ENVIRONMENTAL ASSESSMENT

Landform Classification for Land Use Planning in Developed Areas: An Example in Segovia Province (Central Spain)

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ABSTRACT / Landform-based physiographic maps, also called land systems inventories, have been widely and successfully used in undeveloped/rural areas in several locations, such as Australia, the western United States, Canada, and the British ex-colonies. This paper presents a case study of their application in a developed semi-urban/suburban area (Segovia, Spain) for land use planning purposes. The paper focuses in the information transfer process, showing how land use decision-makers, such as governments, planners, town managers, etc., can use the information developed from these maps to assist them. The paper also addresses several issues important to the development and use of this information, such as the goals of modem physiography, the types of landform-based mapping products, the problem of data management in developed areas, and the distinctions among data, interpretations, and decisions.

Developed regions have in common an intense competition for land. A high concentration of uses and infrastructures takes place in and around urban areas, whereas the traditionally extensive agricultural and rural zones are more selective and intensive in their activities. This pressure often entails fast and dramatic changes in the landscape.

Planners, managers, and politicians have the task of accommodating the many social needs in these regions, mainly by making decisions concerning those elements of the environment that can be manipulated (Warrington and others 1989). Allocation of land uses affects many of those controllable elements of the environment and may become a key component of decision of any land use plan.

For a workable allocation of land uses, planners and land managers need to consider information from both the physical and biological components of the environment and from the social and economic situation. In this paper, we deal with the former—the land, focusing on its inventory and evaluation.

Land evaluations depend on the purpose of the planning, but two distinctive characteristics normally have to be considered in developed areas: limited availability of natural resources and land, and the risks involved in the high concentration of goods and infrastructures. Safety from natural hazards and the protection of natural resources, ecosystems, and landscapes are, therefore, among the priorities of any land-use planning and management of developed areas.

To provide input for these evaluations, an inventory must be constructed to document relevant properties of individual resource elements. The inventory should be carried out to meet the objectives of the evaluation. While the specific objectives of any inventory and evaluation may vary, there must be effective two-way communication between the decision-makers and the scientists gathering the information. The decision-maker

KEY WORDS: Land classification; Landform mapping; Terrain analysis; Physiography; Landscape; Land use/territorial planning; Segovia;

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Table 1. Selected references describing landform-based physiographic classifications (in approximate chronological order)

Land Classifications	Selected references
American physiographic pioneers (landform-based classifications at regional scale)	Powell (1895), Salisbury (1907), Fenneman (1917)
Birth of the land-type concept (United States)	Veatch (1937)
The beginning of land classification by aerial photo interpretation (British foresters and soil scientists)	Bourne (1931), Unstead (1933), Milne (1935).
British Geography	Wooldridge (1932), Linton (1951)
Initiation of landscape ecology (Central Europe)	Passarge (1919–1920), Troll (1950)
Russian physical geography	Vinogradov and others (1962), Solntsev (1962), Sochava (1974)
Australian CSIRO (Commonwealth Scientific and Industrial Research Organization) method and diffusion of the land-system concept	Christian (1958), Christian and Stewart (1968), Stewart (1968)
British engineering geology applications (MEXE—Military Engineering Experimental Establishment—system)	Beckett and Webster (1969), Brink and others (1966), Howard and Mitchell (1980)
Other East and Central European schools of physical geography and geomorphology	Neef (1963), Haase (1964), Bertrand (1968), Pecsi and Somogyi (1969)
Australian engineering geology applications (PUCE—pattern, unit, component, unit—system)	Aitchison and Grant (1968), Grant and Finlayson (1978), Finlayson (1984)
CSIRO and PUCE method-based for landscape and environmental planning in Australia	Arnot and Grant (1981), Christian (1982), Finlayson and Buckland (1987)
Land surveys of the International Institute for Aerial Survey and Earth Sciences (ITC, Holland)	Van Zuidam and Van Zuidam (1979), Meijerink (1988), Zonneveld (1989)
Books and reports on land/terrain analysis/evaluations	Way (1973), FAO (1976), Mitchell (1991)
The updating of landscape classifications and physiography from Geology in the United States	Godfrey (1977), Godfrey and Cleaves (1991)
Ecological land classifications in the United States and Canada (for forest planning and natural resources management)	Hills (1961), Lacate (1969), Wertz and Arnold (1972), Rowe and Sheard (1981), Bailey (1983), Bailey and others (1985), Moss (1985), Avers and others (1993)

needs to articulate the information needed, while the scientist needs to communicate the gathered information in an easily understandable form. This paper shows how landform-based physiographic classifications, which have been used successfully as a basic land inventory technique in undeveloped land areas (Table 1) can also be used to provide useful information to managers of developed areas.

Modern Physiography

Physiographic classifications seek to organize the complexity of earth's surface and near-surface systems through the definition and delineation of integrated spatial units, at any scale, that are ecologically and functionally homogeneous. They have been also named "landscape" (Mabbut 1968), "terrain" (Way 1973, Mitchell 1991), "ecological" (for example, Bailey and others 1985), "biophysical" (Lacate 1969, Moss 1975), and "phytogeomorphic" (Howard and Mitchell 1980); or, referring to the basic tracts of land that they represent, "land types" (Veatch 1937), "land systems" (Christian 1958, Wertz and Arnold 1972), and "land units" (Zonneveld 1989), among others.

Physiographic classifications and maps adapt well to hierarchical arrangements, which facilitates their correlation with and application to different scales of planning and decision-making (Figure 1) from general information to more detailed, each more-detailed level incorporating the criteria of the more generalized level. This feature enables the effective transfer of information from one level of planning to another.

Physiographic classifications have been used most commonly as reconnaissance techniques for integrating information from a wide variety of sources and for large geographic areas for which environmental information was either lacking or deficient (i.e., undeveloped and rural areas). However, the validity of physiographic landform-based inventories in developed areas or industrialized countries requires verifiable examples. Because of the intense competition for the land in developed areas—and consequent changes in land use—physiographic inventories, in this framework, now require more-detailed units than those commonly used in the past in undeveloped areas.

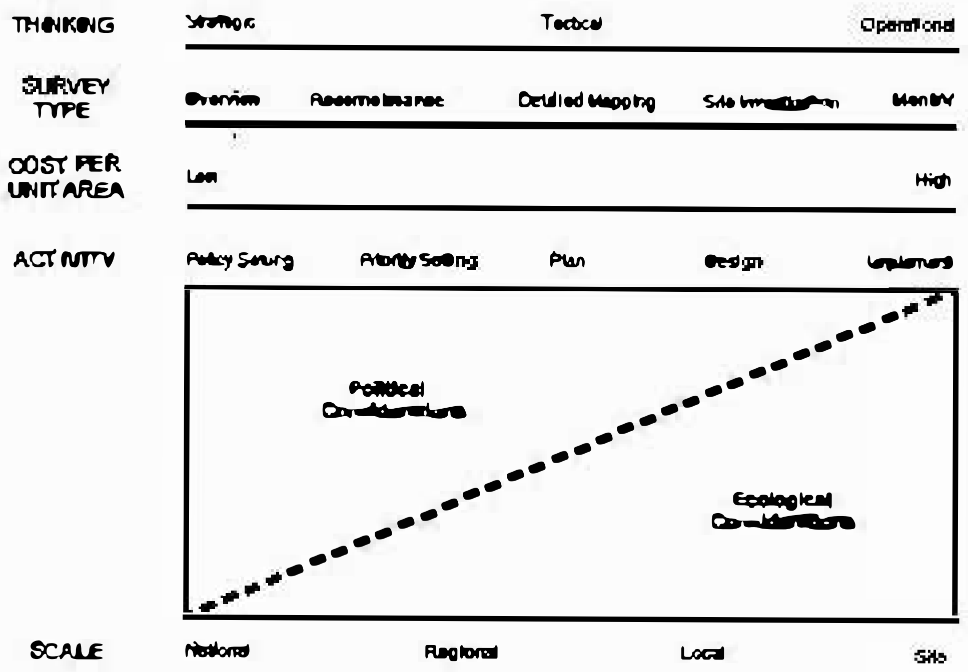

Figure 1. Relationships of scale of an activity or project to the types of planning, inventory, and relative importance of political versus ecological considerations. This figure shows the importance of understanding the scale issue. To be efficient, the type of activity must fit the scale of the project, from the national level to the site location.

Successful physiographic approaches, in the current setting, should include a better understanding of the processes acting within a unit and the quantification of the rates of those processes, because both types of information are essential for understanding and solving environmental problems. As a result, these detailed land units can be used for storing and transmitting information about how a unit will react to natural or anthropological processes or stresses.

In essence, information management is the primary reason for using physiographic/land system inventories. We cannot monitor everything everywhere. Therefore, we have to be able to transfer information gained at one location to other similar locations. Thus, if we conclude that two pieces of land (1 and 2) are similar, and studies show that area 1 reacted one way to one management practice, we can predict that area 2 will react similarly to the same management practice. In other words, physiographic/land system inventories give us a rational basis for transferring management information about one piece of land to another.

While physiographic classifications can provide the conceptual and spatial basis for gathering, storing, and transmitting information about the environment as a system, and for conveying it to land planners, decision makers, engineers, land users, etc., geographic information systems (GIS) can provide a valuable tool for enhancing a classification's ability to transfer this information effectively.

Landform-Based Mapping Products

Physiographic classifications are based largely on landform mapping. This is because the interrelationships among bedrock, topography, and processes within a landform result in morphological boundaries that frequently reflect other common physical properties and ecological conditions, such as water regime (surface water and groundwater conditions), soils properties, or even vegetation and land uses. Thus, landforms are an essential part of any classification of the land on an ecosystem basis. On the other hand, landform maps can form the basis of derivative maps expressing other ecologic characteristics. This is because landform-based landscape units have distinct visual borders and homogeneous visual shaping throughout their expanse. Once landform maps are completed, it generally is relatively easy to use the delineations to compile landscape or ecologic maps. This ease of transformation is due to the landform's strong influence on many ecologic elements, such as microclimates, moisture regimes, soils and vegetation.

Producing Landform Maps: The Problem of Data Management

Developed and undeveloped regions present two distinct sets of problems for landform-based physiographic classification. In undeveloped regions, the main problem is the lack of previous information. Information is often acquired by means of aerial photo interpretation and satellite image classification, which need field surveys to check the interpretations. In developed regions, however, the problem is generally not the lack of information, but rather the opposite. The amount of information available about the landforms and the land can be overwhelming. However, this information is often fragmented, dispersed, not updated, not useful for land management, heterogeneous, and expressed in very different formats. Therefore, the problem of data management in developed areas, for landforms or for any other component of the land, has replaced that of data acquisition (Mitchell 1991). Landform and physiographic units in these developed regions can serve as a very effective and efficient means of cataloguing and sorting previously acquired information.

Distinction Among Data, Interpretations, and Decisions

Decision-makers need to understand and distinguish the types of input they receive from scientists, researchers, or technicians who conduct the inventories and investigations. This input can take the form of data, interpretive models, information, etc. Definitions of these inputs have been synthesized as follows by Warrington (1998, pp. 1–2): (1) inventory data—individual facts obtained during data acquisition; (2) interpretations—projected responses for individual resources; and (3) management information—integration of multiple resource responses. Regarding landforms, examples of inventory data could be stream flow, slope of a landform, soil depth, or land elevation. Examples of interpretations refer to the relationship between a cause and an effect or the relationships of a fact to an issue, problem, or concern; e.g. when water is added to this soil type it swells and expands, slopes developed on this rock type are generally unstable, or weathering of this limestone produces collapse sinks when exposed near the surface. An example of management information could be the location of a proposed structure in relation to the 100-year floodplain.

Lastly, a "decision" is the selection of a course of action with the knowledge of the consequences, for example accommodating a loss in one area to gain a benefit in another.

Example of Application: The Case of Segovia, Spain

The Segovia and Surroundings Land Use Planning Guidelines (SSLPG) constitute a territorial plan, at the subprovincial level, for the area that surrounds the city of Segovia, Spain. This area is located in the southern portion of the Castilla y León Region (formerly Old Castile), in the center of the Iberian Peninsula, north of Madrid (Figure 2). Situated in the southwest portion of Segovia Province, the area includes 71 municipalities and almost 2000 sq k, covering portions of the north slope of the Guadarrama Mountains, its Piedmont, and a southern portion of the Douro Basin. The Guadarrama Mountains, a range of the Spanish Central System, form the hydrographic divide between the Douro and Tagus rivers and the boundary between the Castilla y León and Madrid regions. The northern Guadarrama Piedmont is a rocky plain of the Iberian Massif that surrounds the mountainous area of Guadarrama. The Douro Basin constitutes a high plain of sedimentary terrain almost completely surrounded by mountains.

The SSLPG is directed by two laws that are the framework of the land use regulations in the Castilla y León Region: the 10/1998 Act, for Territorial Planning; and the 5/1999 Act, for Urban Planning.

Article 5 of the 10/1998 Act created an instrument called "planning guidelines," with subregional application. The first planning guidelines in Castilla y León were enacted for the area surrounding the region's capital, Valladolid. The second area chosen for enacting the planning guidelines surrounds Segovia city. Segovia was chosen because the city and its surrounding territory are characterized by the highest rate of urban spreading of the region, because of its proximity to metropolitan Madrid. The area also has a high ecological and scenic diversity and a remarkable historic and cultural heritage.

Physiographic Approach in the SSLPG

The Castilla y León Planning Guidelines framework (10/1998 Act, Paragraph 17.1.f.) requires the establishment of criteria and rules for the protection of the natural and cultural resources, their harmonization with the economic and urban development, the delineation of areas of protection, and the completion of land use plans.

To reach these goals, three specific objectives are called for by the guidelines: (1) characterization of the

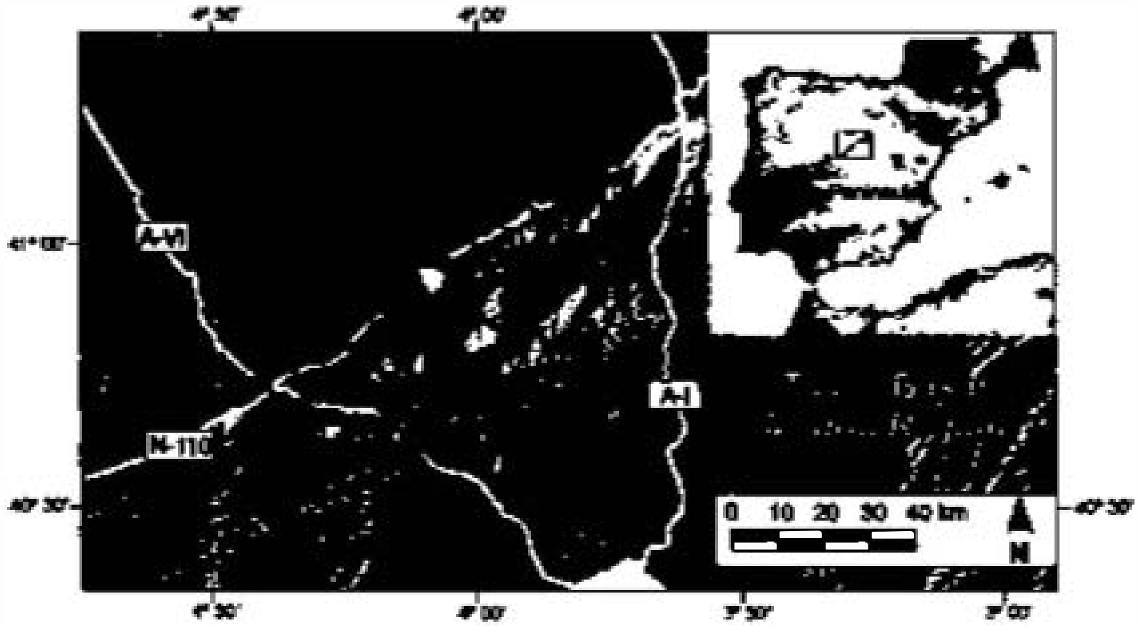

Figure 2. Location of the area studied for the Segovia Land Use Plan (spider web pattern). Symbols A-VI, N-110, and A-I identify the main roads in the area (A, highway; N, main road).

physiographic setting at the regional level, for broad environmental policy and land use guidelines; (2) definition and characterization of homogeneous landscape domains, which would serve as the physical setting to which the environmental management guidelines would refer in considering future developments (priority setting); and (3) provision of management information (at the semidetailed level of a 1:25,000 scale) for establishing land use regulations for local (municipal) planning, for the protection of specific ecosystems and scenic resources, and the minimization of natural hazards. These objectives meant that the classification system had to be multipurpose, comprehensive, and hierarchical to allow for decisions at several scales. For these reasons, we followed a landform-based physiographic approach.

Landform Mapping as a Starting Point

All land classifications are human constructs based on specific purposes and must be measured by their practical utility. The classification used in the SSLPG is not intended to be suitable for all purposes. It is just a framework for building, communicating, and transferring management information by starting with landform mapping. Within this conceptual and spatial framework, both descriptive and interpretative information can be progressively aggregated, from landform/geoenvironmental, to ecological, to landscape.

Land and Landform Data Management

The SSLPG is a good illustration of the problems encountered in producing information for applied purposes in a developed area that has been well studied for academic and other purposes. When the studies for the SSLPG began, geomorphologic information about this region was abundant: the whole area was covered by 1:100,000 geomorphologic maps; furthermore, numerous theses, scientific papers, maps, published reports, and other documents also provided detailed information about the landforms in this area. However, this abundance of cartographic and written reports had been developed using different methods and scales of mapping. Further, this wealth of information generally was produced for reasons other than land use planning applications. Therefore, new landform and physiographic maps had to be produced and new databases had to be constructed that were tailored to the objectives of the plan.

The basic vehicle for gathering the information was the mapping of landform types at a 1:25,000 scale. This was accomplished primarily through aerial photo interpretation and field surveys. By combining landform types, landform domains were obtained. Geomorphic regions were in turn obtained by association of landform domains. Tables 23 show the classification system.

Table 2. Hierarchical landform classification for the SSLPG land inventory.

Level 1: Geomorphic regions	Level 2: Landform domains	Level 3: Landform types
I. Guadarrama Mountains	A, Mountains Summits	0 to 62: see Table 3
	B, Mountains Slopes	
	C, Secondary Mountain Ranges	
II. Northern Guadarrama Piedmont	D, Piedmont	
	E, Interior Valleys	
	F, Cuestas and Mesas	
III. Douro Basin Plains	G, Rolling Plains	
	H, Flat Plains	
	I, Sandy Plains	
	J, Floodplains	
	K, Small Massifs	

Regional Scale, Physiographic Setting, and Geomorphic Regions

Three geomorphic regions comprise the physiographic setting of the SSLPG: Guadarrama Mountains, Northern Guadarrama Piedmont, and Douro Basin Plains (Figure 3).

These geomorphic regions served as the basis for defining natural regions, after the physical and biological environment within each unit were characterized. This level of the hierarchy constitutes the regional scale at which broad policy decisions on the use of land—according to integrated land units—can be made. For example, as a consequence of this type of policy decision, the Guadarrama Mountains natural region is currently being evaluated as a potential national park. The Piedmont regional planning focuses on both urban and infrastructure organization, and the Douro Basin Plains region is undergoing agroenvironmental plans and groundwater protection guidelines.

Subregional Scale, Environmental Management Guidelines, and Landform Domains

Landform domains (Figure 4), by definition, are both subdivisions of natural regions and associations of landform types. Landform domains are defined specifically from a geomorphologic basis, so that they are highly homogeneous with respect to bedrock, topography, hydrologic conditions, and soil associations. These units are also characterized by very similar vegetation, land use patterns, historical use, and environmental diagnosis. When this information is added to the landform boundaries, they become landscape domains. Landscape domains in the SSLPG classification serve as the physical setting for environmental management guidelines related to future territorial development. This is really the level at which the plan pursues an environmental management approach, seeking patterns of land use adapted to the characteristics of the existing environment.

Municipal Scale, Land Management, and Landform Types

The decision-making objectives at this level are the establishment of land use guidelines and regulations, stated by the regional government, for local and municipal planning. Reduction of natural hazards and preservation of singular ecosystems and scenery were the main goals of the SSLPG at this level. These goals were set by the 5/1999 Urban Planning Act of Castilla y León, which established the need for defining a specific land category designated as "not for building" (*suelo rústico*) because of its natural values or hazards.

Landform types were the mapping units for gathering and representing information needed at this level. A total of 63 landform types (Table 3) were mapped and described.

Figure 5 shows the scheme of organizing and transferring physiographic information at this level, by using landform maps as a starting point. It should be noted that the geoenvironmental, ecological, and landscape nature of the information (both descriptive and interpretative) are differentiated. This is important, as the distinction among landform, ecological, and landscape classifications, descriptions and interpretations, and their maps, is not always obvious in the literature. The proposed schema shows the flow of information. It also incorporates and maintains the distinction among data (inventory), interpretations, management information and decisions.

Landform type descriptions and interpretations focus on aspects related to the objectives of land-protection goals of the SSLPG at this level, addressing the needs for municipal guidelines planning. The following paragraphs give examples of some geoenvironmen-

Table 3. Landform types (regional toponymic names, when available)

0—reservoirs
1—gneiss slopes
2—granite slopes *(pedrizas)*
3—torrent gorges *(torrenteras)*
4—glaciated cirques/nivation hollows
5—gneiss-granite colluvium
6—slope debris deposits
7—talus slopes *(pedreras)*
8—peat bogs *(tollas)*
9—moraines
10—landslide/slump deposits
11—torrent floodplains
12—boulder fields *(berrocales)*
13—slope mountain benches
14—alluvial fan deposits
15—thin veneer alluvial fan deposits
16—mountain passes *(collados)*
17—mountain summits *(pelados)*
18—secondary mountain divides
19—high peat bogs *(tollas)*
20—mountain knolls *(cabezos)*
21—gneiss surfaces
22—gneiss rolling surfaces
23—rocky slopeland
24—piedmont hills *(cabezos, oteros)*
25—rocky ridges *(crestas)*
26—granite/gneiss gorges *(gargantas)*
27—mixed alluvial-colluvial deposits
28—piedmont lowlands *(navas)*
29—alluvial piedmont fans *(rañas)*
30—rolling limestone terrain
31—limestone mesas *(lastras)*
32—limestone cuestas *(lastras)*
33—silica sand and shale slopes
34—limestone canyons *(hocinos, cañones)*
35—colluvial limestone deposits
36—silica-sand rolling terrain *(arenales)*
37—alluvial dry valley fill deposits
38—arkosic upland plains *(lomas)*
39—arkosic downhill declines
40—arkosic plains *(llanuras)*
41—silt flat plains *(llanuras)*
42—broad valleys slopes
43—gullied slopes *(cárcavas)*
44—arkosic cuestas
45—arkosic slopes and scarps
46—sandy colluvial deposits
47—peat ponds *(labajos)*
48—alluvial stream beds
49—small arkosic hills *(otones)*
50—colluvial downhill declines
51—terrace scarps
52—high fluvial terraces
53—alluvial floodplains *(vegas)*
54—alluvial terrace deposits
55—sand dunes *(cotarros)*
56—sand sheets *(arenales)*
57—slate slopelands *(pizarrales)*
58—slate surfaces *(pizarrales)*
59—gneiss grus
60—granitic tors *(berrocotos)*
61—granitic scarps
62—doline fields *(hundas)*

tal interpretations that were made at the local (municipal) level.

1. *Natural hazards.* Landform type polygons display areas of similar geologic processes and rates; for example, flooding, mass movement, and soil erosion.

Natural hazard assessments were made for individual landform units, where possible. Hazard consists of the probability that a specific harmful process will occur in a given area. This was done by determining both the processes acting on that landform unit and the rate, or frequency, of events driving the process. The degree of confidence was also supplied by determining the reliability of the data. Examples for individual landform units are:

1. Landform type II-D-28, piedmont lowlands, is subject to seasonal low-intensity floods, which represents a constraint for housing, farming, and industrial development.
2. Landform type III-K-23, rocky slopelands, shows active soil erosion by running water, due to overgrazing, with rates ranging from 1.1 to 1.8 mm/yr (19–31 t/ha/year), determined by using dendrochronological analysis of exposed tree roots.
3. Landform type II-F-33, silica sand and shale slopes, shows high natural slope instability, with frequent landslides throughout. Historical data suggest that these slopes, in the regions around Segovia, have up to a 10% probability per year of failing. Examples of slumps affecting buildings and roads are frequent all over the Segovia area.
4. Landform type III-J-53, alluvial floodplains, undergoes recurrent floods after heavy rains caused by autumn convective storms and winter frontal precipitation events; data gathered from each specific floodplain allowed the evaluation of the recurrence periods of these events for each floodplain.

The description of the nature and rates of these natural hazards then can be combined with a knowledge of existing and planned developments to produce a risk assessment using the UNESCO formula of natural risks (UNESCO 1972). This combines the assessment of a hazard with an assessment of the values or developments that a hazard could impact. Items to consider include whether a hazard could impact human life, such as a housing development or school, or a comparison of developments such as an open park versus an office that produces and maintains high-value unique information. While the probability of a hazard should remain relatively constant, under constant conditions such as climate, the level of risk increases if high-value

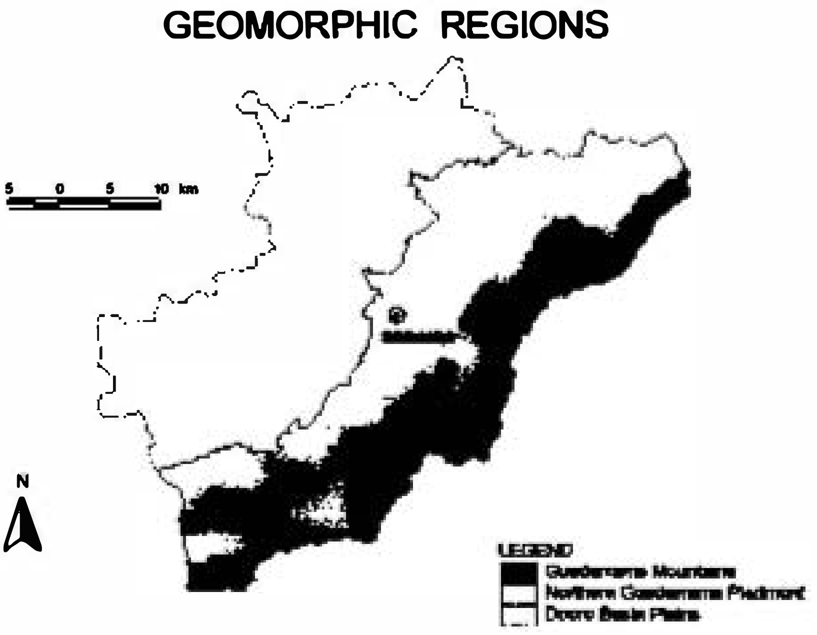

Figure 3. Map of geomorphic regions.

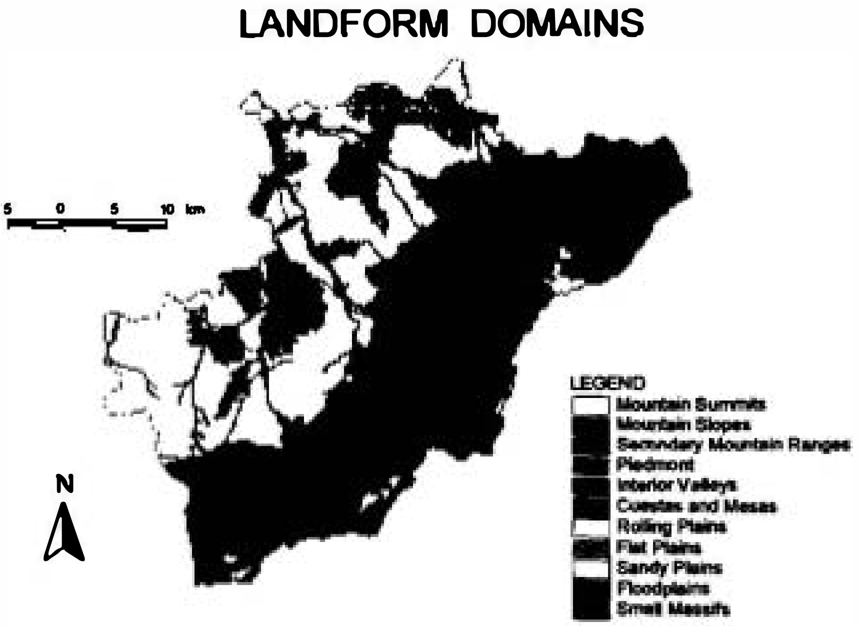

Figure 4. Map of landform domains.

developments are permitted to move into the hazard zone. Planning can avoid this increased risk.

2. *Geosites.* Landform types were assessed according to their potential for educational and scientific purposes and tourist and recreational purposes. In the past, designation of sites for educational or recreational purposes has been done mainly on a political or emotional basis rather than on an objective or scientific basis. We followed a systematic approach that uses intrinsic and extrinsic value criteria. These criteria include: rareness, number of publications about the site under evaluation (as a measure of the availability of research/knowledge), diversity of elements of interest within the landform, total area, association with other elements of the environment (archaeological, historic, ethnographic, flora, fauna, scenery), diversity of possible activities within the landform, accessibility, proximity to towns or cities, degree of preservation, and num-

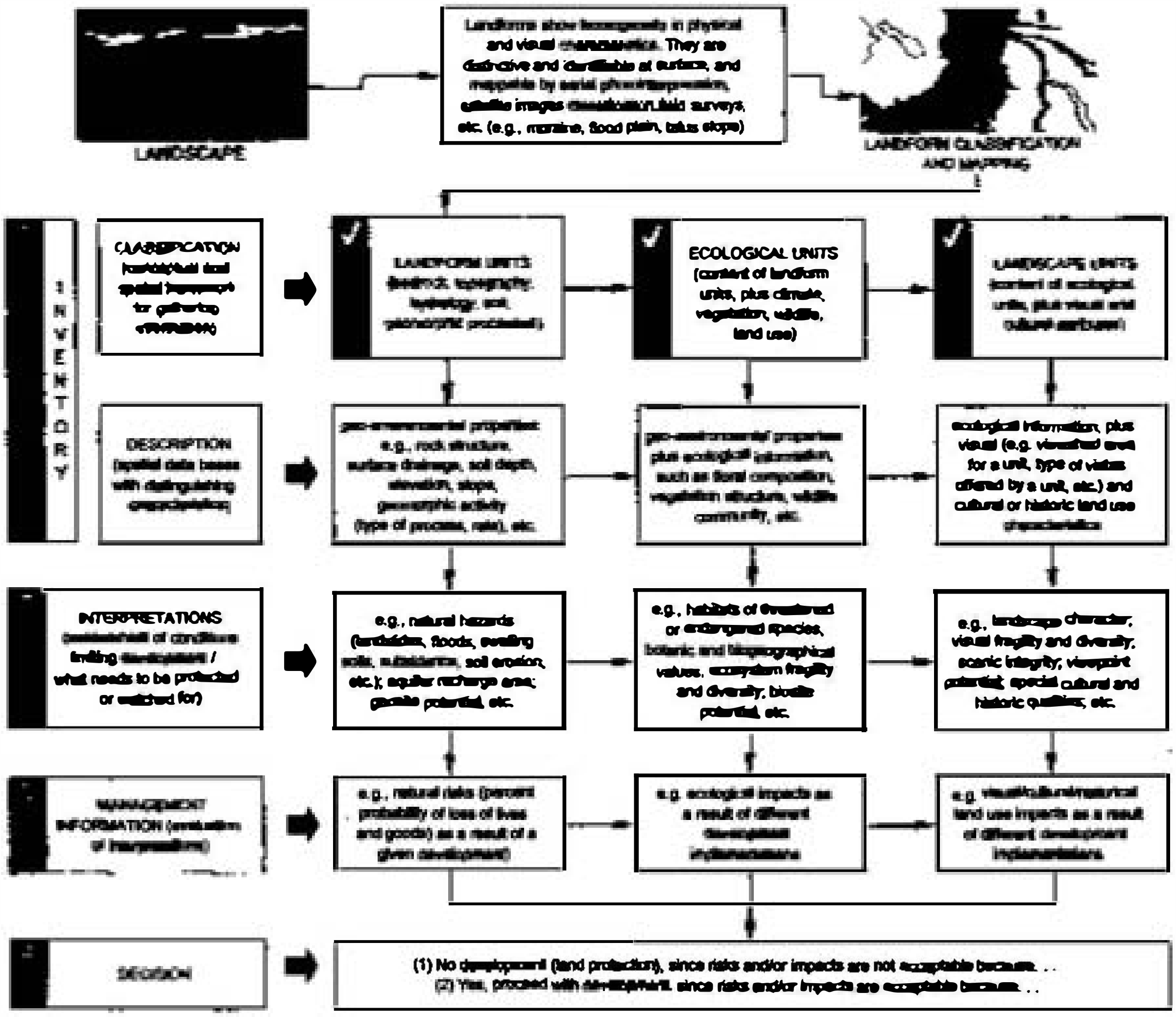

Figure 5. Proposed system for building and transferring land management information at the municipal level, starting from landform mapping.

ber of inhabitants in the surrounding area (Cendrero 1996). Within the SSLPG area, examples of landform types that provide opportunities for scientific and broad environmental education are: I-A-4 (glaciated cirques) and II-F-62 (karstic dolines). Examples of landform types that provide high potential for tourist and recreational purposes are II-F-34 (limestone canyons) and II-D-12 (houlder fields). Following the same criteria, small-size features, such as springs, waterfalls, potholes, ponds, were also mapped and evaluated. These were represented by a point on 1:25,000 scale maps.

3. Other special characteristics. Elements of the geoenvironment that need to be protected or watched out for were identified (e.g., landforms that are aquifer-recharge areas, such as II-F-30, II-F-31, II-F-32; see tables 23).

GIS Physiographic Data Management of the SSLPG

The landform type maps, originally produced in analog format at a scale of 1:25,000, were digitized in vector format. Landform types were identified by a three-part code. The first part (a Roman numeral) refers to geomorphic region, the second (a capital letter) refers to the landform domain, and the third (an Arabic numeral) refers to the landform type. Thus, I-B-2, for example, represents the Granite Slopes type of the Mountain Slopes domain of the Guadarrama Mountains region. This system allows one to produce automatically any of the three levels of the land classification scheme.

While digital information can be represented and plotted at any scale, landform types show their optimum output at 1:25,000, landform domains at 1:100,000 and geomorphic regions at 1:250,000.

Both descriptions and interpretations at all three levels (geomorphic region, landform domain, and landform type) were included in relational databases tied to the vector data. This created a specific physiographic information system for the SSLPG plan and allowed the production of specific maps for any one of the interpreted characteristics (natural hazards, outstanding scenic landform, etc.) and the easy transfer of this information, via Internet or CD-ROM, to the 71 municipalities that constitute the SSLPG plan.

Conclusions

The example of the Segovia Plan shows a procedure for building and transferring natural resource information, based on landform maps, for land use planning purposes. The classification system is hierarchical and purposeful for the three levels considered.

In the example described, landform-based classifications and interpretations provided information to management and assisted planners, enabling them to make decisions concerning the social needs of the area. The Segovia case study provides a scheme for organizing and transferring landform-based physiographic information that might be useful for others to follow when facing similar situations, as it can be easily adapted to other circumstances.

Acknowledgments

We are grateful for a profitable collaboration with the Urban Planning Institute of the University of Valladolid (Technical School of Architecture, Castilla y León) and the INZAMAC company, both organizations in charge of the elaboration of the SSLPG. The role of landscape mapping in environmental management in central Spain was undertaken within the REN2002 – 01361 research project of the Spanish DGI (MCYT). The authors also acknowledge Drs. G. E. Warrington, M. P. Prisloe, and an anonymous reviewer for the revision of the original manuscript. Finally, we greatly appreciate the help of Marie Godfrey for editing the text.

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