact of the few nearby industrial plants is the pollution of some of the streams due to waste water release. In the Opatówka river this pollution exceeds the allowable concentration and is assigned to Class III, while the Koprzywianka and the Kacanka creeks are Class II. On the other hand, the Vistula shows insignificant pollution in the Sandomierz district, partly due to the pure water of the San river which joins the Vistula below Sandomierz.

Around the sites of open-cast mining in the Vistula flood plain, a considerable subsidence of the groundwater table has taken place; this has caused drying-out of some ponds and lakes and led to the ploughing of former meadows and to the planting of tress on the dunes.

Among further changes caused by man's activities the map indicates buildings (usually farmsteads), the railway network, the most important country roads and highways, and road cuttings, active or abandoned, sand and gravel pits, dams and dykes, burial mounds and waste dumps.

In the course of our work we have observed a number of further problems, such as: the transformation of the physical and chemical properties of the soils due to cultivation, the effect of fertilizers and manure upon the chemical composition of surface and underground waters, changes in the floral composition of meadows due to land cultivation, and many other phenomena which require separate detailed investigations by a variety of disciplines like pedology, meadow science, ecology, hydrology, etc. Nor have we taken into consideration other changes caused by industrial activities such as air pollution, noise, etc.; however, here, these are of minor importance in view of the low degree of industrialization in the Sandomierz district.

Despite the fact that this survey is far from exhaustive, some conclusions can already be drawn.

(1) Although the economy has always been almost exclusively agricultural, the natural landscape has undergone very considerable changes. Applying Isachenko's (1965) four-degree classification, the Sandomierz district can be assigned to group III — a strongly transformed landscape.

(2) The transformation of the district is far from uniform and an important factor is the character of the physical landscape. By observing associations of different kinds of changes, we may distinguish three areas: I — the loess upland, where the main landscape-forming process, soil erosion, has been initiated by man's activities; II — the flood plain of the Vistula river where the main source of natural change, alluvial accumulation, has been much reduced; and III — the least altered part of the upland, the area of sandy-loamy deposits.

(3) Reflecting upon man's interference with particular components of the transformations observed, it appears that most completely modified were the vegetation cover and the associated animals, with less fundamental effects on landforms, soils, surface waters, and the meso- and microclimate. Finally, least affected were the underground waters and the geological surface deposits.

(4) In spite of the lack of historical studies it seems, that in man's activities the vegetation cover and the animal world were the first to be transformed, being the most readily changeable elements yielding easiest to short-term moulding into altered forms. Later on, the more indirect effects of man's activities came to be more significant, mainly processes of denudation and their consequences. At the same time, man gradually diverted his direct actions to landscape components more resistant to transformation as he drew on the resources of his expanding technology.

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THE NATURE AND PERCEPTION OF THE BUSHFIRE HAZARD IN SOUTHEASTERN AUSTRALIA

M. C. R. Edgell and E. H. Brown

This first part of this paper reviews the nature and impact of and adjustments to bushfires in southeastern Australia. The second part deals with a preliminary examination of the manner in which the residents of one high fire-danger area, the Dandenong ranges in Victoria, perceive and adjust to bushfires as part of their environment.

BUSHFIRES AS PART OF THE AUSTRALIAN ENVIRONMENT

A wide range of forest, woodland and grassland ecosystems in Australia are dependent upon periodic fires and a large proportion of Australian plants is pyrophylous, having morphological and physiological adaptations that allow them to tolerate, depend upon or utilize high fire frequencies. Additionally, many are highly flammable and burn predictably and inevitably [1].

Fire was therefore as much a part of the Australian environment before white settlement as was drought. James Cook called Australia the continent of smoke. After the colonisation of Botany Bay in 1788 early reports attested to the frequency and ferociousness of fires, and on December 27th, 1790, the first recorded blow-up day occurred [2]. From the middle of the 19th century bushfire records describe wholesale conflagrations that ignited vast areas, especially in Victoria. On February 6, 1851, Black Thursday, with the shade temperature standing at 47°C in Melbourne, the State of Victoria suffered the most extensive fires since white settlement. In 1878, 1886 and 1898, there were further disastrous fires, a major cause was then, as so frequently now, uncontrolled and careless burning-off. The most notorious of these holocausts occurred on Black Friday, January 13, 1939, when much of southeastern Australia was ablaze. More recently, on 7 February 1967, 62 people died in Tasmania in fires that swept over 263,000 ha in five hours [3].

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NATURE OF THE HAZARD

Bushfire in Australia is a general term applied to any fire burning over a large area in a variety of fuels. Three main types can be distinguished. *Forest fires* originate and burn mostly in forests and woodlands of economic, silvicultural or protective importance. *Bushfires, brushfires* or *scrubfires* are terms sometimes specifically applied to fires burning in areas of low timber value, but which may burn in areas of high recreational, aesthetic or residential values. *Grassfires* run predominantly in grassland, but also in open savanna type vegetation and agricultural areas, especially grain crops.

Eighty per cent of Australia is affected by bushfires, and approximately 23,000 km² are burned each year (Figure 1). The remaining 20 per cent does not burn because fuel accumulations are small due to low rainfall. Combinations of fuel availability and continuity, together with climatic conditions, especially of erratic summer rainfall, are such that the probability of major and extensive fires is highest in the densely populated southeastern parts of Australia which

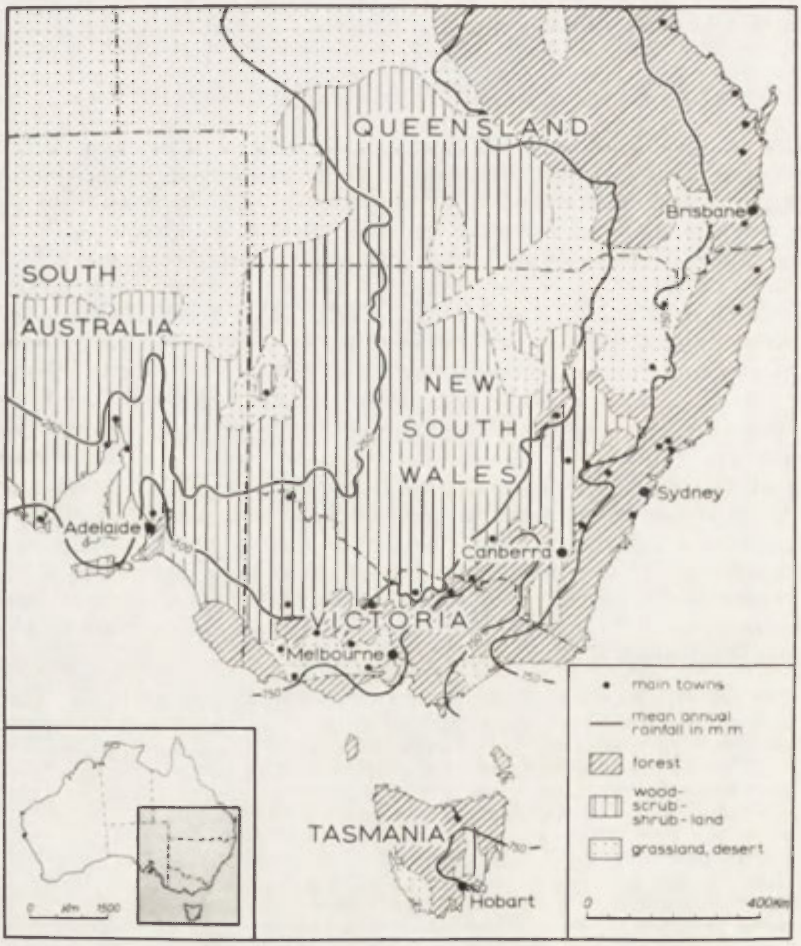

Fig. 1. Southeastern Australia

face major fire problems on average every other year [4]. Highest danger levels and damage potential occur in Victoria, which is rivalled only by California as a fire-prone area.

Under pre-European conditions, the frequency of fires set by lightning and aborigines varied considerably. Sub-tropical and wet temperate rainforests were perhaps never burnt. Wet sclerophyll Eucalypt forests of the subalpine regions were burned at intervals ranging from 50 to 350 years. The extensive dry Eucalypt forests of the 600–1,000 mm rainfall zone were probably burned once every 11 to 20 years, and the vast areas of grassland and savanna woodlands of the 300–600 mm rainfall zone perhaps once very 5 to 7 years. Because of fuel paucity, fire frequencies decreased to once every 30 to 50 years in the arid and semi-arid regions of the interior. Some of the extreme arid regions were probably never burned [5].

Fires are now less frequent as a result of modern fire protection practices, but the flammability of many forest areas has risen due to increased fuel accumulations, a situation not fully offset by recently introduced fuel-reduction programmes of control burning. In general the size and destructiveness of individual fires, especially in the wetter Eucalypt forests of southeastern Australia, have increased.

Adding to the seriousness of the problem are suburban expansions into fire-prone bushland and forest, especially in the Stirling Ranges of West Australia, the Adelaide Hills of South Australia, the Blue Mountains of New South Wales, the Dandenongs of Victoria, and the suburban areas of Brisbane and Hobart. From such difficult and inaccessible terrain many fires have spread to threaten and destroy more densely populated areas.

The least severe and most common form of forest and bushfire is the two dimensional *surface fire* which burns on the forest floor, and which because of unfavourable fuel or climate conditions, or effective suppression tactics, does not develop into the more devastating *crown fire*. The latter is of two types, the *dependent crown fire* sustained from the original surface fire, and the *running crown fire* which progresses independently from, and ahead of, the original surface fire.

Running crown fires are often termed blow-up fires, as their geometry is three dimensional, and their energy output comparable with that of a thunderstorm. Violent convection and severe spotting of small fires down wind are responsible for their uncontrollable and unpredictable behaviour. Whilst they number only about five per cent of the total, they cause the most damage, and little progress has been made in eliminating them. It also appears that they are increasing in frequency.

Fire behaviour is largely dependent upon fuel quantity. A two fold increase increases fire intensity four times. Eucalypt species in particular are prolific shedders of dead material, under favourable conditions producing litter at a rate of 1 ton per ha per year. In areas not subject to fuel reduction programmes tatal fuel levels may reach 60 tons per ha. This material burn freely when its moisture conttnt falls below 18 per cent, a condition reached every summer over large areas [6]. Many species annually shed long sheets of bark, which dry

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[5] McArthur, 1970, *op. cit.*

[6] Hodgson, A., *Historical and present role of low intensity fires in eucalypt forests*, Paper presented to Fire Ecology Symposium No. 1, Monash University, Melbourne 1969.

into tubes 2.5 to 5 cm in diameter and up to 6 m long. Hanging from trunks and branches, or accumulating at the base of trees, this candlebark can contribute up to 30 per cent of available fuel. In the violent convection columns of a fire it can exhibit remarkable aerodynamic properties, and has been recorded at 3,000 m over a high intensity fire. Spotting distances of 8 or 16 km are common ahead of severe fires, and a maximum distance of 29 km has been recorded under extreme conditions [7]; pieces of fibrous stringybark too hot to handle have been recorded 64 km from the fire front. Fire intensity and speed of travel are also increased by topographic channelling of air movement and by the explosive gases distilled from Eucalypt oils and combustible waxes at high temperatures [8].

In grassland and grassland-savanna areas, only when the abundant growth of a wet season is dessicated by subsequent hot dry weather does the grass fire hazard assume major proportions. In forested areas, however, there is generally sufficient litter, irrespective of recent rainfall, to create a hazard at the onset of hot dry conditions. Forests are thus generally more susceptible to fire occurrences than grasslands, but in both areas actual fire outbreaks are associated with antecedent periods of below average rainfall.

The specific meteorological conditions that give rise to high and extreme fire danger in southeastern Australia between December and March are well known. Anticyclonic subsidence in summer leads to the development of air masses with high surface temperatures and low relative humidities. The passage of anticyclones from west to east across southeastern Australia directs hot dry northerly or northwesterly winds from the centre of the continent, and winds often exceed 65 km/h, gusting up to 150 km/h. Temperatures are high, often over 38°C, and relative humidity can drop to below 10 per cent. Rainfall in the previous three or four months is invariably below normal, with shortages often exceeding 75 per cent [9], and drying of accumulated fuel is accentuated. Fire danger usually drops with the passage of a frontal system, and a change from notherly to southerly winds, but when not accompanied by rain such a change can often give a new and unpredictable directional impetus to pre-existing fires.

Definite cyclic relationships between rainfall and fire outbreaks have recently been established. Severe fires resulting in widespread major losses of more than 200,000 ha of Reserved Forest in Vistoria, have occurred at regular 13 year intervals, in 1912/1913, 1925/1926, 1939/1940, 1951/1952 and 1964/1965 [10]. Records prior to 1900 are not complete, but indicate that this cycle extends back to at least the 1968's. Intermediate cycles of six or seven years, which do not extend so uniformly over the State, but which locally produce fires that are very destructive and/or extensive, have occurred also in 1932/1933, 1943/1944,

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[7] Hodgson, A., Control burning in eucalypt forests in Victoria, Australia, *Journal of Forestry*, 66, 1968, 601–605.

[8] Commonwealth of Australia, Bureau of Meteorology, *Manual of Meteorology — Fire Weather Supplement*, Melbourne 1963; Webb, L. J., Environmental relationships of the structural types of Australian rain forest vegetation, *Ecology*, 49, 1968, 269–311.

[9] Whittingham, H. E., Meteorological conditions associated with the Dandenong bushfires of 14–16 January, 1962, *Australian Meteorological Magazine*, 44, 1964, 10–37; Bond, H. G., Mackinnon, K. and Noar, P. F., *Report on the meteorological aspects of the catastrophic bushfires in Southeastern Tasmania on 7 February 1967*, Commonwealth of Australia, Bureau of Meteorology, Melbourne 1967; *Manual of Meteorology — Fire Weather Supplement*, op. cit.

[10] Vines, R. G., A survey of forest fire danger in Victoria (1937–69), *Australian Forestry Research*, 4, 1969, 39–44.

1959/1960 and 1967/1968. With minor variations, this pattern occurs also in Tasmania and New South Wales.

The direct causes of bushfires do not lie in the explosive combinations of climate and fuel that prevail over much of Australia at certain times of the year. As in the U.S.A., where overall, 90 per cent of fires are man caused [11], these combinations set the parameters within which human behaviour acts as the main direct agent in starting fires. However, in the more sparsely populated areas lightning can cause immense destruction and eighty-eight per cent of the 100,000 ha of reserved forests burned in Victoria in 1958 were ignited by lightning, yet only 12.7 per cent of all forest fires were lightning fires. In the more populated areas, lightning accounts for only 6–10 per cent of known causes of fire, the remainder are caused by inadvertent or negligent acts of man, and although smaller than the lightning fires of inaccessible areas, they inflict more social damage just because of their location. Bushfires are mainly accidents [12] caused by uninformed members of the public, but locally in southeastern Australia they are not infrequently the malicious acts of lunatic fringe firebugs.

COSTS OF THE HAZARD

Even allowing for problems of assessment, the dearth of statistics detailing or summarising the direct measurable costs of bushfires is extraordinary. More understandable is the almost complete lack of information concerning intangible costs of social, aesthetic or ecologic nature. There is a concentration on human costs which are high (in Victoria alone there were over 60 deaths in 1926, 72 in 1939, 49 in 1944 and 21 in 1969) but difficult to assess meaningfully in the absence of direct monetary costs.

Only rarely in the aftermath of even major disasters have reasonably comprehensive assessments of material damage been undertaken. The series of fires that swept southeastern Tasmania on 7 February 1967, burnt a total of 250,000 ha in five hours. Damage was estimated at $40 million, including 1,446 major buildings valued at $6.3 million. 1,085 homes were destroyed, 2,000 people were left homeless, and 62 people perished, the largest loss of life and property of any single day in the history of fires in Australia [13]. Yet the monetary costs of tne much more extensive Victorian fires of 1939 were never adequately assessed, apart from general estimates of costs to the forest industry.

The average annual measurable monetary costs of bushfires in Australia have been put at $6–7 million but losses vary tremendously from year to year depending upon the severity of the season, and in mild seasons may drop to $4 million, whilst in extreme seasons a single fire may equal the average damage figure. Such estimates, however, based mainly on insurance statistics, represent merely the tip of a massive iceberg. In rural areas only about 40 per cent of property, stock, fences and crops prone to bushfire damage is insu-

[11] Christiansen, J. R., *et al.*, Forest fire prevention knowledge and attitudes of residents of Utah County, Utah, with comparisons to Butte County, California, *Social Science Research Bulletin*, 5, 1969, 1–26.

[12] Folkman, W. S., *Forest fires as accidents: an epidemiological approach to fire protection research*, Paper presented to Western Forestry and Conservation Association, 56th Western Forestry Conference, Vancouver 1965, and *idem*, Latest development in fire prevention research, *Western Forestry and Conservation Association; Western Fire Commission Proceedings*, 1967, 11–18.

[13] Balanced against this is the 1967 expenditure of the Tasmania Rural Fires Board of $27.418. In 1968 that figure had risen to $236,000.

red. Other losses are less amenable to costing and become apparent only in the long run. Many Australian bushfires burn in areas of recreational, aesthetic and conservation value, not only in national parks and wilderness areas, but also in bushland close to urban centres which is heavily utilized by suburban populations. No methods have yet been devised to measure the impact of fires in such areas, or to transform into social and economic terms the impact of fires upon such ecological processes and parameters as water catchment yields, soil erosion, grazing capacity or wildlife balance.

Costs of fire prevention in forest and rural areas are more readily available. Responsibility for fire protection in rural areas other than State Forests and vacant Crown in Victoria rests with the Country Fire Authority, which obtains two-thirds of its annual running costs from insurance companies, and one-third from the State government. In 1970 expenditure was $3.9 million, or approximately $2 per head of the rural population.

The Forests Commission of Victoria allocated 16 per cent ($4 59,00) of its annual budget to fire protection in 1969/1970, a year of low hazard. In 1967/1968, a year of high hazard, 24 per cent ($731,682) of the annual budget was spent in this way. This represents an average cost of about eight cents per acre for protected State Forest over the past ten years, compared with two and three cents in Queensland and Tasmania with their less extreme fire climates. Higher unit costs in the smaller forest areas of the Australian Capital Territory and South Australia increase the national average annual cost of fire prevention in 14.5 million ha of reserved and private forest to about 7 cents per ha.

There are as yet no national or State estimates of fire damage in economic terms or in terms of loss of timber productivity. Eucalypt species, other than those of the ash-type damp forests of Victoria and Tasmania, are seldom killed outright by fire, but recover with varying degrees of success. The problem thus becomes one of assessing such long term losses as increment decrease and timber degrade, or secondary effects such as increased fungal and insect damage. Poor stocking and high degrade caused by uncontrolled forest fires are the main reasons for the low average annual productivity of Eucalypt forests in Australia of 0.9 m^3/ha compared with annual increment figures of 2.3 m^3/ha for most other countries [14].

ADJUSTMENTS TO THE HAZARD

Bushfire research in Australia has mainly focused upon fire behaviour and protection, and upon the tactical and strategic considerations of containing fires under varying meteorological conditions. Whilst the importance of the human element as an integral part of the bushfire environment is recognized, the bulk of systematic research effort aimed at improving adjustments to, and decreasing losses from the bushfire hazard have concentrated upon forecasting and, where possible, manipulating the *natural* events leading to fire occurrence, rather than upon the more difficult task of understanding and changing *human* behaviour patterns.

In the formulation of adjustment process and decision models in natural hazard situations, three distinct sets of adjustments have been recognized; those that seek to modify the natural events system, those that attempt to modify the human use system, and post-event emergency adjustments [15]. Such a framework

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[14] McArthur, A. G., The influence of fire on the productivity of hardwood forests in Australia, *Australian Forestry Research* 3, 1968, 24–35.

can be applied to an outline of the most salient adjustments to the Australian bushfire hazard.

Modification of the natural events system

Whilst little can as yet be done to modify the climatic conditions associated with high fire danger, there is a strong belief that available fuel is the essential link in the chain reaction of fire, and that control and manipulation of this link offer the only practical chance of reducing the destructive effects of fire [16].

The systematic use of low intensity fires (less than 7,500 cals/s/m) was first developed in West Australia. Here, prior to 1961, 1.6 million ha of Reserved Forest were managed under a policy of complete fire protection. Yet in the period 1951/1961, an average annual 28,000 ha was burnt by wildfires. A policy of broad area hazard (fuel) reduction by control burning was developed, so that by 1968 over 200,000 ha were control burnt each year. The effectiveness of the programme was demonstrated by the fact that only 13,000 ha were affected by wildfires in 1968, and 11,800 of these were in areas not subject to control burning. Between 200,000 and 300, 000 ha of Reserved Forest and Crown Land are now systematically ignited each year in both Victoria and New South Wales. Operational procedures for aerial ignition, with incendiaries dropped from low flying light aircraft, are now routine in all States except South Australia and Queensland, and are supplementing ignition by ground crews, especially in Western Australia and Victoria.

Control burning does not eliminate fuels (from 20–60 per cent of a treated area remains unburnt), but aims to reduce them to a quantity insufficient to support a destructive wildfire. At fuel accumulations of 4.0 t/ha, initial attack fire control methods are unlikely to succeed, and damaging fires will occur. When fuel levels are reduced to about 2.4 t/ha, intensity and rate of spread of subsequent wildfires are reduced, average fire size is decreased and initial control is made easier. In order to keep fuel build-up to this acceptable level burning rotations average four to six years.

Such frequent low intensity burns are thought by some to approximate the fire environment of aboriginal, pre-European Australia, and thus to be closer to the natural fire environment than the devastating conflagrations that have originated in massive fuel accumulations resulting from policies of complete fire protection. Objections are raised to the potential impact of control burning upon water, wildlife, recreation and even timber values. In particular, the deliberate use of fire in national parks, fauna and flora reserves, catchment areas, and other categories of public land where management objectives encompass more than protection of life, property and timber resources, has been strongly criticized [17].

Other modifications include the use of chemical and mechanical means of fuel reduction, the first of which may have significant residual and side effects, while the second is generally too costly to use on anything other than small

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[15] Kates, R. W., Natural hazard in human ecological perspective: Hypotheses and models, *Economic Geography*, 47, 1971, 438–451.

[16] See Hodgson, 1968, *op. cit.* and *idem.*, High intensity forest fire behaviour and associated weather, *Second Australian National Conference on Fire, op. cit.*, 17–23.

[17] Vines, R. G., The forest fire problem in Australia — a survey of past attitudes and modern practices, *Australian Science Teachers' Journal*, 14, 1968, 5–16; *Australian Conservation Foundation, op. cit.*, and Boughton, *op. cit.* For a comparison with conditions in North America, see United States Department of Agriculture, Forest Service, *Prescribed Burning Symposium Proceedings*, Asheville, N. C.: Southeastern Forest Experimental Station, 1971.

strategic areas. Because of the spotting characteristics of Australian bush and forest fires, the efficiency of cleared firebreaks is reduced. Firebreaks used as fire access roads also allows greater public incursions and increased fire incidence. When used in conjunction with mechanical fuel reduction, especially in suburban/forest fringe zones and peripheral to recreation or conservation areas, firebreaks can form an effective barrier to low intensity surface wildfires. In rural and grassland areas cleared areas or green firebreaks of summer crops such as lucerne, rape or potatoes, are used extensively in individual and community fire protection strategies. On a local scale, fire retardant tree species are used as green firebreaks, but many of these are more prone to drought than Eucalypts, and thus may pose a greater fire danger at the time when they are most needed. The use of grazing as a hazard reduction measure shows favourable economics in South Australia, and at Yallorun in Victoria and Wandillo in South Australia, forests have been converted to grassland and grazed to reduce fire risk to adjacent high value mining and forestry assets.

Modifications to the human use system

The greatest damage potential is in the forest/urban fringe areas where increased demands for both recreational outlets and desirable bushland residential sites adjacent to the large population centres have brought increasing numbers of people into contact with high-risk fire environments.

The commonest adjustment is the bearing of losses when they occur. It is often suggested that Australians have a fatalistic belief that bushfires are an unavoidable part of the Australian way of life, and display an innate misinterpretation and underestimation of the forces at hand [18]. On an individual level, damage thresholds can be raised, and damage potential distribution altered by clearing property of flammable vegetation close to buildings, boxing-in of eaves, fitting fly wire screens over air vents and boarding-up below-floor areas. Farm layouts can be designed to reduce damage potential, whilst especially in bushland suburban areas there is a need for the application of more rigid house design standards to reduce damage liability. Community planning for fire protection is increasingly important. At Williamstown, South Australia, strategically placed mown, burnt and ploughed firebreaks around the town periphery have been combined with increased and coordinated protection of individual buildings and subdivisions. In suburban/forest fringe areas of the large cities, however, such comprehensive plans are less evident. Speculative subdivision encroachment into high hazard bushland has often been beyond the planning capacities of local governments, and there have been few attempts to separate residential areas from adjacent bushland.

Evacuation or other extreme adjustments such as broad-scale complete hazard removal, are socially, economically or environmentally unacceptable adjustments in most areas. Minimization of hazard effects thus largely depends upon increasing the efficiency of individual and community adjustments within a high-hazard environment.

Throughout the potential fire damage season, restrictions are imposed upon the lighting of fires in the open. A Prohibited Period exists in State Forests and National Parks in Victoria throughout the year and the Country Fire Authority declares an equivalent Summer Period for the rural land under its

[18] For a discussion of similar attitudes to another Australian hazard, see Heathcote, R. L., Drought in Australia: a Problem in perception, *Geographical Review*, 59, 1969, 175–194.

control. Restrictions during these periods are aimed mainly at property clearing and burningoff, major causes of bushfires. On days when the Bureau of Meteorology issues an extreme fire danger rating, or when blow-up conditions are expected, the Country Fire Authority of Victoria, in conjunction with the Forests Commission, can declare a day of total fire ban, on which no fires may be lit in the open. The onset and lifting of limitations depend upon the severity of the fire season, but usually fall between mid-November and mid-March. Fire protection authorities undertake massive publicity campaigns, especially in spring, to encourage hazard clearance on properties. Directives may be issued to property owners or occupiers to remove fire hazards, and authorities can compulsorily clear at the owner's expense or prosecute if directives are not followed.

In many suburban and rural areas the efficiency of such regulations and publicity is low, judging by the number of fires that do start and the number of compulsory directives that are issued. There is some evidence that general awareness of the hazard situation and willingness to adopt precautionary measures follow the same cyclic pattern as the hazard itself. In low hazard summers the value of such publicity may therefore be questioned. Opposition to increased fire publicity has also been encountered in some high hazard areas adjacent to Sydney and Melbourne, on the grounds that such publicity has an adverse effect on land sales and tourism, and that efficient fire brigades are adequate defence.

Post-event emergency adjustments

Planning for emergency adjustments falls into two main categories. *Operational planning* develops control measures at policy or strategic levels to meet objectives such as: the definition of logistic parameters for initial fire attack systems; delineation of areas to be subjected to hazard reduction and the techniques to be used; development of design standards for fire suppression and detection equipment, and assesment of needs for disaster or relief funds. *Tactical planning* at the suppression stage puts into effect control measures in active fire situations in order to meet planned strategic objectives. Included are, for example: the assessment of rates of forward progress of fires in various fuel and meteorological conditions; definition of specific initial attack sequences for individual fires, with assessment of the likely rate of suppression and consequent logistic details; obtaining the safest working conditions for suppression personnel and the optimum evacuation of threatened areas, and specific allocation of relief funds and supplies.

A basic prerequisite for much of this planning is improved operational weather forecasts that can be converted into predicted fire behaviour. The use of a standard fire danger index in a national system of fire danger rating has improved the efficiency of general advance fire warning [19]. There still remains

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[19] The index in general use in Australia is the McArthur Fire Danger Index, which uses seven variables to predict danger levels. An accuracy of only 80 per cent is claimed, as 14 variables were considered in the initial development of the index. The system does, however, facilitate the conversion of the Meteorological Bureau weather forecasts into meaningful fire danger ratings for grassland and forest areas. See MacArthur, A. G., *The preparation and use of fire danger tables, Commonwealth of Australia, Bureau of Meteorology, Proceedings of Fire Weather Conference* (July 1958), and Cheney, N. P., Predicting fire behaviour with fire danger tables, *Australian Forestry*, 32, 1968, 71–79.

a need for accurate short term forecasts on a 24 hour basis for pre-suppression planning, and on an hourly basis for on-going fire situations, particularly of wind velocities and direction changes.

The mainstay of Australian fire fighting strategy outside of State Forests is the volunteer rural fire brigade. In Victoria, the Country Fire Authority, responsible for fire protection over 65 per cent of the State's area, consists of a small cadre of 250 permanent professionals, and 105,000 volunteers within 1,050 brigades organized in a well defined chain of command. State Forests and National Parks are the responsibility of the respective forest authority in each State, but protection of vacant forested Crown Land varies, and in some areas there is no clearly defined allocation of responsibility for such areas. Most fire fighting is ground based, and depends upon the early spotting of fires and the rapid movement of men and equipment to fire fronts to control fire in the crucial first half hour. The use of aircraft is becoming more widespread in fire prevention and control, but logistic, environmental and economic factors mitigate against the use of aircraft on a scale comparable with that in North America.

The most important of these factors is the rapid spread and intensity of Australian bushfires, which pose enormous problems to be overcome in mounting effective early aerial attacks on wildfires. Many small fires can spread over 400 ha in the first hour, whilst the 1967 Tasmanian fires spread over 260,000 ha in five hours. Aircraft have little chance of providing effective means of direct suppression under such conditions. A rate of fire spread of 80 m/hour, and spotting distances of more than 12 m are beyond the present capabilities of air attack systems. Lack of water pick-up points, rugged topography and high winds associated with wildfire conditions also limit the use of aircraft in southeastern Australia. Both light fixed-wing aircraft and helicopters are, however, being increasingly used by the Forests Commission of Victoria for fire spotting and the transport of men and equipment to fire fronts. In addition to being used in control burning programmes, aircraft have also recently been used for initial attack on lightning fires in inaccessible forest areas, dropping fire retardants such as Phoschek until the fire can be reached by ground crews [20]. Experiments are also being conducted into the use of infrared sensing of fires from the air.

Whilst drought relief funds are an accepted and expected part of Australian rural economics, bushfire relief funds have not been developed to a comparable extent and emergency relief funds are instituted after large disasters. Suggestions have been made for a permanent Bushfire Emergency Fund established with joint Commonwealth and State participation, but as yet the suggestion has not been acted upon.

Two other types of post-event adjustments can be noted. The first is the changes in fire legislation and preventative strategies that have inevitably followed major disasters. After fires in 1926 burnt over 400,000 ha. Reserved Forest and Crown Land in Victoria, the authority of the Forests Commission to order a fire to be extinguished on private property was extended from 800 m to 3.2 km from the forest boundary. The Royal Commission enquiry into the 1939 Victoria fires resulted in greatly extended power of the Forests Commission under the 1939 Forest Act. Not until 1944, however, when extensive fires occurred in northwestern and eastern Victoria, was the present Country Fire

[20] Hodgson, A., An air attack system for forest fires in Victoria, *Australian Forestry*, 32, 1968, 226–232.

Authority proclaimed. The second, less substantiated adjustment is the apparent widespread reestablishment and acceptance of the *status quo* in many rural and especially suburban areas, and a continued over-optimistic reliance on fire fighting technology and organization at the expense of positive individual adjustments [21].

THE BUSHFIRE HAZARD IN THE DANDENONG RANGES

Situated 35 km east of Melbourne, the Dandenong Ranges epitomize the bushfire problem found in forest/suburban fringe areas of southeastern Australia (Figure 2). A readily accessible recreation outlet for the large (2.3 million) and expanding population of Greater Melbourne, the Dandenonge offer a wide range of landscapes, landforms, vegetation and cultural amenities. These factors, in conjunction with proximity to Melbourne, make the area desirable for residential and holiday home development, and extensive low density subdivisions have encroached on to the flanks of the range from Melbourne's eastern suburbs. One of the major resources of the area is an extensive and varied forest cover, with its attendant aesthetic, conservation, recreation and water catchment values. Yet this resource, the maintenance of which is seen as a social planning necessity, is in conjunction with human activity, a major fire hazard.

HAZARD DISTRIBUTION

Although the areas's notoriety has to some extent been overstressed by the mass media and closeness to Melbourne, it is one of the worst fire traps in Victoria. Past fires have been expensive in terms of property damage, and although most fires are small (only 10 per cent of forest fires in the 1960–1970 period were greater than 200 ha, and 84 per cent of scrub fires were less than 4 ha), the periodic large fires are potentially catastrophic in such a densely populated area. The first recorded bushfires occurred in 1851, and extensive fires burned in 1908, 1914, 1919, 1926, 1932 and 1945, although the full impact of the 1939 fires bypassed the area. More recently, in 1962 eight people were killed and 453 buildings destroyed, and in 1968 fires totalling 1,000 ha destroyed a further 53 buildings.

From Forest Commission and Country Fire Authority records for the 1960-1970 period, two distinct hazard zones can be delimited (Figure 2, A, B).

The western, northern and northeastern slopes of the range, heavily forested and rising steeply from suburban and rural lowlands, are a high hazard zone, coextensive with the area burnt in 1962. All of the more extensive and damaging fires of the past 20 years have originated and burnt in this zone, which is exposed to the full force of firebearing northwesterly and northeasterly winds. The dry sclerophyll forests dominated mainly by *Eucalyptus cypellocarpa, E. gonicalyx, E. macrorhyncha, E. obliqua, E. polyanthemos* and *E. radiata* become flammable under high or extreme fire danger conditions, and fires starting at the base of these slopes can spread rapidly. One of the two major 1968 fires spread 230 m in the first five minutes after ignition and was already throwing spot fires in advance of the main front. Where gullies incise into the slopes, rapid ascending fires are even more prevalent, and one such gully. The Basin,

[21] See Heathcote, 1969, *op. cit.* for similar adjustments to drought.

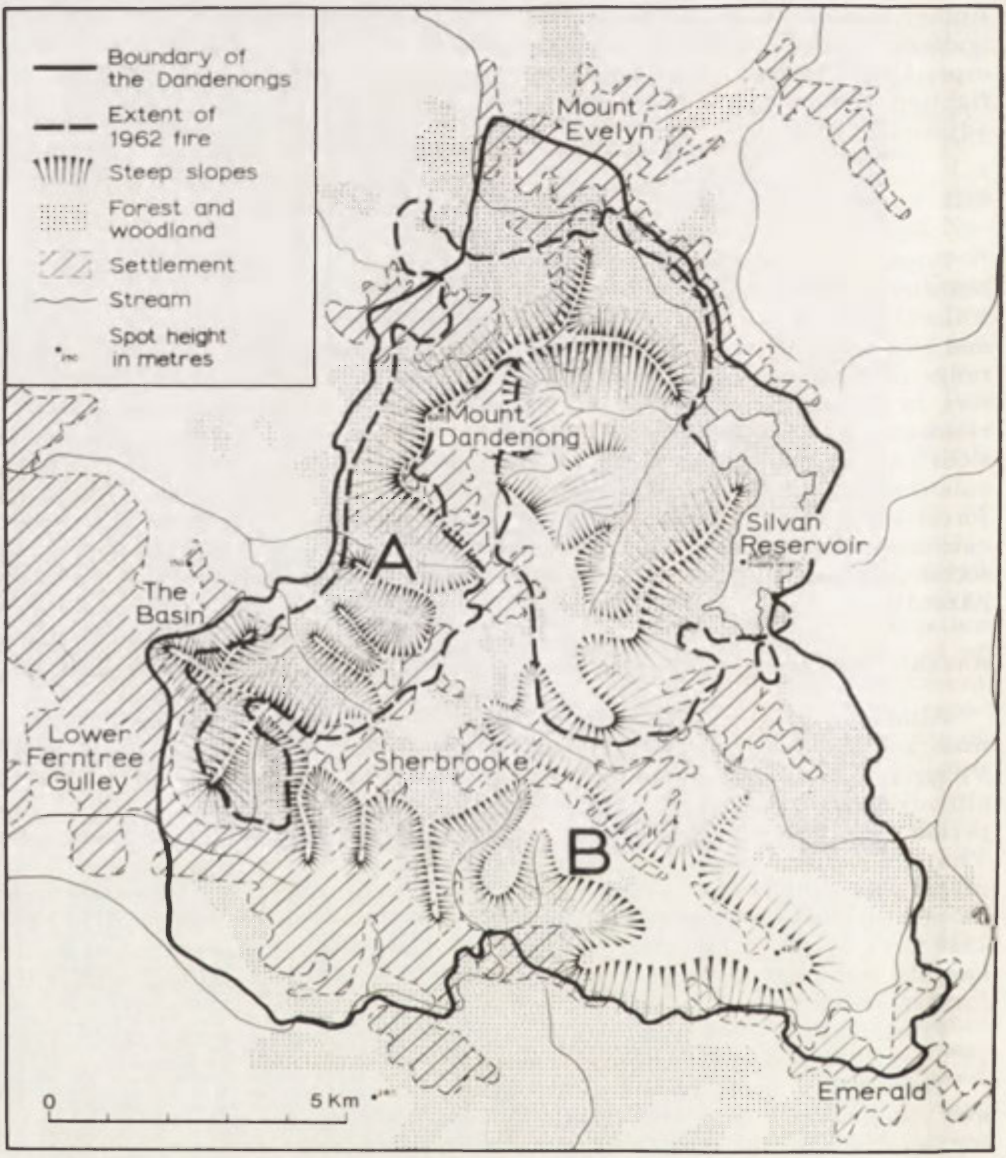

Fig. 2. The Dandenong Ranges, Victoria, Australia

has been the site of origin of all extensive fires in the 1960–1970 period, and in 1968 accounted for 35 per cent of all fires in the Dandenongs.

Southeast of the crest of the main western scarp is a low hazard zone, much of which has been cleared of forest for agricultural and residential purposes. Where the pockets of forest remain, they are mainly a low hazard type dominated by Mountain Ash (*Eucalyptus regnans*). Whilst a few areas of dry sclerophyll forest occur, most fires have been less than 4 ha in extent, and have usually been easily contained surface fires. The less extreme fire climate associated with southerly and easterly aspects also contributes to the low fire incidence.

HUMAN USES, PERCEPTIONS AND ADJUSTMENTS

With regard to the topographic, climatic and vegetation variables of the natural events system, the Dandenongs are no more prone to bushfires than many other regions in Victoria. What gives the region its particularly high hazard potential is the pattern of activities and occupance of the human use system. Some of the most densely populated areas of the Dandenongs lie in or immediately adjacent to the high hazard area. As the attractiveness of a bushland setting is one of the major reasons for people choosing to live in such an environment, many homes are surrounded by flammable bush. There has been little planning effort, to date, to separate residential and bushland areas, and a significant number of homes and subdivisions have limited access and poor water supplies.

Fire records show that residents are responsible, mainly through careless burning-off practices, for a disproportionately large percentage of bushfires, and that this problem has increased as residential densities increased to the level where the hazard potential has decreased because of bushland removal. The large influx of tourists into the area also poses a problem to fire control and prevention programmes, but tourists are directly responsible for a much smaller percentage of fires than residents.

The more extensive methods of fire control and hazard reduction, such as control burning and clearance of wide firebreaks, are considered by strong preservation and conservation groups in the Dandenongs to be at variance with the maintenance of the aesthetic and recreation values of the areas.

Fire protection strategies in the area are thus mainly concerned with the establishment of mechanically cleared buffer zones between the residential and bush areas, limited use of control burning, and increased planning for the exclusion of subdivisions in high-risk environments. Education programmes aimed at increasing knowledge of fire behaviour and prevention strategies are used increasingly throughout the year as well as during the fire danger season, but as already noted, there is some opposition to large scale overt fire publicity.

Bushfires in the Dandenongs are clearly a man-made hazard, a fact emphasised by the high incidence of deliberate, malicious fire lighting. An average of 25 per cent of fires in forested areas is maliciously lit, but some fire authorities put the figure as high as 50 per cent for the area as a whole. The 1962 and 1968 fires were caused in this manner, and prior to the two major 1968 fires, 63 small fires were maliciously lit in The Basin.

THE DANDENONGS SURVEY

In an attempt to rectify some of the lack of information concerning behavioural variables influencing bushfire occurrence, a brief preliminary survey of perceptions of and behavioural responses to bushfires was undertaken in the Dandenongs in 1971. The aims were: to examine the manner in which bushfires are seen as part of the environment and to determine how the impact of bushfires influences residents' perception of environmental quality; to examine the reasons for variations in perception of the hazard; and to briefly examine levels of adjustment to the hazard.

The study embodies the results of two questionnaire surveys of residents. The first of these was a random sample of 417 residential households, 182 from the high hazard area (Zone A) and 235 from the low hazard area (Zone B). A second survey of 120 households divided evenly between Zones A and B was used primarily to examine attitudes to the hazard and coping strategies [22]. Combinations of the two sample populations is considerad feasible as there were no significant differences in socio-economic characteristics between them, or in answers to questions common to both surveys.

The questionnaires used were a modification and extension of one used to examine perception of environmental quality in Tucson, Arizona [23], with the addition of material based upon that used in surveys of fire prevention awareness in North America [24]. The seguenca moves from open-ended questions designed to obtain spontaneous response about environmental quality to more specific questions concerning the busfire hazard.

Environmental quality and bushfires

Residents of the Dandenongs express a very favourable view of their environment; residential quality was rated excellent by 49 per cent of respondents, good by 44 per cent and fair to poor by only 7 per cent.

Bushfires were rarely spontaneously mentioned amongst environmental disadvantage (only 3.5 per cent of total responses). Of Zone A residents, eight per cent mentioned bushfires, compared with three per cent in Zone B. Social problems which affect everyday living or are local public and political issues, appear to be of more direct concern to residents, and consideration of environmental quality seems to be unrelated to awareness of the bushfire hazard.

When respondents were asked to rank 13 given environmental problems in order of seriousness and importance, however, bushfires emerged as the single most important problem. Yet a group of related problems including littering, traffic, quarrying, forest destruction and housing development, ubiquitous modifiers of the Dandenongs environment, together constitute a greater sphere of concern.

Such frequently expressed concern about aesthetic oriented problems relative to bushfires may suggest that residents are conscious of bushfires as a negative environmental feature which disfigures the positive features of scenic attractiveness, and that perception of the hazard is influenced by other factors relevant to environmental quality and not solley to the characteristics of fires as an environmental hazard *per se*.

Significant differences in hazard appraisal between Zone A and Zone B residents also emerged at this stage, with both rating of seriousness and importance ranking being higher in Zone A. Awareness of bushfires as a relevant feature of the environment is therefore more highly developed in areas that have recently suffered damage and disruption, or at least imminent threat, from them. Place of residence in terms of past hazard incidence thus clearly influences hazard assessment.

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[22] Learmont, J., *The attitudes, perception and behavioural response to the bushfire hazard*; Unpublished Honours Thesis, Department of Geography, Monash University, 1971; See also Edgell, M. C. R. and Brown, E. H., Bushfires in the Dandenong ranges — the attitudes of residents, *Victoria's Resources*, 13, 1971, 10–14.

[23] Saarinen, T. F. and Cooke, R. U., Public perception of environmental quality in Tucson, Arizona, *Occasional Papers*, No. 9, Department of Geography, University College London, 1970.

[24] Folkman, W. S., *Levels and sources of forest fire prevention knowledge of California hunters*, Berkeley, California: Pacific S. W. Forest and Range Experimental Station, U.S. Forest Service Research Paper PSW-11, 1963, and *idem.*, *Residents of Butte County, California: Their Knowledge and Attitudes Regarding Forest Fire Prevention*, Berkeley, California: Pacific S.W. Forest and Range Experimental Station, U.S. Forest Service Research Paper PSW-25, 1965.

Perception of the bushfire hazard

Residents' mental maps of hazard distribution in the Dandenongs generally correlate well with actual hazard occurrence. The western slopes, including The Basin, and the main western ridge top are notable for the large proportion of respondents that considered them to be the highest fire danger areas (58 and 41 per cent respectively). Due partially to news media publicity, The Basin's notoriety as a fire-prone area is well established. Many Zone A residents live in localities susceptible to fires commencing near The Basin, and 50 per cent of them mentioned it as a danger area compared with 32 per cent from Zone B.

Although the meanings of "high", "moderate" and "low" hazard ratings probably differ from person to person, and whilst each individual imposed his own interpretation on the meaning of neighbourhood, a highly significant relationship exists between zone of residence (A or B) and assessment of the proximate neighbourhood as a hazard area.

A feature of neighbourhood hazard ratings is their extreme diversity, with hazard appraisal varying from neighbour to neighbour within areas of common fire history. This occurred even in areas burnt by both the 1962 and 1968 fires, where the recent nature of the events might be expected to have resulted in a heightened and uniform awareness. Four long-term residents (more than ten years) in one locality burnt by the two major fires and frequent smaller ones were still able to regard their neighbourhood as one of low fire danger.

Such factors as value orientations towards nature, attitudes towards uncertainty, optimism or territoriality may contribute to such assessments. However, the degree of damage resulting from a fire can be very place-specific, even within generally high-hazard areas. Due to the erratic behaviour of a fire, or the efficiency of preventative measures of fire-fighting, it is possible for a property to escape damage in a fire which severely damages neigbouring areas.

Bushfires in the Dandenongs are clearly seen as a man-made hazard, emanating from a careless and disruptive association between man and his environment, rather than from the environment itself. Only six per cent of responses mentioned climate and lightning as major causes of fire, whilst mention of vegetation and fuel characteristics was always coupled with statements on their management.

General carelessness was seen as the major cause of fires (31 per cent) followed by malicious lighting (14 per cent). Specified *local* carelessness included uncontrolled or lack of burning-off, and burning on fire ban days and accounted for 15 per cent of responses. *Visitor* carelessness, such as cigarettes and matches dropped from cars, picnic fires and tourists accounted for 31 per cent. In comparison, fire records for 1960–1970 show that burning-off practices accounted for 40 per cent of known fires, whilst visitor activities accounted for only 12 per cent.

Temporal spacing of bushfires in the Dandenongs has closely followed the intermediate six or seven year cycle recognised in the coastal regions of south-eastern Australia. Residents, however, tended to overestimate the frequency of serious fires in the area, citing three-year intervals most often (34 per cent).

Contrasting with this overestimate is the widely expressed belief that the hazard situation has improved. Fifty-two per cent considered that hazard severity had decreased during their residence in the Dandenongs. Such optimism is justified in Zone B, which has changed from a locally high hazard to a uniformly low hazard area because of extensive clearance. Even in the high hazard areas, potential damage during moderate fire danger periods has decreased due to improved tactical, preventative and planning measures.

An eventual solution to the bushfire problem was considered possible by 43 per cent of respondents; with Zone A residents slightly less optimistic. There is a strong general feeling that fire regulations and public adjustments are adequate and safe, and need little improvement. Particularly is this so when such improvements are seen to entail inroads into the scenic and bushland characteristics of the area.

Factors influencing perception of the bushfire hazard

The longer a person has lived in the Dandenongs the greater is the possibility of experience with bushfires, and it might be expected that awareness of the hazard would increase. Additionally, awareness of the high hazard environment of Zone A might be reinforced by the fact that residents of this area generally have lived in the Dandenongs longer than Zone B residents. However, perception of bushfires is not clearly related to length of residence *per se*. Local fire officers express the opinion that in the Dandenongs familiarity breeds contempt, and that newly arrived residents are more prepared to take precautionary measures than established residents. It appears, therefore, that in the absence of direct exposure to bushfires, even long-term residents exibit a relatively high acceptance threshould of the bushfire hazard as part of their environment.

Those who consider that they have been threatened by, or who have actually suffered damage from bushfires are more likely to rate their proximate neighbourhood highly as a hazard area, and tend to rank bushfires more highly relative to other environmental problems. Yet 39 per cent of Zone A residents, who had not experienced fires, still ranked them as the most important environmental problem emphasising that residence in a high danger area is an important factor influencing hazard perception.

Of Zone A residents who had actually suffered damage or who considered that they had been threatened, 40 per cent did not rank bushfires amongst the three most important environmental problems. The acceptance threshould of these residents appear to be higher for bushfires than for social and aesthetic problems.

Use has been made in many hazard perception studies of three groups of value orientations towards nature [25]. The dominant view expressed in the Dandenongs was that man could work with nature to reduce the hazard (65 per cent). Thirty per cent of respondents thought that the hazard could definitely be overcome, and only three per cent that bushfires were unavoidable. Such views reinforce earlier responses that bushfires are a man-made hazard and by implication may be overcome, and contrast with responses to questions as to whether the problem could actually be solved, which were less optimistic.

In hazardous situations there is a tendency to eliminate the uncertainty of events by regarding them as repetitive or cyclic phenomena, irrespective of their actual temporal spacing. Yet 81 per cent of all respondents stated that fires could come at any time, therefore regarding bushfires as indeterminant and at least partially uncontrollable events. Of those who did think that fires occur in regular cycles (a more deterministic and perhaps realistic view of bushfire occurrence) more than twice as many lived in Zone A as in Zone B.

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[25] Kluckhohn, F. R., and Strodtbeck, F. L., *Variations in value orientations*, Row-Peterson and Company, Evanston, Illinois, 1961, 363–365; See, for example, Barker, M. L., Beach pollution in the Toronto Region, in: W. R. D. Sewell and I. Bruton (eds), *Perceptions and Attitudes in Resources Management*, Resource Paper No. 2, Policy Research and Coordination Branch, Ottawa, 1971.

Few statistically significant differences in ranking and perception of the hazard were found between respondents of different socio-economic status. Females, perhaps because of their greater daily exposure to potential threat, show marginally greater awareness of bushfires than males. Those with higher education tended to place bushfires in a higher position in the hierarchy of environmental problems. Immigrants, born in less fire-prone environments, ranked them more highly as an environmental disadvantage than did people born in Australia.

Behavioural responses to the bushfire hazard

Fire authorities and residents express strongly conflicting views concerning the efficiency of individual adjustments to bushfires. According to fire protection personnel, the frequency and damage potential of bushfires would be significantly reduced if residents' coping strategies were improved. Only 17 per cent of residents saw any need to increase their range of adjustments.

Of Zone A residents, 95 per cent undertook some precautionary measures, whilst 87 per cent of Zone B residents did so. Only 20 per cent of residents in Zone B undertook three or more such measures each year, but 51 per cent of Zone A residents did so.

Levels of coping strategy are also related to knowledge scores on questions concerning fire behaviour and prevention. Improved knowledge of bushfire behaviour is apparently partially related to education levels. The importance of fire prevention knowledge in reducing the incidence of man-caused fires has been shown in the U.S.A.[26] Knowledge levels of Dandenong residents appear to be relatively low.

Attitudes towards fire prevention legislation have also been found to influence the protective measures carried out by people in fire risk environments [27]. Whilst few respondents place the main responsibility of fire prevention on the fire brigades or consider that fire education is a waste of money, there is a general attitude that present regulations and legislation are adequate. When this attitude is coupled with the dominant view that no changes in individual adjustments are necessary to cope with the hazard, it is difficult to see how behavioural changes and lowered fire incidence can be attained.

The surveys were undertaken in June and July 1971, a period of low danger levels, and the previous two fire seasons had been mild. Different impressions of residents' perceptions and adjustments may have resulted had the surveys been conducted in midsummer, or in a season of high danger levels.

SUMMARY

The place-specific nature of both hazard effects and awareness levels was a notable result of the surveys. Detailed enquiry into spatial changes in, and functional relations between variations in natural events system, residents' location with respect to actual and assessed vulnerability, and perceptions, attitudes and adjustment levels could prove of value. Such basic statistical techniques as multiple regression and analysis of variance may indicate variable interrelationships and group differences. Measurement of fire knowledge levels are crucial to understanding human behaviour in fire environments, especially with respect to fire prevention and coping strategies. Publicity and educational

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[26] Christiansen *et al.*, 1969, op. *cit.*

[27] Folkman, 1965, *op. cit.*

programmes should be examined, as these programmes are potentially a major persuasive force in modifying human behaviour, improving the efficiency of adjustment processes and decreasing the incidence of man-caused fire.

CONCLUSION

Not only the extreme events of nature, but also, and perhaps more significantly, the characteristics of human behaviour patterns and adjustments determine the nature of bushfires in Australia. In common with natural hazards this quasi-natural hazard is

> *an interaction of man and nature, governed by the coexistent state of adjustments in the human use system and the state of nature in the natural events system* [28].

The interplay of these two systems is extraordinarily complex, but the bushfire hazard is essentially man-induced and thus is theoretically amenable to at least partial solution through changes in human activity. Yet in many areas of Australia, especially in the more densely populated southeast, adjustments appear to be insufficient to cope with conditions emanating from interactions of human use and natural event systems. It has been suggested that success of adjustments should be measured by the amount of damage resulting from the few major fires, rather than by the isolated losses from smaller fires which are probably tolerable within the present human use system [29]. Whilst improved fire control has increased the ability to prevent relatively minor fires, it is still ineffective in limiting damage caused by the major outbreaks, and also has mostly failed to prevent them.

Of the variables that produce bushfires, some such as fuel accumulations, the efficiency of fire enforcement and human behavour are capable of modification or control. Others, such as the meteorological conditions giving rise to high danger levels are non-controllable. In attempts to alter relationships between these variables so that the disparity between human activity and the demands of an environment is lessened, two main approaches may be taken.

It may be possible to modify part of the *environment* so that the effects of risk-producing behaviour are minimised. Or it may be necessary to attempt to induce *behaviour* patterns that are either not in conflict with the environment or which increase the capacity to absorb damage. In most instances, fully integrated programmes would entail both of these approaches in varying degrees.

The major systematic and concerted emphases of fire prevention programmes in Australia has so far centred upon the first of these two approaches, and upon a complementary effort to increase the efficiency of fire-fighting techniques. Yet by definition, man-caused bushfires involve human behaviour in a high fire-risk environment. Application of research into perceptions, attitudes and behavioural responses to the threat or occurrence of bushfires is thus no less essential in attempts to reduce hazard incidence and damage potential than is research into environmental modification. Improved adjustments to this almost ubiquitous Australian hazard are more likely to result if the human aspects of the bushfire environment are afforded greater recognition in fire prevention research programme.

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[28] Kates, 1971, *op. cit.*, 438.
[29] *Proceedings of the Rural Fires Conference, op. cit.*, 84.

Note:

The research on which this paper is based was started in 1971 jointly by both authors whilst at Monash University, Victoria, Australia. Since that time Dr. Edgell has been the principal contributor and drafted this paper.

LIMESTONE HYDROLOGY AND ITS RELEVANCE TO APPLIED GEOGRAPHY

David Ingle Smith

Studies of the geomorphology of limestone terrains have, in the last few years, been directed towards an understanding of the nature and rate of erosional processes. This has resulted in the need for detailed observations on the hydrology of the areas studies, including observations on the various forms of water quality. Since, with the exception of regions of permafrost, limestone terrains are normally associated with a paucity, or complete lack, of surface drainage, such hydrological work has required the tracing of groundwater movement. Much of this research has been of an academic nature but there is little doubt that it is also of value in an applied sense. As a background to the applied studies, a brief review will be given of the erosional and hydrological studies.

EROSION STUDIES

(i) SOLUTES

The salient feature of the morphology of limestone areas represents a response to the relative ease with which calcium carbonate and dolomite, the major constituents of all limestones, are dissolved in natural waters. The study of the rate at which calcium and magnesium carbonate are dissolved have proceeded very rapidly since the initial impetus given to the subject by Corbel in the late 1950s. Recent extensive reviews are given by Jennings (1971) and Sweeting (1972). Detailed studies of the calcium and magnesium concentrations of water samples collected from differing sites within the limestone mass enable some generalised comments to be made regarding the nature of the groundwater circulation; these are summarised in Figure 1. The bulk of the solution is normally concentrated at the near surface sites and is enhanced if there is a continuous cover of soil and vegetation, Smith and Atkinson (1976). The concentration of calcium and magnesium at spring sites fed by groundwater circulation has a marked tendency to remain constant regardless of the variations in discharge. Major departures from this constancy of hardness values are usually only observed after periods of particularly heavy discharge. This would appear to represent a generalised case that covers a wide variety of limestone lithologies in which the groundwater properties might be expected to vary between wide limits.

Studies involving the solute composition of waters in calcareous areas yield some information of value in an applied sense. For example, hardness figures from neighbouring boreholes in the Chalk not infrequently show small but

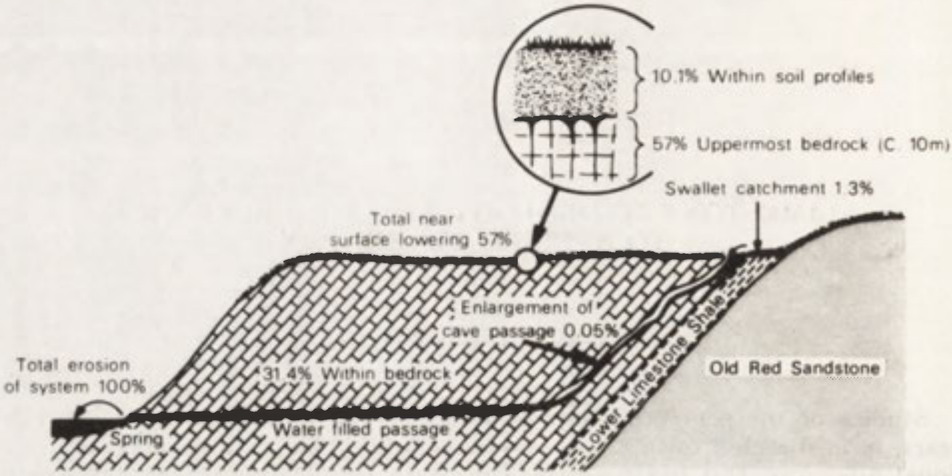

Fig. 1. Proportion of solutional erosion at differing sites in the limestones of the Mendip Hills (after Smith and Atkinson, 1976)

significant differences. This suggests that the underground circulation even at a local scale consists of separate water flows. Also, where hardness values at a spring show considerable variations in relation to spring discharge, it is an indication that the subterranean system feeding the spring is dominantly composed of conduit flow moving very rapidly from the surface to the underground flow system, and through that system to reappear at the springs. This is discussed in detail by Shuster and White (1971), who suggest a classification of limestone groundwater into "conduit" and "diffuse" flow types. In some cases, detailed samples from limestone springs show that the hardness from various parts of the cross-section flowing from the spring have quite differing hardness values. This feature has been recorded from a relatively large number of springs and is a clear indication that in some cases the subterranean conduits unite only a relatively short distance underground from the spring itself; this is discussed in (Smith and Drew, 1975).

The usefulness of observations on hardness is limited but has the great advantage that such analyses are quick and inexpensive. The analysis for hardness using E.D.T.A. titrations can be carried out under field conditions to an accuracy of some ± 2 mg/l (Douglas, 1969). Hardness observations, particularly if they can be carried out under a range of discharge conditions, provide a most useful method of preliminary reconnaissance which can aid in the design of a more detailed and costly programme of hydrological or tracing research.

(ii) SUSPENDED SEDIMENT AND BEDLOAD

Geomorphological studies on the process and rate of erosion of limestone terrain have been particularly concerned with solutional erosion. There are remarkably few accounts in the literature dealing with the suspended sediment load discharged at limestone springs and virtually none that are concerned with bed load. Work by Newson (see Smith and Newson, 1974) produced rating curves for both solutional and suspended sediment, load and concentration, and discharge for springs draining from the Carboniferous Limestone of the Mendip Hills. These rating curves for solute and suspended sediment concentration are given in Fig. 2. It is clear that in this case the suspended sediment concentration

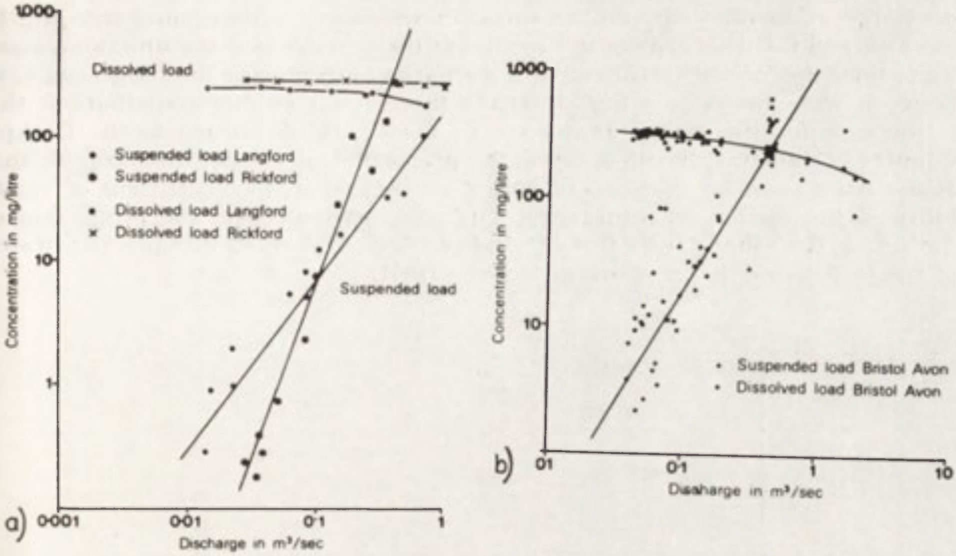

Fig. 2. Relationship of discharge to concentration of suspended sediment and solutes (from Smith and Newson, 1974)
a — for the limestone springs of Langford and Rickford in the Mendips, b — for the Bristol Avon, only fed in part by limestone strata

and load can be of importance and that the suspended sediment load exceeds that of solution at high discharge values. The applied significance of such studies reinforces the observations from the solute studies that much of the subterranean flow in limestone regions, certainly for massive limestones with well developed secondary permeability, is of a fast flow forms since suspended sediment in these quantities can only be carried by turbulent flow of the form likely to occur in conduits. If comparisons are made between the limestone springs discussed above and comparable observations for surface streams in the same region on non-calcareous strata, it can be seen that the suspended sediment concentrations and loads are remarkably similar. Underground flow in limestones of this type is dominated by conduit flow of a turbulent nature closely analogous to that of surface rivers. Further studies on the suspended sediment concentration of springs from a variety of limestone types would enable this conclusion to be tested in a wider context. However, descriptive accounts of limestone springs in other limestone regions would suggest that a similar phenomenon is encountered, although the quantity of suspended sediment may well be less, i.e., the proportion of the groundwater moving in the form of conduit flow is smaller.

Again, studies of this kind can provide a useful background for applied studies, although the relevant observations can only be obtained under conditions of high discharge.

HYDROLOGICAL OBSERVATIONS

Observations on water quality are normally of value only when combined within a broader hydrological programme. Hydrological studies in the narrow sense are concerned with assessing the various components of the hydrological cycle. The salient features for this study are the inputs from precipitation, the discharge of surface streams (swallets) disappearing underground into the limestone and the discharge of the springs at the periphery of the limestone mass. The proportion of the swallet stream discharge to the spring discharge can vary between wide limits (see Fig. 3). Often there is no swallet contribution; this is the case for limestones as diverse as the Chalk of Europe to the Cockpit Country of Jamaica. In other cases, the proportion of swallet discharge to that at the risings can be in excess of 50 per cent. Further, the coefficient of variability of the spring, or resurgence, hardness increases with the proportion of the spring flow that passes through the swallets. This relationship is illustrated in figure 3, based on the work of Newson (1971).

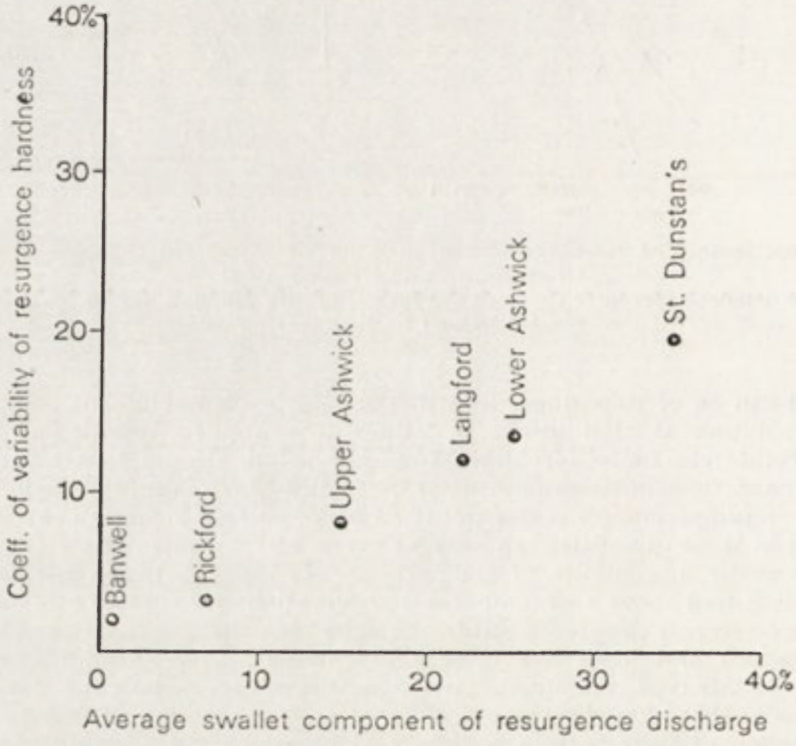

Fig. 3. Relationship between hardness and the contribution of swallet discharge for various limestone catchments (after Newson, 1971)

The most significant sites for the measurement of discharge are undoubtedly at the limestone springs. The response of these springs to rainfall can be used to obtain valuable information on the nature of the underground drainage occurring between the surface and the springs. This relationship, particularly the form of the recession limb of storm hydrographs, can enable meaningful comment to be made regarding the proportion of conduit to diffuse flow. Considering the applied significance of such studies, very little work of this kind has been published. The details of the methods employed will not be discussed here but it is possible to sub-divide the "hydrological cycle" for limestone regions into the form of a flow diagram composed of a series of "stores" and "links". The relative significance of each store and link will vary from one limestone type to another and with varying discharge conditions. Further details of the methods of calculation are given in Atkinson (1971a) and Smith (1975). An outline of the form of the flow diagram is given in Figure 4.

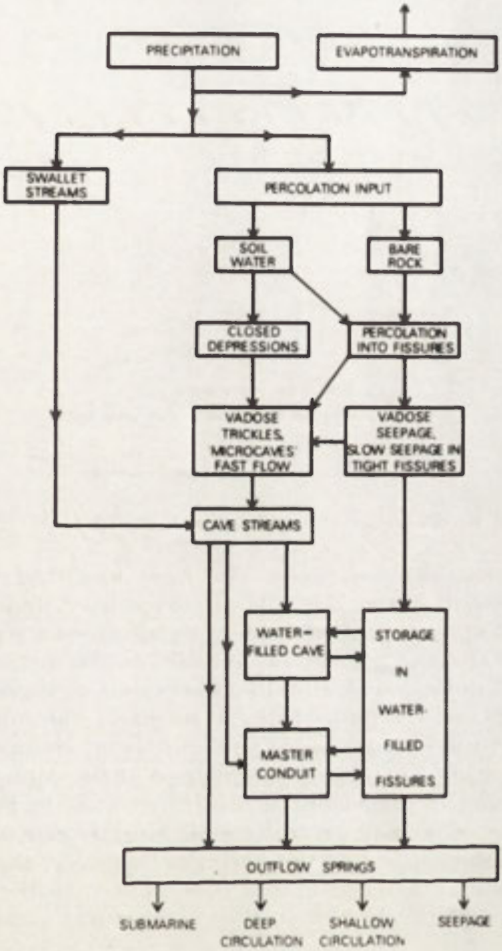

Fig. 4. A flow diagram for the hydrological cycle in limestone regions (after Smith, 1975)

COMBINED OBSERVATIONS ON WATER QUALITY AND HYDROLOGY

In a detailed account of the hydrology of a limestone area, studies of the various water quality parameters are combined with those of discharge. Together the results permit a fuller understanding of how the hydrology of the selected area functions, though for a reconnaissance study individual aspects can be of value. For most applied work it is detail of the form of the underground flow that is required, and particularly the relative proportions of conduit to diffuse flow, and the delimitation of underground catchments feeding the selected springs. In the majority of cases, the most useful information can be obtained by combining the overall hydrological studies with various tracing experiments, but it is possible to obtain some information on these applied

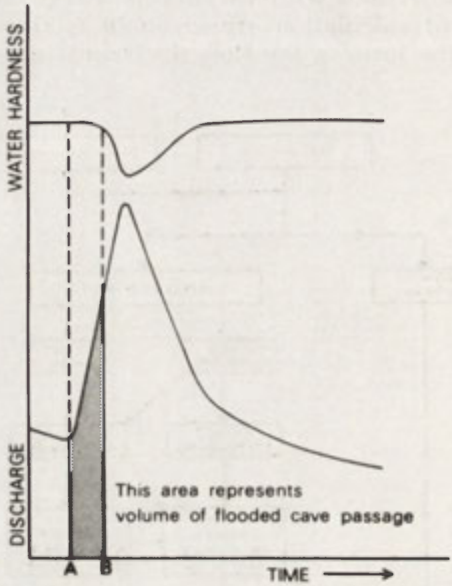

Fig. 5. The principle of flood pulse experiments (after Ashton, 1966)

topics by utilising natural conditions. The most useful of these is the "pulse wave" technique described and initially employed by Ashton (1966); an account is also given in Sweeting (1970) and further elaborations are given in an account by Brown and Ford (1971). This technique relies on the difference in travel time between the actual pulse wave and the associated changes in water quality. If the discharge of a flood pulse from a storm is monitored, the difference between the arrival time of the pulse and associated changes in water quality can be used to obtain information on the nature of the connecting underground system. The technique is diagrammatically illustrated in Figure 5. Under natural conditions, the effects of several swallet inputs can sometimes be disentangled from the observations at the springs. However, the usefulness of this method is considerably enhanced if it is combined with the use of dye tracers and artificial pulse waves rather than those of natural storm events.

WATER TRACING TECHNIQUES

A range of tracers is available for work in limestone regions and, for convenience, these can be divided into three major types. These are particulate tracers, chemical and dye methods, and radio-active tracers. The only particulate tracer of value is the use of Lycopodium spores. This technique was developed by Maurin and Zötl (1959) and has been subsequently described by Drew and Smith (1969). There is a variety of chemical and dye tracers but the most successful technique involves the use of fluorescent dyes and analysis by means of a fluorometer (Brown, 1972; Atkinson *et al.* 1973). If quantitative analysis is required, the best individual dye is Rhodamine WT and this can be detected with a suitable fluorometer to the level of one part in 10^{10}. Radio-active methods are potentially of considerable value but they will not be discussed in detail due to the difficulty of obtaining permission for their use where water abstraction is involved and the relative expense in their employment. An account of this technique and its application to hydrology, including limestone hydrology, is given in Gaspar and Oncescu (1972). A comparative study of the varying methods is given by Buchtela *et al.* (1968).

TABLE 1. Travel times from swallets to springs for massive limestones

	Mean flow velocity (in km/day)	Standard deviation	Number of traces
White Limestone Jamaica	3.45	4.05	40
Carboniferous Limestone Central Mendip Hills	7.36	5.91	23
Carboniferous Limestone Eastern Mendip Hills	6.00	1.68	16

Tracers can clearly be used to establish links between swallet streams and springs but considerably more information can be obtained if travel times are measured and combined with observations on dye concentration and hydrological measurements to produce dye budgets. The salient feature of swallet to spring travel time is the speed of flow even without allowing for the fact that the distances used in the calculations are for the shortest route. The velocity is frequently in excess of 5 km/day. The velocities for a number of traces in the Mendip Hills and from the White Limestone are of Jamaica are given in Table 1, which is further discussed in Smith and Atkinson (1973).

The tracer methods can also be combined with the pulse wave technique, to obtain additional information on the details of the groundwater flow.

APPLIED STUDIES

With a background of the broad conclusions obtained from hydrological studies, and an outline of the techniques and possible applications of tracer methods, a selection of case studies will be described. These, it is hoped, will illustrate the use of such work in an applied geographical context. The illustrations are all from work undertaken by the Geography Department of the University of Bristol, in conjunction with various outside bodies.

The application of limestone hydrology will be considered under two main headings. The first of these concerns the contamination of groundwater by surface pollutants; the second aspect considers problems of limestone quarrying.

CONTAMINATION OF GROUNDWATER BY SURFACE POLLUTION

(i) Massive, cavernous limestones

The simplest case concerns the dumping of wastes directly into surface swallets. In this situation, tracers are added to the swallet stream, and springs in the vicinity are monitored for the re-appearance of the tracer. Thus, connections between the pollution source and its spring outlet can be established. An extension of this work, for areas with swallets, is to prepare a map showing all the trace lines between swallets and springs in the region. This enables not only the flow paths of pollutants to be established, but enables planning of

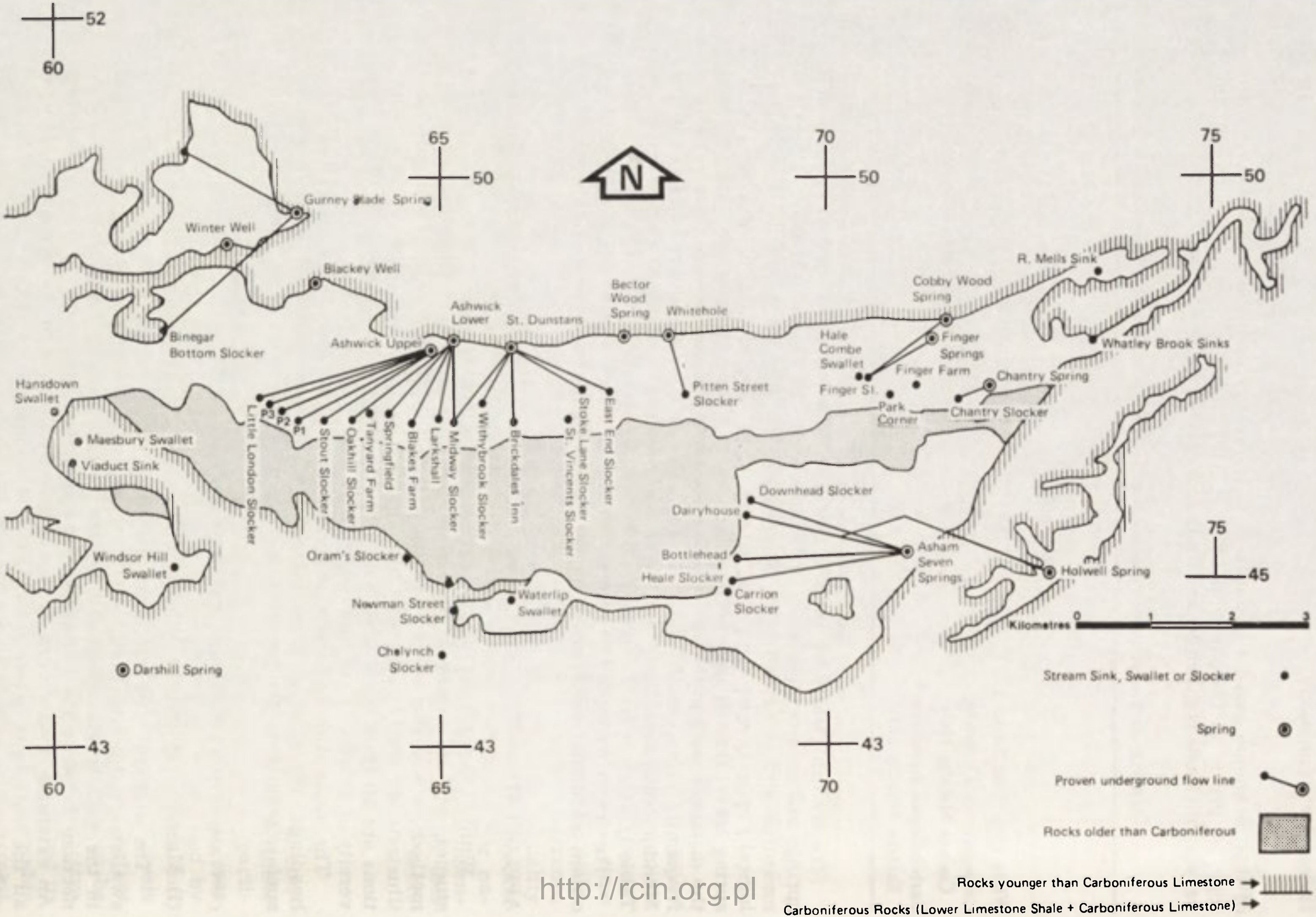

Fig. 6 The underground drainage of the east Mendip area (from Atkinson, Bradshaw and Smith, 1973)

waste disposal to be undertaken, and his the additional advantage that, should a spring show contamination, the likely source is already known and remedial action can be undertaken without delay.

A map for the Mendip Hills showing trace lines for virtually every known swallet feeder has been prepared (Atkinson, 1971b). An extract of this map, for eastern Mendip, showing the results for 24 swallets, is given in Figure 6. These tracing lines were established by a series of experiments over a period of years; details of individual experiments are available in Atkinson, Drew and High (1967), Drew (1968) and Atkinson *et al.* (1973). This map has been utilised for both the planning of water resources and to establish quickly the source of spring pollution. An example of the latter use is described by the Bristol Waterworks Company (1972). In this case, phenol and bacteriological contamination of a spring (Lower Ashwick Grove, see Fig. 6) was found to be due to silage liquor discharging *via* a land drain into a small swallet at Blake's Farm (on Figure 6). Remedial measures were immediately undertaken.

The significance of such work for pollution studies is greatly enhanced when the travel times are taken into account. The tests on which the map in Figure 6 is based were undertaken under a variety of discharge conditions but the mean velocity for eastern Mendip is 6 km/day. With travel times as rapid as this, there is no time for any appreciable natural filtration or modification of the pollutant to lake place. Indeed, the situation is directly comparable to the dumping of pollutants into surface streams.

Care must also be taken that probable connections and travel times between swallets and springs are not assumed from general geological considerations. Such assumptions are frequently inaccurate as the "underground catchments" for various springs can overlap and individual swallets (even when these are at very low discharge) can feed more than one spring. Also, springs are sometimes fed by two distinct flows resulting from the junction of two, or more, conduits only a short way underground from the spring — a phenomenon described above where detection was due to hardness variations. This situation is found at the spring marked "St. Dunstan's Well" on Figure 6. This is a "double" spring and, to add further confusion, the water to the west of the spring is fed by a swallet located to the east and the east side of the spring from swallets that lie to the west. The flow lines appear to cross underground without any mixing taking place.

It must be stressed that the rapid flow described above refers only to tracers injected into swallet streams. For Mendip, the proportion of the spring discharge that is derived from the swallets only accounts for perhaps 1–10% of the total discharge. We will consider later the groundwater flow rates that are applicable for water that is not directly of swallet derivation.

(ii) Chalk aquifers

It could be argued that rapid flow is limited to massive cavernous limestones. Earlier work on the Cretaceous Chalk of Britain suggested that a true water table model could be applied to account for groundwater movement in such limestones, and that the proportion of conduit flow was negligible. Recent work either by direct water tracing, or by other geohydrological techniques (for example, Ineson, 1962; Edmunds *et al.* 1973) indicates that a not inconsiderable portion of the groundwater movement is by conduit flow. A particularly impressive example is the direct observation of fissure flow in a chalk borehole seen by means of a borehole camera (Tate *et al.* 1971).

The importance of conduit flow can be illustrated by a study of the Chalk of southern Hampshire, which is presented in more detail in Atkinson and Smith (1974). The problem in this case was to dispose of the surface drainage from a new motorway. The most convenient solution, and that favoured by the road engineers, was to lead the road drainage underground into the Chalk near to a series of small swallets. These swallets were only active during heavy storms, and it was suspected on the grounds of water quality by the local water company that the swallet drainage fed quickly through to major springs located some 6 km distant. The largest of the swallets was injected with 500 ml of Rhodamine WT which was flushed underground by the addition of some 5,000 m^3 of water. The dye reappeared at the springs, being detected at two distinct but neighbouring springs 53 hours later. This gave a mean travel time of more than 2 km/day.

As the major fear regarding the motorway drainage was a possible spillage of chemicals, the amounts of dye recovered at the springs were also calculated. Some 70% of the input dye was recovered and it proved possible to present details of the level of concentration of pollutant that would be expected at differing time intervals if a road accident involving a spillage of 20 tons of water-miscible pollutant had occurred. The details of the time after the dye peak for differing levels of concentrations are shown in Table 2. As a result of this work, the plans for the disposal of the road drainage were modified.

TABLE 2.

Acceptable concentration of pollution	Time after peak	Total time after accident for which spring is polluted
1,000 μg/l	44.5 hrs	5 days
100 μg/l	61 hrs	6 days
10 μg/l	77 hrs	7 days
1 μg/l	94 hrs	7 days

It is also worth recording that studies in the Chalk of Sussex showed that dye from a tidal section of the River Arun moved into the groundwater circulation of the Chalk. The dye was recovered from a number of boreholes and showed flow rates in excess of 2 km/day. The natural flow pattern, in this case, was disturbed by pumping from the Chalk aquifer, and it would appear that under certain tidal conditions water from the river is pumped into water abstracted for use in the public water supply.

QUARRYING AND GROUNDWATER

Quarrying of limestone in the United Kingdom is increasing at a rapid rate and the major limestone units of the Carboniferous Limestone are of particular value for their use as roadstone and as concrete aggregate. The last twenty years or so have seen a fast growth both in the national output of hardstone and in the size of individual quarry units. The planning problems of this expansion are two-fold. Firstly, large quarries may interfere with groundwater circulation and affect water resources. This particular poblem is severe as many of the sites suitable for quarrying are also tributary areas to springs which are important water resources. The significance of the Carboniferous Limestone as a utilised aquifer in the United Kingdom is discussed by Newson (1973). Secondly, the expansion of large quarrying units is causing considerable areas to be lost to agricultural production.

(i) Interference with groundwater circulation

This problem is particularly difficult as in the Carboniferous Limestone a large proportion of the underground flow is of a conduit nature. This has the dual effect that it is impossible to locate precisely the position of the conduits and, should quarrying operations intercept a large conduit, a major pumping problem arises. More significantly, the water is lost to the spring discharge which is normally used for water supply.

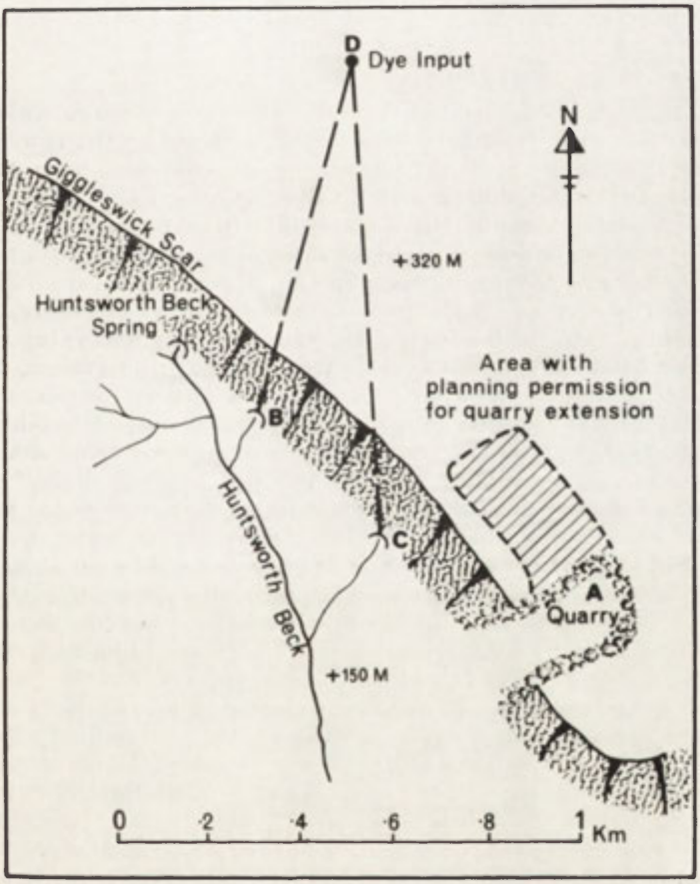

Fig. 7. Quarrying and water tracing in the Giggleswick area, Yorkshire

The Mendip water tracing map (discussed above) is of value in defining regions to be avoided for quarrying but possible problems of the interference with water supply will be illustrated by an example from the Carboniferous Limestone, near Settle, in Yorkshire. The situation is that the relatively small quarry marked as A on Figure 7 has planning permission to expand to take in the area outlined. In the long term, further expansion to the west may well be desirable from a quarrying viewpoint. However, several springs occur at the foot of Giggleswick Scar and the largest of these is the major supply for a modern industrial estate. In order to establish the pattern of subterranean drainage, it was necessary to introduce a dye tracer into the upland area that was thought to represent the catchment for these springs. The upland area is totally devoid of swallets. Earlier studies based on hardness and hydrological observations had led to the supposition that the connection between such surface depressions, infilled with soil and other debris, and neighbouring springs would also be dominated by conduit flow. Thus, the dye was washed into the selected surface depression (D on Figure 7 with some 50 m^3 of water. The dye reappeared at the springs marked B and C on Figure 7, with a speed of flow slightly less than 1 km/day. This indicates that any further extension of the quarry is likely to interfere with the discharge of the springs at the foot of Giggleswick Scar.

(ii) Sub-water table quarrying

The second problem associated with the extension of large scale quarrying relates to the loss of agricultural land and the effects on the spoilation of the landscape of such large units. The planning situation has been described by Stanton (1966, 1971) and the Somerset County Council (1971). The production of limestone on the Mendip Hills was some 6 m tonnes in 1971 but will probably rise to 20 m tonnes in the late 1980s. The reserves from the planning consents already granted amount to 700 m tonnes. However, Stanton points out that these reserves are calculated on the basis of limestone reserves above the "water table" that can be worked by traditional dry quarrying methods. He argues cogently that if sub-water table working was undertaken, the reserves from the current area of planning consent would be very considerably increased. The exact increase depends on the depth to which sub-water table quarrying could be extended, but the increased tonnage from the same area would be anything up to ten times as large as that obtained by conventional methods.

The major problem with sub-water working is the interference with groundwater movement. There is no doubt that the supply of water to the springs would be seriously affected and also that considerable pumping would be necessary to allow such sub-water extraction of the stone. However, it is conceivable that a comprehensive plan could partially reconcile the problems of the quarrying and water supply industries. The water pumped from the quarries could be used to replace the losses at the springs. Further, as large deep quarries become worked out it may prove possible to use them as reservoirs in which the pumped water could be stored. This far sighted scheme is currently under consideration by the relevant water bodies, the planning authorities and the quarrying industry. There is no doubt that potentially it has much in its favour, although it is essential that considerable research is needed into the details of the groundwater hydrology before it could be implemented. A review of the groundwater problems involved is given by Atkinson, Bradshaw and Smith (1973). The range of problems involved are far reaching and include the designation of the optimum areas for large scale quarrying, major changes in the economics and techniques of limestone quarrying, the possible relocation of the road network, considerations of the recreation potential and the preservation of cave systems and archaeological sites of national importance.

CONCLUSION

The hydrology of limestone terrains with its emphasis on groundwater may initially be considered as falling within the province of the hydrogeologist. However, a full understanding of the hydrology is intimately associated with aspects of surface hydrology and morphology and recent studies in physical geography with their emphasis on the measurement of process have an important role to play in this field. Indeed, it could be argued that the inter-relationship of limestone hydrology to planning problems is a field in which the applied physical geographer can make a worthwhile contribution.

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The examples used to illustrate this paper are all taken from work in which the Department of Geography at the University of Bristol has been involved. Examples have been drawn from the doctoral studies of T. C. Atkinson, D. P. Drew, M. D. Newson and P. L. Smart; research grants were in a number of cases provided by the Natural Environment Research Council. Co-operating institutions have included the Bristol Avon River Authority, the Hampshire River Authority, the Somerset River Authority and the Sussex River Authority, as well as the Bristol Waterworks Company and the Portsmouth Water Company. Much practical assistance with field work in the Mendip Hills was given by the University of Bristol Spelaeological Society, the Wessex Cave Club, and by individuals too numerous to list.

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GEOGRAPHIA POLONICA 34, 1976

THE INFLUENCE OF RIVER REGULATION AND LAND DRAINAGE UPON WATER CONDITIONS WITHIN THE SANDOMIERZ BASIN

ANNA KOWALSKA

The Sandomierz Basin is one of the so-called Subcarpathian Basins which form the depression between the Carpathians and the Lesser Poland Plateau. The region studied differs from other Subcarpathian Basins not only because it is especially large, but also owing to a peculiar configuration of its main rivers; in the northernmost part of the region the San river joins the Vistula river to form a regular triangle.[1] The study area is located within this triangle. Two different subregions can be distinguished within the area. One is the Kolbuszowa Upland situated in the south and the other one, called the Rozwadów Plain, is a low-lying area (Fig. 1).

Fig. 1. The study area

[1] Investigation was carried on by the whole staff of the Hydrography Department of the Institute of Eearth's Sciences from 1971–1974. The whole work contains many problems. The article is dealing with one of them.

One of the characteristics of the region as a whole, that can be easily noticed on the topographic map, is the high value of the drainage density. The drainage net of the Rozwadów Plain is quite different from that of the Kolbuszowa Upland. In the first case artificial elements predominate; canals and ditches have been joined with river channels in various ways. In the latter case, man-made changes are far less visible. Well-developed river systems of single catchment areas are dendritic. The density of the drainage network in this case is such that only a very small proportion of the area is greater than a kilometre from the nearest stream. Rivers and streams draining the Upland are characterized by a great variability of water abundance during the year. During the period of field work it was noticed that a number of small streams were dry; during the growing season they are devoid of water almost every year. However, after sudden torrential rains or thaws intermittent streams are formed.

The surface hydrographic condition depends on the hydro-geological situation. The bedrock-geology of the whole region consists of a series of Miocene deposits whose upper part consists of impermeable clay and shale. The surface of this clay is sculptured by erosion and covered with Quaternary deposits of varying lithological character and thickness. Deep, extensive fossil-valleys exist under the contemporary valleys of the Vistula, San and Wisłoka rivers (Laskowska-Wysoczańska 1971) and are infilled mainly with sands whose thickness is generally no greater than 30 metres. These are areas of the Rozwadów Plain.

The fossil Miocene surface of the Kolbuszowa Upland is covered with several metres of Quaternary deposits which exceptionally are over 20 m in thickness. In some places there are no Quaternary deposits. Moreover, within the Pleistocene deposits there are boulder-clay and loess-like deposits which show a variable vertical sequence.

Sands of the plains bordering the Kolbuszowa Upland are saturated with water from the base of the sequence too close to the surface. Permeable sands also dominate in the upper part of the profile so the water table, which occurs at a depth of about two metres, has the character of a free water surface. Water table fluctuations between annual extreme stages amount to 1–1.5 m, and the differences between mean yearly water level stages within the period of the ten years 1961–1970 are only exceptionally in excess of 100 cm. This great stability of the water table has been verified by the analysis of data from the 12 ground water measuring stations located throughout the entire Plain. It demonstrates the equal state of saturation and the continuous nature of the water table throughout the area.

Water conditions on the Kolbuszowa Upland are far more complicated, first of all because of the quite different lithological character of the Pleistocene materials. There is much more boulder-clay and loess than sandy deposits in them, and therefore confined waters are more frequent than normal water table conditions.

Investigation of the conditions has been undertaken in the field. Hydrographical mapping covered the area of circa 2,500 sq km. Moreover, numerous hydrological and hydrogeological data have been collected and used in order to produce a map of ground water conditions.

Areas of very shallow water (up to two metres) dominate on the Rozwadów Plain as on the Kolbuszowa Upland. Greater depth to the water table occurs in the southern part of the Upland. A feature of note is the depth to the water table within the valleys of the San and Wisłoka rivers. Here the ground water level is at a depth of 2–4 m during the summer and winter months. The vertical distance to the ground water table close to the stream bed of the San river is, in some cases, in excess of four metres. The Wisłoka river drains the ground water even more intensively.

This interesting hydrological phenomenon is reflected in the landscape. Instead of riverine meadows, arable fields reach the very river beds. Such a hydrological situation is anomalous in the climatic conditions of this country. It is not found in the valley of the Łęg river that drains the central part of the area, or in the valley of the Vistula river. However, the phenomenon has been found along some small streams in the Kolbuszowa Upland. All the streams associated with greater depths to underground water probably drain much more intensively than the others described.

The anomaly that has been described poses the question of whether we are dealing with a natural phenomenon or with a man-made situation.

The contemporary hydrological situation differs from that which existed in the Sandomierz Basin at the end of the 19th century. One can verify this from the old topographical maps of the period 1855–1894. These old maps show marshes and swamps which cannot be found on modern maps. On the other hand, the density of stream network is much greater nowadays, and there are numerous artificial elements within it. Changes are also evident in the shape and width of the river beds.

A map of soils at a larger scale gives us evidence of the changes that have happened in the region. On this map, there are small but numerous occurrences of black earths, the so-called bog-soils, which indicate a falling ground water table. According to the opinion of pedologists, soils of this type have formed within this century during a period of several decades (Strzemski 1954). In some cases they are still black earths but this is not always the case. Here and there they have undergone degradation due to a depletion of soil moisture. The same phenomenon applies to the hydromorphic soils that have been formed on the peat. As a result of falling ground water levels the processes that had produced the peat stopped. The muck soils, the so-called "mursh", are formed on organic or inorganic deposits. Hydromorphic soils are particularly frequent in the valley of the Wisłoka river and on the Rozwadów Plain. The data from large scale soil mapping have been used to estimate the amount of the fall of the ground water level (Oczoś and Partyka 1971). In thousands of profiles iron hardpan layers exist testifying to the earlier level of the water table (Książkiewicz 1968). It is accepted that the iron pan is produced at the contact between the saturated and unsaturated zone. It is a result of the downward leaching of compounds of aluminium and iron from the upper parts of the soil profile. The line of the contact is mobile; it moves together with the water level. Numerous limonite layers are formed in association with this process and each layer corresponds to a certain ground water level.

In the region studied the thickness of the iron hardpan layers is variable. In the forests, near the town of Nisko on the San, a hardpan stratum over one metre thick has been found. It was covered with 30–40 cm of sandy soil (Kuźniar 1948). The thickness of the hardpan of over one metre corresponds to the yearly amplitude of the ground water table fluctuations in the district in question. In the fields the upper part of the formation is usually disturbed by ploughing and for this reason the original thickness of the layer cannot be accurately estimated.

The hardpan has also been noted in well profiles, everywhere it occurs quite near to the surface. In the valley of the San, close to the town of Nisko and Stalowa Wola, the hardpan may be found at a depth of 20–30 cm, sometimes deeper, but only exceptionally at depths in excess of one metre. The same situation has been recorded on the Łęg river and near to Mielec on the Wisłoka.

The conclusions of these observations are as follows: in those places where the mean annual ground water level is now at a depth of two metres, in former times the water table was just beneath the ground surface, and in local depressions occupied by swamps and marshes, at the surface itself. The greatest lowering of the water table occurred in the valleys of the San and Wisłoka rivers. Here the fall of the water tables amounts to some four metres.

The overall fall of the ground water level is the result of human activity associated with land reclamation. In this district the activity commenced in 1884. The triangle between the Vistula and San rivers was an area that had been destroyed by river floods time after time, and more intensively than in other parts of southern Poland. Not only the Vistula and San rivers used to burst their banks but also small streams. The entire plain used to be under water during flood periods.

At first work was conducted within the catchments of three small tributaries of the Vistula. An overall flood control plan for the Vistula, San and Wisłoka rivers was postponed, only their valleys were protected against inundation with embankments. The channels of the small streams were dredged, straightened and narrowed. Their slopes were diminished and locally new river beds were designed in order to do away with local bifurcation in swamp areas. Simultaneously field drains were constructed within all the catchments. Peat-bogs were drained and changed into arable fields, vast forested areas were also drained as were large swamps near to the towns of Nisko and Rudnik on the San. The work was completed before the First World War (Kędzior 1929).

The flood control of the San began in 1907. The channel was narrowed markedly, the banks were consolidated, numerous meanders were cut off in order to shorten the river course and to increase its gradient. In the 19th century the river bed was very wide, locally reaching widths of 800 m. However, it was 2–3 m shallower than the present river course. Locally the rate of horizontal erosion amounted to 40 metres per year in the period 1890–1900 (Szumański 1975). After the flood control work had been completed this erosion was stopped almost completely. The contemporary course is straight or slightly curved. River banks of the San are 3–8 m above the low water level. There is no possibility for the accumulation of large quantities of material — as was the case before — in the present stabilized channel. Nowadays predominance of vertical erosion over accumulation is the most characteristic feature of the river. As a result the floor of the river bed has been further lowered, though the phenomenon has been diminishing in recent years (Szumański 1975).

The effect of the flood control of the Wisłoka river is the same; that is the vertical erosion is far more intensive than the accumulation. The floor of the river bed has been deepened 1–3 m during a period of 60 years. The present bed is much narrower than it was in the old days. The channel is stabilized by continuing work (Szumański 1975).

One may answer the question that was formulated earlier "What is the origin of the anomaly recorded in the terrain?". The answer is that it is a man-made phenomenon caused by river regulation. Both rivers, the San and Wisłoka, became gaining streams which drain very intensely the riverine zone within a distance of 2–5 km.

The anomalies found along some small streams on the Kolbuszowa Upland are less. These anomalies are also a result of human activity dealing with the flood control. Though the man-made phenomenon is not so prominent here, its influence upon the natural environment is greater because of special hydrogeological conditions of the district.

The hydrological role of the Vistula river within its valley looks quite different. The stream formed the frontier between the Russia and Austro-Hungarian Empires while the flood control work, discussed above, was being undertaken. In such a political situation every water project had to be accepted by the government of both countries and they were not seriously interested in the plans. In reality each of the projects was only partly realized. Due to these problems, the river gradient between the mouths of the Wisłoka and San rivers grew smaller during the years 1857–1887. Within the period between the two World Wars the regulation of this part of the Vistula had to be postponed. In the fifties the state of control of the river was poor, the width of the channel amounted to 190–370 m and the river was progressively reverting to its natural condition. These conditions have continued to the present time. Lack of the complete regulation of the Vistula is responsible for the hydrological equilibrium between the river water and ground water within the valley.

A similar situation applies to the Łęg river. The river was fully regulated about 60 years ago, but flood control measures have been devastated by sudden surges of flood waters (Szumański 1975). The present river is a stream that has become 'wild' again.

Drainage activity has continued to the present time. As much as 86 per cent of the whole usable land been drained in the Mielec district which is situated along the rivers Vistula and Wisłoka. The Tarnobrzeg district, located within the fork of the Vistula and San rivers, occupies the second place; (according to data for the 1st January 1969). Very poor sandy soils cover 62 per cent of arable lands in both districts (Oczoś and Partyka 1971).

Soil is a very sensitive indicator of the changes of hydrological conditions in the environment. On the Kolbuszowa Upland there are control fields where soil mapping was undertaken before the drainage work. Such mapping will be repeated every three years in order to assess the trend and value of change.[2] Quaternary deposits, mostly sands, are 0–3 m thick in this area.

The soils of excessive moisture, or those that used to experience excessive moisture conditions periodically, comprised almost 46 per cent of all the control fields before reclamation. The soils with balanced moisture conditions covered over 28 per cent, and the percentage of constant or periodically dry grounds amounted to 26 per cent. The results of land drainage were forecast to give the following values: wet soils only 9 per cent, soils of balanced moisture — 41 per cent, but dry soils as much as 50 per cent. The first mapping made three years after the drainage action verified the forecast. Of course, the new hydrological equilibrium cannot be expected to have been fully stabilized over a three-year period. However, there is a clear tendency for the acreage of soils which are constantly or periodically too dry to increase. This is typical for the area of the Kolbuszowa Upland.

The drainage work leads to a decrease in agricultural value for the sandy soils. In the Kolbuszowa district the poorest soils cover 76.1 per cent of arable land, and 60.6 per cent of meadows (Oczoś and Partyka 1971).

In the light of the above facts the consequences should be considered in an overall environmental setting. The whole region has become too dry. One arrives at the conclusion that the former hydrological and biocoenotic equilibrium of the environment has varied.

It is necessary to consider this new state of equilibrium. Either it is transistory or there are certain signs showing that the situation has stabilized and

[2] Investigation and mapping in the fields are carried on by the Institute of Soil Cultivation, Fertilizing and Pedology in Puławy.

the new correlation between respective components of the environment has been formed. Knowledge of the dynamic processes acting within the valleys of the San and Wisłoka rivers lead to the conclusion that the geomorphological and hydrological situation is maintained only by means of man-made drainage works. If these were abandoned specialist opinion states the area would quickly revert to the conditions of 60 years ago (Szumański 1975). The artificial maintenance of the ground water level at the depth of about two metres beneath the earth's surface, on the Rozwadów Plain, represents a similar situation.

Soils and vegetation depend on the water conditions. In fact, changes, which have been recorded in soil types, are persistent and mostly irreversible. Humus blown out of the black earths because of their loss of moisture is wasted for ever. Hydromorphic soils have undergone degradation and have lost their value. About 20 years after the first phase of reclamation had been made, namely in the 'twenties, the argicultural effects were very good. Nowadays, the soils in the same fields are perennial or periodically too dry and yields are small. Soil-forming processes proceed very slowly and even irrigation will not restore lost values to the soils in any reasonable span if time.

On the Kolbuszowa Upland the consequences of excessive drainage are far more prominent because of different hydrogeological conditions. Moreover, shortage of water for people is also a problem in this district. About 30 per cent of wells are devoid of water during summer droughts and the further 15 per cent do not provide water in sufficient quantities.

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THE EFFECT OF FLOOD DAMAGE ON LAND USE PLANNING

Edmund C. Penning-Rowsell

INTRODUCTION

Several fundamental problems are presented by the use of flood plain land. These areas, subject to periodic and unpredictable innundation, have traditionally been used at a very low level of intensity, largely for agricultural production and often rather marginal at that. In the 20th century however pressures have built up for the development of these areas, which are frequently situated conveniently close to expanding urban areas historically located next to flood plains but on slightly higher ground. These pressures result from the increasing value of land and particular flat land suitable for residential or industrial development. Parallel to this pressure for urban development has come the need to increase agricultural production to feed a growing population. Hence there has been a tendency to use the once more marginal areas for more intensive agricultural production. The flood plain areas situated within easy reach of urban markets have been affected by these changes, with the result that the agricultural land uses have generally risen in intensity, and correspondingly risen in flood damage potential.

Urban development of flood plain areas was particularly active in the inter-war period before the planning controls embodied in the 1947 Town and Country Planning Act came into operation. In the case of Nottingham for example (Figure 1) the flood plain of the river Trent has seen an invasion of urban land uses in this period, resulting in substantial damages in the critical 1947 flooding. In the country as a whole piecemeal development on flood plains has continued since 1947 where planning control has been less strict, adding to the increased damage potential left by the inter-war legacy of unplanned development.

While the role of flood plain areas has changed towards more intensive land uses, the hazard unfortunately has remained. Floods are still serious and unpredictable environmental events, still highly damaging when of sufficient magnitude, and — perhaps most aggravating of all — still relatively infrequent in any one part of the country to lower local awareness but frequent enough somewhere to be a nagging overall problem. In general terms the engineering works constructed over many decades to "protect" flood plain areas have alleviated the damage to urban areas caused by the minor floods occurring every two or three years. But the twin problems of infrequent major flooding of urban areas and frequent flooding of agricultural land have not been tackled. The summer floods of 1968 in southern England resulted in very substantial financial loss, particularly through flooding of agricultural crops, but still the temp-

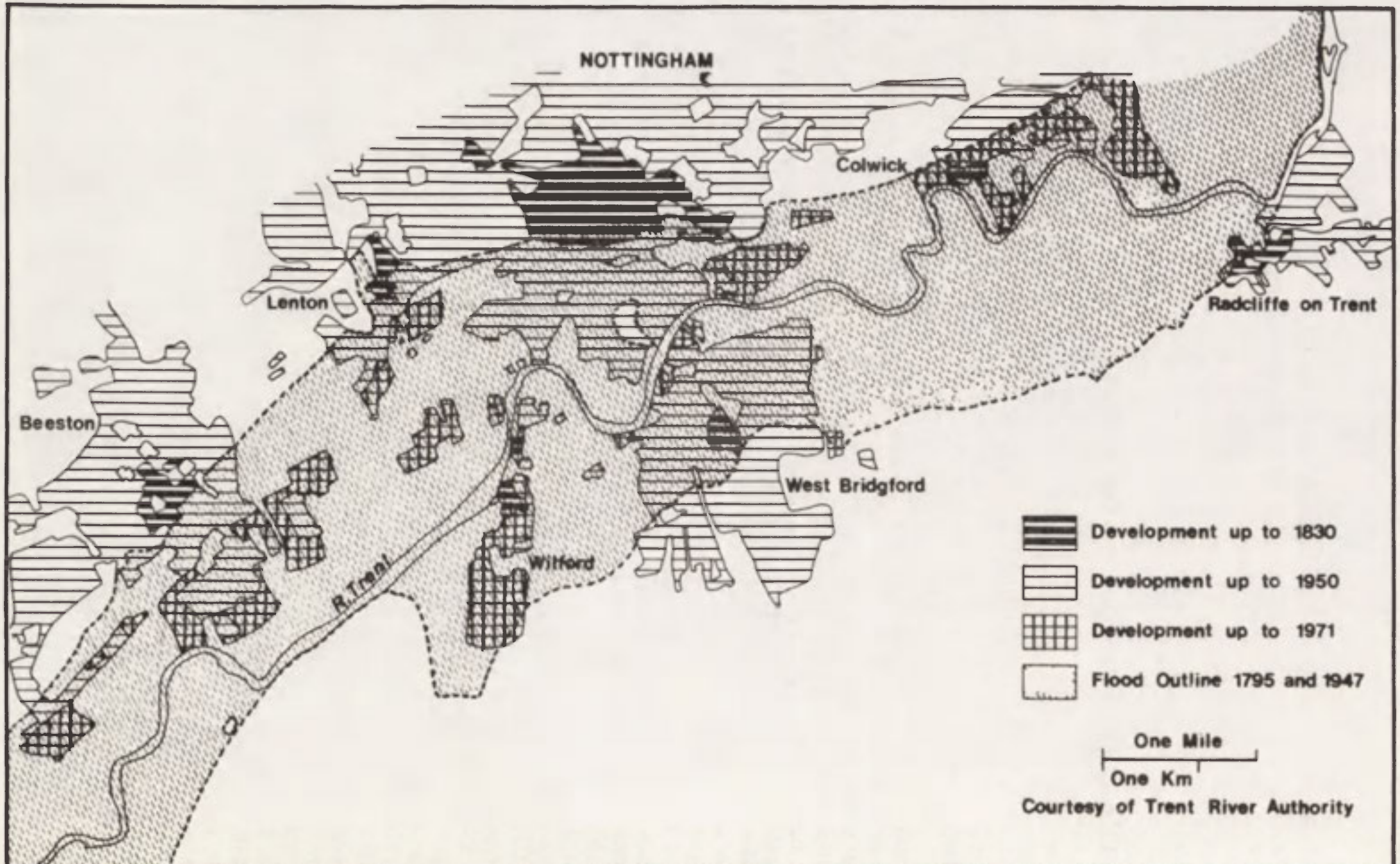

Fig. 1. Invasion of the flood plain at Nottingham

tation of flood plain managers or planners and flood plain occupants is to think that it cannot happen again, especially to them.

The development of flood plain areas is not necessarily unwise but the fundamental management problem is whether the benefits accruing to the community at large resulting from the development of these once neglected areas outweigh the losses to be incurred through damage when (not if) the subsequent floods come. This is a question that cannot yet be answered adequately. In theory a proper land use management framework is required, balancing costs and benefits of alternative land uses for flood prone areas before arriving at decisions whether to develop or not. In practice the cost/benefit equation has been difficult to construct owing to data deficiencies and nearly impossible to use owing to the emotional hazard context which surrounds flood danger situations. The insitutional framework exists to tackle this vexing problem, being the statutory liaison procedure between planning and water authorities, but the data on which to base the necessary land use decisions has not yet been available.

THE CURRENT LAND USE MANAGEMENT FRAMEWORK

Since 1947 development on flood plain areas has been very restricted, although there are exceptions either where planning control has been loose or where adequate protection was thought to be available. This restriction was largely brought about by Circular 31/47 issued by the then Ministry of Housing and Local Government. Since then the principles contained in the Circular have been strengthened with a new Circular in 1962 (Number 52/62) and more recently with powers to refuse permission to develop land off the flood plain which might exacerbate the flooding problem on adjacent flood plain areas by increasing runoff. Each of these Circulars is directed to the development control function of local government planning departments.

When an application for development of land is made to the local planning department permission may be refused on a number of grounds; one of these grounds is that the development is in an area liable to flooding. In this situation the relevant Water Authority should be consulted on the likely potential flood damage. The Water Authority advises the local planning department for or against granting permission to the developer but the final authority rests with the planning department. The referral process to the Water Authority is to a large extent informal, and in some parts of the country the liaison between the two authorities is somewhat tenuous and in others much depends on the personalities of the chief planning officer and the chief engineer. Unwise developments have resulted from this uncertain situation. If the developer is refused permission because of the liablity to flooding but appeals against the decision, it is to the Planning section of the Department of the Environment that the appeal goes, not to the Ministry of Agriculture with its interest and expertise in land drainage and flood protection. Unwise developments may also result from this appeals procedure.

The reorganisations of both local government and the Water Authorities in April 1974 has meant that the liaison is now between the new local District Councils rather than the old County Councils and the 10 Regional Water Authorities rather than the 29 River Authorities. This important change, summarised in Figure 2, means that the responsible authority for granting or refusing permission to develop flood plain land is now the numerous, small and often ill-equipped District Planning Departments, after liaison with the large and inevitably distant Water Authority, whose engineers probably best appreciate the flooding problem. Prognostication is naturally difficult at this stage but one would be surprised if flood plain management improved in the short term following this dual reorganisation.

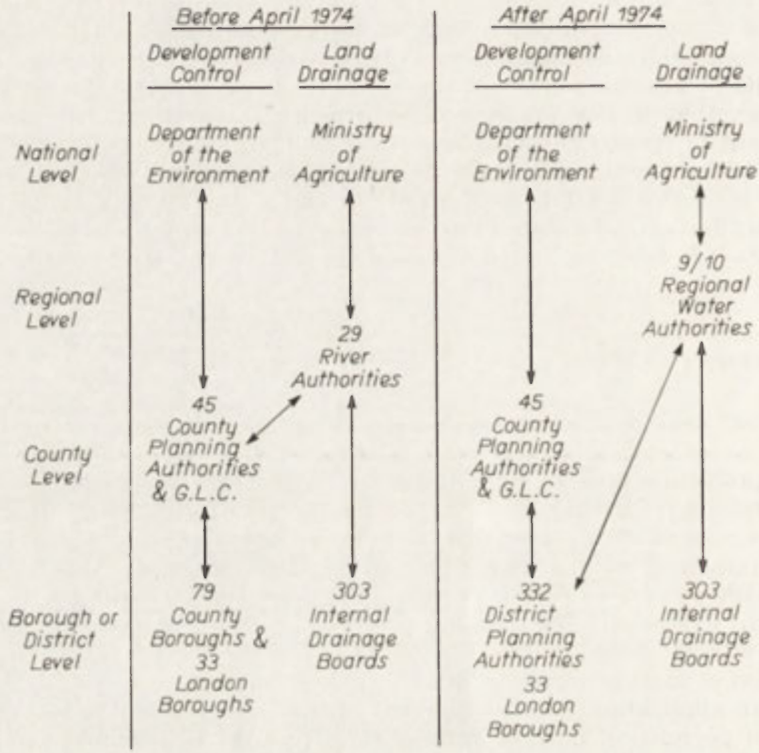

Fig. 2. Simplified structure of responsibilities for flood plain development control in England (arrows indicate liaison between organisations)

The objectives of management of flood plain land use should be to maximise the benefits that can be obtained from the use of flat, fertile and usually very accessible land, while minimising the costs through flood damage. This latter part of the equation means providing measures either to reduce the frequency of flooding, or to reduce the damage from floods when they occur. It is reasonable that where benefit accrues to the community through development of flood plain land, part of that benefit should be foregone to protect that development with flood alleviation works or other adjustments of land use or the structural design of buildings. It is clear that with the existing rather low level of liaison between Water and Planning authorities the situation as far as proper management of flood plain resources may not be optimal, although the organisaticns themselves are not necessarily at fault. The dearth of data on potential flood damage, the all important variable within the management equation, is partly responsible for the lack of a rational approach to land use management. This is because without details of potential damage from flood events it is neither possible to review protection measures for existing flood plain developments nor plan future developments so as to achieve a balance between community benefits and likely flood damage costs. A preliminary attempt to measure flood damage potential for the lower Severn catchment is described below and the policy implications discussed.

LAND USE AND FLOOD DAMAGE POTENTIAL IN THE LOWER SEVERN

The flood plain of the lower Severn between Tewkesbury and the Bristol Channel (Figure 3) is predominantly an area of agricultural land use. Table 1 shows that nearly 78 per cent of the area below the 50 ft. (20 m) contour is farmland.[1] The urban component of the land use at 7.4 per cent represents the

TABLE 1. Lower Severn Land Use Proportions

Farmland	%	Dry Acid Habitat	%
Allotments	0.2	Festuca Agrostis	TRACE
Cereals	6.5		
Grass	64.0	Woodland	%
Industrial Crops	0.1	Broadleaved	0.3
Green Fodder	0.6	Unspecified	0.2
Ley Legumes	0.4		0.5
Mixed Market Gardening	0.1		
Orchards with grass	5.3	Coast, Marsh and Water	%
Root Crops	0.1	Freshwater Marsh	0.3
Vegetables	0.5	Salt Marsh	0.5
Fallow	0.1	Salt Turf	0.4
		Unvegetated Intertidal	6.7
	77.9	Water	5.7
		Unvegetated Beach & Cliff above high water mark	TRACE
Settlement	%		
Airfields	TRACE		
Public Buildings	0.1		14.6
Caravans, etc.	TRACE		
Derelict Buildings	0.1	Reverted Land	%
Factories	0.6	Bush Scrub	0.2
Commercial & Residential	3.2	Rough Grass	0.3
Locomotive Tracks	0.5		0.5
Open Space	0.5		
Ports	0.1		
Quarries & Pits	TRACE		
Roads & Tracks	2.1		
Tips	TRACE		
Utilities	0.2		
	7.4		

The land use data for this Table is derived from an analysis of the field sheets of the Second Land Utilisation Survey of Britain, by kind permission of Miss Alice Coleman of Kings College London. Sixteen points per kilometre square were sampled systematically.

[1] The 50 ft. contour is taken as the limit of the flood plain in this area, as recognised in the North Gloucestershire Sub-Regional Plan, being the probable maximum upper limit of innundation. No allowance is made for the gradient of the river, for the sake of simplicity, which results in a fall of approximately 10 feet (3.0 meters) in the altitude of the river over the case study area.

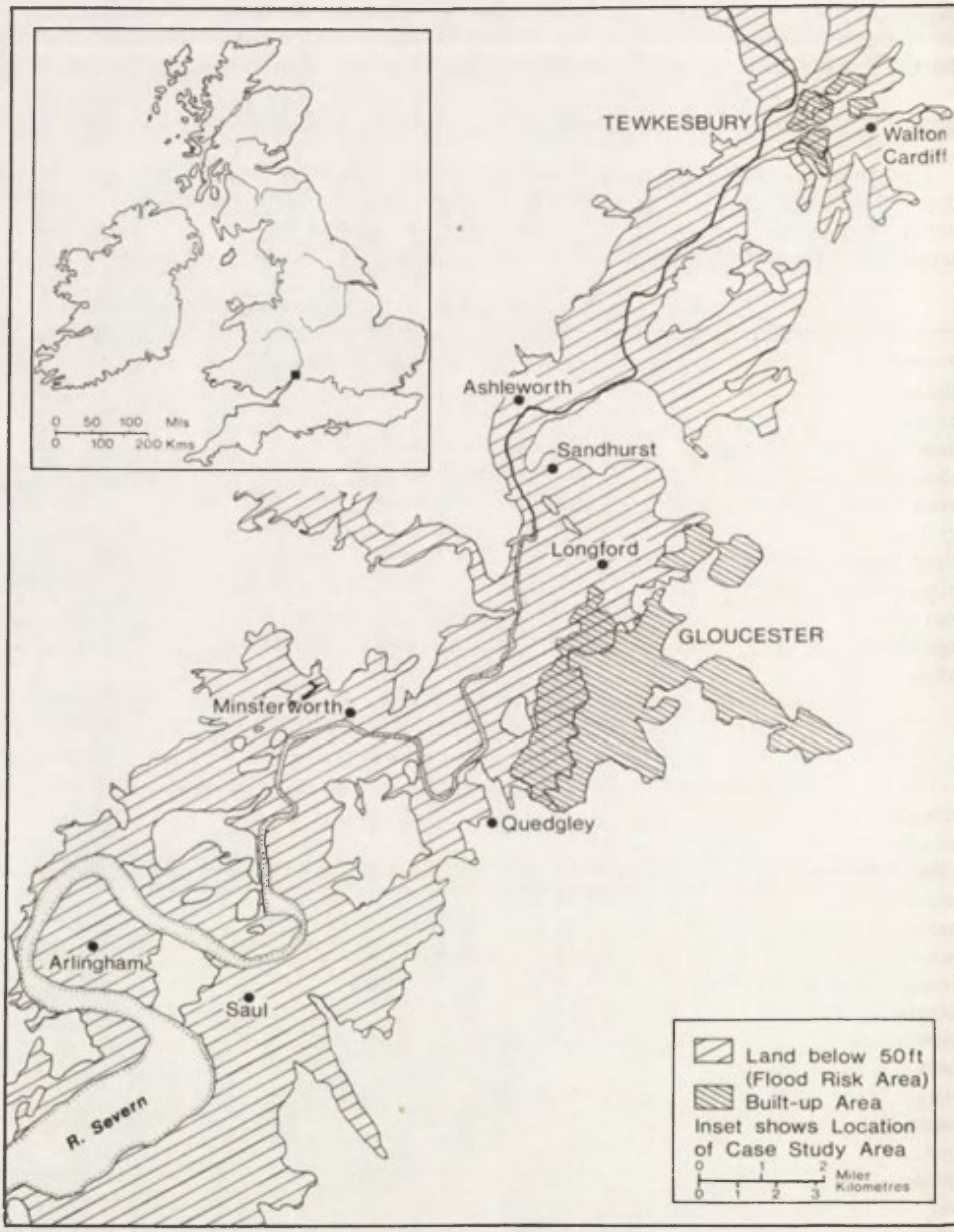

Fig. 3. Lower Severn Case Study Area

majority of the town of Tewkesbury and about one third of the extent of Gloucester. Tewkesbury is a town of ancient origins situated at the confluence of the rivers Avon and Severn and little of this urban development below 50 ft. (20 m) took place in the 20th century although naturally the individual buildings themselves may be modern. The majority of the part of Gloucester on the flood plain is composed of 19th century housing, modern industrial estates and inter-war suburban development. Table 2 gives the breakdown of the urban land use component of the flood plain derived from a field survey in 1973 showing the dominance of pre-war residential property, built before the 1947 planning controls brought restrictions to flood plain development. There is a sprinkling of very recent development on the flood plain either as a result of the poor operation of the liaison procedure between planning and water authority, or more justifiably as a result of crude cost/benefit estimates on the part of the Water Authority resulting in a balance in favour of the developments. It is the industrial developments that largely fall into this latter category.

TABLE 2. Survey of land use sectors

Residential (Pre 1947)	4805
Residential (Post 1947)	2252
Agricultural Buildings	134
Miscellaneous Land Use	32
Public Buildings	154
Professional and Office	50
Retail Trading	486
Industrial (including Public Utility Holdings)	171
	Total: 8084*

Source: Field Work

* 74 Land Use units (i.e. buildings, or groups of buildings in the case of industry) have been classified as public utility holdings or miscellaneous.

In order to improve the accuracy of these cost/benefit evaluations, surveys have been conducted into the direct flood damage potential of four of the categories or sectors of urban land use.[2] In addition the damage potential of agricultural buildings has been investigated. Several basic assumptions have been made in these analysis, and to some extent the results of the research may reflect these assumptions. Firstly, *potential* damage rather than actual damage is measured. While it is necessary to verify damage data derived synthetically (potential damage data) against actual damage suffered by loss through flood waters entering buildings, nevertheless actual damage assessment in the immediate post-flood situation is likely to prove inaccurate. Long term effects of flood waters on building structures will not be discernible in the immediate post-flood period and direct damage to building contents and retail stock for example cannot be accurately assessed because the residual value of those contents and stock after flooding cannot be determined. Secondly, the *maximum* potential damage to all the land uses is the data sought. Maximum potential damage is that damage which would occur to the relevant land use or type of building given no warning and consequently no damage-reducing action of the part of the owner or occupier. The reason for measuring maximum potential damage is that only when this maximum figure is known can warning schemes designed to reduce damage from that upper figure be evaluated on a cost/benefit basis of damage compared to the costs of the schemes. Thirdly, at this stage

[2] This research is sponsored by the Natural Environment Research Council. Potential damage information is now available for all flood plain land uses, both urban and rural.

of the investigation it is assumed that the most important hydrological variable affecting damage to property is *depth* of flood water. Silt content of flood waters is taken into consideration with an investigation of clean-up costs necessary after flooding, but the effect of velocity of flood water on buildings structures and consequent damage is assumed to be zero. Damage to decoration and structural fittings through contact with flood water is however included in the maximum damage figure. A variety of sources and methods are used in the damage assessment surveys (Table 3). Wherever the occupant of the building is

TABLE 3. Basic Data Sources in the Development of Guidelines for Damage Estimation

Land Use Type	Data Sources
Residential Units	1. Independent surveys of actual flood damage in areas other than the Lower Severn. 2. Second-hand dealers and merchants. 3. Household equipment manufacturers. 4. Interview and inspection surveys. 5. Data on damage experience in Lower Severn (from 4).
Retail/Professional Units	1. Factual Interview and Inspection survey. 2. Census of Distribution. 3. Public Health Authorities. 4. Salvage companies. 5. Loss Adjusters. 6. Shop Fitters and Builders. 7. Equipment manufacturers. 8. Structural engineers.
Agricultural Units and Land Uses	1. Factual Interview and Inspection Survey. 2. Ministry of Agriculture (local and central). 3. Agricultural Development Advisory Service. 4. 2nd Land Utilisation Survey. 5. Soil survey of England and Wales. 6. Existing research (crop damage). 7. Land use up-dating exercise (farm interview). 8. Agricultural equipment manufactures and distributors.
Industrial Units	1. Factual Interview and inspection survey. 2. Management damage estimations. 3. Companies House records.
Public Buildings	1. Local Authorities (County and City surveyors, Architects and Valuers).
Public Utilities & Services	1. Midland Electricity Board. 2. S. W. Gas Board. 3. N. W. Gloucestershire Water Board. 4. General Post Office. 5. British Rail Engineers. 6. City and County Highways Department. 7. Bristol Omnibus Company. 8. Severn-Trent Water Authority. 9. Flood Relief Services (e.g. Civil Defence).

likely not to have expertise to assess damage to his property at different levels of innundation, the approach used was to complete a check list of the contents, structural design and fittings of the building. Following this inspection survey, damage estimates were made for each type of content, fitting and structure, using the experience of shopfitters, loss adjusters and structural surveyors. Only by analysing all the properties in this level of detail could an accurate assessment of maximum damage potential be made. This approach was used to survey the residential, retail and professional office sectors of the flood plain land used. Wherever the managers or occupiers of the premises had the necessary expertise, as for example in the case of the majority industrial properties, an assessment of potential flood damage was made by the interviewers in conjunction with the managers, backed up by the same secondary sources such as loss adjusters as in the other sectors.

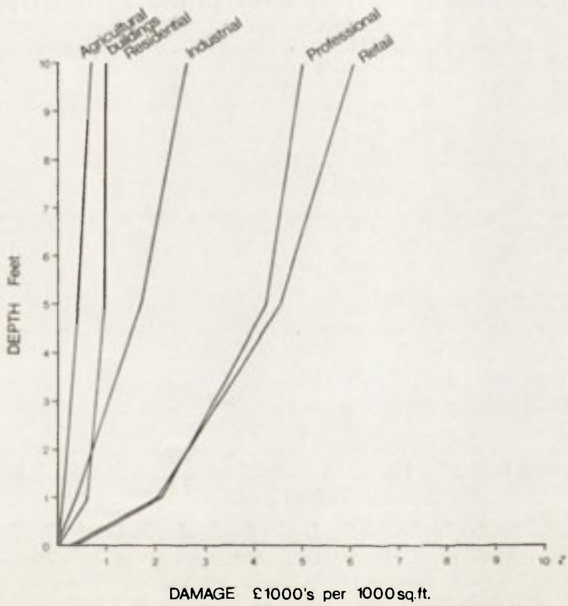

Fig. 4. Sector depth/damage curves (lower Severn)

Figure 4 gives the averaged depth/damage curves for the different land use sectors, based on a total sample of 380 properties (102 residential; 25 agricultural buildings; 108 retail premises; 20 professional premises and 125 industrial properties). In each case the curves show a characteristic half 'U' shape indicating diminishing increase in damage with depth of flooding. However, the levels of maximum potential damage differ considerable from the very low figures for agricultural buildings to the very high values for the retail properties. Deductively it was assumed that industrial damage would be the most substantial yet this is not the case. The stock and equipment components of damage to the retail land use sector, with its high intensity of use of space within buildings, yields the highest figures for maximum potential damage.

The curves in Figure 4 show the potential effect of flood damage on land use. When assessing flood plain developments it may be that industrial development can be justified as yielding greater community benefit that potential cost through flood damage. Residential development might be justifiable in cost/benefit terms but probably not justifiable if one adds to these direct damage figures the intangible elements of anxiety, ill-health and inconvenience caused by flood events. The professional premises and retail sectors of land use would not be so suitable for flood plain location, as their potential damage is some six times as great as the damage potential of residential properties.

The damage potential of the whole lower Severn area is shown in Figure 5, which is constructed using simple average damage potentials for the different land use sectors. The increasing damage potential with altitude is clear, particularly above the 35 ft. (14 m) contour where the large industrial developments near Gloucester contribute substantially to the total potential damage figure. Given these data on damage at different altitudes it would be possible to assess the relative merits in cost/benefit terms of providing different levels of protection against flooding; thus flood plain management by Water and Planning Authorities becomes a quantitative reality rather than an intuitive guessing exercise.

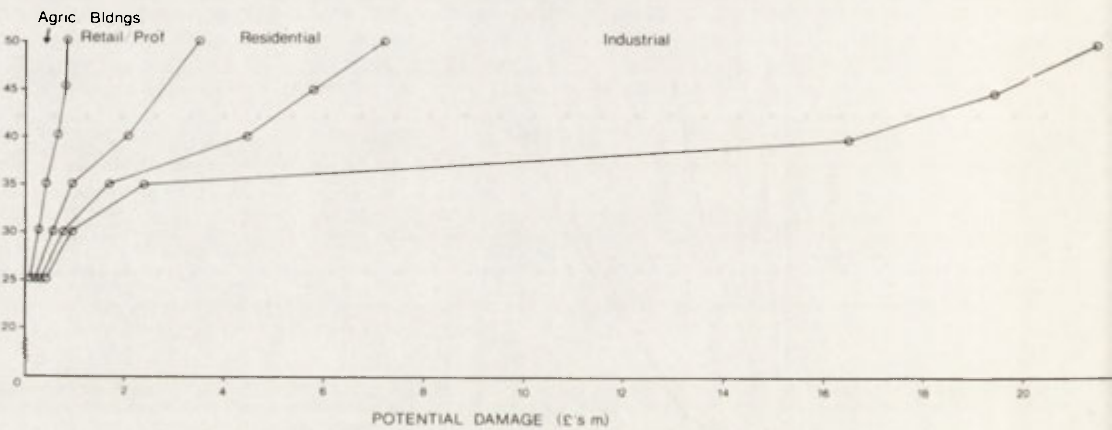

Fig. 5. Components of total potential damage for the lower Severn

THE INDIVIDUAL'S RESPONSE TO THE FLOOD HAZARD

The results presented in Figures 4 and 5 represent the maximum damage that would occur given no warning and ignoring the presence of all the adjustments that are possible for each land use to reduce the actual damage caused by flooding. A parallel survey to assess the level of adjustment by the residents of the flood plain has investigated the type of action already existing in this area to reduce damage potential, and the factors that affect the individual's readiness to protect himself with these types of actions.

The 8,741 households on the electoral registers of the flood plain case study area were used as the sampling framework and every fifth household approached either with a postal questionnaire or with a personal interview. From this 20 per cent target sample a total of 723 responses were obtained, approximately 40% of the target sample and some 8.1% of the total population of households. The overall response rates were virtually 100% for the interviews and 13.5% for the postal survey. Preliminary investigation shows that these different response rates do not bias the results markedly.

Table 4 summarises the response of the flood plain inhabitants to the flooding problem in the area, showing that the most popular adjustment is a special insurance policy to recoup the financial losses of flooding. Here 15.6% of the respondents made this adjustment, whereas of the other possible adjustments only sandbagging and raising valuables in the face of flood conditions achieved a positive response greater than 10 per cent of the sample, although 11.9 per cent of the sample live in dwellings already flood proofed in some way. It is clear that the level of response is very low, but the reasons for this lack of readiness on behalf of the flood plain users to protect their property is not clear. This area has a very long history of flood problems yet only a small minority of the residents choose to take any precautions.

TABLE 4. Adjustments used by individuals against the flood hazard in the lower Severn

	Whether Adopted or Not		
Adjustments	"Yes"	Per cent	"No"
Sandbagging	62	10.4	536
Insurance	101	15.6	546
Permanent Structural Changes	35	5.4	612
Raised Valuables	86	13.3	562
Special Flood Warnings	15	2.3	634
Temporary Accommodation	28	4.3	621
Boat	6	0.9	643
Building flood proofed partially when purchased	82	11.9	605

To unravel this complex situation and determine what factors affect the inhabitants' readiness to make adjustments other questions were included in the survey to measure respondents' experience of flooding, their awareness or perception of the flood problem and their socio-economic status. Past experience of flooding emerges as the critical factor affecting the level of response (Table 5). Sixty-nine per cent of those flooded at some time in the past have made at least one of the adjustments listed in Table 4; only 15 per cent of those with no previous flood experience had made any of these adjustments to protect their property. In addition the length of time since the last flood experienced affects the level of adjustment; of those flooded within the last five years 76 per cent have made some response to counteract future flooding but of those last flooded more than five years previously only 60 per cent had made the same level of adjustment. Furthermore the rate of response, measured by the number of adjustments made, is related to the amount of damage suffered previously.

While experience affects the willingness of flood plain inhabitants to make precautionary adjustments, their socio-economic status does not. Table 6 shows that the occupation of the head of household has no effect on the rate of adjustment to the flood hazard. Nor does the age of the head of household have any effect on adjustments made, although the older respondents do spend significantly more on their adjustments, perhaps indicating a higher degree of awareness of the magnitude of the flood problem.

The awareness of the flood hazard by the flood plain occupants is in fact related to their level of adjustment, although the direction of effect is not

TABLE 5. The relationship between flood experience and adjustment

Experience of Flooding	Adjustment Made: None	Some	
Flooded	55	123	178
Not Flooded	461	84	545
	516	207	723

Chi-square = 188.9
significant at 0.01 level

Date of Flooding	Adjustments Made: None	Some	
1-5 years since flooded	26	84	110
6+ years since flooded	21	32	53
	47	116	163

Chi-square = 4.94
significant at 0.05 level

Damage	Number of Adjustments made: 1	2	3+	
£0	13	4	4	21
<£250	12	28	22	62
£250+	7	4	9	20
	32	36	35	103

Chi-square = 15.91
significant at 0.01 level

totally clear. The respondents were asked what 'geographical problems' exist in their neighbourhood and of those that mentioned flooding 42 per cent had taken some adjustment measures. Of those who did not mention flooding in the same context, only 26 per cent had made the same level of adjustment (Table 6). Naturally the respondents who had made some sort of adjustment would be more likely to be aware of the problem, but their increased awareness did not necessarily lead to their making the adjustment in the first place.

Perception of future flood hazards also affects the rate of adjustment. By dividing the number of flood experiences by the number of years of residence, and comparing this to the number of future floods that the respondent expects

TABLE 6. Relationship between adjustment and socio-economic and flood awareness variables

Socio-Economic Class	Adjustments Made: None	Some	
"Working"	72	28	100
"Middle"	262	105	367
"Upper Middle"	182	74	256
	516	207	723

Chi-square = 0.03
Not significant

Age Group	Cost of Responses: Below average	Above average	
Young	45	5	50
Middle	28	13	41
Old	11	7	18
	84	25	109

Chi-square = 9.22
Significant at 0.01 level

No. of Adjustments	Geographical Problem: Mentioned	Not mentioned	
None	122	394	516
1	28	80	108
1+	61	18	99
	211	512	723

Chi-square = 58.20
Significant at 0.01 level

No. of Adjustments	Pessimists	Optimists	
None	26	30	56
1	12	24	36
1+	13	59	72
	51	113	164

Chi-square = 11.98
Significant at 0.01 level

in the next twenty years, an index of optimism and pessimism can be derived (Figure 6). Those who expect more floods in the future than they experienced in the past are pessimists, those who expect less are optimists. As shown in Table 6 the pessimists make a lower level of adjustment to the flood hazard than the optimists, despite their perception of the flood risk.

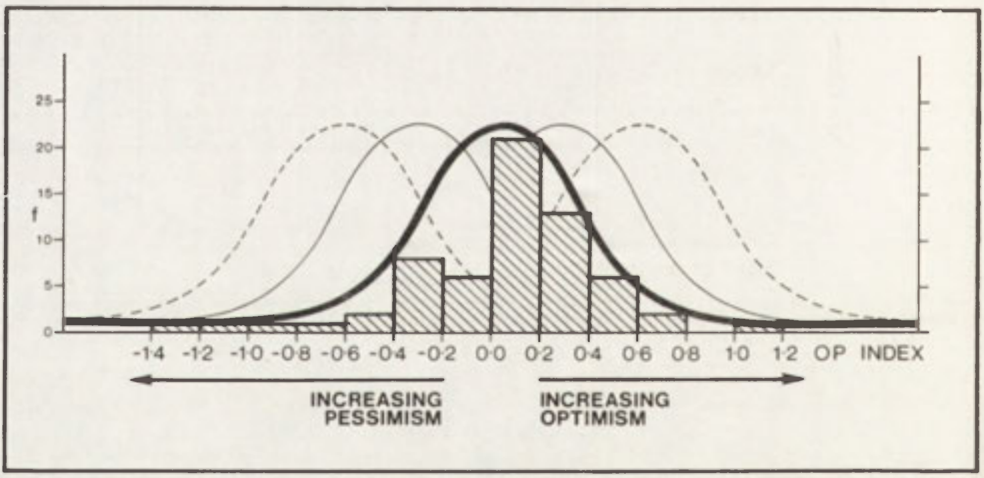

Fig. 6. Optimism and pessimism about future flood frequencies (for explanation see text). Traces parallel to observed near-normal distribution show possible shifts following periods of frequent or infrequent flooding

A further variable affecting level of adjustment is whether the flood plain dweller lives in an urban or a rural area. Taking the former as being the built- up area shown on 1 : 25,000 Ordnance Survey maps 78 or 20.3 per cent of the urban population have made at least one adjustment, whereas 129 or 38 per cent of the rural population had made the same level of adjustment. The awareness of the flood problem is much lower in the urban areas, probably owing to a more mobile population, and it appears that as a result of this lesser awareness adjustments are not made so readily.

CONCLUSION

The level of adjustment to the flood hazard in this area is very low and the situation is very probably similar in other areas. The factors that affect the willingness of the flood plain occupants to take precautions or adjustments against flood damage and loss appear to be basically experience of flooding in the past, followed by the general awareness of the flood problem and the perception of the future rate of flooding in the area. This relationship of adjustment to experience must cause problems for flood plain managers or planners attempting to reduce flood damage — the paradox is that what is needed to increase the level of adjustment and thereby reduce flood damage potential is a series of substantial floods causing unwanted damage! Nevertheless the low overall level of adjustments suggests that the maximum potential damage figures derived for the area may not be too great an overestimation of actual damages. The slight relationship between flood perception and adjustment gives some encouragement; flood plain managers clearly should educate their public to the dangers they face and wait for the damage-reducing adjustments to appear.

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DRAINAGE BASIN ADJUSTMENTS AND MAN

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Although some nineteenth and early twentieth century studies in Britain demonstrated the consequences of man's activities for the river, the river channel and for the drainage basin, it is paradoxical that the implications of the changes noted have not been further investigated until the last decade or so. Several types of adjustment in the drainage basin had been isolated for specific areas prior to 1920. Thus the impact of man upon drainage basin processes was indicated by T. L. Lauder (1830) who suggested that flooding must have increased in Scotland as a result of agricultural improvement of the land. Subsequently N. Beardmore (1862) drew attention to the progress of agriculture and drainage and he noted that "these operations are rapidly contributing to affect the levels at the mouth, or on the lower course of our rivers...". Some morphological consequences of these hydrological changes were suspected and descriptions of the sedimentation along the lower parts of river courses, of the extension of peat drainage channels and of changes in channel pattern were reported from a number of areas. Thus in west Cornwall the effects of tin streaming and tin mining upon the hydrology and sediment budgets of the basins draining to Carnon Creek (*1* on Fig. 1) were noted by Whitley (1877) who demonstrated that some 0.75 to 2.7 m of sediment accumulated along the Carnon valley between Higher Carnon and Devoran in the 21 years between 1821 and 1842. The direct implications of such man-induced changes were illustrated by a study (Smith 1910) along the river Trent (2, Fig. 1) based upon evidence from documentary sources and from early maps, which showed the extent of changes of river position between Newark and Dunham Bridge. G. W. Lamplugh commented that the changes demonstrated along the river may have been greater had it not been for the effects of river regulation and control. In addition to changes in channel pattern modifications of drainage networks were also noted as a likely consequence of man's activities and in the Peak District (3, Fig. 1) Moss recorded (1913) the recent extension of peat drainage channels.

In 1914 G. W. Lamplugh reviewed the general consequences of the taming of streams in Britain and he noted that "in a well settled country the water flow from the initial gutter to the final estuary, has been modified by man". More generally R. L. Sherlock (1922) reviewed the effects of Man as a Geological Agent, he cited instances of falling water tables, and he indicated that in the twenty years prior to 1893 all three heads of the River Colne (4, Fig. 1) had shrunk and the rivers Gade and Chess both rose 3.2 km down their valleys.

Although the basis for an interest in drainage basin changes was created by 1922 it is notable that very few studies were undertaken in the next forty years by geographers to illuminate the magnitude and consequences of man's

Fig. 1. Location of places cited in text

effects in drainage basins in Britain. This situation inevitably arose from the lack of studies of fluvial geomorphology in the first part of the twentieth century (Gregory and Walling 1974) and it was not surprising in view of the paucity of streamflow measurements available from gauging stations. During this period engineers undertook work of considerable interest to the physical geographer and thus Nash (1959) forecast the changes in streamflow along the River Wandle (5, Fig. 1) and expressed the changes in terms of the instantaneous unit hydrograph. Nixon, in a well-known study (1959) of the bankfull discharges of England and Wales suggested that, as the sediment load of rivers in England and Wales is so small, then the effect of sediment upon channel shape may also be small so that discharge becomes the factor which has the predominant effect in determining the size of the channel. In recent years work by physical geographers has begun to indicate the extent and some of the consequences of man's changes in the drainage basin. In a catchment on the Mendips (6, Fig. 1) the density of the maximum natural drainage network (4.16 km/km^2) may be compared with the density (10.1) introduced as a result of man's effects on the catchment in terms of road drainage (Hanwell and Newson 1970). The effects of an increase in the drainage network of approximately 1 km/km^2 combined with a change in precipitation amount was thought to have been responsible for a significant increase in flood peaks in central Wales (7 on Fig. 1). Changes of channel pattern and channel geometry should also have occurred as a result of man's influence and low terraces of coarse material have been reported (Crampton 1969) from south east Wales and attributed to forest clearance during the Iron Age which provided coarse debris for river transport.

The most recent advances have become possible in an environment in which the role of man is acknowledged to be an important focus for study (Brown 1970), where the control system (Chorley 1971) provides a conceptual approach, where the records of streamflow now exceed fifteen years at a number of gauging stations, and where instrumented catchments have been employed to provide data pertinent to many specific problems (Natural environment... 1971, and Fluvial processes... 1974). It is necessary to establish the magnitude of direct and indirect changes in the drainage basin system, to document the character and size of the changes in process, and to investigate the results of these changes in process. Although the geographer may be interested in all three themes, it is with the impact of the changes in process that he may be particularly concerned. This concern arises from the need to employ a knowledge of form-process relationsship as a basis for interpretation of the past and equally it provides an opportunity to indicate the consequences of man's effects upon drainage basin processes and to predict the impact which they may have upon future drainage basin characteristics through detailed adjustments. This paper seeks to illustrate the extent of changes in drainage basin processes, to demonstrate the possible significance of such changes for stream channel adjustment and to indicate the nature of channel and network adjustments.

DRAINAGE BASIN PROCESSES

The need to document the extent of man's effects upon drainage basin processes in order to provide a greater understanding of the relationship between drainage basin process and drainage basin characteristics, has given the motivation for the analysis of drainage basin processes in relation to specific types of modification. Thus the effects of an increased drainage density during afforestation was one of the reasons advanced to explain the contrasts in flood heights at Shrewsbury for the 25 year event of 5.11 m for 1911–1940 and 5.94 m for 1940–1964 (Howe 1967). Evaluation of the effects of land use change is often possible by comparison of watersheds with contrasting characteristics and in their comparison of the sheep-grazed Wye catchment and the coniferous-forested Severn catchment (8, Fig. 1) the Institute of Hydrology has demonstrated (Institute of Hydrology 1972) that the Wye has higher peak flows and that the time to peak is greater on the Severn. Although the significance of land use practices and of land use changes for drainage basin dynamics merits further study, the effects of building activity and of urbanisation have been investigated because this often the final land use change, because it has been held to be responsible for increased flooding and for feedback effects, because it may indicate the limits of the scale over which process adjustments occur, and because the 12 per cent of the surface area of England which is already urbanised will be increased to 16 per cent by 2000.

The significance of urbanisation may be studied by comparing records from urbanised and non-urbanised watersheds or by analysing the changing responses of a single watershed as it is influenced by different degrees of urbanisation. The former method has the disadvantage that building activity and eventual urbanisation involve complex changes and also that several watersheds may respond in different ways and differ in several respects, other than in the presence or absence of urbanisation. One recent study (Hollis 1974) analysed the rainfall and streamflow records from the 21.4 km² clay catchment of the Canon's Brook, Harlow, Essex (9 on Fig. 1) over a period in which the area of the catchment drained by surface water sewers extended to cover 16.6 per cent of the watershed area. This study showed that the maximum monthly flood increased from 1.16 to 2.58 m³/s over the eighteen year period; that the frequency of summer flood peaks increased by as much as 11.5 times although the frequency of winter flood peaks changed comparatively little; and that the effect of urbanisation does not seem to be as significant in determining the hydrograph of floods with a return period of approximately twenty five years. In view of the paucity of long-term streamflow records in Britain and also in view of the fact that existing records often relate to catchment areas of substantial size, the instrumentation of a catchment specifically to measure the effects of urbanisation is sometimes the most expedient course of action. The Institute of Hydrology (Institute of Hydrology 1973) has inaugurated a programme of research to investigate the effects of urbanisation upon water quality and quantity produced from two small catchments in the area to be affected by the development of the new city of Milton Keynes (10, Fig. 1). An experiment has been undertaken at the University of Exeter since 1968 to monitor the effects of building activity and of urbanisation upon water, sediment and solute production from the catchment (Walling and Gregory 1970).

The watershed studied embraces an area of 0.26 km² on the north east margin of Exeter, Devon (A on Fig. 1) and it is developed on impermeable Culm shales (Fig. 2). Measurements of rainfall have been maintained continuously

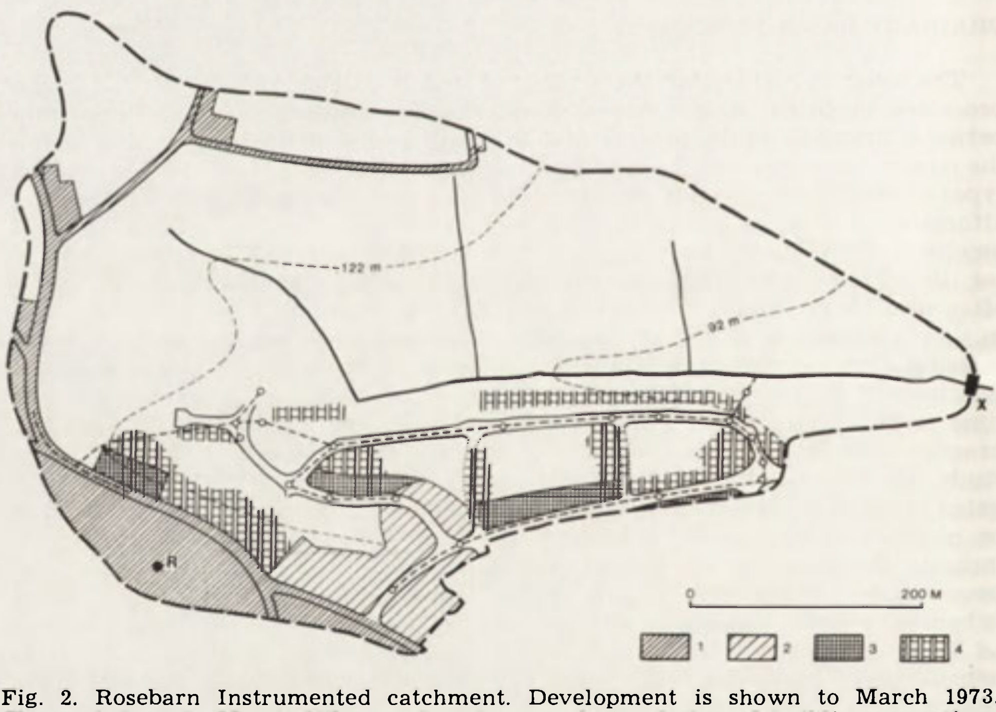

Fig. 2. Rosebarn Instrumented catchment. Development is shown to March 1973. The period up to March 1974 was largely one of completion of building operations in the areas shown above. Location is shown by A on Fig. 1.

1 — Built-up area pre 1960; 2 — Built-up area to Sept 1972; 3 — Houses completed or nearing completion; 4 — Building Activity and unvegetated (3 and 4 — Sept 1972–Mar 1973).

at *R* and comparison of the rainfall amounts with those from a similar rainfall recorder less than 1 km distant indicated agreement of storm rainfall totals within ± 1.5 mm (Gregory 1974). Streamflow is monitored continuously at *X* in relation to a compound, sharp-crested *V* notch weir, and water samples for quality analysis have been obtained using a pumping sampler (Walling 1971). When measurments began in 1968 the watershed was largely under pasture land used for grazing but some residential development already existed along a road in the south west of the catchment and along minor access roads in the north east. Building activity began to extend over the interfluve slopes of the catchment are in 1969, by early, 1971 a network of roads had been laid out, in May 1971 the stream course was diverted to flow into the network of road dreins, and in October 1971 the runoff from the roads flowed into the new drainage network as the roads were then metalled. Since 1971 the number of houses completed and under construction has increased thereby increasing the proportion of impervious area, and the artificial drainage network has also been extended by additional storm water and land drains.

TABLE 1. Sequence of changes in Rosebarn catchment (Figure 2)

Date	Percentage area affected by building activity and urbanisation	New impervious area	Density of water courses, surface water drains and land drains (km/km^2)	
Pre 1968	8.66	—	3.88 to 5.82	
1968–1970	3.77	—	3.88 to 5.82	
1971–Sept 1972	8.45	0.900% roads	+4.26 road drains:	5.01 to 10.08
		0.005% houses	+2.74 stormwater and land drains:	5.01 to 12.82
Oct 1972–Mar 1973	4.78	0.006%	+2.47:	5.01 to 15.29
Apr 1973–Mar 1974	2.10	0.004%	+2.28:	5.01 to 17.57
Total to Mar 1974	27.76	0.915	+11.75:	5.01 to 17.56

A number of phases of development are therefore available from the six years of record and their characteristics are summarised in Table 1. These phases provide a context for the analysis of variations in water yield as influenced by building activity and urbanisation. The record of catchment behaviour during the five year period is summarised in Figure 3. The monthly rainfall figures and the five month running means (Fig. 3A) indicate the general tendency for a winter rainfall maximum and suggest a rainfall heavier than average during the early part of the study period. Whereas 1969, 1970, and 1972 were above the long term annual average (104, 162, and 114 per cent) both 1971 and 1973 were below the long term average (83, 79 per cent). During the five year period the rainfall pattern should have led to some reduction in streamflow and this is reflected in the range of instantaneous monthly peak discharges (Fig. 3C). These indicate that maximum discharges were greater during the early part of the period. However in 1973 more frequent high peak discharges became common. Although the range of discharges showed no major change as a result of building activity and urbanisation, the number of streamflow hydrographs has increased significantly over the period studied. By isolating each hydrograph event as an occasion when the streamflow increased and was followed by a recession, the number of events increased from 171 per year in 1969 to 423 in 1972 when the effect of building activity was reflected in the catchment response. This increase (Fig. 3B) occurred despite the fact that the number of storms and the number of rain days remained comparable throughout the study period (Table 2).

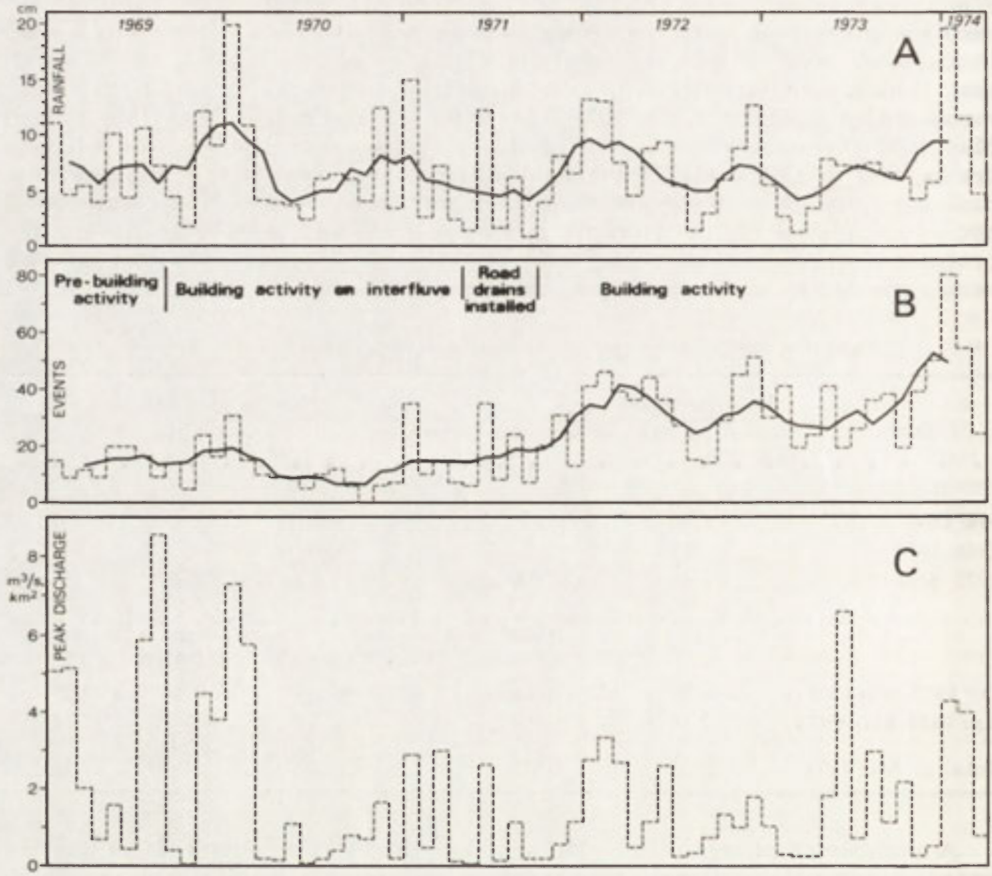

Fig. 3. Monthly rainfall and streamflow during urbanisation of the Rosebarn catchment.

Monthly rainfall totals and five-month running means (heavy line) are shown in A; number of hydrographs per month in B; and maximum peak discharge in each month in C.

TABLE 2. Number of raindays and number of streamflow hydrographs per year in Rosebarn catchment

Year	Number of rain days	Average rain per rain day (mm)	Number of streamflow hydrographs
1969	162	5.21	171
1970	189	4.39	123
1971	151	4.47	711
1972	179	5.20	423
1973	151	4.28	362
Average	166.4	4.72	258

Building activity has been responsible for a more sensitive response of the catchment and in an analysis of data to September 1972 (Gregory 1974) it was shown that lag time was reduced by the first phase of building activity to half its former value. Analysis of the streamflow data may be effected by reference to individual streamflow hydrographs and some 990 of these are available for the period to be end of March 1974, although not all are appropriate because some are compound in nature. Analysis may be undertaken by comparing hydrograph parameters which obtain during building activity with those for the period prior to building activity. A "Control" period when building operations did not have any significant effect upon streamflow from the catchment is represented by the period until April 1971 and so relationships for that period were established between hydrograph parameters and indices of storm rainfall amount, storm rainfall intensity, preceeding conditions indicated by previous discharge level, and soil moisture status indicated by an antecedent precipitation index. These multiple regression relationships can then be employed to indicate the expected hydrograph characteristics according to storm conditions since 1971. The peak discharges predicted from the equations were then compared with those which were actually recorded and the magnitude of increase of peak discharge is indicated for three periods in Table 3. The

TABLE 3. Streamflow changes arising from building activity and urbanisation of Rosebarn catchment

Dates	Lage time (minutes)		Hydrograph peak discharge	Runoff percentage
	Winter	Summer		
Pre 1970	82.4	68.8	—	—
1971	—	50.3	—	—
Oct 1971 – Sept 1972	41.7	35.1	Increased to 2 times former values	) All events increased by) at least 0.9 per cent) corresponding to impervious area)
Oct 1972 – Sept 1973	30.1	26.6	Increased to 2 to 3 times former values	))
Oct 1973 – Mar 1974	23.0		Increased to 3 to 4 times former values	))

individual storms analysed were separated into two groups of winter and summer, in sympathy with the annual trend indicated in Figure 3A, and a relation between storm rainfall amount and hydrographrise is illustrated (Fig. 4) by one feature of the streamflow response before and after urbanisation of the watershed. This shows (Fig. 4) that whereas the hydrograph rise for large storm amounts does not differ from the earlier pre-building phase, that small and moderate amounts of rainfall now induce a more significant hydrograph rise. Runoff amount calculated by separation of the quickflow and baseflow components of each appropriate hydrograph can also be analysed in a similar manner, and this shows that the runoff amount has increased consistent with the area rendered impervious by building operations to date. Related to the runoff changes are changes in sediment and solute production which can be analysed in relation to discharge, including the use of suspended sediment hydrographs to demonstrate the magnitude of change in suspended sediment production as a consequence of building activity (Walling 1974). This shows the way in which suspended sediment concentrations have increased between 2 and 10 times, and specific conductance values have increased between 1.5 and 2.0 times (Walling 1974).

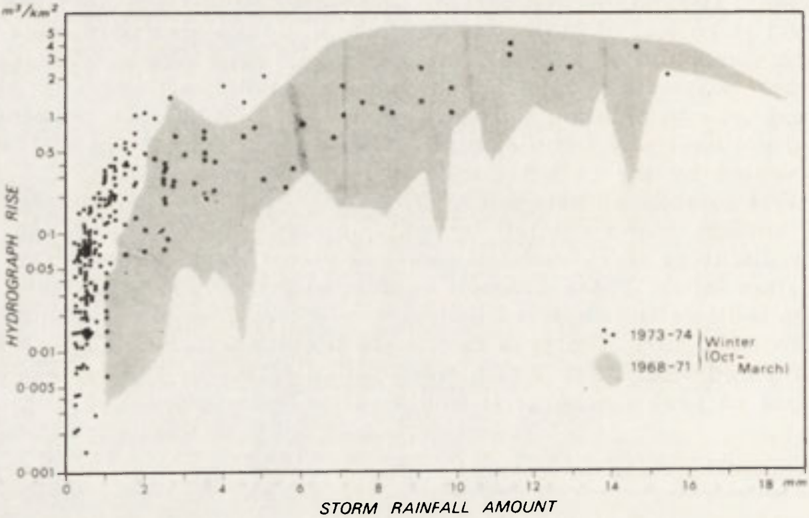

Fig. 4. Hydrograph rise in Rosebarn catchment. 1968–1971 (shaded) represents the period before building activity and the values (dots) for 1973–1974 indicate the change for small rainfall amounts

THE GEOMORPHOLOGICAL SIGNIFICANCE OF CHANGES OF DRAINAGE BASIN PROCESS

Documentation of the magnitude of changes in water yield in relation to stages of building activity and of urbanisation is particularly important in relation to the effect of increased flood peaks and decreased low flows but it is also of interest to know the likely geomorphological effects of such changes. The effect of process changes is not confined to the areas where these changes take place because significant morphological and depositional effects may occur downstream. The lack of sufficient measurements of sediment load for rivers in Britain inhibits the deduction of the effects of changes of sediment delivery rate, but it has been claimed that discharge is the factor which has the predominant effect in determining the size of the river channel (Nixon 1959). Ackers (1972) suggested some ways in which engineering activities are significant in relation to regime and he proposed that whereas river regulation may not significantly change the magnitude of flows with high return periods, the cross sections and slope of river channels may be effected by urban development, by reduction or increase in sediment supply, and by general improvement works. The results from a changing watershed (Fig. 2) may be employed to indicate the likely significance of hydrological changes if the parameters which control channel characteristics are known and understood.

Early studies concentrated upon bankfull discharge (Sunley 1970) as being an important control upon channel character. Whereas bankfull discharge was thought to have a frequency perhaps between one and two years, and probably 1.5 years (Dury 1963, 1973) more recent research has indicated that the channel-forming discharge may vary from one area to another (Harvey 1969), and that a range of stream discharges may be significant in shaping the river channel. Some of the ways in which characteristics of channel discharge have been related to aspects of channel geometry and pattern are collected in Table 4. This demonstrates that whereas some studies have employed bankfull, mean annual flood, or floods with other recurrence intervals, other research has focused upon the range of higher discharge values. This range of higher values involved consideration of tht range of higher flows which may be above average discharge, above average discharge of month of maximum discharge, or above discharge at 10 per cent flow duration; of the rate of hydrograph rise; and of the variability of peak discharge. Analysis of the data described above indicates that whereas the maximum flood discharges may not have increased due to building activity and urbanisation, the frequency of lower peak discharges has certainly increased. The rate of hydrograph rise has also changed (Fig. 4) and this is reflected by the reduction in lag time which must be associated with an increased rate of hydrograph rise. Greater flow variability is also a characteristic feature of the runoff since the instigation of building activity and this is reflected in the incidence of number of hydrographs (Fig. 3).

TABLE 4. Discharge controls of channel geometry and plan

Subject	Area	Channel-forming discharge or significantly correlated discharge	Source
Channel cross section	Britain	Bankfull discharge	Nixon 1959
Channel capacity	Britain, USA	Bankfull discharge	Dury 1961
Braiding of river pattern	China	Average rate at which flood rises and subsides. Variability of discharge in flood season.	Chien Ning 1961
Braiding	Canada, BC	Rapid change of discharge	Fahnestock 1963
Channel geometry	Piedmont, USA	Mean Annual flood	Kilpatrick & Barnes 1964
Channel patterns	Nebraska, USA	Bankfull discharge Discharge variability	Brice 1964
Meander wavelength	USA	Average discharge of month of maximum discharge	Carlston 1965
Hydraulic geometry	Illinois USA	Discharge at 10% flow duration	Stall & Fok 1968
Meander wavelength, Channel cross section in relation to per cent silt clay	USA, Australia	Average, bankfull & mean annual flood discharge	Schumm, 1969
Channel morphology	USSR	Average maximum annual discharges and other factors	Antropovskiy 1970
Channel width & depth	California, USA	Mean annual runoff	Hedman 1970
Channel capacity	Kentucky-Tenn. USA	Flood discharges recurrence intervals 1, 5, 10, 15 years	Brown 1971
Riverbank erosion	Cheshire, UK	Period of discharge less than 5 per cent of flow	Knighton 1974

Thus the process or urbanisation is likely to lead to adjustment in the runoff record and similar, although less dramatic, changes in runoff would be anticipated as a result of other man-induced land use changes. An indication of the significance of runoff changes in the Rosebarn catchment (Fig. 2) may be provided by the analysis of hydrograph peaks. Although partial duration analysis is not easily applied to this data, a comparison of those peaks greater than the average discharge of the 1968–1969, and pre-building operations, flow duration curve may be indicative. Comparing the period October 1968 to March 1971, before building operations affected the response of the catchment, with a period of similar length during building operations provides an indication of the contrast in the pattern of higher peak flows (Table 5). The greatest contrast

TABLE 5. Number of peak discharges in categories above mean flow Rosebarn catchment

Discharge category $m^3/s/km^2$	October 1968 – March 1971 Pre-building activity and urbanisation	October 1971– March 1974 During building activity and urbanisation
0.15 – 0.224	41	75
0.225– 0.337	28	84
0.338– 0.506	39	96
0.507– 0.739	35	73
0.740– 1.138	33	58
1.139– 1.708	20	21
1.709– 2.562	16	12
2.563– 3.843	11	10
3.844– 5.766	6	2
5.767– 8.648	3	1
8.649–12.938	1	0
	Total 233	Total 432

is in number of peaks in the two periods, and the second period has 432 compared with the 233 of the earlier control phase. Inspection of the frequency of peak discharges shows that whereas a substantial increase of peak discharges has occurred above mean discharge, the frequency of very high discharges has not been equalled during the present stages of building activity and urbanisation. This conclusion is similar to that reached for the Canon's Brook (9 on Fig. 1) that urbanisation does not affect the rare events but that it does alter the pattern of more frequent events. Explanation of the pattern of changed peak discharges (Table 5) may be found in the facts that in this catchment urbanisation has hitherto been confined to 28 per cent of the total area, that increased runoff and decreased lag time inevitably lead to lower storage amounts and may therefore produce major peaks no greater than those prior to urbanisation. However the facts that much geomorphological work is thought to be accomplished by moderate rather than extreme events (Wolman and Miller 1960; Gupta and Fox 1974), and that channel change may be effected in relation to a range of higher flows beginning above mean flow, means that such adjustments in the frequency of peak discharges must be evaluated and their impact ascertained.

DRAINAGE BASIN ADJUSTMENT

Changes in runoff characteristics and in sediment production should inevitably have feedback effects upon the fluvial features of the drainage basin. A distinction may be made between the effects upon the channel cross section and channel pattern and those upon the network of channels in the drainage basin.

Changes in channel cross section may be anticipated in several areas and stream channel enlargement consequent upon urbanisation (Hammer 1972) and a general model of channel change in relation to a sequence of land use change (Wolman 1967) must find analogues in Britain. The width of part of the channel in the experimental catchment (Fig. 2) has increased significantly since building operations began. In addition to an increase in channel dimensions some changes may lead to a decrease however. Thus Dury (1973) compared channel geometry above and below offtakes for mill leats and demonstrated a reduction of channel width downstream of the offtake although depth changed relatively little. A similar effect may be expected where impounding reservoirs are constructed in a drainage basin because the pattern of peak flows downstream of the dam may be reduced. Changes in channel character below a dam have frequently been sought in terms of the effect of the dam in reducing the

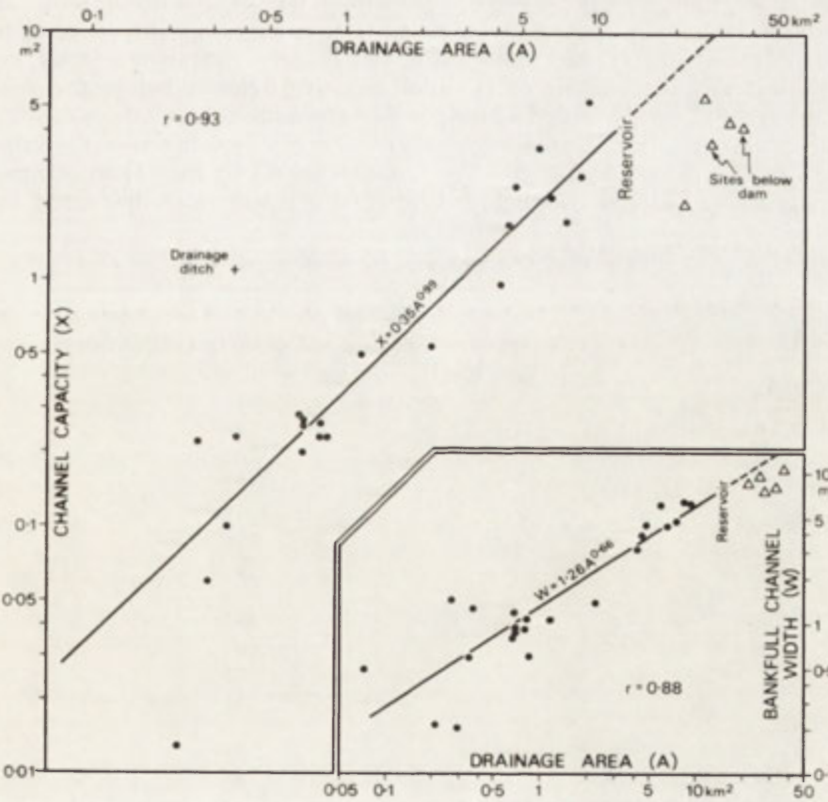

Fig. 5. Channel geometry above and below Burrator reservoir. Location is shown by B on Fig. 1

available sediment load and such changes, which were suspected by Sherlock in 1922, have been outlined generally by Beckinsale (1972) and they have been studied theoretically, especially in relation to bed armouring (Hales, Shindale and Denson 1970) and for particular areas (Hammad 1972). In addition however, a changed runoff pattern may be expected to have an effect upon the channel capacity and this may be investigated by comparing the size and shape of river channels in the area above and below the dam. Such a comparison may be effected by comparing channel widths above and below the reservoir (Fig. 5) but channel width and shape vary considerably throughout the drainage basin. Therefore analysis of the channel cross sectional area may be employed to contrast areas above and below the reservoir, and the relationship of channel capacity to drainage area may afford an appropriate basis for analysis. Burrator reservoir (*B* on Fig. 1) lying on south western Dartmoor affords a suitable site for initial analysis and above the reservoir the relationship of channel capacity to drainage area is well-defined (Fig. 5). When the channel capacity for the river channel below the dam is plotted on the same diagram this illustrates that channel capacity below the dam is some 30–40 per cent of the expected level and this may be ascribed to the decreased channel capacity required for peak flows below the 4.66×10^6 m^3 capacity reservoir since it was constructed in 1893. Analysis of the channel above and below a smaller capacity reservoir in the Burn Basin (D on Fig. 1) in Yorkshire illustrates a similar pattern except that immediately below the dam the channel is not reduced in capacity although a decrease does then occur (Table 6). This may be the result of scour due to sediment loss but the reduction in channel size continues for a considerable distance downstream. These two basins are largely characterised by bedrock channels but the adjustment of channel capacity evident below the reservoir cannot be related to discharge as no records are available.

A programme of measurement of channel cross sections was therefore undertaken in the catchment of the Tone, Somerset (C on Fig. 1) to compare the channel geometry above and below Clatworthy reservoir constructed in 1959.

TABLE 6. Channel capacity below reservoirs

	Distance downstream of dam (km)	Channel cross section as percentage of expected capacity (100%) from regression equation
Clatworthy	0.6	34
Reservoir	2.1	69
(C on Fig. 1)	3.4	79
	6.7	77
	10.1	71
	13.8	97
Burn basin	0.5	102
(D on Fig. 1)	1.1	66
	1.3	73
	2.5	77
Burrator	0.3	27
Reservoir	0.5	64
(B on Fig. 1)	1.5	39
	3.4	41

Several cross sections below the reservoir are compound in nature, the inner segment may be the present bankfull level, whereas the outer element is now completely vegetated and may be the pre-reservoir bank-full level. The relationship between channel cross section area and drainage area above the reservoir is continued below the dam by the values representing the outer cross section area. Immediately below the dam the present channel cross section area values are only 34 per cent of those expected, although channel capacity then increases rapidly downstream for a distance of 11 km until the area draining to the Tone is at least four times the area draining to the reservoir. Although there are no streamflow records from the catchment above the reservoir, average discharge immediately below the dam was 0.49 m^3/s for the 1965–1966 water year whereas gross mean discharge was estimated to be 0.65 m^3/s (Water Resources Board ... 1965/1966). Comparison of the mean annual flood discharge ($Q_{2.33}$) and peak discharge with a recurrence interval of 1.5 years, for three gauging stations on the River Tone with the regional pattern based upon twelve stations, suggested that peak discharges immediately below the dam are 34–40 per cent of those expected, that those downstream with a catchment area of 57.8 km^2 are still less than half of the expected values, but that with a catchment area of 202 km^2 peak discharges approximate to the regional pattern (Gregory and Park 1974). This therefore indicates a situation where the changed frequency of peak discharges may be responsible for adjustments in channel capacity and other adjustments both positive and negative should exist as a result of changes in water and sediment delivery rates.

Further morphological adjustments consequent upon man's activities in the drainage basin may be found in alterations of the drainage network. In the Peak District Moss (1913) deduced a general extension of stream heads by 1.2 km between the Ordnance Survey maps of 1830 and 1870–1880 and a further 0.4 km by the time of the 1912 survey. Although the relative significance of climatic variations and of man's effects are not separately elucidated in upland Britain, a number of studies have revealed significant recent drainage network extensions. Although the pattern of present erosion may have been established prior to human intervention, it has been found that erosion has been greatly accelerated in historic time. Thus on the high moors of Derbyshire and west Yorkshire (3 on Fig. 1) Radley (1962) cited numerous examples to illustrate extension and expansion of drainage networks, and on the peats of the southern Pennines Tallis (1964; Studies on Southern ... 1966, 1973) concluded that stream erosion had proceeded in two phases. First, the slow headward extension of streams into the peat blanket along pre-established lines occurred from circa 3000 B. C. onwards but even by A. D. 1300 may not have reached the "pre-glacial" stream channels in many areas. Secondly, a very rapid extension of gullying after 1770 A. D. when as much as 200 m of stream course developed in 190 years consequent upon increased grazing pressure and burning against the background climatic trend. Whereas these studies have been concerned with areas of blanket peat, others have demontrated how gullying may be induced by sheep grazing in the Plynlimon (8 on Fig. 1) and Brecon Beacons (13 on Fig. 1) areas (Thomas 1956; Sheet erosion ... 1965), and by removal of forest in the New Forest (11 on Fig. 1; Tuckfield 1964). The acceleration of sheet erosion by burning on the North York Moors (12 on Fig. 1) has been shown to be responsible for high sediment yields (Imeson 1971) and the use of the same area for military training may also have had significant consequences (Curtis 1965). The general character of soil erosion on agricultural lands in Britain has recently been illustrated (Morgan 1974).

Ample evidence of the extension of drainage network consequent upon man's influence can now be found from several parts of Britain and in addition there have been cases of deliberate network extension. In general it has been estimated that there is an average of 3.11 km of ditch per square kilometre of England and Wales (Johnson 1966) and in specific cases the amount of extension has been noted as in the Institute of Hydrology Coalburn catchment where the drainage density has been increased by about 50 times (Institute of Hydrology ... 1973) consequent upon the introduction of an artificial drainage network after ploughing of peat bog. Thus in agricultural land, under forest and urbanised areas (Fig. 2, Table 3) the extent of network increase is very substantial when compared with the world range of drainage densities (Gregory and Gardiner 1975). The consequences of such deliberate drainage network extensions have seldom been detailed but a knowledge of their consequences is important in relation not only to drainage basin processes but also with respect to the morphological effects upon channel geometry, channel pattern and floodplain inundation.

One small scale example of the type of change resulting from deliberate drainage net extension may be found in central Devon on Culm sandstones and shales (E on Fig. 1). A small catchment (Fig. 6) includes a very well-marked gully which, according to local residents, has developed during the last twenty to twenty five years, and is now leading to a significant loss of farmland. The gully which is 500 m long is substantially larger than any features in the surrounding area, and it cuts through a fossil fan (Fig. 6) at the junction of the tributary valley and the flood plain. The volume of the gully, less the expected channel capacity, calculated from cross sections (Fig. 6) is approximately 840 m^3 and according to measurements of bedload trapped in the floor of the gully (SI on Fig. 6) some 400 years are required for development of the feature. This is certainly a maximum estimate in the absence of values for suspended and solute yield as these together may comprise some 90 per cent of the total load and so the time period required to produce the gully may be of the order of 40 years. There has been no significant recent increase in rainfall amount, the enclosure at the head of the catchment is long-established, and the reason for the recent development of the gully may be found in the pattern of road drainage. Drainage of the road system was directed into the stream which now drains the gully and this led to an increase in the drainage density from 2.10–4.33 to 2.10–5.99 km/km^2. The road was first metalled just prior to 1947 and so the last twenty seven years have produced an increased drainage network and an increased runoff amount. Records from the instrumented catchment (Fig. 2) show how a significant increase in runoff can arise from the introduction of metalled roads (Gregory 1974) and in this case runoff from the road with small sediment sources has encouraged gullying of the natural channel. Such changes are probably more widespread than has previously been appreciated in Britain and it is necessary to evaluate the controls upon the distribution of incised stream channels.

CONCLUSION

Description and explanation of the form of the drainage basin is an important part of the particular expertise of the physical geographer. Knowledge of the significance of specific drainage basin characteristics in affecting runoff, sediment and solute production, and equally an understanding of the morphological consequences of process changes are both imperative for applied phy-

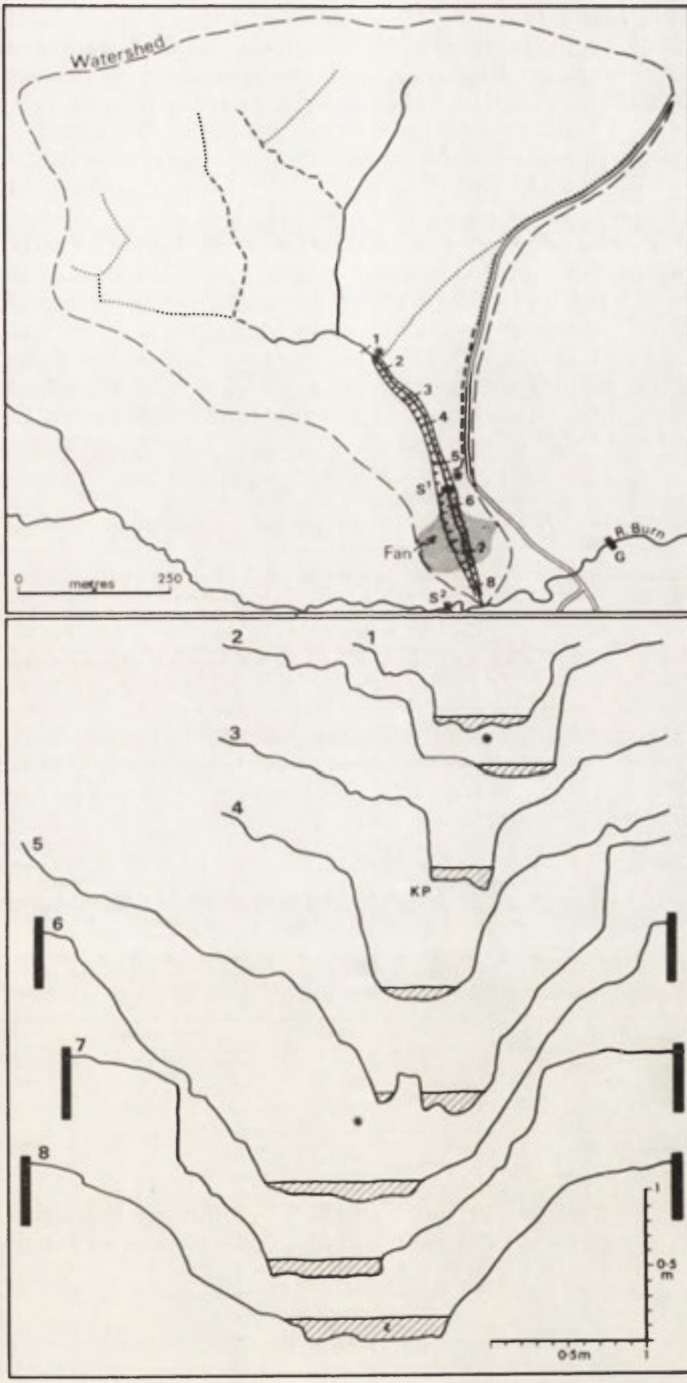

Fig. 6. An example of recent gully development. The drainage network is shown as perennial (solid), intermittent (dashed), ephemeral (dotted) and road runoff enters at points 1 and 5. The gully is located at E on Fig. 1

sical geography. The features of streamflow pattern particularly related to fluvial morphology include peak discharge, the rate of hydrograph rise, and the variability of peak discharge, and changes in these values in a small catchment are summarised in Table 7. Two basic, often interrelated, types of change have been instigated by man. First, the pattern of sediment sources has been changed on slopes or along stream channels, and secondly the pattern of runoff has been altered. The effects of such changes include adjustments of drainage networks, of channel patterns and of channel geometry. Work is proceeding on each of these subjects and it must be succeeded by a clearer understanding of the interdependence of the three. Analysis of the three subjects has often been undertaken separtely and drainage basin characteristics have often been expressed rather independently (Gregory and Walling 1973). It is now necessary to devise integrated indices that express the three dimensional character of the drainage network, perhaps as used by Ardasheva (1971), and this must be applied to problems of morphological adjustment in the light of an improved knowledge of downstream changes in discharge and sediment parameters.

TABLE 7. Changes in runoff relevant to channel geometry

Parameter	Change as a result of installation of road, stormwater and land drains (Fig. 2) giving a drainage density increased from 3.9–5.8 to 5.0–17.6 km/ /km² and involving building activity and urbanisation affecting 28% of catchment area
Peak discharge	Rare events not changed but number of peak flows increased almost two times (Table 4) and peak discharges increased by up to four times former values
Hydrograph rise	Amount of rise increased (Fig. 4), rate of rise increased, and lag time reduced to approximately one third of original values.
Variability of peak discharge	Number of distinguishable hydrographs increased by at least two times (Fig. 3, Table 2)

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TENTATIVE EVALUATION OF THE INTENSITY OF SOIL EROSION AS DETERMINED BY NATURAL CONDITIONS AND TYPE OF LAND USE. A CASE STUDY OF THE VALLEYS OF THE DRWĘCA AND THE LOWER VISTULA

Zofia Churska

INTRODUCTION

Soil erosion and its harmful effects have been identified in Poland for over 100 years. Studies of soil erosion, and of measures designed to prevent it stem from the inter-war period and were greatly extended following the Second World War (Bac 1968; Oświęcimski 1961). The studies were largely associated with the intensification of agriculture, mechanical methods of land cultivation, and after the war with the introduction of a State-planned economy. As a result there are available numerous publications the majority of which, however, specialize in serious soil erosion problems in the mountainous and upland areas of Southern Poland. Studies of similar phenomena in the regions of Northern Poland have been few in number.

With regard to the region under discussion, the potential degree of soil erosion was for the first time fully evaluated by Reniger (1950). Reniger has drawn up a classification that includes all of Poland, comprising eight intensity classes of erosion; in which the lowland region discussed in this paper generally falls into Class I, i.e., those areas not threatened by erosion, or where erosion is limited to small areas. Also, some 12% of the Bydgoszcz voivodship* is threatened by potential soil erosion, though in general only slightly. However, while of considerable value for correlation purposes, Reniger's treatment of the subject provides limited scope for in-depth studies.

An evaluation of the potential danger of soil erosion in Bydgoszcz voivodship, the Drwęca valley and the Grudziądz Basin was made by Roszkówna during 1962 and again in 1973. This study was also of limited scope, approaching the problem through a detailed analytical study of relief forms. On the basis of a five-grade classification, Roszkówna estimated that 9.5% of the total cultivated area of Bydgoszcz voivodship is threatened by intensified (Class III) erosion; 7.26% of this area has fertile soils. Set against this, Roszkówna estimates that 12% of all agricultural land (9% of which has fertile soil) is subject to heavy (Classes IV and V) erosion. A map compiled by L. Roszkówna (1973) shows valley slopes as being most vulnerable to soil erosion, though some authors assert that hilly regions are in greatest danger of suffering erosion (Reniger 1950).

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* The Author refers to the Bydgoszcz voivodship in boundaries of before the administration reform of June 1975 (Editor's note).

METHODS OF INVESTIGATION

An evaluation of the intensity of erosion can be obtained by both direct and indirect methods. The direct methods employ various quantitative calculations of the intensity of soil erosion. As far as surface erosion is concerned, a variety of soil traps are in use, while concerning the effects of linear erosion, gullies, crevices and erosive ravines, as well as the extent of accumulated covers of slopewash material, are measured (Sobolev 1948; Oświęcimski 1961; Field methods ... 1967). Such direct measurements are of great value in an understanding of erosion processes. Unfortunately, however, the time factor and the associated high research costs severely limit their range of application.

Indirect methods are of even greater significance. Their use allows one to estimate on an aerial basis the extent to which soil erosion can be economically damaging in a given region and to decide suitable preventive measures. Indirect methods include estimates of the degree of degradation of soil profiles on inclined surfaces, based on carefully selected criteria (Ziemnicki, Mazur 1955; Illner 1966). In soil profiles, as well as in what might be called "high boundary strips", one recognises evidence of surface erosion due to both water and wind action; since erosion processes reduce the thickness of the humus and soil layers even removing them completely, thereby causing changes in the physical and the chemical properties of such soils.

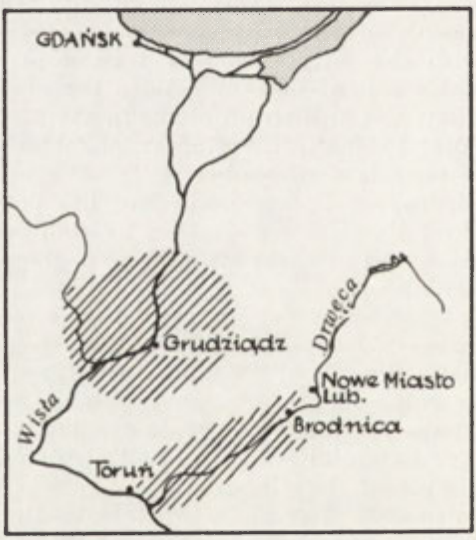

Fig. 1. Area under investigation

Indirect research methods include studies that lead to a recognition of potential erosion; in this way, those factors that cause erosion, including topographic controls, climatic and hydrographic conditions, soil type, and vegetation cover are analysed. With these factors in mind one can suggest the degree of potential erosion from site to site. In such analyses, forested areas are often assumed to be immune to erosion (Reniger 1950; Ziemnicki 1968).

Other methods are available: as for example the recording of soil spots, the analysis of aerial photographs, studies of crop measurements, the use of plan indices, and so on (Krummsdorf 1964).

In northern Poland, which is largely comprised of glacial and fluvioglacial deposits, the slopes of valleys together with an array of glacial channels are most seriously affected by erosion (Churska 1972; Roszkówna 1973).

The discussion that follows deals particularly with two areas: the Drwęca valley, and the Lower Vistula valley in the so-called Grudziądz Basin (Fig. 1); making use of both direct and indirect research methods.

DENUDATION PROCESSES, AND THE RESULTING DEPOSITS AND LANDFORMS

During 1969/1970 and 1970/1971, investigations of the course of erosive processes were initiated. The studies made use of earlier work. It appeared that the Grudziądz Basin region is mainly influenced by aeolian denudation and mass movements, and by scattered or concentrated slopewash also sheetwash. Such processes as they threatened the Drwęca valley have already been described (Churska 1973).

Supranival covers (Fig. 2) occur frequently, and evidence widespread aeolian erosion; they develop over tilled fields which, deprived during the winter of their vegetation, tend to dry out after snowmelt. Wind-borne fine soil particles from these fields are deposited on surviving snow patches. After this snow has melted, a thin and generally silty mantle remains, though it is of an ephemeral nature, being destroyed either by ploughing or by renewed wind action. This is one of the processes that leads to soil impoverishment.

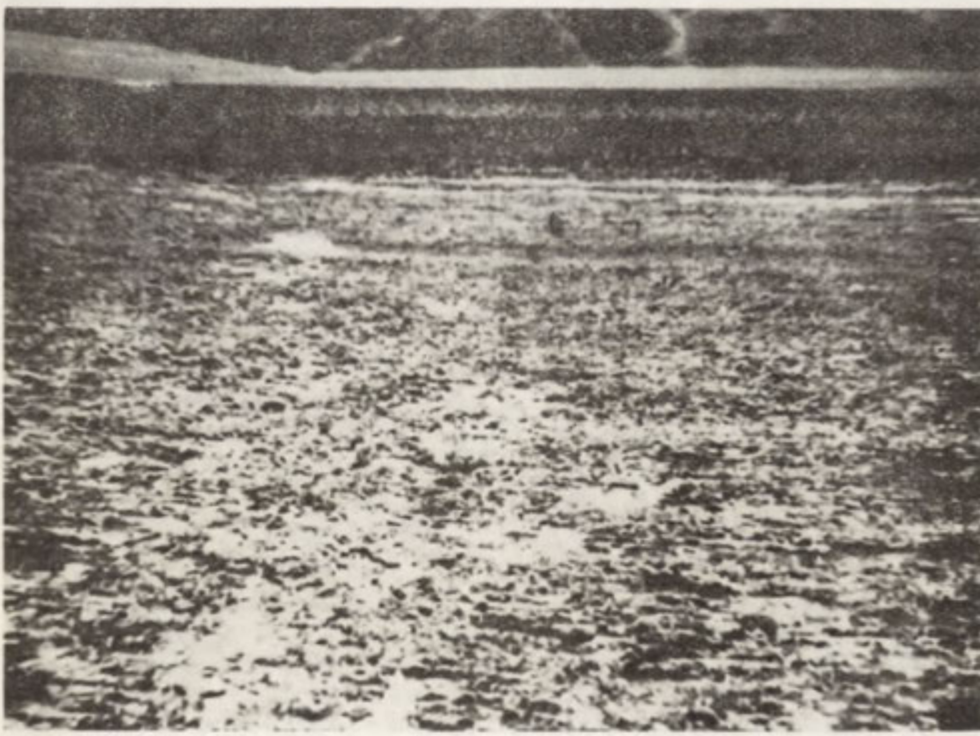

Fig. 2. Aeolian supranival cover

Common forms of mass movement include landslides and slumps, most usually occurring abruptly. To some extent these processes take place irrespective of the protective role played by the vegetation cover, and result from disturbances of the earth balance on slopes. They may occur, for instance because of slope undercutting by streams, of from soaking of the heavy surface layer with water (Figs. 3, 4); while often geological conditions enhance processes of this kind. They particularly affect clayey slopes.

Fig. 3. Soil slump

A process fairly often encountered is soilcreep, especially during spring snowmelt on both cultivated and uncultivated inclined surfaces; leading to the displacement of soil particles due to frost processes acting over tilled fields and sloping meadows; also, the downslope displacement of whole grass tufts with their root systems destroyed by frost action has been observed. Sometimes even a plough used on steep clayey scarps acts like a bulldozer (Bac 1968).

Examples of solifluxion have rarely been observed. Solifluxion processes stem from particular conditions: a high snow cover and rapid thawing of the uppermost layer of soil, while at greater depth the soil is still frozen (Fig. 5).

Most destructive of all in causing the most serious soil erosion is slopewash, either scattered or concentrated; also the so-called "sheetwash". Such processes occur during heavy rainfall and snowmelt. Scattered slopewash, that leads to soil patchiness and selective soil erosion (Jahn 1968), occurs everywhere, especially on the upper slopes; it is usually imperceptible in the initial stage, leading to a gradual deterioration of the soil cover. Indeed, as early as the 1930's it used to be called in Poland "the furtive whiplash of agriculture" (Bac 1968).

Fig. 4. Earth creep

Other processes, such as subnival erosion, often combine with snowmelt; leading to small round depressions caused by drops intermittently falling from melting snow patches. The latter features, which occur as spots, depend upon prolonged survival of snow patches, as will happen on cool slopes that face northward or eastward, or, notwithstanding exposure to the sun, in the shaded area afforded by steep scarps, or where local heavy snowdrifts or snow accumulations occupy ground depressions. Melting of surviving snow patches takes place after normal snow covers have thawed (Ziemnicki 1968). In this manner conditions are produced that favour gully erosion, often initiated by ill-conceived ploughing operations on the higher slopes (Fig. 6).

Where this sort of snowmelt takes place at random points, it is difficult to study erosion quantitatively, due to the difficulty of deciding exactly what areas are affected. During rainfall, the entire slope surface is potentially threatened with erosion; therefore it is possible to mark particular slope strips, and to determine for each of them the loss of soil caused by concentrated slopewash (Sobolev 1948). However, measurements of this type are rendered difficult by the frequent changes in erosion intensity and by accumulation that affects particular slope strips.

Fig. 5. Example of solifluxion tongues (Photo by M. Jasiulewicz)

Surviving snow patches may also lead to the formation of a system of subnival erosive furrows. Often these furrows display hard-frozen sides produced by secondary freezing of the water they carry. Figure 7 shows a partly exposed furrow that extends further underneath the snow. The formation of small drip holes from a thawing snow patch has been observed (Fig. 8). Subsurface runoff, water may carve a series of pipes the roofs of which collapse to form channels (Fig. 9).

Frequently, the small and somewhat insignificant forms of erosion described above pass through a complete evolutionary chain, from hole to pipe to channel thus initiating linear erosion which intensifies and merits careful attention.

Concentrated slopewash and, on occasions, sheetwash also are brought about by torrential showers or by rainfall of long duration — the quantities of water precipitated often exceeding what the soil can retain. Investigations made by Chomicz (1951) revealed that, compared with Poland as a whole, the Grudziądz Basin happens to be one which is frequently afflicted by torrential rains. Such rains occur, on average, twice during June, July and August and once during May. Though this is the warm season so that the soil is protected by vegeation, such heavy rains cause considerable damage, and extreme example of such erosional features are often found (Churska 1973; Roszkówna 1973).

Fig. 6. Example of linear erosion

On sloping surfaces, erosion and accumulation take place at unequal rates. Every variation in slope inclination causes differences in the nature of these processes, irrespective of absolute values of slope gradients (Jahn 1968; Pierzchałko 1954; Churska 1973). Apart from those slope facets less steeply inclined following a break of slope, slope erosion may also develop at all transversely trending obstacles, such as wider ploughing furrows or raised boundary strips, and even changes in the vegetation cover (Fig. 10).

From numerous observations of slope processes, one sees that it is difficult to corellate slope gradients with particular forms of erosion and accumulation. All such observational data must be treated as approximate and merely indicative. Accumulated slope covers are prone to further downslope movement; as newly-deposited sandy material offers little resistance to erosion.

Extreme linear slope erosion leads to the development of gullies (Fig. 11).

Fig. 7. Subnival furrow

SOIL PROFILES

"Erosion results from a very complicated interaction of a number of agencies: climate, topography, soil type, vegetation cover, and man's action dependent on his contemporary social pattern" (Reniger 1950, p. 8). Least variable among these agencies are topography and soil type; moreover, topographical conditions strongly influence the intensity of soil erosion. Such influence is manifest in differences of slope gradient, and in the length and shape of slopes. Reniger (1950) concluded from a numerical analysis of the influence of different slope gradients upon the amount of erosive slopewash that there are marked variations. Even so, in her opinion this influence remains highly significant, whereas the influence of slope length is closely linked with slope steepness and slope type.

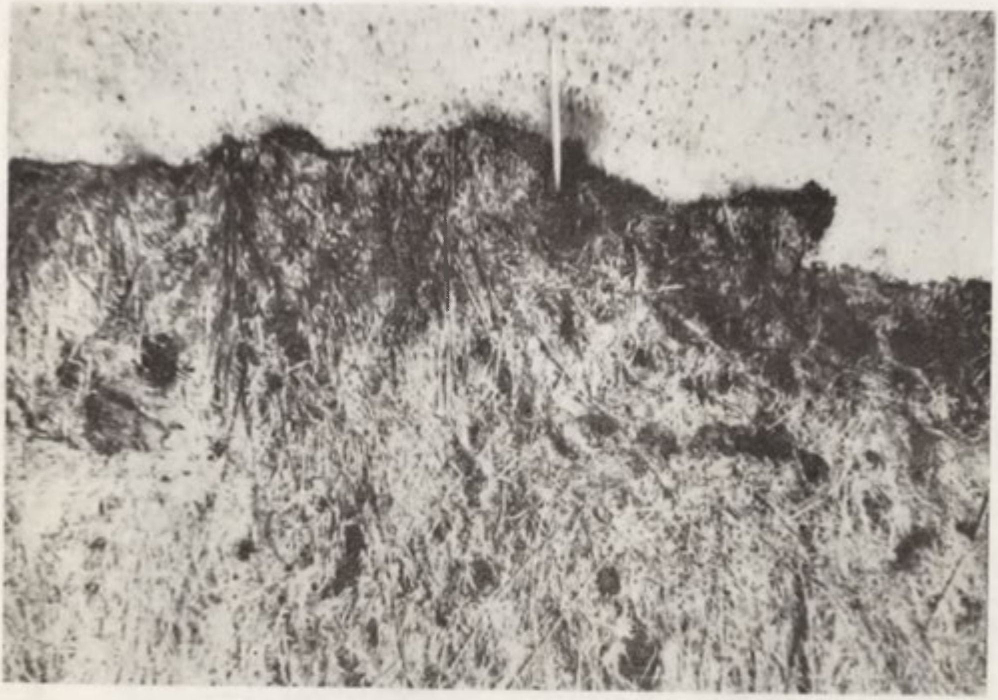

Fig. 8. Tiny drip holes from thawing snow patch

Fig. 9. Example of pipe-like channels

Ziemnicki (1968) asserts after Konke and Bertrand that the amount of erosion measured by the quantity of washed-down soil material is proportional to the slope gradient in % raised to the 1.4 power, and to slopelength in feet, raised to the 0.5 power. Expressed in meters, they adopted the 0.65 power for slope lengths from 20 to 100 meters, and to 0.6 power for slopes longer than 100 m. Other authorities suggest that a slope gradient twice as large increases slopewash from 1.36 times to twice its intensity. Zachar (1970), reviewing investigations undertaken by other workers, believes that slopewash may differ for various lengths of slopes, and that it depends on slope gradient and exposure. While he concludes that the length of a slope bears considerably upon the volume of erosion, this influence is also contingent upon a number of other factors, and that practically every slope displays a different relationship as between its length and the quantity of washed-down material.

The information given above relating to the processes of denudation and accumulation in the area under investigation confirms the difficulties encountered in a numerical interpretation of the various interrelationships involved. The problem is analysed below in terms of cross-sectional details of soil slopes.

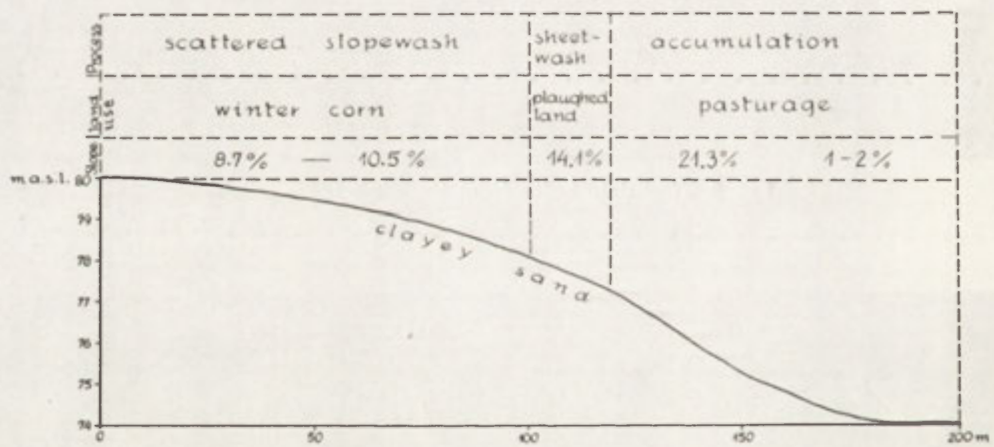

Fig. 10. Example of differences in slope processes

Losses of fertile soil, for the most part caused by such processes as slopewash, soilcreep, and aeolian activity, are manifested in the cross-sectional shape of slopes. More than thirty cross-sections were examined, each reflecting conditions that obtained over an area of some 20 km². Localities were selected at approximately equi-distant intervals, to reflect an array of natural conditions including: differences in slope height, slope inclination, slope length, exposure to the sun, position with regard to a river channel and river slopes either undercut or remote from the river channel. Where possible, differences in geological structure and in land-use (tilled land, deciduous or coniferous forests, fallow land, meadows, and orchards) are also included. On any one cross-section, some 3–7 test pits were dug, to between 1.5 and 2 m.

The upper and lower limits of a slope are designated by the range of slope processes (Jahn 1954; Dylik 1968). In practice, fixing the precise limits requires rigorous field study; for as mentioned above, slope processes will occur even on slopes of only 1 to 2° (1.7–3.5%) inclination. In economic terms, the most important kinds of soil erosion are those that call for erosion control measures,

Fig. 11. Erosive gully

because they have led to economic losses of one sort or another. In the region investigated, the assumption has been that such erosion occurs only on slopes with gradients of 6% or more (Uggla *et al.* 1968).

Slope gradient, shape and length, geological structure, the thickness of the surface layer (or accumulated humus layer) and the degree of denudation for each of the soil profiles involved were determined by the author.

For marking the intensity of damage inflicted upon slope surfaces, the author adopted the same methodology as Illner (1966); dividing the geological soil profiles and their related surfaces into four classes, depending on the degree of the erosion suffered. Class 0 represents surfaces where soil profiles are normal, i.e., where no erosion is taking place. Class I refers to areas which, compared with the initial undisturbed profile, show slight losses in the A-horizon. Class II pertains to areas where the surface has undergone considerable denudation. In this category the A-horizon is thick, and suffers marked losses, whereas in other soil profiles denudation also affects the B-horizon; in both cases, slopewash is identical. Class III comprises surfaces where the soil profile rests directly on the underlying rock. Both the A- and B-horizons, if not denuded, merge with the C-horizon. Class III also includes surfaces in which tillage has affected the D-horizon.

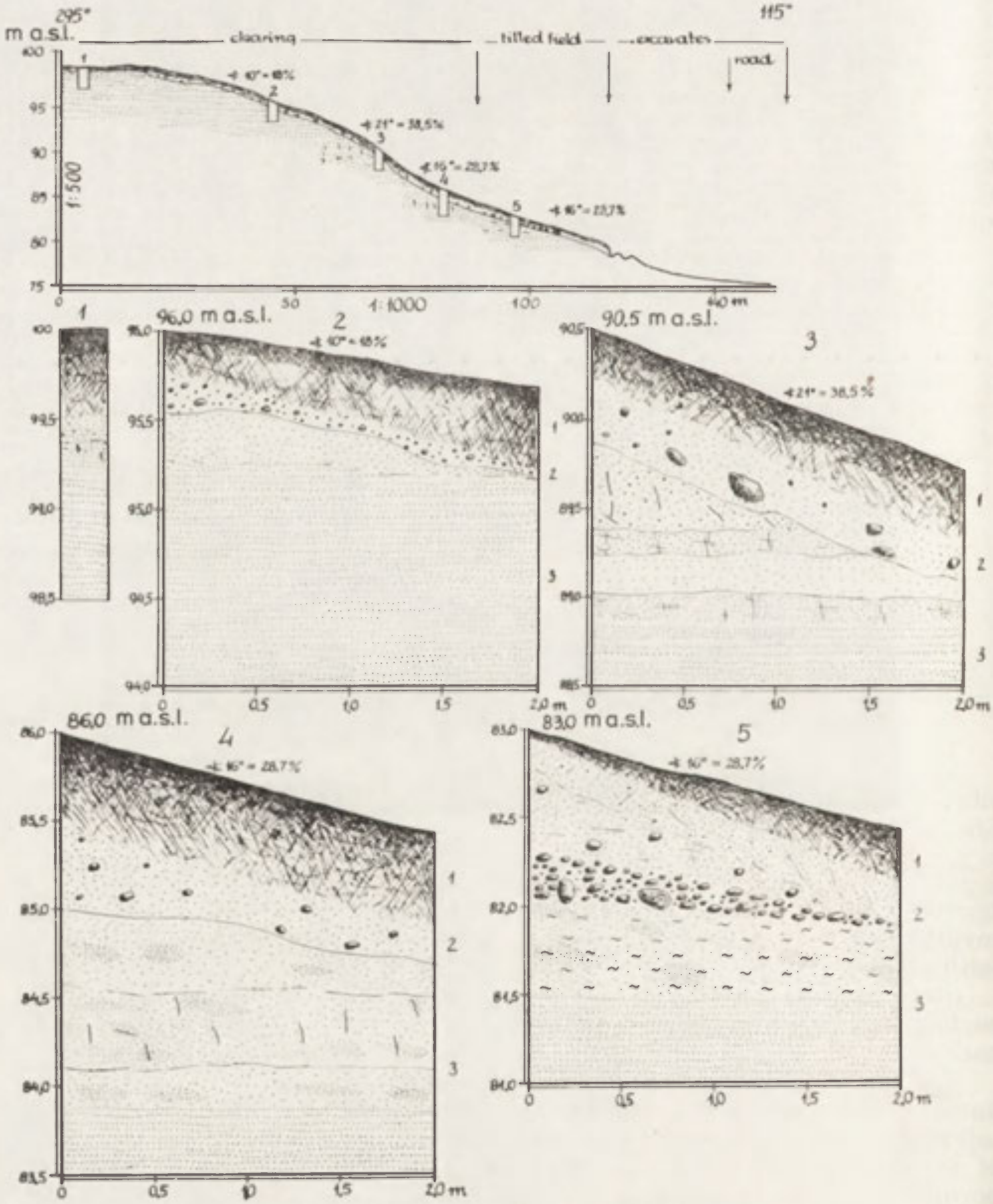

Fig. 12. Cross-section I: Szabda

The sections chosen as examples (Figs. 12, 13), and the theoretical section (Fig. 14) across the flattish surface of a plateau, an outwash sheet, or of a higher terrace extending down to the front of the slope, generally support the conclusions arrived at from the analysis of the investigated soil profiles.

Class 0 includes all areas that are not threatened with erosion, or to such a small extent that it hardly affects the thickness of the arable humus layer. This class includes flat surfaces of morainic plateaus and outwash sheets, the higher fluvial terraces, the floors of valleys with or without drainage, and lower terrace surfaces.

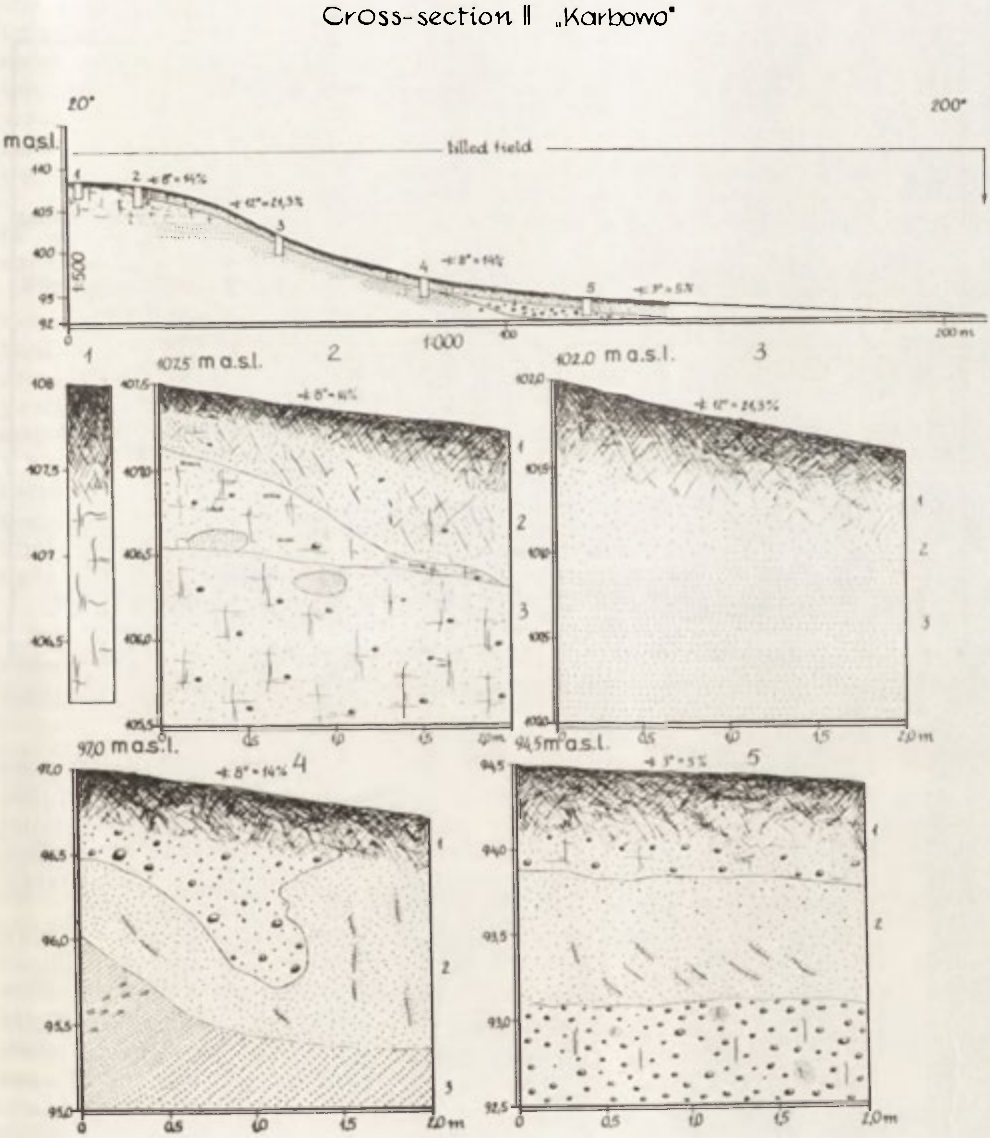

Fig. 13. Cross-section II: Karbowo
1 — soil profile and soil deposits on slope, 2 — mineral slope deposits, 3 — substratum

Class I represents a limited degree of erosion: to this are assigned a number of profiles that are moderately inclined (up to 12%) slope surfaces extending upwards from ground level towards the convex slope elements. Also included in Class I are breaks of slope lying below convex slopes; in this case, actual gradients are of secondary importance, and of greater importance is the fact that there are breaks of slope. Hence, this class includes all surfaces which are less steep than those directly above them; provided they are not much more than 12% slopes, i.e. the upper limit of this class. Class I again includes all remaining parts of a slope which go to form concave breaks, together with profiles of gently-inclined surfaces at the foot of the slope.

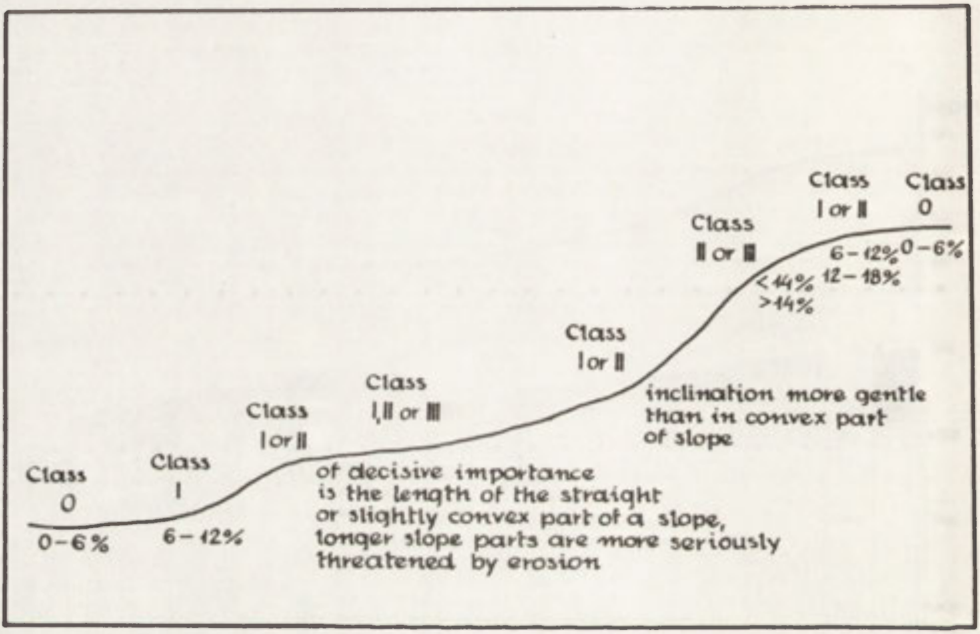

Fig. 14. Hypothetical cross-section of slope showing classes 0, I, II, III of predisposition to erosion .

Class II comprises similar surfaces to those in Class I, provided they possess a steeper gradient, in fact ranging from some 12% up to 18%. Class II includes upper convex slopes with minor diversities in slope gradients, and those slope elements where the inclination of the convexities does not exceed 14%; together with convex lower slope elements in which the profile changes from convex to concave and back to convex.

Class III includes slopes (> 18%) in most danger of severe erosion; convex surface on the upper slopes where the inclination is 14% or steeper. It includes straight or slightly-concave slope elements especially those at the foot of convex slope elements (even though slope gradients may be less than 18%). Slope elements separating two successive convex parts of a slope are also included. These surfaces suffer heavy erosion, especially on account of concentrated slopewash, as manifest in soil profiles where the C- and D-soil horizons are affected.

The authors' analytical study of slope cross-sections shows that the intensity of erosion depends upon the topographic detail of the slope. All breaks in the slope profile are zones of accumulation of material washed down from higher and steeper slopes; in this case, the angle of inclination is of lesser importance than the manner in which steeper, and less steep, elements follow one another. This concept is confirmed by observations of slope processes made by other workers (Dylik 1969; Jahn 1968; Pierzchałko 1954).

The intensity of erosion is enhanced by the convex shape of a slope, the more so when the slope surface carries small local depressions. In such cases even slopes of no more than 14% inclination are liable to be severely degraded. On surfaces of this kind, erosion usually leads to the exposure of the underlying rock, if there is a humus layer of some twelve or so centimetres this is probably the result of tillage. In these cases, the thin soil layer rests directly on an unweathered rock surface, with a sharp boundary between the two. This is most easily observed when the rock is stratified. Another control on the intensity of erosion is the length of a straight or a concave slope element, since water running over a greater slope length can give rise to a very destructive flow pattern. Again, in these cases, erosion normally extends down to the underlying rock surface.

To some extent, the geological structure also affects erosion; slopes made up of sandy material being most susceptible, clayey slopes are less susceptible except when they are convex in shape when they also suffer heavy damage.

It is certain that erosion processes and their consequences depend upon the manner in which the land is used. Geological cross-sections of slopes with identical or nearly identical slope parameters manifest different erosion rates which are especially related to vegetation cover or crop use. The destruction of soil profiles is most severe where the ground has been tilled, especially for root crops, and where the plants are widely-spaced. Less endangered are those slopes which have been planted with fruit trees, especially when the ground itself carries a turf cover. Likewise, meadowland, fallow land, and forested land (especially deciduous forests) are eroded less. Such conclusions, drawn from analyses of soil profiles made by the author, fully accord with other published data (Ziemnicki 1968; Ziemnicki, Mazur 1955).

On the question of the most appropriate utilization of slope surfaces, one must distinguish between surfaces on the basis of erosion rates, although deciding on suitable criteria to allow for a classification of erosion rates is a difficult task. Those authors who assume that slope relief and, most important, slope gradient are the most essential criteria, have failed to agree about the various degrees of slope inclination upon which the intensity of erosion depends. Illner (1966) believes that a slope inclined at 11 to 14% suffers only slight changes in soil profile, and that only on steeper gradients can the profile be eroded to such extent that the underlying rock is affected (Class III of erosion damage). Ziemnicki and Józefaciuk (1965) advise against the use of plough cultivation on surfaces inclined at more than 15 to 20%. Uggla *et al.* (1968) adopted, in the case of the Masurian Lake District, a maximum slope inclination of 18% as the limit for agricultural use, insisting that slopes steeper than 18% should, as far as possible, be excluded from ploughing. Niewiadomski (quoted by Ziemnicki) suggested that, for the same region, a limiting slope value of 25% inclination should be adopted, provided anti-ercsive measures are applied.

The author suggests a limiting value of 18% for the area under investigation, since the more steeply inclined the slope, the more severe the erosion; bearing in mind that a given slope rarely displays uniform relief. Its upper, convex part is usually denuded at inclinations less steep than 18%, while at breaks of slope further down, slope elements even much steeper than this are usually less affected by erosion. The same applies to slope foot elements that are short; whereas slope-foot elements of greater lengths, though probably even less steeply inclined, may suffer heavier denudation. With these facts in mind, a classification of slope elements has been adopted similar to the one chosen for the Masurian Lake District (Uggla *et al.* 1968); according to which slopes inclined at 6–12% constitute surfaces but little threatened by erosion; where at 12–18% erosion is moderate; and at more than 18% one can anticipate serious, even very serious soil erosion.

As stated above, these studies were intended to determine where and to what extent soil erosion is a threat; and to suggest the most appropriate land use on such surfaces. To achieve this, a qualification map was compiled — a map that indicates areas of varying degrees of erosion as defined by the criteria set out above (Fig. 15).

In such a classification, the point of issue is the division of slopes into different classes, using as basic sources of information 1 : 25,000 maps of relief, slope gradient, climatic and hydrographic conditions, lithological and soil-types, land use, and soil profiles. In addition, observational data on contemporaneous slope processes is made use of. One of the purposes of the new map is to call attention to areas where there is a need for anti-erosion measures to improve crop yields and quality. More importantly, the map indicates areas seriously threatened with erosion and requiring radical changes in type of land cultivation. Where the soils are heavy and loamy, and slope inclinations in excess of 18%, tillage of the land should be abandoned in favour of a perennial vegetation cover; sandy soils may call for afforestation.

For the area covered by the Drwęca valley, the % area of cultivated land threatened by different degrees of erosion, was calculated. It appears that sloping areas threatened slightly, moderately, strongly and very strongly by erosion total 115 km^2, i.e., 22.7% of all cultivated land. In detail, surfaces subject to slight erosion occupy 70 km^2, 13.8%, surfaces moderately eroded occupy 25 km^2, 4.9%; and surfaces most seriously affected by erosion amount to some 20 km^2, 4%, of the total area of cultivated land.

Such values may seem rather high compared with other estimates made for the whole of Poland; Reniger (1950) and Zawadzki (1967), for example, put this figure at 20%. On the other hand, Ziemnicki (1968) suggests that the potential danger of erosion averages 15% while the actual danger (after deducting the area under forest) is no more than 10%.

However, considering only Northern Poland, the discrepancies appear to be less striking. According to H. Uggla, in the case of the Masurian Lake District, for all cultivated fields and pasture land, areas little exposed to erosion occupy 36.4%, areas moderately exposed 4.4%, and areas severely exposed 0.9%. It is difficult to campare these figures with others relating to the danger of soil erosion in the whole of Bydgoszcz voivodship (Roszkówna 1973), because the criteria used are different.

In the authors' opinion, the 9.5% value estimated by Roszkówna (1973) to denote the danger of denudation (her Class III) corresponds to average erosion in the Drwęca valley and the Masurian Lake District; and what Roszkówna considers as Classes IV and V (danger of heavy and very heavy denudation of cultivated land) applies to 12% of the area in question. However, acceptable comparisons are possible only for those areas in which identical criteria have been used. Obviously, valley regions, including the slopes of channels. are the most seriously threatened areas, in which percentage values of erosion must be higher than for lowland areas in general. In consequence, this type of area can only be compared with other valley areas treated in similar manner.

Another point worth mentioning is the fact that map indicates areas that are now forested, and where very steep slopes are well protected against erosion by the high tree stands. However, should these areas be converted into tilled land, they would of course be liable to very severe denudation — the more so since every kind of disturbance of ground conditions on slopes is likely to cause, from the outset, heavy erosion.

Further evidence of soil removal by surface erosion can be seen in the great thickness of deluvial accumulation material piled up at slope foot and in erosion troughs; these can be up to 2 m thick. C^{14} analyses made during 1974 of charcoal fragments found underlying one such mass of accumulated material revealed their age to be 450 years ± 150. This relatively short period of time has, evidently, been sufficient to displace large quantities of fertile soil and subsoil. This clearly emphasises the necessity for careful scientific research so as to prevent further soil denudation.

SUMMARY AND CONCLUSIONS

On the slopes of the Grudziądz Basin and Drwęca valley the processes of denudation consist mainly of mass movements, scattered or concentrated slopewash and sheetwash, nival processes, piping, and aeolian processes. The effect of these phenomena are to lead to economic losses of different intensity, to changes in the soil profile and, sometimes, to bring about a considerable remodelling of the slope relief. The degree of such changes depends on a variety of factors; most important among these are the topographic detail, the type of land utilization, the geological structure, and climatic conditions. The more extreme the weather conditions, especially with regard to precipitation and snowmelt, the more conductive are conditions to soil erosion on inclined surfaces.

However, the course of erosion and accumulation on sloping surfaces depends, among other factors, upon the capacity of ephemeral water flows to convey material.

Where nival processes are taking place, their morphological consequences are mainly to be observed during the thawing of old snow patches. After thawing, the surrounding ground surface is readily susceptible to erosion. Subnival grooves and furrows may develop, and meltwater dripping from the rims of thawing snow patches form circular depressions. Related to these features are the processes of piping and the development of sub-surface landforms. Whether a snow cover will last long or not depends mostly on slope exposure, but also to a large extent on height and steepness of the surfaces of inclined natural or artificial slopes; the latter features often being more important than the former. Snow persists longest in the shade of high steep scarps, whether they are cool or warm. It also persists longer in depressions, hollows, narrow gullies, excavated pits and trenches. In all these situations, conditions favour nival processes. Such minor landforms are often simply the initial stages in the ultimate developments of major landform changes.

Related to present-day natural processes are other landforms that include supranival covers, perhaps wind-deposited, or water-laid, or moved downslope onto a snow cover; there are also landslide forms like scars, gullies, slide and solifluxion tongues, rills, furrows, erosive ravines and, derived from these, sandy cover sheets and alluvial cones. Some of these landforms are ephemeral and soon disappear, often because of tillage. Other forms like slides, rockfalls, deep ravines, spring niches and large pipes tend to persist and lead to considerable economic damage; moreover, they may alter some slopes permanently, shaping new surfaces that become susceptible to further erosive processes. On the same surfaces another line of evidence for contemporary erosion processes are what might be called "high boundary strips"; these often protrude 1.5–2.0 m above field surfaces. The intensity of slope erosion, mainly by slopewash, is usually manifest in soil profiles. A theoretical cross-section of a slope, with a division into four classes (0, I, II, and III) of erosive danger, affords some generalized conclusions when allied with analyses made of some (30) actual soil profiles. Theoretical cross-sections of this kind are influenced by the local geological structure: sandy surfaces being more readily denuded than clayey ones; but most importantly the intensity of erosion is determined by the nature of the land use. Of highest protective value is a leafy forest cover; next, a coniferous forest cover; followed by meadow, fallow land, and orchard cover.

Numerous analytical studies of soil profiles have revealed that, in general, slopes occupied by tilled land and inclined at more than 18% suffer heavy erosion — with the exception, however, that on strongly convex upper slope elements, and on longer slope sections, severe denudation is apt to occur even where the gradient is less than 18%. On the other hand, at breaks of slope, erosion is usually slight, even for inclinations much exceeding 18%.

The authors' classification adopts the same criteria as those applied to the Masurian Lake District, i.e. that surfaces inclined at 6–12% are only slightly threatened with erosion, surfaces of 12–18% gradient are moderately exposed to erosion, and surfaces in excess of 18% experience heavy to very heavy erosion.

In giving limits to particular divisions, the author was guided by what the soil profiles actually showed. Apart from slope inclinations, geological structure, slope relief and length, and the role played by meandering river channels lacking bank protection was taken into account. Such criteria were applied both to the Drwęca river and the Vistula in what is called the Grudziądz Basin.

For the region under investigation the area of slopes on which there is actual soil erosion is 115 km^2, 22.6% of the total area of tilled land (506 km^2).

The map indicating the danger of soil erosion is intended to draw attention mainly to areas moderately and heavily endangered, and where suitable anti-erosive measures should be undertaken, or where the current mode of land use should be changed.

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COASTAL DEFENCE POLICY ON THE EAST ANGLIAN COAST

KEITH CLAYTON*

The coast of East Anglia is cut into relatively young and weak rocks. There are appreciable lengths of cliffs up to 50 m high cut into glacial deposits, and extensive areas of salt marsh fronted by dunes and barrier beaches. Over half the coast has been defended in some way, and soon all but some of the nature reserves along the north coast is likely to be defended by banks, sea walls or groynes. Offshore extraction of sand and gravel (and local inshore dredging) requires improved understanding of sediment movement if we are able to forecast with assurance the effect of proposed changes.

Administratively coastal defence is in the hands of District Authorities, and 6 are concerned with the 220 km of the East Anglian coast. Engineering works, if approved, attract a major (up to 80% of the total cost) subsidy from central government. Currently decisions are aimed to achieve coastal stability in eroding areas, and in general to allow accretion to continue. Once most of the coast is defended this situation is unlikely to be achieved without substantial and continuing beach nourishment schemes. This concept has yet to be faced up to by the coast defence authorities, who are only now beginning to appreciate some of the limitations of an engineering solution.

It is suggested that progress will result from a widening of the approach to encompass more aspects of the coastal situation. The proper control of land use in zones hazarded by erosion or the threat of sea flood is fundamental and requires much more attention. The need for beach feeding must be understood by the decision makers, and the part that can be played by allowing natural erosion to continue to provide sediment must be considered. Beaches should be valued properly: they provide an admirable natural barrier against the sea, and have an important recreational role. With time, decisions in this situation will be quantifiable in terms of conventional cost benefit analysis: some idea of the values that are involved is given.

INTRODUCTION

The coast of East Anglia is cut into relatively young rocks, indeed Quaternary deposits predominate, although Chalk and Tertiary deposits also outcrop in the cliffs or below the recent beach sediments. North of Harwich it has few embayments and a relatively simple outline. While parts are low, especially

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along the North Norfolk coast and towards Essex, cliffs about 20 m high occur in Suffolk and between Lowestoft and Yarmouth, while in northeast Norfolk the cliffs reach 50 m. Much of the low coast represents Holocene accretion with barrier bars and salt marshes behind; all the cliffed coast has retreated since sea-level reached its present position, and a number of sections are still retreating at an average rate of 1 m/yr.

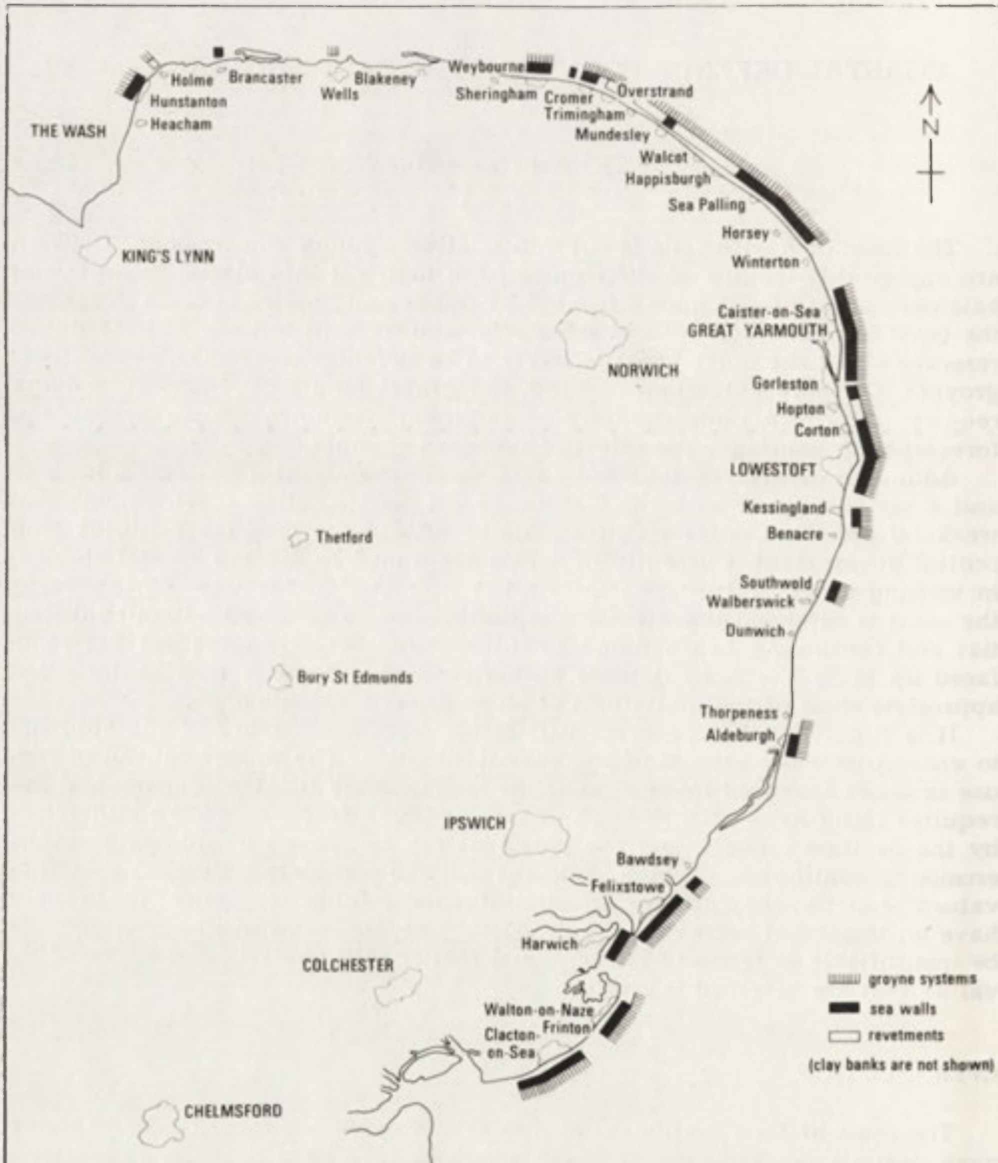

FIGURE 1 EAST ANGLIAN SEA DEFENCES

This account refers to the 220 km of coastline between Hunstanton in the NW and Colne Point in the South (Fig. 1). Much of this coast is now defended; in general defences were established over a hundred years ago at the main ports (especially Yarmouth and Lowestoft), and at the main seaside resorts (e.g. Cromer and Clacton) and have gradually been extended away from these centres since then. By now 67% of this coastline has structures of one sort or another, although only 46% has structures on, or immediately behind, the beach. The rest of the defended coast has sea walls or banks protecting marshes and other low-lying areas from flood. In these cases barrier beaches and dunes may lie up to 2 or 3 km in front of these banks, as along parts of the North Norfolk coast. In other cases the banks run into a dune complex which then forms a natural barrier until the bank begins again. On the beaches, groynes are the most common structures, but these are often associated with sea walls and wave-breaking structures below cliffs. Relatively short lengths of cliff remain undefended, as between Trimingham and Overstrand on the high cliffs of Norfolk, and at Dunwich in Suffolk. Plans exist for completing a wave barrier and associated groynes at Trimingham, but the cost and complexity of the defences has delayed their construction. Much of the low coast of north Norfolk is held in Nature Reserves, and the undefended barrier beaches and dune systems there form a most important area of unmodified coastline.

There are four facets to the administrative structure for coastal defence and planning in the UK: (1) Most of the coast is the responsibility of coast defence authorities. Until 1 April 1974 these were Rural Districts, Metropolitan Boroughs and County Boroughs, but the structure is now simpler and all areas, urban and rural, are organised into Districts — the administrative subdivisions of counties. (2) The River Authorities (again since April 1974 transformed into the Regional Water Authorities) are responsible for those sections of the coast where low-lying (agricultural) land requires protection from flooding by the sea, and thus where drainage systems must be maintained. (3) Planning control of land use is exercised now by the Districts, usually by a Planning Department and separately from the Engineer who is responsible for the sea defence itself. (4) There is a national responsibility for both planning and expenditure on sea defence which is carried by the Department of the Environment. Appeals on planning decisions are the responsibility of this Department, while grants of as much as 80% of the cost of approved schemes of coastal defence are met by this Department — the remaining expenditure is met from property taxes (District Councils) or drainage rates on agricultural land (River Boards).

The District Councils carry out a large number of functions at the local government level, and their coast defence function has played no part in deciding their size and shape. As a result, coastal defence expenditure (and concern over coastal problems) vary a great deal from one District to another. Within each District Council sea defence will generally be the responsibility of a professional civil engineer, although he will need to convince a lay sub-committee and a lay council of the need for expenditure, and the validity of the scheme being put forward. In the case of the Regional Water Authorities (as with the River Boards before 1974), decisions are subject to less lay control and are more likely to lie in the hands of the Engineer. Even so many schemes must get the approval both of a local lay committee and of the Department of the Environment.

COASTAL DEFENCE

There can be no absolute view of what is right and what is wrong in the decisions made on coastal defence. Inevitably there is an emotional tendency to regard erosion as "bad" and accretion as "good", although since accretion is clearly not desirable when it blocks harbour mouths, stability is often seen as the ideal situation. For many years decision-making treated the prevention of erosion as the overriding aim of coastal defence, and although the expenditure was no doubt kept as low as possible, no attempt was made to equate the cost of defence against the value of the land saved. So long as stability seemed to have been achieved, all seemed well, but it has gradually been understood that while time is gained and erosion rates are reduced, erosion is rarely completely halted by engineering works. Indeed, it is now more commonly understood that sea walls in particular can do nothing to reduce the erosion of the beaches that lie to seaward of them, so that these eventually disappear.

Several recent schemes have been looked at on the basis of cost of the defences against value of the land saved. There are no published criteria for a viable scheme: a proposal to build a sea-wall along the shingle bank in front of Salthouse marshes (where two people died and forty-six houses were inundated in the 1953 surge) has made little progress against the juxtaposition of a proposed expenditure of between £ 500,000 and £ 1,750,000 to defend marshland grazing with a reteable value of £ 277. Yet several schemes approved and already built have low ratios of benefits to costs, unless a very optimistic view is taken of the time they are likely to survive. The now almost completed scheme to defend the high cliffs between Cromer and Mundesley has already involved expenditure of £ 2 million to protect the cliffs and hopefully to eliminate a loss of 1–2 ha of land each year (Fig. 2). It would be rash to envisage a life of much more than 20 years so we are taking into account the protection of about 40 ha of land. As agricultural land, this would be valued at about £ 40–80,000 at today's prices, but there are perhaps 20 houses threatened along this stretch, raising the figure to about £ 400,000. On this (oversimple) balance, the costs exceed the benefits by a ratio of about 5 : 1.

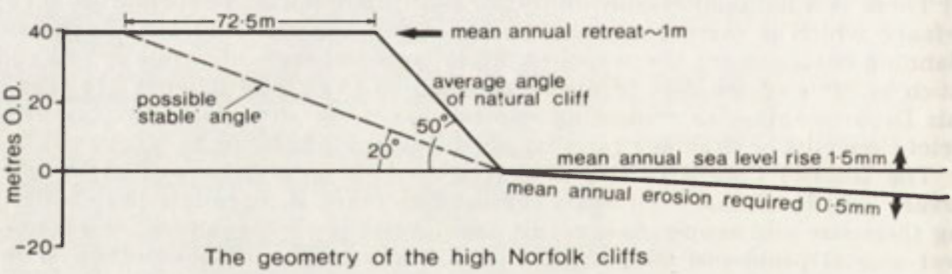

Fig. 2

The contrast between the estimates for agricultural and for developed land stresses the importance of controlling land use near coasts. This point is fundamental to the research work on flood hazard carried out by Gilbert White and others. There are, of course, other reasons why development should be restricted near coasts: unspoilt coastal areas are often of high landscape value, and recently the National Trust, through "Operation Neptune" has sought to conserve the relatively limited lengths of open coast. We may also note that the attrition of agricultural land can hardly be as disastrous as the loss of an individual's house over the cliff top. Finally the geomorphologist may appreciate the concept of a nature reserve as allowing the natural operation of coastal processes of erosion and deposition, as well as its role in the conservation of animals and plants. Indeed, it is interesting to note that one of the objections raised over the proposal to protect the high cliffs of Norfolk was the loss of a classic field site for the study of landslips.

SCIENTIFIC KNOWLEDGE AND RESEARCH

While the more open discussion of the costs and benefits of coastal defence schemes in money terms is to be welcomed, it reinforces the need for adequate scientific knowledge, and the dissemination of that knowledge to the many lay people, administrators and engineers who are concerned in decisions about coastal defence. In the first place, as we have seen, the anticipated life of a structure is a critical item in any calculation. It is in part a matter of engineering knowledge (and choice, since we may expect that a more expensive structure may last longer) but also involves an understanding of the erosional processes and the extent to which they may be modified by the engineering works, e.g., by reducing the rate of littoral drift through the installation of groynes. It is also obvious that continued tight planning control over coastal building permits is a major factor, since almost any scheme can appear viable overnight if land passes from agricultural to residential or commercial use. It is too early to see whether the recent concentration of both planning control and responsibility for coastal defences in the District will be advantageous: an authority with undue faith in its sea defence schemes may be tempted to allow development undesirably close to the coast.

Knowledge must also be gained, and conveyed to the right people about the sources, directions of movement and ultimate destination of the sediments involved in the beaches of the East Anglian coast. Here the immediate problem is that we do not know enough as scientists to be in a position to brief the decision-makers with enough confidence. It is only in the last few years that adequate estimates have been made of the quantities and types of sediment

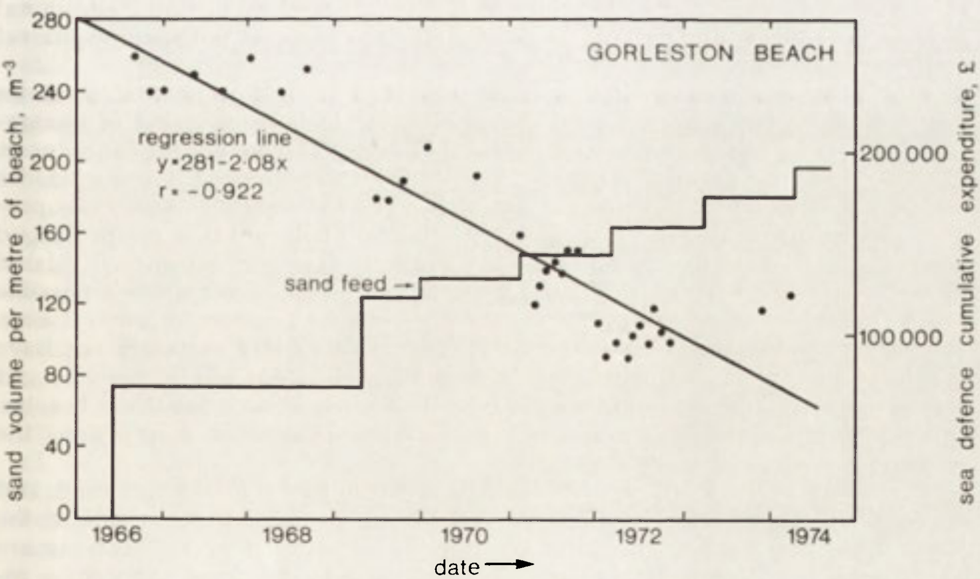

Fig. 3. Sand loss from Gorleston Beach. The steady loss of sand from the beach has continued regardless of the efforts made to stop it

derived from the coastal cliff sources, and that some estimates (of very variable quality) have been made of the rates of littoral drift. An attempt by S. Craig-Smith to estimate a budget for an area of some 330 km^2 centred on Yarmouth demonstrated the difficulties we still face in quantifying transfer between the beach system and the offshore banks. Direct measurement of sediment migration is very difficult (indeed the actual transfer of material has only been demonstrated on a few occasions) while measurement of volume changes in the offshore banks is subject to such large errors that it is of little value for estimating short-term changes. Something can be made of longer term (100 year) trends, and the approximate overall balance of the combined beach/offshore banks system established, but so far little more than that. Even the mud budget, perhaps more easily estimated since so much of the accumulation is above low-tide level, is not fully worked out.

For these reasons there is great interest in achieving an understanding of the energetics of sediment movement. An important part of the work under our present DOE contract is the measurement of wave spectra on different parts of the coast, the comparison of nearshore and offshore spectra, and the use of observers to measure the alignment of wave crests as they come on to the beach. Combined with meteorological observations, and our existing knowledge of tidal currents, these data provide the basis for understanding the relationship between the energy in the water column and the movement of sediment. This approach is likely to be particularly useful in two ways. First it should give an understanding of the theoretical basis of the physical changes along the coast that will give the scientist the confidence he needs to hammer home his advice to the decision-makers. The more advice is hedged about with the usual qualifications of 'so far as the trends of the last few years show' or 'the statistical relationships suggest a strong correlation between', the easier it is for the doubting layman or engineer to put on one side the advice he is offered. This is particularly likely to happen when you are suggesting that he might place additional sand on the beach. We do not even seem to have enough assurance as scientists to convince such a group that it is pointless to build additional groynes on a beach undergoing erosion by offshore removal but with no littoral drift.

The other important contribution of improved scientific knowledge relates to the offshore extraction of sand and gravel, the inshore dredging of navigational channels, and the removal (now rare) of material from beaches and dunes. In these cases the predictive power of scientific understanding is required; we must be able to say if the changes will affect coastal stability. Again our present understanding is quite inadequate; it is widely believed that the prolonged erosion at Gorleston Beach south of the Yarmouth Harbour entrance is related to the reconstruction of the South Pier in 1962. This seems quite a possible cause and effect relationship, but we are not yet in a position to prove it even 12 years after the pier has been rebuilt (Fig. 3). We could certainly not have predicted the erosion as more than 'a possibility' had our advice been sought before the work was begun. Since the commencement of sand loss from beaches and resulting erosion is 'a possibility' on any of our beaches at any time, the scientist is really saying nothing.

In recent years many applications have been made to dredge sand and gravel from the sea floor, and particularly from the southwestern side of the North Sea where gravel deposits are fairly common. These applications are handled by the Crown Estate Commissioners, not by the local authorities responsible for coastal defence. We know that there is a good deal of concern about offshore dredging, and although scientific advice is provided by the Hydraulics Research Station, understanding of the general situation and of local circumstances is necessarily limited. The tendency is to play safe, to allow removal of banks well offshore, but to leave inner banks since we might expect these to reduce wave energies reaching the coast and perhaps also to function as a source of beach sand at times of onshore movement of sediment. So far, the pressure for resources has allowed this rule of thumb approach, but as the need for gravel increases, we must become better informed. We need to know when we must call a halt to offshore extraction, even if this leads to increased pressure on inland sites, or the use of crushed rock or other more costly alternatives. It is becoming increasingly important to predict, with assurance, the effect of changes, and increasingly unsatisfactory to describe the damage done after these changes have been permitted.

THE LIMITATIONS OF AN ENGINEERING SOLUTION

The geomorphologist has long understood the dynamic nature of the land-sea boundary, and the efficient way in which a mobile prism of sediment absorbs the varying energy of wave attack. He has understood the transfers of sediment, usually within the system as when beaches are subject to seasonal or even daily changes, or when sand is transferred from beach to dunes, or from dunes to beach during a period of storms. He has also understood the role of longshore transport in bringing additional supplies to beach segments with the building out of nesses of spits. He has noted the permanent loss to deep waters, as down the canyons of the California coast. Above all he has understood the limitations of permanent structures as stable, and often rather arbitrary, boundaries between sea and land.

He has understood, but he has done little to spread his understanding. In part this is because he has rarely been called in professionally as has the engineer, and because he has not usually involved himself in local government where the decisions are taken. Where he has profferred advice, it has rarely seemed good sense: the assurances offered by the engineer were more acceptable than the warnings (and caveats) of the geomorphologist. As geomorphologist he could have done little more, although he can now point with increasing conviction to the limitations of the engineering approach.

While these limitations are endemic to the engineer's approach, they are becoming increasingly obvious as time goes by. In so far as the engineer has succeeded in stabilizing a section of coast, this is likely to rest either on a change that might have occurred naturally, or on the successful reduction of longshore drift, and the resulting accumulation of sediment. In all cases where groynes have succeeded in trapping sand, a continued supply of material is usually needed to keep the system full, for inevitably some is lost down-drift or by offshore removal.

The defended length of the East Anglian coast is increased almost every year. Already the gross area lost by erosion which averaged over 12 ha/yr from 1880–1950 is down to less than 5 ha/yr, and we may envisage that the completion of the coast defences already planned could reduce this figure below 2 ha/yr. However, we must appreciate what this achievement will do to the sediment balance. On rough figures, the 1880–1950 situation for Norfolk, Suffolk and northern Essex showed the following balance.

Area lost by coastal erosion/yr	12.2 ha
Area gained by coastal accretion/yr	6.5 ha

Of course the volume of sediment released by erosion was much more than the 2 : 1 ratio of the areas, since many of the eroding areas are cliffed, and the accreting areas are low. Calculation suggests a ratio of about 20 : 1 for the period 1880–1950; that is to say only 5% of the eroded sediment was involved in local accretion. Some sediment travelled beyond the limits of the coast under consideration here, accretion in the Wash, in the outer Thames estuary and in southern Essex may well have depended on sediment from Norfolk and Suffolk. Nevertheless, we may envisage that besides the net accretion of 6.5 ha, many other areas (some of them defended) will have been kept in the balance by the sediment supply balancing the natural erosional loss. A reduction of eroded area to 1–2 ha is likely to reduce sediment supply generally to about 1/6 of the original amount. Not only is the gross accretion therefore likely to drop to around one hectare, but areas in balance could lose 5/6 of their incoming sediment, changing them from stability to net erosion. Dr. Cambers has shown that the Norfolk cliffs from Weybourne to Happisburgh still contribute 700,000 m^3/yr sediment, of which 500,000 m^3 is sand and gravel. Although this moves down the coast by longshore drift, most of this must pass into the offshore system, but it could still be a major factor in maintaining the sediment balance of the bank system off Yarmouth and Lowestoft, and could well be the source of the sand for the accreting nesses at Winterton and Yarmouth North Beach.

Indeed, since onshore sediment movement is on the whole less likely than offshore, it is hard to envisage a totally defended coast that would not be losing sediment. If this is so, then it would be necessary, either to accept a concrete wall around the whole coast, or to envisage beach nourishment schemes to maintain beaches for both coastal defence and recreation. Once this is faced, we are bound to turn to the relative merits of natural supply from erosion and the artificial emplacement of sand in beach nourishment schemes.

THE RELEVANCE OF AN ENVIRONMENTAL VIEW

We have stressed the problems of the engineering solution of coastal stability, and the limitations of the geomorphologist as an effective adviser. Scientifically, and also in terms of its effectiveness as advice for the decision-makers in local authorities, there is much to be said for a broad 'environmental' view. We are dealing here with the following elements:

(1) Littoral planning — in the control over coastal land use.

(2) The need for stability at built-up sites, whether this is achieved by engineering structures or beach nourishment (or both).

(3) The sediment balance of the coastal and offshore systems.

(4) The recreational value of a sandy beach.

(5) The hazard of coastal flood during surges, experienced by areas below 6 m OD.

Scientific advice based on these considerations is effective both because it encompasses the full range of environmental considerations in coastal conservation and because the broadening beyond purely "technical" matters means that the problems become more real for the laymen involved in decision-making. We do not dispose of the difficulties we have already noted, in particular the need to acquire adequate understanding of sediment movement, but we broaden the range of choice by accepting only the need to try and defend built-up sites, retaining a choice at other sites. This approach should also allow adequate emphasis on the need to plan and control coastal land use, whatever the contemporary stability of the coastline involved.

In time it will be practicable and we may hope desirable to develop cost-benefit models for appraising alternative strategies of coastal management. In the meantime it may be helpful to quantify the items we have listed to note their relative importance in financial terms. The values are summarized in Table 1.

(1) *Control over coastal land use.* While the loss of agricultural land might be costed at £ 2,000/ha at today's prices, the loss of developed land can easily run as high as £ 100,000/ha. Indeed the gas terminal at Bacton, occupying 20 ha, represents an investment of about £ 10,000,000. Where retreat of the order of 1 m yr occurs, the loss per km of coast will be 0.1 ha/yr, valued at between £ 200/km/yr for agricultural land and over £ 10,000/km/yr if the land is developed.

TABLE 1. Approximate estimates of values and costs, expressed in £/km/yr

(1) Loss of land per m retreat per year	
(a) Agricultural land	200
(b) Built-up land	10,000
(2) Value of sediment from above erosion retained on beach	800
(3) Total value sediment, including that moving offshore	8,000
(4) Sea wall construction and maintenance	10,000
(5) Beach feeding scheme, with continuing maintenance	10,000
(6) Damage due to coastal flood, 20 yr recurrence interval	5,000
(7) Damage due to coastal flood, 100 yr recurrence interval	1,000
(8) Value of beach at seaside resort	50,000

(2) *The cost of stability at built-up sites.* A coastal town with a promenade or harbour will in general seek to stabilize its coast almost regardless of the cost. A substantial sea wall is likely to cost £ 450,000 per km, and in an eroding site may well require repair after 20–30 years. Even if we take a life of 40 years, the cost will work out at about £ 10,000/km/yr. The alternative would be to emplace sand in front of the town, such as in the current beach feeding scheme at Bournemouth. Here the cost of the current scheme is about £ 850,000, and it will no doubt require topping up every few years at a cost of perhaps £ 100,000 each time. The length benefitting from this feeding scheme is about 10 km, giving an average annual cost of £ 10,000/km/yr. This is the same cost as a sea wall, but provides a beach as well as stability.

(3) *The sediment balance.* One difficulty here is our ignorance about how much eroded sediment stays within the nearshore system. The 500,000 m^3 of sand and gravel still eroded annually from the Norfolk cliffs would cost at least £ 500,000 if placed on the beach in a beach nourishment scheme. Even the 50,000 m^3 or so that stays on the beach each year could reasonably be valued at £ 50,000. Since the length of coast involved is of the order of 60 km, the figure per km is £ 800 per year. We may note with interest that this is four times the value of the agricultural land supplying this sediment. Indeed if all the sediment could be retained on the beach, the ratio of value of agricultural land to value of sediment supplied would be 1 : 40.

(4) *The recreational value of a sandy beach.* The tourist industry of East Anglia involves a large number of visitors to the coast. While some of these may get no further than the piers, promenade, amusement parks and other man-made structures, many will sit on the beach, construct sand castles, sunbathe and swim. Here our valuation is difficult but we may note a United States

Government Standard of 10 ft² of dry (i.e. above High Water Mark) beach per person. At this standard Yarmouth beach is capable of handling well over 500,000 people each day over a length of some 5 km. In fact the beach is never used to this extent, although the peak number of visitors is estimated at about 150,000/day. If we value this beach at the price people are prepared to pay for a deckchair to sit on the beach (7p), an average high season visitor figure of 10,000 gives a value of about £ 700 per km per day, or about £ 500,000/km/yr. Where a wall is put in landward of an eroding beach (as at Gorleston to the south of Yarmouth beach) the eventual loss of this beach value should be added to the cost of the wall. In the same way, the estimated cost (£ 250,000) of a beach feeding scheme proposed for Gorleston can be related to the benefits gained from a dry beach: at present hardly any sand is left at high tide, and beach area is limited even at mid-tide.

(5) *Protection from coastal flood.* Following the death of over 300 people in Britain (over 2000 in The Netherlands) in the 1953 surge, dykes have almost everywhere been raised to a foot above the 1953 surge level. In addition, a flood warning scheme has been introduced which (in theory) will allow the evacuation of threatened areas. No additional controls have been imposed over building on threatened sites, buildings damaged in 1953 have been rebuilt on the same foundations, and in Lincolnshire, major areas of summer chalets have been replaced by centrally heated (and thus presumably occupied) bungalows. Some of these stand on land at 3 m OD — the 1953 surge rose here to 6 m OD. The stress has been on physical protection from flood coupled with evacuation plans, rather than a tighter control over occupation of low-lying areas. Review of work of the Chicago School on flood hazard on river floodplains (and associated work on the Atlantic seaboard) demonstrate that this approach must be matched by landuse controls if hazard and damage are to be minimised. In the case of Salthouse, already referred to, the houses destroyed in 1953 have been rebuilt in the same place. Rebuilding higher up the slope would have removed the need for a sea wall of any type. An examination of public awareness of flood danger in the South Town area of Yarmouth in 1970 showed that here too the clear lessons of the Chicago work were being ignored.

In financial terms there can be no doubt that coastal flood damage can dwarf the figures we have been quoting for other aspects of coastal defence, although since surges are only likely to recur every 20–100 years, the annual cost per km comes down to the range of figures we have already quoted. It has not been possible to obtain a reliable estimate of the cost of damage in the 1953 surge, but the restoration of coastal defences alone cost £ 10 million in Norfolk and over £ 5 million in Essex. These figures work out at about £ 100,000/km of coast, or £ 5,000 km/yr over a 20 year return period, only £ 1,000/km/yr over a 100 year return period.

CONCLUSION

This survey of the practical problems faced on the East Anglian coast has emphasised two problems. First the desperate need for an adequate understanding of the coast, and of the factors causing sediment movement. This is particularly important where it is necessary to predict the effects of proposals for construction or dredging. Secondly the need to widen the view of those concerned with coastal defence away from the juxtaposition of erosional loss with engineering solutions, to proper consideration of the need to maintain adequate beaches and perhaps also to accept erosion of some areas as a cheaper alternative than beach feeding schemes. Above all is the need to understand the basic role of land use planning in the coastal zone, whether the threat is from the instability of the coastline or liability to coastal flood.

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PURPOSE, SCALE AND METHOD IN LAND RESOURCE SURVEYS

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The diversity and urgency of land use planning problems throughout the world have led to a proliferation of reports and recommendations concerning land resource surveys and evaluations. These publications are notable as much for their different viewpoints as for their common aims, and recent attempts to coordinate land classification procedures have not always clarified the issues. Many discussions appear to spring from an implicit assumption that all surveys should have a common methodology and follow an accepted sequence of operations (Brink *et al.* 1966; Brinkman and Smyth 1972). Differences of purpose and of scale may invalidate such assumptions (Beckett 1968), but most if not all such surveys attempt spatial subdivisions of the land surface and are therefore concerned with the delimitation of areas having known properties of importance to the prediction of land potential and performance under different uses or managements.

The identification and mapping of land areas (land units) at varying scales of enquiry are therefore central aims and problems in land resource surveys. But many reports avoid discussion of issues inherent in such a situation. Furthermore, although most land units have been defined in part on the properties of their geological and geomorphological foundations, geomorphologists have commonly ignored the difficulties underlying this task. Before exploring this situation in greater depth a number of general principles may be considered.

NATURE AND PROBLEMS OF MULTI-PURPOSE SURVEYS

This discussion will be confined largely to procedures appropriate for multi-purpose surveys, for these may differ fundamentally from the needs of single-purpose surveys. In the latter the intended use of the land area is known in advance, so that a quantitative study of particular land parameters vital to that use may be undertaken. Although the role of the multi-purpose survey may be questioned, its underlying aim will be to lay a permanent foundation for land-use planning and landscape conservation. It is therefore mistaken to expect such surveys to provide all the necessary information for every conceivable use, but it is reasonable to expect that they will provide land mapping units valid for later investigations and for planning decisions.

This expectation may be questioned however, for it depends upon an assumption that land units mapped according to one set of criteria will be equally valid either for sampling additional terrain properties or for predicting them. But the alternative to subjective terrain mapping is the collection of point-sampled data on specified land qualities from which land units may be synthesised, using different combinations of the data. The possible number of land attributes is however very large, and selection from these for multipurpose (as opposed to single-purpose) surveys must be arbitrary and subjective. Moreover, boundaries for land units can only be mapped accurately from these data if sampling points are closely spaced. Beckett (1968) has indicated that these requirements are satisfied only in intensive surveys which allow all sampling points to be visited on the ground, and such surveys are suitable mainly for large scale investigations.

Many land resource surveys have to be undertaken at medium scales (1 : 50,000–1 : 100,000) and until recently were often performed at small scales (less than 1 : 250,000). In difficult terrain and in reconnaissance surveys of developing countries, field sites have to be restricted in number and boundaries drawn on the basis of aerial photographic interpretation and selective field checks. There is already an extensive literature on this problem. However, it is not always adequately recognised that there may be a clear distinction between the mapping of land units and the ranking or combining of them for particular uses. Thus, if land units are mapped according to a consistent classificatory procedure, embodying a scale related hierarchy, then small areas may be combined in various ways to arrive at different larger regions for planning or management needs. This point is of some importance, because it impinges upon several related issues, including the scale of survey; the size of management units, and the establishment of hierarchies for land mapping units. These questions will be explored further.

Related to these questions is that of the permanence of survey information. Most land resource surveys have been based upon relatively stable, inherent land characteristics, usually properties of landform and soil. But, although most agencies in western countries employ these techniques,* they are subject to two apparently different sources of criticism, that are in reality closely related. One is that they neglect socio-economic factors including location; the other is that they rest upon static, morphological criteria and neglect functional relationships within the existing ecosystems (including agroecosystems). Discussion of these points involves several strands of argument.

Socio-economic factors have been incorporated into some survey methods, including the United States Department of Agriculture (USDA) Land Capability Classification, in which certain levels of management and technology are assumed. But these surveys are in fact derived from an assessment of inherent land qualities based on conventional soil and physiographic data. The approach has many uses, but for multi-purpose surveys has not been found entirely appropriate (Brinkman and Smyth 1972). Socio-economic criteria also require constant re-evaluation, so that they are perhaps better considered separately (Hilton 1968). Application of ecosystem concepts to land classification, by focussing upon contemporary, functional relationships (Moss 1968) and neglecting genetic and developmental criteria, must also be considered dependent upon existing systems of land use (or non-use). In any view which places high value on the permanence of survey information the ecosystem approach presents many difficulties.

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* Agencies referred to in this paper include the Commonwealth Scientific and Industrial Research Organisation of Australia (CSIRO); the Land Resource Division of the Overseas Development Administration of the United Kingdom (LRD); International Institute for Land Reclamation and Improvement (IILR); the United States Department of Agriculture (USDA), and the Centre d'Études Phytosociologiques et Écologiques, Montpellier (CEPE).

From these preliminary remarks it may be concluded that multi-purpose land resource surveys are best based upon relatively stable elements of the land complex, and that the identification and classification of areas as land mapping units should take precedence over the arbitrary collection of data on land attributes. On the other hand it is not self-evident that a single, generally acceptable methodology exists for such surveys.

ECOSYSTEMS AND GEOSYSTEMS IN LAND RESOURCE MAPPING

In order to clarify certain of the issues raised by this discussion some preliminary definitions and distinctions are necessary. The first concerns the concept of '*land*'. Many authors have addressed themselves to this problem, and most observations accord well with that given by Brinkman and Smyth (1973): "A tract of land is defined geographically as a specific area of the earth's surface: its characteristics embrace all reasonably stable or predictably cyclic attributes of the biosphere vertically above and below this area..." (p. 63). *Land* is thus a wider concept than *soil* which is included within the definition. It is however defined in terms which describe a set of interrelated features, and Moss (1968) considers this to be conceptually weak, preferring land to be "a theoretical term in a deductive system defining contemporary relationships between soil, plants and animals" (p. 22). The conflict here is not so much over the definition of land, but rather the relationship between notions about land and the concept of the ecosystem. In the discussions edited by Brinkman and Smyth (1973) it was pointed out that "tracts of land are always characterised by more or less strict boundaries whereas ecosystems are usually centrally defined concepts". Similarly it was suggested that "mapped areas of soil represent(ing) concepts, those of land tend(ing) to represent unique tracts of the earth's surface" (p. 16). Advocates of the ecosystem approach, however, consider the ecosystem as more than a centrally defined concept. Rowe (1961) recognised that ecosystems may be "focussed on geographic cores" but considered that "any single perceptible ecosystem is a topographic unit, a volume of land and air plus organic contents extended areally over a particular part of the earth's surface for a certain time" (p. 422). Utilising the "level-of-integration" concept (Feibleman, 1955) he regards ecosystems as natural objects above the level of the organism. Following similar arguments Schultz (1967) states that "when organised entities have strongly marked structural and functional characteristics, they are perceived as autonomous and stand out as natural objects of study" (p. 144).

Nevertheless, in spite of powerful logical arguments, the delimitation of ecosystems remains somewhat arbitrary (as do parallel definitions of "communities" in phyto-sociology). Thus it has been suggested by Cooper (1971) that stream catchments may be suitable units for ecosystem studies. This may be so, but stream basins must be considered as hydrographic or topographic units. Whether they can be regarded as ecosystems *per se* seems debatable. Ecosystems must be defined in terms of biological relationships between plant and animal communities and their environments, and this is the approach to land resource survey advocated by Moss (1968). But as Young (1973) remarks, "what is not clear is how this approach can be translated into practical survey procedure, capable of relatively routine application to a variety of areas" (p. 13). Ecosystem research also requires an intensity of survey that is inappropriate to the initial mapping programmes of land resource surveys. Moss (1968) writes of "the superficial difference of scales" between the CSIRO Land Systems Surveys and his own work in Nigeria. In fact such differences were tenfold (CSIRO 1 : 250,000–1 : 500,000; Moss 1 : 25,000) and must be considered fundamental.

Some geographers have attempted to use the term "geosystem" as parallel with that of ecosystem (Isachenko 1965, 1972; Tricart 1973). According to Tricart (1973), the geosystem is "a unit of tens or hundreds of square kilometres associated with different ecosystems and natural habitats", and is capable of hierarchical classification. The essence of the concept is to incorporate a dynamic framework into the study of the land surface, and Tricart (1973) argues for "integration by successive stages" in which:

(1) the regional framework is formed by climatic and morphostructural units;

(2) the morphodynamic analysis establishes the areal extent of morphodynamic systems (as "lithovariants" or "topovariants" within 1); and involves the study of active processes, anthropic influences, and degree of morphodynamic stability;

(3) the ecologic resources are then analysed within the regional framework by examination of the hydrologic regime, bioclimatic conditions, agronomic soil properties and identification of an appropriate agricultural system; and finally;

(4) planning problems are discussed in the light of these analyses.

It may be noted here that Long (1974) in discussing the methods of the Centre d'Études Phytosociologiques et Écologiques (CEPE) in Montpellier affirms the need to integrate land resource inventories *a posteriori,* and criticises the CSIRO method for its *a priori* reasoning with regard to the existence of Land Systems.

The theoretical work on landscape research by Isachenko (1965) recognises that definitions of natural complexes must be based largely on morphological criteria, even though interactions remain the major aim of analysis. However he admits (1972) that "one of the bottlenecks of the method of modern landscape research is the study of dynamic aspects of natural complexes" (p. 232), and he has warned of the dangers of superficiality arising from the analysis of external features of the landscape complex by geographers concerned mainly with recreational planning.

From this discussion arise several related and difficult questions which may perhaps be summarised:

(1) Can landscape complexes or ecosystems be mapped as such or must they be inferred from a geologic or geomorphic framework?

(2) Do "natural units" of land or landform exist which can be arranged within a hierarchy or hierarchies suitable for mapping at different scales of enquiry?

(3) Is it possible to overcome the criticism that most schemes for mapping land units emphasise morphologic and genetic land attributes at the expense of enquiry into dynamic and functional systems?

MAPPING LAND UNITS

Categorical answers to these questions are difficult to offer, although the Soviet school of "landscape science" and many individual authors have provided logical arguments towards their solution. In view of the complexity of the problem this discussion can only hope to deal with particular, practical issues of relevance to the mapping of land units. The term "land unit" itself appears to imply a mapped area of the land complex, but most maps of such units, whether they are of "land systems" (Christian 1957; Christian and Stewart 1968) or of more uniform "land facets" (Beckett and Webster 1965), prove to be based in large measure upon physiographic boundaries. In some cases it is clear that the land unit boundaries follow different components of the land complex over separate sections. This is mentioned by Isachenko (1965), but is perhaps most evident as a result of pattern recognition from aerial photographs, and is shown in many of the earlier CSIRO Land System Reports.

Perhaps the strongest case for a geomorphological basis for land mapping lies in the extreme sensitivity of the plant and animal communities to sudden changes of character and extent. It has been argued that such changes create new landscapes (Isachenko 1965) and that organic materials must therefore be considered diagnostic of landscape character. But priority is more often given to the mapping of stable components within the landscape. This is recognised in the discussions edited by Brinkman and Smyth (1973), where the place in a hierarchy of definitive factors was to be determined by the degree of per-

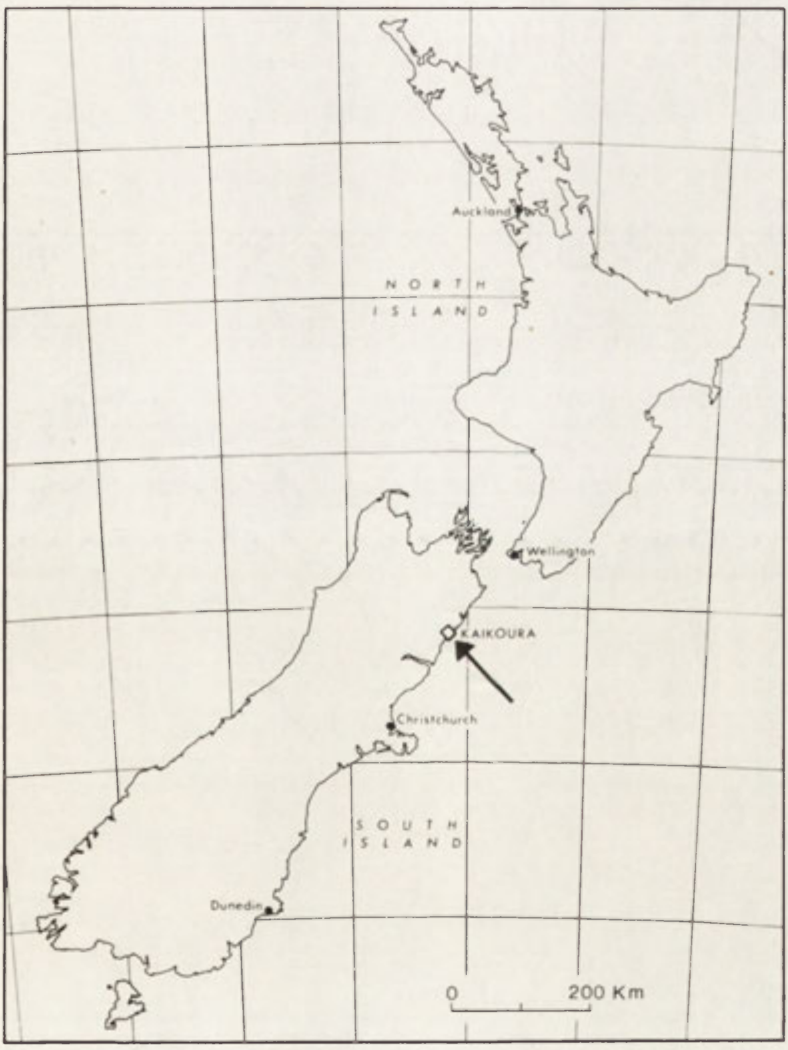

Fig. 1. Location Map — New Zealand showing location of Kaikoura

manence of the land attribute. This in itself raises further problems which will become evident in the illustrations given later.

Before discussing the question of hierarchies of land units further, it is perhaps appropriate to allude to the third question. Land resource surveys are generally required to map areas and these are, by definition, morphological. It may therefore be questioned whether boundaries can be drawn which coincide not only with stable features of the land surface but also with the extent of the more important dynamic systems. For at least three reasons such claims can seldom be justified. In the first place, the boundaries of different systems may not coincide; secondly, system boundaries are not static but fluctuate in extent over time, and thirdly, contemporary processes operate over inherited forms, modifying them as they do so. Hydrographic areas for instance fluctuate

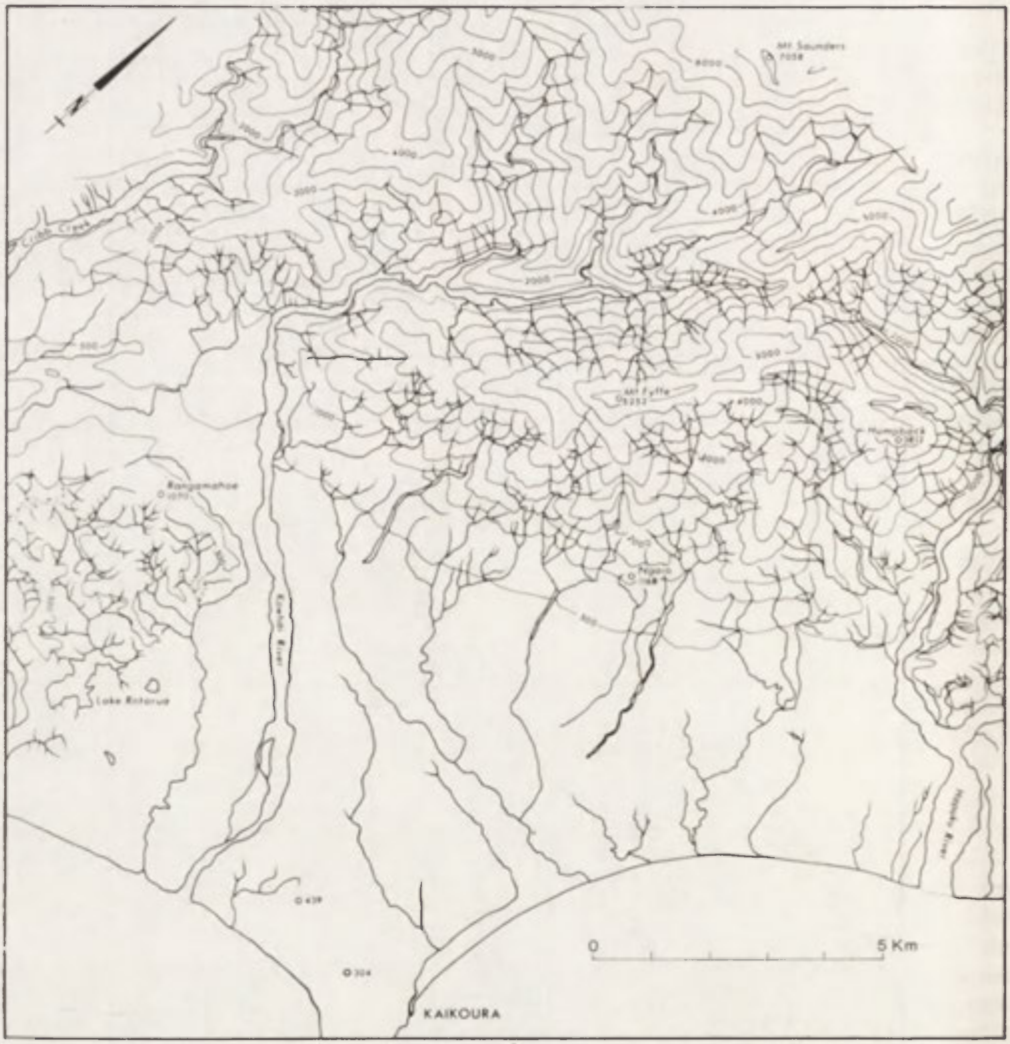

Fig. 2. Relief Map of the Kaikoura Area — Extract from N. Z. Topographic Map 1 : 63,360 Sheet S. 49 Kaikoura. Heights are given in feet

Fig. 3. Land Mapping Units for the Kaikoura Area, New Zealand

A. Morphodynamic Systems (Hydrologic Units)
I–IV major hydrologic systems identified
A indicates erosional catchments
B indicates depositional areas
IA/IB basin and fan deposits of Kowhai River
IIA/IIB basins and coalescent fans of streams draining seaward slopes of Kaikoura Mts.
Zones of interaction between confluent hydrologic systems marked IB+IIB and IB+IIIB. In these areas floodwater and fine sediment are brought in from more than one catchment after heavy rain

B. Morphological Land Systems and Units
I–V major Land Systems (pattern units)
Systems I, III, IV, V are erosional systems
System II is a depositional system
Land System II is subdivided into "landform complexes":
IIA inactive (mainly Pleistocene) fan surfaces, and interfan depressions
IIB active fans (areas of gravel deposition)
IIC alluviated areas of fine sedimentation (subject to frequent flooding)
Such "landform complexes" are internally complex but exist at the "land facet" level within the "land system".

with time, and in depositional areas a single morphological unit may belong to more than one such system as shown below (Figures 2 & 3). It can also be demonstrated that topographic and phreatic divides do not necessarily coincide (Gregory and Walling 1973). These factors contribute to what Ruxton (1968) described as "disorder" in land; the result of inheritance and multi-complexity of process. These considerations should inform our use of boundaries and also affect discussions concerning hierarchies of land units.

THE CLASSIFICATION OF LAND UNITS AND THE PROBLEMS OF HIERARCHIES

The ordering of land mapping units into scale related classes and the establishment of hierarchies of such units have proved to be controversial topics. Theoretical studies in landscape research have commonly been concerned with this question (Hertz 1973; Hills 1961; Isachenko 1965), and several attempts to order landforms have also been made (Fairbridge 1968; Linton 1951; Thomas 1969; Young 1969), but the difficulties are readily apparent from all these works and some writers, such as Haantjens (1968), have concluded that the attempt is mistaken and not relevant to the mapping of land units. Approaches to this question have by no means been consistent. While some authors have sought to recognise "natural" units of the landscape, others have proposed an arbitrary classification of land areas into scale units or have simply recognised a working scheme of land units and patterns. The lack of attention paid to classificatory procedures has recently been discussed by Wright (1972).

The widely used division of land areas into "land systems" and "land units" (Christian 1957; Christian and Stewart 1968), as practised by the CSIRO, illustrates this situation. In the surveys of land systems no other units were mapped or closely defined, and the scales of the maps varied from 1 : 1,000,000 to 1,250,000. Moreover, surveys were undertaken in terrain of widely varying character, with the result that individual land systems differ greatly in internal complexity, and the distinction between units and systems cannot be logically maintained. Subsequently, the concept of the "land facet" has been introduced and more closely defined (Beckett and Webster 1965; Brink *et al.* 1966), but as Young (1973, p. 33) points out "it is not self-evident that the natural landscape is ordered into units primarily at the two scale levels represented by the land system and the facet". Much earlier Linton (1951) had pointed out that he could find no unambiguous units between the undivided flat or slope ("site") and an entire continent, and even the work of Isachenko (1965) and Solontsev (1962) reveals that problems of scale affect the recognition of "landscapes" and "urochishcha" (*uroszyska*), (the use of terms such as sub-*uroszyska* and complex *uroszyska* strongly suggest the difficulty of restricting this unit to a particular scale level).

The underlying problems are more clearly focussed by discussion of the process of classification itself. Wright (1972) has pointed out that some surveys are inventories rather than true classifications and that most others classify by "subdivision" rather than by "association". He comments (p. 354) than "in contrast to the method of association, which depends on observable facts about individuals, subdivision requires that there is some understanding of the cause of variety within a population." Hence "descending" classification systems are mainly based on genetic considerations. The genetic approach to land classification was criticised by Mabbutt (1968) on the grounds that it can only produce units of large size which are also internally complex. This according to Mabbutt (1968, p. 13) "expresses a fundamental limitation of the approach, namely that breakdown cannot proceed beyond the level of unit appropriate to the genetic bond itself". He rejects the introduction of "additional genetically linked criteria of increasing dependence" because the same factor will not enter into the hierarchy at the same level in every area. For this reason genetic relationships become "a secondary rationalisation and no longer a key to division" (Mabbutt 1968). This last observation has seldom been considered, but is of central importance to later discussion.

The "descending" classification is also characteristic of land system surveys for these rest principally upon the recognition of pattern areas on aerial photographs, and the land unit or facet is commonly defined as a component of the pattern. Such schemes tend to avoid the recognition of fundamental units of the environment (Thomas 1969) or what Wright (1972) calls "taxonomic individuals". But unless such individuals can be established, the validity of higher categories in the hierarchy may be doubted. The neglect of this question derives as much from the fact that such units will be too small for mapping purposes at medium scales, as from the conceptual difficulties of the task. Schemes which have considered this question (Brink *et al.* 1966; Isachenko 1965; Linton 1951; Thomas 1969; Young 1969) have usually regarded uniformity of environment and land cover as the definitive characteristics of units such as the "site", "land element", or "facies". On the other hand the ecosystem approach builds up from the ecosystem of a single organism, *via* local to regional ecosystems (Rowe 1961), and the means by which this can be applied to land mapping are by no means clear.

The "landscape" and "ecosystem" approaches to classification depend upon the structural and functional characteristics of the land units themselves. Alternatives are to rank diagnostic features or formative processes. Brinkman and Smyth (1973) suggest the former by ranking land qualities according to their permanence or importance to land use, while Herz (1973) offers a hierarchy built upon the ranking of formative processes; in reality a genetic approach. There are thus clearly several possible choices to be made at a fundamental level of definition which may influence mapping at higher levels in any hierarchy of land units.

Nevertheless, it has appeared relatively easy to propose regional frameworks which can be mapped at small scales and over large areas. This is partly because internal complexity is seldom examined quantitatively and zonal and structural controls are permitted to define landscapes or land systems of varying heterogeneity (Isachenko 1965). A further problem with land systems is that they purport to represent "repeated patterns" of lower units, but many such areas are in fact irregular mosaics of facets and sites.

The subjectivity of these forms of land classification and mapping led Chorley (1969) to propose that the drainage basin should be used as the fundamental geomorphic unit because of its objectivity, natural hierarchy of basin orders, and functional importance within the landscape. It has already been noted (Cooper 1971) that the drainage basin may be appropriate for ecological studies, and the human importance of catchment areas cannot be denied.

Yet the problems of land mapping cannot be resolved as simply as this, for the following factors limit the usefulness of drainage basins as mapping units:

(1) It is necessary to sub-divide even first order basins into component slopes if the mapping is designed to recognise uniform areas at the facet level. Since not all such slopes drain into first order streams, it is not clear how mapping could proceed consistently with respect to the basin ordering system.

(2) Problems of definition are not avoided by the use of the drainage basin.

Difficulties of defining the hydrographic network become evident in a variety of circumstances, and may be intractible in areas of subdued relief; in depositional terrains; in arid or semi-arid environments, and in glaciated areas.

(3) It becomes difficult to attribute land areas (facets) to particular drainage lines in many of the circumstances listed above. Thus streams in recently glaciated terrains commonly either occupy glaciated valleys or flow with little effect across the glaciated valleyside slopes. In many such areas integrated stream networks scarcely exist. In semi-arid (let alone arid) climates a high proportion of the land area may be remote from any stream line.

(4) In terms of land classification the subdivision of watershed areas into several basins may be unrealistic if the stream frequency is low and the watershed areas consequently broad, relatively uniform and suited to a single management.

(5) At every level in the stream hierarchy geological inequalities may occur within the basin perimeter. Such lithological differences may be of central importance to the definition of land units. Furthermore, pattern units such as land systems are generally based upon broadly morphostructural units having no specified relationship with the drainage network.

(6) In mountainous areas, the intensity of dissection can create severe scale problems, and the basin does not afford a means by which altitudinal variations can be incorporated into the mapping.

(7) At higher levels in the stream hierarchy the basin areas encompass many environmental contrasts resulting from differences in regional climate, altitude, structure and lithology and relief. It is therefore evident that the application of basin hierarchies to land mapping involves fundamental problems at both ends of the scale continuum.

These questions are partially resolved if two separate but interacting hierarchies are recognised, one morphostructural and morphological; the other morphodynamic. But the combination of these into a single, rigid classification may be misleading. One factor that may influence the outcome of these interactions is the stability of the landscape. Concepts of equilibrium and stability are clearly relevant both to the understanding of soils and plant communities, as well as to the conservation of land resources. The concepts of "biostasy" and "rhexistasy" (Erhardt 1955) make clear the distinction between morphogenic and pedogenic processes. Similarly the concept of the "K-cycle" developed by Butler (1959, 1967) in Australia, expresses the alternation of soil profile development under stable conditions and truncation or burial during periods of slope instability, involving an acceleration of erosion and deposition. These ideas have recently been employed by Tricart (1973) in a restatement of the argument for a dynamic approach to land resource appraisal, and they are well illustrated by examples of extreme environments from the humid tropics of West Africa and from the South Island of New Zealand.

PEDOGENESIS AND MORPHOGENESIS IN CONTRASTING ENVIRONMENTS

THE HUMID TROPICS OF WEST AFRICA

In extreme environments either pedogenesis or morphogenesis may dominate the "geosystem" and these contrasts clarify some of the issues arising from the previous discussion. In humid temperate latitudes such distinctions are often concealed by the fine balance between these groups of processes, but over the old Basement Complex landscapes of West Africa stable landsurfaces exhibiting deep weathering penetration and advanced pedogenesis are common (Thomas 1969). Across these landsurfaces well developed toposequences of soils have long been considered important to soil mapping programmes (Milne 1935), and the LRD is now using toposequences as mapping units at the scale of 1 : 50,000 (Murdoch and Moormann 1974). The landform characteristics in these areas may be termed "permissive", and groundwater movement is more important than surface flow. The areas concerned generally receive less than 1,500 mm of rainfall and so occur towards the drier margins of the humid tropics.

In Sierra Leone, where precipitation rises to more than 2,500 mm over much of the country, chemical denudation reaches high levels and the leaching of soils is extreme. On the granitic planation surfaces (etchplains), where stream gradients are low, most first and second order valleys are swampy and have only indistinct stream channels. Beneath the swamps are accumulations of fine, slope wash material underlain by residual quartz gravel. According to Hall (1974) a typical profile in the diamond field area is:

0–0.6 m black mud with high organic matter content
0.6–1.6 m grey clay, silt or sand
1.6–2.0 m bleached, angular quartz gravel, sometimes in a clay matrix
below 2 m stiff, white kaolinitic clay (decomposed bedrock)

The streams do not transport the gravel or erode the bedrock, and decomposition may go to depths of 15 m in schists or fractured granites. These "inland swamps" are of major importance to agriculture and mining. The quartz gravels appear to represent residual accumulations following intense weathering and the gradual lowering of the landsurface principally by solution. These areas are under consideration for swamp rice cultivation and have been the subject of recent soil investigations (Van Vuure and Miedema 1973).

Hall (1974) found that a classification of stream basins using standard stream ordering techniques permitted prediction of the nature and extent of diamondiferous gravels. On the other hand Van Vuure and Miedema (1973) distinguished the swampy valley floors as one of three "landscape units" in the Makeni area:

(1) undulating, usually gravelly uplands (67% of area)
(2) valley bottoms containing streams and swamps (19% of area)
(3) recent and sub-recent terraces along valleys (9% of area)

These three morphological units (equivalent to land facets) were mapped independently of stream order and make up 95% of an area which might be termed a land system. Isolated inselbergs were recognised as an additional unit.

Although the two areas in Sierra Leone are not identical, their similarities are such as to demonstrate the relevance of alternative ranking techniques in one range of landscapes. Thus where broad interfluves dominate the terrain and have common characteristics across many drainage divides, their unity may be more important than their membership of particular drainage basins. On the other hand the swampy, valley floors tend to be restricted to 1st, 2nd and sometimes 3rd order stream valleys. It can perhaps be seen from this example that the landscape units or land facets, and the basins of different orders represent alternative units for land mapping, but while stream order may affect the extent of the valley bottom swamps, the basin divides are of little immediate relevance to land use. This reflects the dominance of pedogenesis over morphogenesis.

THE MOUNTAINOUS AREAS OF NEW ZEALAND

Similar principles may be adduced from a study of the tectonically active mountain belts of New Zealand. Along the east coast of the South Island, the seaward Kaikoura Mountains rise to over 1,600 m and are separated from the coast by a narrow piedmont plain, comprised of fan gravels of Pleistocene and Recent ages. Morphologically, the plains are sharply divided from the mountain front which separates the two land systems, one erosional; the other depositional (Figures 2 & 3). The piedmont gravels make up 65% of the contributing mountain catchments which indicates the intensity of erosion in an area subject to repeated seismic shocks and heavy, prolonged rainfalls. The fans are being actively modelled by existing streams and have gradients as high as 50 m.km. In the mountain catchments 38% of the slopes exceed 35°. This naturally unstable environment has been irretrievably damaged by deforestation and overgrazing, as well as by the degradations of rabbits and red deer. Rates of erosion are thought to exceed 2000 mm/1000 years (Thomson and MacArthur 1969) in the upland catchments, and virtually the entire piedmont zone is subject to periodic flooding, and over half to gravel deposition. This is therefore a clear example of an unstable landscape in which surface water and sediment movement dominate the morphodynamic processes and inhibit pedogenesis.

Morphological land units can be recognised at different scale levels, and in this sharply differentiated landscape few are ambiguous. In the piedmont zone the fan segments and inter-fan depressions show up clearly, while in the mountains razor-edged interfluves separate individual stream basins. However, while the dynamic aspects of water flow in the mountain zone are contained within stream catchments, over the piedmont flooding may engulf almost the entire area. Floods from different mountain catchments may occur separately or more commonly interact to produce fluctuating boundaries between the hydrodynamic systems.

The level of complexity associated with the deposition of the fan gravels during successive floods, together with the cumulative effects of erosional events in the mountain valleys, render the mapping of highly uniform land facets impracticable at available scales. In these cases it is possible to identify the "landform complex" (Thomas 1969) as a unit above the facet which represents the level of operation of the "genetic bonds" in the landscape. The significance of this observation will be discussed further.

Ordering of the land mapping units into larger systems of forms may be achieved following either morphologic or dynamic principles, but separate hierarchies and markedly different maps will result (Figures 1 and 2). The inadequacy of the purely morphological "land system" conceived as a land pattern is clearly demonstrated here by the interdependence of the erosional/depositional systems operating across the main morphological boundary. Land planning and management would hardly be conceived by reference only to such boundaries. Equally the simple ordering of catchments would be inadequate, because the dynamic units of importance involve the grouping of mountain catchments contributing the floods and the overlapping of the depositional systems in the piedmont. It is also interesting to note that altitudinal zonation within the mountains, although important, is less significant than the interactions between the individual zones.

DISCUSSION

Some theoretical and practical problems of land classification are demonstrated by these examples. These focus upon the problems of defining and mapping geographic or taxonomic "individuals" and on the difficulties of constructing scale related hierarchies of mapping and planning units which remain valid for different environments.

Strict uniformity in morphology or in the biogeocoenoses cannot be maintained, and at most levels of mapping the basic unit is likely to remain the operationally defined land facet (Beckett and Webster 1965). But, even where descriptive detail is intended to replace the genetic description of land facets, most do in fact reflect the operation of a genetic bond, and where the formative processes have created intricate patterns of erosional or depositional landforms the "landform complex" (Thomas 1969) may become the basic mapping unit. This may be recognised as a pragmatic decision imposed by the size of the terrain and the scale of the mapping, but it will often, if not always, have a genetic basis.

Most maps of land either represent all the basic mapping units equally, or, more commonly, they only indicate combinations of such units within recurrent landscape patterns (Beckett and Webster 1965) or land systems (Christian 1957). In fact, there are alternative choices, and as has been shown above, once the basic land units are recognised they may be combined in various ways to produce different "interpretive" maps.

The importance of the land facet is indicated by several considerations. In the first place, the definition of pattern will lack comparability unless it is based upon a consistent combination of basic units. Secondly, any particular facet may occur in more than one land system, and may have special properties important to the planning of land use (Haantjens 1968). The valley floor swamps in the example from Sierra Leone are a case in point. Thirdly, the unit of land management may range in different circumstances from a subdivision of the land facet to a combination of two or more land systems. In multi-purpose surveys it may be essential to provide information across the entire range of land use scales, from regional planning to the location of housing areas or highways routes.

For planning purposes, it is also clearly necessary to provide interpretive combinations of the basic mapping units. Brinkman and Smyth (1973) indicate the importance of land *pattern* which may provide complementary environments for stock and wildlife in one case, but may render uniform management of large areas sub-optimal in another. Pattern may also be important to highway engineers and in establishing the recreational potential of an area.

Equally, however, an understanding of the dynamics of an area may be important to its proper management, and this becomes strikingly evident in unstable landscapes of mountain areas such as New Zealand. In such cases it is possible to show morphodynamic units which may not coincide with the morphological patterns or land systems (Figure 3).

It is doubtful therefore whether a single hierarchy can satisfy all these requirements or remain valid for all landscapes. Herz (1973) states that each level in any hierarchy should be a unity expressing some dominant or definitive property, and also at the same time be a complex of lower units, defined individually according to a different criterion. He suggests further that microdynamic (soil) processes should unite the lowest units, while morphodynamic (stream) systems define the next higher units and, morphostructural (endogenic) factors the next level. Yet Mabbutt (1968) maintains that the genetic bonds may enter into the land complex at different levels according to circumstances, and the examples given here appear to support this view. In the stable landscapes of the West African shield, small land facets are linked within toposequences by pedogenic processes, while similar basic units in the mountainous areas of

New Zealand are linked by the dynamics of stream activity, so that morphogenesis suppresses pedogenesis. At higher scale levels the contrast is sustained, for in stable landscapes which have developed over long periods of geological time, morphostructural units commonly define land systems of distinctive pattern. On the other hand, interacting basin systems may override the morphostructural or morpholithological patterns in mountain areas to create morphodynamic "geosystems".

It seems likely, however, that biocoenological units must generally enter at the lowest level, both on grounds of scale and stability. Morphological units may of course be of any size and will commonly be related to morphogenetic criteria as in land systems. On the other hand, morphology is specifically expressed at the level of the land facet. Contemporary, hydrodynamic units possess their own scale hierarchy, and may enter into land mapping at levels appropriate to the environment or purpose of survey as suggested in the examples. Problems will arise if boundaries of biogeocoenoses, morphological units and morphodynamic areas do not coincide, or are not related in a consistent and predictable manner.

Hitherto the level at which boundaries have been drawn has varied with different surveys, and this causes confusions in terminology, as well as interpretive difficulties in the maps. If the base unit for land resource mapping is regarded as the morphologically determined land facet, then these can be combined into different higher units according to purpose. In intricate terrain the land facet may have to be replaced by the landform complex as the basic mapping unit (Thomas 1969), but this can be explicitly recognised and related to the nature of the genetic bonds in the landscape.

Two further conclusions are drawn from this discussion. First, while it is agreed with Mabbutt (1968) that genetic criteria in land classification pose special problems, this need not invalidate the use of such criteria in land mapping. In many cases the principal problem is to distinguish the results of inheritance from the functional units of contemporary systems.

SUMMARY AND CONCLUSIONS

(1) Multi-purpose land resource surveys aim to produce maps suitable for planning and development. To be of maximum value and flexibility such maps should be capable of presentation at various scales (over a range from perhaps 1 : 25,000 to 1 : 250,000). To fulfil these requirements land mapping units should be established which possess sufficient uniformity to permit a single use or management. Different combinations of these basic units should be envisaged in order to take account of functional unity in the landscape; either in relation to the operation of natural systems or in terms of land management. Such maps are interpretive and existing Land Capability maps are one example.

(2) Theoretical landscape research (Isachenko 1965) while it is essential to our understanding of natural landscapes, may be too inflexible for *direct* application to land resource mapping.

(3) Although theoretical arguments have been advanced for the recognition of the "ecosystem" as a natural individual for landscape study (Prokayev 1962; Ruxton 1968) it involves both conceptual and practical difficulties and is probably not suitable for land mapping at medium scales or where permanence of survey information is important.

(4) The recognition and mapping of land units has generally rested upon geologic and geomorphic criteria, but a purely morphological approach to the

definition of land units neglects the morphodynamic aspects of "geosystems" (Tricart 1973).

(5) Detailed geomorphological maps do not fulfil all these requirements, although they may often be regearded as base maps from which the necessary interpretations may be made. The distinction between the representation of geomorphic features, and the mapping of land units should be clearly recognised in order to avoid inclusion of unnecessary detail.

(6) It must also be axiomatic that the use of geomorphological units for land mapping has to be justified, principally by their predictive value for soil and foundation studies. Multi-purpose surveys are not solely concerned with agriculture however (Kondracki and Richling 1974), and it can be maintained that agronomic soil studies should form only one component of such surveys.

(7) Beckett (1968) has suggested that the cost effectiveness of what he terms "physiographic" methods of soil survey is reduced at larger scales, and that grid surveys allied to data banks may be more informative. But it is concluded here that the requirements of land resource surveys, particularly in remote or little known areas, are best served by a single methodology capable of being implemented over a wide range of scales. Surveys based on hydrologic and geomorphic interpretations of landscape, appear, for logical as well as practical reasons, to be the most appropriate for this task, although it is recognised that the use of *geochemical* criteria in land mapping may add a further dimension to our understanding of the dynamics of natural landscapes.

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GEOMORPHOLOGICAL INPUTS INTO THE PLANNING PROCESS: CASE STUDIES IN SCOTLAND

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Local authority planning in Britain has been primarily concerned with the control of development and the designation of areas for a specific land use, but recent Town and Country Planning legislation has added a "forward planning" dimension to the process. This new legislation, embodied in the Town and Country Planning Acts, 1968 and 1971 (applicable to England and Wales) and the Town and Country Planning (Scotland) Acts 1969 and 1972, demands that local planning authorities should produce more sophisticated types of Development Plans. The *structure plan* is the fundamental type and should incorporate broad principles for the future planning of the area based on a survey of the district "to examine matters which may be expected to affect the development of that district or the planning of its development..." (Town and Country Planning (Scotland) Act 1969 section 1). At the same time, following the initiative of geomorphologists in other parts of Europe, British geomorphologists are becoming increasingly concerned about the supply of information into the planning process, especially on the nature of the physical environment and the processes in operation; and making assessments of the relationship between these natural processes and the potential of the land for different uses.

Geomorphological input has largely been connected with specific types of existing or proposed developments, rather than evaluating the more general utility of geomorphological inputs into the planning process at local and regional scales. With the impending reorganisation of local government in Scotland and the increasing concentration on strategic planning, together with the growing range of developments largely concentrated outside the industrial areas and in conflict with existing uses of land, it is appropriate to assess the types of input which geomorphologists can make using established techniques. This paper, therefore, discusses the way in which selected geomorphological techniques — geomorphological survey and mapping, landform, classification, geomorphological hazard and geomorphological impact assessments and slope category analysis — could be applied to planning at the District and Regional levels in Scotland.

GEOMORPHOLOGICAL TECHNIQUES

Geomorphological input into the planning proces in other countries has largely been part of an overall assessment of the character of the physical environment and its potential for different types of land use (Mabbutt and Stewart 1963), or has comprised a small component in an assessment of the physical capability of land for certain uses, especially agriculture (Bibby and Mackney 1969; Canada Land Inventory...). It is apparent from work of long standing in Eastern Europe (Problems of geomorphological...) and France (Tricart *et al.* 1971) that numerous standard geomorphological techniques can be used in their own right in the inventory and evaluation of the physical environment for planning purposes. The techniques discussed in this paper are those thought to be immediately applicable to the planning process in Scotland as developed in pursuance of recent legislation on planning methods and organisation.

DETAILED GEOMORPHOLOGICAL SURVEY AND MAPPING

In continental Europe geomorphological mapping has been developed at national, regional and local levels (Problems of geomorphological...), but this technique has only been used to a limited extent in Britain. Apart from the compilation of a national geomorphological map (Brown and Crofts 1973) initiated by Linton (1967), work has for the most part been concentrated on geomorphological mapping at scales less than 1 : 10,000 (Crofts 1974). This technique of detailed geomorphological mapping derives from the work of the IGU Sub Commission on Geomorphological Mapping, and in particular the work of Klimaszewski (1968) and Tricart (1971). It is based on field survey: the mapping of individual landforms in terms of their genesis, and to a lesser extent their age, morphometry and chronology, and the assessment of the dynamics of the individual forms or aggregations of forms in terms of the presence or absence of indicators of change. This technique has been applied to a large area of Aberdeenshire at 1 : 10,560 scale by Crofts (1969) and to sandy beach systems in the Highlands and Islands of Scotland at scales of 1 : 3,520, 1 : 7,040 and 1 : 10,560 by Crofts, Mather and Ritchie (Crofts and Mather 1972; Crofts and Ritchie 1973; Mather and Crofts 1972; Ritchie and Crofts 1974). The complexity of the geomorphological maps *per se*, particularly at the detailed scale, necessitates their simplification prior to presentation to non-specialists. For example, the mapping of the sandy beaches has been simplified by the amalgamation of the individual forms into land units and groups of units or associations.

LANDFORM CLASSIFICATION

Many landform classification schemes have been devised for use in other countries. The *land systems* schemes used by, for example, CSIRO in Australia and DOS in Africa are too generalised for use in Scotland (Crofts 1974). Even the MEXE scheme of terrain analysis (Beckett and Webster 1965) developed for use at large scales and tested in England has proved extremely difficult to apply in Scotland, due to the scale and complexity of geomorphological evolution and the intricacy of the terrain. Crofts (1974) has argued, therefore, that detailed geomorphological maps can form a basis for landform classification in Scotland as a preliminary to the physical evaluation of land potential. The basic taxonomic unit adopted is the *facet* which is defined as "a unit of land surface having homogeneity of origin and overall similarity of surface form, common materials and age" (Crofts 1974, p. 243). Although the definition resembles that given by other workers, for instance the *facet* of Thomas (1969) and the *uroczysko* of Kondracki and Richling (1972), the facet is identified at much larger scales in Scotland due to the intricacy of geomorphological form. These fundamental landform units can be grouped into unique combinations to form *recurrent landform patterns* which are identifiable at scales between 1 : 50,000 and 1 : 250,000 in Scotland. In both cases the taxonomic units have been applied at smaller scales elsewhere and have greater areal extents. No meaningful taxonomic unit at a smaller scale than the recurrent landform pattern could be used in Scotland as it would merely describe basic topographic elements such as mountain massifs, plains, hill country and lowlands.

SLOPE CATEGORY ANALYSIS

The preceding techniques are concerned with an overall geomorphological survey of an area. In contrast, slope category analysis is concerned only with the appraisal of ground surface slope, each particular angle of slope being assigned to a category of slope gradient. The underlying assumption is that slope gradient acts as an economic constraint on human activity, even though the application of modern technology and finance may enable such constraints to be overcome. Soil surveyors, agriculturalists, planners and engineers have recognised that many activities are restricted to slopes of a certain gradient. A review of the published literature and the unpublished opinions of specialists from the above disciplines suggest that certain slope gradients act as a constraint for a number of human activities and can be applied as ruling gradients in land-use planning and land planning in general (Brown and Crofts 1973; Brown and Crofts, paper in prep.) The following ruling gradients have been identified — 2, 5, 10, 15, 20, and 30% and are used as the boundaries of the slope categories. Data on slope gradients can be ascertained from field survey (Mackney and Burnham 1966) but two quicker methods exist. Both involve the use of topographic maps at scales larger than 1 : 100,000 as the data source and rest on the assumption that the contour spacing is a direct reflection of slope gradient. A manual method using a template based on the contour spacing scales of Thrower and Cooke (1968) allows a slope category map to be produced rapidly (Brown and Crofts 1973) but there is considerable operator variation and as a result a photo-mechanical technique (Gardiner and Rhind 1974) is preferred.

GEOMORPHOLOGICAL HAZARD ASSESSMENT

This technique seeks to identify episodic events which are likely to affect projected and existing land uses in a detrimental manner. The technique forms part of a broader method of environmental hazard analysis assessing natural and man-induced environmental hazards and man's response to them. Landform units indicative of rapid physical change are identified in the field and from aerial photographs, and at the same time historical records are checked to aid in the identification of the type of hazard and its frequency of occurrence. The aim of geomorphological assessment using these two simple data sources is to predict the types of hazards and their frequency of occurrence, and to identify the areas most likely to be affected.

GEOMORPHOLOGICAL IMPACT ANALYSIS

This technique is part of a broader method for evaluating the impact of human activities, actual and proposed, on the character of the physical environment. The technique is largely used predictively to analyse the likely consequences of the proposed development or range of developments at a particular site and to identify the intensities of land use permissible before detrimental impact occurs. It can also be used to assess the change in impact of developments through time. The reliability of the prediction depends on the number and extent of known assessments of a similar type and in a comparable physical situation. The assessment of impact at a site or in an area is carried out in stages. Firstly, the effects of natural processes operating on individual geomorphological units are assessed as a controlled situation. Secondly, the type or types of development proposed are identified and their direct effect on geomorphological processes, and hence their indirect effect on the geomorphological units, is measured. The results are commonly presented in the form of a matrix (Fischer and Davies 1973; Leopold *et al.* 1971) where the existing geomorphological characteristics are set against the proposed action or actions which may cause geomorphological impacts of differing magnitudes.

THE PLANNING PROCESS

Planning, as carried out by central and local government in Britain, comprises two basic elements — strategic planning and development control (Fig. 1). Strategic planning, as laid down in the recent Town and Country Planning

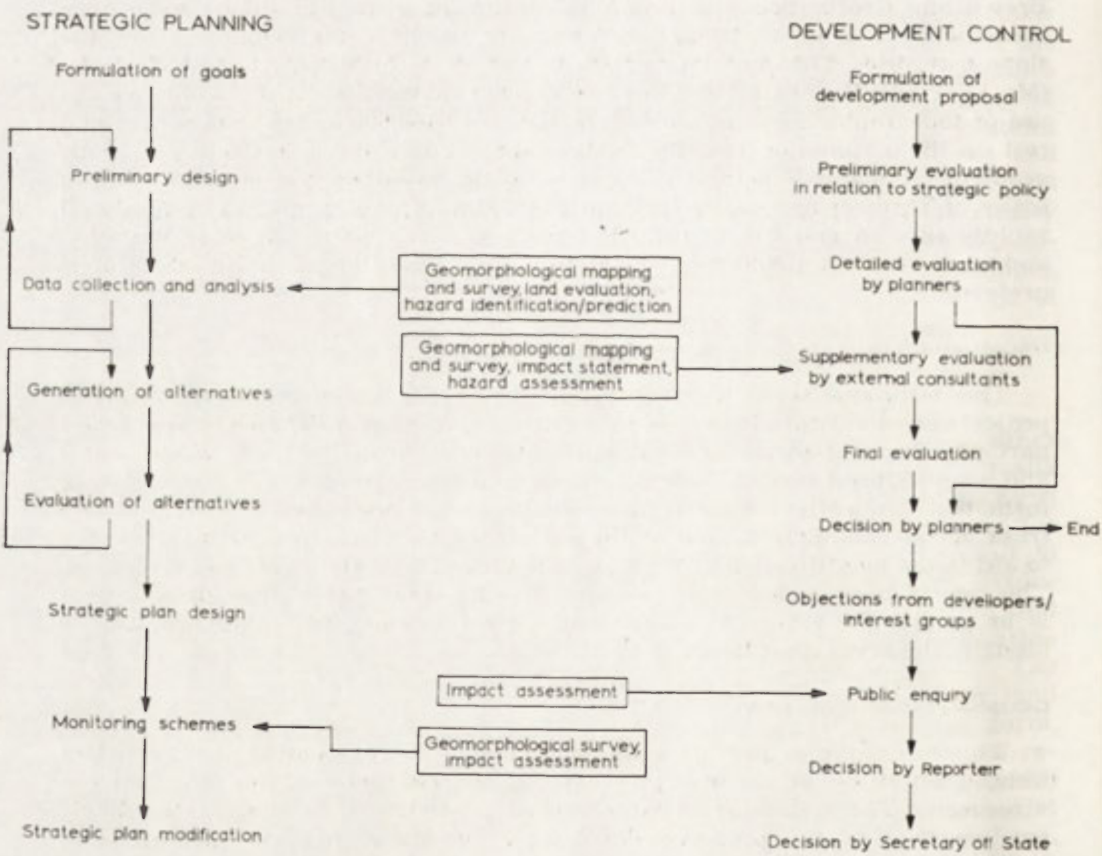

Fig. 1. The two basic components of the planning process and their stages of operation in relation to inputs from different geomorphological techniques

Acts, demands that local authorities create a broad-scale planning strategy for the areas under their jurisdiction in the form of a Development Plan. "The purpose of the Development Plan is to present the local authority's policies and proposals to achieve stated planning aims for the area. The aims of the plan should be designed to satisfy social and economic aspirations as far as possible, through the creation of an efficient physical structure and a good environment" (Scottish Development ... 1971, p. 5). The Development Plan consists of two components: the broad strategic or *structure plan* and its amplification and application to particular areas and cases in the form of *local plans*. The latter consist of different types of plans: detailed plans of relatively extensive areas — *district plans*, comprehensive plans for intensive changes over a short timescale in selected areas — *action area plans*, and detailed thematic plans covering part or all of the area — *subject plans*. It is recommended that the structure plans should be based on detailed surveys which include an "appraisal of the physical structure of the area" (Scottish Development ... 1971, p. 14) as "the use of land should be an important theme in the Development Plan, and this will usually involve an inventory of land resources in each planning authority area, together with an assessment of the qualities and potential of the individual districts" (Scottish Development ... 1971, p. 16).

Geomorphological input can occur at two levels in the strategic planning process (Fig. 1). In the construction of the Development Plan it is necessary to identify the physical environmental constraints influencing both general and specific development and to carry out an inventory of physical environmental resources and an assessment of the potential capability of the land. Development Plans should be continually revised and updated and, therefore, interim and long-term monitoring of the effects of structure-plan policies on the social, economic and physical character of the area should be carried out.

The development control process (Fig. 1) is the direct response of the planning system to development proposals by local government and private individuals. It consists of the appraisal of development proposals in relation to the strategic plan at the local scale or to the general policies of central government at the national and regional scales. In some cases the planner may be able to make his own assessment, but in others it is necessary to seek the help of the specialist as an input into the overall evaluation by the planner. At a later date, if the development application is referred to the Secretary of State and a Public Local Inquiry is instigated, specialist evaluations and assessments may be presented to the Inquiry.

These two basic planning processes were carried out by local planning authorities — Counties and Large and Small Burghs — and from May 1975 are the responsibility of Regional and District Authorities as designated in the Local Government (Scotland) Act 1973. This new arrangement results in three levels of planning activity — central government, regional and district authorities (Fig. 2), except in the islands of Orkney, Shetland and the Western Isels where the functions of the regional and district authorities are combined. The major geomorphological input at the two lowest scales is allied to the construction of Development Plans. Two statutory agencies, the Countryside Commission for Scotland and the Highlands and Islands Development Board, operating at the national and regional levels respectively, have an indirect responsibility for giving informal advice to local planning authorities and for sponsoring research to aid this advice.

Geomorphological inputs appear to be feasible in both strategic and development control planning in the three tiers of the government planning machine, and in the work of the agencies. The work described in the remainder of this

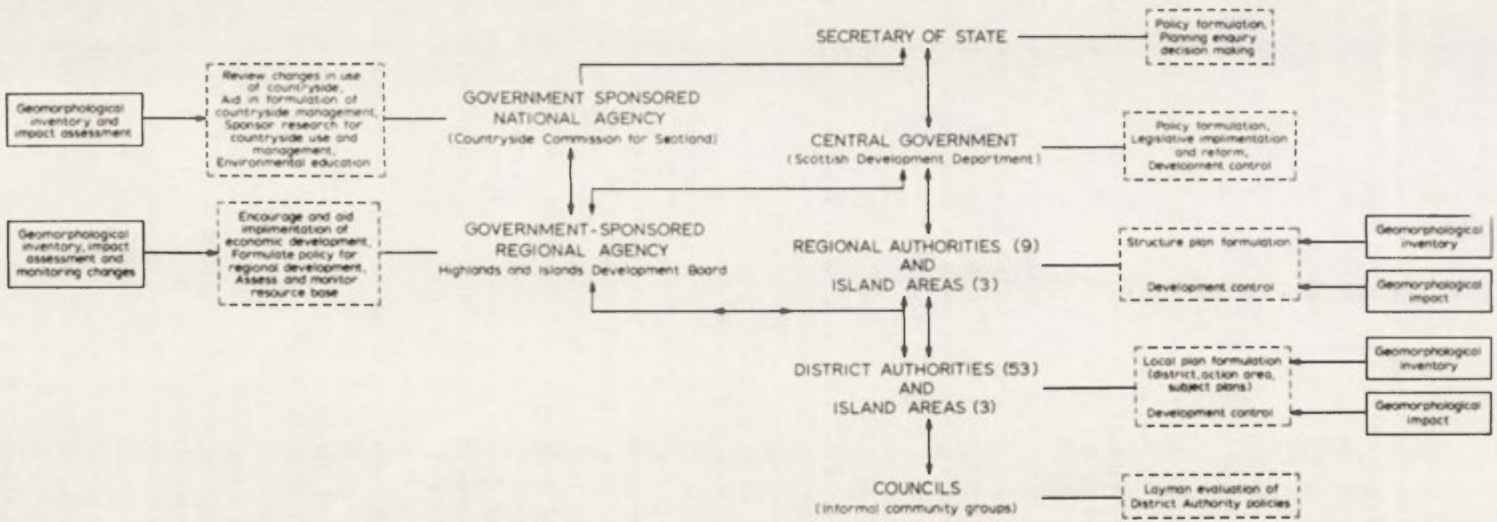

Fig. 2. The organisation of planning and the role of statutory agencies in Scotland, and levels for input of geomorphological data

paper will refer to inputs at the local and regional levels for strategic and development control planning, concentrating on those techniques which have been applied in Scotland or which are thought to be applicable to the restyled planning process.

GEOMORPHOLOGICAL TECHNIQUES AND PLANNING

STRATEGIC PLANNING

Geomorphological information can be input into the strategic planning process at two stages — characterization and the subsequent evaluation of the potential of the physical environment, and the monitoring of physical environmental changes resulting from the land use planning policies adopted by the local authority.

(1) Structure and District Plans

In preparing a Development Plan — Structure Plan or District Plan — Regional and District planning authorities are advised by central government to carry out a survey of their territory and to include a characterisation and assessment of its physical components.

It is suggested that such a survey should focus on two major aspects, both of which influence the land use potential of the terrain. Firstly, landforms should be identified and classified. In most schemes for classifying landform types, genesis is the primary criterion with morphology/morphometry, chronology and lihtology as secondary criteria. There are two commonly used classificatory schemes — geomorphological mapping and terrain analysis. Although the two schemes have been developed independently, it has been demonstrated (Crofts 1974) that landform classification and the evaluation of physical land potential can be derived from the geomorphological mapping of an area. Inevitably there are basic problems in the use of either scheme, in particular the interpretation of landform genesis which is subject to considerable operator variation, but cross-checks between different surveyors can reduce such variations to an acceptable level. Secondly, the dynamic aspects of landform development should be considered to identify the stage of geomorphological development of each landform or landform association, to assess the rate of physical change especially in the superficial layers and to predict the current and future degree and rate of change by applying simple time series analysis.

In order to characterise the geomorphological nature of the land a five stage operation is required. First, geomorphological survey and mapping is carried out in order to identify landform types and their dynamic properties. Second, physical environmental constraints to human activity are identified and assessed. Third, the geomorphological map is simplified and landforms are classified into land units. Fourth, and probably most important from the viewpoint of physical planning, the assessment of the physical potential of each land unit for different types of land use in order to produce a map of geomorphological potential classified on the basis of optimum land use. Finally, the development of an overall evaluation of land potential for a range of possible major land uses (forestry, agriculture, pasture, recreation, residential, industrial, commercial, transport) by combining the geomorphological evaluation maps with maps evaluating other facets of the physical environment of a primarily biological nature (eg. habitat classification and indices of species uniqueness or rarity) and evaluations of economic, social and political factors together with a consideration of existing land use. This last stage is not further discussed in the paper.

The above scheme has been applied to an area of approximately 700 sq km in the Upper Dee Valley of Aberdeenshire in Scotland (Crofts 1969, 1974((Figs. 3 & 4). The scale at which the characterisation and assessment are carried out depends on the area of territory to be covered, the complexity of the terrain, and the subsequent use of the evaluation. At the regional level only a generalised survey is required and hence survey scales within the range 1 : 50,000

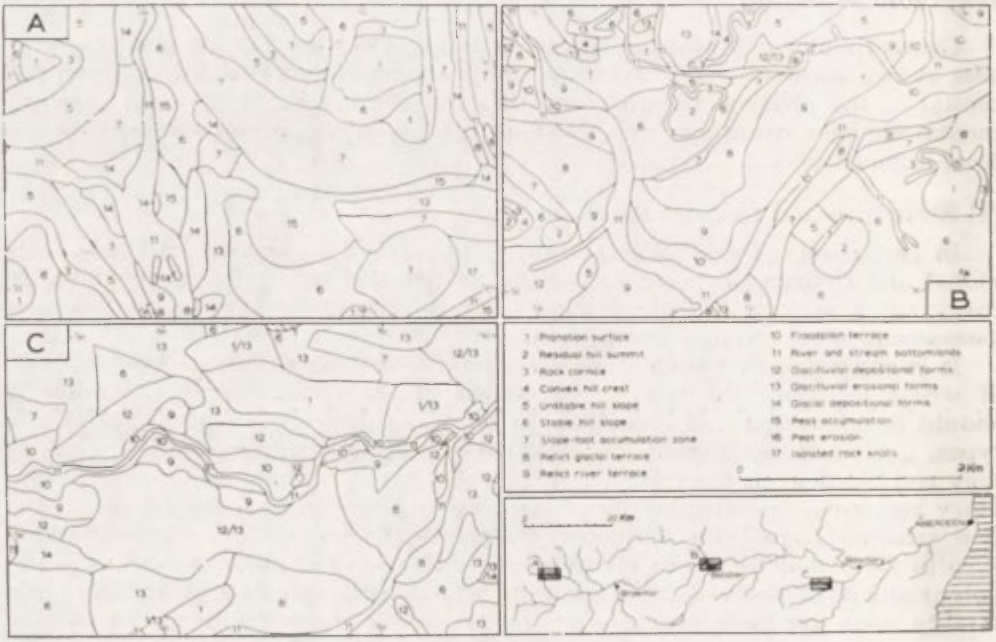

Fig. 3. Facet maps compiled at 1 : 10,560 scale from selected areas of the Dee basin, Aberdeenshire

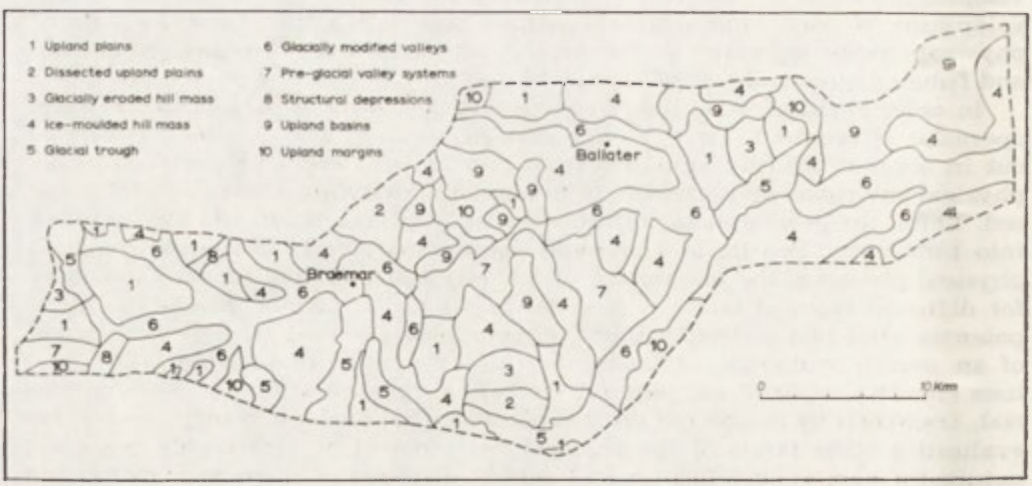

Fig. 4. *Recurrent Landform Patterns* consisting of unique combinations cf ffacets, identified at 1:63,360 scale in the Upper Dee basin, Aberdeenshire

to 1 : 250,000 are most appropriate. In Districts and Islands Areas 1 : 50,000, er possibly 1 : 25,000, is regarded as the most suitable scale. Mapping in the upper Dee Valley was at 1 : 10,560 but this was found to be too detailed for general characterisation and primarily to be of use for preliminary investigation of individual sites. The Dee Valley survey involved, in the first instance, geomorphological mapping and identification of areas and types of rapid physical change which resulted largely from the incoherence and instability of glacial and periglacial superficial slope deposits on glacially over-steepened valley sides in areas of high intensity rainfall.

The mapping process will aid in the identification of many potential physical constraints and hazards, but further analysis is required to ascertain specific processes occurring episodically which may not be readily identifiable in the landscape. Even if the consequences of such activities can be identified, some attempt should be made to assess their frequency and magnitude. Many hazards occur infrequently and are, therefore, commonly ignored but countless examples can be cited to show the pitfalls of such ignorance. For example, the upper Dee Valley, Aberdeenshire is subject to flash flooding and slope activity resulting from episodic and intensive rainfall over the adjacent Cairngorm Massif (Crofts 1969). Records show that intensive rainstorms occurred on 17 September 1768 (Sinclair 1795), 30 August 1799 (Sinclair 1845), 3–4 August 1829 (Lauder 1830), 10 August 1901 (McConnachie 1902), and 13 August 1956 (Baird and Lewis 1957). In each case debris flows and shallow slides occurred, frequently blocking the narrow valleys. The river bottomlands were also inundated to considerable depths, causing extensive damage to the most productive agriculture and pasture areas of the region. The occurrence of such hazards with a frequency between events often greater than one generation necessitates careful land use planning, especially the control of land use in valley bottoms and along the lower sectors of valley side slopes, specifically to control the extent of the improved agricultural land and the development of built structures.

In many areas in both uplands and lowlands, slope gradient also acts as a significant constraint on land use. Planners have recognised the utility of slope category analysis in the determination of the likely physical constraints imposed on development by slope (Scottish Development ... 1973) and in the identification of sites for specific types of development where gradient is recognised to be a primary constraint.

(2) Action Area Plans

There are numerous areas in Scotland undergoing rapid changes in land use as a result of a re-orientation of local economies. Those of direct relevance to this paper are where traditional agriculture and pasture uses are being changed to industrial, and to a lesser extent commercial, uses. In the past the planning process has been forced to regard changes in the intended use of the land as amendments to existing Development Plans drawn up under the framework of the 1949 Planning Acts. However, proposals for industrial development are now more frequent, demand rapid response from the planning machine, are of greater complexity than hitherto, frequently concern industrial types unique to Scotland, and demand a location in predominantly non-urban and non-industrial areas, sometimes where no Development Plan has been prepared. In this situation geomorphological input takes the form of isolating the best sites for particular types of development bearing in mind physical constraints such as gradient, geotechnical characteristics and geomorphological hazards.

Initially the site requirements of the likely range of industrial/commercial and any other developments must be ascertained. Thereafter, the assessment of physically suited sites is underway. In every case, although a site may be highly or relatively suited to a particular development, other factors such as nature conservation, cultural characteristics, economic and political manifestations, must be taken into account.

Field appraisal can in the first instance take the form of morphological assessment of sites — gradient and its areal extent. Here slope category analysis is a simple and rapidly applied tool. Many of the large industrial complexes demand land with a low or negligible gradient particularly in coastal areas where extensive areas of flat land are adjacent to deep water. Such sites have been used for raw material processing industries, for example, the aluminium smelter at Invergordon, Cromarty Firth, and latterly have been in demand as sites for the construction of oil production platforms (Scottish Development ... 1973a) the landing, storage and in some cases treatment of oil and gas, piped ashore from the adjacent North Sea fields (Scottish Development ... 1974a) and as sites for the coating of pipes for offshore pipeline construction. The application of the simple technique of slope category analysis at the national level would have obviated many of the multivarious planning applications which local authorities have had to assess and at the same time the physically suitable areas could have been rapidly identified. For example a map of the land which is essentially flat, gradient less than 2.5%, with a minimum area of approximately 1 kilometre squared was compiled for the coastal areas of Scotland in about 1 working day by 1 operator. The map can be used as a working document for the evaluation of other physical environmental factors which influence the suitability of individual sites and locations. For example, certain areas can be excluded from consideration as their scientific and ecological value is overriding, the re-siting of the proposed terminal for the gas pipeline from the Frigg field, in the Buchan area of Aberdeenshire is an example (Bourne *et al.* 1973). Others contain or are adjacent to physical obstacles such as sand dunes where the removal or control is too costly, as shown by the withdrawal of the Chicago Bridge Co. from using the Dunnet Bay dunes, Caithness as an oil production platform fabrication yard. Extension of the technique to offshore areas adjacent to flat land would aid in the assessment of their potential for developments requiring local access by large vessels. The coastal area between Peterhead and Fraserburgh, Aberdeenshire contains a large amount of land with gradients less than 2.5% adjacent to moderately deep water (Fig. 5). The juxtaposition of these two physical characteristics and the close proximity of the area to a number of proven commercial oil and gas fields has resulted in a large number of developments being located there and others proposed. In each case where extensive sites are required for oil-related industries and power generation, land with a gradient less than 5% has been selected. Other factors such as the geotechnical properties of the substrate are taken into account.

(3) Special Plans

The District Authority will have to make assessments of the land used or potentially useable for particular purposes within its territory. An example of such activity is countryside management for recreation and conservation. In those district authorities with large coastal areas this zone is often the focus of daytime and seasonal recreational activity, but inevitably the special type and intensity of use is frequently detrimental to the physical character of the area and ultimately detrimental to recreational uses. The physically most fragile coastal areas are sandy beach complexes. However, they are usually of infrequent occurrence (eg. only 3% of the coast between Ullapool and Fort William)

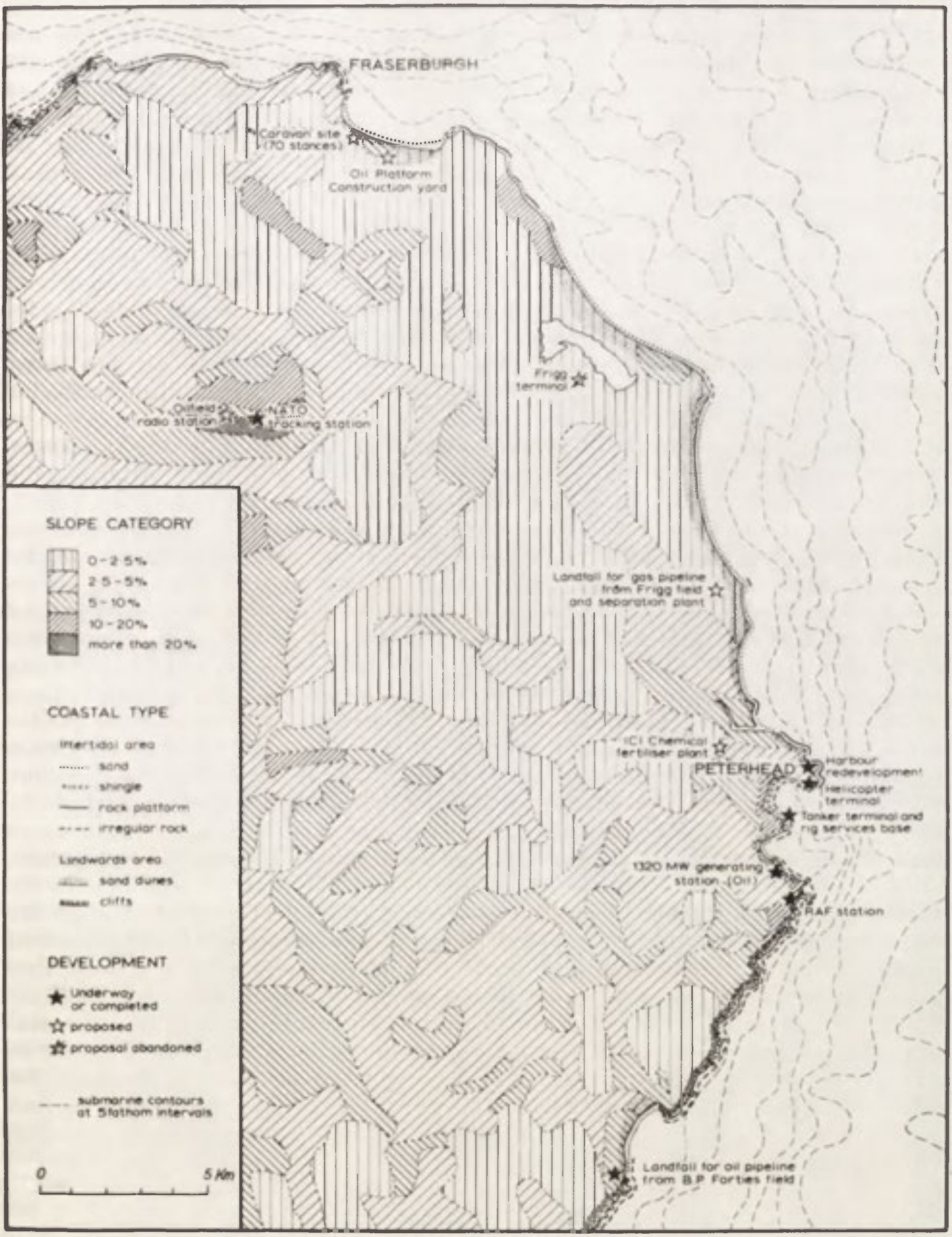

Fig. 5. Slope categories and coastal types in relation to industrial developments in the Buchan area of Aberdeenshire

and often difficult to gain access, hence those accessible sandy beaches are subject to a high intensity of recreational pressure. A long-term project to assess the physical characteristics of sandy beaches and to evaluate present and recommend future uses has been carried out in the Highlands and Islands of

Scotland. Thirteen reports have been published covering all of the sandy coasts (see for example, Crofts and Mather 1972; Crofts and Ritchie 1973; Mather and Crofts 1972; Ritchie and Crofts 1974). In these situations, detailed geomorphological mapping using a modification of the standard conventions (Crofts and Mather 1972) has been the basic tool. The individual landforms are grouped into units of the same origin and subject to the same rates of physical change. On this basis the physical stability of the different sectors and the overall stability of the complex can be assessed subjectively on a 5-point scale — very stable, stable, moderately stable, unstable, very unstable. A more objective assessment of the overall stability can be made. Again using a 5-point scale, a half point is deducted for each of the following factors: no accretion and backshore less than 10 metres wide, undercutting of the coastal edge, widespread wind erosion of the dunes, wind erosion of the links, biotically-induced wind erosion of the links, anthropically-induced wind erosion of the links, beach rotating laterally with a skewness greater than 60%, chord/perpendicular ratio greater than 7. The field survey and stability assessment indicate the stage of development of the complex and from this it is possible to predict the future physical tendencies which the complex may experience. In some instances, the complex is likely to remain in an overall balanced state between the supply of material to and loss of material from the complex as expressed by the state of the backshore and coastal edge sectors which are crucial indicators of the overall health of the complex, whilst highly unstable dunes will often be replaced by lower more stable forms. In other instances it is predicted that complexes will continue to degenerate at approximately the current rate, with some parts becoming more stable and others which were previously stable being reactivated. After analysing the natural situation, the geomorphological effects of present and future land uses can be evaluated. In some areas the predominant use is sheep grazing of moderate intensity and recreational activity is negligible. In others, sheep grazing coupled with cattle trampling and day-time recreation occurs and considerably increases the natural instability, particularly as these activities are usually concentrated in the most naturally fragile areas near to the access points. These areas are incapable of natural recuperation. More intensive human activities, especially daytime recreation, will have in the future a physically deleterious effect on some complexes and hence they are thought to be best suited in physical terms to low or moderate intensities of grazing and low intensities of informal recreational use with a proviso that certain unstable areas should be protected from any human activities. Furthermore, recommendations of specific management measures aimed at either maintaining or seeking to establish a degree of physical stability can be made as a result of this survey. The conclusions derived can be used as the basis for guidance to local planning authorities on the future use of the complexes and enable them to carry out thematic planning, in this case recreational planning, within their territory.

DEVELOPMENT CONTROL

The major geomorphological technique for input into the development control procedure is geomorphological impact analysis. The technique has largely been developed in the USA but a major Government-sponsored study is underway in Britain to ascertain the utility of this technique and the broader technique of environmental impact analysis to evaluate the effect of large scale industrial developments, whilst a simple version of the technique has been applied in selected areas (Sphere Environmental ... 1973). The technique can be applied in strategic planning to eliminate certain types of development which are physically unsuitable and particularly in development control to assess geomorphological impacts of particular development proposals at specific times and to compare the suitability of different sites for certain developments.

The matrix method, presenting a resume of an impact assessment and devised by Leopold and others (1971), is used here. As applied to the assessment of geomorphological impacts along sandy beaches at the district scale the technique comprises four stages each with a summary matrix. Firstly, the geomorphological units are identified up to the sub-facet or site scale as being distinctive units in terms of operative physical processes: they include the lower beach, upper beach, backshore, coastal edge and foredunes. An assessment of the current geomorphological processes which affect the sites is made and the matrix is drawn up. Secondly, the range of uses which the beach complex could experience — forestry, grazing, daytime recreation, oil platform construction — is listed and the effects and probable impact of such uses on each sub-facet is assessed. The third stage involves the assignment of a magnitude factor to each impact; all the major impacts on each side are then listed in the third matrix. Finally, the major impacts on the whole beach complex are evaluated.

The existing literature on the application of environmental impact assessments, particularly in the UK, fails to comprehend in sufficient depth the whole range of impacts — physical, ecological, economic, social — which could occur with a specific development. Hence there is obvious scope for multi-disciplinary teams to carry out such assessments within the context of the development control process, rather than rely on the superficial environmental assessments of commercial consultants.

CONCLUSIONS

The paper has attempted to demonstrate the application of a limited range of geomorphological techniques to both strategic planning and development control. Evidently some techniques are suitable for application to both processes, whilst a number of techniques are only applicable at certain scales. For example, geomorphological impact analysis and landform classification techniques are not applicable at the national scale in Scotland at the present time, whilst other methods such as slope category analysis are readily applicable to all three levels of the planning process. There is obviously a dearth of techniques at the national scale but the main level of demand is at the local and especially the regional level, and here all the five techniques discussed are useable (Table 1).

Each technique has numerous methodological pitfalls deriving from the data base or the mode of analysis and these must be overcome with reference to the demands of the planner. In some cases the geomorphologist's role is to demonstrate the validity and utility of such techniques in providing data inputs to the planning process. In order that such techniques are of maximum benefit to the planner, further research must identify the consumer's requirements as to the type of input and the scale at which the input is to occur; to assess the applicability of existing methodology and techniques; and to develop techniques to satisfy consumer demands. These three considerations have been unduly neglected by geomorphologists so that existing techniques are too complex and unsuitable for consumption by the non-specialist (Savigear 1965; St-Onge 1973; Wright 1972). Hence a compromise between the maintenance of scientific standards and the rapid fulfilment of consumer demands is imperative.

TABLE 1. The relationship between selected geomorphological techniques and planning

Geomorphological technique	Planning Scale		
	National	Regional	District
Geomorphological survey and mapping	o	+	x
Landform classification	o	x	x
Geomorphological hazard assessment	x	x	x
Geomorphological impact assessment	o	x	x
Slope category analysis	x	x	x

x direct application
\+ possible application
o application unlikely

No one of the techniques discussed is necessarily valid in its own right, rather in most instances the geomorphologist will find it necessary to use a combination of techniques to fulfil the demand set by the planner. In the same vein, geomorphological input must be allied to and form part of an overall physical environmental inventory and assessment, and should not concentrate wholly on the development of techniques of restricted use for input into the planning process. The techniques can best be applied by geomorphologists working as members of an multi-disciplinary team serving the specific needs of planners who ultimately carry out the overall evaluations and devise the resulting policies.

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SOME PROBLEMS IN THE EVALUATION OF THE NATURAL ENVIRONMENT FOR THE DEMANDS OF TOURISM AND RECREATION: A CASE STUDY OF THE BYDGOSZCZ REGION [1]

WŁADYSŁAW NIEWIAROWSKI

INTRODUCTION

One remarkable feature of the social progress made after the last World War by the developed countries is the expansion of wide-scale tourist travel. This results from the higher living standard of the post-war years, from shorter working hours, and from the high rate of industrialization and urbanization. Poland is one of the countries where a large increase in tourist travel can be observed: in 1973 as many as 101 million people took part in domestic tourism (Rocznik Statystyczny 1974), spending 353 million days at single centres, and by 1990 it is anticipated that these figures will rise to 240 million and 950 million respectively (Filipowicz 1974).

One of the problems met with in accommodating such numbers of tourists is the setting aside of suitable regions which are valuable for the purposes of recreation and other requirements of the tourist trade. Apart from the interest and quaintness of folklore, architectural monuments, and historical and modern achievements of man, every sort of natural environment is bound to play an exceptionally important part in satisfying the demands of the increasing number of tourists (Bartkowski 1974; Kostrowicki 1970; Marsz 1972; Mileska 1963; *Plan kierunkowy* ... 1971; Rogalewski O. and B. 1965).

In Poland the evaluation of the natural environment on a regional basis for purposes of recreation has been assigned to the research domain of physical geography. To arrive at thorough and dependable results is a complex task due, among other causes, to the fact that tourism and recreation appear in a variety of forms, so that differences in the natural environment come into play. Moreover, any sort of evaluation is always more or less biased because it cannot always be contingent upon truly objective criteria expressed in absolute quantitative terms. For example, how can the beauty of the landscape be rated numerically? Discernment is bound to be affected by personal considerations.

In Polish research and in concepts of statistical classification, the following divisions are adopted:

(a) Tourist travel based on a fixed abode, i.e. recreation at some definite place for a period exceeding one week. Usually this sort of holiday is organized by large firms for their personnel, by tourist enterprises, by the vacationers themselves, or they are set up as summer camps for younger and older school

[1] Corresponding to the area of the Bydgoszcz voivodship as before June 1st, 1975 (Editor's note).

children; a further alternative is a rest cure in a watering place, often combined with medical care and with the use of health-restoring facilities and apparatus.

(b) Sight-seeing or hiking, comprising excursions with overnight accommodation at inns, cabins, motels or other places for one or more days but less than a week.

(c) Recreation after daily work, during short holiday periods, or for only part of the day, without requiring overnight accommodation.

(d) Tourism requiring suitable physical and mental fitness and the ability to use specialized equipment and facilities (often rented) for canoeing, bicycling, sailing, skiing, and similar activities. Distinction must also be made between domestic and foreign tourism.

These recreations all take advantage of the natural environment primarily for recreation, for rest during holidays, and for some kinds of sport. While sight-seeing also profits by the natural environment, this sort of turism is mainly interested in admiring the evidence of folk customs and cultural achievements in the countryside; rarely are such trips intended to study the natural environment.

In his present study of the natural environment and its role in the diversity of tourism and recreation, the author has chosen a survey of Bydgoszcz Region as an example. A study was initiated in the period 1968–1974 to evaluate the natural environment from the point of view of recreation and tourism.[2] The Region had an area of 20,892 sq km and some two million population, and is situated in the Polish Lowland within the range of the last glaciation in which the outstanding surface features are young-glacial and valley landscapes. Hence the conclusions arrived at with regard to the Bydgoszcz Region may be considered suitable for appraising the natural environment of most of the Polish Lowland.

METHODS AND RESULTS OF THE EVALUATION OF THE NATURAL ENVIRONMENT OF BYDGOSZCZ REGION FOR TOURISM AND RECREATION

The basic data for this work were: field investigations, information collected from administrative offices and institutions (such as records on forests and on water purity), cartographical data (topographical, geomorphological, hydrographical, pedological, geological and climatic maps) which were available on a variety of scales, as well as all kinds of information gained from the literature. The results of all these studies were illustrated on maps compiled at the 1:100,000 scale, extracts from which are used to illustrate the present paper.

The work paid special attention to individual elements of the natural environment as well as the sum of natural conditions which was expressed in a multitude of variations of the landscape. The research covered the whole area of the Region even though it is known that only certain areas are of prime importance for mass tourism. These include open water and forests, as well as areas marked by a picturesque and variegated relief, which are not under agriculture. Certain types of tourists like to spend their time in villages in purely rural regions, but this trend has not achieved major proportions. The mass inflow of tourists may well take place into villages sited near lakes and forests because they are attractive to visitors seeking recreation in quiet surroundings.

[2] The following students, working for the degree of M.Sc., participated in this work: Czuba Jan, Marosz Józef, Fedorowicz Anna, Rząsa Andrzej, Sewerniak Janusz, Pawski Antoni, Szczygielska Elżbieta, Burak Szczepan, and Czerwińska Ewa.

Thus all compact rural areas with fertile soils protected against any use other than agriculture have been excluded: such areas constitute some 66% of the surface of Bydgoszcz Region.

Not all elements of the natural environment are alike in their attractiveness to mass tourism. For example, it is important to know that solid grades of fertility classes I to IV are protected by law and thus are automatically excluded from use as tourist developments, the more so since tourists are not as a rule interested in soil studies. Nor are they usually attracted by the geological structures seen here and there is the Lowland, with the possible exception of geological cross-sections unusual from a scientific point of view, or some peculiar outcrops of rarely seen sediments. Nevertheless, an understanding of local geological conditions is indispensable to those who are planning investment in tourist facilities and deciding, for example, on the location of relevant buildings. The most important features of lowland regions in attracting tourists are, in general, the relief of the land, the hydrological conditions, the vegetation cover, and the climate (Bartkowski 1974; Marsz 1972; Mileska 1963; *Plan kierunkowy* ... 1971; Warszyńska 1974; Ziemolożyński 1973). In both Polish and foreign publications these last named elements of the natural environment are the most often investigated; the method of evaluation for recreation and tourism is usually a point scoring technique (Bartkowski 1974; Mileska 1963; *Wskaźniki chłonności* ... 1973; Ziemolożyński 1973).

This method assigns definite numbers of points to particular features of the natural environment according to an adopted scale of values. The sum of points picks out particular features according to their position in the ranking (e.g. land relief, water conditions, climate, vegetation cover) and makes possible a synthetic evaluation of any territorial unit within administrative or physico-geographical boundaries from the viewpoint of its attractivess to tourism This type of evaluation has its admitted shortcomings: it is bound to be more or less coloured by the observer's own opinion, yet it permits the making of correlations and the arrival at a classification based on criteria which are expressed quantitatively.

(Some other authors prefer to use what is called the model method (Wskaźniki ... 1973) and in the present studies the point scoring method was not used but there was an attempt to determine those parameters which emphasize differences between particular features of the natural environment, and which in this manner characterize differences in attractiveness and suitability for tourism and recreation.

In contrast to mountain areas and uplands where the picturesque and diverse relief is one of the principal components of their attractiveness to visitors, the relief of the Polish Lowland, although variable, is not the principal factor in the beauty of this part of the country and its attractiveness to tourists. It is commonly assumed (Bartkowski 1974; Marsz 1972; Mileska 1963; Rogalewski O. and B. 1965; Warszyńska 1974) that the attraction of relief lies mainly in its diversity and lack of monotony. The degree of interest is measured mainly by differences in relative heights and their frequency, in other words by the intensity of relief variances. Obviously it is impossible to expect that the parameters of relief diversity and its intensity should be identical in mountain areas and in the lowland. In the Region of Bydgoszcz we have singled out four different types of land relief which are expressed by differences in relative heights. These are areas where the differences amount to (1) more than 20 m; (2) from 10 to 20 m; (3) from 5 to 10 m; (4) less than 5 m (Fig. 1).

In both Bydgoszcz Region and in the rest of the Polish Lowland, the most diversified relief forms, which are thus the most attractive to tourists and recre-

Fig. 1. Fragment of geomorphological map of the vicinity of Chojnice, Bydgoszcz voivodship, compiled for evaluating land relief regarding its fitness to tourists and rest seekers (after A. Pawski)

1 — moraine elevations of more than 20 m amplitudes, 2 — zones of moraine elevations of 10 to 20 m amplitudes, 3 — slopes of 10 to 20 m relative heights, 4 — slopes of 5-10 m relative heights dissected by valleys 5 to 10 m deep, 5 — scarp edges up to 5 m high, 6 — flat and wavy moraine plateau of up to 5 m relative height, 7 — outwash plains of up to 5 m relative heights, 8 — dry floors of valleys, subglacial channels and ice melt kettles, 9 — dunes, mostly of up to 5 m relative heights, 10 — waterlogged and swampy regions, 11 — sites of ancient settlements, 12 — panoramic viewpoints, 13 — altitude points (in m a.s.l.), 14 — lakes, 15 — streams, 16 — towns and villages.

ationists, are zones of end moraines, deeply incised valleys and their much-dissected slopes, sub-glacial channels and dune fields, and groups of kames and eskers. In view of the interest of individual land forms and groups of them like kames, eskers, drumlins, and ancient fortified settlements, even to casual visitors and transients, it seems advisable to mark their mode of origin on maps. Also essential is the marking of outstanding inanimate features like big erratic boulders or panoramic viewpoints. All such places are highly attractive to visitors when properly provided with facilities and shelter. To those enjoying quiet walks along well marked tourist trails, diversity of relief is especially welcome, but in the lowlands this possibility has not yet increased the period for which visitors stay.

Of the greatest importance for all kinds of tourist development in the Polish Lowland are rivers and lakes, as well as vegetation, especially forests. Lakes are the most prominent attraction in Bydgoszcz Region and also for the most part over the whole range of the last glaciation. They are numerous: some 1500 occupy an area of more than 1 ha; at 83 lakes the water surface extends to more than 100 ha, and at 32 lakes the surface is in excess of 200 ha (Ziemolożyński 1973). Apart from natural lakes the Region contains a number of artificial water bodies formed by the construction of dams or weirs. Among the largest are the impoundments created on the Vistula at Włocławek (70.4 sq km) and on the Brda river at Koronowo (14.6 sq km). Altogether, the waters of Bydgoszcz Region occupy an area of some 640.0 sq km, equal to about 3% of its total area.

In the evaluation of the network of waterways for tourism, it is customary to consider the total area covered by water (Mileska 1963; *Wskaźniki chłonności* ... 1973; Ziemolożyński 1973). This is a gross oversimplification, because by no means all water bodies can be used for recreation. Whereas to walkers, sightseers and people on excursions, practically all lakes and streams are attractive since they embellish the landscape, for holidaymakers staying in one place only a few water bodies and streams are of interest. Small lakes of less than 10 ha are of no use to this type of visitor and they were omitted in the present studies. The size of a lake has some bearing on the use of it that can be made. At larger lakes, usually those of at least 20 ha water surface, facilities for canoeing and sailing can easily be provided, as well as bathing beaches.

An essential element to be taken into account in that evaluation of water bodies and streams is the degree of water pollution. Although the Region of Bydgoszcz is not yet highly industrialized, both industrial effluents and neglect in treating communal sewage have caused many rivers and water bodies to be polluted to a degree which precludes public bathing and in consequence keeps tourists and visitors away. These adverse circumstances prevent large-scale use of the Noteć river and of the many lakes situated in the Noteć valley below Kruszwica, as well as of the Vistula and its large storage basin at Włocławek, and of a number of other lakes contaminated by industrial and domestic wastes. Where the contamination is exceptionally high, even canoeing is prevented. The enforcement of a suitable regime of water treatment would abate the water pollution nuisance to the point where many more visitors could be expected. On the maps the sources of water pollution have been marked.

No less essential a criterion for evaluating water bodies and their potential for recreation during holiday and weekend periods is the nature of the periphery of the lake, both on the land and in the water zone near the land. This refers to the distance to which reeds and other aquatic plants extend into the lake, the nature of the bottom in the bathing zone (sandy, muddy, peaty, etc.), the relief of this zone (a gentle or an abrupt increase in water depth), the height and steepness of adjoining slopes, exposure to sunlight, and the width of the beach zone available for public use. Field work revealed that many lakes, even some of more than 200 ha in size, are unsuitable for recreation because they are overgrown or surrounded by swampy ground.

The present-day utilization of the land surrounding lakes and water bodies must also be taken into account. Where the soils are fertile and under cultivation and where, moreover, no large forests are in the vicinity, not even the zone near the bank can be made accessible to all kinds of visitors. Thus even at Lake Goplo, the largest lake (21.5 sq km) in the Region of Bydgoszcz, there is very little recreational activity. Further restrictions are found at lakes or parts of lakes where there are waterfowl sanctuaries.

Using all the above critieria, the study classified for the purposes of tourism and recreation all the water bodies in the district (Fig. 2), distinguishing four principal types:

(1) Water bodies eminently suitable for all types of holiday and recreation, i.e. water bodies with clean water suitable for bathing, with shore zones completely or predominantly dry so as to produce sandy beaches with a sandy bottom gradually sloping to greater water depth. Here the marginal zones are free of aquatic plants, their slopes are gentle and have for the most part a southern exposure; and mature forests and tree stands (more than 60 years old) are easily accessible to visitors and situated within a reasonable distance.

(2) Water bodies useful to tourists and recreationists: unpolluted water with the width of the aquatic plant zone not exceeding 10 m, beach zone dry or easily made dry, banks suitable for bathing with sandy bottom gradually sloping to a greater water depth over a distance up to 20 m, southern or western exposure of sloping shores, access to nearby forests or tree stands more than 40 years old.

(3) Water bodies at present poorly suited for recreational use but which demonstrate potential for the improvement of natural conditions: water made fit for bathing, sometimes merely by the removal of surface impurities; beach zones marshy only in parts up to a width of some 10 m, a belt of aquatic plants initially up to 20 m wide; the marginal lake bottom muddy or with the ground rapidly subsiding to a greater depth within a strip 10 m wide; slopes some 10 m high or more, obstructing access to the beach; nearby forests of an age of only 20–40 years.

(4) Water bodies unsuitable for recreation: extensive wet and swampy areas along banks, a wide belt of aquatic plants, water polluted and unsuitable for bathing, high and steep slopes, abruptly increasing water depth; the surrounding region consisting of cultivated land or of forests closed to the public.

At small lakes, inaccessibility to recreationists may be due either to one or to several unfavourable features, whereas at large lakes a number of different bank types are available which vary in suitability; in this case the lake must be classified in conformity with its predominant features of a given category.

It should be mentioned that some water bodies which attract resident holidaymakers also attract people on shorter excursions. Some water areas may delight day-visitors but be unacceptable to for longer-stay residential holidays.

In the evaluation of the attractiveness of streams to recreation seekers the study took into account the width and depth of the channel, and hence the possibility of persuing canoeing and other aquatic sports, water purity, and the opportunity of providing well equipped bathing beaches. The study determined that the Region of Bydgoszcz, excursions by passenger boats should only be made on the Vistula, but that apart from the well-known popular canoeing contests in the picturesque valleys of rivers like the Brda, Wda and Drwęca, smaller scale canoeing runs can also be made on streams like the Osa, Noteć and

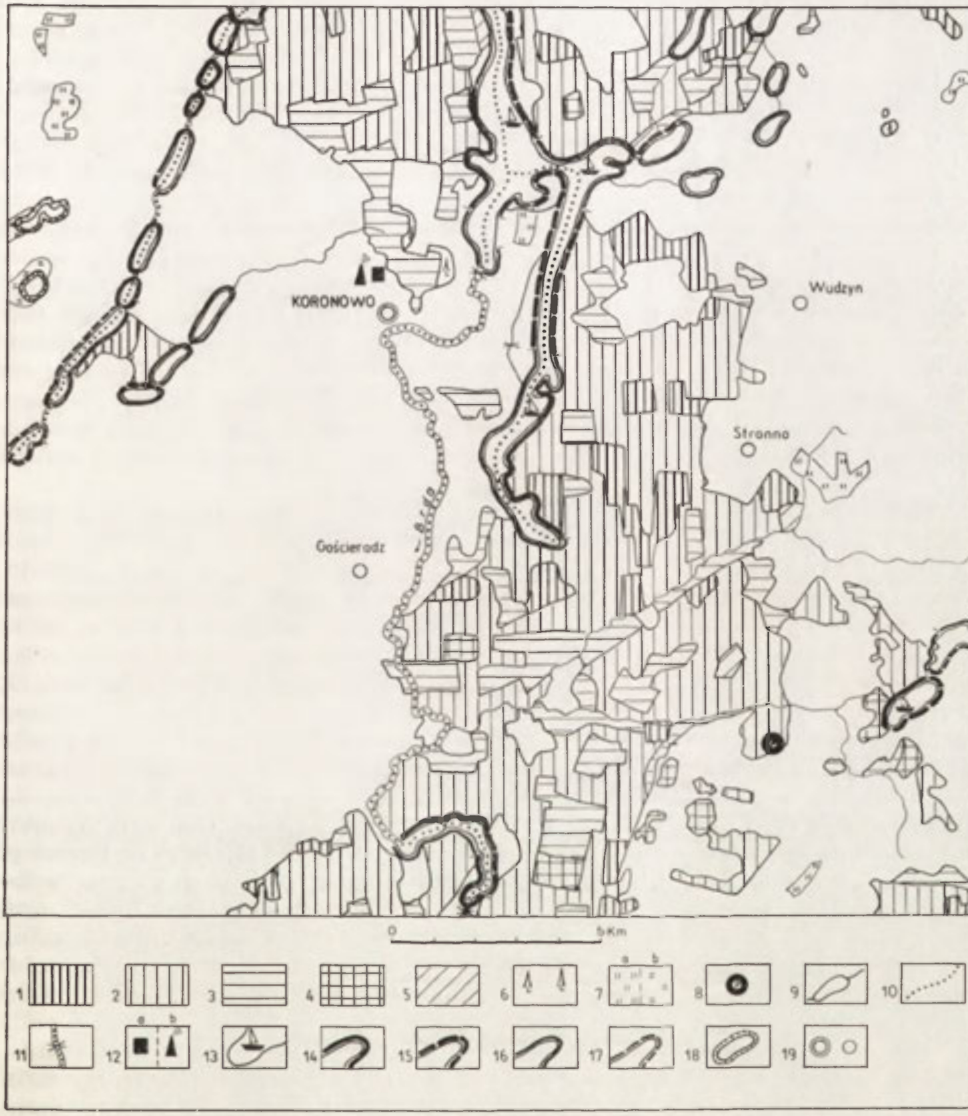

Fig. 2. Map evaluating vegetation and hydrographic network of the vicinity of Koronowo, Bydgoszcz voivodship, from the viewpoint of tourism and recreation (after E. Szczygielska)

1 — forests and tree stands more than 80 years old, 2 — forests and tree stands 40 to 80 years old, 3 — forests and tree stands less than 40 years old, 4 — forests and tree stands of different age, 5 — marshy forests, 6 — privately-owned forests, 7 — (a) meadows and pastures, (b) wet ground, 8 — nature's preserves, 9 — lakes and streams, unpolluted, 10 — canoeing tracks, 11 — obstructions to canoe tracks, 12 — (a) objects polluting surface waters, (b) objects polluting the atmosphere, 13 — lakes serving water sport activities. Shore zones of water basins: 14 — very well suitable for recreation, 15 — suitable for recreation, 16 — less suitable but fit to be improved, 17 — unsuitable but fit to be improved, 18 — unsuitable for recreation, 19 — towns and villages.

Łobżonka. In view of their water purity as well as the width and depth of their channels, the most suitable streams to be equipped with bathing areas are the Drwęca, the Brda and the Wda rivers. Similar possibilities could be applied to many smaller streams if basins were constructed by means of retaining weirs.

Underground saline waters are of marked importance to health resorts and to watering places. These have been used as the basis for the health resorts of Ciechocinek, Inowrocław and Wieniec. There is every chance that many additional resorts of this type will develop along the whole Ciechocinek-Toruń belt and at Marusza near Grudziądz.

Forests are, as previously pointed out, highly important to many forms of recreation as well as the water bodies and streams. Forests occupy some 490,000 ha, i.e. some 23.4% of the total area of Bydgoszcz Region forested land is thus somewhat below the Polish average of 27.1%. For the most part the forests have developed on outwash plains and on river terraces. The largest forest complex is Bory Tucholskie of which about 150,000 ha lies in the Region of Bydgoszcz; there are also large forests stands in the Vistula valley. In these forests pine trees predominate, representing about 90% of all tree stands; mixed and deciduous forests grow mainly on moraine uplands and on valley slopes.

The proper evaluation of the forests to tourists and recreationists is rather complex problem. Many authors (Mileska 1963; *Plan kierunkowy* ... 1971; Warszyńska 1974; *Wskaźniki chłonności* ... 1973; Ziemolożyński 1973) choose to do this by simply determining the total forested area in a particular administrative (Warszyńska 1974; Ziemolożyński 1973) or physico-geographical (Mileska 1963; *Plan kierunkowy* ... 1971) units. This is a considerable over-simplification, probably admissable in general evaluations of large regions but liable to lead to faulty conclusions where smaller areas are concerned. Under Polish conditions, privately owned forests have to be excluded and also all the tree stands which form protective belts like those surrounding some industrial plants or important catchment areas for municipal water supply facilities. In Bydgoszcz Region forests of this type constitute some 15% of the forested area. Generally speaking, it is only the State-owned forests administered by the Ministry of Forestry and Timber Industry which are accessible to tourists, recreationists and holidaymakers. But even here, access to visitors is denied where the forests are the refuge areas of large mammals, where the forests are easily inflammable, where forest nurseries are located, where the trees are less than 20 years old and to some extent where they are less than 40 years old (Kostrowicki 1970; Meissner 1965).

In their specialized investigations, many authors assert that forest stands over 40 years old are best suited for recreation and tourism (Meissner 1965; Ziemolożyński 1973). In Bydgoszcz Region 48% of all forests are younger than 40 years, and 23% are younger than 20 years old. It is recognized that the "age" of a forest is a somewhat imprecise term, because in the course of proper forest practice old trees are cut down and replaced by younger individuals; however cognizance of these facts helps in the laying out and equipping of suitable sites for the tourist trade.

When discussing forests, it is worth discerning the types of habitats involved, because they differ with regard to their suitability for tourists. For example, forests in waterlogged areas are not at all suitable for visitors. At present, the pine and mixed forests which cover some 69% of the total forested area are of the highest value. All data on State forests obtained from their Management authorities or obtained in the course of the field work are illustrated in the map which forms Fig. 2. On these maps nature reserves are shown as well as the forests. These reserves are not usually accessible to tourists, although some of them are extremely attractive and can be visited by naturalists on special tours.

Bydgoszcz Region contains also an abundant relict and endemic flora. Various arctic-boreal and arctic-mountain species grow here and also a relict steppe flora on arid slopes. In fact there are 44 nature preserves of this type in the study area, covering 1,100 ha (Łachowski et al. 1972). One of the oldest is the Wierzchlas preserve of Yew trees (*Taxus baccata* L.) protected since 1827, here some 4000 trees of ages between 100-600 years grow. In the river Drwęca is found the largest fish preserve, intended to protect the spawning grounds of salmonids. Among archaeological sites, the best known one is at Odry where stone discs are arranged surrounding burial mounds of pre-Slav tribes, dated from about 2400 years ago, and where erratic blocks are overgrown with some 40 different species of mosses and lichens from early postglacial times. Also of considerable interest is the reconstruction of the Biskupin settlement, a monument of the ancient Lusatian culture dated from about 2500 B. P. Both these archaeological sites are protected and are highly attractive to both Polish and foreign visitors.

Also very interesting and worth seeing are monuments like large and old trees, picturesque parks and splendid old mazes and landscape gardens which were laid out at the estates of rich landowners of former times.

If the original set of criteria are reviewed, it is now necessary to scrutinize how far the climate is also an important element in the natural environment as far as tourism is concerned, especially in its tendency to affect the way vacationers will spend all their free time at one place or take short periods of leisure, even an afternoon, in pleasant surroundings. A knowledge of the macroclimate is essential in the evaluation of large areas like entire countries where diversified climatic conditions exist. On the other hand the microclimate or topoclimate is more important in smaller regions with minor disparities. Thus, for example, the macroclimatic conditions are much alike throughout the study area: differences in mean annual temperature are a bare 1°C (from 7° to 8°C), differences in annual rainfall are some 100 mm (500 to 600 mm). The same applies to differences in the number of fair-weather days and cloudy days, the duration of snow cover, the wind directions and velocities etc. These differences fail to cause disparities in the suitability of the various areas of the Region for recreation and so were disregarded. Attention was mainly centred upon the microclimate, especially upon its unfavourable features in areas otherwise suited for recreation and holidays.

Since the Region of Bydgoszcz is situated in the Polish Lowland, it is in an area of rather slight differences in relief (the maximum relative relief in no more than 140 m), and it also lies in the zone of transition between oceanic and continental climates. This results in a marked variability of the weather, a short duration of snow cover (with 50–80 days as the mean value but in some years the has been no more than a few weeks or even days), so that the study area affords little opportunity for large scale winter recreation. The main inflow of visitors takes place mainly in the warm season, with spring and early summer as the preferred seasons, at the price of neglecting the potentialities for sightseeing in the winter. Estimation of the future trends of tourism suggests that accommodation for visitors in winter will at most be about 3% of the summer numbers (*Plan kierunkowy* ... 1971). Obviously, a thorough cognizance of all the elements of the natural environment as they affect its attractiveness and suitability for tourism and recreation is indispensable for preparing a quantitative evaluation or "bonitation" map (Fig. 3). Combining all environmental

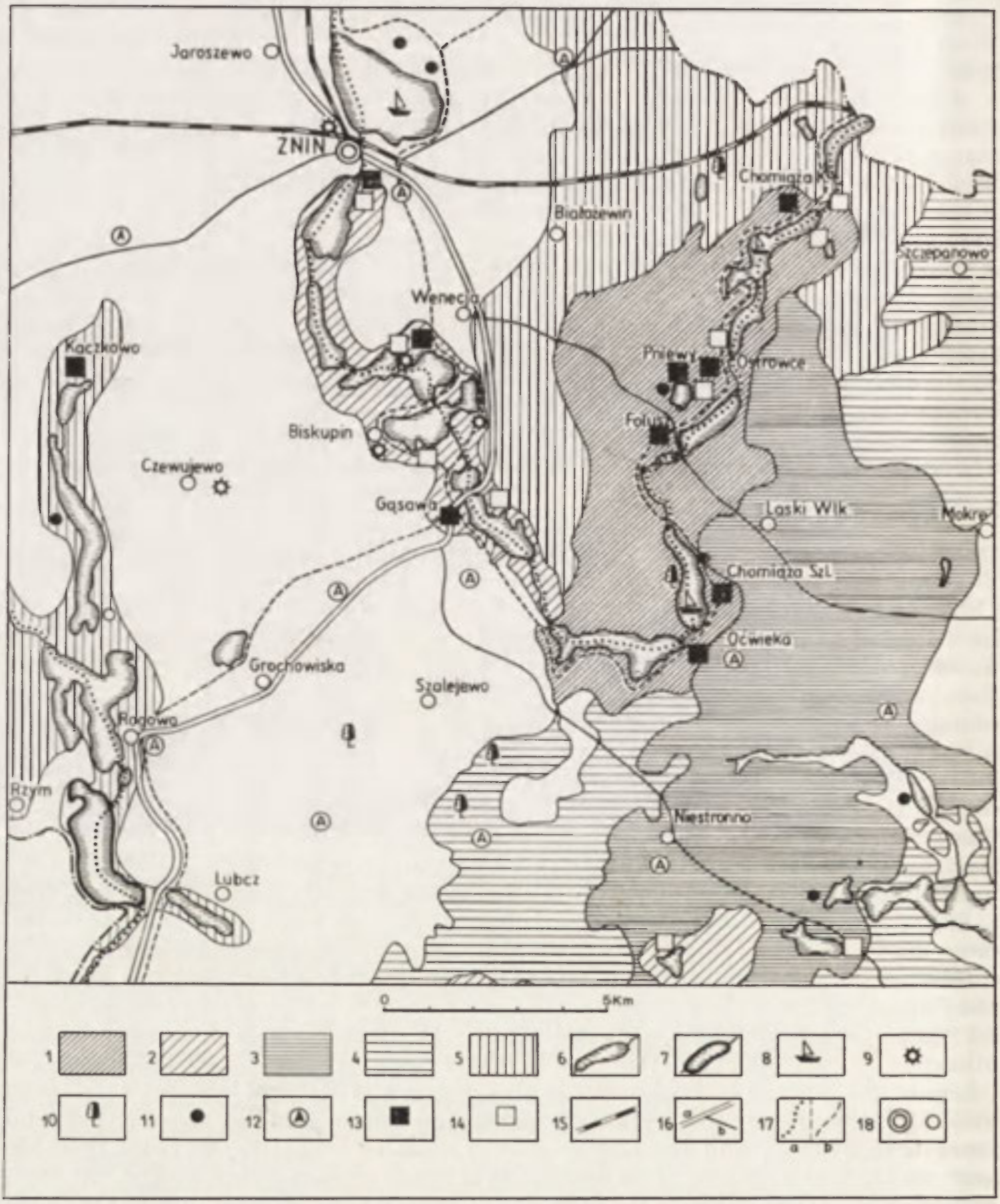

Fig. 3. Map evaluating natural environment of the vicinity of Żnin, Bydgoszcz voivodship, for purposes of tourism and recreation (after J. Sewerniak)

1 — regions particularly suitable for long-term tourist sojourn, 2 — regions particularly suitable for sight-seeing mobile tourists, 3 — regions suitable for long-term tourist sojourn, 4 — regions suitable for sight-seeing mobile tourists, 5 — regions of average attraction to both long-term sojourn and sight-seeing tourists, 6 — unpolluted lakes, 7 — severly polluted lakes, 8 — lakes suitable for water sports, 9 — sites of ancient settlements, 10 — nature's preserves, 11 — panoramic points, 12 — architectural monuments, 13 — existing recreation centres, 14 — regions suitable for establishing new recreation centres, 15 — railway line, 16 — roads: (a) main highways, (b) secondary roads, 17 — (a) canoing tracks, (b) hiking trails, 18 — towns and villages.

conditions, this map singles out areas of particular value for different kinds of tourist travel, recreation and holidays. The study has distinguished areas which are suitable for residential holidays, for sight-seeing excursions, and for various forms of active recreation, and — near large cities — for recreation during leisure hours and short holidays. The map also shows the accessibility of particular recreation sites by depicting the network of highways and railways. While this network is well developed, it is worth mentioning that it can easily be improved and supplemented. Thus our map shows existing places frequented by tourists and recreationists as well as sites suitable for developing new accommodation in future.

We consider our evaluative maps extremely useful to regional planning because they indicate regions well adapted for future development of tourism and point out the high quality of the natural environment met with in particular regions.

THE PROBLEMS OF CARRYING CAPACITY FOR TOURISM AND OF THE PROTECTION OF ENVIRONMENTS USED FOR RECREATION

When appraising the suitability of a natural environment for mass tourism, it is important to define the maximum number that can be absorbed at any one time without destroying or seriously impairing its values. However the determination of the maximum carrying capacity is a rather complicated task. In the Polish literature a number of studies and publications have appeared dealing with this topic (Kostrowicki 1970; Marsz 1972; *Plan kierunkowy* ... 1971; Stalski 1970; *Wskaźniki chłonności* ... 1973; Ziemolożyński 1973), but both scientific papers and planning studies contain different criteria of carrying capacity for tourists and so far no unequivocal criteria for such calculations have been made.

It is commonly believed that the most common element of the natural environment which is threatened with destruction by tourism is vegetation, especially the herbaceous undergrowth (Kostrowicki 1970; Marsz 1972; *Wskaźniki chłonności* ... 1973), and due to this belief vegetation is one of the principal index factors to be taken into account when calculating the carrying capacity of tourists. A list of indices so far used or suggested (*Wskaźniki chłonności* ... 1973) brings forward as many as 80 different index figures which can be applied to define the resistance of a ground cover to damage by trampling. The indices usually indicate how many people may be admitted per unit area of land surface and the range of variation can be as much as 0.2 to 2000 persons/ha; for forests this range is from 0.2 to 163 persons/ha. According to A. S. Kostrowicki (1970) the maximum absorptive capacity of forests is from 23–90 persons/ha, depending on the ecological type of forest. Apart from the ecological type of a forest, the carrying capacity also depends on the age of the tree stand, the duration and frequency of the advent of visitors, and on other factors. A. Marsz (1972) asserts that the resistance of the vegetation cover to trampling is the most essential feature to be considered. However, he also stresses the importance of slope, of the mechanical composition of the subsoil and the manner of development of the sites. An adequately developed terrain (with the construction of roads and paths for walking, the laying out of sports areas etc.) will be instrumental in improving the carrying capacity of a recreation site compared with localities lacking suitable investment. Marsz recommends the calculation of the carrying capacity for tourism of small physico-geographical units (*uroczyska*) so that the sum of these units gives a reliable estimate of the carrying capacity of a proposed larger unit. M. Stalski (1970) advises the application of a linear programming model for calculations.

Opinions are more or less identical about the capacity of water bodies and their shore zones to admit more visitors. The measures suggested vary from 0.2 to 2000 persons/ha. Since the present study did not undertake its own studies on this topic, the rule was therefore adopted that this capacity should be applied only for bank zones of at least 200 m width at natural lakes and impoundments which are suitable for constructing bathing beaches and recreation facilities for semi-transient tourists (type (a) of the classification). The measurements for carrying capacity are (1) for eminently suitable banks — 30 persons/ha; (2) for banks fairly well suited — 20 persons/ha; (3) poorly suited but with potential for improvement — 10 persons/ha. Using these estimates as a basis, the study found that at any one time the carrying capacity of the Region for residential holidaymakers is about 300,000 persons. Using other methods of classifying the natural environment and its carrying capacity for tourism, S. Ziemolożyński (1973) concluded that Bydgoszcz Region is estimated to have a capacity of 313,000 people.

The above figures all show that:

(a) the marked disparities in calculations of carrying capacity result from different methodological premises, and

(b) further investigations of carrying capacity are necessary.

One way of carrying out further investigations is to study existing health resorts where the parameters are known, such as the number and seasonality of visitors, the area used for all forms of recreation, the local environment, and the way in which visitors are accommodated. Full knowledge of these data, together with studies of changes in the natural environment wrought in order to deal with visitors, will very likely throw more light on carrying capacities. Thus the number of visitors which will not cause damage to the natural environment can be determined. No matter how the calculations are made, it is evident that Bydgoszcz Region can satisfy not only its own demands for recreation but those of other parts of Poland where the appropriate resources are lacking.

This statement is additionally important in so far as traditional holiday and tourist areas such as the coast and the Great Masurian Lakes are excessively crowded, and it is felt necessary to divert large numbers of holidaymakers and tourists into hitherto unused areas. In anticipation of such changes, however, it is essential to make preparations for the protecion of the natural environment and for appropriate development.

In Poland, a variety of forms of safeguarding the natural environment have been introduced, and among them are national parks and the so-called preserves, which are sanctuaries against damage. There are no National Parks in Bydgoszcz Region but, as mentioned before, as many as 44 preserves exist at present and several more are likely to be established in the near future. New methods of protecting the natural environment are called "landscape parks" and "zones of protected landscape". So far, one landscape park has been established in the study area; it comprises 120 sq km, and the necessary documentation for others is being compiled. So the most effective way of protecting valued regions against damage may be their inclusion in zones of protected landscape. In these zones the State Council for Nature Protection opposes any fundamental changes of use. Hence these zones are going to be safe from excessive urbanization and from the setting up of industrial plants which would impair the environment and lessen its value. In addition, these zones may be improved for recreation by the planting of new forests and the construction of water bodies.

The study's evaluations of the geographical environment have been very useful in pointing out suitable areas as zones of protected landscape. Twenty-four areas, totalling some 2700 sq km, have been earmarked for this purpose, representing about 13% of the total area of the Region. Twelve of these regions, totalling about 1200 sq km, are to serve residential holidaymakers, while the other 12 are to serve mobile tourists, sightseers, hikers and naturalists.

The study's proposals have been submitted to the nature protection authorities of the Region and are going to be incorporated in the revised map of landscape protection zones for the whole of Poland. This gratifying effect of our work proves how useful the physico-geographical work of University Institutes can be to the planning authorities.

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GEOGRAPHIA POLONICA 34, 1976

AN EVALUATION OF THE RESOURCES OF THE NATURAL ENVIRONMENT FOR TOURISM AND RECREATION

Jadwiga Warszynska

The estimation of the resources of the natural environment for the needs of recreation is one of the main research tasks of the geography of tourism. It is of particular importance because of the increase in the recreational activity of the population and also because economic growth which results in environmental change makes it necessary to secure adequate areas for recreational purposes.

An evaluation of the environmental resources is a methodologically difficult task. The subject of the evaluation is the components of the landscape, whose qualitative features are deemed to be "unmeasurable". Hence the measurement of recreational and tourist values cannot be absolute, but must be relative depending upon the criteria of value adopted and the evaluation method which is used. Thus the result of the evaluation process is not the determination of an absolute value, but a grading based on comparisons which are determined by the method of evaluation.

Of the quantitative methods available, a points scoring system is most often used. Each particular feature is given a number of points according to a chosen set of values. The sum of points is then used for a grading of the spatial units examined. This method reduces the chance of committing errors because it allows choice on the value scales and because to some extent it goes beyond purely subjective values.

The author presents a model which is based upon the transformation of quantitative information by a chosen mathematical function. It is derived mainly for medium scale rankings which are aimed at showing the optimal environmental conditions for the development of various socio-economic activities (Fig. 1). In this case, the basic requirement was the determination of the value of a particular locality for tourism. The main landscape features which were included in the assessment were: relief of the land surface, the surface drainage network, and the forest cover. These were expressed in absolute values by means of measures such as height, surface area, discharge and similar features.

The work uses as a model an exponential with the general form:

$$y = x^z$$

and on this basis the coefficients of attractiveness of chosen elements of the environment were calculated (Fig. 2). The coefficient of relief attractiveness is described by the expression:

$$N_H = \left(\frac{H_i}{H_m}\right)^{\frac{H_w - H_{wi}}{hH_w}} .$$

where:

H_i = maximum height of the locality i
H_m = maximum height of the province
H_w = maximum relative height of the province
H_{wi} = maximum relative height of the locality i
h — degree of relief intensity

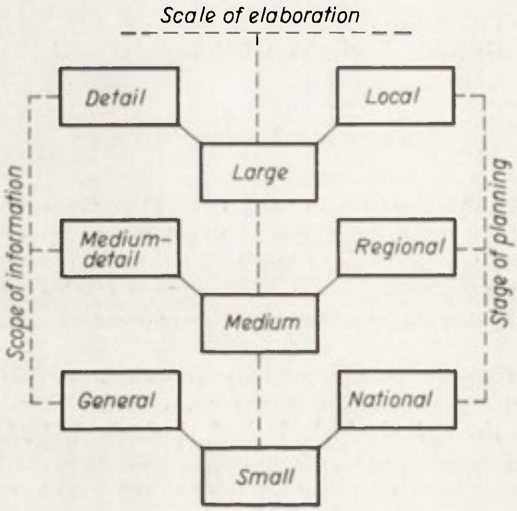

Fig. 1. The interdependence of planning, the scope of the information, and the scale of the evaluation

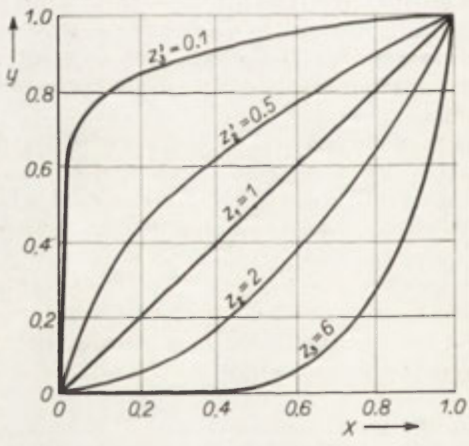

Fig. 2. Graph of a function $y = x^z$

The coefficient of attractiveness of the surface waters is described by the expression:

$$N_W = c\left(\frac{Q_i}{Q_w}\right)^{\frac{r(F_{ci}-F_{wi})}{F_{ci}}},$$

where:

Q_i = mean annual discharge of the largest stream in the locality i
Q_w — mean annual discharge of the largest stream in the province
F_{ci} = total area of the locality i
F_{wi} = total surface area of waters of the locality i
r — a constant ($r < 1$)
c = class of water cleanliness

The coefficient of forest cover attractiveness is described by the expression:

$$N_L = \left(\frac{F_i}{F_{ci}}\right)^{\frac{F_{sw}}{lF_i}},$$

where

F_i = area of forests in the locality
F_{ci} = total area of the locality i
F_{sw} = mean forested area of the province
l = class or ecological type of forest

The author has tried to make an assessment of values of particular environmental features from the point of the seasonality and types of tourist traffic. Three tourist seasons were adopted:

1. The general recreation season during which hiking, bicyling, motoring, sunbathing, open-air games, angling and hunting may be practised. In Poland this season lasts, on average, from mid-April until the end of October and overlaps roughly the duration of the growing season, when the mean daily air temperature is more than 5°C.

2. The bathing season is contained within the general recreation season, but is distinguished because it is the time when it is possible to enjoy bathing and water sports in the open air. The season is closely dependent upon daily weather conditions, but its average duration is about 60 days. It is limited by the temperature of the water, which must exceed 18°C, and by the mean daily air temperature, which must exceed 14°C.

3. The winter season is defined by the ability to take part in winter sports. Its duration is dependent on the persistence of snow cover which in turn is linked with the number of days with mean daily air temperature below 9°C.

As an example of tourism in the general recreation season, mountain hiking was considered. In order to determine the attractiveness of the environment

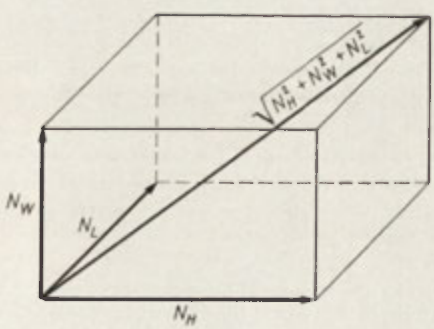

Fig. 3. The magnitude of the vector modulus of the coefficients of the attractiveness of natural environments, N_H, N_L, N_W

from the point of view of hiking, the main factor which played a dominant role in a given season or type of recreation activity was isolated, but in addition the author has tried to take into account the influence of the remaining elements of landscape upon the main factor. The residual influence was expressed by means of the coefficients N_H, N_L, and N_w by relating them to the mean values N_L, N_H, and N_w calculated for the province (Fig. 3).

The coefficient of attractiveness of the main factor N_j which comprises the remaining elements was expressed by the formula:

$$N'_j = N_j \left(\frac{N_H^2 + N_W^2 + N_L^2}{N_H^2 + N_W^2 + N_L^2} \right)^{\frac{1}{2}} = N_j^m,$$

where j — a general index standing for H, L, W.
The main factor in determining the features of the environment for mountain hiking is relief, and this is described in the form:

$$N'_H = N_H^m.$$

For the bathing season the attractiveness of water is expressed as:

$$N'_W = N_W^m.$$

For the general recreation season the square root of the components of the coefficients was used:

$$N_O = \sqrt{\frac{N_H^2 + N_W^2 + N_L^2}{3}}.$$

The attractiveness of the winter season was expressed as:

$$N_Z = N_H \left(\frac{S_0}{S_i} \right)^2,$$

where:

S_o = the mean number of days with snow cover in the province
S_i = duration of snow in the locality i in days

The result of the aggregation of all the indices is presented as Fig. 4.

The method outlined above was used to estimate the value for tourism of the natural environment of the Cracow region.[1] Overall, 1957 localities were studied and the mean values for the coefficients were calculated.

For mountain hiking (N'_H) and for the winter season (N_Z) = 0.46 (In both cases $N_H \geqslant 0.46$).

For the bathing season (N_W) = 0.22.

For the general recreation season ($N_O P$) = 0.36.

When the value of the particular coefficients was below the mean (i.e. for N'_H, N_Z, N_O and N_W) for an individual locality, then it was eliminated; thus 625 localities were excluded from further consideration.

The remaining 1,332 localities each had at least one of the coefficients equal to or higher than the mean values and were used for further analyses. The values of the coefficients were then verified with ground data and the class

[1] A detailed description of the method and the results of its application in the Cracow region is presented in the work by J. Warszyńska: *Ocena zasobów środowiska naturalnego dla potrzeb turystyki (na przykładzie woj. krakowskiego)* (An evaluation of natural environment resources for the development of tourist functions as exemplified by the Cracow province), PWN, Warszawa–Kraków 1974.

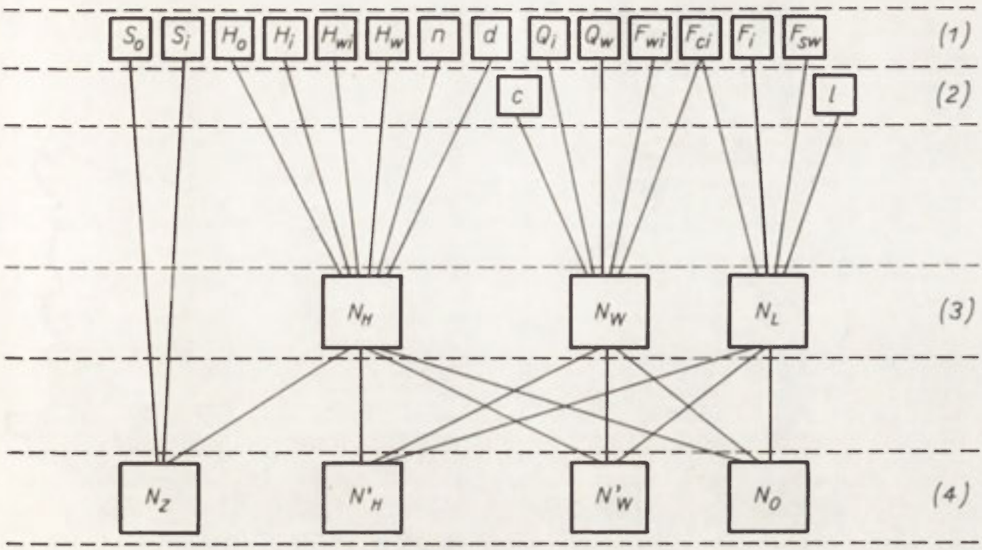

Fig. 4. Net result of the aggregation of features

(1) quantitative information; (2) qualitative information; (3) estimate of the attractiveness of the geographical environment elements: relief, surface waters, forest mantle; (4) estimate of the geographical environment attractiveness from the viewpoint of seasonality and forms of tourist traffic.

intervals were designed to identify the localities according to a typology of the intensity of features. Four classes were determined for each coefficient.

For N_H and N_Z the following class intervals were introduced:

I	1.00–0.90
II	0.90–0.80
III	0.80–0.65
IV	0.65–0.46

Here, class I corresponds with the Tatra Mountains and the higher portions of the Beskidy Mountains, class II covers the lower portions of the Beskidy Mountains, class III the foothills of the mountains and higher portions of the uplands, and class IV covers upland areas (Figs. 5, 6).

The coeficient N_O depends on its components N_H, N_W and N_L, and was divided into the following classes:

I	1.00–0.76
II	0.76–0.64
III	0.64–0.50
IV	0.50–0.36

Class I is composed of localities which each have three components with a high intensity of features (above 0.76) or two components with a maximal intensity (above 0.90); Class II comprises localities with a high intensity of one component as does Class III (Fig. 7). These intervals underline the attractiveness of the Cracow region, the main feature of which is a distinct shaping of two elements of the environment, *viz* the mountains and a rich forest mantle.

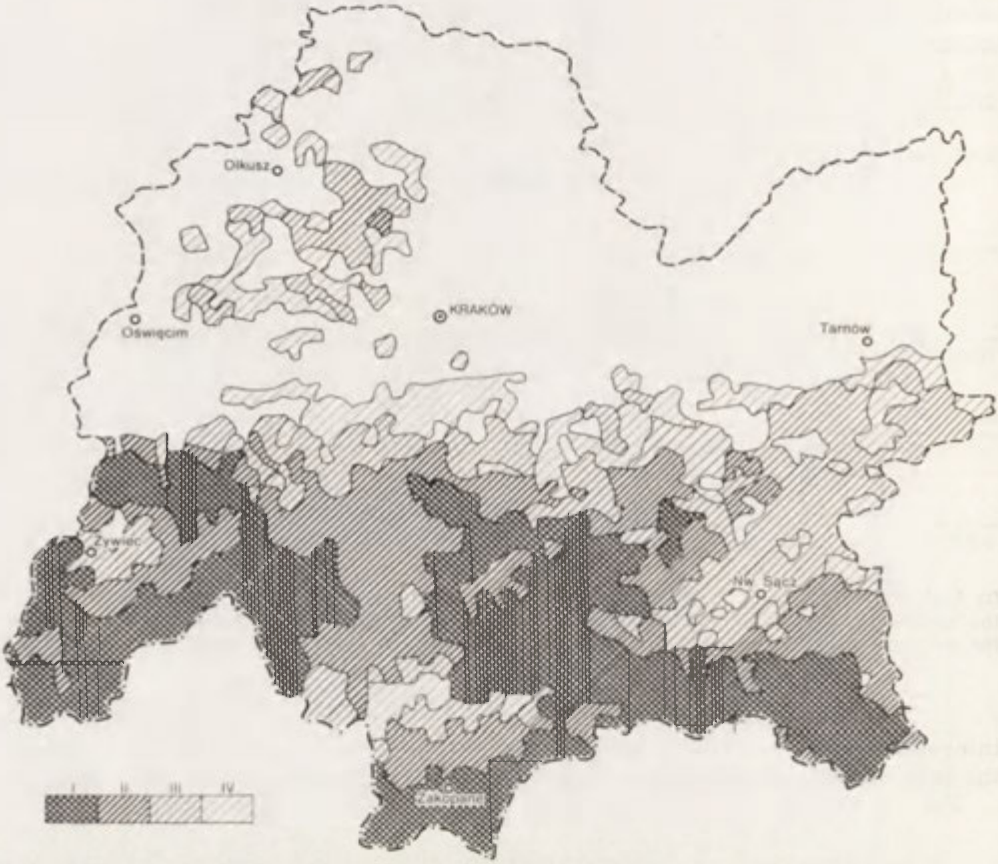

Fig. 5. Localities according to class of attractiveness for mountain hiking (N'_H)

The coefficient N_W has been divided into the following class intervals:

I	1.00–0.80
II	0.80–0.50
III	0.50–0.30
IV	0.30–0.22

Classes I and II show that the conditions for practising water sports are present ($N_W = 0.50$ with $Q_o = 20$ m^3/s). Class I being confined to the surface waters of lakes. Class III offers opportunities for bathing, and Class IV ($Q_o =$ 1–2 m^3/s) affords direct contact with the water, but without the opportunity for bathing (Fig. 8, 9).

On the basis of the classification, localities with supraregional attractiveness (Classes I and II) were distinguished, as were those with intraregional attractiveness (Classes III and IV). The localities with supraregional attractiveness were those with the greates potential for tourist development, and were demarcated into the following types:

1. Localities with an all-round attractiveness:
   (a) with a share of all the coefficients N_H, N_Z, N_O, N_W.
   (b) with a share of N_H, N_Z, N_O.

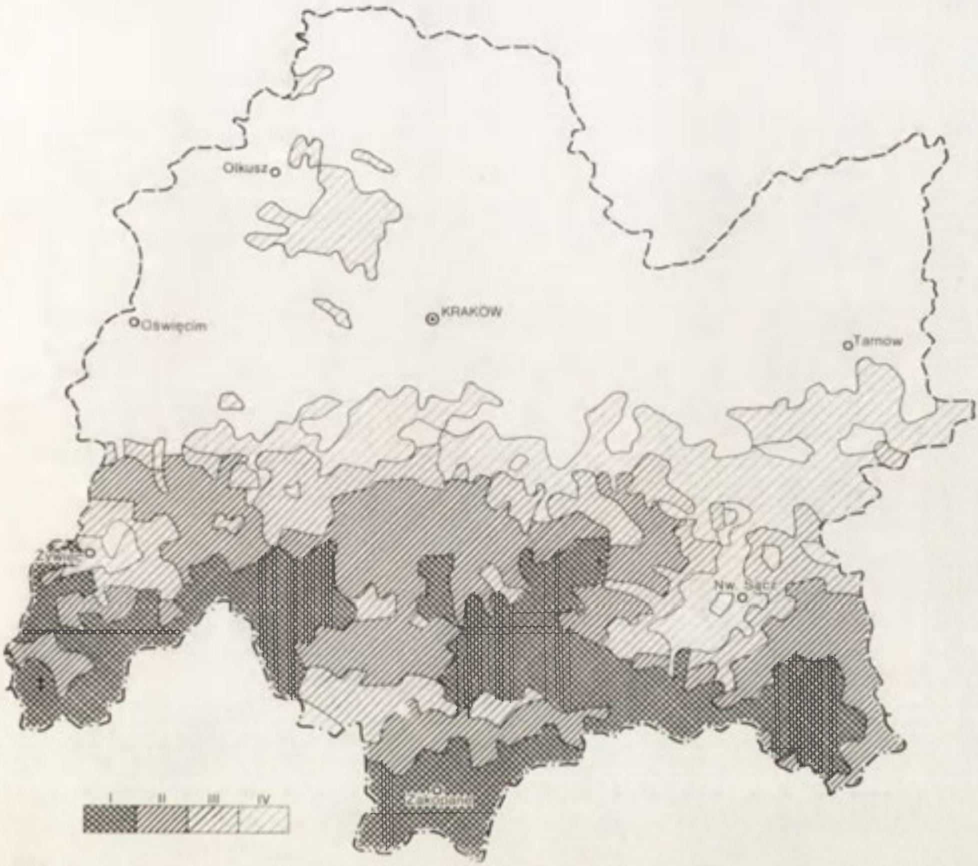

Fig. 6. Localities according to class of attractiveness for the winter season (N_Z)

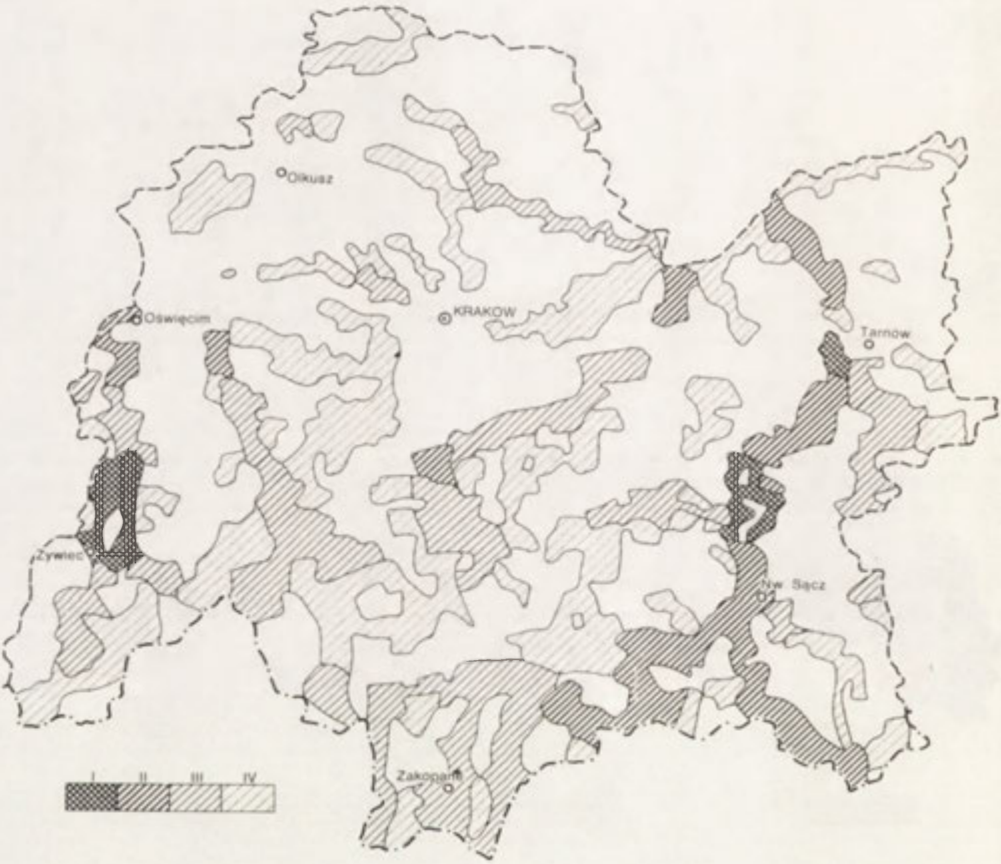

Fig. 7. Localities according to class of attractiveness for the general recreation season (N_O)

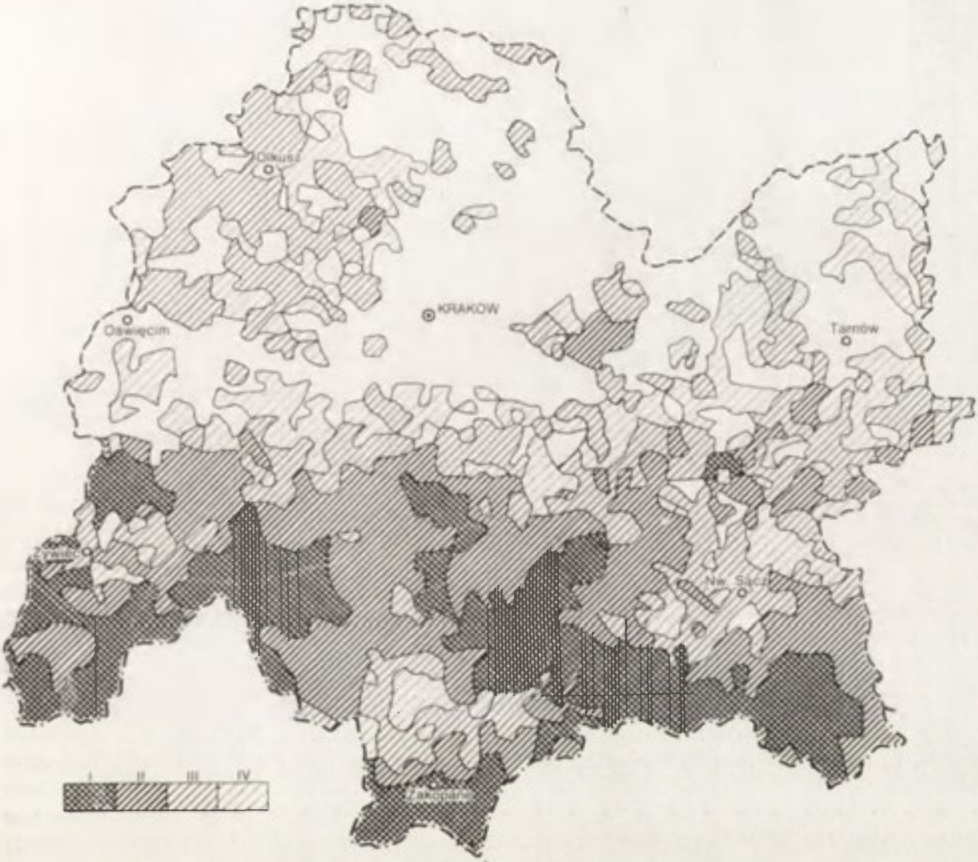

Fig. 8. Localities according to their class of attractiveness for the bathing season (N_W)

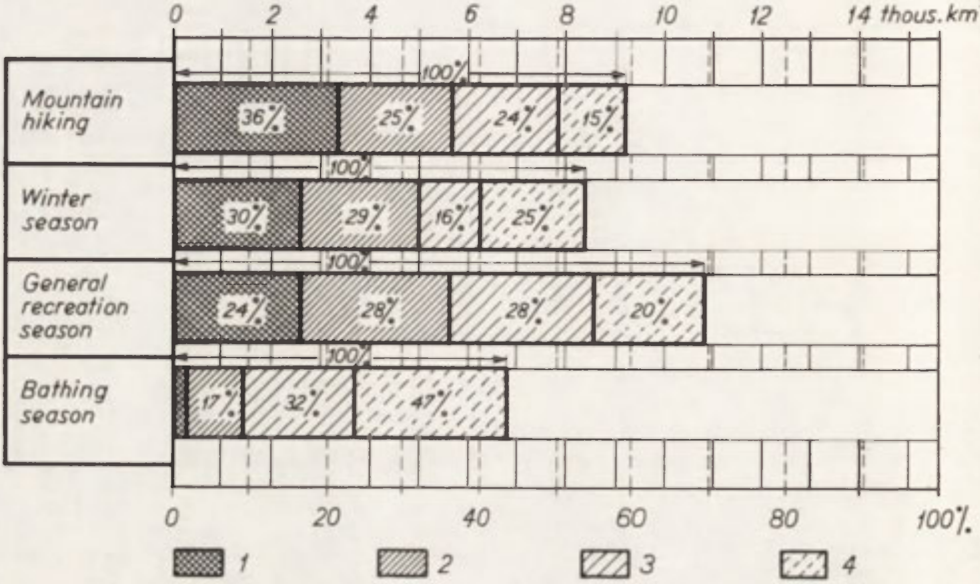

Fig. 9. Attractiveness to tourism of the Cracow region according to the form of the landscape, season and class:

1 — Class I, 2 — Class II, 3 — Class III, 4 — Class IV. Area of the Cracow region — 15,585 km²

2. Localities with an all-round attractiveness for general recreation: (N'_H, N_O, N_W)

3. Localities with an all-round attractiveness for general recreation: (N_H, N_O)

4. Localities with water activities of a general character: (N_O, N_W)

5. Localities attractive during the winter season: (N_H, N_Z)

6. Localities which have only one attractive feature.

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GEOGRAPHIA POLONICA 34, 1976

AN APPRAISAL OF THE NATURAL ENVIRONMENT OF THE ŁÓDŹ REGION FOR THE NEEDS OF ECONOMIC DEVELOPMENT AND RECREATION

HENRYK DUBANIEWICZ

Rational utilisation of the natural environment is an indispensable condition for the favourable economic development of a country's individual regions. The optimum distribution of each section of the national economy allows the formation of a geographical environment of high quality and is also important in its protection. Therefore it is essential for the purposes of any individual organisation that a suitable evaluation of this geographical environment is made, both from the point of view of recreational use, and of the needs of agriculture. housing, and industrial activity. A pilot survey for such an evaluation has been made for Łódź voivodship.[1] Here both recreation and agriculture are intimately connected with the condition and quality of the natural environment and so affect any special environmental protection policy. Recreation and agriculture therefore play a dominant role in this survey.

The full development of man's potential can only take place under the most suitable environmental conditions, and the rational organisation of recreation requires attention to a whole complex of different elements. Of the conditions ensuring this development, primary consideration should be given to "the scenery and nature's music" taken as a whole, as advocated by Korczyński (1931). His opinion is still generally acknowledged, and from this source is also taken the first plan of the role of recreation in the analysis of environmental elements.

In the paper by Dubaniewicz, Maksymiuk and Zych (1971) a survey of the area of Łódź voivodship for recreation development has been presented. Both the climatic and the bioclimatic conditions, the quality of surface water resources, the existence of groundwater resources and mineralised water, and the morphology and character of the earth's surface are considered. Also noted are the distribution, the kind and the range of the influence of industrial plants, some of which impair the quality of the surrounding environment. In the process of the "restoration of man's vigour", air and respiration play a great role; the physico-chemical composition of this complex is a result of advection processes and of air pollution caused by man's activities (emission of impurities from chimneys). In areas of intensive economic activity, correct bioclimatic conditions are acknowledged as the most essential index of the value of the geographical environment — particularly for the needs of recreation. The climatic conditions

[1] The Author refers to the Łódź voivodship in its boundaries of before the administrative reform of June 1975.

are considered by the authors mentioned above as a leading element of the environmental evaluation. The results of analysis have delineated the following regions (Fig. 1):

(1) areas with best bioclimatic conditions for recreation;

(2) areas with bioclimatic conditions favourable for recreation;

(3) areas bioclimatically unfavourable for recreation.

In any particular environment the most valuable resources for recreation become famous. In Łódź voivodship some of these areas are situated in the central area (Łódź Hummock, Szadek Plain, Tomaszów Plain, Piotrków Plain), others on Skierniewice Upland, Rawa Upland, Radomsko Hills, the Włoszczowa syncline, and finally some in the northern parts of Wieluń Upland and Wieruszów Upland, on Złoczew Upland and in the Sieradz Valley.

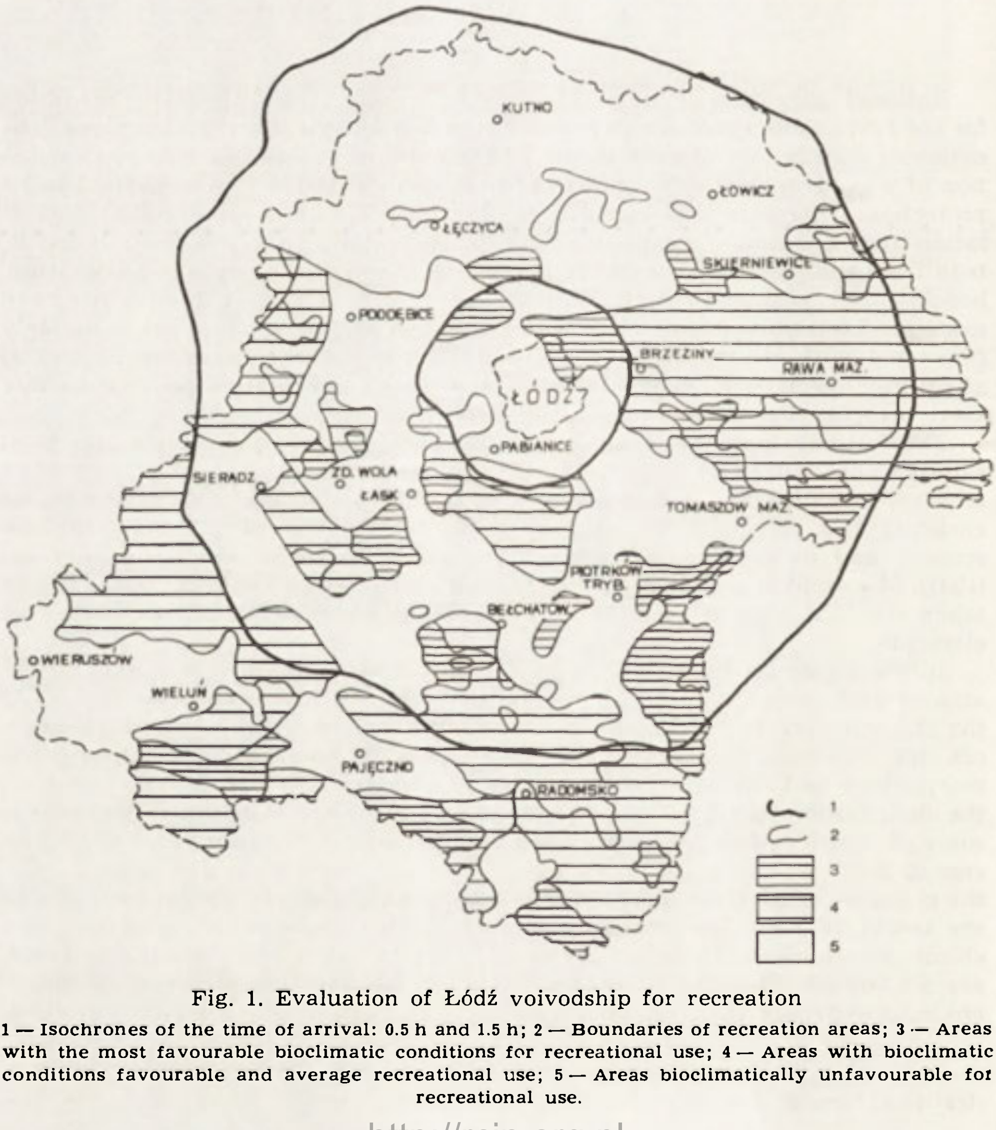

Fig. 1. Evaluation of Łódź voivodship for recreation

1 — Isochrones of the time of arrival: 0.5 h and 1.5 h; 2 — Boundaries of recreation areas; 3 — Areas with the most favourable bioclimatic conditions for recreational use; 4 — Areas with bioclimatic conditions favourable and average recreational use; 5 — Areas bioclimatically unfavourable for recreational use.

Agriculture is one of those sections of the national economy the results of which particularly depend on the quality of the geographical environment. The complex of elements in the natural environment, mainly air temperature, precipitation, sunshine and soil conditions, have a strong influence on crop yields and the costs entailed for successful harvesting. The assumptions have been chosen as the starting point for a synthetic analysis of the area of Łódź voivodship for agricultural needs. An estimation equation has been applied (Molga 1970) for this purpose — the agroclimatic index of Haude and Moese.

$$K = \frac{A(B+C)}{1000},$$

where K = the agroclimatic index;

A = a variable describing thermal conditions;
B = a variable describing precipitation, taking soil type into consideration;
C = an index of rainfall variability.

The meteorological stations considered representative of individual parts of the voivodship were selected on the basis of data collected for the climatic regionalisation of the area. Calculations of the index K have been made with reference to the map of three classes of soil: heavy, average and light (Dubaniewicz 1974). Derived in this way the agroclimatic potential is presented in Figure 2.

The agroclimatic regions should be seen against a background of an apparent transition from lowlands to uplands, following the pattern of climatic regions for the voivodship. Most profitable are agroclimatic conditions in the south-easterly region of the voivodship: Łódź Hummock, Tomaszów Plain, Piotrków Plain, the northern parts of Radomsko Hills and the Włoszczowa Syncline. Most difficult are conditions in the north and north east areas: in the Kutno Plain, Kutno Bank, Koło Valley, the north west part of the Szadek Plain, the north part of the Sieradz Valley, and the eastern part of the Łęczyca Syncline and Rawa Upland.

The evaluation presented above formed the basis of an evaluation of the geographical environment of Łódź voivodship for purposes of economic development and of recreation. Of the areas discussed above, the most favourable are equally well suited for the development of agriculture and for the recreation sector of the economy. On the synthetic map the potential spatial arrangements for economic development of Łódź voivodship are shown (Fig. 3). From the map showing the evaluation of the geographical environment of the voivodship for the requirements of economic development and recreation, the regions profitable for agricultural and recreational use have been omitted, as have also areas which may be destined for both light and heavy industry (Fig. 3). In these omitted areas there appear certain predominant functions: recreation, agriculture, combined recreation and agriculture or industry. The remaining economic functions existing in these regions should be of secondary importance. From such well established linkages arise the limitations of any spatial development of economic activity. The northern and central parts of the voivodship are distinguished by an unprofitable combination of environmental features for recreation development and are likewise climatically unsuitable for agriculture. The Kutno Plain, the Koło Valley, the Łęczyca Syncline and the northern part of the Szadek Plain are distinquished by a shortage of the water indispensable for an industrial complex. Supplying water to these areas would be absolutely necessary to increase their economic activity. In considering necessary to in-

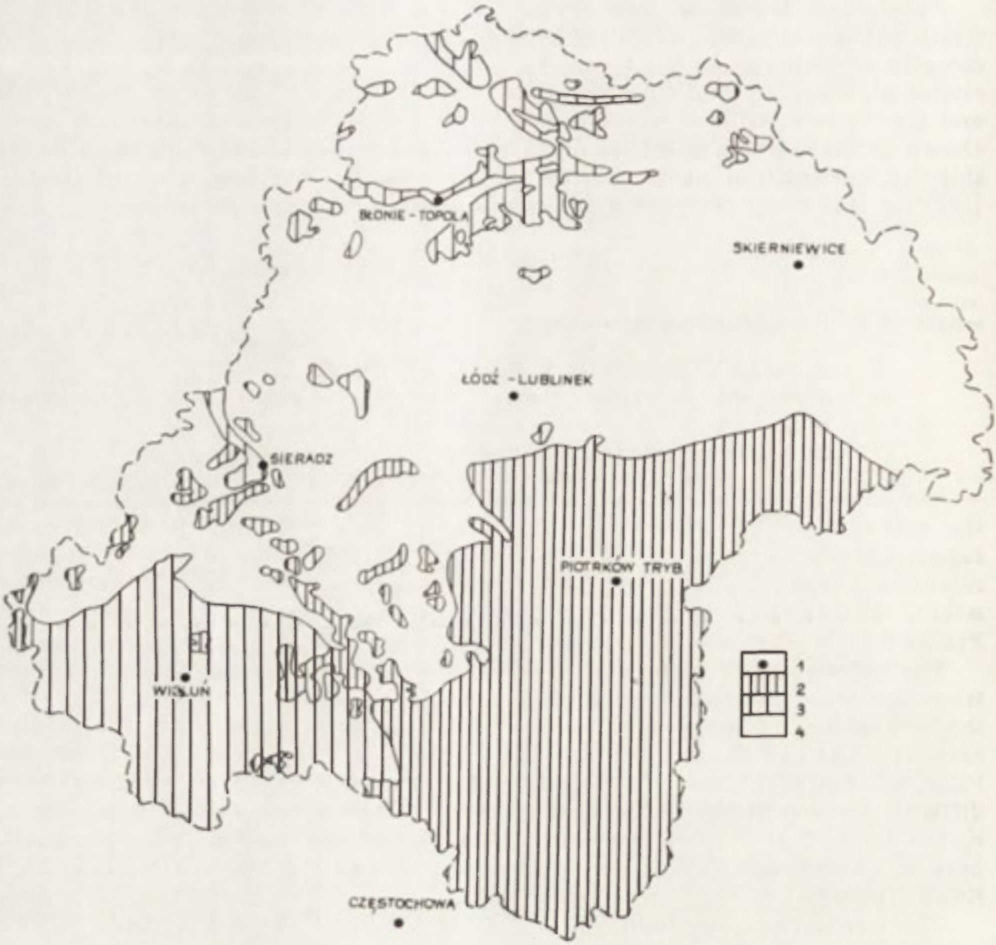

Fig. 2. Agroclimatic evaluation of Łódź voivodship

1 — Meteorological stations; 2 — Areas with the most favourable agroclimatic conditions; 3 — Areas with favourable agroclimatic conditions; 4 — Areas with unfavourable agroclimatic conditions.

crease their economic activity. In considering substantial technical developments, prime consideration should be given to the industrial function of these areas.

The development perspectives of the Łódź City Agglomeration, which forms a separate spatial unit, should be examined only against the background of the whole Region. From the evaluation of the geographical environment of the voivodship as shown in Fig. 3, the necessity arises for some spatial limitation of the intensive urban development of this great city and its industrial complex. The recreation value of the north-eastern and eastern areas, as well as the agricultural and recreational value of the area to the south form a restrictive barrier — or green belt — to further development of Łódź City Agglomeration. Thus one sees only one rational direction of development for the Łódź City Agglomeration; from north-west to south-east.

Development along this direction follows the argument concerning geographical conditions and also finds support in the climatic environment. Attention

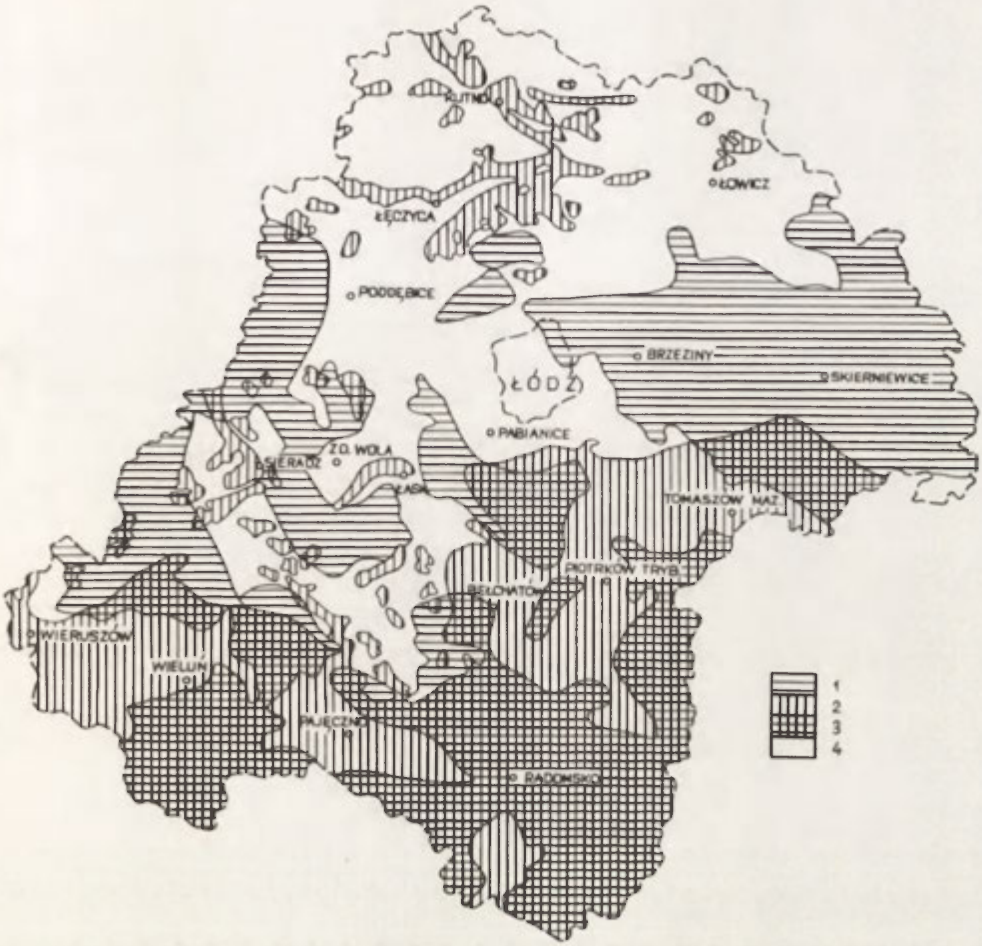

Fig. 3. Evaluation of the geographical environment of Łódź voivodship for economic development and recreation. Areas of dominant functions:
1 — Recreational; 2 — Agricultural; 3 — Recreational and Agricultural; 4 — Industrial.

TABLE 1. Frequency of wind directions in % (n) and intensity of airing from respective wind directions (p) for the years 1951-1960

Station		N	NE	E	SE	S	SW	W	NW	Calm
	n	7.5	6.2	17.1	11.8	8.6	14.4	16.5	9.2	8.7
Łódź–Lublinek	*p*	30.8	27.4	66.6	43.0	36.2	77.8	101.0	47.0	—
	n	5.0	6.7	18.7	10.1	6.6	15.0	19.9	10.6	7.4
Łódź–Ruda Pab.	*p*	15.4	20.4	78.6	37.8	24.2	69.0	100.0	40.6	—

here should be focussed on the greater wind frequency from east and west, also from south-west (Dubaniewicz 1974). The calculated wind intensity from each direction shows, that the best conditions prevail in directions parallel to lines of latitude although the directions from north-west, and south-east are also

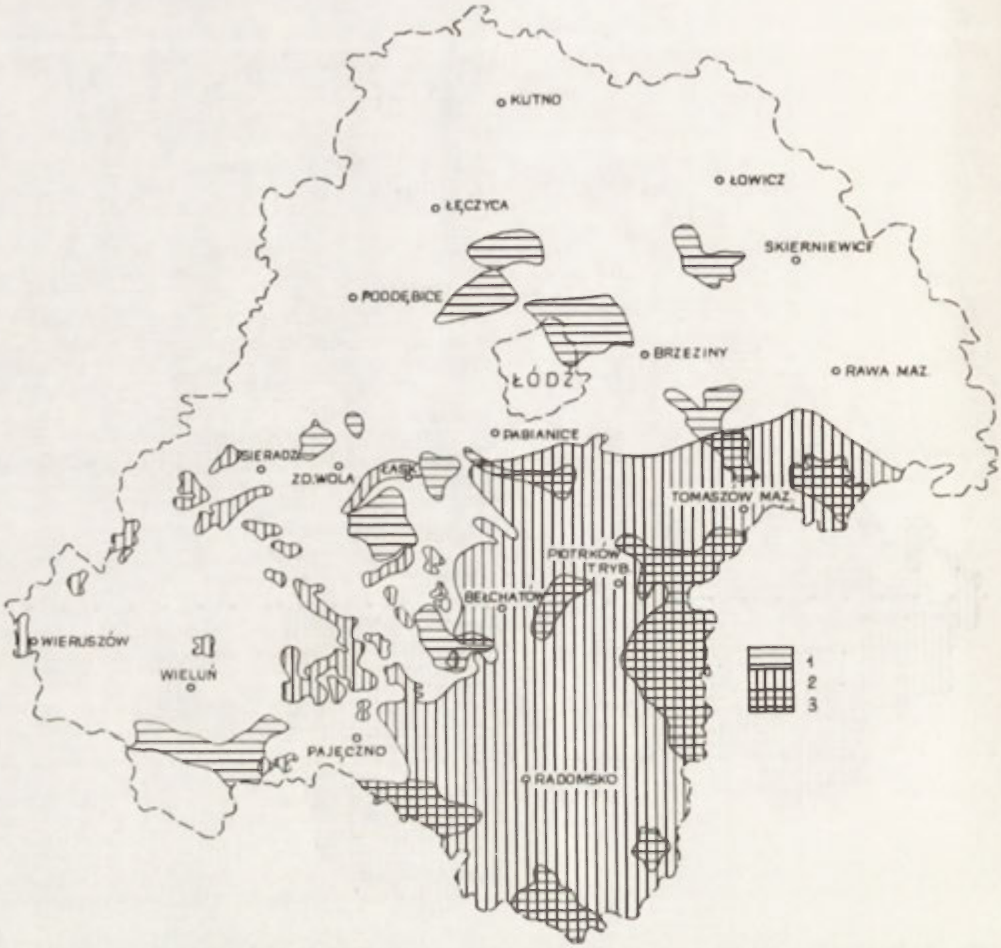

Fig. 4. Areas requiring environmental protection
Protection for:
1 — Recreation; 2 — Agriculture; 3 — Recreation and Agriculture.

favourable (Table 1). Such a pattern of wind directions is the best model for the direction of development discussed for the Łódź City Agglomeration.

Figure 4 shows the areas geographically most favourable for recreation development and for agriculture. Included in any policies for the protection of the natural environment should be the eastern and southern parts of the voivodship. It is worth noting that included in these protected areas are the following: the Pilica with the storage reservoir "Sulejów" and catchment areas for Łódź, and the spring sections of the unpolluted right-bank tributaries of the Warta and Bzura and the left-bank tributaries of the Pilica — all of great importance for the water resources of the voivodship. The rational economic development of these areas requires that before making any development decision a penetrating analysis should be undertaken of any likely changes in the geographical environment resulting from the influence of the new economic forces.

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PROBLEMS OF PROTECTING THE NATURAL ENVIRONMENT AGAINST THE BACKGROUND OF THE ECONOMIC DEVELOPMENT OF LOWER SILESIA

Janusz Czerwinski

Lower Silesia is one of the oldest and largest regions supplying industrial raw materials in Central Europe; the origin of its mining industry goes back to Neolithic times. This region supplies to Poland's economy bituminous and brown coal, and natural gas; it is virtually the only source of copper, nickel, barite, quartzitic schists, refractory and potter's clay, koalins, magnesites, all kinds of rocks like veined quartz, marbles, semi-precious stones and stone for building purposes. It seems probable that tin, fluorite and chromium ores may also be found.

On the basis of these raw materials, a powerful processing industry as well as an urban-industrial agglomeration, has developed. However, such industrialization and urbanization have brought about a number of permanent changes in the natural environment which in turn form serious problems for socio-economic progress.

The last 200 years have witnessed two grave ecological crises reflecting the impact of our modern technological revolution. The first goes back to the latter half of the 19th century when capitalist industrial conditions of production were set in motion; these took the form of numerous medium-sized and small industrial firms together with piecemeal urban growth. During this period, a rapid expansion occurred in the exploitation of hard coal and of ceramic and other rock-based raw materials. The great increase in building activities in towns and in the countryside, the construction of railway-tracks, and other developments led to deforestation in the lowland and the submountain regions of Lower Silesia. The results were permanent transformations in biocoenoses (for instance, the spruce monoculture introduced in the Sudetes), powerful processes of erosion, disturbances in natural hydrographic conditions such as increased surface runoff and diminution of natural ground water retention.

Soon after the Second World War, Lower Silesia was incorporated into the Polish State, and this made it imperative to introduce fundamental changes in the functions and the structure of the economy of tis region and to adjust them to the changed geopolitical and social regime. This transformation was particularly influenced by wartime destruction, widespread migration of the population, and economic hardships experienced during the first post-war years; and no less by the fact that up until that time the Lower Silesian industry had been concentrated in what is called the Sub-Sudetic Industrial District whose northern and eastern boundary runs along the line Ziębice–Niemcza–Dzierżoniów–Strzegom–Złotoryja–Bolesławiec and in the south along the Czechoslovakian frontier and the Sudetes chain. This is a highly urbanized and densely-settled area but it also renders valuable services as a region eminently suitable for recreation and tourism on a supra-regional scale. At the same time, one can recognize a concentration of industry exploiting coal and other rock materials, together with textile plants, works manufacturing metal products, glassware, woodwork products, foodstffs, etc. Most of these industries, however, operated in widely scattered medium-size or small plants with out-dated equipment and technology, and with attendant water consumption for power and industrial processes. The urban-industrial infrastructure so far built up in this region fails to conform to modern standards of fresh-water supply and waste-water treatment, communal amenities and services, interior communication and transport all factors potentially detrimental in environmental terms.

The deterioration in the quality of the natural environment is mainly reflected in air contamination, water pollution and modifications of the land surface. Of the total amount of dust and soot discharged throughout Poland, 12.3% originated in Lower Silesia (within the boundaries of Wrocław voivodship as defined before June 1975) one of the most contaminated regions; lying in third place, behind the Katowice and Cracow voivodships. Regarding the emission of noxious gases (18.3%), Wrocław voivodship holds second place, with Katowice leading. Much of the dust and soot emanate from the exploitation and initial processing of rock materials and chemical raw products, particularly in the Sudetes and environs — in close proximity to human agglomerations and in regions preeminently suitable for recreation and tourism. In some of the regional health resorts, air contamination is as much as 35 times higher than admissible standarts.

However, the principal problem faced by both the economy and the need to protect the natural environment is substantial shortage of water; for industry and communities alone require up to some 140,000 m^3/day. Of 98 towns, 40 suffer from water deficiency, particularly in the Legnica–Głogów Copper District, in Wrocław, in the regions of Wałbrzych, Bielawa–Dzierżoniów, and in certain other regions. Of 2247 villages investigated as many as 889 suffer periodically, and a further 123 almost all the from a water shortage.

In this difficult situation the main source must be surface water and, particularly, water from flowing streams. These streams flow especially from the Sudetes which are for the most part composed of crystalline rocks containing few groundwater resources or lakes. The streams are remarkable because of their variable discharges, the ratio of the lowest to highest flows is 1 to 1000. This leads to very unfavourable conditions, the more so since pollution of river water is steadily increasing, even in the upper reaches of streams. As things stand at present, 40.8% of the courses of the twenty most important rivers in Wrocław voivodship, carrying 90% of all resources of flowing water, are polluted in excess of pollution standards. The industries situated in the Sudetes agglomeration, especially the textile and the foodstuff industries requiring large quantities of water of a high degree of purity, operate under particularly difficult conditions. Of necessity, these factories must manage with less water, but this obviously affects the quality of their products, and clearly obstructs the expansion of industrial production; such conditions are a most significant threshold restriction (cf. B. Malisz's threshold analysis).

Underground water resources are estimated to amount to about 550 M m^3/yr, i.e. some 1.5 M m^3/day. At present, some 30% of these resources are being exploited, mainly in the lowland region because the Sub-Sudetic area lacks such underground water. The available surface water is mainly taken from streams;

calculated on the basis of mean flow volumes, and allowing for flow irregularities, this source can supply some 730 M m^3/year or about 2 M m^3/day water of different quality. Hence, all in all there seems available some 2.5 M m^3/day water equivalent to about 1 M m^3/day per inhabitant in Lower Silesia. This quanity is far from sufficient and indirectly the basis for proposed remedial measures including

(1) the construction of large storage basins with a joint capacity of some 460 M m^3; at least half of these should be situated in the lowland part of Lower Silesia, chiefly in order to supply the Wroclaw agglomeration and the Legnica–Głogów Copper District,

(2) an improvement in techniques for water retention, mainly by making full use of all local storage basins, abandoned pits, mine workings, etc.,

(3) an increase in natural ground retention by protecting forest areas, high-mountain peat bogs, etc.,

(4) technical-organizational ventures in communal services, designed to lead to more economical use of the urban water-supply,

(5) reforms to be introduced for industries that consume excessive amounts of water, including improved and more economical technological processes.

A second, and extremely important, matter is the protection of the land surface against damage in general terms the protection of the natural landscape. As a matter of fact, in Lower Silesia, no original landscapes have survived which hight be considered to contain a biological equilibrium unaffected by man; also, the area of natural landscapes where opportunities exist for biological self-adjustment (homeostasis), and which lack spatial elements introduced by man has also been steadily decreasing. Predominant above all others is a type of cultural landscape characteristic of areas of intensive human economic activities. However, in recent times, areas of degraded landscapes have proliferated in an alarming manner; especially in regions where mining is conducted on a large scale. the Turoszów Brown Coal District, the Nowa Ruda Coal Basin, the Legnica–Głogów Copper District, the Strzegom Basin, etc.

Particularly damaging to the land surface is open-cast mining for it has already caused the permanent devastation of an area of more than 83 sq km. The total area lost annually to mining, industries and expanding towns and villages is some 7 sq km, for the most part tilled land and forests. As many as 32 different minerals are being exploited by open-cast mining; the most important is brown coal, at 17 sites. The largest of these deposits, being exploited in the Turoszów basin, covers an area of 20 km^2, and is expected to reach to depths up to about 200 m. Twice as extensive are the brown coal deposits discovered near Legnica and Ścinawa; their exploitation is bound to result in a very far-reaching transformation of the local land surface — not only by reason of large excavations but also because of large accumulations of overburden (clay, sands and gravels).

A survey of the total area taken up by mineral exploitation in Lower Silesia reveals that brown coal mining occupies 42%, mining of rock material for construction work and road building 20%, and gravel and sand pits 16%. Smaller areas are suffering degradation due to mining of ceramic raw materials, fire clays and bonding minerals. The greatest annual increase in areas exploited for this sort of purposes is caused by removal of sand and gravel, accounting for 12–15% of the new land devastated. The area downgraded by quarrying rock material for construction work and road building is steadily increasing. Barely 8% of the areas exploited are being recultivated mainly by afforestation.

Effective management and control of raw material exploitation, together with a rational recultivation of regions devastated by mining operations, are obstructed by many factors, mainly by the widely scattered nature of such operations. The 32 minerals mentioned above are being mined at what are really quite large sites (182 in number); mainly through the use of mechanical equipment in continuous operation, and at a further 689 smaller localities operated only periodically. Under the present-day industrial structure, all these enterprises are controlled by 10 ministries, 26 industrial unions and 47 larger firms — some of latter having no main office in Wrocław voivodship.

Using as a basis a geological map and another map illustrating the distribution of raw material resources, the author is compiling a map marking areas subject to mining privileges, and a number of other maps showing potential material resources. As part of the national policy of utilizing available raw materials of particular importance are: (1) the concentration of mining and processing industries in areas of mining privileges, (2) the comprehensive use of raw and waste materials, which are often useful as secondary or subordinate raw materials, (3) the protection of mining areas set aside for future exploitation against any sort of permanent modificating, (4) safeguarding cultivated land of the highest (I to III) levels of fertility, (5) the abandonment or limitation of exploitation of ceramic raw materials, and sand and gravel, in areas of high fertility, with the development of alternate sites within areas of mining privileges, (6) changes in the utilization of land foreseen for future mining operations should not take place until actual mining operations start, (7) a preliminary, though critical estimate of gains and losses likely to result from disturbance of the biological equilibrium.

The gradual socio-economic evolution of the region is leading to the formation of three types of spatial structures:

(1) the Wrocław agglomeration and the urban-industrial agglomeration in the Sub-Sudetic and the Legnica–Głogów zones,

(2) areas marked by intensive production in agriculture and forestry,

(3) areas intended to provide recreation, and especially preserved for this purpose.

Obviously, the foreseen, and often unavoidable, evolution of areas of type 1) is bound to take place to the detriment of types 2) and 3). However, since the evolution of agriculture and the production of nutrition is a matter of increasing economic importance, areas of high rural fertility are under special protection. By reason of these two necessities, one has to expect a gradual encroachment upon areas intended to serve recreation, in the sense of preservation of the natural environment; this calls for continued protection of areas of significant natural value and landscape beauty.

In practice, spatial planning of the development of Lower Silesia, has not yet properly taken into account this latter problem. So far the protection of the natural environment has been concerned to protect remarkable natural features, monuments, reservations, and national parks — all of which come under the control of the Ministry of Forestry. However, improved living standards, expanding tourism, increased motorization, and other factors are exerting a heavy pressure upon areas of recreation leading to their rapid deterioration. This is particularly true of what are called protected zones, which fail to serve the purposes for which they ware established. This situation led, in 1971, to the adoption of a new pattern for the comprehensive protection of the natural environment, based on a system of reservations of nature's beauty of national parks, landscape parks and zones of landscape protection and forested zones screening urban-industrial agglomerations.

In its first stage (Kozłowski 1971), this new scheme was to include an area of some 12.1% of Wrocław voivodship and, in its second stage (Czerwiński, Sachanbiński 1974) some 20%. Conformable with Kozłowski's suggestion, the term "landscape parks" would apply to areas of conspicuous natural value, highly attractive to tourists and leisure-seekers. Any sort of encroachment upon the structures of local biocoenoses and of the ecological equilibrium would be prohibited in these parks; in others "natural" land use would be admissable but exclusive of any kind of mineral exploitation. Zones or areas of landscape protection would be set apart for an extensive rural and forest economy, in which it would be prohibited to establish new settlements or new industrial plants harmful to their surroundings; while parallel with any sort of exploitation of mineral raw materials there would have to be suitable programmes of recultivation.

The principles underlying this new pattern are:

(1) restricting the intensity of tourist travel in natural parks and in landscape reservations, by its deglomeration;

(2) providing permanent protection for areas of high natural beauty and usefulness for recreation, especially of zones of landscape protection;

(3) setting aside areas to be used, in the future, for recreation and leisure;

(4) limiting, as far as possible, the concentration of exploitation and processing of mineral raw materials to areas with mining privileges — a procedure which, economic motives apart, would facilitate a comprehensive policy of environmental protection.

The task of determining and delineating areas to be placed under protection is a problem demanding experience in geography and planning, and must be assigned to the research programme of geographers.

The scheme of protected landscape zones in Wrocław voivodship is founded on natural, social and economic considerations. It is based on detailed physiographical investigations, existing and potential mineral resources, hydrographical features, grades of usefulness, pollution control (e.g. the protection of areas rich in magnesium and other trace elements), the degree of modification made so far and aesthetic motives.

In particular instances, when taking natural landscape protection into account, it is necessary to view this from the viewpoint of conservation, as in the safeguarding of species of plants and animals, biocoenoses, unaltered or relatively unaltered natural landscapes, and scientific research purposes, as it applies to phenomena which are unique on a national or regional scale.

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PROTECTION AND DEVELOPMENT IN THE NATIONAL PARKS OF ENGLAND AND WALES: THE ROLE OF THE PHYSICAL ENVIRONMENT

I. G. Simmons

INTRODUCTION

Most of the industrial nations of the world, together with a large number of less-developed countries, have designated parts of their land and water resources as National Parks. In any hierarchy of regions accorded a special status, these areas are usually the highest element and they thus reflect the high value put on them by the people of the nation in wich they are found. Most people want firstly to protect such areas against rapid change due to economic expansion: to control the building of industrial establishments or the destruction of forests. At the same time, people wish to visit these areas and pursue a wide variety of activities in them: to walk, camp and have picnics, to climb mountains, to observe flora and fauna, and increasingly to drive through the parks in their cars with short roadside stops *en route.*

In all National Parks, however, these cultural demands rarely take place in an environment which is capable of manipulation to meet all of man's wishes since the very nature of the terrain's values for Park purposes are often the result of a relatively vigorous physical environment. In such areas, as elsewhere, there is, and has been, a constant interplay between the influences of topography, climate, and vegetation, and the response of particular peoples both to the opportunities offered and the constraints exerted by the environment. So each nation responds in its own way and this paper attempts to describe the situation in England and Wales, looking first at the role of physical geography in the choice of areas to designate as National Parks, and then at the ways in which it affects the management of them.[1] First a brief description of the parks and their history will be attempted.

NATIONAL PARKS IN ENGLAND AND WALES[2]

Although various attempts were made during the inter-war period to have National Parks declared by the central government, it was not until the national stocktaking which World War II provoked that any serious consideration was

[1] Most of the ideas and examples in this paper were gained by the author when he was representative of the Minister of the Environment on a National Park planning committee from 1963–72.

[2] A chronicle of the changes brought about by development and prevented by development control can be seen in the *Annual Report* (HMSO, London) of the cen-

given to the topic. A report was commissioned, and in 1945 John Dower produced a document which set up a case for parks which was considered in detail by the Hobhouse Committee of 1945–47. Their report was widely accepted and formed the basis for the bill which was passed by Parliament as the National Parks and Access to the Countryside Act of 1949. Between the Royal Assent and 1957, ten National Parks were designated (Fig. 1). There was one very significant difference between the parks as Dower envisaged them, and the Act as passed. Dower had in mind the setting up of virtual wilderness areas, where nearly all economic acitivities would ideally be absent or at any rate strictly controlled. But recognizing the nature of the economy of the areas which were in 1947–49 suggested as potential parks, the government decided that designation as a Park should hinder as little as possible the traditional life of the region, while providing for some measures for the control of development and for public access to the countryside. Thus there is inherent in the Act a series of potential conflicts: (a) between economic development and protection of the rural scene, and (b) between protection of valued landscapes and development for outdoor recreation. To some extent, the original impetus for the preservation of valued landscapes has become overwhelmed by the flood of automobile-borne recreation-seekers, yet money for the parks has always been so difficult to extract from the Treasury that it has been easier to emphasize protection at the expense of development for recreation, since it is much cheaper.

In order not to inhibit greatly the economic life of the Parks, two major activities were exempted from development control. These were firstly agriculture, which is dominated by the extensive pasturage of sheep upon rather poor forage, and secondly forestry, which is dominated by plantations of exotic conifers (such as Norway Spruce (*Picea abies*) Lodgepole Pine (*Pinus contorta*) and Sitka Spruce (*Picea sitchensis*) made by the Forestry Commission since 1919. Changes in agriculture, such as the increase in size of modern farm buildings and the practice of ploughing up marginal land for cereal crops, along with the rather monotonous landscape produced by some of the Commission's forests, have produced conflicts between those who favour preservation of traditional landscapes and those who earn their living in the Parks.

Further complications have arisen from the management institutions which have been authorised for the Parks. Each of these has been governed by a committee which has consisted of two groups of people. Two-thirds of the body

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tral government's advisory and beaurocratic (in the sense that it channels finance etc., but does not itself manage land) body. This was the National Parks Commission from 1949–68, and the Countryside Commission from 1968 to the present. The report by John Dower was *National Parks in England and Wales*, Cmnd 6628, HMSO 1945, and that of the Hobhouse committee, *Report of the National Parks Committee*, Cmnd 7121, HMSO 1947. The National Parks and Access to the Countryside Act 1949 was 12, 13 and 14 Geo 6, c. 97; the Countryside Act 1968, 16 and 17 Eliz 2, c. 41. The current financial arrangements are set out in the White Paper, *Leisure in the Countryside*, Cmnd 2928, 1966. Annual synopses of current problems are given in the *Reports* of the Annual Conference of National Park Authorities (Published by the authority of the host park), and immediate reports of some developments in *Recreation News*, published by the Countryside Commission. A valuable synopsis of the first decade or so of the Parks was given by H. C. Darby, "British National Parks" *Advmt Sci 20* (1963) pp. 307–18, and a review by an outsider is W. A. Johnson, *Public Parks on Private Land in England and Wales* (Baltimore: Johns Hopkins Press for RFF, 1971). The present author has tried to place the English/Welsh Parks in an international context in his "National Parks in developed countries" in A. Warren and F. B. Goldsmith (Eds) Conservation in Practice (London: Wiley, 1974) pp. 303–16, and *Rural Recreation in the Industrial World* (London: Edward Arnold 1975).

are members of the local County Council (and hence elected), although not necessarily residents of the Park area; one-third are appointed by the Minister of the Environment. There is thus a feeling on one hand that the running of the parks is not democratic, and on the other that since two-thirds of the com-

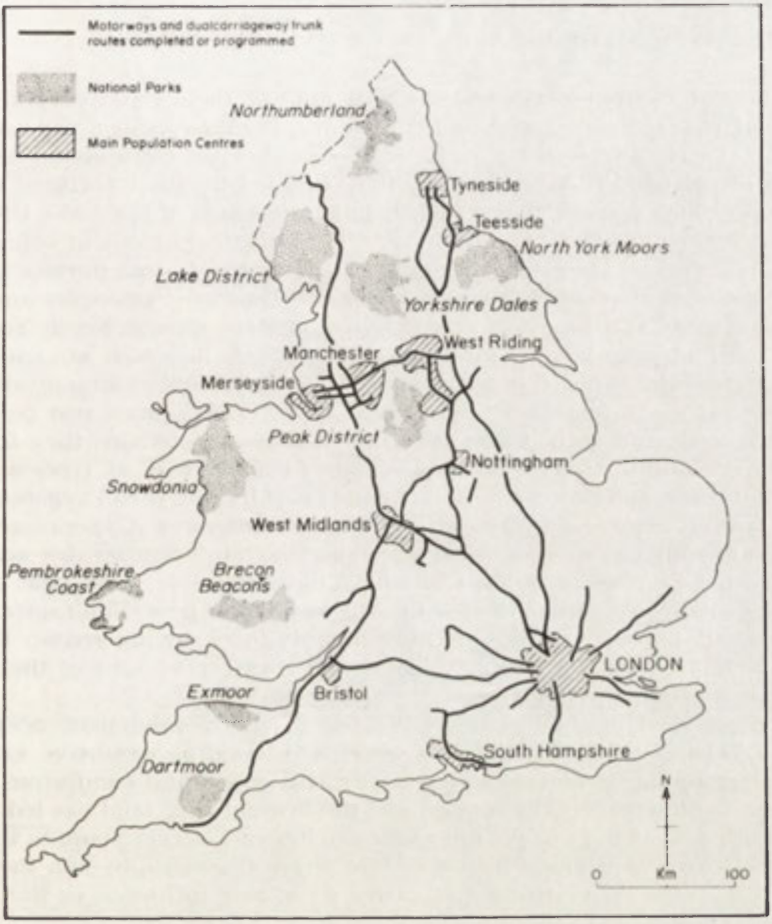

Fig. 1. England and Wales, showing National Parks, major population centres and key roads

mittee are local people, then the parks cannot be truly national; the more so since 25% of all expenditure, plus administration costs, has come from County budgets. Within any Committee, different groups of people view the park and its environment in various ways. Elected Councillors who are tenant farmers of hill-sheep farms are primarily concerned with their income, since farming is not particularly profitable because of the size and nature of their holding and because of the climate and topography, and so they are unwilling to accept constraints on developments such as intensive-use farm buildings and the conversion of unused buildings to vacation homes. A second group consists of long-standing, often aristocratic, land-owners who are opposed to any change (such as more tourism) which means a difference in the economic base of the region but are willing to accept change within that base such as more forestry, and different farming techniques. Yet another group are residents of the park who have retired there and who wish basically to see no change in the landscape at all. Hopefully the last group, which includes most of the Minister's members, try to see the problems objectively and realistically.[3]

ROLE OF PHYSICAL GEOGRAPHY IN THE CHOICE OF PARKS

A study of the ten parks reveals that nine of them have very similar geographical characteristics although the tenth, Pembrokeshire, consists largely of a coastal strip and will be excluded from subsequent discussion unless specifically mentioned. Their geography is dominated by their features as upland areas, with much terrain above 300 m, and in the case of the Lake District and Snowdonia, they are truly mountainous. The geological base is of volcanic rocks or other strata of a resistant lithology, such as the Carboniferous Limestone and Millstone Grit (Peak Park and Yorkshire Dales for example) and various sandstones, grits and limestones in the Brecon Beacons and North York Moors Parks. The higher ground is interrupted by valleys in which are concentrated the most desirable land for settlement, agriculture and communications; and on whose sides afforestation tends to be found. Lakes may also be found in the lower areas and since these are usually accessible by car, they form magnets for recreation. Above 270 m the land is usually bare of trees apart from recent plantings, and the vegetation is dominated by low shrub vegetation often of the family Ericaceae (e.g. *Calluna vulgaris*), sedges (Cyperaceae such as *Eriophorum* spp) and grasses (Gramineae such as *Molinia caerulea* and *Nardus stricta*). On the highest ground, and where there is a low slope, peat up to 6 m deep may cover large areas; this is known as blanket peat. The rainfall at such altitudes will be of the order of 2100 mm/yr, the growing season for plants about 120 days: in all, a damper, cooler and cloudier version of the maritime climate of the British Isles.

These physical characteristics have led to the development of particular patterns of land use in the uplands which are based on extensive rather than intensive cropping of biological resources. Hill sheep and coniferous trees can both grow in this marginal situation and the low value of land has led to appropriation of parts of the valleys for water catchment reservoirs and to the growth of mineral extraction along hillsides. The physical geography can therefore be seen to have exerted a strong and easily detectable influence in the evolution of resource processes in these uplands.

The same processes have also produced landscapes which are highly valued by the British people. The combination of river, farmland and open moor beyond the stone-built farms or simply the vast expanses of treeless moor, are regarded by many as the outstanding landscape scenes of Britain, and the relatively low intensity of land use means that opportunities for walking, picnics, camping and other outdoor recreation activites are all potentially higher than in the lowlands. To those who do not know the institutional arrangements for the Parks, the term "National" conveys a sense of public ownership which is not everywhere the case, although there are large stretches of "common land" to which the public may have *de facto* (and in much of the Lake District NP, *de jure*) access.

[3] See the discussion of this point in the National Park Guide No. 9, *Yorkshire Dales* (London: HMSO, 1971) pp. 61–62.

We can see therefore that these landscapes are "residual" lands with a relatively low monetary value because of their physical environment; but that their intangible valuation by the people is high because of their total geographical characteristics.

THE ROLE OF PHYSICAL GEOGRAPHY IN THE MANAGEMENT OF PARKS

(I) DEVELOPMENT CONTROL IN RELATION TO PHYSICAL FACTORS

The Park planning committees have considerable powers to control certain kinds of development and the major demands for development will be reviewed here,[4] together with the role of factors of physical geography and the attitudes of planners. Some of the relationships are summed up in Table 1.

TABLE 1. Some of the linkages between types of economic use and factors of physical geography with comments on special cultural influences

	Geology	Topography	Climate	Soils	Vegetation	Hydrology	Influence of physical geography		Special Cultural Influences
							Direct	Indirect	
Housing		X						X	Planning control strict
Minerals							X		Planning control strict
Roads		X	X				X		Routing of major roads passes for decision to Environment Minister
Water	X	X	X		X	X	X		Siting of major reservoirs passes for decision to Environment Minister
Military use		X						X	Strong presumption that this is an unsuitable use of NP's
Agriculture		X	X	X			X		No planning control. Some informal agreement
Forestry		X	X	X	X		X		No planning control. Large measure of informal consultation

(a) *Housing*

Demands for housing are of two types. Although these uplands are areas of depopulation or of very slow population growth, the need for new housing both for local residents and for incoming people is persistent. Added to this is a strong demand for second, or vacation, homes which form the weekend and holiday retreats of urban dwellers. Almost any abandoned or saleable structure will be bought for the latter purpose: old hay barns, roofless cattle sheds and tiny miners' cottages all find ready buyers at rather high prices. Physical geography has played its part in this sector of change largely in the past, when the settlement pattern was determined, particularly where an agricultural economy has always been dominant. If the solid geology is included as part of

[4] Popular books on the National Parks which describe their topography include H. M. Abrahams (Ed) *British National Parks* (London: Country Life, 1951) and R. Bush, *The National Parks of England and Wales* (London: Dent, 1973). The Countryside Commission arranges for the publication by HMSO of a short *Guide* to each park.

the environment, then the presence of mineralized veins, which were the basis of a lead industry in the Yorkshire Dales which took settlement into remote valleys beyond the limits of agriculture, should also be included. The contemporary influence of physical factors is less easy to see since modern transport has largely overcome the former barriers of inacessibility which confined settlement patterns, but it can be seen in the refusal by planning authorities to permit housing development in exposed sites visible from long distances, an unnecessary prohibition in tree-clad landscapes.

The exercise of planning control is almost always based on cultural rather than physical values. The policy (as exemplified in the valleys of the Yorkshire Dales NP) usually seeks to fill in gaps in existing settlements and not to let them "sprawl" at the edges, to prescribe harmonious building materials, and in general not to allow buildings to undergo a change of use. A broken-down hay barn may not usually be converted into a vacation house, but it may be "quarried" to build a stone house in the nearest village.

(b) *Mining and quarrying*

The presence of mineral extraction relates directly to the geology of the region and to access for exploitation purposes. Most mineral removal is by quarrying (e.g. limestone in the Peak District NP, slate in the Lake District NP and granite in Dartmoor NP) but underground mining may be found as well, as with potash on the boundary of the North York Moors NP. Whatever difficulties might be imposed in terms of physical factors, via the media of accessibility or extraction costs, they are usually overcome by the high price payable for the product. Constraints are more effectively exerted by planning controls, in the shape of outright refusals to allow quarries or quarry extensions (as at the margins of the Peak Park where the largest quarry in Europe is found), in the restrictions applied to routes taken by quarry traffic, and in the imposition of landscaping conditions such as the screening of installations by trees and the restoration of abandoned sites.

(c) *Road building*

The original road pattern of the Parks served a rural community (both agricultural and industrial) and was dominated by a valley-related pattern although there are exceptions, as with the high moorland roads above Garsdale in the Yorkshire Dales NP, and the interfluve-following roads of the North York Moors NP. Modern road building is very cost-conscious so that the topography exerts a very strong influence. This can be seen in the routing proposals for a major trunk road (A66) to pass through the Lake District NP along the Greta valley and past Lake Bassenthwaite; and for the Sheffield-Manchester motorway to pass through the Longendale valley in the Peak District NP. Planning control generally tries to refuse major road schemes the right of access to the Park, but in the case of major roads, a public enquiry is held into the scheme and Minister of the Environment makes the final decision.

(d) *Water catchment*

The upland areas under discussion often present good sites for the impoindment of water. The high rainfall is frequently accompanied by peaty watersheds which release water steadily, and steep-sided valleys which make good reservoirs when dammed. There is here a direct influence of the physical geography, as shown by examples in the Lake District, (Thirlmere and Haweswater are enlarged natural lakes), the Meldon reservoir in Dartmoor NP, and the new Kielder reservoir in the Northumberland NP. The attitude of the planning committees is similar to that taken over roads, with the possible softening of views if it is apparent:

(a) that the lake will be available for recreation and will add appreciably to the inland water resource for appropriate activities; and
(b) that a refusal in one place will lead to increased pressures for reservoirs at places valued even more highly.

Water resource development is a somewhat emotive subject and some areas feel themselves to be, as it were, saturated with impoundments to the point where all further proposals must be resisted: there is the further overtone of nationalism which occurs when Welsh water is garnered to serve English industry and homes.

(e) *Military use*

The open character of uplands has made them desirable for some kinds of military training and a few such areas are in National Parks: Dartmoor is the outstanding example. A recent government report has recommended the release of much of this land back to non-military uses.[5]

(f) *Agriculture*

The type of agriculture practised in the upland National Parks is principally the outcome of climate, topography, soils, animal breeding and government subsidies. It is therefore apparent that the physical geography exerts a strong and direct influence upon the agriculture: in this case confining it to a very restricted form: mostly hill farming of sheep. The breeding females (ewes) stay on the moorland all year round, and the lambs are sold off for fattening in the lowlands. Government subsidies make this type of husbandry possible, for the small units and low biological productivity combine to make the enterprise basically unprofitable.

Even though the physical environment is distinctly marginal for agriculture, the number of subsidies paid to farmers in the hill lands (e.g. for ploughing up moorland, for fencing and for fertilizers) means that some farmers will plough up moorland (usually near roads) in order to take a cereal crop so long as the rather acid soils will sustain it. Such actions change the landscape considerably and may also enclose and transform land which hitherto had been accessible for open-air recreation. Since the 1949 Act excluded agriculture from development control, the planning authority can rarely interdict ploughing even where they would wish to do so as in the North York Moors and Exmoor NP's. Their first reaction is usually to seek an informal agreement with the landowner to restrict his intaking; if this is unsuccessful and if the area is sufficiently important on landscape or recreational grounds, then compulsory purchase may be applied. This power was granted in the 1949 Act, but first used in 1972 in the Exmoor NP.

(g) *Forestry*

The English uplands were deforested of their "natural" cover of deciduous species during prehistoric and medieval times and when, after World War I, reforestation became government policy, the native species were found to grow very slowly upon the podzolized and gleyed soils which had developed since the tree cover was removed. Further, the open nature of the terrain made the establishment of young trees very difficult since they became liable to wind damage once they were about 0.75 m high. The response to this situation was the use of exotic coniferous species, of which Sitka Spruce (*Picea sitchensis*) is the most important, and these now cover large areas. In ecological terms,

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[5] *Report of the Defence Lands Committee* 1971–3 (London: HMSO, 1973), and the government's White Paper in response, Statement on the Report of the Defence Lands Committee 1971–3 (London: HMSO, 1974). The report is known as the Nugent Report.

the conifers probably increase the rate of podzolization and certainly the second crop will require high rates of fertilizer application to the soils; aesthetically the new forests have attracted much opprobrium on account of the regular rows of trees and the straight edges of the planting blocks. Examples of ugly plantations in the Lake District NP are especially noticeable. They drastically alter the traditional scene and may in addition require the diversion of walking trails. Sensitive to some of this criticism, the Forestry Commission has of late tried to "soften" the edges of its words by following the contour at the upper edges of plantations, and by planting a belt of natural hardwoods round the blocks of conifers. Like agriculture, forestry is not subject to development control by the National Park authorities. All Parks now have however an informal agreement to be consulted by the Forestry Commission before both planting and felling, and most now have maps which indicate

(a) areas where forestry is thought to be unsuitable on aesthetic or recreational grounds;
(b) areas where it may be possible, given special care; and
(c) areas where there is no official opposition to planting.

In all these zones, the local details of slope, exposure, drainage, soils and existing vegetation play an important role.

The exclusion of forestry and agriculture from development control has been a subject of contention since 1949 between the resource managers and the aesthetically-minded public. Successive governments have affirmed the position of the 1949 Act but it is interesting to note that the National Parks Policy Review Committee (the Sandford Committee) recommended in 1974 [6] that both these land uses should be brought under planning control in the National Parks. The government has not accepted these recommendations.

(II) DEVELOPMENT FOR OUTDOOR RECREATION AND ITS RELATION TO PHYSICAL GEOGRAPHY

This section will consider the major ways in which the 1949 Act's provisions (as modified by the increased availability of Treasury money made available by the Countryside Act of 1968) for the development of public access to the Countryside for the purpose of outdoor recreation have been applied. Both public and private sectors of the economy are involved. Some of the linkages are set out in Table II

(a) *Camp and caravan sites*

Both public and private sectors are involved here. Provision of these facilities by profit-seeking individuals tends to be of static caravan sites for use as vacation houses, and irregular and unserviced camp-sites. Caravan sites beyond a certain size are subject to both ordinary planning control and to the Caravan Sites Act 1960 which specifies the provision of certain facilities. Camp-sites, on the other hand, are little subject to control. The National Park authorities have developed a number of sites: in the Lake District NP the policy tries to reduce the rash of sporadic camp-sites all over the park at popular times. They also develop caravan sites in order to cater for touring caravans, which are less catered for by the private sector, and in both cases the planners hope to de-

[6] Department of the Environment, *Report of the National Park Policies Review Committee* (London: HMSO, 1974). Known as the Sandford Report.

monstrate the standards of aesthetics and environmental concern which they feel are appropriate to a National Park.

They are most likely, for instance, to respect the constraints exercised by physical factors, especially where topography is concerned. The demand for sites is heaviest in the valleys, and attempts are made to screen them from public views. Development of publicly-owned sites therefore tries to use those features of the topography which provide greatest cover, such as mounds of fluvio-glacial debris, and small belts of woodland. A particularly interesting linkage comes with the use of flood plains. Topographically these are highly suited to caravan and camp sites but their position in unforested maritime uplands sometimes brings hydrological problems: the Lake District and Yorkshire Dales NPs have had flood problems at such sites. It is not surprising, therefore, that strict planning control and design standards are applied to these features of recreation development; and that the demand exceeds the supply at periods of peak use: illegal camping (in odd corners of fields, for example) and caravan parking (in roadside laybys) occurs frequently in National Parks at major holiday times.

TABLE 2. Some of the linkages between developments for outdoor recreation and factors of physical geography, with comments on special cultural influences.

	Geology	Topography	Climate	Soils	Vegetation	Hydrology	Influence of physical geography: Direct	Influence of physical geography: Indirect	Special Cultural Influences
Camp and caravan sites		X			X	X	X		Public and private sector. Strict control and selection essential
Picnic sites		X	X		X		X		Public sector. Related to land use and road patterns
Youth Hostels		X						X	Related to communication patterns.
Car parks and W.C.s		X						X	Public sector. Related to land use, roads and settlements
Traffic control		X						X	Public sector. Conflict with private sector in settled areas
Access to open land		X			X		X		Aim is to resolve conflict between landowners and visitors

(b) *Picnic sites*

These are developed by the National Park Committees almost exclusively. Their sites are determined by the patterns of roads and land use and so the influence of physical geography is indirect.

(c) *Youth Hostels*

A few of these have been developed jointly by the Youth Hostels Association and the park planning authorities, and are usually placed where a long-distance footpath intersects a public transport route but where inexpensive accommodation does not exist. (Examples are at Hawes in the Yorkshire Dales NP on the Pennine Way, and at Helmsley on the Cleveland Way). In view of these location factors, the influence of physical geography is indirect and rather weak. Since the Park authorities pay part of the cost, planning control is strict on the actual location and materials used in building, for example.

(d) *Car parks and public conveniences*

Since so many visitors to the Parks come by car, and since the narrow roads and small villages offer so few parking places, the Park authorities have developed a number of such facilities either to take the strain off existing places (e.g. at Hawkshead village in the Lake District NP) or to provide a measure of control at places of especial interest (e.g. at Aysgarth Falls in the Yorkshire Dales NP). As might be expected, the influence of the physical environment is indirect and largely historical, via the patterns of land tenure (e.g. the shape and size of the field which is purchased for development) and of the roads. The influence of planning control is equally strict since it is the planning authority itself which is carrying out the development.

(e) *Traffic control*

Apart from trunk roads which cross them, the National Parks have narrow roads derived from pre-20th century agricultural and mining days, and these are unsuitable for the weight of modern recreational traffic. The park authorities and the Countryside Commission have initiated a series of experiments in traffic control in recent years.[7] The most obvious of these has been the exclusion of cars from a very popular scenic area and the provision of a free minibus service into it for those who cannot or will not walk. The Goyt valley in the Peak District NP is the outstanding example, but a similar service has been initiated along the Hadrian's Wall section of the Northumberland NP. Other schemes, including "tidal flow" traffic for narrow roads have usually met with strong opposition from local people who fear either that their own mobility will be restricted or that those in the catering trade will lose money since lower absolute numbers of visitors will go to these outstandingly popular places.

Again, the influence of physical geography is quite indirect and removed in time, since present recreation use is mostly the intensification of the usage of pre-existing pattern.

(f) *Access to open country*

Although the NP's contain much open, unfenced land (especially moorland), this does not mean the public have *de jure* right of access, and in the enclosed farmland, the only legal access is along public rights of way such as footpaths and bridleways. This pattern is modified by the fact that Common Land which was in Urban Districts (before these latter disappeared in the local government reorganization of April 1974) was open freely to the public. Constraints on public access to other Common Land often exist where the moorlands are kept for grouse (*Lagopus scoticus*) which is shot by the wealthy in a season beginning on August 12th. While the birds are nesting, and in the few days preceding a shoot, the owners of the shooting rights are anxious that the birds should not be disturbed. Conflict between walkers and gamekeepers has in some parts of the Peak District NP for instance, been severe to the point of violence. Where these and other conflicts occur, the Park authorities may try to negotiate an Access Agreement whereby the public may gain legal access to a piece of land and in return the landowner is financially compensated for any loss he may suffer. Apart from the factors of the grouse habitat, it cannot be said the physi-

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[7] See for example J. C. Miles, *The Goyt Valley Traffic Experiment* (London: Countryside Commission and Peak Park Planning Board, 1972) and the wider range of Robert Matthew *et al. Transport for Countryside Recreation* (London: Countryside Commission, 1974). The wider context of the role of the car is discussed by J. M. Hall, "Leisure motoring in Great Britain: patterns and policies", *Geographia Polonica* 24 (1972), pp. 211–225.

cal geography is of direct importance in this process except via the route of the visitors' perception of the virtues of their environment and the possible conflicts with the attitude of the landowner. It may be added that if all else fails, the Park Committee may exercise its powers of compulsory purchase but they are reluctant to do so because of the composition of the committees themselves and because of their desire to achieve harmonious relations with the landowning community.

The majority of development for outdoor recreation in the rural areas of the National Parks is undertaken by the planning authorities, and as such is strictly limited to that which the legislation and available finance permits. The Sandford Committee referred to above found that much more money should have been spent on recreation facilities and access. If more is available in future, it is difficult to predict whether it will lessen or exacerbate conflicts of the kinds just described, unless the major developments came in the wilder areas of the parks, a possibility much constrained by the facts of physical geography and by the cultural desire not to impinge on what little wild land is left in Britain.

THE PEMBROKESHIRE COAST NATIONAL PARK

This Park differs from the rest in comprising essentially a low plateau which is terminated by an extremely varied and beautiful coastline.[8] The constraints on all types of use are less than in the upland Parks and its problems are directly related to two particular features. The first is its relative isolation from much of Britain and hence the lack of employment opportunity. This leads to a local desire to bring industry to the region and places the Park values a long way behind industrialization. The second factor is that the geomorphic development of the region has produced the largest and most sheltered deep water harbour in Britain: Milford Haven. Here an oil tanker terminal is situated and consequently a refining industry has grown up, further interfering with both the purposes of the National Park. Short of the immediate exhaustion of the world's fossil fuels, which might solve all this Park's problems, the future industrialization of this Park seems bound to increase.

CONCLUSION

The elucidation of the effect of factors of physical geography upon the course of protection and development (whether for economic purposes or for recreation) is not simple. Some influence can be seen to be direct: witness the effect of climate in the selection of tree species for afforestation, for example. Others, although equally direct, have operated mostly in the past: the combination of climate, soils and topography which has led to the boundary between enclosed land and open moor is an example that comes to mind. Elsewhere, the physical influence may be indirect — the location of roads has been much affected by slope considerations and it in turn is now the genesis of matters such as the location of new houses, of caravan sites and car parks, and of experimental traffic schemes.

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[8] B. S. John, "Oil men go West", *Geogr. Mag.* (June 1972) pp. 590–92; idem, "Geomorphology and land use conflicts in the Pembrokeshire Coast National Park", in J. Norrman (Ed.) *Tillampad Naturgeografi* (Uppsala: Uppsala Universitets Naturgeografiska Institut, 1975).

Equally, people's perception of the environment of the Parks is both direct and indirect. The professional planner sees the area largely as a set of concrete phenomena whose array in space and time is constrained by certain elemental factors which he may not alter: the distribution of mineralbearing rocks, for example, or the tendency of a particular river to flood a certain valley at particular frequencies. By contrast, a city dweller perceives the park mostly as a totally different place from his everyday experience — another world, perhaps — and is only vaguely conscious of the interaction of man, land, and time that has made it so. Both would regard their view as equally 'real' and the political influence of the latter, if he belongs to organizations such as the Ramblers' Association or the Council for the Protection of Rural England, is not negligible.

It is no more easy to decide whether the physical environment of the upland parks is conducive more strongly to development or to protection. The simple arithmetic of Tables I and II, which would lead marginally to the conclusion that development for economic purposes was more closely and directly linked to the physical geography of the regions than either recreation development or landscape protection, conceals a more complex situation in which no one change is made for any purpose without bringing others in its wake. A computer simulation or an analogue model which compared for example natural and man-made energy flows in the Parks might lead to greater objective understanding of the present role of the physical environment. For the present most people have only an intuitive grasp of the meaning of the *zusammenhang* of all elements, cultural and physical, which comprise the parks and the way the components interact. The geographer, perhaps, is well placed to recognize that complexity in terms both of the contributions of nature and the values placed thereon by a particular nation.

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